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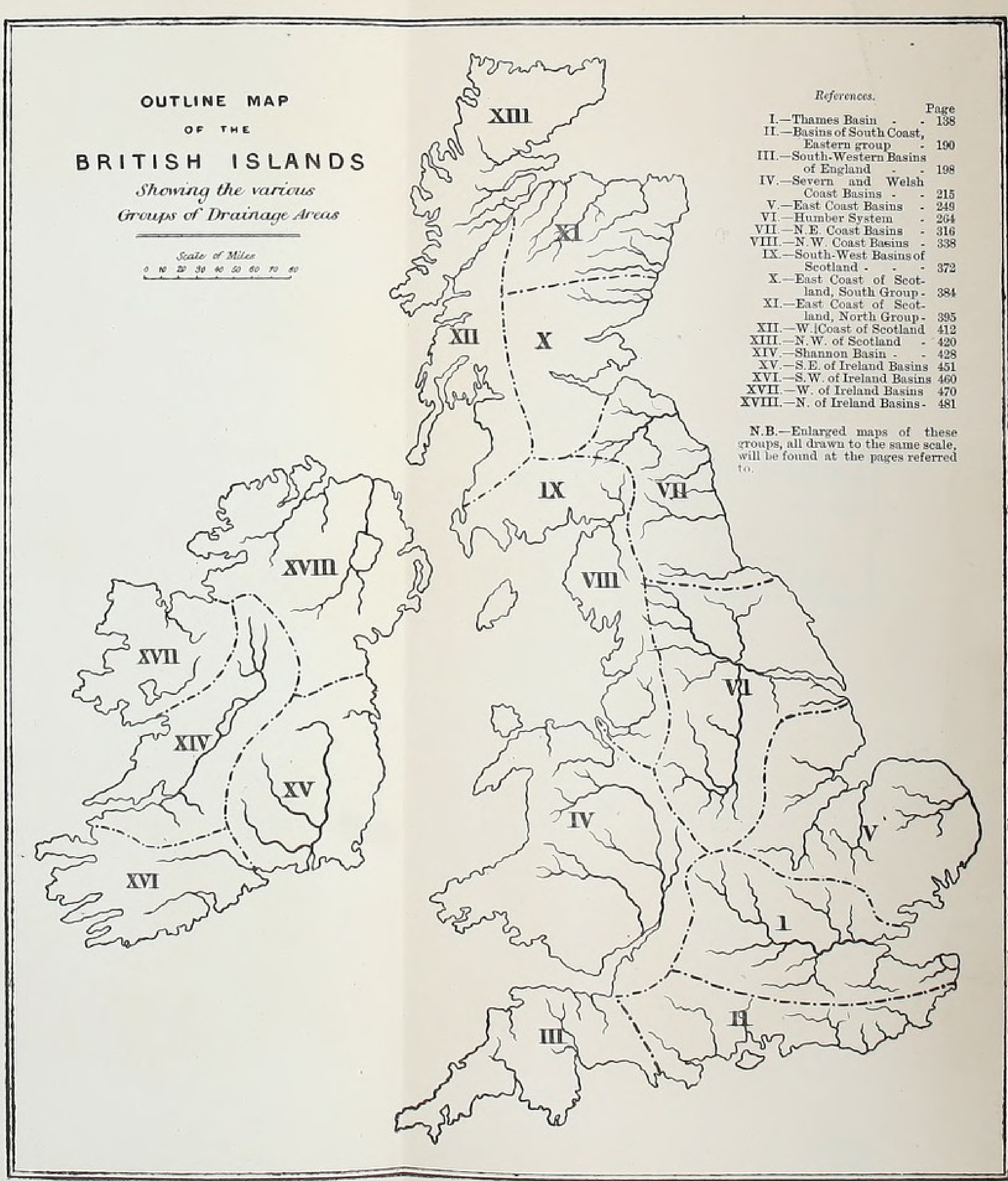
WATER

AND

WATER-SUPPLY.

To face the Title.



WATER

AND

WATER-SUPPLY,

CHIEFLY IN REFERENCE TO THE BRITISH ISLANDS.

BY

PROFESSOR D. T. ANSTED, M.A.,
F.R.S., F.G.S., F.R.G.S.,
ETC., ETC.

SURFACE WATERS.

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PREFACE.

For many years past the subject of water, as required for food, personal cleanliness, sanitary arrangements, and manufactures, has been so much and so often before the public, that no excuse is needed for bringing together into a volume the principal facts on which the knowledge concerning it is based. Much information has from time to time been collected and published by Royal Commissioners, some on water supply, and some on the state of our rivers:—chemical analyses and microscopic examinations of water have been undertaken by observers eminently fitted for such work:—communications have been made to the Institution of Civil Engineers, the Society of Arts, and other public bodies, concerning the storing, distribution, and flow of water:—and much evidence has been given on oath before Parliamentary Committees in reference to public undertakings for water-supply. Magnificent works have been constructed at enormous cost for the storage of water; deep wells have been sunk and deeper borings made in many geological formations, with and without success, to discover natural supplies obtainable by pumping; and elaborate calculations based on careful and long continued investigations have been undertaken, both publicly and privately, in anticipation of useful results in water inquiries.

There is, therefore, a great body of information in existence, justifying an attempt to bring together for the use of practical men an outline of the facts bearing on water supply, and calculated to suggest important matter for study and application. Water-supply regarded from this point of view has a very mixed aspect, and does not appertain exclusively to any one of the many departments of science. Neither the physicist nor the chemist, neither the geologist nor the engineer, can claim it altogether as his own. It is essentially a mixed subject, and requires varied knowledge and experience.

My own share in the investigations concerning the properties and uses of water, and the conditions under which it exists within and upon the earth, and by which it may be made available for supply, dates back from a distant period, and has ranged over many departments. I have had opportunities of suggesting and watching investigations, and observing facts of great importance and deep interest. On such occasions I have generally been associated with, and sometimes opposed by chemists, physicists, and engineers, whose names are honoured throughout Europe. I have endeavoured to profit by this experience, and have, I trust, always been prepared to receive evidence and weigh its value from whatever quarter it may have come. The results are embodied in the following pages.

As a writer whose object it is to bring together, in a convenient form, knowledge obtained by research of various kinds in many departments of chemistry, meteorology, geology, and engineering, I can hardly hope to escape error, and may expect severe criticism. No one can be a specialist in many subjects. All that I can hope for is to be recognised as a useful labourer in a large field, and to find my book referred to, as affording the ground-work of a more complete and more accurate history of a part of the great subject of water than has hitherto been attempted.

I have avoided, as much as possible, the expression of opinion, and especially of dogmatic statement. If in some not unimportant cases, I have ventured to differ from men whose authority is deservedly high, I desire only that the evidence on both sides should be fairly weighed, and the truth brought out.

In the present volume the properties of water and the distribution of surface water are considered, and I have devoted much space to a description of the various river systems, as well subordinate as principal, throughout the British Islands. I hope in a second Part to describe the phenomena of underground waters, and to give some account of water-supply.

D. T. ANSTED.

1 *Princes Street, Storey's Gate,*
Westminster,
August 1878.

Errors of various kinds have already been detected in names and figures, during the progress of the work through the press, but too late for correction. Others, no doubt, exist, that have not yet been found out. To any friends, who will be kind enough to inform me of such errors, I shall be extremely grateful, as in the event of a second edition being called for, I may be able to present to the world a more useful and trustworthy account than I am here able to offer.

D. T. A.

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[An account of the subject-matter of the various paragraphs of each Chapter will be found at the pages referred to above, and forms the heading of the Chapter.]

ILLUSTRATIONS.

CORRIGENDA.

In page 21, line 1, for "one-eighth part, or 500," read "one-fifth part, or 800."

In page 110, by the terms "mean flow," and "the mean daily or annual flow," it is intended to express the ordinary flow exclusive of freshets. The actual mean flow of the Thames is given in Chapter IV. § 6.

In page 321 there are some misprints. *Billingham beck* should be *Bellingham beck; Bolthorpe burn, Bollihope burn; Warcroft beck, Wascrow beck. Cong burn* is generally called *Chester burn*; and *Tursdale beck* should have been inserted opposite Browney river. *Jarrow* river should be *Yarrow* river. In p. 328, in addition to a repetition of some of these errors, *Witton-le-Wear* is incorrectly printed *Wilton-le-Wear*, and *Browney river* is printed *Bromney river*.

Page 366, footnote. The bill introduced into and passed by the House of Commons authorising the works for supplying Manchester with water from Thirlmere, having undergone important alterations in its passage through Committee, failed to satisfy the Standing Orders Committee in the House of Lords, and was therefore thrown out.

CHAPTER I.

PHYSICAL PROPERTIES OF WATER.

(1) Water universally present.—(2) Composition of pure water.—(3) Properties of water.—(4) Water rarely free from foreign matter.—(5) Mineral contents of ordinary waters.—(6) Density and weight of water.—(7) Absorption of gases and atmospheric air by water.—(8) Water always contains various gases.—(9) It also contains organic matter.—(10) It is an universal solvent.—(11) Weight of solid matter in different natural waters.—(12) Substances generally abundant in natural waters.—(13) Presence in water of foreign substances not necessarily injurious.—(14) Definition of wholesome water for town use.—(15) Water left in contact with certain injurious substances not necessarily unhealthy.—(16) Pure water not desirable for general use.—(17) Effect of pure water on lead and iron.—(18) Hard and soft water.—(19) Organic impurities in water oxidised by exposure to air.—(20) Composition of river waters varies with the season of the year.—(21) Difficulty of thoroughly mixing impure water with the natural waters of a stream.—(22) Purification of polluted water by exposure.—(23) Dr. Tidy's experiments on oxidation of sewage water.—(24) Rivers natural sources of water supply.—(25) Lakes as sources of supply.—(26) Injury to rivers from admixture of sewage.—(27) Injury from undeveloped organisms.—(28) Mouths of tidal rivers contain much organic matter.—(29) Derivation of water from the sea.—(30) Only a part of the rainfall conveyed by rivers.—(31) Classification of the sources of water supply.—(32) Qualities of surface and spring waters.—(33) Desiderata for potable waters.—(34) Impure waters often the best for industrial purposes.—(35) Determination of relative hardness of water by Clarke's test.—(36) Preparation of the soap test and standard solution.—(37) Application of the test.—(38) Wanklyn's "Potential" carbonate of lime.—(39) Technical meaning of hard water.—(40) Total and permanent hardness.—(41) Previous sewage contamination.—(42) Dr. Frankland's explanation of the expression.—(43) Case of Dover Beck—(44) No water safe, according to the Frankland theory.—(45) Existence of germs in water assumed, not proved.—(46) Further illustration of the unfit use of the term.—(47) Dr. Frankland's explanation.—(48) Absence of satisfactory evidence.—(49) Source of danger in water not the presence of nitrites, nitrates, and ammonia.—(50) Example illustrating the technical language of

1. Water universally present.—Water is universally present, and forms an essential part of the earth, not only existing in large quantity in the ocean and on the surface of the land, but always a constituent part of the rocks of which the earth's crust is composed, always a part of the atmosphere we breathe and that surrounds the earth, and always also a large and essential proportion of every organised being, whether animal or vegetable. It might seem unnecessary to offer lengthened preliminary remarks as to its nature and uses, but it is desirable that knowledge on the subject should be precise and accurate, and I commence this chapter with a few statements of fact to which the reader may find it useful to refer.

2. Composition of pure water.—Chemically pure water consists *atomically* of one atom of oxygen combined with two atoms of hydrogen (H_2O), and *volumetrically* as one volume of oxygen combined with two volumes of hydrogen, the three volumes measuring after combination two volumes. By weight, the atom of oxygen weighs sixteen times that of hydrogen. Water, therefore, consists of eight parts by weight of oxygen to one of hydrogen. The composition and decomposition of water are accomplished with difficulty under ordinary terrestrial conditions, and cannot take place without the development of heat. The compound molecule of water once formed, is permanent under ordinary conditions, and behaves in a manner so like elementary substances, that it is regarded as a proximate element.

3. Properties of water.—The latent heat of water is 143° F. Thus, if one pound of water at the temperature of 143° be mixed with one pound of ice at the temperature of 32°, the ice will be melted, and the resulting water will have a temperature of 32°. The heat apparently lost is required to bring the frozen water back into a liquid state, and is called *latent*, having lain concealed in the ice. The boiling point of water, at the ordinary pressure on the earth's surface at the sea level (29·992 inches of mercury), is 212° F. When the pressure is diminished, as on rising to a height in the air, the boiling point is lowered, and under a vacuum it is reduced to near the freezing point. Elevation above the sea may be determined by observing the temperature at which water boils. Under increased pressure, the temperature at which water boils increases, thus, under one and a half atmospheres it is 234° F., and under two atmospheres (nearly 60 inches of mercury) it is 249° F.

The conversion of water into vapour is attended with the absorption of heat. When one pound of steam at 212° F. is mixed with 5·37 lbs. of water at 32°, the vapour is condensed, and there result 6·37 lbs. of water at a temperature of 212°.

Water is almost colourless, but slightly blue. The colour is best seen by looking at a shining white object through a column of pure water six feet long contained in a tube blackened inside. Ice is also blue.

Water is very slightly elastic. Under a pressure of one atmosphere its volume is reduced to the extent of ·000046 (nearly one twenty-thousandth part), and, under a pressure of 200 atmospheres, by one-twelfth of its volume.

4. Water rarely free from foreign matter.—The purest water is produced by very slow distillation, but water distilled in the ordinary way, with every precaution, carries over a quantity of solid matter amounting to one-eighth of a grain in an imperial gallon (70,000 grains), and is, therefore, by no means in a state of absolute purity. The solid matter consists of various substances, chiefly chlorides, which come over with the vapour at however low a temperature the distillation is effected. Next to distilled water, rain-water, collected at a distance from towns and human habitations, affords the nearest approach to purity. Rain is distilled water, the distillation being effected in the process of evaporation, followed by condensation which converts it into visible vapour and cloud. Rain is inferior in purity to water distilled in the laboratory, rarely containing less than one grain of solid matter to the gallon, and, in the case of rain collected in towns, often as much as 3 or 4 grains.*

5. Mineral contents of ordinary waters.—Fresh water is obtained naturally at the earth's surface in a potable form and fit for economic use from springs, running water or rivers, and lakes or pools. All these have been derived originally from rain. The water on the surface is derived directly, and that obtained from springs indirectly from rain. The latter has passed into the earth, and has traversed various strata, being generally modified in its progress by contact with foreign bodies. The great store-house of water, the ocean, contains a large

* It is so difficult to realise statements of quantity without some familiar reference that I may be excused for pointing out that one grain of solid matter in a gallon of water is equivalent to 3¼ lbs. in the quantity of rain falling on an acre of ground during a rainfall of one inch, as measured by the rain-gauge. This would be a heavy, but not an exceptional shower.

quantity of mineral substances, chiefly common salt (chloride of sodium), and the bitter salts of magnesia (sulphate of magnesia, or Epsom salts); and is not fitted for drinking purposes without distillation. Freezing produces the same, or nearly the same, effect as distillation, as is known by the experiment of freezing salt water, or by the state of the ice of ice-floes, which is always nearly fresh. Certain lakes, few in number, but including the largest in dimensions, are even more loaded with mineral substances than the sea; but other lakes, usually expansions of rivers (the water merely flowing through them), are fresh. By fresh water is meant, here and generally, any water that does not contain so large a quantity of foreign substances as to be unfit for the ordinary purposes of life.

6. Density and weight of water.—Pure water attains its greatest density at a temperature a little below 40° F. (39·2°), under a barometric pressure of about 30 inches of mercury. When cooled below this point it slightly expands, and continues to expand till lowered to the freezing point (32° F.). Immediately below this point in the open air it usually becomes solid, although if kept perfectly still it may be cooled down much lower before solidifying. In consequence of the expansion that takes place before freezing, ice is lighter than water. The specific gravity of ice is 0·916, that of water at 60° F. being 1·000. Salt water, which is heavier than fresh water, requires a lower temperature to become solid, and the temperature required to freeze it is lower in proportion to the solid matter it contains. This does not apply only to sea-water, but is universal. In freezing, water parts with most of the substances it has held in solution, and thus ice is always lighter than sea-water, on which it floats. Hence the phenomena of ice-bergs, which are fragments of glaciers broken off from the land; and of ice-floes, which are masses of ice formed by the freezing together of surface ice, when it is being drifted and moved by currents in the Arctic and Antarctic seas. The density and saline contents of the ocean vary in different latitudes and at different depths. The specific gravity of the surface water of the North Atlantic, between the Equator and the 50th parallel of latitude, is 1·02664; and that of the South Atlantic somewhat higher. That of the Pacific is lower, and that of the Indian Ocean lower still. In enclosed seas, such as the Mediterranean and the Baltic, the saltness of the water varies according to the magnitude of the streams of fresh water discharging into them. It is also affected by the rate of evaporation in the district (and, therefore, on the climate), and on the nature and position of the communication with the open ocean.

The weight of a cubic inch of pure water at a temperature of 62° F. (the barometric pressure being 30 inches) is 252·456 grains. A cubic foot of distilled water, therefore, weighs 62 lbs. 5 oz. 56½ gr. (62·3206 lbs.) The imperial gallon contains 10 lbs. or 70,000 grains of distilled water, and its capacity is 277·19 cubic inches, or ·16 nearly of a cubic foot. The cubic foot of water thus contains 6·232 gallons ($6\frac{1}{4}$ nearly). A cubic inch of ice at 32° F. weighs 235 grains; and a cubic inch of steam at 212° F., 0·193 grains.*

7. Absorption of gases by water.—Water absorbs air very readily, and always contains a certain quantity. It also absorbs other gases readily. It liberates air on being exposed to boiling temperature, and also, after a time, on being placed in a vacuum. This property of absorption of gases is extremely important in reference to sanitary inquiries. The amount capable of being dissolved depends on pressure, and is generally larger as the temperature is lower. This is not the case with hydrogen gas between the freezing point and 77° F.

Rain-water generally contains nearly $2\frac{1}{2}$ per cent. of its bulk of a mixture of oxygen and nitrogen gases; but both in rain-water and recently melted snow the proportion of oxygen to nitrogen is greater than in atmospheric air. Thus, the composition of common air being 21 oxygen and 79 nitrogen, that of the air dissolved by rain-water is 32 oxygen and 68 nitrogen, and that of melted snow 34·8 oxygen and 65·2 nitrogen.

Under ordinary circumstances water contains nearly 1 per cent. of its volume of oxygen gas (say $2\frac{2}{3}$ cubic inches per imperial gallon), and as this gas weighs about $\frac{1}{3}$ grain per cubic inch, the weight of oxygen in an imperial gallon of water will be ·088 grains, or nearly nine grains in 100 gallons. The limits may be generally stated as ranging from $\frac{3}{4}$ grain to 1 grain in every 10 gallons of water. The quantity of nitrogen, which is a lighter gas, weighs about $1\frac{1}{2}$ grain. The quantity of air in water diminishes with the reduction of barometric pressure, and at the height of 8000 feet the per-centage of air is not so much as 1 per cent. of the bulk. Water almost always contains carbonic acid gas, which communicates a peculiar briskness of flavour; and in some natural mineral waters the proportion is very large, the gas escaping in bubbles when it reaches the surface. Other gases are occasionally met with, and rain-water always contains ammonia. Water readily absorbs poisonous gases derived from decomposition, but these are seldom present in the air in the open country, except under special conditions. In those cases where miasmatic vapours exist, it is not unlikely that the water as well as the air may have something to do with the production of malaria.

When the solution of a solid substance in water is not accompanied by chemical combination, there is often a reduction in the temperature, but

* The density of water in a liquid state is greatest at the temperature of 39·2°. Taking this density as unity, the density at the freezing point is 0·999877, and at 60° F., 0·999107. In the United Kingdom the density at 60° F. is taken as unity, but, on the Continent, that measured at 4° C. (= 39·2° F.) A cubic centimetre at this temperature, under a pressure of 760 millimetres (=29·922 inches) of mercury, weighs 15·432349 grains = 1 gramme, the unit of weight in the metric system.

the solution of gases is generally accompanied by an increase of temperature. Aqueous solutions of solids have a higher density than water, and so also have water solutions of certain liquids and gases, but generally these latter solutions are less dense than water.

8. Water contains various gases.—Besides the gases present in rain-water falling in the open country from the clouds, that which falls in and near large towns is found to have dissolved in its descent a sensible quantity of sulphurous acid and other gases, depending as to amount on the manufactories in the neighbourhood. Thus, rain-water is apt, under certain circumstances, to be slightly acid, containing both sulphuric acid and carbonic acid. It will also contain hydrochloric acid in the neighbourhood of alkali works, and, in some cases, unoxidized sulphurous acid. These facts are not without importance in explaining the action of rain on certain rocks and on building stone, as well as on the receptacles in which water is conveyed or retained.

9. Organic matter in water.—Both river and spring water generally contain indications of the presence of organic matter, either as ammonia or in the form of neutral salts (nitrates and nitrites) supposed to be derived from organic matter. The proportion varies exceedingly, and there cannot be a doubt that, although in some cases and within certain limits the organic matter may be perfectly inert, especially if of vegetable origin (as peaty water), there are many cases in which its presence may be injurious. It may have been derived directly from the rocks and soils over or through which the water passes, or it may have been introduced as sewage. Gelatinous matter, apparently organic, has been detected in hot mineral springs, proceeding from great depths below the surface, in the Pyrenees*; and, in some form or other, nitrogen has been found in almost every surface water. It has even been obtained in considerable quantities from the bottom of the ocean, at enormous depths. Its presence, and the state in which it exists, are of vital importance in determining the fitness of water for human food, and in its determination the utmost resources of the most experienced and intelligent chemists are needed, for the subject is one surrounded with difficulties. Living organisms have been detected in the water of deep wells sunk in solid chalk, and used for the supply of towns.

10. Water an almost universal solvent.—The extreme difficulty of obtaining water chemically pure is due to the property it possesses of dissolving and becoming intimately mixed with minute quantities of most of the known elements, and of a large number of salts and other compound substances. If not an universal solvent, it is very nearly so. Thirty-one elements have been detected in sea-water, and some mineral springs contain definite proportions or traces of others. The following

* Lecoq, *Eaux minerales.*

list of the elements found in water, and the probable source of the foreign ingredient, may be useful for reference :—Oxygen and Nitrogen gases (in the atmospheric air absorbed), Hydrogen and Nitrogen (chemically combined in ammonia), Carbon (in carbonic acid), Chlorine (in common salt and in chloride of magnesium), Bromine and Iodine (in fucoids), Fluorine (with calcium in the salts of lime), Sulphur (in sulphuric acid), Phosphorus (in phosphoric acid), Silicium (in silica and the silicates), Boron (in boracic acid), Silver (in sea-weeds), Copper (in marine plants and animals), Zinc, Cobalt, and Nickel (in marine plants), Iron, Manganese, Aluminium, Magnesium, Calcium, Strontium, Barium (as sulphates in fucoid plants), Sodium (in common salt), Potassium, Lithium, Rubidium, Cæsium, and Arsenic. These, and some others, being all soluble in water in certain states of combination,* their presence is possible in water obtained from any natural sources.

11. Solid matter in solution in water.—The quantity of solid matter held in solution in clear water varies from a small fraction of a grain to upwards of two pounds in an imperial gallon. The annexed list of examples includes instances from waters of all kinds, collected in different parts of the globe, and is interesting for comparison, as showing a scale of gradation. It would be easy to multiply examples to almost any extent between the extreme limits.

Quantity of Solid Matter in Water under various circumstances.

Nature of the water.	Locality and circumstances.	Weight of solid material. Grains per gallon.
Distilled water	Minimum of many analyses	0·12
Rain-water	From the open country	1·00
Lake water	Bala, N. Wales	1·95†
"	Loch Katrine, supplied to Glasgow	2·30†
Gravitation water	Lancashire moors, supplied to Manchester	4·76†
Lake water	Windermere	5·78‡
Gravitation water	Leeds reservoirs	7·00
River water	Spree R., near Berlin	7·98
"	Plata R., S. America	9·21
Lake water	Geneva	10·64
River water	Rhine R., at Bâle	11·86
"	Filtered from the Wharfe R.	13·37§
"	Rhine R., above Schaffhausen (Sept. 6, 1869)	15·80‡
"	Lea R., at Tottenham; Severn R., in February‖	17·00
"	Derwent R., above Derby	19·02
"	Thames R., filtered and supplied to London	20·17§
Well water	Chalk at Dover	22·01
River water	Thames R. at Medmenham	24·60§
Well water	Near Deptford	26·04
"	Magnesian Limestone, Sunderland	29·75
River water	Severn R., in May (summer yield)	32·50‖
"	Supplied to Birmingham	37·70§

* Some of them, as Iron, are insoluble in the metallic form.

† Frankland, *Duke of Richmond's Commission*, 1867.

‡ Frankland, *Rivers Pollution, Sixth Report.*

§ Letheby, Odling, and Abel, *Duke of Richmond's Commission*, 1867.

‖ Dugald Campbell. Parliamentary Inquiry, 1852.

Nature of the water.	Locality and circumstances.	Weight of solid material. Grains per gallon.
Well water .	. Dolomite, Sunderland, deep well, Sept. 1868	44·18*
River water .	. Ouse R., supplied to Bedford, Oct. 10, 1868 .	47·90*
Well water .	. Chalk. Hampstead W. W.	52·70
" .	. Oolite. Northampton deep well, May 11, 1868	57·76*
" .	. Chalk. Trafalgar Sq., London, deep well .	68·25
" .	. Chalk. Mint (Artesian well), May 31, 1869	83·96*
Mineral spring	. Mont Dor, Central France	91·20
River water .	. Sewage discharge into Thames one hour before low water, Sept. 1877 . .	108·01†
Well water .	. New Red Sandstone. Bent's Brewery, Liverpool	122·75
Mineral spring	. Cheltenham	150·00
River water .	. Thames, at sewage discharge, two hours after high water, Sept. 1877 . . .	151·45†
Well water .	. Deal, July 22, 1869 (affected by tide) .	202·14*
" "	. New Red Sandstone, Howard's Brewery, Liverpool	264·00
Mineral spring	. Carlsbad (Sprudel Spring)	463·00
Well water .	. New Red Sandstone. Jack's Works, Liverpool	914·50
Black Sea water	. Near Sea of Azof	1,068·04
Mineral spring	. Kissengen, Bavaria	1,352·00
Atlantic Ocean	. Open water	2,688·00
Salt Lake .	. Tchokrak, near Kertch, Crimea . .	9,855·30
Dead Sea .	. Near mouth of the Jordan . . .	14,488·00‡

12. Principal foreign constituents of water.—The number of organic and inorganic substances present in any quantity in river waters, lake waters, and ordinary spring and well waters adapted for general use is not very numerous, and the substances are nearly the same in all, although the relative proportion of each varies according to the mineral nature of the rock passed over or passed through. Carbonates and sulphates of lime and magnesia, chloride of sodium, nitrates and nitrites of lime, oxides of iron, silica, and a little organic matter, are the usual constituents. In the case of what are called mineral waters, the variety, and, in many cases, the quantity of mineral constituents is much greater than in river or lake water, and, not only are there fresh combinations, but elements appear that are not recognised in ordinary waters. Among these, some have been discovered by the spectroscope that were not before known to exist in the earth; and others, already known as terrestrial elements, have been recognised for the first time in water by the use of this instrument. Though the quantity of these is too small to admit of their being easily separated and determined, the evaporation of large quantities of the water, by concentrating the non-evaporable materials, sometimes enables the chemist to obtain sufficient to admit of measurement. In sea water the number of substances determined in this way is

* Frankland, *Rivers Pollution, Sixth Report.*

† Prof. Williamson. Capt. Calver's Report to Thames Commissioners, 1877, p. 16.

‡ Analysis, by Roux, of water brought by Abbé Peron, in April 1862. Lecoq, *Eaux Min.* p. 184.

exceedingly large. In salt lakes, the concentration of the solution of certain salts having already been carried a long way (as is evident from the altogether exceptional result in the Dead Sea), the work of the chemist is thus simplified. In many cases the quantity of solid material varies greatly at different seasons.

13. Foreign substances not necessarily injurious.—The presence of foreign substances cannot in all cases be regarded as pollution. Such substances, if inert or harmless, are not in any way injurious to the quality of the water as required for ordinary human purposes, whether directly, as for drinking, brewing or cookery, or indirectly for other domestic matters, for cattle, or for trade purposes, and may safely be supplied for town use. Dyeing, bleaching, paper-making, and some kinds of chemical manufactures require the absence of certain ingredients occasionally present in natural water; but none of these manufactures either need or could obtain chemically pure water. Some are much easier and better carried on by water containing much organic impurity. It is generally considered that waters may contain any quantity up to 50 grains of solid matter to the imperial gallon without being unfit for town and house use, provided they contain common air and carbonic acid gas in the proportion of not less than 3 per cent. of the bulk, and provided also that they do not contain more than half a grain of organic matter in the gallon. They must, however, be free from sulphuretted or phosphoretted hydrogen, and they must not have absorbed poisonous gases, such as the effluvia of marshes, sewers, or graveyards. As a matter of fact it is certain that among the healthiest towns in England are some of those supplied with hard water containing both carbonates and sulphates; and, in brewing, it is well known that the water should be distinctly hard and free from oxidizable organic matters to ensure a good result. Beers brewed with soft water are vapid, and do not keep well. A certain amount of solid ingredients in water for human consumption is no doubt conducive to health, as it is certainly conducive to appetite; but it is hardly necessary to point out that the nature of the substances contained in it greatly affects the conclusions to be drawn with reference to its sanitary state.

In this respect spring waters are more likely to be wholesome than either river or lake waters, at least in countries under cultivation.

14. General definition of a wholesome water.—To be wholesome, and fit for the supply of towns, water should be free from colour, taste, and smell. A peaty water, however, of olive brown colour when seen in bulk, is not objectionable. Exposed for a time in a clear glass vessel to the action of light, a good water should not deposit any sediment, neither should there come upon it a confervoid growth when kept for a reasonable time in a warm atmosphere. It should not give out an unpleasant odour, either when cold or heated to boiling. It should contain a certain quantity of gases, among which carbonic acid gas and common air are the principal. In a limestone or chalk district it will hold carbonate of lime in solution. In a sandstone district it will hold silica, and some of the cementing medium which holds the particles of sand together, and which may be carbonate or sulphate of lime. It will always contain a little common salt and some organic matter. Iron is exceedingly common in all waters, and in all waters that have passed over marl there is likely to be argillaceous matter. Sulphate of lime occurs in the waters running over or through rock containing such substance.

15. Water subjected to injurious contact not necessarily bad.—But water that has crossed a district containing injurious mineral or organic substances capable of being absorbed or that has percolated rocks loaded with such substances, is not always or of necessity charged with any considerable quantity of them. By afterwards passing through and amongst strata in the interior of the earth, or simply by passing over the surface in a stream or river, a purifying as well as an injurious effect may be produced, chemical change takes place, new combinations are entered into, and the water becomes altered in its composition either for good or evil. This is the case with organic as well as inorganic constituents.

16. Pure water not desirable for general use.—Exceedingly pure water—water that approaches distilled water in its freedom from solid contents and gases—is not so well fitted for the general supply of towns as river, lake, or spring waters. Lead and the salts of lead are, to some extent, soluble in such water, and may act as a poison which, being cumulative, is insidious, and, if long neglected, may produce serious results. When freshly-cut lead is exposed to damp air, the lead rapidly oxidizes, and is then soluble in water, the fresh surface of metal thus exposed becoming again oxidized and being again dissolved, and so on. Very soft water, therefore, cannot safely be passed through leaden pipes or kept in leaden cisterns. It may be observed, however, that the risk is small, though real, and that the metal must expose a freshly-cut clean surface to allow of a solution being formed in sufficient quantity to become sensible to the analyst. In the present state of knowledge, it would not be safe to assert that injurious results may not be produced by the passage of very pure water through leaden pipe of the ordinary kind, or its retention in cisterns lined with lead under ordinary conditions. It may be considered as proved, that waters called soft act on a newly-cut surface of pure lead, while hard waters do not so act. But this is a matter on which there is still much for the chemist to discover, and it is unsafe to speculate on it in a sanitary sense.

17. Solubility of lead and iron.—It is doubtless important to recognise, as far as possible, the causes which render certain waters capable of dissolving lead, and many efforts have been made in this direction. Chemists have considered that whenever the total solid contents of water are less than 3 grains to the gallon, there may be danger of solution, although it does not follow that waters with much larger proportions are safe. The danger appears to lie rather in the nature of the mineral or organic contents than the quantity. Dr. Clark, in his evidence before the Parliamentary Committee on the Metropolitan Water Supply (Evidence, p. 128), states, that by adding either organic matter or carbonic acid to water otherwise incapable of dissolving lead, he obtained a result similar to that produced by very pure water. Lead may be a safe material for pipes to carry water, but is not a desirable one for cisterns where water is retained for a time, subject to absorb impurities which may render the salts of lead soluble.

The effect of soft water on iron pipes is thus alluded to by Mr. Hawksley, in his evidence before the Duke of Richmond's Commission, 1869 (p. 154): "The oxidation from the soft water, particularly from those waters that come down from the granites, and are a little alkaline, is enormous. * * * Where the water is soft I allow two inches for corrosion, that is, an inch all the way round, but even this is not in some cases sufficient."

18. Hard and soft water.—We have seen (§ 14) that a useful and wholesome water for household purposes, fit for the general use of towns, and free from colour, smell, and taste, will always contain certain gases, certain mineral salts, and some organic matter. The effect of earthy salts. as lime and magnesia, is to render the water *hard*, and waters nearly pure, or slightly alkaline, are usually *soft*. An alkaline water, however, is not necessarily a soft water, nor does the pressure of a small quantity of common salt contribute materially to hardness. Hardness has always been regarded as a quality rather to be preferred for drinking purposes, but decidedly uneconomical for cooking and washing. Waters containing carbonate or sulphate of lime or magnesia, or carbonate of iron, in solution, are almost always hard in proportion to the amount present of these substances. Spring water obtained from near the surface in chalk or limestone rocks is very hard, but the water from very deep wells in similar rocks, is much less so. Spring water, as a rule, is harder than river water, and lake water is perhaps the softest of the varieties of water to be found in large quantities. From 50 to 100 grains per gallon of soluble mineral substances of all kinds may be contained in water without the quality being necessarily objectionable, and a quantity less than 3 grains of almost any kind can generally be held without risk. The flavour of water is no guide to its freedom from injurious substances; and well-water, sometimes filtered through graveyards or manure, is dangerous because it may become injurious by containing unoxidised products. Its pleasant taste is due to the presence of nitrates. It has often been the case that such waters have been used for drinking purposes so long as their deleterious properties were not discovered.

19. Organic matter naturally burnt off in running water.—River water is constantly receiving a certain quantity of organic matter carried in from the land on the banks, or obtained by the death and decay of various aquatic plants and animals. After exposure to the ordinary action of light and air, these offensive matters become combined with oxygen, and are thus converted into oxides by a process which strictly resembles slow combustion. They are then perfectly harmless. The rapidity of flow or the disturbance of the water helps this result. Besides this, the decaying particles of animal and plant life are the natural food of minute animalcules that abound in water, and many tribes of fishes are nourished by similar food, which thus passes back into the condition of living tissue. In this case the decaying matter disappears altogether from the water as an injurious ingredient. The presence of living plants and animals, though often regarded as a proof of the goodness and purity of water, is so only in a certain sense. Few persons, indeed, would refuse to drink, while none could be injured by the water of a clear stream running over cresses, and peopled by trout and the smaller fishes, crustaceans, and other animals, including the animalcules on which they prey. There is no doubt that animalcules of various kinds form a large part of their food. Fungoid growth, on the other hand, and the curious and minute hairs (*mycelium*) that accompany such growth, cannot be regarded in this light, and are undesirable indications, though often accompanied by animalcules. (See § 31.)

20. Composition of river water varies at different seasons.—The quantity of inorganic matter contained in river waters varies much according to the season, being greatest in summer when evaporation is most rapid and the supply from rain small; while, on the other hand, during winter when the rain-fall is greater and evaporation is slow, the frequent admixture of pure rain-water diminishes the proportion. It was found by Mr. Dugald Campbell, in reference to the waters of the Severn, near Worcester, that the quantity of inorganic matter held in the water in January and February 1852, amounted to 17 grains per gallon; while the quantity held in June, the same year, amounted to $32\frac{1}{2}$ grains.* There is no reason to doubt that this is the case with other rivers, though to a smaller extent, the Severn being an extreme case, and that frequently the winter flow is not only larger but less free from salt than the summer flow. But where, as in some cases, there are powerful

* Mr. Hawksley's Report on Water Supply of Worcester, p. 28.

bottom springs always flowing, independently of the state of the weather at the time, it is quite possible that this condition should be greatly modified and even reversed. This is the case with some English rivers running over broken limestone of the carboniferous period.

21. Waters do not readily mix.—When the sewage of a large town enters a river it is assumed that mixture takes place with the stream; and, no doubt, it begins to do so immediately, but a considerable time may elapse before the mixture is complete. This arises from the fact that a current is soon established by the inflow of fluid, and the sewage stream being generelly slightly different from the river water in density and somewhat warmer, it is carried along as in a trough or canal, just as the waters of the Gulf Stream cross the Atlantic without losing their peculiar characteristics. Where the proportion of sewage to the body of water passing down the stream is large, the whole stream, however, becomes infected; the fish die in it, and even vegetation languishes. Such was the case with the Thames below London some years ago. By careful attention and a partial removal of the cause the river is now greatly improved, and the fish are returning. In all cases the waters become purified as they proceed, but the rapidity of the process depends on the conditions of mixture and exposure. The varying condition of the water accounts for the very different results obtained by chemists as to the distance and time required for perfect destruction of the sewage impurities that enter a river; for it is clear that absolute and complete mixture of these substances with the waters of a stream, must always involve time. The sewage, as already explained, will take a certain course in the stream, and will only partially affect other parts. Thus a great deal of the water is but little affected, and up to the last a certain portion, gradually diminishing in volume, is more contaminated than the rest. When a confluent enters a river, or when two branches unite to form one stream, the same slowness and difficulty of mixture may be observed, the waters, if of different colour, composition, or temperature, taking each its own course for a considerable distance.

22. Purification of polluted river water by exposure to air.—The investigations of the Commissioners appointed to report on the Pollution of Rivers, of whom Dr. Frankland was one, led them to the conclusion that the waters of polluted rivers were not rendered potable and safe by any mere exposure to the air present in water. They experimented on certain Lancashire streams—the Irwell, the Mersey, and the Darwen, during the winter season, and the result was unfavourable. It has, however, been pointed out by other eminent chemists that this mode of investigating the subject is not satisfactory, and that observation on the known result in the majority of streams is of more importance in the determination of the fact than minute laboratory experiments in the case of rivers exceptionally polluted. The late Dr. Letheby has remarked that ordinary London sewage containing 100 grains of solid matter to the gallon, of which 14 or 15 grains are organic, mixing with 20 times its bulk of ordinary river water, and flowing a dozen miles, contains no quantity of sewage discoverable by any reliable chemical process. The late Professor Miller, of King's College, London, took specimens of Thames water in 1859, at Kingston, at Hammersmith, at Somerset House, at Greenwich, at Woolwich, and at Erith, on the same day, and examined the quantity of oxygen in each. At Kingston it was the ordinary and normal proportion usual in Thames water; at Somerset House the proportion was much diminished; at Greenwich the whole of the oxygen had disappeared; but at Erith, the water was already very much improved. He regarded this as direct proof of the effect of oxygen in destroying those organic contaminations that are thrown into the river. Dr. Odling says:—"You see in many rivers —even sluggish rivers—having sewage discharged into them, that for a mile or two the appearance of the river is affected by the sewage; but beyond a certain distance there is no recognisable effect at all," and he instances the Soar, in Leicestershire, "which is black and very foul from the refuse of the town; but three miles below you could not tell that it had been contaminated, for it was running clear, with fish swimming in it, and the weeds were clean." Even in the case of the Irwell, experimented on by Dr. Frankland, we have a river which has received pollution of all kinds from a vast manufacturing district, exceedingly foul as it passes Manchester, but altogether changed at Warrington (about nine miles below), where it ceases to be an offensive stream. It is indeed notorious that every stream however it may be affected by sewage, or by impurities of every kind, in the upper part of its course, is invariably rendered much less foul, and is often apparently quite pure after running a few miles through an open country; while even in the cases (not unknown in England) where a stream passes a large number of towns in its course, and receives from each a certain quantity of pollution, the water does not get worse as it goes along, and after passing the last of the sources of contamination, becomes actually in a better state, in a sanitary sense, than between the first and second of the many towns it passes and is affected by. All observers, whether chemists or engineers, are agreed that there is no amount of impurity to which rivers are subject that is not steadily, and even rapidly, diminished, as the stream leaves the source of pollution, and becomes oxidized by exposure to the atmosphere when mixed thoroughly with running water.

23. Dr. Tidy's experiments on the oxidation of sewage water.— Dr. Tidy has recently made a series of laboratory experiments on the rate of oxidation of disturbed sewage water, and is still pursuing these important investigations. I am informed by him that, at the present time, his results prove that, when water containing one pint of ordinary London sewage added to 20 pints of water was allowed to fall slowly from a height of 17 feet in 5½ minutes through the air a number of times, the result was as follows:—

Oxygen required to oxidize organic matter in dilute sewage at commencement of the experiment	1·563
After 10 falls, oxygen required	1·120
20 " "	0·820
30 " "	0·633
40 " "	0·486
50 " "	0·352

The further experiments of Dr. Tidy I hope to be able to insert in an Appendix, if, as is probable, they help to clear up the very important question as to the circumstances that help or prevent oxidation of sewage in running water. The cause of the reduction in the quantity of chlorides by exposure to oxidation when these salts are held in excess is also a subject that will be investigated during these experiments.

24. Rivers natural sources of water supply.—Rivers are the natural sources of water supply for all populations situated on and near them. They are fed by springs and rainfall, conveyed by numerous channels. They are, from their position on the surface, the recipients of every kind of decaying life, but are enabled to recover almost any amount of defilement by natural chemical processes. The animals that inhabit them help to remove much organic matter that would otherwise decompose. Rivers are subject, no doubt, to change, and their waters are greatly affected, both by the tributaries that feed them, and by drainage that enters them from independent sources. Often fouled and seriously affected by the human occupation of the adjacent land, they run clear and comparatively pure water after a sufficient interval. They have been made use of for domestic purposes at all times and in all countries, and most towns of importance are built near them, utilising their contents for food and cleansing purposes, as well as employing them as means of communication by water-carriage. Without running water adjacent, it is hardly possible that a town can be healthy, partly because the river removes the waste and sewage, and partly because it supplies the fresh water that assists to purify that which is fouled. There is, however, no doubt that owing to the increase of population in certain localities in a country where the volume of water conveyed by the rivers is not large, the quantity of impurity may in time become so great as to render the natural cleansing process insufficient to purify the river water between adjacent towns as it passes onwards to the sea.

25. Lakes as sources of supply.—Lakes are natural reservoirs, and consist of accumulations of water, either in depressions scooped out of the general surface of the earth, or of valleys closed at the lower end by some obstacle. They receive running waters, and the overplus of the water, after filling the lake, generally escapes by a stream. Exceptions to this occur (1) when the evaporation from the surface of the lakes equals or exceeds the ordinary supply of water; and (2) when there is some underground and invisible channel either into open rocks, or to running water at a distance at a lower level. Like rivers, lakes are fed by drainage areas, or tracts of land, from the surface of which a greater or less proportion of the total rainfall runs off into a channel or receptacle. They occur either in mountainous districts, as in Switzerland; in large level plains, as in Sweden and Lapland, in the interior of Australia, etc.; on high table-lands, as in the interior of Africa; or in the course of large rivers at different levels, as the great lakes of North America. These natural depressions are the temporary recipients of the drainage of limited tracts of mountain and moorland prevented from running direct to the sea by natural obstacles. They are imitated on a small scale in many parts of England and elsewhere in the storage reservoirs that are formed for the supply of large towns.

The water of lakes is made use of directly for the supply of towns in some cases in Great Britain. These mountain lakes being remarkable for purity the water needs only to be conveyed by pipes to towns on or near the banks. Glasgow is thus supplied from Loch Katrine, and Whitehaven from Ennerdale lake. It has been proposed to supply London from Bala lake, in North Wales; and Manchester from Thirlmere, in the Cumberland lake district. In America the supply for the rapidly increasing town of Chicago is obtained from the adjacent lake Michigan; but, as the waters near the town are fouled by receiving the sewage of the city, it has been found necessary to tunnel under the lake and take the water at a distance of two miles from the shore.

26. Injury from admixture of sewage and waste.—The nature of the injury done to river water by the admixture of the disjecta of animals and human beings, and the waste of towns and factories, cannot be regarded as seriously affecting the quality of running water for domestic purposes, until a certain proportionate amount is reached. It is perfectly certain that, in the open country, river water, under ordinary circumstances, is wholesome and safe for general use. It is equally certain that such water, wherever there are men and animals, must be exposed to the impurities alluded to, and that, unless there were some natural processes of purification, the water of all running streams would long since have become absolutely unusable before reaching the sea. It is certain, on the other hand, that impurities are not cumulative, but tend to be got rid of in the laboratory of nature. Where, however, sewage is collected and poured into a river in considerable quantities at one spot, the conditions of purification are least favourable, and in such cases the water may travel for a long distance in a bad or doubtful state. The improvement of the water depends on the extent to which mixture takes place, and the extent to which the combined sewage and running water gets exposed to the atmosphere. There is not the smallest doubt that town sewage and dead organic matter that has been buried in earth acquires, after a time, highly injurious properties, transmissible to the air and readily absorbed by water. Fresh sewage, though disagreeable to the senses, is probably of little danger, and it is certainly a mistake to suppose that the worst-smelling sewage is the most dangerous. Malarious gases, especially those which are most rapid and fatal in their action on the human system, may be nearly or quite free from sensible odour, and even the odour they emit is more sickly than offensive. Every one who has had experience in Havana or New Orleans during the time when yellow fever is rife, or of the malaria season on the shores of the Mediterranean, is aware of this fact, and I can speak of both localities from personal experience.

The average quantity of dry solid sewage matter (being personal sewage contamination) derived from each head of population in English towns is something less than 3 ounces per diem (say 1,200 grains), and it is delivered in combination with about 40 ounces of water ($2\frac{1}{2}$ pints). In other words the daily personal sewage per head of population consists of ·3125 gallons of liquid, and 1,200 grains of solid matter, partly in solution or suspension. In towns supplied with water at the rate of 30 gallons per head, it may be estimated that for each 1,000 of population there are about 30,000 gallons of effluent, containing 1,200,000 grains of personal sewage contamination, being at the rate of 40 grains per gallon; 100,000 lbs., therefore, of such water would contain 56·15 lbs. of organic impurity. No account is here taken of the rainfall, or the general sewage of a town, or of manufacturing waste or street sweepings. These will all be carried away with the personal sewage, and tend to modify greatly its condition. For obvious reasons, much of the personal sewage does not enter the public sewers.

In the case of London, 100,000 lbs. of ordinary Thames water contains about 30 lbs. of solid constituents, of which nearly a quarter of a pound is organic carbon. The total effluent will, therefore, contain more than 86 lbs. in 100,000 of solid matter, or, in other words, more than 60 grains to the gallon.

The time required for the oxidation of organic matter in a river depends on the nature of the stream, its volume, the rate of flow, the depth, the nature of the river bed, and the season of the year. Shallow rapid streams expose more surface for the absorption of oxygen, and mix more rapidly than slower and deeper streams. Dr. Letheby estimated that in ordinary streams in England, if sewage water containing 100 grains of solid sewage contamination per gallon be mixed with 20 times its volume of pure water in a running stream, it will be oxidised completely within a distance of 7 miles, say in $2\frac{1}{2}$ hours, or a little more, if the stream flow at the rate of 4 feet per second, or $2\frac{3}{4}$ miles per hour.

Dr. Frankland, however, has found by experiment that, in cases that have come under his observation, this result was not obtained. It is likely that the sewage does not always get mixed with the whole of the water of the stream, but, under certain circumstances, is so long in mixing, that complete oxidation is seriously delayed.

According to Dr. Letheby's experiments, if the population on the banks of a stream does not exceed 100,000 for every seven miles, and the minimum summer flow is one million gallons per hour, the water will run pure and safe from town to town. Allowing for manufactures and accidental causes of impurity, it was considered by Dr. Letheby safe to assume that a population of 10,000 per mile would, in such a stream as that assumed, leave no marks of its existence in the river flowing past it.

It will, however, be easily understood, that when the course of a stream is not favourable for the complete admixture of the sewage with the whole volume of the water—an exceedingly probable contingency—the period of oxidation will be delayed, and when, owing to the depth of water and the winding course of the stream, the sewage effluent is either floated in a distinct channel or thrown aside on the banks during the first few hours of its course, whatever mischief may be due to the exposure of sewage matter is not likely to become oxidised and disappear.

27. Injury from undeveloped organisms.—Besides the presence of sewage rendering water injurious and unhealthy by direct admixture, we must also recognise as agents of mischief certain things that in their natural development tend to produce a similar result. It would seem quite possible that when taken at a particular part of a stream water may appear, even under analysis, to be without any source of serious pollution, while the same water, when it has flowed for some distance without being interfered with, may become exceedingly bad without other admixture. This is the case when some foreign matter has been introduced containing seeds or germs too minute for determination in their undeveloped state, but capable, when developed under the influence of light and heat, of loading the water with myriads of organisms. It has happened that where Esparto grass has been used in paper mills for the manufacture of paper, the waste entering a stream has, after a short course, crowded the water with myriads of diatoms, and the result has been the presence of highly offensive and mischievous forms of matter, both living and dead. It is not easy to exaggerate the importance of this result.

It may be that the mere presence of these forms of life is not injurious, and that their extreme and rapid multiplication is only produced when the conditions are unusually favourable; but certainly water in that state is not fit for use in food. There is but little evidence as to the time or circumstances required to bring about suoh a result, or how far it might have been affected by filtration, but the fact referred to occurred some years ago in a stream rising in and flowing over chalk, and was regarded as a very serious matter, involving legal proceedings.

Besides the ordinary impurities that can be seen, weighed, and measured, and those mysterious and indeterminable causes of evil that can only be discovered when their effects have been produced, we must also recognise as real the ova and seeds of infusoriæ, and the spores of some low forms of vegetable organisms, capable of being warmed into life by certain kinds of exposure. Warmth and light are well known to encourage vegetable growth in water; and it is familiar that water kept in covered reservoirs is less liable to become covered with *confervæ*, or mossy vegetation, than when exposed to the air. Dr. Hassall, in his evidence before the Board of Works, in 1850 (Appendix iii. p. 31), states, that he, on one occasion, introduced into pure water living animal and vegetable productions appertaining to each of the principal classes of the lower forms of organic life (viz. (1) *Entomostraca*, (2) *Infusoria*, principally the Thames species of *Paramecium* and *Oxytricæ*, (3) Green infusoriæ of the genus *Euglena*, (4) filaments and spurs of green *Converveæ*, (5) *Desmideæ*, (6) *Diatomaceæ*, (7) *Fungi*.) After exposure for about a week to air and light all these were found to be still living. After five weeks all, except the Thames *Paramecium*, had multiplied greatly, and by that time other species had made their appearance, especially of diatoms and conferveæ, the water assuming the green tint of pond water. The Thames *Paramecium* had disappeared, but the *Oxytricæ* were abundant. In this experiment fresh air was entirely excluded.

28. Mouths of tidal rivers contain much decaying organic matter.—In tidal rivers water is sometimes rendered foul and impure for a long distance, owing to the destruction of minute fresh-water animals constantly coming down the stream and met at a certain point by the tide. The sea water being heavier and denser than the fresh water of the river, forces its way up the stream below the fresh water in the form of a wedge, the thick end of the wedge being the place where the advancing tide is seen at the surface and comes in fresh from the salt water, and the thin end the extreme point to which the highest spring tides reach. Within these limits there is a certain belt where the destruction of the fresh-water animalcules that come in contact with the salt water, and that are not adapted to live in both, takes place twice a day; and another belt, extending further up the river, only affected at spring tides twice every month. So large is the result, that the minute atoms of flint that form the skeleton of these microscopic animalcules have, in the case of the Elbe and other rivers, formed thick deposits interfering with navigation.* Besides this, there is always a large quantity of organic matter in a decaying state brought down within tidal influence, and there drifted backwards and forwards before it is finally got rid of. On all these accounts the water of a tidal stream, even above the point where the salt is recognised by taste, is often unfit for town supply. According to a recent report by Capt. Calver, there is now a portion of the Thames, eight miles in length, above the outfall of the London sewage, where there are portions of the sewage always held in suspension.

29. All fresh water derived from the sea.—Fresh water is obtained apparently in various ways, but ultimately it is derived from the natural process of distillation that takes place from the surface of all water, but more especially from the oceans within the tropics; and the water thus obtained, partly visible as cloud, partly retained in the air, travels rapidly towards the poles, and on its way is condensed on mountain sides, or falls on widely extended plains. The water thus falling is carried over the surface of the earth back to the sea in rivers, or enters the earth by the numerous crevices that exist in all rocks where they are exposed to weather, and after there performing a course more or less long, re-issues from the earth in springs, or may be lifted from wells when it does not rise to the surface. This perpetual circulation of water is the fundamental fact in science on which all questions of water-supply ultimately turn.

30. Rainfall in excess of the quantity of water carried off by rivers.—It is not difficult to show that this circulation involves the whole mystery of water supply. Rivers always running, and conveying very large quantities of water into the ocean, receive the drainage of an area of land, whose extent bears some proportion to the volume of water that they pour into the sea. On this area falls an amount of rain that can be estimated. Every inch of rain that falls uniformly over a square mile of the earth's surface deposits rather more than $14\frac{1}{2}$ millions of gallons of water. If, therefore, the mean annual rainfall at any place is taken at 25 inches, there will be an average daily deposit of nearly a million gallons. Assuming that the river Thames, in the neighbourhood of Richmond, drains 4000 square miles of country, and that the rainfall over it is 25 inches, which is not far from the truth, it is evident that if the whole of the rainfall passed down the river it would run on an average four thousand millions of gallons per day, whereas the measured quantity

* The beds of *polir-schiefer*, or polishing slate, of Bilin, in Germany, and the impalpable siliceous powder used for similar purposes from other rivers, was long ago proved, by the well-known microscopist Dr. Ehrenberg, to be entirely produced by this deposit.

does not exceed one-eighth part, or 500 millions. It results that a very much larger part of the rain that falls fails to enter the stream than is carried off by it. This large margin remains to be accounted for. It may and does vary greatly in different drainage areas, and with different amounts of rainfall; but we shall see in the next chapter, where this subject will be discussed at greater length, that in a large number of recorded instances where careful measurements have been made,—even in those where the rainfall is sudden and torrential, the rock favourable for carrying off the water rapidly and completely, and the measurement taken at a point near the heaviest fall,—the quantity removed by a stream is considerably less than that received on the surface.

31. Classification of sources of water supply.—But whatever becomes of the surplus rain, whether it passes back again into the air, sinks into the earth, or is made use of by animal or vegetable life, the fact remains that if it were not for the rainfall there would be no water to be obtained from the land, and that, therefore, animals and plants as they are now constituted would cease to exist. It is true, however, that besides the water collected into and run off towards the sea by rivers, there is another and very useful store available for the use of man. Water sinks down beneath the surface, and is apparently lost; but it is really only carried out of sight. At a depth that can often be determined, and in quantities that can sometimes be measured, there is a circulation of water in all rocks, whatever they are composed of and wherever they are situated. The current, like that of rivers, is always moving towards an outlet, it is always changing its level, and it is dependent on the rainfall. We may consider water as obtainable for human purposes in several ways, of which the following is a summary:—

Sources of Water Supply.

A. Waters from superficial sources.	running off the surface from drainage areas	1. Rivers, brooks, and streams of running water of all kinds.
	collected	2. Lakes (natural reservoirs). 3. Reservoirs (artificial lakes).
B. Waters from deep sources.	emerging naturally . .	4. Springs issuing from the earth at the surface.
	tapped underground .	5. Artesian wells. 6. Wells of exhaustion.

32. Qualities of surface and spring waters.—The waters obtained by any of the methods referred to in the first group, come under the denomination of *surface waters.* Those in the second group are *spring waters.* The former are occasionally pure, especially in the case of mountain streams, mountain lakes, and reservoirs into which water collects from moorlands, when without peaty stain and with little vegetation. Such waters are less fresh and pleasant to the eye and taste than spring waters. Spring waters are often free from organisms, and generally clear and pleasant, and when not drawn from excessive depths, are almost always cool in summer. There are, however, among surface waters, some that are absolutely poisonous, in consequence of careless management and neglect, resulting in the infiltration of gases and soluble salts. Some also of the river waters are injured by the introduction of town sewage and the waste of manufactories carried on near their banks, so that they cease to be of value for human consumption until naturally purified by oxidation, which can only be effected by sufficient exposure.

33. Summary of desiderata for potable waters.—The following summary of facts regarding the quality of waters for drinking purposes, is deduced from an interesting chapter on the properties of water in a work of considerable reputation in France, by Mr. J. Dupuit, entitled "Traité théorique et pratique de la conduite et de la distribution des eaux." Paris, 2nd edit., 1865. Frequent reference is made in this chapter to the "Annuaire des eaux de la France pour 1851." [It may be observed that several of the conditions (*e.g.* 4, 7, 10,) are not considered essential by English chemists, while one (12,) would admit waters as potable which, with us, would be regarded as almost poisonous. No English water containing more than ·001 of ammonia would be considered good.]

(1) The medical effect of very minute quantities of certain salts in mineral waters is incontestable. Spring water, therefore, if in some cases influential for good, may in others be highly injurious. (2) A little carbonic acid gas is pleasant and advantageous in water, and some atmospheric air is necessary. (3) The smaller the quantity of organic matter water contains, the better it is for drinking purposes, other things being the same. (4) The nearer the air contained in water approaches in its composition to atmospheric air the better. (5) A minute quantity of bi-carbonate of lime in water is desirable. (6) Magnesian salts are not generally injurious, as found in natural waters. (7) Sulphate of lime is undesirable, perhaps mischievous. (8) Nitrate of lime is also objectionable. (9) Chloride of sodium is rarely present in quantity sufficient to do harm; but the iodides and bromides with which it is generally associated, are important, and may be mischievous. (10) All water containing as much as 70 grains per imperial gallon of mineral salts, in a state of solution, is bad, except when the foreign ingredient is bi-carbonate of lime, which spoils the water for other purposes, but little affects its sanitary value. The evil effect of excess of carbonate of lime is

recognised in incrustations, either in the pipes through which the water is carried, or in the vessels in which it is boiled. (11) The limit of gases contained in a litre of water should not be less than 20 cubic centimetres of nitrogen (4·8 cubic inches to the gallon), 9 to 10 of oxygen (2·17 to 2·4 cubic inches per gallon), and 20 of carbonic acid (4·8 cubic inches per gallon). (12) The maximum limit of nitrates is ·7 grain per gallon, and there must not be more than ·007 grain of ammonia in a gallon.

34. Impure waters best for industrial use.—It is a fact better recognised in France than in England, that good potable water and good water for industrial processes are often very different. In a pamphlet recently published by M. Gérardin, some curious instances are given of this which are well worthy of record. A manufacturer at St. Denis found that for wool-washing, muddy and infected water from the Groult, a small neighbouring stream, was greatly superior to the clear water of an artesian well. For the production of gelatin; the Seine water, very indifferent for drinking purposes, was found greatly superior to that of the river Vaune, a pure stream lately brought into Paris for supply. It is also said that water in which the minute foreign substances present are in a state of activity is the more potable, while that in which the foreign substances sink by the action of gravity is more fit for manufacturing purposes. Thus the introduction of sewage matter actually improves water for industrial use. It is a very important fact, and one not generally recognised, that water which appears to have a certain vitality, however produced—which, in other words, contains living organisms—should be the best for food purposes, and that such water is mischievous when decomposing organic matter is introduced, causing it to lose this vitality, but at the same time improving it for certain industrial uses. It is also known that the minute forms of crustacean life, such as belong to the families of *Daphnaidæ* and *Cyclopidæ*, are only found in potable running waters of good quality, though potable well waters are generally without them. It is a fact that filtration does not remove all these organisms, nor does it separate the ova germs. It may be a satisfaction to those who drink water to know that these animals are exceedingly sensitive to changes of temperature, ceasing to live at a higher temperature than 85° F., while an amount of alcohol to the extent of 4 per cent., or the smallest amount of gastric juice, is fatal.*

35. Determination of relative hardness by Clark's test.—All waters are affected by the mineral constituents of the rocks over or through which they pass, as from them they obtain those solid contents which we have already seen may be very considerable in amount without interfering with the wholesomeness of the water. These foreign ingre-

* Social Science Congress 1877. Paper by Mr. W. J. Macadam. See *Sanitary Record*, iii. p. 222.

dients, the proportion and nature of which vary in every case, greatly influence the value of water for the ordinary purposes of life. Water that is too hard, is not convenient or economical for washing,* but it is pleasant to the taste, and makes good beer. Soft water is excellent for washing, and is generally useful, but is perhaps more apt to contain organic matter:—it makes beer that will not keep, and sometimes dissolves lead when passed through or kept in leaden pipes, or reservoirs. Hardness beyond a certain limit is generally felt as an evil, and for this reason a water that is sensibly hard, or in other words that requires a great deal of soap before it will be available for the washing of hands or linen, is objected to for any but drinking purposes, and extreme hardness is regarded as a quality to be avoided. A test of hardness that can be generally applied, was one of the earliest requirements in investigating the quality of different waters. The best of these tests was introduced by Dr. Clark, of Aberdeen, and it consists in ascertaining the quantity of a standard solution of soap in alcohol that is required to produce a permanent lather when mixed with a given quantity of the water under examination. The result is expressed in degrees of hardness, each of which corresponds to one grain of carbonate of lime in a gallon of the water. As this test is now generally received and constantly referred to, the following particulars concerning (1) the preparation of the soap test, and (2) the process for ascertaining the hardness of the water, will be found useful. It is taken from Dr. H. M. Noad's work on "Quantitative Analysis," p. 576.

36. Preparation of the soap test and standard solution.—The first thing necessary is to prepare a standard water from which may be determined the accuracy of the soap test:—"Sixteen grains of pure crystalline carbonate of lime (Iceland spar) are dissolved (taking care to avoid loss) in pure hydrochloric acid, the solution is evaporated to dryness in an air bath, the residue is again redissolved in water and again evaporated, and these operations are repeated until the solution gives to test paper neither an acid nor an alkaline reaction. The solution is made up by additional distilled water to the bulk of precisely one gallon. It is then called "the standard solution of 16 degrees of hardness."

The soap test itself is prepared as follows:—"Good London curd soap is dissolved in proof spirit in the proportion of one ounce avoirdupois for every gallon of spirit, and the solution is filtered into a well-stoppered phial capable of holding 2,000 grains of distilled water. One hundred test measures, each measure equal to 10 water-grain measures of the standard solution of 16 degrees of hardness, are introduced. Into the water in this phial the soap solution is slowly poured from a graduated

* The cause of objection to hard water in washing is purely mechanical. More labour is required and more friction when the water is hard.

burette, the mixture being well shaken after each addition of the solution of soap, until a lather is formed of sufficient consistence to remain for 5 minutes all over the surface of the water, when the phial is placed on its side. The number of measures of soap solution is noticed, and the strength of the solution is altered, if necessary, by a further addition of either soap or spirit, until exactly 32 measures of the liquid are required for 100 measures of the water of 16 degrees of hardness. The experiment is made a second and a third time, in order to leave no doubt as to the strength of the soap solution, and then a large quantity of the test may be prepared, for which purpose it is recommended to scrape the soap into shavings by a straight sharp edge of glass, and to dissolve it by heat in part of the proof spirit, mixing the solution thus formed with the rest of the proof spirit."

37. Application of the soap test.—" Previous to applying the soap test, it is necessary to expel from the water the excess of carbonic acid, that is, the excess over and above what is necessary to form alkaline or earthy bi-carbonates, this excess having the property of slowly decomposing a lather once formed. For this purpose, before measuring out the water for trial, it should be shaken briskly in a stoppered glass bottle half full of it, sucking out the air at intervals by means of a glass tube, so as to change the atmosphere in the bottle. One hundred measures of the water are then introduced into the stoppered phial and treated with the soap test, the carbonic acid eliminated being sucked out from time to time from the upper part of the bottle. The hardness of the water is then inferred from the number of measures of soap solution employed, by reference to the table subjoined. In trials of water above 16 degrees of hardness, 100 measures of distilled water should be added, and 60 measures of the soap test dropped into the mixture, provided a lather is not formed previously. If at 60 test measures of soap test, or at any number of such measures between 32 and 60, the proper lather be produced, then a final trial may be made in the following manner :—100 test measures of the water under trial are mixed with 100 measures of distilled water, well agitated, and the carbonic acid sucked out ; to this mixture soap test is added till the lather is produced ; the number of test measures required is divided by 2, and the double of such degree will be the hardness of the water. For example, suppose half the soap test that has been required correspond to $10\frac{1}{2}$ degrees of hardness, the hardness of the water under trial will be 21. Suppose, however, that 60 measures of the soap test have failed to produce a lather, then another 100 measures of distilled water are added, and the preliminary trial made, until 90 test measures of soap solution have been added. Should a lather now be produced, a final trial is made by adding to 100 test measures of the water to be tried 200 measures of distilled water, and the quantity of soap test is divided by 3, and the degree of hardness corresponding with the third part being ascertained by comparison with the standard solutions, this degree multiplied by 3 will be the hardness of the water. Thus, suppose $84\frac{1}{2}$ measures of soap solution were required, $\frac{84 \cdot 5}{3} = 28 \cdot 5$, and, on referring to the table, this number is found to correspond to 14, which, multiplied by 3, gives 42° for the actual hardness of the water."

Table of Soap-test Measures corresponding to 100 *Test-measures of each Standard Solution.*

Degree of hardness.	Soap-test measure.	Differences as for the next degree of hardness.	Degree of hardness.	Soap-test measures.	Differences as for the next degree of hardness.
0	1·4	1·8	9	19·4	1·9
1	3·2	2.2	10	21·3	1·8
2	5·4	2·2	11	23·1	1·8
3	7·6	2·0	12	24·9	1·8
4	9·6	2·0	13	26·7	1·8
5	11·6	2·0	14	28·5	1·8
6	13·6	2·0	15	30·3	1·7
7	15·6	1·9	16	32	
8	17·5	1·9			

38. Potential carbonate of lime.—It is remarked, in a valuable little work on Water Analysis, published by Messrs. Wanklyn and Chapman, that Dr. Clark has adopted the indirect and not the direct way of registering hardness or soap-destroying power. In other words, the degree of hardness is measured by the quantity of carbonate of lime or its equivalent in other salts contained in the water tried, and not by the quantity of soap which a gallon of it will destroy. It will result from the table that one gallon of pure water requires 0·8 grains of soap test to make the lather. According to Mr. Wanklyn, 1·00 grain is a more correct estimate, and he considers that the total or *potential* carbonate of lime is 1° higher than is given by Clark's test. Taken in this way, the number of grains of potential carbonate of lime is strictly proportional to the soap-destroying power of the water. Thus, if 14° is the degree of hardness of Thames water by Clark's test, the water contains 14 grains of carbonate of lime (or its representative) to the imperial gallon, and, as it takes the equivalent of 1 grain to produce lather in distilled water, it takes the equivalent of 15 grains to do it in the tried water. Thus the potential hardness of Thames water is 15°. It is right to state that this view adopted by Mr. Wanklyn is not generally accepted by English chemists.

39. Technical hardness.—In the practical details of examining the water and preparing the soap test, analytical chemists differ, but this is a matter with which the engineer and the general inquirer need not concern themselves.* It is desirable that Dr. Clark's measure of the hardness of water, which is now generally adopted and constantly referred to, should be clearly understood, and I have given an extended account of it so as to enable any person accustomed to careful observation to make the experiment for himself. To the engineer and manufacturer it is convenient to bear in mind that the loss or destruction of soap by hard waters is at the rate of about 2 ounces per 100 gallons for each degree of hardness, or for each grain of chalk per gallon. Thus, a water of 16 degrees of hardness (Clark's test) contains 16 grains of chalk (or its equivalent) per gallon, and 100 gallons of such water would take 32 ounces or two pounds of soap to reduce it to the condition of distilled water. Two pounds of soap, therefore (costing something less than eight pence), represents the loss sustained by using each hundred gallons of such water for ordinary domestic purposes and manufacturing uses requiring soft water without boiling. According to Dr. Clark, magnesia, when present, causes soap to be curdled, but not destroyed, and he believes that when the hardness exceeds 10° the presence of magnesia is not recognised.† He also states that sulphate of lime and common salt exercise very little influence in hardening ordinary waters, carbonate of lime being the chief ingredient. Oxide of iron is rarely present in sufficient quantity to exercise much hardening effect.†

40. Total and permanent hardness.—The total or "initial" hardness of any water is generally understood to be the soap-destroying power of the water before treatment of any kind. But water is used for many purposes in a boiled state, and as a considerable change is often effected by prolonged boiling, it becomes necessary to estimate its condition both before and after this process. What remains after boiling is now generally called the *permanent hardness* as distinguished from the natural or *temporary hardness*. It is estimated after boiling the water for not less than a quarter of an hour, adding distilled water to make up for the loss on evaporation. Temporary hardness is due to the presence of the carbonates of lime or magnesia, or both, and, during boiling, the carbonic acid being expelled, the carbonates are precipitated. The water, therefore, becomes softer.

"In expressing the hardness of a water by degrees, it is to be under-

* I may observe here that the theoretical hardness of chemists is by no means the practical hardness of common life.

† The action of magnesia on soap is absolute, but slow. In carrying out the investigation for hardness the carbonate of lime first produces its effect, and when that has ceased, after a short interval, the effect of the magnesia begins. The test must, therefore, be continued after the first bubbles are formed, and a general idea may be obtained of the relative proportion of lime and magnesia carbonates by noting at what stage the investigation is thus interrupted.

stood that every degree theoretically represents one grain of calcic carbonate, or its equivalent, in soap-destroying power, in one gallon of water."*

41. Previous sewage contamination.—Next to the hardness, and of much greater importance in a sanitary point of view, is the consideration of the nature and history of the water with regard to organic matter. This, and the amount of ammonia, which is closely connected with it, are matters of vital importance, and must ultimately be referred to the chemist. The presence of nitrates and nitrites, or rather of nitrogen in these forms, has lately been regarded as affording proof that water so characterised has, at some time, been mixed with sewage matter. From the nitrogen existing as nitrates and nitrites, Dr. Frankland estimates the quantity of sewage he supposes to have been originally mixed with the water, taking as his *datum* the quantity of nitrogen present in 100,000 parts of raw London sewage. This constitutes what he has called *previous sewage contamination.* Nitrates and nitrites, however, exist in waters which have had no recent access to such sources of injury, and this name, till lately adopted in official returns, was calculated to excite unreasonable prejudice rather than suggest useful precautions. At any rate it would not be right to speak of such contents as nitrates and nitrites as in any fair sense dangerous or undesirable. Many waters contain from one-tenth of a grain to two or three grains per gallon of these salts, without having had at any time direct access to decaying organic matter. It is admitted that vegetation taking place in rivers and lakes containing nitrates is more likely to withdraw from them nitrogenous salts than to add to them, and it is evident that the mere presence of such foreign substances cannot practically be allowed to limit our choice of water, or prevent our using samples which have been exposed to impurity. It is stated by Mr. Wanklyn, that "the total solid residue left by a water, the hardness, the amount of chlorine, and the nitrates, are data which in themselves are seldom of much direct value in enabling a judgment to be given, whether a water be potable or not;"† but this view is not generally accepted.

42. Explanation of the term.—The expression *previous sewage contamination* has involved much discussion of late years, owing to the difficulty of not attributing to it a meaning very different to that which its author intended. The term being introduced by Dr. Frankland into his periodical reports on the result of analysis of the various waters submitted to him by the public authorities for the Metropolis, the Registrar-General had adopted it in his own reports without further explana-

* Tidy's "Handbook of Modern Chemistry," p. 208.
† Wanklyn and Chapman's "Water Analysis," p. 40.

tion, until the commencement of the year 1877. It is now discontinued, owing, perhaps, to the alarm spread by the use of language so easily misunderstood. It is, however, important that its true value and meaning should be clearly explained, and this is best done, as far as possible, in the words of Dr. Frankland himself.

In the first place, Dr. Frankland has very distinctly stated* that he does *not* mean by this term any actual impurity that can be detected by chemical analysis. He believes that the whole of the ammonia and the nitrogen existing in any water in the form of nitrates or nitrites, both being soluble salts, has been so introduced by the admixture at some time or other of manure or sewage, in other words, of animal or vegetable matter in a state of decomposition, or arising from the excreta of animals. Matter in this state (*i.e.* as organic matter) is not in itself necessarily injurious, but it may be dangerous as containing, in a state of mechanical admixture, certain spores or germs which, when developed, are believed to induce choleraic or other diseases. Dr. Frankland goes so far as to say that no running water that has been exposed to the possibility of pollution by receiving human exuviæ is safe water for human use. Rain-water (though containing ammonia), gravitation water that has not passed inhabited or cultivated districts, spring water issuing out of the earth from hill sides or from great depths, and lake water in certain parts of England, he considers pure, as containing no nitrates or nitrites, and therefore no "previous sewage contamination," or at least containing only the most infinitesimal proportion. All other water without exception he regards as liable to suspicion, and therefore unfit for use. He considers natural filtration through chalk and sandstone likely to separate disease germs and sources of contamination, but he doubts the effect of artificial filtration. I have been careful in stating what I believe to be Dr. Frankland's meaning as fairly and clearly as possible, and almost in words he himself has used.

43. Case of Dover Beck.—As an example—perhaps an extreme example—of the singular result of the application of this mode of stating a fact about which all are agreed (viz., the presence of certain salts and mineral compounds, determinable by analysis), I give an analysis made by Dr. Frankland in a case before Parliament (Nottingham Water Bill), and the extent of this apparent source of danger in a water otherwise pure to which he objects.

It was proposed to take for the use of Nottingham the waters of a small stream, the Dover Beck, entering the Trent a few miles below Nottingham. The waters of this stream rise in very strong springs yielding from two to three million gallons per day from the pebble conglomerate of

* See evidence given in the case of the Nottingham Water Bill, 1869. House of Commons Committee.

the Bunter, or lower part of the New Red Sandstone. The whole of the ground over which the stream passes, almost from the source to the proposed pumping station, consists of the same rock, and the water was found to be increased within that distance, almost entirely by bottom springs, to more than double its original amount, without the inflow of any tributary. Close to the proposed pumping station, and below it, several other exceedingly powerful springs were found to break out from the waterstones or lower beds of the Keuper. The water, except during floods after heavy rains, received scarcely any accretions from surface drainage, both the soil and the rock being exceedingly porous. This water analysed by Dr. Frankland showed the following result, and therefore in ordinary cases would be regarded as a first class water. The total solid contents amounted to 9·97 grains per gallon, and the total hardness was 6·42, reducible on boiling to 3·09 :—

Organic carbon - - -	0·168	grains per gallon.
Organic nitrogen - -	0·011	do.
Ammonia - - -	0·004	do.
Nitrogen as nitrites and nitrates -	0·323	do.
Total combined nitrogen - -	0·338	do.
Chlorine as salt - - -	0·910	do.
Previous sewage contamination -	3038	*grains per gallon !*

This estimate of previous contamination is obtained by multiplying by 10,000 the total combined nitrogen after making certain deductions for nitrogen in atmospheric air, and other sources not belonging to the result.

From this it appears that the actual quantity of sewage matter estimated on the scale of London sewage, and presumed, according to Dr. Frankland's theory, to have been present in the water at some time to account for the quantity of combined nitrogen found in it, amounts to about 7 ounces per gallon, or *more than one twenty-fourth part of the whole volume of the water* (a gallon being 10 pounds, or 70,000 grains). The whole population of the district included in the watershed in the case before us, according to the census of 1861, was only 391 persons, and in 1869, when the water was analysed, the population had not increased, and there was scarcely a house in sight of the stream from its source to the place where the water was taken. There is no evidence that the district was ever more peopled than it is at present.

44. No water safe according to the Frankland theory.—It must be clear that if Dr. Frankland's view be correct, and that no water is safe which contains evidence of previous sewage contamination, whilst there is no chemical or other proof to be obtained of the existence of the germs assumed to be the cause of danger, even when this supposed previous condition is most strongly indicated, we cannot logically escape from a further conclusion. The germs are invisible under the microscope, and indeterminable on analysis. How can they escape being present in those natural lakes and reservoirs filled from gathering grounds which cannot possibly be free from the occasional pollution of human presence? The Rhine at Schaffhausen, the lakes of Cumberland, Westmoreland, Wales, and Scotland, and the reservoirs at Rivington Pike and Woodhead, supplying Liverpool and Manchester, are declared pure. But as, although the gathering grounds of these waters are little inhabited, men certainly do pass over all of them occasionally, we are bound to ask why they should not have left invisible and inappreciable germs here as well as in rivers, and why should waters that show previous sewage contamination, as determined by the existence of nitrates and nitrites, but which have hardly any visible sources of contamination, be worse or more dangerous than other waters which, though they do not contain these salts, have certainly been exposed to the causes which produce the supposed mischief. So also with the waters issuing as springs from rocks. It is not reasonable to assume that germs have not been carried through with various materials from the surface into the crevices in sandstone and other rocks, and these occasionally yield water abundantly. In the case both of sand-rocks and chalk there is an absolute certainty that infiltration takes place largely and rapidly, both by absorption into the rock and by open fissures, and it is proved that even organic matter in a very sensible form can penetrate downwards and injuriously affect the waters obtained by pumping from deep wells beneath towns.

But still further. These germs which it is presumed are conveyed by water and preserved in it undeveloped till they enter the human system, appear to be also transmissible through the atmosphere. During ordinary seasons there seems no intention to assert that the waters of streams tolerably pure are in any sense dangerous or unwholesome, and during such seasons the air is free from infection. When cholera and other epidemics have been introduced, it is difficult to see why river water alone should become dangerous, and why, if taken under favourable circumstances and fairly treated, river waters should be more likely to do mischief than the water of lakes, selected gathering grounds, or springs. If men, or human excreta, do not convey the poison, the air may do so, and the result upon the human frame in a case of this kind when quantity is not regarded must be nearly, if not quite, the same whether the number of germs introduced be few or many.

45. Existence of germs only assumed.—It must be clearly understood that the existence of these germs in waters is inferred, not known. "Previous sewage contamination" represents the quantity of sewage in a gallon of water of standard impurity which, when rendered perfectly innoxious by actual decomposition, would yield the number of grains of nitrates and nitrites found by analysis to be present in the water. The very fact of the nitric and nitrous salts being formed proves that decomposition has been complete, and that the water is now free from real sewage contamination. The purifying work has been effected, and to all human knowledge the water is as safe as if just fallen from the heavens. But this real purifying of the water by natural oxidation, and the formation of new and harmless compounds by the elements of such organic matter as was present, being admitted, there rises up in the imagination of those who agree with Dr. Frankland, a vague and mysterious shadow of possible future epidemic disease derived from germs they suppose may remain, and which they believe to be developable when taken into the body, and this although no human eye can discern them, and no process of chemistry is subtle enough to detect them, and though it is impossible to be sure that any other water taken anywhere is more free from them.

46. Singular results in estimating previous sewage contamination.—Illustrations of the liability to mislead in the statement of high figures in reference to previous sewage contamination may be given from the tables published by Dr. Frankland in his reports. It appears that at the Water Street well, at Liverpool, on the 21st May 1868, distant 2340 yards from the Town Hall, 300,000 gallons of water were pumped per day from a depth of 156 feet, and that in the water there appeared 1·989 parts in 100,000 of total combined nitrogen, of which 1·976 parts were in the form of nitrates, nitrites, and ammonia, leaving therefore 0·013 parts in 100,000 of organic nitrogen. This water indicated, according to Dr. Frankland, a previous sewage contamination of 19,440. On the same day from the Windsor well, where three times the quantity was pumped per day from about thrice the depth, the well being 3230 yards from the Town Hall, the total combined nitrogen was ·444, the nitrogen as nitrates and nitrites ·411, leaving 0·033 parts in 100,000 of organic nitrogen. In this case, however, the previous sewage contamination amounted only to 3,790, or about one-sixth that at Water Street well. This water must, therefore, be regarded as being derived from a different and much safer source. The increase of depth might be assumed to be the cause of this, if we suppose that the whole water supply from the rock is liable to injury by the absorption of polluted matter from the surface; but in this case all deep waters, which are regarded by Dr. Frankland as specially to be recommended, must be treated with no less caution and suspicion than the shallow wells near old towns. Much more striking instances are, however, given in the Sixth Report of the Rivers Pollution Commission, p. 73, where we are told, among many others, of a shallow well water from the coal measures next Walsall, which was "clear and palatable," and contained in 100,000 parts :—org. carbon ·139, org. nitrogen ·020, ammonia ·170, nitrogen as nitrates and nitrites 10·102, chlorine, 21·50, and previous sewage contamination 102,100. 100,000 lbs. of this water, therefore, or 10,000 gallons, are presumed to contain the mineral residue of an amount of animal organic matter equal to that found in 102,100 lbs. of average London sewage, amounting to nearly 6 lbs. Another well water from the town pump at Thame, was found to be slightly turbid and saline, and contained 121,930 parts of previous sewage contamination, or the mineral residue of upwards of seven pounds of animal organic matter in 10,000 gallons.

Dr. Frankland considers a water reasonably safe if it contain less than 10,000 parts of previous sewage contamination in 100,000 parts, provided it be from a well more than 100 feet deep, or from deep-seated springs (*vide* § 24).

Observations are not wanting to prove that certain rocks, such as chalk, are liable to suspicion of previous sewage contamination, and may not be trusted without investigation. From the deep well in the chalk at Croydon Water Works there has been proof of organic matter existing in the water, and according to Mr. Baldwin Latham, whose evidence on the subject is admitted in a recent report by Mr. Bateman, the impurities of the surface are sometimes there carried down to the lower strata, and the water containing them pumped back for the use of the town. This appears to be one of the inevitable results of exhaustive pumping.*

47. Dr. Frankland's expression of his views.—In order, however, that the views of so high an authority in a matter of such extreme moment to the health of the community should be fully and fairly expressed in the form most favourable to their author, I insert here the following extract from Dr. Frankland's report on the Pollution of Rivers (Mersey and Ribble, 1870, p. 112), which may be allowed to speak for itself :—

"There is no process known by which the total weight of organic

* By exhaustive pumping is meant the pumping of a larger quantity of water per day than is naturally supplied in that time to a well by the fissures or percolation conveying water to it. When this process has been carried on for a certain time, the level of the water in the well, which was at first the natural level of water in the rock, becomes lowered, and the water surface in the adjacent rock, and in the fissures that carry the water, assumes the form of an inverted cone, or funnel, more or less regular in shape, whose base is the earth's surface at the top of the well, and its apex the bottom of the well. The area of the base of the cone will increase with the depth of the well. These facts were proved by experiment, in the chalk during investigations made in the case of the Bulbourne mill-owners *v.* the Grand Junction Canal Company in 1849, and in the New Red Sandstone, by the late Mr. R. Stephenson, in reference to the water supply of Liverpool from wells, in 1850. It has long been known that the level of the water reached by deep wells in the London basin has been steadily lowered by the continual pumping that has been going on for many years for the supply of the large breweries on both sides of the Thames.

matter in water can be ascertained; but by the determination of its two chief elements, carbon and nitrogen, the relative quantities of organic substances in different waters are approximately indicated, whilst the relative proportion of these elements in each sample frequently gives a clue as to whether the organic matter be of animal or vegetable origin. With more certainty, however, can the quality of the organic matter be judged of by the previous history of the water, recorded in the mineral ingredients which it contains. It has been proved elsewhere that the organic matters of animal origin contained in water, such as those derived from sewage, the contents of privies and cesspools, or farm-yard manure, undergo oxidation in rivers and streams very slowly, but in the pores of an open soil very rapidly. When this oxidation is complete, they are resolved into mineral compounds, their carbon is converted into carbonic acid, and their hydrogen into water products, which can no longer be identified in the aerated waters of a river or spring; but their nitrogen is transformed partly into ammonia, chiefly, however, into nitrous and nitric acid, which, combining with the bases contained in most streams, frequently remain dissolved in the water for a long time, and constitute a record of the sewage and other analogous contamination to which it has been subjected since its last descent to the earth as rain. Such previous sewage or animal contamination is conveniently expressed in so many parts of average filtered London sewage as would, if thus completely oxidised, yield a like amount of nitrogen in the form of nitrites, nitrates, and ammonia. For this purpose average filtered London sewage has been assumed to contain 10 parts of combined nitrogen in 100,000 parts."

48. Evidence not satisfactory.—Dr. Frankland then proceeds to give an example, preceding his remarks by pointing out that, according to observation, the amount of nitrogen in rain-water averages ·032 parts in 100,000 of water, and that this must be deducted from the observed quantity in the water under examination before calculating the previous sewage contamination. "Thus a sample of water that contains in the form of nitrites, nitrates, and ammonia, ·326 parts of nitrogen, has obtained ·326—·032=·294 parts of that nitrogen from animal matters. Now this amount is contained in 2940 parts of average London sewage, and hence such a sample of water is said to exhibit 2940 parts of previous sewage contamination in 100,000 parts; or, in other words, 100,000 lbs. of the water contain the *mineral residue* of an amount of animal organic matter equal to that found in 2940 lbs. of average London sewage. This evidence of the amount of animal organic matter previously in the water is liable to be weakened, or even altogether destroyed, by several influences to which water is sometimes subjected. Thus we look in vain for the full evidence of anterior animal pollution in the effluent water from fields irrigated with sewage, because the growing plants have removed a considerable proportion of ammonia and nitrates from the liquid as it flows over their rootlets. In like manner the aquatic vegetation of rivers, lakes, and reservoirs, slowly removes these compounds from the water, and to that extent destroys the evidence of animal contamination. Nitrates are also rapidly destroyed when the organic matter of the water containing them enters into putrefaction, a condition which often occurs in streams or reservoirs containing much polluting organic matter. It also not unfrequently takes place in water-bearing strata far removed from the surface, although the water in this case may contain but a comparatively small amount of organic matter; the latter, however, being cut off from a supply of oxygen from the air accomplishes its oxidation at the expense of the nitrates, and thus destroys them. Owing probably to this cause the evidence of previous animal contamination is not met with in some deep chalk wells in which it might be expected to occur. The gases dissolved in the water of these wells are always found to be nearly, if not quite, devoid of oxygen.

"The previous animal contamination of water, as deduced from chemical analysis, must, therefore, always be regarded as an indication of possible danger, and not a proof of present unfitness. It does not represent the comparative freedom of different samples of water from anterior pollution; but whenever analysis shows this excess of nitrogen in the shape of nitrates, nitrites, and ammonia, the water stands convicted of previous contamination to the extent so indicated."

49. Other sources of danger.—Dr. Frankland then proceeds to point out that the importance of the history of water as regards its anterior pollution with organic matters of animal origin, does not arise from the presence of the inorganic residues (nitrates, nitrites, and ammonia) of the original polluting matters, *for they are in themselves innocuous;* but from the risk lest some portion of the noxious constituents of the original animal matters should have escaped or will escape that decomposition which has resolved the remainder into innocuous mineral compounds. "And the danger is the more to be feared, because it is quite impossible by chemical analysis, or indeed by any other process of investigation short of administration of the water to human beings, to discern whether or not such noxious substances are still left in the water."

In the sixth annual report of the Local Government Board, 1876-1877, Dr. Frankland makes the following remarks in reference to the occasional absence of evidence of contamination:—"During the spring and summer months the combined nitrogen in river water is largely diminished by the abundant animal and vegetable life then existing in the streams," p. 123. The presence of living organisms may even obliterate altogether the evidence of previous sewage pollution, water delivered under certain conditions exhibiting considerable evidence of previous contamination by animal organic matter, although when stored for two or three weeks before being filtered, the evidence is effaced.

50. Example illustrating the quality of water.—The following copy of two analyses of the Harrow water will serve to illustrate the whole subject by a special case :—

Ten thousand gallons or 100,000 lbs. of the Harrow deep well water, on two occasions when samples were taken, contained $\left\{\begin{matrix}104{\cdot}42\\100{\cdot}88\end{matrix}\right\}$ lbs. of solid constituents ; the organic matter, constituting a portion of these constituents, contained $\left\{\begin{matrix}{\cdot}063\\{\cdot}059\end{matrix}\right\}$ lb. of carbon, and $\left\{\begin{matrix}{\cdot}067\\{\cdot}030\end{matrix}\right\}$ lb. of nitrogen. The above quantity of water also contained $\left\{\begin{matrix}{\cdot}001\\{\cdot}118\end{matrix}\right\}$ lb. of ammonia, and $\left\{\begin{matrix}{\cdot}012\\{\cdot}0\end{matrix}\right\}$ lb. of nitrogen in the form of nitrates and nitrites, whilst the total amount of combined nitrogen in every form amounted to $\left\{\begin{matrix}{\cdot}08\\{\cdot}127\end{matrix}\right\}$ lb.

After its descent to the earth as rain, 100,000 lbs. of the water is assumed to have been contaminated with animal matter equivalent to that contained in $\left\{\begin{matrix}0\\650\end{matrix}\right\}$ lbs. of average London sewage. This, therefore, represents the amount of *previous sewage contamination.*

By gradual oxidation, this presumed contamination had been, so far as analysis can show, converted into innocuous inorganic compounds before the water was submitted to investigation.

The above weight of water contained $\left\{\begin{matrix}16{\cdot}58\\16{\cdot}3\end{matrix}\right\}$ lbs. of chlorine.

Finally, the 100,000 lbs. of water contained $\left\{\begin{matrix}48{\cdot}49\\44{\cdot}40\end{matrix}\right\}$ lbs. of carbonate of lime, or an equivalent quantity of other hardening or soap-destroying ingredients, expressed as *total hardness;* of these $\left\{\begin{matrix}29{\cdot}46\\18{\cdot}98\end{matrix}\right\}$ lbs. would be got rid of by boiling the water for half-an-hour, and are therefore called *temporary hardness,* whilst $\left\{\begin{matrix}19{\cdot}03\\25{\cdot}42\end{matrix}\right\}$ lbs. would still remain in solution, constituting *permanent hardness.* According to the usual mode of expressing hardness, these figures represent $\left\{\begin{matrix}34{\cdot}0^\circ\\31{\cdot}1^\circ\end{matrix}\right\}$ total, $\left\{\begin{matrix}20{\cdot}0^\circ\\13{\cdot}3^\circ\end{matrix}\right\}$ temporary, and $\left\{\begin{matrix}14{\cdot}0^\circ\\17{\cdot}8^\circ\end{matrix}\right\}$ permanent hardness of Dr. Clark's measure.

51. Previous sewage contamination, if a fact, renders analysis useless.—It will be observed that the estimate and statement of what has been described by Dr. Frankland as "*previous sewage contamination,*" have no real reference to the quality of water, and that the chemical examination of waters had better be left alone altogether, if, as he states, in those samples that contain even the strongest indication of so unpleasant an early history, all calculable and discoverable danger has disappeared, while on the other hand those which contain little, do so only because, although really not less dangerous, they have had the evidence of their danger destroyed. Those waters even that contain none at all, must be presumed, for this very reason, to be the most dangerous of all, being those in which the destruction of evidence has been carried to the greatest extent. It seems clear that no natural waters can, under any conceivable conditions, be safe from the presence of those invisible and intangible germs which, in the interests of humanity, he so greatly dreads. It would, perhaps, be desirable, if such is the case, to omit for the future all reference to an estimate so useless and so apt to mislead, unless it is desired that no water shall be supplied hereafter for purposes of human consumption, except that which has been recently distilled and preserved in a safe place. It must neither be exposed to the air, nor to the absorption of gases that emanate from human beings, nor to the place in which men have lived, and it must not have been exposed to the presence of those invisible germs of disease, or of incipient putrefaction, presumed to be everywhere floating in the air and contained in water.

52. Nitrogen communicated to water in many ways.—The presence of nitrogen in river water, in the form of ammonia, nitrites, and nitrates, is assumed by Dr. Frankland to be due exclusively, though sometimes indirectly, to organic life. There seems, however, much reason to doubt whether this is justified by what we know of other waters, where no such origin can well be assumed. To say nothing of the instances in Chili and India, where enormous deposits of nitrates exist in beds and masses far removed from any human population, there are proofs in mineral springs that nitrogen may be separated from the atmosphere in quantity amply sufficient to account for much of what we find in streams. In the sulphurous waters of the Pyrenees, obtained from a great depth, and certainly free enough from human influence, nitrogen is always present. At Wildbad and Aix-la-Chapelle the gases contained in the mineral waters consist of more than 80 per cent. nitrogen ; only about 12 per cent. being carbonic acid, and the rest oxygen. In central France, also, nitrogen is disengaged in abundance from some mineral springs.*

Ammonia is a very usual constituent of mineral waters, proceeding from many varieties of rock not actually metamorphosed to such an extent that its original individuality is gone. It is also found in most volcanic compounds.

53. Analysis of water—Ignition method.—The analysis of water, and the various means adopted by chemists to determine, not only the actual elements in their various proportions, but the combinations pre-

* Lecoq, *Eaux Minerales*, 1864, p. 48.

sumed to exist in solution, is a matter for chemists to determine, and does not at all belong to the plan of the present work. Volumes have been written on the subject, and the most accomplished chemists have their special methods—each the result of long experience and repeated trials. It may, however, be permitted to one not conversant with the details of laboratory work, to observe that all ultimate analyses that give an account of the combinations of the elements found to exist must be derived from theory to some extent, and that, even at the present time, there is much to be learnt in this important department.

The determination of elements should be facilitated by the use of the spectroscope; but this method, though very valuable and suggestive, will not supersede the old methods. Among the methods used by chemists to determine the organic matter in water, one that has been very generally adopted is that of finding the loss occasioned by burning the solid residue obtained on evaporating the water. It is assumed that all that can be thus burnt away is organic matter; but waters containing little or no organic matter may contain nitrates which give off oxygen and nitrogen on ignition, and may pass into carbonates or chlorides which are volatile. There may, therefore, be loss by ignition without the presence of organic matter. On the other hand, evaporating to dryness may destroy organic matter, and thus the loss may fail to represent the quantity really present in the water. There may even be a gain instead of a loss of weight on ignition. The blackening of the residue during ignition is a fair proof of the presence of organic matter, but none as to the quantity. Thus the method by ignition is not a process to which great value can be attached.

54. Per-manganate of potash method.—Another common method of measuring the organic matter is by finding how much per-manganate of potash a given volume of water is capable of reducing. The consumption of the oxygen is considered to measure the organic matter. This method appears, from recent investigations, to be singularly accurate for small quantities. It is found in practice that different kinds of organic matter are variously affected. The nitrites act immediately on the per-manganate.

55. Frankland and Armstrong's method.—A third method, recommended by Dr. Frankland and Mr. Armstrong, is by estimating the quantity of carbon and nitrogen by actual combustion in a known quantity of the water residue. The process is one of the most elaborate nature, and, besides certain chemical difficulties involved, entails more than ordinary manipulative skill. The graver objection to the process, which specially applies to the estimation of the organic nitrogen in any ordinary water, is that the total quantity obtained falls within the limits of the available error of a combustion analysis.

56. Ammonia method.—A fourth method is suggested by Mr. Wanklyn, and described in his "Water Analysis" (p. 44). It may be called "the ammonia method." It is dependent on the assumption that, by estimating the amount of ammonia obtained by distilling the water with an alkaline solution of potassic per-manganate after all the free or saline ammonia has been estimated, we have a measure of the nitrogenous organic matter present. Most kinds of water, however, contain ammonia, or some ammoniacal salt, which has been or will become a constituent of organic matter.

57. Uncertainty of all the methods.—Practical difficulties exist, and theoretical objections have been raised in reference to all the methods hitherto suggested to determine the organic contents of water, and chemists must decide as to which method of investigation is the best. So much, however, depends on the nature and amount of organic matter present in water, that no conclusion can be arrived at with regard to the fitness, or otherwise, of any particular sample until this question has been determined. It is evident that chemists, following different methods, may arrive at different results, and the cause of these differences should be understood. It may also seem that in a matter on which so much depends, and which is so imperfectly understood, very decided conclusions are hardly warranted.

58. Metals contained in water.—Besides the carbonates and sulphates of lime and magnesia, the common salt, the silica, and the supposed and real organic contents, many waters contain traces or definite quantities of various metals. Of these, iron is the most frequent, and is, indeed, very common. It is not only present in waters called *chalybeate*, but exists sometimes in such large quantities as to leave a slimy red deposit of oxide on the stones over which it passes. A sensible quantity of carbonate of iron gives hardness to water, and is objectionable where the water is needed for domestic or manufacturing purposes. Still more is it injurious in bleaching, dyeing, paper-making, &c. Iron waters are, however, pleasant enough for drinking. Manganese is rarely or never present in important quantities. Lead is sometimes held in solution, but it is not often in sensible quantity. If dissolved, however, it is to be regarded as dangerous, however small the quantity, as it is not known with certainty what is the cumulative effect of waters containing even minute traces of this or other mineral poison on the human system. It has been suggested, and is possible, that certain forms of disease, such as cretinism, may be the result of long-continued absorption of infinitesimal doses of lead into the system, and thus it becomes desirable to estimate the proportion that may be regarded as safe. Perhaps the cumulative result may not even be limited to the lifetime of one individual, but may be inherited from one generation to another; the evil effect, however small in the parent, rendering the constitution of the child more susceptible to the same influence, and thus very slowly but surely bringing on one of those terrible forms of disease that are impossible to cure in the individual, because they have been engrafted on his system even before birth. Copper and zinc, like lead, but probably with less serious results, and arsenic, are all occasionally present in water, and, in certain cases, have been poisonous. These cases are exceedingly rare. The minute analysis of water under the spectroscope, with a view to determine the presence of metals, is a subject that promises very interesting and important results to the chemist, but in the case of lead, zinc, and arsenic, it does not yield decisive evidence.

59. Instructions for taking samples.—Before concluding these remarks on water analysis, it may be useful to give a few instructions and suggestions as to the mode of collecting samples for chemical analysis and investigation. The kind of bottle generally used is that called the "Winchester quart." It contains about 6 lbs. weight, or six pints, of water, and is well stoppered with a glass stopper. The quantity of water it contains is sufficient for an analysis, but scarcely enables the chemist to retain a sample, and, if necessary, repeat the analysis. Where it is very inconvenient to convey bottles so large and heavy, half the size is sufficient. The bottle should be cleaned with strong sulphuric acid, and washed with clean water till the rinsings cease to be acid. Before filling it the bottle must be rinsed with the water of which a sample is to be taken. It should be filled nearly, but not quite full. If the sample is taken from a pipe the water should be allowed to flow for some time before being taken. If from a running stream, pool, or reservoir, the bottle must be held with the mouth a little below the surface, carefully avoiding any floating scum. If the water is a river, the middle of the stream should be taken at a distance from any feeder, and especially from the outfall of any sewer. It should be noted whether the water is in its ordinary state, and whether there has been long drought or recent rain. The exact spot where the sample is taken should, of course, be carefully noted at the time. When the bottle is filled, and the requisite notes taken, the stopper should be securely tied, the string sealed, and a label attached. This precaution is very necessary, as I have myself seen samples taken in the ordinary way, and given to a countryman to carry, rendered entirely useless by neglect of this precaution. By accident the man was separated from the party, and it was found that one of the bottles, having become partly emptied by the falling out of the stopper, the attendant had filled it again from the nearest brook or pool. When the sample is taken it should be kept stoppered in a cool and dark place until examined. For organic contents, the examination should be made within forty-eight hours, if possible. The physical characters of the water (clearness, colour, and smell) should be observed at the time the water is taken and when the analysis is commenced. The colour is best seen by making use of a two-foot tube of clear glass with a flat bottom, closed by a sheet of clear glass. Looking through a tube of this kind, filled with the sample under consideration, and not less than two feet in length, the eye recognises at once differences of clearness and colour that are quite insensible in smaller quantities. A brown colour of water indicates peaty extract, a yellow colour is generally the last remains of muddiness and turbidity. Perfect clearness, without colour, is comparatively rare. In determining the odour of water, it should be frequently and sharply shaken in the bottle before the stopper is taken out. In this way if there be any sensible odour it will be at once detected. The sparkle of water is also seen by shaking, and the fresh pleasant flavour of water, though sometimes proved to be consistent with the presence of an enormous quantity of organic impurity, is in most cases the result of exposure to the air and the presence of a little carbonic acid gas. Without aeration, water generally has an unpleasant and flat taste, though it is certain that in this as in so many matters the taste is governed by habit, and what to one person is pleasant and desirable, to another is positively disagreeable.

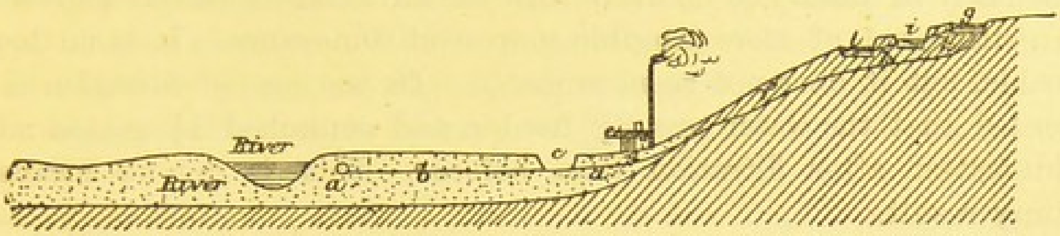
60. Improvement of water by filtration.—The improvement of water by mechanical or chemical methods so as to obtain a reasonably good supply, when for any cause the water procurable is not so clear or pure as is desirable, is often a matter of very serious consideration. The processes adopted though usually limited to the removal of matter held in suspension, sometimes extend to the removal or modification of substances held in solution. The former process is called filtration, and is entirely mechanical. By the use of charcoal, which is highly absorbent of gases, both ordinary filtration and chemical change are effected; and by the admixture of lime to diminish the hardness of chalk-water, the essential qualities of the water have been improved. These latter methods, both mechanical and chemical, have sometimes been attempted on a large scale for the water supplied to towns; but more frequently on a very small scale for the use of public institutions and private establishments. The small house filters commonly used, are very effectual for a time, but require attention, and are apt to become choked. They are in some cases complicated in their structure and contrivances.

61. Natural filtration.—Natural filters are obtained near streams in which the mud deposited by the filtered water is removed by the part of the water that is not filtered, and the effect of filtering is sometimes produced by running a drift or tunnel which receives and conveys the filtered water by the side of the stream, the mechanical force of the running water washing away the mud deposited. This is the case with the Garonne, at Toulouse, where a moderate quantity of clear water is obtained in this way, though not without costly works. After a preliminary experiment, apparently successful, an ellipsoidal excavation was made, measuring 33 metres long and 23 wide, and of which the bottom was 5 metres below the lowest level of the river. The river alluvium was the bed through which the water passed to enter the excavation. The quantity not proving sufficient, the excavation was enlarged by a tunnel; but the quality of the water was not altogether satisfactory until arrangements had been made with artificial filter beds. The city of Lyons also receives water obtained from excavations near the Rhone.

62. Mechanical filtration downwards and upwards.—Mechanical filtration on a large scale is effected in various ways. The simplest method is carried on by means of a shallow tank provided with a perforated or permeable bottom covered with clear fine silica sand and gravel which forms the filter-bed. A communication is open from below the filter-bed into a service reservoir at a somewhat lower level. The foreign matter and mud will be retained on and near the top of the filter-bed, and must be cleared away from time to time by scraping off the dirty sand and replacing it by fresh.

Occasionally, however, the filtration is conducted in a different manner, the water entering below the bottom of the filter-bed under pressure, and being forced to rise through the bed to the reservoir, which is thus at the same time a filtering and a supply reservoir. The mechanical and engineering contrivances are somewhat different, but the general result is not much altered. To clean a filter-bed of this kind, it is only necessary to pass water through it downwards for a certain time, and this may be both more convenient and more economical in time, as well as money, than the former method. In both cases more than one reservoir must be provided, if the supply is large and constant; but in small establishments the filtration upwards may be carried on with little intermission by a single reservoir.

63. Lateral filtration by tunnels.—Lateral filtration is sometimes effected either naturally, by opening tunnel filters in river silt and gravel at some distance from its bed, or artificially by forcing water by pressure through a vertical wall of filtering material. The tunnel-filters entirely clear the river water from the muddy impurities brought down to some extent at all times, but especially during floods, and thus adapt it for use. If, at the same time, we introduce some saline substances, and somewhat modify other constituents, the result is not likely to be injurious, though it may add hardness to the water.



System of double filtering by natural filtration and Artificial filter bed.

Derby, W.W.

- *a* Tunnel filter.
- *b* Conduit to collecting reservoir.
- *c* Lower collecting reservoir.
- *d* Pipe to engine house.
- *e* Engine house and pump.
- *f* Pipe to upper collecting reservoir.
- *g* Upper collecting reservoir.
- *h* Pipe to filter bed.
- *i* Filter beds.
- *k* Pipe to service reservoir.
- *l* Service reservoir.

An excellent illustration of the processes of horizontal filtering through natural filter-beds combined with filtration downwards, is seen in the works of the Derby Water Works Company. The waters of the Derwent are received into a filter tunnel (*a*) about half a mile long, distant from 60 to 100 feet from the river. Thence, as shown in the annexed diagram, they are conducted by a covered culvert (*b*) to a collecting reservoir (*c*), where they mix with waters brought some distance from springs. The combined waters are lifted about 130 feet, to a second collecting reservoir (*g*), and are then passed through a series of three filter-beds (*i*), about twelve feet below the collecting reservoir. When filtered the water passes into the service reservoir. The diagram will give a general idea of this method. It has been found very successful.

64. Material for filtering beds.—For filtration on a large scale there is nothing better than pure sharp silica sand and gravel, as in passing through this it is impossible that the water can gain anything but silica to add to its solid ingredients. But it is next to impossible to obtain such material to the extent required, except in certain districts, and thus less pure sands are often resorted to. There can be no doubt that a minute proportion of the alkaline salts, a little carbonic acid, iron, and many other substances contained in sand, will act chemically on water in contact with them; and during filtration through certain kinds of filtering sand, it is possible that the water may be altered in the nature of its solid ingredients. This may result either in a benefit or an injury.

It is for the chemist to say whether, in ordinary cases, the water is injured sufficiently in quality to do away with the advantage certainly gained by the getting rid of more tangible sources of annoyance. It is no doubt possible, but it does not seem probable. In one case of filtration it is recorded that the water was $2\frac{1}{2}°$ harder, and contained $2\frac{1}{3}$ grains more solid matter after filtration than before. This is by no means a solitary result.

Great difficulty is sometimes experienced and much expense incurred to obtain good filter material in sufficient quantity and at moderate cost in the neighbourhood of towns or reservoirs. In the method lately adopted at Manchester for getting rid of sewage matter by combustion, the clinkers are found to consist of an admixture of siliceous mineral with animal charcoal, which is essentially a waste product, and could be brought into use with great advantage if ground to the requisite degree of fineness. There would seem to be no limit to the production of this sand, if the Manchester process continues to be employed.

65. Spencer's filtration by magnetic carbide.—The complete purification of water should include not only the getting rid of matter mechanically suspended, but also the depriving it of organic and other matter held in chemical solution. These, by reason of their nature and specific gravity when undissolved, are much more difficult to get rid of. It has long been known that charcoal, particularly charcoal derived from animal matter, possesses this property, and such charcoal has been used with success in house-filters of various kinds. The action is peculiar, and is called by chemists *contact action*, or *catalysis*. By its means the combination of two bodies, or the decomposition of a compound, is, in certain cases, brought about by the intervention of a substance which shows no tendency to unite with either of the bodies concerned, and remains unaffected by the changes that take place.* Charcoal, however, though useful, and often effective as a filter, rapidly becomes choked by mechanical obstructions, and we owe to Mr. Thomas Spencer (a gentleman who for many years has been pursuing investigations with regard to water, as an analytical chemist,) the introduction of a preparation of iron that appears to answer all purposes. This preparation is called by Mr. Spencer the *Magnetic Carbide,* and it consists of natural ores of peroxide of iron deprived of a portion of their oxygen, and reduced to protoxide, combined it is believed with some carbon, and converted into a carbide of iron.

It is easily proved by experiment that the ordinary crystalline magnetic oxides of iron act only as sand if used as filter material, and have

* Familiar examples of catalysis are seen in the numerous and varied phenomena of fermentation and putrefaction.

no effect whatever on matters retained in solution, while the peroxides, if used, would be partially dissolved, and render the water unfit for ordinary food purposes, and still more for cleansing. The preparation used by Mr. Spencer is uncrystallised magnetic oxide, and it is produced by reducing hæmatite ore to a state of granulation, and putting it with granular charcoal into a crucible, which is covered, and exposed to the heat of an ordinary coke fire for about twelve hours. It is found, on being allowed to cool, that the charcoal has now to some extent combined with the oxygen of the ore, the result being a highly magnetic protoxide of iron, hard, black, and porous throughout. This material is made on a large scale, and acts perfectly as a filter material. It is considered to retain indefinitely its power of acting (owing, no doubt, to the peculiar catalytic nature of the action) without undergoing change, and filter-beds made with it have not required cleansing or renewal. This was proved by an investigation as to the result at Southport, where the method had been in use upwards of eight years in 1866, and the water was then filtered as perfectly as at first. The method has been employed in some important cases for the purification of water in towns, for which it seems in every respect well adapted. It is not less valuable and available for house filters, while for purifying unwholesome fen waters the result is apparently perfectly satisfactory.* A modification of this method, the iron being in lump and not granulated (spongy iron), has been suggested by Dr. Bischoff, but the principle is the same.

66. Chemical results with ordinary filtering material.—The effect, even of mechanical filtration with such simple materials as fine and coarse sand and gravel, seems to be more than merely mechanical. Some experiments were conducted in 1856 at the Chelsea Water Works by the late Mr. H. Witt, an accomplished chemist, which are of great interest in reference to this subject, and are worthy of record. The filtering surface was 270 sq. ft., the thickness of filter material, 7 ft. 6 in., and the passage of the water through was at the rate of $6\frac{1}{4}$ gallons per sq. ft. of filtering surface per hour. The filtration was by descent through fine sand 2 ft. 6 in., coarser sand 1 ft., shells 6 in., fine gravel 3 in., coarse gravel 3 ft. 3 in., disposed in waves. The depth of water over the sand was 4 ft. 6 in.; the upper layer was renewed about every six months, but the lower materials had lasted twenty years at the time

* Mr. Spencer's system, though less known than it deserves, has received on many occasions public attestation of its excellence. It received the only prize medal in the second great London Exhibition in 1862 (*see* Jury Report), the highest prize medal for purification of water at the great Paris Exhibition of 1867, and the highest award for the purification of water at the Amsterdam International Exhibition in 1869. Results of analysis on waters filtered through this material are given in the Sixth Report on Pollution of Rivers, p. 220. The organic carbon and nitrogen, and the nitrates and nitrites are very greatly reduced. The water is also much softened.

of the experiment. The result is the mean of experiments made at different seasons.

	In grains per gallon— Before filtration.	After filtration.	Quantity separated.	Per-centage of separated matter.
Suspended matter - -	28·93	2·285	26·645	92·10
Dissolved salts - -	22·62	19·216	3·404	15·04
Organic matter - -	4·05	1·349	2·700	66·66
Lime - - -	8·72	8·426	0·293	3·36

It is, therefore, clear that in this case simple mechanical filtration removed, in addition to nearly all the suspended matter, about 15 per cent. of the dissolved salts, and nearly 67 per cent. of the organic matter.*

When charcoal is used as a filter material, the chemical effect is even greater; and, in a case recorded, out of $24\frac{1}{2}$ grains present in the water, the sand only removed $8\frac{1}{2}$, while the charcoal removed $15\frac{1}{4}$ per cent. As before stated, charcoal filtration is liable to clog the filter, and requires frequent cleansing, in this respect being certainly much inferior to the magnetic carbide. Animal charcoal, however, as prepared by burning the town refuse according to the method lately adopted at Manchester, seems to possess many advantages, and can, if necessary, be re-burned.

The rate of filtration now adopted varies greatly. For the Metropolitan supply the rate varies from $1\frac{1}{3}$ to $3\frac{1}{4}$ gallons per hour per square foot of filter surface. Perhaps, as a general statement, about $2\frac{1}{2}$ gallons per square foot per day is a fair allowance.

67. Use of the lime process.—The treatment of water by the lime process, with the object of softening hard water where hardness is derived from the presence of an excess of bi-carbonate of lime, was suggested by Dr. Clark, and has been practised in some places on a comparatively large scale, for softening chalk waters. The chief experiments have been tried at Caterham, at Canterbury, Tring, Aylesbury, Red Hill, and by the Kent Water Works Company. As originally suggested, the object of softening was to be attained by the addition of a certain proportion of lime, which should combine with the carbonic acid holding the carbonate of lime in solution, thus precipitating the lime added as carbonate of lime pre-existent in the water. The result is the production of an insoluble powder, believed to be available for practical use, the sale of which would diminish the cost of the operation. It has been found, however, that the pipes conveying the water thus softened become rapidly choked with a mass of minute crystals of carbonate of lime. Little economic use has been made of the deposit which, when the operation was carried on continuously for town use, is exceedingly large in quantity, and found no sufficient market.

The following explanation of this method of softening water is taken

* Phil. Mag. for Dec. 1856.

from a letter from Dr. Clark to the Duke of Richmond, published in the Evidence of the Royal Commission on Water Supply in 1867. Dr. Clark points out that every pound weight (16 oz.) of chalk consists of 8·64 ounces of lime and 7·36 of carbonic acid, and that the 8·64 ounces of lime (which could be separated by burning the chalk in a kiln) would be soluble in 40 gallons of water. The pound weight of chalk, however, would require 5,000 gallons of water for its solution. He then explains that, by combining a pound of chalk already containing seven ounces of carbonic acid with seven ounces of carbonic acid in addition, the resulting substance (bi-carbonate of lime) would be soluble in 400 gallons of pure water, the result being a water of the same average hardness as ordinary well-water obtained from the chalk strata.

If, then, 40 gallons of clear saturated lime water, containing nine ounces of lime, is mixed with 400 gallons of clear chalk spring water, also containing nine ounces of lime, the ingredients would combine, so as to form two pounds of chalk in a light, impalpable, but insoluble form, which soon subsides, leaving clear pure water above, containing about $1\frac{1}{2}$ grains of chalk per gallon. The practical difficulties in applying the method have been alluded to above; but, besides these, which are very serious, it was recorded in 1851, in the report of a Chemical Commission appointed to consider the value of this process of lime purification, that, even when combined with filtration, it was insufficient to remove the yellow tinge of Thames water during flood, nor did it appear to abate an objectionable taste of vegetable matter which the water also possessed at such times.*

68. Purification of rivers.—The purification of rivers is a matter that has been very seriously considered of late years, partly with reference to the re-peopling many of our English rivers with fish, when, owing to neglect and mis-management, this source of food has been reduced in quantity or entirely lost by poisoning, and partly for the sake of the human populations existing on their banks. Some of the impurities that have been allowed to enter might, it has been thought, be economized and made a source of profit; but there will always be a certain amount of expense incurred beyond the value of the material obtained if it is required to remove from the large centres of population the sewage that is formed.

69. Modes by which water is injured.—There are three distinct ways in which water becomes unfitted for domestic use and manufacturing purposes. The first is when, by natural floods or the result of manufacturing operations, large quantities of mud, sand, and other

* There is a recent modification of this process introduced by Mr. J. H. Porter, and adopted at Banstead, where about 6,000 gallons per hour are purified. By this method the water is cleared by passing through cloth, but the operation is both slow and costly.

substances not in any sense injurious, are combined mechanically with the water, discolouring it, and thus rendering it ill-adapted for distribution for town supply. So far as this matter is simply a mechanical admixture, it is readily and, for the most part, quickly removable by filtration, whether natural or artificial. Thus, wells in river silt continue to yield pure water when the water of the streams that run near and supply the wells is thick and muddy. In the same way peaty discolouration, which is to some extent mechanical, and can hardly be said to be mischievous, though certainly unsightly, is nearly if not quite discharged by sufficient mechanical filtration. After a long time of exposure to oxygen in the air, it becomes burnt off by oxidation.

The second mode in which streams become impure, owing to the works carried on by human population on the banks, is when the waste water from mines, from chemical manufactures, from paper-making, from dye-works, wool-cleansing, or other works, really injure the water by mixing it with deleterious substances, which are carried into the nearest stream in order that they may thence pass to the sea. In a country like England, where the manufactures are on a gigantic scale, and the streams, though numerous, are comparatively small, it follows that in certain districts the streams are fouled, and some are so injured that the water becomes an offensive nuisance instead of a source of health and pleasure.

70. Sewage as the cause of pollution.—But the third and most universal cause of injury to water arises from the modern system of sewage. By this the waste water supplied to houses is passed into drains which receive the sewage matter from the human population, together with the storm waters of the town, all being carried to the nearest river. In large towns situated on small streams the result, after a short time, becomes in the highest degree mischievous, and efforts have been made, and are being made, to remove the evil. In the case of London, the volume of river water is large, even compared with the enormous population, and the whole volume of sewage and waste water is allowed to enter the Thames during the time the tide is running out, the operation being presumed to take place so far down the stream, below London, as to prevent all chance of the in-coming tide bringing back the impure water. It is, however, found that constant dredging is needed a little above the sewage outfall to keep the river free from shoals, which form rapidly, and are composed of a chocolate-coloured mud peculiar to sewage, and it appears that indications of sewage brought back by the tide have been seen so far up the river as on the piers of Westminster Bridge.

In other towns the difficulties of removing the sewage without injury to the health of those who live on the river banks has been attempted to be overcome by establishing sewage farms in which the mischievous and offensive parts of the sewage are presumed to be rendered altogether innocuous by conversion into growing crops. This result also cannot be said to have answered the required purpose effectually, though, no doubt, irrigation with sewage water is occasionally very valuable to the farmer. Unfortunately it cannot be applied to advantage at all seasons or in all situations.

A third process adopted has been to separate the solid part of the sewage, as delivered from the sewers, by the aid of chemicals, and attempt to obtain, by treatment of various kinds, a solid manure of sufficient value for agricultural purposes to justify the operation. Like the other proposed methods of dealing with sewage, the success has been only partial, the value of the resulting manure being very small. The actual destruction of the organic matter by burning, leaving only animal charcoal and cinder, has lately been adopted at Manchester, Rochdale, and other towns. The regulations, however, to secure success, are ill-adapted to the habits of the people in the Metropolis.

71. Disposal of sewage.—It is evident that the disposal of sewage involves practical difficulties not yet surmounted. The excreta of the human population must be removed, the waste of manufactures must be got rid of, and yet these things must be done without poisoning the water of our rivers, or introducing either into the air or water the germs of disease. There can be no doubt that some process must be found that will prevent this constantly-increasing danger to the health of towns, and with the present appreciation of danger, the inhabitants of large towns near the outflow of rivers have a right to insist on the adoption of means to prevent the sewage of other towns higher up on the stream from being mixed up with their natural sources of supply.*

72. Improvement of water by continuous pumping.—It has been noticed that water from deep wells is often more free from impurities of all kinds, both mineral and organic, than water from shallow depths of the same rock. In the chalk there has been observed a marked diminution in the mineral contents, especially those that produce hardness, so that these deep waters are softer than ordinary chalk waters. But, in spite of this, the observations recently made in Croydon would seem to show that the water pumped from the bottom of a lined well, constructed to exclude the upper chalk supply, is not less influenced by the impurities present on the rotten chalk and overlying gravel, than water obtained from smaller depths. This proof of the rapid and inevitable effect of exhaustive pumping from chalk on the surface water is only one of many, all tending in the same direction. The wells in Croydon from

* *See* § 70 on the method adopted at Manchester. It is right to say that on the Thames the sewage is effectually diverted from the river at the present time in the case of all towns from Oxford to Hampton, and also in the case of the river Lea. These rivers are the chief sources of water supply for London.

which the water-supply is obtained are situated in the centre of the town, and are sunk through the loose sand and alluvial gravel overlying the chalk, and the rotten chalk at the top of the rock. The well is lined, but the pumping affects the level of the water in the neighbouring wells.

In the sands below the London clay near London, according to Mr. R. Mylne, "the water drawn from new wells is occasionally charged with impurities impregnated with iron, and unfit for domestic use. But in these cases, either by continuous pumping or after a lengthened use, a progressive improvement in the quality of the water invariably takes place." Mr. Mylne adds, that "in one district a few miles north of London, the water obtained from the sand by any new boring usually has a strong odour, with a peculiarly disagreeable taste, which continues two or three months, after which the water attains its proper condition.*

73. Penetration of sewage into well waters.—There is no doubt that water drawn from wells, even of considerable depth, in places where there is access from the surface to some permeable rock, may be affected by the surface conditions. Where there is sewage passing over the surface, or where there is an old church-yard not far off, the result may be to convey into the body of the rock the seeds of disease sufficient to infect a whole neighbourhood. The water entering is loaded with organic matter, but its appearance and flavour as it emerges are not interfered with. The decomposition of the organic matter that takes place on exposure is a known source of danger, often concealed by the mineral contents of the water. Too many examples of this are on record to admit of any doubt as to the possibility of contamination by such means.

On the other hand, it is certain from experience, and confirmed by experiment, that water percolating through a large body of sandstone rock or chalk, and afterwards lifted to the surface, is often free from impurities that can be detected by analysis. The oxidising effect of this kind of natural filtration, when acting properly and for a long time, cannot be doubted. It remains to determine, and this can be done only by further experiment in critical cases, what is the effect of exhaustive pumping when a large body of water is conveyed rapidly downwards from the surface over a considerable area near a deep well, the water delivered entering chiefly by fissures, and subject to contamination in the manner indicated. It will be necessary to return to this question in another chapter, when we treat of sanitary questions as connected with water.

* Prestwich, Water-bearing Strata of London, p. 218 *note*.

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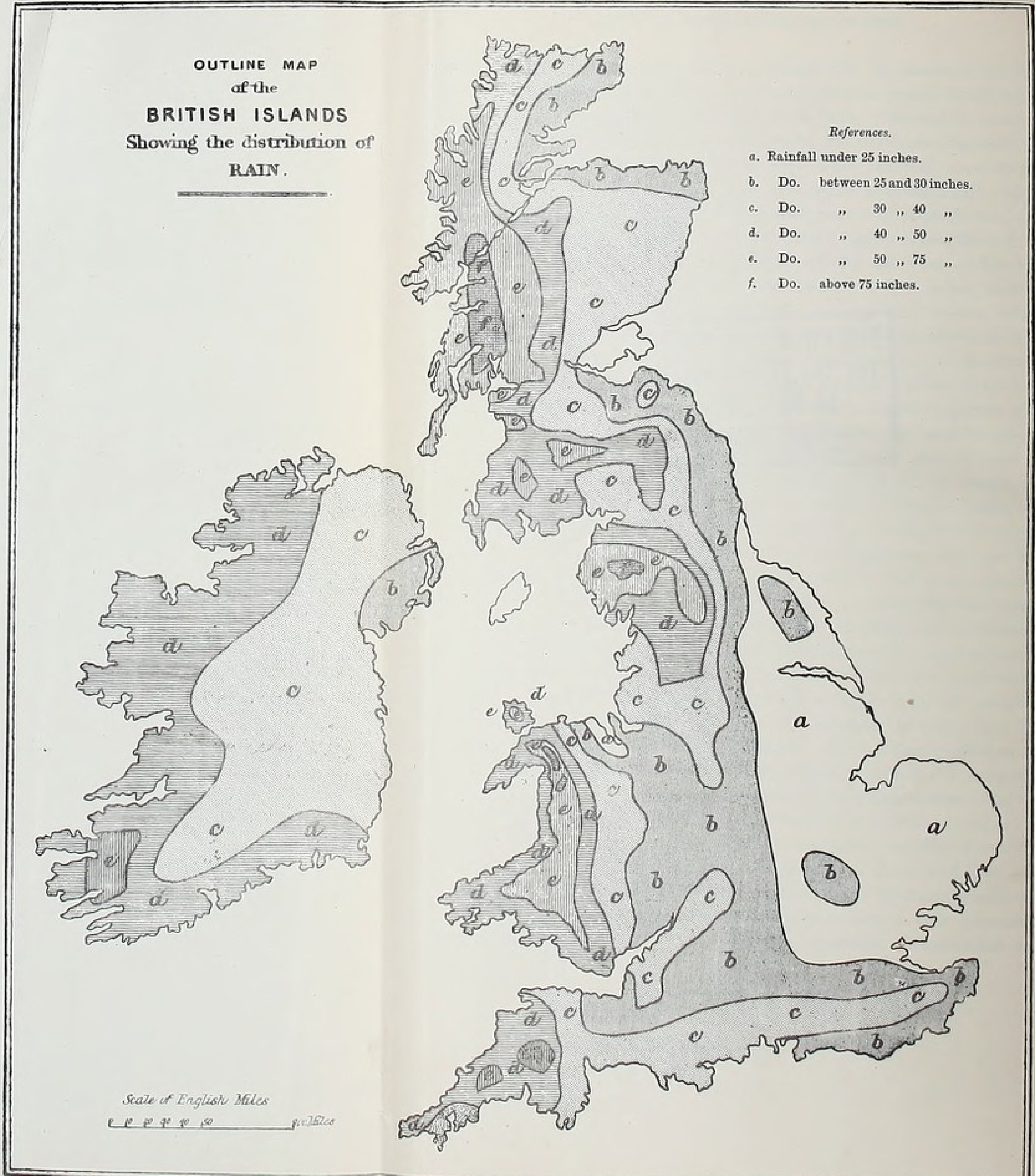


CHAPTER II.

RAINFALL, EVAPORATION, AND PERCOLATION.

(1) Water a constituent part of the globe.—(2) Essential in the composition of rocks. —(3) Value of hypothetical considerations.—(4) No proof of large quantities of available water in rocks.—(5) Few large cavities in rocks.—(6) Absorbed water not available water.—(7) All available water derived from rain.—(8) The atmosphere the agent conveying vapour.—(9) Conditions of rainfall.—(10) Rainless districts.—(11) Rain in the British Islands.—(12) Illustration in the north of England.—(13) Origin of rain.—(14) Quantity of water taken into the atmosphere.—(15) Rainfall area on land.—(16) Rainfall distribution.—(17) Days of rainfall per annum.—(18) Excessive rainfalls.—(19) Heaviest fall not on the windward side of the water-shed.—(20) Rainfall different in adjacent places.—(21) Season of rainfall variable.—(22) Quantity of rain greatest near the ground.—(23) Rainfall on hill sides greater than on lower levels.—(24) Exception at Bezançon.—(25) Laws governing rainfall.—(26) Sun-spots as influencing rainfall.—(27) Measurement of rainfall.—(28) Estimated total rainfall.—(29) Rainfall in zones of elevation measured in France.—(30) Evaporation.—(31) Proportion of rainfall removed by evaporation.—(32) Evaporation in the British islands.—(33) Evaporation from various rocks.—(34) Evaporation on the slopes of the Penine chain.—(35) General laws of evaporation.—(36) Percolation.—(37) Dr. Dalton's experiments on percolation into soils.—(38) Conclusions drawn from observations on Dalton's gauge.—(39) Percolation into rocks.—(40) Absorption of water into chalk.—(41) Water not available without fissures.—(42) Available water in chalk.—(43) All chalk not alike.—(44) Natural reservoirs in chalk. —(45) Percolation through oolitic limestone.—(46) Percolation through the older limestones.—(47) Percolation through sand and sand-rock.—(48) Percolation through schists and other metamorphic rock.—(49) Percolation general through all rocks.—(50) Sometimes impeded for a time, but never prevented.—(51) Permeability not measured by the absorbing capacity of a rock.—(52) Condition of clays with regard to water.—(53) General conclusions as to evaporation and percolation.—(54) Available rainfall.—(55) Principle of the mean of three consecutive driest years.—(56) Deduction for waste during floods.—(57) Deduction for absorption and evaporation.—(58) Equation for available fall.—(59) Possible permanent absorption of water.

1. Water a constituent part of the globe.—The fact that a perpetual circulation of water is kept up on the earth's surface by means of the atmosphere, though familiar, can only be properly appreciated by an intelligent consideration of the conditions of matter in the three states of solid, fluid, and aerial (earth, water, and air), which may, perhaps, only belong to a limited period in the history of a planet. There would seem to be at present neither water nor air on the surface of the Moon, though both may once have existed there in the forms we are familiar with, and although both may be present in large quantity in the solid nucleus presented to our view. There is possibly no solid nucleus as yet in the planet Jupiter, or it may be that there is a nucleus still enveloped entirely in vapour and atmosphere. There may have been a time when the earth was in the condition of Jupiter, and the time may come when it will resemble the Moon. As a habitable globe, the duration of a planet may be limited to that part of its history when earth, water, and air are all in existence together at the surface, mutually influencing each other. Before this phase the superficial shell or crust may have been long in a state of preparation, the excess of vapour, which at one time loaded and obscured the atmosphere, having been gradually absorbed into the rocks in the course of their formation, rendering the whole crust by degrees more and more fit for the higher forms of life.

2. Water essential in the composition of rocks.—The quantity of water present in the solid crust of the earth, and now forming an essential part of rocks, not removable without altering their nature and condition, is very large. All stratified rocks contain a great deal of water, and almost every known combination of elements in a solid form contains a certain amount, known as the water of solidification. The presence of this water is quite independent of the capacity of the mass for absorbing water, and it is never given out so long as the body retains its condition. It is probable that, as the crust of the earth formed and gradually thickened by the cooling due to the radiation of heat into space, water was, from the first commencement of the formation of a crust, constantly removed, at first directly from the vapour atmosphere, and afterwards from the liquid ocean, to form the cooling mass of the interior into rock. How long this process went on before the earth, sea, and air were definitively formed as they now exist, how far it may have been going on since then in a constantly decreasing ratio, and whether it may not still be in progress, there is not sufficient proof at present to determine; but it is not unreasonable to assume that the great scheme of creation may involve a method of development more or less like that here suggested, and that the gradual removal of water to increase the thickness of stratified rock may be still in progress.

It will serve to give some idea of the magnitude of the quantities involved in these considerations if we reduce to figures the effect of some such operation as has been suggested. The earth's mean diameter being 7912 miles, the contents of a shell or crust 20 miles thick would be nearly 200 millions of cubic miles. Supposing this to be composed of compact homogeneous stratified limestone or sandstone in its ordinary dry state, it would contain about five gallons of water in every cubic yard, and the quantity of water in the whole solid shell would amount to nearly six millions of cubic miles. The surface of the earth has an area of 197,000,000 square miles, of which three-fifths, or 140,000,000 are now covered with ocean, and the water of the present oceans to a mean depth of 36 fathoms, would be absorbed and entirely removed from the face of the earth in the formation of a shell of rock such as that described, assumed to be cooling down from incandescence and becoming a stratified deposit. A mean rainfall of 60 inches over the whole surface of the earth would amount to something less than 187,000 cubic miles, or about $\frac{1}{32}$nd part of the quantity absorbed in the shell assumed.

3. Value of hypothetical considerations.—It may be thought that in a treatise on water, whose object is more practical than speculative, these hypothetical views are not in place. They are, however, useful, if only to fix attention on causes that will account for much that is mysterious and difficult of explanation in those terrestrial phenomena with which we have to do. We are often told, sometimes by engineers, and very frequently by those teachers of the public who take up and discuss in newspapers the great sanitary questions of the day, that in the interior of the earth there is a vast, if not inexhaustible, supply of pure water to be obtained by sinking wells into some or all rocks. We are assured that springs and wells are the only safe sources of water supply for food purposes, that they may always be depended on for quantity, that their quality is unassailable, and that surface waters, being subject to injury from pollution in many ways, should be neglected and abandoned in favour of these better and purer sources.

4. No proof of large quantities of available water in rocks.—It behoves us, therefore, to consider the question fairly, and endeavour to discover what these sources are, what is their history and origin, and whether geology can help us to understand how and where they exist. I confess that I know of no reasonable view of the nature and history of rocks which bears out the expectation. No rocks have yet been discovered whose cavities are so large and so charged with water under pressure that they would yield millions of gallons per day at the surface by continuous pumping, without showing in time symptoms of exhaustion, either by a lowering of the level of the water, or, which is quite as significant, by a change in the mineral ingredients affecting the quality of the water, proving that the water was now derived from other and more distant sources than those originally tapped. The number of known natural springs or wells yielding more than a million gallons a day is very limited.

The rocks that supply large bodies of water freely, and are subject to exhaustive pumping in England, are the Chalk, the New Red Sandstone, the Magnesian limestone, and some of the sandstones of the Coal-measures. From all these rocks there are, in various places, large quantities of water obtainable. They are generally porous, and are for the most part cracked and fissured, the fissures communicating more or less freely with the surface. Besides the chalk, water issues in large quantities from some of the harder limestones and sandstones (carboniferous limestone and millstone grit in England), and from the oolitic rocks; but there is in all these cases direct communication with the surface. Where water issues from deep fissures, or is obtained from unusually deep wells, mines, or borings, the temperature is higher in proportion as the depth is greater; the water is loaded with mineral ingredients, and the quantity has never been so far tested by pumping as to justify the assumption that it is inexhaustible.*

Mining operations are carried on in rocks of various kinds, stratified and unstratified; but, almost invariably in England, the rocks are cracked, disturbed, faulted, disrupted, or distinctly and deeply fissured. In other words, they are openings into the interior of the earth in places where there is access to the atmosphere, and which must receive surface water. The deepest operations of this kind do not much exceed 700 yards, which is much less than half a mile, and at this depth the temperature is already so high that mining work is difficult. Since steam power has been introduced, there are no mines in which water enters so rapidly that it cannot be pumped down in a short time, and the bottom kept dry. In those cases, therefore, in which the interior has been reached by penetrating the surface indifferently through rocks of all kinds, no stores of water have yet been met with that are not easily exhausted, and no inexhaustible springs have been reached.

5. Few large cavities in rocks.—Once more:—In mining operations it is necessary to remove a certain part of the strata, and it is invariably found that, without reference to the depth or nature of the overlying

* Here, as elsewhere, a definite statement of figures will help to render clear a statement whose importance is not sufficiently considered when expressed in words. For every million gallons of water pumped daily from any cavity or fissure in a rock by continuous pumping, nearly six thousand cubic yards of matter are removed from the interior of the earth. If the space thus left vacant were not again filled up, it would certainly soon be occupied by rock falling into the cavity. By removing three millions of gallons per day from a well in the chalk for a year, the space occupied by the water removed would be equivalent to a chamber nearly half a mile square and ten yards deep. If this were left unsupported, the roof of chalk would fall in, and a creep or depression would take place at the surface.

strata, the vacuity caused by the mining work, or the removal of coal, salt, or ore, the roof falls in, and all the strata, from the surface downwards, are affected, and present an appearance which at the surface is called *creep*. The buildings are cracked and injured, the roads sunk, and surface or land springs are drained. It would seem impossible, therefore, to remove any large quantity of material from the earth's interior without the surface falling in and filling up the gap. No doubt there will be large interstices left, and water may be contained in these; but all the water that reaches them must come in from the surface, for it is in that direction that the new fissures open. The effect of mining may be to increase, in some measure, the containing power of the surface rocks in the districts where the work is carried on; but it proves clearly that water, if it circulates underground, and removes on its passage a certain quantity of calcareous, argillaceous, and siliceous materials, by dissolving them as it passes, can only make cavities which, as they become extensive, are filled up by the descent of the overlying rocks, effectually preventing the formation of any large natural reservoirs that could yield continually increasing supplies.

There is, in fact, no place among the rocks of the earth, so far as they come within our knowledge, for any body of water or natural reservoir from which water could be continually removed for the use of man, in larger quantities than it is received by percolation from the surface, without the supply being gradually reduced, and ultimately exhausted. Everything known in geology with reference to water seems to point to it as a comparatively recent, although most powerful agent in the formation of stratified rocks, and as having helped to produce igneous and metamorphic rocks; but nowhere is there evidence of the presence, now or at any former time, of any quantity of water in the interior independent of that which is derived from the surface. Active volcanoes, which can hardly erupt without steam, are found invariably in the neighbourhood of water.

6. Absorbed water not available water.—That rocks contain, in their ordinary state, a very large quantity of water; that, under certain circumstances, their water content is much increased, either permanently or for a time; and that the depth of the surface of saturation in rocks varies at different seasons, and is distinctly affected by exhaustive pumping, there is no doubt. If we could obtain from an area twenty-five miles square and a hundred feet thick, composed of saturated chalk or loose sand, the whole of the water that it is capable of holding, we should have enough water to supply the three millions of inhabitants of London with 35 gallons per head per day for a year. But, on the other hand, if this mass of chalk or sand were compact, and not in any way fissured or cracked from the surface downwards, and we were to sink wells or borings into every acre to the depth of 100 feet, we should not be able to obtain water enough by continuous pumping from all these wells to supply the sheep feeding on the grass that grows on the surface. This will be illustrated in a future paragraph, where the nature of chalk as a water-yielding rock will be considered in reference to experiments made to determine its water capacity.*

The water obtainable by exhaustive pumping, or received by natural springs, is not the water that has existed from time immemorial in the substance of rocks, but that which has entered from the surface, is conducted downwards by gravitation, is checked for a time in its progress by friction, occupies it may be for a time cavities and crevices in rocks, and is either on its way to escape by some natural outlet, whence it can reach the sea, or it refills natural underground reservoirs that have been exhausted of their contents by artificial means.

7. All available water derived from the rain.—If, as seems to be the case, there is no known source of water beneath the surface that is not in some way connected with the surface, we are justified in assuming that the ultimate source of all water available for human purposes on the earth is that which is accumulated in the great oceans which cover three-fifths of the surface, and whose depth, though very variable, amounts generally to several thousand feet. This water circulates and is rendered available by the agency of the atmosphere.

8. The atmosphere, the agent conveying vapour.—The atmosphere which floats over the whole surface of the globe (but whose height above the surface, under sufficient pressure to retain large quantities of water, is not considerable), is exceedingly mobile, and very elastic, consisting of mixed gases and vapour. The proportion of the gases is constant, but the quantity of water contained in each cubic foot of air is exceedingly different at different times and in different places. The dry gases (oxygen and nitrogen) act in some measure as a sponge, and the quantity of vapour they carry depends on their density and temperature, The air, being elastic, is most dense nearest the earth, and lighter in the upper strata. When heated it expands, and therefore becomes lighter,

* The following tabular statement of the water capable of being held in a cubic yard of solid stones used for building purposes, and of chalk, may be useful for reference; none of the water thus contained would enter a well by natural drainage, or percolation, or be in any sense available by pumping:—

Craigleith sandstone - - - -	13·6 gallons.
Mansfield red sandstone - - -	17·5 „
Portland stone (limestone) - - -	27·2 „
Bath (oolitic) limestone - - -	28·5 „
Parknook magnesian limestone - -	37·3 „
Upper chalk (Tring cutting) - - -	60·0 „

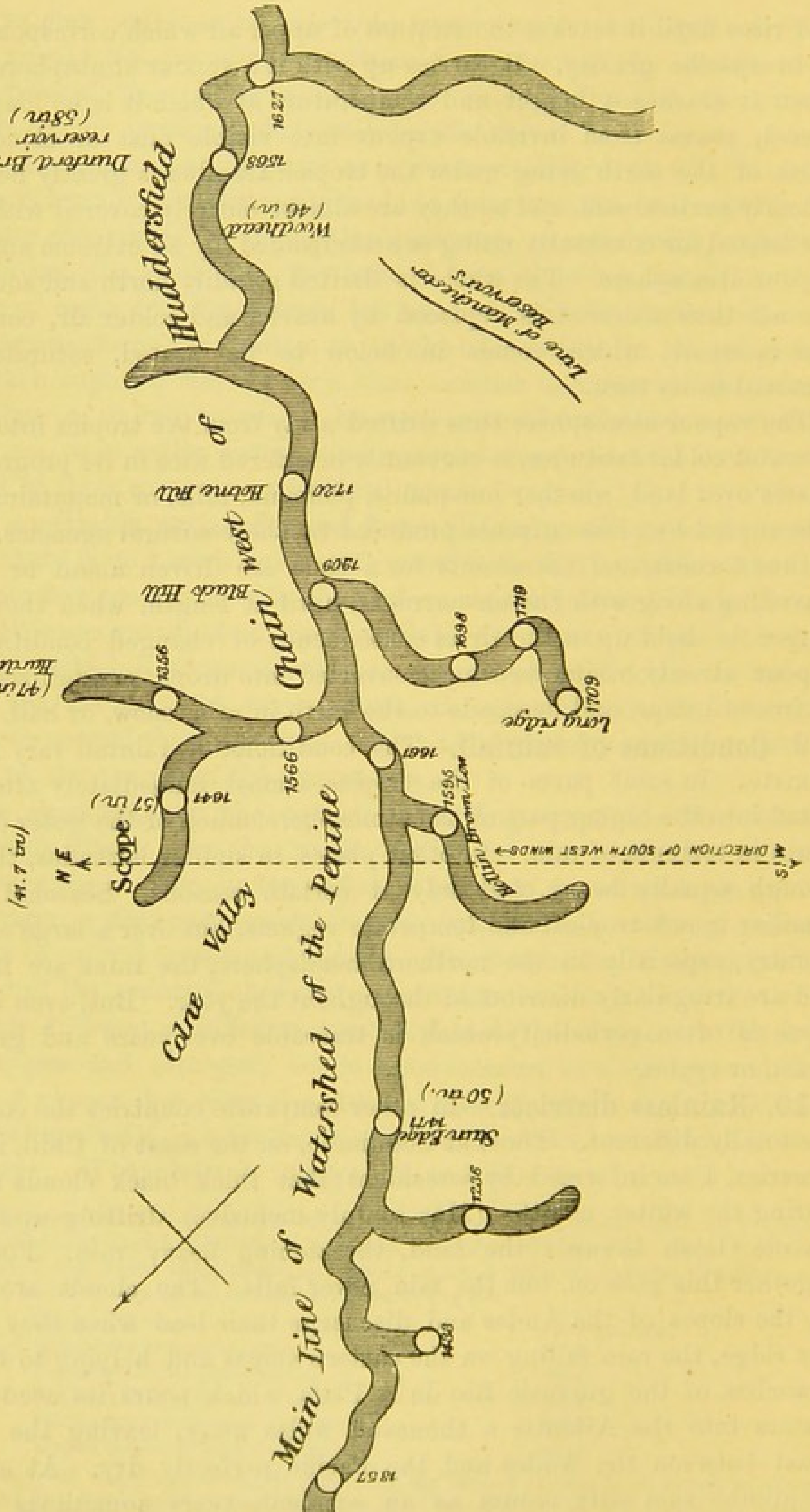
The quantity of water contained in ordinary dry stones varies from three to about eight gallons in a cubic yard, when they are in a natural state, and perfectly dry in appearance.

and rises until it reaches the stratum of upper air which corresponds with it in specific gravity. It carries up with it a vapour atmosphere which, when it reaches a height and temperature at which it is no longer sustained, passes from invisible vapour into visible mist or cloud. The parts of the earth lying under the tropics are always greatly heated by a nearly vertical sun, and as they are almost entirely covered with ocean, the heated air constantly rising is accompanied by an extreme amount of vapour atmosphere. The whole is drifted steadily north and south, and the air thus removed is replaced by heavier and colder air, containing less moisture, which comes in below to be heated, saturated, and removed in its turn.

The vapour atmosphere thus drifted away from the tropics into temperate and colder latitudes, is constantly interfered with in its progress as it passes over land, whether low plains, plateaux, hills, or mountains, and is interrupted by cross currents produced by these natural agencies. Cloud is thus formed, and the clouds for a time are driven about or drifted, travelling along with the air-currents, until at length, when they can no longer be held up in the air in consequence of changed conditions, the vapour already visible becomes converted into drops, crystallized atoms, or frozen lumps, and descends to the earth in rain, snow, or hail.

9. Conditions of rainfall.—The conditions of rainfall vary in every climate. In some parts of the tropics, almost immediately after being lifted into the higher part of the atmosphere, much of the water descends again in torrents of rain. In other places, in similar latitudes, the rains, though equally heavy, fall only at certain seasons. Seasonal rain is familiar in sub-tropical and temperate regions, but over a large extent of country, especially in the northern hemisphere, the rains are frequent, and are irregularly distributed throughout the year. But, even in these, there is often periodicity which is traceable over years and groups of years, or cycles.

10. Rainless districts.—In other temperate countries the conditions are totally different. Thus, at Coquimbo, on the coast of Chili, in South America, I am informed by a resident that thick black clouds are seen during the winter months (May to July inclusive) drifting up from the Pacific Ocean towards the land, threatening heavy rain. For weeks together this goes on, but the rain never falls. The clouds are carried up the slopes of the Andes and discharge their load when they overtop the ridge, the rain falling on the eastern slopes and helping to feed the branches of the gigantic Rio de la Plata, which pours its accumulated waters into the Atlantic a thousand miles away, leaving the western coast between the Andes and the Pacific perfectly dry. At and near Coquimbo rain only occurs as an accident, years sometimes passing without a shower.


Main Line of Watershed of the Pennine Chain west of Huddersfield
Colne Valley
Scope
Woodhead (46 in.)
Holme Hill
Black Hill
Long ridge
Stan Edge
(50 in.)
(57 in.)
(41.7 in)
N E
S W
DIRECTION OF SOUTH WEST WINDS
1627
1568
1720
1909
1698
1719
1709
1356
1566
1641
1661
1595
1471
1236
1433
1357
1388

The whole area of rainless districts has been estimated to exceed five millions of square miles. The deserts of North Africa, Arabia, Persia, Beloochistan, and Tibet, are districts of this kind in the eastern hemisphere. In the western we have the table-land of Mexico, parts of Guatemala, California, and the coasts of Peru and Chili. There are long periodic droughts in South Africa and the Pampas of South America.

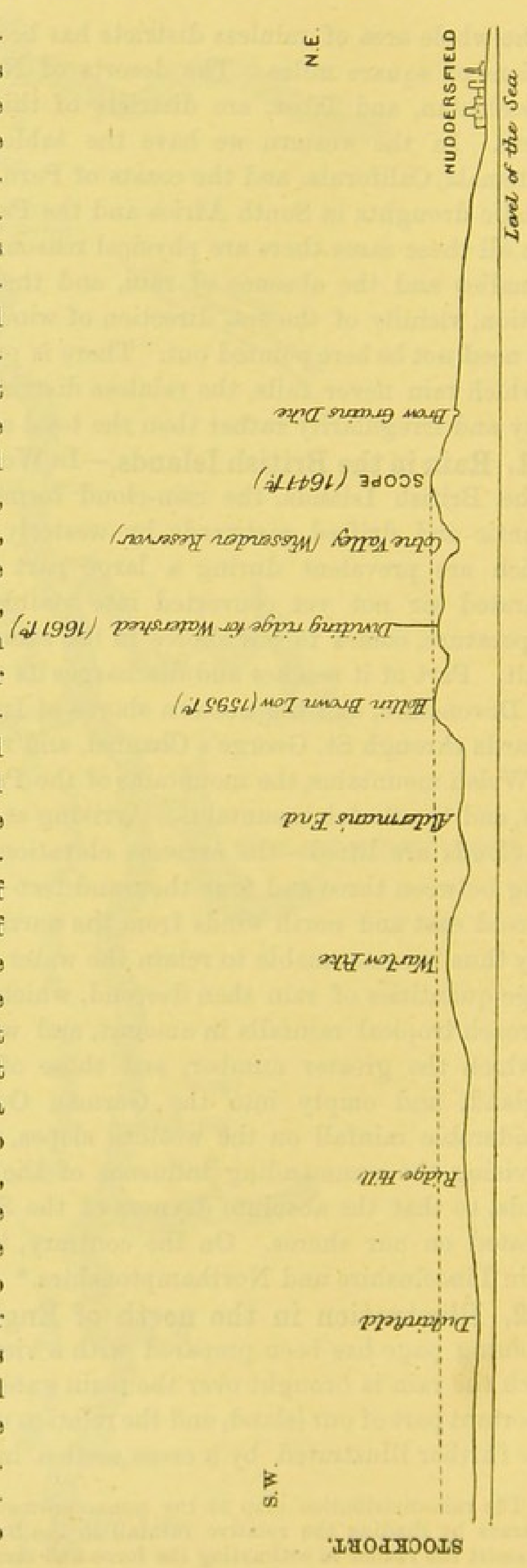
In all these cases there are physical reasons to account for the apparent anomalies and the absence of rain, and these depend on geographical position, vicinity of the sea, direction of wind-currents, and other causes that need not be here pointed out. There is probably no spot on the earth on which rain never falls, the rainless districts being remarkable for the rarity and irregularity rather than the total absence of this phenomenon.

11. Rain in the British Islands.—In Western Europe, and especially in the British Islands, the rain-cloud formed over the surface of the Atlantic and drifted eastwards by westerly and south-westerly winds (which are prevalent during a large part of the year), or the warm saturated air not yet converted into visible cloud owing to its high temperature, comes to our shores in the same way, but with a different result. Part of it reaches and discharges its rain on the hills of Cornwall and Devonshire, and the western shores of Ireland. Part of it is carried onwards through St. George's Channel, and reaches the western slopes of the Welsh mountains, the mountains of the Penine chain, the Cumberland hills, and the Scotch mountains. Arriving at the coast, the moist air and the clouds are lifted—the extreme elevation of any continuous barrier being between three and four thousand feet—and at the ridge they meet the cold east and north winds from the northern plains of the old world. They thus become unable to retain the water with which they are loaded. Large quantities of rain then descend, which in a few isolated localities approach tropical rainfalls in amount, and which supply water to rivers, of which the greater number, and those of chief importance, traverse England, and empty into the German Ocean. There is, however, a considerable rainfall on the western slopes, the hills in our islands not exercising the commanding influence of the Andes over the wind and clouds, so that the absolute dryness of the South American coast is not repeated on our shores. On the contrary, the driest parts of England are in Lincolnshire and Northamptonshire.*

12. Illustration in the north of England.—The diagram on the adjoining page has been prepared with a view to illustrate the mode in which the rain is brought over the main water-shed of England, in a very important part of our island, and the relation of rainfall to local conditions. It is further illustrated by a cross section in the next page. The plan

* The rain-distribution map at the commencement of this chapter is intended to illustrate by shading the relative rainfall in the British Islands. A reference to it will assist the reader in estimating the force and meaning of the above remarks.

is reduced from the Ordnance map, and represents the dividing line or ridge which separates Lancashire from Yorkshire in the neighbourhood of Huddersfield. The distance represented is 14 miles, and all the principal summits are marked with their respective elevations. In the southern part it includes the line of the Manchester reservoirs, and the Manchester, Sheffield, and Lincolnshire railway, which passes parallel to the reservoirs near Woodhead, and then continues through the ridge emerging near Dunford bridge. At Woodhead, on the west side, and at Carlcotes beyond Dunford bridge, on the east, are gauges which mark respectively 46 and 58 inches of rainfall. Near the centre of the diagram is a remarkable and lofty spur of the Penine range, running south-west from a culminating point at Black Hill to Longridge, a distance of more than two miles. The south-west winds, loaded with moisture, are divided by this transverse ridge, one branch passing to Carlcotes, and the other ridge over the line of hills indicated in the sectional diagram towards Scope. The fall near Scope is 57 inches. A little further to the north-east, the fall is reduced to



Section from Stockport to Huddersfield in the direction of the south-west winds, crossing at right angles the line of watershed of the Penine Chain on the dotted line of the plan, and showing the form of the ground. The heights are proportional. Distance represented, 20 miles.

47, and a mile further to 41 inches. Beyond this ridge, towards the north, on the line of the water-shed at Standedge (1100 feet), there is a fall of 50 inches close to the hills, but it reduces very rapidly towards the east, and at Blackstone Edge (1360 feet), outside the map towards the north, it is 41 inches.

The Scope is a very remarkable detached hill, the highest part 1641 feet above the sea, presenting a curved sloping face towards the north-east, and a steeper slope towards the south-west. A number of streamlets converge towards the centre of the curve, on the eastern side, and form the Brow-Grains dyke, which runs a large stream, whose head-waters are now collected and conveyed by a catchwater drain into the Black-moor-foot reservoir for the use of Huddersfield. The dip of the gritstone rock in this part of the chain is on the whole easterly, and the conditions are particularly favourable for the reception and storage of the storm waters which come down with great rapidity and in very large quantity after heavy continued rain.

13. Origin of rain.—Wherever warm moist air is met by colder air, whether saturated or not, mist and cloud will be formed, but rain does not necessarily fall. The condition of the air is, however, materially altered, as the conversion of invisible into visible vapour cannot take place without the liberation of a large quantity of heat and a change of electrical condition. These events follow again on the formation of rain-drops, and are still more marked when hail or snow are formed. The instant that rain commences to fall, heat is liberated, the surrounding air is warmed, and part of the rain taken back again to saturate the slightly warmed, and, therefore, more absorbent air around. The quantity re-absorbed is small compared with the whole, and the rest falls towards the ground by gravity, accumulating moisture as it descends and reaching the earth in drops of rain of definite size. It is well known that when rain falls from mist resting on the ground, the rain may be so fine as barely to form drops. Such rain is close and wetting, though not perceptible.

The circulation of water by the agency of the atmosphere is greatly assisted by the irregular currents of air caused by the form and variety of surface of the land. It is an operation of gigantic magnitude connected very closely with the condition of the earth as a habitable globe. As far as we can judge, life is inconsistent with a surface that has not something of this circulation which gives to the earth itself a species of vitality corresponding to that possessed by organic beings.

14. Quantity of water taken into the atmosphere.—The moisture taken up from the surface of the ocean by the continual passage over it of air absorbing the water with which it comes in contact, and immediately passing away when saturated, has been roughly estimated as equivalent to the removal of 60 inches of water from the whole surface of the globe during the year. This would amount to nearly two hundred thousand cubic miles. The water surface of the globe from which this vast quantity is removed, is rather more than 60 millions of square miles in the northern, and more than 80 millions in the southern hemisphere, or about 140 millions of square miles in all.

15. Rainfall area on land.—The surface of land over which a large part of the saturated air delivers its excess of moisture, is nearly 58 millions of square miles, and if the whole of the rain fell upon it the total would represent a sheet 17 feet deep. But as the ocean surface is much more than twice as large as the land surface, and it is known that the rainfall on the sea within the tropics is especially frequent and heavy, the total annual rainfall on the land is not likely to average more than 80 inches in the year, and may be less.

15. Rainfall distribution.—In the tropics generally the rainfall is very heavy, but there are great differences. In the island of Ceylon it appears to average a little less than 100 inches, on the main land of southern India it rises in some places to 150, but in Madras is very much less, not exceeding 40. In tropical Africa, as far as observation goes, it is nowhere considerable. The fall at Sierra Leone is stated at 86. In the West Indies the quantity is exceedingly different in different islands, being stated at 128 inches in Santo Domingo, from 83 to 97 in Jamaica, 75 in Barbadoes, and only from 50 to 55 in Cuba. At Honduras it is 153, and in Mexico (Vera Cruz) 66. In South America the fall in Brazil is, in one place, quoted at 276, and in Guiana 229.

In the temperate zones the rainfall also varies exceedingly, according to position rather than latitude. The average in England is estimated at 32 inches, but the range is considerable, though the extremely wet spots are very small in extent. In France the average is 30·3 inches, but the fall is only 20 inches at Marseilles and Toulon, while at Nice, not far off, it reaches 55 inches. On the south-western coast, at Bayonne, it is nearly the same (54 inches). In the north and east the average is much lower. On the Atlantic coast of Spain the fall is upwards of 100 inches, but at Madrid is barely 9. In Italy the range is limited, the quantity varying between 30 and 40 inches. In Portugal the fall is very high at Coimbra, being variously stated at 118 and 224 inches. The former figure is given by Mr. Buchan, the latter by Mr. G. J. Symonds. At Oviedo it is 74 inches, but at Lisbon only 23. The rainfall on the level parts of Prussia varies generally between 20 and 24 inches, but on the Brocken is 59. In Austria it is little more than 15 inches. The northern countries of Europe have a small rainfall, varying between 16 (at St. Petersburgh), and 22 (at Copenhagen). In Bergen, in Norway, however, the fall reaches 89 inches. At Astrakhan it is said to average 6 inches only.

In Asia, the rainfall at Canton is nearly 70 inches; in northern India it rises to an enormous quantity in one or two exceptional localities, but is generally moderate. On the Mediterranean shores of Asia Minor it varies greatly, but is moderate. At Tiflis, south of the Caucasus, it is 19 inches; and at Tobolsk, in Siberia, 23.

The rainfall in India generally has a wide range, as might have been expected from the great differences of local conditions in different parts of the country. The highest mean is in the north-eastern provinces, in latitudes 23 to 26, where it reaches 93; but in these provinces in latitude 20°, the mean is only 78, though the maximum is 612. In Ceylon and Bombay it is 80, the maximum rising to 312. In the south, on the west coast, it is about 52. In many parts of Bengal it is from 40 to 46. At Delhi, and in many other places, the mean does not exceed 30, at Lahore it is only 17, and on the Indus only 9 inches. The maximum recorded at Lahore is 57, and on the Indus 30.

In temperate Africa we find a fall of from 30 to 40 inches on the Mediterranean coast, 37 in Abyssinia, and from 24 to 27 at the Cape of Good Hope.

In North America the range over a large extent of the eastern states of the Union is between 40 and 50 inches. On the Mississippi-Missouri basin it varies from 50 to 60 inches. In Canada it is not very different, but diminishes towards the west. In California it is 23 inches at St. Francisco. At Sibka Sound (north-west extremity of North America) it is 90 inches, and at Astoria 86. In Florida it varies from 57 to 63, and in Alabama is 64. The range is inconsiderable.

In Australia, the fall is 23 inches at Bathurst, 20 at Adelaide, 30 at Melbourne, and 25 at York, in West Australia. In New Zealand it ranges between 31 and 38 for different stations.

In high latitudes in the north temperate zone, and within the Arctic circle, snow falls in large quantities. About six inches of snow are equivalent to one inch of rain. Nothing is known of the quantity of snow falling in the year in either the Arctic or Antarctic circles.

17. Days of rainfall per annum.—In many parts of the world the rains fall periodically, sometimes in autumn and winter, sometimes in spring and autumn. In some places and districts the total fall is not excessive, but rain falls at all seasons; in others, where the fall is heavier, it is limited to certain seasons and to a small part of the year. In western Europe it rains on twice as many days in the year as in the eastern part away from the sea. In Ireland, which is an extreme example, it rains on an average on 208 days in the year out of the 365, which is three times the number of days on which rain falls in Italy. In the interior of Europe and in northern Asia the number of rainy days diminishes rapidly as we advance eastwards; and in Siberia it is reduced to sixty in the year. In mountain districts in the north-western counties of England, where rain falls very heavily and in large quantities, the number of rainy days is exceedingly large. The average at twelve stations thus situated is as much as 194 days.

The average number of rainy days in the year, the months of the year in which rain chiefly falls, and the number of years that are required to form a cycle within which the chief varieties of distribution are recognised, and which is repeated in something of the same order time after time, are points of great interest, but they have as yet been only partially determined. At the same time, indications exist of such cycles, and continued observation can hardly fail to bring to light some of the laws which govern the changes. These will be alluded to in another paragraph.

18. Excessive rainfalls.—It is important to put on record extreme cases of rainfall, as those whose opinions are formed from the ordinary run of phenomena are apt to forget how completely ordinary calculations may be rendered useless by events which the engineer should always be prepared to regard as possible. The following examples, therefore, with the authorities for each statement, may be useful.

An enormous quantity of rain fell in a very short time at Genoa, on the 25th October 1822, amounting to 32 inches in 24 hours. It was very local, and produced a local deluge.* At Joyeuse, Departement de l'Ardêche, France, on the 9th October 1827, 29 inches 3 lines French (more than 31 in. English) fell in 22 hours.† At Catskill, (U.S.,) on 26th July 1819, between $3\frac{1}{2}$ P.M. and 11 P.M. ($7\frac{1}{2}$ hours), there fell in an empty barrel 18 inches of water.‡ At Gibraltar, on 25th November 1826, 33 inches of rain fell within 26 hours.§ At Viviers, on 6th September 1801, $14\frac{1}{2}$ inches fell in 18 hours.§ I myself observed and measured a fall of 7 inches on 18th October 1868, at Villeneuvette, near Clermont, Departement de l'Hérault,‖ within 18 hours. Of this, 6 inches fell between 6 P.M. of the 17th and $7\frac{1}{2}$ A.M. of the 18th; but as the rain was not remarkably heavy during the night, and the heavy fall only began at 5 A.M., the greater part must have fallen in $2\frac{1}{2}$ hours. At Geneva, on 20th May 1827, there fell 6 inches in three hours.§ At Perth, on 3rd August 1829, there fell eight-tenths of an inch in half an hour.§ At Naples, on 22nd November 1826, nine-tenths of an inch fell in 37 minutes. Hail, in this case, accompanied the rain.§ At Cayenne, in the tropics (5° N. lat.), in February 1820, there fell, in 10 hours, $10\frac{1}{4}$ inches.§ In Scinde, in the year 1866, 20 inches of rain fell in 24 hours.‖ In the

* This fall was measured and reported by M. Pagans, and the record was accepted after careful inquiry at the time by Arago. Ann. de Chimie, xxvii. 207.

† This is reported by M. Tardy de la Brossy, and is also adopted by Arago. Ann. de Chimie, xxxvi. 414.

‡ Silliman's Journal, vol. iv.

§ James Forbes. Report on Meteorology, Brit. Assoc. Reports, vol. for 1840, p. 114.

‖ Mr. John Brunton, C.E., quoted by Tylor, Quart. Geol. Journal, vol. xxiv. p. 124.

highlands of Scotland 3 inches not unfrequently fall in one day.* On the 5th December 1863, there fell at Portree, in Skye, $12\frac{1}{2}$ inches in 13 hours; and, on the same day, at Drishaig, near Ben Cruachan, 5·2 inches fell.* Two days afterwards, in this same place, 7·12 inches fell in 30 hours.* At Seathwaite, in Cumberland, 6·62 inches fell on 27th November 1848, and this fall has been nearly reached six times since that date.* In the hills above Bombay 24 inches have fallen in one night, and on the Khasia Hills, north-west of Calcutta, 30 inches on each of five successive days.* At Cayenne, 151 inches fell between 1st and 24th February 1820.

The heaviest recorded rainfalls are within the tropics in India, the most remarkable being a fall of 600 inches in a year, about 500 inches of the total being within seven months. This was during the south-west monsoon. In the Ghauts, in lat 18° N., Col. Sykes records 302·21 inches, of which 120 inches fell in the month of July. The following are other tropical rainfalls:—Maranhao (Brazil), 280 in.; in the Atlantic, within the *doldrums*, 225 in.; Vera Cruz, 183 in.; St. Benoit, Isle of Bourbon, 160 in.; Caraccas, 155 in.

Excessive rainfall occurs at irregular intervals in England, and is usually followed by local floods. In other countries these floods are more severe, and the rainfall much heavier. During the summer of 1875 there were instances of rainfall followed by floods carefully recorded, and hence valuable for reference. An account of them was given to the Institution of Civil Engineers, by Mr. G. Symons, and is published in the Excerpt Minutes of the Institution for 1875-1876, Part III. On that occasion the rainfall during 24 hours, ending at 9 A.M. on the 15th July, was measured at five stations as follows:—

Newport Water Works - - -	5·33 inches.
Tintern Abbey - - - -	5·31 „
Newport - - - -	5·30 „
Cardiff (average of three) - -	4·75 „
Caerleon - - - -	4·64 „

In nearly all these cases the amounts are twice as great as had been measured previously, and the rain fell steadily for several hours, not in a water-spout or in unusually large drops.

In India, Major Jacob, when Astronomer in charge of the Madras Observatory, measured, on one occasion, five-sixths of an inch fall in 10 minutes; and, it is stated by Mr. Neville, that as much as 4 inches fell in one hour in the Holborn and Finsbury sewers district in London.

19. Heaviest fall not on the windward side of water-shed.— According to the evidence of Mr. Bateman, given before the Duke of

* Buchan's "Handy Book of Meteorology," 2nd edit., pp. 190, 191.

Richmond's Commission in 1868 (Evidence, p. 356), the measurement of the rainfall at various stations on lines of country crossing the Penine chain from south-west to north-east, proves conclusively the fact of the increased fall on the eastern side of the water-shed in England. Commencing with a section from the Wigan Water Works at Standish, and reaching to the Blackburn Water Works at Pickup bank, the mean fall for eight years ending 1865 was as follows:—At Standish, elevation 300 feet, 41·14 inches; at Rivington (Liverpool Water Works), 700 feet, mean of ten years, 45·22; at Belmont (Bolton Water Works), elevation 800 feet, also ten years, 52·72; and at Pickup bank (Blackburn Water Works), elevation 720 feet, 45·8 inches. In another section, from Rochdale to Sowerby Bridge, in the same direction, calculated from 1846 to 1848, both inclusive, the fall at Rochdale, at the foot of the Penine range, westerly side, averaged 34·2 inches; near the summit of the hills of the range at Blackstone Edge (1200 feet), 52·9; at the toll-bar on Blackstone Edge, a little further east, (1,000 feet), 53·2; at Black House, Blackstone Edge, still further east, same elevation, 51·8; and at Sowerby Bridge, 300 feet, at the foot of the chain, on the east side, 29·85. On the line of the Manchester and Sheffield Railway, running from west to east, we find that at Manchester, the mean of twenty-five years ending 1876, was 34·14 inches (elevation 194 feet). In the valley of Longdendale, for the same period, at Rhodes Wood reservoir (500 feet), the mean was 45·94; at Woodhead reservoir (680 feet), 50·5; in the valley of the Don, at Dunford Bridge (954 feet), the mean was 56·7 inches; at Penistone (717 feet), 32·5; and at Sheffield (188 feet), 27·83 inches.

On the ridges between Loch Lomond and Loch Lubnaig, in Scotland, where the rainfall is very heavy, we have, in the same evidence, a statement to the effect that, while the average fall of 12 years ending 1867 was 98·6 inches on the eastern flanks of Ben Lomond, 1,800 feet above the sea, it was 85 inches on a ridge a little to the E.N.E. at only 1,500 feet, while on the westerly flanks of Ben Ledi, still further to the E.N.E., and also 1,800 feet above the sea, it was only 59·17 inches. In this case it is clear that the rain-clouds were drained before reaching the easterly range.

There is, indeed, abundant proof of the general truth of this statement so far as England is concerned. The diminution of the rainfall is a joint factor of distance to the east from the high ground near the west coast, and the depression below the highest ground. The hills near the east coast, belonging chiefly to the oolites and chalk, are distinctly lower than those of older and harder rock towards the west. At the same time local changes in the form and direction of the plains and valleys are sufficient to prevent any general law from being applicable. For practical purposes, in the estimation of rainfall where storage is concerned, it is absolutely necessary that series of observations by rain-gauges should be obtainable if certainty is needed. Mr. Symons, who has paid great attention to this subject, and whose tables are extensive and minute, believes that, by a system of averages, a good general idea can be arrived at from gauges in different parts of the same district; but little dependence can be placed on calculations of averages in a subject dependent so much on local conditions, and the opinion of Mr. Glaisher is distinctly adverse to this mode of estimation.

20. Rainfall different in adjacent places.—The amount of rain falling within a district is not the same at the same time over a wide area except in large expanses of nearly level country, and under special conditions of weather; and when different parts of a district or country vary in geographical and physical conditions, the difference is often marked and considerable. Thus, on the Pentland Hills, near Glencorse, the mean fall of twelve years (1849 to 1860, both inclusive), was 37·6 inches, the elevation above the sea being 735 feet, and the station at the eastern foot of the hills. At Colzium, 1,030 feet above the sea, on the western side of the same hills, the mean rainfall was 43·3 inches. On the two sides of the hills of the Penine chain, the difference is even more marked; but there the fall is heaviest almost immediately to the east of the dividing ridge. There are, however, instances on record of similar weather over very large areas of land and sea at the same instant.

It has already been stated that in England, and throughout western Europe, where the prevalent winds are south-westerly, and arrive at our shores loaded with moisture and relatively warm, they are immediately deprived of a great part of their moisture by being drifted up and over the western faces of the hills on our western coast. Thus it is that Ireland has a heavier rainfall than England, and that in some parts of the lake district of Westmoreland the rainfall is almost tropical. In Wales and Cornwall there is also more rain than in the middle of England; and more rain falls on the midland counties than on the eastern side of the land.* There is also a heavier rainfall in the British islands than in France; more rain on the Atlantic shores of France than in the interior; more in western Europe generally than in central or eastern Europe, and more in Europe than in the vast plains of Tatary. After the clouds have been deprived of their first and large supplies of water, the atmosphere carries the remainder very far, and distributes it according to laws which we need not now consider.

21. Season of rainfall variable.—The season of the greatest rainfall, and the mode in which the heaviest rain falls, are both matters that vary a good deal according to local circumstances. In some cases the whole

* Not universally, as some parts of the midland counties are among the driest in England; but this is owing to local conditions.

of the rain falls in a few exceedingly heavy torrential showers. Elsewhere there will be almost continuous rain for a long time, the total fall being comparatively small. These are matters of considerable moment in estimating the results of rain, and the quantity available for storage.

During the season of heavy rain, in some countries, the rain-clouds are carried by the wind with the extraordinary velocity of twenty to thirty miles an hour, so that there is often a wide range of country within the influence of precipitation at the same, or nearly the same, time. Intervening mountain chains are the most effectual causes of modifying the amount and conditions of rainfall, but they are by no means the only ones. To this cause, however, must be attributed the exceptional falls in western Europe and northern India.

22. Quantity of rain greatest nearest the ground.—It has been shown by experiment and observation that during rain the quantity falling increases as the ground is approached; in other words, that the drops increase in size and number, or both, the nearer they approach the earth. It may be considered proved that both the rate and amount of the increment continually increase till the ground is reached. In certain cases the diminution between places situated at a higher and lower level varies directly as the square root of the height; but this law is subject to many interferences by season, climate, and position. At York, during twelve months (1833–1834), the rain falling on the ground was 25·706 inches. Measured at a height of 44 feet above the ground, it amounted to 19·85 inches, and, at 213 feet, only to 14·963 inches.* The following table is the result of other observations, and will be found useful and suggestive. A similar result is obtained by other observations, the difference being so small as to be unimportant.

Proportion of rain that may be expected to fall at various heights from one to fifty feet for each inch of rainfall measured on the earth.

	inches.
At 1 foot elevation the fall is	·996
2 feet ,, ,,	·986
3 ,, ,, ,,	·979
4 ,, ,, ,,	·972
5 ,, ,, ,,	·965
10 ,, ,, ,,	·933
20 ,, ,, ,,	·881
30 ,, ,, ,,	·839
40 ,, ,, ,,	·804
50 ,, ,, ,,	·775

It is not likely that at another station the precise law of diminution would be identical, or that a proportional result would always obtain.

* So long ago as in 1766, Dr. Heberden observed that at an elevation of 100 feet the rainfall was only half that on the ground. In a garden near Westminster Abbey, the amount of rain collected on one occasion was 22·61 inches. That on the roof of an adjacent house 18·14 inches, and on the square tower of the Abbey 12·10 inches.

The table applies to one locality (York), and possibly may not be always applicable even there. It is, however, valuable as the illustration of a general truth. The fact of increase of rain as a shower nears the earth is quite established.

23. Rainfall on hill-sides greater than on lower levels.—It does not follow, from the action of this law, that the rainfall on places at different levels on a mountain side is less at the higher than the lower stations. On the contrary, it is, as a rule, greater, and often very much greater. The fall of rain is almost always more frequent and heavier on the sides and slopes of mountains than in the plains below, although this, like other general statements in meteorology, must be accepted subject to many modifications by local causes.

As a further illustration of this law, the following table, prepared with reference to a Parliamentary inquiry in 1869, and now modified by extended returns in some cases, will be valuable. With two exceptions, the periods of observation range over at least 17 years; the stations are moderately near each other, and the results may be depended on as correct, and are given on the authority of Mr. Glaisher.

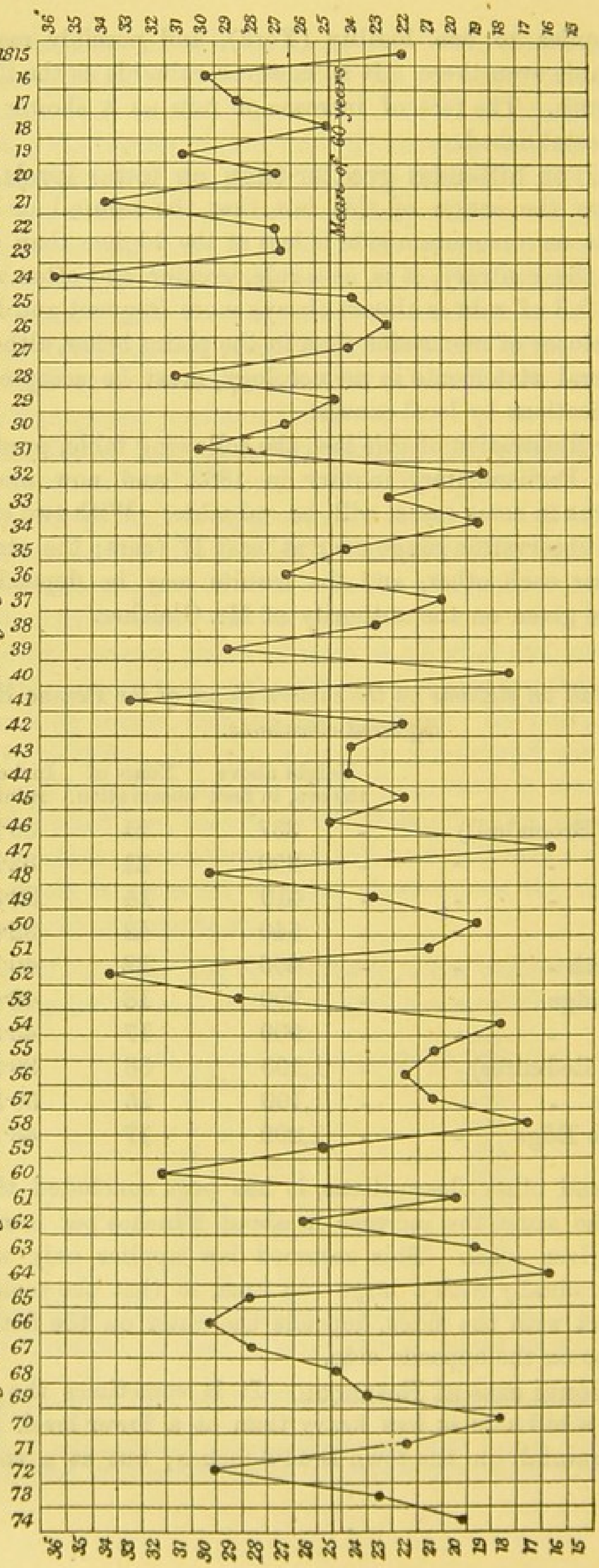
Mean rainfall on stations on the eastern slopes of the Penine Hills at different elevations.

	Height above the sea, in feet.	Years of observation.	Inches of rainfall.
Sheffield (Broomhall) -	337	21	30·9
Dalton - - -	350	21	32·1
Rastrick - - -	410	14	32·8
Halifax - - -	540	42	32·48
Saddleworth - - -	600	22	40·7
Naden Bridge - -	900	18	42·4
Lenches - - -	900	17	43·6
Sheffield (Redmires) - -	1,100	38	39·94
Standedge - - -	1,100	25	50·5
Blackstone Edge - -	1,200	17	43·6

From this, and other observations, it has been concluded that, other things being the same, the increase is about 2 inches per hundred fee rise above a given level. This assumed law applies only where the ground rises gradually with a large top area, so that the cooled air, by being in contact with the sides, deposits the water on the flat top, and not on the slope on the opposite side.

24. Exceptional case at Besançon.—It is sometimes the case that the rainfall on a hill side is less heavy than at a lower level. Thus, at Besançon, the rainfall in the town is 44·2 inches; but at a station 600

Diagram showing the annual rainfall at Greenwich for sixty years from 1 Jan. 1815 to 31 Dec. 1874.



N.B.—In this diagram the figures at the sides refer to the lines below them, not to the middle of the space. The mean is 25·17, which is, therefore, the mean annual rainfall in the neighbourhood of London. The range is seen to be about 20 inches (from 16 to 36), and it has hardly ever been the case that more than five years have elapsed without a considerable range.

feet high, on the same mountain, it is only 25 inches. Local conditions necessarily supersede general laws in such a case.

25. Laws governing rainfall.—In all inquiries involving the consideration of the available rainfall, by which is meant the quantity of water that can be depended on for supply in any district, the first thing to be determined is the mean annual fall over the tract of land under consideration. The laws by which rainfall is governed are not at present accurately known, but the fact is certain, that in our own country, which is remarkable for its variable character, the rainfall of one year is little guide to that of the next, and that observations carefully made over many years are necessary as the basis of calculations.

To understand the nature and magnitude of the difference of rainfall in successive years in the temperate but uncertain climate of England, it will be useful to study the annexed diagram of the mean annual rainfall at Greenwich for a period of sixty years in this century. The frequency and irregularity with which the maxima and minima recur mark the irregularity of the climate. The diagram shows sixteen years of maximum fall (above 28 inches), and eight between 25 and 28 inches; sixteen of minimum (less than 22 inches), and twenty between 22 inches and the mean. On the whole, about half the years had a rainfall within 3 inches of the mean, and the other half were marked by maximum or minimum falls. One important result is worth notice, namely, that there have sometimes been three or four consecutive years of minimum fall, but rarely in any case two consecutive years of maximum fall. Perhaps if a table could be made to show the results of another half century, we might trace indications of some law governing the formation of wet periods of several years (or of years averaging above the mean), and dry periods of several years (averaging below the mean). We see that in one period of sixteen years (1816–1831 inclusive), the mean was 28·47 inches, whereas in the following sixteen years (1832–1847 inclusive), the mean was only 23·6. It is important also to notice that if we take the three consecutive driest years (1854–1856, and 1856–1858), we shall find that the average of each of those three years was below 21 inches, while the mean of the three wettest years (1822–1824) is not more than 30 inches. The maximum was 36½ inches in 1824, which was approached in 1821, when 34½ inches fell. In 1852 there were 34, and in 1841 there were 33¼. The years of minimum rainfall were 1847 and 1864, the amount in both cases being under 17 inches. The fall was only 17½ inches in 1858, 18 inches in 1847, and 18½ inches in 1840 and 1854. The average of the four wettest years was 34·56, or nearly 2 inches below the absolute maximum, and of the five driest years, 17·9 inches, or only nine-tenths of an inch above the absolute minimum. These facts are important in estimating the number of years provision required in storage for supply in reservoirs, and there are few such continued series of sound observations available. Such a record on the hills of the Penine chain, on the borders of Lancashire and Yorkshire, would be equally valuable, and would give means of comparison ; but the observations hardly reach back far enough in time to be available.

26. Sun spots as influencing rainfall.—In India, and other tropical countries, where meteorological conditions of all kinds are more regular and more easily recognised in relation to cosmical causes than in the temperate zones, results have been obtained showing periodicity of a very important kind in connection with the state of the sun's surface. It has been known for some time that there is an eleven years cycle of sun-spots, during which the number and magnitude of the spots attains a maximum and sinks to a minimum with remarkable regularity.

Sun-spots are an indication of solar energy, although they do not measure its amount. The amount and distribution of solar energy vary during the cycle of eleven years, and heat, magnetism, electricity, and chemical action on the earth, which are all governed by solar energy, are affected by the changes. Professor Balfour Stewart has recently represented the number of solar spots, the magnetic declination, and the auroral displays from 1776 to 1871, in a series of curves, and these curves follow each other with remarkable coincidence.

The sun-spot cycle appears to regulate solar radiation and thermometric variations, as well as magnetic declination and auroras, and it has seemed possible that the aqueous vapour produced at the period of minimum sun-spots may be more transparent to heat rays than that produced at other times, the heat rays consisting of two kinds, differing in intensity and subject to periodic changes. It has been proved, too, that wind disturbances in the tropics follow the same law, hurricanes being more frequent and more violent and losses at sea more numerous during the years of maximum than during the years of minimum sun-spots.

All these facts lead to the conclusion that rainfall within the tropics recurs at intervals, in cycles of about eleven years, the years of maximum rainfall being years of maximum spots. In North America, it has been stated that fluctuations of level of the great lakes indicate a similar law.

These matters have been specially considered lately in reference to the Madras famines of 1876 and 1877. In Madras there are three seasons, so far as rain is concerned. Scarcely any rain falls in the first season, from January to the end of April. At that time the south-west monsoon sets in with heavy rain, commencing in May, and continuing, with more moderate rain (the whole fall averaging about 18 inches), to October. Then succeeds the north-east monsoon, lasting during the months of October, November, and December, during which 30 inches fall. In the course of sixty-four years that have elapsed during this century, from 1810 to 1865, the average rainfall of the years of minimum sun-spots during the north-east monsoon has been 16·94 inches, the average of the rain of the same part of the year of the whole sixty-four years being 28·90 inches. The rainfall during the south-west monsoon during the same years of minimum sun-spots averaged 12·12 inches, the general average for the whole period being 15·13 inches.

The following tabular statement* shows the average number of sun-spots per annum; the average number in the years of maximum and minimum spots; and the average number in the years intervening between maximum and minimum spots, during sixty-two years of the present century, from 1811 to 1872 inclusive. It shows also the mean magnetic declination, occasions of auroral display, rainfall in various places, cyclones, and West Indian hurricanes, in those years:—

Years.		Mean Annual Number of Sun Spots recorded.	Diurnal inequality of Magnetic declination.	Auroras.	Madras Rainfall. N.E. Monsoon.	Madras Rainfall. S.W. Monsoon.	Madras Rainfall, Total Annual.	Bombay Rainfall.	Cape of Good Hope Rainfall.	Greenwich Rainfall.	Cyclones, Indian Ocean.	Hurricanes, West Indies.
Minimum group	1821, 32, 43, 54, 66 1811, 22, 33, 44, 56 1812, 23, 34, 45, 57	12·63	6·74	26	23·92	14·65	40·39	68·78	21·85	24·82	7·30	2·53
Intermediate	1813, 24, 35, 46, 57 1814, 25, 36, 47, 58 1819, 30, 41, 52, 64 1820, 31, 42, 53, 65	43·55	7·72	42	30·27	16·71	49·07	71·89	23·59	25·69	8·25	2·72
Maximum	1815, 26, 37, 48, 60 1816, 27, 38, 49, 61 1817, 28, 39, 50, 62 1818, 29, 40, 51, 63	76·80	9·45	55	31·06	19·31	53·50	75·28	27·95	24·96	13·25	4·25

N.B.—The years underlined are the maximum and minimum years as calculated. The others are years of greater or less than mean.

In this table the mean annual rainfall for the groups of years observed at Greenwich is also inserted. The maximum fall in Greenwich occurs in the intermediate years, and the fall in the maximum and minimum sun-spot years does not vary much. If, however, we take the years immediately succeeding maximum sun-spot years, we shall find the average to be considerably higher than the mean, reaching 27·7 inches. By referring to the diagram, it will be seen that maximum Greenwich rainfalls (those above 30 inches) are recorded in the years 1816, 19, 21, 24, 28, 31, 41, 48, 52, and 60, and the minimum years of rainfall (below 20 inches) were 1832, 34, 40, 47, 50, 54, 58, 63, 64, 70. The causes that induce heavy rainfall and drought in our climate are so much complicated

* N. Lockyer, *Nineteenth Century*, 1877, p. 600.

by local conditions as to mask the direct effect of solar energy, as made known to us by the state of the surface of the sun; and there are, at present, no observations to justify the idea that a direct reference is traceable.

27. Measurement of rainfall.—Rain is measured by noting the quantity received in a vessel called a rain-gauge, exposed to the weather under proper conditions. There are several forms of rain-gauge in use; but the principle involved is the same in all. The simplest is a metallic cylinder, provided with a funnel to receive the rain and prevent evaporation. At the bottom the cylinder opens into a glass tube fixed to the side, divided into inches and tenths. The water, after being measured, can be emptied by a stop-cock at the bottom, or, if preferred, by a hole in the rim of the funnel; but, in the latter case, the instrument must be inverted. To prevent injury from the breakage of the glass, a float is sometimes used with a graduated neck rising above the gauge when the rain enters. This is called Fleming's gauge, and is used in Scotland; but it does not admit of very exact measurement. Mr. Symonds recommends and uses a separate graduated glass vessel, into which the water collected in a simple cylinder is poured. In all these cases the actual diameter of the cylinder, within certain limits, is of small consequence, as the ratio alone is required; but it has been stated that, unless at least three inches in diameter, the gauge is not trustworthy. From five to eight inches diameter is a convenient size, eight being desirable in the opinion of Mr. Glaisher. Perhaps the simplest gauge is a metallic cylinder, terminating upwards in a funnel, the diameter of the cylinder being 4·697 inches, and, therefore, the receiving area, 17·33 square inches. A fluid ounce of water containing 1·733 cubic inches, it follows that, for every fluid ounce collected, one-tenth of an inch of rain has fallen. This measure may be made of tin, at an expense of a few shillings; and the receiving measure is very easily procured, and may be graduated with extreme nicety. According to experiments made by Mr. Symonds, increasing the dimensions of the gauge does not affect the result if the diameter be as much as five inches, but in this he differs from Mr. Glaisher. Care must be taken that no evaporation of the water passing into the reservoir takes place before the register is taken, as, where the gauge is placed in stations inaccessible in bad weather, the observation is likely to be seriously interfered with by this cause. Frequent and periodical visits to the gauge are desirable, though not always possible.

The position of the gauge is a subject of considerable importance. If placed against a wall, or near houses or trees, the true fall will certainly not be obtained. If placed unenclosed on the ground, it is liable to injury, and, may be turned aside by a drift of wind. Thus the recorded quantity might easily be very different from the real by neglecting proper precautions in placing the instrument. Practical hints on this subject from some experienced observer should be obtained before a rain-gauge is placed, and its results should in all cases be placed on permanent record.

The height of the gauge, both with reference to the sea and the ground at the station where it is placed, must be carefully noted, and mentioned in the record. The difference, even of a few feet, in affecting the quantity, has already been pointed out; and, near the earth, the result, in some cases, is such as to become very serious. There is danger of the accidental intrusion of water, if the instrument is placed on the ground within reach of men, children, or animals; and there is risk of drifted rain being received, if the receiving pan is of too great depth. As an example of some causes of error, it may be pointed out that the influence of surrounding buildings and rocks, however small, such as a tower or steeple at some little distance, or an overhanging cliff, affects measurably the quantity of rain falling on a given spot, and thus it is absolutely necessary for accuracy that a rain-gauge should be so placed as to be free from local influences of all kinds.

28. Estimated total rainfall.—The amount of rainfall estimated from the observed averages in different parts of the world has been stated as follows, in approximate figures :—

	Area of land in square miles.	Total annual rainfall— in millions of cubic feet.	Total annual rainfall— in millions of gallons.
North and south torrid zones	19,400,000	4,282,750,000	26,767,200,000
North temperate zone . . .	25,150,000	2,160,500,000	13,503,100,000
South temperate zone . . .	4,350,000	261,500,000	1,612,600,000
North and south frigid zones	2,600,000	70,250,000	439,060,000
	51,500,000	6,775,000,000	42,321,960,000

The total weight of the rainfall on this estimate is about 190 millions of millions of tons per annum. The figures here given are, no doubt, to some extent hypothetical, and must not be taken for more than they are worth. For purposes of comparison, however, and to give some rough approximation, they are worth putting on record.

29. Rainfall in zones of elevation measured in France.—The remarks and observations on rainfall are usually limited, in England, to the places of observation. It is, however, convenient, for reference and comparison, to be aware of the phenomena observed in other countries, especially those adjacent. It has been calculated that the rainfall in France is distributed in the manner shown in the subjoined table. The first column states the mean heights above the sea of areas, or zones, into which the country is supposed to be divided; the second, the extent of land within these zones, in English acres; and, the third, the mean annual rainfall in inches over the same zones:—

			Acreage of land in France.	Mean annual rainfall in inches.
Below	40 metres	(say 0 to 130 feet*)	2,220,217	15·75
Between	40 and 60 ,,	(130 to 200 ft.)	21,173,505	19·69
,,	60 and 80 ,,	(200 to 260 ft.)	66,879,098	27·56
,,	80 and 100 ,,	(260 to 325 ft.)	27,199,533	35·43
,,	100 and 120 ,,	(325 to 400 ft.)	5,896,547	43·30
,,	120 and 140 ,,	(400 to 460 ft.)	3,201,428	51·18
,,	140 and 160 ,,	(460 to 525 ft.)	5,108,792	59·06
,,	160 and 180 ,,	(525 to 600 ft.)	272,304	66·93
Above	180 ,,	(600 ft.)	80,308	43·30

From this it appears that the mean annual rainfall over an area of about 115 millions of acres (180,000 square miles) is at the rate of 28 inches nearly, the level of this large tract being between 130 and 325 feet above the sea. The mean rainfall on the low lands (below 130 feet) is not much more than half this quantity, and that on the high lands above 400 feet is nearly double; but the areas in the former amount only to 3,470 square miles, while in the latter they reach 22,750 square miles.

30. Evaporation.—The rain from the clouds falling on hill tops and mountain sides, is almost immediately conducted into grooves and channels that intersect the surface, and the water is collected into streamlets which trickle down, or tumble headlong into valleys. It thence flows onwards and downwards, filling up depressions, and proceeding through natural channels to the great ocean from which it originally came. But it must not be supposed that the whole rain runs off in this way. It has been pointed out that as the clouds are dissolved into rain, the water passing from the state of vapour to that of fluid liberates heat, which had hitherto been employed in separating the molecules and retaining them in the gaseous state. No rain falls without an increment of temperature to the air, and the air thus warmed becomes by that change capable of retaining more vapour of water than before. Re-absorption of part of the fallen rain is called *evaporation*, being in fact a re-vaporisation of water which takes place from all wet substances over which air passes. Thus of the vast quantity of rain that reaches and wets the ground, a certain proportion is almost instantly taken back into the air, unless a fresh supply of air saturated with vapour continues to pour in, and the conditions are such as to tend constantly to produce a further discharge of rain.

It may safely be assumed that under all circumstances in the tem-

* These conversions into approximate English figures are given only for the reader's convenience. They are easily corrected by applying the rule 10 metres = 32·8 feet nearly.

perate zones, and often in the tropics, no sooner has rain fallen than the removal of water by evaporation also sets in and continues until the state of the air is such that no more can be taken up. It does not follow that the air is always damp, because, in the first place, air is not damp when it contains less water than its temperature and density would enable it to hold, and next because rain is often accompanied or succeeded by wind removing moist air and drying the surface.

31. Proportion of rainfall removed by evaporation.—The proportion of the rainfall that is immediately or ultimately removed by evaporation varies very greatly in different places and under varying conditions. It might be supposed to be at a maximum when the rainfall is least, for then the surrounding air is most likely to be dry and absorbent, but this is not always the case. It is greater when the temperature is high than in cold weather, and as already pointed out is likely to be in excess when wind is blowing, and there are steady currents proceeding from a quarter in which there is no large body of water.

According to the observations of Mr. Conybeare, the quantity of water removed from the surface of a sheet of water in India in the course of a year is 40 inches, 30 inches in the dry months (eight), and 10 in the wet season (four months).

32. Evaporation in the British Islands.—It has been estimated that the annual evaporation from a sheet of water in the north of England is at least 30 inches, and, therefore, that in estimating the yield of a gathering ground for a reservoir, the area of the reservoir ought not to be included in the total. It is certain that in all cases the evaporation would be nearly equal to the total rainfall, and in some it would be even greater.

It was determined by Howard, at the beginning of this century, that the evaporation round London, in different parts of the county of Essex, varied from 21 to 38 inches, the latter being the measured amount at Tottenham, at a height of 40 feet from the ground. It was, however, only 20 inches at the ground. In Dorsetshire, 26 inches has been measured near the ground. The total evaporation calculated from observations of dry and wet bulb thermometers, observed at Oxford during five years (1852–1856 inclusive), averaged 31·04 inches, the mean rainfall being 27·2 inches.

In the British islands generally, where the rainfall is moderately large, where the atmosphere is generally moist, if not saturated, where the surface is almost everywhere weathered, where the rocks when hard and impermeable are to some extent fissured, and where it is rare not to find vegetable soil, the mean amount of evaporation from the land may be safely stated as varying between 10 and 20 inches in an average year, according to situation. In a dry year it will be greater than the mean, and in a season remarkable for an unusual number of rainy days, whether with a small or large rainfall, it will be somewhat less. The wind, however, may produce a large evaporation, even during rainy weather, and the number of rainy days does not indicate the amount of evaporation.

Many observations have been made on this subject, some of them independently, and others in connection with observations on percolation, or the quantity of water passing into a rock. Some of these will be noticed presently when treating of the subject of percolation. As a general conclusion, it may be stated that as much water is removed from a water surface by evaporation in ordinary years as falls upon it.

33. Evaporation from various rocks.—When rain falls on hard compact limestone, gritstone, or sandstone; or upon granite, slate, or basalt, forming a wide expanse or plateau; or on a regular slope, uncovered by vegetation and unaltered by weathering, the absorption into the rock will be a minimum. It does not follow, however, that there is no evaporation from large naked exposures of impermeable rock even when bare of trees and uncultivated; for almost every non-absorbent rock when the surface is smooth and level, is liable in damp climates to become coated with vegetation, which in time may be converted into bog. The rain falling on surfaces thus covered, passes below the vegetation, and often forms a water-bed on which the moss and peat float, the overflow of these pools and lakelets escaping at some convenient spot, perhaps at a distance. From such surfaces, of which there are thousands of square miles in Ireland, and a large area in England, the evaporation is regular, constant, and large, and the proportion of rain that flows off is comparatively diminished. In some cases, indeed, these plateaux are fissured, and the water passes down into cavities in the interior of the rock. But if these are exposed, or the rocks above are dry, evaporation would remove their waters from whatever depth.

On the other hand, where the rain falls on a thick stratum of absorbent rock having a disintegrated and weathered surface, the rock itself being fissured or of loose texture, and where there is a moderate coating of vegetable soil and vegetation, a large proportion of the rain will disappear from the surface for a time, and only begin to run off when the rock is saturated to some depth and the fissures are choked. Between these extremes lie the ordinary conditions of the earth's surface.

34. Evaporation on the slopes of the Penine chain.—Evaporation proceeds rapidly from the surface of all absorbent rocks, so long as there is water in them in any part however deep, and whatever the temperature may be; but the rate of evaporation will vary according to circumstances. The mode of distribution of the rainfall, the humidity or dryness of the winds, the clearness, mistiness, or cloudiness of the sky, all affect the result more than the absolute quantity of moisture that is present in the rock, or than the temperature of the air.

Judging from a considerable amount of evidence of various kinds obtained by observations in different parts of England, but chiefly in the north, it would seem that the average evaporation on some parts of the western side of the Penine chain may not exceed 12 inches in the year; but on the eastern side it is safe to estimate it at 14 inches. Thus at Woodhead, the site of the reservoir of the Manchester Water Works, on the eastern side of the chain, Mr. Bateman has stated* the case as follows in reference to the gathering ground in the district.

Woodhead Reservoir, Manchester.

Year.	Rainfall in inches.	Amount of water collected in reservoir in inches of rain.	Loss by evaporation and absorption in inches of rain.
1864	45	31	14
1865	41·3	32·3	9
1866	65·5	54·2	11·3
1867	56·5	49	7·5
1868	53·5	42·5	12
Mean of 5 years	52·3	41·8	10·5

It must be pointed out, however, with reference to these observations, that the position of the gauge at Woodhead is not such as to receive the maximum of rain on the gathering ground above, and that a little to the east of the ridge it is well known the fall is heavier.† It is not unlikely that the mean annual rainfall over the whole of the gathering ground may exceed 55 inches, giving for evaporation and loss nearly 14 inches.

For the gathering ground that supplies the Rivington Pike reservoir for the service of Liverpool, I am able to quote the following figures supplied by Mr. Jackson, the resident engineer, from actual observations.

Year.	Water collected in reservoir in inches of rain.	Rainfall in inches.	Loss by evaporation and absorption in inches of rain.
1861	46·38	58·	11·61
1862	48·51	56·94	8·43
1863	51·01	61·3	10·29
1864	39·03	50·46	11·43
1865	34·80	46·24	11·44
Mean of 5 years	43·95	54·70	10·75

* Evidence given before the House of Commons Committee on the Huddersfield Water Works Bill, April 1869.

† In the year 1847–8, the rainfall at the Woodhead gauge (the site of the reservoir) was 53 inches, and on the hill at Woodhead station 5 inches higher. Nearly the same fall (58¼ inches) was registered at Dunford Bridge, on the eastern side of the ridge. —Bateman's evidence, *ante cit.*

The same objection, however, applies to this case with reference to the rainfall, as to that of Woodhead. The rain-gauge is placed below the gathering ground and where it can hardly receive the full supply or give a proper average. It must certainly, therefore, show a result below the mean.

At Sheffield the measured evaporation during the dry year 1868, showed a quantity equivalent to 15 inches of rainfall. According to Mr. Hawksley, whose experience ranges over nearly fifty years, the amount of 14 inches properly represents the evaporation and loss that may be expected, and will have to be subtracted from the total rainfall on the Yorkshire moors, in order to obtain the available rainfall. He deduces this from a large amount of observations in cases with which he has been professionally connected.* These results apply only to the district in which the observations were taken. In the south of England, where the rainfall is smaller, the air drier, and the rock more absorbent, the evaporation is larger, and may amount to 16 or even 18 inches.

35. General laws of evaporation.—As a general principle it will be admitted that the evaporation must be greatest when the radiation is greatest, and, therefore, under a clear sky. It is not necessarily the case that there is most evaporation either in that one of two or more places in which there is the smallest rainfall, or in any one place on the driest of any number of seasons. Under certain circumstances, in dry calm weather with a clouded sky, there is little evaporation. On the other hand, evaporation is very rapid when heavy showers are succeeded by a bright sky, and accompanied by strong wind. It is slow in all weathers when the air is still and moist but without much precipitation, when light rain falls frequently, and when the sky is constantly covered with cloud. Rapid precipitation is caused by electrical changes in the atmosphere, as during thunder storms, when torrents of rain fall and are soon followed by change, the conditions being such that evaporation is at a maximum.

In a communication to the Institution of Civil Engineers, by Mr. C. Greaves, in 1876, published in their Transactions, the following results are recorded:—*First,* the evaporation is assumed to be the difference between the measured rainfall and the percolation taken by a Dalton gauge adjoining. (The observing sites in this case were in the valley of the Lea, near Lea bridge, and the observations range over twenty-two years.)

Rainfall - - -	25·837 inches.
Percolation (ground) -	6·866 „
Evaporation (ground) -	18·970 „

Secondly, the evaporation from a water surface calculated over fourteen years was found to average:—Rainfall, 25·721; Evaporation, 20·613.

* Evidence before the House of Commons Committee on Huddersfield Water Works Bill, 1869.

The excess (nearly $2\frac{1}{4}$ inches) shows that in such conditions as exist in the south of England, a lake would dry up if not kept supplied with water from rivers or springs, and it agrees well with known facts with regard to lakes and pools.

Mr. Greaves also gives some other tables and calculations, and his conclusion is that evaporation is an agent by which the total rainfall is diminished by 75 per cent. He finds that evaporation from the earth approaches uniformity from year to year, its range being smaller than that of the rainfall, the total seldom exceeding 25 inches or falling below 12. Evaporation from water surfaces is more uniform, the maximum being 27 inches, and the minimum 17 inches.

These results are valuable as having been the result of careful observation continued for a sufficient period in a known locality. They require repeating in many different parts of the country to justify any definite conclusion.

36. Percolation.—The quantity of water that has fallen from the atmosphere as rain, although always diminished, and sometimes very greatly diminished by early evaporation before absorption can act, must still in every considerable shower leave a large quantity of water on the ground. Part of this disappears as soon as fallen, passing downwards into the earth by the innumerable minute crevices and fissures that exist at the weathered surface of all rocks. These are often connected with other larger fissures, and with interspaces or caverns in the interior of rocks, permitting the water to penetrate to a great depth, sometimes in large quantity. It will be evident that the quantity thus sucked in must depend on the nature of the rock on which the water falls, and the extent to which it has been affected by exposure. An absorbent rock, like chalk, or one which lets water percolate readily through it, such as occurs where there is gravel, loose sand, or rotten limestone or sandstone, will afford the conditions most favourable for absorption and percolation, but such soils and rocks only exist in certain localities. Where there is tough clay, or where the underlying rock is unweathered limestone, shale, or compact sandstone, the absorption will be much smaller. Few, however, except those who have observed closely are aware, how rare it is that water does not to some degree find an entrance even into the soils and rocks that seem least likely to permit it.

37. Dr. Dalton's experiments on percolation.—The water abstracted by percolation can only be estimated for particular kinds of rock and soil by experiment. This has been done for soils by means of a gauge first introduced by Dr. Dalton, and since modified by Mr. Evans and others. The results, though neither complete nor altogether satisfactory, are worthy of being recorded.

In the communication by Mr. Greaves, already referred to, a Dalton gauge and its results are described. The gauge is a strong slate box or tank, open-topped, and water-tight, exposing a surface of one square yard, and being one yard deep. Through the middle of the bottom a lead pipe is passed which conducts to another fixed vessel with a close bottom set upright as a receiver, and its base several feet below the tank. A glass gauge pipe is fitted to the side of the receiver with stop- and outlet-cocks, and provided with a graduated scale. The whole is placed where it is always entirely free from the action of frost. The slate tank is sunk into the ground, the inside of the bottom covered with a thin coat of cement to the level of the outlet pipe, and the whole filled with soil or earth to within two inches of the top. The soil is turfed over, kept level, and the grass occasionally cut, but nothing is done to tighten the soil. The water in the receiver never reaches the bottom of the tank.

In such a tank there has been no overflow, and water has never been seen to accumulate on the surface of the earth or grass. The gauge was first set in October 1851, but suffered some interruptions to the beginning of 1855, since which the register has been maintained continuously. It is supposed to represent a fair ordinary thickness of natural soil. A gauge of the same construction filled entirely with sand was placed by its side in 1852. A rain gauge of similar superficial area one foot deep was fitted at the same time adjoining these gauges, and all the gauges have been observed continuously. The gauges stand at Lea Bridge, in the valley of the Lea, one and a half miles west of the meridian of Greenwich, and six miles north of the Observatory, the surface being about 10 feet above Trinity high-water level. They are read at 9 A.M.

38. Conclusions drawn from Dalton's gauge observations.—The following are the general conclusions drawn by the author of the communication after an observation of the results continued over twenty years:—(1) a great amount of percolation through sand; (2) a small percolation through earth; (3) a large evaporation. In the fourteen years, between 1860 and 1873 inclusive, there fell in all 360 inches of rain (average 25·7 inches), as measured by the rain gauge, and, of this quantity, 300 inches (average 21·5 inches), percolated through sand, and only 105½ (average 7·4 inches), through earth. The mean annual evaporation from a water surface during this period was 20·6 inches, and the evaporation from the gauge supplied with earth was at the rate of 18 inches per annum.

According to the observations made by Mr. Greaves on this gauge, the yield of springs corresponds with percolation. He found that the rainfall in 1872 being 37·62 inches, and in 1864 only 15·891 inches, the annual percolation through the ground varied from 12·587 inches to 3·761 inches. He states also that the percolation through sand in 1872 was 30·050 inches, and in 1864, 12·636 inches. The evaporation from a water surface varied only from 26·933 to 17·332 inches in extreme years.

With a rainfall then of a little more than 25½ inches, with an average soil derived from the disintegration of various underlying rocks nearly impermeable, the loss of water by percolation would seem to be about two-sevenths of the rainfall. It must, however, be evident that this quantity is subject to great variation, and that the facility or otherwise of carrying off the percolated water must be an important factor in determining the quantity in any particular case. With regard to percolation, as well as evaporation, only a roughly approximate estimate can be made, and even that can only be regarded as valuable when applied over a series of years.

39. Percolation into rocks.—Percolation into rocks is very different in many respects from percolation through soils, and cannot be determined. It can be roughly estimated, but only from year to year, by separate observation. Except chalk and sand, there are no rocks sufficiently absorbent at the surface and throughout to give results from experiment, and even these, though yielding valuable facts for consideration must not be assumed always to behave in the same manner.

As a rule chalk is a rock which absorbs and contains enormous quantities of water. This water is readily transmitted from one part of the rock to another, but it is not accessible by ordinary well sinking and boring, and is not available for the supply of large towns. This, I believe, may be stated to be the experience of those engineers who have had their attention specially directed to the subject, and in the course of an inquiry made in the year 1851, on the part of one of the London water companies, I had occasion to investigate the matter experimentally, and arrived at the same result. The general statements subjoined, and the conclusions quoted from my report on the subject, after carrying out laboratory experiments, are as follows:—

40. Absorption of water into chalk.—" Chalk absorbs water with extreme facility and rapidity, and conveys it in every direction at a nearly equal rate. In other words no hydrostatic pressure is exerted by the water contained in wet chalk." This statement expresses in a few words the result of a number of experiments, but, although beyond doubt all chalk is rapidly absorbed, it is equally true that no two masses of the rock absorb at the same rate. There are, therefore, no means of calculating with any approach to accuracy the time it would take to transmit water to a given distance in solid chalk. As a general rule the lower parts of a deposit of chalk are certainly wetter than the upper, the water descending gradually. But when the water is being removed from the surface by evaporation, it is constantly and incessantly supplied from below as long as any remains. There seems no practical limit to the transmission upwards by capillary attraction. The absorption of water downwards by dry or nearly dry chalk from a saturated surface, though rapid, cannot be accurately measured, but an approximate average, the result of many experiments is, that about two pints of water per square foot of surface may be carried down per day under such circumstances, and that the evaporation in dry summer weather from all chalk under an average English climate is about two-fifths of a pint per day per square foot of surface. This represents rather more than 2,000 gallons per acre, and is equivalent to a rainfall of something less than one-tenth of an inch. No account is here taken of the fissures which abound in all kinds of chalk, especially near the surface. The effect of exhaustive pumping is to carry down water from the surface within a certain distance of the well, but not with regularity.

41. Water not obtainable without fissures.—" Water does not pass out from solid chalk by percolation, except when there is hydrostatic pressure. *Fissures in wet chalk do not become filled with water through the walls of fissures, but on the other hand, water circulating through the fissures may be sucked from them into the mass of the chalk.*" This second important result was also, I think, clearly proved by experiment, and is of general application to all chalk, although it is impossible to determine with accuracy the rate of transmission in any particular case without trial. The percolation in the samples experimented on, where there was no actual hydrostatic pressure, did not exceed the hundredth part of a gallon per square foot of surface per day. It may be regarded, I think, as certain that none of the water obtained from wells sunk in the chalk is derived from percolation, but that all must come, when the sinking is successful, from fissures more or less nearly vertical, permitting water to run more or less freely from one part to another, checked only by friction; and that the whole, whatever it may be, is derived from the rainfall falling on the surface within the district.

42. Available water in chalk.—It results from these experiments and investigations:—

First. That the available water in chalk rocks consists only of so much as exists in the crevices and fissures of the rock, and does not include that existing in the mass of the chalk itself; so that, if it were not for the crevices, absolutely no water could be obtained from wells of any depth, however great, notwithstanding that one-third part of the bulk of the rock may consist of water. It is possible that the crevices and fissures are originally due to the contraction of the mass during consolidation, and may be measurable in particular cases and within certain limits. They may, however, be connected with and derived from natural joints and bedding or exist as open joints or faults. However originated they may subsequently have become enlarged by the passage of water through them, dissolving the chalk, the result being the formation of cavities, opening and widening gradually, lasting for a time, but always subject to crush in, and never of very great capacity.

Secondly. That there is not any free and open communication between crevices, and that water, existing in some of them under considerable hydrostatic pressure, may be transmitted through them, though with comparative slowness and much friction, from one place to another, the friction placing an absolute limit to the quantity of water obtainable from any single well, as it limits the distance from which the water can be drawn.

Thirdly. That although crevices in chalk are numerous, and often contain water, still the existence of large cavities, in which much water exists under hydrostatic pressure is rare, and its discovery must be a matter of accident; notwithstanding this, it is true that certain positions are more favourable than others, and that lines of natural springs, or of chalk rendered rotten by weathering, and yielding copious springs, may be regarded as good indications of such favourable spots.

Fourthly. That if one or more such cavities should be met with, and a well sunk, and the water be pumped exhaustively it will reduce the general level of the springs coming near the surface in the neighbourhood. Although a considerable time may elapse before any distinct change can be traced in the extent of water-supply to the district, there must be an effect produced in time which cannot fail to be injurious to this supply, and ultimately affect the level of water in the surface streams, besides checking the discharge of the surplus to a lower level.

Fifthly. That little or no addition can take place to the water-supply in the crevices, and none in the mass of the rock, during the summer months of the year, owing to rapid evaporation from the surface and rapid diffusion through the mass of the chalk. During the rest of the year the height of water in the crevices can only rise when the whole mass of the chalk to that level is saturated. There is always greater tendency for water to be received into than given up by chalk, except in the way of evaporation from the surface.

43. All chalk not alike.—It will be understood that these remarks apply to the ordinary English white chalk of the north and south downs of Surrey, Wiltshire, Hampshire, the Isle of Wight, etc., in the south-west of England, and of Hertfordshire, Cambridge, Norfolk, etc., in the east. Some varieties of chalk on the Yorkshire coast are different in texture. Small differences also are observable between the upper chalk with flints and the lower chalk, but they are not important, and for all practical purposes of water-supply the chalk is one rock. The chalk of parts of the north of France is of the same kind as that of the south of

England; but the uppermost beds of the cretaceous series at Maestricht in Belgium, and at Faxoe in Denmark, and the representative beds of the great body of the rock in the south of France, and elsewhere in Europe, are different in texture, and need not here be considered. For water purposes the latter behave rather as limestones, being comparatively non-absorbent. The former act more as gravel.

44. Natural reservoirs in chalk.—But although it is certain that solid chalk, even when most soaked, and so loaded that each cube foot contains two gallons of water, would yield hardly any appreciable supply to a well sunk into it to any depth; it still remains equally certain that wells sunk into ordinary chalk in many parts of England yield very large supplies, rising to a great height in wells, or overflowing at the top in springs. There are, no doubt, reservoirs in chalk existing under pressure; but, as has been observed already, these must communicate by vertical and comparatively open fissures reaching to a higher level and full of water. Where there has been little disturbance of the mass of the rock by elevatory movements, these fissures and open reservoirs are comparatively few in number, and are not large, so that any attempt to sink wells, under such circumstances, is likely to result in disappointment. On the other hand, where the rocks have been disturbed by upheavals, and where, therefore, open crevices and natural reservoirs abound, the exact position of the fissures may sometimes be estimated roughly. Judgment and experience are often at fault in endeavouring to point out where in a great chalk district there would be the best chance of dropping down on a reservoir, and obtaining a considerable supply. The limit of dimensions and content of these reservoirs will be the subject of discussion in another chapter, but they may be said to be due partly to the presence of impermeable beds of chalky marl, and partly to beds of flint. The term *pan* is applied by well-sinkers to the impermeable bands that keep down water.

There is rarely evidence on the surface of chalk downs or plateaux, and with a few remarkable exceptions there is not much proof in natural sea cliffs or railway cuttings, of the places where the principal water-bearing fissures reach the surface. Some of them certainly are confined to the interior of the mass of the rock, and these are occasionally found in boring, by the dropping of the boring tools into a cavity. There are examples of streams of water issuing as ready formed rivers from an opening in a hill side, and of streams running over chalk, disappearing for a time, and re-issuing at a lower level. Similar phenomena are known in other varieties of limestone.

45. Percolation through oolitic limestone.—The oolitic limestones vary considerably in absorbing power, and none of them at all approach chalk in the quantity of water they hold in their ordinary state. In the limestones of this kind that form the escarpment, ranging, though in a broken form, and in a different condition, from the wolds of Yorkshire, through Lincolnshire, and thence by Northamptonshire into Gloucestershire, the water passes into these rocks readily, and emerges in a countless multitude of springs at the bottoms of hills and in valleys; but there is rarely any great body of water as in the chalk of the south-east of England.* Abroad, the limestones of this period are in some places more cavernous, and receive larger bodies of water. Some of these form underground rivers, running for a considerable distance.† In some cases even these waters are greatly diminished by evaporation, as is proved by the fact of their sustaining vegetation on the surface during the whole of perfectly dry hot summers, with no water supply whatever on the surface. This I have had occasion to notice, especially in the Ionian islands, where the vines bear and ripen their fruit planted only on limestone gravel, without soil; and it seems also the only rational explanation of a curious phenomenon in the island of Cephalonia, where, within a mile of the capital of the island, large quantities of sea water are constantly entering a series of cavernous holes, opening at a point a little below the level of the sea. The fall of the sea water to enter these caverns is sufficient to create a water power which has been utilised from time immemorial to drive mills for grinding corn.

46. Percolation through the older limestones.—The older limestone rocks are in some cases still more remarkable, having vast connected openings worn by the passage of water, and also capable of conveying subterranean streams of running water. Through some of these caverns actual rivers flow for miles, and others, as the caverns of Kentucky in America, are of gigantic dimensions. We have many such caverns in the mountain limestone districts of England, some of the principal tributaries of our large streams rising out of them in a full and permanent stream, or passing through them on their course.

47. Percolation through sand and sand rock.—Although soft sand is not generally regarded as a rock, it must be recognised under that name in geology. Where present in large quantity, water passes in and out of it as it does in and out of chalk, and it absorbs and gives off almost any quantity. Thus there is, in sand and in the softer sandstones, as in chalk, an underground surface of permanent saturation, which is more or less nearly parallel to the earth's surface where there is an extended plateau, but which curves downwards rapidly towards the deep narrow valleys that often intersect such elevated level tracts.

* The average quantity of water present in the limestones in England, in their ordinary state as building material, varies from three-quarters to one per cent. of the weight, or from eighteen to twenty-three ounces to the cubic foot.

† The celebrated caverns of Adelsberg in Styria, and the caverns in the Saxon Switzerland, are examples.

Harder sand rock, in some cases, is almost as open in its texture as the most open and cavernous limestone. I have been consulted in a case where it was necessary to prepare a trench for the puddle wall of an embankment through a rock of this nature, in which fissures wide enough for a man or boy to enter succeeded each other at intervals of a few yards along a certain part of the trench. The quantity of water that could be conveyed by such channels would, of course, be practically indefinite, and, if unstopped, they must have left a way of escape to the water it was desired to retain in the reservoir. The rock in this case was horizontally bedded, not very thick, and not at all disturbed. In other cases within my own experience large open spaces have been found on lines of fault, and on the crowns of small anticlinals in sandstone rocks alternating with shales. Broad fissures in sandstone are rare, but a comparatively open condition of the rock, permitting water to pass, is the rule rather than the exception.

48. Percolation through slates, schists, and other altered rocks.—Shales, schists, and even slates, and sometimes the harder varieties of slate rock, are occasionally fissured so largely and frequently as to offer no resistance to the passage of water. Shales are sometimes so far weathered by exposure and irregular squeezing as to permit water to pass freely. Metamorphic rocks, granites, and quartzite are rarely so compact for any long distance that their fissures will not transmit water, even if the rock does not really absorb part of the water falling on their surface.

In many parts of the country where these rocks abound, and, indeed, in all cases where they are presented on a large scale, the igneous and metamorphic rocks exhibit fissures originally very wide, though now partially filled up with crystallized minerals. Such fissures are called *mineral veins*, and they not unfrequently permit the passage of water very freely. Where they do not, it is generally because they have been filled up by the deposits left by water when it has been transmitted through them. These fissures often open upwards, being wider at the surface than at a considerable depth. Elsewhere they are alternately wide and narrow, but they almost invariably communicate with the surface in some way.

49. Percolation general in all rocks.—Thus it appears that into all rocks, though in very different proportions, a part of the rainfall must enter, and be carried for a time out of sight. Percolation, in the sense in which we here use the term, is universal, and accounts for the temporary disappearance of an enormous quantity—often of a large proportion—of the rainfall.

In addition to the percolation through rocks in the ordinary sense of the term, a large amount of water passes out of sight for a time, when the rocks are covered with tertiary sands, gravels of any kind or age, boulder clay alternating with sands and gravel, and alluvial sands. These materials frequently cover the surface to a great thickness, and range very widely, but they are usually present in patches, and are rarely continuous over a wide space. The rainfall on these quaternary deposits, though it occasionally passes off rapidly into the rocks beneath, is not unfrequently stopped and accumulated into underground pools and sheets of water, which are easily reached by shallow wells. The "land springs," so common in most countries, are examples of this. They yield water only by pumping, but, the depth being small, they are very convenient. They become exhausted after a short drought, and are immediately available after heavy rain. They may, and often do, feed the rocks below by running over the edge of their basin when the rains are heavy, and thus help percolation, but they more frequently pass back their water contents into the air by evaporation. Instances are not unknown in which water entering the earth by the fine sands and gravels at the bottom of boulder clay, rises in artesian springs above the surface when the stratum is pierced at a lower level.*

It will, then, be evident that percolation is a phenomenon occurring constantly in every country, in every season, and affecting all rocks and all materials accumulated at the surface. Besides the first result of conveying water from the rainfall into the interior of the earth, it acts also very powerfully in weathering the rocks through which the water passes, and causing a rock, previously little permeable, to become more so by its action. If the rock be calcareous, the fissures already existing may be enlarged, not only by mechanical abrasion, but by actually dissolving out the material through which the water passes.

50. Percolation sometimes impeded, but not prevented.—It must be remembered also, that where, as sometimes happens, rocks are for a distance impermeable, or are covered with a considerable thickness of impermeable clays, the amount of percolation is necessarily much diminished over large tracts. Water will collect into lakes or pools in such impermeable surfaces, but, having risen to a certain height, it will run over the edge, to enter a permeable material that crops out from below, and in this way the surplus water is carried off. There will, in all cases, be a limit, and, generally, a very easily reached limit, beyond which water is no longer kept back. In many cases there can be no doubt that rivers run over porous soil, and lose, during part of their passage to the sea, much water that had come into their beds at a higher level. There are, indeed, instances in which rivers entirely disappear,

* A case of this kind came within my experience lately in one of the branches of the upper valley of the Tees, where boring to 30 or 40 feet in boulder clay resulted in spouting wells at a distance of less than a mile from places where the sands came to the surface.

and never reach the sea. Such cases are not confined to Australia, where they are characteristic, but belong to all countries in all parts of the world. In the south of Spain this is the usual condition of the smaller streams, which are very numerous, and which carry off through rocky ravines, whose floor consists of fragments of fallen rock, a large part of the drainage of the mountain slopes direct to the sea, the water rarely appearing at the surface till close to the coast. In England there are examples of the same kind on a smaller scale, which will be noticed in the detailed description of rivers.

51. Permeability not measured by the absorbing capacity of a rock.—The permeability of the surface rock is by no means the measure of the extent to which water enters into the interior of the earth. Besides the actual permeability of a rock, we must know the extent to which it is cracked, fissured, and jointed, the mode in which it weathers, the nature of the soil that forms upon the weathered rock, and the extent to which it is covered with transported alluvial mud or diluvial gravel. But there are still other matters hardly less important. I mean the angle and direction of the inclination of the rock, if bedded, the thickness or thinness of the strata with which it is associated, and the permeability of the thin beds that generally intervene between those which make up the principal mass. Thus, where we have chalk as the principal rock, we shall find it extremely permeable when exposed, but where it is choked by the mud of streams running over it, or covered by tenacious mud left by water that has, at any former time, run over its surface, there will not only be a coating of alluvial material keeping up water, but the pores of the chalk itself below will be also more or less closed. The bottoms of valleys in chalk are thus sometimes hardly permeable, while the hill-sides and tops absorb water greedily. On the other hand, where chalk has been long exposed to the air, innumerable minute crevices are formed, extending some depth below the surface, and, when these are occupied by the roots of plants, or filled by decaying vegetation, they absorb even more rapidly than the soft rock itself. At intervals, also, as has been shown, there are extensive tracts covered with gravel and fine sand, and through these the water passes readily to the surface of the chalk, into which it enters freely. On the other hand, if clay underlies the sands, there will be pools of water accumulating in wet weather, but ultimately overflowing into the rock below.

52. Condition of clays with regard to water.—Clays, however, though themselves impermeable, are not always in a state to keep water from entering the interior of the earth. Clays become cracked by exposure to dry weather more than any other rocks, and into these cracks the water pours. Being once brought into the interior, it cannot easily escape; and when the clays alternate with more permeable rocks, even though the distance may seem great, some part, at least, of the entering water from the surface contrives to penetrate to them, and thus enters again into the general circulation. The pressure of a superincumbent mass of rock, and the irregularity in the texture and composition of the clays, assist powerfully in this result. Instances are not rare in which small quantities of water are left in cavities of clay during the operation of puddling, where they form blebs or bubbles. Such cavities remain in that state for an indefinite time under very great pressure, but, when approached by boring or tunnelling operations, the compression is sufficient to produce an explosion, driving the water out, with stones and earth, to a considerable distance. If this is the case in embankments, and under a pressure which is rarely greater than eight or ten atmospheres, it is not difficult to understand that, in nature, where the quantity of water held in all rocks is very large, and where the pressure is that of many hundred yards of rock which has a mean specific gravity exceeding 2·25, the result must be important. That all rocks are liable to have cavities, and that these may be filled with water, is known by the universal experience of well-borers, engineers, and miners, and experience has also proved that the water is frequently under so great pressure that, when reached artificially, it rises instantly considerably above the level of the surface. Such water usually lowers after a short time, and, if removed by pumping, the limits of available supply are soon reached. Should the pumping be continued and become exhaustive, the mineral condition of the water will soon indicate that the water, if it continues to be supplied, is removed from a distance.

53. General conclusions as to evaporation and percolation.—It may, then, be assumed that, of the rain that falls on the earth, but a small part, in comparison with the whole, escapes the effect of evaporation and percolation. That which is evaporated goes back to the atmosphere to be re-formed into cloud, and re-descend as rain. That which enters the earth by absorption and percolation is buried among the strata, and pursues a course governed by the laws of gravitation, ever seeking to descend to a lower level, and filling up all rocks and all fissures, so that there must be everywhere, in all countries, a surface of permanent wetness, which has a certain reference to the form and elevation of the actual surface of the land at any given place. The remainder —that which is not evaporated and not absorbed, but which is left to run over the surface—must next enter into our calculation.

54. Available rainfall.—The available or effective rainfall on a drainage area is that portion of the fall which can be collected and stored, or which can be depended on to run off the surface in streams. For practical purposes, we must estimate this by making certain deductions or allowances for water wasted by being permitted to pass along and run into the sea without being utilized, and also for water absorbed by vegetation and animal life, as well as that evaporated into the air and passed into the earth by absorption and percolation. There must be great deductions from the total fall before we can estimate the available rainfall.

Waste of water to a very considerable extent is inevitable, or, in other words, it is uneconomical to store the whole of the water falling on a given area, and running off the surface. In estimating the quantity of the water that can be stored, regard must be had to the circumstances of the rainfall, because, in some districts, the fall is more equally distributed through the year than in others, because cycles of wet years and dry years may succeed each other, and because the utility of a reservoir must depend on the number of days during which, under the least favourable conditions, it will continue to yield a certain supply of water. But, if it were attempted to store all the water falling as rain within a certain district, the reservoirs must be so large, and, therefore, so expensive in construction in proportion to the required supply, as to make the cost of collecting and storing water greater than the value of the water. There would also, in such a case, be so heavy a loss of water by evaporation as to counterbalance the gain in storage. It is, therefore, better to increase the drainage area than endeavour to store the whole of the flood waters.

55. Principle of "mean of three driest years."—It is a question of serious consideration what, as a general rule, is the best estimate of the proportion that may be stored. For this purpose we must refer to actual observation for the longest time possible, to obtain a starting point. At Greenwich, during the last sixty years, the total fall has averaged 25·18 inches. The actual maximum (1824) was 36·3″, and the fall in 1825 only 24·6″; the actual minimum (1864) was 16·8 inches. In the year 1865, following the minimum, the fall was 28·6″, and, in the year preceding the minimum (1863), it was 19·8″, the mean of the three years being 21·7″. It is evident that if storage is provided for a sufficiently long period (six calendar months has been thought sufficient in England), the evil effects of drought will not be felt, but the storage must have reference to the possible groups of dry years. The two successive years of smallest fall at Greenwich during the last sixty years were 1863 (19·8), and 1864 (16·8), the average being 18·3 inches. There have been no other two successive dry years in which the average did not exceed 19½ inches. But, in 1862, the fall was 26·5, making an average of three years 21 inches; and, in 1865, it was 28·6 inches, showing a still larger average. In the years 1832, 3, 4, the average was 20·63, the driest year having 19·3 inches. In 1854, 5, 6, the average was 20·67, and in the years 1856, 7, 8, it was 20·47, this being the lowest average of three consecutive years in the whole term. If we take four years, the figures will stand:—years 1861, 2, 3, 4; the mean being 20·8 inches; and, for five years, the mean is still higher. Thus, so far as Greenwich is concerned, if we arrange for the three consecutive driest years, we have the driest group of years within sixty, and probably for a longer period, and this averages 20·47 inches per annum. Now, the actual mean of sixty years at Greenwich being 25·18, we have a convenient basis of calculation, for it is nearly one-sixth less, as will be easily seen, $25{\cdot}18 - \frac{25{\cdot}18}{6} =$ 20·47, which is about half an inch above the actual minimum.

As, however, the position of Greenwich is not that of the most important rainfalls for gathering grounds, let us take another example. At Redmires, near Sheffield, there have been careful records since 1836. The mean total fall for the forty-two years from 1836 to 1877 inclusive was 40·3 inches, and the mean of the three consecutive driest years (1853, 4, 5,) was 33 inches. Now $40{\cdot}3 - \frac{40{\cdot}3}{6} = 33{\cdot}6$, and therefore a sixth less than the mean of forty-two years near Sheffield, is half an inch more than the mean of the three consecutive driest years at the same station. The position of Redmires, on tolerably high ground to the east of the Penine chain, which determines the rainfall of that part of England, is important and significant.

I take, next, the extreme case of the lake district, where the rain is not only very much heavier, but also more irregular than in any other part of England. At three places the rainfall has been taken for 22 years, from 1845 to 1866. At Keswick, the average is 58·53. At the Howe Troutbeck, Windermere, it is 79·85. At Seathwaite, in Borrowdale, it amounts to 140·03. It is known to be much higher at no great distance, but there the period of observation is shorter. In these cases the averages of the three driest years are respectively 43·92, 52·7, and 103·47, being, in each case, more than a fourth part less than the mean. In these cases, as in others, the rainfall in the driest years is considerably less than half the fall in the wet years.

56. Deduction for waste during floods.—Great floods recur only at long intervals—sometimes seven, sometimes fourteen years, and, occasionally, twenty years. It is evident that, to make a reservoir to hold a flood that only occurs once in twenty years, and distribute the water thus accumulated over the twenty years (or about 7,000 days), we should only add to the daily supply $\frac{1}{7000}$th part of the flood water. It is recognised by all hydraulic engineers that, even where it would be possible to construct so large a reservoir as to include all floods, the expense would be so enormous as to render the project altogether out of the question. It has been considered by some engineers that 180 days is about the time for which it is necessary to provide; others have thought as much as 250 days necessary. At any rate the average of the three driest years of a recorded rainfall of not less than twenty years, or five-sixths of the estimated mean annual fall, is a quantity on which calculations may be based.

57. Deduction for absorption and evaporation.—Besides, however, the deduction just explained, a larger amount must be taken from the mean annual rainfall before we can arrive at the available fall. This consists of the quantity utilized directly by plants and animals, the quantity evaporated, and the quantity passing into the earth. Absorption and evaporation, as we have seen, vary in different climates, at different seasons, and in different places. They are by no means smallest in showery or rainy districts; and evaporation depends much more on radiation and a clear sky than on temperature. When the air is cool and loaded with vapour, and when there is cloud or visible vapour, evaporation is slow. When there is a clear sky, and owing to electrical conditions, the air has just discharged its vapour, it is precisely in the most favourable condition to re-absorb it. I have already stated that the amount of evaporation may be estimated in England to range between 10 and 18 inches, and may be even more. In extreme cases the evaporation has been known to equal the rainfall, in which case there can be no available fall. In Lincolnshire this has occurred in very dry years, but in the western counties it can hardly happen. It is clear that the economic construction of gravitation works for water supply must depend on the excess of the fall over evaporation.

58. Equation for available fall.—It is convenient to express in an easy formula the meaning and value of the expression "available rainfall." In a general way, and for most parts of England, the following is sufficient:—

Let m = mean annual rainfall, of not less than 20 years, in inches.

E = mean evaporation from the surface for the district.

m' = available rainfall in inches.

Then $m' = m - \frac{m}{6} - E = \frac{5m - 6E}{6}$ inches.

The general value of E in the valleys of Yorkshire and Lancashire is about 14 inches. In the south-east of England it rises to 16 inches, and is probably more than this over a chalk surface. Accurate records and well-designed experiments are needed to obtain a more definite value of this quantity in different parts of the country.

59. Possible permanent absorption of water.—We must not conclude without referring to a possibility suggested of late years, and alluded to in the remarks at the commencement of this chapter, that a part of the rainfall entering the earth and penetrating the strata may be permanently absorbed as a component part of the thickening crust of the earth as the surface continues to radiate heat into space.

Cavities and fissures we may safely assume to exist in all rocks and strata, however solid, and, most of all, in those masses of igneous rock that underlie, in some sense, all stratified rock, although, perhaps, they have not yet been reached by human investigation. There are, therefore, ample opportunities for water to penetrate to the interior mass; and the quantity of water required to solidify this into an increased thickness of crust of any known rock is a real absorption, and would diminish *pro tanto* the quantity of visible and available water on the globe.

Such a suggestion, strange as it may seem, and little affecting practical views of the use and circulation of water, must not be cast aside as absurd and of no interest. It is not necessary here to repeat the well-known fact that water enters into the actual composition of all matter, organic and inorganic, not as a liquid, but as an essential part of solids, which cannot be got rid of without absolutely disintegrating the substance, whatever it is. There is no known substance in which the ultimate atoms touch each other, otherwise there would be substances through which no thermic or magnetic current could pass. Drops of water have been forced through the solid metal of thin shells of gold and other metals, by enormous pressure, and the existence of actual cavities in crystals of all kinds, visible under the microscope, is a familiar fact. But, at present, no one has been able to measure the interstitial spaces, and no approach has been made to a knowledge of the magnitude of the interval between material atoms in comparison with the volume of the atoms themselves.

We may assume that in the formation of the earth as a habitable globe, it has passed from a very early stage, during which the water and air existed only in a gaseous and uncombined state, and there was no solid matter, into a second stage, when radiation of heat into space had resulted in the production of a crust of oxidised material, enclosing a fluid nucleus. For the formation of the true igneous rocks there would not at first have been much absorption of water; but, as soon as the crust was formed, and the presence of a mixed air and vapour atmosphere established, the crumpling up of the crust by contraction, arising from further cooling, would be followed by the formation and deposit of stratified rocks by mechanical action in the presence of water and air, in which the presence of water of solidification is essential. It is conceivable that the conversion of the igneous into aqueous rocks may have so far reduced the quantity of water originally forming the permanent vapour atmosphere covering the whole earth as to bring it into a state in which land vegetation and the lower forms of animal life could exist. The gradual absorption of water, therefore, may be a part of the system of development of planetary existence through which some bodies of our system have already passed, while others are only commencing their course. The earth, in this view, must be regarded as being in the intermediate stage adapted for the presence of life. Water is not only abundant at the surface, but it forms part of the solid earth, and of the atmosphere. It is circulating through and on the surface, and entering the earth. That which enters the earth is, for the most part, either rendered back directly to the sea by springs, or is returned by evaporation into the atmosphere; but there remains a part which still penetrates to the interior fluid nucleus, where it is fixed, increasing the thickness of the crust, and diminishing the quantity of water on the globe.

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CHAPTER III.

DRAINAGE AREAS, RIVERS, AND RIVER BASINS.

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1. Object of the chapter.—That part of the rainfall which is not carried back into the air by evaporation, and is not utilized by plants or animals, and which fails to find a way into the earth, either by absorption into soils or rocks, or by percolation into minute fissures, open clefts, or cavities, cannot do other than flow over the surface of the earth, obeying the law of gravitation, running down hill sides, entering narrow and precipitous gorges, gradually reaching larger valleys, detained occasionally in lakes, opening out occasionally into wide and level bottoms, and, at length, making its way back to the sea from whence it originally came. I propose to treat in this chapter on the proportion of the rainfall thus flowing, the nature of the channel or complex system of channels through which it flows, and the grouping of the areas including the channels into systems, variously designated as catchments, drainage areas, or river basins. In other words, I propose to consider generally the phenomena of running water, but chiefly so far as they illustrate the systematic circulation of water, and the task will be chiefly limited to that part of the earth's surface comprised within the range of the British islands.

2. Causes producing drainage areas.—As the ocean is the source of water supply, and the land, whether continental or insular, is the place on which all the available rain falls and over whose surface a part is conveyed back to the sea, it is easy to understand that the mode of conveyance, whether by one or many channels, arranged with more or less complication, must depend on the form of the land, on the lines of elevated or depressed land, the distance of the higher lands from the sea, and the position of the main axes of elevation of the district, as indicated by the present surface and the geological structure.

The irregularities of the surface, however produced, must ultimately govern the distribution of the water, although experience shows that, in many cases, the main channel of a river and the course of its large tributaries crosses what are apparently natural obstacles of no ordinary kind. In considering the course of a large river we find that the drainage of the whole stream is made up of a number, often very considerable, of smaller areas or catchments, each of which is independent of the others until it falls into the main stream. There are some cases in which the river is made up of several almost equal branches. Other streams are characterized by one main channel, whose feeders are comparatively unimportant. The various maps and plans of the principal river basins of England that are given in subsequent pages will show examples of all these phenomena, and will assist the reader in understanding the mode in which the various tributaries combine in different cases.

3. Drainage results dependent on geological conditions.—The natural inequalities of the land are originally referible to various causes, some dating back to the original construction of the globe and its passage from the nebulous state to that of a solid, but most of them to subsequent changes and movements, partly cosmical, partly local, caused by upheaval from below, or produced by mechanical abrasion, the result of the movement of water over the surface. The chief lines of elevation and their subsequent modifications are, for the most part, but not always, independent of local denuding action, and are probably very ancient. Of these, the mountain axes ranging east and west in the old world, but north and south in the western hemisphere, are striking examples. The meridional systems of elevation in western Europe, affecting the oldest rocks, are hardly less important, and perhaps even more ancient, but the lines of elevation affecting in succession the deposited rocks of all ages are comparatively modern, and may be the result of causes still in action. Both classes of elevations, each forming chains of hills and mountains and breaking up the country into drainage areas, have to be considered. In the smaller divisions of the land the natural subdivisions formed by the principal mountain axes are frequently broken up into areas, small even in proportion to the extent of the country. On each of the great continents there are gigantic river systems, combining the rainfall of wide tracts of country before they reach the sea. Even the largest of the river systems of Europe however, such as those of the Danube and the Rhine, are insignificant by the side of those of northern Asia and India; and much more unimportant do they seem when brought into comparison with the rivers of Africa—the Nile and the Congo,—those of North America, such as the Mississippi, and those of South America, such as the Amazons and the Plata.

4. Relations between drainage areas, structure, and elevation axes in England.—In the British islands the geological conditions are in close relation to the elevation axes, as will be understood by a comparison of the outline maps intended to illustrate these phenomena. Neither of them is intended to do more than remind the reader of the general grouping of the facts, and assist him in obtaining a general idea of their mutual bearing. In another paragraph an attempt will be made to point out in a few words the various peculiarities of the elevation axes, and their mutual relations. The geological question must be studied in detail, with the assistance of more minute illustration; but sufficient will be seen by reference to these maps to justify the assumption that, while on the one hand there is a remarkable harmony in the general distribution of the drainage areas and the out-cropping hard strata of the three great geological periods, there are abundant examples of a certain kind of independence between the general elevation axes, the general range of strata, and the actual course of rivers. That there is mutual relation, however, between the drainage areas, elevation axes, and geological structure, is too clearly indicated, even by these rude diagrams, to admit of the smallest doubt as to the fact. It is to be remarked that in almost every case an important stream makes an acute angle with the axis of the mountain chain from which it originates.

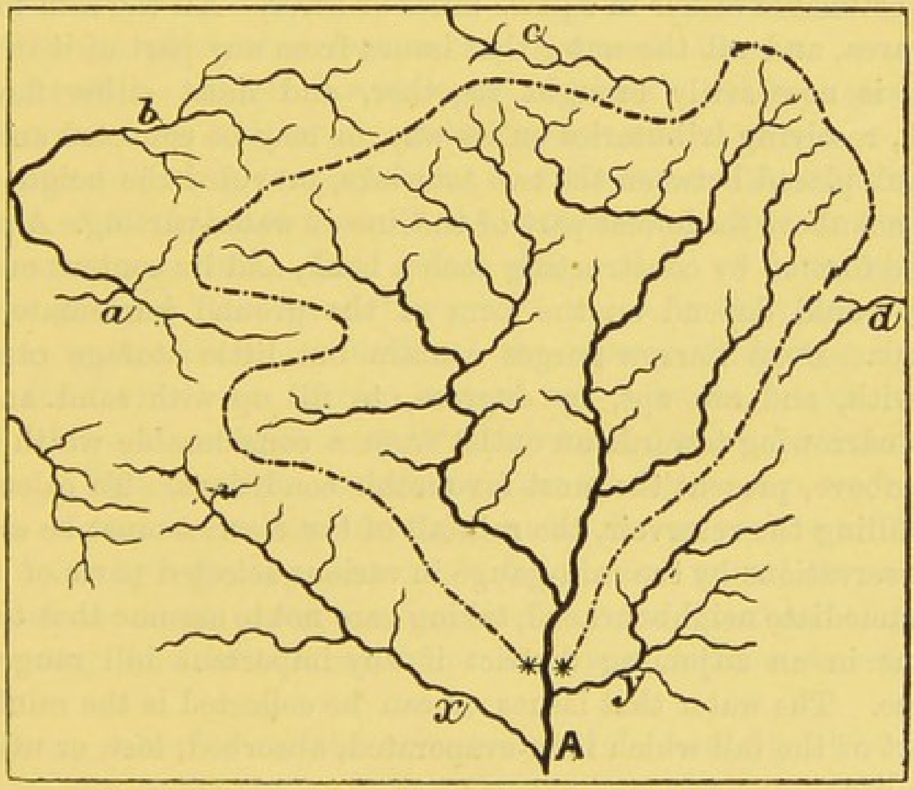
5. Conditions of drainage on the great continents.—On the great American continent the conditions of elevation are simpler than they are in Europe. In that part of the world, where the mountain axis is continuous throughout in an approximately north and south direction, the axis of drainage areas is much more nearly, though still not invariably, from north-west to south-east. To this general rule there are exceptions, but the rule is worth noting. The result is seen in the vast rivers that traverse both the northern and southern divisions of the continent, each of which contains within its great basin, comprising hundreds of thousands of square miles, numerous sub-basins, drained by tributaries, each larger than the principal rivers of other parts of the world. The smaller divisions of the earth, including the larger islands, are similarly divided into drainage areas. The records of rainfall in South America are comparatively scanty, but on the eastern slope of the Andes the fall is certainly heavy, and the enormous areas of drainage of the great rivers ensure an approach to an average in their rate of flow. They are, however, entirely without lakes, and there are not, in the Amazons and the Plata, as in the Mississippi, extensive bottoms into which flood waters can be received. In all respects the great rivers of northern Asia, which flow over nearly level ground into the Arctic sea, differ in a very marked manner from those of South America. Australia may be regarded as the type country of flood regulators. During the dry season the rivers in that country cease to show themselves at the surface, and at no time do they deliver a large body of water into the ocean. The rainfall in the interior is, no doubt, small, but over a large part of the country it is torrential. The absence of vegetation is unfavourable to the permanent retention of water on the surface. The great rivers of India now flow over an enormous thickness of alluvial mud in their course after leaving the mountains, and where the depth of the channel is not very great they spread over very large tracts when in heavy flood.

6. Geological features of drainage systems.—Irregularities of surface being assumed to have reference to structure, it follows almost as a matter of course that drainage systems and the boundaries of river basins are due to causes of very ancient date, having reference to the first formation of the continents and islands, and this being the case, the Physical Geographer and the Hydraulic Engineer must often refer to the Geologist for an explanation of the phenomena. It is, in fact, only since geology has been pursued systematically, and since our own country has been carefully mapped by efficient surveyors, followed by sound geologists, that a correct idea has been formed of the origin and limitations of river basins and drainage areas.

The proportion of rainfall that may be expected to run off from a given drainage area, the consequent supply yielded to the rivers, the quality of the water, the additions received to the surface-supply by springs, and the seasons of maximum, mininum, and mean flow, are all influenced by the nature of the rock over which the water flows, the character of the country where the river takes its rise, and the physical features of the surface along its course. The nature of the climate is also a matter of consideration.

Of all these conditions the permeability of the rock, whether due to a spongy and absorbent nature, or to the presence of numerous fissures into which water passes, is necessarily the most influential. In an absorbent rock it rarely happens that, under heavy rainfall, in a wet season, the pores do not become choked, and the absorbency checked; but, in the case of a fissured rock communicating with the interior by large crevices, there may be practically no limit of this kind.

It has been observed that drainage areas are not necessarily basins in the ordinary sense of the term, and that lines of water-parting are not always those of greatest elevation. The term "river basin," therefore, though commonly used and convenient, does not apply strictly, except in a few instances. Geologically, rivers more frequently run across formations than along their strike; they more often enclose elevated ground than are bounded by it, and they often flow through mountain domes and points of quaquaversal dip.



Ideal Drainage Area of a portion of a River System.

References.

** Converging points of the line of water-shed.
a, *b*, *c*, *d*, *e*, feeders of the rivers beyond the water-shed.
x, *y*, streams entering the river beyond the area defined.

7. Theoretical drainage area.—The annexed diagram has been prepared with a view to show the mode in which a limited drainage area, or a portion of a river system, is represented on a map for practical purposes. The dotted line represents the line of water-shed or water-parting, obtained by connecting the various places where the water may be observed to flow in two directions. The ridge of a roof is a very simple instance of a line of water-parting on the top of a house, but in nature there are water-partings where the ground is not ridge-shaped, and where a pool of water or morass serves as a water-shed, the water flowing on two opposite sides. In a certain sense only is the water-parting a ridge, for it is not always the line connecting the highest summits of a district, and higher ground may exist on both sides, within or without the drainage area. On a contour map, the line of water-parting may be approximately drawn, but it needs rectification if accuracy is required, and this can only be done by walking over the ground. In the diagram the branches *x*, *y*, are excluded, though belonging to the same stream, while adjacent streams *a*, *b*, *c*, *d*, may either belong to different drainage areas, or may enter the stream under consideration at some lower part of its course. Where the two asterisks are placed is the limit of the drainage area as represented, and the whole area included within the dotted line is the measurement, which may be estimated either in square miles or acres. All the rain that falls on this area, and all the water that issues from any part of it in natural springs, is necessarily brought together, and must either flow down below A, receiving tributaries on its way, or may be collected and stored by a bank placed between the two asterisks, provided the height of the bank is not above the lowest part of the line of water-parting. A reservoir would be formed by constructing such a bank, and its content or storage capacity would depend on the form of the ground immediately above the bank. Deep narrow gorges contain but little storage capacity to begin with, and are apt, by degrees, to fill up with sand and mud. Valleys narrowing towards an outlet from a considerable width of open bottom above, present the most favourable conditions. To calculate the rate of filling the reservoir, the rainfall of the district must be estimated from observations by the rain-gauge in various selected parts of the area or its immediate neighbourhood, taking care not to assume that the fall is the same in an adjoining district if any important hill range should intervene. The water that issues or can be collected is the rainfall, less that part of the fall which is re-evaporated, absorbed, lost, or utilised by organic life.

8. Uniformity of geological conditions in drainage areas.—The geological conditions that affect water-supply to rivers are similar over a wide extent of country when the direction or axis of the basin corresponds with the line of strike of the rocks, whether they are lifted to form a mountain chain or consist only of a range of hill-tops or a plateau. This is the case in England with the mountain limestone, and with its overlying rock, the millstone grit. These rocks, whether as limestones and gritstones, as the names imply, or as alternating hard shales, grits, flag-stones, and bands of limestone, as is the more common characteristic, mark the line of country which serves as the water-parting between the larger rivers of northern England flowing to the German ocean and those of inferior importance that enter the Irish sea.

But the conditions may be continuous over a large area in other ways, and examples of this occur also in England, owing to the presence over a wide expanse of some rocks, such as New Red Sandstone, occupying extensive plains, or, again, where low hills of chalk and oolitic limestone enclose the basin of a considerable stream, as the Thames. These points will be recognised more clearly by referring to the outline maps accompanying this chapter.

Lastly, the rocks that form the mass of the earth's crust at any place may be masked and entirely unrecognisable, owing to the presence of a thick coating of comparatively modern transported material, of which clay, boulders or rolled fragments of rocks, sand, and gravel, are the constituent parts. This, also, is not unusual. It occurs rarely in the higher ground near the sources of rivers, but frequently in the lower valleys through which they flow as they approach the sea.

This part of the subject, however, and the bearing of geological conditions on river flow, will come under further consideration in another chapter; the object, at present, being to estimate, as far as possible, the proportion of rainfall that runs off the surface under various conditions, physical and geological. But, before doing this, we must define, as briefly as possible, the term "river," of which, in the present chapter, we have to treat. Having considered the nature of drainage areas as limited districts whose surface waters are brought within a single channel, we must now show how far this channel is an important object in nature. Under certain conditions, the drainage of a tract of land may pass at once to the sea, terminate in a lake, or be lost in the earth without being brought together into a definite and united stream. That this is not the usual condition is proved by the existence of rivers in every country, and by the nature of the river systems to which they belong.

9. Rivers.—A river is the collected drainage of a tract of country making its way to the sea, or to some inland lake, by a natural channel, uniting many tributaries, cut out for it by the action of the water that has been continuously flowing through it from time immemorial, or shaped for it by some catastrophe affecting the rocks over which it passes. It is not necessary here to describe the varieties of physical condition under which river channels have been formed, as the object in view is rather to consider the phenomena of running water than the reasons why it has selected a certain course; but some notice is required of the history, the progress, and the termination of rivers as agents which have from time immemorial played an important part in the preparation of the earth's crust.

To understand the nature of a river, we must consider it first in its very earliest stage. A sloping surface, more or less saucer-shaped, but with its bottom inclined, allows any water entering it to run off and not accumulate in a pool. It receives rain from the clouds over its whole extent, but permits it to escape only at one part. The stream running out is called by various names in different parts of England; brook, beck, dyke, and burn, being common synonyms. The area is a drainage area. Both stream and drainage area in such a case are of the simplest description and on the smallest scale. This is a unit of drainage, and a river may be regarded as a multiplication of such units. Sometimes the water flows into the saucer or drainage area from a spring rising within it, and sometimes it is only fed by the rain that falls upon it. It may happen that both assist. A few such brooks combining their waters, a rivulet is produced, and several of these united make a river. The rim of the saucer is the line of water-shed or the water-parting separating two basins.

Rivers have their origin on land which is, at least comparatively, high, and the largest rivers are, in many cases, traceable to the loftiest mountain chain of a continent; but, provided there is sufficient fall to enable the water to flow on in its course from the source to the sea, a very small slope (if there are no interruptions) is sufficient to run off the water through a river channel.

Many streams originate on high ground, run at first over comparatively steep ground, flow rapidly to the plains, where the slope is gradual, and finally communicate with the ocean, often flowing a great distance, pushed on from behind, over ground that has no perceptible slope. A river course is thus divisible into the three parts, upper, middle, and lower. In the upper division the water rushes through ravines, tumbles over rocks, and has a great but interrupted rapidity. In the middle course the flow is generally more equal, but, in some cases, there are ledges of rock or broken ground interrupting its progress, and causing it to expand into lakes, break over rapids, or fall in a vast sheet over cataracts, such as those of Africa or North America. In its lower course a large river generally meanders through level plains till it approaches the coast, where it meets the tide, and is more or less obstructed by sand-banks, shoals, or bars.

It is by no means necessary for the existence of a great river that the fall of ground or slope should be large. The Volga, the largest river of Europe, runs for two thousand miles through a level country, its source not being more than 1,100 feet above the sea. The gigantic Mississippi rises in a low undulating country far in the interior of a great continent, not more than 1,500 feet above the sea level. See § 50.

When rivers leave the mountains and enter the plains to run their middle course, the bed of the river, which, while in the mountains, follows the natural inequalities dependent on the physical features of the country, and on the nature of the mountain chain or hill elevations, becomes more regular. At this point also—in some cases near the lower mountain slopes—the character of the stream alters, and it assumes an even, regular flow, widening out and adapting itself to the new condition. Here commences, generally, the deposit of *alluvium*, matter brought down by the river during its more rapid course, and deposited when the flow becomes more regular. Through and over this alluvium the river continues to cut its way, altering its channel from time to time when unusual floods bring down a larger quantity of mineral accumulation, sufficient to choke the channel originally cut. Sand-banks and islands are soon formed in the channel, and, at first, soon removed, but by degrees the river settles itself within certain limits, which are rarely—perhaps never afterwards—over-passed. The channel becomes wider and deeper, and the main stream receives tributaries conveying more or less water, and each contributing its share of detritus, forming a deposit at the confluence.

When a river has thus continued through the plains, and approaches the sea, a change often takes place in this, its lower course, owing to the check given to the advancing water where it comes in contact with the tide. Where the volume of water is great, and the channel deeply cut through the plain, the water begins to be retarded in its course at a great distance from the sea, and deposits the finer mud which has been brought down and which has been derived from the mechanical erosion of the stream, and the grinding of the stones constantly moved under water. The fine mud thrown down sometimes forms a large and continually increasing heap, projecting gradually beyond the original coast line, and through which the water makes its way now in one channel, now in another. The deposit is level, and nowhere rises much above the level of the stream. It is a *delta*, so called from its triangular form, which resembles the Greek letter of that name. The name was originally given from the delta of the Nile, which is typical. This form, however, is not always assumed, for the delta of the Mississippi is thrown out as a tongue to a great distance in the Gulf of Mexico, and has no resemblance to a triangle. The deltas of rivers are largely increased, and sometimes permanently raised, by inundations and floods.

This outline description of a typical river was necessary in the present chapter, in which the phenomena of rivers are considered, but I do not propose to enter into a more detailed account, for this belongs rather to a treatise on physical geography. I desire only to present to the reader the main features of the subject that we shall afterwards have to discuss.

England has no river of great magnitude, and none of its rivers terminates in a typical delta. It has, however, many rivers and river systems of extreme importance to the well-being of the country. They are valuable for the circulation of water they ensure, for providing a supply of water for economic purposes, and as natural channels for conveying, at a very cheap rate, the heavier produce that it is sometimes desirable to transport from one part of the country to another.

10. Shifting sources of rivers, or Bournes.—It is usually the case that the source of a river is a fixed point, the outflow of water diminishing or even failing, it may be, in extreme drought, but not changing its position. Where it is derived from immediate rainfall, the first rain brings it back to the recognised site; and, where it is a spring, the site of the spring is permanent.

It occasionally happens that a river, under peculiar conditions of strata, actually rises in a new place, commencing its course at a point which, although in the same valley as that which it usually drains, is situated at a much higher level. The phenomena thus introduced are marked, and sometimes important; and there is a familiar instance near London, in the "Bourne," which occasionally breaks out in the valley of the Wandle, some miles above the usual sources of that stream. In Surrey there are other similar phenomena, also called "bournes;" in Kent they are "nail bournes," in Sussex, "levants," in Dorsetshire and Hampshire, "winter bournes." These are all in chalk districts. In Yorkshire they are known as "gypsies," and occur in hard limestones. All these are instances of springs breaking out occasionally and irregularly after unusually wet seasons, and running special courses. Most of them can be explained simply, and the following account of them given by Mr. Topley, in the Memoirs of the Geological Survey, vol. iv., p. 392, "Geology of the London Basin," is correct and easily understood, so far as chalk is concerned:—

"The dip of the beds of chalk underlying the valley is in these cases generally steeper than the slope of the valley bed, so that, in ascending the valley, the lower beds of chalk are successively passed over until the steeper rise of the valley head is reached, near the escarpment, where the slope of the ground becomes greater than the dip of the beds. Near this point the outbreak usually occurs. The water from the rainfall accumulating in the chalk, rises most readily along the lines of bedding, with which the fissures occasionally correspond. The water-level in the chalk gradually rises with the increasing rain of the district, and the breaking forth of the bourne is indicated by a rapid rise in the wells near."

In Yorkshire, where the springs proceed from limestone, they are probably connected with crevices in the rock which, as a whole, act the part of a syphon. The water only occasionally reaching the level at which the syphon can act, the phenomenon is even more irregular and less dependent on immediately preceding seasons than those of the south of England. The rivers proceeding from or fed by these sources differ in no respect from other rivers, and need no special consideration.

Rivers occasionally disappear, being lost by descending among rocks and through fissures to a level below the surface. In some cases they re-appear at a distance at a lower level. In some, however, they are not again traceable, the water passing under the broken rock into the sea, or being evaporated from sands among which it is dissipated.

11. Rainfall in relation to river-flow.—The quantity of water conveyed by a river to the sea is a result dependent on several elements. These are as follows :—(1.) The extent of the drainage area, or district in which all the water-channels converge ultimately into one stream, whether at a certain point in the river course, or where the stream enters the sea ; (2) the total rainfall on this district as measured by rain-gauges in different parts, the measurements ranging over a sufficiently long period ; (3) the seasonal distribution of the rainfall, and the general climate of the district ; (4) the amount of evaporation from the surface, as estimated from general rules or from special observation ; (5) the form of the surface of the drainage area, the elevation of the higher parts of the gathering ground, and the proportion of land above the mean level of the whole ; (6) the position of the high ground and the steepness of the slopes ; (7) the position of the district with reference to the ocean ; (8) the nature of the rocks, both of the high lands and the valleys ; (9) the mechanical condition of the rocks at the surface, and the nature and extent of the weathering they have undergone ; (10) the general plan of the drainage, the number of principal tributaries, and the condition of the channels, both of the feeders and of the main stream.

The seasonal distribution of the rain, the variation in the flow of the feeders and the main stream at different periods, the extent of marsh and low-lying lands near the river outlet, and other physical conditions, are also important in reference to the ultimate discharge of water to the sea. It is very rarely indeed the case that a river having important tributaries entering from various directions discharges its waters in equal proportions day by day, and not unfrequently the bed of a stream is almost or quite dry at certain seasons, and serves merely as a channel for occasional floods. This is the case with some of the Spanish rivers, as the Ebro. In England there are seasonal changes, producing occasional floods, causing a wide range between maximum and minimum flow.* The streams flow in our country most abundantly in late autumn and winter, and are low in summer; but there is occasionally very heavy rain accompanied by flood in the spring. The mean summer flow, the mean annual flow, and the maximum and minimum flows, all require consideration, but they have only occasionally been measured and recorded, as these operations are troublesome and difficult. Accurate gauges of our English rivers are rather to be desired than discovered, and too little has yet been determined as to how far our rivers are increased from point to point by springs, and especially by what are called "bottom springs," or water entering the bed of a river without showing its origin, except by its addition to the flow.

12. Streams small and few over absorbent rock.—The number and magnitude of streams is much less in districts where the underlying rock is absorbent than in those where it is impermeable and compact. In the chalk the extreme of this condition is seen, although parts of the New Red Sandstone approach it. According to the evidence of Mr. Homersham, given before the Select Committee on the Metropolis Water Supply Bill (p. 157 *et seq.*), water is absorbed into the chalk as fast as it falls. In an area of 13,000 square miles round London, divided among several formations, he states that there are 5,353 square miles of chalk and upper green-sand, over which the total length of streams and watercourses is 2,391 miles, the length of river per square mile of drainage area being 782 yards. As a contrast to this, he finds that in the London and plastic clay, on an area of 4,071 square miles, there are 4,741 miles of water-courses, being at the rate of 2,087 yards per square mile. Even this does not represent the real state of the case, as much of the country included in the chalk area is covered with impermeable clays and gravels.

13. Flow of the river Lea.—The quantity of water running off from definite areas of gathering ground has been measured in small districts, and, in some cases, the measurement has been repeated over a series of years. The river Lea, which supplies the New River Company with water, conveyed to London for distribution, was carefully gauged some

* The Severn affords a remarkable instance of wide range. At Tewkesbury, where the drainage area is nearly 3,000 square miles, the lowest recorded flow has been stated to be only ninety millions of gallons per day, but is probably more. In the Thames, for the same area the lowest flow is nearly twice as great, although the rainfall over the greater part of the Severn catchment is higher than on that of the Thames.

years ago by the late Mr. Simpson, and the results, though of limited application, are interesting. The gathering ground to the place of gauging amounted to 421 square miles, the rock being chalk, of which $53\frac{1}{2}$ square miles were covered by tenacious clays. The mean rainfall over the district (which is near London) is taken as 25 inches, and of this the total quantity running off was found to be equivalent to 7 inches of fall (·357 of the total) or 450 gallons per day for each acre. No estimate was made of the extent to which the stream may have been increased by bottom springs.*

In the same drainage area, however, on the occasion of a flood in the Lea basin, in November 1852, causing the stream to run nine miles an hour, the late Mr. Beardmore estimated that 440,000 cubic feet of water per minute came off the district from an area of 330 square miles. This is a rate of 18,750 gallons per day per acre; but we are not told how many hours it continued. On this occasion the rain had been nearly constant for nine days previously; the ditches were filled with water, and the soil had become thoroughly saturated. Regarding this as the maximum observed flow it amounts to rather more than forty-one times the mean.

14. Discharge of the Wey.—Very careful observations were made by Captain James, R.E., during the progress of the Ordnance Survey, on the proportion of the rainfall on the upper part of the Wey delivered through the gorge of the hills at Guildford. The area of the water-shed to this point was found to be 229·4 square miles. On this district there were observations from fifteen rain-gauges, placed at altitudes varying from 120 feet to 814 feet above the sea, so distributed as to show the mean fall. By continuous observations from the 1st May to 31st December 1867, the total rainfall was found to be 18·105 inches, giving as the total fall 9,683,612,200 cubic feet of water. During this period observations were also taken of the transverse section and velocity of the river Wey at Guildford. At one place 107 observations were taken, and at another, half a mile further down, 97. From the mean of these the volume of water flowing down the stream was calculated to amount to 3,230 million cubic feet, or 377 gallons per day per acre. Captain James considers that an allowance of one-eighth should be made for flood waste, and that the true proportion of outflow to rainfall was as 2 to 5.

15. Discharge of the Eden.—Captain James also measured the outflow and rainfall in the case of the river Eden, near Carlisle, in 1864,

* It is well to point out that the upper part of the river Lea runs over chalk, which is usually saturated, very copious springs rising out of the rock at various places. Owing, no doubt, to this cause the Lea is partly fed from the chalk instead of losing water while passing over it, as is usually the case with rivers in this rock.

and found the former to exceed the latter by an important amount. The Wey runs over chalk and porous rocks; the Eden rises on granitic and slate rocks, runs over mountain limestone, and crosses the New Red Sandstone. It is, no doubt, largely fed by bottom springs from the latter rock, and the result affords a remarkable contrast to that obtained in the river Wey. [Proc. of Inst. of Civil Eng. 1867–68.]

16. Measured flow of the Thames.—The Thames, as will be seen in the description of its course in the next chapter, is well circumstanced for illustrating the conditions of river flow, its water-supply being derived from many feeders from an area of known geological character, not mountainous in any part, and having a tolerably even slope throughout. It is not interrupted in any part of its course by rapids or falls, and has a moderate rainfall distributed pretty equally through the year.

The Thames has been gauged frequently, and at many points of its course. According to observations made by the late Mr. Simpson, and recorded in the Minutes of Evidence given before Mr. Ayrton's Committee of 1867, the mean flow at Teddington was 430 millions of gallons per day, the drainage area at this point being two and a half millions of acres. This flow is equivalent to 172 gallons per day per acre of drainage area, or, if expressed in inches of rainfall, amounts to 2·785 inches in the year out of an assumed total rainfall of 25 inches, being ·1114, or about one-ninth part of the whole. The maximum flow at Teddington has been roughly estimated at ten thousand millions of gallons per day, or 4,000 gallons per day per acre, being 23 times the estimated mean.

At Staines, where the drainage area is only 1,975,000 acres, the mean daily flow has been estimated at 360,000,000 gallons, or 182 gallons per acre per day, representing a rainfall of 2·93 inches, or ·117 of the whole. We have seen that the Lea, a tributary of the Thames, draining 421 square miles, or about 270,000 acres, delivers 450 gallons per day per acre, being ·357 of the whole fall of 25 inches.

Above the confluence of the Medway, where the drainage area of the Thames is 5,162 square miles, the mean annual flow is estimated at 263,522,700,000 gallons, which is equivalent to 3½ inches of rainfall, or 219 gallons per acre per day. This, is about one-seventh of the total rainfall.

The following figures record the number of gallons per acre per day running off the Thames basin at Kingston (drainage area, 3,376 square miles). They are estimated or quoted by Mr. Beardmore (Man. of Hydrology) (B.), Mr. Stevenson (S.), and Mr. O'Connell (O'C.):—

Mean annual flow	B.	382 gallons per day per acre.
Do.	S.	390 „ „

Ordinary summer flow	B.	153	gallons per day per acre.	
Minimum flow	do.	134	,,	,,
Maximum flow	B.	1,530	,,	,,
Do	O'C.	1,827	,,	,,
Extraordinary flood	do.	2,295	,,	,,

It is stated that at Albert Bridge, Windsor, during a flood, a discharge of 880,800 cubic feet per minute was gauged, the ordinary winter flow at that place being 44,600.

The ordinary winter discharge of the Thames at Oxford is said by Mr. Stacy, as quoted by Mr. J. T. Harrison (Royal Commission on Water Supply, 1869, p. 193), to be 320 million gallons per day, and, at Kingston, between 800 and 900 millions (400 gallons per day per acre), about one-third coming from the oolite, which is an extremely open rock. In summer, the ordinary discharge at Oxford is stated to be 73 millions of gallons per day. The drainage area above Oxford is 384,000 acres, which would show a rate of about 888 gallons per day per acre in winter, and 190 in summer.

Another of the feeders of the Thames, the Colne (Hertfordshire), has a drainage area of about 72,500 acres, to Bushey Mill, near Watford, and a mean annual rainfall of 25 inches. The flow on the 25th June 1850 was measured at Bushey Mill to be ten million gallons per day, or 138 gallons per day per acre (one-eleventh part of the rainfall).

17. Flow of the Medway.—The river Medway, an important feeder of the lower Thames, measured at a point where its drainage area is 300,000 acres, has been found to discharge into the Thames $22\frac{3}{4}$ millions of gallons per day, being at the rate of only 74 gallons per day per acre, representing a rainfall of 1·19 inches. The Medway runs chiefly over chalk, and is a fair example of the small flow to be expected from a permeable rock in its ordinary dry and absorbent state, and may be contrasted with the flow from the similar rock over which, when loaded with water, the river Lea flows.

18. Flow of the Severn.—In the case of the Severn, the largest of the British rivers where it finally enters the Bristol channel, but which receives several of its chief feeders very near the sea, the flow is derived partly and largely from the eastern slope of the Welsh mountains, supplemented by that from the northern and western slopes of the low hills of the middle of England. The rainfall is heavier than over the basin of the Thames, and the mean flow differs much more widely from the extremes in consequence of the nature of the rock, the form of the ground and the extreme rapidity with which rain runs off.

The Severn at Worcester (just above the junction of the Teme) has a drainage area of something less than 2,000 square miles, and at this point the average summer flow is estimated at 160 million gallons per day, or 125 gallons per day per acre. Lower down, at Mythe Bridge, after the confluence of the Teme, and near the Avon junction, the mean daily summer flow is stated to be 200 millions of gallons. Between Worcester and Tewkesbury the lowest summer flow has been said not to exceed ninety millions of gallons per day.* Below Gloucester, at Stonebench, after receiving the Upper Avon, and some small brooks, the flow is given, in a report by Capt. Beechy, as 298 millions of gallons per day, or 120 gallons per day per acre. This is equivalent to a rainfall of 5·76 inches over an area of 3,900 square miles (about $2\frac{1}{2}$ millions of acres). As the total water delivered during the year is considered to be equivalent to nearly three times this fall (16 inches), it will be seen how very large a proportion must be carried down in floods and freshets. There can be no doubt that this is characteristic of the river, for its waters increase suddenly and largely after rain in the mountains, and flow off very rapidly in torrents.

19. Flow of the Nene.—The river Nene is a sluggish stream, having very little fall from its source to its outfall, and everywhere free to overflow its banks. At Peterborough, where it drains 400,000 acres, it discharges 45 million gallons per day, as its mean flow. This is equivalent to a daily discharge of 113 gallons per acre, representing an annual rainfall of 1·88 inches, or about one-twelfth part of the observed rainfall. The course of the Nene is chiefly over impermeable clays. At Higham Ferrers, where the drainage area is 383 square miles, or 245,120 acres, a flood discharge is stated by Mr. Beardmore to have amounted to 79 cubic yards per second, which represents a flow of 1,152 millions of gallons per day, being at the rate of as much as 4,700 gallons per day per acre. This is very large in proportion to the mean, and is a good illustration of the absence of any effective regulator in this and other rivers running over the level expanse of clay on the eastern side of the middle of England.

20. Flow of small rivers.—In the case of smaller rivers in England, the proportion of rainfall that passes down, though sometimes about the same, is in others much larger. Thus, the Lodden, a feeder of the Thames running over the greensand, draining an area of 140,000 acres, has a flow of 27 million of gallons, being a daily discharge per acre of 190 gallons, equivalent to 3·01 inches per annum out of a rainfall of 25·4 inches. But the Plym, a small stream running over granite in the west of England, draining 5,000 acres, flows four and a half million gallons per day, or 925 gallons per day per acre, representing a rainfall of 15·10

* It is not likely that so small a flow has really occurred. There would seem to be a probability of inaccuracy arising from the escape of water under the sill of the weir.

inches out of a total of 45 inches. This is the result of a short course over impermeable rock in a district where rain is constantly falling.

21. Gathering ground and flow of Dover Beck.—I am enabled to give another instance from the Dover beck, one of the smaller feeders of the Trent, entering below Nottingham. In this catchment the rainfall is moderate, the rock absorbent, and there is a little flood water. The rock consists of the pebble conglomerate of the Bunter sandstone, belonging to the lower member of the New Red Sandstone series. There is a drainage area of 12,698 acres, measured to a gauge placed at a point where a number of springs enter. These springs are partially fed from a stony band belonging to the upper New Red Sandstone, or Keuper, covering the lower beds on the eastern side of the district, and well known as a water-bearing stratum over a large district in the midland counties.

The gaugings in this case showed a minimum flow of six million gallons per day in summer and an ordinary winter flow of eight millions, giving an average of about seven millions per day independent of floods. The rainfall at Highfield House, Nottingham, as determined by Mr. Lowe, taken on an average of 25 years, is 25·3 inches. Four years average at Oxton, within the district, during the years 1865–68 inclusive, show 26·3 inches, and the corresponding years for Highfield, 26·6 inches. Thus, we can hardly estimate the mean annual rainfall at Oxton as much exceeding 25 inches. Six million gallons per day from an area of 12,698 acres, is equivalent to 7·62 inches in the year over the whole area, or ·305 per cent. of the fall, being $472\frac{1}{2}$ gallons per day per acre. Eight millions per day is 630 gallons per acre.

In this case the quantity of water entering the rock must vary greatly in different parts of the area. Near the source, where strong springs originate the stream, the strata are always saturated, and the greater part of the rainfall runs off; but, where they are not saturated, the proportion absorbed would be large, as the material is very open.

Below the gauge the stream continues to run for some miles before entering the Trent. It thus drains an additional area of 5,250 acres, making a total drainage area of 17,948 acres. The quantity of water passing into the Trent from the whole area on the 15th March 1869 was 12,877,000 gallons per day (715 gallons per day per acre) the weather being fine, and no rain having recently fallen. It is stated by the local residents (but there is no absolute proof) that the quantity of water diminishes but little in summer, and is only increased during a few hours after heavy rain in autumn. The amount is equivalent to about $11\frac{1}{2}$ inches, or 46 per cent. of the rain, running off in regular flow, leaving a balance of $13\frac{1}{2}$ inches. In this case the flow during March might be expected to represent an approximate mean for the whole year, including flood waters, but the proportion is exceptionally large.

23. Flow of the river Lene.—As a further illustration of some interest bearing upon water discharge from the bottom beds of the New Red Sandstone, I may quote the case of the river Lene, entering the Trent above Nottingham. An area of 3,920 acres, draining into a valley at the outcrop of the Permian rocks over-lying the coal measures, yielded, in the middle of March 1869, about three million gallons per day, or 765 gallons per day per acre. The rainfall here may be somewhat greater than at Oxton, as it is a little to the west of that village, and lies nearer the high ground of the district. It may be estimated at 26 inches. The discharge is equivalent to 12·35 inches per annum over the drainage area, being $47\frac{1}{2}$ per cent. of the whole fall. The elements in this calculation are less complete than in the foregoing, but the result is interesting. There can be little doubt that the mean flow of the Lene is much smaller than that measured.

The country drained by the Dover beck is under cultivation, but not much peopled. The cultivated parts are partly pasture lands, partly arable. The waters of the Lene issue in strong springs from the bottom beds of the New Red Sandstone where they cover up the red marls of the Magnesian limestone, but these springs are not permanent. Almost the whole of the drainage of the magnesian limestone goes to the west.

24. Gaugings into reservoirs near Sheffield.—A case of some interest is recorded by Mr. Leather in his report on the "Condition of the Sheffield and Bradford Reservoirs, 1864, App. C., where are tables of the daily flow of some of the streams in the Wharfe valley. It appears that the average daily flow of these streams from March 1854 to February 1855 inclusive was $9\frac{1}{4}$ million gallons, distributed as follows: January, February, and March, 5,650,000; April, May, and June, 3,350,000; July, August, and September, 3,430,000. In October, when the heavy rains began, the quantity was about four millions; and in November, when they increased, five millions. December was altogether wet; the average daily flow amounted to fifty millions, or, deducting two exceedingly heavy floods, thirty-two millions. In Barden beck, at no great distance, the maximum flow in the same years was more than 900 millions, and the minimum flow 41 millions. The relations between maximum, minimum, and mean flow are not stated, but the difference is certainly very great. The rocks are, to a large extent, shales and non-absorbent gritstones, often covered by non-absorbent boulder clay. The whole are little liable to admit of percolation to any large extent, and the rainfall is rather heavy, especially in wet seasons.*

25. Flow of French rivers.—It is useful to compare these results with those of rivers in other countries. The Saone, draining an area of

* See table, p. 69.

7,400,000 acres in the middle of France, discharged per day at Lyons, according to observations during the four years 1852–1855 inclusive, 9,168 millions of gallons, being at the rate of 124 gallons per day per acre, equivalent to 1·97 inches of rain in the year. The mean rainfall, taken from an average of twelve stations in different parts of the drainage area, was 32·6 inches, so that the proportion of mean flow to rainfall is about one-sixteenth. The observed evaporation at Dijon, on an average of the same four years as those above alluded to, amounted to 21·02.

26. Flow of the Tiber.—The Tiber drains about four and a quarter millions of acres, chiefly of hilly ground; and its mean flow at Rome, according to observations extending over 28 years, is as much as 5,500 million gallons per day, being 1,294 gallons per day per acre, or about $21\frac{1}{2}$ inches of rainfall in the year. The observed rainfall at Rome and Perugia is 31·06 inches, but it is probably larger in the Apennines. The proportion of rainfall running off by the river is, therefore, enormously greater than in any other case here recorded, and this is, no doubt, due to the mountainous character of the country, though partly, perhaps, to the extremely irregular flow, and the difficulty of obtaining a true mean. The Tiber has always been an exceedingly torrential river, and always flows with a very swift current.

27. Mississippi-Missouri system.—The vast system of the Mississippi-Missouri receives the water that falls on a million and a quarter square miles of land, being about one-sixth part of the total area of North America. The length of the main stream is between four and five thousand miles. It is difficult to deal intelligibly with areas and distances so great, for the drainage areas of the chief tributary streams are as large as those of many first class rivers, and six of these combine before their united volume is poured into the gulf of Mexico.

Very important and interesting information on this subject is given in Messrs. Humphrey and Abbott's well-known account of the Mississippi river (*vide* chap. vi.), an abstract of which, though to be found elsewhere, will be useful in this place for comparison and reference. There are no recorded observations on the flow of large rivers so complete, and the meteorological observations of rainfall are also of unusual accuracy and range. The Mississippi system includes (1) the *Upper Mississippi*, rising from a multitude of small lakes near the head of Lake Superior, with a rainfall of 26·8 inches, receiving the *St. Peters's*, or *Minnesota* river (rainfall, 30·4 inches) from the west, the *Wisconsin* river from the east, and the *Des Moines* river from the west, and, lastly, close to St. Louis, the *Illinois* river, from the western shores of Lake Michigan on the east; (2) the *Missouri* river, a much longer and more considerable stream, coming from the Rocky Mountains. Its upper member is joined by the

Yellowstone river, and it receives, among many others, the *Platte* river and the *Kansas* river, both from the west, before joining the Mississippi at St. Louis near Jefferson; (3) the *Ohio* river, from the Alleghanies, entering at Cairo, near Columbus, and receiving the *Kanawha*, and many large streams; (4) the *Arkansas* river, from the west, joined by the *Canadian* river; (5) the *Red* river, also from the west. Between the Ohio and the Arkansas the *Francis* river comes in from the Ozark mountains, a little below Memphis; and below the Arkansas, at Vicksburg, the *Yazoo* river enters. These two, and the *White* river, are remarkable for their effect on the river discharge rather than for their magnitude. Both the Arkansas and the Red river receive large feeders from swampy lands to the north shortly before joining the main stream. It is a remarkable fact with regard to the feeders of the Mississippi, that the rainfall over their respective drainage areas is much larger about midway in their courses, and where they enter the valley of the Mississippi, than near the mountains. Near New Orleans the rainfall amounts to from 50 to 65 inches, while in the mountains it is in many places not more than half that quantity.

The river runs for the most part between low cliffs of alluvial mud called *bluffs*, through which there are occasional openings, called *crevasses*. In many places the openings thus made are closed by artificial dykes, called *levees*. There are besides natural channels opening into land at a lower level, known as *Bayous*. The following tabular statement of the principal sub-basins of this great stream, will be useful for reference and comparison, being much more trustworthy than is usual in large measurements:—

Principal Sub-basins of the Mississippi-Missouri System.

	Area of basin in square miles.	Annual discharge in millions of cubic feet.	Rainfall in inches.	Proportion of discharge to rainfall.
Upper Mississippi - -	169,000	3,300,000	35·2	0·24
Missouri - - - - -	518,000	3,780,000	20·9	0·15
Ohio - - - - -	214,000	5,000,000	41·5	0·24
Arkansas - - - -	189,000	2,000,000	29·3	0·15
Red River - - -	97,000	1,800,000	39·0	0·20
Yazoo River and St. Francis	24,350	2,340,000	43·7	0·90
Whole Mississippi basin*	1,244,000	21,300,000	30·4	0·24

Expressed as in the preceding paragraphs this would mean that the flow from the sub-basin of the Upper Mississippi is 522 gallons per day per acre, equivalent to 8·4 inches of rainfall out of a total of 35·2. In

* The total includes a small drainage area and its discharge, not included among the sub-basins.

the Missouri it is 195 gallons per day, or 3·4 inches out of 20·9. In the Ohio, 625 gallons, or $10\frac{1}{2}$ inches out of 41·5. In the Arkansas, 283 gallons, or 4·6 inches out of 29·3. In the Red river, $496\frac{1}{2}$ gallons, or 8 inches out of 39. In the Yazoo and St. Francis, 2,570 gallons per day per acre, being nine-tenths of the whole fall. From the whole basin of the Mississippi-Missouri the discharge is 460 gallons per day per acre, equivalent to a rainfall of 7·4 inches out of the mean annual fall of 30·4 inches.

It appears from these figures (1) that the rain falling on the western slopes of the Alleghanies and on the low lands in the Lower Mississippi valley, is very much heavier than that on the eastern slopes of the Rocky mountains; (2) that the proportion of discharge to rainfall, with the exception of the comparatively small basins of the Yazoo river and the St. Francis, is greatest in the Ohio and Upper Mississippi, where the rainfall is greatest; and (3) that, as a general result, one-fourth of the rainfall runs off by the river into the sea.

In the valley of the Mississippi the basin of the Yazoo river may be regarded as a natural receptacle of flood waters, serving as a reservoir. During a flood this swamp is under water, the flood waters of the main stream backing into it by channels called crevasses. In low states of the river these channels drain off not only the water that naturally falls on its drainage area, but that which has accumulated. During and after seasons of flood, the flow from these reservoirs is very large, a quantity equivalent to nine-tenths of the measured rainfall of the district running off through the crevasses. In this instance, therefore, although there are no lakes in the whole great system of the Mississippi-Missouri, the wide alluvial bottoms in the lower part of the course of the stream, accessible only through channels comparatively narrow, act as flood-regulators, the flood waters entering these bottoms by means of the bayous and crevasses, there covering a vast expanse of land at a low level, and being discharged afterwards with comparative evenness and regularity without materially raising the level of the great river below the crevasses, or causing dangerous rushes of water over the delta. Reservoirs occupying more than 20,000 square miles are flood-regulators that are not likely to be rivalled by any work of man. A corresponding reservoir in the Thames valley, occupying, when full, about 100 square miles, the depth being inconsiderable, would act in like manner. In such a case the land, not being covered except during heavy floods, and then improved by warping, would not be withdrawn from cultivation.

28. Formula for water discharge of river basins.—It has been suggested by Col. O'Connell, in his valuable communication to the Institution of Civil Engineers on the fresh-water floods of rivers, that the number of cubic feet of water flowing off a drainage area in one second of time may be calculated for the steepest districts from the formula $5a^{\frac{2}{3}}$, in which a represents the area in acres. As the land becomes flatter the coefficient 5 would have to be varied to 4, 3, $2\frac{1}{2}$, or 2. This rough rule, though in some cases useful for suggestion, cannot be expected to apply generally, or without regard to local conditions.

29. Influence of the banks on the flow of a stream.—There are many circumstances that affect in an important manner the quantity of water delivered by a stream, and the circumstances and regularity of its flow. Among these one of the most influential, especially in rivers of moderate size, is the form of the river bed, and the way in which it is shut in by its banks. There are instances—the most remarkable being in the south-western part of the United States of North America—where the whole river runs between narrow precipitous gorges called *cañones* (canyons), through deep fissures in limestone plateaux. Such phenomena are marvellous and picturesque in the highest degree; and they are repeated on a smaller scale elsewhere, being, indeed, less uncommon than is generally thought. They occur even in our own country, although they belong chiefly to forms of the land not frequent in England. More generally rivers rise in mountainous or hilly country, intersected by valleys through which the water finds its way, at first with interruptions, and afterwards more quietly. Away from the mountains the ground becomes more open, and the valleys widen into broad plains.

30. Lakes as flood regulators.—Natural lakes are sometimes expansions of valleys among mountains, and sometimes broad open sheets of water in level plains in the lower part of a river's course. Examples of the former kind in the British islands are the lakes of Cumberland and Westmoreland, some of the lakes of Scotland, and the lakes of Killarney in Ireland. Of the latter kind the larger loughs or lakes of Ireland and the broads of Norfolk are instances. Lakes have little or no relation in point of magnitude with the rivers to which they belong, the largest lakes being sometimes connected by narrow channels, and their overflow passing to the sea by small streams.

The presence of lagoons or of open flat bottoms, dry at ordinary times but capable of retaining large volumes of water coming down after heavy rain, and checking the course of floods on their way to the sea by the large surface they present for the water to spread over, has great influence on the flow of rivers so provided. When the banks are high and not far removed from the bed of a stream, any sudden rush of water in addition to the ordinary flow backs up to a certain height, and in returning acquires force and velocity. If narrow steep banks continue, this process of backing up causes a large body of water to accumulate and become almost irresistible when it rushes down the stream; but, if the banks gradually open out in a funnel shape, the water never attains a great height, and, if there are lakes, it is soon and evenly distributed, a rise of a few inches over a large surface receiving sufficient of the flood to check the force of a very considerable torrent. In this sense lakes are flood-regulators. The form of its banks and the expansions of its bed are thus influential in modifying the flow of a river. It will be evident that, so far as they go, artificial reservoirs act the same part as lakes, and diminish the injurious effect of floods, but it is difficult to construct them of sufficient magnitude to prevent floods in a district naturally liable to be flooded, unless the ground is specially favourable for storage.

31. Other flood moderators.—Besides lakes, there are other important conditions of a river that serve to moderate floods and keep back the rush that takes place after heavy continued rain in the mountains, when the combined waters of a large number of feeders enter the plains. Among these may be named the soil, the nature of the stratification, and the period of the year at which rain chiefly falls. Heavy rains occurring when the ground is dry, at the end of a hot summer, will produce a comparatively small effect, but when the soil and the strata are wet and cold, half the amount of rainfall will do an amount of mischief altogether beyond that which might seem possible. In the one case hardly any of the rain will affect the lower stream, but, in the other, two-thirds or more of the total fall may find its way down, and, if interrupted by obstacles, will obtain force sufficient to carry away bridges and remove houses and other buildings on the banks of the stream. Such results are especially to be dreaded in the case of rivers that rise and have their principal feeders in mountainous countries.

In estimating the value of a gathering ground, or the conditions of a river at any part of its flow, a careful study of these details is indispensable. It may be, if the conditions are favourable, that a bank of moderate height enclosing a tract of low-lying land will store a large quantity of water, while, if the circumstances are different, a very high bank will yield but small results in water storage. In the natural course of a river there may be in one place ready means of preventing flood by small works constructed at favourable points, while in other places there may be no available means of seriously checking the rapid flow of storm waters down the stream, even by the largest and most costly efforts. In all cases careful consideration of the natural conditions, and their bearing on the result, must be accompanied by some knowledge of the physical geography and geology of a district, to ensure a satisfactory conclusion on the part of the engineer.

32. Dangerous floods.—Dangerous floods often occur by a sudden rush of upland water covering and masking for a time the regular though much-increased flow of water from the lower tributaries of a stream in the main channel. The following graphic description of such a flood in India, abstracted from Mr. Jackson's Hydraulic Manual (p. 186), will apply in principle to the smaller floods in our own rivers :—

"Let us imagine ourselves to be standing on the bank of a river as wide as the Thames at Hammersmith. Heavy rainfall has been going on for some time ; the river swells—increases in depth and velocity; the water runs steadily, and tolerably clear. The rain increases in the plains, and the sky gives prospects of a heavy storm in the direction of the uplands. Let us watch the effect. The down-pour all around increases the depth and velocity of the river, but its colour is unchanged, and it seems nearly pure. Suddenly a roaring of waters, like that below an over-topped mill-weir, is heard, and up stream we notice a white line of foam approaching : three or four minutes, and a flood sweeps by on the surface of the river like a wall of water, three or four feet in height. All this water is muddy and dark with detritus. The waters after this again rise still higher for twenty-four hours, but are yet muddy ; the low-lying lands near the river are submerged. We learn afterwards that a considerable fall of rain has taken place in the uplands of the river, and that towns and villages in the plains have been inundated." Such is a flood of a type which causes serious catastrophes. The lowland water flows steadily and clear, at the rate, perhaps, of one mile an hour. The upland water comes down with a velocity of nearly six miles an hour and charged with silt, and tops the lowland water. The combination gradually decreases in speed, but spreads widely beyond the natural bed of the river, and leaves a deposit.

Many of the English rivers are subject to floods, and very great mischief is occasionally done by the sudden and unexpected rush of water when the ground is saturated in consequence of heavy rain. It is almost always the case that a large part of such streams runs over clay, or other impermeable rocks, whether regularly stratified or superimposed on the ordinary strata. A very permeable rock loaded with water to the surface will of course act the same part as an impermeable rock, and cannot in any way help to prevent a flood.

33. Boundary lines of drainage areas.—The lines that part the waters feeding great river basins, though they need not, as has already been explained, be situated on a continuous ridge, will generally be drawn on comparatively high ground ; but this ground, though relatively high, compared, that is, with that adjoining it on either side, may be absolutely low—not much above the sea level, in some cases—while much higher ground may exist in the interior of the area thus bounded. Such hills in the interior of a drainage area must, necessarily, be detached. With a good contour map it is possible to obtain a sufficiently correct notion of the outlines of all the river basins of a country, and thus to divide it into districts, each of which shall be a drainage area, and the sum of them comprise the whole country.

The determination of the actual lines of water-shed in a country is a matter of detail, but the general outlines of the river basins and drainage areas of a country are fixed by the prevalent lines of hilly ground or mountain range, so that in all countries the physical structure must be studied to understand the general laws that govern these phenomena. It is necessary that this should be familiar to all engineers who require to know by what laws the natural divisions of the land are governed, and how small catchments can be most conveniently separated from the river basins to which they belong.

34. Ranges of elevated slopes in the west of England.—The British islands are strongly marked in structure, for they contain systematic and generally parallel lines of high ground, crossed by others more or less nearly at right angles, thus breaking up the interior into a number of blocks. It will be convenient to describe these governing lines before indicating the position and magnitude of the principal drainage areas which, as we shall find on investigation, have very distinct and close reference to them. The elongated form of the island of Great Britain, which includes England, Wales, and Scotland, indicates to the eye of a physical geographer the great facts of this nature, while the square form of Ireland marks some of the physical peculiarities of that island.

The outline maps, showing the general direction of the elevation axes of Great Britain and Ireland and the geological distribution of the strata, though on a scale which only permits the representation of large groups of facts, will, it is hoped, present useful illustrations of the remarks that follow, pointing out the general relations of the drainage systems of our islands. Although mere outlines, they are sufficiently correct to guide the eye of the reader in following the descriptive remarks. In the absence of carefully constructed contour maps, more elaborate maps than these would be liable to mislead, owing to the present imperfect state of knowledge of details in physical geography.

35. High lands of Cornwall and Devon.—Commencing with the south-western extremity of England, we find a series of nearly continuous east and west ranges of high lands in Cornwall, which are very closely connected with geological structure, and which reach, in Brown Willy, to an elevation of 1,364 feet. These high lands are continued into Dartmoor, where they attain a height of 2,050 feet. Five successive masses of granitic rock, terminated by the largest of all in Dartmoor, form, as it were, the ridge or back bone of the promontory of Devonshire and Cornwall, and show the existence, at some long distant time, of a great east and west elevation axis that distinctly affects, if it did not absolutely cause, the direction of the channels by which that part of the rainfall which runs off the surface finds its way to the sea. How large this proportion is in the district, and by how many streams and rivers it reaches the ocean, we shall see in another chapter.

Most of the rivers of this district originate in the granite, which, from its hardness and resistance to weathering, stands out above the general surface, and allows a large proportion of the rainfall to run off by numerous small streams. To the north of Dartmoor, and at some distance, is the table-land of Exmoor. Between Exmoor and the granitic range is a basin or trough, partly filled up with rocks of the same geological age as the coal-measures. The hard rock is of an age anterior to the coal-measures, and is contemporaneous with the Old Red Sandstone of Wales and Scotland.

The ridge of Exmoor is succeeded northwards by a deep depression forming the estuary of the Bristol channel, and beyond it rises a great ridge—the mountains of South Wales—which is nearly parallel to it. These mountains are composed of hard old sandstone rocks, contemporaneous with those that form the ridge of Exmoor, but not of the same material. The main line of elevation now turns to the north, and, for some distance, remains north-east and south-west. Towards the west the Brecknock mountains appear and influence the drainage. This chain continues almost as far west as the granite promontory of Cornwall, from which it is cut off by the entrance to the Bristol channel.

Proceeding further northwards, we find the great mountain system of Wales, consisting of a multitude of disconnected ridges, or mountains intersected by short deep valleys. The general range of the ridges is north of east and south of west.

The system of east and west ridges and troughs which we have thus traced from Cornwall to the northern extremity of Wales, is cut off to the east, first by valleys and comparatively low plains in Somersetshire and Dorsetshire, composed of rocks of a date much more modern than the granite and old red sandstones of Devonshire and Wales. The Dorsetshire hills nowhere rise above 900 feet, and are generally much lower. Beyond them, to the north, we enter, as has been already noticed, the wide valley of the Severn.

36. The Welsh mountains.—The western division of England and Wales contains all the loftiest elevations. These rise in Snowdon to 3,690 feet, and in the Cumberland mountains from 3,000 to 3,200 feet, while in the western highlands of Scotland they reach 4,406 feet. All belong to a mountain chain of very ancient date, connected probably with the elevation that brought up the granite of Brittany, and, it may be, with the first movements which decided the form and position of land in the eastern hemisphere.

37. The Cumberland mountains.—The high lands in the north-western extremity of England, though, undoubtedly, parts of a main line of elevation of very ancient date, have but little influence on the river systems of the part of the country in which they occur. Although, however, no great stream is connected with them, they feed a vast number of smaller rivers, many of which expand into lakes celebrated for their picturesque beauty. The supply of rain to this district is exceptionally large, and, these natural reservoirs receiving the rainfall and accumulating it during storms and floods, prevent the serious injury that would follow were the whole fall to be precipitated rapidly and without interruption to the coast.

38. The Penine chain.—Far to the east and north of the granitic range of Cornwall and Devon—to the east, also, of all the slates, Cambrian and Silurian rocks, and early igneous eruptions of Wales, and of the mountain country composed of contemporaneous rocks in Cumberland —there is, in England, another great line of elevation separated from the former, and affecting rocks of newer date, as well as those old deposits characteristic of the western division. The valley between these two systems of elevation is generally filled with nearly horizontal beds of New Red Sandstone, seen to some extent in the valleys of the Severn, in the Mersey, and in some other of the rivers of the north of England, and filling up the depressions connected with the upheaval of the mountain masses.

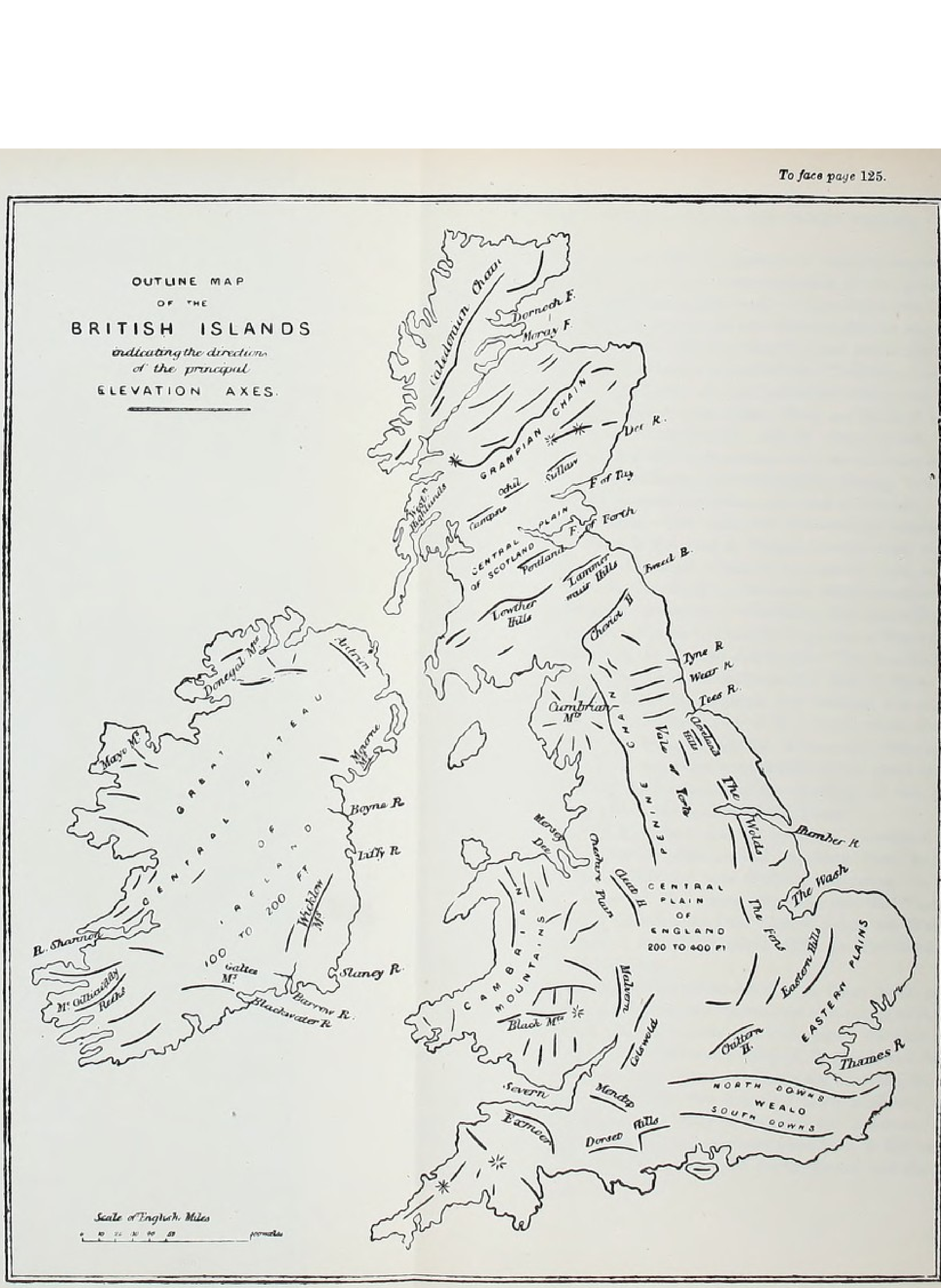
Indicated in the middle west of England by the presence of coal, and by rocks of more ancient date than the New Red Sandstone, through which they have been thrust, we find a remarkable and considerable range of high ground, ranging sometimes north and south, but trending generally to the west of north, though sometimes to the east. First recognised in Warwickshire and Staffordshire, the hills of this range form a continuous chain towards the north, where the mountain limestone rises in the Peak of Derbyshire. This range is lofty compared with the general elevation of the land, and very continuous. It is called the Penine range, and can be traced almost into Scotland, being exceedingly persistent in its character throughout. Its highest elevations are, Pen-y-gent (2,273 feet), Ingleborough (2,373 feet), and Cross Fell (2,892 feet). Beyond these principal elevations the main chain advances into Scotland, where are the yet more lofty Cheviot hills (2,676 feet), continuing the direction of the mountain system to the north.

The Penine chain is everywhere a line of water-parting, and is, perhaps, one of the most persistent, in this respect, of any chain in Europe north of the Alps. Vast numbers of streams take their rise, either directly or by their tributaries, from either the eastern or western slopes of this remarkable line of hills, among them being included all the great rivers of England north of the Thames, and west of the catchments draining into the Wash. The escarpment is on the western side, the slope being longer and more gentle on the eastern, where in some places the rainfall is heavier. All but one of the main feeders of the Yorkshire Ouse, most of the great feeders of the Trent, all the Lancashire rivers, and all the north-eastern rivers, rise among these hills. They are thus of primary importance in relation to water-supply, and as they consist, almost without exception, of carboniferous limestone and the varieties of shale and grit that make up the millstone grit series, their geology is uniform, and their waters, almost without exception, pure and wholesome.

39. The Cotswold hills.—The range of hill-country forming the escarpment of the oolites in the west of England overlooking the Lias, is known by this name. It ranges a little to the east of north and west of south, cut off towards the south by the much older elevation of the Mendip hills, consisting of carboniferous limestone, but traceable northwards for a long distance. It is part of the dividing line or line of watershed between the valleys of the Thames and Severn. The New Red Sandstone coming up below the Lias, which forms the base of these oolitic hills, occupies the central plain of England, and between the extremity of the Cotswolds and the commencement of the Penine chain there are outbursts of volcanic rock, bringing up the older rocks (Silurian and Carboniferous), showing the extension southwards of the great elevation axis of the Penine chain, and separating the drainage of the eastern tributaries of the Severn from the feeders of the Trent.

40. The Chiltern hills.—These are the principal elevations (rising above 900 feet) of a range of high ground reaching from Salisbury Plain in a north-easterly direction into Suffolk, separating the waters of the Thames from those of the rivers emptying into the Wash. Its breadth in places is 15 or 16 miles, and the highest points are Wendover Hill in Buckinghamshire, and Kingsworth Hill, on the borders of Bedfordshire and Hertfordshire.

41. The Wealden elevation.—Connected with these lines of high ground ranging north and south, and north-east and south-west, there are ridges in the south running nearly east and west. Of this nature are the chalk hills parallel to the south coast of England, and forming spurs proceeding from the large mass of chalk not far from the great valley of Dorsetshire. They form two detached lines, produced by the upthrow of the Weald, and the hills of Tilgate and Ashdown forest. These hills and ranges, however, are nowhere more than a few hundred feet above the sea. They are known as the North Downs and the South Downs.


OUTLINE MAP
OF THE
BRITISH ISLANDS
indicating the direction
of the principal
ELEVATION AXES.
Caledonian Chain
Dornoch F.
Moray F.
GRAMPIAN CHAIN
Dee R.
Ochil
Sidlaw
F. of Tay
CENTRAL PLAIN
F. of Forth
CENTRAL OF SCOTLAND
Pentland
Lammermuir Hills
Tweed R.
Lowther Hills
Cheviot H.
Tyne R.
Wear R.
Tees R.
Cumbrian Mts
PENINE CHAIN
Vale of York
The Wolds
Humber R.
Mersey
Dee
Cheshire Plain
CENTRAL PLAIN OF ENGLAND 200 TO 400 FT
The Wash
The Fens
Eastern Hills
EASTERN PLAINS
CAMBRIAN MOUNTAINS
Malvern
Black Mts
Cotswold
Chiltern H.
Thames R.
Severn
Mendip
NORTH DOWNS
WEALD
SOUTH DOWNS
Exmoor
Dorset Hills
Antrim
Donegal Mts
Mayo Mts
Mourne
GREAT CENTRAL PLATEAU OF IRELAND 100 TO 200 FT
Boyne R.
Liffy R.
Wicklow Mts
R. Shannon
Galtee Mts
Slaney R.
Barrow R.
Blackwater R.
Scale of English Miles

Throughout England the slopes of high ground running north and south are steeper towards the west than towards the east.

42. The Yorkshire and Lincolnshire wolds.—The oolitic rocks in the north of England form a series of hill ranges that serve as the water-parting, and rise in Yorkshire to the height of 1,485 feet. These extend from Lincolnshire through Yorkshire, and, occurring as they do between the beds underlying the chalk and the New Red Sandstone valleys, they form a succession of hills of no considerable elevation. These hills are called, in the north of England, *wolds*, having been formerly clothed with forest trees. They separate the waters, sending down part at once eastwards to the sea, and a larger part in a circuitous route running far to the south or north before turning eastwards.

43. Dividing ranges of Scotland.—In the north of England the hills of the Penine range, which consist of hard limestone of the carboniferous period, are continued by a cross line of elevation nearly to the eastern shore. South of this, the eastern coast of England is comparatively tame and flat.

Still further to the north, the range of mountains behind the shores of the Solway firth corresponds in some measure to those of Cumberland and Wales, and is succeeded, a little further north, by the Grampians. Beyond the Grampians there is a large extent of mountain and moorland, forming a continuation of the same structure. The general range of mountain and valley is still north-east and south-west, the part towards the west coast showing a marked tendency to a more northerly trend.

44. Relations of British river basins to elevation axes.—By these main lines of elevation the whole of Great Britain is separated into a small number of large areas, which may be regarded as main drainage areas, and a considerable number of smaller basins collecting the waters from the seaward slopes of the hill ranges. Of these basins and drainage areas the largest and most important drain towards the east. The Severn, an apparent exception, but most of whose larger tributaries run from west to east, flows southwards, and finally discharges its waters to the west. The smaller basins of England drain towards the nearest coast line. The Clyde, which has a westerly drainage, is fed chiefly from the northern slope of the Campsie and Ochil hills.

A study of the outline map of Elevation axes, which indicates in a simple manner the principal lines of ridge, hill, or mountain, without reference to river basins, will show, better than any description, when compared with the outline maps of river basins, geology, and rain, how completely the physical geography and geology of Great Britain correspond with the hydrography.

45. Irish drainage areas.—The surface of Ireland is very different from that of Great Britain, and is of the nature of a plateau on the western side of the elevation axis of England, formed by the same rock, but separated from the main mountain chain by a deep trough filled with the waters of the Irish sea, and broken into mountain and valley by a few wide gaps. A few hill chains, rising to elevations varying from 2,700 feet to 3,400 feet, form isolated groups towards the coast. The central plain is 250 to 300 feet above the sea, and is covered to a great extent with bog. The natural boundaries of the various basins are less strongly marked than in the larger island, and the drainage altogether partakes more of that seen in plateaux than that observed where the hills are separated by broad valleys.

46. Correspondence of geological with physical features.—If, now, we refer to the geological map of the British Islands, which is a map of the surface of the country, in which the rocks at the surface lying under the vegetable soil, and the alluvial and diluvial gravels, are depicted by lines and shading, we shall find that the lines indicating the principal rocks, such as granite, slates, hard sandstones (Old Red Sandstone), hard limestones (carboniferous or mountain limestone), softer limestones (oolites and chalk), soft sandstones (New Red Sandstone), and tertiary clays, range in such directions as to point out distinct relations when compared with the orographical map on which the directions of the mountains and valleys are shown. In these outline maps the relation is made very prominent, but it merely indicates observed facts, so represented as to communicate a distinct notion with regard to the parts of the country where certain rocks come near the surface, and invite comparison. It thus becomes evident that the high ground of the western districts of England and of Wales, extending as it does through western Scotland, is due to a great upthrow of the older rocks, which, having been lifted on a north-east and south-west line at a comparatively late period in the earth's history, have thrown off on their slopes the newer rocks originally deposited many thousand feet below their present level. The rocks forming the mountains of Wales and Cumberland are very ancient, but those of Cornwall and Scotland are perhaps older. The hills of the Penine chain partly screen these old rocks, and form a distinct series overlying the others, but not brought to a higher level above the sea. At intervals south of the Penine chain, the Silurian rocks form lower hills jutting out with igneous rocks from beneath them, and partly covered by the great plain of New Red Sandstone, which has been deposited long after them, and in many places has not been greatly disturbed by their elevation. The nature of these older rocks, their position, and their relative hardness, afford a clue by the help of which the geologist can work his way through the intricacies of the British river systems.

47. Structural peculiarities.—Reverting to the geological map, we shall see that there is an independent east and west elevation in the south-east of England, known to geologists as the anticlinal axis of the Weald. The whole of the southern part of England, from the mouth of the Thames to the Bristol channel, has been affected by a movement of this nature at an early period, to which the Wealden elevation is subordinate. This latter has not greatly influenced the drainage, although the form of the surface is changed, and the chalk now takes the form of two parallel ridges uniting and forming a line of water-shed a little to the north of Salisbury Plain. Between the chalk hills and the mountains of the Penine chain is a large trough, divided into two parts by a ridge of hard oolitic limestone, overlooking the clays and sands to the west, and sloping gradually towards the eastern sea. Thus England is divided on the eastern side into three principal drainage areas, indicated geologically as we have before traced them orographically.

The north of England is, to a certain extent, cut off from this system by ridges of hard limestone, gritstone, and other rocks of the older series, extending eastwards from the Penine chain, and by the liassic and oolitic hills of Cleveland. Another ridge of hard rock in Scotland is produced by the upheaval of the Carrick, Moorfoot, and Lammermuir hills, and still another by the granite of the Grampians. These range north-east and south-west.

48. Complete river basins.—Having now considered in outline the nature of the surface governing the distribution of rain into its larger channels in the different parts of the British islands, it will be desirable to know the principal groups under which to include the hydrography or water phenomena of the country.

The British islands discharge into the sea a certain part of the rain falling on the surface at all seasons of the year, but in very variable proportions. There are few instances of dry river beds, and the river channels, though fed with much smaller supplies in times of drought, always carry water. The upper part of some rivers, and many of the smaller feeders, remain, however, for a time, without any visible stream, the water in some cases making its way underground, either through fissures in rock or undergravel.

Regulated by the general direction of the high ground, and especially by the continuous ridges, both parallel and transverse, the whole country is subdivided into a limited number of large areas, each collecting water from smaller districts, and discharging the whole available rainfall in one principal channel. A larger, but still limited, number of areas are drained by smaller feeders; and, lastly, there is a very large namber indeed of yet more minute basins occurring between the larger systems, each draining only a small tract of land, but running the waters of that small basin direct to the sea, and, therefore, independent.

In the British islands there are only four drainage areas of the first class,* each gathering the waters of upwards of four thousand square miles of country, and carrying them to the sea in a single great channel. The Humber, the Severn, and the Thames, in England, and the Shannon, in Ireland, are all that lay claim to consideration as of this character; and it will be found, by comparing their drainage areas with those of the great rivers of the world, that, in point of magnitude, they are all insignificant as compared with the principal river basins of the continents.

The second class of British rivers, those whose drainage is of moderate extent and complication, may be considered to number about fifty. This number is, in some respects, arbitrary, but it includes most of the permanent independent streams that have a recognised name. Of the third class, the number is incalculable, because there are no means of determining them.

49. Compound river systems.—It will be understood that in this estimate we speak only of complete river systems. The Humber system, the largest in England, consists of two branches, each of which is nearly of the same magnitude as the other river basins of the first class. Each branch comprises a number of principal streams, every one of which is in turn made up of a number of smaller rivulets. The boundaries of a river basin or drainage area are distinct natural phenomena, and quite independent of relative or positive magnitude. They are governed by those ridges and continuous higher levels to which attention has been already directed, and although in some few instances the waters of one system connect with those of another by a natural channel, the line of water-parting is, in almost all cases, continuous and unbroken.

50. Fall of rivers.—Rivers differ very much in the amount of fall in the parts of the stream where the fall takes place, and in the proportion of fall to length of stream. The annexed diagram will illustrate these differences in the case of some of the principal rivers of the British Islands, and will be referred to in subsequent pages, when the rivers come under consideration. It will be understood that a rapid and considerable fall is characteristic of torrential rivers.

51. Coast drainage.—In treating of the drainage of land by rivers, there are two ways of considering the subject. We have hitherto chiefly regarded it with reference to river basins, or distinct areas, each provided with one regular channel for carrying off water, such channel

* The term "first class" can only be applied locally in reference to our own country. None of the English rivers approach in drainage area, or in volume of water discharged, the great rivers or even the larger tributaries of rivers on large continents in all parts of the world.

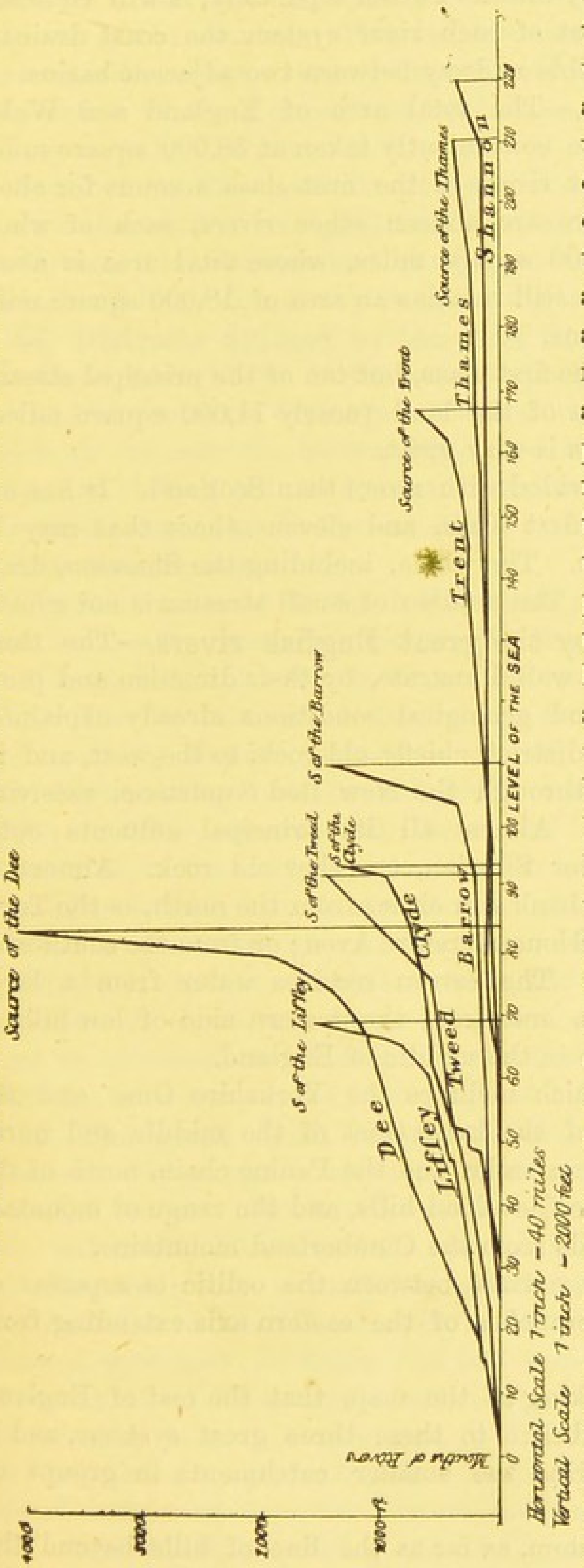


DIAGRAM SHOWING THE COMPARATIVE FALL OF THE PRINCIPAL BRITISH RIVERS.

being formed by a multitude of water-ways, all converging to this one. Looked at from another point of view, a country may be divided into groups of drainage areas which shall together include the whole area. By the first system all drainage areas must narrow down by degrees, and terminate almost at a point, including only so much of the coast as is taken up by the width of the river. Between each two principal rivers there must then be an interval, and a large part of the coast and a certain extent of country within the coast line must be excluded from the river basins, regarded in this light. By the other method the drainage areas include the whole area of the country, the coast drainage within a certain distance of a stream being included within the drainage area of the stream.

As, for purposes of calculation of rainfall and the proportion of rainfall that runs off to the sea, we can only estimate the measured quantity flowing at the mouth of the river, the former method is followed in reference to such matters. In the present treatise it is proposed to adopt it in principle, but, as it would be impossible to refer to every minute stream separately, it will be necessary to include in the account of each river system the coast drainage to a point as nearly as possible midway between two adjacent basins.

52. Number of basins.—The total area of England and Wales, exclusive of islands, may be conveniently taken at 58,000 square miles, and of this space three great rivers of the first class account for about 25,000 square miles. There are sixteen other rivers, each of whose basins drains more than 500 square miles, whose total area is about 15,000 square miles. There still remains an area of 18,000 square miles drained by very small streams.

Scotland has no river of the first class, but ten of the principal streams drain a very large proportion of the land (nearly 11,000 square miles). The number of small streams is very great.

Ireland is even better provided with rivers than Scotland. It has one river, the Shannon, of the first class, and eleven others that may be considered as large streams. The whole, including the Shannon, drain nearly 22,000 square miles. The number of small streams is not great.

53. Districts drained by the great English rivers.—The three principal rivers of England well illustrate, by their direction and peculiarities, the geographical and geological conditions already explained. The Severn drains a large district, chiefly old rock, to the west, and its main stream is conducted through the New Red Sandstone, receiving tributaries from the east. Almost all its principal affluents enter from the west, and flow over Silurian, or other old rock. Almost all those entering from the left bank run either from the north, as the Tern; from the north-east, as the Gloucestershire Avon; or from the south-east, as the Somersetshire Avon. The Severn receives water from a large mountain district of Wales, and from the western side of low hills of lias and New Red Sandstone in the middle of England.

The Humber system, which includes the Yorkshire Ouse and the Trent, takes the drainage of the large tract of the middle and north of England east of the Severn valley and the Penine chain, north of the Ouse valley and south of the Cleveland hills, and the range of mountain limestone continued eastwards from the Cumberland mountains.

The Thames drains a large tract between the oolitic escarpment of the Cotswold hills and two branches of the eastern axis extending from Cornwall and Devonshire.

It will be evident, by looking at the map, that the rest of England must be regarded as subordinate to these three great systems, and it will be convenient to describe the smaller catchments in groups of basins.

North of the Humber system, as far as the line of hills beyond the Scottish border, there are several river basins. These all drain into the

German Ocean, and group themselves with reference to the physical features of the country. They include, also, several smaller catchments having independent courses. On the west of the Penine chain a number of streams of some importance, and some draining the English lakes, empty into the Irish sea.

South of the Thames there are two well-marked groups of small river basins, the eastern emptying into the English channel, and the western partly into the English and partly into the Bristol channel. None are streams of large magnitude, or conveying much water to the sea.

54. Districts drained by the chief Scottish rivers.—In Scotland, the Clyde basin is one of the most important, and receives the greater part of the western drainage. The country to the south of the Clyde basin drains into the Solway Firth, and belongs, more properly, to the drainage of England; and most of the west coast beyond the line of the Clyde connects with the sea direct by a very large number of small independent channels.

The chief rivers of Scotland, like those of England, run from west to east, and empty themselves into the North sea. The Dee, and the North and South Esk, enter the North sea between Aberdeen and the Firth of Tay. The Tay receives a large drainage from the north and north-west, and, passing Dundee, enters an arm of the sea of the same name. The Forth, rising near Loch Lomond, runs also to the east, and the Firth of Forth connects with the Clyde by a canal crossing Scotland. The Clyde is the only important stream having a western drainage. It takes the waters from a considerable district south-east of Glasgow, while the south-western and southern extremity of Scotland drains chiefly by a number of small streams, and by the Nith, the Annan, and the Esk, into the Solway Firth. The eastern part of the south of Scotland is traversed and drained by the Tweed and its tributaries, whose drainage area is separated from England by the Cheviot hills.

55. The great Irish rivers.—In Ireland, the great basin of the Shannon, occupying the whole of the central part of the island, is the principal feature. In the rest of the country we find the eastern district subdivided into a northern and southern drainage area. A number of streams also here expand into systems of lakes, which greatly affect the drainage areas. The largest is Lough Neagh. The total surface covered with water in Ireland is 336 square miles. The lakes act, to some extent, as flood regulators, and prevent much of the injury that would arise in a country so wet as Ireland by occasional floods from sudden storms or unusually wet seasons. They are distributed over the island, but in an irregular manner, and are not all of the same kind, the lakes of Killarney being essentially mountain lakes, while those of the north and central parts of Ireland are hollows in low plateaux. The northern part of the eastern division of Ireland drains into the Irish sea by the river Boyne, and the southern part into the Atlantic by the Barrow. The other principal rivers are the Blackwater and the Lee in the south, the Foyle in the north, the Bann and Lagan in the north-east, and the Slaney and Liffey in the south-east.

56. Drainage of the smaller islands.—The drainage systems of the numerous islands adjoining the main land of the British islands has not been considered. There are rivers in the Isle of Wight, the Isle of Anglesea, the Isle of Man, and the western islands of Scotland; but they offer no special features, and the extent of land drained is too small to allow the streams to attain importance. They offer, in all cases, repetitions on a small scale of the phenomena presented in the larger islands, of which they are, in some sense, portions.

56. Grouping of the drainage areas.—Referring to the Index map which forms the frontispiece of this volume, and to the various maps that will be given of each river system in its place, it will be convenient to summarize here the groups of rivers and river systems that will be described in future chapters. In doing so we may also with advantage point out the general geological conditions of the various groups.

I. *The drainage system of the Thames.*—The Thames basin includes that part of England within the lines of escarpment of the oolites, near Cheltenham, of the chalk in the North Downs, and of the lower cretaceous rocks beyond the South Downs. Many of the feeders, and portions of the main stream, cross the lower tertiary beds on which London is built —thence called London clay. The drainage area, besides the Thames basin, includes a small tract of country beyond the mouth of the Thames draining towards the north. The basin of the Severn bounds it to the north-west, and the basin of the Great Ouse to the north. To the north-east, south-west, and south it is bounded by the basins of a number of small and comparatively unimportant streams.

II. *The river basins draining southwards into the British channel.*—These are separated from the Thames basin by a well-marked line of watershed. Most of the streams originate in the chalk, but some in the rocks below the chalk, as far down as the Wealden deposits. Some of the largest in the western part of the group cross the older tertiaries.

III. *The river basins of the south-west of England.*—These include a large number of streams, mostly of inconsiderable volume and short course, some draining the oolites, lias, and New Red Sandstone, as developed in the south of England, and others (west of the Exe) rising in the granite hills of the promontory of Cornwall and Devonshire, and almost confined to the older rocks, either palæozoic or metamorphic. They form two groups, one draining southwards into the British channel, and the other northwards into the Bristol channel.

IV. *The drainage systems of the Severn and of Wales.*—Under this head is included the great basin of the Severn, and the general group of river basins connected with the Welsh mountains. Although the numerous streams that carry the rainfall on the southern, western, and northern slopes of the Welsh mountains are very distinct from the Severn, the whole form one group, of which the Severn, one of the largest rivers of the British Islands, is, of course, the principal.

The greater part of Wales consists of rocks of the oldest part of the Palæozoic period, including Cambrian, Silurian, and Devonian; the Lower Silurian and Cambrian greatly preponderating. Other parts of this drainage system include a certain quantity of igneous rock, and the conditions under which the western feeders of the Severn and the smaller Welsh rivers receive their chief supply of water are nearly the same. The eastern tributaries of the Severn convey water from triassic districts and lias, and a large part of the main stream runs over the New Red Sandstone.

V. *The drainage systeme of the east coast of England.*—North of the Thames basin there is a large tract of country of little elevation, extending to the north as far as the basin of the Humber, but nowhere rising to any considerable elevation. The chief part, near the centre of England, is occupied by the clays of the oolitic series, and several large but sluggish rivers traverse it, all terminating in an inlet of the sea called the Wash. Besides this group, which only takes the water falling between the escarpment of the chalk and that of the oolites, there is another, occupying a tract sloping towards the sea from the chalk water-shed, comprising a number of small streams, taking their rise in the chalk, but crossing the newer tertiaries, and sometimes, in the southern part, the London clay.

VI. *The system of drainage of the Humber.*—This system, in some respects the most important in England, drains a large extent of country, partly the north central, and partly the north-eastern part of England. It is separated from the basin of the Severn, and from the rivers of Lancashire, by the high range of hills known as the Penine chain, which consist of the mountain or carboniferous limestone overlaid by the millstone grit, and in many parts by lower coal measures. The system includes the drainage areas of the Yorkshire Ouse and the Trent. Each has numerous large tributaries, those of the Ouse, with one exception, rising in the limestone and millstone grit, and many of those of the Trent also rising in these rocks, either where they form a part of the main chain, or are detached masses rising out of the New Red Sandstone. All traverse the New Red Sandstone for a considerable distance. The Ouse and Trent unite about 35 miles from the sea, and after their confluence receive the name of Humber. The Humber is rather an estuary than a river for the greater part of its course, but it receives affluents both from the north and south, and has an independent drainage area.

VII. *The rivers north of the Humber system.*—Beyond the northernmost water-shed of the Humber, the east coast of England is drained by a small number of not unimportant streams rising in the carboniferous limestone, crossing the millstone grit and the coal-measures, and running a straight course into the German Ocean. The northernmost of these rises on the southern slopes of the Lower Silurian hills of the south of Scotland, and only in the lower part of its course reaches and crosses the mountain limestone.

VIII. *North-western rivers of England.*—On the opposite or western side of the Penine chain, a number of rivers take their rise and flow westwards into the Irish sea. Those to the south cross the New Red Sandstone, which extends on the west coast as a fringe covering the carboniferous rocks. Further north, where the Cumberland and Westmoreland mountains rise through these Palæozoic rocks of the carboniferous period, there are streams draining the country northwards, between the Lower Silurian rocks of the mountains and the carboniferous limestone.

IX. *South-western rivers of Scotland.*—The southern drainage of the range of Silurian hills forming the south-west of Scotland, and emptying into the Solway Firth, is effected by a number of streams of small length, but subject to heavy floods and carrying much water to the sea.

X. *River basins of the east of Scotland.—Southern group.*—From the northern slopes of the Lammermuir hills in Scotland, which form the boundary of the Tweed basin, to the river Dee, there is a considerable tract of land draining to the east. It consists chiefly of rocks of the carboniferous and Devonian periods, resting on the granite which comes out and forms a wild rugged mountain district to the north. This district is drained by a number of rivers, none large, but all of some interest. They are for the most part very torrential, some of them rushing down as impetuous torrents after heavy rain.

XI. *East of Scotland basins.—Northern group.*—The drainage of eastern Scotland north of the Dee, as far as the Moray Firth, is effected by a number of somewhat important torrential streams of considerable interest. They carry off the water from the northern slopes of the Grampians, chiefly consisting of Lower Silurian rock interrupted by granite.

XII. *West of Scotland drainage areas.*—From the Carrick hills, whose southern drainage enters Solway Firth, to the Caledonian canal, there is a large district of mountain and lake which drains westwards by a number of rivers, the chief of which is the Clyde. The rocks are those of the carboniferous series in the south, and Silurian rocks, much metamorphosed, in the north.

XIII. *North-west of Scotland drainage areas.*—The north-western extremity of Scotland, beyond the Caledonian canal, drains almost without exception to the east by a number of streams, none of them of great magnitude or importance. The country consists of rocks of the Silurian age, fringed by Old Red Sandstone or Devonian rocks, interrupted at intervals by granite. There are small patches of oolitic rock.

XIV. *The basin of the Shannon.*—Of the rivers of Ireland, which all rise in the great expanse of table land which characterises that island, and distinguishes it from Great Britain, the Shannon is not only far the largest, but is the most typical. It runs through important lakes, and carries off the surplus water from a district, which, but for those lakes, would be subject to very serious and heavy floods in a country where so much rain falls as in Ireland. Almost all the rock in the basin of the Shannon is carboniferous limestone, which being covered with bog retains much water in pools on the surface, but is little absorbent and not greatly fissured. The drainage system of the Shannon includes a small district that has no drainage to the sea, and a small area of the Irish coast which has independent drainage.

XV. *The drainage areas of the south-east of Ireland.*—In the south-east of Ireland the rocks near the coast consist chiefly of Silurian strata, overlaid towards the interior by the carboniferous limestone series which here contains coal. There is a large quantity of igneous rock intervening between the two, which forms the water-shed between two of the principal rivers.

XVI. *South-west of Ireland drainage areas.*—The south-west of Ireland is, for the most part, of the carboniferous period, but has some Silurian rocks at the extremity. It is a mountain and lake district, including the exquisite Killarney lakes, and it comprises several river basins, not very large, but owing to the wetness of the climate, and the nature of the rocks, conveying much water.

XVII. *West of Ireland drainage areas.*—The west of Ireland is so covered with lakes that the drainage to the sea is comparatively unimportant. The ground is chiefly level, consisting of carboniferous limestone interrupted by a band of metamorphic rock. The rivers are not numerous, nor are they important.

XVIII. *Drainage areas of the north of Ireland.*—The north of Ireland comprises rocks of various geological age and igneous rocks in large quantity. As in other parts of Ireland, the lakes are numerous, and the number both of principal streams and feeders considerable. In the western part there is an extensive tract of granitic and metamorphic rock, and on the eastern side cretaceous rock interrupted by basalt. In the interior, the carboniferous rock appears, and Silurian rock comes to the surface in the south-eastern extremity.

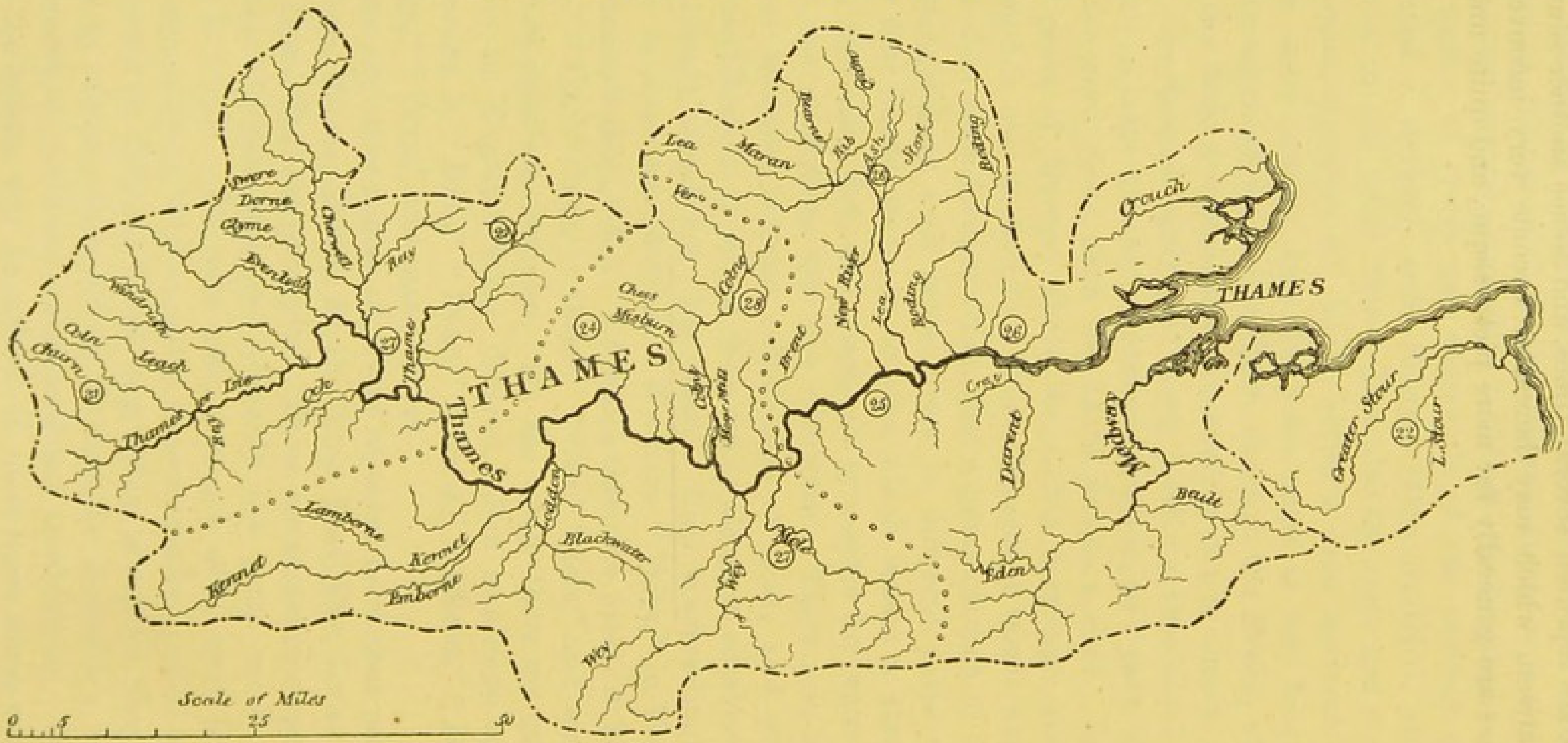
57. Names of rivers.—A few words may be said here with advantage concerning the names of British rivers. It has been well pointed out in the interesting and suggestive " Primer of Geography," by Mr. Grove, that names of rivers are memorials of the earliest races who have inhabited a country, and, though often modified, are in substance retained to the latest time. It is also the case, and it results from the little communication, till lately, between even moderately distant parts of the same country, that the same name is very frequently repeated. In oriental countries and in Spain, through the Moors, who came thither from the East, a river-course occasionally dry is almost always called a *wadi* (the Spanish equivalent being *guad, e.g. Guad*alquivir *Guad*arama). In Italy, a large number of streams contain, as a part of their composition, the word *fiume*, from the Latin *flumen*, a river. In England, and other parts of Europe where the Celtic language and dialects long remained in use, we find four short elementary words which are so often repeated in some form or other, that a great amount of confusion arises in distinguishing even large rivers in different parts of the country. These four words are *avon* or *afon*, which means a stream of running water, and *dur*, *don*, and *uisge*, all synonyms for water. Of all these words the repetitions are very numerous. There are, in Great Britain, at least fourteen streams called *avon* or *afon;* and several called by some modification of *dur* or *door*, either alone or combined with the affix *gwyn* (clear), signifying clear water. *Uisge* is exceedingly frequent, but chiefly in some modification. We have " Wisk," in Yorkshire, " Usk," in Monmouthshire, " Esk " (of which there are nine), in England, " Exe," " Axe," " Ux," " Ouse," " Ousel," " Ose," " Isis," and many others. All these are manifest examples. On the whole there are not less than fifty streams in England hence derived. *Don* is almost equally common. It appears in " Dun," " Dean," " Dane," " Davon," " Devon," " Tyne," " Teign," " Teyn," and many others.

There are other names of rivers repeated in various parts of England. Of these, Frome, Bourn, Blyth, Colne, Dart, Eye, Loone or Lune, Looe, Taw, Tame, Taf, are examples. These are sometimes spelt differently in different counties, but are evidently the same word. Others might easily be found. The affix *aber*, a mouth of a river, is frequently met with, especially in Wales ; and it is occasionally applied to the river.

It would be difficult, if not impossible, to replace these often-repeated names by others, nor would it, perhaps, be desirable ; but it introduces an element of confusion sometimes very troublesome. In the following pages the county will be affixed in most cases where confusion is likely to arise.

A practice has unfortunately arisen in our colonies of applying to native rivers the names familiar in the old country. In many colonies the same names are repeated several times, and hence another source of confusion has arisen, which may hereafter become very inconvenient. The native names are generally far more picturesque, and quite unobjectionable.

I.—Drainage System of the Thames.



In this diagram the principal subdivisions of the basin are separated by lines marked thus ° ° ° °. The eastern portion of the diagram comprises the catchment of the Stour, which is not included within the Thames water-shed. The figures within circles represent the mean rainfall in the surrounding district.

In the preparation of this map the scale has accidentally been omitted. It is the same as in all the other maps of rivers, where the scale is given.

CHAPTER IV.

THE DRAINAGE SYSTEM OF THE THAMES.

1. General description.—The River Thames, although not draining so large an area as the Severn or the Shannon, or including such important manufacturing interests as the combined streams of the Trent and Yorkshire Ouse; and extremely small, when compared even with the tributaries of rivers of large continents; is, beyond doubt, the most important and interesting river of the British Islands. This is the case, not only because of its relations with London and its gigantic population, but because, in many of its peculiarities and characteristics, it is a typical river, because it traverses England from west to east, nearly at right angles to the general stratification of the country, and because it has been, in some respects, the most carefully studied of our larger streams. It crosses a rich, cultivated, and pleasing, but, on the whole, a little peopled country, for more than the first half of its course; it has a remarkably even and moderately rapid flow; its waters are little affected by manufactures carried on upon its banks; it runs between banks rarely precipitous, receiving, at intervals, tributaries derived from pure and unpolluted sources, and, though subject to floods, and unprovided with lakes, or other natural flood-regulators, it is generally within control, and probably might, at moderate cost, be rendered comparatively safe from dangerous irruptions of water.

The catchment area of the Thames is separated from that of the Severn by a water-shed, whose elevation is a little more than 800 feet above Ordnance datum in its highest part, but which is in most places under 400 feet. This is the eastward slope of the Cotswold hills. From the Ouse basin the line of separation is much lower, not being more than 300 feet in some places. The upper Thames basin collects the rainfall chiefly from the long line of the oolitic slope facing the south-east, and is fed by some powerful and valuable springs from various members of the oolitic group. Passing through a natural gorge in the chalk, it enters a distinct basin, in which it is fed chiefly from chalk sources, though some of the feeders rise in lower secondary and some in tertiary formations. The highest springs—those of Thames Head—break out nearly 800 feet above the sea.

The direct length of the Thames basin, measured from its most distant source, near Tetbury, in Wiltshire, to the Nore, is 136 miles, the line of direction being nearly from west to east. The extreme breadth of the basin is from Daventry, in Northamptonshire, to Alton, in Hampshire, a distance of 78 miles from north to south. If we except the valley of the Cherwell, which runs up to a point towards the north, much beyond the northerly limit of any other tributary, the total breadth is not more than 66 miles. Omitting this small tongue, therefore, the length from west to east is double the width from north to south.

The total length of course of the main stream of the Thames is 225 miles. The measured navigable stream, from London to Lechlade is 148 miles; the distance from Lechlade to Cricklade, 11 miles; the length of the Churn, which joins the shorter stream coming from Thames Head at Cricklade, 21 miles; and the distance by river from London to the Nore, 40 miles. The navigable stream is shorter than the natural bed, owing to the artificial cuts made where the river formerly had a very tortuous course. In most cases, however, the old channel remains, and is useful in floods. The total length of the principal tributaries is about 700 miles, and the length of the secondary feeders is probably even greater. There are thus about 1,800 miles of water-way in the area watered by the Thames, which is at the rate of about a mile of water channel in every three and a half square miles of area.

The counties included within, or partly containing the Thames basin, are as follows:—Bedfordshire, Berkshire, Buckinghamshire, Essex, Gloucestershire, Hampshire, Hertfordshire, Kent, Middlesex, Northamptonshire, Oxfordshire, Surrey, Sussex, Warwickshire, Wiltshire, Worcestershire.

The estimate of the area of the water-shed is different, according to the point regarded as the outfall. Including the Medway, and the parts of Essex drained by the Crouch, as being within the Thames drainage, and the Nore as the limit of the stream, the total was estimated by the late Sir Henry James, R.E., at 6160 square miles, of which about one-sixth (997 square miles) forms the basin of the Medway. This corresponds with the area given in the Sixth Report of the Rivers Pollution Commissioners.

The fall of the Thames, though for the first few miles the stream is somewhat rapid, when compared with other British rivers, is very gradual, as will be seen by looking at the diagram, page 129. From where the collected stream first forms to Cricklade (about 20 miles), the fall is 132 ft. 6 in., being at the rate of nearly seven feet per mile; but below that, for about 130 miles, the mean fall is only 18¾ inches per mile. For the next 20 miles, the fall is about 12 inches per mile, and for the last 40 miles there is hardly any fall.

2. Physical features and geology.—Except that a few of the upper branches that supply the Thames originate at points more than 700 feet above the sea, and others between 400 and 700 feet, we may regard the highest effective supply as derived from 376 feet above the sea. The principal tributaries, the main stream of the Thames, and the valleys near the course of the stream, are all remarkably free from sudden changes of level. Part of the principal river indeed, and some of the southern tributaries, pass at right angles through the strata for short distances, and produce picturesque scenery; but this is exceptional. Geologically, most of the upper feeders of the Thames, as well as the main stream, rise close to the upper lias shale, and immediately below the lowest bed of the oolites. They run for some distance over the lias, scooped out by the action of the water after cutting through the oolitic rocks, and their course is between cliffs of oolitic strata, sometimes tolerably steep. The water supplied by the upper springs is strictly oolitic water, and exceedingly clear and bright. Two of the early feeders of the Thames, and one other, entering lower down but supplying the upper basin, proceed from the chalk, but flow over lower cretaceous or oolitic rock. Those feeding the middle and lower basin for the most part rise in the chalk, but many of them cross the tertiaries (chiefly the lower and clayey beds). A few of the tributaries from the south rise from the Wealden formations of Sussex.

No part of the drainage area of the Thames is in any sense mountainous, but the river flows generally through undulating country. Some tributaries of the river pass through gorges cut across the stratification of the rocks; parts of some of its streams, and the whole of one of them, disappear underground during their course; and the sources of some occasionally shift to different parts of the valleys which they drain. But the Thames has no lakes, no rapids, and no waterfalls. The country it runs through is moderately wooded, and generally cultivated. The population in the upper part of the basin near the river is small, and does not increase rapidly. In the middle part it is still small, but in the lower part very dense.

Geologically, the catchment area of the Thames is entirely occupied by secondary and tertiary rocks; the tertiary rocks, chiefly eocene, occupying a basin-shaped depression between two ranges of chalk hills, which stretch away to the east from the northern and southern extremity of the plateau around Salisbury. The oolites come out below the cretaceous rocks to the west, and the interval between the oolitic range of the Cotswolds and the chalk hills of the Chilterns, forms a distinct basin, which would exist as a lake and drain northwards into the Greater Ouse, but for the gorge through the chalk hills between Goring and Pangbourne. The ultimate sources of most of the feeders of the Upper Thames consist of springs just beyond the general line of rocks that seem to form a natural limit of the basin; but the surface drainage yields the principal supply.

3. Subdivisions of the basin.—The catchment area of the Thames consists of two basins very distinct, and only connected by a narrow channel about 4 miles in length, between Goring and Pangbourne. This has been already pointed out, but it must here be again insisted on as a very important feature in the natural history of the river, and one which has great influence on its waters. The alluvial bed of the river through this gorge averages about a quarter of a mile in width.

A barrier of a few hundred feet in any part of this gorge, which is less than a mile wide in its narrow part, would drive the waters of the upper Thames northwards into the catchment of the Ouse, while a bank not more than 120 feet high, which might be constructed without incurring great engineering difficulties, would cause the formation of a very large lake, extending many miles eastwards, westwards, and northwards, entirely modifying the condition of an extensive tract in the middle of England. The upper basin of the Thames is thus almost disconnected from the part below. It is greatly to be regretted that engineers and others, interested on public grounds, in the condition of the Thames, have not taken systematic measurements of the volume of water passing through the gorge, as there are many places where this could readily be done, and many important points concerning the flow of rivers might in this way have been decided.

Besides this natural division of the Thames basin, the lower part can again be subdivided into two: the one reaching to Teddington (Tide-end-town), and uninfluenced by the tide; the other including the lower course of the river from Teddington to the sea. The Thames between Pangbourne, ($6\frac{1}{2}$ miles above Reading), and Teddington, flows through an intermediate or middle basin, the river and its tributaries below Teddington, together with that part of the main stream affected by the tide, forming the lower basin.

The whole drainage of the Thames is thus separated into three parts, the upper, the middle, and the lower, each of which will admit of independent description.

4. Rainfall, evaporation, and percolation.—The rainfall in the Thames basin may be said to range between a mean of 32 inches among the high western hills, and a mean of 24 inches on the lower eastern declivities. October and June are stated by Prof. Phillips to be the wettest months; February and December, the driest. The average is assumed by Mr. Bravender, of Cirencester, to be 30 inches for the whole upper basin, but this is probably too high. There is a smaller fall in the middle and lower basins. The average usually assumed for the whole basin is 25·5 to 26 inches, which is somewhat higher than the mean fall at Greenwich.

The loss in the Thames basin by evaporation, even after making full allowance for the percolated water that reappears in bottom springs, and is measured with difficulty, is very large, and there can be little doubt that the evaporation from the surface of the chalk during dry weather must materially diminish the quantity of available water, and is sufficient to keep down the water-level in the rock.

There is a large percolation over most part of the drainage area of the Thames. The upper basin is almost entirely oolitic and open, and of the lower basin, though a large part is covered with impermeable tertiary clay, and part of the rest by diluvial clay and gravels, still, much of the rain-water that cannot penetrate these clays runs off from them to chalk, or into open gravel overlying chalk, and the water disappears into the earth. It is not possible, in all cases, to say where or how it reappears, but probably a good deal comes out in strong springs that issue in many parts of the Thames basin, on the sides of valleys, and in the river bed.

The evaporation in the Thames basin, as usually estimated by engineers, is equivalent to about 15 inches of rainfall. It differs greatly in different years; in dry seasons going up to 20, while in damp and cloudy seasons, when there is little wind, it may not amount to 12 inches. The percolation can hardly be said to have been estimated with accuracy. It may amount to about 7 inches of rainfall on a long average of years. It will be evident from these figures that the river carries off but a small part of the rainfall. It is probable that not more than 3¾ inches of rainfall on an average are conveyed by the river to the sea. This is equivalent to nearly 1,000 million gallons per day.

5. Quality of the Thames water.—So much has been said, and so much is thought of the quality of Thames water, and so much suspicion has been thrown upon it, that a fair statement of recorded facts on the subject cannot be considered out of place here. The upper waters of the river are universally admitted to be good; but much, of course, of the value of the water for town use must depend on its state at various points along its course, where it passes large towns or receives important tributaries.

The drainage area of the Thames being to a great extent occupied by calcareous rocks overlying clays, the springs always contain carbonate of lime. The surface water also dissolves a certain quantity of this salt, but, in addition, it is affected by the clays by which, in many cases, the water is held back. The waters of the sources are clear, pure, rather hard, and their excellence is undoubted. They have been analysed from time to time, and probably vary little. The following analyses of three of the most distant sources of the river are interesting. The figures represent grains in a gallon:—

	Total solids.	Hardness.	Nitrogen as Nitrates and Nitrites.	Ammonia.	Chlorine.
Thames Head	18·9	12·3	·203	·002	0·98
Seven Wells	15·6	10·5	·285	·000	0·50
Syreford	16·4	13·7	·225	·000	0·43

The Thames Head is the reputed source of the Thames, and the analysis is by Dr. Frankland, from a sample taken 3rd May 1873. The Seven Wells is the source of the Churn, and the Syreford spring the source of the Coln—two of the principal early feeders. These analyses are from samples taken in January 1878 by Dr. Tidy and myself, and are given on his authority. The source of the Windrush is, no doubt, nearly identical, and the general character of the water of the Upper Thames basin may be expected to show very similar results.

Between the sources of the Thames and the point at which the Upper Thames enters the gorge at Goring, the river is made up of the confluence of a large number of streams, all, with two exceptions, proceeding from oolitic sources, and all flowing over oolitic rocks. The exceptions are, the Ock and the Thame, the two last to enter. Both come from the chalk hills, one from the west and south, and the other from the east and north; but almost the whole course of both is over lower secondary or upper oolitic rock.*

The following analyses of the Thames waters are deduced from Dr. Frankland's Sixth Report of the Rivers Pollution Commission. They represent grains in a gallon (70,000 grains):—

Upper Thames.

Date of Sample.	Tributaries.	Total solids.	Organic Nitrogen.	Organic Carbon.	Ammonia.	Nitrogen as Nitrates & Nitrites.	Chlorine.	Hardness. Initial.	Hardness. Perma-nent.	Hardness. Total.
3 May 1873	Swill brook (source) - - -	21·9	·048	·154	·006	·050	1·02	13·8	4·0	17·8
,, ,,	Ray river (confluence) - - -	24·5	·086	·388	·016	·158	1·84	12·3	4·7	17·0
,, ,,	Churn river (confluence) - -	18·8	·035	·104	·008	·117	1·02	10·9	3·1	14·0
,, ,,	Ampney brook (confluence) -	18·2	·016	·057	·001	·251	1·01	10·9	3·5	14·4
,, ,,	Cole river (confluence) - -	20·6	·045	·193	·006	·104	1·26	12·0	3·1	15·1
,, ,,	Coln r. (1½ m. above confluence) -	18·7	·020	·068	·002	·126	0·98	10·8	3·4	14·2
,, ,,	Leach brook (confluence) - -	19·4	·026	·085	·003	·250	0·98	12·6	3·7	16·3
9 Dec. 1870	Windrush river (above Witney) -	19·8	·023	·074	·001	·205	0·79	12·6	3·5	16·1
29 May 1873	Evenlode river (confluence) -	19·3	·073	·254	·001	·164	1·33	11·0	4·9	15·9
29 Apl. 1868	Cherwell river (above Oxford) -	22·1	·030	·183	·004	·158	1·30	11·0	4·8	15·8
29 May 1873	Ock river (confluence) - - -	23·2	·060	·280	·017	·088	1·43	14·0	3·5	17·5
30 Apl. 1868	Thame river (confluence) - -	24·6	·061	·278	·003	·062	1·00	12·8	4·1	16·9
	Mean - -	20·9	·044	·177	·006	·145	1·16	12·1	3·8	15·9

To these I may add two analyses taken of the Thames below Oxford by Dr. Frankland, in April 1868, which showed the following result:—

20 Apr. 1868	Thames below Oxford - - -	22·1	·196	·151	0	·194	—	7·6	5·9	13·3
30 ,, ,,	Thames at Abingdon - - -	22·1	·182	·164	0	·171	—	9·1	6·3	15·4
	Mean - -	22·1	·189	·157	0	·184	—	8·3	6·1	14·4

Middle Thames.

The analysis of waters of the Thames and its tributaries, between the gorge which opens out at Pangbourne and Teddington, the place where the tidal waters reach, is thus given by Dr. Frankland:—

Tributaries.

24 Apr. 1868	Kennet r. (just above Reading) -	17·9	·027	·160	·001	·020	0·83	12·0	1·7	13·7
29 May 1873	Lodden river (Twyford Bridge) -	16·7	·050	·214	·004	·054	1·30	9·5	2·7	12·2
28 Oct. 1868	Colne river (confluence) - -	22·5	·050	·196	·012	·211	1·11	12·4	2·7	15·1
,, ,,	Wey river (confluence) - -	12·7	·047	·053	·004	·063	1·28	2·8	4·3	7·1
4 May 1868	Mole r. (1 mile above confluence)	16·5	·154	·116	0	·162	1·24	8·2	3·1	11·3
	Mean of tributaries - -	17·1	·046	·156	·004	·102	1·15	9·0	2·9	11·9

Main Stream.

24 Apr. 1868	Thames above Reading - -	22·9	·224	·204	·001	·020	—	9·0	5·7	14·7
31 May 1873	,, below Reading - -	20·2	·050	·152	·005	·171	1·19	11·1	4·8	15·9
2 May 1868	,, above Windsor - -	21·7	·020	·020	·001	·144	—	10·4	5·2	15·6
,, ,,	,, above Staines - - -	21·8	·020	·213	·001	·149	—	8·9	6·3	15·2
	,, above Hamp. Ct. (mean)	20·2	·028	·176	·002	·140	1·13	11·4	2·8	14·2
	,, ,, (mean of four)	22·0	·031	·176	·003	·246	1·25	12·3	4·1	16·4
	Mean of middle Thames	21·5	·062	·157	·002	·145	1·19	10·5	4·8	15·3

* The Ray and the Cole, like the Ock, rise in the chalk, but flow almost entirely over lower cretaceous and oolitic rocks.

The results of analysis of nearly 1,000 samples of Thames water, taken from near Hampton Court, over a long period, is given by Dr. Tidy in his account of the London Water Supply, and from it we obtain the following mean :—

Total solids - - - -	20·62
Total hardness - - - -	13·66°
Nitrogen as nitrates and nitrites - -	0·132
Chlorine - - - - -	0·924
Oxygen required to oxidize organic matter	0·064

From this it will appear that the quality of the Thames water, taken on a long average from Hampton, is distinctly better than the average of samples taken by Dr. Frankland from different parts of the stream, the total solids, the nitrogen, the chlorine, and the hardness, being all smaller. That part of the supply for London that is not taken from the river Lea, or from chalk springs, is from the Thames near Hampton, and is represented by the above mean.

Lower Thames.

The waters of the Lower Thames basin can only be considered in the tributaries, as, when they enter the Thames, they are affected by the tide which brings sea water. The quality of the principal tributaries is thus given by Dr. Frankland.

Date of Sample.	Tributaries.	Total solids.	Organic Nitrogen.	Organic Carbon.	Ammonia.	Nitrogen as Nitrates & Nitrites.	Chlorine.	Hardness.		
								Initial.	Perma-nent.	Total.
11 May 1868	Wandle river, below sewage farm	21·0	·022	·070	—	·290	—	9·2	6·0	15·2
17 Apr. 1873	Ravensbourne, affluent - -	9·2	·039	·307	·008	·014	1·84	0	4·0	4·0
24 Jan. 1873	Lea river, New River intake -	24·1	·047	·206	·004	·267	1·26	1·38	4·2	17·0
1 Feb. 1873	Lea river, East London intake -	25·8	·040	·168	·010	·270	1·37	13·2	5·6	18·8
6 July 1870	Cray river, above Joynson's mill	21·0	·070	·115	·010	·227	0·97	14·4	2·2	16·6
22 Feb. 1873	Medway r., supplied to Tunbridge	10·6	·036	·145	·006	·126	1·68	0·7	4·9	5·6

The importance of the Lea water is very great, as nearly half the supply of London is derived from that stream. The following is the average of monthly analyses of samples taken from the East London Company's works, continued for 10 years, from 1868 to 1877 both included. These analyses have been recently published by Dr. Tidy, and represent the water after subsidence and filtration :—

Total solids - - - - - -	19·86
Total hardness - - - - -	14·4
Nitrogen as nitrates and nitrites - -	0·128
Chlorine - - - - - - -	1·131
Oxygen required to oxidize organic matter	0·055

The water of the Thames is in all cases in its worst condition in the early part of February, and gradually improves till the month of August, after which it deteriorates. This remark applies to causes that usually affect the purity of water, but does not apply to seasons of flood.

6. Ordinary flow and floods.—The Thames flows in ordinary summer weather at an average rate of about two miles an hour between Oxford and Teddington. In its upper course the flow is more rapid, the fall being greater, and in its lower course it is governed by tidal action. In winter, while in partial flood, the stream attains a speed of double this rate, or four miles an hour, and during occasional heavy floods much more. The locks modify the rate in particular parts of the course.

Floods in the Thames are neither unfrequent nor unimportant. Those in the upper and middle basins are due to the physical conditions of the basin, and the complete separation of the two, except by one narrow passage. Those in the lower basin are greatly affected by tidal action. Ordinary floods in the middle basin occur to the extent of twenty to thirty in a year, and are rarely of serious injury, the surplus water expanding over the alluvial bed, which is in many places at a lower level than the banks. Exceptional floods are rare, and occur only once or twice in a cycle of several years. In seasons already characterised by excessive rain, when the surface and the strata are choked, and the ordinary channels full, a small extra rainfall will produce a flood, and therefore more than one may be expected in the same season. The floods in the lower river may be said to arise from the accidental concurrence of three causes: an exceptionally heavy land flood, meeting an equinoctial spring tide, accompanied by a great westerly gale, heaping up a Channel sea, and shifting to the north-west so as to drive an accelerated tidal wave up the Thames estuary. These conditions may occur at six periods of the year, viz., in February, March, April, August, September, and October.

The daily flow of the Thames above Oxford, with a drainage area of about 600 square miles, and a rainfall of 30 inches, varies from about 73 to 640 millions of gallons, the former being the dry summer weather flow, and the latter the flow during floods. The flow per day per acre is therefore 190 gallons in summer and 1,666 in flood.

In the Appendix to the Sixth Report of the Rivers Pollution Commission, is a table showing the daily volume of water flowing down the Thames, near Thames Ditton, from 1853 to 1873 inclusive, and in the minutes of the Proceedings of the Institute of Civil Engineers, the monthly flow of the river at the same site is given from 1853 to 1875. It hence appears that on an average of twenty-three years the mean daily flow of the river at that place was a little above 800 million gallons. The actual minimum year was 1871, when the mean daily flow was 500 millions. In the maximum year it reached 1,247 millions. The drainage area at Teddington is 3,676 square miles, and at Thames Ditton about 3,500 square miles. A daily flow of 800 millions of gallons from 3,500 square miles is equivalent to a rainfall of 6·67 inches in the year, or a flow of 358 gallons per day per acre. The minimum daily flow was 137 gallons, and the maximum 557 gallons per day per acre.

As regards the upper basin, Mr. Taunton, the engineer of the Thames and Severn canal, has ascertained by gaugings that the maximum flow at Lechlade is twenty-eight times the summer flow, which may be calculated at about 26 million gallons per day. The floods of the upper part of the river naturally accumulate above Goring, where the narrow funnel-shaped passage through the chalk commences, and should heavy rain in the middle basin continue to fall and produce floods, while the accumulated waters from above are coming down freely, it will evidently cause a large addition spreading over the alluvial bottom near the chalk hills.

Other statements relative to the flow of the Thames are given in Chapter III., in illustrating the general subject of the proportion of rain that flows to the sea by rivers.

The great floods of the Thames in the lower part of the middle basin are many times greater than the ordinary flow, but unless continued for many days they would not equal the ordinary tidal volume. The great flood of 1875 was measured at Windsor by Prof. Unwin, and found to amount to 7,615 million gallons per day. The ordinary winter flood at Windsor running about 400 millions, this shows nearly twenty times as the difference. The tidal volume is, however, equal to sixty days of the ordinary daily discharge in winter at Twickenham, which is estimated at 800 million gallons.

7. Tidal influence and range.—The Thames feels the influence of the tide as far as Twickenham, and the saltness of the water consequent on the tide is traceable to London Bridge. At Tilbury, opposite Gravesend, the water at high tide was found by Dr. Letheby to contain 1556·4 grains per gallon of common salt, and at low water 1224·9. At Greenhithe, about five miles higher up, the quantities were 1444·3 and 662·3 respectively. At Rainham Creek, at a distance of another six miles, 1146·2 and 646. At Barking Point, four miles beyond, it is reduced to 858·5 and 111; but this is no doubt influenced by the quantity of sewage water that has entered, which forms a sensible part of the volume of the water. At Woolwich, the quantities are 453·6 and 60·6, and at London Bridge 26·5 and 24·9 respectively.

The ordinary rise of the tide at the Nore is 14 feet, and at London Bridge 17 feet. From London Bridge to Teddington the distance is 20 miles, and the fall of the bed of the river nearly 12 inches per mile. The low water level at Teddington is 16 feet 9 inches above that at London Bridge, and the high-water level 1 foot 6 inches above ordinary high-water mark there. The distance from the Nore to London Bridge is 40 miles, and is traversed by the tidal wave in two hours. The remaining 20 miles to Teddington is reached in about the same time.

The speed of the tidal current of the Thames has been measured by Capt. Calver (1878) near Barking Creek, nor far from the metropolitan sewage outfall. The average rate between high-water and half-ebb is about 2 miles in the centre of the stream, and only $1\frac{1}{4}$ miles at a point 200 feet from the quay wall near the sewage outfall. The maximum flow in the centre of the stream was under 3 miles about two hours after flood, and the minimum less than $1\frac{1}{2}$ miles within a little of high-water. The mean was 2·142 miles per hour, the mean rate near shore is only 1·283 miles per hour.

The tidal water entering and leaving the Thames twice in every twenty-four hours, cannot fail to have a very marked effect on the country at the mouth of the river. In some streams where the banks are high, and the river shut in, the effect of the influx of the tide is seen in the formation of a large wave which, forced up from behind and resisted by the advancing stream, rushes up with a crest, and is a great encumbrance to navigation. This is the case with the Severn. Other streams, such as the Shannon, expand at a short distance from the sea into a large lake into which the tide enters, simply producing a backing up of the fresh water which, spreading itself over a large surface, is hardly recognised. In the Thames the alluvial bed of the river below Greenwich is wide, and widens as it approaches the sea. It is nowhere elevated, and the entrance of the tidal wave floods a large surface of country, producing salt marshes; but there is no great wave of the nature of a bore.

The following is the estimated total quantity of tidal water brought in between Teddington and Sheerness, as stated by Mr. J. B. Redman (see *Proc. Instit. Civil Eng.*, 1877):—

	Miles.	Feet.	Feet.	Cubic Feet.	
Sheerness to London Bridge - -	43 ×	1,500 ×	15 =	5,108	millions.
London Bridge to Teddington - -	20 ×	500 ×	10 =	500	„
Gravesend to Sheerness, extra width -	16 ×	4,000 ×	15 =	5,069	„
				10,677	„

A part of this large body of water (66,730 millions of gallons), would, in former times, spread over large areas of marsh land, partly in Essex partly in Kent. It is now more or less completely shut in by embankments enclosing the land, but the presence of these banks exposes the cultivated fields to a chance of serious injury during and after heavy floods. All the bridges and other public works constructed near the river help to enclose the stream, and render it dangerous when this pent up condition is relieved during occasions of extreme flood, by which all obstacles are sometimes carried away.

The Thames is occasionally subject to the phenomenon of double tides, arising from unusual ranges of tide due to gales. There are also at certain seasons very heavy tides and extremely low tides. The records of double tides are few. Double tides consist of a high tide, followed after an interval of an hour or more of ebb by another flood. Ordinary high floods rarely rise more than three feet above Trinity standard. At rare intervals these limits are exceeded. Thus a tide occurred in 1763 (13th February), which covered the floor of Westminster Hall to the height of 4 feet. On the other hand, owing to a violent westerly wind, the tide has sometimes ebbed so low, that persons could walk across the river at Old London Bridge. There are natural beaches in various parts of the river below London, marking the limit of some of the ancient floods.

Since the changes that have been made during this century by embankments and bridges, the flood, brought within narrower limits of width, has occasionally risen above any former recorded height. Thus on the 20th March, 1874, it rose to 4 feet 6 inches above Trinity standard, and on 15th November, 1875, to 4 feet 9 inches above. These latter floods occurred after a strong westerly gale, raising the Channel sea to a very unusual height. The range of the tide is now as much as 27 feet.

8. Population of the Thames basin.—The population within a drainage area is a matter of some importance in a sanitary sense, and habitations being generally situated where there is available water for the ordinary purposes of domestic economy, and concentrated in spots where there are means of carrying off the accumulations of sewage, when they cannot conveniently or profitably be applied to the land, the river-bank population is an element which influences the purity of the water.

It will be easily understood that an agricultural population may be expected in all cases to use, for enriching the soil, all such manures as can be readily collected and put on the surface. Manure is so valuable, and indeed so essential a material for the farmer, that he puts into the soil and utilises all the products of this kind made by his stock, and even by the human population. It is, therefore, only such sewage as is derived from towns of sensible magnitude that is at all likely to enter a river and affect the water. Towns also far removed from the main stream, and situated so that the river that conveys the sewage has a run of a few miles in pure air from one small town to another, are known, as a matter of fact, to produce no effect on a stream that can be measured by the analyst or the microscopist. Thus in considering the population, we need only refer to towns of more than 600 inhabitants, say a hundred houses, nor are these objectionable unless they are situated within a few miles of some tributary, or of the main stream.

With this limitation the account of the population of the Thames is easily given. From the source to the gorge of Goring, the only towns on or within two miles of the main stream, are the following, with the populations as nearly as can be determined :—

Cricklade	1,850	Abingdon	6,340
Lechlade	1,270	Wallingford	2,970
Oxford	31,400	Goring	970

Within the same limits the tributaries of the Thames pass the undermentioned towns :—

River.	Town.	Population.	Water distance from Thames.
Churn	Cirencester	4680	8 miles.
Coln	Fairford	1630	4 ,,
Leach	Southrop	1270	4 ,,
Windrush	Burford	1400	16 ,,
,,	Witney	2970	8 ,,
Evenlode	Charlbury	1335	10 ,,
(Glyme)	Woodstock	1200	8 ,,
Cherwell	Banbury	4120	26 ,,
;,	Deddington	1540	1 ,,
(Ray)	Bicester	3330	10 ,,
,,	Islip	635	5 ,,
Ock (Branch)	Wantage	3295	10 ,,
Thame	Aylesbury	6960	27 ,,
,,	Thame	2820	17 ,,
,,	Dorchester	870	1 ,,

The total town population, therefore, of the Upper basin of the Thames, with a drainage area of about 1,800 square miles, is 44,800 on the main stream on a distance of 70 miles. Of the towns, Oxford alone contains three-fourths of the population. The drainage of Oxford will shortly be entirely diverted from the Thames, and an area of 320 acres is set apart for irrigation with the sewage effluent after purification. Abingdon, which contains three-fifths of the remaining town population, is now spending a sum of about £20,000 for the same object. The Wallingford sewage is already diverted from the river.

The town population of the tributaries of this part of the Thames basin is about 31,000. Most of the towns either have no regular drainage, or the sewage is diverted. The distance of the towns from the Thames by water is given above, and amounts to more than 100 miles.

In the Middle Thames there are several towns, and the population is larger. The towns on the main stream are as follows:—

Pangbourne	760	Eton	2,810
Whitchurch	800	Slough	4,910
Reading	32,350	Datchet	990
Henley	3,740	Staines	3,660
Great Marlow	4,700	Chertsey	3,150
Maidenhead	6,170	Shepperton	1,130
Windsor	11,770	Walton	5,380

The total population of these towns, some of which, however, include a large rural population, is about 83,000, Reading and Windsor comprising more than half. The whole of the sewage of these latter towns will be diverted from the Thames at enormous cost, and the sewage works are nearly completed. Maidenhead, Great Marlow, Staines, Slough, Henley, and indeed all the other towns have their sewage diverted from the Thames. The waste and sewage from the various mills is kept from the river.

The towns on tributaries of the Middle Thames are also numerous. They are as follows:—

River.	Town.	Population.	Water distance from Thames.
Kennet	Marlborough	3,360	34
"	Hungerford	2,300	24
"	Newbury	6,600	17
Loddon	Basingstoke	5,580	23
Wick	High Wycombe	4,800	7
Colne	St. Albans	8,300	28
"	Watford	7,640	21
"	Rickmansworth	5,340	17
"	Uxbridge	3,360	9
"	Colnbrook	1,150	3
(Chess)	Chesham	2,240	25
Wey	Alton	4,090	42
"	Farnham	4,460	32
"	Godalming	2,130	21
"	Guildford	9,100	16
"	Woking	6,590	10
"	Weybridge	2,600	1
Mole	Dorking	8,600	22
"	Leatherhead	2,460	17
"	Cobham	2,130	11

The total town population on the tributaries of the Middle Thames is thus nearly 94,000, the drainage area being about 1,800 square miles. None of the towns are large, and there is little injury done to the waters of the different streams, either by population or manufactures. This will be seen by reference to the paragraph on the quality of Thames waters.

In the evidence given before the Duke of Richmond's Commission in 1869, the total population of the Thames above Thames Ditton was stated at 235·3 per square mile, or rather more than three acres per head. It is probably not very different at the present time. The water for the supply of about half the population of London is taken from the Thames about this point. The quantity of water taken is 110 million gallons per day.

The Lower Thames has on its main stream the vast population of London and its environs, which may be said to cover nearly a fourth part of the distance from Teddington to the sea. The tributaries are, of course, crowded with the overflow of the metropolitan population within a considerable distance of their confluence with the Thames. There are, however, some statistics concerning the population of the parts not so crowded that are deserving of attention.

The Lea is the most important of the rivers below London in its reference to water supply, as the water for nearly half the metropolitan population is hence derived. The Medway has far the largest catchment, but its waters are little utilised.

The towns on the Lower Thames are as follows:—First, London, and those which are suburbs of London, namely, Kingston, Richmond, Kew, Chelsea, Deptford, Greenwich, Blackwall, and Woolwich. Of these it is not necessary to consider the population. Secondly, those away from London.

The town population on that part of the tributaries that does not belong to the metropolis is as follows:—

River.	Town.	Population.	River.	Town.	Population.
Lea	Luton	17,300	Lea	Chingford	1,270
"	Hertford	6,800	Dart	Dartford	8,300
"	Ware	4,920	Medway	Tunbridge	8,210
"	Hoddesdon	2,090	"	Maidstone	26,200
"	Broxbourne	780	"	Rochester	12,330
"	Cheshunt	7,520	"	Strood	4,190
"	Waltham Abbey	3,000	"	Chatham	45,800

Compared with any other part of the Thames valley, the Lea and the Medway are evidently very thickly peopled. The Lea, however, is under the care of an active Conservancy Board, and the sewage of all the towns is diverted from the river, and either purified or passed over irrigation farms. The waters of the Lea are practically exceedingly pure, as is rendered evident by the periodical analyses made and published by Dr. Frankland and Dr. Tidy. The mean of the last ten years, during which many sources of pollution have been gradually removed through the action of the Lea Conservancy Board, and the mean of samples taken each month for 10 years ending 1877, will be found in § 5.

9. Scheme of the chief tributaries.—The following general scheme, showing the relative position, approximate run, and approximate distance from the source, of the principal feeders of the Thames, will be found useful for reference :—

Thames Head. *Upper Basin.* Seven Wells.

Swill brook, 11 miles. Churn river, 20 miles.

THAMES.

Length of course.	*Right bank.*	Distance from source in miles.	*Left bank.*	Length of course.
		21 . .	Ampney brook	10
11	Ray river	22		
		$23\frac{1}{2}$.	Meysey brook	5
		$29\frac{1}{2}$.	Coln river . . .	29
14	Cole river	33 . .	Leach brook .	19
		49 . .	Windrush river	34
		58 . .	Evenlode river	31
		64 . .	Cherwell river	44
18	Ock river	73		
		83 . .	Thame river .	39
		Middle Basin.		
53	Kennet river . .	105		
14	Tittlebourn brook	108		
30	Loddon river . .	109		
		124 . .	Wick river . .	10
		140 . .	Colne river . .	40
12	Bourne brook . .	146		
41	Wey river	$146\frac{1}{2}$		
42	Mole river	$153\frac{1}{2}$		
5	Hog's Mill river .	156		
		Lower Basin.		
		$161\frac{1}{2}$.	Cran river . .	20
		163 . .	Brent river . .	20
14	Wandle river . .	170		

Length of course.	*Right bank.*	Distance from source in miles.	*Left bank.*	Length of course.
10	Ravensbourne r.	181		
		183	Lea river . . .	50
		188	Roding river .	38
		191	Bourne brook	12
		192	Ingerburn river	12
20	Darent river (and Cray)	195		
60	Medway river . .	221		
		225	Crouch river .	20

It is desirable to point out the distribution of the tributaries and the sub-basins. The principal feeders of the Upper Thames, with the exception of the Ock, enter from the left or north bank, the early feeders draining only country to the north-west. In the Middle basin, on the other hand, almost all, with the exception of the Colne, enter on the right bank, draining the country to the south. In the Lower basin the drainage is about equally divided, the number of streams being greater from the north, but the drainage area of those on the south much larger. This is chiefly owing to the Medway, which is almost a detached basin, and drains more than a seventh part of the whole Thames basin.

10. The Upper Thames Basin.—It has already been pointed out, in § 3 of this chapter, that the Thames catchment is naturally divided into three parts. The line of the chalk hills encloses the upper basin, which connects by a natural gorge through these hills with the country to the south. It is this northern and almost detached drainage area that we have first to consider. Looking at the outline map of the basin at the commencement of this chapter, and referring to the outline maps of the British islands marking the geological structure, the elevation axes, and the rain distribution, the correspondence of the physical features and the hydrological conditions will be easily recognised.

The Upper Thames basin is separated from the basins of the Severn and the Great Ouse by well-marked lines of water-shed. The upper sources of the Churn, and the springs at Thames Head, are in the same rocks as those which feed the Chelt, whose waters run into the Severn. The upper sources of the Cherwell are in rocks that supply the early feeders of the Great Ouse, and run into the Wash.

A study of the same maps will also show the remarkable uniformity of direction of the subordinate basins of the Upper Thames. With the single exception of the Ock, no stream of the smallest importance comes from the slopes of the hills that form the southern boundary of this sub-basin.

The drainage area of this upper basin is made up of a number of small catchments, not very greatly different in extent. With the one exception already pointed out, these convey the oolitic or northern drainage, and they are six in number, all being nearly parallel. They consist of the basins of the Churn, the Coln, the Leach, the Windrush, the Evenlode, and the Cherwell. Entering the main stream below all these, there is the extensive but not productive basin of the Thame from the north-east, and the basin of the Ock, a narrow strip between the main stream and the chalk hills that limit the water-shed to the south. The rain-fall in the Upper Thames basin diminishes from 30 inches on the oolitic hills to the west, to 25 in the middle of the basin, and is reduced to 21 on the eastern chalk valleys.

11. The sources of the Thames.—Several groups of springs have been mentioned by different authors as the head waters of the Thames, but none can be properly spoken of as the source. Those usually described are Thames head, whose waters, diminished by pumping, enter the Swill brook; the Seven wells, the source of the Churn; and the Syreford springs, the source of the Coln; these being all considerable springs at all seasons. None of them, it will be seen, bears the name of the principal stream, and the first time that the name of Thames is applied in the Ordnance map is at Waterhay bridge, about a mile below Ashton Keene's village, and three miles west of Cricklade (Wilts), a little above the confluence of the Swill brook with the Churn. Professor Phillips, and others, recognise this upper stream as the Isis, using the name Thames only after the confluence of the Thame with the Isis. However this may be decided, the position of the two main springs is well defined; and, besides them, is the third and equally interesting group of springs at Syreford, which deserves, almost as well as either of the others, to be regarded as the source of the Thames. The whole river, from the junction of the Swill brook and the Churn, is now called the Thames.

Of the various springs, those at Thames Head break out at the highest level, and the Seven wells at the most distant point. The former are more generally regarded as the source of the Thames, and the others as those of the Churn. There are other hardly less important feeders that unite with the water from Thames Head to form the Swill brook and others that feed the Windrush, the Evenlode, and the Cherwell.

12. The Swill brook.—The actual outflow of the waters at the head of the Thames valley that form this stream is at a lower level than formerly, having removed from the point where the springs originally broke out, which was nearly 800 feet above Ordnance datum, to a point a little down the valley, owing to the pumping carried on to feed the summit level of the Thames and Severn canal. The natural efflux now takes place half a mile below the former source.

The Thames Head springs deliver a strong current of sparkling water, estimated variously at from 200 to 400 cubic feet per minute, the absolute minimum being stated by Mr. Taunton at 200 cubic feet. The water is collected in the joints and cavities of the upper Bath oolite above the Fuller's earth bed, which is here 27 feet thick, and argillaceous. Lower down are the Ewen springs, which yield 150 cubic feet per minute, making in all 450 cubic feet per minute, or 4 million gallons per day. The yield of the springs is liable to rapid and large increase during and after heavy rain, and, on the other hand, the large supply ceases, or reduces to a very moderate quantity, after continuous drought. For canal purposes the pumping is irregular, and time is given for the supply to be renewed in the fissures of the rock, when they have become exhausted by continuous pumping.

From Thames Head a brook, running about 3 miles to join the Swill, is regarded as a part of the stream bearing that name.

At the point where the feeder from Thames Head spring joins the Swill brook, another feeder comes in from the south-west, and the combined waters, after a further run of 8 miles, join the Churn at Cricklade.

13. The Churn.—This river originates in a group of springs just within the escarpment of the oolitic hills near Cheltenham, and may, with some reason, be regarded as the main source of the Thames. A detached spring (the most distant) rises close to a large farm named Ullen; the others at a short distance, consist of several springs breaking out through joints in the oolite in a dell almost buried in foliage, and are known as the "Seven Wells." This spot is 650 feet above the sea, the source at Ullen being 700. Both sites are close to the sources of the Chelt, which runs into the Severn.

The outrush of water from Seven Wells forms at once a small rivulet, which issues from the lower part of the oolite and runs over the lias. Measured in the autumn of 1849 by Mr. Taunton, the flow was 3,780,000 gallons per day. In 1859, during the dry autumn, the discharge was only 100,000 gallons per day. This great difference is sufficient indication of the dependence of the flow on the rain of the season.

The two little rivulets of the Churn unite at Cubberley, and the stream runs southward in a pleasant narrow valley excavated in the upper lias clay, contracting after a little distance. Its course to the Swill brook is 20 miles.

On its way from its sources the river Churn runs about 5½ miles over the upper lias, receiving continual additions from springs bursting out from the oolites above. Measured in 1859, under the superintendence of Mr. Simpson, the stream was found to increase as follows, the discharge at the spring head being 11 cubic feet per minute* :—

After $\frac{1}{4}$ mile the flow was	31	cubic feet per minute.		
$\frac{3}{4}$ „ „	61	„	„	
1 „ „	73	„	„	
2 „ „	105	„	„	
$2\frac{1}{2}$ „ „	165	„	„	
$4\frac{3}{4}$ „ „	312	„	„	
$5\frac{1}{2}$ „ „	320	„	„	

At this distance the lias clay terminates, and the river runs over oolites. A reduction in the flow immediately takes place, and the result of gauging was as follows :—

After $6\frac{1}{2}$ miles the flow was	290	cubic feet per minute.		
7 „ „	235	„	„	
$7\frac{3}{8}$ „ „	179	„	„	
$8\frac{1}{8}$ „ „	113	„	„	
$8\frac{7}{8}$ „ „	45	„	„	
$9\frac{3}{4}$ „ „	33	„	„	
$12\frac{1}{2}$ „ „	30	„	„	
$14\frac{1}{2}$ „ „	10	„	„	

Thus, after a nearly fifteen mile run, less water was delivered than at the source; and at 20 miles from its source, where it joins the Thames at Cricklade, the river only delivered 110 cubic feet per minute, or one million gallons per day.

The total drainage area of the Churn is 73 square miles, and the proportion of the mean annual rainfall of 30 inches thus delivered is exceedingly small, being, in fact, a flow of only 23 gallons per day per acre, equivalent to about 1,900 gallons per day for the whole catchment. No doubt a large part of this absorbed flow enters the stream lower down, either in visible or in bottom springs; but the fact is significant in estimating the value of measurements of parts of rivers unless all the circumstances are known, and the possibility of percolation into the strata foreseen. In the case of rivers running over hard limestone, the fissures swallow up almost any amount of water and carry it in an underground course, while in chalk the water is quietly absorbed, and does not emerge except at a low level, or where the bed is interrupted by impermeable strata, or by fissures, joints, or faults that are filled with clay.

14. The Ampney brook.—The Churn and Swill brook uniting at Cricklade, flow only a very short distance before receiving tributaries.

* A cubic foot of water per minute is equivalent to 9,000 gallons per day.

The Ampney brook combines several small feeders, which enter the main stream after a course of 10 miles, chiefly over Oxford clay. Its source is in the Great oolite a little to the east of Cirencester, and it has a southerly course through the Forest marble, draining (with *Marston brook*) about 32½ square miles of country.

Besides the Ampney brook, some very strong springs rise in this part of the valley of the Upper Thames, and enter the river from the oolites. A group of springs breaks out at Ampney Cracis, two miles east of Cirencester, proceeding from the Fuller's earth in consequence of a fault. One of the springs was measured by Mr. Bravender, and found to flow 4 million gallons in 24 hours, and the whole group, at that time, taken some distance below where the different springs had come together, measured double this quantity, but this was only for a short time. In the autumn of the same year (no date given) Mr. Bravender states that, after wet weather, when an intermittent spring called Winterwell was running 3 million gallons daily, the whole flow amounted to 12 millions. He states also that in summer Winterwell ceases, and the other spring is greatly lowered.*

15. The Rey or Ray.—This river enters from the south, and originates in the chalk escarpment to the west of Swindon. It then flows over the upper greensand, gault, and lower greensand, to the Kimmeridge clay, and crosses the Coral oolite (receiving there a small tributary) to the Oxford clay, reaching the main stream near Water Eaton between Cricklade and Lechlade, about 1½ mile below Cricklade. The drainage area is estimated at 65½ square miles. The Ray has a long winding course, chiefly to the north, and receives on its way a number of small feeders, both from east and west, from a belt of country about three miles on each side of the stream. Like the other early tributaries of the Thames, it is subject to sudden and rapid increase, and goes down in dry weather.

The *Meysey brook* is a small feeder coming in from the north about a mile and a half below the Ray. It passes two villages, and has two principal and nearly equal forks.

16. The Coln.—This considerable feeder has its origin in the bottom beds of the oolites in a group of small springs near Charlton Abbots, within a few miles of the source of the Churn. Like most of the springs from the oolites in this part of the Cotswolds, those feeding the Coln vary in yield, but, as their temperature is more equable than in the case of the Seven Wells, it may be expected that the springs give a more average yield, the water issuing from the earth after a longer sojourn and from a greater depth. After a course of about 2 miles, receiving springs at Brockhampton and Sevenhampton, the stream is

* Sixth Report on the Pollution of Rivers, Appendix.

joined at Syreford by a group of strong springs, which fill a pool and turn a mill within a couple of hundred yards of their outflow. Leaving Syreford, the Coln continues with a southerly course, running between cliffs of Fuller's earth and Great Oolite, the water flowing over the clay for 6 miles, and the stream receiving feeders from springs at Andover's Ford, Frogmill, and Withington. It then turns a little to the east, the lias disappears, and the stream flows for 10 miles, passing many villages, and receiving a branch from the north through a singular anticlinal valley. After taking in water from many strong springs, it gradually becomes a considerable stream. At Fairford, during full water in March 1854, it was measured by Mr. Taunton to flow 4,700 cubic feet per minute (at the rate of 42 million gallons per day); but this is very much larger than its average flow. The whole drainage area of the Coln is 87 square miles, and its length of course nearly 30 miles. During a great part of its run it winds in very small curves through its valley, which is cut out of the soft clays, and it occasionally becomes almost lost in subterraneous fissures, greatly reducing its volume in dry seasons.

17. The Cole.—This river joins the Thames by a narrow cut above the Leach brook, but its principal stream, after running parallel to the Coln (its course being less than a mile to the east) for two miles, joins the Thames a little below Lechlade, nearly 2 miles below the confluence of the Coln. It rises, like the Ray, in the somewhat elevated country to the south, and has a generally north-eastern course to the Thames. Its actual sources are near the escarpment of the chalk which runs from Marlborough to Ilsey Downs and White Horse Hill, south of Swindon, and it originates in a number of feeders which cross the upper and lower greensand and Kimmeridge clay, and carry a large quantity of water during flood. It enters the Thames at Lechlade, between the Coln and the Leach brook, having drained about 48 square miles. Its length of course is 14 miles. A small district between the Ray and the Cole, occupying about 10 square miles, is drained by a stream entering a little above the confluence of the Cole.

18. The Leach brook.—Nearly opposite to the inflow of the Cole the Leach brook enters the Thames from the north. This tributary is smaller than the Coln, but drains 36½ square miles, having a course of about 20 miles. It rises in the Cotswolds, a mile above North Leach, at a place called "Seven Springs," about 570 feet above the sea. It collects water from the country around by a number of small feeders. All its sources and feeders are in the oolites. The town of Lechlade, where the brook enters the Thames, is 258 feet above low water at London Bridge, and up to this point the river is still navigable. Formerly the navigation extended to Cricklade.

19. The Bampton districts.—Between the Leach and the Windrush (the next important tributary), and on the north bank of the Thames, is a somewhat extensive district of 120 square miles, drained by several small streams, not collecting into one river, but discharging their waters at various points into the Thames. The small town of Bampton, in this district, may be assumed as the designation of this drainage area. The *Charney brook* is the principal stream. The Thames here flows over Oxford clay.

There is no drainage from the south bank in this part of the Thames, as the line of water-parting between the Ock and the Thames catchments runs quite close to the latter. The bed of the river winds about a good deal in a valley which is about a mile in extreme breadth. This valley, like that of the streams on the other side, is cut out of Oxford clay, or rather the oolites have been eroded to that bed, no doubt by the under-cutting of springs issuing from their bases, and the gradual removal of the fallen rock. The banks of the river, therefore, which alone are seen, are harder than the bed. The alluvial bed is wide, but the channel or water-way, except after heavy rain, is small. This character of the upper tributaries of the Thames is peculiar, and deserves notice, as it has some influence on the quality of the Thames water.

20. The Windrush.—This important feeder of the Thames has several branches. It begins by the union of three forks on the slopes of the high ridge of Broadway and Stanway, beyond and much higher than the sources of the Coln. One of these runs southward from near Snow's Hill by the open country of Ford, and the wooded region of Temple Guiting. It here receives the collected waters of several short streams, and descends into the deep glen of Naunton, and then emerging into an open valley, passes by Hartford Bridge to the large village of Bourton. Here another branch comes in called the *Dickler*, which rises on Broadway Hill, where "Spring Hill" marks the presence of a small source. A few miles lower down, the Windrush is joined by a rivulet coming from the country between Naunton and Sherborne, and then proceeds through ridges and slopes to Taynton, and afterwards to Burford. The several branches unite above Burford, and supply water power to important mills. The course of the stream is now nearly east for 7 miles to Witney, whence, after a further course almost due south for about 6 miles, it enters the Thames at New Bridge, after a course of rather more than 30 miles through oolitic rocks. Its drainage area is 141 square miles. It is a valuable stream for power, turning several mills. Throughout it is rapid and picturesque, and a favourite river with the angler, the waters being exceptionally clear and pure. This remains the character of the stream after passing Burford and Witney, as will be seen by referring to the analysis in page 145.

21. The Evenlode.—After receiving the Windrush, the Thames turns northwards with a sharp curve, and continues in this direction 9 miles to the confluence of the Evenlode, another considerable affluent proceeding from the oolitic rocks in the north. This river, like the Windrush, with which it has a generally parallel course, rises from the eastern slope of the inferior oolite hills, and runs over the clay beds of the middle oolites. Its sources are in the lias, near Moreton-on-the-Marsh, and it is fed by a number of small streams to the south and west, coming from the hills which separate the course of this stream from that of the Windrush. It runs about 12 miles south-east to Shipton, when it turns round to the north, and has a winding course to the vicinity of Woodstock, receiving on its way very few tributaries. At Woodstock it receives the *Glyme* from the north, a stream rising in the oolite hills near Dunstan, and afterwards the *Dorne,* and one or two other small feeders. The Glyme is conducted as ornamental water through Woodstock Park, and joins the Evenlode below. When the confluence has taken place the Evenlode assumes the direction of this tributary, and runs southwards to the Thames, three miles further. The drainage area of the Evenlode is 189 square miles, and its total length of course about 31 miles. It is a somewhat sluggish and rather muddy stream.

After receiving the Evenlode the main stream of the Thames, turning south, soon approaches Oxford, and, after a short run, receives the Cherwell.

22. The Cherwell.—This important stream is one more of the oolitic tributaries of the Thames, the waters springing from the overflow of the water supply in the limestone strata, and either running over the lias, or the strata of clay that alternate with the bands of oolitic limestone.

The Cherwell, unlike the other feeders of the Thames, rises on the western side of the escarpment of the oolites, and takes water from impermeable beds at the foot of the western escarpment. Its source is in the Marston Hills, in Northamptonshire, at Cherwell House, a little to the west of Weedon, and the stream is formed by the junction of feeders draining several valleys. The highest springs are traceable to the capping of oolite, which is here found in outliers, but the great body of water supplying the stream comes from the lias into which the heavy rainfalls not being able to enter, the water rushes rapidly down the valleys, causing considerable and frequent inundations. The same tract of lias that feeds the Cherwell also gives origin to branches of the Warwickshire Avon and the Nene. The elevation summit at its lowest point near Fenny Compton is 450 feet.

Below Cherwell House the Cherwell receives rivulets from Byfield and Aston, and reaches Banbury after a somewhat tortuous course, the direct distance being little more than 15 miles, but the length of the stream and its windings nearly double. The drainage area to Banbury is considerable, the feeders proceeding from various points within a large curve, whose chord, measured from a point east of Canons Ashby to near Fenny Compton, is about 12 miles, and the distance of the extreme sources from the centre of the chord 8 miles.

Below Banbury the Cherwell is a considerable stream, the country on both sides yielding feeders flowing in valleys cut down to the lias, with high marlstone banks, capped occasionally by oolite. At Banbury this character is very noticeable. The streams entering from the west run through narrow valleys and glens, originating in the high tract stretching from Epwell and Edgehill. One of these, with many branches, passes Wroxton Abbey, another, called *Sorbrook,* passes Broughton Castle, a third springs at Epwell, and flows by Madmarston Camp, and a fourth runs by Bloxham and Adderbury. Where these join the Cherwell the river *Swere*, a more important tributary, comes in from the west, near Deddington. This river rises a couple of miles east of Chipping Norton, and has a course of 12 miles nearly due east, receiving on its way an important branch at Wigington, and entering the Cherwell quite close to the confluence of another stream, which has drained a wide tract of country a little to the north by many branches. Below Dedington another feeder enters from the west, after which the hills close in, and the drainage of the country to the west joins the Evenlode. From the east the drainage is small until, at Islip, the river *Ray* joins it. This little stream, giving a considerable but variable supply, rises near Bicester, and flows through the flat plain of Ottmoor, where it expands when in flood, and forms a lake. The lake, though small, is a flood-regulator, and is interesting on this account. The stream is fed by a number of small tributaries from the north, several of which have a course of nearly ten miles. The length of the course of the main stream of the Ray is not great.

The river Cherwell is cut through all the members of the lias formation, almost reaching the underlying "Rhætic beds," which are laid bare in the railway cutting at Harbury station. At Euston Bridge it enters the continuous range of the oolites, which are here of moderate thickness. After 3 miles it reaches the Oxford clay, and continues to run over that rock till it enters the Thames. The whole course of the stream is 44 miles.

23. The Ock.—From the confluence of the Cherwell the Thames pursues its course southwards for about 5 miles, turning westwards as it approaches Abingdon, where it receives the Ock, the largest tributary of the upper basin entering on the right bank. The Ock drains the broad vale of the White Horse, principally excavated to the Kimmeridge clay, and flows the whole way between the chalk downs on the south and the coral rag hills on the north. The latter form a low escarpment overlooking the soft clayey beds of the upper oolites. The valley of the Ock is cut in the Kimmeridge clay.

The Ock rises at the foot of the chalk hills of Berkshire, between Beauchamp and Ashbury, and flows eastwards, receiving at short intervals small feeders from the greensand hills on the south and the coral rag hills on the north. The whole course of the Ock is 18 miles. Near the confluence with the Thames it passes through a wide extent of low land, swampy in winter, and the volume of water delivered is considerable. A canal accompanies it on the right bank. The confluence is within the town of Abingdon.

Below the Ock there is little added to the Upper Thames basin from the right bank, one small rivulet only joining it at Sutton. The river winds a good deal in this part of its course, and, leaving the oolites, enters the greensand. Turning to the east, after a wide curve, now cut off by a direct artificial channel, it assumes the character of a broad, even, steady stream till joined by the Thame.

24. The Thame.—The river Thame originates in a number of springs breaking out from the lower part of the chalk to the north, between the chalk escarpment at Tring and the greensand at Wingrave. It has also some sources among the oolitic hills of Quainton and Brill. After a course of a few miles the Thame passes near Aylesbury, receiving other streams which rise near Stewkley, between Fenny Stratford and Aylesbury, and join it near that part of its course. The stream thus formed runs to the south-west, passing near several small towns, and receiving additions at various points, till it reaches the town of Thame. It has now attained a considerable magnitude. The direct course of the stream, from Tring to Thame, is nearly 20 miles, but, including the windings, much more.

From Thame the river runs west for about 8 miles, receiving no tributary of importance. It then turns abruptly to the south, and, after about 12 miles, joins the Thames below the village of Dorchester, the entrance being narrow, and giving no idea of the magnitude of the stream. The length of course of the Thame is estimated at 39 miles. The chief part of the course is over Kimmeridge clay and calc grit till it enters the gault near Dorchester.

Below the mouth of the Thame the river Thames continues to flow for some miles in a wide stream, the country gradually closing in, and the higher part of the chalk escarpment approaching the course of the stream. The Upper Thames basin may be considered to terminate at Goring, where this funnel-shaped passage begins to contract, and all access on either side for tributary streams is completely closed.

25. General summary of the Upper Thames.—It has already been remarked that the Upper Thames is a complete basin, dissevered from the rest of the catchment. All the waters of this part of the stream collect into a large open valley between 100 and 200 feet above the sea, a great part of which is a tolerably level plateau or elevated flat valley between the nearly parallel escarpments of the great and lower oolites and that of the chalk. The former rises to 700 feet, the latter to about 600, and the total area is not less than 1,800 square miles. The rainfall over this basin is heavier than on the lower part of the drainage area of the Thames, and the bed of the river, being almost entirely cut in clays, there is not much loss of water after the tributaries have reached the main stream. The loss of water that takes place where the stream runs over the fractured oolitic limestones is for the time very great, but there can be little doubt that a considerable portion of what appears to be lost really enters the river at a lower point by bottom springs. It will be seen that this upper basin is altogether oolitic, and the water of the principal tributaries is thus rather more loaded with sulphates, and the permanent hardness is distinctly greater than in the case of the tributaries of the middle stream, whose beds are more limited to the chalk and overlying tertiaries.

The fall of the river from Cricklade to the confluence of the Thame is 120 feet, the length of the course being 63 miles, showing a mean fall of 23 inches in the mile. The fall, however, is better estimated and understood by considering the rates between the principal confluences, which are as follows :—

	Height above sea. Feet.	Distance from source. Miles.	Fall per mile. Inches.
Confluence of the Churn and Thames -	278	20	—
Thence to confluence of the Coln - -	243	28½	50
Thence to confluence of the Evenlode -	203	51	21¼
Thence to confluence of the Cherwell -	190	56	31
Thence to confluence of the Thame - -	169	72	15¾

It is evident, therefore, that the chief fall is in the upper course, and ends with the confluence of the Cherwell. From the Thame to the mouth of the gorge the flow is even, and the bed of the Thames almost horizontal.

Before being joined by the Thame, the course of the Thames has ceased to be over oolitic strata, and has entered the lower greensand or Neocomian beds, which, however, it soon leaves for the upper greensand, which is largely developed. The confluence of the Thame is near where the upper greensand covers the lower beds of the cretaceous series.

Below the junction of the Thame the river enters the chalk, which it crosses nearly at right angles to the strike of the beds, and its channel is for several miles extremely narrow ; no tributaries whatever enter from either side, and possibly some water may be lost. Should it, however, be thought desirable at any time to render available the surplus waters of the Upper Thames, it does not seem likely that there would arise any engineering difficulty in doing so, as the construction of a bank in the narrow part of the gorge between the chalk hills would readily admit of the retention of the storm waters to any required extent. There is no doubt that by thus shutting off the upper basin, and retaining the excess of water that enters it, the floods in the Middle Thames might be rendered much less injurious, and at the same time a good supply of water would be obtained. Such a proceeding need not interfere with navigation.

26. The Middle Thames.—We may conveniently include in the Middle Thames that portion of the river commencing where the gorge of the river closes in a few miles north of Pangbourne, and terminates at Teddington, to which point the tide has access. Whether the precise tidal limit would remain at Teddington, if all incumbrances were removed, it would be difficult to determine with certainty, nor is it important. Above this point the water is taken for the supply of London by all the companies that make use of Thames water, and analysis shows no such infiltration of salt into the water where the supply is taken as would suggest tidal influence. (See § 5 of this chapter.)

The commencement of the Middle Thames is in chalk, but the chalk is soon covered thickly with London clay. The character of the tributaries of the river in this part of its course is quite different from that of the feeders of the upper basin ; their number is smaller, but they drain larger areas, and have larger and more important affluents. About half the distance traversed is over chalk, and half over London clay.

On emerging, near Pangbourne, from the gorge that connects the Upper and Middle Thames, the river has a southerly course. Close to Pangbourne the *Pang*, a small brook, enters, and, as it leaves that town, the river Thames winds round to the east under the chalk hills which shut it in to the north, and, after flowing about 5 miles further in this direction, it arrives at Reading, where it is joined by the river Kennet, one of the more important of its feeders, bringing in a contribution of water from a large drainage area to the west.

27. The Kennet.—This tributary rises among the chalk hills on the western side of Marlborough Downs, whence it proceeds in a nearly straight stream, flowing from west to east, and gathering many small branches, to Avebury, where it meets a feeder from the west on the extreme ridge of the chalk hills near the northern and western escarpment. From Avebury the united stream flows a little further south till it reaches the town of Kennet, at which point, nearly 8 miles from its various sources, the stream turns abruptly to the east, retaining that direction along the whole of the remainder of its course.

Flowing over the downs in this manner, there is very little cross drainage, and, for a distance of 5 miles, when Marlborough is reached, no feeder enters. Here the *Ogbourn* comes from the north after a course of about 5 miles, and, 6 miles further, another small stream, the *Aldbourn,* enters, also from the north. After another four miles, Hungerford is reached, and an obscure drainage system from the south comes in. From Hungerford onwards the Kennet runs in an alluvial valley and through marshy gaound, receiving small additions from both sides, but chiefly from the south. About 10 miles below Hungerford, and a mile below Newbury, the Kennet is joined by the *Lambourne,* rising on the downs a mile beyond the village of Lambourne, and running about 12 miles almost in a straight line to the south-east, over the downs to its outflow in the Kennet valley. After another 7 miles the *Embourne,* originating about 2 miles south of Hungerford, runs parallel to the course of the Kennet at a distance of 2 miles, and enters the alluvial valley of the Kennet at Brimpton, but does not actually join the Kennet till nearly 3 miles further. The whole of the drainage is entirely over the tertiaries. After receiving the Embourne the Kennet continues without further incident, entering the Thames just below Reading after a course of 53 miles, running over chalk to Hungerford, and afterwards entirely over the London clay.

28. The Tittlebourn brook.—A small stream bearing this name enters the Thames from the south, close to the mouth of the Kennet. It originates in springs from the chalk, rising near Pamber Forest and Silchester common, about 14 miles to the south-west. The streams from these springs unite, and are joined by other small streams from the left bank, and then run for some distance nearly parallel to the course of the Loddon, but gradually approaching that stream as if to join it. Just before reaching it the brook abruptly turns to the north, and runs into the Thames at Reading. The whole course lies over London and plastic clay.

29. The Loddon.—This river joins the Thames on the right bank draining the country to the south, having crossed the tertiary beds that here overlie the chalk.

The River Loddon rises in Hampshire, about 2 miles west of Basingstoke, just where the chalk is covered by the lowest beds of the London clay series. It runs east a few miles, and then turns towards the north-east, receiving small tributaries from the chalk, both from the south and west, the latter from a distance of 7 or 8 miles. Although, however, these tributaries take their rise at the contact of the cretaceous beds, their whole course is over the lower tertiaries.

About three miles below Strathfieldsaye, through whose beautiful park the Loddon runs for more than a mile, the *Blackwater*, an important tributary, enters from the south-east, after receiving a branch from the south called the *Whitewater*. The Blackwater takes its rise from the northern slope of the ridge of chalk between Guildford and Farnham, called the "Hog's back," and has cut a valley through the Bagshot sands, running nearly due north over the London clay, and separating Aldershot and Pirbright commons. From its source it runs about 8 miles past Farnborough, to Frimley, a little beyond which it receives a feeder from the west. At Blackwater a small brook enters from the east, and the course of the stream then turns towards the Loddon. After the confluence of the Whitewater, which has come from the northern slope of the hills near Farnham, not far from the source of the Blackwater, but with a shorter course, the two streams together run north about a mile and a half into the Loddon.

Before reaching the Thames, the Loddon receives two other small feeders from the sand-hills of Bagshot heath, and, as it enters the main stream, it is divided into many channels. The whole length of course is calculated at 30 miles.

Beyond the confluence of the Loddon the Thames makes a considerable curve to the north, receiving no tributary of importance for many miles. Before reaching Maidenhead, the left bank of the Thames is of tertiary origin, and, after passing that town, the river enters the beds of the London basin, continuing for the rest of its course over these deposits. The bed of the stream now becomes comparatively wide, running between banks of gravel more ancient than the alluvial bed, and the river takes a winding course between these banks, which are at a considerable distance apart, the actual water-way being comparatively narrow, and subject to shift within the limits of the gravel banks on occasions of flood.

30. The river Wick.—This small stream enters the Thames on the left bank, near Cookham, 15 miles below the confluence of the Loddon. It receives the drainage of a hilly district called Bledlow Ridge, and passes through a wooded country to West Wycombe, flowing to the south-east. Two miles beyond, in the same direction, it goes through the town of High Wycombe, where it receives a small feeder from the north. It continues in a widening valley, carrying a good stream much employed by mill-owners, of whom there are several in the valley. The great paper mills of Loudwater are about 3 miles below High Wycombe. The river then continues about 4 miles, turning to the west before joining the Thames, and further utilised by mill-owners. From Cookham to the river Colne there is no feeder of importance; and the Colne delivers its waters to the Thames by so many small channels that it is hardly possible to determine which is the main stream.

31. The Colne.—This river rises near North Mims, about 3 miles east of St. Alban's, where the beds of the London clay first show themselves overlying the chalk. Several small streams, some from the north and some from the south, converge near Colney Hatch, and run south-west for about 4 miles from this point to the village of Colney Street, where they meet the Ver.

The *Ver* is more considerable than the Colne at the confluence of the two streams. It rises about 9 miles north-west of St. Alban's, in the chalk, not far from the northern escarpment of that rock, overlooking the greensand. Passing Redbourn and St. Alban's, it runs 3 miles further, to Colney Street, with a southerly bearing. Meeting there the Colne, which comes from the west, the united stream takes the direction of the Colne, and, under that name, runs over the chalk about 5 miles further to Watford. It then turns west, for about 3 miles, to Rickmansworth, where it receives two considerable tributaries within a distance of half a mile. These are the Gade and the Chess.

The *Gade* rises on the chalk near Little Gaddesden, and has a course of nearly 6 miles, past Hemel Hempstead to Two-waters, where it receives the *Bulbourne*,* a small feeder from the north-west, rising close to the summit level of the Grand Junction Canal, and conveying the water from the hills for a distance of about 7 miles. Past Two-waters the Gade runs nearly south for 7 miles, and then turns abruptly to the south-west, to enter the Colne. The *Chess* rises near Chesham, about 9 miles north-west of Rickmansworth, and has a somewhat winding course to the Colne, over chalk.

After passing Rickmansworth the Colne turns to the south, and runs 7 miles in that direction to the junction of the *Misbourne*, which rises at Great Missenden, not far from the chalk escarpment, and runs in a south-easterly direction nearly 16 miles, entering the Colne a little above Uxbridge. It receives no feeders. At Uxbridge the Colne flows over the London clay, and continues over this bed for 9 miles to the Thames. In this part of its course the channel is much broken up, and the river receives a large amount of surface drainage, especially after the valley of the Thames is reached. The stream enters the Thames by many channels near Egham, its whole course being about 40 miles.

The chalk being an absorbent rock, the rain that falls on the surface is generally sucked into the earth rapidly, so that the proportion carried off by small tributaries to the river, and thence towards the sea, is much smaller in this part of the course of the Thames than in the upper part. Between the confluence of the Thame and Uxbridge, almost all the

* This stream is interesting as having been the site of experiments conducted on a large scale to prove the abstraction of water from the surface of chalk by pumping from a deep well in the neighbourhood of the stream.

catchment areas of the river, and of all its affluents, traverse rocks of the upper cretaceous series partly covered by tertiaries.

The river Colne at Bushey Mill, above Watford, drains 113½ square miles (72,640 acres), and the mean annual rainfall of the district is 25 inches. The flow, measured on the 25th June 1850, was about 10 million gallons per day, equivalent to 138 gallons per day per acre.

32. Bourn brook (Surrey).—Between Staines and Weybridge the Thames pursues a tortuous course, its channel being cut through a wide alluvial bed. At Chertsey Mead it is joined by a small stream from Virginia Water, in Windsor Park, called the Bourn Brook, which rises at Bagshot, near Chobham ridges, and, after passing Chobham and receiving many small feeders, reaches the Thames. It has a winding course of more than 12 miles through a most picturesque district. Close to this junction the Wey comes in.

33. The Wey.—The river Wey is the chief of the southern tributaries of the Thames in its middle course. It rises in the chalk and upper greensand in Hampshire, close to the town of Alton, where a number of small streamlets collecting water from the hills converge into a stream, which becomes almost immediately valuable for water power. The springs that supply the stream come from the bottom of the chalk, which is here in immediate contact with the lower cretaceous beds, over which the stream runs for a large part of its course.

From Alton the Wey has a remarkably straight course in a north-easterly direction to Farnham, running through the gault, and receiving at Tilford, 3 miles south-east of Farnham, a stream which rises from the upper greensand, a quarter of a mile from the source of the Wey, and it is joined by other smaller streams from the south during the first 5 miles of its progress.

Farnham is about 10 miles from the source. One mile beyond Farnham the river bends at right angles, and, after 3 miles, it receives a considerable tributary from a large group of springs and brooks around Frensham Common, having a general course parallel to that of the Wey for nearly 8 miles.

At Tilford Bridge, where the confluence of the Wey with this tributary occurs, the main stream takes the direction of the tributary, running nearly east to Godalming, with a very winding course, in a valley south of the very remarkable chalk ridge called the "Hog's back," that extends in a straight line from Farnham to Guildford. At Godalming it bends round to the north, and flows over an inlier of weald clay, and across the strike of the beds, and, after receiving a feeder coming from the south, breaks through the chalk hills between which Guildford is built, and emerges immediately into the older tertiary beds of the London basin, over which the whole of the rest of its course is run.

A tributary which enters the Wey between Godalming and Guildford rises on the southern escarpment of the lower greensand at Hurtwood Common, overlooking the weald, and runs to the south over the weald clay for about 4 miles. It then turns west to Brockhurst, receiving several feeders from the greensand hills and the weald clay district of Cranley. Arrived in the line of the great cleft through the chalk hills, the stream turns northwards for 6 miles to join the Wey near Godalming. The combined stream continues northwards 2 miles to Guildford, and afterwards about 5 miles to Woking, where a stream joins it from the west, draining a large extent of the Woking sands by a number of small streams, its drainage area being adjacent that of the Blackwater. From Woking to the Thames the Wey is very tortuous, and about a mile from Weybridge a small stream joins it from the south after a course of about 6 miles, receiving some branches. The whole length of the Wey is 41 miles. The volume of water discharged by it has been carefully estimated, and is referred to in Chapter III., § 14.

After receiving the Wey, the Thames continues its very winding course to Walton-on-Thames, below which a small feeder comes in from the north, and then, with a straighter channel, the river passes Hampton Court, where the Mole enters. The windings of the stream are now fixed by embankments, and sometimes avoided by artificial cuts, but there can be no doubt that the actual bed has shifted greatly within the historic period.

34. The Mole.—This river corresponds in some respects with the Wey, crossing at right angles the barrier of chalk hills that encloses the Weald. These hills form a natural boundary between the wealden rocks, which have been brought up on an anticlinal axis, and the London clay basin, which fills up a depression between the two escarpments of the chalk, one facing the south, called the South Downs, and the other, the North Downs, facing the north.

The Mole, though crossing the lower greensand into the weald, and obtaining water supply for some of its tributaries from the escarpment of the lower cretaceous rocks, differs in having the sources of its principal and most distant tributaries in the Hastings sand, among the lower beds of the Wealden formation. The sources of the river are, in fact, situated not far from the middle of the weald, and close to the ridge of the anticlinal, which is the water-parting of the district.

The Mole rises in Sussex, about 5 miles south of Horley, and is the union of a number of separate small streamlets that have their origin in the lower greensand and Hastings sand, and convey the drainage of the northern slopes of Tilgate forest. At Horley it is a considerable stream, which has received a number of feeders, and is already of some importance. From Horley it flows in a northerly direction, continuing to receive on both sides the drainage of a large tract of country. At Kinnersley Bridge (2 miles south of Reigate) a small tributary enters, draining a district to the north and east. This feeder rises in the gorge entering the chalk at Merstham, and, passing Red Hill, turns to the east at the foot of the hills of upper greensand at Nutfield. Receiving other tributaries from the east, it joins the Mole at Kinnersley, as before stated. Beyond this point the Mole continues to receive a number of feeders entirely from the west, proceeding from the lower greensand hills which rise at Leith Hill to a considerable elevation. Continuing to turn towards the west, it gradually approaches the line of the chalk escarpment, which here ranges nearly due east and west for a long distance, and, leaving Dorking to the left, it enters a gap in the chalk hills. This gap is nearly a mile wide at Dorking, but narrows as it proceeds, till it is reduced to a few hundred yards. In passing through this gap, the channel of the river is sometimes completely buried, and the river entirely disappears, running under-ground: hence the name of Mole. At other times, and when the volume of water is large, there is a surface channel, but a considerable part of the stream always passes under-ground. At all times the river emerges on the further or northern side of the gap near Leatherhead, in a greatly increased volume. Beyond the chalk hills, and before reaching Leatherhead, the surface rocks are entirely tertiary. After passing Leatherhead the Mole takes a northerly course, and winds a good deal until it passes Cobham, when it turns to the north-east and runs parallel to the Wey to its outflow. Its whole course is 42 miles.

35. Hog's Mill river.—Below East Moulsey, where the Mole enters the Thames, the river makes a curve to the south, embracing Hampton Court Park, and reaching Kingston, where a small stream called *Hog's Mill river* enters from the south. It rises from the upper chalk in the village of Ewell in several copious springs, and is increased by surface drainage from the adjacent hills of London clay, joining the Thames near Malden after a course of 5 miles. The flow in summer is small, but, measured after dry weather in April 1878, near Malden, after the various streams were collected, it ran more than 7 million gallons per day.

36. Summary of the Middle Thames.—Bringing together the facts regarding the drainage of the middle basin of the Thames, we find that the number of tributaries received is smaller than in the upper division, though the length of river is greater, and that the tributary streams coming from the south are very much more considerable and important than those from the north.

The principal tributaries rising in the cretaceous rocks run, to a large extent, over tertiary clays and sands, but with slight fall.

The fall of the Thames in its middle basin is 133 feet, and the length of course being about 100 miles, there is a mean fall of about 16 inches per mile. It is evident, therefore, that the sudden accumulation of a large body of water immediately above the gorge, which not unfrequently takes place after heavy rain in wet seasons, is not unlikely to produce great floods in the lower part of the basin, where the surplus waters cannot be readily carried off, owing to the comparatively level bed of the stream, and the want of fall between that point and Teddington. To that point the tide reaches, and the down-flow of the river during heavy floods, and at unusually high tides, is liable to be met by a corresponding wave advancing in the contrary direction.

The tributaries of the Middle Thames are all so extensively utilised, both for purposes of navigation and for water-power, that before they reach the main stream, they are broken up into numerous small branches, the volume of water brought down is diminished, and its effect on the main stream dissipated. On going up the river, it is difficult to discover where the most considerable of the feeders enter the Thames, and, indeed, the channels are hardly perceptible even when their exact position is known. Their influence on the state of the water, as well from the absorption of part of the water as from the complete breaking up of the remainder into small narrow channels, is not appreciated by the observer proceeding up the stream ; but it cannot be doubted that they do produce a considerable effect, assisting in purifying the stream by mixing with it a large volume of good water, and causing the water to be oxidized by exposure to the air, notwithstanding the multiplication of the channels by which the waters enter.

The banks of the Thames between Reading and Pangbourne are low and flat for some distance from the shore, and there are but few signs of population recognisable. The actual population within a few miles on either side is very small, and there are no large towns in this part of the course till we approach Kingston but Reading, Henley, and Maidenhead.

37. The Lower Thames.—The part of the Thames subject to tidal influx forms a distinct portion of the basin, and as the Upper basin is separated from the Middle by a ridge of chalk hills, so the Middle is separated from the Lower by an alluvial flat. In this part of its course the river bed has hardly any fall, the water being carried onwards by the pressure of the moving water behind, and by the impetus it has derived. The tributaries are here comparatively few, two principal streams only coming in from the north, and, except the Medway, only two, much smaller, from the south. The Medway, a large and important river, enters the Thames at its mouth, and is sometimes regarded as a separate river basin, although it will be considered here as part of the Thames. The Crouch, one of the Essex rivers, is rather wide, but does not carry much water. It runs parallel to the Thames over low flat land for some miles, and terminates as the river merges in the sea, immediately opposite the mouth of the Medway. It belongs geographically to the Thames basin.

The tributaries of the Lower Thames, excluding the Medway, and the river itself as far as London, run over the lower tertiaries of the London basin. Most of them, however, rise in the chalk, and in its lower course the river itself flows over chalk.* The sources of the Medway are in the Weald, and a large part of its course is over rocks of the same age, but the stream, when it has become large, crosses the upper cretaceous series.

An account of the tide-way of the Lower Thames has been given in a previous paragraph (see § 7), and should be referred to by the reader if he would duly estimate the nature of the lower basin, which is greatly affected by it.

38. The river Cran.—Below Kingston the Thames turns northwards to Kew, winding in large curves the whole distance, and then flows eastwards through London in a succession of similar large curves. During this part of its course it receives the Cran and the Brent, both from the north, and a brook passing through Barnes from the south.

The Cran rises on the western slopes of Harrow Hill, near London, and runs in two parallel streams, called the *Yedding brooks*, towards the south-west, for a distance of 4 miles. These brooks combining their waters; the united stream enters Cranford after a southerly course of 6 miles, and, finally turning east, approaches the Thames near Twickenham. It does not, however, enter there, but takes a turn to the north, and finally enters at Isleworth. The whole course is nearly 20 miles, part of which is in the line of the Grand Junction Canal.

39. The river Brent.—This river originates from a number of streams flowing from the southern slopes of a semicircular range of hilly ground, extending round the north of London from Stanmore heath to Highgate. These streams converge about Twyford, having had a course which, in parts, is very tortuous. They are none of them long, their total length ranging from 5 to about 10 miles. From Twyford the Brent runs 3 miles to the west, and then takes an abrupt turn to the south, passing Hanwell and Brentford, where it enters the Thames after a course of nearly 20 miles.

A small stream rising from strong springs in the chalk near Cheam and Sutton, at the foot of Banstead Downs, and passing through Coombe Wood and Richmond Park, enters the Thames at Putney, after a course of about 10 miles. It is called the *Beverley brook.*

40. The river Wandle.—This small stream, important from its vicinity to the Metropolis, enters the Thames 7 miles below the mouth

* Chalk has been brought up by anchors at Grays, a little above Gravesend.

of the Brent, draining a small extent of country to the south. Its usual source is at a point near Croydon, but at intervals of some years its waters begin to flow higher up the valley that leads from Croydon to Caterham, and this occasional addition to the length of the river course is recognised as a distinct feeder, and is called the Bourne.* The Bourne breaks out from time to time, always in the early months of the year, but varying from February to the beginning of June. The cases recently recorded are in 1853, '58, '61, '66, '73, and '76, and the quantity of water flowing has varied from $\frac{3}{4}$ to 28 million gallons in a day. With single exceptions in each case, however, the quantity has been from $3\frac{1}{2}$ to 20 million gallons. After continued rain the previous autumn, and when the chalk of the neighbourhood is fully charged with water, the stream breaks out, and continues for a period varying from a few weeks to four or even five months. It is, however, only a part of the main stream of the Wandle that is affected by this Bourne. The river flows west from Croydon to Carshalton, receiving a large addition from strong springs rising in Carshalton Park amounting to 6 or 7 million gallons per day, and then northwards, by Mitcham and Wandsworth, into the Thames, its usual length of course being about 11 miles, but liable to increase to 13 or 14.

41. The river Ravensbourne.—This river enters the Thames at Greenwich, from the south. It rises close to the outcrop of the chalk near Farnborough, and flows, first north-west through Lewisham, and then north to its outflow. Its whole course scarcely exceeds 12 miles, and is entirely over rocks of the Eocene period. It receives on its way several small feeders from the east and west. Immediately before its confluence with the Thames, it is joined by a brook which rises near Farnborough, passes Bickley, and flows for about 8 miles nearly parallel to the Ravensbourne.†

42. The river Lea or Lee.—This important feeder of the Lower Thames enters below the Ravensbourne on the opposite bank, draining about 600 square miles of country. The volume of water it pours into the Thames is comparatively small, an important portion having been taken for the supply of London, partly in the upper part of its course and partly near London. Notwithstanding this, it carries at all times a considerable body of water by an artificial channel for the purposes of navigation, only the surplus being abstracted by the East London Waterworks Company, near London. A large quantity, equiva-

* Bournes under various names are recognised phenomena among British rivers, and they have been referred to in a former chapter.

† An addition is made from time to time to this stream by a bourne, which breaks out about 2 miles from one of its sources. This phenomenon occurs rarely, and generally late in the season—not earlier than June. The water-supply is not large.

lent to half the river, has been already taken at a higher point, to assist the supply of the New River Company.

The Lea, at the commencement of its flow, is very small, but, after running a few miles, it is joined by a number of similar streams, which unite near Hertford, all originating on the slopes of the chalk hills that separate the drainage of the Ouse from that of the Thames. These hills range a little to the east of north, from Dunstable to Saffron Walden, and rise to heights varying from 300 to 500 feet. The most distant source is to the extreme north-west, near Dunstable, and bears the name of Lea from the commencement. It is a beautiful and permanent spring, rising through gravel from near the foot of the chalk hills, close to the station of Leagraves, on the Midland railway, in a farm of the same name. By the addition of small feeders, a stream is almost immediately formed, which soon attains good proportions.

Rising thus, near Dunstable, at the foot of the chalk hills, in a springy district, and collecting springs and brooks on its way, the Lea runs on to Luton, reaching that town in about 5 miles, and thence it continues to flow over the chalk in a south-easterly direction for 12 miles. Its course is parallel to that of the Ver, one of the tributaries of the Colne, the valleys of the two streams being separated by a narrow ridge of chalk.

Below Luton the river increases slowly till it approaches Hatfield, where it turns to the east and receives a very fine permanent spring at Woolmer. It is shortly afterwards joined by the river *Mimram*, or *Maran*, a pure stream rising in the hilly ground south of Hitchin, and flowing south-east nearly parallel to the course of the Lea, through beautiful park lands, the seat of Lord Cowper, at Panshanger. Both the Mimram and the Lea occupy narrow valleys in the chalk, and are doubtless added to by bottom springs, but neither of them receives any regular tributary. Immediately after receiving the Maran, the united stream enters the town of Hertford, where it is joined by the river *Beane* from the north, and within a very short distance by the *Rib* from the north-east. Both are mill-streams, with moderate fall, and afford useful supplies of pure water.

The Beane rises close to Baldock, which is on the water-parting between the basins of the Thames and Ouse, and close to the outcrop of the greensand. A number of small streams (one of them coming south for a distance of nearly ten miles) unite near Watton to form this river, which flows, after their confluence, about five miles further into Hertford, to join the Lea.

The Rib river rises from the chalk ridge near Royston, a little to the east, and after flowing about eight miles to the south is met by the *Quin*, another stream from the same range, rising a little further east than the Rib. The Rib and Quin combined, proceed at first towards the south, and afterwards to the west, about ten miles further, entering the Lea at Hertford. The union of so many streams in the flat district around Hertford, produces a wide expanse of swampy land liable to flooding. From this point as far as Ware, and for some miles beyond, the Lea flows through a wide alluvial bed, shifting its course whenever the waters come down in flood.

The principal feeders of the Lea unite at a point about sixteen miles from the Thames, where the elevation is 100 feet above the sea. The confluence is thus referred to by Mr. Beardmore in his Manual of Hydrology :—" Below this point there are clay lands on one side of the valley, and faults which cut off the chalk beds occur on the opposite side, so that in dry periods there is but little additional feed to the valley. The river is well known for its pure sources in the tertiary sands and chalk hills of Hertfordshire, hence it has always been a favourite water for the supply of London." " One of the branches of the Lea has such great beds of sand and perennial springs that the heaviest rains will not produce a flood. It is not uncommon for many months to pass without a sensible discolouration of the water by floods." The springs at Hertford are, however, affected after heavy rainfall in the country a little distant to the west, where the accumulated water sinks into the earth by pot-holes, and the water of Chadwell spring is often cloudy.

Close to the part of the Lea we are now considering, and situated between Hertford and Ware, about twenty miles from London, are the remarkable springs of Chadwell and Amwell, originally feeders of the river, but the former now taken for the supply of the aqueduct, or canal, known as the New River, whose waters are conveyed for domestic use to London. Originally, the river only took the water of these springs; but a large part of the upper water of the Lea is now diverted to add to the supply.

Up to the point where the New River supply is taken, the river Lea runs over chalk. Turning now southwards, after a mile the river is joined by the *Ash*, coming in from the north-east, and also contributing surface drainage from the chalk. The drainage area of the Ash is less considerable than that of the Rib, but precisely similar in character. It has a course of about twelve miles, and collects water by several small feeders.

Three miles below the Ash the *Stort* enters, and is the last to the east of the river channels from the chalk that belong to the Lea basin. To the east of its drainage area there is a ridge of chalk that forms the water-parting between the feeders of the Thames and the Ouse. The early feeders of the Stort are limited to a small area north-west of Clavering, and the river runs thence in a nearly straight course for six miles between parallel ridges of chalk almost to Bishops Stortford, where it receives one small feeder coming four miles from the east. It then runs five miles south past Sawbridgeworth, where it receives the *Pinsey brook*, which rises east of Bishops Stortford, and runs parallel to the Stort four miles, turning west to fall into that stream. The course of the Stort beyond is westerly for about six miles to Roydon, passing which place a final bend to the south-west brings it into the Lea at Broxbourn.

From this point the Lea continues to run for some miles due south, through a wide alluvial bottom, with the New River by its side, receiving near Broxbourn a few small tributaries from the west. Below Waltham Abbey, five miles from Broxbourn, the *Cobbin brook* enters from the east. It rises seven miles to the north-east, and has a nearly straight course, receiving one or two small feeders. Beyond to the south, the water-parting between the Lea and the Roding approaches too near the bed of the former stream to allow of any drainage from the east, and all that would naturally enter from the west, consisting only of a few insignificant brooks, is intercepted by the New River. The Lea enters the Thames in Plaistow level, just beyond the considerable bend forming the Isle of Dogs.

The river Lea is at present, and has been for some years, a navigable stream under the control of a board of conservancy ; and the Stort is kept in order by another board. In this way under very effectual supervision the waters are in exceedingly good condition, and the river is crowded with fish. For the greater part of the distance the natural bed of the Lea is quite distinct from the present navigable channel, and the latter runs a tolerably straight course, whilst the former winds greatly, and is not unfrequently left dry. The length of the Lea in its natural state if not less than 70 miles; but the navigable course is not quite 28 miles between Hertford and the Thames. The navigation terminates in Bow creek, between the Victoria and East India Docks.

An important part of the water-supply for London is taken from the river Lea, near Cheshunt, by the East London Water Company. The river at that part of its course has already lost a sensible part of its water by abstraction at Ware for the use of the New River Company, and only the overplus from the navigation water is permitted to be taken. The quality of the water, as indicated by the average of the monthly analyses for the ten years ending 1877, has already been shown (see p. 146).

43. The New River.—The artificial channel thus named originated in a scheme, projected by Sir Hugh Middleton in 1609, and effectually carried out in 1613. Its object was to supply London with water from the chalk springs of Chadwell and Amwell by an aqueduct, whose original length was 38¾ miles. After a time the Amwell spring was lost, breaking out some distance below the New River. By degrees as the supply was found to be insufficient, other waters were taken by sinking wells into the chalk, and lifting the water by pumping, and at length the river Lea itself was drawn upon, and a cut was made to connect the Lea with the New River close to Chadwell spring. This took place a century ago. By an arrangement entered into under an Act of Parliament passed in 1852, the New River Company are authorised to take a quantity of water from the Lea, equivalent to $22\frac{1}{2}$ millions of gallons in any one day. Since the Act, the New River has been greatly improved, its length reduced to 28 miles, and its banks and bed carefully protected. Receiving the whole of the Chadwell spring near Ware, it is added to in summer by the pumping from Amwell-end near Ware, by pumping from another well sunk at Amwell Hill, and again by the waters of another chalk well near Cheshunt. Thus increased from time to time in case of drought, the New River delivers to London about one-fourth of the whole quantity of water supplied for the population of the metropolis, amounting to between 20 and 30 million gallons per day.* The qualities of this water are chiefly those of chalk water, and its purity is very great, as may be known by the weekly analyses published by the Registrar-General. According to analyses made monthly by Dr. Letheby, and continued since his death by Dr. Tidy, the average quality of New River water for the ten years ending 1877 was as follows, expressed in grains per gallon :—

Total solids - - - - -	18·95
Initial or total hardness - - -	14·2°
Nitrogen, as nitrates and nitrites - -	0·121
Ammonia - - - - -	0·004
Chlorine - - - - -	0·983
Oxygen required to oxidise organic matter -	0·036

The solids consist chiefly of carbonate of lime, with a little carbonate of magnesia, and some sulphate of lime. The water differs from that of the Lea river, containing more chalk water from springs, and in summer a very large quantity of chalk water from deep wells is pumped into the river from several points on the line of the river from Ware to Cheshunt. Including the Chadwell spring, as much as from 10 to 14 millions of gallons of such water is obtainable. Compared with Thames water from Hampton, the total solids will be seen to be smaller, the hardness rather greater, the nitrogen as nitrates and nitrites smaller, the chlorine larger. A smaller quantity of oxygen is required to oxidise organic matter. Thus the character of the water approximates more to well water from the chalk, as might indeed have been expected.

* Two other wells are in progress intended to obtain water, not only from the chalk, but from the lower greensand formation below the gault; one of them is nearly completed to the greensand, and already yields water from the chalk. The experiment is interesting, but, from what is known of the lower greensand, was not likely to be successful so far as that rock was concerned.

44. The river Roding, Roothing, or Rodon.—The river bearing these names enters the Thames from the north, 4 miles below the mouth of the Lea. It rises a little to the west of Dunmow, close to some of the sources of the Stort, and has at first a course to the south through a narrow valley, receiving only a few very small rills from exceedingly short lateral valleys. It runs in this way nearly 10 miles, when its drainage area expands and tributaries come in. The stream now turns to the west for about a mile, and then recovering its direction passes Ongar, where it is joined by the *Cripsey brook* from the north-west, this stream having run six miles in an easterly direction from near Epping. Receiving a few small feeders, the Roding now follows a winding course to the south-west for five miles, fed chiefly from the west, and then continues in a tortuous course for about 6 miles to Loughton. After this it runs through many small towns and villages for about 12 miles, reaching the Thames at Barking Creek, after passing Chigwell, Woodford, and Wanstead, and being fed from time to time by small brooks from both banks. The drainage area of the Roding is 317 square miles.

45. Bourne brook (Essex).—Four miles below Barking Creek a small stream crosses Dagenham Marsh and enters the Thames from Romford. This is the Bourne brook (the second feeder of the Thames of that name), draining the country south of the water-parting that forms one boundary of the valley of the Roding. Its total course is about 12 miles.

46. The river Ingerburn.—This stream enters the Thames from the left bank in Rainham Marsh, a mile below the mouth of the Bourne brook. It has two principal branches, one rising by several small brooks around Brentwood in Essex. These when united flow about a mile south-west, and there receive additions from a group of feeders from the north. After another mile a western branch comes in from the country adjacent to that drained by the Bourne brook. The united stream now flows south for about 7 miles into the Thames, receiving small feeders from the east.

Rainham marsh, where the Ingerburn enters the Thames, is a portion of the alluvial bed of the Thames, subject to the incursion of tidal waters. It is about a mile wide at Rainham, and is a portion of other marshes ranging east and west on the left bank of the Thames between the river Lea and Purfleet. At Purfleet a small stream enters the Thames from the north.

47. The rivers Cray and Dart or Darent.—Opposite Purfleet, Dartford creek, a narrow inlet entering the alluvial bed of the river, permits the waters of the Darent, or Dart, to enter the Thames, after first receiving those of the Cray. These two independent streams unite about a mile before they make their way into the main stream.

The Cray is a charming little stream of bright pure water rising from chalk springs near Orpington, and running about 5 miles to Bexley, below which it receives a tributary, and then continues to flow 3 miles further, passing Crayford before reaching the Dart.

The Dart or Darent is a much more considerable river than the Cray. It rises near the escarpment of the lower greensand at Westerham, and runs in an easterly direction towards Riverhead, near Sevenoaks, a distance of about 5 miles. It then turns northwards, and continues in a northerly direction, cutting through the chalk hills more than 12 miles to Dartford, having a somewhat winding course, but receiving no tributaries. From Dartford to its junction with the Cray, and thence to the Thames, is nearly 3 miles. The total course of the Darent is about 20 miles.

Although the beds of the London clay cover the chalk generally in this part of the basin of the Thames, it is not so in the valley of the Darent.

Below Purfleet, the valleys on the north bank of the Thames are almost entirely parallel to the course of the stream, and there is only one river (the Crouch) to convey the drainage of this part of the basin. The principal channel enters the estuary of the Thames close to its outfall, and is the last tributary entering the river. It comes in opposite the mouth of the Medway.

On the south side there is no stream of importance below Gravesend till the Medway is reached.

48. The river Medway.—This principal affluent of the Thames originates in the wealden district south of the line of the North Downs, cuts through the chain of chalk hills at right angles, and conveys towards the north the waters flowing off a district which would appear to drain naturally to the east. The Medway is a larger and more important stream than either the Wey or the Mole.

The stream that forms the most distant branch of the Medway rises near, but to the west and south of East Grinstead, in the wealden district of Sussex. Within three or four miles of its most distant source it has already collected into one stream a large number of brooks and small rivulets from the low hills in that part of the Weald. After running in an irregular course about 10 miles to the east, it is joined at Hartfield by a branch of similar nature, whose sources are a little east of East Grinstead, and, 2 miles beyond, by a third branch from the neighbourhood of Tunbridge Wells, which comes in after a course of about 5 miles, after receiving on its way a small brook. At the confluence of these streams another comes in from the south-east, and the united stream, running northwards for a mile and a half, meets still another of some magnitude rising a little to the north of East Grinstead, and running parallel to the two first-mentioned tributaries. The stream now for the first time assumes the name of Medway, and flows a little east of north, to Penshurst, before reaching which town it is joined by the Eden, nearly as important as the Medway itself at this place.

The *Eden*, like the Medway, commences as a river with the collected drainage from a considerable area, which in this case is nearly 7 miles from north to south. The various branches, after running from 3 to 6 miles, unite near Edenbridge, and then pursue a very tortuous course of 5 or 6 miles, at first east, and then turning south, to the confluence with the Medway. The whole length of the Eden is 16 miles.

After receiving the Eden, the main stream of the Medway continues to flow to the east, passing Tunbridge, and running through a wide alluvial bottom for about 16 miles to Maidstone, receiving tributaries both from north and south, at intervals of a few miles. The chief of these are the Teise and the Beult. The *Teise* rises near Tunbridge Wells, and runs nearly 8 miles east by Lamberhurst to Gondhurst, receiving a small branch from Frant on its way, and, beyond Lamberhurst, another feeder from the south. Near Gondhurst it turns north, and, after about 8 miles, reaches the Medway, its total length of course being 17 miles.

The *Beult* is a considerable stream, draining a large extent of country to the south-east. It originates in a number of brooks and rivulets east of Headcorn, and converging near that town. They have a course varying from 4 to 7 miles to the confluence, and thence to Yalding, where the united stream enters the Medway, there is a further distance of about 10 miles. In this part of its course, an arm of the Teise unites that stream with the Beult.

Leaving Maidstone, the Medway takes a course to the north-west, gradually turning to the north, as it approaches and breaks through the barrier of cretaceous rock. Before entering the gap the river bed is exceedingly tortuous, but, after passing Lower Halling, it continues in a large steady stream to Rochester, where, after some large windings, it turns to the east to enter the Thames.

The length of the Medway to Yalding is about 32 miles, and, below that town, to the mouth of the Thames, a little more. The total length is about 69 miles, and the drainage area 997 square miles. After passing the turn beyond Rochester and Chatham, the river becomes an estuary, which expands gradually to a considerable width, and forms a valuable harbour for a part of the British navy. Numerous creeks or arms of the river penetrate the marshes which here spread inland to a considerable extent on both sides near the mouth of the stream. The flow of the Medway will be found stated in Chap. III., § 17.

49. The Crouch.—The extent of the Thames seaward may be properly regarded as reaching on the northern bank the eastern extremity of Foulness (an island in Essex), and, on the southern, the eastern extremity of the Isle of Sheppey. This would mark the limit at 9 miles east of Sheerness, and brings in as part of the drainage area of the Thames the catchment area of the river Crouch, which is connected with the river by various channels separating Wallasey island, Foulness island, and some smaller and similar tracts. The river Crouch originates in and is chiefly supplied by streams flowing south from the hills near Billericay, but it is also fed by some small streamlets from the south. The main stream flows nearly due east, past Wickford, until it enters the marshes about 10 miles from its source. It has then a further course in the same direction to Burnham, opposite Wallasey island, whence it continues for another six miles before reaching open water. Before reaching Burnham it communicates with the Thames by creeks entering between Shoebury-ness and Foulness. The Crouch is the last river entering the Thames.

50. Summary of the Lower Thames.—The Lower Thames is tidal, the tide which originally advanced several miles above Teddington being now retarded by bridges and by embankments constructed in various places. The river channel throughout, but especially in its lower part, has been greatly modified from time to time by various engineering contrivances, whose objects were to preserve an available channel for barge and ship navigation, to retain the lands on each side, and to preserve them from flooding. The result has been that a distinct channel now exists throughout, although formerly the river had a free course through a wide alluvial valley ; but this result, advantageous enough when the floods to which it is periodically subject are moderate, rather tends to increase the evil when they are excessive. Within a few years, owing to the rapid increase in the number of bridges and the frequent encroachments made by embankment, especially as the river approaches and passes through London, the bed of the Thames has been limited in sectional area, and though the increase of speed hence attained when the waters are in flood might be expected to produce the effect of scouring and deepening the channel, it has in many cases had the contrary effect, producing sand-banks, owing to the quantity of solid material brought down being in excess of the moving power. The result has been the rise of the bed, and the necessity of dredging, in default of which the floods spread over the low-lying lands on both sides, and cause the accumulation of large quantities of alluvial deposit.

The Thames has no true delta, and no bar, but its mouth is encumbered by shifting sands. These are not usually dangerous to navigation, and the changes that take place are not so rapid as is the case in larger and more rapid streams.

There is hardly any fall of the bed of the Thames below London.

The bed of the Lower Thames in various places where the chalk crops out, and is uncovered by tertiary clays, yields large supplies of water from springs breaking out between high and low water, and no doubt receives much water from bottom springs, especially where the bottom consists of chalk only covered by permeable gravel. Owing to the position of the London clay resting on the Thanet sands, the water falling on the chalk round the edge of the London basin is received and passes down below the impermeable beds, often under considerable pressure. Where that pressure is removed, either by sinking a well or by the natural exposure of the contact of chalk and lower tertiaries at a low level, water often rises abundantly; but although theoretically this should be the case in all parts of the London clay, it is practically very limited, wells having often been sunk completely into the chalk without any water being reached.

It may be convenient for reference to insert here a complete analysis of a good specimen of unfiltered Thames water as a standard of comparison, and as showing the various mineral substances contained in it. I am indebted to Dr. Tidy for this analysis:—

Thames Water, Hampton, February 1878.

	Grains per gallon.
Free or saline ammonia - - -	0·001
Nitrogen as nitrates - - - -	0·127
Oxygen required to oxidise organic matter -	0·072
Carbonate of lime - - - -	11·91
,, magnesia - - -	0·26
Sulphate of lime - - - -	3·35
,, magnesia - - -	0·12
Chloride of sodium - - - -	1·87
Nitrate of magnesia - - -	0·75
Silica, alumina, &c. - - - -	0·28
Organic matter (estimated) - - -	0·58
Total solids -	19·12
Hardness before boiling - - -	14·8°
,, after ,, - - -	3·7°

51. Drainage of East Kent.—The small catchment of the Stour to the east, beyond the Thames basin, and south of the general line of the river, now requires attention, as completing the drainage of this part of England. It consists almost entirely of chalk, covered in the northern part by a small patch of London clay, and passes to the sea by a channel that once formed the Isle of Thanet, but is now a mere ditch. The drainage is eastwards to the sea, and the quantity of water delivered very small compared with the drainage area.

52. The Stour river.—The river Stour enters the sea between the North and South Foreland, two lofty chalk headlands standing as sentinels in that part of England which approaches most nearly to the mainland of Europe. It consists of two distinct branches, called respectively the Greater and the Lesser Stour.

The *Greater Stour* is formed by two streams uniting at Ashford, which flow along the valley between the North Downs and the greensand hills. The chief of these rises near Hythe, and has a general westerly and north-westerly course of 9 miles to Ashford. The other rises at Lenham, and runs about 8 miles south-east to the confluence. After uniting at Ashford, they have a direct north-easterly course running in a depression of the chalk hills past Wye and Chilham to Canterbury, a distance of about 14 miles, leaving which city they proceed for another 8 miles to Sarr. At this point one branch proceeds northwards to Reculver, and another eastward towards Pegwell bay, the two branches insulating that part of the coast known as the Isle of Thanet. At Pegwell bay the Stour turns south a couple of miles to Sandwich, and then turns again northwards, conveying the water after this detour into Pegwell bay.

The *Lesser Stour* rises also near Hythe, about a mile from the source of the Greater Stour. It runs north-east to Barham, about 6 miles, and then north-west towards Canterbury. When within 2 miles of that city, it turns abruptly north-east, and joins the Greater Stour at Sarr.

The whole length of the Stour may be estimated at 45 miles. It is known that so lately as the reign of Henry VIII., there was a navigable channel between the Isle of Thanet and the main land, so that the reduction of this channel to a river course is a modern result of silting up, and the two streams of the Stour originally flowed into salt water separately.

CHAPTER V.

DRAINAGE AREAS OF THE SOUTH OF ENGLAND.

(1) General account of the district.—(2) Condition of the surface and geological structure.—(3) Subdivisions.—(4) Sources of supply.—(5) Rainfall.—(6) Quality of the waters.—(7) Scheme of the rivers and their chief tributaries.—(8) *Eastern Group:* The river Rother.—(9) The river Ashbourn.—(10) The river Cuckmere.—(11) The Sussex Ouse.—(12) The river Adur.—(13) The river Arun.—(14) The Titchfield river.—(15) The river Hamble.—(16) The river Itchen.—(17) The Test, or Anton river.—(18) The Beaulieu, or Ex river.—(19) The Lymington river.—(20) The river Avon (Wilts and Hants).—(21) The Dorsetshire Stour.—*Western Group: English Channel drainage.* (22) The Dorsetshire Frome.—(23) The Way and the Bredy.—(24) The Brit, and the Char.—(25) The river Axe.—(26) The river Sid.—(27) The river Otter.—(28) The river Exe.—(29) The river Teign.—(30) The river Dart.—(31) Coast between the Dart and the Aulne.—(32) The Avon, or Aulne river.—(33) The river Earme.—(34) The river Yealm.—(35) The river Plym.—(36) The Hamoaze.—(37) The river Tavy.—(38) The river Tamar.—(39) The St. Germans river.—(40) The river Seaton.—(41) The river Looe.—(42) The Fowey river.—(43) The coast: Fowey river to Carrick road.—(44) The river Fal.—(45) The Helford river.—(46) Coast drainage to the Land's End.—*Western Group: Bristol Channel drainage.* (47) The Hayle or Heyl river.—(48) North-west coast of Cornwall.—(49) The Alan or Camel river.—(50) The Bude river.—(51) Bude haven to Bideford bay.—(52) The river Torridge.—(53) The river Taw.—(54) North coast of Devon and the river Lyn.—(55) The river Parret.—(56) The river Brue.—(57) The river Axe.

1. General account of the district.—The country here understood as the south of England consists of two parts: one is the long narrow strip south of the Thames basin, extending from the South Foreland at Dover westwards for nearly 150 miles to the Isle of Portland, very narrow at the eastern extremity, but widening towards the west to about 40 miles. This forms the eastern district. Beyond it, and still more to the west, there remains the promontory of Cornwall and Devon, reaching for nearly 180 miles further in the same direction. The breadth of this latter part, at first about 60 miles, gradually narrows to little more than 10 at the extreme west. The whole area may be roughly estimated to contain about 8,000 square miles, and it includes the whole or parts of the following counties, viz.:—Kent, Sussex, Hampshire, Wiltshire, Dorsetshire, Somersetshire, Devonshire, and Cornwall. The country in the eastern division rises rather rapidly to about 640 feet, but nowhere attains any considerable elevation. It drains almost everywhere towards the south. The western district rises in Dartmoor to nearly 1,800 feet. Beyond Dorsetshire, the promontory including Cornwall and Devonshire no longer drains entirely to the south, but has an irregular line of water-parting connecting a succession of granitic bosses, and throwing off the water chiefly to the south, but partly to the north. The whole district is without any large river. The waters that fall on the surface run quickly into the sea by a number of streams from about forty catchments; but the lines of water-shed that part them only rise in a few places much above the general level.

The climate of the whole tract is greatly influenced by its position with regard to the English channel and the Atlantic ocean. It is everywhere mild, and inclined to be damp, but this is chiefly recognised in the south-western part where the atmosphere is generally near the point of saturation.

2. Condition of the surface and geological structure.—The South Downs, consisting of chalk hills which present a steep face to the sea for a long distance, terminating at Beechy Head, form a characteristic feature of the south-east of England. They are flat-topped; the chalk is very near the surface, and, being an absorbent rock, the rain that falls rapidly disappears. At intervals the line is interrupted by depressions, admitting of the passage of the rivers by which the surface is drained, and, as is very generally the case in the chalk districts, the rivers intersect the strike of the chalk almost at right angles. Eastwards, from Beechy Head to Folkestone, the country is low and flat, and consists of rocks underlying the chalk, but covered with alluvium.

Advancing westwards into Dorsetshire, the oolites appear, but they occupy only a small breadth of country. From the isle of Purbeck, where the upper wealden beds are found, to Portland island, where the upper oolites are developed and yield a valuable building stone, the distance is very small; and from Portland Bill to Lyme Regis, where the lias comes up from beneath the oolites, it is also inconsiderable. The New Red Sandstone, which then succeeds, is of greater breadth, but by far the most completely developed deposits are those still further to the west, and much older, belonging to the Devonian period, the intervening carboniferous series being abundantly but not characteristically represented.

Granite bosses have brought up these rocks, and the surface has been subsequently denuded. It is only in the northern parts of Devonshire and in parts of Cornwall, that the slates and shales of these ancient periods come to the surface; but there they entirely replace the more modern deposits. The nature of the rocks has a marked influence on the quantity, as well as the quality, of the waters that run off the surface, as the physical condition of the surface and its orography influence the quantity of rain that falls in the district.

3. Subdivisions of the district.—The whole district naturally divides into two. The eastern portion extends from the South Foreland to the western water-shed of the Hampshire and Wiltshire Avon, and includes the country south of the Thames basin. This part is the smallest, has the fewer streams, and the smaller rainfall. With the exception of the drainage area of the Stour, which is the western branch of the Avon, the rivers are all short, commencing only a few miles back from the sea. The western portion of this extensive district has a much larger surface, many more streams, higher elevations, and a heavier rainfall; but the streams are scarcely more important, and none of them possess more than local interest. The western group of streams is again subdivided into two: those which drain southwards to the English Channel, and those which empty themselves into the Bristol Channel, flowing towards the north.

4. Sources of water supply.—The eastern rivers of this district have their sources in the wealden rocks or chalk, or the rocks immediately underlying the one, or overlying the other. Those that rise in the lower cretaceous, or wealden deposits, break through the line of the chalk hills and cross a considerable distance of chalk. Those, on the contrary, that rise on the eocene deposits, hardly leave them till they reach the sea. Advancing westwards, where the oolites and lias are crossed, and the New Red Sandstone entered, we find a few streams of no great importance running over those rocks, especially in the eastern part of Devonshire. After this we enter the region of igneous and metamorphic rocks, and the drainage, whether to south or north, runs almost entirely over material little permeable, and not likely to retain, even for a short time, any considerable part of the fall. The flow of the streams here is large compared with the rainfall, but on the whole inconsiderable for want of breadth in the country crossed. The country rises to a considerable elevation in Cornwall and Devonshire, and the sources of the rivers whether from springs or surface drainage are often very abundantly supplied. The rainfall being frequent they rarely fail, and are not often lowered for a long period at a time.

5. Rainfall.—The rainfall over the western part of the district is heavy, and the number of rainy days very considerable; but advancing eastward the quantity of rain sensibly diminishes, and the distribution is also greatly modified.

In some parts of Cornwall the fall amounts to 47 inches; but even in that county, exposed to warm moist winds blowing from the Atlantic, there are spots where it is said not to exceed 22 inches. The average of the district is taken at 36 inches. In Devonshire, on Dartmoor, the fall exceeds 52 inches; but at Sidmouth is said not to exceed 16½. The fall is very great on the high ground in the middle of the country; but in the sheltered nooks on the coast looking towards the east, is everywhere comparatively small. In Somersetshire, the fall is only 19 inches at Taunton, but increases towards the west and north. In Dorsetshire, it ranges from 18½ at Abbotsbury, to 29 at Blandford. In Hampshire, it appears to be considerable, and towards western Sussex is found to amount to 34, while in parts of eastern Sussex it appears to be 33. At Hastings, though still considerable, the fall is 29 inches.

It will be evident from these figures that the rainfall over the district moderately heavy, but is very dependent on local conditions. On the whole, here as elsewhere, the amount diminishes towards the east, and is greatest on the high ground, but there are many apparent exceptions.

6. Quality of the waters.—Flowing generally over favourable soils through agricultural districts not thickly peopled, and over tracts of country not much cultivated, the waters of the south of England from whatever source are generally good. The rivers coming over the granite of Cornwall, and the granitic and metamorphic rocks of North Devon, carry excellent water, and the chalk waters of the eastern district are also excellent.

The following analyses* show that some of the waters running off uncultivated, or little cultivated, metamorphic and palæozoic rocks of the western district are exceptionally pure. The results are expressed in grains per gallon:—

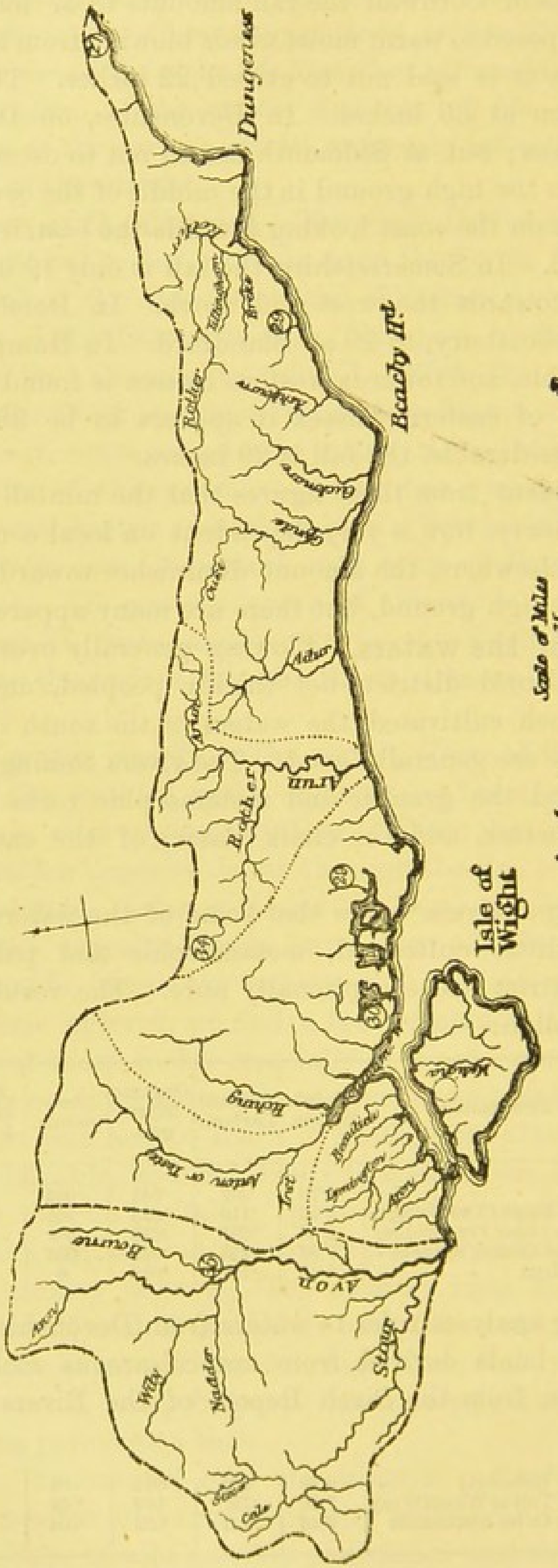
Date of Sample.	Tributaries.	Total Solids.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates & Nitrites.	Chlorine.	Total hardness.
26 Sept. '72	Teign - - - - -	4·26	·407	·041	·003	0	0·98	1·8
27 " "	South Teign (Yeo Bridge)	2·53	·116	·013	·001	0	0·98	0·8
Mean of two	Earme (near Ivy Bridge)	2·48	·087	·012	·001	0	0·88	0·9
21 Sept. '72	Alan or Camel, affluent -	7·87	·235	·042	·006	·022	2·34	2·8
2 Oct. '72	West Lyn - - -	4·45	·121	·017	0	·018	0·87	1·8

The following analyses refer to waters from Devonshire rivers, flowing over cultivated lands derived from non-calcareous rocks, and like the others are taken from the Sixth Report of the Rivers Pollution Commissioners:—

25 Sept. '72	Tamar (affluent) - -	6·89	·157	·014	·001	·074	0·98	3·2
24 Sept. '72	" Tidi at Wheal Wray	7·36	·787	·078	·039	·030	1·54	2·2
Mean of three	Exe at Culm confluence	6·45	·121	·022	·004	·036	1·11	3·6

* Sixth Report of Rivers Pollution Commissioners.

II.—Drainage Areas of the South Coast of England.—Eastern Group.



The small figures included in circles represent the mean annual rainfall, in inches, of the surrounding district.

It will be evident that all these waters are unobjectionable, and indeed unusually good. Those from the eastern part of the district are much more loaded with solids, containing sensible proportions of the calcareous rocks they pass over. On the whole, however, the waters supplied from the rivers of the south coast, on the east as on the west, are of excellent quality, and little injured by the population on their banks.

7. Scheme of the rivers of the south of England, and their chief tributaries:—

1. *Eastern Group.*

- Rother.
  - Tillingham Brook.
  - Brede.
- Ashbourne.
- Cuckmere.
- Ouse (Sussex).
- Adur.
- Arun.
  - Western Rother.
  - Western Arun.
  - West Bourne.
- Titchfield river.
- Hamble.
- Itchen.
- Test or Anthon.
- Beaulieu or Ex.
- Lymington River.
- Avon (Wilts and Hants).
  - Nadder.
  - Bourn.
- Stour (Dorsetshire).
  - Cale.
  - Allen.

2. *Western Group.—English Channel Drainage.*

- Frome (Dorsetshire).
  - Piddle.
  - Corfe.
- Wey.
- Bredy.
- Brit.
  - Eype.
- Char.
- Axe (Dorsetshire).
  - Yart.
- Sid.
- Otter.
- Exe.
  - Barle.
  - Balham.
  - Loman.
  - Dart.
  - Culm.
  - Creedy.
  - Clist.
- Teign.
- Dart.
- Aulne.
- Earme.
- Yealm.
- Plym.
- Tavy.
- Tamar.
  - Werrington.
  - Lyd.
  - Inny.
  - Tavy.
  - Lynher.
    - Tidi.
- St. German's river.
- Seaton.
- Looe.
- Fowey.
- Fal.
- Helford river.

3. *Western Group.—Bristol Channel Drainage.*

- Heyl or Hayle.
- Alan or Camel.
- Bude.
- Torridge.
  - Waldon.
  - East Okement.
  - West Okement.
- Taw.
  - Little Dart.
  - Mole.
- Lyn.
  - East Lyn.
  - West Lyn.
- Parret.
  - Ile.
  - Yeo or Ivel.
  - Tone.
  - Cary.
- Brue.
- Axe.

EASTERN GROUP.

8. The river Rother.—This river rises about 3 miles east of the eastern slopes of Ashdown Forest in the Weald of Sussex, commencing at the confluence of two groups of streams, one group collecting on the one, and the other on the other side of the village of Mayfield, and each having a course of about 4 miles. The united stream flows to the east, and after another mile is joined by a stream from a third group, a little to the north of the other two. Formed in this way into a considerable stream at Withernden bridge, the river runs 4 miles further east to

Etchingham, where it receives another tributary proceeding from Heathfield, and flowing nearly north-east. Another 2 miles adds yet another tributary, and the river then runs about 4 miles through a wide marshy bottom into which a stream enters from the north-west. Four miles further at Newenden the country opens out once more, and the great flat of Romsey march is approached. The main stream of the river runs south-east into the marsh, reaching it in about 6 miles, and a branch runs off to the north of east re-entering after a flow of about 6 miles. The intervening land is called the Isle of Oxney. In its course through the marsh the Rother turns to the south, keeping close to the high ground, and enters the sea below Rye by two branches, the westernmost of which receives two tributaries, one from Beckley, called the *Tillingham brook*, running 7 miles. The other is the *Brede,* a river rising at Mountfield, near Battle, and fed by a few small branches, after which it flows in a straight course to the east, passing through Winchelsea to the Rother. The course of the Brede is about 13 miles, and its drainage area 312 square miles. The mouth of the Rother is an estuary forming the harbour of Rye.

It is almost certain that the outflow of the Rother has greatly changed its position within the historic period, and the effect of storms on the coast, or the continued action of the sea, might now produce a similar result.

9. The river Ashbourn.—The Ashbourn is a small river entering the sea at Pevensey, and consisting of several branches, three of the chief of which rise in the slopes of a ridge of high ground extending eastwards from Dallington, about 9 miles from the coast. The principal stream passes by Ashburnham, and has a south and south-westerly course to Pevensey, draining a considerable area. Pevensey Level is traversed by channels which carry their water into the same stream before it reaches the sea. Its course is about 12 miles.

10. The Cuckmere river.—This is a larger river. It originates in a number of streams from the slopes of the Forest Ridge along a distance of 6 miles between Waldron down and Heathfield, the various streams uniting at a distance of 7 miles south of the ridge near Hellingley, whence they run south-west in a tolerably direct course, entering the sea west of Beachy Head, and receiving no tributaries from either side. Although the general direction is preserved, the stream makes a number of small curves throughout its course. It drains 75 square miles.

11. The river Ouse (Sussex).—The Sussex Ouse begins at Ryland in the country south of Tilgate Forest, and almost on the slopes of the high ground of the Forest. It flows east for about 6 miles, and receives another stream from the north composed of several branches rising on different parts of the eastern slope of the Forest. The Ouse turns towards the south-east after this confluence, and continues in this general direction, but with some sinuosities to Isfield church, a distance of about 12 miles, where a tributary joins it coming from Ashdown Forest in the north-east. The main stream takes the direction of this tributary and continues to the south-west, draining some extent of country on each side, and after a very tortuous course reaches Lewes, the distance in a direct line being 6 miles, but much greater if measured on the windings of the stream. From Lewes the Ouse runs in a tolerably straight course nearly due south to Newhaven where it enters the sea.

12. The river Adur.—This next stream has three sources, and drains a considerable tract of country by distinct branches, one obtaining its supply from the east as far as Cuckfield, one from the north in St. Leonard's Forest, and one from the north-west from the country between Billinghurst and Itchingfield. The breadth of country from east to west is fully 16 miles.

The main branch of the Adur is the north-western, the stream coming from this direction originating at the most distant point from the outflow. A few small feeders near Itchingfield unite after running south 3 miles, and after another mile they receive a small branch from the west. The stream continues 3 miles to West Grinstead, receiving important additions from the west. It then runs south for 2 miles, receiving another westerly branch, and there the main branches from the north and east come in. The northern branch coming for about 8 miles from the slopes of St. Leonard's Forest is small, but the eastern branch, originating near Cuckfield and draining an extensive country to the south by many tributaries, is important. The drainage from the northern slope of the South Down hills, from Ditchling Beacon to the gap through which the Adur flows to the sea, enters this part of the basin by a large number of streams.

From the junction of the branches near Ashurst the Adur flows in a direct line, but with a very tortuous course, through a narrow gap in the chalk hills to the sea a direct distance of 8 miles. The Adur enters the sea at Shoreham.

13. The river Arun.—This river has, with the exception of the Avon, the largest drainage area of all those entering the English Channel belonging to the eastern group, and it is remarkable for the wide extent of its drainage from the higher parts of the Weald. Its tributaries extend a long way to the east, far overlapping those of the Adur, the adjoining basin in that direction. They also extend west into Hampshire.

The sources of the Arun are to be found in the forest of St. Leonard's, adjoining and to the west of Tilgate Forest, a classical district in Sussex and Wealden geology. The whole of the forest ground is furrowed with parallel channels, between 2 and 3 miles long, carrying down the rain that falls on the hills to the level ground to the south of the Forest. The collected waters are carried off to the west by a long channel and are constantly increased on their way by small streams from the same direction all running south-west. This long channel follows the line of the hills, curving slightly northwards, and after continuing about 12 miles it bends round abruptly to the south for 5 miles where it is met by another stream starting from the hills to the west, 4 miles north of Petersfield, whence it runs south to Petersfield, and there turns east, having a course of at least 10 miles to the east to this confluence. From Wisborough green, where the two principal branches meet, the river continues running to the south with some windings, passing Pulborough, where it receives the *Western Rother* from the west, draining the country at the foot of the South Downs for a distance of more than 16 miles. This river passes Midhurst, and receives some important tributaries from the north, one of them running more than 6 miles before reaching its destination. Another, the *Western Arun*, enters at Selham after a similar and parallel course. From the confluence of the Western Rother, the Arun runs a tortuous course of 12 miles to the south, passing Amberley and Arundel, and entering the sea at Little Hampton.

Beyond the Arun, no river channel is found to the west till we approach Southampton Water. Near Havant there are, indeed, one or two very small streams, as the *West Bourn* at Emsworth, and another feeder entering Langston harbour at Bedhampton, but they do not penetrate far inland. Fareham is also situated on a small stream, having a course of about 4 miles to the town, and a further course of 6 miles through an estuary to Portsmouth.

14. The Tichfield river.—We next come to the Tichfield river, which rises on the downs near East Meon, and runs in a semicircular curve northwards by West Meon, and then southwards again by Warnford, Exton, Meon Stoke, and other villages, and then by Wickham and Tichfield to the open water at the entrance of Southampton Water. The whole course is nearly 20 miles, and entirely over chalk.

15. The river Hamble.—At the entrance of Southampton Water the Hamble river enters by Hamble creek, a long arm of the Southampton Water. This little stream rises near Bishop's Waltham, and receives one or two small feeders, having a total course of 10 or 12 miles.

16. The river Itchen.—This stream and the Anton, or Test, open into Southampton Water. The former rises on the downs about 3 miles east of Mitcheldever, and flows 4 miles south to Ovington, where it receives a small feeder from the south, and runs about 5 miles west, through a wide bottom, to King's Worthy, when it again turns to south, and in 3 miles further reaches Winchester. It then runs on about 12 miles to Southampton, its channel being frequently branched as it flows through a wide alluvial bed. Before reaching Southampton it makes a considerable curve, and receives at South Stoneham a tributary from the north. The total course is 25 miles.

17. The river Test.—This river, sometimes called the *Anton*, is duplex, comprising two principal branches, called the Test and the Anton. The easternmost, or Test, rises in the chalk about 5 miles north of Andover, and runs about 7½ miles to the south-east to Hurstbourne Priors, where it receives a considerable feeder, rising 6 miles to the east, and flowing past several villages to Whitchurch and Tufton. Having joined the northern branch, the combined stream runs 6 miles further to the south-west, where it is joined by the *Anton*. This river, the other branch, rises near Andover, and proceeds southwards 6 miles, having received the *Pilhill brook* from the west before reaching that town. After this confluence the river flows 10 miles further over the chalk in a direction a little west of south to Mottisfont, where it receives a tributary from the west, running 6 miles from the water-shed of the Avon between West Grinstead and Alderbury. Another 3½ miles to the east of south brings it to Romsey, where there is a small feeder from the east, and after another 8 miles it joins the Test, and Southampton is reached. The total course of the Anton is 27½ miles, and of the Test 35 miles.

18. The Beaulieu river, or Ex.—This stream rises near Lyndhurst, in the New Forest, and, after a course of 5 or 6 miles, expands into an estuary, entering the Solent opposite Gurnet bay in the Isle of Wight. Its total course is 13 miles, and its drainage area 52 square miles.

19. The Lymington river, or Boldre.—The river thus named collects the water of several streams rising near Lyndhurst, in the New Forest, and conveys them south-east to the town of Lymington, and thence to the Solent, opposite Yarmouth, in the Isle of Wight. Its total course is 15 miles, and its drainage area is 91 square miles.

20. The river Avon.—This river, distinguished from many others of the same name as the "Wiltshire and Hampshire" Avon, is by far the largest and most important, as it is the westernmost, of the rivers of the eastern group draining southern England. It originates in several chalk springs, situated on a line extending from Devizes to a point 12 miles east of that town. These springs supply small brooks and rivulets; one group of them from the east, which comes through the Vale of Pewsey, running west a distance of 8 miles from the high ground south-east of Marlborough, and the other running east nearly 10 miles, from the hills north of Devizes. They meet in the small village of Upavon, both having turned southwards towards the confluence. From Upavon the united stream runs due south about 16 miles to Salisbury, passing Amesbury, and having a somewhat winding course, but receiving no tributaries. Near Salisbury two principal branches enter, one from the north-east running a similar course to that of the Avon for 9 miles; and another, called the Wiley, from the north-west. After the junction it passes through a number of villages, receiving on its way other smaller tributaries, and enters Hampshire at a distance of 40 miles from its source. It continues to flow towards the south through that county for about 25 miles to Christchurch, where it is joined by the Stour, and the two streams combined form the estuary of Christchurch Haven.

The *Wiley* originates in a fine spring on the borders of Somersetshire and Wiltshire, and its course is very capricious. In ordinary seasons it runs under-ground in a hidden channel as far as Kingston Deverill, where it first appears at the surface as a permanent stream, which flows, under the name of the *Deverill*, past Warminster, to a point where it receives a small feeder called the *Were*. Passing Heytesbury, it is soon joined by the *Winterborne*, and after some distance, as it approaches the Avon, the *Nadder* joins it from the west. This tributary rises at Dowhead, in Dorsetshire, from the union of several rivulets, which are first known as the *Don*. The name of Nadder is not assumed till after the junction of the *Sem* rivulet with the Don, which takes place at West Hatch. The course of the Nadder is 18 miles. The Wiley joins the Avon at Salisbury, after a total course of 27 miles. The whole drainage area of the Avon basin is 673 square miles.

The *Bourn* rises in the chalk at Collingbourne, and flows southwards, passing a number of villages, and reaching the Avon below Salisbury after a course of 23 miles.

21. The Dorsetshire Stour.—This stream, one of the many English Stours, joins the Avon in Christchurch harbour, and is the chief river of the country of Dorset, from which it takes its distinctive appellation. It originates in six streams, three of which rise in Stourhead park. Winding round the hill at the foot of Shaftesbury, and then to the south, the combined waters soon receive the *Shreen water*, also from the north, and shortly after the *Lidden* from the north-east. The stream then flows in a very winding channel to its junction with the *Cale*, and afterwards continues its course receiving another feeder at Stourminster Newton, and then running nearly south-east past Blandford, and turning still more to the east it receives on its way the *Allen* and the *Cranbourn* (18 miles long) from the east. It joins the Avon in Dartmouth harbour, after a course of 65 miles, of which 40 miles (as far as Stourminster Newton) are navigable. In part of its course it runs through a depression in the Downs. The drainage area of the Stour is 460 square miles.

The Avon and the Stour together drain about 1,310 square miles of country. They are nearly equal in length of course, and have their sources in the secondary rocks, the former in the cretaceous, the latter in the oolitic series. Both cross the chalk, but the Stour runs principally over the middle oolites.

2. Western Division.

English Channel Drainage.

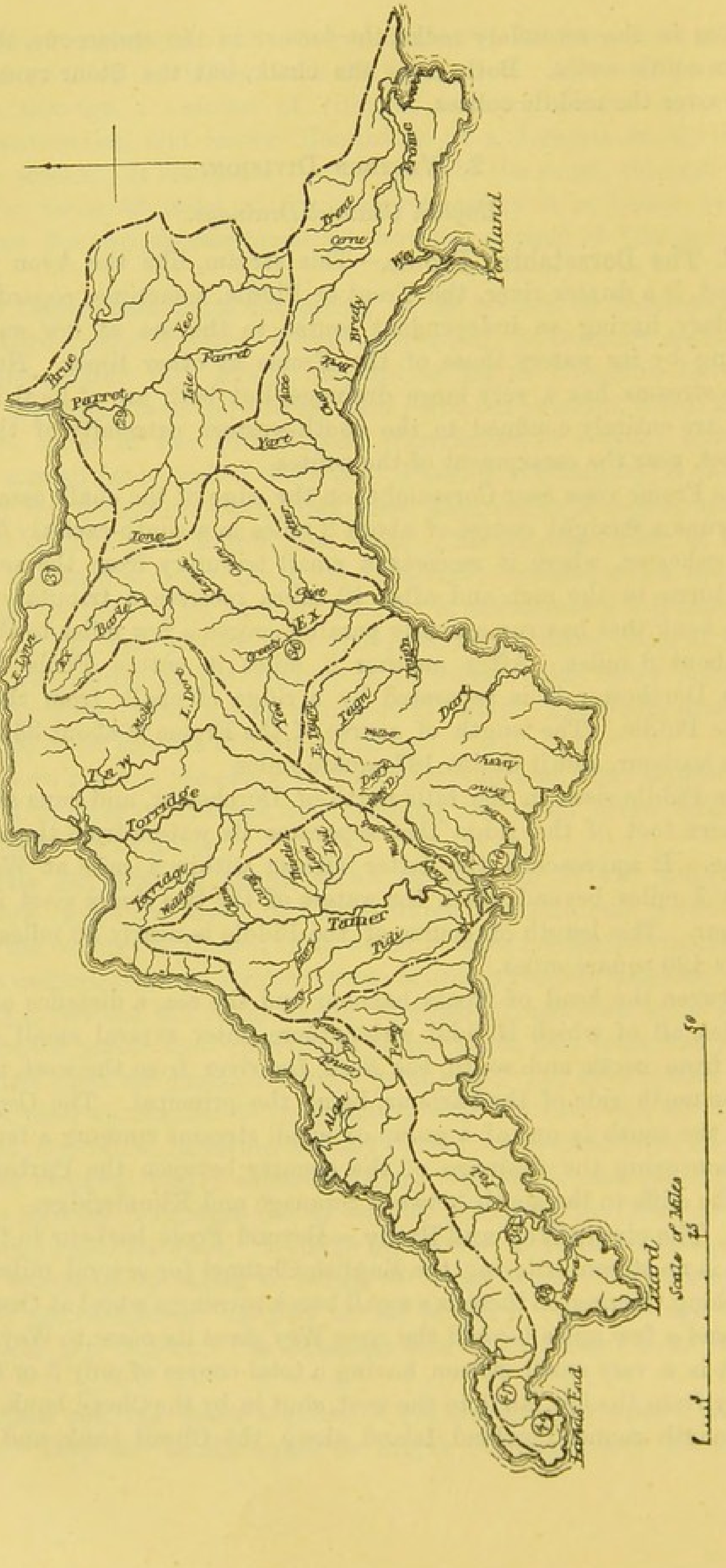
22. The Dorsetshire Frome.—This stream, like the Avon just described, is a duplex river, the Trent or Piddle, sometimes regarded as a tributary, having an independent course to the sea at low water, but feeding by its waters those of the Frome at other times. Neither of these streams has a very large drainage, but both are of local interest. Both are entirely confined to the south-western extremity of the chalk district, near the escarpment of the oolites.

The Frome rises near Corscombe, on the edge of the chalk escarpment, and runs a straight course of about 8 miles in a south-easterly direction to Dorchester, where it receives a small tributary from the north. It then turns to the east, and after 10 miles receives a tributary on the right bank that has run a nearly parallel course a few miles to the south for about 8 miles. After another 8 miles it enters Poole harbour. From Dorchester it is separated by a ridge of chalk from the course of the Piddle. The length of course of the Frome is about 35 miles to Poole harbour, and it drains 187 square miles.

The Piddle rises in the hills north of Dorchester, and runs along the northern foot of the ridge that separates its waters from those of the Frome. It approaches the latter stream within a mile at Wareham, about 2 miles beyond which the waters of the two rivers meet in Poole harbour. The length of course of the Piddle is nearly 30 miles, and it drains 120 square miles.

Between the head of Poole harbour and the sea, a distance of about 8 miles, all of which is tidal water, there enter several small streams both from north and south, the *Rock Lea* river from the west, entering on the north side of the harbour, being the principal. The *Corfe* river from the south is one of a group of small streams running a few miles, and conveying the drainage of the country between the Purbeck hills and the cliffs to the south between Swanage and Kimmeridge.

23. The rivers Wey and Bredy.—Beyond Poole harbour to the west there is no stream entering the English Channel for several miles. Approaching Osmington there is a small brook turning a wheel at Osmington mill, and a few miles beyond the river Wey gives its name to Weymouth; but it is a very small stream having a total course of only 5 or 6 miles, chiefly from the low lands to the west, shut in by the Chesil bank. From Weymouth round Portland Island along the Chesil bank, and on the



III.—Drainage Areas of the Rivers of the South-west of England.

straight line of coast beyond for more than 20 miles to the mouth of the Bredy, there is no indentation whatever.

The Bredy drains about 20 square miles of country. It flows from the east for a considerable distance, having a westerly course of about 9 miles from near Little Bredy, and turning abruptly into the sea at a sharp angle through a gap in the cliff which immediately succeeds the western extremity of the great Chesil bank.

24. The Brit and the Char.—A mile beyond the mouth of the Bredy the Brit enters the sea from Bridport. It rises on the chalk near the junction of the North and South Downs, and flows in a nearly direct course 9 miles to the sea from the north, being joined by a small feeder called the *Eype.* The expanded mouth of the Brit forms the small harbour of Bridport. It drains about 52 square miles.

The Char, a similar small stream, rises at Pillesdon Pen, and has a south and south-west course of about 9 miles to the sea, entering at Charmouth, and receiving many small feeders on its way. It drains nearly 40 square miles.

25. The river Axe.—This river rises at Axnoller, near Beaminster, Dorset, its sources being close to those of the Brit and the Parrett, and also of the Frome, the former running east and south, and the latter conveying its waters north to the Bristol Channel. The Axe flows at first westwards, and soon receives small feeders from near Crewkerne in the north, and from hilly ground on the south. It continues its westward course till it receives a small feeder coming southwards, and passing near Chard. It takes the direction of this tributary, turning southwards and westwards, to Axminster, a little beyond which it receives the *Yart,* its principal tributary, which has had a nearly straight southerly course of 14 miles from Otterford on the Black Down hills. The Yart is fed near its confluence with the Axe by a smaller stream running nearly parallel to it. From Axminster the Axe has a winding course to the south-west, receiving another considerable tributary from near Honiton in the north-west, after which passing Axmouth, it enters the British Channel through a break in the cliff near Seaton. The whole length of course is 23 miles, of which about 2 miles are tidal. Its drainage area is 165 square miles.

26. The river Sid.—This is a very small stream rising at the head of a narrow valley at a point about 7 miles north of the town of Sidmouth. As it nears Sidmouth, it receives several small feeders from the east and west. The mouth of the Sid is nearly 8 miles west of the mouth of the Axe.

27. The river Otter.—Four and a half miles south-west from Sidmouth, the Otter enters the British Channel. It rises at the eastern extremity of the Black Down hills, familiar to geologists as presenting an interesting phase of the lower greensand. It flows south, turning a little to the west and receiving a few small feeders, and reaches Honiton after a run of about 10 miles. It then turns south-west and south for about 6 miles to Ottery St. Mary, where it receives a tributary from the north. It thence flows nearly due south for 9 miles to the sea, passing several villages, but receiving few tributaries. Most part of its course is between steep banks and hills on both sides. Its total length of course is about 26 miles, of which $1\frac{1}{2}$ is tidal.

28. The river Exe.—From the mouth of the Otter to the mouth of the Exe is about 5 miles, measured along the rocky cliffs from Budleigh Salterton to Exmouth. The main stream of the Exe rises at Exe Head in the wild hills of Exmoor in Somersetshire, and the river flows first to the east and south-east for about 9 miles between high hills, and then receiving a tributary from the eastern part of the same hills, it takes a southerly course, flowing through a deep valley for about 19 miles into Devonshire, forming the county boundary between Somersetshire and Devonshire for some distance. In this part of its course the Exe is a beautiful river, rapid at first, but soon becoming tranquil, and passing through a well cultivated district. Its descent from the moor is peculiar, and its change of character from a furious torrent to a placid stream abrupt.

Cleaving a passage through the hills it enters an Alpine valley between banks richly clothed with wood, occasionally reaching to the margin of the stream, and is soon joined by another similar stream, the *Barle*, from the west, still more picturesque, and running parallel to the Exe for some distance before joining it.

A little below the junction of these two streams the Exe leaves Somersetshire, and sinks into a well wooded Devonshire valley, receiving before reaching Tiverton the *Balham* (10 miles), and the *Loman* (10 miles), both from the left or eastern bank, and the *Dart* (6 miles) from the right. The *Creedy*, from Crediton (16 miles), and the *Culm* (26 miles) from Cullumpton, the former from the north-west, and the latter from the north-east, come in about 13 miles further, and add their waters to the Exe, the valley then opening out as it approaches Exeter. The Culm has received on its way some considerable feeders, and the Creedy has been joined by the *Yeo* (13 miles long).

Five miles below Exeter the *Clist* (18 miles long) joins the Exe at Topsham, and the river becomes tidal, the tide-way being 7 miles long by the low-water channel. The whole water-way of the Exe is 55 miles, and the drainage area is 645 square miles. The basin of the Exe reaches northwards to within about 4 miles of the north coast of Devonshire.

29. The river Teign.—Six miles south of the estuary of the Exe is another smaller estuary, at the mouth of a stream of some importance called the Teign. Between them, nearly midway, is a small rivulet entering at Dawlish. The Teign rises on the slopes of Dartmoor, near

Siddaford Tor, collecting the waters of several small valleys. The chief sources are on the eastern face of Dartmoor close to the sources of the Dart and the Okement (a feeder of the Torridge), and are several in number, the *Walla* being the most important. Collected into one stream as the *North Teign*, the river, flowing a couple of miles east, receives two more principal branches, one (the *South Teign*) from the south, and another from the north near Chagford, and thence proceeds towards the east, increased by small feeders for about 7 miles beyond Chagford. Turning then abruptly south, it continues to flow about 6 miles to Chudleigh receiving small affluents, and 2 miles beyond it is joined by the *Bovey river*, a considerable stream passing Bovey Tracey. The length of the North Teign to the junction is 30 miles, and of the Bovey river 15.

After the confluence of the two streams they form a large basin filling the whole space of a winding valley between hills of some elevation beautifully clothed with wood, or richly cultivated lands. The bold red rock which forms the western barrier of the Teign, as it enters the large bay at its mouth, is a grand and picturesque object.

At this point are Newton Bushel and Newton Abbot, about 3 miles from the confluence of the stream, and the river is turned abruptly to the east to reach the sea, through a wide tidal channel extending from Newton nearly 6 miles before opening out to the sea. At Newton a small feeder comes in from the west. The whole course of the Teign is 33 miles, of which 5 are tidal, and its drainage area is 203 square miles.

30. The river Dart.—From the mouth of the Teign there is no coast drainage for a considerable distance, there being a succession of hills near the shore for more than 16 miles. The river Dart then enters the sea. It is the principal river of Dartmoor, its sources being in the centre of that rocky granite mass, which rises as a huge boss in the middle of Devonshire, rivalling in wildness, though not in elevation above the sea or in extent, the mountainous parts of Wales and Scotland.

The Dart collects into one stream the numerous rivulets proceeding southwards from the granitic boss of Dartmoor. There are two principal forks called the *East Dart* and *West Dart* respectively, the former advancing farther towards the central boss of Dartmoor, the latter having a more complicated system of branches. After running a long distance, and receiving several tributaries, they unite at a point about 9 miles in a direct line from the central nucleus of granite, and pursue a tortuous course more than doubling the distance in the first 6 miles from the confluence. They here receive a bifurcated rivulet, the two forks being called the *East Webber* and the *West Webber*. Four miles below this confluence, the Dart receives a tributary from the north which has passed Ashburton, and comes into the main stream at Buckfastleigh. Thence winding in large curves for 8 miles it reaches Totness, where it receives a considerable tributary from the north, and then continues to wind, but in smaller and more tortuous folds till it reaches the sea after another 10 miles. The whole course is estimated at 36 miles, of which 10½ are tidal. The drainage area is about 200 square miles.

The last six miles is through a wide and noble estuary, occasionally expanding so as almost to resemble a lake, and soon narrowing and running between hills. The last town on the stream is Dartmouth, which is passed about a mile and a half before the river discharges its waters into the Channel. The Dart is throughout a very beautiful and picturesque stream, rapid, clear, and pure, running over a rocky bottom, and passing through charming scenery, both of rock and woodland.

31. Coast between the Dart and the Aulne.—There is now another long sweep along the shores of Start Bay, between the mouth of the Dart and Start point, a distance of 9 miles, in which there is no direct drainage to the sea. This coast line is characterised by a number of lagoons, receiving a small supply of water from the interior, but shut off from the sea by sands. Five or six small streamlets here approach the sea, but have no apparent outlet. From Start point to Bolt head, a distance of about 6 miles, are almost continuous high cliffs with scarcely any coast drainage.

Before reaching Bolt head there is a considerable inlet running up nearly 6 miles to Kingsbridge, with several branches receiving small streams from the interior. Though sufficient to turn mills, none of these are large enough to be worthy of special notice. Between Bolt head and Bolt Tail (4 miles) there are no streams, and thence to the mouth of the Avon or Aulne (3 miles) there are only small rivulets, draining the coast to a distance of about 2 miles inland.

32. The Avon or Aulne river.—This is the first of a group of small streams rising on the southern slopes of Dartmoor Forest, and entering the English Channel by estuaries which appear to indicate in former times more important streams than now exist in connection with them. The Avon rises at Aune head on Dartmoor, and has a run of 23 miles in a curved direction, rounding first to the east, receiving a few insignificant feeders, and turning west to enter the sea. The tide runs up nearly 4 miles. The drainage area is 54 square miles.

33. The river Earme.—Three miles west of the mouth of the Auln the river Earme enters the sea, rising on Dartmoor about a mile west of the Aulne, and having a course of 15 miles, nearly 3 of which are tidal. The Earme has a few small feeders, one of which, entering near its mouth, passes the town of Modbury. It drains 43 square miles.

34. The river Yealm.—After 6 miles further of rocky coast the Yealm enters the Channel. It rises about a mile to the west and as much to the south of Erme head, and has a tolerably straight course of about 9 miles to Yealm bridge, where it turns to the west, and passing Yealmpton. After 2 miles it enters a tidal estuary with branches, by which its waters reach the Channel in another 4 miles. The drainage area is 46 square miles.

35. The river Plym.—From the mouth of the Yealm it is only 3 miles to the entrance of Plymouth Sound, a large bay which is continued inland by a wide salt-water channel, into which the Tamar enters. In the eastern part of the bay there is another and smaller inlet called the Catwater, which receives the waters of the Plym, a more important stream than either of those just described.

The Plym originates on the slopes of Dartmoor at Plym Head, a mile to the west of Erme head, the source of the Erme river. Collecting the water from the granite hills on both sides by a number of small rills, it runs for about 8 miles to the south-west in a narrow valley to Shaugh bridge, where it receives a considerable branch coming down from near the prison establishment at Prince town, in a winding course of 10 miles, longer, therefore, than the stream that bears the name of the river. From Shaugh bridge the combined stream runs on to the south with a further course of 7 or 8 miles to the Catwater. On its way it receives small feeders from both east and west.

36. The Hamoaze.—The Plym entering Plymouth Sound by the Catwater in the east of the sound, the Tamar in like manner enters on the west from the Hamoaze. The sheet of water thus named is a large and remarkable estuarine expansion penetrating into the land for a long distance, singularly picturesque in its surrounding scenery, and receiving a number of streams, of which the Tamar and the St. Germans, or Lynher, are the most important. The Hamoaze is the anchorage of Her Majesty's ships "in ordinary." It extends first about a mile to the west, giving off in succession the creeks of Millbrook (2 miles), and St. John's Lake ($2\frac{1}{4}$ miles), both to the west, and both with smaller branches. The main estuary then turns north for more than 4 miles to Saltash with an important branch to the south-west, which receives the St. Germans or Lynher river. At Saltash there is a wide expansion, and the creek assumes the character of a lake, and about $1\frac{1}{2}$ miles from Saltash four branches are seen, that to the east being a short creek of about 2 miles, the north-east the river Tavy, the north the river Tamar, and the west a creek about a mile in length terminating in a small stream running 2 or 3 miles from the north.

37. The river Tavy.—This beautiful stream rises on the west side of Okement hill on Dartmoor, its source being separated only by a low ridge from the waters of the Okement that flow northwards into the Torridge. Like the other rivers flowing off Dartmoor, the stream is fed by a number of branches, some of them 3 or 4 miles in length. It flows in a south-westerly direction about 12 miles to Tavistock, passing some mines and several villages. Beyond that town it has a winding course for nearly 5 miles to the south, and then receives the *Wallcomb river*, a considerable feeder rising on Dartmoor, and receiving several small confluents on its way. Its general course is parallel to that of the Tavy. From this junction which takes place at " Virtuous Lady " copper mine, where it is within a mile of the main stream of the Tamar, it has a further course of about 6 miles to the south into the creek, and after another 3 miles makes its way into the upper part of the lake above Saltash, where it merges into the Tamar before entering the Hamoaze. Its drainage area is 85 square miles.

38. The river Tamar.—This river, one of the largest of its group, has its origin on the southern and western slopes of the moors, within 6 miles of the north coast of Devon at Bideford Bay, close to the sources of the Torridge. It rises in Cornwall, and has at first a long course to the south, separating Cornwall from Devonshire, and flowing 12 miles in a narrow valley between two ridges within 3 miles of the west coast of Cornwall. For some distance it is accompanied by a canal, which at one point connects with Bude Harbour. Bending a little to the east the river continues for another 10 miles, gradually diverging from the coast. It then receives two feeders, the *Deer* and the *Claw*, from the north-east, within a mile of each other, these being the first that have joined of any magnitude. Both drain the hilly country in that part of Devon. After another 8 miles another feeder enters from the west, followed after a mile by one from the north-east, after which it receives the *Ottery* or *Werrington river* from the west. Launceston is situated on this stream, about 3 miles from the junction. The Tamar now alters its direction, running nearly due east for about 2 miles, where it is joined by the Lyd.

The *Lyd* rises among the granite hills at the western extremity of Dartmoor, and after a picturesque course of abont 10 miles to the west, passing Lydford, it is joined by the *Lew water*, a considerable mountain stream from the same direction as the Lyd. At Lydford, the stream falls in a cataract in a wooded dell amid rocky scenery. After another 4 miles, still to the west, the *Thistle brook* comes in from the north-east, after receiving a feeder from the north, and reaches the Tamar after a further course of 2 miles. From the confluence of the Lyd, the Tamar flows south about 5 miles, and then turning abruptly to the east and winding a little, it receives the *Inny*, a feeder from Cornwall. This river rises near Davidstow, about 4 miles from the west coast of Cornwall, and flows nearly 20 miles a little south of east through a valley about 3 miles wide, shut in for the whole distance, but receiving several small feeders. The scenery is very beautiful.

After receiving the Inny, the Tamar winds in a loop round Warmwood, and continues winding in other curious curves till it approaches Hingston Down, round whose spurs it makes its way in a succession of curves, doubling its length as it passes between Hingston and Morwell Downs. Finally, making another large curve and receiving a few small tributaries, its bed widens out into an estuary, and it approaches the beautiful open tidal water of Saltash.

The Tamar drains an area of about 600 square miles, and resembles in some respects the drainage area of the Exe. It is remarkable for the number and importance of its tributaries.

39. The St. Germans or Lynher river.—This western extension of the Hamoaze has four branches, two to the north receiving rivers from that direction, one to the west, and one to the south, both which are creeks with very little land water.

The branch that first requires notice is a stream rising among the granite hills in the north-west, not far from the course of the Inny. The drainage of these hills collects after a course of 4 or 5 miles at Trebartha, and the stream flows nearly south-east for about 10 miles, receiving small feeders on each side. It then turns south, and continues for another 10 miles, gradually turning towards the east, and receiving no tributaries of importance. In its lower part it passes through a pleasing and cultivated country.

The second branch is shorter and less important. It rises about 10 miles north-west of the town of St. Germans, and passes through a pleasing country, turning several mills on its way. It turns east and south, widening as it approaches St. Germans and enters the estuary. The whole drainage area is about 75 square miles.

40. The river Seaton.—There is no drainage to the coast from Plymouth sound, round Cawsand bay and Rame head, into Whitesand bay, till we reach the entrance of the Looe bay, when the Seaton, a small stream enters, rising about 4 miles north of Liskeard, passing near that town, and having a southerly course of about 12 miles, fed by one or two very small tributaries.

41. The river Looe.—The stream thus named, enters Looe bay between 3 and 4 miles west of the mouth of the Seaton. It consists of two branches uniting within a mile of the outflow of the river to the sea, which is entered by a narrow estuary between the towns of East Looe and West Looe. The eastern branch called the *East Looe*, originates about 3 miles to the north-west of Liskeard in several branches, which combine near that town, and run about 10 miles south to the estuary. The other branch is called the *Black Looe*, or *Duloe*, and has a course of about 7 miles, passing chiefly through wooded country.

42. The river Fowey.—From Looe bay to Fowey harbour, about 10 miles of coast, there is no drainage into the sea, except from a small stream at Polperrow, about midway. The Fowey, however, is a somewhat important stream.

The eastern branches of the Fowey are short and of small importance. The main stream originates in a number of small narrow valleys between the numerous hills of granite, extending in a large irregular curve from Brown Willy to the Cheesewring, two remarkable granite hills in the east of Cornwall. It is, however, only the rain that falls on the eastern slopes of Brown Willy that feeds the main stream of the Fowey, and it is not till after a flow of 10 miles to the south-east, that the stream takes its final direction westwards, which conducts it to the sea.

At this point, near the source of the Seaton, the Fowey is already a considerable stream, and after running 5 miles south and west, it receives an important feeder from Bodmin moor in the north, and less than 3 miles beyond, and due east, a second equally important tributary enters from the same direction. The river continues its course to the east for 5 miles further, another but smaller feeder entering from the north, after which it continues about 4 miles in a southerly direction to Lostwithiel, and after another 3 miles also south it expands considerably, and flows for 6 miles through a wide flat-bottomed valley, up which the tide flows. The river has a total course of 36 miles, and traverses some of the prettiest country in Cornwall. Its drainage area is stated at 120 square miles.

43. Fowey to Carrick Road.—Except a small stream fed by a number of brooks between Roach and Lanivet, passing Luxilion, and entering St. Blazey bay three miles south of Luxilion in the wide tidal flat of Par Sands, there is no drainage whatever to the coast west of Fowey, till we reach Mevagissy bay. Through this bay a small stream called the *Winnick* makes its way to the sea, passing St. Austell, and coming from the granite hill of Hensbarrow, which is upwards of 1000 feet above the sea. The coast here trends south for a distance of nearly 10 miles from Fowey, and then turning west into Verryan bay, after 2 miles admits the passage to the sea of two other small brooks near Carclaze, a place very remarkable for a vast open working, from which tin ore has been obtained from time immemorial. The working, once a mine, is now an open cutting of decomposed granite, worked into china clay. From Carclaze, the coast still trends to the south and south-west for nearly 12 miles, with no break admitting a stream of the smallest importance, until we approach Falmouth bay, and enter the large and wide sound called Carrick road.

Carrick road is an inlet about a mile wide, running north into the interior for nearly 5 miles, with several tidal branches and harbours on each side. The first to the east is St. Mawe's harbour, which after entering for half a mile east, runs up north nearly 3 miles with two branches. It terminates in a branch of about a mile, which receives a small stream. The next branch is at St. Just. The end of the roads forms a passage of about a mile and a half, and then again branches to east, west, and north. The east branch receives the *Fal river.* The north is called Mopus road and leads to St. Clement's creek, which communicates with the interior by three principal forks running up 5 or 6 miles, and from the end of the roads, before the creek is given off, there is another large branch to the north-west which receives two rivers, one from the north, the *Kenwyn,* and the other from the north-west. The *St. Allen's* river is a branch of the Kenwyn. On the western side of Carrick roads there is a wide creek opening at Restronguet point, which receives a river on a branch of which is Gwennap, and south of this there is another much smaller creek. Lastly, at the entrance to the roads on the west is Falmouth harbour, a large and important roadstead on whose southern shore Falmouth is built, and this runs up about 2 miles to Penryn, where it receives two small and unimportant streams. This very complicated water-way includes sufficient anchorage, and its picturesque creeks and harbours afford ample shelter, to admit every kind and any quantity of shipping in the worst weather.

44. The river Fal.—This stream, which is by no means important, but which passes through a pretty wooded country, and by the towns of Grampound and Tregony, rises near St. Columb and flows through the Vale of Creed. It is utilised to some extent for stream works for separating tin ore. It runs about 8 miles before receiving any considerable feeder, and is then joined by a parallel stream passing St. Stephens, and some smaller feeders from the east and west. After about a mile, Grampound is reached, and 2 miles beyond Tregony, where other small feeders join it. It soon expands, and after about 5 miles, gradually widening its channel and putting on more the character of a creek, it enters Mopus road, at the head of King Harry passage, and ceases to exist as a fresh-water stream. It drains about 50 square miles.

45. The Helford river.—From the entrance to Carrick roads to the Helford river mouth is 4 miles, and for 5 miles up the Helford is a tidal estuary, or creek, running into the land almost exactly west, and receiving feeders from both sides, but especially from the north. The river itself is unimportant, and made up of many small branches, draining a district enclosed by a semicircle of metamorphic rocks rising into hills of moderate height, and extending to the north-east and south-east from behind Helston. A small stream drains the country south of the Helford river, and has an independent course of a few miles, entering the sea by a creek within the headlands that may be said to form the natural limits of the wider estuary.

46. Coast drainage to the Land's End.—From Helford river round the Lizard to the Land's End the coast is broken by a number of small valleys, which carry down direct to the sea the rain that falls on their slopes. Scarcely any of these penetrate into the interior more than 2 or 3 miles until we reach Marazion, or Market Jew, where there is a stream of somewhat more importance utilised for power. Beyond this, near Penzance, there are five or six small parallel brooks, the last of which, entering the sea a mile below Penzance, has a course of 6 or 7 miles. Two more similar streams, and others smaller, drain the country on the southern side of the line of water-shed that extends from Land's End into the interior towards the north-east. The coast is rocky, and very inacessible, but extremely bold and picturesque, and as the rainfall is heavy, owing to the prevalence of warm south-westerly winds, there is always a run of water through every valley.

Bristol Channel Drainage.

47. The Hayle river.—From the Land's End to St. Ives, a distance of 18 miles measured from headland to headland, is a wild rocky coast broken at intervals by narrow gorges, conveying a small drainage to the sea. Owing, however, to the position of the line of water-shed, which approaches much nearer the north than the south coast of Cornwall, the drainage rarely proceeds from a distance exceeding a mile or two, except near St. Just. Beyond the headland on which St. Ives is built, is the wide and deep bay bearing the same name, and into the head of this bay two streams enter, one draining a considerable stretch of country to the south and east, and the other a small tract to the east. The former, the Hayle or Heyl river, originates in the drainage of Godolphin and Tregonning hills close to the south coast, and it takes the drainage of another hill further east. These combine at Tregember, the stream from the east having had a run of 5 miles, and the united river flows north-west for about 3 miles to St. Erth, where its bed widens out considerably and becomes tidal, entering the open bay by a passage beyond Lelant. The other is a small river entering St. Ives bay, at the north-eastern extremity, and draining a tract of country to the east as far as Camborne.

48. North-west coast of Cornwall.—From the extremity of St. Ives bay to Trevose head, a distance of 27 miles in a direct line, the Cornish coast trends to the east of north, and is broken through at many points to admit the passage of streams carrying off the drainage of the northern and western slopes of the hills. But none of the streams entering the sea are of any magnitude, and few of them are recognised by any but local names, or have courses of more than 3 or 4 miles. The exceptions are three, one entering at Cranstock bay, another passing St. Columb Minor and entering a little to the north of Cranstock, and the third passing St. Columb Major. All flow from the interior towards the north-west for 6 or 7 miles.

49. The Alan or Camel.—The first stream of importance entering the Bristol Channel finds its way into the sea near Padstow, not far from Pentire point, about 4 miles east of Trevose head. Like many of the Cornish rivers, it enters a tidal creek of considerable length, and receives tributaries of some importance near its outfall, and within the tidal range. The Alan by means of its tributaries drains a wide extent of country, having a very complicated system of feeders, and a long tortuous course. It originates in the surface drainage of a valley near Davidstow, and after about 4 miles passes through Camelford, in which part of its course it is called the Camel. Thence it flows south for a long distance. After 2 miles it receives a branch from the east, and after 5 miles further is joined by the *De Lank* river also from the east. This feeder drains the western slope of Brown Willy, and takes some of the northern drainage of Bodmin moor. These united run in a considerable stream, but with a tortuous course of about 6 miles to the confluence. Thus increased, the Alan curves to the south-west for 2 miles, but again turns south for 3 miles, after which it finally leaves this southern course and curves round for 2 miles to the west, receiving a small feeder from the south-east, and another, much more considerable, from the south-west before taking a direct north-west course to the creek by which it enters the sea. This distance is 4 miles, but about midway the river is fed by an important stream from the north-east, flowing nearly 10 miles in an almost direct line, passing St. Teath, and receiving a few small feeders on its way. A mile beyond this confluence another and much smaller stream comes in from the south-west, and a little below where the united stream enters the creek, it is joined by a tributary from the north-east, passing St. Kew, and having a course of about 5 miles.

After this the river makes its way for about 3 miles due west, through a tidal channel a quarter of a mile wide to St. Michel, opposite which town there is another shorter inlet to the south, receiving some inconsiderable streams from the same direction. At this point the inlet is nearly a mile wide, and continues narrowing a little beyond Padstow, and then again expanding till, after 3 miles in a northerly direction, it opens out in the bay between two headlands. The total length of course of the Alan is about 30 miles. Its drainage area is 150 square miles.

50. The Bude river.—Beyond Pentire point there is no coast drainage of the smallest importance for a long distance. At Bude haven the small river Bude enters, conveying the drainage of a narrow strip of country near the coast. There are two principal branches, both made up of the confluence of a number of small short feeders from the hill range parallel to the coast, from which it is only distant 4 miles. The southern branch has a run of nearly 5 miles in a direct line to the main channel of the Bude, the northern is rather shorter. The combined streams flow north about 3 miles into Bude haven, which is a small creek.

51. Bude haven to Bideford bay.—From Bude haven it is about 14 miles to Hartland point, in a direction almost due north, and along the whole distance the cliffs are broken at short intervals by narrow clefts and small valleys, each of which conveys the surplus rainfall of the district to which it belongs. Some of these little valleys are not more than half a mile, others are more than 5 miles in length. From Hartland point across Bideford bay to the wide creek that enters the land about the middle of the bay is 14 miles measured across the bay, the line of coast, trending nearly due east from the point to the promontory that terminates the line of rocky cliff in this direction, being nearly 15 miles. The extremely picturesque character of this part of Devon is well known, and there are hardly any indentations connected with drainage of the interior. The general direction of the streams is everywhere to the west.

Two rivers of some importance enter Bideford bay by a wide inlet which opens into the land about 4 miles, but is nearly filled above the level of high water by blown sand, accumulating in large hills, and covering many thousand acres of low-lying land. The first of these rivers is the Torridge, one of the largest of the streams emptying into the Bristol Channel from the south. The other is the river Taw.

52. The river Torridge.—This river drains a wide extent of country by a course of considerable length, complicated, and exceedingly circuitous. Its head-waters are the southern slopes of the coast range that extends from Hartland eastwards, being the southern boundary of cliffs that form Bideford bay. Very numerous feeders proceed from this line of hill, commencing, in many cases, within a mile of the coast, and flowing southwards for 4 or 5 miles under various names to enter the main east and west valley of the Torridge, which commences about 3 miles from the west coast on the eastern slopes of Hendon moor. After flowing about 6 miles due east, the river turns to the south-east, and, after a further course of 7 miles, receiving few feeders, it meets the *Waldon river*, which brings the waters of a wide valley entering the country to the west after a course of 10 miles. Turning now to the east, after a somewhat tortuous course of 10 miles, receiving small feeders both from north and south, the Torridge is joined by an important branch from the south, draining a country of considerable extent by a large number of feeders. The sources of this tributary are found in a considerable range of moorland west of Okehampton and close to the sources of the Tamar, where a multitude of streams unite and form a river at a point about 4 miles south-west of Hatherleigh. This is further increased by another feeder which proceeds from the south-west, and about 2 miles north of Hatherleigh falls into the Torridge.

About a mile and a half beyond this confluence, the river taking a north-easterly direction is joined by another important affluent from the south. This is the river *Okement* which originates on the slopes of one of the northern spurs of Dartmoor, called Okement hill. From the north-eastern and western slopes of this hill the surface waters collect into two streams. On the eastern face a river is formed (the *East Okement*), which after a northerly course of about 4 miles turns west to meet another stream (the *West Okement*), which collected from the north-western slope of Okement hill makes a large westerly curve to the north, and comes round again after a course of 8 miles, uniting its waters with the shorter eastern stream just beyond the town of Okehampton. Flowing northwards together, and bearing to the west, the Okement joins the Torridge as a large stream, after a course of about 10 miles from the confluence of its two branches.

The Torridge now takes a northerly course nearly direct for about 2 miles, but then winds in a large curve which nearly returns to the same point. After a succession of curves of this kind, passing Torrington and flowing through a richly wooded country, it reaches Bideford. The direct distance from below the first curve to Bideford is about 12 miles, but the river course is very much greater. Several feeders, none of large dimensions, but draining a considerable range of country on both sides, enter the Torridge in this part of its course, and about $1\frac{1}{2}$ mile before arriving at Bideford it is increased by a larger stream proceeding from the west about 10 miles, and joined by another of almost equal length from the south. Before reaching this point, the bed of the Torridge has already begun to expand into a creek, and it continues to widen for more than 3 miles before reaching the low flat lands at the head of the bay. The whole course of the Torridge is 54 miles, and except where it takes water from Dartmoor, it is entirely within the altered carboniferous rocks of Devonshire. The drainage area is about 336 square miles.

53. The river Taw.—The river Taw has its origin within half a mile of the sources of the East and West Okement, collecting the drainage of the south-eastern slope of Okement hill, a spur of the Dartmoor granite. It flows nearly due north for about 5 miles, then rounding Cawsand hill to the east after 2 miles it again flows to the north, its course being remarkably straight for another 6 miles, and it then flows to the north-east 6 miles further. Up to this point, though a few small streams join it at various points, it has received no considerable affluent. It now receives a more important tributary from the south-east, draining the country east and west for about 6 miles in that direction, and then proceeds in the direction of this tributary towards the north-west.

After 4 miles, approaching Chumleigh, it is joined by the *Little Dart* river, a feeder of some importance from the east. Three miles further it again receives a considerable addition by the river *Mole*, draining a country partly consisting of Devonian rocks, by a branch called the *Bray*, coming from hills 25 miles distant to the north. The Mole drains the country more to the east, and is joined by the *Yeo* after a course of 20 miles. Both the Mole and the Yeo take their rise and flow through rocks of the Devonian period, generally metamorphic. Much of this eastern drainage is from Exmoor.

After receiving the Mole, the Taw takes a north-westerly direction, and makes some large curves, and after a further course of about 12 miles through a wide alluvial bed, it reaches Barnstaple and opens into a tidal creek or inlet through which it flows about 8 miles into the sea at Bideford bay. Close to Barnstaple it receives a considerable feeder from the north-east, and a mile further another which drains a tract of country to the north. The course of the Taw is about 50 miles, and the creek opening into the bay, after the junction of the Taw and the Torridge, is about 2 miles in length. The drainage area of the Taw is 455 square miles.

54. North coast of Devon and the river Lyn.—The north coast of Devon from Mort point, a few miles west of Ilfracombe to the mouth of the Parret, where the coast turns abruptly northwards to the mouth of the Severn, is about 50 miles in length. This line of coast, though not everywhere bold, is backed by hills along the whole distance, which are for the most part east and west lines of water-parting, and send almost the whole drainage of the country towards the south. It belongs entirely to the Devonian system, and consists of slaty and altered rocks. The streams that enter the sea are very insignificant, and hardly bear distinctive names. They are, however, numerous. From Rocky bay, passing Ilfracombe to Linton, there are four streams: one entering at Heddon mouth, about 12 miles to the west of Rockham bay, being the principal. It has a course of only 6 miles, almost entirely in a northerly direction. Four miles beyond this the *East Lynn* enters. It is formed of several branches, the chief coming from the east, having a course of about 11 miles, and passing close to Linton. Its drainage area is more than 40 square miles. Near its outflow it receives the *West Lynn*, after a course of 5 miles. Both streams have small feeders. Eighteen miles beyond (about 2 miles east of Minehead) a stream enters from the west, passing Dunster castle, but it drains only a small extent of country. Four miles beyond, a similar stream enters at Watchet, and after another mile another having a somewhat longer course. This brings us to the Quantock hills, whose western slopes are drained by this stream. The eastern slopes of these hills drain by another stream which is distributed over the rocky coast, and has no direct channel to the sea.

Twelve miles of coast occur without a break between Watchet and the hollow of Bridgwater bay. The whole of the drainage of the interior is here conducted eastwards, and belongs to the system of the Parret.

55. The river Parret.—This considerable stream, draining 653 square miles chiefly in Somersetshire, originates in the slopes of the oolitic hills between Crewkerne and Yeovil, and runs chiefly over lias. A number of streams converge after a run of 3 or 4 miles, and at West Chinnock form a stream already considerable. Fed by other tributaries from the east and west, the stream flows northwards for about 7 miles, and is then joined by the river *Ile* or *Isle*. This river rises on the lias near Chard, close to the sources of the Axe, and flowing to the north about 4 miles to Ilminster, receives a number of short feeders from both banks. Curving round to the east, and receiving other tributaries, chiefly from the west, after a further course of between 3 and 4 miles it turns abruptly to the north-east, and after 2 miles receives the *Ilmoor*. This stream has a nearly straight course from the west of about 10 miles, entirely over lias, and is joined on its way by a few branches draining a hilly country. After this junction, the Ile continues another 3 miles to join the Parret.

In less than 2 miles from this confluence, the stream, flowing northwards, is joined by another large feeder, the *Yeo*. This river is first formed by the drainage of a group of oolitic hills round Sherborne, at which town the main feeders have had a course of 4 or 5 miles. Passing for 4 miles through a narrow valley with a wide alluvial bottom in a south-westerly direction, the stream, after receiving a feeder rising in the lower greensand and draining the country nearly 10 miles to the south, takes a northerly turn of about 2 miles to Yeovil, and then, winding about in the lias and turning to the east, it has a direct northerly flow of 4 miles through an open level country, and turns west, winding about in small curves to Ilchester. From this town to the confluence of the Yeo with the Parret is a distance of about 7 miles nearly north-west through a perfectly flat country which yields no feeders.

The Parret, after receiving the Ile and the Yeo, continues to flow through a wide expanse of alluvial lands for rather more than 10 miles to Bridgwater, receiving on its way the river *Tone*, coming in from the west. This river rises on the slope of Brendon hill, and flows over rocks of the Devonian slate formation for about 10 miles. It then turns eastwards, and flows 23 miles over New Red Sandstone in the rich vale of Taunton, and, passing by the town of Taunton, it reaches the Parret after an easterly course of 34 miles, receiving many tributaries from north and south, and conveying a large body of water to the main stream, which, indeed, at the confluence is hardly larger than the confluent.

Below Bridgwater another smaller stream enters also from the west, and the river, now occupying a very wide alluvial valley, takes a tortuous course to the north for several miles, interrupted by numerous sand-banks. Receiving then another rather considerable feeder from the west, draining the south-eastern slopes of the Quantock hills, it soon widens to a large shallow stream, passing through many miles of sandy flat to the head of Bridgwater bay, where, as it enters the sea, it is joined by the Brue. The total length of course of the Parret is 43 miles.

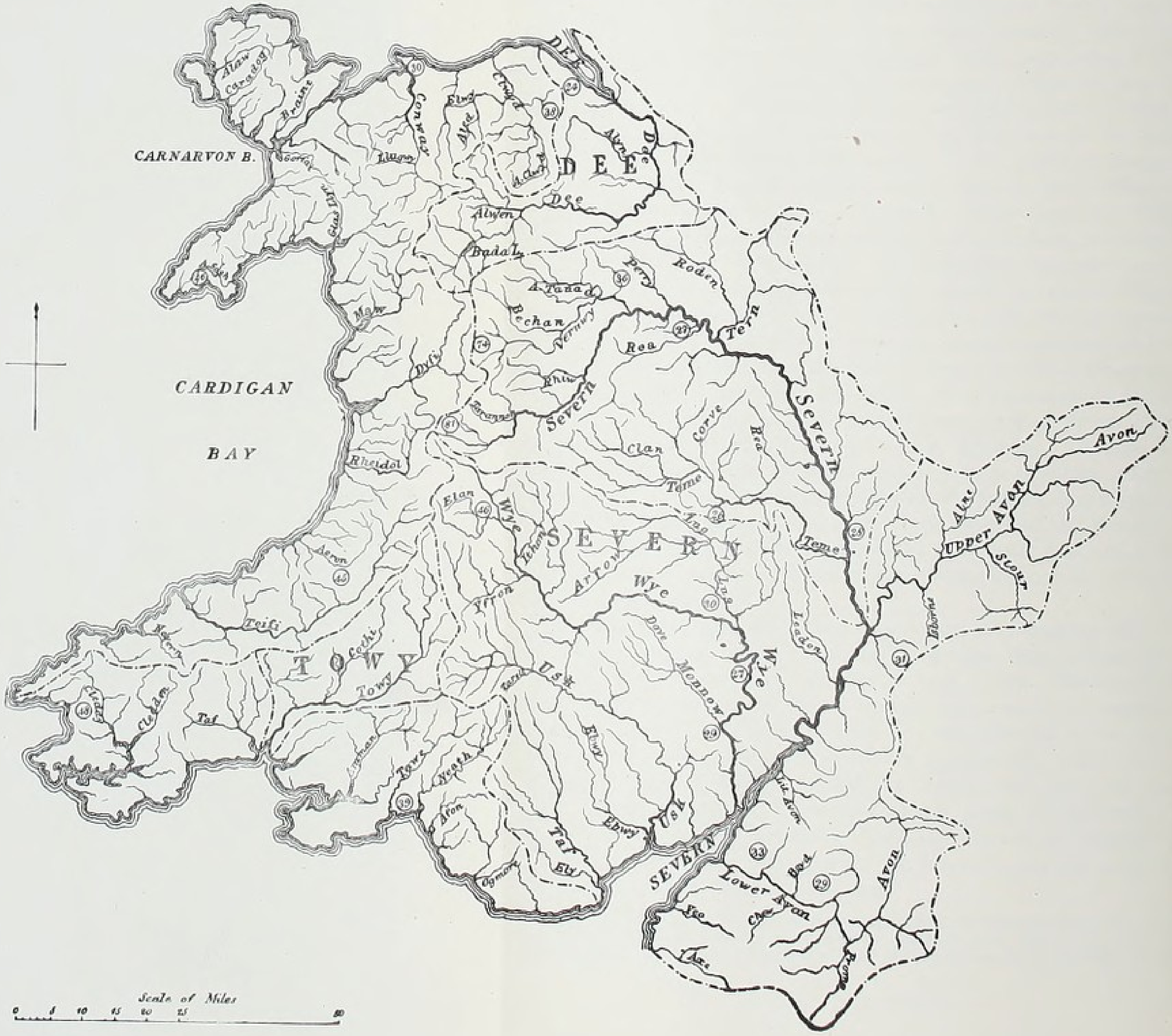
56. The river Brue.—The sources of the Brue are on the western slopes of the oolitic escarpment ranging to the north of Mere, and consist of several feeders uniting about a mile to the south-west of Bruton after a course of 4 or 5 miles each. The stream, then entering the lias, flows about 12 miles nearly west to Glastonbury, receiving few tributaries and none of importance. Entering then the wide expanse of low flat land that is characteristic of this part of the west of England, the river has a further course of about 14 miles, with only one important tributary. This feeder flows from the east, rising beyond Shepton Mallet, passing Wells, and entering the Brue a little beyond Glastonbury by numerous artificial channels. The course of the Brue is about 35 miles.

From the mouth of the Brue to the promontory of Brean Down, a distance of about 7 miles, there is no coast drainage. The Axe, which enters at present on the northern side of this promontory, might for that reason be regarded as a tributary of the Severn, but a glance at the physical geography of the district will show that the Mendip hills form the natural limit of the Severn basin, so that the Axe, which drains only the country on the southern slope of those hills, must be included in the present chapter.*

57. The river Axe.—The Axe rises among the limestone hills of the Mendips, emerging from a cavern called Wookey Hole, a short distance west of Wells, as a stream sufficient to turn a mill. Passing through the village of Wookey, it almost at once enters the level country, and passes through a flat valley between the Mendips and a low range of hills to the west. Here it receives a considerable feeder from the limestone rocks of Cheddar, called the *Cheddar water*, and soon passing the western extremity of Wavering Down, it passes under Bleadon hill, and enters the Bristol Channel in Uphill bay, close to the northern slope of Brean Down. The latter part of its course is over the levels which extend for miles to the south and east.

* In the map of the Severn the Axe, discharging its waters within the estuary of that river, has been included as within its drainage area, and in the map of the drainages of south-western England in page 198 it has been inadvertently excluded.

IV.—DRAINAGE AREAS OF THE RIVER SEVERN AND OF THE WELSH COAST. To face page 215.



CHAPTER VI.

THE BASIN OF THE SEVERN AND THE WELSH COAST DRAINAGE.

1. Nature and extent of the district.—The part of Great Britain that will be considered in the present chapter in reference to its rivers is very extensive and sufficiently well marked. It includes the whole principality of Wales, and its southern, western, and northern boundaries are parts of the seas that surround our island. To the east it is bounded by a low water-shed. This is connected with a succession of hill ranges, commencing with the Mendips in the south and continued by the Cotswolds, which form the escarpment of the oolites, and are the south-eastern boundary. Leaving the oolites, the line of water-shed separating the Severn and Thames basins enters the lias near Moreton in the Marsh, close to the source of the Evenlode (a Thames tributary), and continues in a north-easterly direction on the strike of the lias into Northamptonshire, where are the sources of the Upper Avon, a Severn tributary. Turning across the lias, it enters the New Red Sandstone, and, crossing a part of the midland coal field, takes a north-westerly direction in the great New Red Sandstone plateau, which is continued at a level little above 300 feet through the Cheshire plains into the promontory that separates the Mersey from the Dee.

This great extent of country comprises at least 13,000 square miles, and its characteristic feature is the presence of the Welsh mountains. These occupy the western half of the district, sloping down to the Bristol Channel in the south, the St. George's Channel in the west, and the Irish Sea in the north. The eastern slopes of the Welsh mountains, and the western side of the low, gradual slope of secondary rocks that terminates the water-shed of the Severn on the east unite their waters into one broad channel—the river Severn, which flows southwards and westwards into the Bristol Channel. Thus, while the drainage of one half of the Welsh mountains is broken up into a multitude of small catchments entering the sea immediately, the other half collects to form one of the largest of the British rivers.

It is undesirable to separate the general drainage of this tract, but the catchment of the Severn, as being by far the most important, will first occupy attention, the smaller streams of the mountains afterwards coming under brief notice.

To the west, north, and south of the Severn basin the rest of the principality of Wales is broken up into drainage areas of moderate dimensions, all communicating after a short course with the sea, and conveying thither the rain falling on them and received from the mountain slopes. Of the rivers formed, the Dee and the Clwdd, both in North Wales, and the Towey, in South Wales, are the principal. The number of less considerable independent river basins in the district is considerable, and together they convey a large body of water southwards, northwards, and westwards, derived from the frequent and heavy rainfall on the high mountain land of Wales, much of which is deposited before reaching the water-shed of the Severn basin.

The annexed map of the district will be useful for reference, but must not be depended on for entire accuracy. By comparison with the outline maps, it will, however, enable the reader to comprehend the physical phenomena that have contributed to subdivide the district into drainage areas, and to indicate the directions of the principal streams. The rainfalls have been inserted on the authority of late observers and meteorologists, but are perhaps rather in excess, especially in the south-eastern part of the district. In some cases the figures in the map will be corrected in the pages that follow, and where there is a difference the letter-press should be taken as the most likely to be correct.

2. Geological and physical features.—By far the larger proportion of the tract of land under consideration consists of rocks of very ancient date, which have been for the most part so modified by time and heat as to have lost to a great extent their stratified character. Thus, the clays, which form a large part of the whole, have become slates; the sands are quartzites, while the limestones, generally associated in the old rocks with clayey matter, are not large in quantity, and are not readily soluble. This altered rock, being thrown up into mountain masses, and in many cases inter-penetrated by mineral masses of igneous origin, and the whole having been exposed for an exceedingly long period to severe water action, the conditions are eminently favourable for collecting and conveying pure water. Thus it is that some of the Welsh waters are almost as pure as rain-water fallen in mountain districts, and are carried down a long distance in this state. This peculiarity has been noticed in the waters from some of the Cornish granitic and altered rocks.

Much more than half the total area being composed of very ancient and altered rocks, whether Cambrian, Silurian, or Devonian, and these occupying entirely the western part of the tract, except that in South Wales there is a considerable extent of coal-measures, the remainder is covered with New Red Sandstone. An area in the south-eastern corner, and the projection of the Upper Avon into the middle of England, present liassic and oolitic rocks overlying the triassic rocks. These occupy 2,000 square miles.

The whole of Wales is mountainous, and wherever the older rocks come to the surface the features of the country are more or less picturesque. Deep, narrow valleys, often little cultivated and very thinly peopled, are the characteristics of the district in the whole of the upper parts of all the mountain rivers. Towards the mouths of the South Welsh rivers, and in the lower parts of the tributaries that join the Severn from the east, the country becomes level, and there are large tracts where blown sands are forming permanent additions to the land.

3. Subdivisions.—The district is naturally subdivided into two principal parts, the first including the whole drainage area of the Severn, and the other the subordinate basins. The latter deliver their water to the sea along the line of coast extending from the mouth of the Severn to the mouth of the Dee. The number of large catchments or principal sub-basins is not large. All the rivers of the west coast have short courses, as the mountains there approach the sea very closely, and in few cases have the rivers flowing through the steep narrow mountain valleys an extensive catchment. Few of these streams are utilised, though the water proceeding from them is almost without exception of extraordinary purity. For the most part they are torrential. The southern group drains chiefly the South Welsh coal-field, and includes some catchments of larger area. The northern rivers are few in number, but include two of considerable importance. These also drain a coal field.

4. Rainfall, evaporation, and percolation.—The rainfall in the western extremity of the Severn basin, on the Welsh mountains, and near the summits of the mountain range is very heavy. For a certain distance, as may be observed in the Rain map, p. 51, it is as much as from 50 to 75 inches, and in two still smaller tracts in North Wales it exceeds 75 inches. Round the coast the range is generally from 45 to 50, and in many places under 40. In the lower valley of the Severn, however, the rainfall is very much less heavy, falling below 30 inches, and ranging in different places between 26 and 30. In small parts of the Upper, or Warwickshire, Avon it rises again to 32 inches, but in the basin of the Lower, or Somersetshire, Avon, and in the small catchments near Cheltenham, it does not exceed 25 or 26 inches. In parts of the district beyond the Severn basin, and in South Wales, as at Swansea, 34 inches are measured, and in Flintshire, in North Wales, 38 inches. The map of rainfall and a reference to the map of the district at the commencement of this chapter will enable the reader to see without much difficulty the nature of the distribution. The eastern tributaries of the Severn may be described as sluggish, and they bring comparatively small contributions to the water supply of the Severn, but this supply is delivered much more equably during the year than that from the mountains, and is less liable to sudden increase after rain or diminution during continued drought.

The rain throughout the western district is torrential, falling, however, on a large number of days in the year, and falling in every month. The rivers come down occasionally in heavy flood, caused by excessive rainfall, and there is no year in which some floods do not occur.

The evaporation throughout the district is comparatively high, and is probably nowhere below 14 inches. The wind that almost invariably accompanies rain, and the rapid alternation of wet and fine weather, ensures a rapid evaporation. In the eastern district, over the rocks of the secondary period, the mean annual evaporation is likely to be larger, probably reaching 15 inches, and in places to 16. The range is generally large.

Percolation through rocks of the older formations has not been determined by experiment, but must be small. On the New Red Sandstone, on the other hand, it is rapid and large. Where, however, as is often the case, the rocks of this geological period alternate with marls, or where they are covered up by impermeable clay, the percolation will be greatly interrupted. The total loss of water by all causes—percolation, evaporation, and organic life,—can hardly leave more than an annual average of from 5 to 6 inches of rainfall to run off to the sea, and this is distributed very irregularly.

5. Quality of the water.—The water of the district is derived, to a very large extent, from the altered Silurian rocks and Old Red Sandstone. All the streams discharging on the west coast of Wales flow over these rocks exclusively, and carry large quantities of water exceptionally pure, soft, and pleasant. With regard to the Severn, until the river arrives at, and begins to receive tributaries from, the New Red Sandstone, its waters are soft and free from mineral solids, but below the confluence of the Perry the effect of the tributaries from the Permian and triassic rocks and the lias is seen by increasing the hardness, and the quantity of total solids. These alter, but do not necessarily injure, the quality. Between Shrewsbury and Worcester much effect of this kind is produced by small tributaries from the east, but analyses of samples taken above the latter city show a good water, fit for ordinary purposes, and in no way injurious to health. Subjoined will be found an analysis of the water above Worcester, made by Dr. Tidy in the early part of 1878, and other analyses made at various times, some by Dr. Tidy and some by Dr. Frankland. In its ordinary state in winter the water at Tewkesbury, 16 miles below Worcester, and after the river has received the Teme, contains about 15 grains of total soluble solids in the gallon, of which 4 grains are alkaline chlorides and $3\frac{1}{2}$ sulphate of lime and magnesia. When the waters are turbid after heavy rain the solid matter amounts to 18 grains per gallon. This is practically the same water as that used at Worcester, and as the city of Worcester is constructing works for preventing sewage from entering the river, and no other sewage enters the river below, it may be expected that a permanent improvement will take place in the quality of the water at Tewkesbury.

It will be evident from these analyses that the Severn water takes up, and indicates the presence of, a portion of the rocks over which it has passed. The sulphate and carbonate of lime and the salt are all due to the triassic beds of the lower course.

For many reasons, however, the Severn is a very variable river, in the nature of its waters as well as in the quantity of water it conveys. One of the chief reasons, no doubt, is the fact that a large proportion of the water in wet weather proceeds directly and rapidly from mountain sides, and soon runs off the surface. In dry weather there is from this source scarcely any flow, while the smaller and more permanent supply from the liassic rocks and New Red Sandstone then preponderates, and modifies the quality of the water in a certain sense. The waters of the tributaries of the Severn, when the sewage of towns on their banks is excluded, are good or bad as they flow over the metamorphic and hard rock, or the New Red Sandstone and lias. The Wye is an example of the one, and the Avon of the other. Examples of both rivers, analysed by Dr. Frankland and given in his Report on River Pollution, are quoted above.

The Welsh waters obtained from rivers flowing direct to the sea are exceedingly good. Those that pass over the coal-measures and manufacturing towns in the coal and iron districts are, of course, affected by such a history.

ANALYSES OF SEVERN WATERS.

Date of Sample.	Locality.	Total solids.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates.	Chlorine.	Hardness.
June '67	Early tributary - - - -	2·36	·140	·004	·002	·005	0·57	0·6
"	Tarannon river - - - -	3·09	·197	·001	·006	·017	0·62	1·3
"	Banw & Eira, confluence (after flood)	3·40	·185	·003	·003	·016	0·60	1·4
"	" " (in flood) -	3·43	·728	·008	·002	·004	—	0·8
"	Vyrnwy river " - - - -	2·61	·153	·003	·002	·008	0·52	1·0
Jan. '78	Teme river, confluence - -	13·93	·042	·007	·003	·045	0·65	9·5
Sept. '73	Wye (Hereford town supply) -	4·55	·343	·011	·001	·000	0·49	2·5
Apr. '68	Avon (Rugby town supply) - -	18·37	·086	·026	·001	·267	1·42	11·1
Mar. '70	Frome, at Gloucester - - -	19·25	·043	·006	·000	·208	0·74	16·5
Jan. '78	Severn above Worcester (part. fld.) -	16·26	·284	·050	·006	·045	2·30	10·5
"	" at Mythe bridge (partial flood)	15·95	·148	·013	·003	·045	1·66	11·5
Sept. '7	" " - -	24·58	—	—	—	—	5·66	14·8

ANALYSES OF WELSH WATERS.

Date of Sample.	Locality.	Total solids.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates.	Chlorine.	Hardness.
Mar, '67	Dee basin (mean of Bala lake feeders)	2·87	·218	·008	·002	·008	—	0·8
Apr. '71	Rheidol (above mines) - -	2·37	·117	·011	·001	0	0·69	1·8
"	Ystwith, Pont Llanychaiarn - -	4·13	·116	·018	·001	·008	0·84	1·8

6. Ordinary flow and floods.—The flow of the Severn varies greatly in different parts of its course. For a long distance, at least as far as the confluence with the Vyrnwy, it is little more than a mountain torrent, rushing and tumbling along over temporary obstacles after rain, and reduced to very small dimensions after long drought. Receiving then several affluents, it assumes a more even character, and before it reaches Shrewsbury has become a rapid but regular river. After this it continues to flow evenly and at a speed varying from 3 to 4 miles an hour during the winter season, when there is a small flood, but it increases rapidly and seriously after heavy rain from the west. At all times the flow is subject to sudden and unexpected changes.

There is an extremely large difference between the maximum and minimum flow of the Severn. Assuming the actual rainfall that can be depended on to amount to six inches, the mean daily flow at Worcester would be 480 millions, and at Tewkesbury 640 millions. The absolute minimum flow, or the lowest quantity that has been observed, has been stated to be 90 million gallons per day at Mythe bridge, Tewkesbury, near the mouth of the Avon. It is not recorded for how many hours or days this minimum has continued, nor is it altogether clear that in estimating the quantity allowance has been made for leakage from under the sill of the weir. It is rare that many days pass, even in a dry summer, without rain on the mountains, and the effect of a fall of so little as a tenth of an inch in a day over the western water-shed would undoubtedly be felt almost immediately in the river below Shrewsbury, unless there had been previously a long drought. The Severn being without any means of checking the rapid delivery of water from the higher to the lower ground, probably delivers a greater proportion of water to the sea by freshets than any of the large British rivers. At the same time, perhaps, it is the one which is the most subject to extreme depression. This has been already alluded to in Chapter III. § 18.

The Welsh rivers are all torrential. They deliver a great body of water to the sea at certain seasons, leaving the beds of the rivers almost bare at other times when continued drought occurs. Rain, however, falls so frequently that this condition is rare and exceptional.

7. Tidal phenomena.—The tide in the Severn at present rarely reaches above Tewkesbury, being stopped off at that point by weirs. It formerly reached nearly 20 miles higher, and still influences the stream to that distance by checking the onward flow where it meets the high tidal wave. The tide at all times rushes up the funnel-shaped mouth of the Severn with great force and rapidity, and not unfrequently at certain seasons with exceptional results. It occasionally lifts over the weir at Tewkesbury, and backs up the water as far as Worcester, but only for a short time, and in cases when the equinoctial spring tide meets a freshet and is assisted by strong south-westerly gales. In such cases a false tide appears to be traceable resulting from the tide lower down. This is often, but incorrectly, spoken of as a tide by those concerned in the navigation.

The Severn below Tewkesbury is so greatly affected by the tide as to render it dangerous for boat navigation, and the river is subject to a very remarkable phenomenon, occurring to a certain extent every spring tide, but especially at the high equinoctial spring tides of the month of March. It is called the *bore*, but is elsewhere known as the *hygre*, *eager*, or *egre*, and, though exhibited very strikingly in the Severn, is by no means confined to that stream. In the Severn it is a result of the local conditions under which the tidal wave advances up the Bristol Channel and enters the Severn. The whole water-way is essentially funnel-shaped, narrowing in width and decreasing in depth as it advances from the mouth of the channel up the stream. The ordinary flood or rising tidal wave entering this funnel from the Atlantic is almost immediately converted into a wave of translation, the magnitude and force of which is increased by each advancing wave in succession, the advance being greater than the recession in each case. This advancing wave, small at first, becomes larger, higher, and more distinct as it is forced up the diminishing channel. As it advances it meets the descending stream of the river, and checks its progress. The continued flow of the river downwards being thus interrupted, the water backs up while the wave is still advancing, and if the river is at the time in flood the effect of the flood is necessarily increased in the lower part of the river bed, where, if the banks are high, the level of the stream is raised considerably. In place, therefore, of rising over the surface, or pushing like a wedge under the stream, as in rivers where the reflux of the wave is possible and the total rise is produced by successive undulations, the up-flow of the tide at and above a certain point becomes in the Severn continuous and rapid, without a returning wave. The wave, heightened in this way, soon curls over, and forms a head as if a number of sluices were opened upon a quiet surface of shallow water, or like heavy breakers in the sea over a shallow shore. The level of the head in the Severn is on an average from 2 to 3 feet higher than the low, still, backed-up water immediately in front of it, but it varies much with the depth of the water, decreasing as the depth increases, and at length presenting an almost unbroken vertical and foaming surface. The water not unfrequently runs up with a wave 6 feet high, and on some occasions very much more. The roar of the water and the suddenness of the rise are phenomena exceedingly striking.

8. Population.—The town population on the Severn is, in the upper part of the river, excessively small. The river rises in and receives its early tributaries from the slopes of the Welsh mountains, and from numerous mountain valleys that conduct the rain from the mountain tops with extreme rapidity into the valleys. There are but few roads into these parts of the drainage area, and there are few human habitations. The small town of Llanidloes; the town of Newtown, somewhat larger; Montgomery, a very small town, though the chief place of a county; and Welchpool, are the only places of the smallest importance on or near the banks of the river from its sources to Shrewsbury. The total town population to that point is under 14,000, and Shrewsbury itself has less than 25,000 inhabitants. Sixteen miles below Shrewsbury (more than 20 by the river), is a group of manufacturing towns (Broseley, Ironbridge, and Coalbrook Dale), with a total population of about 16,000. Eight miles further is Bridgnorth (5,320); 12 miles further is Bewdley (3,021); and 4 miles below Bewdley is Stourport (3,081). Beyond Stourport to Worcester (33,500) is 12 miles, and thence to Tewkesbury (5,409) 16 miles. At Tewkesbury the stream is met by the tide, and the water ceases to be available for domestic use or manufacturing purposes. The total town population does not, therefore, exceed 105,000, while the length of the stream is 180 miles; showing that for every mile of river there is a town population of under 600.

The town population on the upper tributaries as far as the Avon, entering at Tewkesbury, is as follows:—On the Vyrnwy there is no town; on the Perry there is also none. On the Tern there is only Market Drayton, whose distance from the Severn is 21 miles; on the Roden, a feeder of the Tern, are Ellesmere at the source, and Wem half way down the stream. The Stour rises and passes through a manufacturing and iron district, but touches only Hales Owen and Kidderminster before reaching Stourport. On the Teme are only the three small towns of Knighton, Tenbury, and Ludlow.

The Upper Avon, like the Stour but on a much larger scale, flows through a manufacturing district, and passes large manufacturing towns. Rugby, Coventry, and Kenilworth, Warwick, Stratford-on-Avon, and Evesham are its principal towns. On the Wye are Hereford, Monmouth, Ross, and Chepstow. On the Lower Avon and its tributaries are Chippenham, Bath, Bristol, and Frome. On the Taff, the last feeder, is Cardiff. There are several much smaller and for the most part insignificant towns, especially on the lower tributaries. For a long distance from their mountain sources all the rivers entering from the right bank flow over land which not only is thinly peopled but is not in high cultivation.

The population of the coal and iron districts of South Wales is large, but most of the towns are situated close to the sea. In North Wales this is also to some extent the case. The Dee, however, passes Chester.

The agricultural and town population within the Severn drainage area, as far as the confluence of the Upper Avon, has been carefully estimated, and does not exceed 350,000. The greater part of the agricultural portion is altogether independent of the stream and its tributaries.

9. The basin of the Severn.—The drainage area of the Severn includes three-fourths of Wales and large parts of seven English counties. These are Gloucestershire, Herefordshire, Monmouthshire, Shropshire, Somersetshire, Warwickshire, Worcestershire. One of its tributaries rises in Northamptonshire, and another in Wiltshire. It forms an irregular square, with a promontory or projection towards the east, one tributary, the Upper Avon, bringing the drainage of the middle of England into it from that direction. The square part measures more than 90 miles on each side. The total drainage area is 8,580 square miles, according to the map published in the Report of the Rivers Pollution Commission. The actual quantity of water delivered into the stream per square mile of drainage area by the western tributaries is, no doubt, very much greater than that received from the north, east, and south-east.

The Severn feeders above the confluence of the Vyrnwy, and the Vyrnwy itself, descend rapidly from high and steep mountain slopes, and rush down for the most part as impetuous torrents after heavy rains, the fall of the ground being very great.

Below Shrewsbury the main stream falls at the rate of 32 inches per mile as far as Bridgnorth, and then 28 inches to Stourport. Below Stourport the fall is 21 inches in the mile as far as Worcester; after this it is very gentle, not exceeding 4 inches in the mile.

The Severn enters the Bristol Channel by a large and wide estuary, widening gradually from a few hundred yards at Tewkesbury to 7 miles between the rock of Penarth and the extremity of Brean Down.

10. Scheme of the Severn tributaries.—The chief tributaries of the Severn and their distances from the source are as follows :—

Length of course.	*Right bank.*	Distance from source in miles.	*Left bank.*	Length of course.
		12	Clwedogg	13
		19	Tarannon	12
		19½	Afon Garno	18
5	Mule	33		
		38	Rhiw	14
		60	Vyrnwy	35
			Banw or Einion.	
			Tanat.	
		70	Perry	12
8	Meole brook	80		
		88	Tern	30
12	Cound brook	90		
		107	Worf	13
9	Mor brook	111		
12	Borle brook	116		
7	Lemp brook	120½		
5	Gladder brook	124		
		126	Stour	17
8	Dick brook	129		
4	Shrawley brook	131		
		135	Salwarp	17

Length of course.	*Right bank.*	Distance from source in miles.	*Left bank.*	Length of course.
64	Teme	140		
	Clun.			
	Onny.			
	Corve.			
		156 . .	Upper Avon . . .	85
			Swift.	
			Sow.	
			Leam.	
			Tach brook.	
			Stour (Warwickshire).	
			Arrow.	
			Alne.	
			Isborne.	
		157 . .	Swilgate brook .	8
		162 . .	Chelt	12
22	Leadon	167½		
		182 . .	Frome (Glo'stersh.)	15
		197 . .	Little Avon . . .	10
125	Wye	207		
	Afon Marteg.			
	Elan.			
	Ithon.			
	Yrfon.			
	Edwy.			
	Lug.			
	Frome (Herefordshire).			
	Monnow.			
	Trothy.			
6	Nedden brook . . .	211		
		214 . .	Lower Avon . . .	48
			Frome (Somersetshire).	
			Boyd.	
			Chew.	
			Frome (Lower Glo'stershire).	
56	Usk	223		
	Afon Llw.			
	Ebwy.			
20	Rumney	229 . .	Yeo	13
28	Taf }	232		
20	Ely }			

11. Source and early feeders.—The source of the Severn is a chalybeate spring, called Maes Hafren, on the north-eastern side of Plynlimon, close to the northern source of its great tributary the Wye, and very near the sources of the Rheidol (a river which enters Cardigan bay at Aberystwith), and of two other streams. The height above the sea is

2,600 feet. The young river first traverses a narrow valley running to the south of east, and in this early part of its course it flows for 12 miles over rocky ground, with many considerable falls, as a mountain torrent, bearing (until it reaches Llanidloes) the name of *Hafren*, an ancient British word, of which Severn is believed to be a corruption. The rocks over which it falls are slates. At Llanidloes the *Clwedog* joins it from a nearly parallel valley a mile to the north, and it is also here joined by a much smaller stream from the south, another mountain torrent. The Severn now turns abruptly to the north-east, the valley widens, and continues 6 miles with little change to an ancient Roman station, "Caer Sws," where two streams join it—the *Tarannon* from the west, whose course is parallel to that of the Clwedog, and the *Afon Garno* from the north-west, both inconsiderable. In this part the Severn valley is extremely picturesque, and before long it winds round to the east, continuing in that direction 5 miles to Newtown, when it again returns to its north-easterly course, and, after running another 8 miles, the little river *Rhiw* enters it from the west after a course of nearly 15 miles through a narrow mountain valley. After another 15 miles in the same direction, the river having throughout a very tortuous course, we reach the Vyrnwy, the first principal tributary.

All this upper part of the Severn is through a wild, rocky country, and the descent throughout is rapid. In rainy weather the quantity of water coming down is very large, and it accumulates rapidly till the open valley is reached.

12. The river Vyrnwy.—This is essentially a mountain stream. It is formed by the union of a multitude of branches, each made up in the same manner. The principal branches are two—the *Banw*, passing into the *Einion*, and the *Tanat*. The Banw rises in the mountains, and runs 8 miles east before joining the Einion, which is a much smaller stream, having had a short tortuous course among the mountains, receiving two or three branches from the south-west, and running in all perhaps 4 miles. Under the name of Einion the stream continues another five miles, when it receives the *Bechan*. This river has had a course of at least 22 miles among the mountains from the north-west, receiving one considerable feeder on its way, and rising from many sources. From the junction of the Bechan, part of which is sometimes also called Vyrnwy, the river continues with a singularly tortuous course to the north-east for 6 miles nearly parallel to the course of the Severn and 5 or 6 miles distant from its bed. It then continues to wind about, doubling its distance by its sinuosities, and, making a wide curve to the north, comes round into the Severn. Llansaintfraid is situated in the northerly part of the curve, and near that small town the *Tanat*, the other principal branch, comes in from the north. The Tanat rises in the Berwyn mountains, about 15 miles to the west, and its principal course is east, turning south as it approaches the Vyrnwy.

The drainage area of the Vyrnwy contains 350 square miles, and is entirely from a mountainous and little peopled country. The length of its course is 35 miles.

13. Summary of the Upper Severn.—It will be seen from this brief outline that the Upper Severn, including the Vyrnwy basin, is altogether a mountain stream, fed by torrents proceeding from the slopes of the Welsh mountains to the west, and rushing along through winding valleys, each tributary having made for itself a wider channel than it occupies, and wider, perhaps, than its waters, even in flood, could ever fill. Through these channels the present stream flows, making elbows and rounding curves at every mile. The drainage area is 1,320 square miles. Towards the junction of the Vyrnwy the valley, both of the main stream and of its tributary, widens, and becomes open and flat.

A wide open alluvial bottom, and the confluence of the Vyrnwy and the Severn, mark the natural termination of the Upper Severn, which is almost entirely torrential. Below this tributaries enter from flatter land with more level beds, and the Middle Severn commences.

14. The river Perry.—After the confluence of the Vyrnwy, although the Severn becomes a more considerable stream, it retains its sinuous course. The general direction, however, is almost immediately turned first to the south-east and then to the east. This continues for several miles to Shrewsbury. Up to this point only one tributary is received, and that a small one. It is called the Perry, and drains a comparatively level country to the north, having a course of 12 miles, and receiving on its way several small branches. It rises near Ellesmere, and runs over New Red Sandstone and a narrow belt of magnesian limestone and carboniferous rocks.

15. The Meole brook.—Immediately below Shrewsbury the *Meole brook* enters the Severn on the right bank. It drains a considerable area of level ground to the south and south-west, and it is made up of several branches, among which are the *Rea brook* and the *Rea river*. The extreme distances of the sources of these rivulets from the Severn, where they enter, is not more than 8 miles.

A small stream comes in from the north about 3 miles below Shrewsbury. It drains an area to the north, extending about 6 miles in that direction.

16. The river Tern.—The next stream that joins the Severn enters near Wroxeter. It is a more considerable river, and drains a large area, being joined by several tributaries.

The river Tern rises in Staffordshire, and runs for about 9 miles south-west to Market Drayton, where it receives the *Coal brook* from the east.

It then continues 4 miles in the same direction, receiving the *Bailey brook* from the west, and beyond this it continues 6 miles to the south, where it is joined by the Mees, having received on its way the *Allford brook* from the east. The *Mees* rises about 9 miles east of the course of the Tern, and has a long winding course, being fed by several brooks. After receiving the Mees, the united stream flows about 6 miles south to Walcot mill, where the Roden joins it, and then, after another 4 miles towards the south-west, it enters the Severn. The *Roden*, though of some length, is not a stream of great interest. Its principal feeders take their rise from the hilly ground east of Ellesmere, at a distance of more than 15 miles to the north-west; and others may be found at a distance of fully 10 miles to the north. The chief stream passes by Wem, where a number of small tributaries come in from all points of the compass.

The whole course of the Tern is about 30 miles, and the drainage area of the basin of the Severn from the junction of the Vyrnwy to the junction of this stream is 280 square miles. It is almost entirely New Red Sandstone.

17. The Cound brook.—The course of the Severn, after receiving the Tern, is now south for nearly 3 miles to the *Cound brook*, which enters from the west on the right bank, combining the waters of a number of brooks and rivulets, draining the wide valley between the Caer Caradoc range and the hills to the west. These all run north-east, but, when united, flow nearly due east into the Severn. Owing to the presence of a series of ridges in this part of the country approximately parallel, near together, and generally ranging north-east and south-west, there is no other outlet for the rains that fall over a considerable area except by this stream. About 7 miles lower down there is, however, another, but smaller brook, draining one of these long valleys.

18. The river Worf.—Passing through Coalbrook Dale and Iron Bridge, with Broseley on the other bank, the Severn now passes through an important manufacturing district, but there is no river entering from either bank till the little river *Worf* comes in, about a mile and a half above Bridgnorth. This stream rises to the north of Shifnal, and runs along to the south for 9 miles parallel to the course of the Severn, at a distance of about 3 miles. A little below Worfield it turns abruptly to the west to enter the Severn.

19. Small catchments from Bridgnorth to Stourport.—Below Bridgnorth a similar drainage comes in from the right bank, conveyed by the *Mor brook*, also about 9 miles; and a few miles further the *Borle brook* brings a similar contribution from a yet greater distance on the same side. On the east side the ground rises rapidly, and there is no drainage. About 4 miles below the Borle brook, and close to Bewdley, another small feeder from the west joins the Severn. This is the *Lemp brook*, draining a considerable district to the right. Its course is 7 miles. Four and a half miles below the point where the Lemp brook enters the *Gladder brook* joins the Severn, and two miles further, the river Stour comes in.

20. The river Stour.—This, though not a large stream, runs over coal-measures and New Red Sandstone through a thickly peopled manufacturing district. It rises in the high ground in Worcestershire, on the slopes of the Clint hill and Bromsgrove Lickey, and is formed by the convergence of a large number of small rivulets, all flowing towards the north, and converging a little south of Hale's Owen. Turned aside by the ridge running from the Lickey towards Dudley, it has then a westerly course for about 7 miles through an important manufacturing district, passing Stourbridge, and stopped in its westward course by the hills at Stourton, which belong to the north-east and south-west ranges of the district. Here a tributary from the north joins it. This is the river *Smestow*, which rises at Tettenhall, close to Wolverhampton, and, first flowing south-west for 3 miles, bends round to the south, and, after another 9 miles, joins the Stour, the two streams being there about equal in length of course. Proceeding then south-west for 5 miles, Kidderminster is reached, and, after another 4 miles to the south, the Stour reaches the Severn at Stourbridge.

21. Catchments between the Stour and the Teme.—Three miles below the Stour, the course of the Severn being nearly due south, the *Dick brook* enters from the west and north-west, having run a course of 8 miles, and, after another 2 miles, it is joined by the *Shrawley brook* from the same side. The river now continues its course, receiving the Salwarp from the east about 4 miles before passing Worcester, and then continuing without other tributaries till it is joined by the Teme, one of its most considerable affluents from the west.

The *Salwarp* rises in the Lickey hills, north of Bromsgrove, and flows over New Red Sandstone to the south-west, passing through Bromsgrove and Droitwich, receiving many small feeders. Beyond Droitwich it runs about 5 miles further in the same direction to the Severn, and in this part of its course receives other and larger feeders, one of which, the *Doverdale brook*, merging into the *Hadley brook* near its outfall, has a southerly course of 7 or 8 miles.

22. The river Teme.—The Teme rises in Radnorshire, on the eastern slope of the Kerry hills, not 5 miles from Newtown, through which the Severn runs. The Kerry hills are continued in a direction north of east by a high range serving as a water parting, and from the southern slopes of this range water runs off, which collects in rills and brooks, serving as feeders of the Teme and its larger tributaries. This line of water-parting is continued unbroken for about 12 miles. The feeders of the main stream of the Teme are confined to the Kerry hills, and converge after about 3 miles, the collected waters running then for 10 miles in a remarkably straight course south-east to Knighton, receiving numerous tributaries from both sides, though chiefly from the north. All these run through narrow mountain valleys. Below Knighton the course of the stream is due east for 7 miles to Leintwardine, where it is joined by the Clun. On the way it receives only one affluent from the north—a mountain stream coming from the north-west nearly 8 miles.

The *Clun* at its confluence with the Teme is larger than the principal stream. It rises in the continuation to the east of the Kerry hills, and runs a course nearly parallel to that of the Teme for 10 miles, passing Clun and Clunbury, and receiving a complicated series of affluents from the mountains. A little beyond Clunbury it turns abruptly to the south 5 miles to join the Teme.

From the confluence of the Clun the Teme flows nearly 9 miles in a winding course to Bromfield, where it is joined by the Onny, another considerable tributary, also from the mountain country in the north and west.

The *Onny*, by a number of nearly parallel streams, drains both slopes of a remarkable series of ridges, well known in Shropshire, and of extreme geological interest. These are the Shelve hill, the Stiper stones, the Long Mynd, the greater part of a ridge continued southwards from Caer Caradoc, and the western slope of Wenlock Edge. The most distant source is between Shelve hill and Stapeley hill, in Corndon Marsh, nearly 1,000 feet above the sea. After 3 miles this is increased by a stream from between Shelve hill and the Stiper Stones, and, after another mile, by the *Black brook* from the eastern slope of the Stiper Stones. It then runs in a south and south-eastern direction for about 7 miles, crossing, near the village of More, 750 feet above the sea, a level water-parting between the Onny and the Upper Severn, whence a stream (the *Camlad*) flows to the Severn, entering it about half way between Newtown and Welshpool.

During this part of its course the Onny receives, by small feeders, the drainage from the wide valley between the Stiper Stones and the Long Mynd, after which it runs 4 miles further to receive the *Quenny brook*, a tributary rising at Church Stretton, and conveying, in a course of 6 miles a little east of south, the drainage from the eastern slope of the Long Mynd.

Near its junction with the Onny the Quenny brook is joined by the *Byne brook*, which, in the upper part of its course, is called the *Eaton brook*, flowing south-west along the western foot of Wenlock Edge for 9 miles, and towards its upper extremity receiving water from numerous streamlets to the north. Thus increased, the Onny continues for about 6 miles flowing south and south-east to join the Teme.

Two miles below the confluence of the Onny the Teme reaches Ludlow, and receives the *Corve river*, draining the country on the eastern side of Wenlock Edge, having a course of 12 miles in length, and then turning south in a further course of 5 miles to the confluence. On its way the Corve receives a considerable number of small affluents, and one of some magnitude from the western slopes of the Clee hills.

Below Ludlow the Teme receives small feeders from the west, flowing south about 4 miles, and it then turns east, running 5 miles beyond to Tenbury. Two miles below Tenbury it is joined by the *Rea*, which, by several brooks which converge near the outflow, drains a considerable tract to the north. Beyond this the river continues with a winding course, having a generally south-easterly bearing till it enters the Severn. In this part of its course the country on the left bank to the north and east is chiefly drained direct to the Severn, and on the right there are a number of brooks, none of considerable size owing to the water-parting being within a few miles of the river bed. The *Sapey brook* and the *Leigh brook* are the most important, both receiving the drainage for some distance to the north and south by many feeders, some running long distances. There is a drainage from the south of 12 miles into the Leigh brook, prevented by the Malvern hills from issuing direct into the Severn, which runs at no great distance to the east. The length of course of the Teme measures 64 miles, and its separate drainage area is 650 square miles. It runs almost entirely over hard rock, and is rarely much loaded with mineral matter even in time of flood.

From the Teme to the Avon the distance is about 14 miles, and, with the exception of a few small streamlets chiefly from the west, no feeders enter the Severn for this distance.

23. The Upper Avon.—This important river rises in Northamptonshire, in a group of springs between Naseby and Welford, proceeding from the oolitic hills. A considerable stream is formed at Welford, within a distance of about 3 miles. The river, once established, flows on, making a turn to the north and then proceeding towards the south-west, for about 9 miles to Rugby, receiving on its way several small feeders from right and left, and at Rugby the little river *Swift* from the north. Beyond Rugby the course is west for about 8 miles, the river approaching within a mile of the bed of the Sow. It then turns south-west, and, after winding about for 4 miles, its general course being nearly parallel to that of the Sow, enters that river at right angles. The *Sow* rises near Astley, and flows in a very tortuous course to the south, passing several villages. Joining the Avon, this river, which is the principal stream, takes at once the course of the smaller tributary, and continues for some miles towards the south, doubling its distance by its windings till Warwick is reached, where occurs the confluence of the river *Leam*, which comes in from the east after a long and straggling course, receiving on its way the *Rains brook*, the *Itchene*, and many smaller streams from the extreme edge of the Severn basin to the east. The Leam rises on the northern slope of Marston hill, close to the source of the Cherwell; thence it runs north 6 miles, continues north-west 5 miles, and finally west for another 15 miles. The Itchene drains the country 10 miles to the south.

From the confluence of the Leam the Avon continues its winding course south and west to Stratford-on-Avon, receiving near Warwick the *Tach brook* from the south-east, and, a mile and a half below Stratford, the river *Stour* (Warwickshire), a short feeder from the south. After another 8 miles the river *Arrow* joins it from the north. This latter is a remarkable stream, and derives its name from the straightness of its course. Its source is in a valley between the Lickey hill and a nearly parallel range about 3 miles to the east, and from the convergence into a narrow valley of the rainfall within the drainage area enclosed by these hills on either side, a stream is obtained which runs in a nearly direct course 16 miles almost due south, receiving at Alcester, 4 miles before reaching the Avon, a considerable feeder called the *Alne*, rising in the old forest of Arden, and flowing south-west for 8 miles. The Avon now, after another 6 miles, reaches Evesham, round which it winds, the town being built in a loop surrounded on three sides by the river, and from this it winds in large curves by Pershore to Tewkesbury, the distance measured on the river being more than 20 miles, though in a straight line it is not more than 11.

Except the *Isborne*, which comes in from the south at Evesham from the oolitic hills east of Cheltenham, a distance of 12 miles, there are no feeders of importance in the lower course of the Avon. At Tewkesbury the *Carron brook* from the east joins the stream before the Severn is reached, and the *Swilgate brook*, also from the east and south, partly discharges into the Avon, though there is a branch direct to the Severn.

24. Summary of the Middle Severn.—The Avon enters the Severn at the point to which the tide reaches under ordinary conditions, and below this confluence the river is essentially tidal and soon becomes salt. Here, therefore, the Lower Severn commences.

The peculiar conditions of the Middle Severn have been already pointed out, and need not here be repeated. It is essentially a double river, two streams flowing in the same channel, one a mountain torrent of pure water and the other a comparatively sluggish river running off secondary clays, marls, and sandstones, always contributing a fair proportion of the ordinary summer and winter flow, and occasionally swollen by rains of long continuance in the midland counties. The western stream passes over a country very thinly peopled, but, after continued dry weather, its larger tributaries are greatly reduced, and what drainage there is comes over comparatively flat land. Owing to these causes the condition of the river is not unfrequently bad in summer, though good in autumn, winter, and spring.

25. The river Chelt.—Between Tewkesbury and Gloucester the *Chelt* joins the Severn. It rises on the lias at the foot of the oolitic escarpment behind Cheltenham. Its course is over the lias for nearly 12 miles, and it enters the Severn nearly midway between Tewkesbury and Gloucester, about 6 miles from each. Its waters are derived from the overflow of the springs in the Cotswold hills.

26. The river Leadon.—At Gloucester the Severn receives the *Leadon* from the north-west. This river rises in the hilly ground west of the Malvern hills, and has a course of 10 miles in a nearly straight line due south, passing Ledbury. It then turns south-east for nearly 6 miles, when it receives an important branch draining a parallel valley, as is often the case in this part of the country. This is called the *Glynch brook.* It rises near Little Malvern, and flows through Eastnor Park, having a total course of nearly 10 miles. The united stream, after the confluence of the Glynch brook, runs south and east for about 6 miles to the Severn.

27. The Frome (Gloucestershire).—Winding in large curves for some miles, the Severn next receives the *Frome,* a useful river entering from the south-east, and another small stream coming in at Westbury from the north-west; but, except a few brooks from both sides and the Little Avon from the south, there are no other affluents of the Severn till the Wye is reached.

28. The Little Avon.—This river originates in two nearly equal streams, one rising at Boxwell, and the other at Kilcot, uniting at Alderly, not far from Wotton-under-Edge. The united stream drains the country, chiefly on the western side, for about 10 miles, receiving many small feeders, and it flows into the Severn through the vale of Berkeley towards the north.

After receiving the Little Avon, the Severn becomes so wide that it is convenient to consider the streams coming in from the two banks, without reference to their relative positions. Those on the right or northern bank will be first described.

29. The river Wye.—This noble stream is with reason regarded as one of the most beautiful of the English rivers, and it is one of the most interesting. It rises in the wild mountain district of Montgomeryshire, on the southern slope of Plynlimon, only 2 miles from the source of the Severn. Flowing some miles south and east through a desolate valley, it reaches Llangurig, when its direction is changed to south, and it runs through a narrow valley between the mountains about 8 miles to Rhaidr, receiving on the way a few tributaries, one on the left bank, called *Afon Marteg*, having a long course from the north-east and north. Below Rhaidr the river *Elan* enters from the west, conveying an extensive mountain drainage, conducted through valleys more or less parallel with that of the Wye. The Wye runs now south nearly 12 miles to Builth, about 3 miles before reaching that town receiving the waters of the *Ithon*, another large tributary draining the mountain slopes by many valleys and receiving water from the mountains which supply the Teme and the Lug. The Ithon is fed by many tributary streams.

At Builth another considerable affluent, the *Yrfon*, enters from the south-west, draining the mountain sides in that direction by numerous valleys. The length of course of this stream is upwards of 20 miles. Beyond Builth, about $4\frac{1}{2}$ miles, a beautiful stream, the *Edwy*, enters from the east. After this the Wye continues to flow south another 6 miles, and then bends round to the north by a curve of large radius, bringing it almost to the parallel of Builth, when it turns back again towards the south. In all this part of its course the valley of the Wye is gradually widening, and at length becomes as much as a mile across. Within these limits of width the channel or water-way, which is always much smaller, takes a sinuous course, frequently altered owing to the torrential nature of the stream. The beauty of the river is in this way much enhanced. Before reaching Hay a small feeder is received (the *Llythe*), conveying water from a lake (*Llyn Safaddu*) 8 miles to the south, and close to the Usk valley.

Arriving at Hay, the valley of the Wye widens out rapidly, and the mountain character of the scenery disappears. The river, which for 50 miles has pursued a rough mountain course, now becomes a winding surface of smooth water, its beauty being dependent on its wooded banks rather than on torrents dashing through rocky glens. As far as Hereford, and, indeed, below Hereford to Mordiford, no tributary of importance joins the river since its emergence from the mountains. At that point the Lug enters, receiving almost at its confluence with the Wye the waters of the Frome.

The *Lug* rises among the Welsh mountains of Radnorshire, close to the sources of the Ithon, and runs through a tolerably straight valley for about 12 miles in a south-easterly direction to Presteign. About 2 miles beyond it receives the waters of a branch rising nearly the same distance to the south-west, and passing New Radnor. The united streams spread out over a wide, marshy tract, and flow on about 5 miles east to Aymestry, where the scenery is very beautiful. Turning now south-east, the river flows through a comparatively open country to

Leominster, having hilly ground on the left bank, when it turns south, and receives in succession a number of large tributaries from the west, draining an extensive tract of level country in that direction. With the exception of a large loop to the east at Dingmore, the Lug continues a southerly and uninterrupted course of about 18 miles from Leominster to its junction with the Wye, bearing throughout the character of a torrential stream.

The *Frome* (Herefordshire) rises about 3 miles south of the course of the Teme, where it passes from Tenbury and curves round to the south to make its way to the Severn. Receiving a few tributaries, it flows uninterruptedly to the south about 13 miles, passing Bromyard, and then turns, running 6 miles south-west, to enter the Lug close to its outflow into the Wye.

The distance from Hereford to Ross, measured by road, is 11 miles, but measured on the course of the stream it amounts to 27 miles. The windings below, from Ross to Monmouth, are of the same kind. During this part of its course the Wye receives very few tributaries, and none of importance. The banks of the river generally rise abruptly from the water's edge, and are clothed with forests or broken into cliffs; the general character of the scenery is wildness and solitude. The distance from Ross to Monmouth by water is 21 miles.

At Monmouth the river *Monnow* enters. It originates in the junction of three brooks—the *Eseley brook*, the *Olchon brook*, and another draining the slopes of the Black Mountains of Wales a few miles south of Hay,—and flows in a southern direction for a few miles, till it meets the *Afon Honddhu*, which has come down a parallel valley to the west. After the confluence the united stream turns to the north-east for a short distance, when it receives an affluent, and then flows 15 miles south-east to Monmouth, where it enters the Wye.

The *Trothy* enters a little below Monmouth from the west. It rises near Abergavenny from high ground, and has a course of about 20 miles to the south-west and west. It pursues a very sinuous course, and is not a river that carries down a large supply to the main stream. The Wye below Monmouth is shut in by lofty, precipitous banks, and the scenery is very magnificent as far as Chepstow. Below that town the course is more open, and after 2 or 3 miles the Severn is reached. The total length of course is 125 miles.

The course of the Wye from the Lug to its termination in the estuary of the Severn is throughout singularly tortuous, and much of it is cut through thick beds of old sandstone rock. For almost the whole distance it affords a never-ending succession of lovely scenery.

The Wye is remarkable among the English rivers for its rapidity, and for the grand and majestic features of the valley through which it makes its way. Descending from the slopes of Plynlimon, it dashes with great fury through the arches of the bridge at Rhyadergowy, forcing its way between the mountains to the plain of Builth. It then enters a romantic gorge, and tumbles in a succession of falls for some distance. Beyond this, turned by the Black Mountains to the east, it preserves its great rapidity and torrential character as it enters the Herefordshire plains, after which, till it reaches Ross, it is comparatively sluggish.

30. The Nedden brook.—From the Wye to the Usk there is little drainage on the coast. The Nedden brook, entering near Portskewil, drains a small tract of hilly ground in Went wood, and has a course of nearly 6 miles to the south-east. The shore along the whole distance is low, flat, and alluvial.

31. The river Usk.—This is a large river, remarkable for its lovely scenery. It enters the Severn on low ground from its right bank about 16 miles below the Wye. It originates in a number of streams collecting the water from the eastern slopes of a fine mountain range on the borders of Brecknockshire and Carmarthenshire, most of the streams converging within 4 miles of the range. From the union of these streams the river runs nearly east 10 miles to Brecknock, receiving several considerable feeders both from north and south, some of the branches having their sources among the high mountain slopes at a distance of 10 miles. From Brecknock the river flows south-east in a wide valley through charming scenery, and, after 6 miles, receives a tributary running through a wide valley called Glyn Collwng. After this the Usk continues to wind for 15 miles through a beautiful valley past Crickhow to Abergavenny, when it turns south, and runs 12 miles in this direction, finally turning south-west for about 8 or 9 miles to the Severn.

Before reaching the Severn the Usk receives two not unimportant tributaries from the mountain chain extending west of Abergavenny. One of these, the *Afon Llyw*, enters at Carleon, 3 miles above Newport, after a course of 16 miles south parallel to the course of the Usk. The next, the *Ebwy*, comes in close to the mouth of the stream. It has two principal branches, one of these again branching into two. All run parallel to the valley of the Afon Llyw the greater part of the way, rising in the same mountain range. The main stream runs south 15 miles, under the name of the *Sirhowy*, and then turns east 3 miles, where it receives the *Ebwy*, after a course of 12 miles also south. They meet at Risca, and the united stream runs 8 miles south-east into the expanse of flat land at the mouth of the Usk, through which it passes by a meandering course. The drainage area of the Usk is 540 square miles.

32. The river Rumney.—Six miles below the mouth of the Usk a small river, called the *Rumney*, enters the Severn, proceeding from the same mountain chain as that which feeds the Ebwy, and running a parallel course about a mile west of that river and its tributary for 20 miles. This stream also has two parallel branches or forks, meeting after about 5 miles. A line of water-parting, ranging nearly north-west and south-east, separates the basin of the Wye and the streams naturally dependent on it from the basin of the Taf, the next stream to the west.

33. The river Taf or Taafe.—This is a mountain stream entering the Severn 3 miles below the Rumney, and rising in the lofty summits of the Van of Brecknock. It begins as a torrent, tumbling in successive cataracts till it becomes a river, and passes Merthyr Tydvill. Thence it is precipitated with great force and rapidity into a gorge which slopes rapidly for many miles, the river passing under the picturesque Pont-y-Pridd (new bridge), immediately below which it receives the *Rhonda* from the west, a mountain stream with two main branches running about 10 miles. Below this confluence the Taf flows 9 miles through an alluvial valley, gradually widening and expanding into a spacious plain, in which is built the ancient city of Llandaff. Through this plain it runs to Cardiff, where it meets the tide, and falls into the sea opposite the high rock of Penarth.

34. The river Ely.—The river Ely rises in the hills south of Newbridge, where the Rhonda enters the Taf, and flows about 9 miles to the south-east. It then has a winding course close to the hills that enclose the valley of the Taf to the south-west, and after 5 miles, reaches the plain of the Taf, near Llandaff. It flows into the little creek by which the Taf enters the Severn, and the mouths of the two streams are thus combined.

From Penarth the coast runs due south 3 miles to Lavernock point, which is the extreme termination of the basin of the Severn on the north side of its channel. From this headland across to How Rock, the extremity of Brean Down, in a direction nearly south-east, the distance is a little more than 7 miles. Between the two headlands are three rocky islands, which connect very distinctly the margin of the basin and the end of the river. From this point the Bristol Channel commences.

35. Lower or Somersetshire Avon.—We must now return to the rivers on the left bank of the Severn, which we left at the Little Avon draining the vale of Berkeley. From the point where this stream joins the Severn there is no drainage whatever entering the river from the left or southern shore, except from small brooks not cutting through the alluvium of the valley, till the Lower Avon is reached, a distance of nearly 17 miles.

The Lower Avon (so called to distinguish it from the numerous other British Avons, and especially from the Upper, or Gloucestershire, Avon, another important tributary of the Severn), rises on the eastern slopes of the oolitic hills of the lower Cotswolds at Sherston, about 6 miles west of Malmesbury, and is soon joined by a considerable feeder from the north-west, rising at Tetbury. Thence it continues in a winding course southwards to Chippenham (only 9 miles in a direct line, but nearly doubled by the river), and then flows another 7 miles to Melksham. Between Malmesbury and Chippenham it receives from time to time, and from both sides, small feeders, and near Melksham the river *Marden*, its first large affluent, enters from the east, passing Calne, and conveying a good body of water.

From Melksham the Avon begins to turn more to the west, and after 2 miles receives a tributary at Whaddon, coming from the hills about 8 miles to the south-east. A few miles further, receiving in the interval other affluents from the south, Bradford is reached, 2 miles below which the river *Frome* comes in from the south. This Somersetshire Frome (which must be carefully distinguished from other rivers of the same name, also feeders of the Severn or its tributaries) rises in Witham wood, near Bruton, and runs northward 6 miles to the town of Frome, receiving many feeders, the most important of which is from the west, and runs about 8 miles. From Frome it continues northward with a beautiful and tortuous course of about 8 miles to its confluence with the Lower Avon. It passes through a very pretty country, and receives frequent affluents from the west, some of them having large drainage areas. Three miles below Bradford the Lower Avon makes a large curve to the north, and returns south to pass through Bath, after which, in 6 miles, it reaches Keynsham. Near Bath several small streams enter it. Near Keynsham the river *Boyd* comes in from the north through the Golden Valley, and at Keynsham the river *Chew*, which has had a course of nearly 18 miles from the south-west, receiving a large number of tributaries.

Leaving Bath and turning north the Avon soon reaches Bristol, where it is joined by the *Lower Gloucestershire Frome*. This river, rising at Doddington from the foot of the oolitic escarpment, flows west through Chipping Sodbury about 6 miles, where it receives the *Laden* from the north, then, turning south about 8 miles, it enters the Avon within the city of Bristol, nearly at right angles to its course, and, with the exception of the *Trim*, a small stream also from the north, is the last affluent received before the final confluence with the Severn. The Lower Avon is remarkable for its singularly romantic valleys and the rich country it passes through. It generally flows between deep banks, and its colour is strongly affected after heavy storms, the flood waters from Wiltshire tinging it white with chalk, and those from Somersetshire red with ochre; but it is generally dark and deep, and occasionally rapid.

The entire drainage area of the Lower Avon is a little under 900 square miles. Above Nelham it has been measured to be 795 square miles, and the Gloucestershire Frome, entering below that place, drains 68 square miles, being a total of 863 square miles draining into Bristol harbour. Below Bristol there are about 31½ square miles of country whose drainage also passes into the Severn.

The fall in the bed of the river from Bath to the Severn is 79 feet, the distance being nearly 26 miles to the junction with the Severn. The mean rate is, therefore, not far from 3 feet to the mile.

The area drained by the Lower Avon is remarkable for the great variety of formations it includes. About two-thirds consists of the oolites; but every other formation, from the chalk to the Old Red Sandstone (Devonian), is to be found in the remaining third. The general character of the soils is non-absorbent, and water runs off rapidly after heavy rain.

36. The river Yeo.—This river enters the Severn 12 miles south-west of the Avon, there being no intervening coast drainage. It rises in the Mendip hills in a strong spring issuing from the limestone rock, and, after passing through the Vale of Blagdon, is joined by a stream whose origin is also a copious limestone spring. Its course is north-west, and it runs in a nearly straight line about 13 miles to the Severn.

Six miles below the Yeo, and immediately at the foot of Brean Down, the extreme edge of the Severn basin, where it is intersected by the river, the Axe enters. Although, judging by the position of its outflow, this stream appears to belong to the Severn, its drainage area is altogether beyond the line of water-shed of the Severn basin on the Mendip hills. It has, therefore, been judged more fit to include it in the group of rivers described in the last chapter, where a short notice of its physical history will be found.

37. General summary of the Severn.—The general character of the Severn as a drainage area is rather that of a group of principal streams uniting to enter a common estuary than one great and overwhelming river, always maintaining its character, and swallowing up the individuality of its feeders by its own importance. The Upper Severn (including the Vyrnwy), the Wye, the Teme, and the two Avons, have features quite characteristic, and by turns influence the main stream. Each of these separate parts of the Severn requires, indeed, to be studied separately, and admits of distinct treatment for supply purposes, and each drains districts geologically distinct. There is no length of course below the junction of the main feeders, for the river has already passed into the condition of an estuary before the confluence of its largest tributaries.

As a fresh-water river, properly so-called, the Severn terminates at Tewkesbury, and as far as that point has only received from secondary rocks the small streams of the Perry, the Tern, the Worf, the Stour, the Salwarp, and a few small brooks. All the rest of the water has come from the Welsh mountains, and the altered slates and quartzites of that country. The water of the river should be, therefore, pure, and though containing a certain amount of mineral salts derived from the New Red Sandstone, and thus rendered moderately hard, the quality for drinking purposes should not be affected.

Owing, however, to the torrential nature of the flow from the mountains, the eastern tributaries, though bringing little water in comparison, appear to exercise considerable influence in summer, when the water is low.

Below Tewkesbury the tributaries from the east and south are much larger, and swell the volume of the river, but the extent to which they affect the quality of the water of the Severn need not be considered, the tide coming up from the Bristol channel rendering it unfit for domestic or manufacturing use.

Welsh Coast Drainage.

38. General account.—South Wales is chiefly drained by a number of streams proceeding from the mountains of Glamorganshire, Carmarthenshire, and Pembrokeshire, and fed from the almost innumerable valleys that open out southwards towards the Bristol Channel. They terminate for the most part in creeks, inlets, and estuaries, some of them large, and forming excellent harbours, and some of them navigable for a considerable distance.

The whole length of coast along which this drainage takes place is about 100 miles, measured, not on the deeply indented coast line, but from headland to headland, from Lavernock Point, where the Severn terminates, across Carmarthen bay, Milford Haven, and St. Bride's bay. The distance inland from the coast to the sources of the rivers is rarely more than 30 miles, but the rainfall being heavy, and the fall of ground considerable, the quantity of water coming down is large, and most of the streams partake, more or less, of the nature of mountain torrents. There are several large estuaries, each receiving the water of rivers having distinct drainage areas, and thus the character of the drainage is somewhat exceptional.

The west coast drainage of Wales is affected by a number of small but beautiful and picturesque mountain streams, entering estuaries in a broken coast line after short courses, conveying torrents of water into the sea after storm rains, and rarely dry, owing to the frequent rainfall on the mountains. Most of these torrents are too small and unimportant to have other names than the general Welsh designations for water and water channels. There are, however, several that admit of brief description.

The northern rivers are few in number, but far more important, their courses partaking in some measure of the character of mountain torrents, but combining with this in the lower part great beauty of a different kind. All of them enter the sea in estuaries, and in the case of the Dee the inlet is of great magnitude.

The length of coast line along which the western rivers are delivered is very great if the whole of the windings are included, but the north coast except for the deep inlets already alluded to is more regular and less broken. There are not, however, so many or such important harbours in the west or north coast as in the southern part of the principality of Wales.

39. Scheme of the Welsh coast rivers.—The following is the order in which the Welsh coast rivers occur, commencing with the mouth of the Severn, and proceeding westwards, northwards, and eastwards to the eastern water-shed of the Dee:—

South Coast.

Ogmore.	Tawe.	Towy.
Afon.	Burry or Lougher.	Taf.
Neath.	Gwyndraeth Fawr.	East and West Cleddan.

West Coast.

Teifi.	Dovey.	Glas Llyn.
Eiron.	Dysynwy.	Gwrfai.
Ystwith.	Mawddach.	Seiont.
Rheidol.	Drwydd.	Ogwen.
	Gwynedd.	

North Coast.

Conway.	Clwydd.	Dee.

40. The river Ogmore.—The first considerable stream that enters the Bristol Channel from Wales, beyond the mouth of the Severn, is the Ogmore. There are, however, previously, three or four streams of smaller importance, and the distance along the coast to this river is more than 25 miles. The Ogmore rises in a small lake in the central mountain group of Glamorganshire, in the Old Red Sandstone, and flows about 18 miles chiefly over Permian rocks and New Red Sandstone, receiving the *Garan* and the *Llynn-fai* on the right bank, and the *Ewenny* on the left. It has a drainage area of 114 square miles, and empties itself into a wide creek more than a mile in length near Bridgend.

41. The river Afon.—About 12 miles beyond the Ogmore, the river Afon empties itself into Port Talbot, a wide creek running into the land to Aberafon. The sources of this stream are also in the higher valleys of the Glamorganshire mountains, and it has a run of 15 miles to the creek, being fed by several branches. The Afon flows entirely over coal measures, its drainage area being 87 square miles.

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42. The river Neath.—This stream, considerably larger than those just mentioned, descends from the Brecknockshire mountains with great rapidity through precipitous gorges into a deep valley, through which it flows to the south. Being fed chiefly by mountain torrents, of which the number is very great, it increases rapidly after heavy rain. It has one principal feeder, the *Dulas*, also torrential, which enters the parent stream near the town of Neath shortly before it expands and, like the Afon, enters a creek that opens out into a wider inlet. The river course is 23 miles, of which the last two alone are navigable. The mouth of the inlet receiving the creek is about 4 miles to the north-west of Port Talbot. The inlet receiving the Neath is at the head of Swansea bay. The course of the river lies over coal-measures. Its drainage area is 118 square miles.

43. The river Tawe.—The Tawe, on whose banks Swansea is built, opens into the middle of Swansea bay, nearly 5 miles west of the mouth of the Neath. It rises in the mountain limestone on the slopes of the Talsarn mountain (2600 feet above the sea), and combines three principal parallel branches, which unite about 10 miles south of the mountain source. Turning then to the south-west, and gradually fed by other tributaries, it reaches Swansea after a further course of 15 miles, and shortly after enters the sea. It crosses the millstone grit, but runs chiefly over coal-measures.

44. The Burry and the Lougher river.—From the mouth of the Tawe the coast extends westwards, broken into several bays and creeks for nearly 20 miles, when it turns abruptly to the north to enclose Carmarthen bay, a noble sheet of water from which there are four principal openings into the land. The first of these is called the Burry river. It is 5 miles across at the entrance, and runs in 7 miles retaining an average width of 4 miles. It then narrows, and the continued inlet, still between one and two miles wide, receives a small drainage from the interior by the *Llwchwr* or *Lougher river*. This stream originates in the Black Mountains, and flows down about 10 miles, receiving small tributaries, and then gradually widens for another 3 or 4 miles, forming a succession of wide channels and open expanses of water. It continues to be called the Lougher river for another 3 miles, and beyond that it merges into the Burry river. The last three miles are tidal. Like the other rivers of South Wales, the chief part of the course is over coal-measures. It drains 156 square miles of country.

45. The Gwendraeth Fawr.—Four miles beyond the wide opening of the Burry river in the bay of Caermarthen the Gwendraeth Fawr enters the sea by another creek at Kidwelly. It rises in the Caermarthenshire hills, and has a course of about 15 miles to the south-west, but receives few tributaries. Great accumulations of sand take place near its mouth. It drains 73 square miles.

46. The river Towy.—Rounding the point at the northern bank of the Gwendraeth Fawr inlet, the river Towy opens out by a large creek, entering the land to the north about 5 miles. This stream is more important than those hitherto described. It rises on the altered Silurian rocks in a large morass near the borders of Brecknockshire, and flows westwards and southwards entirely over Silurian strata for about 60 miles to the bay of Caermarthen, where its waters unite with those of the Taf and the Gwendraeth Fawr. It is a noble mountain river, beginning in the dreary waste of Roscol forest, and receiving a number of tributaries of which the Cothy is the principal. It waters a varied and interesting district, gradually becoming less wild as it proceeds, and it winds through much beautiful country, passing numerous villages, the banks being well wooded and the scenery often extremely beautiful. It abounds with fish. Its tributary, the *Cothy*, rises on the borders of Cardiganshire, and joins the Towy after a course of 25 miles. A little above Caermarthen another small feeder, the *Gwite*, enters. The number of feeders of the Towy is exceptionally large, and the drainage area is extensive, being estimated at 514 square miles.

47. The river Taf.—Another inlet, or rather another branch of the great inlet in the north-eastern part of Caermarthen bay, enters at the mouth of the Towy towards the north-west, and after about 2 miles, when the town of Laugharne is reached, turns northwards for a mile, and then again turns north-west, when it receives the Taf, draining a tract of country to the north. The Taf rises on the borders of Pembrokeshire, and has a course of 27 miles, at first through a well wooded country. In the upper part it receives a few tributaries, of which the *Cathgenny* and the *Cowen* are the principal. These enter near the point where the river begins to open out to the creek or inlet. A considerable addition takes place to the land at the point between the Taf and the Towy by blown sand, which is carried up by the tide, and moved by the wind. The channel of the river is exceedingly small near the mouth, the water being lost and sucked up by these sands. The drainage area is 183 square miles.

48. Milford Haven.—From the inlet into which the Gwendraeth Fawr, the Towy, and the Taf, enter Carmarthen bay, along the coast as far as Milford Haven, there is no coast drainage of any importance. At Tenby, at the south-western corner of the bay, two small streams come in, draining the country for 3 or 4 miles in the interior, and there are two or three similar brooks entering between Tenby and the entrance to Milford Haven.

This remarkable inlet opens to the Bristol Channel by a narrow entrance of about 2 miles facing the south. The main creek, however, ranges at first east and west for nearly 15 miles, the average breadth being little more than a mile, but with bays of considerable size opening out from it. The number of branches of the creek thus formed is very considerable, and some of them connect with the interior, receiving a drainage of a few miles of country. On one of these is Milford ; on another Pembroke. At the eastern extremity, the creek turns abruptly, nearly at right angles, and is continued in a north-westerly direction for more than 5 miles. It is also continued to the east and south-east, in each case receiving streams of fresh water. At the furthest point to the north there is another fork, both branches being of considerable width, and 3 or 4 miles in length, and both receiving streams of greater importance than those in the other inlets.

49. East and West Cleddan.—The streams thus entering the head of Milford Haven are the East Cleddan and the West Cleddan. The former rises in the Precelli mountains of Pembrokeshire (1750 feet), and flows southwards for about 12 miles, receiving a number of feeders. The latter passes through a romantic dell to Haverfordwest, and is navigable for small vessels. It is sometimes called the *Hiog*. It receives some feeders from the hilly ground to the west. It drains 212 square miles.

There is no coast drainage beyond Milford Haven to St. David's head, no streams entering St. Bride's bay except one very small brook near St. David's.

50. Western catchments of Wales.—From St. David's head through the long coast line of Cardigan bay to Bardsey island, and again from Bardsey island round the shores of Carnarvon bay to the Isle of Anglesea, the number of rivers is not great. The mountains approach the shore, leaving but little space for the waters to collect, and the streams that convey the surplus water carry off the rainfall at once into the sea, for want of space to accumulate and regulate the discharge. Thus, although the rainfall is heavy, and the total quantity of water conveyed must be very great, the rivers are all small, and not unfrequently disappear. The total length of coast line is not less than 180 miles, and the number of named streams is considerable ; but we can only mention those which are important, either as estimated from the volume of water they convey, from the length of their course, or from the circumstances of their discharge.

51. The river Teifi.—It is more than 30 miles from St. David's head to the mouth of the Teifi or Tivy, which enters Cardigan bay by a small estuary at Cardigan. This river rises in a lake near the sources of the Ystwith and the Towey, and not far from the source of the Wye. It takes at first a course to the south, and then flows south-west for a considerable distance between steep banks to the plains of Cardiganshire. It then turns northwards to enter the sea. This river is wild and torrential in its upper course, coming down from the Cardiganshire mountains, and receiving on its way a multitude of small feeders. In one part, near Newcastle Emlyn, it becomes engulfed between high rocks, and precipitates itself in a cataract, up which, however, the salmon are enabled to make their way. After making this leap it enters less broken ground, and becomes a placid stream; but near the mouth the scenery is very fine, as the river makes its way to the sea through a grand pass. At the mouth is a dangerous bar. Its drainage area is 386 square miles.

52. The river Eiron.—For nearly 20 miles from the mouth of the Teifi to Abereiron the coast is broken in a large number of places by narrow valleys, which carry into the sea the drainage of the coast range of hills. These rise within 5 miles of the coast to the height of upwards of 1,000 feet. The first river that drains the country behind this range is the Eiron, which rises near Lampeter, and flows through a romantic valley for 12 or 14 miles, receiving small tributaries. Beyond Abereiron, for 15 miles towards Aberystwith, there are only small valleys draining the near mountain slopes.

53. The rivers Ystwith and Rheidol.—These two rivers enter Cardigan bay nearly at the same point, close to Aberystwith. The Ystwith is a small stream draining 75 square miles of the hilly ground near the coast. The Rheidol drains 70 square miles, and is well known for its wild and picturesque scenery. It rises in the rocky district at the base of Plynlimon, close to the source of the Severn. It is a rapid stream from its source to its mouth, and runs southwards for about 10 miles through a romantic valley bounded on each side by irregular mountain masses. It receives many torrential feeders, some of them commencing their existence as cataracts. The most remarkable of these streams is the *Mynach*, which tumbles in a series of lofty falls after cleaving its way through a deep channel beneath the two curious arches of the Devil's Bridge. After receiving the Mynach the Rheidol continues running west for another 10 miles to the sea.

53. The Dovey or Dyfi.—The Dovey enters Cardigan bay 8 miles north of Aberystwith. It rises in a corner of the Welsh mountain district, not far from Bala lake, and near the source of the Vyrnwy. Like most of the streams of this belt of country, it runs southwards for some distance before turning westwards to the sea. The early part of its course is through wild and picturesque country to Dinas Mowddy, whence to Machynleth it waters a rich, cultivated, and well-peopled valley. The mouth of the Dovey is a wide estuary.

54. The river Disynwy.—Five miles beyond the estuary of the Dovey, a little beyond Fowyn, is an inlet with a very narrow entrance, into which enters a small river of this name. It receives several tributaries, one from the south-eastern slope of Cader Idris, and one of more importance near its outlet. It drains 64 square miles.

55. The river Mawddach.—This river, with its tributary the *Afon* or *Eden*, enters Cardigan bay by a noble estuary at Barmouth, about 15 miles north of the estuary of the Dyfi, and 9 from the Dysynwy. It receives the waters of the Afon, and drains 151 square miles of country to the north of Dolgelly. The estuary enters for about 8 miles to the north-east.

The main stream of the Mowddach is short, precipitous, and rapid, and it receives several torrents, almost all of which form cataracts in their upper course. The Afon is a much more placid stream, and waters a delightful valley for some distance. The united stream passes near Dolgelly, and the widening estuary is exceedingly picturesque at high water, being closely shut in by high mountains, which give it the appearance of a lake.

56. The river Drwydd.—The next considerable stream that enters the bay comes in about 14 miles north of the Mawddach; but there is a small intervening stream flowing into an inlet called *Afron Astro*, which runs up to the north-east a couple of miles south of Harlech. The name of the larger stream, which is situated in the north-eastern angle of Caernarvon bay, is the Drwydd. It enters by an estuary called the Traeth Bach, about 6 miles long. The river is a short but highly-picturesque mountain stream, watering the valley of Festiniog. It proceeds from the north-east, and winds about a good deal.

57. The Gwynedd.—Near the extremity of the Traeth Bach, at Port Madoc, the Gwynedd enters. This stream, which rises under the southern base of Snowdon, flows with great rapidity past Beddgelert, and rushes along in a series of falls to its outflow in the Traeth Mawr sands, a mile below Tremadoc. Its course is nearly south.

58. The Caernarvon coast and Menai straits.—The drainage of the promontory of Caernarvon, which exposes a long line of coast facing the south-east in Cardigan bay, and the north-west in Caernarvon bay, is effected by a large number of insignificant brooks, but, with the exception of the Seiont, which enters the Menai straits at Caernarvon, there is no stream of importance. There are, however, a few streams whose names it may be desirable to mention. The *Glas Llyn* rises near Moel Hebog, and falls near its source in a very lofty cascade. It enters Cardigan bay about 6 miles west of Port Madoc. Near Pwlhelli another small stream enters, and, in St. Tudwall's Road, near the southern extremity of the promontory, there is another. On the north-western side there is no drainage of importance. Entering Menai straits, the *Gwrfai* comes in from the north-western slopes of Snowdon, draining some extent of country, and, a little beyond, at Caernarvon, the *Seiont*, a small but rapid river, rising in Snowdonia, and expanding on its way westwards into the Llanberis lakes. The Seiont and the Gwrfai run in nearly parallel courses at no great distance apart. A little further to the north, at Bangor, the river *Ogwen* comes in. This is a small but rapid stream rising on the northern slopes of Snowdon, flowing through a lake (*Llyn Ogwen*), and having a course a little west of north. This river completes the list of those that take the western and north-western drainage of Wales.

59. The river Conway.—The Conway, the Clwydd, and the Dee, are the chief streams by which the water falling on the country north of the Severn drainage area finds its way to the sea. They are all streams of some importance.

The Conway rises in Snowdonia, originating in a small lake, and tumbling from precipice to precipice, swollen by many smaller waters to the junction of the *Llugwy*, near Capel Curig. This, the *Machno*, and the *Ceirw*, are three furious torrents adding their waters to those of the Conway, and emerging in a beautiful valley bounded by lofty mountains at Llanrwst, where navigation commences. The Conway runs in all 30 miles, about 12 of which are navigable, and it widens into an estuary as it approaches the sea. It drains 222 square miles.

60. The river Clwyd.—This stream rises in the Berwyn mountains, and runs northward and eastwards through a beautiful and fertile valley, well cultivated and thickly peopled, past the town of Ruthin. The vale of Clwyd extends for 15 miles below Ruthin, being generally from 5 to 7 miles wide, and studded with villages. A little below St. Asaph it is joined by the *Elwy*, which adds a large body of water. Its total course is 30 miles. In the lower part of its course it passes through a fertile marsh, and enters the sea by a small estuary. Its drainage area is 319 square miles.

61. The river Dee.—The Dee issues from the north-eastern end of the lake of Bala, the largest sheet of water in Wales, though only about 3½ miles in total length, and 40 feet deep. The lake is fed by two rapid streams which descend from the heights separating Dolgelly and Dinas Mowddy from Bala. Leaving the lake, whose waters are remarkably clear, the river flows in an open valley, increased from point to point by considerable mountain streams of which the *Alwen* is the chief. At Corwen it begins to descend the table land of North Wales, falling 300 feet with great rapidity between that town and Trevor. It then enters and flows through the beautiful vale of Llangollen. In its upper course on leaving the lake at Corwen it receives the *Treveryn*, a furious torrent from the west, and the *Ceiriog*, another torrential stream falling in the singular cascades of Glyndyffys. After entering the plain it receives the *Alyn* from the west, and runs northwards to Chester where it is 100 yards wide. Below Chester the channel is artificial for about 9 miles through marshes, and it then passes into a noble estuary 3 miles wide, which at high-water forms a magnificent arm of the sea, being about 6 miles wide where it reaches the coast. The length of course of the river is about 80 miles from Bala lake to the beginning of the estuary, and the length of the estuary is 14 miles. Its total drainage area is 862 square miles.

The flow of the Dee was estimated by Mr. Rawlinson on the occasion of an inquiry into the water-supply of Liverpool in 1847 as amounting to 63,000,000 gallons in the driest season. He estimates the drainage area above Llantsilio at 289 square miles, and that of the Ceiriog 38 square miles. The rainfall is estimated at 42 inches. The area of Bala lake is 1352 acres, and its height above the sea 1000 feet.

62. Utilisation of Bala lake.—It need not be said that the water rushing with great rapidity to this lake from the wild mountain land of Wales is as unexceptionable in quality as it is considerable in quantity. The country through which it passes is but little cultivated, and is thinly peopled, so that there is nothing to injure its quality. It is, however, for the most part inaccessible, and any attempt to collect the surplus water would be costly and troublesome. It has been proposed to convey the waters of Bala lake by pipes, or by an open conduit, along the great highways of England to the metropolis, giving off for the use of towns on the way such portions as could be spared. A work of this kind outdoing all works of a similar nature in magnitude and cost, could not be seriously carried out unless there were a greater need than is at present recognised. It has not of late years been mentioned among the schemes by whose means London is to be delivered from the supposed incubus of obtaining its water-supply from the Thames, its natural source. Another scheme has been projected by which the waters of this lake should be conveyed to Liverpool for the use of that city.

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V.—Drainage Areas of the Middle East of England, between the Thames and Humber Basins.

CHAPTER VII.

DRAINAGE AREAS OF EASTERN ENGLAND BETWEEN THE THAMES AND THE HUMBER BASINS.

1. General account of the district and physical features.—The part of England lying north of the basin of the Thames, east of the Trent and its tributaries, and south of the Humber, is drained by a number of rivers, and forms a natural district which comprises the whole of Norfolk and Suffolk, Cambridgeshire, Huntingdonshire, and Rutlandshire, almost the whole of Bedfordshire, large parts of Essex, Northamptonshire, and Lincolnshire, and part of Buckinghamshire. Hydrographically and physically, the whole tract arranges itself conveniently into two portions, the western which is by far the larger and most important, comprising upwards of 6,000 square miles of low-lying flat country, draining by four considerable, but not altogether independent rivers, into the Wash, and the eastern containing rather less than 4,000 square miles of a low plateau draining by a number of small and quite independent streams into the German ocean.

The Wash, into which the western area empties itself, is a bay entering the land between Norfolk and Lincolnshire, receding 20 miles from the German ocean, having a width of only 10 miles where it opens to the sea, but being 15 miles across at the end of the cul-de-sac, between the mouths of the Ouse and the Witham.

2. Geology.—Geologically this part of England presents at the surface no rocks older than those of the middle part of the secondary period, and the western district is almost limited to the large expanse of argillaceous strata characteristic of that period in England. The Kimmeridge and the Oxford clays here attain great thickness, and the intermediate limestones are absent. Owing to this the country is flat, the rocks hardly admit of percolation or absorption, and the rain that falls is conveyed slowly and with difficulty to the sea, producing a large tract of marsh or fen land in which the rivers stagnate, or from which, in many cases, the water has to be lifted by mechanical agency into artificial channels at a higher level to ensure its running off to the sea. The western district occupies a valley between the escarpment of the chalk and that of the oolites. The eastern drainage is to the sea by a number of small streams. It is impossible to understand the nature of the drainage, or the conditions of the country with regard to springs, without a knowledge of these geological conditions, and a study of their meaning.

The rock over the whole of the eastern district is chalk, occasionally covered towards the coast by tertiary and quaternary beds, the London clay often overlying the chalk, and being covered by the different varieties of crag. The crag, however, in some cases rests immediately on the chalk, and the surface is in many places covered by modern gravels and sand. The district is traversed by a number of unimportant rivers conveying little water. The only stream of any magnitude is in Norfolk; the rest are all small, though many of them open into tidal estuaries of considerable magnitude entering far into the land, and to some extent navigable.

3. Division into catchments.—The whole area under consideration may be conveniently considered under the following heads:—

Western Division.

Basin of the Great Ouse - - -	2960	square miles.
Basin of the Nen - - - -	1132	„
Basin of the Welland - - -	708	„
Basin of the Witham - - -	1050	„

Eastern Division.

Drainage of the Norfolk coast beyond the basin of the Yare and of the Lincolnshire coast beyond that of the Witham - - - - -	1000 square miles.
Basin of the Yare - - - -	1180 "
Drainage areas of the East Suffolk and Essex rivers - - - -	1800 "

4. Rainfall, evaporation, and percolation.—Over this area the mean annual rainfall varies in different parts from 27 inches in the south-westerly part near the valley of the Thames, to as little as 19 on the chalk hills of Norfolk. The highest rainfall is near Bedford, on the Lower Greensand. Probably the western part of the area has a mean rainfall of $24\frac{1}{2}$ or 25 inches, and the eastern part of $22\frac{1}{2}$ or 23, showing a general average throughout of nearly 24 inches. The rain chiefly falls in the winter and early spring, the later spring and summer being frequently very dry. Evaporation is certainly very active on the eastern coast, the exposed surface being either chalk or loose sand and gravel, but over the Oxford and Kimmeridge clays in the valley to the west it must be comparatively slow, except when the water is allowed to accumulate on the surface. The greensands, no doubt, admit of evaporation and percolation freely, but they are only local. The percolation is rapid in the chalk and gravel districts, but slow on the fen country underlaid by stiff clays.

5. Quality of the waters.—The quality of the water in the fen district is affected by the conditions of the surface, and is not very good. That running off the broken weathered chalk and that which is obtained from the tertiary beds are almost equally liable to objection. Well water from the chalk, drawn from a considerable depth, is frequently good, but this rule is by no means without exceptions, as many wells have been sunk into the chalk in Essex, Suffolk, and elsewhere, with very unsatisfactory results. The water from shallow wells is easily obtained, but soon exhausted in dry weather. It is objectionable, and liable to contain injurious ingredients. The following analyses taken from Dr. Frankland's Sixth Report of the Rivers Pollution Commissioners, are illustrative of the various kinds of water met with in the larger streams :—

Date of Sample.	Tributaries.	Total solids.	Org. Carbon.	Org. Nitrogen.	Ammonia.	Nitrogen as Nitrates.	Chlorine.	Hardness.
Oct. '68 -	Great Ouse, Bedford - -	33·53	0·434	0·062	0·003	0·704	1·88	20·0
Feb. '71 -	Little Ouse, Thetford - -	30·87	0·291	0·062	0·003	0·431	2·20	20·4
Nov.'73 -	Welland, near Spalding -	77·28	0·930	0·111	0·56	0	8·93	47·1
June '72 -	Wensum, Norwich - -	21·64	0·302	0·056	0·010	0·025	2·17	18·6

6. Ordinary flow and flood.—All the rivers of the western group, though in their earliest course running streams, soon become slow, and through the greater part of their way through the clays of the oolitic group of rocks are very sluggish. They are subject to floods whenever heavy rain falls on the uplands, and can only expand over the flat plains through which their courses lie. To enable them to reach the sea it is sometimes necessary to construct extensive works preventing the influx of the tide, and enabling the water to be drained off during low water. To permit even this their meandering course has to be straightened, so as to render their small fall available. Sometimes they require to be lifted and conveyed to the sea by artificial channels. The streams of the eastern group are short, but many of them open into estuaries. These receive the tide for many miles, and the fresh-water stream is often lost sight of. They are not subject to serious floods.

7. Scheme of the rivers and their tributaries:—

Western Group.

The Great Ouse.

Right.		*Left.*
Padbury brook . .	16½	
	23	. . . Tove.
Ousel	30	
Ivel	76	
	82	. . . Kym.
	90	. . . Alconbury brook.
Cam	112	
Lark	118	
Little Ouse or Brandon	125	
Wissey or Stoke . .	130	
Nar or Setchy . .	146	

The Nen.
Ise.
Harper's brook.
Willow's brook.

The Welland.
Eye or Wye brook *l.*
Chater *l.*
Gawsh *l.*
Glen *l.*

The Witham.
Brant *l.*
Till *r.*
Langworth *r.*
Southbeck *r.*
Bain *l.*
Sleaford *r.*

The Steeping.

Eastern Group.

The Wensum or Yare.
Bure *l.*
Waveney *r.*

The Blythe.

The Alde.

The Deben.

The Gipping & Orwell.

The Stour.

The Colne.

The Pant or Blackwater.
Brain *r.*
Chelmer *r.*
Sandon brook.
Ter.

Western Group.

8. The Great Ouse.—The principal river of the western group of catchments in the part of England now under consideration is the Great Ouse, which collects and conveys to the Wash the rain that falls over an area of 2,960 square miles of country. But although ranking highly among English rivers when only drainage area is considered, the Ouse is far from being really so important as this would indicate. It drains a flat country on which little rain falls, and for a very long distance the channel of the river would be unable to carry off the water if it were not for artificial help. Its stream is lazy, and it neither gives nor receives much beauty in the great tract through which it passes. It flows through the largest extent of level country, and has the most tortuous course, of any river in the British islands.

9. Head waters of the Ouse.—The Ouse originates in a number of springs from the low oolitic escarpment that overlooks the valley of the Cherwell, and extends for a long distance as a line of water-parting between the basin of the Thames and the basins of the rivers draining into the Wash. The brooks and rivulets that combine to form the Ouse, occupy a corner of land 7 or 8 miles in breadth, and those of its early and small tributary the Tove drain the country several miles beyond towards the north, the former being in the lower oolites, the latter in the lias. The elevation above the sea at these sources is nearly 300 feet. First receiving its name at the confluence of these early feeders about Brackley, the Ouse runs 6 miles with a sluggish stream in an eastward course to Buckingham.

10. The Padbury brook and river Tove.—Two miles beyond Buckingham the Ouse is joined by the *Padbury brook* coming in from the south. This small stream rises in Oxfordshire, within a mile of the bed of the Cherwell, and here if the gorge through the chalk hills near Pangbourn did not exist, the drainage of the Upper Thames would flow northwards into the Ouse. After about 6 miles, winding about to the north-east, the Ouse receives the *Tove*, entering from the north and west. The early feeders of the Tove collect into a stream at Towcester, and the Tove joins the Ouse near Wolverton station, where another and much smaller feeder enters from the south.

11. The Ousel.—Beyond this junction the Ouse becomes a large, but not a rapid stream, and flows in a winding course about 3 miles to Newport Pagnell, where it receives the Ousel from the south. The Ousel is formed by the junction of several small streams rising from the chalk on the north slope of the Chiltern hills, whence it runs for nearly 30 miles almost due north through the lower cretaceous beds and oolites, passing Leighton Buzzard and Fenny Stratford, and receiving the *Crawley*, a considerable brook, before it reaches the main stream.

Leaving Newport Pagnell the Ouse turns to the north, and winds for some miles, making a large bend to the north and flowing in a series of sweeps, first passing Olney Harrold. It then proceeds 8 miles to the country north of Newport Pagnell, and returns almost to the same parallel, making a distance of 9 miles before it reaches Bedford, whence it has a more regular and less tortuous course eastwards for 6 miles to Tempsford, where it receives the Ivel.

12. The river Ivel.—This stream originates near Baldock in a small unnamed brook flowing north and afterwards turning west, having a course of about 5 miles to its confluence with the river *Hiz*, a larger stream rising near Hitchin, receiving some branches, and flowing northwards for between 7 and 8 miles to meet the brook. From the confluence the united waters flow northwards under the name of the Ivel. The stream flows under this name for 10 miles to the Ouse, but before reaching the main stream it is joined by a small feeder, to which the name of Ivel is also given. This second Ivel rises in the hills near and to the west of Ampthill, and is joined by several small feeders on its way to the south-west to meet the larger Ivel. The united stream flows past Biggleswade, and shortly after enters the Ouse.

13. The river Kym.—After receiving the Ivel, the course of the Ouse is northwards, and near St. Neot's where it enters Huntingdonshire, it is joined by the Kym on the left bank. This stream rises in the neighbourhood of Higham Ferrars in Northamptonshire, passes Kimbolton, and has a course of 17 miles to the Ouse, chiefly in a south-easterly direction.

From St. Neot's the Ouse takes a north-easterly direction to Huntingdon (about 8 miles), and after another 5 miles passes St. Ives. It then flows east, and soon enters Cambridgeshire.

14. The Alconbury brook.—Near Huntingdon the Ouse is considerably increased by a number of small feeders, of which the Alconbury brook is the most important. This river has a course of 14 miles fiom the north-west, and just before its confluence with the Ouse it receives a stream which has come through about 13 miles of country from Northamptonshire, and another feeder from Huntingdonshire coming from the west.

15. The Fens.—Soon after leaving Huntingdon, the Ouse begins to enter the great expanse of the fens, through which it continues to move either by natural or artificial channels for the rest of its course. After flowing in its natural channel eastwards about 5 miles it is artificially embanked on the right side for about 3 miles, and reaching Earith comes under the influence of one of the great drainage works by which the valuable lands of the fens have been protected from flooding and rendered cultivable. The works here commence with two great parallel drains formed by embankments extending in straight lines for upwards of 20 miles across that part of Cambridgeshire called the Isle of Ely, and terminating at Denver in Norfolk. They are called the Old and New Bedford rivers, the latter being navigable throughout. The ancient course of the Ouse may still be traced, and is found to run nearly east to Stretham for about 10 miles at the foot of some low elevations. At Stretham the Ouse receives the river Cam entering from the south.

16. The river Cam.—The Cam, or Granta, now chiefly known by the former name, rises near Quendon in the north of Essex, close to the sources of the Stort, and has a long straight course to the north over a chalk bed, receiving a few tributaries both from east and west. After continuing this course for 16 miles to Shelford, it there receives a feeder on the right from the Bartlow hills, about 8 miles to the south-east. This is sometimes called the *Bourne river*, and is fed by two branches meeting at Bartlow. Three miles below Shelford the river *Rhee* comes in from the south-west, rising at Ashwell, not far from the course of the Ivel, and having a course of more than 15 miles, being fed by a branch coming through Wimpole Park. Almost immediately beyond the junction of the Rhee, the *Bourne brook* enters the Cam at Grantchester, draining the country to the west for a distance of about 7 miles. Beyond Grantchester, the river runs through Cambridge, and continues its course a little to the east of north through the fens to the Ouse, without receiving other tributaries.

17. The river Lark.—The Ouse now continues about 6 miles, passing Ely to its confluence with the Lark. This river originates in a few small brooks coming from the chalk, which unite to form a stream about 3 miles south of Bury St. Edmunds in Suffolk. Flowing to the north-west through that town, and about 12 miles beyond to Mildenhall, the Lark enters the fens, through which it has a further course of 9 miles before reaching the Ouse, the direction of the course being still north-west.

18. The Little Ouse.—Six miles below the confluence of the Lark, passing Littleport in the fens, the mouth of the Little Ouse is reached. It is also called the *Brandon river*. It originates in the union of two branches, commencing in chalk springs a little south of Botesdale in Norfolk. Collecting these waters and running about a mile and a half over chalk, the stream inosculates with the Waveney at the source of that river, and from this inosculation the two streams proceed in diametrically opposite directions, the Little Ouse flowing nearly due west for nearly 10 miles, while the Waveney runs due east. The former stream then turns abruptly, and flows 2 miles north to Thetford, continuing in the same direction 2 miles: it then turns again to the west passing the town of Brandon, and proceeding in the same direction for 12 miles. Before turning to Thrapston it receives a considerable feeder from the south, passing Ixworth and Fakenham, and flowing more than 12 miles in a direct northerly course. With the exception of this tributary, the Little Ouse is a stream singularly devoid of affluents.

19. The Wissey or Stoke river.—Five miles from the confluence of the Little Ouse the Wissey enters the Ouse from the chalk escarpment in the east. It is sometimes called the Stoke river. It flows about 12 miles nearly west, first taking the name of Wissey after passing Stoke Ferry, and having no feeder. It drains 243 square miles.

Between the Wissey and Downham Market, a distance of $2\frac{1}{2}$ miles, the *Well creek* joins the Ouse, entering from the west at the end of the Bedford level. It connects with some of the main cuts.

20. The Nar river.—North of Downham Market the Ouse continues its course about 13 miles to Lynn, where it receives the Nar or Setchy, a narrow but deep and rapid river rising at Litcham, and flowing 13 miles west through the fens past Narford and Narborough, and finally turning northward a few miles to enter the Ouse. It drains a very small area.

At Lynn the Ouse is a broad river, and immediately below it the shallow estuary of the Wash is entered. It is believed that formerly the Ouse entered the Wash by Wisbeach, and not Lynn, that town being then watered only by the Little Ouse.

21. Summary of the Great Ouse.—The whole length of the Ouse is not less than 150 miles, and the lower part of the country through which it passes is remarkable for the large body of water it retains on the surface after heavy rain, especially at the time of the equinoxes. The stream, as has been already observed, is generally sluggish, and any overflow spreads rapidly over a very large area. This expansion serves as a flood regulator, and interferes with the scouring action which takes place during floods in other rivers that have a freer outlet to the sea, and a more rapid flow.

The length of course of the Ouse through the fens is greatly reduced by the artificial cuts to which its channel is now confined. The system of drainage adopted is complicated and has been long in operation, and mechanical force is employed in places to lift part of the waters of the river into higher levels to enable it to enter the sea. The sea is kept out by embankments on a very large scale. Formerly windmills were very largely employed to lift the water, but steam-pumping is now more usual.

Throughout the greater part of its course the Ouse itself, and most of its tributaries, are unpicturesque. It is uniformly dull, even in Buckinghamshire, where it runs through the princely domain of Stowe, and it does not improve in traversing Bedford and Huntingdon. It is occasionally useful as a navigable stream, but at St. Ives it sinks into the great marshes which occupy so large a part of Norfolk, Huntingdonshire, Cambridgeshire, and Lincolnshire. The Cam as it passes Cambridge, and before reaching the fens, is the source of much beauty as it slowly makes its way at the backs of the colleges, were it only for the opportunity it has afforded to vary the scenery by the construction of the bridges.

22. The river Nen or Nene.—This river rises in the oolitic hills of Northamptonshire in two principal branches, one to the north, and the other to the south of Daventry, the former proceeding from the village of Naseby, 300 feet above the sea, the latter from Upper Catesby and Staverton, the two meeting at Weedon Beck. The united stream flows eastwards about 8 miles from Weedon Beck to Northampton, receiving near that town a considerable feeder from the south-east. From Northampton it is navigable. Turning a little to the north, and passing through a pleasant valley for nearly 10 miles to Wellingborough it receives from the north the river *Ise*, and flows north-east to Thrapston. At length reaching Oundle it enters Huntingdonshire, forming for some distance the county boundary. Its chief tributaries are the Ise (24 miles long), which passes near Kettering and joins the main stream at Wellingborough, *Harper's brook* (15 miles), and *Willow's brook* (15 miles). Both these rise in Rockingham forest in the north-western part of the county.

Leaving Northamptonshire, the course of the Nene runs eastwards to Peterborough, where it enters the fens, which it traverses in a north-easterly direction, spreading out into various streams more or less artificial, one of which leads to Wisbeach. The river then separates Lincolnshire from Norfolk, reaching the Wash in a small estuary a few miles from the mouth of the Great Ouse.

The upper part of the Nene is through a beautiful country, and its character is that of a gentle but full stream flowing quietly through meadows. It passes through Rockingham forest, which not long ago occupied the interval between the Nene and the Welland. After passing Wandesford the country becomes more level, and after Peterborough there is nothing but fen. Formerly there existed large lakes in this part of its course, but these are now reclaimed, and the drainage of the whole district is nearly complete.

23. The river Welland.—This stream rises from a gentle range of hills between Lutterworth and Market Harborough, and in its early course it separates Northamptonshire from Leicestershire, Rutland, and Lincolnshire. The source is very near that of the river Ise, a tributary of the Nene, and the two streams run parallel for some distance; but the Welland continues its north-easterly course, while the Ise turns south to meet the Ouse, of which it forms a part. After running 50 miles through Northamptonshire, skirting the country between Rockingham and Stamford, the Welland flows through a narrow valley enclosed between hills of some height, on one of which is Uppingham church.

Between Market Harborough and Stamford, several feeders enter from the left bank, draining the country to the north-west; but, on the other side, the line of water-shed between the Welland and the Nene approaches very near the river, and admits of no tributary streams. The *Eye* or *Wye brook*, and the *Chater*, are the most considerable of these feeders, and the *Gawsh*, or *Guash*, enters a little above Stamford, on the same bank, after passing the town of Okeham. These small tributaries traverse the little county of Rutland with a nearly easterly course, running through pleasant valleys, and carrying the drainage of the oolitic rocks into the Welland, mingled with supplies obtained from some natural mineral springs.

24. The river Glen.—Below Stamford the Welland enters the fen country in Lincolnshire, passing Deeping and Crowland on its way to the Wash. It is there joined by the Glen, a stream which runs for as much as 36 miles, draining an extensive tract of country to the north-west between the Welland and the Witham basins. In the lower part of its course, the waters of the Welland are made to pass into artificial channels, forming part of the great system of the fen drainage. The Welland estuary is the northernmost of those opening into the Wash.

25. The river Witham.—This river rises at Thistleton in Rutlandshire, near South Witham, about 10 miles north of Stamford. It runs at first north by Grantham to Lincoln, close to the line of water-shed between the catchment of the Witham and that of the Trent, and receiving the *Brant* (nearly 15 miles long) from Brandon. At Lincoln the main stream turns to the east, and after flowing in that direction some miles, and receiving two small feeders (the *Langworth* and *South beck*), it turns south-east, and enters the Wash close to the mouth of the Welland, passing Tattershall where it is met by the *Bain*, a stream entering on the left bank. The Langworth rises in the chalk hills between Market Rasen and Louth, and has a course of 18 miles. The Bain also rises in the same chalk hills, and flows southward about 26 miles, receiving the *Waring*, *Scrivelsby*, and *Enderby becks*. The *Sleaford* river is another tributary entering on the right bank near Tattershall, a little below the Bain. This river rises near Ancaster, and flows north-east about 22 miles, having a navigable channel, partly artificial, to Sleaford. From the junction of the Sleaford and the Witham, the main stream flows by an artificial cut to Boston, after which it proceeds to the Wash in its natural channel.

The course of the Witham presents nothing remarkable, but its banks are not without interest in the upper part of its course, and it passes many objects of great beauty. Near Lincoln this is especially the case, the noble cathedral crowning the summit of a considerable hill with its three lofty towers, and the city descending from the top of the hill in a steep street from the cathedral which it thus connects with the river, there crossed by a bridge. After entering the fen district, the Witham passes the bold ruin of Tattershall castle, and the elegant Gothic pile of Boston church, from whose lofty tower the prospect over the vast levels that encompass it is almost unlimited. From this point the two distant cathedrals of Lincoln and Peterborough may be seen.

26. Drainage works on the Witham and other Fen streams.—A minute account of the works carried out on the course of the Witham connected with drainage was published in Vol. XXVIII. of the Proceedings of the Institution of Civil Engineers. This memoir (by Mr. Wheeler, M.I.C.E.) refers chiefly to the effect of the works on the tidal portion of the stream, and the present state of the estuary, and I am indebted to it for the following facts. The works in question affect, or are affected by, the river in its course from Lincoln to the outfall, during which it flows over fen land.

From its source to Lincoln, besides the upland waters, the Witham receives the water from the northern portion of the Lincolnshire fens, the Wildmore fens, and Holland fen, comprising about 137,000 acres of land. It is believed that this land, at the time when England was conquered by the Romans, was from 10 to 18 feet lower that it now is near the outfall, while the upper part was only 5 feet lower. The lower part was then daily covered by the tide, but the upper part was sound and good, and covered with forest. The Romans removed the trees, and constructed embankments, in consequence of which the silt and mud were retained, and the upper level raised. These banks were many miles in length, and were works of stupendous magnitude, and on them the safety of the fens depends. Until about a century ago the lower levels were in the condition of a swamp. By means of deep and long cuts the waste waters are now drained off, and the surrounding lands made cultivable. The total area of the fen country drained by the Witham is 680,392 acres, or 1,063 square miles. The river discharges into a haven, which commences a little above the town of Boston, and after a devious course of more than 7 miles joins the Welland, which drains 35,000 acres of fen land, and merges into the Wash. It varies in width from about 100 feet above the town to about 250 feet.

27. The Wash.—This remarkable estuary which is common to the Witham, the Welland, the Nene, and the Great Ouse, is entered by the Witham at right angles to its direction. Its area is about 300 square miles. It is shallow, and full of shifting sands, which are gradually but surely gaining on the sea, for the mud held in suspension by the rivers in time of flood mixes with the silt washed up by the tides, and where the opposing currents meet, and dead water occurs, a deposit is caused which the back-water of the ebb is not sufficiently powerful to remove. The silting up of the Wash is greatly increased by the embanking of the lands, the erection of sluices, and the improved surface and deep drainage of the lands for agricultural purposes. It was at one time supposed that the sluices would rather diminish than increase the amount of deposited mud, but this is by no means the case, and it is found in practice that the removal of the sluices improves the navigation of the river.

About two-thirds of the Wash consists of shifting sands, dry at low water, with a tortuous and difficult channel. Where the Witham debouches there is a hard stiff clay, called the scalp, which causes the river to enter at right angles to its previous course. A cut has been proposed to avoid this and carry the river at once to the estuary before joining the Welland. At present the two streams form the north channel, called Boston Deeps, which is separated from the south channel, called Lynn well, by a wide and long belt of sand.

28. Lincolnshire drainage east of the Witham.—There is a small drainage from the country east of the water-shed of the Witham entering the German ocean, but the chief water-supply runs southward, and enters the Wash at its extreme north-eastern extremity near Wainfleet by the *Steeping* river which rises near Ashby-puerorum, and flows south-east near Spilsby, entering the sea after a course of about 20 miles.

Eastern Group.

29. Drainage of the north-west coast of Norfolk.—The drainage from the north-western corner of Norfolk into the Wash is very insignificant. Towards the German ocean there are one or two small streams, but the chalk cliffs looking towards the sea are steep, and though broken here and there by clefts communicating with the interior, the plateau-like character of the chalk, and the absorbent nature of the rocks, both tend to reduce the flow of water to the sea to a minimum. The rainfall on this coast is also veiy small.

30. Basin of the Yare.—The Yare is the only considerable river of the eastern counties, and even this stream is much more remarkable for the length of its course (74 miles), and the extent of its drainage area (1,180 square miles), than for the quantity of water it carries to the sea.

The upper stream of the river basin, described as the basin of the Yare, is called the *Wensum.* It rises near Fakenham, makes a circuit round that town, and then flows east in a winding channel for 45 miles to Norwich. Two miles below Norwich it is joined by the smaller stream of the Yare, which rises near East Dereham, and flows nearly due east to its confluence with the Wensum, after a course of 25 miles. The united stream, sometimes called the Wensum, but more generally the Yare, flows through land formerly a marsh, and expands into a sheet of water called *Breydon waters*, 4 miles long, and in some parts a mile broad, at the south-western extremity of which it is joined by the Waveney, and on the opposite side by the Bure, after which the united streams run on about 3 miles into the German ocean.

31. The river Waveney and the Bure.—The Waveney rises at Lopham, near Thetford, inosculating with the Ouse. From its source it flows north-east past Diss, Bungay and Beccles to the Yare, a distance of about 50 miles. The *Bure* rises near Holt in the northern part of Norfolk, and also flows about 50 miles before joining the Yare. Both streams receive several feeders, and in the lower part of their course run through flat marshy valleys often flooded, and known as the "Broads" of Norfolk. These lagoons are also called "meers."

There is every appearance of the sea having formerly extended up the valleys of the Yare and its tributaries on both sides to a considerable distance inland. There are local traditions of the sea having reached up the valley of the Yare as far as Norwich, up the Waveney to Bungay, and up the Bure as far as Burgh. Between the Bure and the coast north of Yarmouth there are extensive tracts occasionally covered with water, and connected by water channels.

32. The rivers Blythe and Alde.—Several small river basins each conveying its water independently to the sea, either by an estuary, or directly into the German ocean, drain the coast between the mouth of the Yare and the Thames, a distance of 80 miles. The *Blythe* enters at Southwold, after a course of 16 miles; the *Alde* enters the sea some distance below Orford, having crossed the county of Suffolk for 11 miles to its confluence with the Ore, and then running 15 miles to the sea. Near Aldeburgh it approaches within 200 yards of the sea, being only separated by sand-banks, over which in very high tides and strong winds the sea-water is poured into the river. The mouth of the river, however, is 9 miles below this point, the course being parallel to the shore, and the long narrow peninsula that intervenes consists of sand-banks gradually working their way southwards.

In the upper part of its course, where the Alde receives the Ore, the latter stream, which has had a course of only 6 miles, no longer retains its name. Lower down, however, after passing Aldeburgh, the river again takes the name of Ore, and passes the ancient town of Orford, but there is no appearance of there having been at any time an independent channel of the Ore to the sea. Below Orford the water-way to the sea is called the *Butley river*, and is a small estuary.

33. The river Deben is the next stream. It takes its rise near Debenham close to the line of water-shed which separates the coast drainage from the valley of the Yare. It runs through an agricultural district about 20 miles to Wilford Bridge at Melton, a mile above the town of Woodbridge, where it meets the tide and passes into an estuary which opens gradually to the sea, reaching it close to the mouth of the Orwell. The length of this estuary is about 10 miles, and its width from a quarter to half a mile. A mile below Woodbridge there is a small feeder, entering from the west and north, flowing from Otley, past Bealings, where it receives another branch before entering the Deben.

34. The Gipping river and the Orwell.—In like manner the *Gipping*, which rises between Stowmarket and Bury St. Edmunds, is formed by the union of several streams, and runs 20 miles to Ipswich, carrying very little water, but at Ipswich it becomes tidal, and takes the name of the *Orwell river*, opening out into an estuary which has all the characters of a beautiful tidal river, joining in its lower part where it approaches the sea another estuary, that of the Stour, which is the outlet of a river coming from a still greater distance in the interior. The Orwell is about 12 miles long, and more than half a mile wide at high water. It has no tributaries, and the banks are steep on both sides.

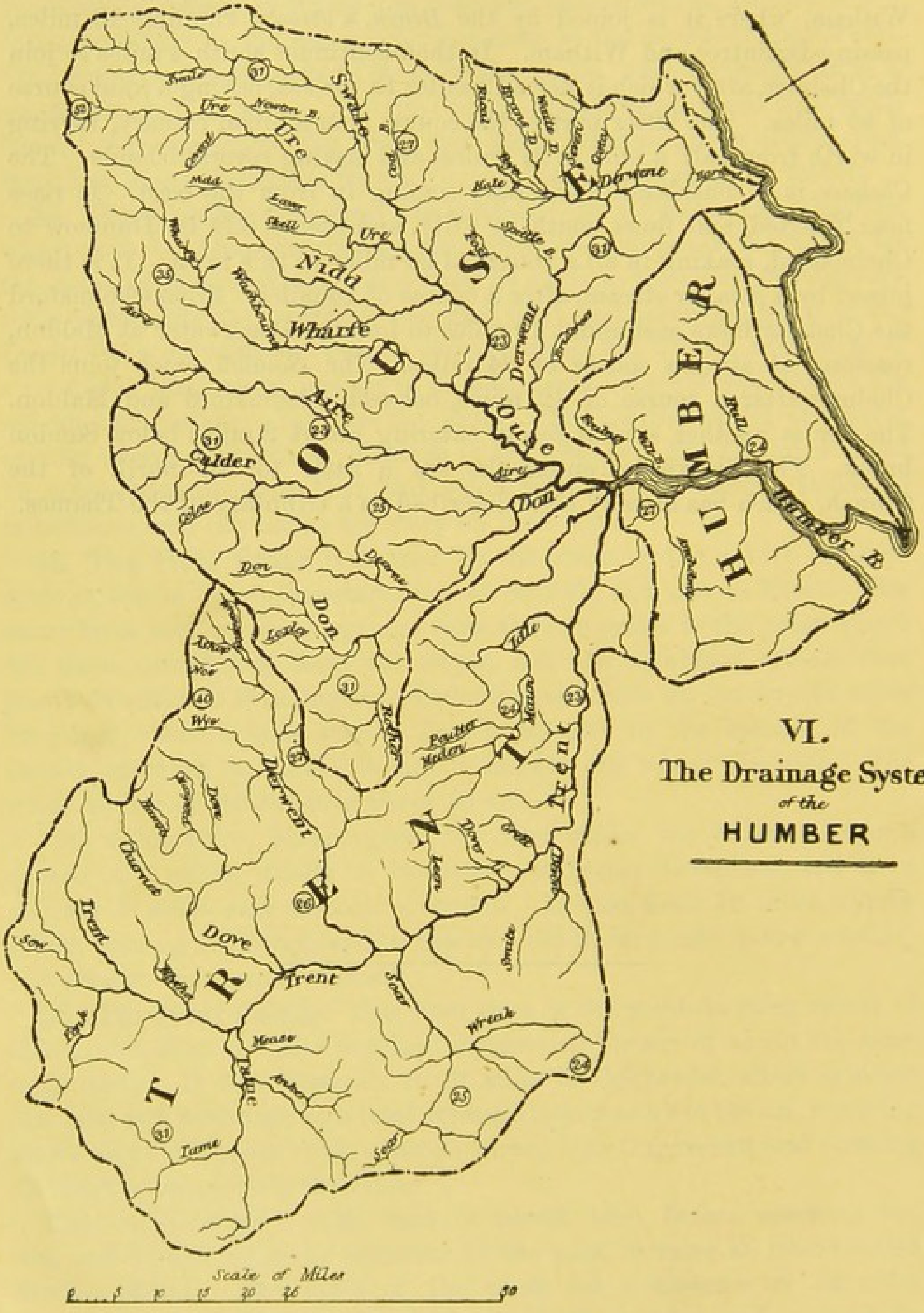
35. The river Stour is formed by the union of the waters of three springs, one in Cambridgeshire, one in Suffolk, and one in Essex. The water from each of these springs runs about 8 miles to the point where the three combine to form the Stour, and the combined stream runs about 30 miles to Manningtree, where it opens into an estuary 12 miles long and about a mile wide. This terminates in the estuary of the Orwell, entering the Orwell before it reaches the sea at Harwich. The whole course of the Stour is about 50 miles.

Five miles above Manningtree the *Bret* enters the Stour. After a course of 6 miles, chiefly to the south, it passes Lavenham, and flows another 6 miles east to meet a branch. It then flows 10 miles, chiefly south, passing Hadleigh, and comes into the Stour a mile below another, but smaller and parallel branch.

36. The river Colne.—This river rises in the north-western corner of Essex, and after 7 miles is joined by another stream of about the same magnitude. It then flows about 20 miles to Colchester, where it meets the tide, and continues as a tidal stream about 9 miles to the sea, receiving on its way the *Roman river*, a stream rising near Coggeshall, and running 13 miles in an easterly direction.

The Colne enters a wide tract of marsh land before reaching the sea, and passes by many channels to the west, forming an island called Mersey island. The whole of the coast for a distance of 62 miles east and west of the mouth of the Colne is marshy, and covered by the sea at high water. Several small streamlets enter the marsh from the interior, after a course of a few miles.

37. The river Blackwater.—This stream also rises in the north-western part of Essex, and in its upper course is called the *Pant*. It flows south-east and south about 30 miles to the neighbourhood of Witham, where it is joined by the *Brain*, a stream running 13 miles, passing Braintree and Witham. It then continues south 4 miles to join the Chelmer, after which it flows 12 miles to the sea, having a total course of 46 miles. The latter part of the course is in a broad estuary, varying in width from half a mile to $2\frac{1}{2}$ miles, and having several islands. The *Chelmer* is a considerable tributary coming in from the west. It rises near Thaxted, and flows south to Tilty, and then S.S.E. by Dunmow to Chelmsford, making in all a course of 24 miles to this town. It is there joined by a smaller stream, after a course of 14 miles. From Chelmsford the Chelmer flows east about 10 miles to join the Blackwater at Maldon, reaching it after a course of 34 miles. The *Sandon brook* joins the Chelmer after a course of 12 miles, between Chelmsford and Maldon. The *Ter* is another similar feeder entering about 2 miles below Sandon brook. The Blackwater enters the sea a little to the north of the Crouch, which has already been described as a tributary of the Thames.



VI.
The Drainage System *of the* HUMBER

CHAPTER VIII.

THE HUMBER SYSTEM.

THE BASIN OF THE OUSE.

1. General description of the district.—The hydrographic basin of the Humber is much the largest drainage area of the British islands, comprising nearly one-fifth of the whole area of England. It includes almost the whole of Yorkshire, Derbyshire, and Staffordshire, the whole of Nottinghamshire, a considerable part of Leicestershire, and part of Lincolnshire. It is composed of the river systems of the Yorkshire Ouse and the Trent, the former draining chiefly the country to the north, and the other to the south. At their confluence these rivers continue to the sea in a single tidal stream, the Humber, which receives the drainage of a considerable tract of country to the north and south. Besides the three drainage areas thus defined, there is a narrow belt of land beyond the eastern water-shed of the Humber, that it will be convenient to consider as part of the basin.

This large area, measuring about 140 miles from south to north, and nearly 70 from west to east, is the source of much mineral wealth, chiefly coal, iron, and lead, and contains many of the most important manufacturing towns in England. The chief minerals are in the northern part, and the southern part is rich in agricultural land. As will be seen by reference to the map, the whole district is well watered. Both the great rivers, the Ouse and the Trent, are fed by a number of important tributaries, and these again by many smaller streams. All those of the Trent, and most of those of the Upper Ouse, originate at high levels from the eastern slopes of the Penine hills. The southern feeders of the Trent drain only the plateau of the New Red Sandstone, which nowhere reaches a high elevation.

At the confluence of the Ouse and Trent there is a great expanse of low alluvial land, occupying an area of 160 square miles, below the level of high water in the German ocean. Here commences the Humber, which is a channel nearly 40 miles in length common to the two rivers. The land near the Humber is below the level of high water spring tides in the open sea, and as much as 6 feet below high-water mark in the estuary at some distance from the sea. It is evident that the whole tract, if undefended by embankments, would be a salt marsh, covered more or less entirely every tide, and over which spring tides and exceptionally high tides or river floods would spread periodically, converting the whole at these times into a water channel encumbered with innumerable shoals and mud banks. The thickness of alluvium in the channel, and on the banks of the river, affords abundant proof that this has been the ancient history of the Humber.

The whole extent of the drainage area under consideration is estimated at 10,500 square miles. It is bounded on the west by the escarpment of the Penine hills, on the east by the sea, and on the south by low lines of water-parting on the New Red Sandstone plain. The lower part of each of the two principal rivers, the Ouse and the Trent, flows over the Bunter and Keuper sandstones of the triassic period, and the Keuper marls have been so far removed by mechanical abrasion as to form large accumulations of sand and mud at the confluence of the streams. In the bed of the Humber they have formed at one time a delta that has gained rapidly on the sea. Subsequently it would seem that owing to diminished rainfall, or to rainfall and drainage differently distributed, the accumulation has diminished and a portion of the accumulated detritus has been dispersed by the sea. There is at present an annual loss of coast in this part of England, and the German ocean tears away from time to time large quantities of the old delta. The average waste of the east coast of Holderness from Bridlington southwards has been estimated by Mr. James Oldham* as equivalent to a strip of land $2\frac{1}{4}$ yards wide per annum along the line of coast. The whole of this is shifted seawards to some distance, but must be distributed on the floor of the German ocean, where it mixes with similar material removed from the shores of Holland, and brought down by the Rhine. The material thus

* Min. of Proc. Inst. C.E., vol. xxi. p. 454.

accumulated forms banks of sand and mud, that may in time greatly affect the geological conditions of the sea between England and the continent.

2. Physical features and geology.—Although the features of the country must of course vary considerably in so large a district in an island like England, the general outlines are easily described in a few words. The Penine chain consisting of hard semi-crystalline carboniferous limestone, capped with the still harder beds of millstone grit, and often intercalated with hard shales, rises to a considerable height above the sea in a long line of flat-topped hills and moors, and is often called the back-bone of England. This chain separates Yorkshire from Lancashire, and is continued southwards into Derbyshire forming the characteristic picturesque features of that country. There is a spur of the chain in the north, passing eastwards, and carrying the line of water-shed to the sea, separating the basin of the Ouse from the Tees. South of Derbyshire the line of water-shed sinks much lower, and is within the central plain of New Red Sandstone. To the east the low escarpment of the marlstone in Lincolnshire shuts in the river Trent, and north of the Humber the whole country is included as far as the German ocean.

Within this water-shed the ground slopes both ways towards the vale of York through which the Ouse flows southwards. The valley of the Trent, through which that river flows northwards, is a continuation southwards of the same structure. The tributaries of the Ouse rise for the most part on the carboniferous limestone or millstone grit, and run over Yoredale rocks and coal-measures, but they all ultimately cross the Permian sandstones, and enter the New Red Sandstone as they advance eastwards to the main stream. The Derwent, the only tributary of the Ouse from the east, drains the oolitic hills or wolds of Yorkshire and the cretaceous rocks which cover up the oolites as the eastern coast is approached. The northern tributaries of the Trent proceed from the carboniferous limestone and millstone grit, but the southern feeders rise among the oolites. Important bands of ironstone occur in the Cleveland hills among the lower oolites and lias, but they hardly affect the drainage. The coal-measures are crossed by some tributaries of both rivers.

The basin will thus be seen to comprise all without exception of the rocks of the secondary and newer palæozoic periods. The latter are chiefly developed in the Ouse basin, while the triassic rocks and oolites predominate in the Trent. The oolitic rocks cover an area comparatively small, and the cretaceous very much smaller. They are, indeed, practically unimportant. Some details of their quantities are given in another part of this, and in the next chapter.

Although the prominent features of the whole drainage area are derived from palæozoic rocks, consisting of mountain limestone, millstone grit, coal-measures, and magnesian limestone, nearly half the area is covered with triassic rock, consisting of sandstones and marl, through which the principal streams make their way. Of this area, estimated at 5,000 square miles, about 1,500 square miles are thickly covered with alluvium and gravel. Many of the upper tributaries have cut their way through these, or flow over boulder clay, which is also largely present, especially in the upper valleys of the Ouse.

3. Subdivisions.—We have already seen the nature of the great subdivisions of the Humber system. They are four:—

I. The catchment of the Ouse.
II. The catchment of the Trent.
III. The basin of the Humber.
IV. The Yorkshire coast east of the water-shed of the Ouse.

These are by no means of equal interest or importance. They are very distinct. The two great rivers, Ouse and Trent, are among the most interesting of the English streams. The Humber is little more than an estuary, and the small rivulets on the Yorkshire coast east of the Ouse water-shed will need very slight description.

4. Rainfall, evaporation, and percolation.—In so large an area as that of the Humber system, ranging through nearly a hundred miles of country in latitude, and half that in longitude, there must be a very wide difference in rainfall, and a glance at the Rain Distribution map, facing page 51, will sufficiently illustrate the general nature of the difference. On the whole the heaviest rain falls on the western water-shed, the eastern boundary of the basins being comparatively dry. There is a fall much above the average of the district in the belt of land occupied by the mountain limestone and millstone grit, and a fall below the average in the low and flat valleys near the German ocean. The hilly district of the oolitic tract in the north-east of Yorkshire, offers indeed a partial exception, the rainfall there being heavier than in the New Red Sandstone plain, through which the main streams flow; but this is due to the increased elevation, and the mode in which the clouds are conveyed from the table land of the Penine chain.

The rain map, and the figures in the map of the district at the commencement of this chapter, will give a general idea of the rainfall; but they fail to show how admirably adapted are the Yorkshire valleys for receiving the rain, and conveniently storing the surplus. Almost all the upper feeders of the main streams are already utilised for storage, wherever their structure renders them available. It is in reference to the construction of the reservoirs of the Yorkshire and Lancashire valleys that the great parliamentary battles concerning compensation to mill-owners and others, for the abstraction of water for town supply, have been chiefly fought, and the principle of compensation, whether in money or water, decided. These have been already alluded to in another chapter, and will come under further consideration elsewhere.

As a general rule it may be said that the average evaporation and loss of water throughout the Yorkshire valleys is about 14 inches. In the Trent valley it is probably larger. This question has long been a subject on which there were great differences of opinion, and it has been discussed with some minuteness in a previous chapter, Chapter II., §§ 33, 34. So far as the Ouse is concerned, the amount stated will not be found excessive, and the case of the northern feeders of the Trent is not different. The drainage area of the Trent is, however, drier, and continued summer evaporation is more probable than in the Ouse valley.

The loss of water by percolation into the rocks, though very great in the fractured limestones and grits in the upper parts of the streams, and in the fractured shales of the lower coal-measures, must be partially redeemed by the springs breaking out from these rocks at a lower level, and it is not unlikely that in this way the New Red Sandstone is fed where it overlies these fractured beds. No measure of the loss can be obtained as there are no means of determining the flow into the river bottom by these springs. The measurement of a New Red Sandstone river must, under any circumstances, be of doubtful value as well as difficult to obtain. There will be found in another place (Chapter III. §§ 21, 22) a few facts with regard to the supply sometimes obtainable from small areas of New Red Sandstone in the Trent basin; but these are exceptional, and must not be assumed to apply to larger districts where the rock is not present under specially favourable conditions for water-supply.

5. Quality of the water.—The waters of almost all the principal feeders of the Ouse, and many of those of the Trent, as well as the waters of the main streams, have been frequently submitted to analysis, and so far as those proceeding from the mountain limestone and millstone grit are concerned, the results are invariably satisfactory. The rain running off from the moorlands is liable to be discoloured with peaty matter, especially after flood; but the organic carbon thus derived has not been suspected of any evil tendency. Gravitation water from these rocks has always been regarded as unobjectionable, and now supplies the wants of most of the large towns of Yorkshire. In some parts of the drainage area, as at Harrowgate, there are powerful natural springs of water containing a sensible quantity of sulphuretted hydrogen, and these may be expected to occur in all the springs within a considerable area. The effect, however, is generally too small to be recognised by taste and smell when diluted with running water. The quantity and nature of the mineral salts in the surface waters may be estimated in a general way from the analyses subjoined.

The river Trent runs over a large quantity of that part of the New Red

Sandstone that contains salt in many parts of the middle of England, and the effect of this is very visible in the occasional increase of the quantity of this mineral contained by the water of the main stream. The presence of salt springs in the bed of the river is thus indicated.

The water pumped from the coal-measures and passed into the water that ultimately forms part of the Trent is not unfrequently charged with mineral matter in sufficient amount to affect the river water; but there are instances, as in the Dearne, a feeder of the Don, and near Wakefield, of exceedingly good water being supplied to rivers in this way.

Of the following analyses of the principal streams, some are deduced from Dr. Frankland's series in the Reports on Rivers Pollution, and others are given on the authority of the late Dr. Letheby.

Date of Sample.	Tributaries.	Total solids.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates & Nitrites.	Chlorine.	Hardness.
	Ouse Basin.							
27 Jan. '74	Ure, Ripon supply - - -	11·93	·026	·026	·001	0	0·84	8·3°
27 Jan. '74	Laver 9 m. from source - -	4·42	·132	0	0	·009	0·84	2·8
Dec. '71	Nidd above Knaresborough -	8·20	·165	·027	0	·019	0·75	6·3
4 Oct. '69	Wharfe, Bolton Abbey, Derwent	11·31	·255	·016	·001	0	0·64	9·7
30 Sept. '69	Aire, Malham tarn - - -	8·71	·191	·021	·001	0	0·66	9·5
28 Sept. '69	Aire, above Leeds - - -	17·15	·524	·057	·046	·083	1·24	9·4
26 Jan. '71	Calder, Ramsden Clough - -	5·42	·065	·009	·002	·029	0·77	2·7
20 Dec. '72	Don, Loxley valley (Sheffield sup.)	5·85	·249	·040	·001	·022	0·60	3·1
	Trent Basin.							
20 April '71	Head water - - - - - -	17·25	·505	·062	·002	0	1·19	10·1
17 Nov. '69	Blythe at Whitaker - - -	26·92	·317	·052	·004	·107	1·35	12·7
Oct. '72	Derwent, Buxton supply, mean of three reservoirs - - -	6·29	·360	·047	·002	·010	0·49	3·1
Nov. '67 Aug. '71	Soar, Leicester supply, mean of two analyses - - - -	17·50	·347	·033	·001	·002	1·04	13·4
Feb. '69	Dover beck - - - - - -	13·98	·148	·022	·004	·273	0·92	7·1
Dec. '70	Idle above canal feeder - -	15·48	·159	·034	·002	·094	1·09	11·9

To these are added the result of three analyses of Trent waters by the late Dr. Letheby, expressed in different terms, and each being a mean of three samples taken respectively 8th April 1868, 8th March 1869, and 26th March 1869.

Locality.	Total Grains per gallon.	Earthy Sulphates.	Earthy Carbonates.	Nitrates and Nitrites.	Hardness	
					Before Boiling.	After Boiling.
River Trent, at Nottingham	25·82	9·63	10·48	2·86	16·8°	8·3°
River Lean - - - -	21·40	4·74	11·14	2·90	14·9	8·3
Dover beck - - - -	10·14	2·92	5·39	0·61	5·3	4·1

6. Ordinary flow and flood.—The quantity of water passing down to the sea at ordinary summer flow and during flood, has been measured in certain parts of the river course both in the Ouse and Trent. By observations on the Ouse made by Prof. Phillips, assisted by Mr.

William Hill, in the neighbourhood of York, where the drainage area was 1,268 square miles, the result of seven months continuous record, commencing November 1, 1851, showed a discharge of 250 cubic feet per second (135 million gallons per day), being at the rate of 2·66 inches of rainfall per annum over the whole area. This was the mean flow, but there is no account of the freshets. This quantity is equivalent to 165 gallons per day per acre. Considering that the months from November to May include those in which most rain falls, this must be regarded as a very small yield. The freshets, however, not being included, the total flow is very much larger.

There is no reason to suppose that the outflow of the Ouse and Trent to the Humber, is smaller in proportion to the catchment than in the other great drainage systems of England.

The upper tributaries of the Ouse are all torrential, the streams rising among the mountains, and the feeders flowing over rocks generally hard and non-absorbent, and often falling in cataracts till they reach the level ground at a great distance from their sources. The heavy rains on the hill-tops run off rapidly, and produce partial floods.

But although the sources are generally on high ground, and the flow of storm waters rapid, the effect of floods in the Ouse is not so serious or widely felt as in the Trent valley. The valley of the Trent, cut through the flat sandstone plain between the oolitic hills to the east and the older rocks with their edging of Permian rock to the west, is too low-lying and level to permit of the accumulated waters after heavy rain finding an escape by their natural channel into the Humber. They must, therefore, spread over the surface and flood the country. On the whole the floods of the Trent are both more frequent and more mischievous than those of the Ouse.

7. Tidal action.—The tidal wave within the Humber system affects chiefly the Humber itself. The Ouse and the Trent deliver their waters into the large tract of low land where the Humber commences, and which has been already alluded to in this chapter; but the Trent is little affected by the changes below, and the Ouse not at all. The subject will be better considered in the next chapter.

The River Ouse.

8. The basin of the Ouse.—The Ouse is sometimes called the Yorkshire Ouse, to distinguish it from another considerable stream of the same name emptying into the Wash. This river, although only a part of the Humber system, is one of the principal rivers of England in respect of the extent of its catchment area, the number of its tributaries, and the volume of water it discharges, but it belongs to a class of rivers important rather for the number and magnitude of its feeders than as having a long independent course, or conveying in one channel for a long distance a large body of water. Its drainage area is 4,290 square miles, and the total length of course of the main stream only 63 miles. It first acquires its name, 67 miles from the most distant source, at the confluence of the Swale and the Ure, and on its way to its confluence with the Trent, it receives the Nidd, the Fosse, the Wharfe, the Derwent, the Aire, with its important branch the Calder, and the Don. Each of these again receives tributaries, and each will require careful separate consideration.

The rivers that form the Ouse, derived from many springs and brooks running over the surface of carboniferous limestone, or from springs from the millstone grit capping the limestone, consist almost exclusively of rain-water, collected from a wild mountain and moorland district. They run pure and bright, except where discoloured by peat. The older carboniferous rocks dip to the east, and are frequently affected by faults and geological disturbances, and there are a few places where the waters are retained for a time in small lakes, pools, or tarns, but these are of little importance in regulating the flow of water in the stream. The limestone and millstone grit are covered up to the south-east by the coal-measures, which are extensively worked in Yorkshire, commencing near and to the north of Leeds and Bradford ; but the Aire and the Don are the only large tributaries that flow over these deposits. The upper tributaries after flowing over the millstone grit reach at once the Permian rocks, which are covered by the New Red Sandstone, and afterwards, on the eastern side of the vale of York, by liassic and oolitic rocks. These rise into hills of considerable elevation, and close in the catchment area.

The older rocks of the north of England have not only undergone great geological disturbance at a very distant period, but within comparatively recent times icebergs loaded with mud and fragments of rock have been drifted over what is now land, and have been left in wild confusion and great irregularity, occupying many of the valleys, and often capping the lower hills. Compact limestone, gritstones of various kinds, and shales, are thus covered at intervals with *boulder clay*, as this accumulation of ice-carried stones and clay is called. The clay generally alternates with bands of small gravel and fine sand, the boulders, or fragments of rock more or less rolled in water and partially rounded, being distributed quite irregularly through the clay.

The upper part of the district, where the rivers take their origin, consists for the most part of plateaux, or elevated and flat-topped land, frequently and deeply intersected by ravines and gorges, and occasionally by more open valleys. Many of these, however, have precipitous walls of rock bounding them on each side, and some of them are filled by the deposit of boulder clay just referred to.

9. Scheme of the affluents of the Ouse.—The following general statement of the chief feeders of the Ouse and its tributaries, will assist the reader in understanding their relative position :—

Distance from source in miles.

Birkendale beck. } Gt. Sleddale beck. } 3 Swale.

Ure.			
Eastgill	6		
Widdale beck	6¾		
Easedale gill	7		
Duerley beck	8		
Bain river } Sargill beck }	12½	5	Whitsundale beck.
		9	Muker beck.
Walden beck	19½	14	Arkle.
Cover	30	28	Skeeby beck.
Burn	40	52	Whisk.
Laver	52	60	Cold beck.

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Ouse.

Right bank.		*Left bank.*
	74½	Kyle.
Nidd	76	
	84	Foss.
Wharfe	94	
	109	Derwent.

Nidd:
Howstone beck.
Ashford side beck.
Greenhaw sike.
Ear beck.
Darley beck.
Thornton beck.
Oak beck.
Crimple beck.
Nor beck.

Wharfe:
Skirfare.
Dibb river.
Blea beck.
Gill beck.
Bardon beck.
Ken beck.
Washbourne.
Cock.
Fosse.

Derwent:
Jagger Howe beck.
Black beck.
Trout's dale beck.
Rye.
Dove.
Seven.
Costa.
Stainedale beck.
Hartford brook.

Right bank.	Distance from source.	*Left bank.*
Aire	112	

Aire.	Calder.
Otterburn beck.	Hebden.
Eshton beck.	Rybourne.
Eller beck.	Colne.
Worth river.	Holme.
Hardon beck.	
Bradford beck.	

Right bank.	Distance from source.	*Left bank.*
Don	127	
Little Don.		
Ewdon.		
Loxley.		
Sheaf.		
Rother.		
Dearne.		
Went.		

10. Early feeders of the Ouse.—The two streams whose waters combine to form the Ouse proceed from the same moorlands, and are not very different, either in length of course, or extent of drainage area. Each runs for a distance of about 60 miles, their channels being separated by a narrow strip of country, 6 to 10 miles wide, narrowing as it approaches the confluence. The rainfall near their sources is the same, averaging in places 52 inches in the year. Their course is through millstone grit, cut through to a great depth by the action of running water, the bed of the stream being the underlying carboniferous limestone. Both flow through country very wild and desolate. Both are torrential. In floods they are mighty rivers, bursting with prodigious effect through magnificent gorges, but in time of drought they are gentle rills trickling over ledges of gritstone or limestone. There are no lakes or broad flats where they can expand during freshets, and be afterwards delivered by a gradual flow. The country through which they pass is little peopled, but contains some lead mines, which provide an occasional population.

11. The upper course of the Swale.—This river, the furthest to the north of the system of the Ouse, originates in the union of a group of mountain torrents, or *becks*, on the borders of Westmoreland. The first of these, called *Birkendale beck*, flows south-east in the direction of the main stream for about 3 miles. It is then joined by *Little Sleddale beck* from the south. The two unite shortly after with the waters of *Great Sleddale beck*, which has had a course of a mile and a half from the south-west. The three streams combined may be regarded as the Swale. Professor Phillips describes it as originating "in many branching hollows which undulate the eastward slope of the high crescent of moorland sweeping from Water Crag by Nine Standards (2,153 feet), Fell End, High Seat, Lady's Pillar, and Shunnor Fell (2,346 feet). The rivulets (called gills), which run in these branches, have very elevated beds, and no deep glens connect them with branches of the nearest rivers." "Thus shut in and surrounded by a high and dreary expanse of moorlands, the valley is wild, picturesque, and not very accessible."* Besides the two forks the stream is soon joined by a third one mile below, called *Whitsundale beck*, coming fully 5 miles south-east from deep clefts in the mountains.

The moors that shut in the Swale, and form the boundary line between Yorkshire and Westmoreland, act as a water-parting between the Swale and the Eden, and culminate in Standards Rigg. Swaledale head, the reputed source of the Swale, is 1,700 feet above the sea. The hills that separate it from the Tees form the northern boundary of Yorkshire, between that county and Durham. From the source the stream receives numerous small feeders, chiefly from the north, and always from high ground. It runs first 7 miles to Catrig force, a small waterfall; and about a mile below is another fall, called Keardon force. Beyond this the river flows through a narrow ravine intersecting the high plateau of the moors, and is very picturesque. The whole of the upper part of the dale is unfrequented and rugged, and has been described as "cragless, treeless, undulated sweeps."

About 2 miles below the point where the Swale receives its name, is the small village of Keld, and after another 3 miles, the stream turning round to the south-east and south and shut in by lofty hills on each side, Muker is reached, where a torrent bearing the same name *(Muker beck)* enters the Swale from the west. Between the village of Muker and Reeth the river flows due east, receiving small feeders from both sides, the chief being *Barney beck*, from the north and west. At Reeth, the river *Arkle* enters from the north-west, crossing an extensive tract of moorland, where are several lead mines of importance. The Arkle is a considerable tributary, joined in its progress by several mountain torrents. From its source to its confluence with the Swale at Reeth, it flows about 9 miles, and its valley, especially about Reeth, is subject to heavy and sudden floods during the winter rains, and in early spring, at which time great mischief is often done by carrying away banks and buildings. The valley is here narrow, with limestone cliffs *(scars)* running along the edge of the dale, frequently capped with millstone grit. The floods of Arkle beck are especially serious among those of the upper feeders of the Ouse.

Below Reeth to Richmond (about 12 miles) the river winds a little, but its general course is east. It gradually becomes less wild, and the

* Phillips's Physical Geography of Yorkshire, 1853, p. 51.

scenery more picturesque. On its way it receives a considerable tributary from Holgate moor, entering near the village of Marske, and called *Marske beck.* It has several branches running up the valleys to the north and west. There is a small feeder, the *Gill beck,* from the south, that enters above Marske. The country now opens out, and at Richmond the upper or mountain flow of the Swale may be said to cease.

12. The lower course of the Swale.—After passing Richmond the Swale enters more open country, and in this part of its course receives many affluents, both from the right and left banks. Close to Richmond is *Badger beck* from the south-west, and a couple of miles below, *Colburn beck* enters from the same direction. Half a mile further *Skeeby beck* comes in from the north. It drains a considerable tract of moorland to the north-west, and flows under various names for a distance of nearly 12 miles. Two miles below the confluence of Skeeby beck the river turns abruptly to the south, and the valley through which it flows ceases to bear the name of Swaledale, merging into the great vale of York. The course of the river is now south-east, and though joined by a number of small streamlets it receives no important feeder for many miles. It flows through a low but not flat country to near Leeming, where it receives the *Grimscar beck* from Bedale and Bellerby, and continues in the same direction as before to Breckenbrough, where the *Whisk,* its largest tributary, enters at a distance of about 25 miles below Richmond. This river rises near Ingleby Arncliffe, on the edge of the Cleveland hills, and flowing at first north-westward nearly to the Tees, returns south by North Allerton to join the Swale. After this the main stream continues to flow south-east, and receives at Topcliffe (about 9 miles) another feeder from the Cleveland hills, called the *Cod beck,* or *Cold beck.* Hence to Myton the stream flows for about 8 miles nearly due south to join the Ure at Swale nab.

The Cod beck, or Cold beck, rises near Osmotherley, winding round the moors for about 3 miles, and then flowing west for another 2 miles. It then takes a sharp turn to the south, and proceeds about 9 miles to Thirsk, and winding about a good deal, and turning south-west, it continues for 5 miles, joining the Swale a little below the town of Topcliffe.

The drainage area of the Swale is 543 square miles. In its upper course it runs generally over mountain limestone, enclosed on both sides by banks of millstone grit, which often rise to a considerable height above the valley. Where the valley opens out at Richmond, the Permian rocks are crossed, and the New Red Sandstone entered, and the whole of the lower course of the stream is in the triassic rocks. The length of the Swale, including the windings of the river, is about 67 miles. The direct distance from Swaledale head to Richmond is about 25 miles, the direction being nearly east. From Richmond to Swale nab the direct distance is nearly the same, and the direction a little east of south. The difference represents the windings of the stream.

13. The upper course of the Ure.—This river commences by the union of a number of mountain rivulets on the eastern side of the same moors which on the western side give rise to the Eden. It rises very close to the sources of the Swale. On the Lancashire side, as well as the Yorkshire, the country is exceedingly wild, and we are informed by Camden, that for this reason, " certain little rivulets that creep here are called by the neighbourhood Hell becks (rivers or streams of hell), and especially that at the head of Ure, which runs under a bridge of a single rock in so deep a channel as to strike beholders with horror."

Professor Phillips says:—" The many torrents collected from the sides of Shunnor fell, Whiddale fell, and Dod fell, unite into a considerable volume before reaching Hawes, a small town at the head of Wensley dale, one of the finest of the Yorkshire dales, and there take the name of Ure. They run thence for about 18 miles." The name of Wensley dale was formerly given only to the upper part of the valley from the sources of the various rills and rivulets to the point where they unite in the Ure, about 5 miles from Hawes, but is now applied to the continuation of the valley to Leyburn.

The *East gill*, with its important branch *Howl gill* from the north; *Fossdale gill*, with an equally important branch *Heath beck*, also from the north; and *Widdale beck*, a considerable affluent from the south; besides other smaller feeders, have all joined the Ure before it reaches Hawes. *Duerley beck* joins the stream from the south at Hawes. Of all these Widdale beck is the chief. It has several feeders, the *Snaizholme beck* being the largest of them. All have courses varying from 3 to 6 miles. The scenery here is exceedingly fine, and varied by many cataracts. Cotter Force and Hardraw Force are, perhaps, the most remarkable; the latter is close to Hawes, and is a noble leap of 99 feet, and when there is much water it fills the large basin of rocks with sheets of vapour, but, like many other waterfalls in rainy countries, it is only after showery or stormy weather that these grand effects are produced. The glen is very short, and the water rapidly collects in places where at other times the stream can be crossed at a step. In all conditions, however, the deep, narrow, and winding chasm, through which the beck flows from the cascade, is of great beauty and interest. A little to the south is Gale Force, where the water falls over limestone resting on shale.

From Hawes the stream runs about 4 miles to Bainbridge, receiving only small feeders, but at that point the river *Bain* enters from the south, bringing the overflow of *Simmer water*, the only lake in this part of Yorkshire. This lake is fed by streams descending from three dales, Bardale, Raydale, and Cragdale. It occupies 105 acres, and is pretty but not picturesque. Like other similarly situated lakes, its area varies at different seasons. It is spoken of highly by Professor Phillips, who had seen it in different conditions of weather, but is not generally quoted as having much interest.

Opposite the mouth of the river Bain is *Sargill beck*, draining a small catchment to the west, and half a mile below is another small beck from the north. The little town of Askrigg lies between this and another feeder of inferior importance. Near the town are no less than three waterfalls, two of them over limestone rock. One of these is a fall of 12 feet, and the other 69 feet. The third is a fall of 42 feet over grit-stone overlying the limestone, and is not very accessible. Below Bain-bridge the valley contracts, and the stream becomes more rapid. At Aysgarth (4 miles) rapids begin, which soon become cataracts, and the fall known as Aysgarth Force is about half a mile below. The river descends over a series of limestone ledges, and when in flood the effect is extremely fine.

Between Aysgarth and Wensley, the village from which the name of the Ure valley (Wensleydale) is taken, and which is celebrated for its dairy produce, there is a distance of 7 miles, and about half way considerable streams join from the south, converging from Bishopsdale and Walden dale, and running up to a ridge which separates the Ure from the Wharfe. Both have waterfalls and many fine views. *Apedale beck* comes in from the north. All are wild and striking.

Bishopsdale beck rises on the slopes of the high hills that separate the basin of the Ure from that of the Wharfe, and runs with a very straight course 7 miles to the north-east, receiving small gills from each side to the junction with *Walden beck,* which has had a flow for almost the same distance through a parallel valley 2 miles to the south-east. After uniting, the stream flows about a mile further to the Ure as the Walden beck. The sources of the two branches of the Walden beck are within 2 miles of the valley of the Wharfe.

After receiving Walden beck from the south, and two smaller streams (Apedale beck being the most important) from the north, the Ure continues to flow to the east to the town of Wensley, after which the valley becomes more open and the scenery changes. The whole valley of the Ure, from its commencement to Wensley, is a glen whose scenery is very beautiful and characteristic. Beyond Wensley the river bed widens, and the river begins to wind about. After about 5 miles the river *Cover* enters. It is a considerable stream, rising not far from the Wharfe, near the head waters of the Walden, and its valley (Coverdale) is parallel to that of Walden beck and not much more than a mile from it to the east. The Cover flows more than 12 miles in a north-easterly direction, receiving small feeders on its way; then, turning east, it has a further course of 4 miles, emerging into open country.

14. The lower course of the Ure.—After receiving the river Cover, and before reaching Masham, the Ure enters on its lower course. Up to this point the river has flowed entirely over the carboniferous limestone, which is not here, as in the case of the Swale, capped with millstone grit close to the river valley. It now enters the magnesian limestone, and continues to flow over that rock to Ripon, which it reaches after a tortuous course of about 16 miles (the direct distance being only 9), not receiving on its way any important tributary except the river *Burn*, which joins it a mile below Masham. The Burn rises in the moors about 9 miles west of Masham, and is made up of the confluence of a large number of becks, each fed by numerous mountain streams, and proceeding from a semicircular range nearly 10 miles in length. After receiving its tributaries it has an easterly course of 4 miles to its confluence with the Ure. At Ripon the Laver enters, having first received the Skell about a mile and a half before it joins the Ure.

The *Laver* drains a considerable extent of country to the west coming from Masham moor, and is enlarged by several branches and small feeders. The *Skell*, a less considerable but not unimportant feeder, comes from Pateley moor, and drains the country south of the watershed of the Laver. The celebrated Fountains Abbey, one of the most interesting ruins of its kind in the north of England, and one of those most charmingly situated, is on this stream. Neither of the streams rises more than 9 miles in a direct line from the Ure, but they wind considerably.

From Ripon to Boroughbridge the general course of the Ure is east-south-east through New Red Sandstone, the distance being about 8 miles. Three miles below Boroughbridge the Ure joins the Swale at Swale nab, half a mile below Myton-upon-Swale, and the united waters thenceforward flow as the Ouse.

15. Early course of the Ouse.—The junction of the Swale and Ure takes place near the outcrop of the lower or Bunter beds of the New Red Sandstone from under the Keuper marls that cover them up towards the east, and the bed of the Ouse is excavated in the lower marls.

Throughout its course the Ouse can only be regarded as the channel by which the mountain streams of the district—the Swale, the Ure, the Nidd, the Wharfe, the Derwent, and the Aire—are connected. This channel is in the vale of York, and extends between the two escarpments of the Palæozoic rocks on the west and the oolites on the east. Regarded in this light the river appears to be subordinate to its tributaries, reversing the usual order, according to which the river is important and its branches inconsiderable.

Commencing as a full stream at the union of the Ure and Swale, the Ouse first flows south for about half a mile, and then turns east for a mile through a wide valley, low-lying and level. After this running nearly south for 3½ miles, it turns again to the east for a couple of miles to the town of Newton, where it receives its first tributary, the *Kyle*, a small stream coming from the north-east, having a rambling course fed by many small tributaries from the upper New Red Sandstone. A mile and a half below the Kyle the river Nidd comes in from the south-west.

16. The river Nidd.—The valley of the Nidd, or "Niddersdale," commences with the drainage from a remarkable semicircle of lofty hills, of which Great Whernside, rising to 2,245 feet, is the nearest to the west. This is followed by Little Whernside (1,984 feet), and this by a series of other mountain masses varying in height from 1,800 to 1,450 feet. The diameter of the semicircle is about 6 miles, and the Nidd, rising under Whernside, flows round at the foot of the other hills, receiving feeders along the whole distance. As it completes its course it is joined by the *Howstone beck*, an important tributary, which collects the drainage of an inner circle of hills rising to nearly 2,000 feet.

The upper part of the Nidd before this confluence runs through a wild mountain country in a contracted channel, partly limestone partly grit, having on the left bank very bold edges of gritstone with coal strata interposed. Between Gorden Pothole and Lofthouse the river disappears, taking a sinuous underground course for 2 miles, and its nearly dry channel is enclosed between rocks of limestone overhung by lofty gritstone hills.

Below Lofthouse the Nidd emerges as a fresh and full stream running in a picturesque wooded dale between hills from 800 to 1,000 feet high, and having been joined by *Howstone beck*, it flows south-east 6 miles to Pateley bridge, receiving from both sides a large number of tributaries, none of which have a course of more than 3 miles, but which all flow through narrow gorges, and convey rapidly the rainfall to the chief stream. The principal affluent is the *Ashford side beck* from the west, and it is the last but one before reaching Pateley bridge. Rising in the hills close to the course of the Wharfe, it runs nearly 6 miles south-east. Below Pateley Bridge the *Greenhow sike* comes in, and still further *Ear beck*, from Pateley moor to the east. Five miles below Pateley Bridge the *Darley beck* enters, draining the country to the north-west for some miles, its course being near the Washbourne, a tributary of the Wharfe. Beyond this the river turns east, and flows 5 miles to Ripley. Near Ripley the *Thornton beck* joins it from the north-west, and a smaller stream from the south-west. Below Ripley the *Oak beck* enters, after having received a small feeder from the overflow of the mineral springs of Harrowgate. Passing Ripley and Knaresborough, and after 12 or 15 miles of very winding course in small curves, the *Crimple beck* enters from the south and west after a long course of at least 12 miles from Stainburn moor, during which it receives the *Nor beck.* After the confluence of the Crimple beck the Nidd turns north-east, and has an exceedingly tortuous course through 7 miles of country to join the Ouse at Nun Monkton.

The river Nidd rises in and flows almost entirely over the millstone grit till it approaches Knaresborough, when it crosses the lower sandstones of the Permian series, and makes its way across a considerable breadth of magnesian limestone. It then crosses into the New Red Sandstone, and flows over a considerable breadth of the lower or Bunter division till it enters the Ouse. Near its source it passes over a small breadth of mountain limestone. Its length, measured along the course of the stream, is 52 miles. The windings add much to the length, as it is barely 32 miles in a direct line from Whernside to the Ouse at Nun Monkton, where the Nidd enters the main stream. The general direction of the course is east-south-east.

From the confluence of the Nidd to the city of York, where the Ouse receives the Foss, the distance is 8 miles, the river flowing in a south-easterly direction always on the outcrop of the Bunter sandstone as it emerges from the bottom beds of the Keuper. It is probable that in this part of its course it may receive considerable additions from bottom springs breaking out where the impermeable bands of marl, and pans, or compacted bands of conglomerate, underlying the water-bearing beds of the Keuper, rise to the surface. For this distance no tributaries of the smallest importance enter from surface drainage.

17. The river Foss.—The Foss drains a considerable tract of country to the north of York. It has a course of about 15 miles, more than half of which has been rendered navigable, but it is not in any sense an important stream. It rises on the oolitic hills forming the wolds of Yorkshire, about 230 feet above the sea, and crosses the lias to the New Red Sandstone, over which it flows in its lower course.

After receiving the Foss, the Ouse continues to flow southwards and a little to the west for about 10 miles, when it is joined by the Wharfe. The whole of this is over the Bunter sandstone. The Wharfe enters about a mile above Cawood. Between York and the confluence of the Wharfe, the Ouse receives no tributary of the smallest importance.

18. The upper course of the Wharfe.—The Wharfe, one of the most charming and romantic rivers of Yorkshire, well merits the high reputation it has among English streams for picturesque beauty. From its source down to Bolton, its character is wildness and sublimity. Below Bolton it becomes softer and more open, and is very beautiful as it passes Otley and Harewood. Below Wetherby the scenery contracts, passing for a time between lofty and almost perpendicular limestone rocks, and after this it sinks into the great plain of York.

The sources of this noble and beautiful stream are to be found in an extensive district called Langstroth dale, separated by a narrow water-shed from the sources of the Ribble in the west, and those of the early feeders of the Ure in the north. Two becks, draining the north and south slopes of Cam fell (1,690 feet), unite at the eastern extremity of the fell in a small stream, which after their confluence is called the Wharfe. The scenery in Langstroth dale is wild, and the fine hills of Dodd fell (2,189 feet), Whernside (2,384 feet), Ingleborough (2,361 feet), and Penyghent (2,270 feet), present themselves to the view, almost forming a semicircle. After the confluence of the two branches, the river flows nearly 4 miles east through a gorge to Kettlewell, and at that village approaches Great Whernside, the scenery being crowned by several high hills capped by rough rocks. Scarcely any feeders come in during this early part of its course, but about 2 miles below Kettlewell the *Skirfare* * enters, bringing the drainage of a considerable tract of moorland as far back as the slopes of Penyghent. This drainage flows for 12 miles into the Wharfe, through a long valley nearly parallel to that of the Wharfe, from which it is generally 2 miles distant. Receiving the Skirfare, the main stream continues about 3 miles in a southerly direction to Grassington, and afterwards 7 miles to the south-east to Barden fell, where it is again turned south for 2 miles. Throughout this distance there is only one feeder of the smallest importance (the *Dibb*), which comes in from the north, and which is joined by the *Blea beck* from Grassington moor, and receives several other feeders. The country traversed is a romantic wooded glen with fells towering above, and rocks contracting below to form narrow channels, of which the *Strid*, immortalised by Wordsworth, is the principal. Past these obstructions, below Barden fell and tower, the Wharfe emerges into that sweet and picturesque combination of cliff, meadow, forest, and monastic ruins, which has rendered Bolton Abbey so dear to the painter of nature. Bolton Abbey owes no small share of its witchery to the graceful sweeps and ever changing face of this beautiful mountain stream.† Before reaching Bolton the Wharfe has received *Gill beck* and *Bardon beck* from the west, and immediately below the abbey the *Kex beck* enters from the east.

Five miles below Bolton is Ickley, celebrated for its cold springs,

* This stream has three names in its course down the valley. It is at first *Cash beck*. Receiving a small feeder (*Foxup beck*) it becomes *Halton beck*. Then receiving *Haselden beck*, it becomes *Broad beck*, and arriving at Arncliffe, where it receives a considerable branch from the south-west (*Cowside beck*), it takes the name *Skirfare river*.

† Phillips's Physical Geography of Yorkshire, p. 80.

utilised at the hydropathic establishment of Ben Rhydding. The Wharfe now turns east, and 8 miles further passes Otley. A few small feeders come in here from the north, but to the south-west the high moors are too near to allow of much contribution, and the principal drainage of these moors being towards the south, the streams run to the Aire.

19. The Washbourne and its reservoirs.—Two miles below Otley the Washbourne enters the Wharfe. This tributary has a comparatively large drainage area, which has been granted by Act of Parliament for the supply of the important town of Leeds with water, and owing to the completeness of the observations and calculations that have been made respecting its flow, the magnificence of the works constructed, and the difficulties met with, it has an unusual amount of interest.

The basin of the Washbourne is contained between the basins of the Nidd and the Wharfe, and comprises a total area of 23,329 acres (27·8 square miles). It collects the drainage from the southern slopes of Craven moor, part of the drainage of Beverley moor, and almost the whole of that from Rock Stones moor. These supplies are received from a number of gullies within the first two miles of the course of the beck to the south-east. They are soon added to by *Harden beck* which has an independent drainage of some magnitude from the moors to the west, and the stream then descends another mile and a half through a narrow gorge without further additions. A small valley now opens from the west, through which a stream comes, having been added to in its course by several branches. This enters at a place called West End, and soon after the gorge again narrows, and so continues for another 2 miles to Blubberhouses, receiving on its way one gill from the west. At Blubberhouses there is a reservoir site not utilised, the valley opening out, and being well adapted for storage. Below the village the valley remains open, and at Fewston a bank has been projected, and is now nearly completed, permitting a large body of water to be stored in this part of the valley. To the bank at Fewston there is a collecting ground of 13,295 acres, and the area of the water surface, when that reservoir is full, will be 135 acres. The water will be again held back between the foot of this bank and another bank placed at Swinsty, a short distance below. This work also is nearly completed. Another 3,689 acres is thus added to the drainage area, and the extent of the water surface of this reservoir is the same as that of Fewston. A third bank completing the system is constructed and in use at Lindley wood, about 5 miles below the upper reservoir. In this way the water is collected and stored from a total area of 21,322 acres. The area of the Lindley wood reservoir is 117 acres.

Lindley wood bank is about 3 miles from the confluence of the Washbourne and the Wharfe, adding to the drainage area of the stream 1,620 acres, making it in all 22,952 acres, or 35·86 square miles. The mean annual rainfall over the district is estimated at 36 inches.

This system of reservoirs is one of the most important works of its kind that have been constructed, and is of the greatest interest to all who desire to become acquainted with the modern system of gravitation works for the supply of towns with water for domestic and manufacturing purposes. The construction of the banks has presented in some parts great engineering difficulties, owing to the presence of boulder clay in the valley and the fractured condition of the rocks, introducing a large body of water during the sinking of the trench in which the puddle wall is placed. Although in overcoming these difficulties a considerable loss of time has been inevitable, and the cost rendered very great, the ultimate result is in the highest degree satisfactory.*

20. Lower course of the Wharfe.—After being joined by the Washbourne, the Wharfe flows eastwards in a somewhat winding course for about 15 miles over comparatively level country consisting of the millstone grit, to Wetherby on the Permian rocks, receiving only a few small becks from either side. All this part is a broad rich valley, bordered by wooded slopes and ornamented grounds. The river thence flows across the magnesian limestone 6 miles in a south-easterly direction to Tadcaster, the limestone cliffs beginning to shadow the stream, and the valley becoming narrower and shut in on the south. A mile beyond the river *Cock* enters from the south-west having had a winding course from the eastern slope of the hills near Leeds, and draining a considerable area. A little further the *Fosse*, draining a valley parallel and to the north of the Wharfe, joins it, and, after another 2 or 3 miles of pleasant winding stream, the Wharfe loses itself in the Ouse at Cawood.

The drainage area of the Wharfe is 359 square miles, and its length of course 65 miles. In the lower part of its course the river runs over the lower or Bunter beds of the New Red Sandstone.

From Cawood to Selby the direct distance is only 4 miles, but the windings of the Ouse double this distance. The river sweeps with a broad current through a rich level country, and receives no feeders of importance.

21. The river Derwent.—About 3 miles south-east of Selby in a direct line (but much more if measured on the windings of the river) the Ouse receives the Derwent on its left bank.

The Derwent first receives its name between Fylingdale moor and Wickham High moor, collecting the drainage chiefly from the northern

* In this basin the mean annual rainfall being estimated at 36 inches, and deduction made for evaporation and loss, there remains 11 inches of available fall over the gathering ground, equivalent to an average daily supply of 14½ million gallons. The engineers constructing these great works are Messrs. T. & C. Hawksley and Mr. E. Filliter.

slopes of the latter range of oolitic hills, which rise to nearly 900 feet above the sea. Flowing east for about 4 miles, it is joined by a tributary collecting the waters of Fylingdale moor by several brooks. The principal of these feeders is the *Jagger Howe beck*, which drains a large extent of country to the north and north-east, and, after a course of 5 miles, joined by several feeders, receives the *Helwath beck* from the north and *Bloody beck* from the west. It continues to flow for another 3 miles, at first to the south and then to the west, to join the Derwent. At the confluence of the two streams the Jagger Howe beck is the larger and more important, and has had the longer course.

After uniting with the Jagger Howe beck, which is called the *Lownorth beck* in its lower course, the Derwent takes a southern course for about 3 miles through a deep narrow valley, and is then joined by the *Black beck*, another large tributary draining an extensive district to the west, known as Alleston moor. This stream is joined by several others before the confluence. Shortly after the *Trout's dale beck* comes in, also from the west, and after 2 miles another much smaller affluent from the north. After this the Derwent has a course of nearly 10 miles, during which it is joined by no feeders of importance from either side. At Ayton it leaves the vale of Hackness and turns abruptly to the west into the broad open valley called the Vale of Pickering.

All these upper sources of the Derwent proceed from the southern side of the moorlands that range eastwards from the Cleveland hills to the coast, a distance of more than 25 miles. With the exception of the small independent drainage area of the Esk, which enters the sea at Whitby and separates the lower part of the Tees drainage area from that of the Ouse, the Derwent drainage commences from the coast. The width of the district whose waters combine to feed the stream is, therefore, very considerable, and the number of tributaries is also great. Many of these are of about equal importance, none of them being remarkable for the quantity of water they bring down, but all contributing a certain supply. The rainfall over the upper part of the Derwent system is as much as 31 inches, but towards the coast is very small compared with that over the western moors supplying the Ouse.

22. The lower course of the Derwent.—Entering the vale of Pickering, and near Malton, the Derwent is joined by the *Rye* coming from the Cleveland hills, and is fed also by the waters of the *Dove*, which has previously received the *Bran*. This river (the Dove) disappears in part of its course while traversing the cavernous oolitic limestone which contains the celebrated caves of Kirkdale, but it reappears in the valley below.

The *Seven*, another feeder of the Derwent, passes down and drains Rosedale. It rises near Byland Abbey and enters the Rye. Besides these there are many smaller tributaries, and the whole district abounds with objects of interest in archæology as well as natural history. It is thought that the vale of Pickering was covered with water and formed a lake before the channel existed by which it drains down by the Derwent at Malton.

Almost all the feeders entering on the right bank of the Derwent proceed from the north, and have a southerly and easterly course. With the exception of a few small affluents from the east and west, conveying very little addition to the stream, the Derwent runs a nearly straight course of 30 miles from Malton to its confluence with the Ouse without any addition to its waters.

Throughout its course the Derwent drains the Yorkshire oolites, whose general condition, however, is altogether different from the contemporaneous beds in the middle and south of England. The limestones are generally very hard and flaggy, and not oolitic. With them are numerous bands of shale, often of a pale blue colour working easily into mud, and sandstones, some of which, as the Stoughton stone, form excellent but rough building stone. Many of the beds are of estuarine origin. For the most part they are regularly stratified and little disturbed, lying almost horizontal. There are, however, some faults, and an important *whin dyke*, or band of basalt, rises like a wall between the parted strata.

The following account of the course of the Derwent is extracted from the description given by the late Professor Phillips, who knew the country very familiarly :—

" Rising by many branches in the north-eastern moorlands, the Derwent drains the whole of the region lying south of Eskdale by the Rye of Bilsdale, the Bran and the Dove of Bransdale and Farndale, the Seven of Rosedale and Hartoftdale, the Costa of Newtondale, the Staindale beck, and the many streams which water the region of Hackness and Harwooddale. We are thus brought near the coast at Scarborough, but if we turn to the south a more singular thing is observed. The Hertford brook (or river) rises almost on the very cliff near Filey, at a height of about 100 feet from the sea, and flows westward, southward, and eastward 100 miles before reaching the sea."*

23. The river Aire.—Three and a half miles below the junction of the Derwent the Ouse, flowing in an easterly direction, receives the river Aire. Although, however, the old channel of the Aire here connects with that of the Ouse, a large part of its waters is conducted by an important navigable canal (the Aire and Calder canal) entering the Ouse 5 miles below, and carrying with it the waters of the Don.

* Phillips's Physical Geography of Yorkshire, p. 85. The Hertford brook after flowing about six miles to the west enters the Derwent and ceases to be known by any other name.

The river Aire is hardly less remarkable than the Wharfe for the romantic beauty of the scenery it passes in its early course. Few rivers leap into existence with such brilliant accessories, few run through and past so great a variety of all that is most beautiful in river scenery, few pass through more important towns, or do more important work, and few it must be admitted, after a history so interesting, are reduced so completely to the state of a public nuisance before they finally lose themselves in the larger streams of which they are such significant members. The Aire drains 342½ square miles of country before being joined by the Calder, and when it enters the Ouse it has received the rainfall from a small additional catchment. Much of the drainage area is exposed to heavy rainfall during part of the year.

Unlike most rivers, especially those of Yorkshire, the Aire springs at once a full stream from under a huge cliff of limestone, called Malham Cove, not far from a small lake, called Malham Tarn, among the high moorland country of Craven, close to the sources of the Wharfe, also connected with the Aire. Another little lake below Malham tarn, is about 3 miles in circumference, and 1,243 feet above the sea. The level of these sources is 570 feet above that of the Aire where it falls into the Calder. The limestone of the district is cavernous, and much fissured, and the water of the spring that forms the Aire proceeds by a subterraneous channel of more than a mile from Malham tarn. A mile east of Malham cove is Gordale, where a small rill, *Gordale beck*, dashes over and amongst the rocks in one of the most picturesque spots that can be found in England. A vertical precipice of limestone is called a scar in the old dialect of Yorkshire, and thus the locality is known as Gordale scar.

The stream of the Aire formed by the union of these two picturesque sources flows for 4 miles due south, and then receives the *Otterburn*, a considerable affluent coming in from a large number of branches from Kirkby fell in the north-west. Having received the Otterburn, it continues another 4 miles to Gargrave, where the *Eshton beck* enters. This, like the Otterburn, is a combined stream having many feeders. It proceeds from the same slopes as those which feed Gordale beck, and the principal stream, which is known by many names in its progress southwards and is joined by many tributaries, has a course of fully 9 miles without including windings.

From Gargrave the Aire winds on to Skipton where it receives the *Eller beck*, and a smaller feeder from the south-west. It here occupies a wide valley which continues southwards to Kildwick, where it is fed again from the west, and a few miles after it reaches Keighley, running through a deep valley.

At Keighley the river *Worth* enters from the south-west, joined by a smaller stream from the west. The Worth drains a considerable area of moorland to the south.

Another 3 miles brings us to Bingley, where the *Hardon beck* comes in from the south, also from the moors. Three miles below the *Bradford beck* comes in from Bradford, also from the south; and the river flows on to Leeds, passing Bramley fall and Kirkstall Abbey, and continues on its way through pleasant meadows after emerging from the hilly ground. From Leeds to the confluence of the Calder at Castleford is about 9 miles. In this part of its course the river once swept through fertile meadows; but coal is now dug everywhere, and the once pleasing country is covered with all the indications of active industry.

The basin of the Aire to its junction with the Calder, is made up geologically as follows:—Scar limestone, 95½ square miles, millstone grit, 137½ square miles, coal-measures, 110 square miles.

24. The river Calder.—The Calder* originates in a marsh about 3 miles north-west of Todmorden. The waters run south-east through rude craggy fissures, called cloughs, and the stream when formed runs through a narrow dell between Rochdale and Todmorden, near one of the sources of the Roch, and 1,500 feet above the sea. It descends thence to Todmorden through the millstone grit, where it receives a feeder from the south, it then runs nearly east 4 miles to Hebden bridge, where the *Hebden* comes in also from the north. At Sowerby bridge, 4 miles beyond, the *Ribourne*, or *Rye burn* joins it from the south. The Ribourne is a considerable stream with two branches from the slope of the Penine chain at Blackstone Edge, and carries a good body of water. Two miles beyond, a stream enters from Halifax coming about 8 miles from the north, and at Cooper bridge the river *Colne* arrives from Huddersfield, bringing water from Marsden, Pale hill, and Stanedge.

25. The river Colne.—This river has a drainage area of 65,280 acres, and enters the Calder 3 miles below Huddersfield. It rises on the slopes of the Penine chain near Stanedge, its feeders receiving the drainage of about 10 miles of the most rainy part of the range. The main stream, collected from 6 miles of the north-western extremity of the chain included in the water-shed, flows about 10 miles north-east to Huddersfield, meeting there the river *Holme* draining the four miles of the chain to the south-east. Both the main stream of the Colne and the whole of the Holme have been extensively utilised at one time exclusively by mills and more recently for water supply, the water being collected in storage reservoirs, of which there are several. The Huddersfield sys-

* This stream is usually called the Calder, but it is properly the *East Calder*, another stream originating in the same marsh and running west to join the Ribble being called the *West Calder*.

tem is the largest and the most complete, the Blackmoor foot reservoir receiving the water brought by catchwater culverts from a considerable tract of gathering ground. There are many reservoirs in the numerous valleys, both of the feeders of the upper Colne and of the Holme. Below Huddersfield the Colne is fed by one principal tributary from the south and two of smaller importance from the north.

About 4 miles below the confluence of the Colne the Calder receives another stream from the north passing Heckmondwike, and then passes Dewsbury, where there is also a small contribution from the same direction. There are several reservoirs in the upper valleys of the Colne feeders supplying these and other towns.

Seven miles below Dewsbury, Wakefield is passed, and the river pursues a tortuous course of about 8 miles into the Aire. The separate drainage area of the Calder to its confluence with the Aire is 366 square miles.

The Calder runs through 191 square miles of millstone grit, and 175 square miles of coal-measures. The drainage area of the Aire and Calder at their confluence is 708 square miles. The length of the Calder is 35 miles.

26. The Aire and Calder.—At Castleford the Aire and Calder, taking the name of Aire, meet, and enter the magnesian limestone, which is crossed for several miles by the river running east. The course of the river then continues through low lands in the New Red Sandstone to Snaith, Rawcliff, and Airmin, where it joins the Ouse. In this part of its course the river drains a further area of $85\frac{1}{2}$ square miles ($30\frac{1}{2}$ of which is Permian rock and the remainder New Red Sandstone). The total area drained by the joint system of the Aire and Calder to the confluence with the Ouse is 794 square miles.

27. The upper course of the Don.—The Don, or Dun, enters the Ouse 5 miles below the mouth of the Aire, and its original course rendered it a tributary either of the Aire or the Trent. It commences with the convergence of a group of mountain torrents or cloughs on the eastern slope of the high moors near Holme moss (1,859 feet) and Ramsden edge, not far from Penistone. The Etherow, a feeder of the Mersey, the Holme Firth, which enters the Calder, and other streams rise very near it. The Little Don, which joins the Don near Sheffield, also receives feeders from within a few hundred yards of some of these sources. The whole district containing these sources is the extreme south-western part of the Penine chain, extending southwards to the Peak of Derbyshire, which is only a few miles distant.

From Dunford bridge, where, after a flow of from 4 to 6 miles, the chief early feeders of the Don have come together, the river flows nearly due east for about 6 miles to Penistone through a barren and not very interesting country, receiving water from several small tributaries, chiefly from the north and west. The *Scout dyke*, which joins it at Penistone, is the most important. Leaving Penistone the river turns to the south-east and the scenery improves, the ground rising rapidly on the left bank. After 3 miles the course changes, and the river makes a large sweeping curve between steep wooded banks, and continues to wind about, passing Wortley amid richly wooded scenery which reaches to the edge of a cliff overhanging the water. After another 3 miles, and not far from the village of Wortley, which lies on the high ground to the left, the *Little Don* enters.

This tributary rises near the sources of the Don from the slopes of Harden moss, and, like the Don, is fed by several cloughs running courses of 2 or 3 miles. After uniting into one stream passing Langset, the river has a nearly straight course a little south of east for about 7 miles to join the main stream.

About $1\frac{1}{2}$ mile below the junction, and opposite the picturesque scenery of the Dragon's Den, in Wharncliffe Park, the *Ewden* comes in also from the west. It has a similar and nearly parallel course to that of the Little Don, the total length being about 7 miles.

The Don then flows on in the same south-easterly direction for 5 miles, the left bank continuing high, and then receives an important tributary from the west, called the Loxley river.

28. The Loxley river and its reservoirs.—The river Loxley rises on the slopes of Derwent edge and the hills to the north, several small branches converging at Strines bridge, which is situated in a gap between Strines edge and its continuation into Bole edge. Beyond this to the west a natural basin is formed among the hills having a drainage area of nearly 3,000 acres. The conformation here being very favourable, a reservoir has been formed by placing a bank across the valley at a convenient point at Strines bridge, and this is the commencement of the magnificent series of engineering works supplying Sheffield with water. The Strines reservoir itself occupies 53 acres, and immediately below its bank is the tail of a second reservoir, called Dale Dyke.

The valley of the Loxley from Strines downwards is called Bradfield dale, and is formed in the lower coal-measures, which are here very hard, and pass into the Gannister rocks, the name given to an important series of grits and hard shales which form the bottom beds of the coal-measures in South Yorkshire. These rocks have undergone disturbance, and are a good deal fractured. The valleys have been partially and irregularly choked with ice-driven deposits of boulder clay, consisting of boulders of many kinds of rock irregularly mixed with tough clay, and often containing bands and seams of smaller gravels and running sand. Owing to this condition the construction of reservoir banks is liable to be attended with unexpected difficulties and some risk, and the bank originally placed a couple of miles below Strines, near Lower Bradfield, to form the Lower Bradfield reservoir, was the scene of a terrible disaster a few years ago. The boulder clay below the outer bank appears to have been disturbed, and caused to slip over sands after unusual rain. The bank was broken through almost immediately after it was completed, and the result was very serious, the whole contents of the reservoir being carried down the Loxley valley into the valley of the Don with terrible force, tearing away all buildings exposed to it, and destroying life and property to a very large extent.

A new bank has since been constructed, not without great difficulty and at great cost, a little above the position of the former bank. The difficulties of construction arose from the fractured condition of the rocks and the irregular nature of the boulder clay. It is now completed and in full operation. It receives the drainage of 1,695 acres below the collecting ground of Strines.

Below Dale Dyke reservoir, at Lower Bradfield, a small tributary, the *Agden water*, formerly entered the Loxley. A long bank has been put across this valley, and a reservoir of 60 acres has been enclosed, which stores the water obtained from a drainage area of 2,939 acres. About a mile and a half below this, and a little below the point where a small brook (the *Ughill brook*) entered the Loxley, a fourth bank has been constructed to form the Damflask reservoir (111 acres). This is the last and the finest of this series of reservoirs for the supply of Sheffield. The whole series is calculated to supply water for more than six months of extreme drought in two consecutive years for a much larger population than exists at present at Sheffield.

Over this district the mean annual rainfall averages 40 inches, the maximum being $49\frac{1}{4}$, and the minimum $28\frac{3}{4}$.

The Loxley river enters the Don 4 miles below the lowest reservoir. About a mile before it enters it is joined by the river *Rivelyn* coming in from the south-west, and receiving in its upper part the *Wyming brook*. In this valley there is yet another Sheffield reservoir receiving the water from an area of 4,461 acres.

29. The lower course of the Don.—A mile and a half below the confluence of the Loxley the Don passes through Sheffield, and there receives the *Sheaf*. This little river originates in the moors about 7 miles south-west of Sheffield, and, being formed by the junction of several brooks draining about 5,000 acres of moorland, continues with few additions in a nearly straight course for 5 miles. On its way it receives *Meers brook* from the east, and is joined near Sheffield by the *Porter brook*, rising in the moors north of the main stream and draining a considerable tract. The union of Porter brook with the Sheaf is within the town of Sheffield, but the united stream where it joins the Don is small. Both the Sheaf and its tributaries flow through lovely and romantic scenery in their upper course.

Leaving Sheffield, the Don turns at once in a north-easterly direction with a somewhat tortuous course. It flows 6 miles to Rotherham, where it is joined by the Rother. On its way it receives the *Hartley brook* from the north-west.

The *Rother* rises near Padley, and flows in a remarkably straight course 8 miles to the north beyond Chesterfield, then, turning east, it passes Staveley, where it is joined by the *Dawley*, which rises in the south and runs parallel to the Rother for about 8 miles at a distance of 4 miles. From Staveley it again flows north 12 miles to enter the Don. It receives few tributaries and none of importance.

Below the confluence of the Rother the Don runs through a varied country in a broad and beautiful valley 5 miles north to Mexborough, and then 3 miles east to Conisborough, where it receives the *Dearne*, which rises near Cumberworth, in the southern part of the West Riding of Yorkshire. Four principal branches of this stream meet near Darton, and flow about 3 miles to Barnsley, and thence 3 miles beyond in the same direction to a point where the stream turns abruptly to the south for 2 miles to Darfield, where it receives the *Dove* from the west after a course of 8 or 9 miles, rising very near one source of the Dearne. It then continues to flow about 7 miles further eastwards to the Don. This part of the course is through the coal-measures.

From Conisborough the Don flows 6 miles in a north-easterly direction to Doncaster, receiving no important contributions. The country is hilly, and consists of Permian rocks, chiefly magnesian limestone. Before reaching Doncaster, however, it enters the New Red Sandstone, which it does not afterwards leave. From Doncaster to Thorne the direction is north-east. The country on the right bank is hilly and pleasing, but on the left the ground for some miles is perfectly level. The stream is tortuous, and there are numerous straight channels cut for the more rapid removal of accumulated water. The distance to Thorne is 12 miles not counting the smaller windings. Leaving Thorne, the river turns due north, and, after a straight course of 3 miles, receives the *Went*, a small river rising west of Pontefract and running nearly 15 miles due east, not fed by any stream of importance.

30. Ancient course of the Don.—Formerly the northerly course of the Don was continued about 2½ miles from the Went confluence into the Aire, but it is now conducted by a straight cut a little north of east, commencing a mile north of the Went, and conveying the water direct into the Ouse. This canal is about 5½ miles in length, and is called the Dutch river.

Besides the old bed of the Don and the present cut, indications exist of other channels by which the waters of the Don entered the estuary of the Humber. One of these, perhaps the original stream, was a winding course commencing near Thorne, where the river now turns to the north, and retaining the generally easterly and north-easterly direction of the river to that point. This channel had a very winding course past Crowle to the Trent, which it entered close to the Trent falls, near Adlingfleet. This course united the Don with the river Idle, one of the tributaries of the Trent, both entering the Humber by a common channel parallel for some distance with the main stream. These various old channels prove clearly that the large tract of low, flat land extending between the Don and the Trent is, in fact, a delta, perhaps the delta of the Trent before the Humber existed as a river, and that it was formed by the joint action of the two streams. Hatfield chase and Thorne waste are great expanses of peat marsh now artificially drained. They and the low country adjacent contain an area of about 250 square miles, connecting with the fen lands of Lincolnshire on the other side of the Trent.

From the present entrance of the Don, by the Dutch river, to the Trent is 7 miles in a straight line, and about 9 miles by the river.

The drainage of the Don is essentially over the coal-measures in the early and middle part of its course, and it then crosses the Permian marls and sandstones and the magnesian limestone to enter the New Red Sandstone. All its chief tributaries partake of the same character. Unlike the other feeders of the Ouse, its direction is chiefly to the north, resembling in this respect the Trent. Some of its sources lie considerably to the south of some of those of the Trent.

CHAPTER IX.

THE HUMBER SYSTEM—*continued.*

THE BASINS OF THE TRENT AND HUMBER.

(1) General account of the Trent basin.—(2) Geological character.—(3) Subdivisions.—(4) Ordinary flow and floods.—(5) Tidal action.—(6.) Scheme of the principal tributaries and their affluents.—(7) THE UPPER TRENT: Source and early course.—(8.) The river Sow.—(9) The river Blythe.—(10) The river Tame.—(11) The river Anker.—(12) The river Mease.—(13) Summary of the Upper Trent.—(14) THE MIDDLE TRENT.—(15) The river Dove.—(16) The river Manifold.—(17) Henmoor brook.—(18) The river Churnet.—(19) The Tean brook, and the Stonyford brook.—(20) Picturesque character of the Dove.—(21) The Carr brook.—(22) The river Derwent: its early course.—(23) The river Ashop.—(24) The river Noe.—(25) The river Wye.—(26) The middle course of the Derwent.—(27) The river Amber.—(28) The Ecclesbourne river, and Bottle brook.—(29) Gaugings of the Derwent.—(30) Proportion of rocks drained by the Derwent.—(31) The river Soar: upper course.—(32) The river Wreak.—(33) The lower course of the Soar.—(34) The river Erewash.—(35) The Fareham beck.—(36) The river Leen.—(37) Summary of the Middle Trent.—(38) THE LOWER TRENT.—(39) The Dover beck.—(40) The river Devon.—(41) The river Idle.—(42) The ancient channel of the Idle.—(43) The Torne river.—(44) THE HUMBER.—(45) Scheme of the tributaries.—(46) Early affluents.—(47) The Ancholme river.—(48) The river Hull.—(49) The Tetney river.—(50) The river Ludd.—(51) Coast drainage east of the Derwent basin—" Gipseys."

1. General account of the Trent basin.—The river Trent, draining an important part of the middle of England, including within its drainage area many thickly peopled towns and districts, and watering a rich and well cultivated country, forms the southern member of the Humber system, being somewhat smaller than the Yorkshire Ouse, the northern member of the system, in extent of drainage area, and somewhat different in the nature of the country drained, and in some of the conditions affecting river systems. It collects waters from every point of the compass, and from rocks of almost all ages, though its bed chiefly flows on triassic rocks. Most of its tributaries converge near Nottingham, whence they are carried to the north over a country almost entirely level for a distance of 60 miles, with comparatively slight additions, until the waters of this stream unite with those of the Yorkshire Ouse to form the Humber.

The drainage area of the Trent is 4,082 square miles, or 2,612,500 acres. The total length of course of the stream is 172 miles.

The drainage area of the Trent is separated from the greater part of the basin of the Ouse, and partly also from that of the Mersey by a line of water-shed at a high level over rocks of the carboniferous period; but from the rest of the adjoining river basins the water-parting is drawn on triassic or oolitic rocks. This part of the line of the water-shed is at a low level.

2. Geological character of the basin.—As the Ouse is especially a river draining rocks of the newer palæozoic period—the carboniferous limestone, millstone grit, coal-measures, and Permian rocks—so the Trent is essentially a river draining the great central plateau of New Red Sandstone. It derives a part of its waters from the older rocks, and crosses the detached coal fields of the middle of England where they are uncovered by the triassic rocks; but its features are as a whole quite different from those described as characteristic of the northern river of the Humber system. Its floods are apt to expand over the plains, and deposit the loose sand and marls which they bring down on the low lands that extend far and wide, as the river approaches its outflow.

The actual area of old rock at the surface within the drainage area has been calculated to amount to 1,200 square miles, of which 850 square miles are millstone grit or carboniferous limestone, and 350 square miles coal-measures, magnesian limestone, and Permian rock. But there are no less than 2,500 square miles of triassic rock, of which almost the whole (2,135 square miles) belong to the upper marls and sandstones distinguished as Keuper. The rest is Bunter sandstone, belonging to the lower division. There is also a certain area covered by the lias, and a small tract of lower oolite.

Over a large part of these tracts the rock is never seen at the surface. It is covered, often very thickly, with drift, alluvium, gravel of various kinds, and other surface accumulations. No river basin in England has so large a part of its catchment thickly covered with alluvial deposits and gravels, accumulated in the bed of the river and in the low-lying land adjacent, but sometimes met with at a considerable elevation.

3. Subdivisions of the basin.—The Trent comprises a large number of separate catchments. These have been in many cases the object of careful study for various economic purposes, and their area and conditions have been estimated with much care. The following statement represents these results as far as I have been able to obtain them for the Upper and Middle parts of the Trent basin. It has not been thought necessary, and could indeed serve no useful purpose, to take out the exact drainage areas of the intervals between the streams, or of the streams that flow through the alluvial lands near the outflow of the river. The drainage areas of the streams below Nottingham are also of inferior interest, and the only important basin is that of the Idle.

Much of the lower basin of this latter tributary, together with the lower part of the Don basin, forms part of the expanse of alluvial land that may be considered to form common ground with the Humber.

Drainage Areas and Length of Course of the Feeders of the Upper and Middle Trent.

	Length of course in miles.	Drainage area in acres.
Upper Trent to the confluence of the Sow -	30	239,082
The river Sow - - - -	20	150,130
The river Blythe - - - -	23	40,594
The river Tame - - - -	42	376,820
The river Dove - - - -	45	251,668
The river Derwent - - - -	65	300,659
The river Soar - - - -	35	344,951
The river Erewash - - - -	20	53,341
The Fareham beck - - - -	14	21,727
The river Leen - - - -	13	31,772

These are the principal tributaries. Six of them are of considerable magnitude, each draining from 230 to nearly 600 square miles. The others, though smaller, draining from nearly 50 to more than 80 square miles each, are of some interest. The Derwent and the Dove, both among the larger streams, alone drain the older rocks.

It will be convenient to consider the Trent as divided into three sub-basins:—the upper, which includes the north-western tributaries terminating at Burton; the middle, which takes in both northern and southern feeders, terminating at Nottingham; and the lower, which includes the river from Nottingham to the Humber.

4. Ordinary flow and flood.—For a large part of its course the Trent is a full, transparent stream, gliding gently between rich meadows, exceeding the Thames in rate of flow, but nowhere rapid until the Dove and the Derwent enter.

The fall of the Trent as will be seen by reference to the diagram in page 129, is at first considerable. The main stream falls 520 feet in the first 50 miles, and a great part of this heavy drop in the bed is within the first 11 miles. The fall in 5 miles from the source is at the rate of 50 feet per mile. Afterwards the slope is regular and moderate for a long distance, and averages about a foot to the mile till the river enters the great alluvial flat in which it meets the Ouse, and where after a time its waters combine with those of the Ouse to form the Humber. In the lower division of the river there is little fall.

The Trent is subject to floods which are often serious and mischievous. In the year 1875 when there were heavy floods throughout the middle of England, the valley of the Trent did not escape. The water at flood times covers a large space of low-lying country both at the termination of the upper part of the river, and below Newark, besides occupying the alluvial bed in other parts. It frequently does great injury to property. The floods of the Dove are very frequent in the spring, and they are sometimes very destructive, but the waters of its tributaries are lost to so great an extent by passing into the cavernous limestone rock as to render very considerable freshets unlikely.

5. Tidal action.—The tides which enter the Humber and have a free course to the extremity of the estuary also enter the Trent, and are felt several miles above Gainsborough. The spring tides run with great velocity, passing at the rate of more than 9 miles an hour, and in certain states of the bed of the river, and at certain times of the year, they are converted into a *bore* or *egre*. This phenomenon has been already described in the Severn. At such times the water flows in with a white curling wave, varying from 1 to 4 feet in vertical height, running along the flats and shallow parts of the river with considerable noise, and causing much commotion in the stream.

The Trent for the most part, however, may be regarded as little affected by tidal action. All the chief tidal phenomena are confined to the Humber, and terminate in the alluvial flat where the Trent and Ouse come together.

It may be well to point out here that the conformation of the valley of the Trent, which alternately expands into large low-lying tracts receiving several rivers, and narrows into channels which only permit water to run off, is well adapted to limit the mischief which might otherwise take place during freshets. It is not often that the north-west and south feeders that converge in the space between the upper and middle basins would be in flood at the same time, as they proceed not only from distant sources, but from sources very differently affected by rain. While the northern district, for example, would run off very quickly, the southern would for a time absorb. Notwithstanding this, continuous rain produces a large result at the mouth of the river.

6. Scheme of the principal tributaries of the Trent and their affluents.—The following scheme of the chief tributaries of the Trent and their feeders may be useful, and will suggest interesting facts with regard to the sub-division of the basin :—

Right bank.	Distance from source in miles.	*Left bank.*
Fowlea brook	10	
Lyme river	12	
Filly brook	20	
Sow river	30	
Mease brook.		
Clanford brook.		
Penk river.		
	39	Blythe river.
Tame river	46	
Rae brook.		
Blythe river.		
Cole		
Bourne river.		
Langley brook.		
Bourne brook.		
Anker river.		
	46½	River Mease.
	56	River Dove.
		Manifold river.
		Hamps river.
		Henmoor brook.
		Churnet river.
		Tean brook.
		Stonyford brook.
		Schoo.
Carr brook	70	
	77	River Derwent.
		Ashop river.
		Noe river.
		Wye river.
		Dakin.
		Amber river.
		Bottle brook.
River Soar	80	
Sence.		
Wreak.		
Eye		
	83	Erewash river.
Fareham beck	87	
	88	River Lene or Leen.
	98	Dover beck.
Devon river	112	
Smite.		
Car Dyke.		
	164	River Idle.
		Rainworth water.
		Maun.
		Meden.
	171	River Torne.

7. The Upper Trent.—Source of the river.—The source of the Trent is between the village of Biddulph and the hill called Mow Cop, in the pottery district of North Staffordshire, about 700 feet above the sea, and near the borders of Cheshire. The stream almost immediately passes into Knypersley pools, where a number of small rivulets unite with the surplus water proceeding from Biddulph moor. The Trent now commences to be a river, and flows on 3 miles to Norton, below which a considerable tributary comes in, called the *Fowlea*, starting at almost the same distance as the Trent, and coming through a parallel valley. This feeder is, perhaps, quite as important as that which bears the name of Trent. The united stream flows about 3 miles to Stoke-upon-Trent, passing the town of Hanley and a long line of thickly peopled country, which it leaves to the west. Beyond Stoke it runs 2 miles further to Hanford, where it receives the *Lyme* from the north, a brook about 5 miles long running through Newcastle. Soon afterwards it enters Trentham Park, where it expands in a beautiful artificial lake of about 80 acres. In the first part of its course the Trent hardly gives promise of its future importance, but, after leaving Trentham, it increases sensibly, still retaining the same course nearly to the south. Winding gently for 4 miles, it reaches Stone without receiving any affluent of importance. Here the *Filly brook* comes in, and the stream, turning a little to the east of south and fed by occasional small brooks, continues in an uninterrupted course till, after 10 miles, it receives the Sow at Great Heywood coming in from the west.

8. The river Sow.—This river rises in the western part of Staffordshire about 6 miles north-west of Eccleshall, and flows through a pool named Copmere, and then to the village of Chebsey, where it receives the *Mease brook*, which rises on Whitmore moss, and has a course of 10 miles south-east parallel to the line of the North-western Railway, and almost parallel to the course of the Sow. From the confluence of the Mease the Sow continues 4 miles south-east to Stafford, receiving on its way the *Clanford brook* from the west. Passing Stafford, after a little more than a mile the Sow is joined by the Penk from the south, and then, after flowing 4 miles to the east, it enters the Trent. The total course of the Sow is about 20 miles.

The *Penk* collects the water of several streams rising on either side of the hilly range west of Wolverhampton, and conveys them northwards about 16 miles to the Sow, receiving on its way a few small brooks.

From its confluence with the Sow the Trent flows on towards the south-east to Rugeley, after passing which town it turns to the east, and continues to wind along in the same direction for 9 miles, receiving a few brooks but no important feeder. It is then joined by the Tame, which comes in from the south, the Trent immediately and abruptly taking the direction of that stream. At their confluence the two streams are about equally important.

9. The river Blythe.—This river rises in Staffordshire, not far from the Churnet valley, a low range of hills a little east of Hanley, in the Potteries. Its early course is parallel to that of the Tean brook, a feeder of the Churnet, and in places it is not more than a mile distant. Its flow is generally south-east. It feeds a few mills, and in about 9 miles reaches the village of Leigh, after which it bends round to the south and has a nearly straight course of about 14 miles to the Trent, passing no large village, and receiving only very small feeders till it nears the Trent, when a small stream enters it from Abbots Bromley on the left bank, and another, *Purt brook*, a mile below. It joins the Trent about 5 miles below Rugeley.

A couple of miles below the Blythe the *Swarbourn* brook enters the Trent from the north after a flow of nearly 8 miles due south, parallel to the course of Purl brook. The *Bourn brook* also comes in from the south, draining the slopes of Cannock chase.

10. The river Tame.—This river takes its rise in the south of Cannock Chase, collecting water from the Silurian hills in the neighbourhood of Dudley, and also from the country east of Wolverhampton, especially from the western side of the ridge commencing with Hamptead Hill and extending northwards several miles. The numerous feeders bring their waters together near West Bromwich, and proceed thence passing to the north of Birmingham. Birmingham itself is watered by the *Rea brook*, a small tributary coming from a few miles south of Birmingham, and running a mile and a half north of it into the Tame.

From the junction with the Rea the Tame flows east for 6 miles in an alluvial bottom, and then receives the *Blythe*, which has received the *Cole* about a mile before the confluence of the former with the Tame. The Blythe* rises near the small town of Solihull in Warwickshire, and flows northwards past Packington. It is a stream of some importance, having a course of 23 miles. The Cole is a more winding river, coming from the country further west, and having several branches. The two streams approach, and the town of Coleshill is between them.

Receiving the Blythe from the south, the river Tame bends round to follow that direction, and the little river *Bourne* comes in from the east. It is now a considerable stream, and continues to the north about 8 miles to Tamworth, receiving from both sides, but chiefly from the east, many small tributaries. The *Langley brook*, and the *Bourne brook*, are, perhaps, the most important, and both come from the west.

* This Blythe must not be mistaken for the river of the same name described above, which is one of the direct tributaries of the Trent.

11. The river Anker.—Near Tamworth the Anker flows in from the east. It originates in many small streams 3 or 4 miles south of Nuneaton, and proceeds through that town, and in a north-westerly direction past Atherston, receiving from the north-east the river *Sence.* This stream rises in Charnwood forest, 20 miles to the north-east, and has a long course, receiving many tributaries from a wide extent of country in that direction. After receiving the Sence, the Anker continues to flow north-west and west, but in a winding course, for 8 miles to Tamworth, passing Polesworth, and making a considerable curve to the north between that place and its confluence.

The valley about Tamworth is wide, and the Tame here turns about 2 miles to the west, but then recovers its northerly course. In its further progress of about 8 miles to the Trent it makes some large curves. The whole course of the Tame is 42 miles, and it drains nearly 600 square miles of country.

12. The river Mease.—Less than half a mile from the confluence of the Tame and the Trent, the river Mease enters from the east. It rises near Ashby-de-la-Zouch in Leicestershire, and is the combination of a number of streams within a radius of 3 or 4 miles. The principal feeder flows south by Pakington, more than 4 miles from the source, and then flows round to the west by Measham, continually receiving fresh contributions. In this way it reaches Nether Seat, after a somewhat long and divergent course, whence it has a run of about 8 miles to the Trent. On its way it receives two more small brooks.

The Trent, which has hitherto flowed in an easterly direction, on receiving the Tame and Mease, makes a sharp turn to the north, and takes the direction of the Tame at the confluence. After a further flow of 6 miles in that direction, it reaches the town of Burton-on-Trent, and 2 miles below Burton it may be considered to complete the upper part of its course.

13. Summary of the Upper Trent.—The Upper Trent possesses some points of special interest. The direction of the main stream during this part of its course is on an average south-south-east. The sources of all the feeders, and of the main stream, are comparatively high, and the slope of the beds somewhat rapid. The area of this part of the basin is about 800 square miles, and in a distance of about 50 miles or less, the bed of the river has fallen from 700 feet above the sea to 180 feet, most part of this great fall of 520 feet occurring in the first 11 miles, between the source and the confluence of the small brook called the Fowlea, where the bed of the stream is not more than 370 feet above the sea. The mean fall of the first five miles of the Trent is at the rate of nearly 50 feet to the mile, and of the next five about 18 feet. After this the fall nowhere exceeds 8 feet in a mile.

14. The Middle Trent.—This division of the Trent commences a few miles below Burton, where the Dove comes in from the west. The main stream flowing north from the confluence of the Tame now again changes abruptly as it receives the Dove, and flows to the east for many miles until it receives the Derwent and the Soar, after which it turns towards the north-east to Nottingham. The whole of this middle part of the Trent is in the upper member of the New Red Sandstone, which occupies the country between the Derbyshire and Leicestershire coal-fields. A large part near the river is an alluvial flat, in which the main stream is joined by the Dove, the Derwent, the Erewash, and the Soar, and here the waters conveyed from north, south, and west, frequently accumulate during flood, and cover a large expanse of valuable land.

Immediately on entering this level tract the Trent receives the Dove from the west. The Dove is one of the most important of the tributaries of the Middle Trent, draining an extensive district to the north among the rocks of the carboniferous period, having a large number of tributaries, and a long course.

15. The river Dove.—The source of the Dove is a natural spring rising on the eastern slope of the elevated mountain-limestone ridge called Axe edge, ranging north and south, and commencing a little south-west of Buxton, in Derbyshire. The stream issues as a considerable body of water, and runs swiftly down the slope to be joined at its foot by a branch originating in another spring in a part of the ridge a little to the north. Pursuing a rapid course towards the south-east through a narrow valley it reaches Longnor after a course of 4 miles, where it receives a small feeder from the west, rising on the slopes of the hills that continue Axe edge towards the south. After flowing another 4 miles through a similar narrow straight valley in the same south-easterly direction, Hartington is approached, the river turning more towards the south. After a couple of miles the stream enters a long desolate glen, called Narrow glen, the entrance being marked by a mass of solid naked rock, through which the river appears to have forced its way. At the extremity of Narrow dale, Mill dale succeeds it after a short open space, the village of Alsop lying to the east. Mill dale, like Narrow dale, is enclosed by steep craggy hills, and immediately beyond, and to the south, the famous Dove dale is reached.

Dove dale is nearly 3 miles in length, and is entered by a noble portal of lofty rocks and cliffs, surmounted by isolated crags, locally called Tors. The rocks rise in perpendicular masses on both sides of the river, and the scenery is exceedingly wild and grand. This upper part of the dale is perhaps the finest in this respect. Passing it and leaving the fantastic imitations of spires and battlements buried in thick foliage, we enter and pass through the richest portion, which is followed by more gentle scenery in the third and least romantic part of this most beautiful valley. Here the stream murmurs gently along over a pebbly bed, or rushes rapidly over rocky interruptions into deep pools, and at last enters a broad and fertile valley in which it receives, almost as it emerges from the hills, the waters of its considerable affluent the Manifold.

16. The river Manifold.—This river is fed originally by the streams that flow from the continuation southwards of the limestone ridge of Axe edge. These collect to the west of Longnor, close to the course of the Dove, and flow southwards, fed at intervals by other feeders from the same source.

The course of the river is through the limestone in the romantic valley of Welton, remarkable for its fine natural caverns. In this part of its course the river disappears for 6 miles, passing through an underground channel, and emerging at Ilam. While thus submerged, its course is indicated in the valley.

A tributary of the Manifold, called the *Hamps,* enters the main stream as it emerges at Ilam, the Hamps having also disappeared for several miles of its course. It rises near Leck, in the district west of that drained by the Manifold, and winds through a very beautiful valley receiving several tributaries. It disappears underground for about 4 miles ; but in wet weather the level of water in the underground channel rises to the surface, and there is a small water-way joining the Hamps to the Manifold. From the emergence of the streams at Ilam to the confluence with the Dove, is about a mile.

17. Henmoor brook.—The Dove now turning southwards for a few miles, receives a considerable feeder after 3 miles from the hills of scar limestone to the north-east, and after another mile a stream of similar character, called *Henmoor brook*, from the country more to the east. The latter stream passes through Ashbourne.

From this last confluence the Dove continues in a winding course through a gradually widening valley for 7 or 8 miles to the confluence of the Churnet, a principal feeder.

18. The river Churnet.—The Churnet is originally fed by the waters from the millstone grit which form the western portion of the hills near the source of the Manifold, but it receives numerous contributions from a number of small streams taking the drainage of a semicircle of hills around Leek. These collect at Cheddleton after flowing from 4 to 7 miles. One of them has been utilised for water supply, and its valley contains a large reservoir (Rudyerd reservoir). At Cheddleton the Churnet enters a beautiful valley in the coal-measures, having well wooded hills on each side, and flows south-east for about 12 miles, fed only by a few small brooks chiefly from the west. As it advances the hills become more rocky, and the stream flows at the foot of the noble and picturesque grounds of Alton Towers. Emerging from the hills, the Churnet enters the wide expanse of flat lands through which the Dove here passes, and, bending round to the south, joins that river.

19. The Tean brook and the Stonyford brook.—Continuing to receive feeders from the west, the Dove now flows southwards to Uttoxeter, being increased by two streams, the Tean brook and the Stoneyford brook, both coming from the west. The Tean brook has a long course of more than 12 miles parallel to the Churnet; the Stonyford brook a much shorter course. The country now becomes open, and the Dove continues to flow with a very tortuous course through a wide alluvial valley about 12 miles further east to Newton Solney, where it enters the Trent, first receiving the *Schoo*, which rises at Wirksworth and has a course of 10 miles.

The total length of the Dove is 45 miles; it drains nearly 400 square miles of country; and it falls 1,550 feet from its source to its confluence with the Trent.

20. Picturesque character of the Dove.—The following description of the Dove is extracted from Rhodes's Peak Scenery, and describes it when less known and less visited than it now is:—"The Dove is one of the most beautiful streams that ever gave a charm to landscape, and, while passing through the first and least picturesque division of the dale (Dove dale) the ear is soothed by its murmurings and the eye delighted with the brilliancy of its waters. In some places it flows smoothly and solemnly along, but never slowly; in others its motion is rapid, impetuous, and even turbulent. Huge fragments of stone toppled from the rocks above, and partly covered with moss and plants that love and haunt the water, divide the stream into many currents. Occasionally large stones are thrown across the stream and interrupt its progress; over and amongst these it rushes rapidly into the pool below, forming in its frequent falls a series of cascades, about which it foams and sparkles with a beauty and brilliancy peculiar to it." "The waters have a clear blue tint, deepening through various shades into deep purple. It frequently overflows its banks in the spring, and sometimes the waters rise with such rapidity and violence as to be very destructive."

21. The Carr brook.—From the confluence of the Dove to the mouth of the Derwent the Trent receives no affluent on the north bank, and only a few small brooks, of which the *Carr brook* is the principal, from the south. The distance across country is rather less than 12 miles, but, much more if measured on the windings of the river.

22. The river Derwent.—This very important feeder of the Trent collects the water flowing from a large proportion of the great limestone mass that forms the Peak district of Derbyshire. This tract is an extensive and wild moorland, deeply indented with gorges, which serve to conduct into valleys the water not re-evaporated from the surface after rain, and as the rainfall is heavy the quantity is large, so that when there has been continued wet weather or unusual rains, the waters rush down with great impetuosity. The earlier sources of the stream are in the Wrongsley or Ronksley branch of the main feeder, which drains the north slopes of Ronksley moor. The other branch, called *West End*, drains the southern slopes of the same moor. They unite after the former has had a course of 5 miles, and the latter 3, both collecting water from the many gorges and cloughs on their way. At Abbey brook a small feeder from the east is added, and the united stream is thenceforth known as the Derwent.

23. The Ashop river.—Flowing south and south-east for 4 miles past the village of Derwent, the stream is joined by the *Ashop river*, which conveys water for 5 miles by several branches, receiving the drainage of the northern slope of the Peak and the southern slope of Alport moor. The main stream then turns to the south, and flows through a narrow valley for $2\frac{1}{2}$ miles to Mythom Bridge, where it is joined by the *Noe*, or *Now* river.

24. The Noe river.—This considerable affluent drains a valley to the south between the Peak and Rushup edge. The valley is 5 miles long and nearly 2 miles wide, and collects a large quantity of rainfall. After passing through this valley the Noe runs about 4 miles to the Derwent, receiving *Peak's Hole water* from Castleton and *Bradwell brook* from the south. Flowing 2 miles further, passing Hathersage, where small feeders are received, (*Hucklow brook* from the south-west is the largest), the Derwent turns due south, and pursues a rapid course in a valley fringed with the finest foliage, through one of the most interesting parts of Derbyshire, running 10 miles to the confluence of the Wye. Passing Barlow, the river enters Chatsworth Park, through which it flows for 2 miles, forming a principal ornament of this superb domain.

25. The river Wye.—The Wye joins the Derwent about 2 miles below its emergence from Chatsworth Park. It rises near Buxton from the bottom of the escarpment of the upper limestone where it overlies the scar limestone, and collects water in Buxton from a number of feeders north and south. It is here a singularly romantic river, running in a deep rocky ravine, its clear stream sparkling along a confined and rugged bed. It flows almost due east for 9 miles from where its waters first collect, the scenery becoming gradually less rocky, and consisting of deep dales often crested with craggy knolls. About half way through the valley becomes contracted, and the river pursues a sequestered course between lofty precipitous rocks, sometimes naked, but sometimes finely covered with foliage. On the way several small glens open from each side, and some feeders are received. At Monsal dale the river makes a turn, and exchanges its rugged features for scenery of a softer kind, with fertile meadows bounded by lofty hills. After this turn it passes the village of Ashford, and, after 2 miles, that of Bakewell, and, winding about, reaches the Derwent in about 4 miles, having received on its way the river *Dakin*, draining the lower country for about 5 miles to the west. The whole course of the Wye is 20 miles.

26. The middle course of the Derwent.—After receiving the Wye the Derwent continues south, turning a little to the east, and reaches Matlock after flowing about 5 miles through the very beautiful scenery of Darley dale. Matlock dale is about 2 miles long, and is celebrated for the extreme beauty of its scenery, derived from the lofty cliffs and nearly detached Tors met with at every turn, and the rich clothing of wood that forms an exquisite contrast to the rocky masses jutting above the surface. During its course through this valley, which is entirely in limestone, the river receives no tributaries, but the volume of water running through it becomes much increased by springs rising in the bed of the river.

27. The river Amber.—Below Matlock dale the river turns south-east, flowing through a succession of more open dales for 6 miles to its junction with the Amber, a stream which rises from the eastern slopes of Darley moor, and flows along a valley nearly parallel with that of the Derwent for 3 miles to the east. Pursuing then a south-easterly course, passing Ashover and running 6 miles, it receives a tributary from the north, and flows southwards 6 miles, after which, turning round to the west, it has a further course of 2 miles into the Derwent. The drainage area of the Amber is 30,000 acres, and it flows chiefly over the coal-measures.

28. The Ecclesbourn river and Bottle brook.—From the Amber the Derwent flows 5 miles south, passing Belper, to its junction with the Ecclesbourn river, a small stream coming south from Wirksworth, and receiving a few insignificant brooks. It drains 12,000 acres, chiefly of limestone shales. Two miles below is the Bottle brook, draining about 8,000 acres of coal-measures, and after 3 miles Derby is reached, where another feeder enters from the north-west. This small stream is expanded into ornamental water in Kedleston Park. From Derby to the Trent the Derwent runs through a wide alluvial valley, having a very winding course to the south-east. The direct distance is 7 miles; the course of the river 12.

The total length of course of the Derwent is 65 miles.

29. Gaugings of the Derwent.—The Derwent, much of whose course is over the fissured semi-crystalline limestones of the carboniferous period, was carefully gauged on several occasions, and in different parts of its course, during the progress of a Parliamentary inquiry in the session of 1868, relative to the water-supply of the district. It appeared from these measurements that when the river at the Derby Water-works conveyed 333¼ millions of gallons per day, at High Tor it ran only 98 millions. Between High Tor and Masson mill, about a mile distant, however, there appears to have been an increase of the supply from bottom springs, amounting to 21 million gallons per day. Below Masson mill the increase was again very large, and much beyond the measured flow of the feeders. The Amber on this occasion yielded about 18 millions, the Ecclesbourn 10 millions, the Meerbrook sough (a level from old mines) 16¾ millions of gallons pêr day. The whole stream of the Derwent is remarkable for the number of additions it receives from invisible sources.

In the part of Derbyshire watered by the Derwent there are many mines, some of ancient date and unknown extent. The excavations here made in the limestone veins are now open spaces to receive water, and besides these, many of the veins are sufficiently open to allow of the free passage of water. This and the known fractured state of the limestone strata will account for the remarkable phenomena mentioned above.

30. Proportion of rocks drained by the Derwent.—It may be useful to place on record here the proportion of different rocks within the drainage area of the Derwent, in its course to join the Trent, these having estimated carefully for practical purposes connected with water supply. The following is the result:—

	Acres.
Alluvial lands - - - - -	15,159
New Red Sandstone - - - -	35,500
Limestone shales - - - - -	6,000
Coal-measures - - - - -	24,000
Millstone grit - - - - -	155,000
Carboniferous limestone - - - -	65,000
Total -	300,659

31. The river Soar—its early course.—The Soar enters the Trent 2 miles below the confluence of the Derwent, and drains a large and important district to the south, comprising for the most part rocks of considerably newer date than those of the tributaries yet considered. It is, however, not only from such rocks that the Soar receives its water supply, as it also traverses coal-measures, and its sources lie partly among the metamorphic slates and schists and the porphyritic rocks of Charnwood forest.

The Soar first becomes a stream near Narborough, by the union of a number of brooks (of which the Soar brook is one) at a point where the upper New Red Sandstone rises from under the lias near Hinchley, and between that place and Lutterworth. These streams converge after a few miles, but it is not till about 7 miles from the principal source that they are of sufficient importance to form a river.

Some of these streams rise in the east, some in the west, and some in the south, but all are small. The principal is the river *Sence.*

32. The river Wreak.—From Narborough the Soar flows 5 miles north-east to Leicester, but before reaching Leicester is joined by the Wreak, or Wreke, which rises in the range of hills a little north of Oakham, but receives feeders from near Holwell. A group of streams rise near Oakham and flow in an irregular course of nearly 10 miles to Melton Mowbray, frequently fed by small streams, and from their source to that town are called the river *Eye.* Beyond Melton they are joined by streams from Holwell after a course of 3 miles, and the united stream thenceforward known as the Wreak, flows nearly 12 miles a little south of west into the Soar, receiving from the east near its mouth the *Queniborough brook*, which has a course of nearly 15 miles from the south-east, and receives a nearly parallel feeder from about the same distance.

33. The lower course of the Soar.—After receiving the Wreak the Soar continues to flow north-west, passing the granitic outburst of Mount Sorrel, and in less than 4 miles arriving at Barrow-on-Soar. At Rothley it receives a small feeder. At Quorndon, which the river passes just before reaching Barrow, another stream joins it. This latter feeder rises on the east side of Charnwood forest, and flows through and round the old rocks upheaved in this part of Leicestershire. The Soar has a long course, and receives a great many tributaries. It passes through Bradgate Park, and is there retained in a reservoir for the use of the town of Leicester. It flows chiefly over lias and New Red Sandstone. Its drainage area is 1,100 square miles, and, except the Tame, it is the largest feeder of the Trent.

From Barrow it is 3 miles to Loughborough, and passing that town the Soar continues to flow north-west for about 8 miles to the Trent, receiving a small feeder from the east and west.

34. The river Erewash.—Past the Soar the Trent continues to flow north-east, and after 2 miles is joined by the *Erewash* from the north. This river rises from a western spur of the Robin Hood hills, and flows west for nearly 3 miles. It then curves round to the south, and for the rest of its course its direction is a little east of south. Coal is worked in its neighbourhood on both sides, and till it approaches the Trent it has hardly any tributaries. The *Gilt brook* from the east, and the *Nut brook* from the west, are the chief exceptions. The drainage area of the Erewash is nearly 83 square miles, and its length of course 20 miles.

35. The Fareham beck.—Four miles beyond Attenborough, where the Erewash joins the Trent, the Fareham beck enters the river from the south. It rises in the hills by Widmerpool, and is indeed the union of three small brooks meeting at Widmerpool. It flows thence 5 miles west, and then about 3 miles in a northerly course to the Trent.

36. The river Leen.—The river Leen enters the Trent at Nottingham 2 miles below Fareham beck. It rises in the beautiful grounds of Newstead Abbey, whence it proceeds southwards through Papplewick, where it receives the overflow from several springs, and continues an uninterrupted course of about 13 miles in the same direction, receiving a small tributary from Nuthall. Its drainage area is something less than 50 square miles, chiefly consisting of the variegated sandstones and conglomerates of the New Red Sandstone covering red gypseous marls, magnesian limestone, and red sandstone, all of the Permian series. The coal is worked under the triassic and Permian rocks in many parts of the area.

37. Summary of the Middle Trent.—The Trent valley at Nottingham, and, indeed, for a long distance before the confluence of the Derwent, is wide and flat, the river channel being cut in an alluvial bed through which it winds. There can be no doubt that natural artesian springs, some of them of salt water, add considerably to the volume of water in this part of its course, in addition to the large supplies from so many tributaries. Up to this point the Middle Trent has received the drainage of 2,023 square miles, in addition to that of the upper stream at the junction of the Tame, and has now attained its full dimensions and reached a level less than 60 feet above its outflow, from which it is still more than 50 miles distant. Its fall from the confluence of the Tame has been 107 feet in 41 miles, or 31 inches in a mile.

38. The Lower Trent.—Below Nottingham the character of the Trent alters, and it becomes little more than a channel by which the water already accumulated by the various tributaries from the mountains and uplands is carried on to the termination of its course in the Humber. The river has still nearly half its course to run, but receives few tributaries, and these few deliver comparatively small water contributions. The only one having any length of course enters the Trent near its outflow. The greater part of this division of the river occupies the country between two low escarpments, that of the Permian rocks to the west, and the lias to the east. It consists of a long narrow valley with little drainage from either side. The western hills, however, supply a few streamlets, feeding the one principal river, the Idle. Beyond the Idle the country is entirely level.

39. The Dover beck.—From Nottingham the river Trent flows towards the north-east in very large windings, reaching, after about 6 miles, the Dover beck. This small stream enters from the north-west, taking its rise in a group of strong springs in the old forest of Sherwood. There are collected at Salterford dam, a pool of remarkably pure fine water, whose overflow runs down in a considerable stream, passing near Oxton through a country little peopled, and entering the Trent after a course of 10 miles, receiving a small feeder at Lowdham, near the place where the beck enters the alluvial valley of the Trent. Some interesting details with regard to the catchment and yield of this stream will be found in another place (see Chapter III. § 21). It affords a remarkable instance of excessive yield from a part of the New Red Sandstone frequently absorbent. The whole of the drainage area of the Dover beck, the country to the west as far as the Leen, and the country to the east in this part of the river course, consists of those members of the upper New Red Sandstone series which yield water freely. The drainage area of the Dover beck has been exactly ascertained, and amounts to 17,951 acres.

40. The river Devon.—Passing on from Dover beck the valley of the Trent assumes the character which it afterwards retains till it joins the Ouse. This valley consists at first entirely of the New Red Sandstone, enclosed to the east by the low escarpment of the lias, which, running almost in a straight line from south to north, and effectually shuts off drainage from the east, the river running almost under the brow of the escarpment. Further north the palæozoic rocks advance eastwards, narrowing very much the valley of the Trent. As far as Newark (9 miles) the stream flows towards the north-east, receiving near Newark a group of brooks and branches running under various names (*Car dyke* and *Smite river*) in different parts of their course, but entering a canalised branch of the Trent near Newark as the river Devon. They drain the country to the south, and flow within 2 miles of the river Witham, which enters the Wash.

Beyond Newark the course of the Trent is due north about 22 miles in a straight line to Gainsborough. A few small brooks enter from the west along this part of the stream. Four miles below Gainsborough the old channel of the Idle comes in.

41. The river Idle.—This is a large tributary of the Trent. It is formed by the junction of two streams from Sherwood Forest (the Meden and the Maun), which unite a little to the east of Thoreswood Park.

The *Meden* rises on the eastern slope of the magnesian limestone close to the coal-measures 5 miles west of Mansfield. It flows towards the north-east, receiving, for the first 4 miles, feeders from the same slope, and, after continuing about 15 miles further in that direction, enters Thoresby Park, which it crosses for 3 miles. For half that distance the stream is expanded into a large sheet of artificial water. Emerging from the park the river flows 4 miles to the east to West Drayton, and is there joined by the *Poulter*. This feeder, rising 2 miles south of Bolsover and running over the magnesian limestone, has a course nearly parallel to the main stream, and enters Clumber Park after flowing 10 or 12 miles, being there banked up and converted into a sheet of ornamental water 2 miles long. After this it passes through water meadows, and continues nearly 5 miles to the Meden. The *Maun* rises near Mansfield, and flows north-east through a long series of water meadows for 8 miles to Ollerton at the south-eastern extremity of Thoresby Park, where it receives a small feeder from the south. It then flows to the north 3 miles, part of it being called *White water*, and, approaching the Meden, it flows in a parallel course to that stream in the same bottom for nearly 3 miles before the actual confluence of the two streams takes place.

The Idle first receives its name at the confluence of these streams. It then flows 4 miles north to Retford, and, making a curve near that town, continues 7 miles further in the same direction. It next turns west for 3 miles to Scrooby, about a mile beyond which place it receives the *Ryton river*, draining by a number of branches a considerable tract of country to the west and south. Shortly after this junction the Idle passes Bawtry and turns again to the east, where, after a further course of about 4 miles, it reaches Misson, and passes on to join the Trent at West Stockwith. Below Misson Car the water-way bears the name of *Bycar dyke*, the river having been diverted from its original channel, which ran more to the northward, and carried it into the old Don 3 miles south-west of Crowle.

42. Ancient channel of the Idle.—In describing the outflow of the Don in the last chapter, allusion has been made to the fact that its ancient course, or one of its old channels, communicated with the Idle, and that both may have delivered their waters either to the Trent or into the sea before the estuary of the Humber was silted up to the present extent. It is not impossible that they may have formed an independent stream, delivering their water into Thorne waste, which is now reclaimed.

The valley of the Trent below Gainsborough is a vast expanse of fen land drained by numerous cuts. It is known as Axel or Haxey Car, Hatfield Chase, and Thorne Level. Out of these flat lands rises the higher ground of Axholme, which is an island of lower New Red Sandstone, capped by Keuper marls, standing out of the fen, and separating the present course of the Trent at the foot of the lias escarpment from the old course of the Don below Doncaster.

43. The Torne river.—Hardly to be recognised now as a distinct river, the Torne or Thorne river must be mentioned as one of the channels by which the waters of a small hilly district round Tickhill reach the Trent. Rising in the vicinity of that town, it flows in a very irregular course to the north-east, separated from the valley of the Don by intervening high ground. After meandering through the low levels near Hatfield Chase, it forms for some distance the county boundary between Yorkshire and Lincolnshire, and joins the Trent just before its confluence with the Ouse, having the same artificial channel as the Idle river in its latter course. On its way it receives the *Catherine's well stream.* It passes through a limestone district.

The Humber Basin.

44. The river Humber.—The nature of the Humber has been already sketched. It is a great estuary, but also in some sense a river. It is subject throughout to tidal influence, but receives a definite water supply from one considerable river (the Hull), and from a number of smaller streams on both sides, partly from the Yorkshire, and partly from the Lincolnshire shores. It drains on the whole nearly 1,200 square miles of country, extending more than 50 miles from north to south, and 30 miles from east to west. We cannot but admit its claim to consideration as a river basin, as well as a great tidal channel conveying the waters of the Trent and Ouse to the sea.

At its mouth the Humber flows over a large accumulation of alluvium and diluvium, below which chalk is found by boring. Opposite Sunk island the chalk is about 20 feet below the bed of the estuary. A mass of clay and pebbles rests on the chalk, and in some places forms islands, which have resisted the action of the river. These beds form the hills and high land of Holderness, part of which, Dimlington height, rises 139 feet above the mean level of the sea.

The area of the Humber at high water spring tides is 110 square miles, and the total area of reclaimed land in the estuary below high-water spring tides at sea is about 290 square miles.

The course of the Humber from the confluence of its two great feeders to Spurn head, where it enters the German ocean, is nearly 40 miles. It is embanked throughout, much of the country on each side being below the level of high water, and there are extensive marshes and reclaimed lands on both sides, some parts of them as much as 9 feet below high-water spring tides.

It has already been mentioned that at the confluence of the Trent and

Ouse, where the Humber commences, there is an alluvial tract, 160 square miles in area, which is as much as 2 feet below high-water mark, and therefore liable to overflow, were it not for the means taken to prevent influx of the tide to the lands on either side.

45. Scheme of the tributaries.—The following scheme represents the drainage into the Humber, and the relative position of the tributaries :—

Humber.

Right bank.	Distance from confluence of Ouse and Trent.	*Left bank.*
	4	Mill beck.
Ancholme river . .	8	
North Kelsey beck.		
	17	Hull river.
		Lambwith stream.
Tetney river . . .	39	

46. Early affluents of the Humber.—The flat country on the north bank of the Humber where the Ouse first merges into the estuary is artificially drained by a number of cuts and canals for about 6 miles to the foot of the wolds, all this country being reclaimed and occupied. Close to the wolds there is natural drainage by a stream called *Mill beck*, commencing near Holham, about 6 miles from the Humber, and passing North Cave. Two miles below there is another small brook coming down Welton dale, and after 6 miles a still smaller run at Hessle. On the south side the drainage from the foot of the low escarpment of the marl-stone is carried into the Humber by *Halton drain* at Winteringham, nearly 7 miles from the mouth of the Trent. This drainage proceeds from Frodingham, and runs 12 miles. At Frodingham are important bands of ironstone. Three miles below Winteringham the Ancholme enters the Humber, draining an important valley to the south.

47. The Ancholme river.—This river flows through a large expanse of marshy low-lying tract on the Lincolnshire side of the Humber, being chiefly conveyed by artificial cuts.

The Ancholme rises between Lincoln and Market Rasen, and flows at first to the west but afterwards turns north. It now runs for 20 miles in an artificial cut, but its original course through the valley was tortuous and much longer. It flows through marshes 2 to 3 miles wide, which it now drains, also carrying off the drainage of an extensive tract between the Lincolnshire chalk wolds and the stonebrash hills which form a low imperfect escarpment, serving as the water-parting of the Trent. The works carried on in reference to the Ancholme valley have rendered cultivable as much as 50 square miles of marsh land. The *North Kelsey beck* is the principal of a few small feeders to this river.

48. The river Hull.—The Hull is by far the largest of the independent streams feeding the Humber. It rises at the eastern foot of the Yorkshire wolds by clear trout streams at Driffield and Killiam, which unite into one channel at Frodingham. The source at Killiam is the most distant, and flows under the names of *Kelk beck* and *Frodingham river* to the confluence. The other stream is called both *West beck* and the river Hull, and it receives the *Skerne beck* from the west. From Frodingham the stream flows 9 miles south towards Beverley, which is a mile from the river. It then continues for about 10 miles below Beverley, passing through the town of Kingston-upon-Hull. It has no feeders of importance, but two small brooks come in from the west and the *Lambwith stream* from the east. The latter rises between Aldbrough and the coast, within a few hundred yards of the sea, but its drainage is due west nearly 12 miles.

The Hull is the river of Holderness, a great natural district of extensive marshes and silt lands among low hills of gravel, sand, and clay, drifted from the northern and north-western parts of England, and enclosing some rocks drifted from more distant regions.

The lower part of the Hull river for about 9 miles runs through and drains a tract of not less than 60 square miles of marsh lands, gradually widening from 4 to as much as 8 miles on the course of the river, and extending to the south-east parallel to the north bank, enclosing the Humber for more than 10 miles as far as Sunk Island, having a tolerably uniform breadth of from 3 to 4 miles. The important town of Kingston-upon-Hull, with all its dock accommodation and public buildings, is built on the reclaimed land of this marsh, which is now from 3 to 5 feet below high water ordinary spring tides. The embankment of this part of the north bank of the Humber commenced at a very early date, and may, perhaps, be Roman. It was repaired in 1313.

Below the Hull about 5 miles, at Hedon Haven, is another small outlet conveying the waters of the interior to the Humber by a mixed natural and artificial channel. Two smaller natural drains come in between. About 9 miles beyond Hedon Haven is *Otteringham drain*, connecting with the *Keyingham drain*, of the same nature. From the opposite or Lincolnshire side there are similar cuts and drains, some of them, as the *Laceby beck*, having a considerable run.

49. The Tetney river.—Twenty-two miles below Hull and near Grimsby the Tetney river enters from the south-west. It rises from two springs, one near Normanby and the other at Thorpe-le-mire, near the south-western escarpment of the wolds of Lincolnshire, between Binbrook and Market Rasen. The stream from these sources forms the Tetney, which has a course of 22 miles to the German Ocean, passing on its way a number of villages, and entering the mouth of the Humber at Tetney

Haven. The mouth of the Tetney is made navigable as far as Louth by artificial cuts.

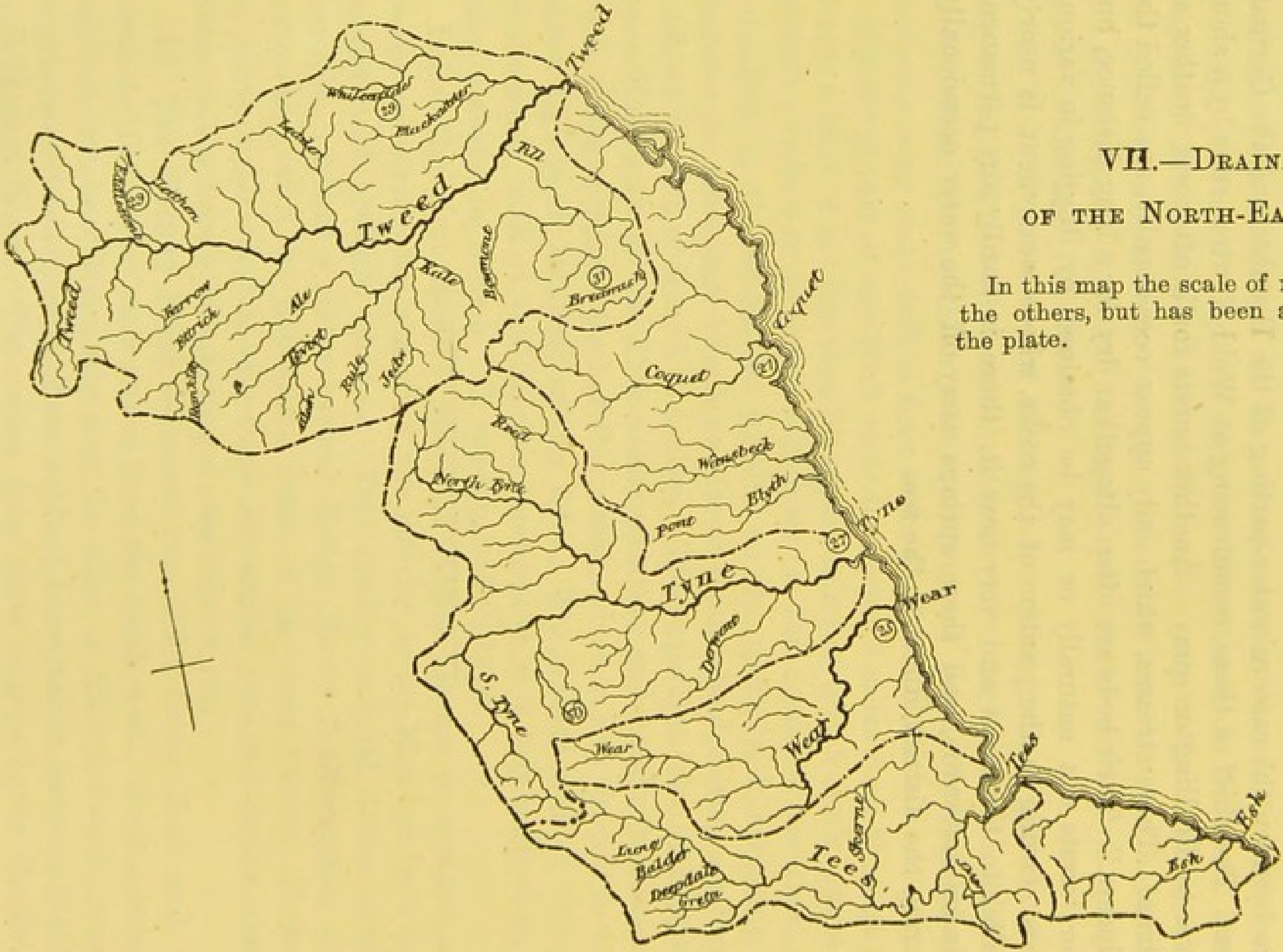
50. The river Ludd.—This river rises near the chalk escarpment at Louth, collects water from several small streamlets, and, passing Louth, has an irregular course northwards to the sea, which it enters a couple of miles beyond the Tetney, just outside the mouth of the Humber.

51. Coast drainage east of the Derwent basin.—A number of variable and intermittent streams rise in the chalk valleys of Yorkshire between the eastern water-parting of the Humber and the German Ocean. The chief of these, commencing at Wold Newton, runs by a short course to Bridlington quay. Another bursts forth after wet weather at Killiam. These streams, which only appear occasionally, are called the "Gipseys." Their beds are often altogether dry for a long distance, but water bursts out naturally or may be obtained by digging in various places. Owing to the position of the rocks, whose escarpment is nearly parallel to the coast and very near it, there is hardly any permanent drainage eastwards, and these springs carry off the water occasionally entering the district, direct to the sea.

VII.—Drainage Areas

of the North-East of England.

In this map the scale of miles is the same as in all the others, but has been accidentally omitted from the plate.



CHAPTER X.

DRAINAGE AREAS

OF THE NORTH-EAST OF ENGLAND.

(1) General description of the district.—(2) Physical features and geology.—(3) Subdivisions.—(4) Rainfall, evaporation, and percolation.—(5) Quality of the water.—(6) Ordinary flow and floods.—(7) Tidal action.—(8) Scheme of the rivers and their principal affluents.—(9) The river ESK.—(10) The coast drainage beyond the Esk.—(11) The river TEES:—Its early feeders.—(12) The river Lune.—(13) The river Balder.—(14) The Deepdale beck.—(15) The river Greta.—(16) The Alwent beck.—(17) The river Skerne.—(18) The Lower Tees.—(19) The river Leven.—(20) Bellingham beck.—(21) Streams between the Tees and the Wear.—(22) The river WEAR:—Its sources.—(23) The Wear to Bishop Auckland.—(24) The river Gaunless.—(25) The Wear below Bishop Auckland.—(26) The Cong burn.—(27) The TYNE basin.—(28) The South Tyne.—(29) The North Tyne.—(30) The river Tyne.—(31) The river Derwent.—(32) Coast drainage beyond the Tyne.—(33) The river Blyth.—(34) The river Wansbeck.—(35) Coast between the Wansbeck and the Coquet.—(36) The river Coquet.—(37) The river Aln.—(38) The Aln to the Tweed.—(39) The TWEED:—Its early course.—(40) Middle course of the Tweed.—(41) The river Teviot.—(42) The river Till.—(43) The river White-Adder.

1. General account of the district.—The part of Great Britain whose drainage areas come under consideration in this chapter occupies the country between the northern water-shed of the Yorkshire Ouse and the southern water-shed of the Forth. It includes the whole of Durham and Northumberland, small parts of Yorkshire, Westmoreland, and Cumberland, the whole of the Scotch counties of Roxburgh, Berwick, and Peebles, a large part of Haddingtonshire, and a small part of Edinburghshire. It comprises several rivers of some importance and interest, and a number of smaller streams having independent drainage emptying into the North Sea along a coast line about 125 miles in length between

Whitby and St. Abb's Head. It is approximately quadrangular in shape, containing an area of about 5,000 square miles. Its general width in England is about 40 miles, and in Scotland 50 miles. Its general bearing is north-west and south-east, its boundaries being the extension of the Penine chain into Scotland towards the west, the Moorfoot and Lammermuir hills of Scotland to the north, the Cleveland hills and their extension to the Penine chain to the south, and the North Sea to the east. Thus limited it may be regarded as one great natural trough, dipping to the east and drained by several streams, which are all more or less parallel, and which flow from west to east, being separated by ranges of high ground—spurs of the great chain forming the backbone of England.

2. Physical features and geology.—A very large proportion of this tract is hilly and mountainous, and, with the exception of the south-eastern corner, where the lias and lower oolites form hills of considerable elevation, and where the New Red Sandstone plains intervene between the middle secondary and newer Palæozoic deposits, the rocks are all of the oldest geological period. The Permian sandstones and the magnesian limestone are more largely developed in this drainage area than elsewhere in England ; the whole of the rich and valuable coal fields of Durham and Northumberland are included ; important lead-mining districts in the millstone grit and carboniferous limestone are present, and there is a large tract of lower Silurian rocks in the Scottish part of the area. Besides these is a considerable development of porphyritic rock in the Cheviot hills that separate England from Scotland.

For the most part the water-shed is very high, and it is only where the Cleveland hills terminate to the west, and low rolling hills of New Red Sandstone intervene where the dividing line between the tributaries of the Derwent and the Tees passes over this rock, that it approaches a low level. In this part, however, the highest points separating the Tees drainage from that of the Wiske, a feeder of the Derwent, are, for some miles, little more than 200 feet above the sea.

3. Sub-divisions.—The principal catchments of this district are three —that of the Tees in the south, the Tyne in the middle, and the Tweed in the north. But between the Tees and the Tyne the Wear is an important sub-basin, and, south of the Tees, the Esk. Between the Tyne and the Tweed there are also several sub-basins of considerable magnitude, of which the Blythe, the Wansbeck, and the Coquet, are the largest. The whole district may be considered as being drained by eight principal, and a few smaller streams, grouped as follows :—

1. Small catchments north of Whitby.
2. The basin of the Tees.
3. The basin of the Wear.

4. The basin of the Tyne.
5. Small catchments between the Tyne and the Tweed.
6. The basin of the Tweed.

4. Rainfall, evaporation, and percolation.—The rainfall on the Scotch hills and on the high table-land and ridges of the north-western extension of the Penine range is heavy, and the number of days of rainfall in the year considerable. On the western side, where the various streams take their rise, it ranges from 30 to 50 inches, but does not reach the higher figure over large tracts. On the Cleveland hills it is 30 inches, but in the valleys and lower ground it is certainly much less, and on approaching the east coast the rainfall is often very low, not exceeding 25 inches and often below 20. In the basin of the Tweed generally the fall is believed not to exceed 29 inches, but is certainly much higher where the chief tributaries rise. A reference to the map of the district and the general rain map will illustrate these remarks, and will show the need of repeated local observations to the engineer.

The evaporation throughout the district cannot be estimated at less than 14 inches. The rocks are often impermeable, and in such cases, when bare, the evaporation is small, but where they are covered with peat, as is usually the case, there is no doubt that a large quantity of rainfall is retained on the surface after rain, and is got rid of by evaporation when drying winds pass across the surface.

Percolation must be small over the whole area except where there are facilities for the ingress of water by fissures in the limestones and other hard rocks. These in some parts are common, and the result very marked, especially in the mountain limestone; but in the Silurian and igneous rocks there is little opportunity for the entrance of water. Over the coal-measures, however, and in the magnesian limestone there must be a very large percolation, vast quantities of water entering the strata, part of which is removed by pumping from the numerous mine shafts.

5. Quality of the waters.—The waters coming off such rocks as those that are met with in the upper parts of all the streams of this district are almost necessarily pure and good. Except that in some places they are subject to injury from lead washing, and that they are not unfrequently discoloured and even flavoured by peat, there are no objectionable elements. The country is thinly peopled, and, though cultivated, it is not so highly and systematically manured as to cause injury.

As the streams descend into the lower country and cross the coal-measures they become affected partly by the impurities derived from washing the waste coal at the surface by heavy rains, after the pyrites, with which the small coal and slack abound, have become decomposed by exposure to moist air, and partly by the pumping required to unwater the coal mines in work. In this way, as they approach the sea, the waters cease to retain the good qualities so characteristic of their upper course. The following analyses, chiefly adapted from Dr. Frankland, are sufficiently explicit. The difference between the waters taken near the sources, whether of the river or the tributaries, and those taken low down on their course is exceedingly striking in the case of some of them.

ANALYSES OF WATERS OF THE NORTH-EAST COAST RIVERS.

Date of Sample.	Tributaries.	Total solids.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates & Nitrites.	Chlorine.	Total Hardness.
4 Oct. '71	Tees, head waters, mean of two -	5·25	·687	·049	·001	0	0·51	2·4
May '70	" R. Skerne above Darlington	32·56	·139	·028	·001	·083	1·75	13·5
6 Oct. '70	" above Darlington - -	12·54	·128	·014	0	0	0·66	9·4
Oct. '71	Wear, head waters, mean of two -	5·78	·483	·048	·001	0	0·54	3·5
29 Sept. '71	" Allenheads - - -	60·2	·717	·053	0	·017	0·60	2·8
5 Oct. '70	" above Durham - -	34·69	·116	·021	·017	0	3·22	15·5
30 Sept. '71	Tyne, Stonecroft burn - -	12·43	·568	·068	0	0	0·81	8·6
5 Apr. '70	Tweed, above Peebles - -	5·71	·068	·007	0	·030	0·69	3·4
4 Apr. '70	" above Kelso - - -	6·23	·108	·010	·001	·041	0·84	3·4
2 Apr. '70	" Ettrick r. above Selkirk -	4·34	·128	·080	0	·016	0·56	2·6
27 May '71	" Yarrow r. " " -	2·60	·216	·013	·001	0	0·49	1·7
5 Apr. '70	" Till r., Braidford burn -	10·08	·152	·027	·001	·056	1·36	6·0
31 Mar. '70	" Jed r. above Jedburgh -	12·21	·164	·017	·001	·008	0·74	9·6
4 Apr. '70	" Whiteadder r. above mill -	8·58	·229	·018	0	·039	1·13	5·3
"	" Blackadder, j. of Whiteadd.	16·52	·253	·025	·002	·081	1·33	9·1

6. Ordinary flow and floods.—The ordinary flow of almost all the north-eastern rivers, and of their early tributaries, is rapid, and they come down in flood time with a great volume of water; but, although this is almost uniformly the case, and especially so in the upper valleys, there is rarely any flood that produces much mischief near the mouth of the river. The larger rivers are navigable for some distance, and their course is not interrupted.

7. Tidal action.—Of all the rivers of the group described in this chapter the Tees is the only one that delivers its waters into an estuary sufficiently large to admit of independent tidal action. The Tyne and the Wear both admit the tide to some distance, and the Tweed and smaller streams are in some measure affected by it, but there is nothing abnormal in their conditions.

8. Scheme of the rivers and their affluents.—The following outline of the various streams and their principal tributaries will be useful:—

The small Catchments near Whitby.

The river Esk.
Birk Head beck.
Rousby beck.
Skelton beck.

The River Tees.

Right bank.	Distance from source in miles.	*Left bank.*
Maize beck	10	
	13	. Harwood beck.
Lune river	$21\frac{1}{2}$	
Balder river	$26\frac{1}{2}$	
Deepdale beck	30	
Greta river	33	
	38	. . Alwent beck.
	51	. . Skerne river.
Leven river	73	
	82	. . Billingham beck.

Crimdean beck.
Castle dean beck.

The Basin of the Wear.

Burnhope burn. (7) — Killhope burn. (4)

The Wear.

	13	. . Rookhope burn.
Bolthope burn	19	
	22	. . Wascroft beck.
Lidburn beck.	$28\frac{1}{2}$	
Deerness river	42	
Browney river	43	
Cong burn	58	

The Basin of the Tyne.

South Tyne (40).	North Tyne (36).
Cross gill.	Lewis burn.
Tipalt burn.	Chirdon burn.
Haltwhistle burn.	River Rede.
Allen river.	Crook burn.
Settingstone.	Dry burn.

The Tyne.

Dilston river	44	
Scawley burn	55	
Derwent river	62	
Team river	64	
	66	. . Ouse burn.
Jarrow river	74	

The Basins between the Tyne and the Tweed.

Breerden burn.
Seaton burn.
The river Blyth.
The river Wansbeck.
The river Coquet.
The river Aln.

The River Tweed.

Right bank.	Distance from source in miles.	*Left bank.*
	14	. . Biggar water.
	21	. . Tarth water.
	24	
	32	. . Leithen water.
Ettrick river	42	
Yarrow water.		
	45	. . Gala water.
	46	. . Allan water.
	50	. . Lauder river.
Teviot river	68	
Allan water. Slitrig water. Rule water. Ale water. Jed water. Kale water.		
	79	. . Leet river.
Till river	82	
Beaumont water.		
	93	. . Whiteadder river.
		Dye river. Blackadder river.

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9. The river Esk.—The Esk is a beautiful and romantic river commencing from two mountain streams in the Cleveland hills. The southern feeder is *Basedale beck*, which receives the drainage of Basedale moor, nearly 1,300 feet above the sea. The western and northern is *Steddale beck*, rising in Guisborough moor. The former flows north and east nearly 7 miles, receiving several small feeders. The latter runs south-east about 6 miles. A branch less considerable than either, but from a similar elevation and bearing the name of Esk, rises in a ravine in Westerdale moor, and flows 5 miles nearly north to its junction with Basedale beck. The various streams flow through a wooded tract, having much rural beauty. Uniting at Castleton, another small feeder comes in from the south, and after 5 miles of a very winding course *Fryup beck* enters the Esk from the high moors in the same direction. About $3\frac{1}{2}$ miles beyond *Stonegate beck* comes in from the north, and a mile further *Glazedale beck* from the south. The lower part of this glen is very bold. Three miles below, passing near Eyton, the river receives an important affluent from the south, draining an extensive tract of moorland extending more than 10 miles from west to east. This drainage comes through a gap in the hills about 4 miles long, at right angles to the direction of the Esk, which almost throughout flows from west to east. The western branch of this drainage comes from Glaisdale moor, 1,300 feet above the sea, and flows 3 miles eastwards as *Bluewall beck*. It then receives a chalybeate spring, and continues another 3 miles in the same direction as *Wheeldale gill*, when it enters *Wheeldale beck* at right angles. This stream rises on the western side of Wheeldale moor, and flows round the foot as *Rutmoor beck*. It is first called Wheeldale beck, after receiving a small brook from the east.

Thus formed, Wheeldale beck continues northwards through a deep wild valley after receiving the gill for 2 miles, when it is joined by *Eller beck*, which commences with the junction of several small branches close to the sources of the Derwent, and flows 6 miles to the confluence. The united stream flows 2 miles further to the Esk, which then continues its easterly course to Ruswarp, 5 miles distant. The scenery in this part of its course is very striking, the river passing through romantic heights. At Ruswarp the valley opens out into a large natural amphitheatre, the river having a very tortuous course but turning on the whole towards the north. It reaches Whitby after 2 miles, where it enters the sea in a gap between lofty and precipitous cliffs. The coast scenery at the mouth of the river near Whitby is very fine.

10. The coast drainage beyond the Esk.—Two and a half miles beyond Whitby to the west another deep glen opens from the coast into the interior, and the *Birkhead beck* enters the sea. It drains the country to the south for about 5 miles by a number of small branches. Seven miles beyond it, at Staiths, another small stream enters, called *Rousby beck*, of the same nature, and 5 miles beyond this (at Saltburn) *Skelton beck* enters, draining a much larger tract and passing the town of Guisborough. The Skelton beck receives a number of tributaries, and collects the waters from the north-westernmost extremity of the Cleveland hills, where these hills sink down towards the sea level and are succeeded by low New Red Sandstone hills to the west. Beyond this we enter into the drainage of the Tees.

11. The river Tees. Early feeders.—The basin of the Tees has a drainage area of 744 square miles, and its south-eastern extremity is separated from the adjacent water-sheds of the Esk and the Yorkshire

Ouse by a very low water-shed, little more than 200 feet above the sea. The Tees occupies a long narrow valley, measuring about 55 miles in a direct line from its source to the sea, but its length of course is 88 miles, including the windings of the stream. Its sources are in the carboniferous limestone, but its early course is over millstone grit. In its lower course it crosses a considerable breadth of magnesian limestone and New Red Sandstone.

The sources both of the Tees and the Tyne, which are within a very short distance of each other, are in the great mass of the upper carboniferous limestone, attaining in Cross fell the height of 2,892 feet above the sea. The northern slopes of this mountain supply waters that feed both streams, whose early channel is separated by a lofty ridge that extends from the summit of Cross fell to the south-east for nearly 4 miles, rising into three successive peaks, each nearly 2,800 feet above the sea. The line of water-parting between the Tees and Tyne basins is irregular, and after continuing in an easterly direction for nearly 5 miles runs along an exceedingly narrow and not lofty ridge, which separates the two streams.

The recognised source of the Tees is called Tees Head, and is just under the eastern side of Cross fell, one of the loftiest and most lonely mountains of the Penine chain. From this source it flows due east about 4 miles through a narrow valley, fed by torrents from the mountain sides. It then receives two tributaries, *Trout beck* from the right, and a smaller beck from the left. At this point are the workings of several old lead mines, and the river is bent aside from its course, turning south-east for 5 miles to a place where it makes a considerable leap into the valley below. Prof. Phillips thus describes this early course of the river:—"Descending from Cross fell, and gathering small feeders on its way, the Tees expands into a long irregular surface called the 'Weel,' which is a deep mountain pool about a mile and a half in length, and the overflow from this pool falls over a cliff of greenstone 200 feet high in a wild and dreary cataract, called Caldron scout." Here it is joined by its first large tributary, called *Maize beck*, which proceeds from the south-west, and flows between Mickle fell (2,590 feet) and Merton fell (2,206 feet). It is fed by several small torrents from both sides.

Flowing 3 miles further through a winding valley, *Harwood beck* is reached. This stream rises about 6 miles to the north-west, and is supplied with water from a large number of torrents entering from each side between Herdship fell and Three Pikes, both more than 2,000 feet above the sea. The bed of the Tees now widens, and the stream runs another mile over a shallow stony bed till the High Force is reached,—a celebrated waterfall, where the river projects its waters over a huge rock of greenstone 69 feet high. This noble fall is usually in one sheet; but in times of flood it is divided. Below the fall the river runs over a rocky bed between cliffs, of which that on the right side is greenstone, and the left limestone.

From the junction of Harwood beck the main stream of the Tees takes the course of that tributary, and proceeds south-east for about 8 miles to the confluence of the Lune, receiving only a few small feeders, till at Middleton, a mile above the Lune, a somewhat larger brook comes in from the north.

12. The river Lune.—The Lune is one of the larger tributaries of the Tees, and is entirely within the mountain limestone formation. It collects the waters that fall on the south side of Mickle fell, and a range of fells of a horse-shoe form, of which Mickle fell forms the northern half. The rainfall from the hills collects in numerous channels, running various distances from 2 to 4 miles. Through this hollow, and converging at Lune-head house, where have been some old mines, the Lune is formed. The stream then runs for about 3 miles east through a rocky valley, and then turning north-east flows another 3 miles into the Tees. It receives on its way several small feeders from each side. The bed of the Lune, especially in its lower course, is irregularly covered with a thick deposit of boulder clay and sand.

A little below the confluence of the Lune the *Eggleston beck* enters the Tees from the north, through a rich and fertile valley.

13. The river Balder.—The Tees flows about 5 miles below the Lune junction through a country with a small population, but passing some villages, and is then joined by another affluent, the *Balder*. The sources of this river lie in a depression of the plateau north of Stanmore common, and it runs altogether through the millstone grit. Two principal parallel becks, of which one is called *Balder beck*, unite after about 2 miles, and then flow as the river Balder about 8 miles to the Tees, receiving on their way a few small feeders. Balder dale is a rocky and picturesque valley.

14. The Deepdale beck.—From the Balder the Tees continues 3 miles to Bernard Castle, and near that town receives the *Deepdale beck*. It is a small stream, but has a course of nearly 10 miles from the eastern extremity of Stanmore common, which is there between 1,500 and 1,600 feet above the sea.

15. The river Greta.—Three miles below the Deepdale the Greta joins the Tees, coming from the eastern and northern sides of Stanmore, and running through an open valley nearly due east 7 miles to Bowes, and then curving round to the south flowing 8 miles further in the same general direction till near the Tees, when it curves round to the north through Rokeby park to its destination. It receives a few small feeders.

16. The Alwent beck.—The Tees next winds round to the north for about 6 miles, passing a few small villages to a point where it receives the Alwent beck from the left. This stream, rising in the hills that shut in the course of the Tyne between the confluence of the Lune and Balder, is called the *Langley beck* in the upper part of its course. It flows almost in a straight line to the east for 6 miles into Raby park, and through the park on its southern edge to the little town of Staindrop. It then flows south about 3 miles into the Tees. It is a very small stream. Below Staindrop it receives the name of *Staindrop beck*.

From the Staindrop as far as Darlington, there are no tributaries of importance. The direct distance is little more than 9 miles, but measured on the course of the stream, which winds considerably, it is very much more. Two or three small feeders enter the stream in this part of its course, which is through an open level country, the drainage of which passes eastwards and enters the Skerne. Other feeders from the north also enter the Skerne.

17. The river Skerne.—This river rises in the magnesian limestone of Durham about 5 miles from the coast, and runs west and south-west, receiving small tributaries. After an irregular course of nearly 10 miles it approaches Sedgefield. It then turns round to the south, passing Aycliffe, and continues a very winding course to Darlington in the same direction. From Darlington it continues south to the Tees, which is about 3 miles distant.

18. The Lower Tees.—Below Croft, where the Skerne enters the Tees, the course of the river is exceedingly tortuous, much more than doubling its distance in the 8 miles that intervene between Croft and Yarm. The only feeders that enter, conveying any important addition to its waters, are the *Clow beck*, opposite the Skerne, and the *Staindale Stell*, coming from the east a few miles below its confluence. Of these the Clow beck requires notice from the great distance it travels, although under a curious succession of different names. It rises close to the Greta river 2 or 3 miles from the confluence of that stream with the Tees. It flows first as *Nor beck*, then as *Hutton beck*, *Caldwell beck*, and *Aldbrough beck*, till it terminates in Clow beck, the whole distance being 15 miles in a direct line, though much more if measured on the windings of the stream. Its course is nearly east, and parallel to the Tees, turning north to enter the river.

19. The river Leven.—At Yarm the Tees is joined by the *Leven river*, from the Cleveland district. It rises on the north side of Kildale moor, close to the source of the Esk, and makes a small curve to the north along the northern part of the western slope of the Cleveland hills, turning at Ayton to the south-west for a couple of miles. It there meets a branch called the *Broughton Bridge beck*, which has had a direct course of nearly 4 miles east from the southern part of the western face of the same hills. The whole of this part of its course is highly picturesque, and less than a mile below the junction of the two streams the small river *Tame* comes in from the north. The stream now flows in a very winding course for 5 miles (not including the windings), and then turns north and north-west for another 4 miles to the Tees. The scenery of the whole of the upper part of the stream is singularly beautiful, and in its lower part, after receiving a small feeder at Rudby, it flows peacefully through a rich and well wooded vale.

20. Bellingham beck.—From Yarm the Tees flows as a large and important stream by Stockton and Middlesbrough into a wide estuary, by which it opens to the German ocean. Below Stockton it receives the collected drainage of a considerable tract of low, flat lands to the north and west by the *Billingham beck*, and of another similar tract to the south by the *Stainsby beck*. Below Middlesbrough the *North burn* and *Greatham beck* convey a certain extent of northern drainage into the estuary of the Tees.

The general character of the Tees is that of a broad, shallow stream, flowing rapidly, and subject to frequent inundation.

21. Streams between the Tees and the Wear.—From Hartlepool, at the mouth of the Tees, to Sunderland, at the mouth of the Wear, the distance along the coast is about 18 miles, within which distance five small streams enter the sea. The two first are the *Crimdean beck* and *Castle Dean beck*, entering within 3 miles. They drain the country for a breadth of about 6 miles to the coast. The *Hawthorn burn* follows at another distance of 3 miles. A small stream enters at Seaham harbour, and another between Seaham and the Wear.

22. Sources of the Wear.—The Wear, though a stream of some magnitude, is very inferior in this respect to the Tees. It first obtains its name at the confluence of the *Killhope burn* and *Burnham burn*, two mountain streams of about equal magnitude, both rising in the eastern slopes of the line of water-shed forming the eastern limit of Alston Common. The adjacent hills rise to about 2,200 feet in the northern, and 2,450 feet in the southern, part of the basin. The Killhope burn, joined, after a couple of miles, by *Wellhope burn*, receives the drainage of a tract of between 5,000 and 6,000 acres of mountain and moor land a little south of Allenheads, and runs about 7 miles to Wear Head, bearing the name of *North Grain* during the latter part of its course, and fed by several small torrents. *Burnhope burn* drains about 3,000 acres, but has a course of only about 4 miles.

23. The Wear to Bishop Auckland.—At Wear head, where these streams unite, Wear dale begins, and continues nearly due east for a distance of 15 miles to Walsingham. Through this valley the river Wear flows, receiving feeders chiefly from the south, and conveying the water from a rocky and mountainous ridge more than 2,000 feet high, which separates the Wear from the Tees. The principal feeders from the north are *Middlehope burn*, *Rookhope burn*, and *Stanhope burn*. Of these Rookhope burn drains a wide valley, the sources of the stream being within a mile of Allenhead, where are well known lead mines. The most important from the south are *Swinhope burn*, *Westernhope burn*, and *Bollihope burn*. The latter enters about 2 miles from Wolsingham, where it is joined by the *Wascrow beck*. This stream rises in Waskerley Park, and has a course of about 8 miles, receiving some considerable feeders before adding its waters to the Wear. Wear dale is a picturesque and interesting valley, shut in on both sides by mountains and high moorland. Beyond Walsingham the Wear turns south-east towards Wilton-le-Wear, a distance of about 6 miles, and, a little before reaching that town, receives the *Bed burn*, one of its largest tributaries. This stream enters from the west, and drains a considerable district of moorland to the west and south-west by a number of gorges and narrow valleys. The whole length of course of the principal stream is upwards of 10 miles. The *Lidburn beck*, another considerable feeder from the west, joins the Wear just before Wilton is reached. The valley of the Wear has widened out gradually before reaching Wilton, and thence to Bishop Auckland the river runs through a broad bottom with a winding course. The direct distance is about 4 miles, and in this part the *Beckburn beck* enters from the north.

24. The river Gaunless.—At Bishop Auckland the river *Gaunless*, with its tributary the *Humber beck*, unites with the Wear. The Gaunless rises on the eastern slopes of the water-shed of the Tees, near the sources of the Bed burn, and has a long course, chiefly to the east, amounting to 15 miles in a direct line, and very much more including its many small windings.

25. The Wear below Bishop Auckland.—Passing Bishop Auckland the Wear takes first a northerly and then a north-easterly course, receiving *Stockley beck* from the north-west, the *Valley burn* from the south, and two smaller streams from the east. A few miles from Durham it is joined by the river *Bromney*, draining with its feeders (of which the *Deerness* is the most important) a wide country to the north-west and west. Where the Deerness joins the Bromney it is not 2 miles to Durham in a direct line, but by water, following the windings of the Bromney and the Wear, the distance is nearly 12 miles. The Wear, as it winds round and almost encloses Durham, is singularly picturesque.

26. The Cong burn.—From Durham, in a direction on the whole northerly, but with many windings, the Wear makes its way to the sea at Sunderland, passing Chester-le-Street, where it receives the *Cong burn* on the left bank. This is a considerable stream rising in the hills to the west, close to some large tributaries of the Tyne, and having a course of about 6 or 7 miles, being fed by the *Twisell burn*. As it nears the sea the Wear becomes a considerable and navigable stream, and it divides the important town of Sunderland into nearly equal parts. It is there crossed by an iron bridge 100 feet high and 240 feet span.

The greater part of the course of the Wear lies through the exceedingly important and productive coal-fields of Durham, and the coal got in the district is conveyed to Sunderland for shipment. The length of course of this river is 70 miles, and it is navigable from Durham a distance of 20 miles.

27. The Tyne basin.—From the mouth of the Wear below Sunderland to the mouth of the Tyne a little below North and South Shields, the distance measured along the coast is between 7 and 8 miles, and, with the exception of a small stream that enters the sea a mile north of Sunderland, there is no drainage from the interior, the hills and cliffs of magnesian limestone throwing off the water to the interior, where it falls into the Tyne.

The drainage area of the Tyne is about 1,100 square miles, but its total length of course is not more than 76 miles. It is a large and important stream, the lower part running over the richest and most valuable coal-field in England, while the upper waters proceed from the carboniferous limestone and millstone grit, and traverse a country which has yielded valuable supplies of argentiferous galena.

28. The South Tyne.—The Tyne receives its name at the confluence of two principal branches of which the South Tyne comes first for consideration. It is only separated by a narrow mountain ridge from the drainage of the Tees.

The South Tyne is itself formed of the confluence of two nearly equal streams, one (the eastern) bearing the name South Tyne, taking the drainage of the eastern slopes of Alston common, where the elevation is from 2,000 to 2,400 feet. The western fork, which carries the more extensive drainage, has its origin on the northern slopes of Cross fell (2,800 feet), and the eastern slopes of the line of water-shed extending thence to the north-west, and separating the sources of the Tyne from those of the Eden. The drainage of this almost circular area, 8 miles in diameter, including a space of more than 40 square miles, is brought into a single channel about 2 miles south of Alston, and thence proceeds in a northerly direction for nearly 10 miles, receiving only small feeders from the east and west. It then turns to the east, passing the town of Haltwhistle, running in a comparatively open valley for 14 miles to the junction with the North Tyne, which takes place two miles above Hexham. On its way it receives several feeders from the north, some of which run a course nearly west, and then turn more or less abruptly to the south. The *Tipalt burn*, entering west of Haltwhistle, and the *Haltwhistle burn* are the principal. A much more important stream, the *Allen river,* flows in from Allendale, draining a large extent of country in the south. There are two principal branches running through east and west Allendale, both proceeding directly from the moors east of Alston common. The *Settingstone* is the last feeder of importance.

29. The North Tyne.—The North Tyne originates in a number of small streams rising in the Cheviot hills on the borders of Scotland. These unite and flow for 10 miles under the name of the *Kielder burn*, and the northernmost of the sources is nearly 50 miles due north of the sources of the South Tyne in Cross fell. After assuming the name of North Tyne, the river flows to the south-east, and, 4 miles beyond, receives the *Chirdon burn*, an important tributary from the south-west, and almost opposite another feeder from the north-east. Two miles below Bellingham the river *Rede* enters from the north-east, draining a large district in that direction. It rises in the Cheviots near the Kielder burn, and flows 24 miles chiefly parallel to that stream. After this confluence the united waters flow in the same direction for some distance, receiving feeders from the west, of which the *Wark burn* is the principal. Shortly below Wark burn, *Crook burn* enters, also a considerable stream, from the right, and *Dry burn*, draining a large district, from the left. Both have several feeders. No considerable tributary joins the North Tyne below these till its confluence with the South Tyne.

30. The river Tyne.—The river Tyne now formed flows in an easterly course through a somewhat wide valley for 4 miles, when it is joined by the *Dilston river*, draining the country to the south and south-west. This tributary is composed of three principal branches, the most easterly rising in the moors on Hexham common, flowing east for more than 6 miles, receiving small feeders, then turning north. It is called *Devil water*, and, after flowing north about 5 miles, receives the second branch of the Dilston, named *Rowley burn*, from the south-west. The united waters after 2 miles join the main stream, which has had a course of about 6 miles nearly due east. The whole then flows north-east about 3 miles into the Tyne. Eleven miles below, the river is joined by the *Scawley burn*.

31. The river Derwent.—Passing Corbridge, the Tyne continues to flow east, receiving only small tributaries, nearly as far as Newcastle, where it is joined by the Derwent. This large tributary rises in the moors not far from Allenhead, and has a long easterly course through the hills, fed by many tributaries, and winding very much among the hills. Near Muggleswick it bends round abruptly to the north, and continues for some miles with that bearing. It then turns once more to the east and north-east till it reaches the Tyne, draining no great extent of country in this part of its course, and having no important tributaries. Between the Derwent and Newcastle the river *Team*, also from the south, enters the Tyne, but its course is not more than 6 or 8 miles. Just below Newcastle the *Ouse burn* joins the Tyne from the north, and there are one or two other small streams whose waters join those of the Tyne between Newcastle and the mouth of the river. Of these the *Yarrow river*, entering at Yarrow, is the principal.

For a large part of its course the Tyne, like the Wear, flows over the coal-measures, which are worked under it with great activity. From Hexham onwards to the sea (about 30 miles) the river is utilised as much as possible for the traffic of the coal, and from Newcastle to Shields it is one continued harbour, its banks being wharfs and quays alternating with staiths for the loading of the colliers which take up their berths alongside. The river enters the sea by an estuary of considerable width.

32. Coast drainage beyond the Tyne.—Proceeding northwards from the mouth of the Tyne along the coast of England, we find the *Breerden burn* at a distance of 3 miles, draining a few square miles, and at Seaton, 6 miles from Tynemouth, the *Seaton burn*, proceeding from the hills about 9 miles inland, and fed by several small tributaries. In the 3 miles that intervene between Seaton and Blyth there are other very small brooks or burns.

33. The river Blyth.—The *Blyth*, whose mouth is about 10 miles from the mouth of the Tyne, is not a stream of first rate importance, but it drains a considerable tract of country between the water-sheds of the Tyne and Tweed. Its principal sources are in hills from 600 to 800 feet high, ranging nearly parallel to the coast of Northumberland about 20 miles inland. This range of hills extends from about 3 miles north of Corbridge on the Tyne for a distance of about 9 miles, and the number of the feeders of the Blyth hence supplied is very great. The stream that bears the name of the river rises among the hills near Kirkheaton, about 700 feet above the sea. It runs a straight course for nearly 9 miles without tributaries, and almost due east. It then receives the *How burn* from the north, which has run a long course in the same direction. After a couple of miles of winding course, turning south, it receives the *Ogle burn*, a shorter stream, but also parallel. A mile further south it again turns east, and after 2 miles it receives the *Pont*, its chief tributary, and, indeed, the more important stream of the two at the confluence. It is the most southerly of all the feeders of the Blyth, and has a longer course than the Blyth, flowing in nearly the same direction. It is made up of a number of small streams combining near Stamfordham, and thence flowing east 6 miles to Ponteland, receiving several feeders. It then turns north and receives two burns from the west before reaching the Blyth. From the confluence of the Pont with the Blyth the river proceeds with a tortuous course, receiving the *Catraw* *burn* at Stannington and the *Sleek burn*, one of its larger feeders, as it widens into an estuary immediately before entering the sea.

Without offering anything remarkable the Blyth is a pleasing river, and passes through a country not devoid of interest. The rainfall on this coast is not heavy, and the streams which cross the country in numerous small threads drain it easily and effectively.

34. The river Wansbeck.—This small stream, rising in the same range of hills as the Blyth, and running a parallel course at a distance of 3 miles to the north, enters the sea about 2 miles north of Blyth. Some of the sources of the Wansbeck approach within a mile of those of the Blyth. It receives one feeder with a course almost parallel to its own and rising in the same elevated line of hill ground, and another and more considerable tributary, the *Font*, also generally parallel, whose course is longer and whose feeders are more numerous and larger than those of the Wansbeck of which it is regarded as an affluent. Three streams having different names, and of some magnitude, unite to form this river, which enters the Wansbeck near Morpeth. Below Morpeth the Wansbeck flows through a narrow valley about 7 miles to the sea.

35. Coast between the Wansbeck and the Coquet.—More than 12 miles of coast intervene between the Wansbeck and the Coquet, drained chiefly by the river Lyne and the Chevington burn. The *Lyne* rises in the hills about 8 miles in the interior, and, after receiving several feeders, enters the sea about 4 miles north of the Wansbeck. Its whole course is about 10 miles in length. Its chief feeders are from the north, but are very short. *Chevington burn* drains chiefly the western slope of the coast hills, and feeders run north and south to join it, but none of them take their rise more than three miles from the coast.

36. The river Coquet.—The Coquet is a gentle river flowing through a pleasant country in the latter part of its course. It rises in the Cheviot hills not far from the source of the Rede, and has a course of at least 20 miles to the south-east till it reaches Rothbury. The stream from its source to this point is rapid, and runs through a wild country, passing some small villages. At Rothbury it rushes through a gully in the rock not more than a yard wide for a distance of 60 yards. Below the town, where it leaves the hills, it winds greatly till it reaches the sea, taking a course, at first south-east for 3 or 4 miles and then east and north-east, to Warkworth, where the estuary opens out. The scenery in the neighbourhood of Rothbury is exceedingly beautiful. The Coquet receives many tributaries on its way, both on its right and left bank, but none of them are very considerable. They run for the most part through deep narrow valleys. The general course of the Coquet is from west to east, but as it approaches the coast it turns to the north, and its flow, though very tortuous, has a general direction at first north-east and ultimately north. It enters the sea about 9 miles north of the Tyne, the lower part of its course expanding into an estuary which forms Warkworth harbour. Its length of course is about 40 miles.

37. The river Aln.—After another 3 miles of coast the Aln is reached. It rises near Alnham, close to one of the tributaries of the Coquet, and also very near the course of the Beamish, one of the feeders of the Tweed. Running east to Whittingham about 5 miles, it receives two small feeders from the south, and 5 miles beyond is joined by the *Shiply burn,* a somewhat important river from the north and west. Soon afterwards it reaches Alnwick and winds through a country of no great interest past Lesbury to Alnmouth bay. Its whole course is about 20 miles. It runs generally nearly parallel to the Coquet, but is a much smaller stream. On leaving the hills it enters a charming valley running beneath the walls of Hulme abbey, and through the spacious park surrounding Alnwick Castle, the residence of the Dukes of Northumberland.

36. The Aln to the Tweed.—From the mouth of the Aln northwards to Berwick, where the Tweed enters the sea, there are no streams of importance. This long line of coast, extending for nearly 40 miles, is flanked by a chain of hills rising from the shore to the height of between 500 and 600 feet. At first, near Alnwick, the hills are 5 or 6 miles inshore, but the distance from the coast gradually diminishes until approaching the Tweed they form a bluff coast line. Wide spits of sand extend in many places some distance seawards, but the main drainage of the country lies within the range and is carried by northern feeders to the Tweed. The rainfall on this coast is small, and the conditions of the surface unfavourable for the production of rivers.

A small stream, *Embledon burn,* enters the sea at Embleton, 8 miles north of Alnmouth, another about 3 miles beyond, and a third about the same distance beyond that. Beyond Bamburgh, near which town and castle there are transverse hills, there is a wide range of sands occupying between 20 and 30 square miles, intersected with channels, but not representing drainage areas except in the case of the *Elwick beck* and *Mill burn,* which both receive water from sources in the hills. From Holy island to Berwick there is practically no coast drainage, but two small streamlets convey a small portion of the land water into Goswick sands.

39. The river Tweed.—The basin of the Tweed is a rounded oblong containing about 1,870 square miles, within which are numerous grassy hills, many of them more than 2,000 feet high. It is bounded by the pastoral slopes of the Cheviots on the south, and is enclosed on the west by high hills, separating it from the basin of the Clyde. On the north it is shut in by the Lammermuir hills, which separate it from the basin of the Forth. It is made up of a large number of considerable streams conveying very pure water to the main river, except when affected by floods, or the drainage into the affluents of the peat bogs which abound on the hills. On the Yarrow is a lake called St. Mary's loch, whence water is drawn for the use of Edinburgh.

The river Tweed belongs more to Scotland than to England. For some distance it forms the boundary between the two countries, and it receives only one tributary of importance (the Till) exclusively from Northumberland.

The Tweed rises in Peeblesshire, near Moffat, 1,500 feet above the sea, among the lofty hills that connect with the Pentland hills near the sources of the Clyde and Annan, and close to the borders of Dumfriesshire. At first it flows to the north-east as far as the town of Peebles, and then nearly due east through the county of Peebles, and also through the adjoining county of Selkirk, where it receives the united streams of the Yarrow and the Ettrick, after which it turns north-east to Melrose. In the first 20 miles of its course it descends through a height of 1,000 feet.

Nothing can be more wild and dreary than the early course of this great river, as it is fed by innumerable torrents from the bare hills it divides. The first important feeder is the *Biggar* from the west, whose waters in flood bifurcate and connect with the Clyde. The scenery improves as we approach the pleasant valley of Tweeddale, where Peebles is situated, but after this the country is again rude and bleak. During this part of its course the river is constantly fed by mountain torrents. The course then continues nearly east for a long distance. Above Peebles the *Manner* enters from the south, and the *Lyne* from the north and at the town of Peebles the *Eddlestone* also comes in from the north. The *Leithen* from the north, and the *Quair* from the south, are the next in order. From the hilly character of the country through which they flow, these rivers are subject to sudden inundations.

40. Middle course of the Tweed.—Entering Selkirkshire the Tweed now receives the Gala from the north, and the Ettrick from the south. The *Gala* has the greater part of its course in Edinburghshire. Its sources are in the Moorfoot hills, and its course is nearly straight, passing Galashiels to the Tweed. The *Ettrick* rises near Moffat, near the source of its important tributary the Yarrow, and the two streams run a parallel course to Selkirk, where they unite, and soon after enter the Tweed not far from Melrose. The *Yarrow* has a course of 20 miles, passing through the two small lakes of *Lowes* and *St. Mary's*, which are both expansions of the stream, and separated by a very narrow neck. The former is a mile long, a quarter of a mile broad, and 70 feet deep; the latter is 3 miles long, half a mile broad, and 80 or 90 feet deep. Both are about 560 feet above the sea. The Ettrick rises in the south-west corner of

Selkirkshire, and flows north-east to its junction with the Tweed near Abbotsford, its course being nearly 30 miles.

Beyond Abbotsford the *Lauder* enters the Tweed from the north, rising near the sources of the Gala, and running nearly parallel to that stream. Its whole course is about 17 miles. There is no other important feeder till the Teviot comes in near Kelso from the south.

41. The river Teviot.—The Teviot rises in the wild hills in the centre of Roxburghshire towards Dumfriesshire, and flows north-east past Hawick and Dinholm to Eckford. A little above Hawick it is joined by the *Borthwick* from the left, and the *Allan* from the right bank. At Hawick another feeder enters. Soon afterwards it receives the *Rule* from the left bank, the *Ale* from the right, and the *Jed*, the *Oxnam*, and the *Kale*, all from the left, draining nearly the whole county of Roxburgh. The short course of this rapid stream after its exit from the hills is through the beautiful and highly romantic district of Teviot dale, profusely adorned with seats, and well sprinkled with villages. The town of Hawick occupies a charming spot overlooking the river at the entrance of this part of the valley.

The Jed and other feeders of the Teviot are remarkable for historic interest, as well as picturesque beauty. The *Oxnam* and the *Kale*, as well as the Jed, come in from the Northumbrian border. The whole course of the Teviot is about 38 miles, and the junction of this important tributary with the main stream, which takes place a little south of Kelso, overlooked by the ancient seat of the Dukes of Roxburgh, is extremely beautiful.

42. The river Till.—Below the Teviot at Coldstream there is a small feeder entering the Tweed, and at a short distance the *Till* comes in, draining a considerable tract of country to the south. This river rises south of the Cheviot hills, and is fed by a great number of springs from that wide expanse. The upper part of the stream is called the *Breamish*. It runs for some distance to the east through a wide flat valley shut in at both ends, and after emerging from a gorge beyond this valley, first assumes its name of Till. Just at this point it receives the *Lilburn* from the west. Proceeding then northwards for 4 or 5 miles it turns abruptly to the west 5 miles, where it receives a stream from the south, passing the town of Wooler. Three miles beyond it is joined by the river *Glen* from the west, and flows north-west about 12 miles to the Tweed.

The Glen rises on the Scottish side of the Cheviots as the *Beaumont water*, not far from the source of the Beamish, collecting the waters of several small streams from the valleys among those hills. It then flows northwards by Kirk Yetholm about 10 miles, where it receives a small tributary, which expands into a fine sheet of water of irregular form called *Yetholm loch.* Up to this point the Beaumont water is a rapid stream, subject to frequent inundations. Passing this town, it crosses the border and enters Northumberland with a north-easterly course, but almost immediately turns east, and, passing through a hilly country, is joined by the *College burn* from the south, and first takes the name of Glen. Thence it has a winding course of about 5 miles, turning north to enter the Till.

The whole course of the Breamish or Till is about 40 miles, almost entirely in Northumberland. It forms for itself a pleasant valley, but passes through a waste. Its course is at first east along the flanks of the hills, but afterwards north, and its bed approaches closely to the line of water-parting on the right bank along its northerly course.

43. The river White Adder.—The last tributary of the Tweed before reaching the sea at Berwick is the White Adder, a stream of some importance coming in from the west on the left bank, and draining an extensive district north of the basin of the Till. More than a fourth part of the whole basin of the Tweed is under the sub-drainage of the Till and the White Adder, which with the Teviot are by far the largest tributaries.

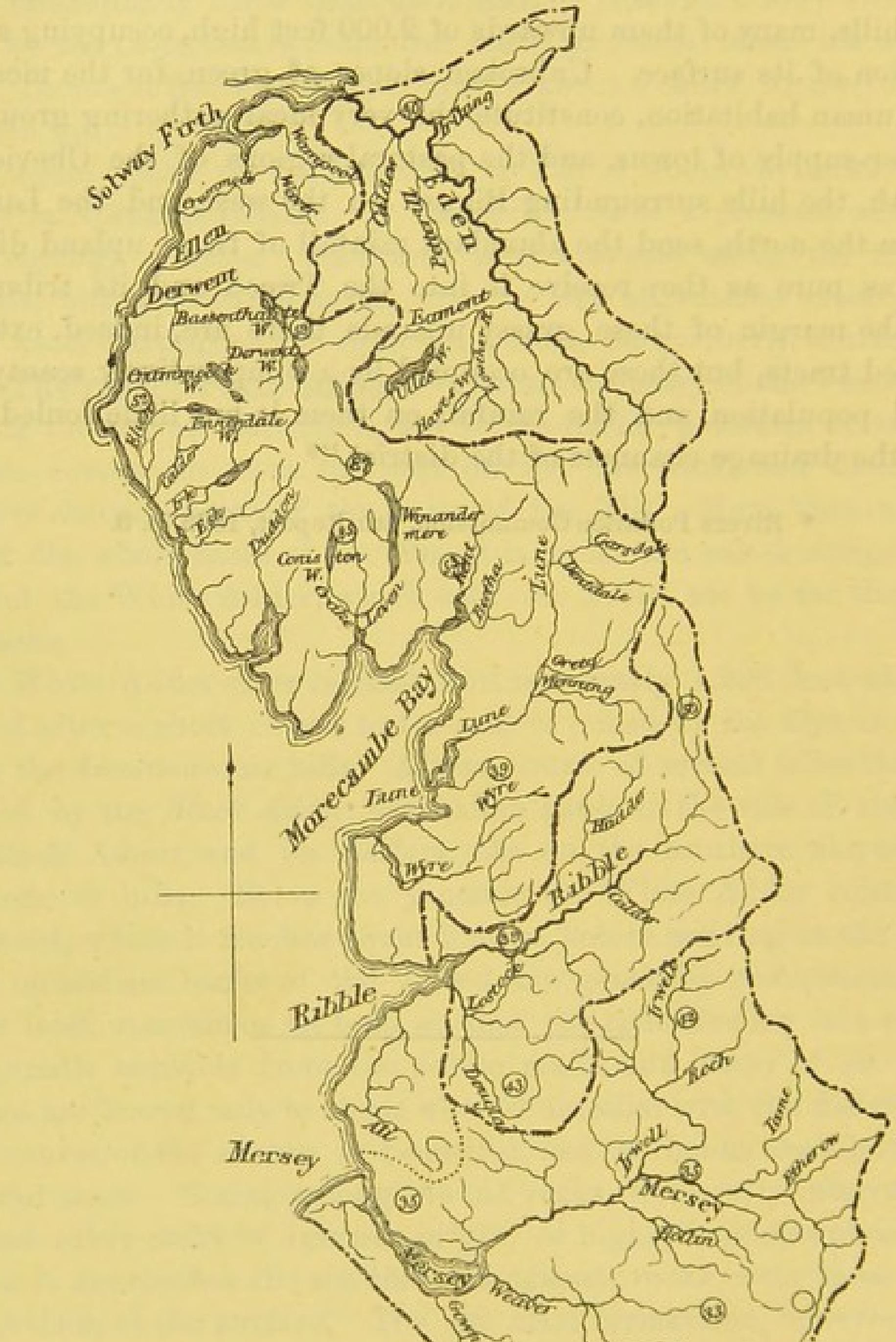
The White Adder rises in East Lothian, nearly 1,200 feet above the sea, and after a short course to the east is joined by the *Dye,* in a valley among the Lammermuir hills. After a course of several miles the stream is joined by the *Black Adder*, near Allan bank, in the vale of the Merse. The Black Adder, and its feeders, rise on the southern slopes of the Lammermuir hills. Below the junction the White Adder continues to the Tweed, which it reaches about 3 miles before arriving at the sea.

The immediate banks of the Tweed are generally precipitous, on one side at least, sometimes on both, so that the river flowing in a deep bed is frequently invisible from the public roads, and many of its striking beauties are known only to those who are familiar with the district. The whole course of the stream is beautiful, and its banks are adorned with beautiful seats. Rising among the old rocks, frequently interrupted by trap and other rocks of igneous origin, or highly metamorphosed, it is only as it approaches the sea that the triassic rocks cover these up, and replace them at the surface. The red marl formations, however, extend along the valleys of the Tweed and Teviot for a long distance, and the coal-measures appear in the valleys of the Jed and Kail.

Athough not represented as free from the sources of pollution which must be presumed to attach to every river flowing through an inhabited country, but which are of course more noticeable when the population of a district, however comparatively small, is collected in towns, the waters of the Tweed were described by the Rivers Pollution Commissioners, in 1872, as being singularly pure, except when the abrading action of floods or the drainage water of peat bogs affects them. In point of fact the whole drainage area of the river is under highly favourable circumstances for delivering the rain-water falling on the surface uninjured to the sea. "From its edge on all sides inwards there is a wide margin of grassy hills, many of them upwards of 2,000 feet high, occupying a large proportion of its surface. Unbroken slopes of green, for the most part above human habitation, constitute the very ideal gathering ground for the water-supply of towns, and the pastoral regions of the Cheviots on the south, the hills surrounding Biggar on the west, and the Lammermuirs on the north, send the abundant rainfall of those upland districts almost as pure as they receive it into the Tweed and its tributaries. Below the margin of these grassy uplands there are, indeed, extensive cultivated tracts, but these are occupied by a comparatively scanty agricultural population, and the rainfall on them is but little fouled on its way to the drainage channels of the district."*

* Rivers Pollution Commission, 4th Report, 1872, p. 3.

VIII.—Drainage Areas of the North-West of England.



CHAPTER XI.

DRAINAGE AREAS OF THE NORTH-WEST OF ENGLAND AND OF THE SOUTH-WEST OF SCOTLAND.

(1) General account of the district.—(2) Physical features and geology.—(3) Subdivisions.—(4) Rainfall, evaporation, and percolation.—(5) Quality of the waters.—(6) Ordinary flow and floods.—(7) Tidal action.—(8) Scheme of the rivers and their affluents.—(9) The Basin of the Mersey.—(10) The early feeders of the Mersey.—(11) The river Tame.—(12) The river Irwell.—(13) The river Roch.—(14) The river Tonge or Croal.—(15.) The Wych brook and Glaze brook.—(16) The river Bollin.—(17) The Sanzey brook.—(18) *Estuary of the Mersey:* The river Weaver.—(19) The rivers Alt and Douglas.—(20) The Basin of the Ribble: its early course.—(21) The Tosside beck.—(22) The Bashall brook.—(23) The river Hodder.—(24) The river Calder.—(25) The middle course of the Ribble.—(26) The river Darwen.—(27) *Estuary of the Ribble:* Douglas river.—(28) General summary of the Ribble basin.—(29) The river Wyre.—(30) The river Brock and the estuary of the Wyre.—(31) The river Lune.—(32) The river Rawthay.—(33) The river Greta.—(34) The river Wenning.—(35) The Artle beck and the estuary of the Lune.—(36) The river Kent.—(37) The river Gilpin.—(38) *The Lake district:* General account.—(39) Scheme of the distribution of the lakes.—(40) The river Leven, Codale tarn, Easedale tarn.—(41) Grasmere lake.—(42) Rydal water.—(43) The Brathay, and Elter water.—(44) Windermere lake and Esthwaite water.—(45) The Leven below Windermere.—(46) The river Crake and Coniston water.—(47) The river Duddon.—(48) The river Esk.—(49) The river Mite.—(50) The river Irt.—(51) Wast water.—(52) The river Bleng.—(53) The river Calder.—(54) The river Ehen and Ennerdale water.—(55) The Derwent: general account.—(56) Early course of the Derwent.—(57) Derwent water.—(58) The river Greta and Thirlmere.—(59) Bassenthwaite lake.—(60) The river Cocker, Buttermere, and Crummock water.—(61) The river Ellen.—(62) The Waver and the Wampool rivers.—(63) The Basin of the Eden: early feeders.—(64) Ullswater lake.—(65) The river Eamont.—(66) The river Lowther and Hawes water.—(67) The lower course of the Eden.—(68) The river Irthing.—(69) The rivers Petterill and Caldew.

RIVERS OF THE SOUTH-WEST OF SCOTLAND.

(70) The Dumfriesshire Esk.—(71) The rivers Sark and Kirtle.—(72) The river Annan.—(73) The river Locher.—(74) The river Nith.—(75) The Urr water.—(76) The river Dee.—(77) Loch Ken and the Dee water.—(78) The Fleet water.—(79) The Cree river.—(80) Luca Bay.

1. General account of the district.—In this chapter it is proposed to consider the numerous drainage areas of the north-west of England, and of that part of Scotland delivering its waters into the Solway Firth. The former slope westwards and the latter southwards towards the Irish sea, and, except the rivers of North Wales, the district includes the whole of the drainage of Great Britain into that sea. The tract is large, comprising not much less than 10,000 square miles, and is naturally enclosed. It consists of two oblong troughs, partly bounded by the Penine hills of England and the Carrick and Moorfoot hills of Scotland. There are several separate catchments in each trough, but the dimensions of none of them are very considerable. There are, indeed, out of the whole number of rivers that will be described, only three, the Mersey, the Ribble, and the Eden, that are in any sense important, though many of the smaller streams offer points of great interest, especially in connection with the expansions of their beds to form lakes. Their summer contributions of water to the ocean are small, but most of them deliver very large quantities during freshets following heavy rain.

2. Physical features and geology.—The Penine chain north of the High peak of Derbyshire consists of a ridge of millstone grit covered on the eastern and western flanks by the coal-measures—on the one side those of Yorkshire and on the other those of Lancashire. This chain forms the boundary line which separates the drainage of the Yorkshire Ouse from that of the Lancashire rivers. Further north the carboniferous limestone thrust up through the millstone grit is the dividing line. For a long distance, therefore, amounting to 70 or 80 miles, the tilted edge of the southern trough consists of middle or lower palæozoic rocks, which the coal-measures, the Permian sandstones, the magnesian limestone, and some of the lower beds of the New Red Sandstone overlap in regular order as we proceed down the slope to the sea. The rocks towards the coast are widely and thickly covered with alluvium and thick beds of transported material. Beyond Lancashire the metamorphic rocks of the Cumberland and Westmoreland mountains rise to a considerable elevation near the coast, being only covered by a narrow fringe of coal-measures, magnesian limestone, and Permian sandstone, and a deep valley or depression occurs through which the Eden, the most northern of the English rivers on the western side of our island, makes its way. The Scottish chains of Silurian rock, known as the Carrick and the Moorfoot hills, ranging north-east and south-west, meet the Penine hills nearly at right angles, but rise from beneath them, thus forming the higher side of the northern trough. The whole of the country draining south into the Solway Firth is occupied by Silurian rocks.

The whole of the northern part of this drainage area, whether in the Scottish Silurians or the equally ancient rocks of the Lake district, or in the mountain limestone and millstone grit, is mountainous, wild, and picturesque. Almost all the rivers originate as mountain torrents and run through deep narrow glens or over waterfalls, and, even in the streams flowing through the south of Lancashire, this condition exists. But in the southern district the glens soon widen into valleys and the valleys open out into plains, so that the rivers gradually resemble those of less hilly countries. They do not in this lose their peculiar features, and all of them, except the most southern—the Mersey—which is largely fed in its lower part by more regular streams from secondary rocks, indicate, even at their termination in the sea, the peculiarly mountain character they had derived from their early history.

The characteristic of this drainage area is its lakes. These expansions of the streams of Cumberland and Westmoreland are remarkable in many respects. They are also eminently picturesque. They are due to the peculiar mode of formation of the river valleys, radiating from central points, and are intimately connected with the irruptions of igneous rock very frequent in this district. They belong essentially to the early upheavals which have affected the western extremity of the Old World; and the old metamorphic and igneous rocks result from an extension northwards of the elevation axes whose influence is seen in the mountains of Wales and the granitic bosses of Cornwall and Devon. They are not, however, in all cases true rock basins. In some the lakes are formed by barriers of transported material, and in others they have been scooped out of soft rock by the action of ice during the glacial period.

Another peculiarity of the district is the occurrence of large estuaries and of enormous deposits of sand at the mouths of the rivers or within the estuaries. The material has been brought down by water from the higher ground.

3. Sub-divisions.—The area naturally subdivides itself into the two principal troughs or drainage districts already indicated. These are totally distinct, and the enclosing rim of the smaller and most northerly tract forms one side of the larger trough, of which the Penine chain forms another side. The third or southern side is low and imperfect.

The northern district comprises three principal and a great number of smaller catchments. They are naturally separated, but do not suggest any points of special interest.

The southern trough is by far the most important. The Mersey and the Ribble drain 2,540 square miles of country, comprising a very large part of Lancashire. Each of them has many tributaries. The Wyre and the Kent drain comparatively narrow strips of mountain land. The Cumberland lakes are drained by unimportant streams, and the Eden, which drains nearly 1,000 square miles, is the only other considerable river.

The southern tract, therefore, is naturally subdivided into three principal basins as well as the northern, but the rivers are in all respects more important.

4. Rainfall, evaporation, and percolation.—The recorded rainfall in the southern part of this district near the line of water-parting between the basins of the Mersey and the Trent is as low as 29 inches, but, advancing northwards and eastwards within the water-shed of the Mersey, it rises considerably, the mean fall in the hills ranging from 42 to 47 inches. In one place, at the head of the Irwell, it is recorded as amounting to 60 inches.

The general set of the winds through a large part of the year in Great Britain being from the Atlantic, and the whole range of high ground shutting in the drainage areas we are now considering looking towards the Atlantic and facing the west and south, there would, under any circumstances, be a somewhat heavy rainfall over the higher ground. But the presence of the Cumberland mountains, almost detached but within the drainage area, renders the effect far more striking. These mountains being much higher than the rims of the enclosing basin, attract and empty the rain-clouds, so that on them we have rainfalls not only much heavier than on the general range of the Penine chain, but heavier than are observed elsewhere out of the tropics. Attention has already been drawn to these excessive rains in Chapter II., and the Seathwaite fall has been quoted. These rains fall torrentially, and run off to the sea by short river courses, and with extreme rapidity. Were it not for the lakes, which act as flood-regulators, the effect of these torrents on the sandstone plains below would be very disastrous. As it is, the effects are very visible in the sands that encumber the mouths of the rivers and form deposits along the coast.

The lake district is remarkable for its large rainfall. The average annual fall, from 1847 to 1853 inclusive, was as much as 100·56 inches. The subsequent two years were, however, very dry, the quantity being only 64 per cent. of this average. The years 1864 and 1865, also dry, yielded 80·38 inches. The mean rainfall of three consecutive driest years in this part of the district has been assumed by Mr. Hassard at 64 inches. The drainage area over which these observations extend is 177 square miles. Mr. Symonds, however, infers that the true mean of the district is 77 inches, the mean of the three consecutive driest years 61·6 inches, and the driest year 53. It would be difficult, if possible, to determine any true mean, nor would the determination be of value for practical purposes.

In the parts of Scotland draining into the Solway Firth the rainfall is only from 34 to 36 inches, but rain falls very frequently.

The mean evaporation from the surface generally is now usually assumed at 14 inches, and in reference to questions between companies and corporations who desire to abstract water, and mill-owners who require to use it for power, this calculation is no doubt fair. It is probably greater rather than less than 14 inches where the rains are heavy, because of the wind that generally accompanies showers.

The percolation in the case of the old metamorphic and Silurian rocks of the lake district and Scotland, and the carboniferous limestone and Yoredale rocks of the newer palæozoic period, must be small, except where the beds are greatly fissured. In the Permian and New Red Sandstone districts it is certainly large. It has been stated in a former chapter that the river Eden delivers to the sea more water than falls on the surface. This can only be due to water abstracted from other catchments by underground channels.

5. Quality of the waters.—No large drainage system in England presents differences so great in the quality of the waters flowing over its surface as the one we are now considering. Among the samples analysed have been the purest and the most foul on record, so that while in one place we may find rain-water flowing over the bed of a mountain stream, unaltered by any foreign ingredient, it has been possible from another river to take water which could be made use of as ink, samples of which were presented, written on a sheet of paper, as among the results of a Royal Commission on the Pollution of Rivers.

The water coming off that part of a drainage area where coal is being worked by a large mining population is apt to be loaded with mineral matter, and must often show indications of organic impurity. From the mines themselves also it is well known that much water has to be removed by pumping. The general result will be to render the water running into the immediately adjacent streams unfit for food purposes, although it is generally very soft. Such is the character of the coal-measure waters in the catchments now under consideration.

All the waters from the old rocks of Cumberland and Westmoreland are remarkably pure and soft, except that they not unfrequently show a certain proportion of organic carbon derived from peat. The lakes themselves as well as the rivers that feed them are remarkably pure, but the water from the manufacturing districts in the middle and south of Lancashire is rarely sufficiently pure to be potable, except near the sources of the streams.

Owing to the heavy rainfall the supply of water is unusually large, and freshets are frequent. These of course cloud the water, but do not necessarily injure it. With these remarks the following results of the analysis of samples of several of the waters of the district are submitted for consideration. Those of the lakes are of special interest, both from their general purity and from the small though marked differences observable in them. Most of them were taken in late spring or early autumn.

ANALYSES OF WATERS FROM THE LANCASHIRE RIVERS AND THE LAKE DISTRICT.

Date of Sample.	Locality.	Total solids.	Org. Carbon.	Org. Nitrogen.	Ammonia.	Nitrogen as Nitrates.	Chlorine.	Hardness.
	River Mersey.							
27 Apr. '68	Mersey, at Wade br. - -	19·57	0·443	·034	0	·045	1·70	9·8
,,	,, above Warrington -	19·85	0·493	·066	·057	·036	2·38	8·7
12 June '69	,, Irwell near source -	5·46	0·131	·017	·003	·015	0·80	2·6
24 June '68	,, ,, Roch - -	30·31	3·163	·202	·358	·161	3·20	11·5
22 July '68	,, ,, Medlock, source -	8·96	0·116	·010	·003	·008	0·90	4·8
22 July '68	,, ,, ,, nr. Mnchester	8·96	0·116	·010	·003	·008	0·90	4·9
10 Jan. '68	,, Irk, source - -	13·85	0·107	·001	·006	·043	0·99	8·0
31 July '68	Hodder, confluence with Ribble	9·84	0·196	·034	0	0	0·90	6·9
Oct. '68	Wyre, Lancaster supply -	3·21	0·090	·015	·001	0	0·69	0·6
11 Aug. '68	Calder, above Burnley - -	19·36	0·127	·013	·002	0	0·76	7·0
17 Mar.' 71	Kent above Kendal - -	4·54	0·104	·014	0	·031	0·63	2·7
	The Lakes.							
28 Sept. '68	Grassmere - - -	2·93	0·164	·035	·001	0	0·55	1·9
,,	Rydal water - - -	3·11	0·178	·030	·001	0	0·48	2·2
,,	Windermere - - -	4·05	0·210	·053	·001	·013	0·69	2·8
28 Sept. '68	Ennerdale - - -	1·51		·012	0	0	0·76	2·4
,,	Thirlmere (centre of lake) -	1·86	0·136	·003	·002	·001	0·36	0·5
29 Sept. '68	Derwent water - - -	4·59	0·153	·030	·001	0	0·99	1·2
,,	Bassenthwaite - - -	3·25	0·108	·026	0	0	0·87	2·0
,,	Buttermere - - -	2·49	0·089	·028	·003	0	0·62	0·7
,,	Crummock water - -	2·84	0·128	·038	·005	0	0·62	0·9
16 May '67	Ullswater, Pooley Bridge -	2·54	0·047	0	·002	·004	0·42	1·3
,,	Hawes water - - -	2·49	0·111	·003	·003	0	0·38	0·9
	Mean of 11 lakes -	2·88	0·132	·023	·002	·002	0·61	1·5

6. Ordinary flow and floods.—It has already been pointed out that from the form of the basins, their elevated margins, and the heavy rainfall, the streams of the north-west of England and south-west of Scotland are of necessity torrential. The rainfall is heavy, the ground hard, the fall considerable, and the distance short. This is more especially the case with the streams that enter from the lake district and the Scottish hills, which are all rapid and carry down to the sea large quantities of detritus deposited as sand or mud on the coast, or in the large bays and estuaries which there exist. The large Lancashire rivers are less remarkable in this respect, and many of their tributaries passing over nearly level expanses are checked in their course.

7. Tidal action.—The effect of the tide in the numerous and large estuaries of the rivers opening into the Irish sea is very great, and very remarkable. The phenomena described in the Severn and other estuaries under the name of the *bore* or *egre* are here repeated, and are accompanied by other special conditions. The great expanses of the Lancaster and Duddon sand, and the sand of Solway Firth, are results of tidal action, checking the downrush of the water loaded during floods with the sand and detritus brought from the higher ground, and causing a deposit.

The estuaries are those of the Mersey and the Ribble and the inlet known as Morecambe bay, into which enter a large number of streams bearing down at certain seasons enormous quantities of detrital matter which here meets the tide, and is constantly being deposited. The result is seen in the innumerable shifting and treacherous sands at the mouths of all these rivers. The river Mersey differs greatly from the others, being an inlet widening within the entrance. The estuary of the Ribble is funnel-shaped, and this is the general character of most of those rivers that enter Morecambe bay. The Solway Firth partakes of the character of Morecambe bay.

Before quitting this subject it may be well to add a few words on these two remarkable bays, the Solway Firth and Morecambe bay, that enter so deeply within the coast line, and have important influence on the drainage of the country, especially with regard to the tidal wave. The Solway Firth is more especially funnel-shaped than Morecambe bay, and of greater magnitude. A number of streams pour their waters into it from the north, and the vast expanse of its sands at low water illustrate the effect of these streams. The tide of the Solway flows directly east with great rapidity, and the navigation of the firth is difficult and dangerous. "During spring-tides, and especially when impelled by a strong south-wester, the Solway rises with prodigious rapidity. A loud booming noise indicates its approach, and is distinguishable at a distance of several miles. The tide head is often from 4 to 6 feet high, chafed into spray with a mighty trough of bluer water behind, swelling in some places into little hills, and in others scooped into tiny valleys, which when sun-lit form a brilliant picture."—M'Diarmid's "Picture of Dumfriesshire." This phenomenon of the bore, or egre, has already been twice alluded to, in the case of the Severn and the Trent. That of the Solway Firth more resembles the Severn, but differs inasmuch as it is not complicated by the outflow of a large river whose waters in flood meeting the incoming tidal wave greatly affect the result. On the other hand the physical conditions of the Solway Firth are in some respects more favourable for the production and rapid increase of the great wave. The Solway Firth and Morecambe bay are very dangerous to cross, even on horseback, when the bore is entering, and many accidents have happened to persons incautiously venturing on them.

8. Scheme of the rivers and their tributaries.—The following outline of the various streams considered in this chapter and their principal affluents will be convenient.

Southern or English Division.

THE RIVER MERSEY.

Etherow.
- Shelf brook.
- Hollingworth brook.
- 18

Goyt.
- Black brook.
- Sett brook.
- 16

MERSEY.

Right bank.	Distance from source.	*Left bank.*
Tame river	25	
Hull brook.		
Greenfield brook.		
Carr brook.		
Irwell river	43	
Swinnell br.		
Roch river.		
Ash br.		
Shodden br.		
Suddon br.		
Naden br.		
Tonge river.		
Dean br.		
Medlock river.		
Glaze brook	45½	
	46	. . . . . Wych brook.
	48	. . . . . Bollin river.
		Dean river.
		Birkin river.
Sankey brook	61	

The Estuary of the Mersey.

	67	
	69	. . . . . Weaver river.
		Artle br.
		Dane br.
		Ash br.
		Dane river.
		Wheelock r.
	73	. . . . . Gowy river.
	79	. . . . . Dibinsdale brook.
	83	. . . . . Wallasey pool.

Alt river.

Douglas river.

THE RIVER RIBBLE.

Gale beck (5 m.). Cam beck (4 m.).

RIBBLE.

Right bank.	Distance from source.	*Left bank.*
	12	Cowside beck.
Rathmell beck	18	
	20	Long Preston beck.
	27	Stock beck.
Tosside beck	30	
	32	Ing's beck.
Bashall beck	36	
Hodder river Whitendale brook. Langden brook. Loud river.	45	
	46	Calder river. Laneshaw river. Don.
	47	Park brook.
	64	Darwen river. Roddlesworth river.
	Estuary of the Ribble.	
	73	Douglas river. Yarrow river.

Wyre river.
Calder river.
Brock river.

THE RIVER LUNE.

Birk beck	8	
Borrow beck	10½	
	19	Rawthay river. Dee river.
	32	Greta river.
	36	Wenning river.
	40	Artle beck.

Keer river.

Kent river.
Gilpin river.

Leven river.

Crake river.

Duddon river.

Esk estuary.
- Esk river.
- Mite river.
- Irt river.

Calder river.

Ehen river.

Derwent river.
- Greta river.
- Newlands beck.
- Cocker river.
- Marron river.

Ellen river.

Waver river.

Wampool river.
- Wiza river.

The River Eden

Right bank.	Distance from source.	*Left bank.*
	13	Scandal beck.
Betah river	14	
Swindale beck	14½	
	32	Lyvennel beck.
		Leith river.
	36	Eamont river.
		Dacre beck.
	58	Irthing river.
		Cam beck.
		Gell river.
Petterill river	63	
Cardew river	65	
	77	

Northern or Scottish Division.

Esk (Dumfriesshire).
- White Esk.
- Black Esk.
- Ewes.
- Mauchope.
- Tarras.
- Liddel.
- Line river.

Sark.

Kirtle.

Annan.
- Ae.
- Evan.
- Moffat.
- Wamphray.

Locher.

Nith.
- Afton.
- Crawick.
- Menoch.
- Euchan.
- Carron.
- Scaur.
- Cluden.

Orr or Urr.

Dee.

Fleet water.

Cree.
- Bladenoch.

Luce.

Pooltanton.

9. The basin of the Mersey.—General account.—The rivers that find their way into the sea in the estuary of the Mersey rise, almost without exception, from the dividing range of the Penine chain. The whole drainage area of the basin is 1,103,520 acres, or 1,724¼ square miles. The river originates at the junction of two streams above Stockport, which drain areas respectively of 44,960 and 38,240 acres, and is immediately joined by a river from the north draining 38,080 acres. It afterwards receives, also from the north, the Irwell, which combines the waters of several streams and drains 199,520 acres, and several small brooks, also from the north, draining in all 126,720 acres. From the south it receives the Bollin, draining 71,520 acres, and several brooks draining 68,480 acres. Thus, before entering the estuary at Runcorn, it has drained 587,520 acres. Below Runcorn it receives additional drainage from 516,000 acres.

Runcorn Gap is the point where the river, being there 470 yards wide, may be considered to merge in the estuary, but the tide passes up to Warrington, 7 miles above, where the stream is only 40 yards wide. Below the gap the estuary at once widens to 2 or 3 miles, and is a salt-water inlet. It narrows again considerably as it approaches Liverpool.

The tributaries of the Upper Mersey are chiefly in the millstone grit, but the chief waters of the river run over coal-measures, of which the drainage area contains more than 264,000 acres. A very large extent of the catchment in its lower part is covered by New Red Sandstone. The lower part of the river course also passes over and near extensive alluvial flats subject to inundations.

The Mersey, as a river, is more remarkable for the vast amount of traffic carried on on its banks and those of its tributaries, the vast population there collected, and the enormous manufacturing interests of the country it drains, than for its length, its picturesque beauty, or the volume of water it carries to the sea. In all these respects it is a river of small importance. The population within the river basin is probably at least three millions, of which nearly half is concentrated on the Irwell.

10. The early feeders of the Mersey.—The Mersey first takes its name at the spot called Water-meeting, about 4 miles east of Stockport, where the waters of the Goyt, coming from the south, meet those of the Etherow from the north-east. The *Goyt* takes the drainage of an extensive tract of moorland called Goyt's moor, about 3 miles west of Buxton, and, after receiving a few feeders from different parts of the moor and adjacent hills, it runs an almost straight course to the north for about 6 miles, where it is joined by the *Black brook* on the right bank, draining the country to the east as far as Chapel-le-Frith. It then turns north-west and west for some miles with a more winding course, receiving the

Sett brook, till it is joined by the waters of the Etherow. It drains in all about 70¼ square miles, chiefly of millstone grit.

The *Etherow* is formed from the union of several streams, chiefly torrential, proceeding from the extensive moorlands on the western water-shed of the Penine hills west of Penistone. These occupy a range of moor extending about 6 miles from Harden moor, in the south-east, to Holme Moss, in the north-west.

In the upper part of the Etherow, not far from the line of water-shed on the Penine hills, and where the stream first takes a north-westerly bearing, which it retains for 8 miles, is the first of a line of reservoirs constructed by Mr. Bateman for the supply of Manchester. There are three reservoirs, all very narrow, succeeding each other in the valley, and almost touching. The two upper (the Woodhead and Torside reservoirs) are much the largest. Several feeders are received into the reservoirs, chiefly from the south. Their total length is about 4 miles. They are found to silt up very rapidly, and have needed repair. Below the reservoirs the river flows 4 miles further in the same direction, and then turning a little southwards, another 8 miles to its confluence with the Goyt. It receives the *Shelf brook* from the south, and the *Hollingworth brook* from the north. Its drainage area is 59¾ square miles, almost entirely millstone grit.

11. The river Tame.—The Mersey, now formed, flows westwards in a very winding course to Stockport, where the Tame enters it from the north. This exceedingly tortuous stream rises on the western slopes of the Penine chain, 10 miles north of Staleybridge, and flows down past that town, receiving first the *Hull brook* and then the *Greenfield brook* coming from Holme Moss, and having a westerly course. After receiving the *Carr brook* it enters the Mersey.

The Tame runs about 16 miles, and drains nearly 60 square miles of country, chiefly millstone grit. Except where it passes Staleybridge and Ashton and enters the great manufacturing districts of Lancashire, the course of the Tame, and, indeed, of the whole of these upper feeders of the Mersey is very thinly peopled, the population of the Goyt averaging only 260 to the square mile, and that of the Etherow, 500. After the confluence of the Tame with the Mersey at Stockport, the character of the district becomes much altered in this respect.

12. The river Irwell.—From Stockport the Mersey runs a westerly course, measuring only 12 miles in a direct line, but much more including the numerous and complicated sinuosities of the stream. It is then joined by the Irwell, before this receiving a small tributary from the south-east at Cheadle, but no other feeder of importance. The Irwell, which now enters from the north, is one of the chief tributaries of the Mersey, and, though not large, is important, from its position with regard to Manchester and other large manufacturing towns of Lancashire. Its drainage area is 312 square miles, and its length of course 40 miles, chiefly through New Red Sandstone.

The Irwell rises at the Erewell spring, in the moors a little to the east of Haslingden, 1,325 feet above the sea, near the Old Forest of Rosendale on the borders of Yorkshire, and collecting several small feeders, flows southwards a few miles and receives the *Swillen brook* from Haslingden. Thence it continues nearly south for 6 miles to Bury, between hills that close in the valley on each side, and have few breaks. Two miles below Bury the *Roch* enters on the left bank.

13. The river Roch.—The Roch is a considerable stream coming from the western slopes of the Penine hills. After a course of about 12 miles during which the *Ash brook* joins it, it passes the town of Rochdale, where it receives a considerable feeder, the *Spodden brook*, coming from the north and rising in the slopes of the moors east of Bacup. Besides this it receives other smaller feeders, including the *Sudden brook* and the *Naden brook*. The *Longden brook* and the *Cowm brook* also enter. The rainfall on the slopes of the Penine hills to the east is generally very heavy, and the nature of the ground when not too much fissured, affords good reservoir sites. Many of the valleys are more or less filled with boulder clay. The rock below the boulder clay consists of gritstones and shale, and the grits are remarkably open. Large fissures may be seen in quarries opened to supply stone to the neighbourhood, and into these fissures water freely enters.

14. The river Tonge or Croal.—After receiving the Roch the Irwell continues to flow about 3 miles in a westerly course, and then receives the Tonge or Croal coming in from the north-west, and passing on its way the town of Bolton-le-Moors. The Tonge has several small tributaries, many of them from the northern slopes of Rivington moor, and the high ridge to the north.

At the confluence of the Tonge the Irwell makes an acute angle with its former course, taking the direction of the Tonge and flowing south-east to Salford and Manchester, the distance in a straight line being about 7 miles, but including the contortions much greater. Winding round the western part of the city of Manchester it receives the *Irk*, a small feeder from the north, and the *Medlock*, another feeder from the east. It then flows to the west passing through Trafford Park. After a few miles, coasting the great flat waste of Chat moss, it reaches the Mersey between Chat moss and Carrington moss.

15. The Wych brook and Glaze brook.—After flowing for 3 miles after the confluence of the Irwell, the Mersey is joined by the Wych brook, proceeding from the south side of Carrington moss, and having a course of nearly 10 miles from the east, draining a large range of level country. It is also joined by the Glaze brook from the north-west. Winding in a succession of loops for about 10 miles, during which some small feeders enter, Warrington is reached, and after another 8 miles we arrive at Runcorn. There is no drainage of importance into the Mersey along the whole of this part of its course except by the river Bollin, which enters from the south-east, about 2 miles below the Wych brook.

16. The river Bollin.—The Bollin rises on the western side of a ridge adjoining Goyt moss, and is formed by a number of small streams, meeting in the country a few miles east of Macclesfield. Passing through that town, and flowing in a tolerably direct line a little west of north for about 6 miles, it trends to the west, and after another 3 miles receives the *Dean river*, an important tributary which has run a parallel course, a little more than a mile to the east, and almost from Macclesfield. The Bollin after this confluence continues to flow for another 10 miles, making many small twists. It then receives the *Birkin river*, a considerable feeder, which has previously received the *Ashley brook*. Soon after it joins the Mersey. The Bollin drains in all about 112 square miles, and runs chiefly over New Red Sandstone, its direct course being about 23 miles.

17. The Sanzey brook.—About midway between the confluence of the Bollin and Runcorn, where the estuary of the Mersey is reached, a small stream, called the Sanzey brook, enters after passing St. Helens. It proceeds from the north-western angle of the drainage area of the Mersey, partly occupied by coal-measures and partly covered up by New Red Sandstone.

18. The estuary of the Mersey. The river Weaver.—On leaving Runcorn the Mersey widens abruptly, and makes a channel for itself through a wide flat expanse up which the tide flows without obstruction. It here receives the *Ditton brook*. About two and a half miles south of Runcorn the Weaver enters the estuary. It may almost be regarded as an independent stream.

The Weaver drains more than 555 square miles of very thinly peopled country to the south-east and south of the thickly peopled manufacturing districts, and chiefly situated in Cheshire. It rises in Shropshire, near Stych, and receives several feeders, of which the *Dane*, from Staffordshire, is the most considerable. The whole course of the Dane is about 40 miles, and it runs almost entirely through New Red Sandstone, except in its upper course, which is over the millstone grit. The Dane rises from the same marsh as the Goyt, but a little farther north, and near the source of the Bollin. It enters the Weaver on its right bank. The *Wheelock*, a considerable tributary, enters the Dane above Northwick.

19. The rivers Alt and Douglas.—There is a small area on the coast between the basins of the Mersey and Ribble watered by the *Alt*, which rises near Prescot and flows north-west into the sea over the New Red Sandstone. It has a course of 14 miles. Another smaller stream, the *Douglas* river, completes the drainage of this portion of the coast.

20. The river Ribble: its early course.—This considerable stream originates in the Craven district of Yorkshire, close to the sources of the Wharfe. The source of the river is called Ribble Head, and is situated between Whernside (2,414 feet) and Cam End (1,432 feet) 979 feet above the sea. From this point the Ribble descends through limestone into the Silurian rocks, here underlying the limestone. It is at first fed by small streams and rills, whose courses are often interrupted by "swallow holes," into which the water sinks and for a time disappears. The whole country around is wild and picturesque, the hills being scarped and the water rushing in torrents through narrow gorges after rain.

After flowing three miles through a gradually widening valley, but always to the south, the Ribble receives the *Cowside beck* on the left and the *Rathmell beck* from the right or north-west, and after another mile or two, the course being very tortuous, it is joined by the *Long Preston beck* from the north-east. The Long Preston beck is a considerable stream made up of two principal forks, both receiving several names, and proceeding from the southern side of the lofty and exceedingly picturesque line of scarped rock that extends from Giggleswick by Gordale and Malham. The drainage from the northern side of this ridge is carried into the Ribble by the Cowside beck already alluded to, and thus the whole for some distance enters that river, though the eastern part feeds the Aire and runs eastwards to join the Ouse.

Beyond the confluence of these two streams from the opposite banks, the Ribble, after another mile, makes a short turn to the east but soon recovers its south-westerly direction, and after 6 miles reaches Bolton Park, where it is joined by the Tosside beck, bringing a complicated drainage from the north. Throughout this course (nearly 14 miles, measured on the stream,) the Ribble flows in a somewhat deep valley, winding a good deal.

21. The Tosside beck.—The stream that now enters the Ribble drains by two principal forks an extensive hilly district west of the course of the Ribble, uniting after a flow of 3 miles, and, after another 3 miles, receiving the *Cuddy Sike*, a parallel stream of smaller length of course. The names of the main forks are the *Tosside beck* and the *Bond beck*, the former being the principal. From the junction of the Cuddy sike it is nearly another 3 miles to the Ribble, which then takes a south-westerly course to Clitheroe, a distance of 5 miles, being joined about half way by the *Ings beck* from the east after a course of 4 miles from the northern flanks of the hills near the forest of Pendle.

22. The Bashall brook.—Beyond Clitheroe the Ribble flows in the same south-westerly direction about 4 miles, where it is joined by the Hodder from the north-west, and soon after the Calder. Both are important tributaries. In this part of its course, before reaching the Calder, it is fed by many small streams from the western slopes of Pendle hill, an important range rising from 1,200 to 1,800 feet above the sea, and forming a line of water-shed extending from north-east to south-west, and cut through by the Calder. It also receives some not unimportant feeders from the west, the chief being the *Bashall brook,* coming from a group of hills to the north-west, of which Easington fell, rising to 1,300 feet, is the largest. The Ribble runs about midway between Pendle hill and Easington fell, two nearly parallel ridges, and receives the drainage from the western flanks of one and the eastern flanks of the other.

23. The river Hodder.—The river Hodder receives the drainage from the southern flanks of the hill-ground of the Burn moor, where the line of water-shed is from 1,300 to 1,600 feet above the sea. A number of small branches unite to form the Hodder at a point about 800 feet above the sea, whence the river flows in a generally southward direction for several miles, receiving on each side a number of tributaries, some of considerable size, draining the hilly ground to the east for a distance of 4 or 5 miles. Turning then east, it receives from the lofty hill range of the forest of Bowland, 1,750 feet above the sea, a group of streams whose drainage area extends 5 miles west. Among these the largest is the river *Langden,* with its numerous branches. After receiving these additions the Hodder runs south about 4 miles, and is then joined by the river *Loud,* another considerable tributary from the west and south-west, also fed by many branches. Turning, then, east for 2 miles, and then south-east for 4 miles, it enters the Ribble at Whalley Abbey.

24. The river Calder.—The Calder rises in the high ground between Pendle hill and the town of Colne, which is situated on an eastern fork. Each of the principal branches has a course of between 3 and 4 miles, and both flow westwards, but the latter comes from the south as well as east. Proceeding towards the south-west for about 5 miles, it receives from the south-east a considerable stream passing Burnley, and then continues towards the west for about 4 miles, when it is joined by the *Laneshaw beck,* and then turns towards the north-west in a winding course for about 6 miles to the Ribble.

25. Middle course of the Ribble.—Increased by these feeders the main stream has a very tortuous course through a wide valley flowing a little south of west, and receives on both sides a number of feeders from the slopes about 3 miles to the south-east, and from Longridge fell nearly the same distance to the north-west, and about a thousand feet above the sea. *Park brook* is the principal stream from the south, and *Starling brook*, *Boyce brook*, and *Tun brook* from the north. During this part of its course from Ribchester to Preston (about 8 miles in a direct line, but nearly double that distance by the river) the stream winds through a rich alluvial bottom, about a mile wide.

26. The river Darwen.—Near Preston the stream of the Ribble is joined by the Darwen on the left bank. This important tributary rises in the moor-land, near Withnell, and flows northwards, draining a wide range of country to the east and south of Preston by a large number of brooks. The *Roddlesworth* is a large feeder. The moor-land near and to the south of the principal sources of the Darwen receives a heavy rainfall, much of which flows eastwards by the Tonge into the Irwell, and so feeds the Mersey, but there is a considerable surplus which flows to the south as well as that part which supplies the Darwen.

27. Estuary of the Ribble. Douglas river.—A few miles below Preston the Ribble expands into an estuary several miles in width. At the mouth of this estuary the Douglas enters from the south, after a long course through the level expanse of country occupied by New Red Sandstone, that extends almost all the distance from Preston to Liverpool.

The Douglas takes its rise on the moors near Rivington Pike. Its early feeders are supplied from the southern and western slopes of the moors that also supply the Darwen and the Tonge. They are more than 1,500 feet above the sea. Its upper waters are collected in a system of reservoirs for the use of the town of Liverpool. The drainage area supplying the reservoirs is about 10,000 acres, and the mean annual rainfall over this area is 52 inches. The storage capacity of the reservoirs amounts to 4,500 millions of gallons. Some account of this remarkable system of reservoirs will be given in another chapter.

28. General summary of the Ribble basin.—The drainage area of the Ribble above the junction of the Hodder and Calder is 353 square miles, 166 square miles belonging to the streams on the right bank, and 187 on the left. The Hodder drains $103\frac{1}{2}$ square miles, and the Calder 131. The Darwen drains 57, and the Douglas 172. The total drainage area of the system is 816 square miles.

The whole of the Upper Ribble, the Hodder, and all the feeders to this point, flow over rocks either of the lower carboniferous or still older date, but chiefly over carboniferous limestone and shales. The Calder, however, runs over coal-measures, and the Darwen and Douglas rise in coal-measures, but traverse the New Red Sandstone. The main stream below the junction of the Hodder and Calder runs through millstone grit, and some of the feeders of the Calder rise in the same rock.

The course of the Ribble after leaving the moors is through a busy and highly cultivated country, and it passes many manufacturing towns. The part known as Ribblesdale (the valley of the Ribble) is very beautiful, and after passing Preston, and opening out into the estuary, the scenery is exceedingly grand; but the estuary, though 4 miles wide below Preston, is shallow and fordable at low water.

29. The river Wyre.—From the mouth of the Ribble to Fleetwood at the mouth of the Wyre there is no coast drainage. The Wyre is formed by the confluence of a large number of streams, proceeding from the southern slope of Littledale fell and its continuation eastwards, about 1,800 feet above the sea. The Hodder, a tributary of the Ribble, takes its rise in the slopes adjoining. Two principal forks or branches form the main stream, that to the north called the *Tarnbrook Wyre*, and that to the south *Marshaw Wyre*, the former having the longer course and the larger number of feeders. The Tarnbrook Wyre receives also the *Grizedale river* from the north-west, and the whole group of brooks and rivers united flow westwards a few miles, receiving other feeders. The stream then turns abruptly to the south to Garstang, receiving on its course from the north-east the *Grizedale brook* (a second stream bearing the name of Grizedale), and, a couple of miles below Garstang, another *Calder river* from Bleazedale moor, also from the north-east, and having a course of about 8 miles. Two miles further to the south-west the river Brock enters from the east.

30. The river Brock and the estuary of the Wyre.—This tributary of the Wyre takes the drainage of the southern slope of Bleasdale moor at an elevation of 1,500 feet above the sea, and, after receiving many feeders, runs about 6 miles to the south-west. Near its confluence with the Wyre it receives the drainage of an extensive district to the south, conveyed by *Barton brook*, *Blundel brook*, and *Woodplumpton brook*, all supplying power to mills, and having courses of several miles. The Wyre, at its junction with the Brock, changes its direction abruptly, and flows nearly 6 miles due west, receiving *Thistleton brook* from the south. It bends round to the north when it is within 3 miles of the coast, and flows 5 miles a little west of north, through a wide estuary, to Fleetwood, where it enters the wide sandy expanse of Lancaster bay, close to the mouth of the Lune. The whole course of the Wyre is about 28 miles, and it flows through a vast expanse of peaty mud-covered surface. In the words of an old poet—

> "She in her crooked course to seaward softly slides
> Where Pellin's mighty mosse and Merton's, on her sides,
> Their boggy breasts outlay."

31. The river Lune (Lancashire).—The Lancashire Lune is as beautiful and picturesque a river as the Wyre is the contrary. It rises near Ravenstone dale on the Westmoreland moors, and flows northwards and westwards for about 4 miles under different names (*Dale Gill, Greenside beck, Sawdwith beck*), receiving the *Weasdale beck* and other tributaries. After receiving *Bowerdale beck*, which has a northerly course of nearly 5 miles, it first acquires the name of Lune, and then flows nearly due west for 4 miles, joined by the *Langdale, Ellerdale*, and *Tebay becks* from the south and *Chapel beck* from the north. At Tebay it is joined by the *Birk beck* from the north and west, an important tributary draining the southern and eastern slopes of Shap fell, 1,850 feet above the sea, and receiving *Weasdale beck* near its source, and *Bretherdale beck* close to its confluence with the Lune. From this point the Lune takes a fresh departure, and flows 2 miles south to the junction of the *Borrow beck*, a considerable feeder from the west, and thence in a nearly straight course to the south through a valley exceedingly picturesque, and surpassed by few in Lancashire or Yorkshire. This valley abounds in villages and is moderately wide, but it receives few tributaries from either side till Sedbergh is reached, a distance of about 9 miles.

32. The river Rawthay.—At Sedbergh the Rawthay joins the Lune from the east. It has two principal branches. One, called Rawthay, rises on Baugh fell, and flows about 3 miles north-west as a mountain torrent, receiving several feeders, and then turns round sharply and has a further course of about 4 miles to its confluence with the other principal feeder, the river *Clough*, which has an equally long course through a deep narrow valley from the east. Two miles after their confluence the river *Dee* is reached, draining the country for a distance of nearly 12 miles from the south-east by a number of feeders, for the most part very small. The Dee takes the northern and western drainage of the great mountain mass of Whernside, 2,414 feet above the sea. Two miles beyond the junction of the Dee with the Rawthay, the united waters enter the Lune, which has a further course of 8 miles to Kirby Lonsdale.

33. The Greta river.—Two miles below the junction with the Rawthay the *Leek beck* enters the Lune from the north-east, and 3 miles further, passing Tunstall, the river Greta from the east, and *Beckthwaite beck* from the west, add their waters. The Greta rises on the southern slopes of Whernside, and in its upper course is called the *Doe* or *Dale beck*. This stream carries off the rainfall from the slopes of Whernside and Blea moor, and, after a course of more than 4 miles, is lost in a swallow-hole. Its progress continues underground about half a mile in the same direction, when it issues as a considerable stream. Its course is about 4 miles south-west from its emergence to Ingleton, and then about 6 miles from Ingleton to the confluence with the Lune.

34. The river Wenning.—After receiving the Greta the Lune continues to flow south about three miles and a half to its junction with the Wenning, passing the town and castle of Hornby, between hills clothed with wood and backed by the high mountain of Ingleborough. The Wenning, like the Greta, rises among the hills between Lancashire and Yorkshire, but it has a shorter flow. It is joined near Hornby by the *Windburn*, coming from the south. This river originates at the confluence of two considerable forks, draining a large area in the south.

35. The Artle beck and the estuary of the Lune.—Between the confluence of the Wenning and Lancaster, a distance of about 7 miles, the Lune is joined by the Artle beck, a considerable stream from the northern slopes of Littledale fell, but by no other tributary of importance. The river is now wide, and winds between picturesque cliffs in several bold sweeps. Beyond Lancaster it opens into a wide estuary, which narrows again as it approaches the outlet. Two rivers, the *Conder* and the *Cocker*, enter the estuary both from the south and east. These only drain the swamps near the coast. The total length of course of the Lune is 48 miles.

From Lancaster to the mouth of the river the Lune has a course almost due south for about 6 miles, leaving a strip of coast about 3 miles in width which has no drainage towards the sea, or, rather, towards Morecambe bay. This large expanse of shallow water is almost dry in most parts at low tide, but several rivers make their way through it by channels frequently shifting. The first of these beyond the Lune is the *Keer*, a stream of small importance, draining a few miles of high country known as Hutton Roof Park, 500 feet above the sea.

36. The river Kent.—About 5 miles beyond the Keer the river Kent enters Morecambe bay by a similar channel. It rises in a small tarn or mountain lake (now converted into a reservoir, 973 feet above the sea), situated on Kentmere fell, and flows in a southerly course for about 7 miles through a narrow valley, receiving few tributaries till it reaches Staveley, where it is joined by the *Gowan river*, a small stream from the west. It then runs in a more winding course about 5 miles south-east to Kendal, but before reaching that town it is increased by the river *Sprint*, a parallel stream nearly of the same length as the Kent, coming from Long Sleddale, and the *Mint*, one branch of which is also nearly parallel, but is another mile to the east. Both these rivers turn to the west to enter the Kent. Beyond Kendal the course of the stream is more nearly south, and is about 7 miles in length to the estuary, and about 5 miles beyond to the open bay. The river *Beetha* joins the channel of the Kent near Milnthorpe. It receives the *Peasey brook*, and drains a small tract of country to the east. The total length of course of the Kent is about 23 miles.

37. The river Gilpin.—This is another small river parallel and to the west of the Kent, and running chiefly through a wide open bottom. Its channel enters that of the Kent, of which it may be regarded as a tributary.

The *Winster* or *Pool*, also named the *Witherslack*, is much smaller than the Kent. It rises near Bowness, a little to the east of Windermere lake, and has a course of about 10 miles, entering the estuary of the Kent by a wide channel. It flows almost due south, and has no tributary of importance.

Beyond the estuary of the Kent, to the west of a small promontory where Cartmel is situated, the Leven comes into Morecambe bay by another estuary parallel to that of the Kent, and much smaller. The Leven is the first of the group of rivers connected with the Lake district, carrying off the surplus waters from the Cumberland and Westmoreland mountains after a large quantity has been impounded in the series of lakes formed in various parts of these river valleys.

38. The Lake District.—General account.—The lake district of England is a mountainous tract consisting almost entirely of older palæozoic slates, schists, granites, and other metamorphic rocks, occupying the country between the courses of the rivers Eden and Lune and the west coast of England between Morecambe sands and Solway Firth. It ranges for about 30 miles from south to north, and for nearly the same distance from east to west, the whole area occupying nearly 800 square miles. Owing to its geographical position, the elevated character of the land, which rises into considerable mountains, and the numerous valleys by which it is intersected, it is subject to an excessive rainfall, far in excess of that known in any part of England, and only approached in a few isolated districts in Scotland. The rain-clouds that pass over this tract, coming direct from the Atlantic are squeezed out as they pass over the mountain tops and the rain is caught in the valleys. The rocks being for the most part hard and impermeable, there is little absorption, and the result is the rapid accumulation of the water in lakes, tarns, and pools, which by their overflow form rivers, draining northwards, north-westwards, westwards, south-westwards, and southwards.

39. Scheme of distribution.—The following scheme may be useful as affording a general outline of the system. The principal lakes will be found named in the order of their drainage areas, commencing with Grasmere, the most easterly and southerly, and proceeding first westwards and northwards to the basin of the Derwent, and then to the lakes that belong to the basin of the Eden.

There are within the district sixteen lakes of moderate size, and as many as fifty-two smaller lakes or tarns. Many of the latter are exceedingly small, and none of the former more than 10 miles in length. The breadth of the longer lakes is small, and the area of the largest does not much exceed 3,000 acres. Their depth varies greatly, but is in most cases insufficient to approach the level of the sea. The numerous valleys, partly occupied by the lakes, are remarkable for the mixture of wildness with woodland beauty, some being embosomed in wood, and others utterly bare and desolate.

Table of the Principal Rivers and Lakes of the English Lake District.

Rivers and Tributaries.	Name of Lake.	Dimensions of Lakes.			
		Length. miles.	Average width. miles.	Greatest depth. feet.	Height above Sea. feet.
Leven river (or Rothay)	Grasmere	1	¾	—	208
„	Rydal water	¾	¼	—	181
„ Great Langdale beck	Elter water	¾	⅛	—	187
„	Windermere	10	½	—	134
„ Cunsey beck	Esthwaite water	1½	⅜	—	217
Crake river	Coniston water	5½	¼	—	147
Duddon river	———	—	—	—	—
Esk river (Limbeck gill)	Devoke water	¾	¼	—	766
Mite river	———	—	—	—	—
Irt river	Wastwater	3	½	270	204
Calder river	———	—	—	—	—
Ehen river	Ennerdale water	2½	½	80	369
Derwent river	———	—	—	—	—
„ Greta river	———	—	—	—	—
„ St. John's beck	Thirlmere	2¾	1	108	533
„ „	Derwent water	3	1½	72	238
„ „	Bassenthwaite	4	1	68	226
„ Cocker river	Buttermere	1½	¼	90	—
„ „	Crummock water	3	¾	132	321
„ „	Lowes water	1	½	64	429
Ellen river	———	—	—	—	—
Crummock river	———	—	—	—	—
Waver river	———	—	—	—	—
Wampool river	———	—	—	—	—
Eden river	———	—	—	—	—
„ Eamont river	Ullswater	9	¾	210	477
„ Lowther river	Haweswater	2	¼	—	694

40. The river Leven.—Under this name the combined streams of several small rivers draining a considerable extent of country, and expanding into a large number of lakes and tarns, reach the low lands at the head of Cartmell sands, and pass through Ulverstone sands to the wide open inlet of the sea known as Morecambe bay.

The first lake in the upper part of the drainage area is *Codale tarn*, which receives the water draining from Scawfell and Langdale pikes, an important central point in the lake district. The upper valleys in this district are singularly wild and picturesque, and the rainfall very heavy. The stream in this part is called the *Rothay*, and may be regarded as the main branch. Near Grasmere the Rothay is joined by a small feeder (*Easdale brook*) which has passed through *Easdale tarn*, surrounded by lofty cliffs. This pool is 915 feet above the sea, the adjacent mountains rising rapidly and overhanging the lake nearly 1,000 feet.

41. Grasmere lake.—A little more than a mile below the confluence of the Easdale brook and the Rothay, Grasmere lake is reached. The valley of the Brathay is a gorge enclosed between mountain walls rising to upwards of 1,300 feet, and in the short space between the tarn and the Rothay the ground has fallen nearly 700 feet, the distance being less than 3 miles. Immediately below the confluence the Rothay enters low flat ground forming the head of Grasmere lake, which is 208 feet above the sea. The lake is about a mile long, and three-quarters of a mile wide, and the heights around it are covered with wood.

42. Rydal water.—From Grasmere to Rydal water the distance is less than a mile. Rydal water is 181 feet above the sea, and about a mile in circumference. At Rydal, just at the outflow of the lake, the river is joined by *Rydal beck*, which has had a course to the south of about 3 miles. Between Rydal and Ambleside a stream comes in from the north, and at Ambleside another from the north-east, draining valleys contained between narrow ridges more than 2,000 feet above the sea. The length of these gorges is 4 or 5 miles. From Rydal to the beautiful lake of Windermere, the distance is about 3 miles, and a quarter of a mile before reaching the lake, the Rothay is joined by the Brathay.

43. The river Brathay.—Elter water.—The Brathay is formed of two main branches that meet in the little lake of Elter water. The northern branch, called the *Great Langdale beck*, collects the drainage of a number of mountain sides, about 2,000 feet above the sea. Its valley is comparatively open, the length of course of the principal stream is about 6 miles, and it receives on its way many small feeders. At its head is *Stickle tarn* (1,540 feet). There are waterfalls all along its course. The southern branch is called the Brathay, and has a course of about 8 miles, passing between mountains of 2,259 feet to the north, and 2,557 feet to the south. Its sources are nearly 1,500 feet above the sea, but it falls rapidly, and at *Little Langdale tarn*, about 2 miles before it reaches Elter water, the level is 540 feet. Thence to the lake the fall is 353 feet. Elter water is a small irregular mountain lake, communicating by a channel of 3 miles in length with the Rothay, the difference of level being about 50 feet. The Rothay now expands into Windermere.

44. Windermere lake and Esthwaite water.—Windermere is a noble sheet of water, more than 10 miles long, but nowhere a mile across, receiving many tributaries on both sides. It ranges nearly north and south, slightly curving to the east. About $2\frac{1}{2}$ miles from the head of the lake it receives *Trout beck*, a beautiful and picturesque stream from the north, entering on the eastern shore. It has a course of about 7 miles branching at the upper end and receiving a few small feeders. Four miles below the *Cunsey beck* comes in. Rising on the eastern slopes of Coniston moor, nearly 1,000 feet above the sea, in a number of feeders which unite near Hawkshead, after about 3 miles Cunsey beck expands into an irregular lake about 2 miles long, called *Esthwaite water*, its level being 217 feet above the sea, and its breadth more than 500 yards. It is fed by short streams from Hawkshead moor. At its foot there is another small lake, *Dub's tarn*, which communicates by a channel of a mile and a half with Windermere. South of this confluence the great lake of Windermere gradually narrows, receiving few feeders and dying away into the river, which now assumes the name of Leven.

45. The Leven below Windermere.—Issuing from the lake the Leven continues with a regular flow for about 6 miles, when it joins the river Crake, and enters broad flat lands, separated from the bed of the Winster by two considerable bands of high ground. The united stream, under the name of the Leven, has a winding course to the south of several miles before reaching the sea. Several small feeders enter the Leven below Low wood where it first enters the low lands. Of these *Rusland's pool* is the most important, draining a considerable extent of country in a narrow slip towards the north. Under several names, and with several tributaries, it has a nearly straight southerly course of 9 miles, the last four of which are over level open ground, but the rest among the mountains. Another small tributary (the *Colton beck*) joins the Leven before it reaches the Crake.

46. The river Crake.—Coniston water.—The Crake is the stream that flows from the foot of Coniston water. The original feeders of this lake are two, the *Ewdale beck*, which is the largest, and the *Church beck*. The former rises in the high ground south of the Brathay, and has a southerly course of about three miles, with several forks. The Church beck originates in a small tarn, *Levers water*, 1,350 feet above the sea, which descends 1,200 feet in the course of 2 miles by a succession of falls. Another small stream from the north enters the head of Coniston water.

The lake known as Coniston water is $5\frac{1}{2}$ miles long, but narrow, rarely exceeding 500 yards in width. It ranges from north to south, and is 147 feet above the sea. It receives a large number of small streams or torrents from the east. On the west, besides the main feeders and others much smaller, there is one of some importance originating in a small tarn 1,656 feet above the sea, immediately under "the Old Man" (2,633 feet), one of the highest elevations of the district. It has a very rapid fall for about 2 miles, and then a more moderate slope for another 2 miles to the lake. From the foot of Coniston the Crake has a run of about 5 miles to the Leven.

Between the Leven and the Duddon extends the head of the promontory of Furness, drained by a stream which frequently changes its name before it reaches the sea, but which is known in its upper waters as the *Pooka beck*. At Dalton, a mile below, it is called the *Butts beck*.

47. The river Duddon.—This river rises on the northern slopes of Seathwaite fell (2,537 feet above the sea), and Harter fell (2,140 feet). After a course of about 3 miles it receives *Tarn beck*, a stream which passes through *Seathwaite tarn** (1,210 feet), and originates on the southern slopes of Seathwaite fell. From the confluence of these streams the Duddon descends in a S.S.W. course for about 10 miles, receiving several tributaries from the west, of which *Crosby Gill*, *Holehouse Gill*, and *Logan beck* are the principal, to the confluence of the river *Lickle* on the east bank, after a course of about 6 miles to the S.W. Beyond this about 2 miles the *Black beck* enters from the north, coming in on the right bank after a winding course of about 5 miles, much of it through low ground. The Duddon channel now continues, chiefly through alluvial sands and a low-lying district, to the sea, receiving on its way the *Whicham beck*, entering the Duddon at Haverigg, and there called *Haverigg pool*.

48. The river Esk.—There is little drainage to the coast for a considerable distance north of the Duddon estuary, but several small becks convey the heavy rainfall of the district towards the sea, all of them falling into the Esk within a short distance of its outflow. The main stream of the Esk may be considered to originate on the slopes of the Scaw fell (3,162 feet) and Scawfell pikes (3,210 feet), at an elevation of about 1,600 feet above the sea. After a rapid flow southwards of 4 miles, descending 300 feet per mile, an open valley is reached, and a small feeder comes in from the west. After a continued flow of about 3 miles to the west an important feeder enters from Eskdale fell to the north after a course of 5 miles, and another smaller feeder from the south. After a further course of 2 miles to the south-west, through a wider valley, and with some sinuosities, another stream, the *Limbeck Gill*, enters from the south-east, after a course of a mile and a half, being the overflow of a considerable tarn called *Devoke water*, whose level is 766 feet above the sea. This lake is three-quarters of a mile long and a quarter of a mile across. Beyond the Limbeck Gill the Esk has a winding course of more than 6 miles to an estuary, at the entrance of which several streams flow in. Of these the first is the *Samgarth beck*, from the east, conveying the drainage of a ridge of high ground parallel to the

* Near this tarn is the spot where the heaviest rainfall in Western Europe is recorded. A rain gauge in the valley has registered 160 inches in the year, and in one month (Feb. 1848) 30 inches.

coast and the chief mountain ranges, between 1,700 and 1,900 feet above the sea at Stainton fell. Half a mile below Samgarth beck is another much smaller and less important stream, conveying coast drainage from the south.

49. The river Mite.—Two miles beyond the Esk the river *Mite* comes in, having a small independent drainage between two high mountain ridges, one separating the valley of the Mite from Wastwater and the other from the Esk valley. The Mite has very few and very small tributaries till at Ravenglass, within a few hundred yards of the Esk, it receives or is joined by the Irt, a much more important and complicated river system than either the Esk or the Mite.

50. The river Irt.—The Irt originates at Sty head, close to Seathwaite, in two branches, one proceeding from the high ridge connecting Great End (2,984 feet) with Scafell pikes (3,210 feet), and draining the north-western slopes of this mountain mass by several branches round Lingmell (2,104 feet), turning southwards to the head of Wastwater. Just before reaching the lake this branch is joined by another from the north, round Wasdale fell, of smaller importance, and by a third from the east still smaller.

51. Wastwater.—This wild and picturesque sheet of water, one of the grandest of the Westmoreland lakes, is rather more than 3 miles in length, and half a mile across. It is deep, its bottom being considerably below the sea level. It receives some small feeders from the west, but none from the east. Its surface is 204 feet above the sea.

52. The river Bleng.—At the foot of the lake the outflow is nearly due west for 3 miles to the confluence of the Bleng, a tributary of some importance, which has its source in the mountains not far from the principal western feeder of Wastwater, and has a course of more than 6 miles to the south-west and south, and then a further course of 2 miles to the east. From this junction the Irt has a very winding course of nearly 8 miles to the estuary of the Esk at Ravenglass.

53. The river Calder.—About $5\frac{1}{2}$ miles beyond the estuary of the Esk there is another break in the coast line, and the small stream of the Calder enters, accompanied by a much smaller stream, the *New mill.* Both proceed from the mountainous country to the north-east. The Calder has two branches, the easternmost called *Worm Gill,* both proceeding from the southern slopes of the hills that enclose *Ennerdale water.* They are fed by several small streams from both sides.

54. The river Ehen and Ennerdale water.—The Ehen, a much more important stream than the Calder, approaches the coast at a point between 3 and 4 miles to the north of that river, but is driven southwards, and actually delivers its waters to the sea by the same channel. It commences on the north-westerly slopes of the high fells near Sty head, which rise to nearly 3,000 feet above the sea, close to the source of the Derwent. Collecting the waters of several valleys, it runs in a straight course W.N.W. under the name of the river *Liza* to the head of Ennerdale water. It receives feeders on its way, chiefly from the south. The lake of Ennerdale is 2½ miles long and half a mile broad. Its shape is irregular, and it is enclosed by grand mountain forms, some of them very precipitous, rising to nearly 3,000 feet. The level of the lake is 369 feet above the sea. Emerging from the lake the river assumes its name, *Ehen*, and pursues a somewhat winding course to the west for about 6 miles, receives on its way several tributaries. Among these are the *Crossdale beck*, coming in from the north-east at Ennerdale bridge, the *Winderghill beck* and the *Lingla beck*, both from the north. The river afterwards turns south-west and ultimately south at a point where the *Keckle beck* joins it, bringing a considerable drainage from the north. This tributary has a course of about 10 miles, and is fed by the *Dub beck* and other streams. The Keckle beck enters the Ehen near Cleaton, and the main stream then passes on in an even southerly course past Egremont to the coast, where it turns away without finding a direct channel until it reaches that of the Calder.

55. The river Derwent.—Beyond the Ehen there is no stream reaching the Irish sea for a considerable distance, the Derwent, whose mouth is 18 miles to the north, being the next in order. One small rivulet, the *Lowca beck*, is almost the only exception. It enters the sea about 2 miles north of Whitehaven.

The Derwent is one of the largest and most important rivers of the lake district. It has numerous tributaries, and is connected with a very large number of lakes, some of them the best known and the most picturesque of the country. Its source is in the great mountain knot of the district, about 2,000 feet above the sea, where Scawfell (3,208 feet), and Bowfell (2,960 feet) form a central mass flanked by Sty head (2,949 feet) to the west, and Langdale pikes (2,500 feet) to the east. From this central point a number of rivers diverge, Langdale beck and the Brathay going off to the south-east to Windermere, the Duddon to the south, the Esk to the south-west, Wasdale still further west, the tributaries of the Derwent to the north-west leading to Buttermere and Crummock water, and the main stream of the Derwent through Derwent water and Bassenthwaite to the north.

56. Early course of the Derwent.—The principal source of the Derwent is at Styhead pass, 2,014 feet above the sea, but the most interesting is a small lake, *Sprinkling tarn* (1,960 feet), communicating by a channel of about a mile with another tarn (1,430 feet) on Seathwaite fell. The streams from these tarns and the principal source meet after a course of a couple of miles at Stockley Bridge, and passing Seathwaite soon enter Borrowdale, near the entrance of which they are joined by the *Stonethwaite beck*, whose sources are on Styhead pass, not far from Sprinkling tarn. Under the name of *Longstrath beck* the drainage of the mountain sides is conducted northwards, receiving the *Greenup gill*, after which it becomes *Stonethwaite beck*. Joining the Derwent in Borrowdale, the united streams reach Derwent water in about 2 miles, where they are joined by the *Watendlath gill* coming down from *Blea tarn*, whose level is 1,562 feet above the sea. From Blea tarn to *Watendlath tarn* the distance is less than 2 miles, but the level of the latter is only 847 feet, the fall between the two tarns being 715 feet. After leaving Watendlath tarn, there is a further fall of 600 feet before reaching the lake, the stream passing through a ravine and falling at Lodore, near Derwent water, in a noble cascade or 150 feet, which after heavy rain is exceedingly grand.

57. Derwent water.—This lake is a charming sheet of water with wooded banks and islands, about 3 miles long and a mile across, being widest at the southern extremity, which is the head of the lake. It is subject to much increase of volume during and after heavy rains, frequently rising 6 or 7 feet above its ordinary summer level. The islands are of some size, the largest occupying 6 acres. There is some marshy ground at the head of the lake, and a mass of tangled weeds, rendered buoyant by gas evolved during their decomposition, occasionally rises to the surface in that part, forming what is called a floating island. It is sometimes half an acre in extent, and as much as 4 feet thick, but is liable to change. The lake is also subject to a remarkable disturbance of its waters during a time when the air is still.

58. The river Greta and Thirlmere.—The tributary of the Derwent, that joins it as it emerges from the lake, bears the name of Greta for only 4 miles of its course. It commences at the confluence of the *Glendermakin stream*, which comes from the north-east and is joined by many tributaries, with the *St. John's beck*, a stream rising in the Wythburn fells, between Borrowdale fells and Helvellyn (3,033 feet) under the name of the *Wythburn*, and expanding to form *Thirlmere*, or *Leathes water*. This lake (Thirlmere) is about 3 miles long and a quarter of a mile wide, and is 533 feet above the sea. It is not every where picturesque, but affords some grand scenery when seen from the west shore.* The whole course of the beck, including the lake, is about 10 miles from the source to the Greta. It receives very few and insignificant tributaries, but runs a considerable stream of water into the Greta. St. John's vale is subject occasionally to very heavy inundations.

* In the Session of 1878 an Act of Parliament was passed authorising the construction of the works required to convert this lake into a reservoir for the use of the city of Manchester. The proposed works are on a very grand scale, and will not be completed for many years. The engineer is Mr. Bateman, who constructed the reservoirs at Woodhead, which will soon be insufficient.

A mile below the confluence of the St. John's beck, the *Naddle beck* comes in, also from the south. It rises between the hills enclosing Thirlmere on the west, and the mountains shutting in Derwent water to the east, nearly 2,000 feet above the sea. The stream runs north in a straight course for 5 miles. Beyond the junction with the Naddle beck, the Greta runs about 3 miles to the Derwent, entering it as it emerges from the lake close to Keswick.

59. Bassenthwaite lake.—From Derwent water to Bassenthwaite the distance is about 3 miles, the stream flowing north-west. The Derwent is not actually at the head of Bassenthwaite, *Newland's beck* coming in a little to the west and south at the extreme end of the lake to the south-east. This stream rises a little to the north of Seathwaite, and runs a straight course of about 8 miles to the north, receiving several tributaries from the west, but none from the east.

Bassenthwaite is 4 miles long, and about half a mile across. It is flanked on the eastern side by the grand mountain mass of Skiddaw (3,060 feet), but on the western side is less bold. Its elevation above the sea is 276 feet, and it has no feeders either from east or west, except the *Dark beck*, which brings the waters from the north-western side of Skiddaw forest, and is also known as *Chapel beck*.

Issuing from the foot of Bassenthwaite, the Derwent winds considerably in its course through a low-lying country, well wooded and partly under cultivation, curving a little to the north to Ivell, and then abruptly to the south at Cockermouth, where it is joined by the Cocker.

60. The river Cocker, Buttermere, and Crummock water.—The Cocker rises close to the Derwent, about 2 miles north-west of Seathwaite, and is its principal feeder, originating on the slope of Grey Kno (2,287 feet). There are two main branches, the northern passing Honister crag, and that to the south passing through some small pools. After a little more than 2 miles Buttermere is reached. It lies in a hollow, and is singularly gloomy. Its length is $1\frac{1}{4}$ miles, and breadth $\frac{1}{4}$ mile, and it is 330 feet above the sea. A channel about half in mile in length connects it with Crummock water, of which it almost forms a part. This latter lake is much the larger of the two, and is nearly at the same level as Buttermere. Near its lower extremity Crummock water receives a stream which has passed through *Lowes water*, a small lake, a mile long and half a mile wide, lying in a valley, and surrounded with mountains. It is 430 feet above the sea, and its waters descend 108 feet to reach the level of Crummock water. From Crummock water the Cocker flows about 7 miles to its confluence with the Derwent at Cockermouth, and the combined streams continue for about 4 miles in a westerly direction to the junction with the *Marran*. This stream rises on the moors not far from Lowes water, and is fed by several small becks. Beyond this the river continues to preserve its winding character, and after about 6 miles it enters the sea at Wokington.

61. The river Ellen.—Beyond the Derwent, about 6 miles from its mouth, the river Ellen enters the sea at Marypool, after a course of about 20 miles. It rises on the northern slope of the hills that feed Bassenthwaite lake, and is formed by several streams, one of which passes through a tarn called *Over water*. The Ellen flows at first towards the north for about 6 miles, receiving several small feeders. Passing Ireby it turns to the north-west, and continues to receive small affluents chiefly from the south. After some miles it curves round to the south-west, and makes its way to the sea.

62. The Waver and the Wampool rivers.—There is no coast drainage of importance from Maryport to the entrance of Solway Firth, a distance of about 15 miles. At the commencement of the firth two small streams enter, called the Waver and the Wampool. The former rises on the north-western slopes of Caldbeck fell, and has a north-westerly course of about 9 miles to the coast, receiving on its way contributions from a number of valleys. The latter originates in the north-eastern slopes of the same high ground, and has a longer and more tortuous course of about 18 miles, also fed by a number of small streams. Neither of these streams has more than local interest.

63. The basin of the Eden: early feeders.—The river Eden rises on the borders of Westmoreland and Yorkshire, and though it collects no water from the latter county, its sources approach within half a mile of those of the Swale, and within a few hundred yards of those of the Ure. It drains an area of 1,000 square miles, and has a course of 77 miles, including windings. Its course lies about equally through Cumberland and Westmoreland. Its earliest feeders proceed from the southern slope of Mallerstang edge, and run southwards for nearly 3 miles. These early feeders are called *Red beck* and *Hell gill beck*. Turning at the foot of Hell gill the stream first takes the name of Eden, and immediately flows to the north, through a narrow valley nearly 8 miles long to Kirby Stephen, receiving no tributary of importance. It continues in the same direction for about 3 miles further in a winding course, and then receives its first considerable feeder; the river *Betah* coming in from the east from Stainmoor, after a course of 6 miles. Half a mile further north it receives the *Swindale beck,* another considerable stream from the same high land.

After this junction the Eden turns to the north-west, and flows in a somewhat winding course 8 miles to Appleby, receiving on its way several small feeders from both sides. From Appleby to the next confluence is 6 miles, when it meets the waters of the river *Leith* and the *Lyvennet beck,* draining a considerable tract of country to the south and west. The

Lyvennet beck has a nearly direct northerly course through Ravenstone dale of about 10 miles. Between 4 and 5 miles lower the river Eamont comes into the Eden from Ullswater lake.

62. Ullswater lake.—This noble lake, perhaps the grandest and most Alpine of the English lakes, originates in two small streams, the *Coldrill beck* and another, draining a tract of mountain country between Thirlmere and Hawes water. Coldrill beck is the overflow of a small tarn, called *Brotherswater*.

Ullswater consists of three principal reaches. The first, nearly 2 miles long, bears due north from the feeders. The lake then turns east-north-east, and continues more than 3 miles in that direction, and finally turns north-east for another $3\frac{1}{2}$ miles. It is shut in by picturesque mountains on both sides along the whole distance. Its breadth is nearly uniform, varying from half to three-quarters of a mile, and its depth is considerable, averaging more than any of the other lakes. Its waters usually stand at 477 feet above Ordnance data. It has a few very small islands in the upper part, and receives a number of tributaries, none of importance, and almost entirely from the south. The *How grane* is the largest.

Ullswater has several tributary streams, of which the *Ara brook*, leading to Ara Force, and thence to Matterdale, is one of the most interesting. Matterdale, though a wild and interesting spot, has no peculiar features, but in Gowbarrow Park, past which it flows, there is much of interest. "Here is a powerful brook which dashes among rocks through a deep glen hung on every side with a rich and happy intermixture of native wood. Here are beds of luxuriant fern, aged hawthorns, and hollies, decked with honeysuckles, and fallow deer glancing and bounding over the lawns and through the thickets. These are the attractions of the retired views, or constitute a foreground for ever varying pictures of the majestic lake, forced to take a winding course by bold promontories, and environed by mountains of sublime form towering above each other. At the outlet of Gowbarrow Park we reach another stream which flows through a little recess called Glen Coin. Having passed under the steps of Stybarrow Crag, and the remains of its native woods at Glenridding bridge, a third is crossed which is contaminated with the operations of the Greenside lead mines in the mountains above." *

At the head of the lake is a fourth stream, *Grisedale beck*, and after a short distance, another leading to Deepdale, a fine gorge terminated by a cove, which is a craggy, gloomy abyss, with precipitous sides, a faithful receptacle of the snows that drift into it by the west winds. There is a sixth glen on the Cumberland side coming from a cove richly

* Wordsworth's Guide to the Lakes, 1846, p. 87.

decorated with native wood, from which noble views of the lake and mountains are obtained.

On the opposite side of the lake are only two streams of importance, one leading to *Hays water*, and the other extremely beautiful but closely wooded, opposite Gowbarrow.

63. The river Eamont.—The overflow of the great lake of Ullswater, proceeding in a somewhat winding channel, at first to the north, and then to the north-east, reaches the Eden in about 10 miles, passing near Penrith, and receiving on its way two considerable affluents from the south. It is called the Eamont river. It runs with a full stream at all times, and the country is picturesque. The affluents are the *Dacre brook* from the west, and the *Lowther* from the south. The former rises in the moorlands near Penruddock, and flows down a soft sequestered valley for about 6 miles, joining the Eamont a mile before it enters the lake. It is fed by the streams of several branches proceeding from the slope of the hills that shut in Ullswater to the west.

64. The river Lowther and Hawes water.—The river Lowther rises on the northern slopes of Shap fell, about 1,800 feet above the sea, and is formed by three principal streams, which run parallel for about 5 miles, and combine to form a considerable river at Bampton.

The most easterly of these streams bears the name of Lowther, and runs through Wet Sleddale to Shap, with a north-easterly bearing. Near Shap it turns north-west to Bampton. The next and middle stream is the *Swindale beck*, which passes through Swindale, while the third, originating in two small tarns, *Small water* (1,484 feet) and *Blea water* (1,584 feet), runs through Mardale into *Hawes water*, a lake nearly 3 miles long and a quarter of a mile wide, at a level of 694 feet above the sea, receiving several small feeders, the chief of which is *Measand beck* from the west coming through Fordendale. Flowing out of Hawes water the stream takes the name of *Haweswater beck*, and has a somewhat winding course of about 2 miles to Bampton. Here it enters the Lowther. Hawes water is thus described by the poet Wordsworth :—" A sort of lesser Ullswater, with this advantage, that it remains undefiled by the intrusion of bad taste, and from the remoteness of the situation it is long likely to remain so. The eastern bank is clothed by natural wood of no great size or beauty, but richly feathering the hill side and shore of the lake." *

After this confluence the united stream flows almost due north, and in a nearly straight line, about 7 miles to the Eamont. For the first $2\frac{1}{2}$ miles the valley is wide and flat, and receives two small feeders, but, passing Whale, the stream flows through a narrow glen past Askham for about 2 miles. The country then becomes more open, and, passing

* Wordsworth's Guide to the Lakes, 1846, p. 33.

Brougham Hall, the Lowther approaches the larger stream within a few hundred yards, but turns aside and pursues a parallel course for a mile before entering it. After the confluence the Eamont flows about 4 miles before it reaches the Eden.

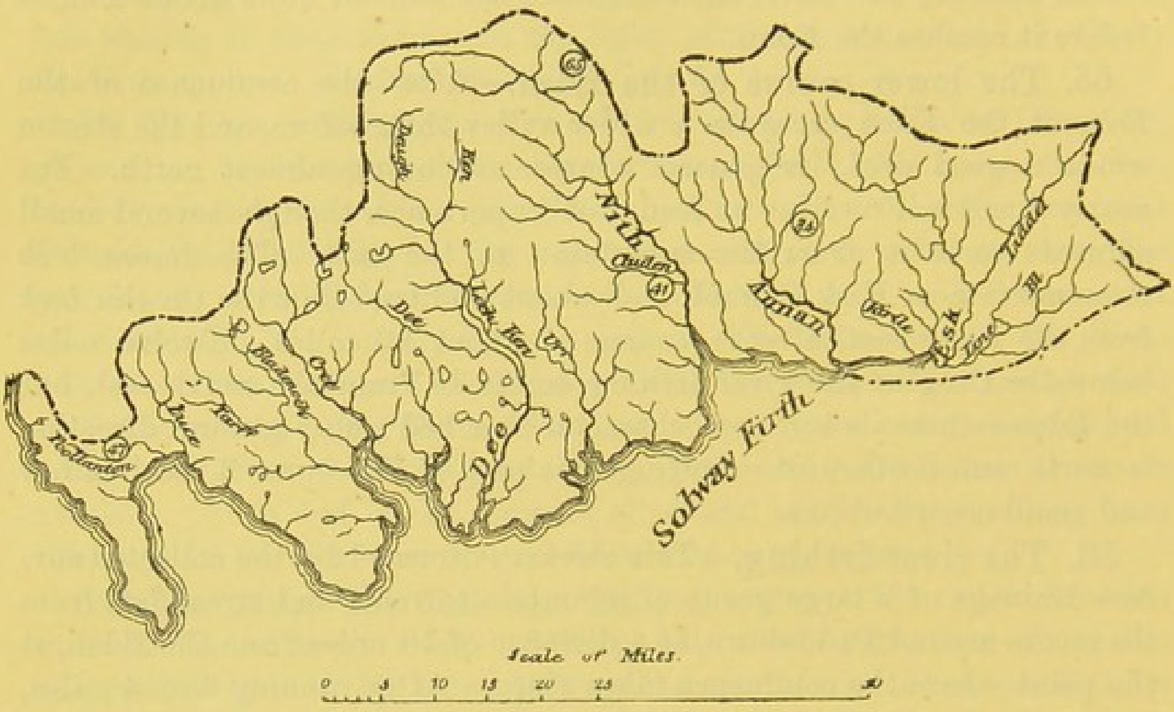
65. The lower course of the Eden.—After the confluence of the Eamont the Eden occupies a wider valley than before, and the stream winds a good deal, its general course continuing almost north. For nearly 8 miles it receives no feeder of importance, though several small affluents come in from the mountains on the east. The *Raven beck* then enters near Kirk Oswald, and about 2 miles below the *Croglin beck* from the north-east, after a course of about 10 miles. Twelve miles below the Croglin the river Irthing comes in from the north-east, but the Eden retains its tortuous character in a bed whose general direction is north and north-west. During this part of its course it receives few and small contributions.

66. The river Irthing.—This stream is formed by the collected surface drainage of a large group of mountain torrents and streamlets from the moors around Paddaburn, at a distance of 16 miles from the Eden, at the point where the confluence takes place. After running 3 or 4 miles, these collect at the foot of Paddaburn moor, and flow about 2 miles in an easterly course. The stream then turns south for nearly the same distance, where the *Butter burn* joins it from the west. A mile and a half below, still to the south, the river makes a sudden turn to the south-west, and flows 4 miles in that direction, receiving a few small affluents from the north. Flowing then for a short distance to the south, the south-westerly course is renewed, and continues 7 miles through a narrow valley to Walton, where a considerable feeder enters which has followed a parallel course for nearly 10 miles, the valleys being about $1\frac{1}{2}$ miles apart. After this it continues about 5 miles south-west to the Eden, winding considerably in the lower part of its course.

67. The rivers Petterill and Caldew.—From the confluence of the Irthing the Eden runs westwards about 6 miles to Carlisle, receiving near that city from the south the *Petterill* and *Caldew*. The former river rises near Penrith, and has a course of about 15 miles, nearly straight, and a little west of north, receiving no tributaries of any note. The Caldew rises on the eastern slopes of Skiddaw, and has a course at first north-east and then north, passing underground for about 4 miles at Haltcliff bridge. It emerges at Sebergham, and then continues about 20 miles to the Eden at Carlisle.

Shortly after passing Carlisle the Eden widens, and assumes the character of an estuary, being there joined by the Esk, a border river which comes in from Scotland and drains a considerable district to the north by a totally independent course.

IX.—Drainage Areas of the Rivers of the South-West of Scotland.



68. The Dumfriesshire Esk.—The first of the small group of rivers now coming under consideration is one bearing the common name of Esk, which rises in the lofty and wild hills which separate Dumfriesshire from Roxburghshire and Selkirk. These hills form an important watershed, branching from the Cheviot hills, and having an elevation varying from 1,500 to 2,000 feet. The Esk consists of two principal branches, the easternmost, the *Liddel water*, flowing through Liddisdale, and joining the Esk about 8 miles above its mouth, and the Esk, flowing through Eskdale. The latter is in all respects the more important branch. Both receive many tributaries, but those of the Liddel are, with one exception, short and unimportant. The *Hermitage water*, from the west, is the largest and longest stream.

The Esk rises on the slopes of Ettrick Pen (2,269 feet) and Loch fell (2,256 feet) to the west, and Craick hill and Ladshaw fell (1,527 feet) to the east. It soon receives the *White Esk* from the west, and soon after *Langshaw beck* from the east. Both these and *Rae beck*, near Langshaw beck, proceed from a lofty semicircle of hills and form a river, which flows to the south for a considerable distance, and then meets the *Black Esk*, a large and important tributary from the west. The Esk now turns east, winding in large curves and receiving several streams, of which the *Megget water*, fed by the *Stennis water*, is the chief.

Passing Langholm, it is next joined by the *Ewes burn* from the north, a considerable stream, and almost opposite to its mouth the *Wauchope* *water* comes in from the south-west. A few miles below the *Tarras water* enters at Irvine from the north, and, not far below, is the confluence with the Liddel. This branch separates Scotland from England for some distance, its tributary, the *Kershope water*, continuing as the boundary beyond its confluence with the Liddel. Still further south the river *Line* enters at Longtown, this little stream flowing entirely over English ground. It is formed by the junction of two forks, the *White Line* to the east and the *Black Line* to the west. The Line is a romantic and beautiful river traversing a deep wooded vale.

At Carrobie on the Esk, where the Liddel joins it, collieries are worked, and the banks of the Esk here are steep and precipitous. The Liddel passes through a very picturesque hilly district, intersected by deep gullies, down which, when it rains heavily, torrents descend with great fury. Parts of the valley of the Esk are exceedingly picturesque.

69. The river Sark and Kirtle.—The small river Sark enters the Solway Firth near the mouth of the Esk. It has a course of about 20 miles from the north, parallel to that of the Esk, rising near Langholm. Solway Moss is a great swampy tract at the head of Solway Firth, between the Sark and the Esk.

The Kirtle also rises near Langholm, a little the west of the Sark, and is fed by several small streams flowing south. These having united, the stream turns to the south-east, and has a run of about 20 miles in that direction, entering the Firth not far from the mouth of the Sark.

70. The river Annan.—The sources of this river are among the hills which also feed the early streams of the Clyde and the Tweed, and are situated a little to the north of Moffat, a town celebrated for its mineral springs (sulphuretted hydrogen). The slopes of Hart fell (2,650 feet) supply the Annan with many feeders. A little below the town of Moffat a considerable branch comes from the north, entering on the left bank, called *Moffat water*, and another on the right bank called *Evan water*. The former originates in a remarkable tarn of glacial origin (*Loch Skeen*), from which a cataract of 200 feet tumbles down a deep gash in the hill side. The road from the falls through Moffat dale is exceedingly romantic. It is entirely in Lower Silurian rock. The Evan has a shorter course than the Moffat water, but is an interesting stream.

From this junction the Annan flows southwards for a long distance, receiving the *Wamphry water* on the left bank, but few other tributaries till its confluence with the *Ae*, a considerable stream rising in the hills to the north-west. These hills separate the early feeders of the Clyde from those of the Annan, and are not far from the course of the Nith. The Ae, like the Moffat, commences with a cataract, but the fall here is only 90 feet, and the quantity of water small. Below the fall the water has cut its way through soft Permian sandstone, and passes through a deep gap, the cliffs rising nearly 50 feet above the stream, and the width so small that a man can leap across.*

The waters of the Ae, collected a few miles below the sources of several early feeders, flow south and east for several miles, and are then joined by the *Kinnel water* from the north, running parallel to the main stream of the Annan. Below the confluence the Annan is reached at Applegarth, and shortly after the *Dryfe* enters, also from the north, and a curious group of nine small lakes, called the *Lochnaben lakes*, is left to the west. The Annan now flows in a winding course for some distance, turns east at St. Mungo for several miles, and then again south, passing the town of Annan, and entering the Firth.

71. The river Locher.—This small stream rises a little north of Dumfries, and flows south, parallel to the course of the Nith, through Locher moss, a moorland district 10 miles in length, after which it takes a south-easterly course into the Solway Firth, running in all about 13 miles.

72. The river Nith.—This is one of the most considerable of the rivers of the south-west of Scotland, and receives the water from the southern slopes of a long line of hills extending from Queensbury Hill in a north-westerly direction. Its sources are in Ayrshire, in a number of small lakes between the Ayr water and the Doon water, both of which streams flow westwards into the Firth of Clyde. Uniting its waters with the *Beoch beck*, it flows a short distance to the north-east, but soon turns eastwards and receives the *Connel beck* and the *Afton water* from the south. It then has a long easterly course, receiving no feeder of importance till it approaches the celebrated lead-mining district of Wanlock head and Lead hills. Here the *Killoe water* and the *Euchan water* join it from the south, and the *Crawick water* from the north. This latter is fed by the *Spangs water* from the west and the *Wanlock water* from the east, collecting the drainage from a long line of hill. After this the Nith begins to turn towards the south-east, receiving the *Menoch water* from the Louther hills to the north, and at Kirkbride it takes a more southerly direction to Thornhill, receiving the *Carron water*, also from the north. A little below Thornhill the united streams of the *Skarr water* and the *Shinnel water* come in from the west, and the river proceeds in a south-eastern direction to Dumfries. Here the *Cluden water* joins it from the north-west, having received several tributaries, of which the *Cavin water* and the *Gleneslin water* are the principal. The Nith below Dumfries opens out and becomes estuarine, entering the Solway Firth in a large bay. Just before entering the Firth it receives the *Pow beck* from the west.

* A scene in Sir Walter Scott's tale of "Old Mortality," between Balfour and Morton, is taken from the recollection of this spot by the great novelist.

The Nith is a beautiful and interesting stream, draining a large district of hilly country, and its banks for a long distance are wooded and adorned with gentlemen's residencies. It has a long course, but its valley is not in any part wide. Measured on the map, and not including the windings of the river, the distance from the source to the sea is not much less than 60 miles. The actual water-way is probably double.

73. The Urr water.—The source of this stream is *Loch Urr*, a small mountain tarn in the western extremity of Dumfriesshire. The stream flows south for nearly 10 miles, receiving some feeders, and then turns south-east. After another 10 miles a considerable tributary comes in from the north-east, and the united stream flows southwards, widening rapidly till it enters the Solway Firth. It has a winding course.

74. The river Dee.—The sources of the Dee are in the western extremity of Kirkcudbrightshire, in a mountain district abounding with small tarns, some of which feed the river Cree and others the Doon. The main stream, however, rises in the north-western part of the same county, on the slopes of the hill called Windy Standard (1,760 feet), and the first and most distant feeder is called *Deugh water*. Another principal branch rises close to Loch Doon. These early feeders unite at Carsphairn and flow to the south-east, receiving, after some miles, the *Ken water*, coming from Black Lorg (2,231 feet). From this confluence the stream, bearing the name of *Ken*, flows southwards into Loch Ken, receiving on its way numerous affluents chiefly from the west, many of them originating in tarns at a very high level.

75. Loch Ken and the Dee water.—Loch Ken is an expansion of the river Ken, and is about 10 miles in length. It is fringed with wood and surrounded by mountains. Its width is inconsiderable. The lower part is sometimes called *Loch Dee*, commencing at the point where the Dee water or *Black Water of Dee*, as it is also called, enters from the west. At this point the Dee is much smaller than the Ken, but the stream for the remainder of its course bears its name. In all this district the rivers frequently expand into lakes.

The wide channel of the Ken, now called the Dee water, continues to the south for a considerable distance to Kirkcudbright, receiving the *Tarf* on the left bank and a number of small tributaries on both sides. It there enters Kirkcudbright bay, and beyond this point the Solway Firth merges into the Irish sea.

76. The Fleet water.—This short stream enters the eastern side of Wigtown bay by an estuary of considerable magnitude. It originates in a small lake or tarn under Fleet fell (1,544 feet), whose outflow is a stream called the *Little Water of Fleet*. After a few miles this is joined by another stream called the *Big Water of Fleet*, and the united waters flow southwards to Gatehouse of Fleet, where they are lost in Fleet bay. The Fleet water is an unimportant stream.

77. The Cree river.—This stream enters Wigtown bay on the west side by a wide and large estuary. It rises among the Carrick hills in Ayrshire, and is soon joined by a stream from the east receiving the overflow of a large tarn called *Loch Moan.* It flows then south for some distance, receiving the *Minnoch water* from the Merrick mountain (2,764 feet), after which it expands into the *Loch of Cree,* and passes on in a south-easterly direction by Newton Stewart into the estuary. At Newton Stewart it receives the *Palkile water*, and a little below the *Polnore water*, both from the north. At Wigton the estuary receives the *Bladenoch river*, a considerable tributary coming from Craigairie fell, a little to the west of the Loch of Cree, and fed by several tributaries. The Cree is a county boundary throughout its course.

78. Luce bay.—Beyond Wigtown bay is Luce bay, a large inlet, receiving at its head a stream called the *Water of Luce,* collected from the hills between Wigtownshire and Argyleshire. It has two principal branches, and its course is nearly 20 miles. Another smaller stream, the *Pooltanton*, receiving many feeders from the north, also enters Luce bay near the mouth of the Water of Luce.

CHAPTER XII.

DRAINAGE AREAS OF EASTERN SCOTLAND.

1. General account of the district.—The part of Scotland whose drainage areas will be considered in this chapter is separated from the Tweed drainage by the Moorfoot and Lammermuir hills, and extends thence northwards to the line of the Caledonian canal. To the east it is bounded by the shore line of the North sea, broken by the deep inlets of the Firth of Forth and the Firth of Tay, and terminating in Moray Firth. To the west it is separated from the Clyde valley and the western drainage of Scotland by a very irregular line commencing near Ben Lomond (3,192 feet), where the Forth takes its rise, running thence to Ben Lui (3,709 feet) near the source of the Tay, thence passing northwards and round the southern and western shores of Loch Lyndoch (which it does not enclose) and leaving Loch Ericht to the west, it reaches the water-shed of the Spey. Following the direction of the southern water-shed of this river, it reaches and crosses the low ridge that separates the head waters of Loch Lochy, which drains to the south, from those of Loch Oich, which drains to the north, at the summit-level of the Caledonian canal, not quite 100 feet above the level of the sea. It then continues westwards, following the line of the southern water-shed of the Garry to the head of Loch Quoich, and turns north-east to Inverness, including the feeders of Loch Ness, and terminating in Inverness Firth.

The area thus enclosed measures about 50 miles from the Moorfoot hills in the south-east to the head of Loch Quoich in the north-west, and its breadth, which is not more than 5 miles from the head of the Firth of Forth to the Clyde water-shed, is more than 75 miles from Peterhead to Ben Lui at the head of the Tay.

This large tract contains some of the most fertile valleys and important manufacturing districts of Scotland. It includes also almost the whole chain of the Grampians, and the wildest and least cultivated parts of the country. It has six principal drainage areas, whose total area is upwards of 6,000 square miles, and a considerable number of less important, but still large catchments, draining direct to the sea.

2. Geology and physical geography.—The geology of Eastern Scotland is comparatively simple. The shores of the Firth of Forth consist of rocks of the newer palæozoic period, chiefly carboniferous limestone, greatly interrupted by outbursts of basaltic and greenstone rock, and succeeded towards the north by a belt of Old Red Sandstone, about 12 miles across, ranging north-east and south-west for 55 miles. Within the basin of the carboniferous limestone, formed by upheavals both to north and south, there is a small tract of coal-measures extending into the drainage area of the Clyde. Beyond the Old Red Sandstone, and rising out from beneath it, is a very wide tract of Lower Silurian and Cambrian rock, through which the granite of the Grampians is thrust up, and on the northern side of these old metamorphic palæozoic rocks is a fringe of Old Red Sandstone, reaching from the middle of Loch Ness to the mouth of the Spey. Except in the coal-measures, there is nothing in the whole district from which running water is likely to obtain any injurious mineral substance.

The physical geography of this part of Scotland is also simple and remarkable. It is throughout a country of mountains, lakes, and rivers. The Grampian chain of mountains forms a line of water-shed, irregular but distinctly traceable, separating the northern from the southern catchments, and ranging on the whole from north-east to south-west.

This determines the main direction of the lakes, and of the stream of the larger rivers. But there is also a constant tendency for the rivers to be turned aside into channels at right angles to this chief direction. The lakes which are without exception expansions of the rivers in the direction of their length, are almost innumerable, though chiefly abundant in the basin of the Tay, where some of them are exceedingly picturesque and grand. The mountains are among the loftiest in the British islands, and their characteristic is grandeur and wildness, to an extent more than justified by their actual elevation above the sea level.

3. Sub-divisions.—This whole country is naturally sub-divided into two parts by the chain of the Grampians. The southern division, which is much the larger, is also conveniently grouped into two sub-divisions, as the basins of the Forth and the Tay are in every respect more important and remarkable than any others. In the northern division we have the separate basins of the Dee, the Don, the Spey, and the Findhorn. The following arrangement will be found convenient:—

Southern division:—

The basins of the Forth and the Firth of Forth.

The basins of the Tay and those of the east coast to Aberdeen.

Northern division:—

The basin of the Dee.

The basin of the Don.

The basins of the north-eastern coast between the Don and the Spey.

The basin of the Spey.

The basin of the Findhorn.

4. Rainfall, evaporation, and percolation.—Except the upper feeders and the sources of the Forth and Tay, and the whole of Loch Katrine, no parts of the drainage areas of the present chapter enter the zone of 75 inches, but a considerable part of the lake district and the early tributaries have a rainfall of more than 50 inches. The zone of heaviest rainfall, ranging between 50 to 75 inches, includes, however, the upper valleys of the principal tributaries supplying the Forth and the Tay. Beyond this there is a zone of about equal width (from 5 to 8 miles) from which other tributaries of the Tay and a considerable part of the Spey and the Findhorn are fed, and within which the rainfall is between 40 and 50 inches.

By far the largest portion of the district, including the whole of the Dee and the Don, the lower part of the Tay, the middle part of the Spey, and the Nairn, receive a rainfall ranging between 30 and 40 inches, this zone extending towards the east coast for a distance of 30 miles, and along a distance of 50 miles from south to north. The actual north coast for about 5 miles, and the shores of the Firth of Forth, have still less rain, the fall there not reaching 30 inches.

The mean fall over the country is undoubtedly large, and the number of rainy days considerable. The evaporation, however, must also be large, and the percolation small. The number of channels carrying off water to the sea is throughout Scotland very great, but there is also a vast accumulation of water in lakes from whose surface the annual evaporation probably exceeds the rainfall.

I am not aware of any estimate of the proportion of the rainfall that runs off to the sea in Scotland. That it is much larger than in England can hardly be doubted, and it is equally certain that an enormous proportion of it passes off in freshets.

5. Quality of the waters.—The waters from all the streams of this drainage area near their sources are unexceptionable. They are pure, soft, and free from any trace of injurious constituent. They flow for the most part over hard altered rock, and, except at Leadhills, where lead-mining is carried on near the sources of the streams, there is no cause of injury. As they proceed on their way some of the streams pass manufacturing towns and coal-mining districts, and thus acquire foreign material; but this applies almost exclusively to the southern districts. The whole of the northern part is thinly inhabited, and has no important towns. The following analyses will be interesting. They are selected from those published by Dr. Frankland in his Sixth Report, and are reduced to grains per gallon:—

Date of Sample.	Tributaries.	Total solids.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates.	Chlorine.	Total Hardness.
23 Aug. 1872	Forth, Bannockburn - - -	8·89	·263	·042	·001	·050	·66	4·1
3 Aug. 1870	,, Loch Katrine - - -	1·68	·130	·015	·001	0	·60	0·6
June 1871	South Esk, at Gladhouse mill -	6·90	·409	·031	·002	0	·54	4·0
15 Sept. 1870	Tay basin, river above Dunkeld -	2·00	·192	·009	0	0	·48	0·9
12 Mar. 1872	North Esk, Mooran burn - -	2·13	·157	·017	0	0	·46	1·3
9 Mar. 1872	Dee, above Balmoral - - -	1·06	·092	·010	0	0	·35	1·1
11 Mar. 1872	Don, Alford bridge - - -	3·96	·078	·018	·001	0	·84	2·5
8 Mar. 1872	Ness, issuing from lake - -	2·31	·253	·039	·001	0	·60	1·8

6. Ordinary flow and floods.—Almost all the rivers of this part of Scotland are torrential. They have very heavy falls in their early course, tumbling over precipitous rocks or forcing their way through narrow and rocky ravines. They thus acquire great velocity, and if the rocks over which they rushed were of a nature to be easily abraded, they would no doubt carry down large quantities of detritus, to be deposited and form alluvial flats at and near their mouths. But this is rarely the case, and as they are not met by a powerful tidal wave, as on the north-west coast of England, the detritus they convey is washed out into the ocean through the two great forths or inlets, or reaches the coast by the numerous small streams where the shores are bold and rocky and the water deep. There are, however, extensive shoals, especially in the Firth of Tay, which show that the quantity of transported rock is of no small extent.

The floods of the Scottish rivers have long been known to exceed in violence those of the English rivers. They occur to some extent every year, but great floods are comparatively rare. Some notice will be found of them in the account of certain rivers, such as the Findhorn, the Spey, the Dee, and others, where great mischief has occasionally been brought about by this cause.

The innumerable lakes and small sheets of water in the rainy and mountainous districts no doubt serve in some measure to keep back the water of heavy rains, and prevent much of the evil that would otherwise occur every season. But there remains enough to render property on the alluvial bottoms of the larger streams very subject to destruction by flood.

7. Scheme of the principal rivers and their tributaries.—The following general statement of the chief rivers and their feeders in the order in which they will be treated may be useful to the reader:—

Southern Division.

Firth of Forth, South Shore.

Eye water.	Water of Leith.
Tyne water.	Almond water.
River Esk.	River Avon.

The River Forth.

Right bank.	*Left bank.*
Duchray water.	
	Gordie water.
	River Teith.
	{ Loch Katrine. Loch Achray. Loch Vennachar. }
	{ Loch Voil. Loch Lubnaig. Lubnaig river. }
	Allan water.
	Devon water.
	South Devon river.
Carron water.	
Avon water.	

Firth of Forth, North Shore.

Orr water.
Leven river.
Loch Leven.
Eden river.

The System of the Tay.

Dochart.
Lochy river.
Loch-Tay.
River Tay.

Garry river.
Loch Lydoch. Loch Ericht.
Loch Rannoch.
Loch Tummel.
Tilt river.
Tummel river.

River Tay.

Right bank.	*Left bank.*
Braan river.	
	Isla river.
	Melgam water.
	Dean water.
	Airdle river.
	Shee river.
Almond river.	
Earn river.	
Loch Earn.	

Firth of Tay to the Mouth of the Dee.

South Esk river.
North Esk river.
Bervie water.
Black burn.

NORTHERN DIVISION.

The river Dee.

Grauley water.	
	Lin water.
	Cuaich water.
Geldie water.	
Girhag water.	
	Gairden water.
Muick water.	
Gairney water.	
Feugh water.	
	Corrichie beck.
	Leicchar beck.

The river Don.

Right bank. *Left bank.*

Leschel water.

Ury water.

Ythan river.

Ugie river.

River Doveran.

Bogie water.

Black water.
Islay.

Turriff water.

Cullen river.

The river Spey.

Nethy water.

Dulnain water.

Avon river.
Dullan water.
Fiddich brook.

Lossie river.

The river Findhorn.

Dorbach water.

The river Nairn.

Loch Duntelchak.

The river Ness.

Loch Oich.

Loch Quoich.
Garry river.
Loch Garry.

Tarff river.

Loch Ness.

Moriston river.

Loch Luine. Loch Cluany.
Doe water.
Glen Urquhart.

Loch Ashley.

The Beauly river.

Loch Affrick.
Loch Benevan.
Affrick water.

Loch Longard.
Loch Cury.
Cannick water.

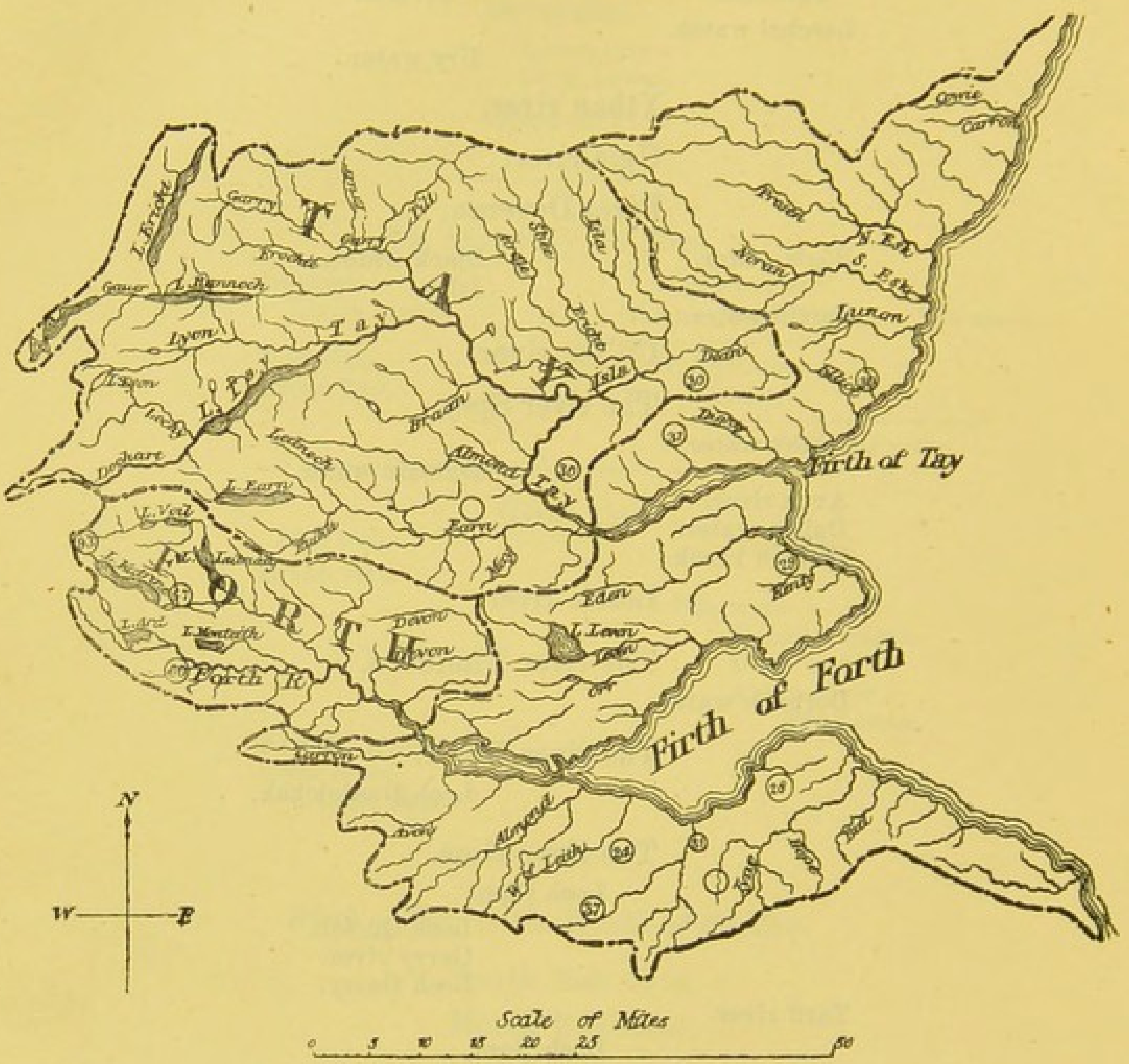
River Glass.

Loch Monar.
Loch Minlie.
Loch Bouchran.
Farrer water.

Beauly river.

Loch Bruaich.

X.—Drainage Areas of the East of Scotland.— Southern Division.



8. The Firth of Forth.—This gulf or deep inlet of the North Sea may be regarded for the purposes of this chapter as commencing at St. Abb's head on the south, and Fife ness on the north, the distance across being there 30 miles. The name is limited in geographical books to the part west of a line drawn from Fife ness to the rocks of Tintallan Castle, where the width is 15 miles. From the entrance as above defined, the width of the estuary narrows quickly to 10 miles, but then expands to 12 miles. Near Leith, 20 miles from the opening of the Firth, it narrows again to 6 miles. At Queensferry, 10 miles further, it is reduced to 1 mile. Beyond Queensferry, however, it opens again, and continues as a nearly regular channel 2 miles wide entering due west till it meets the Forth river. The whole distance from the Forth to the open sea exceeds 50 miles. Several rivers pour their waters into the Firth, besides the river Forth itself.

9. The river Eye.—The first stream of any importance entering the North Sea between the Tweed and St. Abb's head is the Eye, discharging its waters at Eymouth, about 7 miles from the mouth of the border river. The sources of the Eye are close to the northern coast of Berwickshire. Collecting a number of feeders which run south, the main stream flows to the east, and after about 10 miles receives the *Ale water*, its chief tributary from the north-west. This stream, flowing nearly parallel with the Eye, runs near Coldingham. At Ayton, near the confluence of the Ale, the Eye turns north, and after about 3 miles reaches the sea.

10. The Tyne water.—A small stream, called the *Heriot water*, enters the sea near the western extremity of Berwickshire, and another, the *Thornton water*, a few miles beyond in Haddingtonshire; but the only considerable stream in that county is the Tyne water, which enters a small estuary a little to the west of Dunbar. This stream rises in Mid Lothian, and has a course of some length. It is fed by a large number of streams on the northern slopes of the Lammermuir hills, its principal branch, the *Gifford water*, taking its waters from the same hills as the Whiteadder, which feeds the Tweed. The chief tributaries have joined the stream before it arrives at Haddington, after which it runs in a nearly straight course to the sea, which it enters over a bar impeding navigation.

11 The river Esk.—After the Tyne there is no stream of the smallest importance on the coast of Haddingtonshire, but entering the county of Edinburgh we almost immediately meet one of the numerous Esks that belong to Scotland, and one that is so bound up with the history and romance of the country, that it is better known than many streams of greater importance. It enters the Firth of Forth at Musselburgh.

The Esk has two principal branches. The eastern is called the *South Esk*, and the western the *North Esk*. The former rises on the Moorfoot hills, issuing from a small lake in Peebleshire, where the surrounding ground is more than 2,000 feet above the sea. It has a nearly straight course to the north for several miles, receiving only small feeders from each side, and joins the North Esk at Dalkeith. The North Esk rises also in Peebleshire, considerably to the west of the southern river, and passing Penicuik, where it is greatly used for power and for washing purposes connected with manufacture, it proceeds north-east to Dalkeith. Thence the united stream runs north into the Firth. The banks of both branches are picturesque and occasionally romantic. The length of course of the Esk is about 18 miles.*

12. The water of Leith.—This stream rises in the Pentland hills,

* There is a reservoir at the head of the North Esk, having a gathering ground of 1,760 acres. It covers 26 acres, and its bank is 57 feet high. It holds about 150 millions of gallons.

about 1,700 feet above the sea, and receives a number of small feeders from the south-east as it proceeds on its course to the north-east towards Leith, with the range of the Pentland hills at no great distance. It is a stream of considerable local importance. After a winding course of about 20 miles it passes Edinburgh and enters the Firth of Forth, flowing through the harbour of Leith. Less than 5 miles beyond Leith the river Almond enters the Firth, this being the last considerable river of the present group.

13. The river Almond.—This river, draining nearly 140 square miles, is formed of two principal equal and parallel branches rising in the Lothian mountains, each fed from several forks. These unite at a distance of about 10 miles from their sources. Of the two branches, that to the north bears the name of the river, the other being called the *Breich water.* They are both important for trading purposes, several oil and paraffin works being situated on them.

Uniting, and receiving the name of the Almond river about 2 miles below Blackburn, and then flowing another 2 miles, the *West Calder burn* comes in from the south-west, fed by several branches; and $2\frac{1}{2}$ miles below, the *Murieston water* enters, whose early waters are collected into the Cobinshaw reservoir. This river also is formed of two nearly equal branches. The principal branch is the *Linhouse water* from the south. Below the confluence of the Linhouse water, at Mid Calder, the Almond flows north-east for 5 miles, where it receives the *Niddry* and the *Bronburn*, the only streams joining it on the left bank. Both of these come in from the west, and 3 miles below their confluence the Almond enters the Firth of Forth. The general course of the Almond is north-east. It flows for about 20 miles, and its sources are in high ground and hilly country.

Besides the Almond, which forms the eastern boundary of Linlithgowshire, there is the river *Avon*, which forms its western limit, and separates it from Stirling. The *Carron*, rising in the Campsie fells, some distance to the west, runs a nearly straight easterly course of 20 miles to Grangemouth, where it enters the Firth.

13. The river Forth.—The river Forth, though its length of course is inconsiderable, takes rank among the chief rivers of Scotland, on account of its vicinity to the capital and the importance of its tributaries, connecting with large and picturesque lakes. The extent of its drainage area amounts only to 645 square miles.

The northern feeders of the Forth approach the sources of the Tay, but are separated from them by lofty mountains. The upper part of the basin is very rugged, and the line of water-shed irregular. Its catchment receives a heavy rainfall. Below Aberfoyle it is not a rapid river. It is navigable to Stirling.

15. Sources and early feeders.—The sources of the Forth are on the slopes of Ben Lomond, 3,000 feet above the sea, and almost overlooking the grand scenery of Loch Lomond, whose waters flow into the Clyde. The river is formed by two branches, which unite at Aberfoyle after running 16 miles and 12 miles respectively. That which is most important, originating on the north slopes of Ben Lomond, is the *Duchray water*. It flows south-east, receiving several feeders, and after some miles turns east to Aberfoyle. The other stream, flowing from the source of the Forth, expands into three beautiful tarns or highland lakes, *Loch Chon*, *Loch Ard*, and *Loch Dhu*. The united streams from these lakes meet a little above Aberfoyle, and thenceforward are known as the river Forth. The river is almost immediately joined by the *Kelty water* from the west.

The Forth, now formed, proceeds for some miles in a generally eastern direction, till it is joined by the *Goodie water* on the left bank. This river is the overflow of a lake a little to the east of Aberfoyle, and its course is parallel to that of the Forth. This part of the valley is wide, and enclosed by hills of moderate elevation. A few miles beyond it is joined by the Teith, its first considerable tributary.

16. The river Teith.—This stream drains the mountainous country north of Loch Katrine. It is formed of two principal branches, both connected with large and important lakes. The southern branch, rising on the eastern slopes of the mountains that shut in the northern extremity of Loch Lomond, soon expands into *Loch Katrine,* passes then through the Trossachs to form *Loch Achray*, and afterwards it again expands into *Loch Venachar*. About 2 miles below its issue from Loch Venachar this southern branch unites with the northern.

The northern branch originates on the slopes of the western extremity of the braes of Balquhidder, and flows for some miles as the *Balvaig river* its direction being north of east. It then expands into the lakes *Doine* and *Voil*. On issuing from these, after about 2 miles the stream turns through Strath Ife, and after another 3 miles opens into *Loch Lubnaig*. Below the outlet of that lake it meets the southern branch at Callendar, and the two uniting take the name of Teith. This name, however, is first given to the stream that issues from Loch Venachar before the two branches have joined.

17. Loch Katrine.—This celebrated and beautiful sheet of water is 9 miles in length and about 2 miles broad in the widest part. It is enclosed by bold mountain sides, the level of its water is 364 feet above the sea, and the lake is in places 500 feet deep. The scenery of the lower part, where the gorge of the Trossachs opens out, affords some of the grandest views in the British islands.

The water supply for the city of Glasgow is now taken from Loch

Katrine, and for this purpose the waters of the lake have been banked up 5 feet. The supply is taken from a point near the western extremity of the lake on the southern side, not far from the sources of the Forth. At present only 70 million gallons per day are required. The water is conveyed by pipes on aqueducts and through the mountains in various places by as many as 70 tunnels, the distance being 36 miles. The engineering difficulties in the construction of these great works, which were designed and completed by Mr. Bateman, were very considerable, owing to the mountainous nature of the country. The works were completed in 1859, and have since then been in constant operation.

18. Loch Achray.—Leaving Loch Katrine, the stream conveying its overflow takes the name of the *Achray water*, and in about a mile, flowing through the celebrated pass of the Trossachs, it expands into a small lake, called Loch Achray. The level of the water here is 276 feet, showing a fall of nearly 90 feet in this short distance. The scenery of Loch Achray is gentle and beautiful, affording a remarkable contrast to the wild mountain character of the Trossachs.

19. Loch Venachar.—From the Brigg of Turk at the foot of Loch Achray, it is rather more than a mile to Loch Venachar, which is about 5 miles long and $1\frac{1}{2}$ mile broad. The upper extremity is fine, but not remarkable. The lower extremity is bleak and tame. Below the lake the outflowing stream is again called the Teith, and in about a mile reaches Callendar, where in is joined by the river *Leny* from Loch Lubnaig. A small lake, *Loch Drunkie*, a short distance to the south, connects with Loch Venachar near the western end.

20. Loch Doine and Loch Voil.—Returning now to the Balnaig river, Loch Doine, the first of the lakes formed by the expansion of the Balnaig, is hardly separated in any natural sense from Loch Voil. The two lakes are together 5 miles long. The country is singularly wild and deserted, but the lakes are beautiful, and fringed in many places with trees. Both these lakes, which have a north-easterly direction, lie under the braes of Balquhiddar, which rise in Stobinian to 3,821 feet above the sea.

21. Loch Lubnaig.—This lake is 5 miles long, and a mile across. It is a fine sheet of water, and the mountains on both sides are steep and rugged, the general effect being that of massive grandeur, although the banks are clothed with trees, which give a softer character than is the case in some of the lakes. The stream that flows out of the lake is called the *Leny*.

22. The Teith from Callendar to the Forth.—Issuing from the chain of lakes, the Teith is joined soon after leaving Callendar by the *Kelty water* from the north. This stream runs in a south-easterly direction past Doune Castle in a valley very interesting as being the scene selected by Sir Walter Scott for his poem of the Lady of the Lake. A few mountain streams come in, chiefly from the north. Beyond Doune the valley widens, and the Forth is entered.

23. The river Allan.—The Allan joins the Forth about 2 miles below the confluence of the Teith. It drains a considerable district to the north through Strath Allan, receiving on its way many small feeders, and some larger branches. Passing Dunblane, the river reaches the watering place called the Bridge of Allen, where there are mineral springs containing a considerable quantity of common salt and muriate of lime.

24. The rivers Devon.—At Stirling, a few miles below the confluence of the Allan, the Devon enters the Forth from the east. This river rises in Perthshire, and traverses a long stretch of country from east to west at the foot of the Ochil hills, and then turning south it enters the Firth of Forth near Alloa, receiving on its way several tributaries, of which we may mention the *Dollar*, the *Tillicoultry*, and the *Alva*. The *South Devon* is another feeder rising in Fifeshire, and flowing westwards to near Clackmannan, where the North Devon enters. Except during flood this latter is a small stream.

25. The river Leven.—The Leven is the next important stream entering the Firth, after the river Forth has merged in the inlet. It originates in a number of small streams from the Eastern Ochils, which form *Loch Leven*, a beautiful sheet of water 9 miles in circuit, dotted with many islands. Its outlet is at the eastern extremity, and is called the Leven on emerging from the lake. It runs about 12 miles in a nearly direct easterly course to the Firth, which it enters by a small estuary after receiving a few tributaries, of which the *Orr water* is the chief. The Orr water comes from *Loch Fitty*.

26. The river Eden.—There are many small rivulets and torrents, but no streams of importance, entering the Firth on its northern shore between Leven and Fife ness, and none north of the ness till the estuary of the Eden is reached, shortly before arriving at the Firth of Tay. A stream called the *Pitmilly burn* enters St. Andrew's bay, but it has a very small drainage area.

The Eden rises in the Lomond hills, and runs in a slow stream about 20 miles east and north-east through the central vale or Howe of Fife, sometimes called Stratheden.

27. The Firth of Tay.—About 5 miles north of the point where the Eden enters the sea, the entrance to the Firth of Tay is reached. This arm of the sea is greatly inferior in dimensions and importance to the Firth of Forth, being only 3 miles wide at the entrance, and at a very short distance the width is reduced to 1 mile. It afterwards enlarges and continues with a width of about 2 miles, very gradually narrowing for as much as 20 miles to the point where the Tay is met by the Earn. The bed of the Firth is much encumbered by sands. The direction of the Firth from the sea is nearly west-south-west. The Earn may be regarded as an independent stream.

28. The river Earn.—This river originates on the slopes of Ben More, 3,800 feet above the sea, close to the north shore of Loch Voil. Two small streamlets convey the drainage from these slopes to *Loch Earn*, a lovely highland lake 7 miles in length from west to east, and a mile to a mile and a half wide, receiving two small streams from the north. From St. Fillans at the lower end it runs about 5 miles to Comrie, where two feeders join it, one (*Lednock river*) from the north, and one (*Buchil water*) from the south. After another 5 miles Crieff is reached, and the river begins to take a less direct course, retaining, however, its general direction to the east. From Crieff the distance to the outfall in the Firth of Tay is something more than 20 miles.

29. The river Tay.—This important Scottish river takes its origin from a small lake on the borders of Argyleshire, near Tundrum, on the slopes of a mountain 3,650 feet above the sea. A small channel fed from minute lakes, and called the *Dochart,* conveys the waters from the upper sources to Loch Tay, a distance of nearly 20 miles to the north-east. Just before entering the lake, a considerable tributary is received, the *Lochy,* which has had a circuitous course of 16 miles, rising close to the main sources of the Dochart. The Lochy passes over some rapids on its way to the lake, and its course is broken and picturesque.

30. Loch Tay.—This lake is 15 miles long, and $1\frac{1}{2}$ miles broad at its widest part, running north-west. About half-way from the end on the north-west side is Ben Lawers, one of the loftiest mountains of this part of Scotland. It rises immediately from the lake, nearly 4,000 feet above the sea. The banks of the lake are steep and shelving, and the depth of water in some parts is believed to exceed 600 feet. Below the lake the Tay issues in a large volume of water, and is almost immediately joined by the river *Lyon,* whose sources (including a small loch of the same name), are within a couple of miles of the source of the Lochy. This river, as already pointed out, rises close to the course of the Dochart (or Tay) at Tyndrum, and its course is, therefore, nearly parallel to that of the lake and the Dochart for its whole distance. The Lyon also receives a small tributary near its outfall coming from Schehallion in the north (3,564 feet).

31. The Tummel river.—After the confluence with the Lyon, the Tay, flowing eastwards 14 miles, receives the Tummel river. This important tributary, and its almost equally important confluent, the Garry, both take their rise in the same mountain mass, but do not receive the names they are ultimately known by till after they have performed a large part of their course. *Loch Lydoch* occupies a part of the long lonely moor of Rannoch, and is a singularly irregular sheet of water. From it there is a short passage of 6 miles, called the *Gauer river*, flowing north-east, which conducts to *Loch Rannoch*, a beautiful piece of water 11 miles from west to east, and a mile wide, the banks being partly cultivated. Near the upper part of this lake, where the Gauer enters, a short stream running south-east brings in the waters of *Loch Ericht*, a long narrow lake running up in a northerly direction for a distance of 14 miles. The stream as it issues from Loch Rannoch is then first called the Tummel, and it continues with a few small windings, but in a general easterly direction, through *Loch Tummel* to the Tummel falls, where it joins the Garry. The distance is 18 miles. The view of Loch Tummel from the hill above, coming up the valley, is exceedingly fine, and the falls of Tummel (about 18 feet) are picturesque.

32. The Garry river.—This stream rises in the angular mountain space between Loch Rannoch and Loch Ericht, by a number of small channels which unite in *Loch Garry*, a small lake about 3 miles long, and extending from south to north. Issuing from the lake the stream turns in a south-easterly direction to Strowan (11 miles) where it receives a small feeder from *Loch Chon* coming down Glen Erochkie. Almost at the same spot another feeder enters from the west, and another from Glen Bruar, among the Grampians, in the north. Three miles below is Blair Athol, where Glen Tilt opens out from the Grampians, and the river *Tilt* flows through the Pass of Killiecrankie to join the Tummel. From the confluence of the Garry and Tummel to the Tay is about 6 miles. The whole course of the Tummel is about 40 miles, and the length of the course of the Garry about 30.

33. The Braan river.—From the confluence of the Tummel the Tay runs about 6 miles to Dunkeld, where it receives the Braan river. This stream originates near Loch Tay, and after running a few miles through Glen Quoich passes through a small lake. It is only on emerging from this lake that it is called by the name by which it reaches the Tay. It has a total course of 20 miles from the south-west. Passing Dunkeld, and running about 10 miles east, the river turns to the south, receiving at this angle the river Isla from the north, and before arriving at Perth (10 miles from the bend) it also receives the *Ordie* and the *Shee*, two small streams, and the *Almond*, a more considerable feeder. The length of course of the Almond, from its source near Loch Tay, is about 24 miles.

34. The river Isla.—This is an important tributary rising from numerous torrents among the Grampian summits on the north-west of Forfarshire, and proceeding by a number of separate glens, parallel to each other and all about the same length, to meet in one stream (the Isla) a little south of Blairgowrie, where they join the Tay. The course of the Isla is south-west, and in escaping from the Grampians some of its branches have worn perpendicular chasms in the granite rocks, over which the water pours in magnificent cascades. The *Melgam water*, the *Dean water*, and the *Shee*, or *Ericht* (nearly 30 miles long), which joins the *Airdle* (20 miles), are the names of the more important of these streams.

The total length of course of the principal branch of the Tay is 105 miles, and the river is computed to carry to the sea a larger volume of water than any other in Great Britain in proportion to its drainage area, which amounts to 2,250 square miles.

34. Summary of the Tay.—Rising as we have seen in the central part of the Western Highlands of Scotland, in a very wild, elevated, and mountainous district, this great river flows first south-east and then north-east to form a great expansion between Killin and Taymouth. It then flows to the north for some distance till its junction with the Tummel, when it bends round to the south to meet the Braan, near Dunkeld. After this it flows eastwards to the Isla, and then curves round by west to south till it reaches Perth, and terminates its course in the Firth of Tay. It is certainly one of the most beautiful as well as one of the most considerable rivers of Scotland, passing through the richest districts of that country, and forming the principal ornament to some of the most romantic tracts in nature. It rushes with singular and characteristic rapidity through the gloomy hollow of Glen Dochart, where it forms a small and melancholy lake with a bare island. It then expands into another, but in this case a charming lake, surrounded partly by lofty mountains and partly by well-wooded, populous, and cultivated country. Loch Tay is not, as is often the case, a monotonous sheet of water, but makes three beautiful turns, by which it is divided in its great length, and good roads are constructed on its banks or on eminences overhanging the water on both sides, commanding every species of the sublime and beautiful in landscape. Few scenes are more beautiful than that near Taymouth, where the lake passes once more into the condition of a river.

Beyond the lake the Tay, now a great river, rolls in majestic state, increased by the waters of the Lyon, till it is joined by the Tummel, which alone with its noble tributary, the Garry, would be sufficient reason for selecting the Tay as affording the finest river and lake scenery of our islands. The river retains its picturesque character throughout the rest of its course until it expands into the estuary or Firth of Tay, on which is situated the flourishing and handsome city of Dundee.

The Sidlaw hills, ranging north-east from Perth, parallel to the northern shores of the Firth of Tay, are distant from it about 5 miles. There is no opportunity for any considerable stream from the mouth of the Tay at Perth to the mouth of the Esk at Montrose, a distance of about 50 miles along the coast; but there are a great number of small channels at short distances apart, serving to carry off the surplus water in this district. There are no lakes on this part of the coast connected with the eastern drainage.

35. The South Esk.—The South Esk river originates in the overflow of *Loch Esk*, a small mountain lake in the Grampians. Fed by some small branches near its source, this stream runs through a narrow valley to the east and south-east, receiving hardly another feeder till it is joined on the right bank by the *Prosan*, which rises not far from the sources of the South Esk, and runs a parallel but rather shorter course. The united streams run east about 5 miles, and then proceed north-east to Brechin, receiving the *Noran water* from the north-west. The South Esk then takes a turn to the south-east and enters the sea in a small basin at Montrose. It is a rapid stream, and has a course of more than 40 miles.

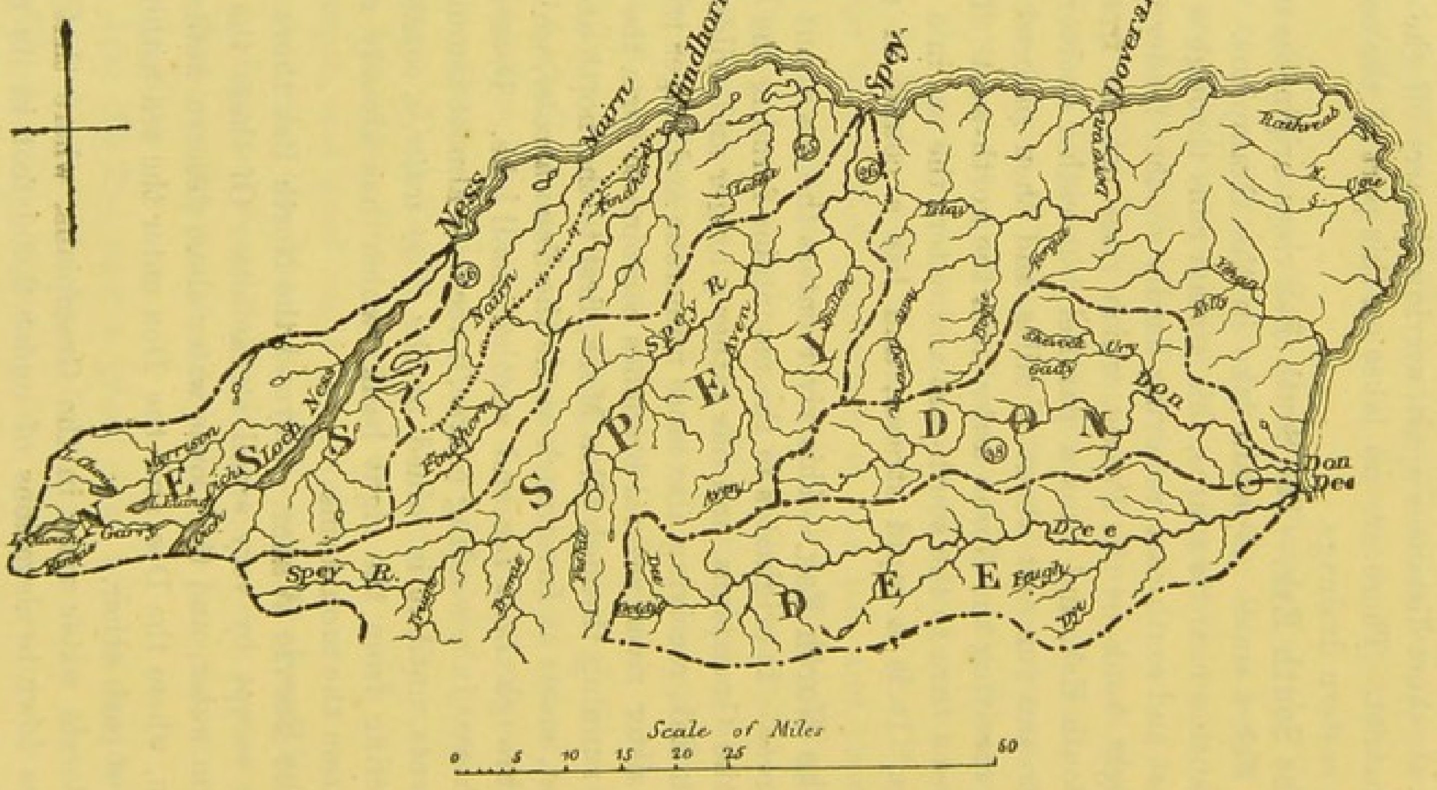
36. The North Esk.—This river enters the sea about 3 miles north of Montrose. It originates in the mountains forming the eastern extension of the Grampians, and has rather a longer and wilder course than the South Esk, receiving also more numerous and larger tributaries. As with its sister river, several branches combine to form the stream. One of these running through Glen Mark, first to the north and then to the south-east, meets at Invermark castle the *Ennoch water*, which has already passed through *Loch Lee* and another small lake. Descending then to the south-east in a winding course, it receives almost innumerable mountain torrents, until it is joined by the *West water*, a considerable tributary entering from the right bank, which has already received many feeders from the mountains.

37. The Bervie Water.—Beyond the North Esk there is little coast drainage except by very small streamlets. Of these the Bervie river, the Carron water, and the Cowie water alone deserve notice till we reach Aberdeen, where the Dee and the Don enter the sea within a very short distance of each other.

The Bervie water rises in the Grampians, where that great granite chain dies down to elevations of under 2,000 feet in its eastern extension. The course of the river is south-east for about 15 miles, to the town of Bervie, where it enters the sea. The *Carron water* is a still smaller stream, entering near Stonehaven. Both rise at an elevation of 1,800 feet, and are little more than mountain torrents. The *Cowie water* enters about a mile north of Stonehaven.

XI.—Drainage Areas of the East of Scotland.

Northern Division.



Northern Division.

38. The Grampian chain and the drainage north of the Grampians.—The great chain of the Grampians crossing Scotland from west to east completely separates the drainage areas of the northern and southern parts of the eastern water-shed of Scotland, and we have now to enter on another district, of which the axis of the river basins as far as Dornoch Firth is more generally to the north of east, whereas the general direction of the Forth and Tay, and their numerous tributaries, has more or less a southerly bearing. There are no drainage areas in the northern district so large or so important as those of the south. From the northern flanks of the mountain chain the drainage is effected for the most part by rivers of moderate size, with few and small lakes, so far, at least, as the Moray Firth, and the chain of lakes extending south-west to the sea on the western side. Beyond this remarkable line of depression the drainage is by very small river basins, but the number of lakes is almost incalculable. The annexed map will enable the reader to form a general idea of the position and relative magnitude of the various catchments.

39. The river Dee.—The Dee, which must be distinguished from the number of other rivers of the same name as the Aberdeenshire Dee, commences with five springs of limpid water issuing from among granitic detritus on the declivity of the Cairngorm mountains, which are nearly the highest points of land in Scotland, the height of the sources being 4,060 feet above the sea. The stream from these springs, two of which never fail, flows a short distance to the south, and falls over the edge of a craggy precipitous rock, and is seen as a white stripe on the mountain side from a long distance. The early waters have been occasionally turned to flow into the Avon, a feeder of the Spey, which rises a few hundred yards distant from the springs. Four miles from the springs the young river is joined by the *Garrachorry burn*, coming from the west $1\frac{1}{2}$ miles. To this confluence the fall of the Dee has been in all about 2,000 feet, or at the average rate of 500 feet per mile, a heavier fall than occurs in any other river of the British Islands.* The course of the stream continues south in a narrow valley, and after 3 miles another stream comes in from the west, after rounding the mountain of Cairn Toul (4,249 feet). This is the *Guisachan burn*, which passes through a small lake. The rate of fall during this part is reduced to 114 feet a mile, but the stream is still a torrent. The next 5 miles, passing through Glen Dee, bring us to the *Geaully water*, the fall being at the rate of 70 feet per mile. During all this upper part of its course the Dee is a raging torrent after heavy rain. The

* The relative amount of fall will be recognized at once by referring to the diagram in p. 129.

Geaully is a large tributary from the west, flowing more than 10 miles, and receiving large feeders from the south and north. The southern feeder (*Brennock water*) drains an important mountain tract.

Two miles below this confluence the Dee takes an easterly course, after passing the Linn of Dee, where the river descends to a lower level by three small falls, amounting in all to 30 feet. After this it forces its way through a narrow ravine for 2 miles, and then receives from the north the *Lui burn*, whose course is parallel to that of the Dee, and which has two sources, both nearly adjoining Loch Avon. A mile below the *Ey water* enters from the south, after a course of 8 or 9 miles. Three miles further the river Cuaich or Quoich* comes in from the north, a stream resembling the Lui, and from the same mountain sources. There is a waterfall near the confluence of the Cuaich, and as far as the confluence of that river the Dee and all its tributaries are little more than mountain torrents.

The next river that joins the Dee is the *Clunie water*, from the group of mountains to the south. It is formed by two principal and equal branches; that to the west is called *Baddoch water*, the eastern fork being the Clunie. Two miles before reaching the Dee the Clunie receives the *Callater burn*, passing through Loch Callater. It is an important tributary. A mile below the Clunie the *Sluggan water* enters from the north, and the stream then continues for 3 miles without additions.

A group of torrents rushing over cataracts now joins it from the south, and, after 5 miles, Balmoral is reached. Near the Castle two torrents come in from the north, and one, the *Geldie water*, from the south, passing through the Forest of Balmoral.

From this part of its course to the next important tributaries the distance is as much as 7 miles. An important valley to the north (Glen Gairn), reaching nearly to the sources of the Dee, is drained by the *Gairn water*, collecting the water from the mountain sides by many tributaries and flowing from the west for a distance of 18 miles, after which it turns south for 2 miles to deliver its waters into the Dee at Ballater, nearly opposite the point where the *Muic water*, bringing the overflow of *Loch Muic* and *Loch Duloch*, enters from the south. The Gairn enters the Dee about 40 miles from the source of that river. Up to this point the Dee flows in a deep valley bed, but its fall for the last 26 miles is not more than 15 feet per mile.

After receiving the Gairn and the Muic, the Dee winds round the plains of Ballater, and continues with a somewhat heavier fall to Banchory, receiving a succession of feeders from the north, some being the

* This river is so called from the circular holes which have been worn into the micaceous rock. The word *cuach* means a drinking-cup. The waters of the river here are exceedingly clear and pure.

overflow of small lakes. During this part of its course the bed of the main stream falls at the rate of 26 feet in a mile. At Banchory it is joined on the right bank by the *Feugh*, this stream having a course nearly east, and being composed of several branches. Beyond this confluence the Dee enters the plains, and continues to Aberdeen, a distance of nearly 20 miles, having now a mean fall of less than 5 feet per mile. During this lower part of its course it continues to receive small tributaries both from the right and left bank.

The scenery of the upper course of the Dee is exceedingly wild and bold, the mountains at its source being among the loftiest in the British islands; and the features of the country strongly recall to mind many parts of the Alps. Sir T. D. Lauder remarks, in reference to this, "I do not speak of those regions bordering on glaciers and eternal snow, which the savage aspect of the lonely Loch Avon so much resembles, though the mountains about the source of this river possess many such specimens. But I allude to the magnitude of the features of Braemar, where the immense extent of its pine forests and the huge bulk of its timber give quite a Swiss character to the country. The rapidity and wildness of many of the streams, their craggy channels, the infinite variety displayed in the grouping of their birches and picturesque firs, often partially interposing their deep green mantles before the white foam of the waterfalls, and the accidental glimpses of the misty mountain tops caught between them, combine to form an endless variety of pictures, such as are to be met with among the upper Alpine ravines.* The drainage area of the Dee is 765 square miles.

40. The river Don.—The Don rises in a peat moss on the hills bordering the eastern mountains of the Cairngorm group, in the western border of Aberdeenshire, 1,600 feet above the sea, not far from Gairn water, a tributary of the Dee, and about 10 miles due north of Braemar. It has a winding course of 62 miles, the direct distance from the source to the sea being 40 miles. Its drainage area is 530 square miles, or nearly three-fourths that of the Dee, and its length of course is much less. It is liable to torrents, which are, however, less serious than those of the Dee, as it receives fewer and smaller tributaries from the high mountain sides before it emerges from the mountains.

41. The river Ury.—At Inverary the Don is joined by the Ury or Urie, which rises in the hills east of Strathbogie, 1,500 feet above the sea, and receives several feeders before it reaches the sea. Its length of course is 24 miles. Before the confluence of the Ury, the stream of the Don, which at first is rapid, the river rushing over a shallow bed, has become quieter, but it is still liable to heavy inundations. There are some smaller tributaries between the Ury and the sea. The Don has

* Great Floods in Morayshire, p. 352.

been celebrated in former times for its pearl fishery, and pearl oysters are still frequently found in its bed.

42. The river Ythan and the Ugie.—The Ythan and two much smaller streams enter an estuary on the coast about 10 miles north of the mouth of the Don. The Ythan is generally a slow and gentle stream rising in the north-west corner of Aberdeenshire, and having a considerable volume of water, but it is subject to inundations, and its mouth is obstructed by a bar. Its whole course is 37 miles. The estuary by which it enters the sea is wide and shallow, the channel frequently shifting. It has several tributaries, but all are inconsiderable. The *Ebrie*, one of the principal, is about 12 miles long.

The Ugie is formed by two streams, called respectively *North Ugie* and *South Ugie*. It is a slow stream, liable to be flooded. After the confluence of the two branches the river runs east 6 miles to the sea at Peterhead.

43. The river Doveran.—The Doveran or Deveran rises among the lower hills of the Cairngorm group at the extremity of the north-eastern branch of the Grampians, and is fed from both sides of the mountains. It is a rapid stream, having a course of about 50 miles towards the north-east and north, passing Huntly, and reaching the coast at Banff. There are two principal streams, the western branch being called the *Blackwater*, which flows north about 12 miles, and there meets the *Bogie water*, a considerable tributary from the south, rising among the highest hills in the neighbourhood, and flowing more than 10 miles through Strathbogie. Three miles below the confluence with the Bogie the *Islay* joins the stream from the north-west, and the combined waters take a winding course towards the east for 12 miles to the junction with the *Turriff*, which enters from the south after a course of 13 miles. The stream then runs 10 miles to the sea. The Doveran is a rapid and beautiful river, with high wooded banks, in the midst of a wild and bare country; but both the main stream and its tributaries are subject to heavy floods.

A small stream, the *Cullin*, enters the sea between the Doveran and the Spey, draining the country between the sea and some low hills from which the Isla receives feeders.

44. The river Spey.—The Spey holds the third place among Scottish rivers, and is one of the most rapid streams in the British islands. It has a course of about 96 miles, and drains nearly 1,200 square miles of country. It originates in a small lake (*Loch an Spey*) in the centre of rocks and precipices, just beyond the northern extremity of Glen Roy, and about 20 miles north-east of Ben Nevis. It receives the waters proceeding from a narrow channel of mountain country between the Monaghlea mountains and the north-eastern extension of the Grampians, full of small lakes and having a multitude of mountain torrents coming down after every shower from the steep slopes that characterise the rugged district of the Western Highlands. Nothing can be imagined more rude and desolate than the early part of this river's course, as the water tumbles in a succession of precipitous cataracts from the base of the Corryaraich, and rolls with fearful rapidity along a valley cut through an uninhabited district till it reaches Garviemore, a distance of about 10 miles of country, without important feeders. Just before reaching Kingussie the *Truim* joins it from the south, and a little below the *Tromie* is received also from the south, and the river expands into a lake (*Loch Inch*) about 3 miles long and a mile broad. At the lower extremity of the lake the *Feshie* comes in from the south, bringing occasionally a large body of water. Below the Feshie the Spey is joined by several mountain torrents conveying water from both sides of the stream, carrying the overflow of small lochs or tarns, until the *Nethey* is reached, entering from the south-east, fed by numerous burns from the northern and western slopes of the Cairngorm group, and at times flooded to an enormous extent. This river is composed of two principal feeders, that to the east, the *Dorbach*, driving the waters of the Nethey across the stream, and doing much injury in freshets.

45. The floods of the Spey.—The bed of the river where these streams unite is subject to frequent and strange changes. About 150 years ago the Dell, a small plot of ground near the confluence, was the seat of some important ironworks. The effect of a flood completely obliterated the whole, and in place of the works there was nothing but huge blocks of stone. Subsequent floods brought deep and fertile soil, and converted the ground into rich land 6 or 8 feet above the old level. On it had grown tall and majestic trees, and the memory of the iron mill was lost, when the great floods of Morayshire, in August 1829, described in the interesting record of Sir T. Dick Lauder, tore away all this shroud and brought back the traces of the old mill. The river has frequently cut for itself a new passage in this part of its course.

45. The river Dulnan.—The Dulnan, one of the most considerable feeders of the Spey, entering from the left bank, rises a few miles north of Loch Inch, and drains a straight valley of some length, parallel to that of the Spey, which it joins at the bridge of Carr. It has no large tributaries. From this confluence the Spey runs for some miles through a widening valley till it is joined by the Aven.

46. The river Aven.—This stream runs on the southern and eastern flanks of the Cairngorm mountains from a lonely crystal lake surrounded by precipices, which rise almost vertically to ridges that overtop almost every height in Great Britain. The whole group of mountains around is very grand and Swiss-like, and is remarkable for the almost total absence of life of any kind, vegetable or animal. The river issues in a large stream from the lake, and flows through a deep and dark glen. The first inhabited place on the stream is Inchnory, where a small feeder is received. The bed of the river which runs through a narrow gorge is here 44 feet broad. In the great flood of 1829 the river rushed along with a depth of 23 feet through this gorge, having a sectional area of 1,200 square feet. Continuing to flow for some distance through rocky scenery past the bridge of Campdale, the Aven is joined by the *Livat,* a considerable feeder from the south-east, and like the other feeders, very subject to flood.

The *Fiddich* is the next considerable stream enclosing the Spey. It drains the country to the south-east, and has an important feeder, the *Dullin*, from the left or west. Both are torrential.

47. The Lower Spey.—In the lower part of its course, between the confluence of the Fiddich and the sea, the Spey passes through the beautiful plain of Rothes. The valley is here about a mile wide, but below the plain it closes in again at the Pass of Sourden, where the width is only 237 feet. In time of severe flood the river has been known to rise 21 feet above its ordinary level at this place. A few small burns enter from the south between the Pass and Fochabers, beyond which the river expands into an estuary before reaching the sea.

48. The river Lossie.—Between the Spey and the Findhorn the river *Lossie* enters the ocean, rising among the hills that separate the two streams. Its course is direct, and between 20 and 25 miles in length. It is nowhere rapid, and in the lower part of its run, from Birnie downwards, it is a sluggish stream. Like the other rivers of this part of Scotland, however, it is subject to heavy freshets, which cause it to rise in places 18 or 20 feet above its ordinary level. A part of its course below Birnie is the bed of an ancient lake. Several feeders join the stream as it runs picturesquely between deep ravines. Among these the *Lochty*, or *Blackburn*, is one of the largest. After receiving these the river winds round Elgin, and reaches the sea at the entrance of Moray Firth.

49. The river Findhorn.—The Findhorn rises from a wide morass covering the flat summit of a mountain of the Monadh-leadh group, and has a course of not less than 60 miles, measured in a straight line, its windings making the length of flow about half as much more. Leaving the morass it runs through a deep ravine in primitive rock to a beautiful pastoral glen and valley bound by steep and high mountains, generally clothed with luxuriant herbage through which the naked rock occasionally peeps. It receives no important feeder for a long distance. Below Freeburn, where a small stream joins it, the valley expands into a plain, probably an ancient lake, through which it now takes a changeable and shifting course. Near here a small lake (*Loch Moy*) discharges its surplus water into the Findhorn. The backing up of the bed and course of Findhorn by a permanent barrier 20 feet high in a glen a little below this point, would drive the water into the Nairn by the lake of Moy, and thus permanently divert a large part of the Findhorn drainage. The course of the river through the narrow pass thus easily blocked is extremely romantic. The glen winds considerably, running for 8 miles in a generally north-easterly direction between high vertical cliffs till it reaches Dulsie Bridge, a single lofty arch of 46 feet spanning the yawning chasm. The great flood of 1829 brought the water 40 feet above its usual level at this point. Below the bridge the river sweeps round a high peninsula through very wild scenery, gradually becoming more open till at Relugas it is joined by the *Divie*, which with the *Dorbach*, its principal feeder, carries a large body of water. Both streams rise in the hills to the south-east, and are formed of a number of small burns. The scenery after the confluence, where the Divie leaps into its glen in a wild cataract is exquisitely beautiful. The Dorbach proceeds from a lake, and is fed by other smaller streams from smaller lochs.

50. The Lower Findhorn.—Below Relugas as far as Sluie the character of the scenery is wild, grand, and picturesque, tempered with peculiar beauty from the luxuriance and extent of the forest growth. At the Esses the river rushes through a series of falls, rapids, and salmon leaps, about a mile above Sluie. Here during the great floods, already so often alluded to, the river rose 50 feet above its ordinary level. From Sluie downwards the scenery becomes tamer, the Old Red Sandstone replacing the metamorphic rock, and the river valley widens into the plains of Forres, and beyond these plains into a large sheet of water opening at Findhorn by a narrow passage into the Moray Firth. As the river enters the estuary it is joined by the *Burn of Dyke*, draining the country to the west between the Findhorn and the Nairn.

The mouth of the Findhorn widens considerably in the lower part of its course, and occupies a delta more than 2 miles in length, and nearly 2 miles across in the widest part near the bay of Findhorn. The usual channel of the river is through the western side of this delta; but in times of great flood there are channels crossing a considerable breadth of country, and traversing the flat expanse with some regularity. During extreme flood the whole is under water, and new channels are formed, interlacing with the old ones, the conditions of outfall checking the flow by the formation of a natural basin.

Such a basin is, indeed, rarely filled, for the river course is here 200 yards wide; but it acted in an important manner in the unfortunate year already referred to. The water then was 17 feet above its usual level at the banks, but was probably much more in the middle, for, in violent floods, the fury of a stream is so great that in whatever direction it sets the water is raised many feet above the other parts in the same cross section.

51. The river Nairn.—The Nairn is the last of the series of river basins before reaching Moray Firth and the line of the Caledonian canal. It flows almost in a straight valley through a long strip of country for about 30 miles, but it winds greatly in its course, and its length is much greater if the windings are included. It takes the drainage of the western extremity of the mountains of the Monadh-leadh group. The scenery is bold, but the valley is wide and cultivated, and the outlines of the country are everywhere picturesque. It has few tributaries; the *Fernac* is the principal one, proceeding from a large lake between the Nairn and Loch Ness. Like most of the rivers of the east of Scotland, the main stream of the Nairn runs through a succession of open plains and very narrow passes, so that in time of flood the swollen river is alternately expanded, and checked by natural barriers.

52. Floods of the Scottish rivers.—The whole of the district from the Dee to Moray Firth is subject to heavy floods, which from the configuration of the country, rather than on account of excessive rainfall, are occasionally very mischievous. The year 1829 was especially remarkable for the amount of injury done in this way, and the record published at the time by Sir T. D. Lauder, already referred to, is a work almost classical of its kind. It appears, however, that during and before these floods the rainfall though heavy was by no means excessive compared with that of several previous years, or the fall in other districts. The mean annual rainfall for 9 years ending 1829, was little more than 26 inches. As much as 7·36 inches fell in August 1829. The total rainfall of that year was a little under 31 inches, but of the whole August fall more than half ($3\frac{3}{4}$ inches) fell between 5 A.M. of the 3rd, and 5 A.M. of the 4th. This quantity was the amount measured in the plains, and was, no doubt, much exceeded on the hills. The extreme rapidity of the fall, the non-absorbent character of the rocks on which it fell, the narrowness of the gorges by which the water is carried off to the sea, and the occasional lakes and open spaces, alternating with narrow passes, that characterise the whole of the mountain land of the Grampian chain, combined to produce the sad accidents and hair-breadth escapes narrated in the account alluded to.

Among the results of the floods of these Scottish rivers, there are few more remarkable phenomena than the following account of a landslip, recorded by Sir T. D. Lauder, in the volume already alluded to. It occurred where the road to Ballindalloch winds round the northern base of an isolated hill, which appears as an advanced guard of the great masses of the Cromdale mountains. At a point about 70 yards above the road a quaking of the earth was observed, which extended through a circuit of 60 or 70 yards, and continued for some time. At length an immense column of water forced itself through the face of the hill, spouting into the air and tossing around large stones and great quantities of gravel. Sometimes it ceased altogether, and nothing was heard but the rush as of a considerable river. Again it would burst forth like a geyser with renewed energy, tearing up whole banks of earth and projecting them to the distance of 300 yards. The water was quite transparent, and had the appearance of boiling. The noise it made was compared to the rush of a cataract down a steep rock. The quantity of matter thrown out was measured some weeks after the ravine had been formed by this eruption, and was found to amount to about 7000 cubic yards. At that time a tiny rill of water ran from it, but it was pure and cool. It was observed that a neighbouring spring had gone dry.

Beyond the Nairn there is no other stream till we reach the Ness, the outlet of the great chain of lakes, connected by some artificial channels, which separates Scotland into two well marked divisions, and brings the waters of the Atlantic into the same channel as those of the North Sea.

53. Glenmore, or the Caledonian Canal.—That part of the long straight water-way, called Glenmore, but better known as the Caledonian canal, which belongs to the drainage of Scotland east of the main line of water-parting and north of the Grampians, is the portion commencing at Laggan, and including Loch Oich and the rest of the water-way to the North Sea. The level of the water-shed between Loch Oich and the country to the south at Laggan is 100 feet. Here are two locks, and this spot is the summit level of the navigation of the whole channel. The river Spey takes its rise about 8 miles east of Laggan, and the source of the Findhorn is about 20 miles to the north-east of the same hamlet.

54. The Garry river.—Commencing with the Laggan, the first river whose waters are conducted northwards is that which runs through Glen Garry, rising close to the estuaries that indent the west coast of Scotland, and passing through *Loch Quoich*, and one or two smaller expansions of the Garry river. The length of course of this river, which has several tributaries, is not less than 25 miles, and the Garry enters Loch Oich in about the middle of the western shore. *Loch Oich* is a beautiful highland lake 3½ miles long, and has a channel of about 3 miles to the head of Loch Ness.

55. The river Ness and Loch Ness.—Loch Ness receives from the right the *Foyers water*, and from the left the waters coming down Glen Moriston and Glen Urquhart. It is 24 miles long, but only a mile wide, and is enclosed by ranges of hill rising about 1,200 feet above the sea. Its depth is great, and is estimated at 130 fathoms. The lake narrows towards the north, and passes into the river Ness, which flows 5 miles to Inverness, where it opens into *Loch Beauly*, a wider sheet of water, at the head of which is the town of Beauly. The Beauly river and the country drained by it will be described in the next chapter, which completes the account of the Scottish streams, and connects the great promontory of the north of Scotland (the whole of which I have regarded as forming part of the western district) with the eastern hydrology, as described in the present chapter. In this way the northernmost drainage of the eastern part becomes conterminous with that of the south-eastern extremity of the promontory. This division, though in some degree arbitrary, will be found convenient, and, in a certain sense, is natural.

The river Ness emerging from the lake of Ness is a fine wide stream flowing through a grand and picturesque valley which narrows rapidly, and becomes a mere strait where it terminates at Inverness by the firth of that name.

CHAPTER XIII.

DRAINAGE SYSTEMS OF THE WEST OF SCOTLAND.

(1) General description of the district.—(2) Geology.—(3) Sub-divisions.—(4) Rainfall, evaporation, and percolation.—(5) Quality of the water.—(6) Scheme of the principal rivers and tributaries. SOUTHERN DIVISION.—*The South-Western Catchments*:—(7) Description of the district.—(8) The Stinchar water.—(9) The river Girvan.—(10) The river Doon.—(11) The water of Ayr.—(12) The river Irvine. —(13) *The basin of the Clyde.*—(14) Early course of the river.—(15) Falls of the Clyde.—(16) The river Avon.—(17) The Calder waters.—(18) The Clyde at Glasgow.—(19) The river Kelven.—(20) The river Cart.—(21) The river Leven. —(22) The feeders of Loch Lomond.—(23) Loch Lomond.—(24) The Firth of Clyde.—(25) The lake and river Eck. *The North-Western Catchments*:—(26) The Addwater river.—(27) The river Awe, Loch Awe, and the Orchy river.—(28) Etive water, and Loch Etive.—(29) The Creran water, and Loch Creran.—(30) Loch Leven, and the river Leven.—(31) Loch Eil, and its feeders.—(32) The river Spean.—(33) Loch Lochy, and Loch Archaig. NORTHERN DIVISION.—*West Coast Catchments*:—(34) Loch Shiel.—(35) Loch Morar.—(36) Loch Carron, and Carron water.—(37) Loch Maree.—(38) Loch Assynt.—(39) Loch Laxford. *North Coast Catchments*:—(40) Dionard river.—(41) The Naver river.—(42) The Strathie river.—(43) The Thurso river, and the Forss.—(44) The Ullie river.—(45) The Brora river.—(46) Loch Shin, and the river Oykill.—(47) Cromarty Firth, and its drainage.—(48) Beauly river.

1. General description of the district.—Western Scotland, north of the Firth of Clyde, is deeply indented by inlets, so that the coast presents a succession of narrow promontories separated by deep water. In the southern part these are due to the extension of the mountain axis of the Grampians to the south-west, and the low level of the valleys between the ridges, but further north the conditions are somewhat different. The Firth of Clyde and Loch Long, Loch Fyne, and the Firth of Lorn, continued by a series of lakes connected by the Caledonian canal, illustrate the former conditions, and are all more or less nearly parallel, running up long distances to the north-east. Further north the inlets become more numerous, but are smaller, and their general bearing is to the east, and sometimes the south of east, instead of north-east. This continues to Cape Wrath. The mountain ridges, on which these promontories depend, and between which they occur, will be found generally to indicate the existence of local axes, though when considered on a large scale they form connected chains, ranging north-east and south-west.

The drainage of the country, as a matter of course, adapts itself to this peculiarity of physical conformation. The rivers are short with many branches, and expand constantly into long narrow lakes, connected by very narrow passages. The lake takes the place of the river in the hydrography of the district, these expansions of the stream storing the heavy rainfall, and not permitting it to reach the sea except through the narrow channels alluded to. The rainfall is thus stored, and is conveyed to the sea in a manner much less torrential than would otherwise be the case. The mountains in many cases approach the sea line, and rise from the coast to elevations varying from 2,000 to 4,000 feet.

The river systems south of the Grampians, where the valleys are larger and the mountains less broken, resemble those of eastern Scotland and the north of England, but those in the north are very different. The only really large drainage area of western Scotland is that of the Clyde. All the other catchments are comparatively unimportant in this respect.

The country whose drainage is treated of in this chapter, is a very large proportion of the whole land of Scotland, but its extent in square miles is of little importance and has not been carefully estimated, nor does the exact length of coast line give any useful idea. The line of coast extends over 3½ degrees of latitude from Loch Ryan, in Wigtonshire, to Cape Wrath; but except in the valley of the Clyde the surface is everywhere much broken, and rises rapidly into mountains comparatively lofty, close to the coast.

I include as part of the west of Scotland the whole of the promontory beyond the line of the Caledonian canal, and in this part the breadth from north-west to south-east is about 60 miles. The district is about 120 miles in length, and thus the superficial extent may be roughly estimated as approaching 7,000 square miles.

The line of water-parting through the northern extremity of Scotland, as will be seen by referring to the outline map on page 420, approaches much more nearly to the west than to the east coast, and leaves an intervening space between north and south, forming a detached catchment. This delivers its water into the Dornoch Firth, and is connected with a lake of considerable magnitude (Loch Shin). The number of small catchments on the coast is exceedingly great, but there being no town of importance throughout this part of Scotland, the streams are not likely to be much utilised. It will not be possible to describe any but the largest and most important.

2. Geology.—Although complicated, and very troublesome to decide in matters of detail, the general structure of western Scotland is sufficiently simple, and well indicates and illustrates the peculiarities of its hydrography. Commencing with the country immediately north of the great expanse of old rock (Silurian or Cambrian) drained by the Tweed and the rivers entering the Solway Firth, we find a wide belt of country occupied by middle and newer Palæozoic rocks of all the familiar varieties in their respective positions, but interrupted by large outbursts of basalt and greenstone, chiefly developed in the north of the Clyde basin, where they separate the Old Red Sandstone from the carboniferous limestone and the coal-measures. There is in this part of Scotland a large and important deposit of valuable coal-measures, containing with the coals some beds of remarkable shale, loaded with mineral bitumen. This is enclosed on all sides by the igneous rock, which has no doubt contributed to effect the change that has resulted in the production of this shale.

On the whole, this part of Scotland south of the Grampians may be regarded as part of a wide shallow trough of metamorphosed Lower Silurian rock, lined first with Old Red Sandstone, and then with carboniferous limestone and coal-measures, and interrupted everywhere by greenstone and basalt. Here and there are patches of Permian rock, but they are few and small, chiefly in the drainage areas south of the Clyde. The Clyde itself crosses the coal-measures for a long distance, after traversing the rim of the trough. There is a large extent of limestone, but in the western part is not to be traced far without interruption or cover.

North of the Grampians (which consist of outbursts of granitic rock through metamorphic slates and schists) the metamorphosis of the rocks at the surface is complete, and they differ little so far as their effect on water is concerned, whether described by the geologist as Silurian, Cambrian, Laurentian, or even eruptive, such as basalt and greenstone. These latter are small in quantity on the mainland compared with their extension in the western islands of Scotland, and on the north-eastern corner of Ireland. They are continued beyond the extremity of the Grampian chain between Loch Awe and Loch Linnhe.

3. Sub-divisions.—It will be necessary in considering the drainage areas of this part of the British islands to adopt certain lines of demarcation that shall bring them within compass.

A principal dividing line of this nature commences near the 57th parallel of latitude, where the line of water-shed between the Spean and the Spey connects with the northern Grampians, and extends westwards to the head of Loch Lochy, which is the summit level of the Caledonian Canal. The drainages into the lower waters that extend to the entrance of Loch Linnhe may all be regarded as belonging to the southern division, while that of the coast from the sound of Mull and Loch

Sunart northwards must belong to the northern division, the catchments all draining to the west coast.

Of sub-divisions the basin of the Clyde in the south is a very definite example. The catchments draining into the sea between Loch Ryan in Wigtonshire and the basin of the Clyde form another, and a third will be found north of the Clyde, but within the southern main group of drainage areas.

In the northern division we have as many as five groups. The rivers entering the sea to the west, those entering to the north, those to the north-east as far as Dornoch Firth, and those between Dornoch Firth and Moray Firth, are all distinct. The drainage of the Shin lies between the two latter. We may, therefore, express the grouping. of the catchments in this chapter as follows :—

Southern division—

1. South-western catchments.
2. The basin of the Clyde.
3. North-western catchments.

Northern division—

1. West coast catchments.
2. North coast catchments.
3. East coast catchments.—Northern group.
4. The basin of the Shin.
5. East coast catchments.—Southern group.

4. Rainfall, evaporation, and percolation.—The rainfall in the north-western part of Scotland ranges exceedingly high, and throughout the district alluded to in this chapter, except on the north-east coast, is nowhere less than between 40 and 50 inches, and in many places exceeds 75 inches.

At Stanraer, a well-known station in the south-western extremity of Scotland, the rain-fall averages 47 inches, and ranges between that and 44 inches in the whole group of the south-western catchments. Probably about 45 inches is the average, though in the basin of the Ayr and Irvine it would seem smaller, and perhaps does not exceed 43. The basin of the Clyde, which receives the drainage from the slopes of higher ground, is more productive, and on the higher land within the basin the average may be as much as 60 inches. This considerable fall is not over the basin generally.

North of the Clyde the head waters of all the principal streams, at least as far as the Moray Firth, come within the range of the heavy rainfall of the western mountains of Scotland, and receive the drainage from slopes where there is a usual average of more than 75 inches. On the western side of Scotland a large part of the course of the streams is within this line, but the rivers that flow eastwards immediately get into a drier climate. North of the Isle of Skye the fall is also diminished, even on the mountain sides. As far as the head waters of the Shin it is between 50 and 75 inches, but beyond this not more than from 40 to 50 inches, and this only for the rivers flowing west. The northern and eastern drainage is from land when the fall is below 30 inches on the coast, and not much above 30 in the interior.

The evaporation from the surface in Scotland has not, I believe, been measured, but it must be enormous. The constant alternation of rain and wind, and the exceedingly non-absorbent soil, must induce very rapid evaporation after rain, unless, indeed, as is sometimes the case, the air is saturated. That it soon ceases to be saturated is evident from the rapid reduction of fall towards the east. The percolation, except in a few parts of the coast, must be reduced to the smallest minimum, as there are hardly any absorbent rocks, and but little surface cover admitting of free and rapid percolation. There is also little coating of absorbent gravel. The granitic, metamorphic, and unaltered palæozoic rocks of Scotland are not fissured to the extent recognised in the older rocks in the north of England, but there are instances in which large crevices exist and rivers are lost in underground channels.

5. Quality of the water.—The water obtained from the rivers and lakes of western Scotland, though often discoloured by peat, and containing an excess of organic carbon, is generally pure so far as essentials are concerned, and almost always very soft. There is also a general absence of the salts of lime and magnesia, and when the waters are taken from the upper valleys they rarely contain anything objectionable. It should be mentioned that in the neighbourhood of the lead mines, of which there are some in Scotland on a large scale, traces both of lead and of metallic arsenic in the water are not unknown, though whether they are present in such quantity as to be injurious may fairly be doubted. In the instances mentioned in the analyses given below, the quantity amounts to four or five parts in a hundred million.

ANALYSES OF WATERS OF THE WEST COAST OF SCOTLAND.

Date of Sample.	Rivers and Localities.	Total solids.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates.	Chlorine.	Hardness.
3 Oct. 1870	Doon, at the Brig - - - -	4·62	0·200	·016	·001	0	0·63	2·2
22 July ,,	Clyde, Elvan, above Leadhills -	3·01	0·064	·011	·001	0	0·53	1·3
15 Mar. 1872	,, Douglas, Standish R. S. -	8·04	0·544	·037	·001	0	0·67	4·4
13 ,, ,,	,, S. Calder confluence -	24·04	0·919	·084	·008	0	1·65	15·1
14 ,, ,,	,, N. Calder confluence -	50·12	0·730	·103	·006	·182	2·35	28·5
25 July 1870	,, Kelvin, near Glazcot -	21·98	0·143	·021	·003	·083	1·55	12·1
21 ,, ,,	,, Cart, above Paisley -	30·54*	1·299	·170	·272	0	3·20	10·6
23 ,, ,,	,, Leven, at L. Lomond -	3·46†	0·194	·027	·003	0	0·90	1·8
15 Mar. 1872	,, above junction of Kelvin -	10·30	0·741	·074	·034	·010	1·60	6·1

* ·004 Metallic arsenic.
† ·005 Ditto.

In the above table, which is deduced from Dr. Frankland's Sixth Report, the analyses of samples of waters of the manufacturing districts of North and South Calder, the Cart and the Kelvin, are included, not as samples of the rivers in their natural state, but as indications of the effect of manufactures on the water. No analyses taken at the same time of the waters lower down stream beyond the influence of the town seem to have been made, and it certainly would not be fair to assume that the Clyde as it reaches Glasgow is in an offensive state.

6. Scheme of the principal rivers.—The following outline of the chief rivers, and the tributaries of those which are most important, will be convenient:—

Southern Division.

1. *South-Western Catchments.*

Stinchar water.
- Duisk river.
- Tig water.

Girvan water.

Doon water.
- Loch Doon.

Water of Ayr.
- Lugar water.
- Burnock water.
- Coyl water.

Irvine river.
- Glen water.
- Ann beck.
- Polheath beck.
- Cesspock water.
- Fenwick water.
- Annach water.

Lugton water.
- Bye water.
- Caff water.
- Dusk water.

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2. *Basin of the Clyde.*

Elvan water. Daer water.

Clyde river.

Right bank.	*Left bank.*
	Powtrail water.
Camps water.	
	Glengonner water.
	Duneaton water.
Culter water.	
Medwin water.	
	Douglas water.
Dippool water.	
	Nethan water.
	Avon water.
South Calder water.	
North Calder water.	
Kelven water.	
	Cart river.
Leven river.	

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3. *North-Western Catchments.*

Eck water.
Ruel water.
Fyne water.
Add water.
Loch Awe and Awe river.
 Orchy river.
 Etive water and Loch Etive.
Etive water.
Creran water.
 Loch Creran.
Leven river.
 Loch Leven.
Spean river.
 Loch Laggan.
 Gulbin water.
 Loch Treig.
Lochy river.
 Loch Lochy.
 Loch Archaig.
Loch Eil.
 Finnilie water.
Cona water.

NORTHERN DIVISION.

1. *West Coast Catchments.*

Shiel water.
 Loch Shiel.
Loch Morar.
Long river.
Carron river.
 Loch Carron.
Loch Maree.
Shallag water.
Mashak water.
Kirkaig river.
Inver river.
 Loch Assynt.
Laxford water.
 Loch More.
 Loch Stack.

2. *North Coast Catchments.*

Dionard river.
Strath more.
 Loch Hope.
Kinloch water.
Borgie river.
Naver burn.
Strathie river.
Malladale river.
Isauld burn.
Forss burn.
Thurso river.

3. *East Coast Catchments.—Northern Group.*

Lyth river.
Kildonan burn.
Brora river.
Golspie burn.
Fleet river.
Evelex water.

4. *The Basin of the Shin.*

Loch Shin.

Right bank.
 Orkill river.
 Black water.

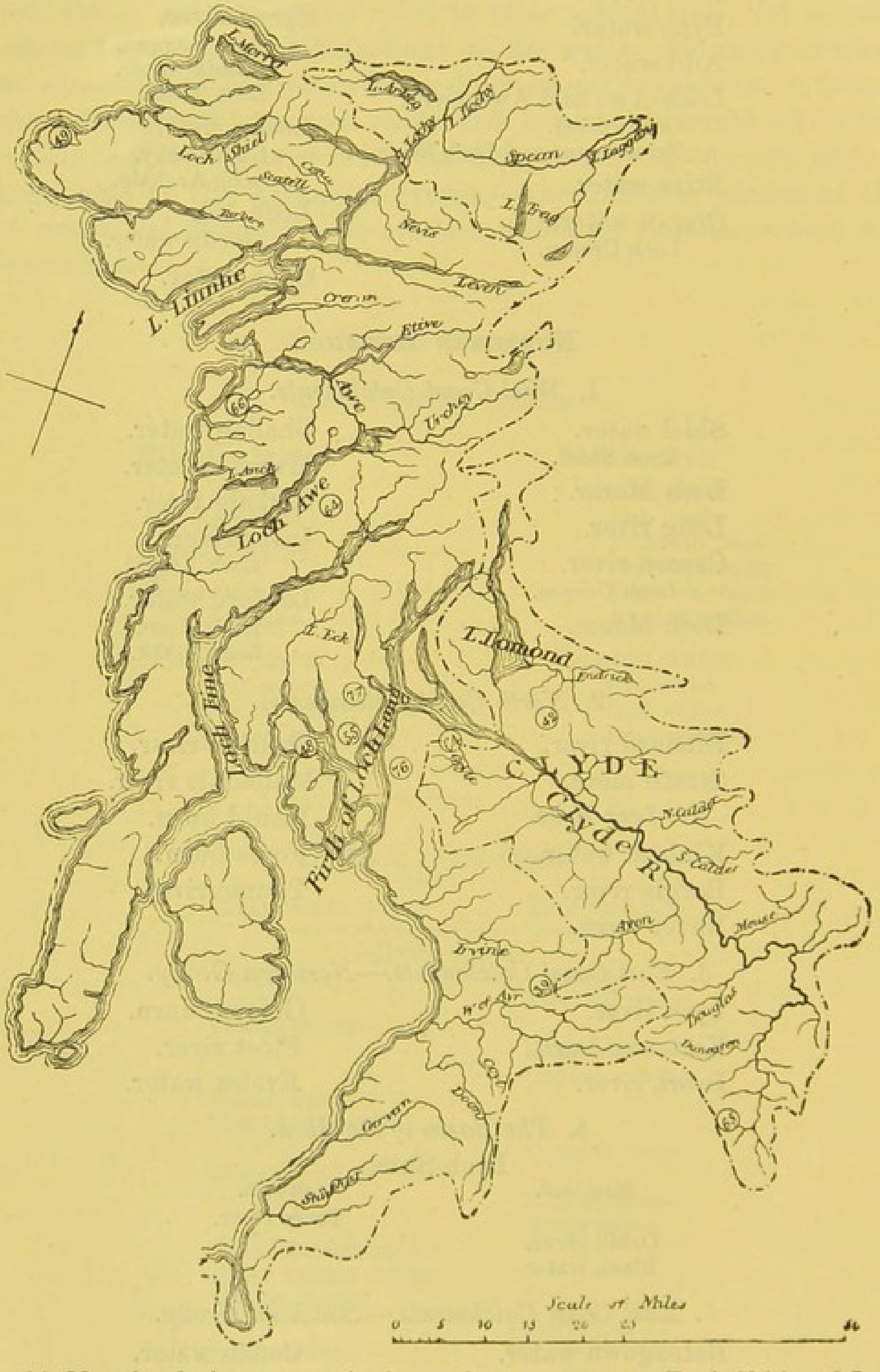
Left bank.
 Terry river.

5. *East Coast Catchments.—Southern Group.*

Balnagown water.
Alness water.
Alt Graat.
Conan water.
 Loch Linchart.
Beauly river.

XII.—Catchments of the West of Scotland.

Southern Division.



In this Map the drainage areas in the north-western corner (Loch Shiel and Loch Morar) are misplaced. They will be described with the Northern Division, of which they naturally form a part.

SOUTHERN DIVISION.

South-Western Catchments.

7. Description of the district.—From the Mull of Galloway, the south-western extremity of Scotland, a long peninsula extends northwards, connected with the mainland by a narrow neck of land between Luce bay and Loch Ryan, and from the shores of that inlet there is a comparatively unbroken line of coast to the mouth of the Clyde, the distance being about 70 miles. This is the line whose drainage is now under consideration. Its breadth is inconsiderable, nowhere exceeding 20 miles, and generally not amounting to 10; and it is separated by high ridges from the basin of the Clyde, the Nith, and the Dee. Several streams, though none of any magnitude, carry down the rainfall from the western slopes of these ridges to the sea.

8. The Stinchar water.—This stream enters the sea about 4 miles north of the entrance to Loch Ryan by a small estuary at Ballantrae. It rises in *Loch Spaig*, a mountain tarn in the wild hilly district of the southern part of Ayrshire, and runs at first about 15 miles to the south-west to Daljarroch, where it is joined by the *Dusk*, a feeder originating in other small lakes among the hills, and coming in from the south-east. After this confluence, the Stinchar continues to flow in its original south-westerly direction, and reaches the sea after 9 miles, having previously been joined by the *Tigwater*, a small stream from the east.

From the Stinchar river to the next river of importance, the distance is about 12 miles; and as the course of the Stinchar is nearly parallel to the coast, from which it is only distant 5 miles, there is no opportunity for any streams to be formed between.

9. The river Girvan.—This is another stream from the same group of hills as the Stinchar, entering the sea at the town of Girvan, after a course of about 25 miles. It rises near Loch Spaig, and makes a nearly semi-circular curve to the north, turning then towards the south-west to reach the sea. There are no considerable streams entering the sea for a long distance north of the Girvan.

10. The river Doon.—The Doon is a more considerable stream than the Girvan, some of its sources rising among the same hills as those which feed the Stinchar and the Girvan, but the main stream originates far to the south, where it is fed by several lakes, of which the most important is *Loch Doon*, the principal sheet of water in this part of Scotland.

The Doon rises in *Loch Enoch*, under the stern and savage escarpments of the hills of the Merrick range, rising in Mount Merrick to 2,764 feet. Loch Enoch is 1,650 feet above the sea, and is surrounded with rocky scenery, dotted here and there with small tarns, or pools of peaty water.

It is 6 miles from this lake to Loch Doon, the direction being north. Where the stream enters the lower lake another feeder enters from several lakes to the west and south. Loch Doon is $5\frac{1}{2}$ miles long, and about half a mile wide, and is not picturesquely situated. From the west it receives the waters of *Loch Finloch* by a short channel.

The Doon, commencing as a river from the foot of Loch Enoch, is conducted by a narrow and very picturesque glen, called the Ness, to Dalmallington, whence it continues its course without any remarkable change to the sea near Ayr, a distance of 15 miles, flowing north-west.

11. The water of Ayr.—From the mouth of the Doon to the mouth of the Ayr water, the distance is 3 miles. This river takes its rise near the line of water-shed of the Clyde, and flows for about 20 miles in a westerly direction. On its way it receives the *Lugar water*, a considerable feeder, and the *Coyl water*, both from the south. The course of the Ayr is upwards of 20 miles. Ten miles of coast intervene between the mouth of the Ayr and the next stream of any magnitude that enters the sea in this part of Scotland.

12. The river Irvine.—A group of streams, of which the Irvine is the first met with in advancing from the south, bring the drainage of a considerable extent of country to the sea, near the town of Irvine, about 10 miles north of Ayr.

The river Irvine rises at the foot of the Loudoun hills, and has a course of nearly 20 miles due west, passing Kilmannock, and receiving a number of tributaries from the north, and the *Cesspock* and one or two smaller feeders from the south. These feeders drain a considerable tract of country in the interior. Approaching the coast there are several streams that come from the north, some belonging to the Irvine, and others converging from northerly directions, and entering an inlet that extends northwards from Irvine. Among these the *Lugton* is the principal. This and the *Gurnock water* both yield large contributions to the fresh water that pours into the small inlet after rainy weather. The Lugton river has several tributaries, of which the *Bye water*, the *Caff water*, and the *Dusk water*, are the chief. It is a considerable stream, its feeders running southwards, parallel to the coast from the high ground near Largs.

Beyond the Irvine to the north of Largs there is little coast drainage, the ground chiefly falling away from the coast in the direction of the Clyde valley. The distance along the coast from Largs to the Clyde mouth is about 14 miles, and one or two independent but short streams, of which the *Noddle* is the most important, here reach the sea.

13. The basin of the Clyde.—The river Clyde, in some respects the most important river of Scotland, drains an area of about 1,580 square miles, but has a comparatively short straight course, with many small and a few large tributaries. It originates in the lofty hills which bound Lanarkshire to the south, commencing at Queensbury hill (2,259 feet), and running northwards more than 20 miles in an unbroken line to Culter hill (2,459 feet). This high ridge separates the drainage southwards to the Solway Firth, by the Annan and the Nith, from that northwards by the Clyde. Two branches, the *Daer*, and the *Elvan water*, unite to form the Clyde, draining a cul-de-sac, or "cirque," formed by a north-westerly branch from Queensbury hill to Lead hills.

14. Early course of the river.—The Clyde thus commenced runs northwards as a rapid mountain stream for 12 miles, receiving feeders from both sides. The *Powtrail* from the left, and the *Camps water* from the right, are the first. The *Duneaton* comes 15 miles from the eastern slope of Cairn table (1,949 feet). The *Culter water* succeeds, and the *Medwin* and the *Douglas water* afterwards come in; the former after receiving a large feeder from the south. Both join the Clyde a little above the point where it leaps down in a succession of falls shortly before reaching Lanark.

15. Falls of the Clyde.—The precipitous descent of the bed of the Clyde, after the junction with the Douglas water, produces these falls—certainly the finest under ordinary circumstances in the British islands, as in the course of 6 miles the whole river descends 230 feet. The first fall is called Bonnington Linn. "The banks of the Clyde have here risen into high cliffs, and a bend in the channel causes it to sweep round a sharp turn, dividing it into two branches. Between them is a rocky island."* The height is about 30 feet, and the surrounding rocks add picturesque effect.

Three-quarters of a mile below this fall the water of the Clyde again leaps down a rocky precipice, but this time to a depth of 86 feet. This fall is called Cora Linn, and here also the banks of the river are bordered by cliff, while rich wooded scenery adds greatly to the picturesque effect.

About 3 miles below Lanark is a third fall of 10 feet, called the Fall of Stonebyres. This is of smaller importance. Just below Lanark the *Dippool water*, joined by the *Mouse water*, enter the Clyde from the right bank, and are soon followed by the *Nethan* from the left.

16. The river Avon.—The next considerable tributary is the Avon water. It rises in a number of small streams from Loudoun hill, and runs with a north-easterly and northerly course into the Clyde at Hamilton, receiving small feeders, and passing many places of interest. Between the Douglas and the Avon the river has recovered its ordinary flow.

17. The Calder waters.—Two rivers draining a tract to the east, enter the Clyde on its left bank between Hamilton and Glasgow. One

* Murray's Handbook for Scotland, p. 90.

of these rises at a spot not far from Torbane hill and Bathgate, remarkable for a peculiar deposit distilled for mineral oils, and passes through a small lake near its source. The waters of both streams are greatly affected by the manufactures carried on on their banks.

18. The Clyde at Glasgow.—At Glasgow the Clyde is a very considerable river running in a broad and deep channel, into which the originally shallow stream has been changed for the purposes of commerce. It is now 20 feet deep at high water, but is only kept to that depth by continual dredging. Below Glasgow it assumes even greater importance, and gradually widens till it reaches Greenock. Here the Firth of Clyde may be considered to be entered, and the width of the stream is nearly 4 miles. The distance from Glasgow to this point is rather more than 20 miles.

19. The river Kelven.—Immediately below Glasgow the *Kelven* joins the Clyde on the right bank, after a course of about 15 miles. On its way it is fed by streams from the Kilsyth hills and Campsie fell.

20. The river Cart.—Shortly after receiving the Kelven several streams conveying water into one channel, called the Cart river, enter the Clyde. These drain a district to the south of the main stream. The *White Cart* river, the *Black Cart* river, and two tributaries of the latter, the *Calder* and the *Cryffe*, are the names of the chief streams.

21. The river Leven.—On the north bank of the Clyde the river Leven enters at Dumbarton, 13 miles below Glasgow. This stream communicates by a short channel of 4 miles with the celebrated Loch Lomond.

22. Feeders of Loch Lomond.—The waters that supply Loch Lomond proceed from the slopes of lofty mountains, which culminate in the peaks Stobinian (3,821 feet) and Ben More (3,843 feet) to the east, and Ben Lui to the west. The latter separates the waters of the Clyde from those of the Tay. All these streamlets have short courses of three or four miles and they unite in Glen Falloch, entering the head of Loch Lomond at Ardlui, between Ben Voirlich (3,092 feet) and Ben a Choin (2,524 feet). At short intervals other feeders come in on both sides, one on the left bringing the overflow of *Loch Arklet*, while about half way down the lake from the right, through Glen Douglas, there comes in a feeder, and another still more to the south, through Glen Frain, by a very winding channel. Towards the lower part of the lake there are many islands, and here, in its widest part, a winding stream enters from the south-east, bringing the waters of two principal feeders, one from the north and the other from the south slopes of the Campsie Fells, and from the Gargunnock hills. The length of course of the chief of these (*Endrick water*) is upwards of 20 miles. The mountain Ben Lomond (3,192 feet) rises from the shores of the lake about 8 miles from its head, and the depth near and above this point is more than 100 fathoms.

23. Loch Lomond.—This is the largest fresh-water lake in Scotland, measuring 24 miles in extreme length, and 7 miles across in its widest part. It contains 24 islands. It is described by Maculloch in the following glowing terms.

" Loch Lomond is unquestionably the pride of our lakes—incomparable in its beauty as in its dimensions, exceeding all others in variety as it does in extent and splendour, and uniting in itself every style of scenery which is found in the other lakes of the Highlands. As with regard to its superiority over all others there can be no question, so in the highly contrasted characters of its upper and lower portions it offers points of comparison with the whole—with all those at least which possess any picturesque beauty—for it has no blank. Nor do I think that I overrate its richness in scenery when I say that, if Loch Achray and Loch Katrine be omitted, it presents numerically more pictures than all the lakes of the Highlands united."

24. The Firth of Clyde.—Beyond the river Leven, bringing the surplus waters of Loch Lomond, no considerable stream enters the Clyde from either side. At the point, however, where the river turns to the west, and curves round to form the firth, an arm of the sea called *Gare-lock* runs up nearly 8 miles to the north-west. A little further another but much larger inlet, called *Loch Long*, forms a continuation northwards of the Firth of Clyde. From this, again, about half way from its entrance, there is a branch 8 miles long, called *Loch Goil*, and from the opposite point, where the Clyde passes into the firth, a smaller and shorter inlet, connecting by a river channel with Loch Eck. This latter lake is fed by streams from the hills that separate the Firth of Clyde and its extension in Loch Long, from Loch Fyne, the next great inlet to the west. Of these it is only the latter that needs notice, as the others are rather curiosities of physical geography than connected immediately with the drainage areas and river basins of the country.

24. The lake and river Eck.—*Loch Eck* is a fine lake $7\frac{1}{2}$ miles long and half a mile wide, the hills rising abruptly from the water's edge on the west side, very wild and solitary. It is fed by small streams, and its waters enter an inlet to the west of Loch Long, called *Holy Loch*, by the river Eck, which has a course of about 3 miles in a south-easterly direction.

The peninsula between Loch Long and Loch Fyne, partly drained by the Eck river, is traversed from north to south by another stream, the *Ruel water*, which enters the inlet that branches into the Kyle of Bute.

Loch Fyne receives at its head two small streams, the river *Fyne*, and another river of greater length, passing down Glen Shira to near Inverary.

North-Western Catchments.

26. The Addwater river.—Returning now 80 miles to the south, along the eastern side of the long promontory of Kantyre, which is nearly, but not quite, converted into an island at Tarbert, and returning by the west coast from the Mull of Kantyre northwards for nearly 100 miles to Oban, we pass a multitude of small streamlets, conveying into the sea the heavy rainfall of the coast, but hardly a river of sufficient importance to deserve to bear a name.

The Addwater, a small stream that enters the sea by Loch Crinnan, is the only exception. It is fed by branches deriving their water from the slopes of the hills that enclose the southern extremity of Loch Awe.

27. The river Awe, Loch Awe, and the Orchy river.—Passing Oban, and entering the loch that leads to Loch Etive, we at length reach the river Awe, now communicating with Loch Awe, one of the larger lakes of Scotland. The river Awe is about 8 miles in length, and it enters the lake at right angles. The lake is part of a very long depression, more than 50 miles in length, its direction being north-east and south-west, parallel to all the great inlets and mountain chains, and opening naturally in the direction of Lake Crenan. The lake is 25 miles in length, and extends northwards by two valleys. One of these, the Orchy river, bears at first to the east, and connects it with a small lake, *Loch Tannay*, fed by a stream from Rannoch moor. The high lands of this moor present an important line of water-shed, separating the eastern from the western drainage of Scotland, the former going into the Tay, and the latter running at once to the western sea by a much shorter course.

Besides Glen Orchy and the stream that passes through it to Loch Awe, a smaller stream (*Strae water*) enters the head of Loch Awe by a parallel valley in the same direction as the lake, and a third and smaller contribution is received from the west, conveying the drainage of the eastern slopes of Ben Cruachan (3,670 feet). About midway in the lake there is also a picturesque stream, alternately rapids and pools, entering from the west from *Loch Avich*, a somewhat large sheet of water in that direction.

Loch Awe has not always discharged its waters by its present channel at its northern extremity, but must formerly have entered the sea towards the south-west, in Loch Crinan, by one of the branches of the Addwater. This natural channel is now closed, and the pass of Brander, by which the waters make their way to Loch Etive, is sometimes, though improperly, regarded as the foot of the lake. The pass of Brander is magnificently grand, the great mass of Ben Cruachan filling up the landscape, and constituting one of the most striking scenes of the Highlands.

28. Etive water and Loch Etive.—The Etive water feeds Loch Etive, which enters the inlet into which the river Awe conveys the surplus waters carried down by Loch Awe and the Orchy river. The wild country south of the range that shuts in Glencoe on the south side abounds in glens and water-courses, which carry to the sea the heavy mountain rains, and these first pass into Loch Etive (about 10 miles in length), and, leaving the lake, have a further course of about 8 miles to the sea.

29. The Creran water and Loch Creran.—These form an almost exact parallel to the Etive water and Loch Etive, rising in the same forest (Dalness forest), and entering Loch Linnhe about 5 miles beyond to the north-west. Both are parallel to the direction of Loch Linnhe and its extension in the chain of lakes connected by the Caledonian canal.

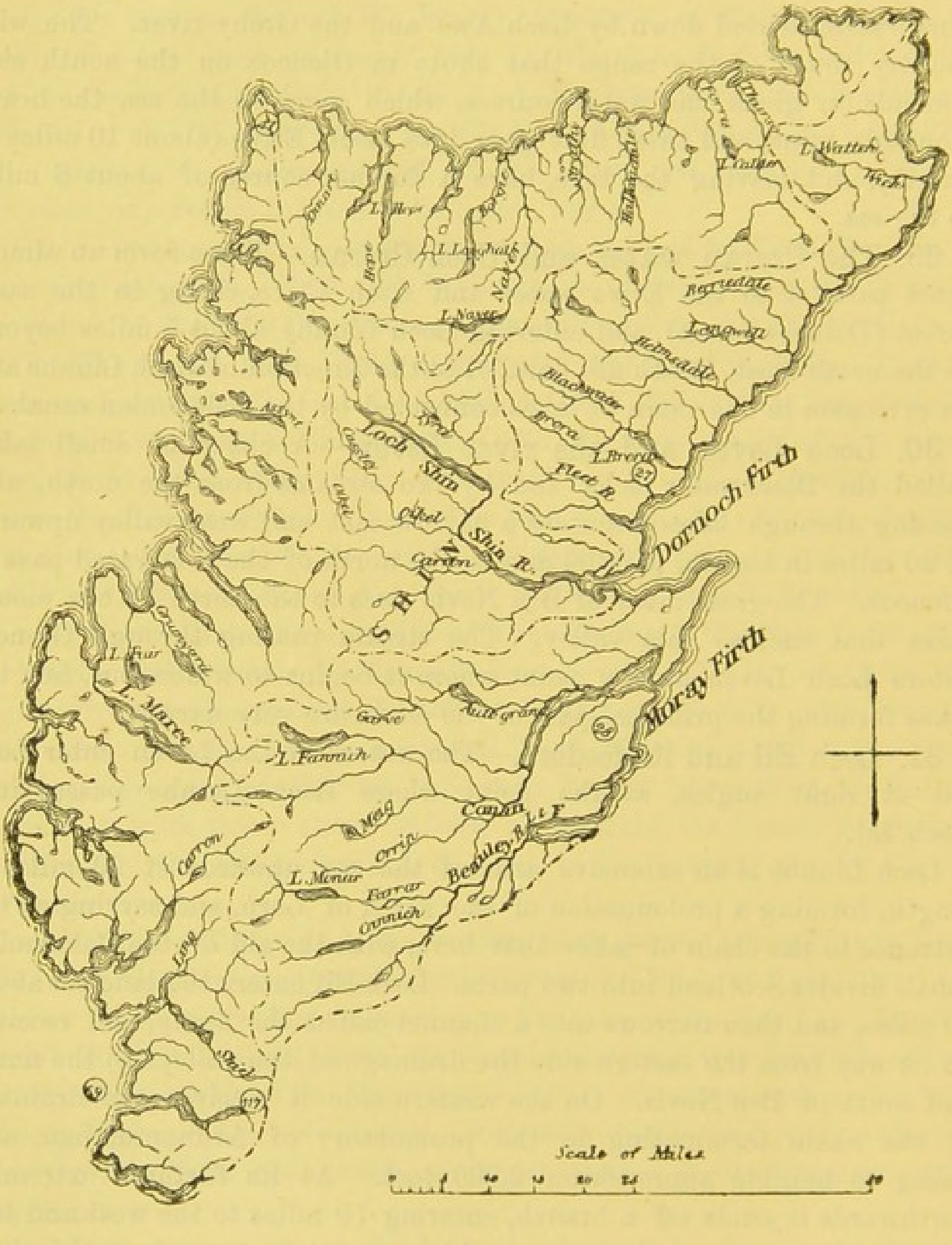
30. Loch Leven and the river Leven.—A chain of small lakes called the Blackwater lochs, fed by two streams from the north, also passing through lakes, occupies a narrow east and west valley upwards of 20 miles in length, parallel and to the north of the celebrated pass of Glencoe. The great mass of Ben Nevis rises to the north of the mountains that enclose this valley. The stream passing through Glencoe enters Loch Leven at the point where it begins to widen out, but the lakes forming the principal part of the chain are very narrow.

31. Loch Eil and its feeders.—The waters of the Leven enter Loch Eil at right angles, at the point where Loch Linnhe passes into Loch Eil.

Loch Linnhe is an extensive arm of the sea, upwards of 20 miles in length, forming a prolongation of the Firth of Lorn, and serving as the entrance to the chain of lakes that here, with the aid of the Caledonian canal, divides Scotland into two parts. Loch Eil enters the land for about 10 miles, and then narrows into a channel called the *Lochy*, and receives on its way from the eastern side the drainage of the valleys to the north and south of Ben Nevis. On the western side it receives the drainage of the chain terminating in the promontory of Ardnamurchan, and rising to heights approaching 2,800 feet. At its furthest extremity northwards it sends off a branch, entering 10 miles to the west and terminating in narrow valleys down which mountain torrents make their way. Beyond the head of Loch Eil, before the branch is given off, the river Lochy forms an extension to the north-east, and after about 7 miles it receives the river Spean from the east, and opens out into Loch Lochy in the continuation of its former direction.

XIII.—Catchments of the West of Scotland.

Northern Division.



In this Map the drainage areas of Loch Morar and Loch Shiel at the south-western extremity are not inserted, although they naturally belong to the division. They will be found in the map of the Southern Division, at p. 412.

32. The river Spean.—This important river rises within a short distance of the Spey river, among the hills that overhang Loch Ericht. The principal source runs at first north, parallel to the banks of Loch Luggan, which it afterwards expands into. Flowing northwards 6 or 7 miles, passing through another small lake, the stream turns suddenly and enters *Loch Luggan*, which is about 6 miles long and a mile wide, and receives two feeders from the west. Two miles further the *Gulban* enters from the south, originating in a lake (*Loch Oisian*) more than 2 miles long. After running 4 miles further to the north, it receives a small feeder which has passed through *Loch Gulban*. After this the stream continues for more than 4 miles further in the same direction to enter the Spean. After another few miles *Loch Treig* discharges into the Spean by a very short channel. This lake is 7 miles long, and is fed from a stream coming through Glen Treig from the south-west. Still further the *Roy* enters, coming through Glen Roy, celebrated for the nearly parallel benches on the hills enclosing it, well known as the "Parallel Roads of Glen Roy." The Spean terminates its course of 33 miles at the head of Loch Eil, where it passes into the Lochy at Kilmanivaig.

33. Loch Lochy and Loch Arkaig.—Of these lakes the latter is fed by the *Arkaig water*, and a few streams from the head of the lake form the termination northwards of the district which has been considered as forming the southern division of the western water systems of Scotland. Beyond Loch Lochy the natural line of water-shed crosses the line of the Caledonian canal at a height of 96 feet above the sea. This is the summit level of the canal and the lakes that form a continuous chain to the north-east, draining in that direction. They are only united artificially, and for the purposes of navigation, with the western water-shed.

Northern Division.

West Coast Catchments.

34. Loch Shiel.—Loch Shiel receives a small drainage from the country between Loch Eil and the Cora water. The lake is more than 10 miles in length, and expands between lofty chains of mountains. It receives a feeder from the south-east, near its outlet, this feeder proceeding from another lake of much smaller size.

35. Loch Morar.—This lake is a few miles to the north of Loch Shiel, and is considerably wider, but it has no feeders of importance. It occupies a hollow between two high ranges, from whose slopes it is fed.

36. Loch Carron and Carron water.—Immediately north of Loch Morar and Loch Archaig there is a string of lakes connected by the Garry river, but draining eastwards to Loch Oich, and not westwards towards the Atlantic. These and another parallel series a little further north, belong to the eastern water-shed, and drain to Loch Ness, although they take their rise only a few miles from the western coast. Still further to the north the *Shiel water* enters *Loch Duich* by a short channel, and the *Elchaig river* and *Long beck* enter a northern branch of the same inlet. Before entering open water these pass through *Loch Alsch,* and come into Loch Carron at its southern expansion. Loch Carron has two principal branches entering north, one bearing the same name, running in nearly 8 miles, and the other, *Loch Kishorn,* about half that distance. Both receive drainage from the interior. The Carron river has a straight course of about 15 miles to the south-west, expanding into two lakes on its way. A stream, passing through *Loch Kinloch* and two smaller pieces of water, enters Loch Kishorn after a southerly course of about 8 miles.

37. Loch Maree.—The next drainage to the west coast is by Loch Maree, which originates in a group of very small sheets of water collecting from the south and expanding into this lake, which is more than 12 miles long and runs from south-east to north-west, discharging into *Loch Ewe* by a short channel. Beyond Loch Ewe is an inlet called Gruinard bay, into which *Loch Fuir* discharges from the south, and the *Shallag water* conveys the surplus waters of *Loch Shallag* from the country a little to the east. There is also a small drainage into the head of *Loch Broom,* another inlet a little beyond in the same direction.

38. Loch Assynt.—Beyond Loch Broom there is no western drainage till we reach *Loch Enard,* into which the *Kirkaig river* enters, conveying the overflow of a complicated string of narrow lakes from some distance in the interior. Not far from it the *Inver river* brings the water of Loch Assynt, a larger sheet of water connected with another complicated series of small lakes.

Loch Assynt drains the slopes of Ben More Assynt (3,243 feet), and is a fine lake 10 miles long, with varied scenery. The other lakes occupy a district described as an alternation of patches of verdure, rocks, hills, mountains, and pools. Every hollow cradles a sheet of water.

39. Loch Laxford.—Still further north we come to Loch Laxford with its corresponding chain of lakes commencing close to the head waters of Loch Shin, and extending north-westwards for about 16 miles. Its lakes are *Loch More* and *Loch Stack,* which connect with Loch Laxford by the *Laxford river. Loch Inchard,* a little beyond, is the outlet of a corresponding but shorter chain. It is the last of the larger inlets before reaching Cape Wrath.

North Coast Catchments.

40. Dionard river.—East of Cape Wrath the first drainage from the northernmost extremity of Scotland is by the Dionard river, which enters the Kyle of Durness, an inlet about 8 miles east of the Cape, and opens inland about 4 miles. The river originates in a small lake (*Loch Dionard*), and has a course of 10 miles to the Kyle. The country is very wild, the mountain of Foinaven rising to 3,015 feet at the river source. Five miles east of the Kyle of Durness is *Loch Erriboll*, a wide and deep inlet, receiving the drainage of a string of lakes in Glen Golly, and another string ending in *Loch Hope*, 8 miles in length, connected with some large lakes.

41. The Naver river and the Borgie river.—Passing the Kyle of Tongue another deep inlet, which receives at its head the *Kinloch water*, connected as in almost all these streams with a series of lakes, we reach first the Borgie river, and then the river Naver. They both enter the same small estuary. The Borgie river connected with several small sheets of water, drains one large lake, called *Loch Laoghall* (*Loch Loyal*), on whose western bank rises abruptly Ben Laoghall to the height of 2,500 feet. The lake is nearly 8 miles in length, and half a mile wide, and is irregular in shape. Four or five miles to the east is Strath Naver, the vale of Naver, which originates in two lakes, one of considerable size, nearly 20 miles from the coast. It is the central and principal drainage in this part of Sutherlandshire, and its small feeders rise from the northern slopes of the mountains that enclose the Shin drainage. The lakes are *Loch Naver* to the west, and *Loch-a-Choir* and *Loch-a-Vellich* to the south-east, separated by Ben Klibreck (3,164 feet). The latter lake, about 5 miles long and a quarter of a mile wide, is entirely enclosed by high mountains, leaving only a narrow passage to the north by which the river *Mallert* conveys the surplus waters to the foot of Loch Naver by a channel nearly 5 miles in length. The Naver river is 15 miles in length, and flows north from the lake.

42. The Strathie river.—About 10 miles east of the Naver the Strathie river drains a narrow valley from a distance of about 15 miles, flowing nearly due north, and just beyond it the river *Halladale* drains another similar valley. The water-shed to the east of Halladale is the county boundary between Sutherland and Caithness.

43. The Thurso river and the Forss.—The drainage of Caithness is towards the north, and is conducted by the two rivers thus named. The Forss is the further to the west, but much the smaller. It commences in *Loch Beg*, and receives the water of two other lakes, both of larger size. It has a course of about 15 miles to the north. The Thurso river commences near the south coast of Caithness in a number of small lakes, which after flowing north 5 miles enter a wide valley (Strath More) where, in *Loch More*, is collected the drainage of a large district into a multitude of streamlets, expanding at intervals into lakes. The distance of the sources of the Thurso from the sea is as much as 30 miles, and the river traverses a wild tract of moor and morass.

Besides the streams already mentioned draining Caithness, there is one more entering at Wick, on the east coast. This, like the others, originates in lakes in the interior, but it flows to the east instead of to the north. *Watten lake* is the largest of the sheets of water through which it passes.

44. The Ullie river.—The sources of the stream bearing this name are several sheets of water, some of large size, situated among the mountains in Eastern Sutherlandshire, which give rise, on their western slopes, to the Naver. From there the Ullie flows 25 miles to the sea, near the Ord of Caithness, passing through a grand valley between the Morven hills and a group of much more lofty mountains a little to the south.

45. The Brora river.—From the mouth of the Ullie to Brora is about 10 miles, and here another river enters the sea. The Brora river is formed by the union of these streams draining narrow parallel valleys, all rising in hills which culminate in Ben Armine (2,306 feet). It has a course of about 20 miles to the south-east. The common channel after their junction, is the Brora river, which flows about 8 miles, expanding in a lake (*Loch Brora*), which is 3½ miles in length. Ten miles south of Brora is Dornoch, at the mouth of the Dornoch Firth, into which the drainage of the Shin enters.

46. Loch Shin and the river Oykill.—The basin of the Shin occupies a large proportion of the central part of the county of Sutherland, its waters being collected from the slopes of many lofty mountains, some of them not far from the west coast of this part of Scotland, and within the zone of heaviest rainfall. These waters are collected and stored in one lake of considerable dimensions, and a multitude of much smaller sheets of water. The drainage is effected by two principal branches, the Oykell river and Loch Shin.

The Oikel or Oykill has its source in so many small lakes and pools connected with channels which are generally almost accidental waterways, that it is difficult to define them, and would be much more difficult to identify them on the spot. Two small lakes, *Loch Ailsh*, and another from the Cromalt hills, combine to form one branch running south-east about 10 miles to Oikel bridge. They are there met by another branch, part of which comes 7 miles from the west, small branches joining them from the south. After 5 miles the river *Cassley*, a considerable tributary, joins the stream from the north-west, after a course of 15 miles, and the united river runs 10 miles east to Invershin, where it expands into a small lake, previously receiving the waters of Loch Shin conveyed by the river *Shin*.

The drainage of this basin from the north-west, passing through Loch Shin, is a very important part of the whole. Loch Shin is 20 miles in length, and is fed by streams coming 10 miles beyond to the north and north-west, through two smaller lakes, *Loch Merkland* and *Loch Geam*, or *Griam*. The upper portion of the district is wild and picturesque, but the lake itself, which is about a mile wide, is enclosed in its lower part by low monotonous hills. About half way from the head of the lake on the left shore it is joined by a small stream, fed also by a lake, and passing through Glen Fiag. Further down, and near the foot of the lake, the *Terry river* brings a further contribution from the north-west, fed by several branches, one of them expanding into a lake, and having a course of nearly 15 miles. At Luirg, at the foot of the lake, is another feeder from the north, also from lakes. The length of course of the Shin from the lake to the confluence of the Oykill is only 5 miles, during which it is joined by the *Grudie river* from the north-west. Its drainage area is 727 square miles.

Below the lake, near Invershin, after the junction of the Shin and the Oykill, the banks of the river expand and form part of an inlet entering nearly 15 miles from Dornoch Firth, and known as the Kyle of Sutherland.

44. Cromarty Firth and its drainage.—South of Dornoch Firth is Cromarty Firth, forming the northern portion of Moray Firth. This inlet, at first very narrow, expands into a large bay 5 miles from the entrance, and then continues with varying breadth, but nowhere much more than a mile, to Dingwall, a distance of more than 12 miles to the south-west. Above Dingwall it narrows rapidly, and receives the drainage of Strath Bran and Strath Conan, two long valleys nearly parallel, uniting in the *Conan water*, and there receiving other additions from the north and south.

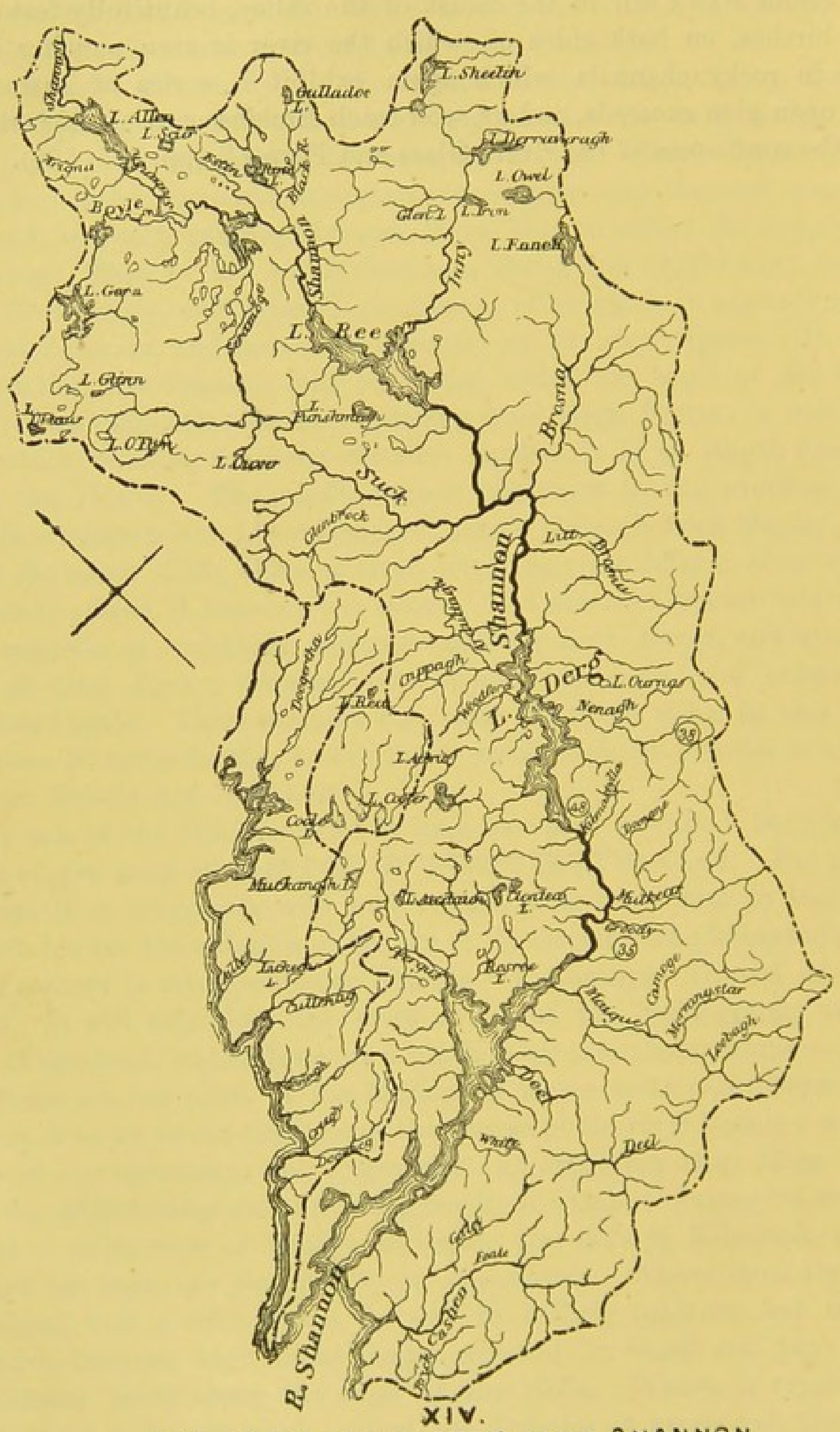
By far the most important of this complicated group of streams and lakes is that passing through Strath Bran. It commences 50 miles in a direct line west of Cromarty in a small sheet of water called *Loch Sherlett*, and continues in an easterly direction through *Loch Cran*, *Loch Roshk*, the *Sheen water* (8 miles), *Loch Kular*, *Loch Luichart* (6 miles long), and the Conan water. Between Loch Kular and Loch Luichart it receives the waters of *Loch Fannich*, a large lake parallel with Sheen water to the north. At Conan water it meets the *Meig water*, which has had an easterly course of 15 miles through *Loch Lenachan*. After 5 miles the Conan water receives the *Rasag* from the north, after that stream has passed through *Loch Garve*. Four miles below the Rasag the *Orvin* comes in from the south-west, after a course of 25 miles parallel to the Meig water. From Conan bridge the course of the main stream is turned to the north for 3 miles into Cromarty Firth at Dingwall.

45. Beauly river.—The last of the rivers, expanding into lakes and fed by numerous waters from the mountains of this part of Scotland, is the Beauly river, entering the Beauly basin, where the river Ness enters the Firth of Inverness. The course of the river is parallel to that of Loch Ness, the distance apart being about 10 miles.

The Beauly, like many of the Scotch rivers, originates in several streams bearing different names, and only assumes its final designation in a part of its course very far from its source. Three streams, each rising in a rocky waste and mountainous country near the west coast of Scotland, and each passing through lakes, help to collect the supply for this river. That to the south rises near Ben Altow (4,000 feet), passes down Glen Grivie, and enters *Loch Affaric*, after which it expands again in *Loch Lenevian*, and runs some distance as the river *Affaric*. It soon receives the river *Cannich*, and continues under the name of the *Glass river* till an important feeder, entering from Glen Farrer, is received, after which, running for some distance further, it is at length denominated the Beauly. The middle branch originates in the overflow from a small mountain lake (*Loch Lungard*) passes through Loch Mayley, and, under the name of the Cannick river, joins the river Affaric, after which, as already stated, it becomes the Glass. The northern branch originates in a number of mountain torrents entering *Loch Mongr*, and running through *Glen Farrer*, forming two small expansions, and enters the Erchless Castle. These streams run from 20 to 30 miles to this spot, and then 20 miles further to the Loch, which is about 8 miles in length between Beauly and Inverness.

The vale of the Beauly, which in its upper part is called Strathglass, is one of the most attractive in its scenery in all Scotland. For a long distance it is singularly wild and rugged, and from first to last it is remarkable for the extent and beauty of its forests. The following notice of its scenery is extracted from Black's "Picturesque Tourist of Scotland." It will fitly close the brief notice of the hydrography of this part of Scotland, which deserves a much more extended account:—

"There are few parts of the Highlands where more picturesque river scenery is to be found than along the course of the river Beauly; nor are many of our mountains more gigantic and imposing than those which gird the Alpine lakes and central glens from which it derives its sources. About 2 miles west of Beauly it makes the falls of Kilmorak, which, though not high, are picturesque in appearance. Above them the river for about half a mile works its way in boiling caldrons and broken cascades, between high rocky banks crowned by birch and pine trees. A pathway leads along the edge of the cliffs. Where it rejoins the public road a longer reach, called the Drhuim is presented, the river threading its way for two or three miles between more open banks, partly cultivated, and the hill-sides clothed to their summits with weeping birches. Fantastic islets and pinnacles of rock jut out in the bed of the river. At the top of the Drhuim the road brings us in front of a round rocky hill in the midst of the valley, beautifully festooned with birches, on both sides of which the river is seen pouring itself down in rocky channels, which again exhibit a series of cascades." "An open glen succeeds, and we soon reach Erchless castle, which stands near the confluence of the rivers Glass and Farrer" (pp. 525, 526).



XIV.
THE DRAINAGE SYSTEM OF THE SHANNON

Scale of Miles

0 5 10 15 20 25 50

CHAPTER XIV.

THE BASIN OF THE SHANNON.

(1) General description of the basin.—(2) Geology and physical geography.—(3) Subdivisions.—(4) Rainfall, evaporation, and percolation.—(5) Ordinary flow and flood.—(6) Tidal influence.—(7) Scheme of the tributaries and lakes of the Shannon. *The Upper Shannon:*—(8) Sources of the Shannon.—(9) The river Owenmore.—(10) Lough Allen.—(11) The Boyle water.—(12) Lough Boderg and Lough Bofin. *The Middle Shannon:*—(13) Lough Ree.—(14) The river Inny.—(15) The river Suck.—(16) The Brosna river.—(17) The Little Brosna river.—(18) Lough Derg.—(19) Lough Derg as a flood regulator.—(20) Falls of the Shannon. *The Lower Shannon:*—(21) The river Maigue—(22) The river Deel.—(23) The river Fergus.—(24) The river Cashen.—(25) Clare coast drainage.—(26) The Inchiquin loughs.

1. General description.—The Shannon being not only the most important of the Irish rivers, but draining a larger area than any single river of the British islands, deserves to be the first for consideration among the rivers of Ireland. It is in some respects also a key to the general system of river drainage in the country, and it is almost typical in the number and magnitude of the lakes that intervene at various points to prevent its water-supply from running off to the sea, which it would otherwise do, almost as rapidly as it falls on the ground. The Severn has few tributaries of importance, but most of those which it has, partake of the same peculiarity, and expand into lakes.

In his account of the industrial resources of Ireland, Sir R. Kane described the Shannon in the following words. He speaks of it as " that great river which, penetrating the interior of Ireland, navigable from the ocean to its source, rising in one coal formation, emptying itself through another, and washing the banks of our most fertile counties, delivers into the sea the rain collected from an area of 3,613 square miles of country north of Killaloe. This noble river, which at Lough Allen, near its source, is but 146 feet above the sea, passes slowly along, falling only 50 feet in 150 miles, until it arrives at Killaloe, where its waters rush down the great rapids towards Limerick, and in a space of 15 miles present a difference of level of 97 feet."

The drainage area of the whole basin of the Shannon is estimated at 6,946 square miles, and the total length of course 225 miles. It will be evident from what has just been said, that the last 50 or 60 miles of the river must be over a country nearly level. Below Limerick, indeed, the river almost becomes an estuary, and ceases to have any appreciable fall.

The height of the source of the Shannon above the sea is 345 feet.

2. Geology and physical geography.—With the exception of some small patches of Old Red Sandstone and Silurian rock in the neighbourhood of Lough Derg, enclosing the lower part of that lake, two similar but much smaller patches around the northern lakes and northern tributaries, one at Lake Boderg and the other on the river Boyle, and lastly a small tract of millstone grit, with occasional patches of coal-measures, near the source of the river and around Lough Allen, the whole basin of the Shannon is on the great carboniferous limestone plateau characteristic of the interior of Ireland. This wide expanse of the mountain limestone spreads far to the east and west of the Shannon basin, reaching the coast on both sides. It reaches also northwards as far as Lough Neagh, and southwards to the Blackwater river.

In its course from Lough Allen to Lough Derg the Shannon flows with a slight current, half lake, half river, through the nearly level limestone plain. At Killaloe it crosses a curious dome of Silurian rock, its channel being cut through Old Red Sandstone and Silurian grits and slates, instead of passing westwards to the ocean in Galway bay. It is, therefore, clear that the ridge that now exists, and is cut through by the river, did not exist as a barrier when the stream cut its present channel, which must, therefore, be of very ancient date.

Another Irish river, the Blackwater, is also deflected from what would seem its natural course, but for a different reason. In this case an obstacle must have existed, which has since been removed, but both it and the Shannon are interesting as examples of peculiar conditions of river channels, met with in England as well as Ireland.

3. Sub-divisions.—The course of the Shannon is naturally divided into three parts. In the upper, the country drained is but a small portion of the whole area. It includes a district abounding in lakes, chiefly of small size, including one that is large. This division terminates at Lough Forbes, below the Black river. The middle course runs through a very large district, almost level as far as Killaloe, and including the country about 15 miles beyond that town to the extremity of the Falls of the

Shannon. The Lower Shannon, below the falls, is almost level, and is tidal.

4. Rainfall, evaporation, and percolation.—The sources of the Shannon, and of the early feeders, not only of the main stream, but of its chief tributary the Suck, and also a large part of the lower course of the river, including the district below the head of Lough Derg to the sea, are subject to a heavy rainfall, ranging between 40 and 50 inches, and occurring at short intervals, as the heavily-charged south-westerly winds, warm and moist from the Atlantic, reach and rise over the edge of the great limestone plateau. The whole of the west coast of Ireland feels this influence, and though the heaviest falls are received by the more mountainous country in the south, there is rarely a want of rain at any time of the year. The result is seen in the number of tributaries, and the complexity of the small lakes and pools connected with them.

The middle basin of the Shannon, including the whole of Lough Ree, and the country around to the foot of Lough Derg, belongs to a zone of smaller fall, in which 40 inches is not commonly reached, and between 30 and 40 are the limits.

The evaporation in Ireland must, no doubt, be comparatively low, although the prevalence of wind, and the frequent alternations of rainy and drier weather, particularly common in a country which has rain almost every day, are no doubt the cause of the re-absorption into the atmosphere of a large amount of the discharge. The atmosphere is, however, very near the point of saturation in Ireland, and this being the case, the mountains not being very lofty, and the temperature very equable, the evaporation must be to some extent diminished in this respect. Of the rain that falls, a large quantity is unable to enter the rock, which is rarely permeable, except when fissured; but it certainly does not run over the surface in rivers. It much more frequently, perhaps, reaches a short distance below the surface, and is there detained on the limestone rock, buried under a vast mass of peat bog that has been accumulating for centuries, and which often floats over vast pools, delivering their excess of water as a dark chocolate coloured fluid to the streams below, when the accumulation is in excess. For this reason the streams are frequently discoloured by peat, and the country is rendered almost inaccessible. Evaporation, no doubt, takes place largely (when the atmosphere is not already saturated) by the exposure of so large a quantity of wet surface to the winds. The form of the table-land, scooped out at intervals in hollows, whether by the action of ice or other ways, renders it well adapted for this result.

"In the geographical character of the basin of the Shannon we find all the conditions for great evaporation fulfilled. The country whose waters it receives is flat, its streams sluggish, and the soil upon its banks either deep and retentive clays, or extensive bog. Expanding into numerous lakes of considerable size, and often overflowing the low lands on its banks, it may be considered as almost in the condition of presenting a true evaporating surface in dry or windy weather; but the quantity of water it carries to the sea is very large. It has been observed that in wet weather the level of the water in Lough Derg often rises 2 or 3 inches in 24 hours, and has been known to rise 12 inches."*

Of actual percolation into the soil there must be little over the basin of the Shannon, except where the limestone or other rock is fissured, and admits water freely through large openings, by which there is ready access to the interior. None of the surface rocks are in any sense permeable. The reader will, however, see in the account of the sources of this river, how extensive and important are the openings by which water obtains access to the interior of the hard and impermeable rock, which prevails almost everywhere at the surface.

The evaporation and percolation, always to some degree dependent on the nature of the rock that preponderates in any district, are affected in an extraordinary degree in Ireland, and especially in the basin of the Shannon. Nowhere in the British islands are there found such wide expanses of level limestone, semi-crystalline in its texture, and not only cracked by metamorphic action and elevation, but eroded and penetrated to a great depth by water. Much of the peculiarity of the climate and the state of the surface depends on these conditions.

5. Ordinary flow and flood.—The flow of the Shannon is exceedingly different both in the conditions that cause it, and in the nature of the flow, from any of the English rivers. The peculiarity of the surface, and the character of table-land, are points that apply generally to Ireland, but especially to the Shannon valley, and are a chief cause of this. The enormous area covered with bog also affects this result very seriously. The following statement, and the table that follows, will illustrate the conditions, and explain many of the peculiarities. The reader will do well to refer to the diagram in p. 129 to see the relation of the Shannon fall with that of other British rivers.

The average fall of the Shannon may be considered to have four stages. In the first 18 miles it amounts to as much as 184 feet, or 15′ 9″ per mile. Beyond this for 135 miles the whole fall is only 71 feet, or little more than 6 inches per mile. There is then a sudden fall of 55 feet in about 4 miles, and a further fall of 13 feet in $3\frac{1}{2}$ miles. Thence to the sea there is hardly any perceptible difference of level. The interruption caused by the heavy and continued fall on approaching the sea level, though at a distance of 64 miles from the present shore, is overcome by lochs.

* Kane's Industrial Resources of Ireland, p. 81.

The distance from lake to lake, and the length of the lakes which so greatly affect the flow of the Shannon, will be understood by the following statement :—

	Miles.
Source to Lough Allen - - - -	11·6
Course through this lake - - -	7·0
Lough Allen to Lough Boderg - - -	23·5
Course through Lough Boderg - - -	4·7
Lough Boderg to Lough Forbes - -	4·6
Course through Lough Forbes - - -	2·2
Lough Forbes to Lough Ree - - -	10·0
Course through Lough Ree - - -	17·5
Lough Ree to confluence of the Suck - -	16·7
Confluence of Suck to Lough Derg - -	22·6
Course through Lough Derg - - -	23·0
Lough Derg to Limerick - - -	17·1
Limerick to the sea - - - -	64·5
Total - -	225·

Owing to the frequent expansion of the river into large lakes that admit of a vast increase of water without any rapid increase of the river below, floods are little known in the Shannon. The heaviest storms may expend themselves in vain over the large water-shed of this stream without any serious result in the lower part of the river. The lakes act as flood regulators, the water, however highly it may be raised in the upper part, must first fill to overflowing Lough Allen and then the other lakes, until the whole stream is a succession of basins, emptying one into another as each becomes full, and at last reaching the lowest where there is abundant room for a large accumulation. The overflow of the upper lakes, no doubt, passes into those below very rapidly, but time is required for the process, and by the time that a heavy flood has reached the large lakes, its fierceness is lost, the waters rise gradually, and those first arriving have had abundant time to escape.

In the cases where, for a distance of some miles, a river like the Shannon runs between its ordinary banks in a water-way adapted to its ordinary volume, and is provided with storage room in natural lakes, it may receive a large addition to its volume before becoming a torrent, and even when in a torrential state in the upper part the distances from pool to pool, during which there may be an occasional rush, are too small to allow of serious mischief.

The water surface in the various expansions of the Shannon is so large as to place this river in a very advantageous position when compared with any of the English rivers, or even with the larger Scottish rivers that traverse or expand into lakes. The length of course through the lakes is nearly one-fourth of the whole length of the Shannon, and if we assume the average width of the lakes to be only 2 miles, and their length 50 miles, we shall have an area of 100 square miles. A little calculation will show that to raise the general level of the lakes 2 feet, a quantity of water must be added to the usual supply, equal to $1\frac{1}{4}$ inch of rainfall over the whole area of 3,000 acres between the source and the foot of Lough Derg, assuming that every drop of the fall could be made available. As not more than one-fourth of the rainfall generally passes over the surface in ordinary streams, it would take 5 inches of rain to produce the effect mentioned, but during the time that so heavy a rainfall must take place, the lakes would all be discharging their surplus water without flood. Lough Allen, the highest lake, varies 4 feet in level between summer and winter, and the other lakes are capable of great increase.

6. Tidal influence.—The mouth of the Shannon between Loop Head and Kerry Head is as much as 10 miles across, and the entrance to the river is funnel-shaped, narrowing gradually to Limerick. The spring tides rise in the river from 17 to 18 feet; the neap tides 14 feet. The velocity of the stream, which at the mouth does not exceed one mile an hour, increases as the river becomes narrower to upwards of 3 miles an hour; and this meeting the advancing tidal wave, it results that during the flood it rushes up, forming a bore, with great strength and velocity.

7. Scheme of the feeders and lakes of the Shannon.—The following general outline of the relative position and names of the chief feeders and lakes of the Shannon will be useful.

Right bank.		*Left bank.*
		Owenmore river.
	Lough Allen.	
Diffagher river. Lough Belhavel.		
		Yellow river.
Arigna river.		
	River Shannon.	
Feorish river. Lough Skean. Lough Meelagh.		
Boyle river. River Lung. Lough Gara. Lough Key.		
	Lough Boderg.	
Lough Kilgass.		Lough Bofin.

Right bank.		*Left bank.*
	River Shannon.	
		River Rinn.
		Lough Rinn.
	Lough Forbes.	
	River Shannon.	
	Lough Ree.	
		Inny river.
		Lough Sheeling.
		Lough Kin.
		River Glose.
		Lough Glose.
		Lough Derravaragh.
		Lough Garr.
	River Shannon.	
Suck river.		
		Brosna river.
		Lough Owel.
		Lough Ennell.
		Clodiagh river.
		Little Brosna river.
	Lough Derg.	
Coppagh river.		
Woodford river.		
		Nenagh river.
Graney river.		
	River Shannon.	
		Mulkear river.
Goinna river.		Maigue river.
Fergus river.		Deel river.
		Cashen river or Feale.

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8. Sources of the Shannon.—The recognised, or, rather, traditionary source of the Shannon is at Legmonshena, 7 miles from Swanlinbar, a decayed town very picturesquely situated among the calp limestone hills of Leitrim, on the border line of the counties Leitrim and Fermanagh, between two chains of lakes, the easternmost of which comprises the upper lakes of Earn and the upper lake Macnean. The scenery of the carboniferous limestone is exceptionally fine. "The source or spring is of a circular form, about 50 feet in diameter, called the Shannon Pot. It boils up in the centre, and a continuous stream flows from it about 8 feet wide and 2 feet deep in the driest weather, running about 4 miles an hour."* Adjoining, and forming a water-shed towards the north, is the

* Murray's Handbook for Travellers in Ireland, 1871, p. 67.

Cuilcagh mountain (Cavan county), 2,188 feet above the sea, whose summit and sides receive much rainfall, but have no water channel, and, the limestone being fissured, there can be no doubt that a large quantity of water passes into the interior, which is very cavernous, and is thence conveyed and finds its outlet at the rocky point called Shannon Pot.

Assuming the correctness of the measurement of the water in the above quotation, the flow would amount to about 500 gallons per second, or upwards of 40 million gallons per day. This large quantity must be derived from the rainfall of a considerable district. If we imagine that as much as 12 inches of the total rainfall of the district entered into the crevices of the rock and emerged in the Shannon Pot, it would require nearly 50,000 acres to supply the quantity estimated. It is, however, impossible that the whole could be thus delivered at one spot, and the area of collection must, therefore, be much larger.

9. Owenmore river.—Although this circular pool, yielding a large and steady supply of water, is popularly regarded as the source of the Shannon, it is by no means the only, nor is it the most distant source. The water flowing from it runs for a short distance (about 2 miles), and there combines with the Owenmore, a tributary, if it must so be called, which has already run a course of 5 miles, receiving some rivulets on its way. Before as well as after the junction, the water coming from the Pot bears the name of Shannon, and the united stream flows in a deep sluggish stream for about 6 miles to Lough Allen.

The Owenmore drains the broad moorlands of Erris, formed of Lower Carboniferous beds, and takes a westerly course, although the present configuration of the country would suggest the opposite as the natural direction.

10. Lough Allen. — This great and important lake is the first of the numerous expansions which characterise in so remarkable a manner the bed of the Shannon. It is a great reservoir, collecting in its wide basin, 8 miles long and 3 miles wide, numerous streams draining the high moorlands and wide valleys to the north and on each side. The most important of these is the *Diffagher*, which, before it enters, has already expanded into the small lake of *Belhavel.*

Lough Allen occupies a deep depression between hills rising to 1,700 feet on the east and 1,400 feet on the west. Its usual level is about 115 feet below that of Shannon Pot. The distance being 8 miles, the fall to the head of the lake is nearly 15 feet per mile. The waters of the lough average 161 feet above the sea (159 in summer and 163 in winter). At the lower end is the town of Arigna, where a stream bearing that name

(*Arigna river*) enters the lake, conveying the drainage of a small district to the north-west. There are ironworks at Arigna.

11. The Boyle water.—Leaving Lough Allen, the Shannon is obstructed by shallows, and on this account a canal of 5 miles has been cut from Drumshambo to Battle Bridge, the fall being overcome by locks. From this point the river runs in a southerly direction, with a mid-channel depth varying from 5 to 20 feet for 6 miles, when it receives the tributary called the Boyle river, proceeding from the west and south-west through the lakes *Gara* and *Key*. The former of these lakes receives the waters of the *Lung* and some smaller streams, and is of irregular shape, but the views over it are very picturesque. Issuing out of Lough Gara, the waters first receive the name of Boyle water, and, after an irregular course of 4 miles, they enter Lough Key, the prettiest and most varied of the northern group of small lakes, studded with islands and fringed with wood. The town of Boyle is near the entrance of Lough Key from Lough Gara. By the removal of shoals and the construction of a lock the navigation is now open from the mouth of the Shannon to the entrance of the town of Boyle.

From Boyle, through Lough Key to the Shannon at Carrick-on-Shannon, the distance is nearly 8 miles, the water channel being exceedingly irregular in form, expanding and narrowing frequently within a short distance. Two miles below Carrick is a small expansion of the stream called *Corry Lough*.

12. Lough Boderg and Lough Bofin.—Making a large curve by Jamestown, the Shannon, now a river, turns to the south at Drumsua, a village situated in the neighbourhood of very lovely scenery, and, after a few miles, begins to expand into Lough Boderg, which is connected by a branch channel with *Lough Kilglass* to the south-west, and narrows into Lough Bofin to the south. These lakes are all expansions of the Shannon. The scenery they pass through is pretty, as the indented shores are covered with wood and the district is fertile. A few miles below Lough Bofin there is another small expansion called *Lough Forbes*. This lake has a depth of only 7 or 8 feet, but the shoals that once interrupted the navigation have been cleared.

13. Lough Ree.—From Lough Forbes to Lough Ree, the next of the lakes, the distance is about 7 miles, and the river has an average breadth of 250 yards. Lough Ree is more than 20 miles in length from north to south, and its breadth in the northern or upper half is about 2 miles, and in the northern half about 4 miles. It stretches out from the middle part some miles to the east, and has several islands of considerable size. The character of the scenery around is not hilly, but the banks are in many parts richly wooded, as are also the numerous islands. One of them, Hare island, is considered to be a perfect gem of woodland scenery. Near the southernmost extremity of the lake is an expansion bearing a distinct name. It is called *Lough Killinure.* A little beyond the extremity is the town of Athlone.

14. The river Inny.—The eastern extension of Lough Ree receives the river Inny, an important feeder expanding, like every part of the Shannon, into several lakes, some of considerable dimensions. This stream originates in a number of small lakes, whose waters combine, and, after an irregular flow of 8 or 9 miles, expand into *Lough Sheelin,* one of the largest lakes in the county of Cavan, $4\frac{1}{2}$ miles long, and covering 8,000 Irish acres. The scenery is pleasing, but not striking. By a short passage there is communication with a smaller lake, *Lough Kinile.* From this the Inny proceeds as a large stream, running due south for nearly 10 miles to *Lough Derevaragh,* an irregularly-shaped lake 6 miles in length, and 211 feet above the sea. On its way it receives the river *Glore* from a lake of the same name. The Inny enters Lough Derevaragh at its north-western extremity. The sides of this lake are boggy and tame, but at the south-eastern end it narrows, and the scenery is fine, the lake being enclosed in that direction by hills rising abruptly from the water to the height of 600 or 700 feet. Issuing from the lake at a point not far from the entrance, the Inny proceeds southwards to another lake, *Lough Iron,* and then flows almost due west for nearly 20 miles to Lough Derg.

15. The river Suck.—Proceeding beyond Athlone, where the Shannon issues from Lough Ree, and is already a large river, it runs about 17 miles in a southerly and south-westerly direction to Shannon Bridge, where it receives the Suck, one of its most important tributaries. This river rises near Castlereagh, among a group of tarns, or small pools, on the north-western water-shed of the Shannon, about 267 feet above the sea. The drainage from these lakelets forms a stream which flows a little east of south, gradually increasing by the confluence of tributaries from each side, and after a sluggish course of nearly 60 miles through an open valley, reaches the Shannon with a volume of water little inferior to that of the Shannon itself. On its way it receives some tributaries. In the upper part the *Cloonard river* enters from the left bank, and lower down are several streams draining chiefly the right bank. The course of the Suck being parallel to that of the Shannon, and not far distant, there is little opportunity for drainage on that side from the east. The feeders from the west also have none of them a long course. The Suck, however, drains a large district, and flows at least 60 miles. It is the principal tributary of the Severn.

16. The Brosna river.—The Suck joins the Shannon about 8 miles above Shannon harbour, at which place the main stream is joined by the Brosna from the north-east, entering on the left bank, but not bringing a large water contribution. The Brosna originates in the overflow of two large lakes near Mullingar, 20 miles east of Lough Ree, and close to the river Inny. The first of these lakes, *Lough Owel*, is 329 feet above the sea, and has an area of 2,300 acres, or between 3 and 4 square miles. The scenery around is not striking, but the slopes are well wooded. There is excellent trout in this lake.

From Lough Owel the Brosna flows past Mullingar about 5 miles to *Lough Ennell*, also called *Belvidere lake.* It is a pretty lake, about 5 miles long, and wooded on one side. There is good fishing. Its level is 274 feet above the sea. The river issues from its southern extremity and flows south for 7 miles, when it turns to the west for about 25 miles to the Shannon. On its way it receives the river *Clodiagh* from the east. The early course of this stream above the town of Tullamore is called the *Tullamore river*.

17. The Little Brosna river.—From Shannon harbour, where the Brosna river joins the Shannon, the distance to Lough Derg is about 16 miles through a pleasant and cultivated country, passing several places of interest. On the way the Little Brosna enters from the left bank, passing Parsonstown and draining an important tract of country to the south-east. It is fed by several small tributaries, and enters the Shannon at Meelick Abbey.

Along the whole distance from Shannon Bridge to the entrance of Lough Derg ($22\frac{1}{2}$ miles), the shores are generally low, consisting of lands of rich marl, producing large crops of coarse grass generally backed by bog land 20 or 30 feet above the river. There are few places where good firm land comes down to the river's edge.

18. Lough Derg.*—This large and important sheet of water is 25 miles in length, and varies in breadth from three-quarters of a mile to 3 miles. There are large bays on both sides, which in some places cause an expanse of 7 or 8 miles. The scenery is beautiful towards the southern extremity where the lake lies between hills of considerable elevation, terminating abruptly on its shores. All the north-western shore is low, and abounds in bog land. The eastern side is much broken in outline, consisting of rounded limestone hills towards the north, and more abrupt hills of slate to the south. The slates are worked. There are few islands, but numerous rocks and shoals; and the shores are difficult of approach, being shallow and stony. The greatest depth is 20 fathoms, the southern part being much deeper than the northern. The bottom is marly, and is dredged for agricultural purposes.

The total area of Lough Derg is about 30,000 acres (Irish), but the water level varies much at different seasons, and this involves a considerable

* There is another lake of this name in Donegal County, very much smaller, but celebrated as the place of a pilgrimage.

difference in the area of water. At times the water rises 2 or 3 inches in 24 hours, and it has been known to rise as much as a foot in that time.* The average difference between summer and winter level at Killaloe, a mile below the lake, but where it first assumes the river character, is about 6 feet; but the total range in the height of the water during the year is as much as 11 feet. The water rises and falls periodically, the total duration of the period of rise being on an average 77 days, while 107 days are occupied in falling to the summer level.

19. Lough Derg as a flood-regulator.—The importance of Lough Derg as a flood-regulator of the waters of the Shannon, is well illustrated by the calculations as to the quantity of water affected. The area being taken at 30,000 acres, one inch depth of water over this area would weigh 3 millions of tons, and therefore in an extreme rise of 12 inches as much as 36 millions of tons would be accumulated. This has happened in a single day and night. The excess of the winter over the summer content of the lake being upwards of 400 millions of tons, which is discharged in 107 days, we have a continuous flow for that time of 1,552 cubic feet per second, in place of a series of sudden and unmanageable floods, by which the whole country would be injured, and no advantage gained. It will be seen that practically the navigation of the Shannon is due to the existence of this and the other lakes and expansions of its bed; and these again are the result of the geological conditions of the country through which it passes.

Besides some smaller streams from the west, of which the *Graney* is the principal, the *Nenagh* comes in from the east about midway down the lake. The Graney passes through two lakes.

Opposite Mount Shannon, on the south-western side of the lake, the shores narrow suddenly to a width of a mile and a half, and at this width they continue due south to Killaloe. Thence the river runs 7 miles a little west of south to the rapids of Castle Connell. The minimum discharge of the river at Killaloe is given by Sir R. Kane on the authority of Mr. Mullvany, as only amounting to 100,000 cubic feet per minute, or little more than the quantity due to the flow from the winter accumulations in the lake above. Without the lake the stream would be reduced to a mere rivulet in a dry summer, whereas now by the aid of a canal there is water enabling steamers of 200 tons to ply regularly during the driest season. Near Killaloe the *Kilmastulla* enters from the east.

20. Falls of the Shannon.—At Castle Connell "the Shannon pours an immense body of water, 300 yards wide and 40 feet deep, through and above a congregation of huge stones and rocks which extend nearly half a mile, and offers not only an unusual scene, but a spectacle approaching

* Sir R. Kane, Industrial Resources of Ireland.

much nearer to the sublime than any moderate stream can offer, even in its highest cascade. None of the Welsh waterfalls, nor the Griesbach in Switzerland, can compare for a moment in grandeur and effect with the rapids of the Shannon."

From Castle Connell to Limerick the Shannon winds considerably for a length measured on its course of nearly 10 miles, the banks being covered with residences. About half-way it receives the *Mulkear*, a small tributary from the south-east. The river bifurcates as it approaches the city, forming King's island, on which the older buildings are situated. Just above this bifurcation is the last fall of the river. The *Groddy* and other small feeders come in in this part of the river course.

Below Limerick the Lower Shannon commences, and the stream soon opens out into an estuary. Several rivers here join the main stream, some of them of considerable magnitude.

21. The river Maigue.—The first important tributary of the Shannon after passing Limerick, and attaining the condition of a tidal stream, is the river Maigue, which enters on the left bank 9 miles below Limerick, draining an important tract of country to the south. The Maigue rises on the northern slopes of the Ballyhourac hills that form the northern boundary of the Blackwater. These hills extend nearly east and west, and are connected westwards with other hills, the source of a number of feeders of the Lower Shannon. It is formed by two branches, that to the east is the Maigue, and that to the west is called the *Loobagh river*. Their sources are nearly 16 miles apart, but in the same range of hills. The two streams joining, they flow at once to the north, passing Croom and Adare, and reach the Shannon after a northerly course of nearly 25 miles.

22. The river Deel.—Ten miles below the confluence of the Maigue, the Deel, another feeder from the same line of hills comes in, after a somewhat shorter course past Newcastle and Rathkeale. Both rivers discharge their waters into the Severn by wide open channels, greatly interrupted by sand banks.

23. The river Fergus.—Opposite the Deel there is a very wide and large estuary opening northwards more than 10 miles to Ennis, encumbered with sands, which are quite uncovered at low water. This is the river Fergus, and it drains a considerable tract of country to the north. The river Fergus originates in the limestone district near *Lough Graney*, which enters Lough Derg from the west, midway in the length of the lake by a short channel. Its upper waters pass through several small tarns, and occasionally disappear or pass under natural arches between very steep banks. This curious district is called Toomeens.

A considerable branch joins the Fergus below Ennis from the south-west, called the *Claureen*, and another still lower, called the *Affrick*. The

Fergus is a considerable stream as it approaches the Shannon. It is tidal and navigable, the open navigation reaching Clare, a distance of 9 miles. It opens into a large expanse of sands.

There is no considerable tributary of the Shannon after the Fergus and the Deel for a long distance. The channel widens gradually, and some small streams as the *White river* on the south, and the river *Cloon* on the north, convey their waters into it; but they are unimportant, and until we reach the open water between Dunmore head and Kerry head, where the width of the river is upwards of 7 miles and it forms a bay of considerable dimensions, there are no additions. Here the river Cashen enters from the south-east, the last feeder of the Shannon.

24. The river Cashen, or Feale.—The sources of the Cashen are among the hills in which the Blackwater originates. In its upper course the river is called the Feale, where the waters of a large number of feeders from the Mullagherick mountains unite into a single stream. It soon receives the *Clydagh* and the *Owveg* from the south, and afterwards the *Allaghaun* and the *Oolagh* from the north. It then flows to Listowal, receiving the *Smearlagh* from the south, and as it nears the sea receives the *Galey* from the north near Ennismore, where it is first called the Cashen. Afterwards it has one more tributary from the south, the *Brick*, before reaching the mouth of the Shannon. The course of the stream is upwards of 40 miles, and the extent of country drained is considerable. The Cashen is a noble salmon and trout stream. Its total course is about 40 miles.

25. Clare coast drainage.—Beyond the mouth of the Shannon to the north is a district nearly 60 miles in length, measured in a direct line from Loop head at the mouth of the Shannon to Galway, and about 10 miles in breadth. This tract lies between the basin of the Severn and the Atlantic coast, and includes a small area from which there is no drainage to the coast. Several small streams enter the sea on this line of coast. The principal, named as we advance from Loop head, are the *Doonbeg river* and the *Cullenagh river*, originating in the *Inagh river*. They expand in their upper courses into tarns, and are fed by smaller streams, also connected with sheets of water, of which *Lough Lickeen* and *Lough Drumcullaun* are the principal.

26. Inchiquin lakes.—There is a remarkable group of lakes in Clare county extremely interesting from an antiquarian point of view, and receiving the drainage of a small district which has no outlet to the sea. The lakes into which the drainage of this tract of country is received, are several in number, and connected by a stream, called the *Fergus river* in part of its course. The lakes range from *Lough Inchiquin* and *Lough Atedaun* in a north-easterly direction parallel to the coast, for about 9 miles to *Lough Bunny*, and the whole tract of country abounds with castles, round towers, and other Celtic and Norman monuments. There being no access to the sea by any natural channel, the area of water exposed by these lakes to the action of the atmosphere must be that from which the evaporation balances the excess of rainfall, after deducting absorption into the soil and by vegetation, percolation, and the evaporation from the land on which the rain falls.

CHAPTER XV.

DRAINAGE AREAS OF THE SOUTH-EAST AND THE SOUTH OF IRELAND.

1. General account of the district.—The part of Ireland whose drainage systems will be considered in this chapter, comprises the whole of the island south of Dublin, and east or south of the basin of the Shannon. The east and west line of water-shed between the basins of the Liffey and Barrow and that of the river Boyne, reaches from the northern side of the Bay of Dublin to the Shannon basin in an irregular line, and this effects a very complete geographical separation. The district includes the whole of the counties of Wicklow, Carlow, Wexford, Kilkenny, Tipperary, and Waterford, and the counties of Cork and Kerry, besides a part of King's county and Queen's county. These are situated in the provinces of Leinster and Munster; but the political divisions of the country are not mainly dependent on its hydrography, and thus a precise reference to them is not required. The eastern water-shed of the Shannon basin forms everywhere the limit to the district till it is met by the southern water-shed of the Boyne. The area comprises some of the highest ground of Ireland, as both the Wicklow mountains and those near Killarney are included, and all the principal rivers rise in mountain districts. The whole area may be roughly estimated as comprising nearly 8,000 square miles. There are five distinct and well marked drainage areas, besides a number of small basins communicating directly with the sea.

The line of water-shed separating the various basins from those adjacent and not included, is for the most part comparatively low, though rising in places to upwards of 1,600 feet. For a long distance it does not exceed 300 feet. The Wicklow mountains included within these shallow basins rise in their highest peak to upwards of 3,000 feet, and the Kerry mountains to nearly 3,500. Even in Wexford and Waterford there are elevations of 2,600 feet. The character of the land is, therefore, somewhat exceptional.

2. Geology and physical geography.—The south-eastern and southern counties of Ireland are remarkable for the broken ground, hills and mountains, which characterise this part of the island. They are also exceedingly picturesque, and abound in places whose natural beauties are very great. This is especially the case in the Killarney district, and in the Wicklow mountains. The rivers have, however, little to do with these. The Liffey and the Slaney have their origin in the latter group, but little natural drainage of importance connects with, or is fed by the lofty and grand mountains of Kerry. They doubtless receive a vast quantity of rain, but it runs off at once to the sea by short water-courses conveying torrents rather than streams. There is, however, much that is interesting in the hydrography of the southern rivers, and though not of the first magnitude, they convey large quantities of water. The coast of the south of Ireland is very much broken into inlets, bays, and coves, exceedingly convenient for navigation, and very picturesque, and with most of these is connected some surface drainage. All the principal rivers enter the sea by estuaries. The breaking up of the coast-line into deep inlets is almost as remarkable in the south-western extremity of Ireland as in Western Scotland; but the streams draining into them are too short to be important. Beyond Bantry bay, on the west coast to the mouth of the Shannon, the coast is a succession of narrow promontories jutting out towards the south-west into the Atlantic, and separated from each other by channels of salt water, whose width is equal to that of the promontories themselves. On the south-eastern coast are many lagoons, some of them of large extent, receiving the fresh water from the rivers, and shut off from the sea by long tongues of sand, leaving only a very narrow inlet. These are phenomena elsewhere very rare on the shores of the Atlantic.

It is evident that in many points of physical geography the group of Irish catchments now to be considered abounds in objects of interest, some of them rarely met with in western Europe.

The east coast of Ireland contains an underlying mass of granitic rock nowhere very far from the surface, and in many places appearing above it. This is especially the case in Wicklow, where there is a long stretch of country nearly 80 miles from north to south, consisting almost entirely of rocks of this kind. Further to the south these rocks are covered by metamorphic slates and schists, and then by Old Red Sandstone, but in Kerry the old metamorphic rocks reappear. Both in the Wicklow and the Kerry mountains there is a large extent of country covered by bog; but there are no lakes, and the bog is nowhere continuous as in Galway.

There are in the south and south-east of Ireland large districts in which metalliferous minerals exist, and are to some extent worked. Both lead and copper mines are opened in the counties of Wicklow, Waterford, Cork, and Tipperary. The effect on the waters of the district has not, however, been traced, nor is it likely that it should have any injurious influence. There is, indeed, too little continuous working on a large scale to justify any idea of such result.

There are few lakes in the south of Ireland, and there is nothing to check the rapid flow of the streams to the sea after heavy rain. The small mountain tarns that are found as expansions of the upper valleys of some of the streams can hardly do much in modifying the flow of the rivers to the sea during freshets. It is, however, the case that almost all the rivers expand so much and so rapidly in their lower courses as to render floods, except in the upper parts of the valleys comparatively unimportant. Considering the heavy rainfall of the country this condition cannot but be regarded as very favourable.

Although the great expanses of morass and bog for which Ireland is celebrated are not unknown in the south-east of Ireland, they are not predominant, and are chiefly limited to the northern portion. Elsewhere the drainage from the hard rocky mountain tops is rapid and unobstructed.

3. Sub-divisions.—There is no difficulty in grouping conveniently the catchments of the part of Ireland we are here treating. They may be considered to form two divisions, those draining to the east and south-east coasts, and those draining to the south and south-west coasts. The general direction of all, however, except the main streams of the Slaney and Barrow, is eastwards until we reach the Kerry mountains, the few occurring beyond that range draining westwards by very short courses. The general plan of the division is, therefore, thus stated:—

Eastern group—

The basin of the Liffey, and the catchments of the east coast.

The basin of the Slaney.

The basin of the Barrow, Nore, and Suir, and the catchments of the south-east coast.

Western group—

The basin of the Blackwater.

The basin of the Lee.

The catchments on the south coast beyond the Lee.

The western drainage of the Kerry mountains.

4. Rainfall, evaporation, and percolation.—The rainfall on the east coast of Ireland is by no means excessive, but it is very frequent, long droughts being rare, even in the driest parts. They are not, however, unknown. At Dublin, on the east coast, the mean fall does not exceed 31 inches, and at Cork it is not more than 40 inches; but a very small part of Ireland, and that only north of Dublin and the Liffey basin, comes within the zone of 25 to 30 inches.

Speaking generally, the whole of the Liffey catchment, that of the Slaney, and the middle and upper part of the great basin that comprises the three rivers of the Barrow system, lie within a great zone over which from 30 to 40 inches of rain annually fall. The lower part of the Barrow, the Nore, and the Suir, all pass through a wetter district as they approach the coast than that in which the rivers have their sources. These rivers, the lower part of the Blackwater, and the Bandon, receive a rainfall exceeding 40 inches but less than 50, while the sources of the Blackwater in the Kerry hills are in the zone of heaviest fall, exceeding 50 inches. The feeders of the lakes of Killarney, and the streams that flow into the Atlantic at the south-western extremity of Ireland, carry off a quantity of water very large in proportion to the small area of country drained. They are within the zone of heaviest fall. The middle course of the Blackwater, like the Liffey and the Slaney, has no heavier fall than from 30 to 40 inches.

Compared with England the rainfall in Ireland is not only heavy but frequent, and almost continuous. There is no dry season. But it does not thence follow that the evaporation is small, although the rocks are for the most part bare. On the contrary there is in all probability a very large evaporation commencing instantly after rain has fallen. Much of the country is covered with vegetation, detaining the water near the surface for a time, and the winds are constantly blowing.

Percolation into the rocks in the condition of those in the south of Ireland must be too irregular and partial to be estimated. In the limestone districts it is probably large, but in the slates and sandstones inconsiderable.

5. Quality of the waters.—The Irish waters almost without exception are peaty, but many of them, especially in the south-eastern district, where there is little drainage from boggy moors, are of the best quality. Those supplied to Dublin are from the river Vartry, and are remarkably good, flowing off slates and igneous or granitic rock. Few of the rivers of Ireland are utilised for town supply. All those of the south and east are good fishing streams, and their waters are pure and clear. It would be difficult to find circumstances better adapted to preserve water in a potable state than those met with in this part of the British islands.

6. Scheme of the rivers and their principal affluents.—The following general outline of the various rivers of this division of Ireland will be found convenient:—

The river Liffey.

Right bank.	*Left bank.*
	Kings river.
Hartwell river.	
	Rye river.
	Lyreen river.
Brittas river.	
	Tolka river.
Dodder river.	

Dargle river.
Vartry river.
Potters river.
Redcross river.

Avonmore river.	Avonbeg river.

Avoca river.

Aughrim river.

Derry river.	Ow river.

Kilgorman river.
Quanavoragh river.

The river Slaney.

	Derreen river.
	Derry river (or Shillelagh).
Cloda river.	
Glasha river.	
	Bann river.
	Blackwater river.
	Urrin river.
Boro river.	
Glenmore river.	
	Sow river.

The System of the Barrow.

The river Barrow.

Right bank.	*Left bank.*
Owenass river.	Little Barrow river.
	Figile river.
	Philipstown river.
	Abbey lough.
	Cushina river.
	Finners river.
	Greer river.
Douglas river.	
	Lerr river.
	Burren river.
Monefelim river.	
	Dinin river.
	Polmounry river.

The river Nore.

	Delour river.
	Mountrath river.
Erkina river.	
	Owbeg river.
Nuenna river.	
	Dinin river.
Kings river.	

The river Suir.

	Drish river.
Multeen river.	
	Aherlow river.
	Ara river.
Tar river.	Nier river.
Clodiagh river.	Glashawley river.
	Lingaun river.

Mahon river.
Tay river.
Ballygan river.
Colligan river.

The river Blackwater.

	Owentaraglin river.
	Allua river.
	Duallua river.
Glen river.	
Clyda river.	
	Awbeg river.
	Funshion river.
	Finisk river.
Bride river.	
Tourig river.	

Womanagh river.

The river Lee.

Lough Allua.
Toon river.
Sullane river.
Douglas river.
Laney river.
Awboy river.
Dripsey river.
Bride river.
Blarney river.
Glashaboy river.
Cork harbour.
Owenboy river.
Owennacurra river.

The river Bandon.

Caha river.
Blackwater river.
Brinny river.

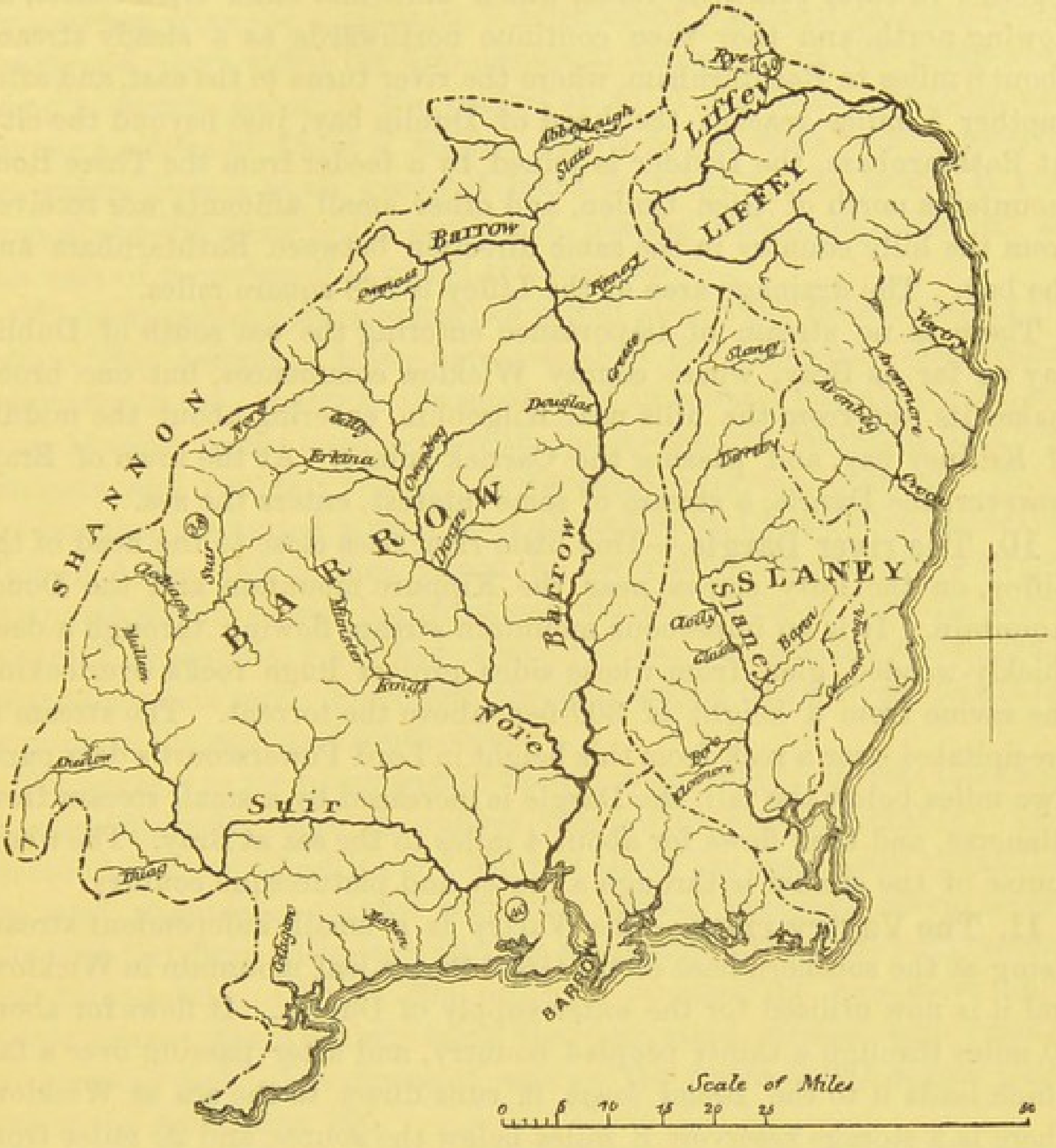
Aigideen river.
Ilen river.
Owvane river.
Coomhola river.

River Roughty.
Glenlee river.
Slaheny river.
Sheen river.

River Inny.
River Flesk.
Killarney lakes.
River Laune.
River Maine.

7. The river Liffey.—This river rises in a bog near Croghan pond in the Kippure mountains, and receives several branches from the Dublin mountains on the north. Its course, at first west for about 10 miles, winding about among the hills, runs through a little inhabited country to Blessington, near which town it is joined by the *Kings river*, a considerable stream from a bog-covered district to the south and south-east. Past this confluence there is a succession of fine cataracts, the river making its way by leaps into the valley, the total depth of the falls being 150 feet. The middle fall is the finest, and at its foot is a small tarn, called *Phoul-a-phooka*, or Puck's lake. Entering Kildare, the river now more tranquil flows westward about 8 miles to Kilcullen bridge, and then turns to the north and north-east. At Kilcullen it receives a feeder from the south. Passing the Curragh the river continues its course through the county of Kildare to Leixlip with little change, and there entering Dublin county receives the river *Rye*, a considerable stream coming from the west and passing Maynooth. The Rye is fed by the *Lyreen*, from the hilly country to the south-west, on the line of water-shed that separates the basins of the Liffey and the Boyne to the east of the bog of Allen.

X.—Drainage Areas of the South-East of Ireland.



8. The lower course of the Liffey.—Entering Dublin county the Liffey assumes a more important character, and it is joined by some small tributaries. One enters at Lucan from the south, proceeding from the mountains and passing Rathcole. Another and larger feeder from the same mountain district, but a little to the east, rising on the northern side of the Kippure range, whose southern drainage originates the Liffey, has a course of nearly 20 miles. It is called the *Brittas river* at its source, and passes Saggard and Clondalkin to join the Liffey near Dublin. From the north there is another stream also of some importance, rising in the hills near Clonee, and flowing east nearly 12 miles, parallel to the Liffey, and at a distance of 2 miles entering Dublin bay, close to the mouth of the Liffey. This is the *Tolka river*.

9. The river Dodder.—The Dodder, the most important affluent of the Liffey, originates in a number of streams proceeding from the northern slopes of the Kippure mountain and ridge (2,475 feet). These come together in three principal forks, which unite and enter Glen Smool, all flowing north, and they then continue northwards as a steady stream, about 8 miles to Rathfarnham, where the river turns to the east, and after another 5 miles reaches the head of Dublin bay, just beyond the city. At Rathfarnham, the Dodder is joined by a feeder from the Three Rock mountains north of Glen Cullen, and other small affluents are received from the hilly country in the same direction between Rathfarnham and the bay. The drainage area of the Liffey is 568 square miles.

There is no stream of importance entering the sea south of Dublin bay as far as Bray, where county Wicklow commences, but one brook makes its way from the hills near Kilgobbin, entering about the middle of Killiney bay, and passing the Carrick mines. At the town of Bray, however, the Dargle, a stream of some interest, enters the sea.

10. The river Dargle.—This little river rises close to the head of the Liffey, on the lofty slopes near the Kippure mountain and the Douce mountain. It is an impetuous mountain stream flowing through a deep thickly-wooded glen, from whose sides project huge rocks overlooking the ravine from a height of 300 feet above the torrent. The stream is precipitated over a rock from this height in Lord Powerscourt's deer park. Two miles below the fall, the Dargle is increased by a small stream from Glancree, and then flows for about 4 miles to the sea at Bray. The whole course of the stream is through a pretty and picturesque country.

11. The Vartry river.—The Vartry is a small independent stream rising at the southern base of the Great Sugar-loaf mountain in Wicklow, and it is now utilised for the water supply of Dublin. It flows for about 10 miles through a thinly peopled country, and after passing over a fall which leads it to the *Broad lough*, it runs direct to the sea at Wicklow. There is a storage reservoir 8 miles below the source, and 20 miles from Dublin, receiving the drainage of about 14,000 acres. The river enters the sea after passing through a lagoon or creek, called the *Murragh*, connected with coast drainage from the north. The lagoon is about 2 miles in length, and opens out to the sea at Wicklow.

From Wicklow southwards there is very little coast drainage for a long distance. There are three small streams, of which the largest is called *Potters river*, but they drain only the country within 6 or 8 miles of the coast. The next important stream is the Avoca or Ovoca.

12. The river Avoca.—This river proceeds from the Wicklow mountains in the north by several principal streams bearing different names. It enters the sea at Arklow, 15 miles south of Wicklow.

The principal and most northerly feeder rises close to the source of the Liffey, and receives the drainage of the Kippure mountain group. Flowing south, after about 3 miles it expands into a small lake (*Lough Tay*), after which receiving a branch from the west, and flowing 2 miles further to the south, it again expands into a larger lake (*Lough Dan*), which is fed by a stream from the north-west. After about 5 miles it passes Glendalough, and there meets the first principal branch from the north-west, being a stream rising in the central mass of mountain and bog, and having a course of about 7 miles. Nearly at the same point it receives the waters from a small group of lakes or tarns to the west. It now flows about 10 miles to the south-east, passing Rathdrum. During all this part of its course it is called the *Avonmore*.

The picturesque spot now reached is well known as "the meeting of the waters," the Avonmore being here joined by the *Avonbeg*. This branch originates in the country to the north-west in a small mountain lake, and flows 15 miles to the confluence with the Avonmore, falling at first over cataracts, and running through picturesque mountain scenery. Below the junction the united stream flows about 5 miles through the celebrated Vale of Avoca, and is then joined by the river *Aughrim*. It is formed by the confluence of two branches, one, the *Ow*, rising in the lofty mountain of Lugnaquilla, 3,070 feet above the sea, and passing the Croghan mountain on its way. The other, the *Darragh*, or *Derry*, river, drains the country to the west and south-west.

The scenery in the upper part of the valleys opening out from the Avoca is exceedingly fine, and the valleys themselves are remarkable. They include lakes, one of which is 1,380 feet above the sea, others situated in the most picturesque manner with lofty vertical precipices rising several hundred feet from their edge, and the mountains around are lofty, barren, and inaccessible. Of the two principal streams the Avonmore has a gentle current, the Avonbeg being the more rapid stream, and running over a rocky bed. The drainage area of the Avoca is 281 square miles, and of the Avonmore, 200.

About 7 miles south of the mouth of the Avoca river, a small stream (the *Kilgorman river*), conveys coast drainage by several branches, and 5 miles further another river (the *Quanavoragh river*), drains a large extent of country east of the water-shed of the Slaney. There is no other considerable stream till, at Wexford haven, the Slaney enters the sea.

13. The river Slaney.—This river takes its rise on the lofty slopes of Lugnaquilla, close to the sources of the Avonbeg, and its most distant branch originates to the north of the Table mountain. The various branches meet in the Glen of Imale, and flow west for about 8 miles, receiving another and principal feeder from the western side of Lugnaquilla. Arriving at Stratford-on-Slaney the river turns south, passing Baltinglass, near which town it enters county Carlow. It reaches Tullow after 12 miles, and after 3 miles receives the Derreen.

14. The river Derreen.—The Derreen, like many of the Wicklow streams, has its origin in the slopes of the mountain mass of Lugnaquilla by a number of feeders which flow south for about 10 miles in Wicklow and Carlow counties, forming the boundary between the two counties for some distance, and constantly receiving feeders from the south. Eight miles below the confluence with the Derreen, and flowing constantly in the same direction, the Slaney leaves county Carlow at New Town Barry, before reaching which town it is joined by the river Derry from the north-east entering on the left bank.

15. The river Derry.—This river is formed by a number of feeders from the hills near Tinahely, on the other slopes of which (towards the east) another stream, the Darragh (sometimes also written Derry), takes its rise, and is one of the feeders of the Avoca already referred to. This western Derry (that of the Slaney basin) is sometimes called the *Shillelagh.* In one part of its course it expands into a small lake. The whole course is about 15 miles.

Four miles below New Town Barry the river *Cloda* comes in from the south-west, bringing a small drainage from Mount Leinster (2,610 feet), which is about 7 miles distant, and, shortly afterwards, the *Glasha* from the same neighbourhood. After this the Bann enters from the north-east.

16. The river Bann.—This river rises in the Croghan mountains, nearly 2,000 feet above the sea, receiving a number of feeders from the lofty hills that form the boundary separating Wicklow from Wexford. The various branches collect into a stream passing through a gap between Slieve Bawn and Laraheen, 5 miles from the sources. The river flows south 12 miles to Ferns, receiving some tributaries, and expanding at intervals into small lakes. From Ferns it continues to flow 4 miles in a south-easterly direction to enter the Slaney. A mile below the confluence another small stream enters from the same side after a course of 8 miles; and after another mile the *Black water* comes in from the north-east under similar conditions. Two miles below is Enniscorthy, where an important drainage is received by the river *Urrin* from the lofty ridge extending southwards from Mount Leinster and known as the Black stairs mountain, and the White mountain. A few miles below, the *Boro river* comes in with another part of the same drainage. Both rivers are fed by several branches. The Bann drains 1,266 square miles.

17. The lower course of the Slaney.—After receiving these tributaries the Slaney becomes a wide river, and flows in a nearly straight line to the south for about 6 miles, when it curves round to the east to enter Wexford haven. In this part of its course it receives only land drainage from the west. Approaching the Haven there is a considerable extension to the north-east, forming a small separate inlet, at the head of which a stream enters, conveying the surplus waters that flow from the Bog of Itty. This stream is called the *Sow*. It flows parallel to the Slaney for some miles, and is joined at the mouth by another similar and nearly parallel stream. There is also a small drainage into the southern extension of Wexford harbour. The total drainage area of the Slaney is 815 square miles.

Wexford haven is very large, but is much silted, and has islands at the northern extremity. It is nearly 8 miles from north to south, the breadth at Wexford being about 3 miles.

18. Coast between Wexford and Waterford harbours.—On the south-east coast, between the mouth of Wexford haven and the entrance to Waterford harbour, there are numerous lagoons, having small openings to the sea, nearly closed by sands. These all receive a certain amount of land drainage, which brings down with the torrent, during freshets, much detritus. The progress of the waters conveying this detritus being much interrupted as it approaches the sea, the sands are deposited, and the accumulation then checks the further advance of the stream, the water accumulating within it, forming a lagoon or coast lake. Thus, from Wexford bay to Waterford harbour there are no rivers actually reaching the sea, though several streams come down southwards towards the coast from the slopes of the Forth mountain (776 feet), and other high ground in the interior. The lagoons have a shifting entrance to the sea. There are many hills along this district, especially in the country on the right bank of the Slaney, and near Waterford harbour.

19. The system of the Barrow.—This river comprises three distinct catchments, which are drained by the Barrow, the Nore, and the Suir. The Nore enters the Barrow about 20 miles above the entrance to Waterford harbour, but the Suir joins it only half that distance from Hook head, where the harbour commences, and it forms a separate drainage area, as the two rivers unite almost at the point where the expansion of their joint streams forms the harbour. All are important streams, draining large tracts of country. The Barrow flows nearly south from the Bog of Allen, but has a considerable branch rising in the Slieve Bloom mountains. The Nore rises in the same mountains, and flows south-east, while the Suir has its sources partly in the Galty mountains, but with an important branch from the mountain range called the Devil's Bit, in Tipperary, which is an extension of the Slieve Bloom range, and flows chiefly to the east. The drainage area of the Barrow system is 3,410 square miles, and, next to the Shannon, it is the largest catchment in Ireland.

20. The river Barrow. Its early course.—The recognised source of the Barrow is in a boggy tract in the north-eastern extremity of the

Slieve Bloom mountains, between the main chain and the ridge of Cupard, about 1,600 feet above the sea. The most distant point is on the western side of the hill called the Cones (1,661 feet), whence two branches proceed northwards, one of them under the ridge of Cupard, and the other a little to the west. They soon unite, and flow still towards the north for about 8 miles in that direction. They then turn to the south-east towards Portarlington, rounding the ridge of Cupard. As they come in that direction they receive the *Owenass*, an important feeder draining the eastern slopes of the mountains from whose western slopes the river originates ; and almost at the same place they receive another feeder from the south. From this junction the river flows east for about 12 miles, receiving from the north, near Portarlington, the *Little Barrow river*, which proceeds from and partly drains a portion of the Bog of Allen. Approaching Monastereven, the river *Figile* enters the Barrow from the boggy districts to the north, after a course of 12 miles, and the united stream turns abruptly to the south, from which direction it does not afterwards change. The Figile receives several feeders. At this part of its course the Barrow emerges from the plateau hitherto passed over and enters its main valley.

21. Middle course of the Barrow.—From Monastereven to Athy (about 12 miles) the river runs a straight course, and receives two tributaries, one from each bank, but neither of them important. That from the east proceeds from the hills south of the Curragh, that from the west from the Dysart hills near Maryborough. From Athy to Carlow, about the same distance, the *Greer river*, flowing south-west from the hills near the Curragh, and the *Douglas*, south-east from the same Dysart hills, are added, and at Carlow the *Burren* enters, crossing the county of Carlow from the northern and western slopes of Mount Leinster and the Blackstairs mountains, from whose eastern slopes the Slaney is fed. For a long distance south of Carlow there are no tributaries of importance, the river running in a narrow valley, with high ridges on each side. After a few miles the *Dinin* enters from the north, and another stream from Mount Leinster from the west. The distance from Carlow to the mouth of the Dinin is about 20 miles, and from the mouth of the Dinin to New Ross, where the Nore enters, about 12. No feeders enter during the last 10 miles, and the mountains approach the river very closely, the White mountain rising to the east to 1,260 feet, within 5 miles of its banks, and the Brandon hills to the west to 1,694 feet, at the distance of 3 miles. These latter hills separate the Barrow from the Nore.

21. The river Nore.—This river rises in Tipperary, close to the source of the Suir, in the lofty ridge of the Devil's Bit. Flowing past Burros, in Ossory, to the north-east, after about 8 miles it is joined by the *Delour*, which is fed by a branch called the river *Tonnet*. Both streams proceed from the Slieve Bloom mountains, the length of course of the Delour being at least equal to that of the Nore at the junction.

Turning round then to the south-east and south, another small branch (the *Mountrath river*) enters from the north, passing Mountrath, and a much larger feeder (the *Gully*) from the same direction, about half way between Mountrath and Durrow. At Durrow the Nore is joined by the *Erkina*, a considerable stream conveying the drainage of a large tract of country to the west, and receiving tributaries, of which the river *Goul* from the south is the principal. A mile below Durrow the *Owbeg*, or *Owveg, river* comes in from the north-east.

Flowing now 9 miles a little east of south, the *Dinin river* (the second bearing this name in the Barrow drainage) comes in from a hilly country a little east of north, passing some collieries, and 4 miles below the junction Kilkenny is reached. After another 4 miles an important tributary is received from the west called the *Oonree*, or *King's river*. This stream is made up of three principal branches, originating in the hills to the north-west of Kilkenny. One of these, under the name of the river *Munster*, has a run of several miles nearly south, and is joined by two other parallel branches near Callan, whence the united stream continues as the King's river, about 10 miles due east to the Nore. After this confluence the river winds about to the south-east for about 14 miles between hills which in some places rise abruptly from each bank, and, receiving two small feeders, one from the north, the other from the south, reaches the Barrow about 2 miles above New Ross.

The banks of the Nore are very pleasant and picturesque about Kilkenny, particularly to the north of the town. Below the town the river passes through a pastoral country at Innistiogue, where the tide coming in from Waterford harbour now ends. Between this point and the course of the Barrow is the hill called Mount Brandon (1,694 feet), the view from whose summit is very lovely, overlooking the two valleys, and showing the fine gorge through which the Barrow passes, between Mount Brandon and the Black stairs. Shortly below Thomastown, at Ringwood, is the actual junction of the Nore and Barrow. The two streams united form a noble and stately river, flowing between high-wooded banks.

The united stream of the Barrow and the Nore, after the confluence, flows south in a rather winding course for 14 miles, opening out into a wide channel in its lower part, and there receiving the Suir, after that river has passed Waterford.

23. The river Suir.—This important branch of the Barrow drainage system rises close to the recognised source of the Nore, in the wild mountain district which separates the basins of the Barrow and the

Shannon, and ranges for a long distance under different names from north-east to south-west. The Devil's Bit mountain, rising 1,583 feet above the sea, has been already mentioned as the extension southwards of the Slieve Bloom group, and from its slopes a number of different streams originate, some proceeding eastwards and southwards to the Suir, and others westwards to feed Lough Derg and the Shannon. The main feeders of the Suir originate in this mountain range, along a distance of about 14 miles between the Devil's Bit and the Keeper mountain (2,278 feet). The branch bearing the name of the river flows at first east and then south, about 16 miles, close to the mountain side, as far as Thurles, without receiving any tributary ; but a mile below that town there is a considerable fork from the east (the river *Drish*). The stream afterwards turns a little to the west, and runs 8 miles without interruption, after which a drainage of some importance is brought in from the north and west, proceeding from the southern extension of the Devil's Bit range. A similar drainage comes in by several branches about 8 miles lower down, at Golden, in the neighbourhood of Cashel. This latter tributary is called the *Multeen*. The river now enters a hilly country skirting the Galty mountains, and flows to Cahir, a little above which town it receives one of its chief tributaries, the *Aherlow*, running through a picturesque glen, and fed from the northern slopes of the Galty range, which comprises some of the loftiest mountains of the south of Ireland, rising to 3,018 feet above the sea. The *Ara*, a large feeder, enters the Aherlow a few miles above its confluence with the Suir.

As it passes Thurles, and proceeds by Holycross to Cashel, the Suir runs lazily through sedgy banks, but, as it nears the Galty mountains, the scenery becomes bolder, and the Aherlow valley is very fine as it opens out to join the valley of the Suir.

From Cahir the river runs south a few miles further, receiving from the west a mountain stream called the *Tar*, and from the Conneragh mountains (2,476 feet) on the east another torrent called the *Nier*. It then turns north by a sharp curve, and flows in that direction for a few miles to Clonmel, where it is a broad and rapid stream, running through a very beautiful valley, and where its upper course may be considered to terminate.

24. The lower course of the Suir.—From Clonmel to Carrick-on-Suir (13 miles) the Suir alters its character. It widens and becomes tidal, and the valley is very picturesque, shut in on both sides by lofty elevations, thickly wooded almost to the banks of the stream. Advancing still further towards Waterford, the scenery continues very fine, especially at Fiddown, where the banks rise abruptly to a considerable elevation.

The first tributary that enters the Suir in its lower part is 3 miles below Clonmel, where it is joined by the *Glashawley*. This river combines a number of separate streams from the hilly country to the north, skirting the Slievenaman mountain (2,364 feet), and fed by the river *Anner* from the east. The drainage extends almost as far as Cashel. Ten miles below the Glashawley is Carrick, and, 1 mile below, the river *Lingaun* enters, bringing another important contribution from the high ground to the north. The Suir forms the county boundary between Waterford and Kilkenny as far as the junction with the Barrow.

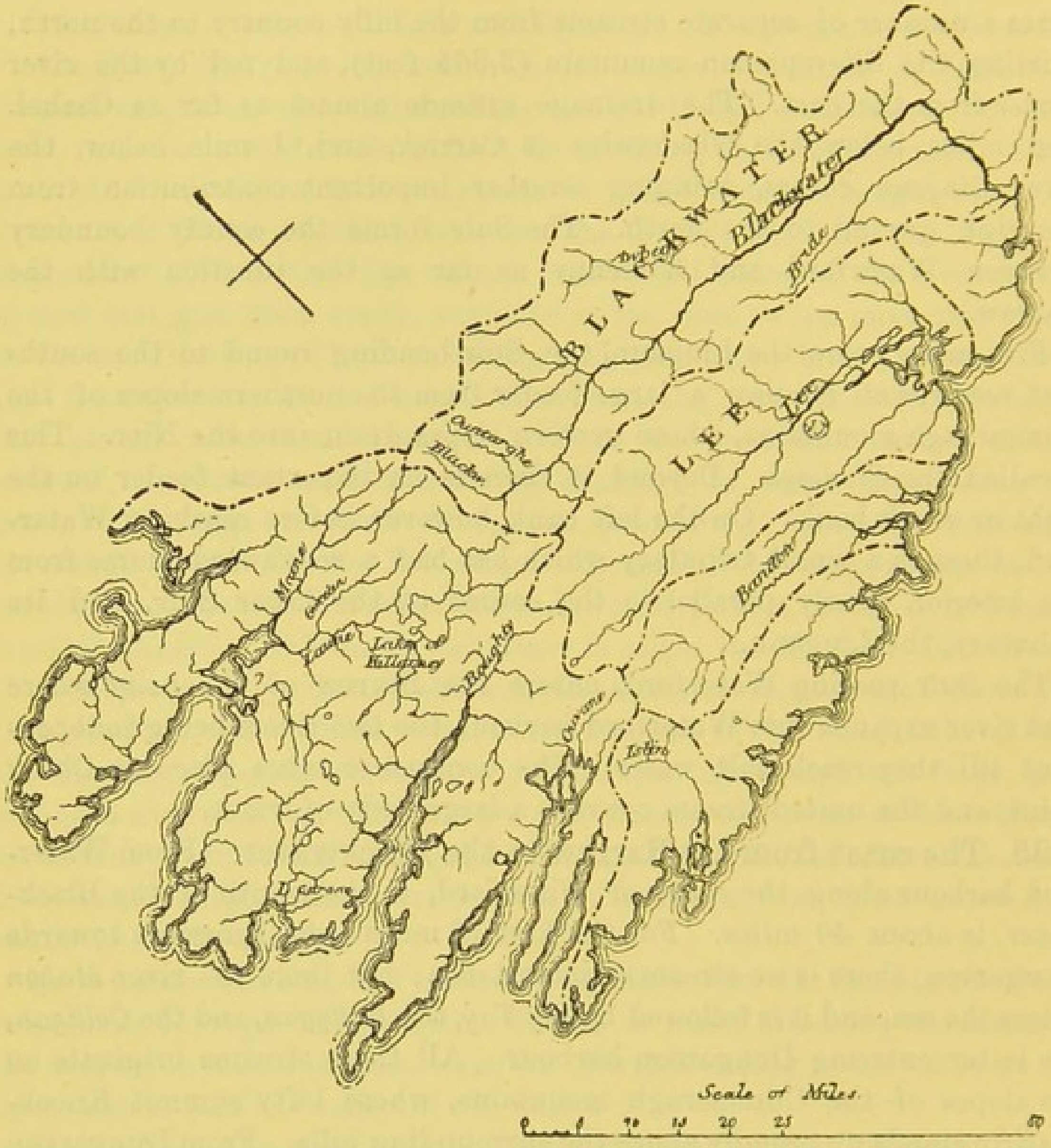
Five miles below the Lingaun, the Suir bending round to the south-east receives at Portlaw a large feeder from the northern slopes of the Cummeragh mountains, whose western slopes drain into the Nier. This is called the *Clodiagh*. Beyond it there is no important feeder on the right or south bank. On the left bank, however, before reaching Waterford, there is a small tributary which has had a southward course from the interior, nearly parallel to the course of the lower Suir, and its tributary, the Lingaun.

The Suir passing Waterford, enters the Barrow at the point where that river expands into Waterford harbour, the two rivers being independent till they reach salt water. The confluence takes place at Check point, and the united stream conveys a large body of water.

25. The coast from the Barrow to the Blackwater.—From Waterford harbour along the coast of Waterford, to the mouth of the Blackwater, is about 40 miles. For the first 12 miles from Dunmore towards Dungarvon, there is no stream of importance; but there the river *Mahon* enters the sea, and it is followed by the *Tay*, the *Ballygan*, and the *Colligan*, the latter entering Dungaroon harbour. All these streams originate on the slopes of the Cummeragh mountains, whose lofty summit Knockanaffrin stands up proudly above the surrounding hills. From Dungarvon to Youghal the hills come close to the sea, and there is no drainage of more than a few miles. Youghal harbour is the mouth of the Blackwater.

26. The river Blackwater.—The source of the Blackwater is in the Kerry mountains, on the south side of a ridge called Taur, whence a number of streams proceed in every direction. The Blackwater at first flows nearly due south for more than 16 miles, closely shut in on both sides as far as Shinnegale, and then turns almost due east, retaining that direction for nearly 60 miles. Three miles after taking this course it receives the *Owentaraglin* from a parallel valley, the stream being fed from the same ridge as that which supplies the main stream. Other large and important groups of streams bring their united waters into the Blackwater from the same range of mountain side.

XVI.—Drainage Areas of the South-West of Ireland.



The upper part of the valley of the Blackwater is through a slightly elevated and comparatively level plateau of the coal-measures, which contain workable coal near the source. Commencing at the point where the river turns to the east, the first tributary after the Owentaraglin is the *Allua*, entering about 10 miles below. This stream rises in the high ground, about 16 miles to the north, and receives no feeder till it reaches Kantuck, within 3 miles of the Blackwater. It is there joined by the *Duallua*, rising near the Allua, and after receiving two or three tributaries combining its waters with that stream. The country here is dreary and barren. Immediately opposite the Allua, a small stream called the *Glen* comes into the Blackwater from the south. From the confluence of the Allua, the distance to the next tributary, the *Clyda*, is 10 miles. This river also enters from the south. Ten miles below, passing the towns of

Mallow and Fermoy, the Awbeg enters. The river between Mallow and Fermoy is very picturesque, and its banks are finely wooded.

27. The lower course of the Blackwater.—The *Awbeg* drains the country east of the Allua, two of its sources being near the course of that stream. After uniting these the little river runs south-east past Buttevant and Doneraile in a dreary country, and soon turns south to enter the Blackwater. The banks are precipitous and picturesque. The *Funshion* is another feeder a little farther down, rising in the Galty mountains, running first west at the foot of the mountains, and then south-east, and entering the river a little below Fermoy. Near the Blackwater it receives a small tributary running through Ara glen, a romantic valley at the foot of the Knockmeildown hills drained by the *Ara*. Mitchelstown, on the Funshion, is very beautifully situated at the foot of the mountains. From this point to Lismore the river Blackwater is very fine. At Cappoquin, below Lismore, it turns south nearly at right angles, and is joined on the left bank by the *Finisk* from the north.

The *Bride* is the last important tributary of the Blackwater. It rises at the foot of the Nagle mountains, not far from Mallow, and runs within 5 miles of the Blackwater, and parallel to it for a distance of more than 30 miles nearly due east, entering on the right bank, and fed by many tributaries, all nearly parallel to its course.

The Blackwater widens considerably in the lower part of its course as it approaches Youghal, and opens out finally into a large shallow lagoon with flat shores on either side. After this it narrows once more, and as it approaches the sea its banks change to rocky and precipitous headlands. Near Youghal the *Tourig* enters from the east, after a short southerly course from the hills a little to the south. The Blackwater drains 1,165 square miles of country.

Along the coast from Youghal harbour to Cork harbour, a distance of 20 miles, the principal stream that enters the sea is the *Womanagh*, rising in the hills to the north that shut in the valley of the Bride, and conveying the drainage of several valleys to the sea.

28. The river Lee.—This river rises in Kerry, in a small and deep tarn surrounded, except on the east, by mural precipices and mountains nearly 2,000 feet above the sea, leaving only a narrow outlet for the infant river to escape. It is called "Gougane Barra," or Gurgling head. From this source the stream after running east about 4 miles expands into another lake (*Lough Allua*), also finely situated, and then continues to flow in an easterly direction for about 10 miles to its junction first with the *Toon*, and soon after with the Sullane, both from the same direction. The *Sullane* rises in two principal branches among the Muskerry mountains, and after running 12 miles in an easterly direction, meets a small feeder from the north. It then continues 3 miles to Macroom, where another tributary comes in from the north, and after 2 miles it joins the Lee. In this part of its course the Lee flows for a considerable distance through morass. At Macroom it receives the *Laney* from the north, with its tributary, the *Awboy*.

From its junction with the Sullane, the course of the Lee to Cork is about 20 miles, and in this run it receives various tributaries from both sides. The *Dripsey* proceeds from the Bograh mountains and the Nagle mountains on the north, and the *Bride* and other small streams from the south. The northern feeders are the most considerable, but the distance of the water-parting is very small. The chief feeder from the south is the Bride, entering near Inishcara, after a course of 13 miles. The scenery at Inishcara is exceedingly fine. A couple of miles lower down the *Blarney river* enters from the north, after receiving the *Shournagh* and other feeders. The Lee now approaches Cork, and begins to widen out, and soon expands into the celebrated and magnificent harbour of Queenstown.

29. The lower course of the Lee.—As far as Blackrock the river runs on from Cork in a straight course to the east, and then expands, forming a large and very irregular bay, nearly filled with the large island now called Queenstown, and the much smaller island to the north called Little island. There are also other islands, of which Spike island is well known. A small stream, the *Glashaboy*, enters the Lee from the north, nearly opposite Blackrock castle, and before it has expanded into the harbour, and another stream, the *Owennacurra*, also from the north, beyond Great island (Queenstown). A third and more considerable stream (the *Owenboy*) enters the harbour from the west at Camden Fort.

According to a calculation made for Sir Robert Kane,* the average flow of the Lee at extreme low water is about 100 millions of gallons per day, or nearly 184 cubic feet per second. This is one-eighth of the mean rainfall, and it is considered that the average delivery, measured throughout the year, would be three times this quantity.

The drainage area of the Lee is 595 square miles; but, according to Sir Robert Kane, it amounts to 735 square miles.

Between Cork harbour and the Old Head of Kinsale, where the Lee enters the sea, the distance is 13 miles. With the exception of a small stream which enters Ringabella bay, there is no coast drainage.

30. The river Bandon.—The small basin of the Bandon is drained by a stream which rises near Dunmanway, not far from the head of Bantry bay, and is soon joined by several feeders. These uniting a few miles below Dunmanway, have a course of 20 miles to Inishanon, and then turn southwards for 4 miles to enter the sea in Kinsale harbour.

* Industrial Resources of Ireland, p. 85.

The upper sources of this stream are the overflow of small lakes in a wild and mountainous district among the Sheehy mountains. Some of the small tributaries above Dunmanway unite to form the *Caha*, commencing on Sheehy mountain, and some others proceed from the west. Lower down the Bandon receives the *Blackwater* and the *Brinny*, both from the north. The latter enters near Inishanon, which is beautifully situated, and near this the valley of the Brinney is exceedingly picturesque. The whole course of the Bandon is fine, and it is a celebrated fishing stream. It drains 228 square miles.

31. The coast drainage west of Kinsale.—From the Old Head of Kinsale to the south-western extremity of Ireland is about 60 miles, but at least one-third is a promontory enclosing to the south the long sweep of Bantry bay, and the high hills that jut out into the Atlantic are continued inland for some distance, always near the coast. There is, therefore, but little coast drainage.

Beyond the Bandon, the first river of interest is the *Arigadeen*, which drains a small extent of coast south of the Bandon basin, entering an inlet beyond the Old Head of Kinsale. The *Ilen river* comes next, entering at Skibbereen and taking the water from the moors west of the sources of the Bandon. There is also a small drainage into the head of Bantry bay by two little streams.

32. Drainage between Kenmare river and Dingle bay.—Beyond the promontory formed by the extension to the south-west of the Muskerry mountains, and between Kenmare river and Dingle bay, is the district of the Killarney lakes, and of the great system of lakes in this part of Ireland. The overflow from these lakes enters the sea chiefly by the river Lane, which terminates in Dingle bay ; but there is also drainage of some importance from this wet district by many other channels into the Kenmare river and Dingle bay. Into Bantry bay the *Owvane* and the *Coomhola* enter, but they are too insignificant to require special notice.

The drainage into the estuary called Kenmare river is by numerous streamlets and rivers, the chief of which is the river Roughty, entering at its head and draining 475 square miles. The *Roughty* collects the waters from the slopes of three mountain masses, the Muskerry, the Glanerought, and the Mangerton. On its way to the estuary it receives the *Glanelee*, the *Slaheny*, and the *Sheen* rivers, all from the south, and small feeders from the north. The Sheen, which is called the *Baurearagh* in its upper part, drains the Caha mountains in the south-west, and enters the river after it has widened out. Of the other streams that enter the Kenmare river, we may name the *Blackwater* and the *Ardsheelhane* from the north, and a short river conveying the waters from *Inchiquin* and *Cloonee* lakes from the high ground in the south.

There are similar streams entering at intervals on the same side. All these run a short course, and are rather torrents than rivers.

Between Kenmare river and Dingle bay there are intermediate and smaller bays, one of which, Ballinskelligs bay, receives the *Inny* river, fed by many branches in the interior, and the river *Cummeragh*, by a short course, after connecting a number of lakes, the last and largest of which is *Lough Currane.* The Inny with the Maine (p. 465) drains 511 square miles. We now enter Dingle bay, into which the lakes of Killarney enter.

33. The Killarney lake system.—The lake district of Killarney, regarded as a drainage area, collects the waters of a somewhat extensive mountain district in Kerry, and conveys the surplus by the river Laune into Dingle bay. The mountains around these lakes are the loftiest in Ireland, and the scenery the grandest; but the lakes themselves, though marvellously beautiful in the surrounding scenery, do not approach in area or in volume of water the great lakes of the north.

It is necessary to bear in mind that the lakes of Killarney are essentially mountain lakes occupying parts of a basin on the northern foot of a great mountain mass. The narrow rock basin of the upper lake which fills the bed of the deep gorge of the Black valley is in the line of an ancient glacier which descended from the base of the Macgillicuddy Reeks. The larger lake is in the limestone.

The mountains around Killarney form two groups, one to the east and the other to the west, but the general mountain axes of the whole of Ireland, and especially of the south-western part, is north-east and south-west, so that the Killarney lake system occupies a break and interval in the mountains. To the east of Killarney the culminating points are the mountain Cahirbarnagh (2,239 feet) and the range of the Paps (2,268 feet), so called from two conical eminences separated by a deep ravine, which are Crohane (2,102 feet) and Mangerton (2,379 feet). To the south the lofty highland valley of the Flesk leads to the mountains beyond the sources of the Lee.

34. The river Flesk.—This river, collecting the waters from the slopes of the lake mountains, is the channel that feeds the great hollows among the mountains occupied by the Killarney lakes. Its various branches penetrate between the summits north and south of the Paps, draining a range about 12 miles from north to south, and its main stream originates far in the mountain valley to the east, so that the upper waters travel 20 miles from their source, near Slieve Riagh, to the lakes. In this journey the Flesk leaps from rock to rock as an impetuous torrent, only attaining a temporary repose in the expanse of waters accumulated in the lower lake of Killarney.

35. The lakes of Killarney and the river Laune.—There are at Killarney three lakes, each receiving water from different sources. The upper lake (whose level is only 5 feet higher than the others) is about $2\frac{1}{2}$ miles long, and three-quarters of a mile in breadth, and is separated from the other lakes by a projecting neck of mountain land. It is fed from the west by the *Cummeenduff river*, by the *Owenreagh*, a stream flowing from the same glen, and by a small stream from the south. The middle, or Turk lake, receives the waters of the Mangerton group flowing in by the *Owengarriff river*. The lower lake, which is the northernmost and largest, receives the Flesk, and is also supplied by the *Muckross river* and the *Deenagh*, a small stream entering close to Killarney town.

The drainage from the lakes flows to the north-west, and merges in the river Laune, which name is assumed as the waters issue from the north-western extremity of the lower lake. From hence the Laune has a course of rather more than 10 miles to the open water in Dingle bay. About half way between the lake and the bay it receives the *Gesteen*, a considerable tributary from the east, and a smaller stream comes in from the west.

There are several streams entering Dingle bay from the south shore besides that which carries off the surplus water of the Killarney lakes. Among these is the *Caragh*, which has a small lake system of its own near the coast, and the river *Ferta*, also expanding into a lake as it nears the sea. The mountains here rise to 2,540 feet, but the lakes are generally near the sea level. A small group, of which *Lough Coomasabarn* is one, is situated, however, 550 feet above the sea.

36. The coast from Dingle bay to the Shannon.—At the head of Dingle bay the *Maine*, a stream of some importance, enters the bay after a course of about 22 miles, draining the country to the east. It receives on its way two or three small tributaries from the left bank, the principal of which is the *Brown Flesk river*, being larger than the Maine at the confluence.

There is no drainage area of large extent along the north coast of Dingle bay, by Dingle to Brandon and Tralee bays, but several small streams there enter the Atlantic. A few mountain torrents coming from the high broken land of the promontory north of Dingle bay either carry the heavy rains at once to the sea, or collect their waters into minute tarns whose overflow is more regular. The largest stream is the *Lee* which enters at Tralee.

CHAPTER XVI.

DRAINAGE AREAS OF THE NORTH-WEST OF IRELAND.

(1) General account of the district.—(2) Physical geography and geology.—(3) Sub-divisions.—(4) Rainfall, evaporation, and percolation.—(5) Scheme of the principal rivers and their affluents.—(6) The drainage system of the Corrib.—(7) The upper feeders of Lough Mask.—(8) Lough Carra.—(9) The river Rove.—(10) Lough Mask.—(11) The river Owenbrin.—(12) The Cong.—(13) The Cong river.—(14) Lough Corrib.—(15) The Claregalway.—(16) Coast from Galway Bay to Clew Bay.—(17) Drainage of the west coast of Mayo.—(18) The water system of the Moy.—(19) The river Moy; its upper course.—(20) The river Polbagh.—(21) The lake system of Lough Conn; southern portion.—(22) The lake system of Lough Conn; northern portion.—(23) Loughs Conn and Cullen.—(24) The lower course of the Moy.—(25) Coast drainage between Killala Bay and the river Erne.—(26) Lough Gill.—(27) Lough Melvin.—(28) The lake system of the Erne.—(29) The early course of the Erne.—(30) Lough Oughter.—(31) Upper Lough Erne.—(32) Lough Erne.—(33) The river Erne.

1. General account of the district.—The north-west of Ireland—the district whose hydrographical condition is the subject of this chapter—includes first a tract of 3,800 square miles of very wild country, largely covered with bog, and with sheets of water almost without number. This part comprises nearly all the county of Galway, the whole of Mayo and Sligo, and part of Leitrim and Fermanagh, occupying the country between the Atlantic coast from Galway bay to Donegal bay, and the western water-shed of the Shannon continued to Donegal bay by a small part of the water-shed of the Erne.

There will also be included in this chapter the remarkable lake system of the Erne, draining 1,550 square miles, chiefly situated between the basin of the Shannon and that of the Bann. It occupies a district in the interior of the country, but connects with and naturally belongs to the country to the west, with which it is very nearly associated in all essentials of physical geography. The map delineating its hydrography will be found in the next chapter.

2. Physical geography and geology.—The west of Ireland consists partly of table-land less than 200 feet above the sea, and partly of a mountainous district near the coast, where the level occasionally rises to 2,400 feet. Parts of the coast, and part of the interior between the coast range and the valley of the Shannon, are less than 100 feet above the sea. Within the district are some lakes of considerable area, and three important river basins, while the number of small sheets of water and less important streams can hardly be estimated. The coast line towards the Atlantic is very broken, and receives the full force of the ocean on its shores, while the water-laden south-westerly winds blowing over the great expanse of the Atlantic pass on until they reach the interior. The country is subject to almost incessant rain, which partly runs back quickly to the sea, and partly flows into and over the low lands east of the coast range. The drainage is irregular and complicated, and the lines of water-shed of no great elevation.

The middle and eastern part of the district presents at the surface the carboniferous limestone, from beneath which, in the northern part, Old Red Sandstone and metamorphic rocks appear. The western extremity largely consists of metamorphic and granitic rock, with some Old Red Sandstone, but more than three-fourths of the surface is covered by bog, of which the kind called red bog is much the largest in proportion. A belt of it ranges uninterruptedly for a breadth of nearly 40 miles in the western parts of Mayo and Galway. The granite rock is chiefly in the south, forming the southern rim of the basin of the Corrib, while metamorphic rocks shut in the basin of the Moy. It is these old and altered rocks that rise into the high hills of the Galway coast. The limestone is generally very cavernous.

The whole of the coast of Galway and Sligo consists of a succession of promontories and islands jutting out into the Atlantic. There can be no doubt that land once extended for a long distance beyond the west coast of Ireland to the west, and has been depressed and undermined, notwithstanding the hardness and toughness of the rock. The state of the sea bottom, as learnt during the investigations made for telegraphic purposes, suggests and confirms this view.

3. Sub-divisions.—The sub-divisions of the district are very simple. There are the two distinct basins of the Corrib and the Moy, each connected with its lakes, and somewhat complex, and the coast drainage to the Atlantic, which includes a multitude of small basins. There is also the basin of the Erne. The subjoined table will show the magnitude of the different catchments and their grouping.

	Estimated area in square miles.
1. The basin of the Corrib and Lake Mask - -	1,160
2. The west coast drainage - - - - - -	800
3. The basin of the Moy - - - - - -	1,033
4. The catchments between the Moy and the Erne	800
5. The lake system of the Erne - - - - -	1,585
Total - - -	5,378

4. Rainfall, evaporation, and percolation.—The whole of the west of Ireland is remarkable for a heavy rainfall and a clouded atmosphere. It lies within the zone over which the rainfall varies from 40 to 50 inches. On the hills near Clew bay it is probably more. In the eastern parts of the basins of the Corrib and the Moy it is no doubt less, but not very much so. The line of water-shed between the river basins is not high, and probably affects but little the amount of the fall, but in the ordinary course there would be a somewhat heavier fall towards the interior than towards the sea.

It is difficult to estimate the evaporation from a surface constantly wet, in an atmosphere generally loaded with vapour. It is probably very high, in spite of the latter condition, as the winds are constantly driving over the surface, and the temperature is not low. The whole district is wet at all times.

But little knowledge can be had of percolation into the underlying rocks in a country so covered as the west of Ireland, but it is certain that the mountain limestone which occupies so large a part of the surface in the basins of the Corrib and the Moy is very much fissured, and permits the passage of large quantities of water underground. This probably reappears at the contact with the older rocks, which, being less brittle, are perhaps more compact. The communication between the extensive lake called Lough Mask with the still larger sheet of water, Lough Corrib, is chiefly of this nature. Few of the small lakes are much less than 100 feet above Ordnance datum, and the plateau, whose elevation varies from 100 to 200 feet, reaches almost everywhere to the coast.

The limestone, not only in the places already alluded to between the lakes of Corrib and Mask, but elsewhere in the courses of many of the rivers, is so pierced and fissured that the water is often lost sight of for some distance.

5. Scheme of the rivers and their affluents.—Although there is comparatively little of system in the singular grouping of lakes, pools, and rivers in the west of Ireland, the following statement of the more important water-channels and lakes may be useful for reference.

The System of the Corrib and Lough Mask.

River Aille. River ——.

Lough Cloon. Lough Carra.

LOUGH MASK.

River Robe.

River Owenbrin.

Lough Nafooey.

Cong (subterranean) river.

LOUGH CORRIB.

Bealanabragh river. River Black.

Claregalway river.

Galway river.

The Coast Drainage of Galway and Mayo.

Owen-boliska river.	Owenduff river.
Cashla river.	Owenmore river.
Owenglin river.	Owening river.
Erriff river.	Glenamoy river.
Newport river.	Ballinglen river.

The Basin of the Moy.

The River Moy.

Owengarve river.	Lough Cullen.
Pollagh river.	Lough Conn.
Manulla river.	Deel river.
Clydagh river.	

River Easky.

Lough Arrow.

Lough Gill.

Bonet river.

Lough Melvin.

The System of the Erne.

Lough Gowna.

River Erne.

Lough Oughter.

Annalee river.

River Erne.

Finn river.

Upper Lough Erne.

Right bank. *Left bank.*

Woodford river.

Colebrooke river.

Claddagh river (Swanlinbar).

River Erne.

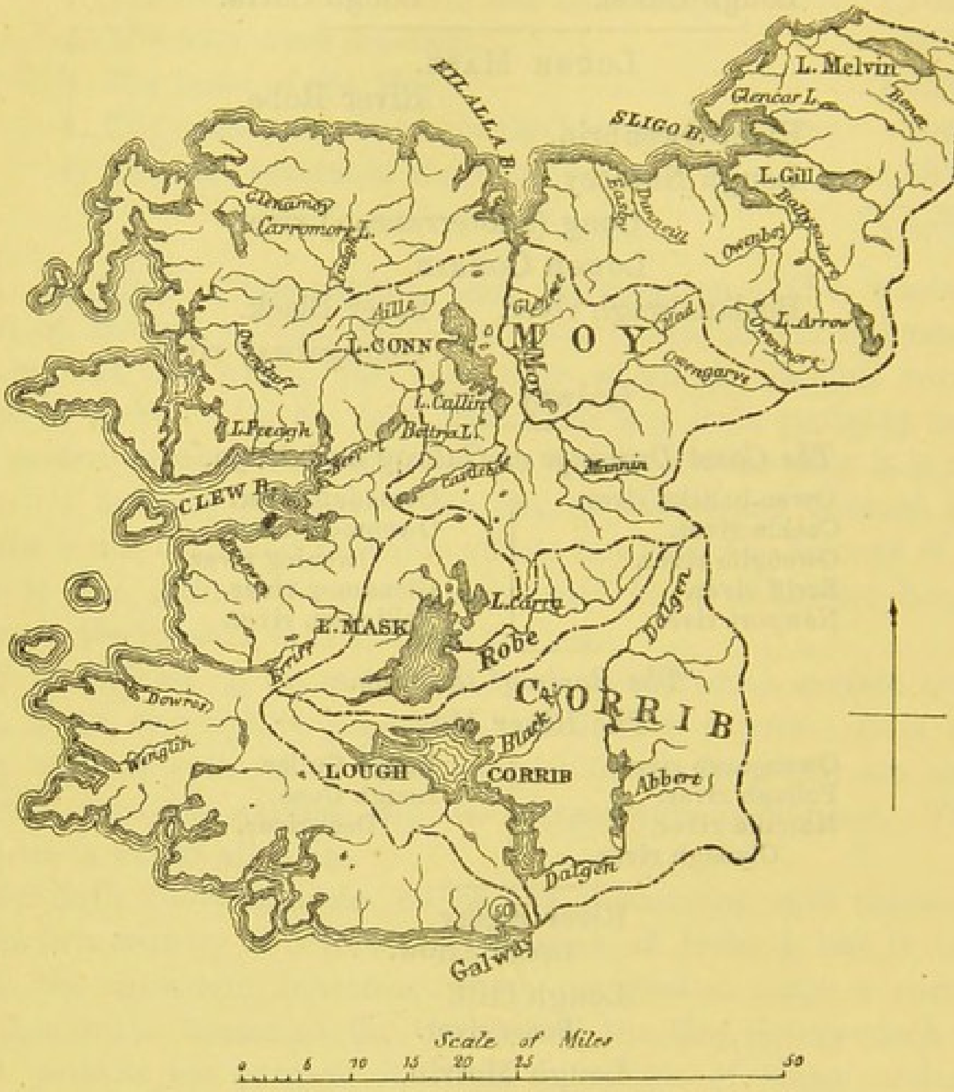
Lough Macnean. Sillee river.

Arney river. Lough Ross.

Lough Erne

River Erne.

XVII.—DRAINAGE AREAS OF THE NORTH-WEST OF IRELAND.



6. The drainage system of the Corrib.—Owing to the peculiar physical and geological conformation of the country in the western part of Galway, and the singular mode in which the water communication is effected from the upper plateau containing Lough Mask (whose level is 64 feet above the sea), to the lower plain, in which is Lough Corrib, only 28 feet above the sea, the drainage system which includes these two lakes and their feeders is double, and more nearly independent than any interrupted basin in the British islands. The lakes have no surface communication. There is a large drainage into the upper lake, which includes the overflow from a smaller lake system at its north-eastern extremity, and is fed by several rivers of local interest; and between the upper and lower lakes is a neck of land more than 2 miles wide, traversed at Cong by a channel, partly subterranean, delivering the surplus water into Lough Corrib, 36 feet below. Like Lough Mask, Lough Corrib has several tributaries, and, after a course of 2 miles, conveys its waters by the Galway river to the head of Donegal bay, at the town of Galway.

7. The upper feeders of Lough Mask.—The principal river feeding the Mask is the *Aille*, or *Ayle*, which rises at a point about 4 miles west of the middle of the western side of the lake, and flows northwards about 8 miles, when it turns abruptly east, expanding into small lakes, and receiving streamlets from the mountains. After receiving a larger feeder passing Ballyhean, it enters *Lough Cloon* about a mile north of Lough Mask, and passes into the latter lake, after a course of 2 miles, at its northernmost extremity. The course of the Aille is over the mountain limestone plateau, which is very cavernous, and the river occasionally disappears from the surface.

8. Lough Carra.—On the eastern side of Lough Mask, about 4 miles from the mouth of the Aille, there is an inlet conducting from Lough Carra, a large but irregular sheet of water, whose level is 3 feet higher than those of Lough Mask, and which extends considerably to the north of and parallel to it. Lough Carra measures nearly 7 miles from north to south, and approaches in one part within a few hundred yards of Lough Cloon. It is less than a mile wide in the upper part, but expands and has an extension to the north about half way down. It receives no feeders till this expansion takes place, and then a considerable stream enters, which rises in some small lakes near the source of the Manulla, the chief feeder of the upper basin of the Moy. This river has a course of more than 12 miles.

9. The river Robe.—Lough Carra communicates with Lough Mask by a short course, and about a mile further south the river Robe enters the lake, draining the country for a long distance to the east. The Robe rises near the source of the Clare, and connects with a group of several lakes in the interior, where the country is covered with bog. It has a tortuous course of about 25 miles.

10. Lough Mask.—This is a noble sheet of water 10 miles long. It is pear-shaped, and more than 4 miles broad in the lower part. At the southern extremity there are two inlets opening to the west, one 4 miles and the other 3 miles long. They extend into a district called Joyce's country. The eastern shore of the lake is tame, but the west is bounded by the fine range of the Partry mountains, which rise to nearly 1,300 feet. There are several islands in the southern part, where the lake is broadest.

11. The river Owenbrin.—There is very little drainage into Lough Mask from the west, but one river, the Owenbrin, rises on the slopes of the higher peaks of the Partry mountains, and carries a considerable body of water to the lake. Each of the two western inlets already alluded to terminates in a mountain gorge, bringing water from other slopes of the same range. One of the feeders passes through the large lake called *Lough Nafooey*, whose waters are 30 feet above those of Lough Mask, into which its overflow is carried.

12. The Cong.—Lough Mask is closed in to the south-west by mountains rising from 1,400 to 1,600 feet, which gradually lower to the east till they form a narrow neck of no great elevation called the Cong, which separates Lough Mask from Lough Corrib.

13. The Cong river.—A rapid stream emerges from Lough Mask and empties itself into Lough Corrib, after a winding course of 4 miles, of which less than a mile is visible, the rest being beneath the rocky surface, and showing little mark of its presence. This half-buried stream is the Cong river. The rock here is limestone, singularly perforated, and undermined or eaten out by the passage of water through its fissures; and near the village of Cong the river disappears. About a mile from the village there is a depression in a field consisting of a natural irregular shaft, 60 feet deep. At the bottom of this shaft, which can be reached by steps, the river is seen flowing through a cavern, and, although water re-appears where the surface is at a lower level, the main body passes out of sight into the lake below. There is no other communication between the two lakes. An attempt was made during the famine in Ireland to construct a canal connecting the lakes by a continuous open channel, but, owing to the fractured nature of the rock, the task was found too difficult, and remains incomplete.

14. Lough Corrib.—This is a larger sheet of water than Lough Mask. The total length from the outflow in Galway river to the presumed inlet of the upper waters at Cong, is 20 miles, but it is divided into two parts, connected by a strait. The breadth at the northern and widest part is 6 miles, and beyond this, to the west, there is an extension consisting of a gorge or inlet entering for 5 miles among the Mamturk mountains, and receiving the waters of the *Bealanabragh river*. There is a length of not less than 50 miles of shore, and the number of islands is very great. The surface is 30,000 Irish acres. The depth is very variable, but nowhere more than 28 feet, except after heavy freshets, when its level rises sensibly. Many parts, however, are not more than 3 feet deep. On the eastern shore, in the upper part of the lake, the river *Black* enters, near the island of Inchiquin.

15. The Claregalway river.—The southern part of the lake runs down from the strait connecting the two parts towards Galway. It is much the smaller part, but receives an important tributary called the *Claregalway river*. This stream rises in the boggy country near the *Annagh loughs*, close to the source of the Suck, a tributary of the Shannon, and has a southward course of nearly 30 miles, after which it turns abruptly to the west, to enter the lake by a channel of about 10 miles before reaching it. After receiving some small feeders from the east, it passes near Tuam, and expands into a series of small lakes before turning west. For the greater part of its course it is called the *Clare river*, but when it enters Galway it becomes the Claregalway river. It is also called in some maps the *Dalgen river* and the *Galway river*, but in this part of Ireland names seem to be changed frequently, and without much reason. The whole drainage area of the district is 1,374 square miles.

16. Coast from Galway bay to Clew bay.—From Galway westwards to the extremity of Galway bay the coast drainage is effected by a number of short streams connected with lakes entering the bay, in some cases directly, but in others opening into small estuaries and inlets, which become very numerous as we advance westwards. The *Owenboliska* is one of those that drain a tract of some size. The *Cashla river* is another. The latter is the outlet of a group of lakes, all of small size. Further on, Mannin bay receives the surplus water of *Lough Inagh*, and two other extensive sheets of water. These, though not at a high level, are buried among the mountains of Connemara, and are very picturesquely situated. Bartlett, in his account of this part of Ireland, speaks of Glen Inagh "cradling its black waters under the tremendous precipice of Mamturk, down which the stream that feeds Lough Inagh falls 1,200 feet, and opens the gorge of its prison upon the East."

Passing into Killary harbour, the river *Erriff*, fed by the Owenmore and the Glenlan, and receiving the drainage of some small lakes, almost reaches the source of the Aille. It is one of the chief rivers of the district. In the mountainous and wild tract that intervenes between this inlet and Clew bay, the number of mountain torrents that reach the sea is considerable. Near the southern extremity of Clew bay the *Owenwee*, the last of these, enters, the next river of any magnitude being the *Newport*. This stream commences as the river *Crumpaun*, and passes through *Lough Beltra*, lying under the Croaghmoyle mountain (1,412 feet), and then only takes its name of Newport river. The drainage of *Lough Feeagh* comes in a short distance to the west.

17. Drainage of the west coast of Mayo.—The only rivers of any magnitude emptying into the Atlantic from the county of Mayo are the *Owenduff* and the *Owenmore*. These enter in the bay formed north of the island of Achill. The Owenduff receives a large quantity of water from the slopes of the high hills rising abruptly from the sea level north of Clew bay. It has a number of feeders, which converge to the main stream about 6 miles from Tullaghan bay, at the mouth of the Owenmore, which, however, is an independent drainage area. The Owenmore rises in the country to the east in a small lake called *Lough Dahybaun*. Flowing a few miles west, the river receives the *Owening*, an important tributary from the north with many branches. It then flows steadily to the west for 10 miles, when it receives the *Munlin river*, conveying the waters from *Lough Garrowmore,* lying to the north. This lake is of considerable size. Receiving the Munlin, the Owenmore assumes the direction of that stream, and flows south about 5 miles, through a wide sandy expanse, into Tullaghan bay.

At the north-western extremity of Mayo the river *Glanamoy* enters the sea, receiving at its mouth the *Muingnab,* a stream of nearly the same length of course as itself. On the north coast of the county the *Ballinglen* enters the sea from the south, receiving some feeders.

18. The water system of the Moy.—This river system, like some others in Ireland, is duplex. The main stream has a distinct basin, draining an extensive district to the east, and bending round at a point about 20 miles from the sea to deliver the collected waters by a northerly channel. At this point it receives, by a channel not more than a mile long, at right angles to its course, a drainage from the west and south-west, collected into a sheet of water 12 miles long, parallel to the course of the river, and between three and four miles distant from it. This singular configuration occurs in a district nearly level, and not 100 feet above the sea, but with mountains rising to more than 2,500 feet to the west of the lake, and 1,400 feet to the east of the river.

19. The river Moy; its upper course.—The Moy rises in a great expanse of bog on the slopes of the Ox mountains of Sligo, which have a north-east and south-west range, and are from 1,200 in 1,380 feet high in the south-western part, rising to nearly 1,800 feet in the north-east. The length of the range is about 15 miles, and along the whole distance feeders proceed from the mountains to the stream, flowing south-east at right angles to the mountains, and running a distance of about 5 miles. Besides these feeders from the north-west, the *Owengarve* river comes in from the east. This is a stream of some importance, obtaining supplies from the western side of the mountains that here form the water-shed between the Shannon and its tributary, the Suck. After receiving the Owengarve the Moy winds round the southern extremity of the Ox mountains for about 12 miles, and at its most southerly point receives the Pollagh.

20. The river Pollagh.—The stream thus named has its sources in a chain of lakes 14 miles to the south-east of the course of the Moy, at a height of 260 to 280 feet above the sea. This low plateau forms the water-shed between the Moy and the Suck basins, the actual source of the Suck being a little further south. The drainage of the lakes that supply the Pollagh flows not more than a mile from the course of the river in its early flow. There are in all nearly twenty of these little lakes or pools, and a very small difference of level would change the direction of the drainage from the Moy to the Shannon. The main stream of the Pollagh, after it has received its tributaries in the south, flows to the north, and it is fed only by a few inconsiderable streams from the west. Five miles below the confluence of the Pollagh the Moy is joined by the drainage from the lakes.

21. The lake system of Lough Conn.—Southern portion.—These lakes receive the drainage of a large district west of the Moy, rising into much loftier mountains than those to the east that feed the Moy, and also far exceeding in elevation those of another district to the south and south-west. The latter is connected with a group of small sheets of water at Castlebar, about 100 feet above the sea, whose outflow is to the north-east, 5 miles from Castlebar. Arrived there, it meets with the waters of the *Manulla river*, originating in the plains of Mayo, nearly 10 miles to the south, and almost anastomosing with the feeders of Lough Carra, one of the feeders of Lough Mask. Shortly after, being joined by the *Castlebar river*, the *Clydagh* enters Lough Cullen, about 3 miles from its southern extremity. The lake usually stands at a level of 40 feet above the sea. It is a square basin of about 1,000 acres in extent, and is separated from Lough Conn by a narrow channel encumbered with islands.

22. The lake system of Lough Conn.—Northern portion.—Lough Conn is fed chiefly by the river *Deel*, which originates in small lakelets at the foot of Nephim Beg (2,065 feet). It is only the eastern drainage of this mountain, however, that reaches the Deel, the northern, and probably the principal part, entering the Atlantic to the north of Achill island by the Owenmore, a river already alluded to. The Deel receives several feeders, and has a course of at least 16 miles, chiefly to the east, to enter lake Conn. The distance from the mouth of the Deel to the mouth of the Manulla or Clydagh is 12 miles, this being the length of the two lakes, which for drainage purposes must be regarded as one.

Besides the Deel, there are some smaller streams entering Lough Conn, all coming in from the west. The chief one proceeds from among the Nephin mountain (2,646 feet), and conveys the surplus waters of *Loch Levally* by a course of 3 miles. Loch Levally is 104 feet above the sea. Besides this there is another small lake drainage entering Lough Cullin, also from the west.

23. Loughs Conn and Cullen.—It has already been stated that these lakes, of which Lough Conn is very much the largest, and slightly the highest above the sea, form, in fact, but one sheet of water, interrupted near the southern extremity by promontories from each bank, and with an island between them, leaving a comparatively narrow and interrupted passage. The usual flow is southwards, the delivery of the whole river into the Moy being at the southern extremity of the lower lake. The lower lake is sometimes called *Lower Lough Conn.* The connected water, measured on the line of greatest length, is 15 miles long, its breadth, though very irregular, being about 2 miles. There are several promontories or projections into the upper lake, and some islands, which are picturesque and richly wooded. The general scenery is fine, especially on the western shore, which is very bold.

Owing to the fact that the combined waters are fed from the north by a mountain stream, and from the south by one which represents the regular overflow of a boggy district at a low level, the water supply varies exceedingly, sometimes the one river and sometimes the other bringing down the principal supply. Usually the mountain stream conveys much more than the Manulla, and the upper lake is at the higher level, but sometimes this is reversed, and, as a comparatively small addition from the south will raise the level of the smaller area of water, there is occasionally an overflow for a time from the south to the north.

24. The lower course of the Moy.—After the confluence of the two parts of the Moy system, which takes place at Foxford, the combined waters have a course of 12 miles almost due north to Ballina, below which the river widens considerably, and opens into an estuary of about 5 miles into Killala bay. This open part of the stream is much encumbered with sands. The whole drainage area of the Moy is estimated at 1,033 square miles.

25. Coast drainage between Killala bay and the river Erne.—A number of small streams convey to the sea the northern drainage of the Ox mountains, the most important of which is the river *Easky,* which has a course of 10 miles, not including its sinuosities. It receives on its way a number of tributaries, and collects the water that flows down many mountain gorges. Beyond the mountains a larger stream enters by an estuary in Sligo bay. It originates in *Lough Arrow,* a pleasant sheet of water about 5 miles long, in a bleak country, the level of the lake being 181 feet, and the mountains rising immediately to 1,029 feet on its western shores. The southern part of this lake is not more than a mile from the northern part of Lough Key, one of the expansions of the river Boyle, which forms an important portion of the Upper Shannon.

From the Arrow there is a stream flowing north-west 10 miles, there meeting a shorter river from the south, bringing the drainage of *Templehouse lough,* which is fed from the hills that enclose the Shannon basin. The united stream has a flow of only 2 miles before it opens out into an estuary 7 miles in length.

26. Lough Gill.—Four miles further east is Lough Gill, which, after receiving a number of streams from the east and north, empties itself into a wide estuary below Sligo, by a short but wide channel of $2\frac{1}{2}$ miles. Lough Gill is a very attractive lake, 5 miles long and $1\frac{1}{2}$ miles wide, situated in a basin surrounded on all sides by hills, those on the south, nearly 1,000 feet above the sea, being rugged and precipitous. There are several islands in it. The estuary into which this lake empties itself is choked with sands, through which there is a narrow water-way. The only tributary of importance that supplies Lough Gill is the river *Bonet*, originating in a small lake (*Lough Glenade*) north-east of Sligo. The course of the stream is south-east at first, and then receiving a few feeders, it turns west to enter the lake.

27. Lough Melvin.—Past Sligo a small stream enters Drumcliff bay from *Lough Glencar*, and the river *Duff* brings a small contribution, shortly beyond which the river *Drowes* enters Donegal bay, conveying the waters of Lough Melvin by a channel 4 miles in length. This lake is 6 miles long and 2 miles wide, and is 90 feet above the sea. It receives two rivers, the *Roogagh* and the *Glenaniff*, from the south, but the extent of the drainage area is very small.

28. The lake system of the Erne.—The basin of the Erne is in many respects the most complicated in the character of its drainage, and the most exceptional, of any in the British islands. There is, indeed, the semblance of a river rising in the centre of the mountain limestone plateau of Ireland, at a level little exceeding 200 feet above the sea, and proceeding northwards for about 60 miles, to a large sheet of water 8 miles from the sea, and 150 feet above its level. As a stream, however, it does not flow for half that distance. The rest consists of expansions, varying from a few hundred yards to many miles in width ; of channels, multiplied and intersecting in the most singular manner ; and of irregular inlets penetrating the country on each side. It has several tributaries, but these in most cases have the same character. In all this the Erne resembles in its general features the Shannon, but is very much more complicated, conveys a much smaller body of water, and is more exceptional in all respects. The Erne has four principal expansions, but only one—that which is nearest to the sea—opens out into a regular lake, and presents a wide unbroken sheet of water. The fall of the bed of the river as far as Lough Erne is only about 60 feet, and the total length of the water-channel, if measured for the whole distance and through all windings, would probably be 120 miles. From Lough Erne to the sea the fall is rapid. By studying this explanation the peculiar physical features of Ireland will be appreciated, and the nature of the plateau over which it spreads its numerous arms will be understood. The drainage area of the Erne is 1,585 square miles.

29. The early course of the Erne; Lough Gowna.—The Erne originates in Lough Gowna, whose shores are but a few miles distant from the bed of the Shannon. This is a very irregularly shaped lake between the hills, buried among the northern districts of county Longford; and its shores are in places steep and well wooded. It receives feeders from the north-east, and also from the north-west, but on the south-east it is only 5 miles west of Lough Sheelin and Lough Kinale, two sheets of water at the head of the Inny, one of the large tributaries of the Shannon.

The north-western feeder of the lake connects by a channel of 5 miles with a long chain of pools ranging parallel to the course of the Erne for 12 miles. The largest and most northerly of these pools is called *Lough Gulla doo.*

The irregular channel by which Lough Gowna narrows into the channel of the Erne, receives a feeder of some importance after a westerly course of 12 miles, from hills about 1,000 feet above the sea, and the river then continues in a tortuous course for some miles. The direct distance from the foot of Lough Gowna to the head of Lough Oughter is little more than 7 miles, but the windings increase this in a marked manner. There are lakes on each side. The ground falls rather rapidly in this upper part of the Erne, there being 50 feet difference of level between the two lakes. The channel is therefore rapid, and the ground broken.

30. Lough Oughter.—The Erne, flowing northwards from the north-eastern expansion of Lough Gowna, and passing some small lakes, enters Lough Oughter at Kilmore, a short distance from Cavan. Lough Oughter is a singular labyrinth of pools and lakes and wide channels, and has been described in the following words by Mr. Fraser : " The country immediately connected with Kilmore and Farnham exhibits a well cultivated, and at the same time a pleasing rural character. The small lakes, which are thickly scattered over a surface of 76 square miles, by their labyrinthine windings, give to that space the appearance of lake and island in alternate series. They are the principal feeders of the Erne, and are connected with each other by small rivers." The general level of the lake is 160 feet above the sea.

The north-eastern part of this group receives the river *Annalee*, a considerable tributary originating in a number of lakes of some size, more than 20 miles to the east of which *Lough Sillan*, *Lough Tucker*, *Lough Eglishe* and *Shantonagh*, are the chief. The river runs in a nearly straight course from Bellatrain to Lough Erne.

31. Upper Lough Erne.—This lake is little more than a repetition of the complication of expansions, pools, inlets, and channels that is so remarkable in Lough Oughter. The difference of level is 9 feet, and the distance about 8 miles from the foot of Lough Oughter to the head of this next lake. Close to the point where the lake begins, the river

Woodford enters from the west. This stream, like that to which it contributes, is a chain of lakelets and irregular channels occasionally expanding. These extend for a long distance, reaching almost to the Shannon.

This member of the Erne series of lakes is long, narrow, and crowded with islands. It is not surrounded by mountain scenery, but has a singularly irregular outline, sufficiently picturesque to be attractive. Its length is more than 10 miles, and its breadth nowhere exceeds 3 miles, and is generally less. In the lower part of the lake the *Colebrook river* enters from the north-east, and the river *Claddagh* from the south-west. The former is the larger stream, and it expands into several lakes. The Claddagh, or *Swanlinbar,* drains an extensive district.

32. Lough Erne.—The water-way from the Upper Erne to the principal lake of Erne is wide, interrupted, and intricate. Shortly after leaving the upper lake it receives the surplus waters of two large lakes in the west called the *Upper* and *Lower Macnean,* which commence close to the head-waters of Loch Melvin. Before reaching Enniskillen a stream comes in from the west called the river *Sillee,* which passes through two lakes in the north-west.

Lough Erne is very much larger than the upper lake of the same name just described. It extends from Enniskillen in a north-westerly direction more than 10 miles, and then turns west and continues for another 10 miles to the outflow of the river, the further distance to Ballyshannon, where the Erne reaches the sea in Donegal bay, being 8 miles.

33. The river Erne.—The stream of the Erne below the lake is wide and swift, and characterised by rapids and falls, especially near the town of Ballyshannon, where an enormous body of water, descending from Lough Erne in a stream 150 yards wide, falls 16 feet with a tremendous roar down a steep cliff into a basin forming the head of the harbour. This cascade is seen to most advantage in winter, when the river is swollen by rains, and at the recess of the tide the noise of the fall may be heard many miles off.

The following general account of Lough Erne, and the curious complication of country in which it is situated, will be found interesting and instructive.

"Lough Erne is one of the largest and most beautiful of the Irish lakes. It boasts little mountain scenery or craggy shores, but is, save at one locality, for the most part sylvan in character, and indeed, for combinations of wood and water, is probably unequalled. The river Erne, which feeds it, rises in Lough Gowna, about 3 miles north of Granard, and runs due north until it expands into Lough Oughter, from whence it emerges with broader proportions, passing Butler's bridge and Belturbet. At or near Crum it is generally called Lough Erne, though in fact it is nothing more than a very broad river fringed with innumerable bays and studded with islands, many of them of considerable size. The upper lake is at its broadest opposite Lisnaskea, and from this point soon narrows to assume the river character again. The reach from the town to the lower lake is about a mile in length, and the channel here has been considerably deepened; and at the entrance to the lake are the ruins of some circular towers of an old fortress. About 2 miles from Enniskillen is the island of Devenish, with the ruins of an abbey, and a remarkably fine round tower. Beyond Devenish the lake gradually expands, and assumes the character of an inland sea, stretching for 20 miles, its greatest breadth being 5 miles, and its least 2 miles. It contains nearly 28,000 statute acres, and 109 islets, many of them small and of trifling importance, others, and not a few, varying from 10 to 150 acres, while Boa island, near the northern extremity of the lake, contains 1,300 statute acres."*

34. The river Esk.—Beyond the Erne the little river *Esk* enters the sea at Donegal, bringing the waters of Lough Esk and a smaller lake 3 miles above. Lough Esk is 3 miles from Donegal, and is 2 miles long. It is 100 feet above the sea.

* *Fraser*, quoted in Murray's Handbook for Ireland, p. 64.

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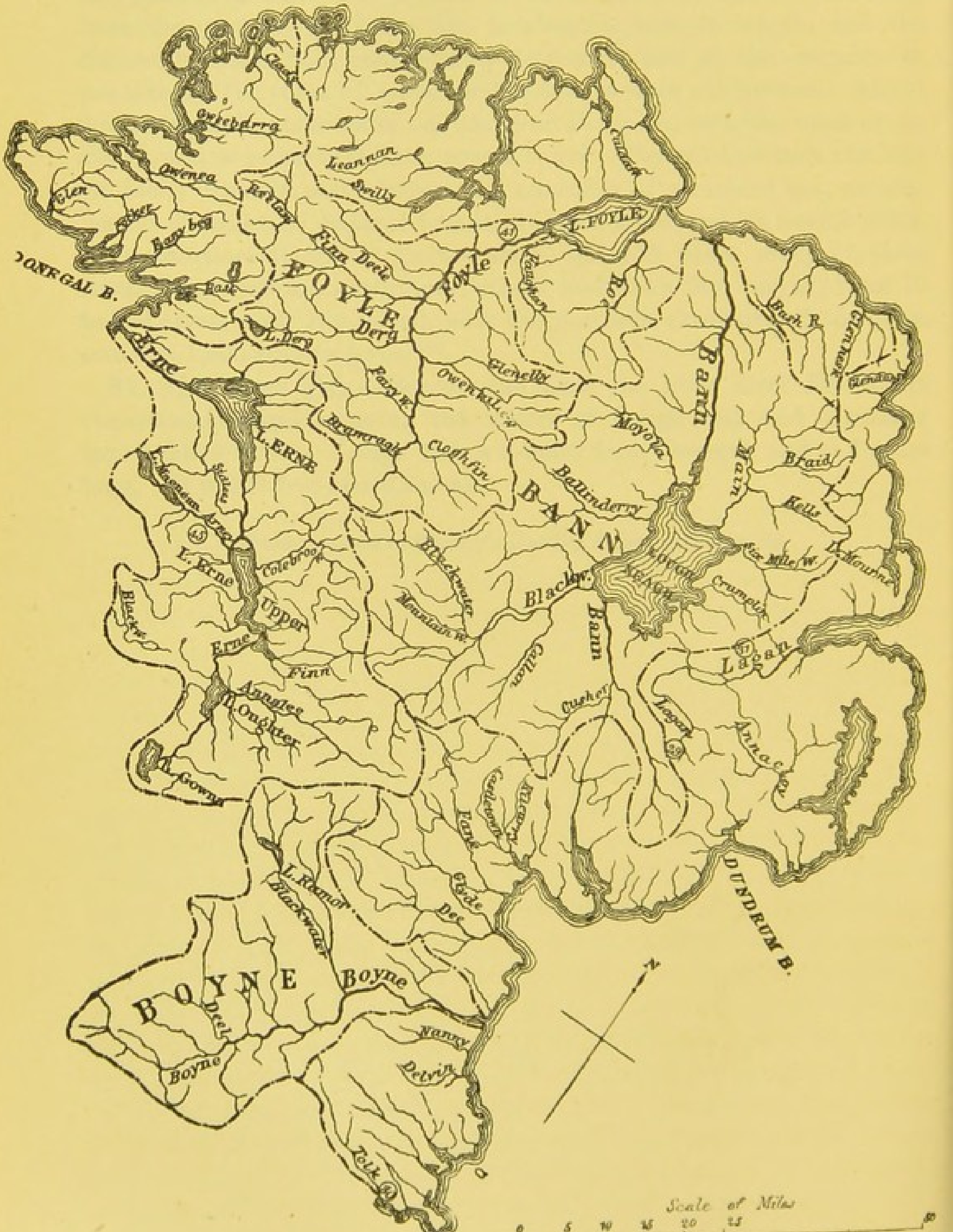
XVIII.—DRAINAGE AREAS OF THE NORTH AND NORTH-EAST OF IRELAND.



CHAPTER XVII.

DRAINAGE AREAS OF NORTHERN AND NORTH-EASTERN IRELAND.

(1) General account of the district.—(2) Physical geography and geology.—(3) Subdivisions.—(4) Scheme of the principal rivers and affluents.—(5) The river Eask.—(6) The Eanymore water.—(7) The Oily water.—(8) The Gweebarra river.—(9) The Gweedare river.—(10) The Clady river.—(11) The river Owencarrow.—(12) The river Leannan.—(13) The Swilly river.—(14) Drainage of the coast of Inishowen.—(15) The river Mourne.—(16) The Owenkillen river.—(17) The Mourne Beg river.—(18) Lough Derg.—(19) The river Finn.—(20) The river Foyle.—(21) The river Roe.—(22) Lough Foyle.—(23) The Upper Bann.—(24) The river Blackwater (Bann).—(25) Lough Neagh.—(26) The river Ballinderry.—(27) The river Moyola.—(28) The rivers entering Sandy bay.—(29) The Six-mile water.—(30) The river Main.—(31) Lough Beg.—(32) The Lower Bann.—(33) The Bush river.—(34) The Glenshesk river.—(35) The river Glendun.—(36) The Glenarm river.—(37) Belfast lough.—(38) The river Lagan.—(39) Strangford lough.—(40) The river Quoile.—(41) Coast from Strangford to Dundalk bay.—(42) Drainage into Dundalk bay.—(43) The Upper Boyne.—(44) The river Blackwater (Boyne).—(45) The Lower Boyne.—(46) Coast drainage from the Boyne to Dublin bay.

1. General account of the district.—We have to consider in this chapter the drainage areas of the north and north-east of Ireland, a wide tract of country including three important rivers, and the largest fresh-water lake in the British islands. The district comprises in all not less than 5,000 square miles, much of it hilly and even mountainous, but less wild everywhere than the district last described, and containing the most settled and prosperous counties of Ireland. Much of the coast line is broken and interrupted. The parts of Ireland included are the counties of Donegal, Londonderry, Antrim, Tyrone, Armagh, Down, Monaghan, Cavan, Louth, and Meath. Of some of these the whole, but of others only a part is contained within the drainage area. A small part of

County Dublin, north of the Liffey, is also included, though only for the coast drainage.

2. Physical geography and geology.—The northern part of Ireland, including much of the county of Donegal, consists of metamorphic rock, rising in places more than 2,000 feet above the sea, and separated by a valley and chain of lakes from a patch of granite in the north-western extremity. The metamorphic rock extends eastwards into Londonderry, including the basin of the Foyle, and reaching to the water-shed of the Bann. It is broken through on the north-eastern corner of Ireland by a great outburst of basalt of comparatively modern date that characterises Antrim, and is developed in a remarkable manner in the Giant's causeway. To the south of this great mass of eruptive rock the metamorphic rock appears, and is covered by carboniferous limestone in the middle and west, but by much older palæozoic rocks on the eastern part south of Lough Neagh and Belfast. The Foyle rises and has part of its course in the Old Red Sandstone, and in County Tyrone there is a coal-field. A small development of secondary rocks amongst which the basalt appears, is traceable in the north-east; but these rocks do not affect the hydrography of the country. A small patch of granite comes through the Cambrian and other old palæozoic rock in County Down, where again there are lofty granitic mountain masses (the Mourne mountains), rising to nearly 3,000 feet. Carboniferous limestone reappears in the south-easterly part of the district, occupying most part of the country drained by the Boyle. Thus the valley of the Foyle is chiefly in the metamorphic rock, but the source and early feeders are in Old Red Sandstone. The Bann flows chiefly over basalt, but it rises in granite and old palæozoic rock. The basin of the Boyne is in rocks of the newer palæozoic period, from carboniferous limestone to coal-measures.

The basin of the Foyle may be described as hilly, often rising to mountainous, the country being broken and wild. The valley of the Bann is wide, low, rich, and cultivated, and it includes the wealthiest part of Ireland. The Boyne, and its chief tributary the Blackwater, pass through much cultivated country, and some important coal-fields.

3. Sub-divisions.—There are several groups of drainage areas in this large tract of country, but with the exception of the three largest they convey the water to the sea by rivers of short course, and little economic importance. Of the main catchments the Bann exceeds in area the two others. The following sub-divisions will be found convenient. They are arranged in geographical order, beginning at the north-west:—

1. The catchments of the Donegal coast draining into the Atlantic.
2. The basin of the Foyle.
3. The basin of the Bann.

4. The catchments of the north-east and east coasts to the mouth of the Boyne.
5. The drainage area of the Boyne and Blackwater, and the country from the Boyne to Dublin bay.

4. Scheme of the principal rivers and affluents.—The following outline of the general distribution of the catchments will be convenient:—

1. *Catchments of the Donegal Coast.*

River Eask.
Lough Eask.
Eanymore water.
River Oily.
Owentocker river.
Gweebarra river.

Gweedore river.
Clady river.
Lough Dunlewy.
Lough Nacung.
Owencarrow river.
Leannan river.

River Swilly.
Lough Swilly.
River Loughnan.

2. *Basin of the Foyle.*

Right bank.

River Finn.
Reelan river.
Cloghan lough.

Left bank.

River Mourne
Owenkillen river.
Owenreagh river.
Mourne Beg river.
Lough Derg.

River Foyle.
River Deele.
Burn Dennett.
River Faughan.
Lough Foyle.
Roe river.

3. *Basin of the Bann.*

River Bann.
River Blackwater.

Lough Neagh.

River Crumlin.
Six-mile water.
River Ballinerry.
River Moyola.

River Main.
Braid river.
River Bann.

4. *Coast Drainage of North-Eastern Ireland.*

Bush river.	Newry river.
Glenshesk river.	Castletown river.
Glendun river.	Fane river.
Glenarm river.	Glyde river.
Lagan river.	Dee river.
Quoile river.	

5. *Basin of the Boyne.*

Boyne river.

Right bank.	*Left bank.*
	Deel river.
	Stonyford river.
	Tremblestown river.
Boycetown river.	
	Blackwater river.
	Moynalty river.

Nanny water.
Broad-meadow water.

5. The river Eask.—At the head of Donegal bay the small river Eask enters the bay, draining the country to the north-east. It rises on the eastern side of the Bluestack (2,219 feet), being the overflow of a small lake, called *Lough Belshade.* Flowing south about 4 miles it enters *Lough Eask,* which is only 100 feet above the sea. The lake is more than 2 miles long, and $1\frac{1}{2}$ mile wide at the lower end. The river Eask flows from its south-western corner, and another river enters at the south-eastern extremity. From the lake the river has a course of 4 miles to Donegal. There are two or three small streams that enter the bay near the river from the east. The head of the bay is a sandy estuary. From Donegal it is nearly 4 miles to the mouth of the tidal estuary of the Eask.

6. The Eanymore water.—About 8 miles west of Donegal on the western side of a promontory, forming Inver bay, the Eanymore enters this bay. It rises on the western side of the Bluestack in a mountain district, and is fed by the *Eanybeg water* from an adjacent valley. The course of the stream is nearly the same in length as that of the Eask, but there are no lakes.

7. The Oily water.—Another promontory follows, and another similar stream enters at the head of McSwine's bay. This is called the *Corker river* at its source among the mountains, but the Oily water as it approaches the sea.

Another river (the river *Glen*) drains the south-western extremity of Donegal, combining the water brought down by several feeders to the north, and entering the extremity of Donegal bay in Teelin bay. There is also a drainage to the north from the same mountains as those which feed the Eask and the Eanymore by the river *Owenea*, which receives the *Owentocker* from the south.

8. The Gweebarra river.—A long straight valley in a direction north-east and south-west, separates the Glendowan mountains from the Derryveagh mountains, and cuts off the drainage of the north-west coast of Donegal. The south-western part is drained by the Gweebarra river, and the north-eastern by the Owencarrow river.

The commencement of the Gweebarra river is nearly 20 miles from Gweebarra bay to the north-east. The upper stream is called the river *Barra*, which rises in a narrow wild glen between the Derryveagh and the Glendowan mountains, the former being between 2,000 and 3,000 feet above the sea. After about 3 miles the river expands into *Lough Barra*. Emerging from this lake the stream flows south-west through Glen Laheen, receiving small tributaries, and then passes through a deep gorge and opens into the Gweebarra river, which gradually widens into an estuary, and after 5 miles turns to the west. Three miles beyond it enters Gweebarra bay. The scenery is very fine.

9. The Gweedore river.—The principal streams that enter the Atlantic on the west coast of Donegal between Gweebarra bay and Lough Swilly, are the Gweedore river and the Clady river, entering Gweedore bay ; the Owencarra river, entering Sheep haven ; and the Leannan river, entering Mulroy bay. Both the Gweedore and Clady pass through several lakes, and enter the sea together in Gweedore bay. The Gweedore, the most southerly, commences with the overflow of *Lough Anure*, and passes through a wild and desolate district, but its whole length of course is barely 10 miles.

10. The Clady river.—This is a much longer and far more interesting river than any of the other Donegal rivers. Its origin is in the heart of the Derryveagh mountains, in a grand amphitheatre, terminating in the lofty rounded head of Slievesnacht, the Hill of Snow (2,240 feet). "A deep corrie known as the Poisoned Glen runs up in a cul-de-sac into the very heart of the mountains, guarded by steep precipices, down which a small stream glances on its way to join the *Devlin river*, just before it falls into *Dunlewy lake*, which together with *Lough Nacung*, forms a sheet of water 4 miles in length, filling up the valley in such a manner as to appear more like an arm of the sea than a fresh-water lake."* From hence the outflow from the lakes proceeds to Gweedore bay by the sides of Arrigal mountain, a very remarkable cone rising with startling abruptness to the height of 2,466 feet, glistening with seams of quartz.

Although there are no considerable streams beyond the Clady river there are mountain torrents, connected with the lakes and tarns, entering

* Murray's *Handbook for Ireland*, p. 97.

the sea by estuaries, and sheltered by groups of rocky islands. Some of the lakes are very picturesque.

11. The river Owencarrow.—This stream commences in Glen Veagh, or Beagh, close to the sources of the Barra, but flows north-east or in a precisely opposite direction to the Barra. Passing through Glen Veagh for 3 miles it expands into *Lough Veagh*, which is more than 3 miles long, and then continues for another 3 miles as the Owencarrow river. Glen Veagh and Lough Veagh are described as formidable rivals even to the beauties of Killarney. The lake is entirely shut in by mountains, and noble cliffs covered with brushwood rise from the water's edge to the height of 1,200 feet, presenting a thick growth in which the golden eagle still breeds. At Astellion there is a great waterfall.

After 3 miles the Owencarrow expands into *Lough Glen* a long narrow sheet of water, from the middle of which, on the west side, is the outlet of the Owencarrow which runs at right angles to the direction of the lake to enter Sheep haven by a short passage of 2 miles. This bay, enclosed by lofty headlands, is much exposed to the north and north-east, and is encumbered by sands which extend for a long distance, and have of late years so much encroached on the land as to cause great destruction of valuable property.

12. The river Leannan.—Under this name a considerable stream, originating close to the sources of the Barra and the Owencarrow, and draining the Glendowan mountains, reaches the sea in Mulroy bay, between Sheep Haven and Lough Swilly. Flowing first about 3 miles to the south of Earl, this river expands into *Lough Gartan*, a fine expanse of blue water, enclosed with wooded banks. A narrow neck of land separates Lough Gartan from *Lough Agibbon*, a much smaller piece of water to the north.

A branch to the east connects Lough Gartan with *Lough Fern*. This, branch bears the name of Leannan. Lough Fern is about $1\frac{1}{2}$ miles in length enclosed on the east by a cliff which rises 500 feet above the shore. Close by is *Lough Sall*, a hollow, like the crater of an extinct volcano, filled by a lovely lake, surmounted by a conical peak, and clothed with brown heath, green fern, grey lichen, and red crow's bill. It is said to be 240 feet deep. A short distance beyond Lough Fern the Leannan passes into Mulroy bay, a long narrow arm of the sea, extremely beautiful, and skirting the base of the Knockalla hills.

13. The Swilly river.—This is the last of the catchments of the coast of Donegal. It commences on the eastern slopes of the Glendowan mountains, and flows east for about 12 miles to Letterkenny receiving a few unimportant feeders. It soon expands itself into an estuary which for more than 25 miles continues to widen, and forms the remarkable inlet called Lough Swilly, choked in some places with sands, but a noble expanse of water from 2 to 3 miles wide for a distance of 20 miles from the sea.

The lower end is tame and bare, but much of it is skirted by hills which rise to a considerable elevation. The direction of this inlet is nearly south, or at right angles to the trend of the coast.

14. Drainage of the coast of Innishowen.—The singular tract of land called Innishowen, forming the eastern extremity of County Donegal, has a width of not more than 8 miles from the head of Lough Swilly to the river Foyle, but expands to nearly 25 miles in its widest part. It stretches out from the neighbourhood of Londonderry for nearly 30 miles to the north, separated from the land by the two large salt-water lakes already named. Its drainage is not unimportant as it encloses the Slieve Snaght mountains (2,019 feet) which form a central range, and receive a heavy rainfall finding its way to the sea by many streams.

Passing along the eastern shores of Lough Swilly near the last station of the railway at Buncrana, a pleasant little bathing place, two rivers come in:—the *Mill* from the south-east, and the *Crana*, a much more important river, from the east. The latter has several branches and receives near its outflow, another considerable river, the *Owenboy*. All these carry off the rain from the southern and western slopes of the mountain chain. The scenery is fine and the country wild.

The extremity of Lough Swilly on the east coast is shut in by high mountain land terminating in Dunaff head, which with Fanad head stand out as sentinels guarding the coast. Though Lough Swilly runs in nearly 20 miles, the extreme width at the entrance of the inlet is only 5 miles.

About 6 miles beyond Dunaff head is the mouth of Trawbreago bay, which enters the land for a long distance and is choked with sand. It receives the *Loughnan* river fed by the torrents from the north side of the central chain. Another smaller stream enters the sea a little to the north.

Rounding Malin head and Glengad head the north coast of Innishowen is little interrupted by water-courses until Innishowen head is reached, and we enter Lough Foyle, a noble sheet of water, the entrance to which is less than a mile in width, but which expands in a sack-like form, and is about 8 miles across at the lower end where it receives the Foyle river.

15. The river Mourne.—The river Foyle does not receive its name till the junction of its two affluents the Mourne and the Finn. The river Mourne for a large part of its course is called the Drumragh, and the first stream that carries its waters to the Foyle must be described under this name.

The *Drumragh* rises in Clogher, north of the sources of the Blackwater (a feeder of Lough Neagh) and the Colebrooke (a feeder of the Erne). After a few miles it receives a feeder from the east or right bank coming from Slieve More (1,033 feet), and shortly after the river *Owenreagh* from the left, after a course of several miles. Flowing most part of the way due north, after a short distance the *Camowen* joins the stream from the right, draining a large area, and fed by the *Cloghfin*, which brings in a good body of water from the hilly country to the south-east; Omagh is then reached, and shortly after the *Fairy water* joins the Drumragh from the west. The river now passes between the celebrated mountains Bessie Bell (1,387 feet), and Mary Gray. Between Omagh and Newtown Stewart it is sometimes called the *Strule*. At Newtown Stewart where the Drumragh, or Strule, receives large and important contributions, both from east and west, the river first takes its final designation, the Mourne river.

16. The Owenkillen river.—This river rises in the lofty chain of the Munterlony mountains and flows to the west. The height of the hills is not less than 2,000 feet, the highest point being 2,246 feet. The Owenkillen is joined on its course by the *Owenreagh river*, and after flowing some distance the *Glenelly* comes in. It is an important branch from the Sperrin mountains, a little to the north, and flows west. The united stream has a course of about 4 miles to the main stream of the Mourne.

17. The Mourne Beg river.—This great branch of the Mourne commences with the overflow of Lough Mourne 554 feet above the sea. It flows south-east, receiving tributaries from north and south, and after about 12 miles reaches Mourne Beg, where it is joined by the river *Derg* from the south-east. This river connects with Lough Derg, a large sheet of water 467 feet above the sea.

18. Lough Derg.—This lake is 6 miles long and 4 miles broad, and contains several rocky islands. It is surrounded on all sides by barren heathy hills, possessing neither form nor elevation to give the slightest interest to the scene. There is no road to it, but in the months of June, July, and August, it is the resort of numerous pilgrims to a place on the largest island (called Station island), which is about half a mile from the shore. It is covered with chapels. Here the limestones of Lough Erne succeed to the mica slates which cover the north-west of Ireland.

Below the Derg the Mourne Beg continues for another 12 miles winding about and receiving a few tributaries before reaching the Mourne river, after which the Mourne continues to flow about 15 miles to the confluence of the Finn.

19. The river Finn.—This principal affluent, which at its confluence with the Mourne forms the river Foyle, rises on the eastern slopes of the Glendowan mountains, not far from the sources of the Gweebarra. Several principal branches unite, and both they and the combined stream pass through a wild mountain country, flowing east, and occasionally expanding into small lakes. The first of these is *Cloghan lough,* into which the river *Reclan,* a large feeder, enters, after a course of several miles. The Finn continues to flow towards the east, passing the town of Cloghan, and receiving several small, but no large affluents. After a long course it turns north-east for 3 or 4 miles, meeting the Mourne, when, as already stated, the two rivers become the Foyle.

20. The river Foyle.—Thus formed at Strabane, the Foyle flows northwards, and after a couple of miles receives the river *Deele* from the west. This stream originates in *Lough Deele* near the source of the Swilly. It has a long course, and about half-way to the Foyle receives the river *Cloghroe* on the right bank. Below the junction of the Deele the *Burn Dennett* adds its waters to the Foyle, draining the country to the east, after which as far as Londonderry there are no feeders of importance. Below Londonderry on entering the Lough, the river *Faughan* enters, draining a wide stretch of country to the south-east. It rises in the Sperrin mountains, and has a length of course of above 20 miles.

21. The river Roe.—This river rises near the sources of the Faughan in the Sperrin mountains, and collects into one main channel the waters from a number of streams in the hilly country south-east of Lough Foyle. It flows due north, and passing Newtown Limavady enters the Lough at Myroe by a small estuary. On its way it receives two rivers, the *Owen Nagh* and the *Owen Beg,* near the town of Dungiven, at the foot of Ben Bradagh (1,536 feet).

22. Lough Foyle.—This large sheet of salt water, almost enclosed by the projecting land of the north-west corner of county Londonderry, which approaches within 2 miles of the coast of the peninsula of Inishowen, gradually expands in a pear-shaped form from this narrow inlet to a breadth of 8 or 9 miles. Its length is 16 miles. There are extensive sands and mud banks on the eastern shore and in the middle, but hills rise rapidly from its banks on the west to 1,058 feet, and on the right to 1,260 near the outlet. Further in the banks become lower, and several small streams enter from both sides, running over level ground.

From Magilligan point, the eastern headland at the entrance of Lough Foyle, there are no important streams entering the sea till the mouth of the Bann is reached at Coleraine. The distance is little more than a mile. The Bann enters by a very narrow channel.

23. The Upper Bann.—The principal sources of the Bann are among the Mourne mountains, between Dundrum bay and Carlingford bay, close to the east coast of Ireland. These mountains rise almost immediately to heights varying from 1,600 feet near Carlingford bay, to 2,084 in the Eagle mountain, 2,450 in Slieve Bingian, and 2,800 in St. Donard near Dundrum. The source of the Bann is on the western slope of Slieve Muck, or the Eagle mountain; but at least five principal branches combine to form the stream within a distance of 4 miles. Once formed, the river flows north about 5 miles, where it meets the *Muddock river,* conveying the surplus waters of *Lough Reavy,* which receives feeders from the south and south-east, proceeding from the high ground in that direction. The length of course of the Muddock from the lake is about 5 miles.

After this confluence, which takes place at Rathfrayland, the river continues to flow 10 miles north and north-west to Banbridge, receiving few and small tributaries, and passing through a level country. It then curves round in a semicircle, and flows 12 miles to Portadown, whence it has a further course of 5 miles to Lough Neagh, which it enters near the south-western corner.

According to Sir Robert Kane, the available catchment area of the Upper Bann is 256 square miles, and the mean annual rainfall over the district 36 inches. It delivers a large body of water into the lake, which it enters within 2 miles of the mouth of the Blackwater. Between Banbridge and the lake, the river receives hardly any affluents. The most important is the river *Cusher;* which comes in at Gilford, between Banbridge and Portadown, from the south-west, after a course of about 12 miles.

24. The river Blackwater.—This river and the Upper Bann differ but little in relative importance, extent of drainage area, or length of course, as feeders of the great lake into which they deliver their waters. The Bann, however, drains the country to the south-east, and the Blackwater that to the west, their courses lying very wide apart.

The Blackwater rises in Clogher, close to the sources of the Foyle and some of the feeders of the Erne, from which it is separated by a high ridge. Near the town of Clogher all the different branches from the high ground collect into a stream, after courses varying from 6 to 8 miles in length. This stream flows eastwards for a few miles, receiving small feeders from both sides, and soon turns south-east to Caledon, where it receives two tributaries, one from the west and the other from the south-west, both rising on the slopes of Slieve Beagh (1,255 feet). The former is small. The latter (the river *Tynan*), has a course of nearly 20 miles, and enters the Blackwater at Tynan Abbey. Here the river turns north, and continues in this direction for 10 miles, when it receives a small feeder from the north, and turns east for about 3 miles, after which it again takes a northerly course of about 12 miles to enter Lough

Neagh. Near Moy, about midway, in this latter part of the course, the river *Callan* joins the Blackwater. It is a considerable stream rising in *Lough Tullynawood* in County Monaghan, flowing north about 12 miles to Armagh, and thence in the same direction 8 miles further to the main stream. It has many small feeders. The Blackwater takes a small turn to the east before entering the lake, and there receives the river *Torrent* from the west, passing through the Tyrone coal-field. The drainage area of this important feeder of Lough Neagh is 526 square miles.

25. Lough Neagh.—The sheet of water into which the Upper Bann and the Blackwater pour their contributions is of an oblong form, about 20 miles in extreme length, and 12 miles in extreme width, the shores measuring 80 miles in circumference, and the area being 153½ square miles (98,255 acres). Its ordinary level is 48 feet above the sea, and its general depth less than 50 feet, though in some parts it reaches 100 feet. The actual level varies to the extent of 6 feet, rising in winter 2 or 3 feet above the mean, and depressed during dry summers to about the same amount below the mean. It contains no large island, and its shores are neither picturesque, rocky, nor beautiful. The chief island is Ram island, remarkable for its round tower, 43 feet high.

The exact shape of this lake is not oblong, the oblong portion being about 14 miles by 9, instead of 20 by 12. Its form resembles the egg-sheath of the shark, so often found on our shores, there being curious bays or recesses in each of the four corners, terminating generally in streams, all with one exception entering the lake. In the south-western corner the main feeders, the Bann and the Blackwater enter. In the opposite, or north-eastern corner, two other streams contribute to swell the supply. These are the *Main* and the *Six-mile water*. The *Crumlin* comes in on the east side, and opposite to it from the west the *Ballinderry*. The Bann carries off the surplus water in a considerable stream, enlarging almost immediately into another lake, whose direction is nearly due north. There are three other less important streams connected with the supply of the lake. Ten rivers in all may be counted among its feeders.

Lough Neagh is the largest lake in the British islands, and is situated almost entirely within the volcanic district of Ireland, of which the effects are seen in the remarkable phenomena of the Giant's Causeway. The whole district is an elevated plateau, sloping gradually to the valley of the Lower Bann, and overlooking Lough Foyle on the north-western, and Belfast lough on the eastern borders. The plateau is bounded by noble escarpments with precipitous flanks, rising to elevations of 1,500 to 1,800 feet. The lake has been supposed to be due to depressions of the surface by faults during the middle tertiary period.

26. The river Ballinderry.—This river enters Lough Neagh from the west, and drains a large tract in the county Tyrone. Its early waters drain from the eastern water-shed of the hills whose western slopes feed the Foyle. It flows east to Cookstown, receiving feeders on both its banks, and at Cookstown is joined by a large tributary from the north-west. Before reaching this confluence, however, there is another and equally large stream added from the south, having numerous branches. Its whole course is nearly 20 miles, without including windings. It enters the lake not far from the bay through which the Bann emerges, carrying the surplus waters to the north.

27. The river Moyola.—This is another feeder from the west entering Lough Neagh in the north-western bay through which the Lower Bann makes its way out of the lake. It has a long course, and several feeders. It rises near the sources of the Owenkillen (an important tributary of the Foyle), and flows 12 miles north-east, when it meets a tributary from the west. Turning then east it continues 6 miles to meet a branch passing Maghera, a quiet place at the corner of the Sperrin mountains. After this junction the main stream continues about 10 miles into the lake.

28. The rivers entering Sandy bay.—The river *Crumlin* enters this bay, which opens out from the eastern shores of Lough Neagh, after a course of about 12 miles from Divis Hill (1,567 feet). It receives some feeders. Another smaller stream enters the head of the bay, after a course of 10 miles, also in a westerly direction. A third river passing through a large nearly circular pool (*Lough Portmore*), comes into the bay at its south-eastern extremity. All these drain the hilly ground stretching from north to south immediately behind Belfast, and parallel to the course of the Lagan.

29. The Six-mile water.—A stream under this name drains the country to the north-east of Lough Neagh, almost from the coast at Larne. It has a straight course to the south-west for 12 miles, and there meets another river coming from Divis Hill in the south, and flowing about 10 miles towards the north-west. The united stream enters the lake in Antrim bay.

30. The river Main.—The last river entering Lough Neagh is the Main. It rises near the coast on the slopes of Slievance (1,782 feet), a hill which also gives rise to some other streams. It has several small branches all flowing south, which unite after a few miles, and form a stream called the *Clogh*, which curving round to the south and west soon unites with another river coming from the north, with a branch from the east. The river thus formed has a southerly course of about 8 miles to the *Braid river*, which unites with it at Ballymena. The Braid is an important stream with numerous branches from the western slopes of the coast hills of Glenarm bay. After combining with the Braid, the Main flows south in a nearly straight course for 10 miles to the lake passing

Randalstown. On its way it receives from the east the river *Kells*, a considerable affluent.

31. Lough Beg.—The overflow of Lough Neagh passes northwards at Toome by a channel less than 2 miles in length, which expands into Lough Beg, an irregular sheet of water nearly 4 miles long, and not less than 2 miles wide at the point where the waters from Lough Neagh enter it. It gradually narrows towards the north to a width of 1 mile. There are a few small islands in the lake, which is not of any great interest, except in modifying the outflow of the waters of the larger lake in time of flood. Owing to the number of the streams entering Lough Neagh, and the wetness of the climate, the shores of that lake are subject to inundations, which in former times appear to have covered as much as 30,000 acres. The opening out of the main channels of the Lower Bann now removes the water more quickly.

32. The Lower Bann.—From the northern extremity of Lough Beg, the Bann flows in a nearly straight channel for nearly 30 miles to Coleraine, receiving on its way some small streams draining the country to the east and west, but having a fall of only 48 feet, a third part of which is expended in a single leap near Cutts. The principal drainage is from the west, the line of water-shed between the basin of the Lower Bann and that of the river Roe, which enters Lough Foyle, being almost due north and south for nearly the whole distance. The principal heights are on the western side of the water-shed. The Bann enters the sea a little below Coleraine, by a narrow and somewhat obstructed channel. There is a bar at the mouth, and the real port of Coleraine, a busy and important place, is Portrush, about 6 miles east of the mouth of the Bann, but connected with the town by a railway. There are extensive salmon fisheries at the Crannagh near the mouth of the river, and again at the Cutt, where is the fall of 13 feet, and a salmon leap. The Bann is tidal for some miles from its mouth.

33. The Bush river.—Five miles east of Portrush a river enters the sea, which drains a tract of country for some distance to the south in the interior. This is the river Bush, which rises close to the source of the Main, on the slopes of Slievance (1,782 feet), and flows north-west about 10 miles to Armoy. It then turns south-west to Stranocum, and after flowing 4 miles to the west receives a tributary from the north-east rising near Ballycastle, and flowing nearly parallel to the Bush. After this the stream bends round to the north, and has a direct northerly course of 10 miles to the sea, which it enters close to the grand basaltic columns forming the Giant's Causeway.

34. The Glenshesk river.—The last river entering the sea on the north coast of Ireland is the Glenshesk. It originates on the slopes of the Slievanorra mountain (1,676 feet), and flows 8 miles due north to the sea at Ballycastle. On its way a small feeder is received from each side, but close to its mouth the river *Carey* joins it from the east, draining a large area to the south-east, and another smaller stream from the south-west, where there is a high hill, Knocklayd (1,695 feet).

35. The river Glendun.—From the mouth of the Glenshesk there are no streams of importance entering the sea till at Cushendun bay, the Glendun comes in from the south-west. It conveys the waters that fall on the high hills of Slievanorra, the Trostan mountain (1,817 feet), and Slievance. Near its mouth it is joined by a small stream, on which there is a picturesque waterfall. The Glendun flows for its whole course between mountains of considerable height, and the country near its mouth is exceedingly picturesque, and of great geological interest.

36. The Glenarm river.—This is another small but interesting river rising in the hills of Collin Top (1,426 feet), and having a northerly course of about 8 miles to the sea, passing a richly wooded park. It has two principal branches of nearly equal importance, uniting about 4 miles from the sea.

37. Belfast lough.—Except the very small river entering the sea at Lough Larne, there is no coast drainage between the Glenarm and Belfast lough. This is a noble sheet of salt water about 7 miles across between White Head and Bangor, entering the land 12 miles in a graceful curve trending south-west, and gradually narrowing till at Belfast it is reduced to a river capable of being bridged. The shores are crowded with towns and villages, and gentlemen's houses. The only important stream that enters it is the Lagan.

38. The river Lagan.—This river rises in the hills beyond the south-eastern extremity of Lough Neagh not far from Dundrum bay. Its source is 880 feet above the sea on the slopes of Slieve Croob (1,755 feet), the highest of the northern spurs of the Mourne mountain. Two principal branches unite at Dromara, and flow thence 6 miles to Dromore in a direction a little north of west, receiving small feeders. Thence its course continues west for 5 miles, after which it bends round, leaving Lurgan 2 miles to the west, and takes a north-easterly course for 10 miles to Lisburn, after which turning more to the north it has a course of 8 miles to Belfast, where it enters the Lough. At its mouth it has a tidal channel which has been deepened and made available for navigation. Its whole course is 40 miles. It receives few important feeders, the chief entering from the south near Lisburn. This stream rises in a small lake about 8 miles distant from the Lagan, in a direction south of east, in a district where there are many small pools of water with some of which it connects. It receives one feeder from the north. The drainage area of the Lagan is stated to be 227 square miles.

39. Strangford lough.—There is no coast drainage entering the sea east of Belfast, and between that bay and Strangford lough. The latter large inland sheet of salt water only communicates with the sea by a short narrow passage. It is separated from the sea by a promontory about 4 miles wide, and 25 miles in length, measured from Bangor to its southern extremity. The rain falling on it runs off directly either east or west without forming streams, except here and there, and on a very small scale. The lough communicates with the sea by a channel 6 miles long, and a mile wide. The actual length of the inlet or lough is 14 miles, and its width 5 miles. It contains many islands, and is much choked by sand banks.

40. The river Quoile.—This river, sometimes called the *Annadoy river*, rises in the country a little south of Belfast, and flows south for a considerable distance, receiving a tributary from the west proceeding from *Lough Aghery*. Arrived at Downpatrick, it commences to widen, and turns to the north, entering Strangford lough at its south-western extremity. Although thus strangely situated, it is the principal feeder of that lake. There are, indeed, two other small streams coming in on the western shore, one near the middle of the line of coast, and the other near the northern extremity, but they are of little importance. The length of course of the Quoile is more than 15 miles.

41. Coast from Strangford to Dundalk bay.—Along this line of coast the drainage is by a number of streams, all of which have a very short course, coming directly from the mountains which here rise rapidly from the shore. As far as Dundrum bay there is no river. Into this bay several small streams enter, but the water-shed of the Bann approaches the shore so closely, that there is no space for the waters to collect on the eastern side. South of the bay the Mourne mountains approach the coast, and their drainage is chiefly to the west, though several small torrential streams appear at various points. We then reach Carlingford lough, a fine inlet quite open to the sea. It receives a small drainage by a number of streams, both on its shores and at the head, but the mountains close in very much, and there is no river of importance. Beyond Carlingford lough, Dundalk bay commences, and into this bay there is considerable drainage from the country to the west.

42. Drainage into Dundalk bay.—A number of small streams, and some of greater importance enter Dundalk bay, the chief being the Castletown, the Fane, the Glyde, and the Dee, the two latter having the same small estuary. First in order is the *Big river*, a small river draining part of the promontory formed by Carlingford lough and Dundalk bay. It has a branch called the *Little river*, flowing south. Another small stream from the same tract of land enters Dundalk harbour, draining the country from the north.

The river *Castletown*, formed by the union of several branches, rising in the Fews mountains in Armagh, flows southwards and eastwards, and before reaching Dundalk is joined by the *Kilcurry*, a river of considerable importance.

The river *Fane* originates above Lough Muckno, a large sheet of water about 300 feet above the sea. Several streams fall into this lake, each expanding into small pools at various points. The form of *Lough Muckno* is very irregular, and it forms three almost distinct lakes, connecting with a fourth 2 miles below the outflow. Forming thus the river Fane the stream continues south-east for about 15 miles into Dundalk bay, receiving few feeders, and none of any magnitude. The whole length of the Fane is upwards of 20 miles.

The river *Glyde* rises in the country to the west, and being joined by the *Lagan*, which has passed through *Lough Ballyhoe*, it makes its way south-east for about 10 miles to the coast. Where it comes into the sea it meets the waters of the *Dee*, a somewhat smaller stream also from the interior, and having an easterly course.

From Annagassen, where the waters of the Glyde and the Dee meet, there is no coast drainage for some distance. The next great river is the Boyne, which has a large drainage area.

43. The Upper Boyne.—This river consists of two principal branches uniting at Navan, the most important coming from the south-west. The other branch is the Blackwater, draining a large district in the north and north-west. There are also tributaries from the western side of the basin joining the Upper Boyne. The drainage area of the Boyne is about 1,000 square miles.

The Boyne originates in the union of a multitude of streams, draining off from the northern side of the great Bog of Allen. The spot named as the source is Edenderry, close to the sources of the Barrow. From hence it winds round by the west to the north-west, passing Grange Castle, where it receives the *Yellow river* from the west, bringing a good volume of water. After running for some distance to the north-east, it receives the *Deel river*, which rises in *Lough Lene* (312 feet above the sea), and is a sheet of water more than 3 miles long, and $1\frac{1}{2}$ mile wide. Emerging from this lake it receives the overflow of another lake, *Lough Bane*, 372 feet above the sea. It then flows to the south-east, expanding after 3 miles into *Lough Adeel*, and then continues 12 miles in a southerly direction to Killiecan, where it expands again and receives a considerable tributary from the west (the *Riverstown*). Its further course is about 8 miles to the east into the Boyne, opposite a smaller tributary, the *Blackwater*, from the south.

Four miles below the Deel the river *Stonyford* enters, after a course of about 20 miles from the north-west. It rises near Lough Bane, and has few feeders, passing no place of importance. The next tributary is the river *Tremblestown*, entering after a course of 16 miles, from the north-west, and passing Athboy.

Two miles below the Tremblestown, flowing east, the Boyne passes Trim, and 2 miles beyond is joined by the river *Boycetown* from the south-east, which receives the *Knightsbrook* close to its mouth, after a course of 8 miles. The Boyne now turns north-east for 6 miles, and afterwards north-west for another 4 miles to Navan, where it meets its principal tributary, the Blackwater, coming in from the north-west.

44. The river Blackwater.—This river first receives its name on emerging from *Lough Ramor*, a fine sheet of water in two reaches at a level of 277 feet above the sea. It is nearly 6 miles long, and is situated in a bold though not mountainous country. It is fed chiefly by two streams from the north, the largest (from the north-west), receiving the overflow of some small lakes at a high level, flowing 8 or 10 miles to enter Lough Ramor. The other is connected with *Lough Skeagh*, and two smaller lakes near the sources of the Annalee, a tributary of the Erne.

Leaving Lough Ramor the Blackwater flows south-east, receiving after 2 miles a small stream from the west. It then continues 8 miles in that direction, passing near Kelly, 4 miles below which town it receives the Moynalty.

The river *Moynalty*, the chief feeder of the Blackwater, rises in the north near Loughanleagh, a hill more than 1,100 feet above the sea. Its course is south and south-east, and it flows nearly 20 miles, receiving a few feeders before reaching the Blackwater. From the confluence of the two streams the Blackwater has a further course to the south-east to Navan, where it enters the Boyne.

45. The Lower Boyne.—The course of the Boyne, after receiving the Blackwater, is at first north-east for 8 miles to Slane, receiving no feeders of importance. It then makes an irregular semi-circle to the south for another 8 miles, where it is met by the river *Matlock*, draining a picturesque country to the north and receiving the *Deylins*, an almost equally large stream from the west, about 3 miles before it joins the Blackwater. After this the Boyne reaches Drogheda in 3 miles, and there commences to widen out as a tidal estuary. Its further course below Drogheda is 4 miles nearly due east. Near the sea it receives small feeders on both sides.

46. Coast drainage from the Boyne to Dublin bay.—The Boyne enters the sea about the middle of Drogheda bay, and 4 miles south of its mouth the river *Nanny* enters. It rises near Navan, and runs a course of about 15 miles east parallel to the Boyne, and passing Duleek near which town it receives the *Hurley*, a principal affluent from the south. Three miles below the Nanny, the *Delvin*, a smaller stream, enters the bay.

South of Drogheda bay the coast trends to the south, and 10 miles below the Skerries, the *Broad Meadow water* enters the sea. There is a smaller stream parallel to it, about 3 miles to the north. The Broad Meadow is the combination of several streams originating about 16 miles from the coast, and draining the intervening country by many small streams passing places of historic interest. The *Ward river* is the chief tributary.

South of the Broad Meadow, the *Main* enters, draining the country between the Broad Meadow and the Liffey. The Tolka, which enters Dublin bay, has been described as belonging to the drainage area of the Liffey.

CHAPTER XVIII.

RIVER BEDS, RIVER BANKS, AND RESULTS OF RIVER ACTION.

(1) River channels not always in accordance with existing physical features of a country.—(2) Rivers of the great continents occasionally agree with physical features.—(3) European rivers rarely show such accordance.—(3) Condition of the British islands.—(5) Antiquity of river beds in England.—(6) Mechanical action of running water as affecting river beds.—(7) Rivers raise their beds by deposits when embanked.—(8) Natural provision against this result.—(9) Natural flood regulators.—(10) Lakes not always flood regulators.—(11) Occasional expansions of river beds.—(12) Origin of ravines and mountain valleys.—(13) Origin and formation of valleys in soft rock.—(14) Nature of *cañons* or fissure valleys in limestone.—(15) Division of a river bed into upper, middle, and lower parts.—(16) Rate of flow of rivers in their middle course.—(17) Examples of fall of some British rivers.—(18) Relation between actual water channel and river bed.—(19) Example of this in the Thames.—(20) Ancient river beds.—(21) British islands too much cultivated to illustrate natural conditions in the plains. —(22) Formation of winding channels in straight valleys.—(23) Formation of diluvium and alluvium in river beds.—(24) River beds cut in diluvium or boulder clay.—(25) Nature of boulder clay.—(26) Example of boulder clay in an English valley.—(27) Effect of fissured rocks now covered by alluvium or boulder clay.—(28) Natural artesian springs under superficial covering.—(29) Water flowing under a superficial covering of alluvium or gravel.—(30) Certain conditions of rock necessary for these results.—(31) Effect of obstructions on the course of rivers.—(32) Nature of river banks.—(33) Banks of rivers in valleys of erosion and fracture.—(34) Landslips.—(35) Reservoir accidents from unsound river banks.—(36) Fissured rocks as river banks.—(37) Loss of water by lateral percolation.—(38) Formation of shoals at river mouths.—(39) Filling up of estuaries. —(40) Distributing action of the tidal wave.—(41) Effect of river action where the river meets the tide.—(42) Formation of shingle bank on the east coast.—(43) Formation of lagoons.—(44) The Chesil bank.—(45) Recovery of land in deltas or on coast lines.

1. River channels not always in accordance with existing physical features of a country.—The actual channel by which a river finds its way to the sea, or proceeds from one point of its course to another, is so far from being the nearest or most direct line, or the line that the present contour of the district will indicate, that any approach to such agreement with existing physical features may almost be regarded as exceptional. Many facts illustrating this statement have come before us, and have been noticed in the account of rivers in previous chapters; cases in which rivers cut across lines of escarpment at right angles, avoid persistently lines of valley apparently the most convenient, wind in perpetual curves through level tracts, reach the sea or their confluents after flowing parallel to them for a long distance, and exercise their motive force rather in making obstacles to check their progress, than in removing material that is readily carried away by water action.

The cause of the selection of its bed is, however, a matter of grave importance when engineering operations concerning a river are required, whether to divert the course of the stream, to prevent injurious action on its banks, to straighten its channel, to canalize it effectually, or to convert a swamp into valuable agricultural land by surface-drainage. These are all works, to carry on which economically the river's history must be studied.

The history of a river is learnt sometimes by reference to geological structure, and the facilities offered to water action by the softness and ready disintegration of some rocks, while others, though much less prominent, are tough and resistant; but more frequently it must be studied in the changes that have taken place in the earth's crust by movements of elevation and depression, and occasionally the intrusion of igneous rock since the river first began to carry off the drainage of a district, which at that period may have had a totally different surface, and a different extension. The line of water-shed of the catchment may since have shifted, the various affluents become changed in direction and volume, and the whole of the river basin altered in almost every respect.

2. Great continental rivers occasionally agree with physical features.—It is not in every country that these extreme changes can be traced, and in many parts of large continents the whole history of a river, from its commencement as a thread of water running down a slope after rain, to its development as a gigantic stream entering the sea after flowing a thousand miles, may be so far unbroken that its physical geography offers no difficulties. Where there are large plains or plateaux, where the rivers run across strata almost or quite undisturbed, one formation appearing from beneath another as we travel up stream, in perfect order and at very long intervals, we may often trace the history of the river with little difficulty. It rises in mountains, whose elevation, continuous and slow, has been contemporaneous with the growth of the river. Its early contortions, and the direction of its early affluents, are well marked and explained by a short consideration of the structure of the mountain chain. Descending with such a stream over vast plains, the river bed for a time indeed is irregular, but by degrees becomes in accordance with physical features, the various affluents make acute angles with the river, which they feed quietly and unobtrusively, and however long the course may be, it is uniform and simple.

Such are some of the rivers of the great continent as they flow towards the Polar sea, or to the Pacific, along the gentle slope of the vast plateau of Northern Asia. On the southern side where there has been more disturbance, where there are outbursts of volcanic rock, and where the features of the earth are irregular, the case is different, and the rivers are less simple in the theory of their respective courses.

On the American continent, where the elevation of the great chain has been uniform and gradual, though not slow, the rivers that convey to the sea the heavy rainfall on the Andes, are in like manner simple, and their course agrees with the present surface. In the northern division of the continent, however, where a second mountain chain—that of the Appalachians—interferes with the regularity of structure, the difference may be easily observed.

3. European rivers rarely show accordance.—When, however, we pass to the western extremity of the Great continent, in which geological changes of a large kind, though not of the first importance, have, almost from the commencement of geological history, incessantly modified the surface, it is easy to perceive by the most superficial study of river courses that little approach to regularity exists. In these parts of the earth there has been so much and such frequent movement, now of elevation, now of depression, vast tracts of land have been so often submerged, and so repeatedly exposed to water action, not only of waves and currents, but of fresh water running over their recently exposed surfaces, that all idea of adaptation of the river courses to the existing physical features is lost. The law is so confused, so complex, and so often broken, that it becomes unintelligible. We must often accept the fact, and leave to a more advanced knowledge of surface and concealed structure to explain it, if explanation be possible. A comparison of the north course of the Rhine with the south course of the Rhone on leaving the Alps, or with the easterly course of the Danube from the Black Forest, will sufficiently illustrate these remarks.

4. Condition of the British islands.—It is, however, most of all in the British islands, that this discordance of rivers with the physical geography of the country is exhibited. This part of Europe has undergone alternations of level, more frequent, perhaps, if not more considerable than any other part, and its geology is beyond comparison the most interesting and instructive of any, because of the extraordinary variety of strata brought under inspection in a breadth of little more than 200 miles. From the deposit of the oldest rocks in the most ancient seas, through the long succession of ages during which strata have been accumulating, the inter-space between the elevation axes of the old world and the new has ever been a scene of movement, leading to the disturbance and disruption of strata. The sea bottom has often risen to become dry land and as often been depressed to receive fresh accumulations of mud, and a warm climate has alternated with ice and glacial deposits ; but the results of the elevation and depression never seem to have obliterated the ancient landmarks. At some early period of the earth's history a water channel has been excavated, in accordance with the then position and nature of the strata. The land of that day has gone down beneath the sea ; but the excavation has remained, and though covered with new deposits, has retained its form. Coming again to the surface, the water in making its way over the newly raised land, has followed the old river course rather than cut for itself a nearer way to the sea, and this has been repeated over and over again. Many instances of this kind have been pointed out in the preceding pages. Among the most remarkable, perhaps, are those in the south-east of England, where the streams make their way through and amongst the chalk hills, to north and south, rather than pursue an easier and apparently more natural course eastwards through the Weald. The Upper Thames, instead of flowing northwards across the low soft oolitic strata into the valley of the Great Ouse and reaching the sea in the Wash, cuts through the chalk hills at right angles to their direction, and then turns east to the sea. The coast drainage of eastern Yorkshire starts from the coast, and travels a long distance before it again approaches an outlet. The same peculiarity is observable in the rivers of Scotland and Ireland, especially of the latter country.

5. Antiquity of English river beds.—To trace, therefore, the history of river beds, and understand why they exist as we now find them, requires a familiarity not only with the descriptive geology of to-day, but with the physical geography of the past. There is little doubt that although some of the British rivers are much more ancient than others, most of them belong to a period older than that of the gigantic streams of Asia and America. Our larger streams pursue courses so independent, not only of recent, but of secondary, and sometimes of palæozoic rocks, as to render it certain that the land, however often submerged, and however thickly coated with material drifted from a distance, or formed on the spot, has not lost its old furrows. These still govern the superficial aspect and drainage of the country, and indicate the skeleton frame on which the muscles and integument that render it so fair and so useful, were long afterwards placed.

6. Mechanical action of running water as affecting river beds.—While, however, a river still pursuing its course among the mountains, and disregarding natural impediments on its passage from the mountains to the sea, is thus seen to depend on other configuration of the country than that which now obtains, a very large and important part of its channel is always the result of more recent action on material which the river itself, perhaps, has helped to deposit. The first action of a river when leaving the mountains, or while rushing along over precipices, or through ravines, cannot fail to be the removal of obstacles in its way. Water in rapid motion undermines and undercuts whatever is exposed to it. These results are inevitable, however hard the rock, or however immoveable the obstacle. Attacking always the weakest part, it disintegrates and removes support from rocks, which in any other way would be free from attack, or on which the action would be so slow as to need centuries to make a perceptible impression. Weathering, frequent changes of temperature near the freezing point, decomposition by atmospheric action, and similar causes, help the action of water on rocks, and enable the water in some cases to reach a weak point, otherwise beyond its reach. The moment a rock begins to be undermined, water action goes on rapidly, and the fallen material, when the undercutting has been carried far enough to remove support, soon becomes broken up by the action of the fragments moved in water one against another. A wild waste of angular rocks and pebbles is a common scene in all the river beds of a country like Spain, where there is little to remove the results from observation, and where the formation of the country lends itself to undermining action. On a smaller scale to the eye, but, perhaps, not really smaller in its effect on masses is the water action of English rivers. The ordinary river action is assisted by occasional floods, and thus the rock is reduced to fragments, the fragments to pebbles, the pebbles to sand, and the sand accumulates in the bed of the river, or is distributed over the surface of the land by floods, or is carried out to sea to form a bar at the mouth of the river, or a shoal at a distance, or a delta increasing the available land, and soon all trace of its history is gone, and the effect can only be attributed to the real cause by the aid of knowledge and experience.

7. Rivers raise their beds by deposits when embanked.—Wherever, therefore, as in a country like our own, there is a great variety of rock, arranged in strata rapidly succeeding each other at the surface, and making room for other strata of different texture, often broken, and occasionally varied by faults, anticlinal or synclinal axes, alterations of condition, or other causes of which many are known, there the rivers will be found to have accumulated for themselves much of the material over which they flow, and to tend to a constant alteration and shifting of the position of the water-way in the alluvial bed.

But here comes in another force antagonistic to this perpetual change. In a civilized country where cultivation is carried to a great extent, and land has acquired enormous value, it is the interest of the riparian owner to preserve as far as possible all his landmarks, and prevent the river from shifting its course. This has been done in all our principal rivers, and occasionally on a gigantic scale. Embankments to keep out the tidal waters, embankments to keep out flood waters, embankments to recover fen lands, enclosures of all kinds—all this constant battle fought by man against nature—is productive of very important results. The river may no longer wind about at its will in its self-formed and acknowledged alluvial bed. It is no longer free to produce deviations dependent on the materials it brings down; but it must either remove those materials, or if it cannot do so, artificial banks are made to prevent it from covering the adjacent lands, and these must continue to rise as additional material is accumulated. Thus are produced the remarkable phenomena seen in the basin of the Po, a river bringing down from the Alps large quantities of detritus, and unable to carry its load to the sea. The river now runs, and has done for a long period, in a gradually rising bed, kept in its place by constructed banks, also constantly raised to meet the addition. Now and then if these artificial banks are neglected, the river breaks out and floods the country. Such an accident happened not long since in the plains of Northern Italy, and such results must happen from time to time where man fights against nature. Times of national excitement and political disturbance distract the minds of a people from these public works, but as nature never sleeps, and knows of no interruption in the operation of her laws, the neglect of precautions, however caused, is sure to be punished.

8. Natural provision against this result.—In nature this tendency of a river when flowing through a plain, and prevented from taking its own course, to elevate its bed and become dangerous, is avoided by the wide spread of the river when in flood, the deposit of the transported matter over the wide surface thus occupied as the water becomes stagnant, and the consequent formation of banks of greater elevation than before, so that on the next, and each subsequent occasion, the river has to rise higher and higher to overflow these new banks. The result of this will be, that deposits which originally took place where the river approached its outfall are now to be found at some distance from the sea. In this way are constructed alluvial plains, limited only by the width of the valley when it is shut in by rocks, which are removed only by the slow process of erosion. Many of our northern rivers, and, indeed, almost all rivers, have portions of their bed expanding, and subject to flood, and these flats generally accumulate detritus. Where the current is rapid, or when there are heavy freshets, the newly added material is readily cut through, but is not swept away when the waters return to their ordinary level, or when the next floods come down. The process is always going on, and in its natural state the bed of a river is constantly undergoing change of two kinds—the action of erosion, widening its banks and deepening its bed where the current is sharp and produces a scour, and the deposit of new material effected whenever floods come down. The extraordinary force of a flood brings with it material left behind when the stream was flowing with its ordinary strength. The accumulation keeps back the flood for a time, backing up the waters till they become powerful enough to break through. Then comes the rush and the flood, the water again losing its motive power as it spreads over the plains, and leaving behind once more a part of the accumulations as it carries the remainder to the sea.

9. Natural flood regulators.—Bearing in mind these facts, which in some sense are universal, as being results of the action of mechanical laws, the natural division of a river into an upper and lower basin, or occasionally into an upper, middle, and lower basin, will be recognised as founded on an instructive fact in nature. There are, however, occasionally in all parts of a river resting places, on which the waters expand and deposit, before being again obliged to pass between narrow channels and recommence the employment of their eroding force. Such resting-places, if enclosed among mountains, or in hollows and irregularities of surface on plateaux, result in lakes, morasses, bogs, or pools. The ordinary flow of water accumulates, and the surplus and flood waters run off by the most convenient channel. The closing in of a secondary range of mountains, separating loftier chains from the plains, in some cases narrows the outlet of a valley, or some natural obstacle left or placed in this part backs up the water and produces a lake, while much smaller obstacles, generally produced by causes evident to the geologist, produce the other phenomena which are on a smaller scale. Occasionally also the counterforts or lower hills approach a river valley, but leave between them intervals through which flood waters pass and become expanded in the country behind. In the lower part of the Mississippi there are remarkable instances of this kind, the river flowing between high banks, which open occasionally either naturally or artificially into vast tracts of country at a lower level than that of the stream when in flood. The flood waters enter these natural reservoirs, whence they can only escape slowly, and thus they form flood-regulators. These have already been noticed in a previous chapter (p. 115). In our own islands there are lakes which perform a similar useful work. The river Shannon, as has been pointed out in the description of that stream, has numerous expansions into which the excess water flows, and where it is retained for a time, so that the general flow is regulated, and a useful stream retained at all seasons.

10. Lakes not always flood-regulators.—There is a distinction between these expansions and mountain lakes. The latter are reservoirs into which a certain quantity of water must enter before they are full, and from which only the surplus water runs off. Unless they have level banks capable of receiving a very large quantity of additional water without their outflow increasing at the same extent as the inflow, they act as flood-regulators because when during dry summer weather they become lowered, and when floods recur, the whole of the flood water is retained until the ordinary level is reached, and the regular channel begins to act. At other times, lakes are accumulations of dead water, and although occasionally they contain water which is singularly pure and soft, they cannot safely and without investigation be drawn upon for the supply of towns. They are also subject to evaporation, which even in our climate is at least equal to the total rainfall on the surface exposed, but in dry warm countries is very much greater. Their contents are liable to become concentrated after long drought, and if as is often the case, they receive water that has flowed over mineral matter in any way objectionable, or if their feeders receive large quantities of organic matter, the quality of the water is inevitably affected. Except when of very large dimensions, their waters are rarely disturbed to any depth by wind waves, and the aeration and oxidation so essential to render water wholesome and palatable, are not thoroughly effected. Their water is flat, and not pleasant to the palate.

While, therefore, lakes receiving their water supply from rain in mountain districts, should theoretically be excellent as receiving only pure water, they are practically subject to objections which detract much from their value. To bring very soft lake-water through a long length of pipes for the supply of a distant town, is an experiment whose success has yet to be proved. A successful instance at present is that of Loch Katrine which supplies Glasgow; but here the conditions are very favourable, for the lake is exceedingly large, and its surface well aerated, the feeding ground is entirely in rocks almost insoluble in water, and containing no deleterious matter, the temperature is always low and equable, and there is little growth of vegetable matter to affect the quality of the water.

11. Occasional expansions of river beds.—But it is not only large lakes in mountain countries, or openings into low-lying tracts in a river course through elevated banks, that modify the action of floods, and affect the condition of the bed of a stream. It is common at the confluence of important feeders of a river to find a marked change in the direction of the principal stream, and a wide open space low-lying and level receiving the two or more streams. Such a condition is seen in the Upper Severn where that river receives the Vyrnwy and other tributaries as it emerges from the mountains. A similar condition is observable in the Trent, where it receives the Tame; and again on a far larger scale, where the waters of the Trent meet those of the Yorkshire Ouse, and form the estuary of the Humber. Those familiar with river phenomena, will call to mind many other instances in the rivers of England. In these cases the river always accumulates in these expanses during flood, and deposits a part of the detritus brought down. From these there is a more regulated flood to the lower parts of the stream. In the Thames basin there are such alluvial flats, and they are well known to be frequently subject to flooding. Although not confined to them, it is only in our larger rivers that these phenomena are noticed, as in others the volume of water is rarely sufficient to be mischievous; but the effects of flood in rivers without them are far more serious than in those in which these flat valleys occur. The Scottish rivers, of whose floods some account is given in Chapter 12, have no such expansions, and the whole volume of the swollen stream, therefore, rushes down at once towards the sea. Sometimes, however, these flats occur as it were in steps, and the mischief is increased. In some cases in the northern rivers the small becks do more mischief when in flood than the whole stream of which they are minute and unconsidered feeders. It may certainly be assumed that where there is so much force exerted, some result may be expected; and no doubt in all such cases the river bed is being altered, widened, filled up, or in other wise modified, in a sense that will in the long run be made manifest, and affect the general surface of the country.

12. Origin of ravines and mountain valleys.—A large proportion of the rivers in most countries originate in mountainous districts, and in the early part of their course are closely shut in by lofty walls, whether of limestone or sandstone, granite or metamorphic rock. It will often suggest itself to the observant traveller to consider how such openings could be excavated, especially when marks of water action are traceable on the irregular surface exposed. A stream tumbles and rushes along over a rocky bottom, lying deep in a narrow ravine. The ravine may have originated as a fault, or joint, or fissure produced by contraction or elevation of the mass of the rock. Under favourable conditions, that is when the eroding power of water can act by undercutting, the continued action of running water will soon form a wide and deep groove, and the width or depth of the valley will have little or no relation to the quantity of water in the stream.

13. Origin and formation of valleys in soft rocks.—When water passes over rock easily eroded, the channel cut is wider, the walls of rock more divergent, and the undermining action of the water less considerable than when the rock is stratified, and alternately hard and soft. Thus a wider channel may be cut in a given time by a stream of a certain force in alternating bands of hard and soft material, than in a soft rock, such as chalk or loose sand.

It results from this, which is a simple mechanical consequence of the mode of action of running water, that before a mountain stream emerges from the hill country into a plain, whatever the rock may be, it has been incessantly employed either in widening or deepening its channel; but the effect thus produced, though at first very considerable, gradually becomes less and less evident as the slope becomes more gentle, the river-bed widens, and more and more sand, gravel, rock, and mud, accumulate on the bottom beds over and amongst which the water flows, but which it has not power to remove so rapidly as it collects them.

The tendency of a running stream must always be to cut its way through clay or soft rock, and be checked by hard rock; but the result is not always in conformity with this tendency. If, as is often the case, the fragments of rock, pebble, sand, silt, and mud, brought down by the stream, accumulate more rapidly than they can be removed by the ordinary flow, or by occasional and periodic floods, the bed of the stream will gradually rise instead of being lowered, and the actual water-way will be shifted to another part of the wide bed or channel excavated wherever the rock admits. Where the rocks are too hard to be excavated and undermined by the stream, the water will rise until the increased volume and force of the water is sufficient to clear for itself a way through all obstacles, and carry them to a distance.

It is important to notice, in reference to floods and water action on river beds and plains, that floods are in almost all countries of two kinds, ordinary and exceptional. Even in climates where rain falls nearly equally at all seasons and very frequently, there are occasions of long drought, and corresponding times of heavy and long-continued rain. The ordinary flood is comparatively small, and its consequences are calculable, but it is not so with the exceptional flood. It may not recur more than once in a century, and when it does the result is incalculable and terrible.

14. Nature of canons or fissure valleys in limestone.—In every case where a stream is not strictly limited in its width by being shut in by natural walls too hard and too little stratified to allow of the undermining action of running water, the river bed is wider than the actual water-way. The only cases in which this does not occur are the great vertical fissures in limestone plateaux described and explained in recent years in the southern parts of western North America. The celebrated *cañons* of the Colorado are typical examples of this condition, the river, which here carries a large body of water, rushing along between vertical walls more than a thousand feet high. Vertical fissures in limestone plateaux are, however, by no means confined to North America. They are familiar in Spain, and common on a small scale in most countries.

15. Division of a river bed into upper, middle, and lower parts.—Excluding *cañons*, as a class of valleys not familiar in our own country, we find other valleys tending constantly to widen and deepen by the gradual removal of their sides and bottom so long as a stream flows in sufficient volume and with sufficient rapidity to exercise on a large scale the mechanical force of moving water. As almost all streams originate in comparatively high ground, and in their upper courses are more rapid and have a larger fall than afterwards, there comes to be a point in the course of the stream, if it is of any considerable magnitude and drains part of a large country, when it emerges from the high lands and enters an expanse of low plains before reaching the sea. A river bed thus consists of two or three portions—the upper portion, when it exercises mechanical force and tends to remove by excavation a part of its enclosing walls and its bed ; a middle part, where it reaches the plains and runs a comparatively level and uninterrupted course before being met by the tide, and where, for want of fall, its rate of speed diminishes ; and a third, or lower course, in which the river becomes converted, more or less, into an estuary, often tidal, where the daily interference with the downward flow of fresh water produces other changes and further deposits, and where in some cases the stream is broken up into numerous channels, flowing through swamps or stagnating in a delta.

16. Rate of flow of rivers in their middle course.—The rapidity of a stream in the valley does not depend so much upon the rate per mile of fall measured from the source to the outfall as upon the evenness of the rate throughout the course. Many rivers with a very great fall have exhausted the motive force obtained in this way by the time they emerge from the mountains, and the rest of their course, perhaps the largest part, is over nearly level ground. The lower part of the stream in this case, especially if there is no lake or convenient place for the reception and detention of the flood waters, is then reduced to a sluggish movement, very liable to be swollen by torrents.

17. Examples in some British rivers.—To illustrate the great difference that exists in regard to the average and partial fall of the waters of rivers in the British islands, we may take the Thames as an instance of small average fall throughout, and the Trent as an example of small average fall after a short rapid flow. The Thames falls 367 feet in a total flow of 225 miles. The Trent falls 700 feet in a total flow of 172 miles. Both receive about the same number of main tributaries, but those of the Thames are more equal than those of the Trent. The mean fall of the Thames is 21 inches to the mile, but the first 22 miles fall 6 feet per mile, so that the average of the remaining 193 miles is reduced to 15 inches. The mean fall of the Trent is 4 feet per mile, but in the first 10 miles it falls 330 feet, or 33 feet per mile, and afterwards 370 feet in 160 miles, or about 28 inches to the mile. After receiving the Tame the fall of the Trent to its outfall averages 250 feet in 128 miles, or 23 inches in a mile. The middle courses of the two streams are, therefore, very different, the Trent falling at a rate half as much again as the Thames.

As a contrast to these rivers of small fall, we may take the Dee (Scotland), which falls 4,060 feet in $87\frac{1}{2}$ miles, or $46\frac{1}{2}$ feet per mile, commencing at the rate of 482 feet per mile, and even in the last 3 miles falling at the rate of nearly 7 feet per mile. Less marked, but still very remarkable, are the cases of the Clyde, which in less than 100 miles falls 1,400 feet, and the Tweed, flowing rather a shorter distance, and falling 1,500 feet. The Clyde, however, about half way from its source to the sea, falls nearly 80 feet in cascades, and the Tweed runs a comparatively even course. These Scottish rivers are extremely rapid streams, and in a certain sense torrential, though, from the shortness and rapidity of their course, they very rapidly run off their flood waters.

Of the Irish rivers, the Shannon falls only 345 feet in a course of 225 miles, having a mean fall of 18 inches, and of this fall nearly half takes place in the first 11 miles, and more than 50 feet in rapids 70 miles from the sea. In 144 miles, therefore, during which the river passes through large lakes, the fall is only 111 feet, or little more than 9 inches in a mile. The Avoca, again, a small stream of only 34 miles run, in county Wicklow, falls 1,770 feet, being throughout a mountain torrent, whose lowest average rate is 11 feet in a mile. It passes through two lakes in the early part of its course. The Barrow, another of the Irish rivers, has a fall of 1,500 feet in 114 miles; but 1,150 feet of this great fall takes place in the first 10 miles, while for the last 25 miles there is scarcely a perceptible fall.

A comparison of these figures will show how extremely various are the conditions under which rivers flow within the small range of the British islands; and render easy the explanation of the great difference to be found in their beds. The diagram in page 129 will illustrate the fact to the eye.

18. Relation between actual water channels and river beds.—It is not often the case that the actual water channel of a large river at the present time fills up the bed of the stream. On the contrary, the ancient river bed frequently extends for a long distance on either side of the channel, and, if not embanked, the stream would constantly shift its course within these limits. Although, therefore, it may be that the river has been prevented for years or centuries from diverting its course, and has now the same bed and the same banks that it had when first embanked or canalized, it does not follow that the bed thus indicated has not changed in direction, even within the historic period. This must be borne in mind when rivers are made use of as boundaries of counties, of parishes, or of estates.

19. Example of this in the Thames.—A case of some importance has recently been decided in the courts of law bearing on this subject, and may be stated in a few words. The river Thames, near Walton-on-Thames, has an excavated bed about 400 yards wide, the banks on each side consisting of old gravel, rising steeply and sharply from this excavated bed, which is filled with alluvium to some depth. The actual water-way is less than 100 yards wide, and the river, embanked during the last century, has not since been shifted, even during the heaviest floods, and is not likely to be, so long as the banks are kept up. A bridge over the present river bed, which is on the north side of the excavated bed, is continued by a viaduct across the rest of the bed, which is liable to be flooded, and is common pasturage. The county boundary between Middlesex and Surrey is for the most part conterminous with the parish boundary between Shepperton and Walton, but differs in this and other places by including within Shepperton parts of the excavated bed now on the Surrey side of the river channel. Assuming that the two boundaries were originally meant to agree, which is at least highly probable, the river must be supposed at one time to have run on the Surrey side, and not on the Middlesex side, as at present, and both bridge and viaduct were then in the parish of Shepperton, in the county of Middlesex. The contention arose from the necessity of repairing or rebuilding the bridge and viaduct, which, though originally private constructions, had been converted into county property by a recent general Act of Parliament. Neither county could lay a rate for the purpose of construction so long as it was doubtful on which lay the legal obligation. On a trial at the assizes of Maidstone in July 1877, before a special jury, it was decided that the county boundary should be drawn, for the purpose of the inquiry, along the middle line of the excavated bed, as marked by the alluvial deposits between the gravel banks, thus recognizing the important physical fact that the bed of a river is the whole excavated bed, and not the actual channel or water-way at any particular date. It appears to me that the verdict was substantially just.

20. Ancient river beds.—Every river rising in a mountainous or hilly country, and flowing over a considerable tract of comparatively level ground before reaching the sea, may be expected to have for a large part of its lower course a wide excavated valley, of which it actually occupies but a narrow channel. The wide valley has in such case never been the permanent river channel, and it must by no means be assumed that the magnitude of the wide valley, which is sometimes called the ancient river bed, indicates the actual magnitude at any time of the present or ancient stream. Even in the mountains, where running water has cut for itself a way through hard rock, it is very rarely indeed the case that the water-way cut is not much wider than the stream cutting it. In level valleys the width of the river bed may be miles, and the breadth of the river only scores of yards. It is important to remember that this difference between the water-way and the river bed is not in any sense a rare accident, but the result of a law of river action, and that any other condition would have to be explained by some special and interfering cause.

In all the great continental rivers, both of the old and new world, this is very familiar, nothing, in fact, being more certain than that after a great flood there will be a considerable change in the course the river takes in its alluvial bed; the divergence amounting in some cases to miles, when the expanse of accumulated mud and detritus at the mouth of the river covers a large area of land regained for the most part from the sea. Very important illustrations of this fact have been obtained from the delta of the Nile, in which objects of interest constructed or shaped by human hands have been obtained, at great depth from the surface, in that large triangular expanse of flat land stretching out far into the Mediterranean, but derived entirely from the material brought down from the interior of Africa by the river Nile.

21. British islands too much cultivated to illustrate natural conditions in the plains.—It is not in England at the present time that the phenomena resulting in such conditions can be studied with advantage, and in the lower parts of our larger rivers they cannot be studied at all. The whole of the country where it is in any way possible is under cultivation, and the most cultivable and useful tracts are the alluvial lands near the rivers, where water is available, where agricultural operations can be carried on with convenience and profit, and whence the produce can readily be transported by road, railway, canal, or river. Thus all our rivers are more or less completely embanked and canalized, and are defended from ordinary and periodical floods by means which effectually prevent the river from creating for itself a new channel. Even in the most unusual and extraordinary floods, when the stream, in spite of all that has been done, bursts through the banks constructed to keep it within limit, and for a time rushes along in a new channel with an impetuous torrent, which renders resistance and guidance equally impossible, means are always taken when the flood is over to bring the stream back into its former line of course, the defences and banks being soon restored, and, if possible, made stronger than ever.

22. Formation of winding channels in straight valleys conveying mountain streams.—In the upper branches of rivers, however, among hills or mountains, where the valleys are narrower, the streams more torrential, and floods more frequent, the case is different, and instances are not uncommon where a river is allowed to take its own way. Thus in the upper feeders of the Yorkshire Ouse, and other rivers rising on the slopes of the Penine chain, we find indications of very recent change in the position of the stream. In such cases, the river bed being many times the width of the ordinary stream in its summer flow, the course is tortuous, and the most rapid and torrential rivers may become the most winding, doubling on their course most frequently. The cause of this is not difficult to make out. A stream rushing rapidly down a narrow valley is turned aside by an obstacle left during the last flood, too great for the ordinary flow to remove. The stream once deflected continues in its new course until it again meets with a similar impassable accumulation of transported material, or with a solid wall of rock enclosing the valley. The stream is thus constantly thrown off at an angle, and in each case tends to cut for itself a way through the lesser obstacles. The result is the formation of a winding channel, even through a straight valley.

23. Formation of diluvial gravel and alluvium in river beds.—It is impossible that a stream can rush along in a channel filled with fragments of detached rock, the result, not only of the violent action of floods, but of the ordinary wearing and undermining action of moving water, without breaking up the larger fragments into smaller stones, wearing off the edges and angles from these stones, and reducing the whole ultimately to pebbles and sand. As long as the river is in the mountains this process goes on rapidly and incessantly. When it emerges, and its rate becomes slower, it can no longer move large rocks or transport the smaller ones with so much force and rapidity, but sand and mud are still carried along, and, whenever the course is checked, they are deposited. A rapid mountain stream conveys across the plains an enormous quantity of such material, which gradually accumulates, spreading widely, and filling up the trough or valley of the river with a great thickness of transported rock and silt. Where this is the result of ancient flood, of the bursting of some natural reservoir, or the rush of some powerful wave, the material consists of large stones, sometimes angular, mixed with coarse silt, and is called *diluvium.* Where it is caused by the daily accumulations of mud and sand, moved by a river in its ordinary flow, it is black in colour, and generally mixed with organic matter, and is called *alluvium.* In all river beds whose width exceeds the width of the water-way, it is common to find accumulations of alluvium through which the actual present river has eaten its way. In most cases it will be found that the limits of alluvial deposit are also the natural boundaries of the excavated bed of the river.

24. River beds cut in diluvium or boulder clay.—Not unfrequently a valley is of more ancient date than its alluvial bed, and the material through which the latter is excavated consists of old gravel, probably diluvial, and gravels derived from glacial drift, quite independent of the modern alluvium. Over a large area in Yorkshire and Lancashire, and often in other parts of England, the valleys, and even the lower hill-tops, are covered with a coating of boulder clay completely masking the rock, and of great thickness. In such cases the present river valley, though deep, is entirely cut in the superficial and irregular deposit, but the depression in which this transported material has been deposited is itself an older river valley, through which far more ancient waters have once cut their way.

25. Nature of boulder clay.—In constructing works in valleys or on hill-sides on which this boulder clay is present, great caution is necessary. The deposit is of all others the most irregular and uncertain. It consists fundamentally of a quantity of very stiff tough clay, of dark brown or black colour, containing, distributed quite irregularly, a multitude of fragments of transported rock, generally angular. The dimensions of the stones varies from many cubic yards to fragments not larger than a nut or a pea. Occasionally there is a large deposit almost entirely of clay, but not unfrequently the stones are very abundant. They are here and there in stratified beds, but more frequently if in large quantity they occupy lenticular hollows in the clay. If these conditions of the boulder clay were the only ones to be expected, there would be hardly any better material to deal with in the construction of banks for reservoirs, but unfortunately there is another that we have not yet spoken of. In any part of the deposit, wherever it occurs, we may look for a sudden change to a running sand and silt, combined with loam, which, though firm when reached in the ground, and difficult to remove with the spade, runs at once to a thin liquid mud on exposure to air and water. Such a deposit, if reached by the eroding action of water from the surface, is of course easily carried away, but it may exist a few inches below the surface without being discovered till actually laid open with the pick or spade.

The beds of sharp running sand, silt, and loam thus met with are sometimes very local, extending only for a few hundred yards. They are, however, sometimes tolerably persistent over a considerable distance, and permit of the passage of water from the stream beneath or amongst them. The water in this case may be present under pressure, and when, by boring or sinking, or by cutting a trench, the bed is reached, the whole mass becomes disturbed, and it would be hopeless to attempt to construct any work on or near it that should be water-tight without cutting through and probably cutting out the whole deposit. It has happened frequently in my own experience to meet with such deposits in boulder clay in the valleys of Yorkshire and Lancashire, and the material can never be trusted. The trouble and cost of sinking through so treacherous a substance cannot be over-estimated, and sometimes requires all the skill and care of the most experienced engineer and the most trusty assistants to overcome.

26. Example of boulder clay in an English valley.—As an instance of the existence of such rock, sands, and loams in boulder clay, I may mention the Lune valley, a tributary of the Tees, which it has been proposed to utilise by constructing a bank and storing its waters for the use of the towns of Stockton and Middlesborough. At the spot proposed for the bank there were surface indications of moved ground, and, during the Parliamentary inquiry before the passing of the bill, experiments were instituted to prove the nature of the ground. The valley was covered with boulder clay at the spot where it was proposed to place the bank, and for several hundred yards above and below. Beyond these distances, however, the bed of the river was in the rock. On examination it was found that borings and sinkings on the proposed central line of the bank, and in the clay above and below, reached water at a depth of 15 or 20 feet, which rose considerably above the level of the water in the stream. It was, therefore, evident that in the boulder clay there were bands of permeable material which had free communication with a head of water considerably above the level of the river. Such a deposit, whatever its nature, must have extended almost throughout the boulder clay near its contact with the rock, and its presence under the clay could not fail to be a costly impediment in the construction of the bank. Whether a bank can be safely constructed on the spot without removing the whole of this permeable material has not yet been decided, but there were very faint indications of the presence of sand at the surface, and, but for the experiments suggested and carried out, the fact of its existence must have remained unproved. I need not point out that to reach and remove an unknown deposit of loose sand under such circumstances is a matter involving some engineering difficulties and heavy cost.

27. Effect of fissured rocks now covered by alluvium or boulder clay.—Where a river flows over a great thickness of alluvial deposits or boulder clay without loss of water, the material resting on rock beneath which is cracked or deeply fissured, it is clear that, whatever the nature of the cracks and fissures, they must have become gradually silted up in the course of time, and are now water-tight. If this were not so the river would disappear, sinking into the fissures, and for a time taking an underground course, re-appearing, perhaps at a distance, as in some English rivers already described. But although fissures are thus often closed and water-tight against any amount of pressure they can be exposed to under present conditions, it does not follow that if a reservoir is constructed, and the water-pressure is increased from 10 or 12 to 60 or 80 feet, there should not be leakage which would by degrees re-open the fissures and produce a free underground channel for the water. This consideration must not be lost sight of when a river-bed is on the line of faulted ground or an anticlinal axis, and renders it very necessary that some notion should be obtained of geological considerations before extensive and costly works are undertaken for the storage of water.

28. Natural artesian springs under superficial covering.—The loss of water that would take place in fractured river-beds where the fissures are open, is sometimes converted into a very large gain by the rushing in of strong springs. In England, as has been mentioned in page 306, the river Derwent, in Derbyshire, is greatly increased in this way, while running through the narrow picturesque gorge past Matlock, and there are other recorded cases. Strong springs of fresh water are seen boiling up through the sea in a narrow channel between the Greek island of Cephalonia and the coast of Albania, the volume of water being sufficient to remove entirely the salt water, so that ships can water while anchoring on the spot. Other instances are known, but when only of moderate force it is almost impossible to detect such sources as additions to a stream, except by the measurement of the flow of water before and after passing over the springs in a spot where there are no other possible additions to the water supply. In the sea this is of course impracticable.

But although waters flowing into river-beds in this way increase the volume of water conveyed by the river, it must not be assumed that they would form useful additions to a reservoir. Water naturally emerges from the rock through which it is flowing at the points of least resistance. It will emerge in a river-bottom, when it there finds no resistance that it cannot overcome ; but if the additional pressure of a few more feet of water are added, sufficient to resist the upward force of the spring, the water will probably change its course, and come out at some lower point in the same valley, or in some adjacent valley. The added water, if it forms part of the contents of a reservoir, will, of course, take advantage of the same channel, and empty the reservoir. It is often very difficult to detect the presence of small springs in mountain valleys, and there are probably few reservoirs without them. According to their position in the bottom or sides of a valley, and according to the nature of the rock, and the circumstances under which they come to the surface, will be the amount of loss of water incurred. Questions of this kind, however, must be reserved for further consideration, when treating of underground waters.

29. Water flowing under a superficial covering of alluvium or gravel.—Where a river runs over alluvium which rests on gravel or transported material of some thickness, among which water can flow, it will generally be the case that a certain quantity of the water of the river will sink and pass out of sight, forming the converse condition to that above alluded to in which rivers receive additions from springs. In mountainous countries where there are numerous valleys consisting of mere gorges, and ravines loaded with fragments of rock such as are common in Spain, the whole volume of the stream will often thus disappear for miles, re-appearing only where the mountains end, and there is a short distance of level, or nearly level ground, near the sea. The water then oozes or flows out continuously, and not always at the same place, the channel sometimes not being indicated except by an open valley with a dry water-course, which runs up into the mountains. Large rivers do not often disappear. They show themselves in alternate pools and partial water-courses; but in countries where a considerable part of the surface is high ground, and comparatively level, the rivers cease to flow on the surface for a large part of the summer, or are merely water-ways for occasional torrents. In Australia, where even the largest rivers only partially occupy their beds, it is often possible to find water by digging or boring in the line of the dry river-bed. In this way the existence of subterranean rivers is proved where the surface is suffering from extreme drought. The well-known Abyssinian or tubular wells are borings taking advantage of this condition of buried streams.

30. Certain conditions of rock necessary for these results.—In order, however, that the river should thus run an underground course, the rock underlying the gravel and transported boulders must be non-absorbent, and not much weathered or fissured. Over the New Red Sandstone in its ordinary state, over chalk, especially the upper chalk, and over some of the oolites in a rotten or sandy condition, the water of a river entering the superficial gravel and alluvial sands, would leak down into the rock, and become a part of the great underground supply. The gravels in such cases would no longer afford a supply, except where the water was occasionally held up by clay bands.

31. Effect of obstructions in the course of rivers.—The causes that act to turn aside a small stream or mountain torrent in its early course when rushing impetuously over a steeply inclined bed, produce a similar result, though under altered conditions, when the river has assumed large proportions, and has acquired a considerable volume of water moving with greater force but diminished rapidity. Those of our English rivers that empty into the Wash, conveying to the sea the rainfall from the slopes of the oolites, and crossing the expanse of the Oxford and Kimmeridge clay in Cambridgeshire, Huntingdonshire, and Lincolnshire, are examples of this kind. Owing to the slow rate at which they move, having for a large part of their course scarcely a perceptible fall, the smallest accumulation of detritus,—a fallen tree, a growth of vegetation, or even the carcase of a dead animal,—becomes a sufficient obstacle to divert the stream. Such diversions being very frequent, and the banks of the rivers composed of little more than soft mud, held together by the roots of plants, the channels are always tending to shift. After floods the first effect of which is by disturbing the water to mix with it a large quantity of mud and silt, the water is slightly checked at each obstacle, and some part of the load of foreign matter left behind, which tends still more to divert the course from a straight line. Ultimately the river is found to double upon itself again and again, and sometimes even to re-enter, cutting through a neck of land left for a time, while the winding stream is sluggishly struggling onwards. A glance at the lower course of any of the rivers of the fens will illustrate the state of the case, and suggest the reason. A remedy is found in artificial cuts, and the river may be forced by embankment to take a direct course, but it will need constant dredging to prevent the bed of the stream from rising above the level of the surrounding country, and thus diminishing the fall, which is already insufficient. Obstructions and diversions of the currents of streams are, however, by no means confined to slow rivers passing through fen lands. In every case when for any cause the flow of a stream is interrupted, its direction is changed, and its current drives with a scour against the opposite bank. This, repeated continually, accounts for the sinuosities by which all rivers are characterised.

32. Nature of river banks.—The banks of a river are chiefly important where they approach so nearly to its bed as to influence the course of the stream. In some cases the distance is a very short distance, but in others the wide range of the old river-bed, over any part of which the river may have wandered when in some previous natural state, is so considerable, that it is necessary to proceed to a distance on one side or the other to determine any matter concerning the details of the existing channel.

Under ordinary conditions it will be evident that the rocky fragments and other materials that form the bed of a river, must have been derived largely from the weathering, undermining, and erosion of the banks, and in fact indicate pretty exactly the nature of the banks. That this is not always the case is due to surface drifts of gravel or boulder clay, conveyed by water from a distance, not rising to the level of the hill-sides, and when the stream has not cut into them to any depth. Very frequently it will happen that the boulder clay, which is a mass of mixed clay and stones pushed forward by the advance of glaciers or drifted over water on an iceberg, covers hills on which the icebergs have been stranded, or fills the upper valleys where the advancing glacier was checked, and has never reached the valley below.

33. Banks of rivers in valleys of erosion and fracture.—The nature and origin of a valley influence greatly the nature and condition of the river bank. Thus true valleys of erosion will be found generally to occur in parts of the country where there are stratified rocks, some of the strata being softer than others, and the strata being inclined. In these cases the undermining force of running water makes itself felt very strongly, especially where the strata dip towards one side of the valley, so that the water acts on them in the most favourable manner. The slope formed will have reference to the amount of the dip on the one side, and on the other there will be nearly a vertical wall. No doubt in nature these conditions are subject to modification, and many varieties occur, but the general rule is valuable. The lower parts of great rivers are rarely valleys of erosion in the sense in which the term is usually understood, for the ordinary flow of a river through a wide and level valley, exercises but little eroding force, and is more likely to deposit a part of the load it has brought down from the mountains than take up additional matter, or move that which has been once thrown down another stage on its journey towards the sea.

A good example of one kind of bank may be seen in the upper valley of the Thames, near the sources of the river. The early tributaries for the most part flow over a bed cut through the lower oolites to the lias. The banks of the river consist of hard calcareous rags and stones of the oolitic series, alternating, in their bands, with some clayey and some sandy strata. The result is the formation of tolerably well defined and often steep banks, almost horizontally bedded, and showing an instructive sequence of this part of the secondary group. Nearly vertical walls of limestone also form the river banks in many of the upper ravines and gorges whose waters feed the tributaries of the Yorkshire Ouse. They are also in many cases quite distinct from the river-bed, which is cut in some lower and older rock.

It is not always easy to say at what distance rising ground enclosing a river channel can fitly be regarded as river bank. Almost every river for a large part of its course flows through a trough, or in other words a cross-section taken at right angles to the direction of the course, presents a curve whose lowest point is where the water flows. But near the mouth the curve is practically too flat to be recognised, and in the middle course the geological structure may be such that the character of a river basin is lost. This is especially so when the rocks are hard, metamorphic, and bear little relation to the features of the country. It is chiefly in the upper course when the river is young, and struggling to emerge from the mountains, that the banks approach so close to the stream as to affect seriously the nature of its progress.*

34. Landslips.—Under certain geological conditions, and also under certain lithological conditions, it results from the action of the stream, or the natural process of weathering and exposure, that a tendency to slide or slip away develops itself in banks that nearly approach a stream. This may arise in various ways; but when once a tendency of this kind is manifested, and has acted, it is difficult to prevent a repetition. Thus where indications of slips are seen in a valley, it cannot be regarded as a desirable site for a reservoir bank. The favourable condition for slips is that the dip of the strata should be towards the valley, that the strata should include some that are permeable, and that these permeable beds should be within the reach of rain or running water. When the stream has so far cut into these permeable beds, that the drainage from the out-cropping part on the ground above can enter and pass down into the stream, it depends only on the angle how and when the slip shall take place. By taking advantage of local conditions, and partly sheltering the intervening permeable bed which would produce the movement if converted into a wet slippery material, the first movement may be long delayed. Thorough surface drainage systematically adopted may also delay a slip, if it cannot altogether prevent it. In reservoir work, however, it is only where such a slip, if it took place, would endanger the lower bank of the reservoir, and reduce the resisting power afforded by this bank to the puddle-wall, that it offers serious objection to construction. The bank itself must evidently act as an abutment, and ought to prevent a slip in its immediate neighbourhood.

35. Reservoir accidents from unsound river banks.—Landslips within a reservoir do little harm beyond diminishing the holding power

* An interesting communication read before the Geological Society in 1872 on "the River Courses of England and Wales," by Professor Ramsay, should be referred to by the reader interested in the solution of geographical problems by the aid of geology. The various elevations and depressions that have affected the earth's crust in England are there represented as the causes of the remarkable divergences from what would seem to be the natural course of some of our principal streams. The cases of the Thames, the Severn, the Avon (Severn), the Trent, and Yorkshire Ouse, and their tributaries, as well as the rivers of the New Red Sandstone, are all regarded as influenced in their courses by successive denudations of rocks that once existed on the surface.—Quarterly Geol. Journ. vol. xxviii. p. 148.

of the reservoir by so many cubic feet as may have been fallen from above top water-line ; but in the construction of the bank any indication of recent movement is to be avoided. There is, I think, little doubt that the cause of the terrible accident that occurred some years ago by the bursting of the bank of the Lower Bradfield reservoir in the valley of the Little Don (one of those belonging to the Sheffield system), was due to the unsteady ground on the left bank of the stream, near, and a little below, the bank. Incessant heavy rain falling shortly after the completion of the bank, penetrated the old loose ground at this part near a small gorge, and the bank placed over this part caused a movement by the greatly increased pressure. The reservoir being quite full, the removal of the bank was followed by a slight pushing forward of the puddle-wall, and this enabled the water to run over the top of the bank and cut a channel. The accident immediately followed.

36. Fissured rocks as river banks.—The banks themselves, as well as the rock below the bed of a river, may be so fissured, cracked, or shattered, either by the contraction or disruption of the mass, that they offer no resistance to the passage of water. As long as the river below carries off all the water of the district, it is of no importance how shattered the rocks in the banks may be, or with what they communicate; but should a barrier be constructed, and the water be stored in a valley of this kind, there is no defence whatever against the lateral passage of the water as soon as it rises in the reservoir sufficiently to reach the shattered part. It is not easy to provide against this cause of loss, for during the preparation of the puddle-trench it is possible that no indication may be given of the state of the case, particularly if the valley is cut in boulder clay of some thickness, and of good quality. It would, indeed, be almost more difficult and costly to discover the weak and broken places, than to stop them when found.

37. Loss of water by lateral percolation.—It is by no means unusual to find when a reservoir has been completed and filled, the river bank being in ground where the strata are much disturbed, that a considerable flow of water takes place at some point in the valley below, indicating waste and a want of impermeability in the rock. In some cases, a water-way being once established from these new channels, the run will continue not only when the reservoir is full, but so long as it remains in use, and may therefore be regarded as permanent. It must not, however, be concluded that the water thus flowing is necessarily removed from the reservoir. The fact of the water-level being brought up in that part of the valley where the reservoir is situated, must raise the surface of saturation in the rocks adjacent. Under the normal state of things this surface would necessarily be lowered towards the valley on both sides till it touched the river level; but so soon as the reservoir is once filled it begins to rise, and continues to do so till it attains the top-water level of the reservoir. The result must be that the springs issuing in the valley below, and depending on the level of this surface, are strengthened, and so long as the reservoir exists they remain permanently higher and stronger than before, without any loss to the reservoir itself. In other cases there is no doubt that a real and sensible proportion of the contents of the reservoir is drained out by infiltration through the rocks on one side or the other enclosing the river valley. Where there is a succession of reservoirs, or where a certain quantity of water is passed down daily as compensation water, this waste is of no consequence.

It is not often that stratified rocks forming the banks of a river dammed back to form a reservoir, convey away any large quantity of water by regular flow through nearly horizontal strata. Such a condition, however, is possible, and a waste thus produced is more likely to increase than diminish, as the continued flow will naturally enlarge the channel by mechanical abrasion. The result must depend on local conditions, and on the tendency of the abraded material to choke the channels into which it is conveyed. This part of the subject, however, belongs rather to the consideration of underground than of surface waters.

38. Formation of shoals at river mouths.—The large quantity of detritus that must be conveyed by every river on its way to the sea, whether immediately derived from its softer banks, or conveyed by the upper stream as the river rushes over its bed in the mountains, and gradually grinds down all fragments of rock to fine gravel and mud, must evidently be carried into the sea, if it does not help to fill up lakes, or is spread over the surface of the low lands, when the river during floods covers large tracts in the lower part of its course. The nature and extent of deposits thus formed, have been to some extent measured, and have been ably described by Lyell in his Principles of Geology, 10th ed. vol. i. chaps. 18, 19; and I may refer the reader to those descriptions for some important facts ascertained on this subject. In the case of a single river, the Ganges, the quantity of mud annually conveyed and deposited, is estimated at about 15 millions of cubic yards, and although this is doubtless very large in proportion to other rivers, there can be no doubt whatever that every river brings down its proportionate quantity, and that in this way the land is constantly being pared away at the surface, its irregularities and roughnesses removed, and a levelling process effected.

On all our coasts some result is produced by river action, but it is by no means of the same kind, nor is it proportional. The force of the tidal wave, of marine currents, and of storm waves, is felt more or less everywhere, and has certainly pared away a part of the coast of England; but this involves only a redistribution of material, and what is thus lost to the land in one place is generally carried not far from the shore, and accumulates in mud, shingle, and sand heaps, which by degrees rise into shoals, and sometimes seriously interrupt navigation. In some cases the result is the formation of a shingle bank or line of beach.

39. Filling up of estuaries.—It must be remembered that detrital matter, held in suspension by water so long as it is in movement, tends to sink to the bottom when the movement is checked. In estuaries, where water is kept in constant motion, owing to the disturbance of the tides, the water may be observed to be always muddy and discoloured, and as the ebbing tide in a river is generally more rapid than the flood, there is a tendency to carry away to the sea a large quantity of such material as can be reduced to a fine state of division. But there is always dead water in some recesses, or at some point where the ebb and the flood meet, and thus there must always be a place of deposit; and as the moving power of water is chiefly at the surface, deposits are often more rapidly made than removed.[1]

In estuaries and bays the small nooks and inlets away from the direct course of the incoming and outgoing tide and the rush of river water, are comparatively still. In such places, therefore, there is an almost invariable tendency to become choked when they are mere dead ends, and they are often nearly silted up even when small streams make their way through them to the sea. On this subject Sir Henry de la Beche, whose minute observation of all facts of physical geography is well known, remarks as follows, in "The Geological Observer," a work full of interesting facts and intelligent deductions :—

" Many minor estuaries round the coasts of the British islands show the filling up not only of sheltered places on their sides, but also of their upper parts where detrital matter is gradually accumulated. If the course of the river has not been long through a level country, the deposits at the heads of estuaries may even be gravelly while mud only is accumulated in the sheltered localities." " In estuaries of this class we should anticipate that there would be much gain of land where the discharging rivers entered them, and accordingly in such situations we often find extensive marshes and flats which would justify this expectation, even if historical evidence could not be adduced. Of such evidence, however, there is commonly no want, and the heads of many estuaries around the British islands, and along the ocean coasts of Europe, are known to have become more shallow, and even to have moved further outwards dry land, supplying the place of marshes and mud banks within historic times." He adds in a note that these changes are produced independently of sea banks, raised to keep out the tides. —Geological Observer, page 97.

40. Distributing action of the tidal wave.—The flow and ebb of the tides produce a motion tending to spread the accumulation of detrital matter deposited on the sea bottom within their influence, but the same causes tend also to form ridges and furrows. Observation has shown that the stream from tidal action travels backwards and forwards for a limited distance, not exceeding 18 miles when the average rate of the tidal stream is about 3 miles per hour, and nearly in the same proportion at other rates; but this stream, assisted or opposed by strong winds, may produce results of considerable importance, though within a limited range. Repeated local action of a similar kind will accumulate detritus, more diversified in character near a shore than at a distance, and will be affected by the strength of the tides, their increased velocity off the chief headlands, and their diminished strength in sheltered bays and estuaries. In this way is explained the existence of some curious pits and deep grooves in the sea-bottom of the English channel, whose position and magnitude, though constantly shifting, always bear a certain relation to each other, and which are never filled up.

41. Effects on a river outfall where the river meets strong tides.—These results of tidal action are curiously modified by and modify results of river action, and affect the outflow of small rivers. Such streams when they meet obliquely, a strong tidal stream rushing along at a more rapid rate than the river itself, are necessarily deflected from their courses. Almost all rivers bear down towards the sea a certain quantity of detrital matter, which when the rate of flow of the river is slow, and the volume of the water inconsiderable, is in a fine state of division. Where such a river meets a tidal stream, the progress of the fresh water is checked, and dead water produced, so long as the level of the sea is nearly equal to that of the river. During this time a deposit of fine mud takes place, and the river is backed up, the deposit being continued for some distance above the outflow. If the tendency of the tidal stream is also to deposit a heap of moved material, such as shingle, parallel to the coast, the shingle, assisted by the fine material, will, if in sufficient quantity, cause the current of the river to be diverted during ebb, and the fresh water of the stream, combined with the ebb, enters the sea at an angle which is governed by the direction of the prevalent winds. These winds and the flowing tide drive the shingle into ridges and furrows, and the result is that the river is driven to lengthen its course, and discharge its waters at a point removed more and more from the original outfall, until the bank formed between the river and the sea is too weak, the sea breaks in, and the river discharges at a new mouth nearer the source than its former outflow. Each time that this change occurs it may be expected that the river should gain something in length, while the shore has gained by the deposit of a permanent shingle bank, now the inner bank of the river, though once the shore line of the bank. Examples of this are not rare on exposed coasts. The united streams of the Yare and the Waveney meeting at Yarmouth, where they once entered the sea, are now forced to proceed southwards nearly 5 miles before they find an outlet. On the south-east coast of Ireland there are other examples.

42. Example near Aldebrough and Orford.—Another remarkable example of this action occurs on the east coast of England. The small river Alde, joined by the Ore, originally entered the sea at Aldebrough, or rather it may be assumed that they entered at some distance seawards to the east of Aldebrough, as that town is believed to have originally extended a quarter of a mile east of the present shore to a point where there is now deep water. The incursions of the sea, once very destructive on this coast, have been checked near Aldebrough, where sand banks of considerable extent have been formed at a short distance in the ocean, and a different state of things has set in. An important drift of shingle now reaches a long distance to the south, and the river Alde, or Ore, is forced to flow southwards 7 miles in order to reach the sea, entering at the southern extremity of this great shingle bank, which forms a secure barrier protecting the lands within the bank from the sweep of the sea. Without this the sea might, on the occasion of a combination of extreme tide and strong easterly gales, make a breach and enter the marshes, where the land is considerably below the highest sea-level.

The river is tidal for a long distance, and the scour of the ebb, especially after unusually high tides, sweeps out a deep channel and keeps it clear.

The effect of the tidal current, assisted by prevalent north-easterly winds during the early part of the year, is very sensibly felt in creating shoals at the extremity of the bank now formed. These shoals are gradually converted into additional bank. Of late years the increase in the quantity of shingle moved southwards is very great; but the precise source of the supply of shingle is not known. The whole shore from Aldebrough northwards for many miles consists of this material, which is due originally to the waste of the tertiary beds underlying the London clay. It is proved by historical documents that the waste of the coast by the action of the sea has been at one time very considerable, though apparently now checked at this particular spot. At present the chief eroding action is confined to the coast south of the mouth of the Alde, and there is reason to fear that unless some protection is given, the mouth of the Orwell may suffer, and the shore at Harwich be carried away. On the northern shore of the Orwell at Felixstowe there is every year a considerable amount of mischief done during high spring tides at the season of the easterly gales in spring.

43. Formation of lagoons.—When there is little tide, and no material far as it recedes almost if not quite as much as it advances, and its force one way is only greater than another, because of local peculiarities of form of coast. So much depends, however, on local conditions, that no general law can be stated as to how the action will take place.

Where the quantity of material brought is greater than the force of the tide can permanently remove, it may be distributed over the bed of the sea, or accumulated on the shore. In the former case, a shoal is the result, in the latter, a distinct addition to the land. As a point of law, it has been determined that whatever addition is thus made by nature to land becomes the property of the owner of the shore from which the addition is made. It may be, however, that the result acts very unfairly, as in this way access to the sea may be cut off by the addition thus accidentally made to an adjoining property. A case of this kind was litigated some years ago, but no relief could be obtained, and the cattle of one who had been a riparian owner were no longer allowed to reach the shore, because a river deposit from adjoining lands was advancing seawards. There would seem no remedy for this injustice. The determination of the cause of the accretion determines the ownership.

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* This list contains the names of all the streams of running water which are referred to in any way in the text. When the name alone is given they are generally known and mentioned as rivers. When they have special designations, br. signifies brook, and w. water, others (burn, beck, &c.) are printed in full. Where there are double references, the first is to the scheme of drainage areas, and the second to the description of the stream. Where there are two or more rivers of the same name some indication is given by which each may be distinguished. In this case when the stream belongs to an independent catchment the geographical position is mentioned, and when it is a tributary, the river or branch it enters.

It may assist in making use of this list to remember that all streams between pages 138 and 371 are English (except the Scottish feeders of the Tweed); between pages 372 and 427 all are Scottish, and from 429 to 498 all are Irish.

* *Bromney* in text p. 328 by error.

* Accidentally omitted in the scheme of Wear affluents, where it should be placed opposite Browney beck.

S.

T.

U.

V.

W.

Y.

Z.

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