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PREFACE.

THE full advantages of irrigation are best realised in dry tropical or semi-tropical countries, where rain falls only at long intervals. There, many a large tract of land, that is naturally barren and worthless, is, with this provision, seen to yield rich and abundant crops. In these countries irrigation is a commercial necessity, and large sums of money are profitably expended on it.

In countries of Northern Europe, where the climate is humid and temperate, by far the largest outlay is incurred, not in irrigation works, but in draining lands which suffer from an excess of moisture. It can rarely be necessary, on such soils, except in periods of exceptional drought, to have recourse to the double and expensive process of subsoil draining followed by irrigation. Subsoil draining is in itself a protection against drought; and deep tillage and frequent hoeing and stirring of the surface soil are to some extent substitutes for rain, in the cultivation of plants. Still, in a climate like that of Britain, where the rainfall varies from 15 inches or less annually in dry districts in dry years, to 150 inches or more in wet districts in wet years, it would be strange if the extremes of drought and flood did not occasion, at different times and in different places, the need of irrigation as well as of drainage.

There are, indeed, few English farms that could not, in average years, with a good command of water for irrigating crops, be made to produce far more largely than they do, and that without incurring outlay upon costly engineering works. It is not very wide of the mark, perhaps, to affirm that English water-meadows are doubled in value by irrigation ; and a good supply of water has been known to increase the value of arable land from four to ten fold.

But because the need of irrigation is not incessant, and because abundance of water is within reach of every farmer in this country, and can generally be drawn upon freely and without cost, the watering of crops in dry weather suffers unaccountable neglect amongst us. We have seen crops allowed to fail from drought, in situations where two or three furrows marked out by a plough, and connected with some neighbouring watercourse, could have been made the means of watering many acres of land.

In countries where irrigation is not such a casual necessity as it is in our own, the agriculturists are more careful to adapt their lands for it, though in most cases they have to pay dear for the water they use, and often also have to raise it, at great additional expense, to the elevation of the lands to be watered.

On small holdings, and especially in garden culture and upon market-garden farms, where the value of the produce is greater than in ordinary farming, the possibilities of irrigation, and the benefits of its practice, can scarcely be exaggerated, even in situations where considerable expense may be involved in obtaining and applying the necessary quantities of water.

Agricultural water-supply, however, involves much besides the watering of crops. With the live stock of the farm, the need of water is more urgent than for irrigation, and the dependence of live stock on artificial supplies is more incessant. Only those who have had experience in stock-keeping on a large scale, in regions where there is little or no rainfall during many months of the year, can realise the full importance of this part of our subject. Horses and cattle require on the average about five gallons each, and a sheep about half a gallon, per day, in dry weather. On waterless formations, therefore, any means of rendering water easily come at does much to enhance the value of the land for grazing purposes.

In the stock-yards, as in the pastures, a plentiful supply of wholesome water is a first necessity; yet what is the real state of matters in this respect, on many farms? A month's dry weather sees the water-supply exhausted; or cattle are compelled to drink from a dirty duck pond, or from some stagnant hole which is too often the main receptacle for sewage and liquid manure. Is it wonderful that animals compelled to drink such water are injured in health? that epidemics break out amongst them? or that milk from cows so treated is a source of danger and disease to the consumers of it?

The supply of water for agricultural engines is now only of secondary importance to the requirements of live stock; and water-power, for driving threshing and other machines, if not an absolute necessity, is certainly a great advantage in most situations. Every acre of land cultivated by steam requires about 100 gallons of water for engine use, and it is of much consequence that this supply should be accessible at every site likely to be occupied by the engines in cultivating an entire farm.

Most important of all, however, is the question of supplying the farmhouse and the cottages of the farm with abundance of pure water. Every adult consumes daily about half a gallon of water, and of course large quantities are required for domestic purposes beyond what is actually consumed in food and drink. The total daily requirements vary from about three gallons in cottages, to ten or fifteen gallons in large houses, for each person. Unless, at the same time, the water is good, a perfectly healthy condition of the body cannot be maintained. Many of the most dangerous forms of disease are known to be introduced into the system mainly through the agency of bad water. It is imperative, therefore, in the interests of health, that all "doubtful" waters should undergo a complete filtering process, which will not merely remove the grosser impurities but change chemically those in solution, before they are considered fit for drinking.

The various methods of irrigating land; of obtaining water by artificial means, and of storing and purifying it for use; of constructing wells, ponds, and reservoirs; and of raising water by machinery, are the subjects discussed at length in the following pages.

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LIST OF ILLUSTRATIONS.

IRRIGATION AND WATER-SUPPLY.

CHAPTER I.

IRRIGATION.—THEORY AND EFFECTS.

IRRIGATION is the watering of land at will. And artificial watering is all the more effectual, as well as all the more easy of accomplishment, from the fact that the need of it is not incessant, but may generally be confined to a few months of the year.

There are few farms, perhaps, that it would be advisable, even were it possible, to lay wholly under irrigation: at the same time, there are few farms that, in average years, could not have been made to largely increase their crops had they had full control of the necessary supply of water.

On many farms which periodically suffer from drought, it is quite possible to control the water supply to a much greater extent than is done at present, and with the best results. Costly engineering works, by which water is conducted long distances for purposes of irrigation, are not practicable in general agriculture; yet many streams which now run by unutilized might be turned to account, and channels which now permit the escape of winter rains might, in many cases, be dammed with little expense, and the rainfall saved for irrigating the summer crops.

On the prairies the plans would sometimes have to be different, and the expense would probably be greater; but the results obtained would well reward the outlay. Where running streams and storage water were not available, tube-wells might be sunk at points where the water could be led across a vast plain, or down a valley, in irrigating streams and ditches, until it has been wholly absorbed by the soil. In California single wells are often made to irrigate sufficiently hundreds of acres, by the aid of a reservoir into which their waters are discharged when the soil does not require them, and there retained until the thirsty soil calls for irrigation.

Reasons for Irrigation.—Soils which do not contain more than 5 to 9 per cent. of moisture, Professor Church tells us, will yield none of it to the plant. Seeds, however, must absorb a very large quantity of water to induce germination. Young growing plants, also, require large supplies of water, and, indeed, all vegetable produce when in a growing state. The actual proportion is often 70 to 80 per cent., and sometimes as much as 90 to 96 per cent. The whole of this water is absorbed by the plant through the soil, and none of it directly from the atmosphere. When the daily evaporation from the leaves exceeds the amount of moisture the plant can take up by its roots, the plant must wither and die: in other words, it succumbs to drought.

Professor Johnson says: "The great deserts of the world are not sterile because they cannot yield the soil-food required by vegetation, but because they are destitute of water . . . . Poor soils give good crops in seasons of plentiful and well-distributed rain, or when skilfully irrigated; but insufficient moisture in the soil is an evil that no supplies of plant-food can neutralize."

The reason of this is obvious; for, in addition to the water which enters into vegetable composition, plants can only take up their food in a fluid condition. Lawes and Gilbert, at Rothamsted, proved that an acre of wheat in five months and eighteen days evaporated through its leaves $335\frac{1}{4}$ tons of water. Every drop of this water was more or less instrumental in transporting an atom of food from the soil to some part of the plant, and when the deposit was made, the water which was no longer needed passed off through the leaves.

The reasons for irrigation are summed up by Professor Church* as follows:—

"1. To make up for the absence of irregular seasonal distribution of rain, or for a local deficiency of rainfall.

"2. Sometimes a particular crop is irrigated because the plant is of an aquatic or semi-aquatic nature.

"3. To encourage early and rapid growth, by warmth of the water, or by the dissolved plant-food which it contains.

"4. That the land may be enriched and its level raised by means of the deposit from the water."

The third of these reasons, he points out, "is the determining cause of nearly all the artificial watering of land in temperate climates. It is not performed because the soil is dry and hot, for it is carried out mainly in the wettest and coldest months of the year. It is not performed because the crop to be raised is of

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* "Encl. Brit.," 9th ed., art. Irrigation.

an essentially aquatic nature, for ordinary grasses and meadow herbage are principally watered. But it is performed that growth may be stimulated and fed through certain agencies which the water brings to bear upon the vegetation in question."

Effects on Soil.—" The immediate effect of irrigation upon the *consistence* of the soil is to soften it and render it more easily penetrable by the plough and by the roots of the plants. Hence, in dry climates, water is frequently applied before ploughing, at the rate of about 400 to 500 cubic yards per acre, or barely enough to loosen the earth to the depth of a foot without drenching it. But it is most important to observe that the ultimate effect of long-continued irrigation is to condense and harden the surface to a very inconvenient degree.

" Irrigation affects the *quality* of the soil by introducing into it common air and other gases, and vegetable and mineral matter held in suspension or solution by the water. In most cases the substances so introduced are beneficial to vegetation; but in some they are highly noxious. Even the water of large rivers sometimes, as has been observed in India, deposits on the surface, or introduces into the texture of the soil, salts, which in the course of time render it wholly sterile."

It likewise acts upon arable soil by facilitating the decomposition of soluble organic and inorganic matter contained in it, and carrying off such matter from it. The extent of this latter action is disputed; but it must be considerable, for constituents of vegetable growth have been found in under-drain water from cultivated fields; and large tracts of ground, impregnated with salts to such a degree as to make them

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incapable of cultivation, have been rendered fertile by washing with fresh water.

On undrained land, irrigation often injuriously affects the subsoil by charging it with water which stagnates in it, and renders it cold and sour to the roots of plants which descend into it.

It also exercises an important influence on the water-supply of lands lying at a lower level, by diverting from their natural channels streams which originally flowed through such lands ; and on the other hand, by discharging upon their surface surplus waters from irrigated fields, or by saturating them with water, conveyed to them from such fields by subterranean infiltration. These effects are seen, not only in the soil itself, but in the diminished or augmented volume of spring and well water.

Finally, irrigation modifies the temperature of the soil beneficially or injuriously by communicating or abstracting heat, and by promoting evaporation from the surface, which is necessarily attended with some cooling of the ground.*

Effects on Vegetation.—Watering the soil promotes the germination of the seeds of cultivated plants, and, unfortunately, of weeds ; and water is in, and of itself a necessary element of vegetable growth. Besides this, it is never quite free from extraneous matter, and it always contains, in solution or in suspension, foreign substances useful or injurious to vegetation. Hence, in climates and on soils where the natural supply of water is insufficient for the normal growth of plants, remunerative agriculture is impossible without artificial arrangements for procuring and administering it.

In many cases, however, although the quantity of

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* Professor Johnson.

the product is increased, there is a deterioration in the quality of it. There is no doubt that all crops which can be raised without watering are superior in flavour and in nutritive power to those grown by the aid of irrigation. Garden vegetables, in particular, when profusely watered, are so insipid as to be hardly eatable. Comparative weight is, therefore, not always a true test: the heaviest potatoes, for example, are not the best.

"Moderate irrigation of herbaceous plants," says an Italian writer, "accelerates their germination and growth, but it checks the ripening of their seeds; and if water is applied in excess, it renders their texture less firm and substantial, and at the same time more subject to decomposition and waste."

Theory of Irrigation.—"Although," remarks Professor Church, "in many cases it is easy to explain the reason why water, artificially applied to land, brings crops or increases the yield, the theory of our ordinary water-meadow irrigation is rather obscure. For we are not dealing in these grass lands with a semi-aquatic plant like rice, nor are we supplying any lack of water in the soil, nor restoring the moisture which a plant cannot retain under a burning sun.

"We irrigate chiefly in the colder and wetter half of the year, and we 'saturate' with water the soil in which are growing such plants as are perfectly content with earth not containing more than one-fifth of its weight of moisture.

"We must look, in fact, to a number of small advantages, and not to any one striking beneficial process, in explaining the aggregate utility of water-meadow irrigation.

"We attribute the usefulness of water-meadow irrigation then to the following causes :—

"1. The temperature of the water being rarely less than 10° Fahr. above freezing, the severity of frost in winter is thus obviated, and the growth, especially of the roots of grasses, is encouraged.

"2. Nourishment or plant food is actually brought on to the soil, by which it is absorbed and retained, both for the immediate and future use of the vegetation.

"3. Solution and redistribution of the plant food, already present in the soil, occurs mainly through the solvent action of the carbonic acid gas present in a dissolved state in the irrigation water.

"4. Oxidation of any excess of organic matter in the soil, with consequent production of useful carbonic acid and nitrogen compounds, takes place through the dissolved oxygen in the water, sent on through the soil, where the drainage is good ; and

"5. Improvement of the grasses, and especially of the miscellaneous herbage, of the meadows is promoted through the encouragement of some, at least, of the better species, and the extinction or reduction of mosses and of unnutritious weeds."

Drainage in connection with Irrigation.—Irrigation is only useful when the water is entirely at command, both to lay on and to take off at pleasure. Drainage is, therefore, a necessary preparation for irrigation.

Any want of good management on this point will entail loss and disappointment. This applies, not merely to the period of intermission which may be advisable between the waterings, but also, on stiff soils particularly, to the thorough under-drainage of the land.

It need not be feared that the thorough drainage of irrigated lands will do more harm than good by washing the most valuable constituents of plant food out of the soil. Phosphoric acid and potash, which are the most valuable components of soils and manures, Dr. Voelcker tells us, are retained in the land almost entirely; while lime, magnesia, sulphuric acid, chlorine, and soluble silica, the less important because more abundant and widely distributed mineral matters, pass into the water of land-drainage in considerable proportions. There may be a loss of nitrogen, however, if the land has been manured with a nitrate, and its application is immediately followed by irrigation. Still the good effects of drainage will always far more than compensate for any losses which may occur in this way.

Impoverishing Effects of Irrigation.—Water, as has been pointed out, stimulates production by its solvent action on the constituents of the soil and of manures. But for this very reason, prolonged irrigation is apt to become injurious, unless the water is rich, or unless adequate manuring, cultivation, and drainage attend its practice. In well irrigation especially, and also in canal irrigation, the water used is often of little fertilizing value, and unless it is rationally used, the results must be disappointing. For the first year or two after it is brought into play it will probably increase the crops; but without the concurrent application of the agencies already mentioned for maintaining fertility, it must eventually reduce the productive power of the soil.

This is exactly what has happened in certain districts of Upper India, where well and canal irrigation has been persisted in for years and generations even, without any attempt at sustaining fertility by the application of manures, or to lessen the impoverishing effect of the water by good drainage and cultivation.

"The real reason," says Colonel Corbett,* "of the falling off in the produce of canal-irrigated lands appears to be the consolidation of the pan by the treading of the cattle in ploughing, and the hardening of the upper soil in irrigation. This causes shallower ploughing, the roots of plants have less depth of soil in which to search for food, and cannot force their way into the hardened pan; and there is the alternate soaking and drying of the land, during which the natural salts of the earth are gradually brought nearer the surface by capillary attraction.

"This process may go on for some years before the lands show any excessive amount of *reh* on the surface; but the soil is steadily being poisoned by its accumulation near the surface, which accounts, together with the increased hardness of the soil, for the diminished fertility of lands some time under irrigation."

Influence of Tillage in mitigating Drought.—Hoeing and frequent stirring of the soil are good substitutes for rain. Those parts of the garden that are most frequently cultivated show the best results in dry weather. A deep, well-manured soil suffers much less from drought than a shallow soil. Under-draining also is a safeguard against drought. The course of the drains can easily be traced in a dry season by the ranker growth of vegetation above them.

Deep cultivation keeps the soil loose and open, and allows the water to sink into it and escape evaporation. In the case of deep cultivation generally, over a country, more especially a level country, there is a reservoir of water under every field sufficient to supply the wants of vegetation, held there by the soil itself.

A writer in the *American Agriculturist* states that,

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* "On the Climate and Resources of Upper India."

since some of the great plains of America have been broken up by the plough, a great amelioration of local climate has taken place. "As soon as the tough sod has been ploughed, and the soil been mellowed and made absorbent, the rain soaks into the ground instead of flowing off, and, percolating through the subsoil, supplies springs, which break out in low spots and furnish water for new rills and brooks. The atmosphere is no longer parched, but becomes moist, and its former extreme variations of temperature do not occur. The climate changes, and the moisture of the air and the consequent rainfalls are increased. A new circulation is established, and the storms and showers are those of a temperate instead of a torrid zone. Facts have shown that these conclusions are correct, and the observations taken in many places near the hundredth meridian, and eastward to the Missouri River, indicate a greatly increased rainfall, the increase amounting, in many cases, to several inches a year. Farmers no longer fear disastrous droughts, and there are few localities where their business is safer."

CHAPTER II.

PRACTICAL ADVANTAGES OF IRRIGATION.

In a climate like that of the British Isles, one can scarcely realise the full advantages which attend irrigation in tropical and semi-tropical countries. In California and Mexico, in Egypt and India, in parts of Southern France, Spain, and Italy, and elsewhere, where rain falls only at lengthened intervals, there are vast tracts of land, now contributing bountifully to the world's commerce and industry, that would be absolutely barren and worthless but for this provision.

In the South-western States of America there are many million acres of the most splendid land now lying idle and waste, unable to find purchasers at even nominal prices, because, without the means of irrigating and watering them, they are practically useless both for cultivation and for stock-raising. Yet the very same lands, which go a-begging at fifty cents an acre, in their natural state, when a supply of water has been brought to them, are eagerly purchased at $5,* $10, and even in some cases at $20, and upwards, per acre.

In Colorado, where land is of little value to the farmer unless water is assured, Mr. Pabor tells us that a quarter-section (160 acres) becomes worth at least

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* 1 dollar = 4s. 2d.

$10 per acre when an irrigating canal has been built. Water has a commercial value of $15 per acre, when in the shape of a water-right, which is a perpetual claim upon a canal for a certain amount of water each year. When water is rented by corporations to consumers it has a yearly average value of $2 per inch, running continuously throughout the growing season, which amount is considered sufficient to irrigate one acre of grain land.

In Madras, taking an average of thirteen improvements, irrigation shows a net annual gain in revenue, after deducting all charges, of 134 per cent. per annum on the capital.

In Spain, unwatered land of the first quality sells for £32 per acre; when irrigated, the same lands bring £128 per acre. In the same country, second-class land, selling at £20 per acre, is at once increased in value to £100 per acre; third-class land, worth £12 per acre, is increased to £72; fourth-class land, worth £6 per acre, is increased to £60, when irrigated. A good supply of water thus increases the value of land from four to ten fold.

In Italy, the increase due to irrigation is also very great. Mr. Jackson puts it at 50s. on sandy soil, and at 40s. on clayey soils, per acre, annually; which is obviously an under estimate if these figures are meant to represent the increase of produce due to irrigation, but would probably be near the increased rental value.

In France, where irrigation is not an absolute necessity, as in Spain and Italy, it is generally considered that land is worth 50 per cent. more when it can be irrigated than when it cannot. In Vaucluse, according to Mr. Moncrieff, the rental of good land is about

£3 4s. unirrigated; if irrigated, it rises to about £4 3s. per acre.

In England, where irrigation is chiefly confined to the watering of meadows, the produce of grass is at least doubled by the operation. In favourable situations, and in good seasons, an irrigated meadow affords —(1) Early spring grass to feed stock, in particular ewes and lambs; (2) a good crop of hay; and (3) a good crop of after-math. A dry meadow of the same quality would only afford—(1) an inferior crop of hay; and (2) an inferior after-math.

It is not, perhaps, too much to assume that the meadow will be all the spring crop the better by watering.

To give these advantages a money value, it may be said that, in England, if a dry meadow of good quality is worth £2 per acre to rent, the same land, irrigated, will probably be worth £5 per acre.

Water meadows not only afford grass at an unusual season, and when most wanted, but the hay crop is more certain and larger; and the land requires no manure. These advantages may well be worth an additional £3 per acre on good land; while upon poor land the increase will be proportionately greater.

CHAPTER III.

CIRCUMSTANCES FAVOURING IRRIGATION.

Water Supply.—The first consideration, and one common to all lands, is the question of water-supply, and the possibility of applying that water, or a portion of it, for irrigation purposes.

Where water can only be procured by sinking or boring wells, or by storing rain or flood water in tanks and reservoirs—or where the lands are on a higher level than the source of supply, and the water has, consequently, to be raised by artificial means—the cost in either case may be greater than the profit to be derived; and under such circumstances irrigation will often be deemed impracticable.

Streams, where they exist, furnish the most ample and most economical supply of water. This is particularly the case when the water can be taken directly from the stream, and brought upon the field by a short conductor.

Springs are often advantageously situated for irrigating lower lands by gravitation, and will, as a rule, furnish more water than would be suspected. A continuous flow of 1 cubic foot of water per second, during twenty-four hours, is sufficient to cover four acres of land to a depth of nearly 6 inches. One such spring would, therefore, suffice to irrigate many fields, watering them alternately. Where several small springs occur near each other, connecting drains can often be put in, and the waters collected and brought into one channel.

Canals which serve for irrigation are frequently only conveyers of water from distant rivers, or from natural lakes. If a canal is formed with the express object of watering a given area of land, the capacity of the canal should be large enough to provide a flow considerably in excess of the actual quantity of water required. Where the water has to be carried a long distance, and the soil is porous, the loss by filtration and evaporation may amount to 25 and even 33 per cent.

Catch-water Tanks and Reservoirs.—In many cases where irrigation is carried on, the supply of water is obtained by impounding the winter rainfall for use during the dry season. The flood-water, in very dry districts even, when stored and made available at the right season, is found amply sufficient for the production of good crops.

Assuming that an inch of water is the least quantity that should be applied at each watering, this, over one acre of surface, is equal to 3,630 cubic feet, or 27,152 gallons. To irrigate 30 acres once, at this rate, would require a tank capacity of 108,900 cubic feet, or a tank exactly $\frac{1}{4}$ acre in extent and 10 feet deep; and to irrigate 30 acres four times, or 60 acres twice, would require a tank four times as large, or 1 acre in extent and 10 feet deep.

A tank or reservoir can often be formed by merely erecting a dam or embankment to impound the water in a natural basin or ravine. Indeed, it will seldom pay to make a ground-tank where the impounding basin has to be wholly excavated. A tank 1 acre in extent and 10 feet deep contains 16,133 cubic yards of earth, measured in place; and this cannot, under the most favourable management, be removed for less than 2d. per yard, or £134 8s. 10d., and generally the cost will reach 4d. per cubic yard, or even more. Even at the smaller sum the outlay would be even £4 10s. per acre for 30 acres; and there are few cases, perhaps, where it would pay a tenant farmer to incur that expense, although the improvement would be permanent, and would ultimately, no doubt, repay itself.

Wells.—Where no better method of procuring water can be devised, wells may be resorted to. The great objection to wells, however, is not merely the first cost, but generally the after-expense of raising the water.

Artesian wells are often recommended as a source of water for irrigation; but they cannot always be depended upon for this purpose, as few of them can yield an adequate supply of water. At the best "wells can only be depended upon for such a small supply as would serve to irrigate a garden or small market farm, where the large value of the crops admit of raising water for a lengthened season, and storing it in reservoirs for use in emergencies. The idea that artesian wells may be made a source of supply for completely irrigating large tracts of land, if ever held by over-sanguine persons, must be abandoned. For partial irrigation they may be made available; but the quantity of water needed for the irrigation of a few acres of land only, in localities where there is no summer rainfall, as upon our western plains, is far beyond the capacity of any artesian well to supply, unless it be one of extraordinary volume.

"Not long ago the *Scientific American* editorially announced that one artesian well would supply a farm of 640 acres upon the plains with water for irrigation, and would also form a nucleus for many large stock farms.

"The late Horace Greeley, who, although an enthusiast upon this subject, was more nearly correct, thought one artesian well would serve to irrigate a quarter-section of land, or 160 acres.

"An artesian well, 6 inches in diameter, would give a stream of 28 square inches, and would deliver 32 quarts per second, if the flow were at the rate of 4 miles an hour.

"Such a well would furnish an inch of water per day for 28 acres, or an inch a week for 196 acres, which would be a very insufficient quantity to irrigate dry open soils in places where the climate is arid.

"The cost of such a well would be at least $5,000 to $10,000, or more than the value of the land when irrigated."*

It will be seen from what follows in another chapter that these estimates of the capacity of artesian wells are far short of the results actually obtained by sinking wells in Australia and elsewhere. Tube-wells, too, can be put down at a comparatively trifling expense, compared with the outlay which has in many cases been incurred in sinking artesian wells.

The multiplication of wells in any district, it need scarcely be remarked, has the effect of lowering the spring level. This creates a necessity for deeper wells, causing the water to be raised from a greater depth, and entailing more expense.

Use of Drainage Water for Irrigation.—It will sometimes happen that drainage water can be utilized for

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* Stewart, "Irrigation for the Farm, Garden, and Orchard."

irrigation purposes; but we by no means advocate the theory sometimes advanced that drainage is imperfect unless accompanied by irrigation. We do not admit the general truth of the proposition that on wet soils it is necessary to have recourse to the double and expensive process of deep draining, followed by irrigation. There is, doubtless, a certain medium depth of drain, dependent of course on the nature of the soil and subsoil, which will remove the excess of moisture in wet weather, as from a sponge saturated with water, and yet retain, like a damp sponge, sufficient moisture for the purpose of vegetation in dry weather. This object, as already explained, may be greatly promoted by deep and frequent cultivation. When the drainage water from high lands can be used in irrigating lower lying lands which are naturally in want of moisture, it may be done with advantage.

Situation.—The lands that admit of irrigation with most success are such as lie in low situations on the borders of rivers, or in sloping directions on hill-sides, where a command of water can be obtained from higher ground. The latter may often be irrigated more profitably than the former, for they are usually less productive in their natural state; while they can be watered at less expense for laying out the ground and with a less quantity of water. In tank or well irrigation, or where there is an impounding reservoir, the situation of the lands to be watered is comparatively immaterial, provided the source of supply is at a higher level.

Soil.—The soils best adapted for irrigation are those of a light and porous nature, such as sands and gravels. Clay soils, and also peat soils, are not so often benefited by it, except in dry and tropical climates, where the nature of the soil is of less importance than the ability to give it an artificial watering in seasons of drought.

These remarks, of course, have reference more particularly to the surface soil. A retentive surface soil prevents percolation, favours evaporation, and cools the land, which are serious disadvantages in irrigation; while a retentive subsoil, underlying a porous surface soil, may be a great advantage in dry climates, as it economises water.

Heavy or clay soils must always be thoroughly under-drained before they can be successfully irrigated. They will also be farmed with most profit when laid down in pasture, for irrigation adds considerably to the labour and difficulty of working them.

The relations of soils to water are extremely various, as will appear from the following table:—

	Percentage of water absorbed.	Percentage of water evaporated.
Loose sand	25	88·4
Ordinary clay soil . . .	40	52·
Loamy soil	51	45·7
Strong clay soil	61	34·6
Garden soil	89	24·3
Peat	181	25·5

M. Debay classifies soils for irrigating purposes under three heads: (1) *Sandy Soils*; (2) *Argillaceous Soils*; (3) *Marshy Soils*. Of these he gives the highest value to sandy soils, the best being a clayey sand, warm, dry, and having some portion of marl in its composition. The finer the grain of the sand, the better adapted is it to irrigating purposes. One feature connected with the irrigation of sandy soils is, the abundance of reeds and rushes which they will produce when first placed into water; but these will gradually disappear as the plants of a higher class of vegetation increase. Of the argillaceous soils it may be said that the more tenacious and impermeable they are, the worse adapted are they for irrigation; and in such cases, where irrigation is adopted, deep drainage and deep cultivation are most essential. Marshy soils are the least valuable of all for irrigating purposes; but when well drained and managed they are capable of large yields.

Climate.—The success of irrigation depends in a great measure on the climate. It answers better in a dry climate than in a moist one, and where heavy wet seasons alternate with severe droughts, it will only be beneficial in the dry seasons. It will also be more profitable in a mild and genial climate than in one less propitious; as under the former circumstances it will not only afford more ample crops, but also a greater number of them, and more certainty of turning them to good account.

Where the climate is fine, irrigated meadows, for example, will yield three crops; first an early and valuable pasture for ewes and lambs; next a crop of hay; and, latterly, an after-math or good pasture.

In less favourable situations, only two crops can be obtained—one of hay and one of pasture; and neither of them so rich, nor so capable of being turned to great profit.

The question of rainfall is here, of course, all important; and not merely the amount of annual rainfall, but its distribution over days and weeks at various periods of the year.

Crops adapted for Irrigation.—Almost any crop may be raised by irrigation, but some plants flourish better under it than others, as the object and purpose of irrigation is merely to supply the natural wants of the plants, and not to stimulate them to an undue or excessive growth. The careful irrigator will study the wants of the plants he grows, and also the character of the soil he cultivates.

In our own temperate and humid climate, and in various other countries of Northern Europe, grass meadows seem to be most benefited by irrigation; but in warm Southern Europe, Egypt, India, and other parts, irrigation is chiefly applied to arable lands and crops. It is worth noticing, perhaps, that while in the latter countries irrigation is a commercial necessity, and large sums of money are profitably expended on it, in the former countries, where the climate is humid or temperate, by far the largest outlay is incurred, not in irrigation works, but in artificially draining lands which suffer from a superabundance of moisture.

Of all the cultivated grasses and leguminous plants, rye-grass and lucerne are the two which yield the best results under irrigation. The different species of cabbage, beet, and turnip thrive well with occasional waterings; as do also grain crops, up to the period of inflorescence, after which watering becomes injurious to them, except for a very short interval when the grain is filling.

Many of the plants cultivated for industrial purposes cannot well be grown without artificial supplies of water at certain times. Too much water injures them; yet much of their success depends on their receiving a regulated abundance of moisture. Madder (*Rubia tinctorum*), the sugar-cane (*Saccharum officinarum*), and many other important plants of commerce are of this character.

The rice plant, and a few others of aquatic or semi-aquatic habits, are extensively grown under swamp irrigation. Watercress is also raised on a large scale, in the neighbourhood of most large cities, under very similar conditions.

CHAPTER IV.

WATER FOR IRRIGATION—QUALITY AND QUANTITY.

Quality of Water.—Although it must often happen that no choice is possible, yet all waters are not alike suitable for irrigating land. The best water for the purpose is no doubt that which brings with it those fertilizing matters which will supply the deficiencies of the soil and the wants of the crop irrigated.

In examining a water, however, as to quality, its dissolved and suspended matters must both be taken into account. Water having no more than a few grains of dissolved matter per gallon answers the purpose in view satisfactorily.

"Should it be thought," says Professor Church, "that the traces of the more valuable sorts of plant food, such as compounds of nitrogen, phosphates, and potash salts, existing in ordinary brook or river water, can never bring an appreciable amount of manurial matter to the soil, or exert an appreciable effect upon the vegetation, yet the quantity of water used during the season must be taken into account. If but 3,000 gallons hourly trickle over and through an acre, and if we assume each gallon to contain no more than one-tenth of a grain of plant food of the three sorts just named taken together, still the total, during a season including 90 days of actual irrigation, will not be less than 9 lbs. per acre."

Clear water, especially if it proceeds from a spring in the same field, produces early and plentiful grass, but not of a good quality; and the land remains unimproved after many years' watering. We have seen the same unsatisfactory result where meadow irrigation was commenced by drawing water from a stream which has its source in the overflow of a lake. The stream is too pure for this purpose, leaving the richer particles in the lake whence it flows. The water, when first applied to the meadows, had the effect of eradicating moss, and helped to decompose waste vegetable matter; and it, therefore, for a time acted as a stimulus with seeming advantage. But when the meadows were annually mown, without an occasional top-dressing, the system in the end produced comparative exhaustion. It must be the same in many other places, where there is no extraneous matter in the irrigating stream, and where irrigation is begun without attending to local circumstances.

Thick and muddy waters, which convey along with them a rich and nutritive top-dressing and deposit it on the land, are productive not only of temporary but of permanent improvement, enriching the soil itself as well as the immediately following crop. In Southern France, Mr. Moncrieff* tells us, the difference between the meadows irrigated with the silt-bearing waters of the Durance canals, and those of the clear cold Lorgues, is so marked that cultivators prefer to pay for the former ten or twelve times the price demanded for the latter.

Artificial richness is sometimes given to waters used for irrigation, as when the water is taken from the very bottom of a stream in order to carry as much

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* "Irrigation in Southern Europe."

sediment as possible along with it on to the land, or where the drainage of sewers is conducted into the irrigating channel. Sewage irrigation, liquid manuring, and the use of light manures dissolved in water, offer the same advantages in a fuller degree, and will be dealt with in more detail farther on in this work.

River waters,—especially such as carry much suspended matter, and such as have received town sewage, or the drainage of highly manured land,—are more suitable for irrigation than water from tanks, wells, or springs. Streams in which fish abound are always considered good for irrigating with. "Hard" waters are also considered better than "soft" waters; this hardness being due to the presence of sulphate and carbonate of lime and magnesia, ingredients which are highly favourable to fertility. It is for this reason that water coming from the chalk formation is so good for irrigation purposes. So again with the water that comes from a granite formation, for it is rich in potash.

Water from forests, moors, and peat bogs, or from gravel or ferruginous sandstone is, as a rule, of small utility so far as plant food is concerned. Water containing much hydrous oxide of iron is generally considered very bad for irrigation; yet Sir John Sinclair tells us that the famous Presley bog in Bedfordshire is strongly impregnated with iron, and that even the water used to irrigate it is partially affected by it. Running water from mines is highly inimical to vegetation; and amongst other injurious sorts of refuse which can find their way into irrigating streams, are the chemical wastes from mills and factories in which the processes of dyeing, paper-making, metal-working, &c., are carried on.

Chemical analysis is the most satisfactory test of the quality of a water before it is used in irrigation; but some estimate of its probable effects may be formed by observing the natural products, the grasses and other plants, that grow on the banks and borders of the irrigating stream. We do not pretend to give a list of the particular plants which will afford this criteria of excellence in every place, for they will be found to vary with the soil and climate; but every farmer knows the plants which in his district will afford this indication of quality in the water used to irrigate with. "As a rule," says Mr. R. Scott Burn, "the water is of excellent quality if water-cresses (*Nasturtium officinale*), the aquatic ranunculus (*Ranunculus aquatilis*), grow near it; or other plants, such as the pond weeds (*Potamogeton perfoliatus*, or *P. fluitans*), and the speedwells (*Veronica anagallis*, or *V. Beccabunga*). The following plants grow in the neighbourhood of water of middling quality: *Sium cutifolium*, *S. angustifolium*, the mints (*menthæ*). If no plants are observable save the mosses and the sedges (*Carex acuta* and *C. stricta*), the quality of the water may be considered as bad."

Quantity of Water required.—On this point it is impossible to lay down any rule, as the quantity of water required for irrigating land so much depends on the climate, the nature of the soil, the object of watering, and the crop grown.

The more arid the climate, the greater of course the demand for water.

The composition and texture of both the super and subsoil greatly influence the amount of water required. M. Gasparin states that a soil containing 20 per cent. of sand needs irrigation once in fifteen days, while with 80 per cent. of sand it requires irrigation once in five days. A gravelly or sandy subsoil will allow of almost unlimited percolation; whilst, if it be clayey and retentive, percolation is reduced to a minimum.

The object of irrigating may be merely to make up deficiencies of rainfall and provide sufficient moisture in the soil for the support of a crop; or it may be for the sake of depositing on the land the fertilizing matters which are conveyed by the water. If the latter is the object in view, very large quantities of water may have to be used to produce the required effect.

In Northern Europe, for example, where irrigated meadows are common, large quantities of water are allowed to flow over the fields; the principal object being to manure the land by the sediment thus deposited. In the warmer climates of Southern Europe, India, &c., on the other hand, irrigation is only used to moisten the ground, and to supply by artificial means the want of rain, which is so much felt at times in those countries; and thus it is that the watering which would be effectual in the latter case would be deemed altogether insufficient for the water-meadows of Northern Europe.

Peculiarities of climate and soil, together with the object of watering, will generally have more influence on the amount of water required for irrigation than the kind of crop grown. Nevertheless some crops call for very much larger supplies than others.

The crops watered are usually classed in the following order, with regard to their special treatment and the amount of water they require:—

1. Grass meadows.
2. Lucerne, rye-grass, and other cultivated forage crops.
3. Cabbage, turnips, &c.
4. Beans and peas.
5. Wheat, oats, barley.
6. Sugar-cane, tobacco, indigo, madder.
7. Rice.
8. Gardens and fruit-grounds.

The quantity of water supplied during the season—which in Europe is only about six months in the year, say from April to October—to ordinary ploughed or hoed field crops varies from 20 to 40 inches. In the rice fields, of course, this amount is vastly exceeded; as it is also in the water meadows and many other grass grounds. The proper quantity, as well as the season for applying it, must necessarily vary under any particular soil and climate.

A flow of water, equal to 1 cubic foot per second, will cover 4 acres to a depth of nearly six inches in twenty-four hours; and, continued one hundred days, it will cover 400 acres to the same depth, or 200 acres with 12 inches of water. A cubic foot of water per second throughout the season has been found sufficient to irrigate from 30 to 90 acres of rice, according to the rainfall of the district.

Moncrieff gives the following table, by M. Conte, showing the acreage of each crop watered on the St. Julien Canal, and the amount of water required for each, as a fair specimen of the irrigation of Southern France:—

—	1. Surface watered.	2. Percentage borne by each to the whole.	3. Number of acres of each, irrigable per cubic ft. per second.	4. Quotient of column 1 by column 3.
	Acres.			Discharge in cubic ft. per second.
Gardens	1183·9	16·	28	42·6
Meadows . . .	789·3	10·8	70	11·3
Lucerne grass . .	592·	8·	70	8·4
Beans	690·6	10·2	50	13·8
Madder	394·6	5·3	168	2·3
Chardon	296·	4·	184	1·6
Sundry other crops	3340·1	45·7	454	7·3
Total . .	7286·5	100·	—	87·3

The table gives a mean duty of 83·4 acres watered during the six months of irrigation, per cubic foot per second. But, as Mr. Moncrieff points out, the large area classified as sundries makes this result of little value, many of the crops included in this area being only watered in an emergency, and not regularly, like some of the other crops. If, for example, a vineyard is looking drooping, or a field of wheat turning prematurely yellow, it gets a watering. In cases of great droughts, wheat is occasionally watered as many as three times.

The meadows are watered from about every seven to about every fifteen days, and yield three crops in the season. Lucerne grass is irrigated about as often as the ordinary meadows, is cut every month, and yields five or six crops during the season. Beans are irrigated every five days. Madder is not often irrigated more than three or four times after being planted out, the last time being immediately before it is dug up.*

In Piedmont and Lombardy, Mr. Jackson tells us,† one cubic foot per second waters 50 to 100 acres of grass land, or only 40 acres of rice. In the Madras Presidency, and in the North-west provinces of India, one cubic foot per second waters, in ordinary seasons, 100 acres of rice, or other very wet cultivation; in very dry seasons 50 acres. The highest duty actually performed in Central India is about 270 acres per cubic foot per second.

The following tables, by Mr. Jackson, furnish some useful details in regard to Italian irrigation :—

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* Moncrieff, "Irrigation in Southern Europe."

† "Hydraulic Manual." (Crosby Lockwood & Co.)

I.

—	Absorbed.		Utilised.		Expended.	
	Meadow.	Arable.	Meadow.	Arable.	Meadow.	Arable.
Volume of water in cubic ft. necessary per acre at each watering	5885	8476	9160	9697	15045	18173

II.

—	Meadow land.		Arable land.	
	Watering once in 7 days.	Watering once in 10 days.	Watering once in 14 days.	Watering once in 20 days.
Quantity of continuous water in cubic feet per second per acre necessary for irrigation	·02486	·01740	·01501	·01005

III.

—	Meadow land.		Arable land.	
	Watering once in 7 days.	Watering once in 10 days.	Watering once in 14 days.	Watering once in 20 days.
Area in acres that can be irrigated by one cubic ft. per second	40·23	57·47	66·66	99·16

IV.

—	Area in acres.	Sandy soil.	Clay soil.
Supply necessary for each acre of the irrigable area . . .	1·00	·01346	·00924

"Result adopted for calculation of supply to 1 acre: in sandy soil, ·01346 cubic ft.; in clayey soil, ·00924 cubic ft."

" In Table I. the quantity of water sufficient for one irrigation or watering is taken at 15,045 cubic feet for meadow and 18,173 for arable land. It cannot be doubted, by any one conversant with irrigation in India or Spain, that this quantity is excessive.

" The object of ordinary irrigation in hot climates is simply to supply the place of rain and soften the soil, and differs much from the irrigation of lands in colder regions, which, partaking of the nature of sewage irrigation, has for its object the deposition of a fertilizing sediment rather than a supply of moisture.

" This latter description of irrigation being excluded from the project and data under consideration, the former alone has to be dealt with ; and for such purposes, in India and in Spain, a watering of 10,000 cubic feet is ample, either for pasture or arable land. One such watering represents a depth of ·23 feet over an acre, and is equivalent to a continuous supply throughout the year of ·000317 cubic feet per second.

" In a hot climate, or with a drier soil, a greater number of waterings might be required, but not a larger supply at each watering."

From the foregoing tables the number of waterings appear to be forty-six and twenty-three in the year for meadow and arable land respectively on sandy soils, and thirty and fifteen on clayey soils. "Leaving out of consideration the fact that these waterings are a half and three-quarters larger than would be requisite in India or Spain, their number seems excessive.

" In India the number of waterings prescribed on the Nageenah Canal, North-west Provinces, is thus :—

For fruit-gardens	8 per annum.
,, hemp	5 per crop.
,, rice, indigo, sugar, tobacco, grass, herbs	4 ,,
,, cotton, wheat, barley, grains, and pulses	3 ,,

"In Spain the number of waterings in the year generally necessary are :—

For corn, flax, potatoes, olives, and pines .	6 waterings.
,, meadows and artificial grasses . .	8 ,,
,, garden produce	20 ,,

and these by no means show the highest duty obtained by water in Spain ; for gardens on clayey soils are irrigated with ·0014 cubic feet per second per acre through the year, and only require double or treble that amount, say ·004 cubic feet per second, in very dry seasons ; whereas the watering of garden land with twenty irrigations, as above, requires ·012 cubic feet." *

The assessment of the water rate is made in three different ways :

1. By fixed outlet, or by measurement.†

"The small channel of supply being constantly full and of a certain section, may be charged at so much per square inch or square foot of section, independently of the amount of pressure, for a certain time, as the day of 24 hours. This has been adopted in Italy, but has not been found to work well.

"A further development of this method is to measure by module all the water as distributed, a mode more

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* Jackson, "Hydraulic Manual."

† There are three methods of measuring the discharge of a stream :—

1. By weir-gauges (for small streams) with notch orifice. The right-angled triangular notch is the best form of orifice, as it measures large and small quantities with equal precision, and has a sensibly constant co-efficient of construction. When orifices are wholly immersed, round or square holes are the best, because their co-efficients of construction vary less than those of oblong holes.
2. By current meters, in which the rotations of a fan driven by the current are registered by wheel-work.
3. By calculation, from the dimensions and declivity. Weeds have been known to increase friction tenfold.

likely to be adopted at present, now that modules are less expensive and more effective than formerly.

"2. By the area of land irrigated, or by crop.

"3. Water distribution by rotation.

"An irrigating channel of fixed dimensions, giving a constant fixed discharge, passes through the lands of several proprietors; a period of rotation is fixed for this channel, from 6 to 16 days, according to the crops. Each landowner can then have the whole volume of the channel turned on to his land once in the total period of rotation for a certain number of hours, as from 2 to 40, or 50, according to the amount of land he owns.

"For example. Let 10 days be the period of rotation, and let him require 12 hours' supply once in that period. His name is placed on the list, say sixth, and he gets his supply turned on at a fixed hour, and turned off at a fixed hour also. If the channel gives 20 cubic feet per section, his amount of water is equivalent to a continuous discharge of—

$$\frac{20 \times 12}{240} = 1 \text{ cubic foot per second.}$$

In this way intermittent supplies admit of mutual comparison." *

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* Jackson, "Hydraulic Manual."

CHAPTER V.

MODES OF IRRIGATING.

The mode of laying on the water must depend on the configuration of the surface, and on whether the land is under grass or tillage.

The systems that deserve to be specifically noticed are —Bed-work Irrigation; Catch-work Irrigation; Sub-Irrigation; Side-Irrigation with open Drains; Pipe and Hose Irrigation; Irrigation by Surface Pipes; Flooding, or Swamp Irrigation; Sewage Irrigation; and Warping. The three last-mentioned systems will be dealt with separately, however, in future chapters. Water-drills, carts, sprinkling-pots, and syringes ought also to be mentioned.

Bed-work Irrigation.—This system is only suitable to grass lands of a level or nearly level surface. It consists in laying out the ground into sloping beds or ridges, 10 or 12 yards wide, according to the nature of the soil, having their upper ends lying in a gentle slope from one end to the other of the meadow (Fig. 1). The main feeder or conductor is taken out of the river or canal, as the case may be, at a sufficient level to command the upper ends of these ridges. From this conductor the water is carried by small trenches or irrigating channels (*a*) along the tops of the ridges. These irrigating channels, or distributors, are made 4 or 5 inches deep, and 12 inches or more wide at their junction with the main conductor, the width gradually lessening as they recede from it. When the distributors are filled, the water overflows on both sides, and is taken up by the furrows or drains (*b*) which occupy the hollows between the ridges. The water thus collected by the furrow drains is received by the main drain, which conveys it back to the river from which it was taken, or carries it on to water other meadows, or other parts of the same meadow below. The main drain is, of course, cut across the lower ends of the beds, and requires to be made nearly as large as the conductor. Fig. 2 shows a section of the bed-work.

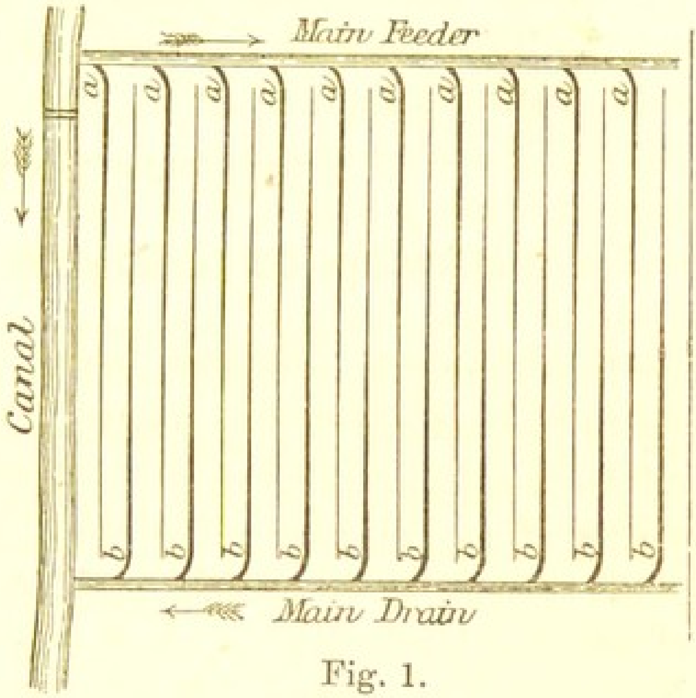

Fig. 1.

Fig. 2.

The dimensions and inclination of the conductor and distributors should be so regulated to the water-supply that the beds can be wholly laid under water to the depth of about 1 inch. The conductor must be tapered off towards its farther end, in order that the diminished supply of water may still overflow; and the distributors must likewise be made to taper towards their farther extremity, both for the purpose of retarding the velocity of the water and of preserving a continuous overflow along their whole length. On the other hand, the small drains and the main drain should gradually widen towards their lower extremity. The distributors and small drains are usually made from 12 to 18 inches wide at their junction, and from 6 to 9 inches at their ends. The inclination of the ridge itself should afford a fall of 1 in 500, and the inclination of the sides of the ridges may vary from 1 in 100 to 1 in 1000, according to the retentive power of the soil. Ridges should not be more than 100 yards long.

Few if any meadows are now laid out on the bed-work system, as it is only applicable to flat meadows, which can generally be rendered productive without the sacrifice of land which is involved in throwing them up in ridge and furrow form, and cannot be carried out without very considerable expense, the cost of the work often ranging from £10 to £20 per acre.

Louden gives an example of a very complete piece of bed-work irrigation (Fig. 3), which was formed for the Duke of Bedford, by Smith, at Priestley, on a meadow of irregular surface. The water is supplied from a brook (*a*), to a main feeder, with various ramifications (*b b*) ; the surface is formed into ridges (*c c*), over which the water flows, and is carried off by the drains (*d d*) to the main drains (*e e*), and to the brook at different places (*f f*). There are bridges (*g*) over the main feeders, small arches over the main discharging drains (*h*), and three hatches (*i*).

Formation of Water Meadows on the Bed-work System.—Sir John Sinclair gives the following particulars on this point : " The water being carried with a proper fall—that is, with from 1 inch of fall in 20 yards to 1 in 30 yards, according to the weight and velocity of the water above the mouth of the conductor—to the highest part of the meadow, the next object is, to make the conductor large enough to receive all the water that the stream contains if there is land enough to use it. If there is a great fall from the wear or dam (sluice) to where the meadow is to begin, it (the conductor) may be made comparatively deep and narrow (Fig. 4); but on nearly level ground it must be made shallower and wider (Fig. 5), as it is only near the top of the stream that the water has any draught. It

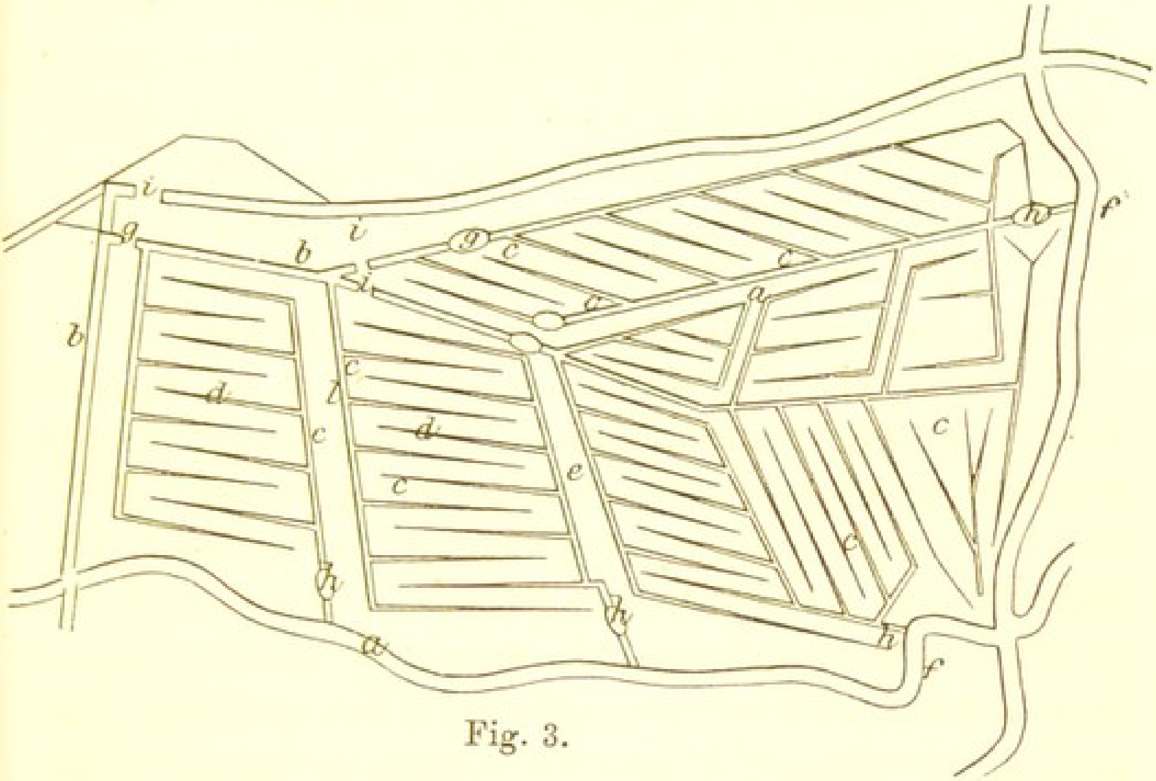

Fig. 3.

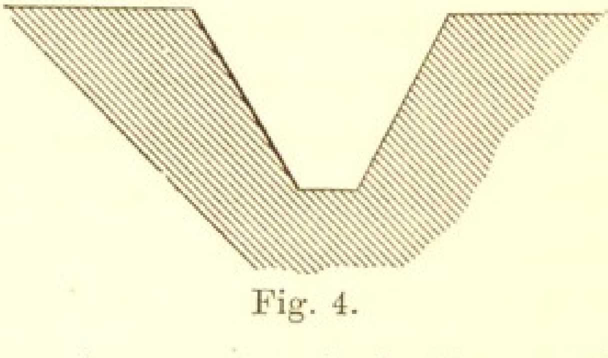

Fig. 4.

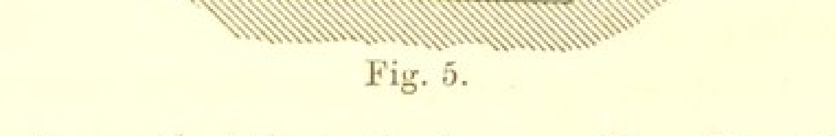

Fig. 5.

is of no use to make the bottom of the conductor deeper than the feeder will draw the water out of it; neither is it of any use to make the bottom of the feeder any deeper than the last floating gutter (or irrigating channel) will draw it off. . . . . In forming the master-feeder it will be necessary to ascertain the breadth and depth that will hold all the water that the conductor brings to it, and thence to the end of the feeder, where the last floating gutter goes out. Its breadth should be diminished all the way; and whatever its breadth may be at the beginning, it should end about 2 feet in breadth where the last floating gutter goes off.

"If the ridges or beds be 10 or 12 yards wide, and about 100 yards long, with 6 or 8 inches of fall, the breadth of the floating gutters should be about 18 inches at the head, or 2 feet, according to the length of the gutter, and about 6 inches at the lower end of the ridge. This diminution of the gutter serves to force the water out over the sides of the beds; and as a part of the water is always going out of the gutter, it is always growing less, and consequently does not require so much room to hold it. The stuff that is taken out of the feeder should be laid smoothly along its sides, with a slope outwardly, and raised about 6 inches above the surface of the ground; and in crossing ridges the hollows must be filled up with superfluous stuff from the high places or out of the drains, so that the top of the banks of the feeder may represent a straight horizontal line, and keep the water above the surface of the ground, which is necessary to make it flow down and over the sides of the floating gutters with proper effect.

"In making the floating gutters, after both sides of one are cut with a spade, by a line, then cut again with a spade down the inside of your lines on both sides, beginning at the head about 5 or 6 inches from your line, so diminishing all the way down to the end, and pointing the edge of your spade so as to make it intersect your outside cut. When both sides are done, the land in the breadth of the gutter will be divided into three strips, the outside of which will be loose, and will turn out whole in triangular furrows, which form the sides of the gutters and keep up the water above the surface of the ground. After the sides are cut, there will remain a fast strip in the middle, which must be taken out and laid in equal portions on the outsides of the said furrows, or into the lowest places. In taking out the fast strip, it is best to leave here and there a piece unremoved, which serves for stops and saves putting in afterwards. These stops will be wanted more or fewer in number, according as there is much or little descent in the floating gutters. When there is nothing left in for stops as above, the defect must be supplied by putting in boards or sods to check and raise the water to the height you want it. Without stops the water would all flow to the lowest end of your work, and there run out too deep; while the higher parts of the meadow would remain dry. Notches are commonly used at first in letting out the water from the feeders and gutters over the beds; but when the sides become older and firmer, it may be made to flow over them. The breadth of the beds should not exceed 10 or 12 yards; but if less than 8 yards, it is best, in general, to put two into one, either with the spade or the plough. The length of a division of floating gutters should never exceed 100 yards in the ridges or beds; because, if they are too long, it makes the water more difficult to regulate, and, if the stream be fluctuating when the water falls in, the upper parts of the beds will be dry. All floating is the better of a descent, from the crown of the ridge to the furrow, of from 1 inch in a yard to 2 inches. This must be attended to if the land is to be formed into beds with the spade or the plough; but where it is in proper ridges before, they may be taken as they are, be the descent less or greater than as above.

"At the lower end of the meadow, and indeed at the end of every set of beds, there must be a main drain, and betwixt every two gutters there must be a small drain, to receive the water that flows over the beds and carry it into the main drain. These small drains must be parallel with and reverse in their dimensions to the floating gutters, least at the upper and largest at the lowest end; whereas the gutters are largest at the upper end and smallest at the lower. These small drains, if in a dry soil, will do 6 inches wide at the head and 18 inches at their junction with the main drain. The stuff that is taken out of them is always wanted to make up hollows, or to make up the banks of the feeders, to carry them through low places to higher ground; but wherever it is put it must be properly smoothed to let the water flow regularly over it.

"When a meadow is large and the surface not all upon one section, but has high and low places in it, more feeders must be made, and more cross or master drains. Sometimes it happens that a feeder must cross a drain in carrying the water from one eminence to another through a hollow: in this case a trunk must be made with boards of the size of your drain and placed in it, and the feeder carried over it. The trunk must be as much longer than the width of the feeder as will be sufficient to give room for proper banks to the feeder, otherwise the weight of the water will force them out. If the feeder be small and the drain large, it will be cheaper to make the trunk or spout correspond with the size of the feeder, and carry the water over the drain in it. Hatches or sluices (one or more according to the size of the feeders) are always necessary in the mouths of them, for excluding or admitting the water at pleasure, and also for changing it when the meadow is divided into divisions."

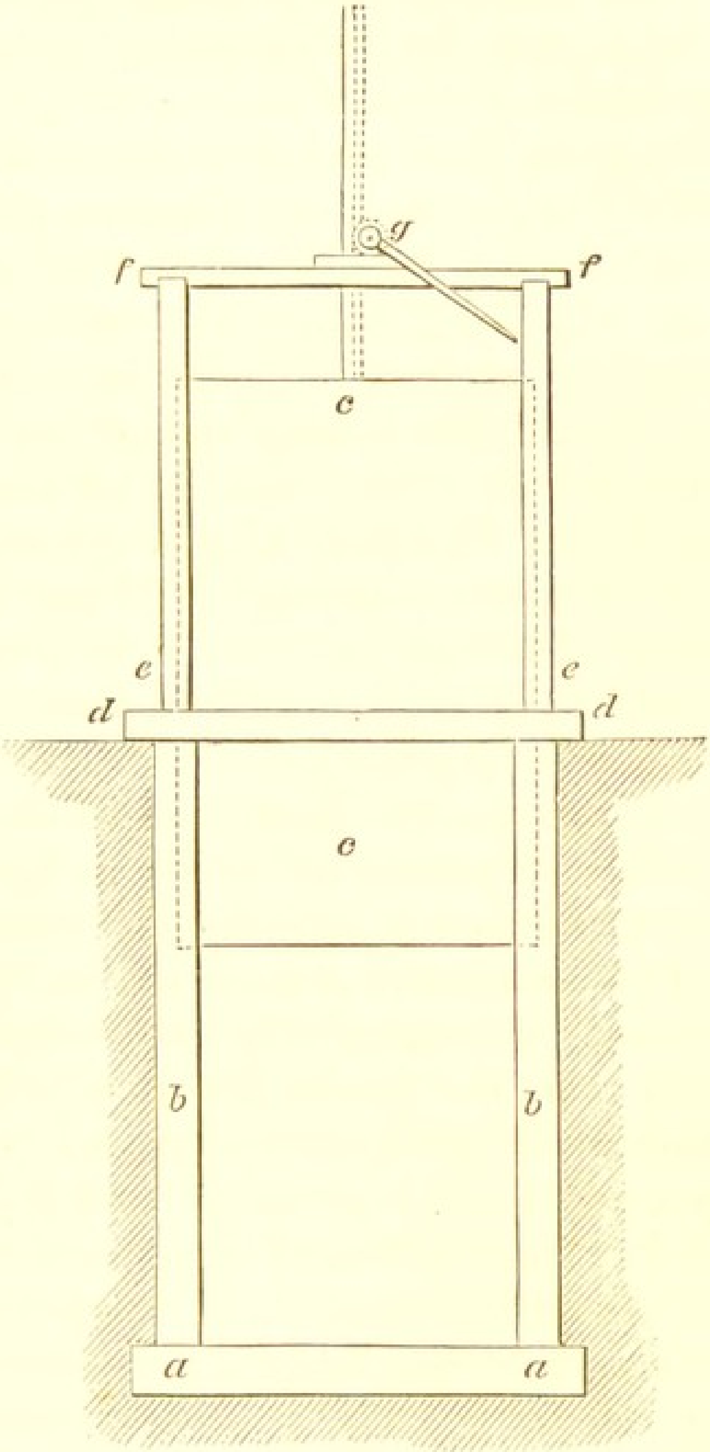

Fig. 6.

Various kinds of sluices are employed to take in water from the river or canal, &c., to the main feeder. Fig. 6 represents a good construction by Mr. R. Scott Burn. "*a a* is the stone sill, *b b* the side quoins in which the grooves are cut, and in which the wood or sheet-iron sluice-door (*c*) slides up and down. The stone flat (*d d*) supports the wooden uprights (*e e*), carrying the cross-bar (*f f*) in which the pedestal of the toothed wheel (*g*) is fixed, this gearing with the rack of the stem of sluice door."

Wooden "stops" for the small channels are seldom used, a turf or a spadeful of earth serving the purpose. Fig. 7, however, illustrates a wooden stop made of "two boards (*a a*) joined together, but kept separate by pieces at the end into which the sluice board (*f f*) is passed, being lifted up by the hand-hole (*g*), and kept apart at any point by the wedge (*h*). The aperture to allow the water to flow through is *b c d e*, the edge (*c e*) being on a level with the bottom of the channel."

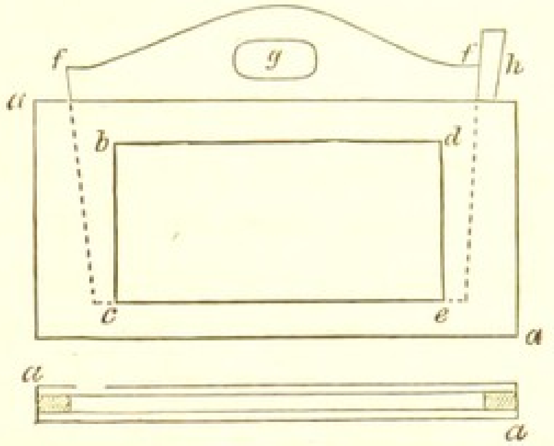

Fig. 7.

Catch-work Irrigation.—This differs materially from the bed-work system. It can be applied to sloping and undulating surfaces as easily as to level lands, and to lands under tillage as well as under grass; it sacrifices no land and costs very little, and it is quite as effective as the more expensive bed-work.

The feeder or conductor, formed as before, is led along the highest side of the field, and a spring or small stream directed into it is made to overflow the side by the end of the ditch being dammed up; but as the water would soon cease to flow equally for any great length, and would wash the soil away in places, small parallel gutters or trenches are cut, at distances of 20 or 30 feet, to catch the water again (Fig. 8); and each of these being likewise stopped at the end, lets the water over its side, and distributes it until it is caught by the next; and so on over all the intermediate beds to the main drain at the bottom of the meadow. Fig. 9 represents a section of this system. The cross gutters must be laid out perfectly level, and of course on most lands will be winding; and these again are sometimes crossed by feeders running from the conductor to the lowest side of the field, thus forming a kind of check work.

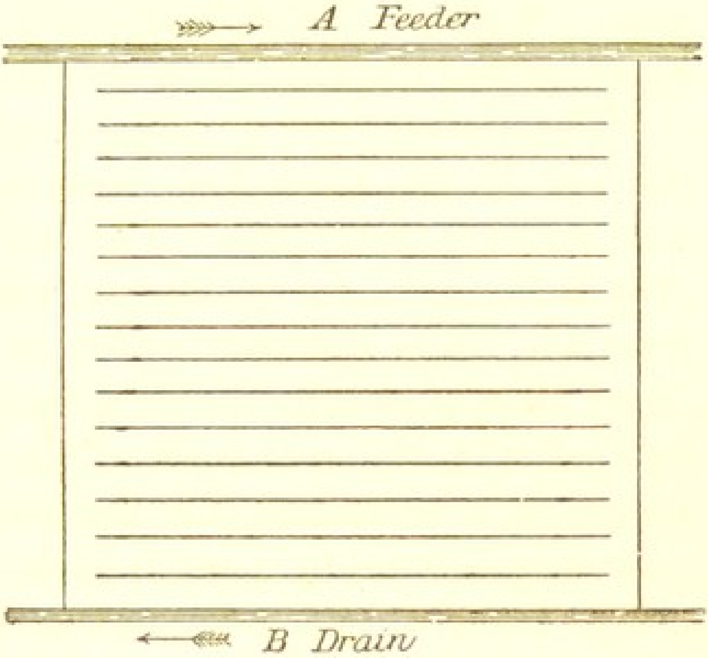

Fig. 8.

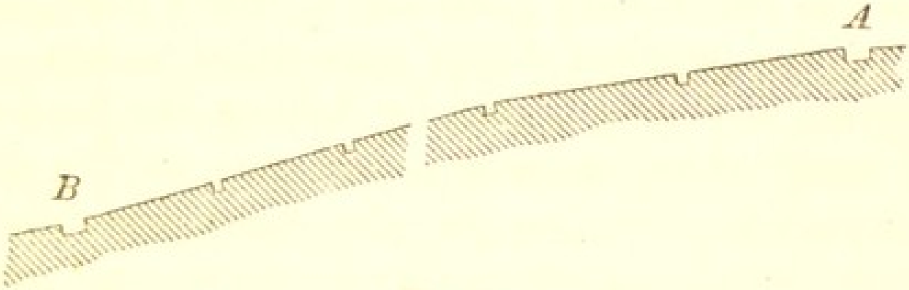

Fig. 9.

Fig. 10 shows the latter plan of catch-work, in which "the channel of supply at *a a* delivers the water to the gutters (*c c*), which again deliver it to the branch gutters (*c*). The water flowing from these over the surface of the land reaches the lowest level, where the catch-drains (*b b*) are placed; these deliver the water to the channel (*b b*) which carries it finally off."

The cross gutters are rapidly thrown out by the plough, and may be renewed every year if necessary on grass as well as on ploughed land; while the principal feeders and drains remain, and at most only require to be repaired and filled with water.

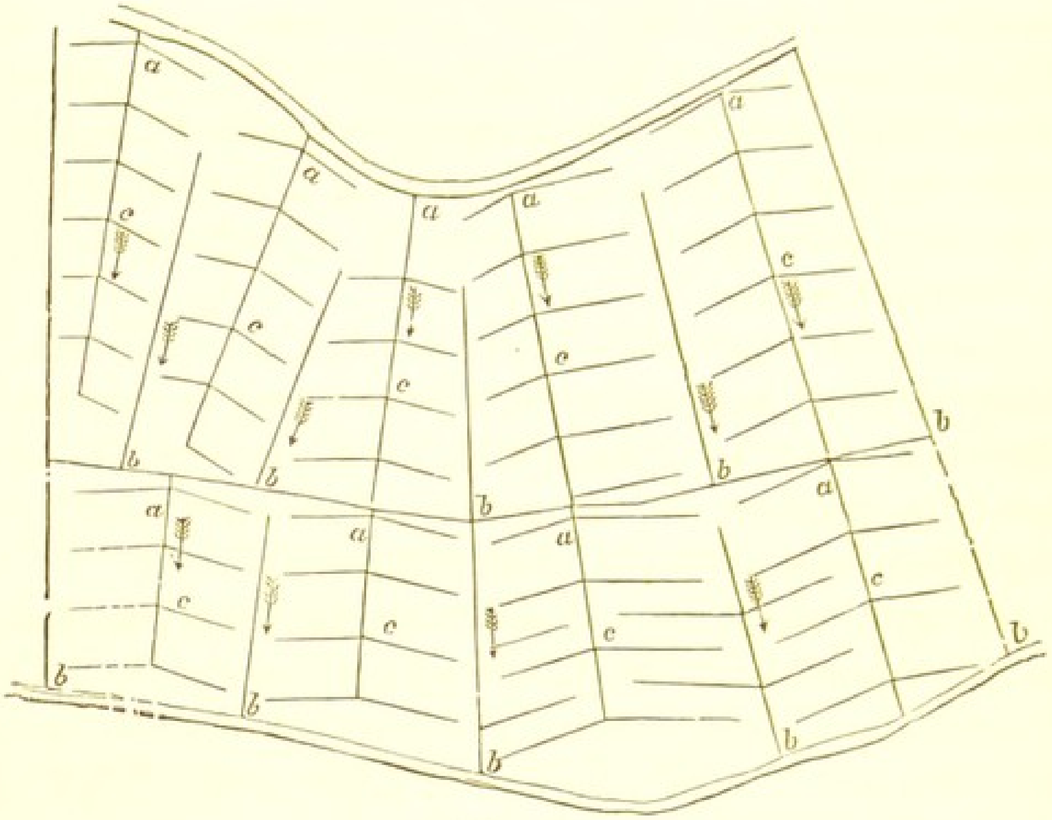

Fig. 10.

As to other modes of watering in catch-work, the diagonal system is perhaps the most effective.

In all cases when the water seems to have sunk, it should be taken up again by opening a new trench for it, in order to collect or *catch* it, for diffusing it over another surface.

In Pennsylvania, Dr. Edwards tells us, "hills so steep as not to be arable are watered, and produce greater quantities of grass than flat grounds, without ever having had a forkful of manure put upon them, and are now richer than they were thirty years ago, after having had two crops of hay, and sometimes three, annually taken from them."

He describes the American plan of watering uplands as follows: "The first object, certainly, is to secure a complete command of the spring or stream to be made use of. For that purpose a drain must be made as near the source as the circumstances of the case may require, and the water must be then brought on the same level, by a canal or ditch all along the side of the hill.

"The spirit-level is made use of for the purpose of finding out the proper line to conduct the water. When the true level is found and the canal made, the water should be turned into it, which, if stopped either at the far end or any part of it, with a gate being shut down, it will flow over and irrigate the land below; or the canal may be made so high on the bank that the lower side of it shall be about 6 inches above the water when standing on a level with its source; and it is then let out by small gutters, about 10 or 15 feet from each other, which are spread a little below by arms each way, so as to meet one another in such a manner as to throw all the ground under water. By this mode, if there be plenty of water, the whole ground may be irrigated; but if it be scanty, half of these gutters may be stopped by small sods one day, or two days if necessary, and the other half afterwards, when the first are taken up; so that the whole can be flooded alternately every other day; a practice preferred by some, even where the water is abundant.

"At a distance of near two rods below the first canal another is made, to receive all the water that has flowed over the ground between the two, and again turned out as above;" repeating the process till the lowest level of the field is reached.

"The whole surface of the land to be irrigated should be made so fair and smooth that where the water is turned out to produce its great effect, there should not, to have it complete, be a hollow or hillock, in which a drop of water can stand, or over which it cannot flow."

Sub-Irrigation.—This consists in saturating a soil with water from below instead of from the surface, and is effected by a system of subsoil pipes, which, proceeding from a main conduit or other supply, can be charged with water at pleasure. In some parts of the United States perforated pipes are used for the purpose, but the common drain-pipe answers quite as well. The usual plan is to surround the field with an open drain or main, and intersect it by covered drains communicating with this main. If the field is level, nothing more is necessary than to fill the main, and keep it full till the ground is sufficiently soaked. The water escapes through the joints of the pipes, and rises into the superincumbent soil, by pressure and by capillary attraction, to as great a height as the water is standing in the main drain. In this manner water may be given to the roots of plants in dry weather; and when the saturation is complete the whole of the water may be removed at will by opening the drain outlets and reestablishing free drainage. When the land slopes, the lower ends of the drains must be closely stopped, and the water admitted only into the main on the upper side; this main being kept full till the land is soaked, after which the mouths of the lower drains are opened to carry off the superfluous water.

It is claimed that this method produces all the good effects of surface irrigation with a much less quantity of water, while the surface soil does not bake. For lands under tillage the plan is an excellent one, particularly on porous soils. Of course, by this method, no deposit from the water is left on the surface of the land. It is chiefly adopted on fens and drained morasses, which are apt to become parched in summer; but it would be very valuable for all light soils under green crop in seasons of drought.

Side-Irrigation with Open Drains.—On this system the field is intersected by open drains, at the usual distances, which communicate with the open ditches or drainage canals. When the land is to be irrigated, water is let into the ditches, and thence to the small drains, till it rises to or near the level of the surface; and the ground is laid dry again by opening the sluice valves, and emptying the side ditches. The Demerara field system (Fig. 11) offers unusual facilities for this method of irrigation, in the simplest form. By stopping up the small drains at *a a* near their junction with the side-line draining trench, and then filling the navigation trenches to overflowing with fresh water, the open drains become collectors, and the water can be made to rise in them to any desirable height, swamping the entire ground surface if necessary. When the watering is complete, the pressure of water from the navigation trenches is withdrawn, the stoppages

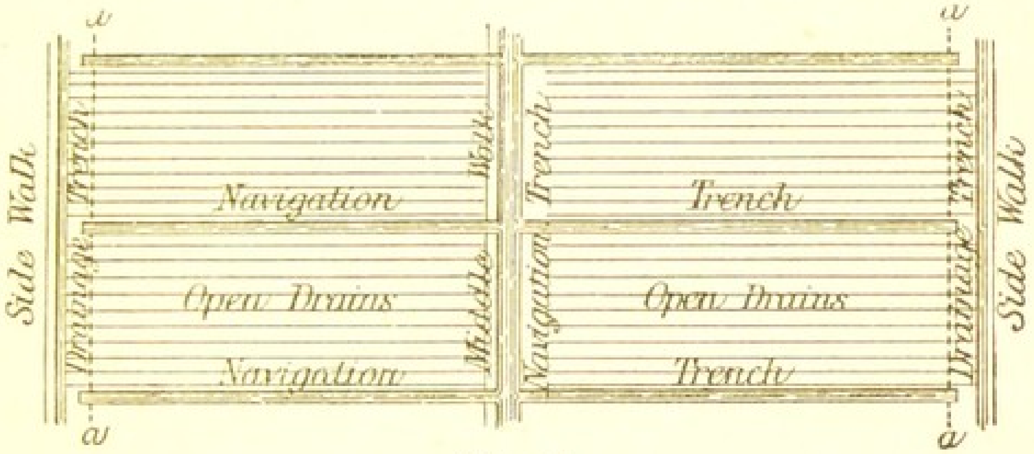

Fig. 11.

in the drain mouths are removed, and the surplus water is free to escape to the draining trench. Where a sandy or gravelly soil rests on a retentive subsoil, this mode of watering may take place without drains by filling to the brim and keeping full for several days surrounding trenches; but the beds or fields between the trenches must not be too great.

Irrigating by Pipes and Hose.—"There are many cases in which the methods of surface irrigation previously described are unsuitable. Where the surfaces are irregular, where the crops are changed several times in a season, where the ground is under biennial or perennial crops, and furrows cannot be maintained, or where the ground is too valuable to be occupied by furrows or water channels; these and other conditions will be favourable to one or other of the following plans. The first to be treated of is that of underground pipes and stationary hydrants, from which

Fig. 12.

water may be distributed under pressure through india-rubber hose and sprinklers (Fig. 12). An elevated reservoir is provided, from which an iron pipe, having a capacity equal to an inch and a half in area for each acre to be irrigated, is carried along the centre of the garden. A 2-inch pipe will be required for two acres, a 3-inch one for four acres, and a 4-inch one for eight acres. From this pipe others are carried at right angles 200 feet apart to within 100 feet of the boundary upon each side. The pipes are laid a foot beneath the surface, or so far that they can never be disturbed by the plough. Upon the lateral pipes, which should be at least an inch and a half in diameter, so that the flow shall not be unduly interrupted by friction, upright pipes, or hydrants, are attached, which project at least three inches above the surface of the ground. These are about 200 feet apart. They are furnished with valves, which operate by means of a square head and a key. Each one is fitted with a cap which screws on or off, and which is attached to the hydrant by a short chain for its preservation. When this cap is unscrewed, a section joint affixed to the end of the hose may be screwed in its place."

"When this apparatus is in operation, the water descending from the elevated tank or reservoir passes through the pipes and the hose, and escapes with some degree of force, depending upon the height of the head, through a flattened nozzle, which scatters it in a thin sheet or broken shower. With this apparatus one man may water copiously five acres of ground in a day or night. Each hydrant being the centre of a plot 200 feet square, serves to irrigate, with 100 feet of hose, very nearly or perhaps one acre of ground. To irrigate five acres in ten hours would give an hour and a half to each plot, and amply sufficient for an active man to get around a plot of 200 by 200 feet."*

An improved nozzle for shower irrigation is manufactured by Messrs. J. Warner & Sons, London, and is represented in Fig. 13.

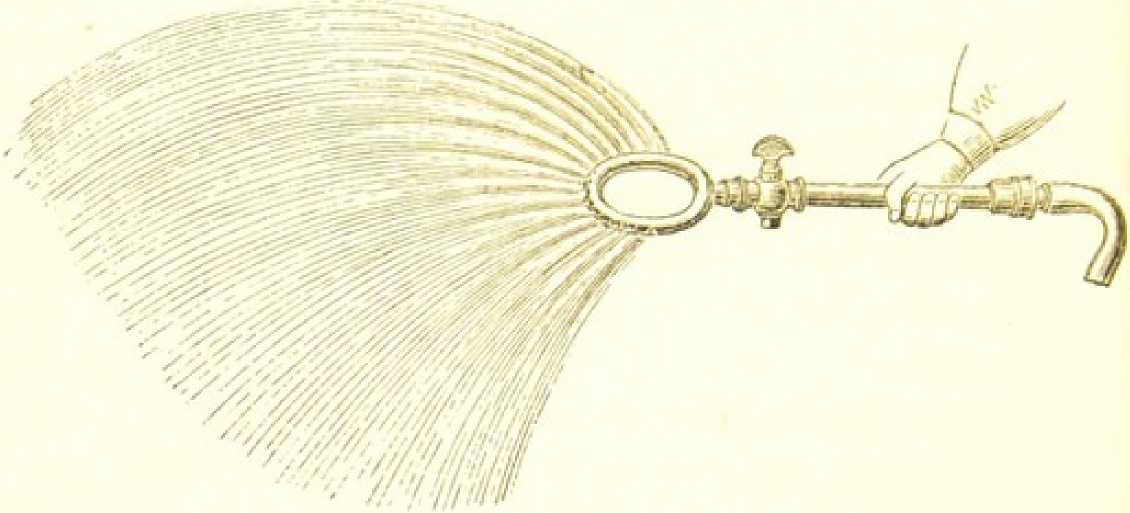

Fig. 13.

Irrigation by Surface Pipes.—By this method the distributing pipes are laid upon the surface of the ground, and are perforated in such a manner that the water is discharged in a shower of spray upon the

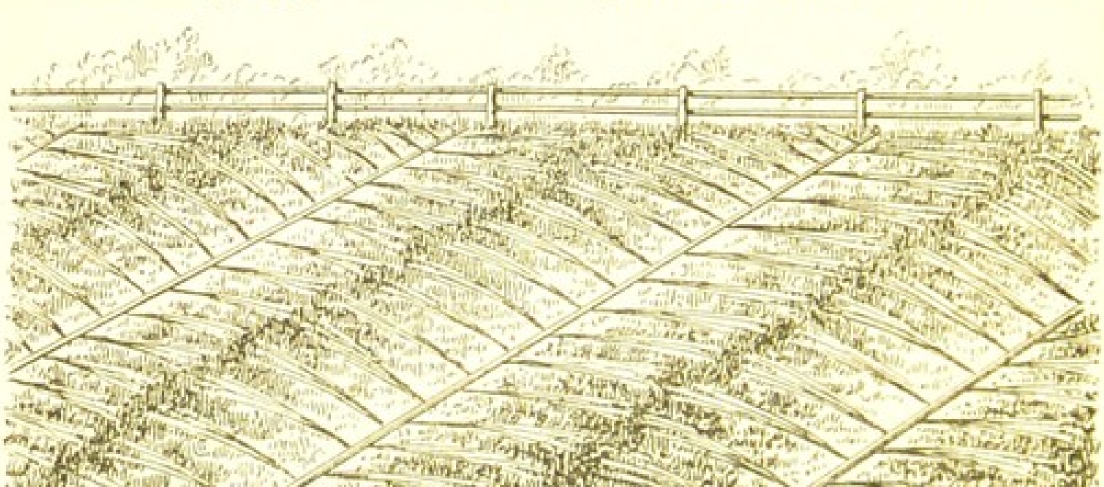

Fig. 14.

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* Stewart's "Irrigation for the Farm, Garden, and Orchard."

ground (Fig. 14). The distance the pipes are laid apart may be 24 feet or more, but this will depend upon the pressure and force with which the water is discharged. The disadvantage of this system is its first cost; but once the apparatus is provided it can be put in operation with little expense, all that is required being the turning on and off of the water at intervals.

Water-Drills, Water-Carts, Garden-Engines, and Syringes.—The water-drill is now in great request for sowing turnip and mangel seeds in dry weather. As these crops are put in at one of the driest periods of the year, its use insures a rapid and healthy braird of the young plants. The drill is a common turnip and manure drill, with the manure-barrel fitted for carrying water and for distributing it in the rows immediately underneath the seed. The quantity of water can be regulated, and either pure water or manure water may be used. In the latter case superphosphate, or guano, is dissolved in water, and the mixture used at the ordinary rate for dry manure per acre. The water-cart is sometimes used in dry weather for watering drilled crops after they are started into growth. Two forms of improved water-carts are shown in Figs. 15 and 16. The former is manufactured by Messrs. Colman & Morton, Chelmsford; the latter by Messrs. James & Son, Cheltenham. Each of these carts is fitted with a short hose for dropping into the tank or well, &c., and a pump for filling it with ease and rapidity. Garden-engines and Syringes, though very

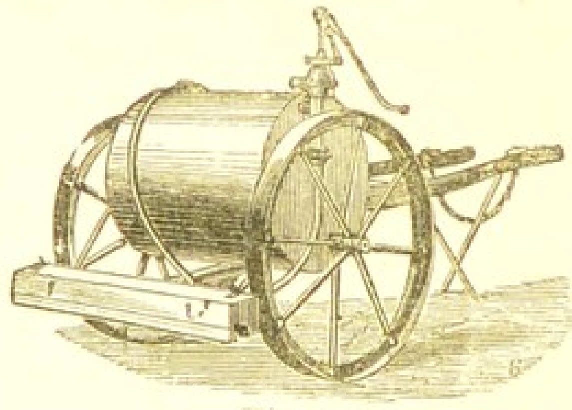

Fig. 15.

serviceable in their place, are of course only useful where a few plants or beds of ground are to be dealt with. Fig. 17 shows a special syringe, manufactured by J. Warner & Sons, for washing hop vines. By means of this instrument all parts of the vine are easily reached, and it effects great saving in the washing mixture.

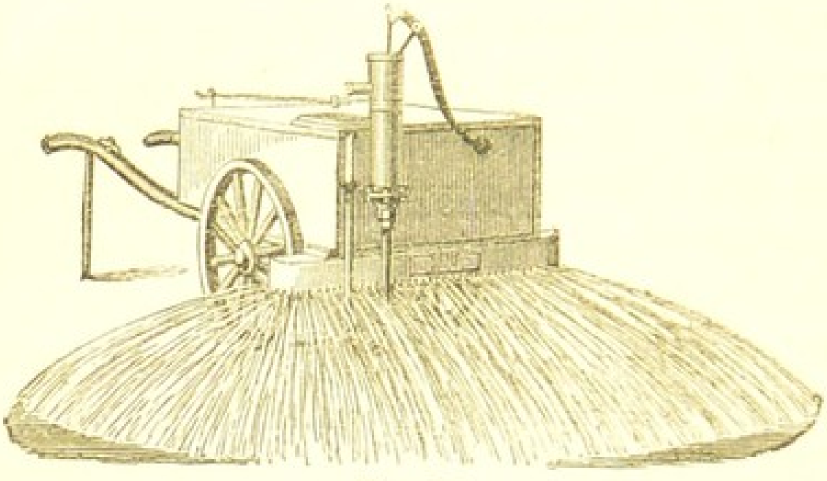

Fig. 16.

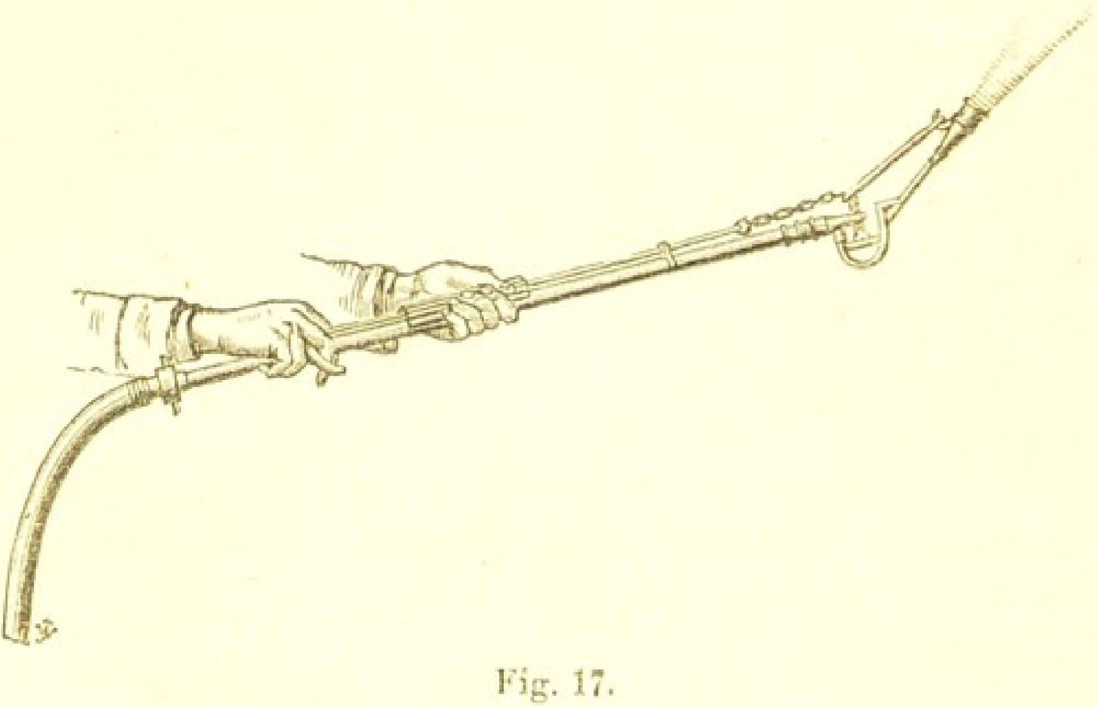

Fig. 17.

CHAPTER VI.

MANAGEMENT OF IRRIGATED GRASS LANDS.

Application of Water.—On English water-meadows, as a rule, the irrigating season begins at the end of October, and is continued till about the first week in April. The usual plan is to keep the land flooded to a depth of about 2 inches during the months of November, December, and January, for a fortnight or three weeks at a time, and then let the water drain off from it for a week or so before flooding again. In February and March the waterings are gradually shortened to eight days at a time. At the beginning of April the land is left dry, and in May the grass crop is cut.

In November the water is used very plentifully for the first three weeks, after which it is taken off for a week, or changed to another part of the meadow. When the grass turns dark the water should be taken off. A standard work on farming directs that it should be taken off on occurrence of frost. The true rule, however, is not to take it off nor to lay it on in a frost;—not to take it off, because the water, freezing on the ground, forms a coat of ice which protects the grass; not to lay it on, because the ground, being already frozen, can be no longer protected.

In December and January the chief care consists in keeping the land sheltered by water from the severity of frosty nights. In very frosty weather it is better to take off the water from the meadows altogether if it is severe, and likely to continue long; but this must be done at the beginning of the frost; if this has not been done the water should be allowed to remain on during the continuance of the frost. The danger from frost is, that if ice forms under and around the roots of the grasses the plants may be thrown out by the expansion of the water. This can only be prevented by keeping the grass protected by water, or else making the land so thoroughly dry that no injury will result from frosty weather. In spring the young and tender shoots of grass are easily nipped and destroyed by frost, if these precautions are neglected.

In February the management is much the same as in January, only, if the weather is mild, the water will require to be taken off or changed more frequently. If the water remains on for many days about the end of this month, in bright weather, a white scum arises, very destructive to the grass; and if the land is exposed, without water, to severe frosty nights, the greater part of the grass will be killed. The only way to avoid this is to take the water off early in the morning, and turn it over at night; or, if the day be very dry, keep the water off altogether during the frost, for it is only when the grass is wet that the frost has a pernicious effect.

In March, as vegetation sets in, care must be taken to shelter the young grass as much as possible. When the water is changed or removed, a mild day must be chosen for it; and it is best to do it in the morning, that the ground may dry before night, and be able to withstand a frost the better. In this month scum on the water must be guarded against; but, instead of changing the water at stated times, it should be done according to the weather, always taking advantage of a fine day, which may vary the time from a week to once in a few days, less or more.

If the meadows are to be spring-fed, the watering ceases about the middle of March, or the first week in April at latest. Early in May, when the spring-feed is eaten off, the water is used for a few days before laying up the meadows for mowing; and again when the hay crop is carried off.

The watering of grass lands, other than water-meadows, is very simple, as it is seldom practicable to lay them under water, and they can only be irrigated by flowing the water over them. This is done at intervals, which will be determined by the weather more than anything else. As the grass is never completely covered, the irrigation cannot be carried on in frosty weather; so that on high lands, and, indeed, on most catch-work meadows, where the ground slopes or is undulating, it is impracticable to irrigate during winter, and watering has to be delayed until the spring frosts are over. This puts off the spring watering until April or May; after which, however, there is still time to grow a crop of hay. Any attempt to irrigate upland meadows in winter, and to pasture them in early spring, would but injure the meadow by means of frost, and at the same time rot the sheep.

Spring-Feeding.—The great value of water-meadows consists in the early spring feed which they afford, between "hay and grass," by which the farmer is enabled to breed early lambs. As soon as the lambs are able to travel with the ewes, about the middle of March or the beginning of April, the flock is put into the water-meadows. Care is taken to make them as dry as possible for some days before the sheep begin to feed them, and, on account of the quickness of the grass, it is not usual to allow the ewes and lambs to go into them with empty stomachs, nor before the morning dew is gone. The general hours of feeding are from ten or eleven in the morning till four or five in the afternoon, when the sheep are taken off and folded on swedes or mangel for the night, or else put into a dry meadow or pasture where a few swedes or mangel and some box-feeding can be supplied to them. The grass on the water-meadows is daily hurdled out in portions, according to the number of sheep, to prevent their trampling it down; but a few spaces are left in the hurdles for the lambs to get through and feed forward in the rich grass. One acre of good grass will be sufficient to last five hundred couples a day. The great object is to make the water-grass last till the winter rye, barley, and forward vetches, &c., come in for feed; the meadow is then laid up for hay.

Late spring pasturing on meadows is objectionable, as it always lessens the hay crop, and the harm done is usually in proportion to the dryness of the meadow. Water-meadows may be fed during April, and then be laid up for hay; but dry meadows should not be spring-fed at all.

Laying-up Meadows.—In regard to the time of laying-up the meadows, quaint old Tusser says:—

> "Spare meadow at Gregory, marshes at Paske,
> For feare of drie summer, no longer time aske;
> Then hedge them and ditch them, bestowe thereon pence,
> Corn, meadow, and pasture aske always good sense."

St. Gregory is the 12th of March; Paske is Easter; and Tusser's meaning evidently is that marsh meadows may be grazed a month longer in spring than dry meadows, and still yield a good crop of hay, however dry the summer.

After spring-feeding, before any water is given, the meadows should be put into the best condition for laying up. The ditches and furrows should be examined and repaired, the drains cleared, and all rubbish taken off the surface. Any inequalities of the surface should also be remedied with the spade, first taking off the turf, and then replacing it and beating it firmly down. The meadows are next bush and chain harrowed ; any rubbish brought up is picked off, and then the ground is rolled with a heavy roller. If any grass seeds are to be sown, it may be done previous to harrowing. Farmyard manure, if given at all, should be applied when the hay crop comes off, and only in a well-rotted state. Artificial fertilizers will rarely be necessary; but if given at all it may be in the form of a top-dressing, after laying-up for mowing.

Cutting.—From the great succulency of the plants produced in water-meadows, the converting of them into hay requires particular attention. It is desirable that the grass should be ready to cut early in the season, not later than the end of June or the beginning of July, when the weather is likely to be favourable for hay-making ; and to this end the meadows should be laid up early. It is not advisable, however, to cut the grass of water-meadows too soon, or before it approaches ripeness, as there is then more loss of weight and substance in the making. The best time to mow is when the bulk of the grasses are in flower, unless in cases where the grass has fallen down, and would spoil if it remained uncut. Attention, however, must be paid to the state of those plants which constitute the bulk of the crop, and if the rough-stalked meadow-grass, the scented vernal grass, the soft meadow-grass, are the most abundant, the grass may be cut earlier. In taking off the grass, carts and waggons should be used very carefully upon the meadows, lest ruts may be cut to the injury of the surface. Roadways across the meadows, from point to point, should be previously laid out, using wooden culverts where the roads cross the irrigating ditches or drains.

Repairs.—In addition to what is done at the time of laying-up for mowing, a water-meadow will require some annual repairs in autumn. Thus, in the month of October, when the after-math is fed off, the banks of the feeders must be repaired where they have been trodden down by the sheep or cattle, and the sand or mud that lodges in any of them thrown out. The sides of the feeders and gutters may be trimmed with a large sharp reaping-hook, and the bottoms may get a light shovelling out. The clearings may be trodden down smoothly at the back of the gutters, or put into hollow places, &c. ; but it must always be observed not to clean the floating gutters so hard at the lower end as at the upper, that the diminishing proportion of their size may not be destroyed.

Water-Meadow Grasses.—These plants, Dr. Singer observes, ought to be perennial, as it can never be intended that the meadow should soon be broken up. In America, timothy, or meadow cat's-tail (*Phleum pratense*), is greatly in favour for water-meadows ; and it is remarked that white clover bears drowning better than any other plant of that nature, although it does not yield the bulk which is desirable in a hay crop. By careful management, re-seeding, and manuring, timothy and clover may be retained in a water-meadow ; but many of the following plants are but slightly inferior to them, and, as they grow more abundantly and constantly, are better adapted to this culture:—(1) perennial red clover, or cow-grass, which naturally prospers where the soil contains a due proportion of marl or lime; (2) soft meadow-grass (*Holcus lanatus*), which thrives well in any soft soil, especially if it be also watered; (3) rough-stalked meadow-grass (*Poa trivialis*), which delights in a soil between loam and bog, possessed likewise of a degree of moisture; (4) crested dog's-tail (*Cynosurus cristatus*), which thrives well in watered loams; (5) sweet-scented vernal grass (*Anthoxanthum odoratum*), which hardly fails in any water-meadow where it has been once established, and whilst it adds to the bulk and weight of hay, it likewise communicates, if made in dry weather, the sweetest odour to the whole crop; (6) bent grasses, in particular white-bent (*Agrostis alba*), and creeping-bent (*Agrostis stolonifera*), or the famous *fiorin*, which some recommend in preference to every other, for water-meadows, long and fully irrigated.

The nature of the herbage upon an irrigated meadow, remarks Mr. Stewart, depends greatly upon the skill with which the irrigation is managed. If water is used in excess, the more valuable grasses disappear and inferior ones take their place—such as couch grass, the spear grasses, and other coarse species.

Italian rye-grass (*Lolium Italicum*) is extensively grown under irrigation in England and elsewhere, and yields repeated heavy cuttings of forage for soiling. It is the chief grass grown upon the Italian water-meadows, upon which it yields an aggregate cutting of forty tons and upwards of green fodder per acre yearly.

CHAPTER VII.

MANAGEMENT OF IRRIGATED ARABLE LANDS.

The irrigating furrows upon cultivated land can seldom be permanent, except in vineyards and the like, where there is not a constant change of crop going on. In such grounds a system of irrigation may be laid out as complete as in the case of a water-meadow, as the work will be permanent in character, and the first outlay will be the last, if the work is properly done. Generally, however, the irrigating channels on arable land will be destroyed at every ploughing, and must be re-made for every crop.

The watering of arable land and crops, though uncommon with us, is universal in warm countries, and even in Southern France, Spain, and Italy. In many cases the crop is grown in drills, and the water is simply introduced in the furrow between each row. In this mode of irrigation, no collecting drains are required, as the whole of the water laid on is absorbed by the soil. The principal expense of the operation is that of preparing the lands by throwing the surface into a proper level or levels. The main conductor carries the water to the higher part of the field, and the rest is easy. A side conductor should be formed along the entire length of the field; so that the field can be watered in sections if wished, by closing the supply-channel at any desired point.

With crops under flat culture, such as wheat or barley, there are other plans available. If the ground slopes, the ordinary catch-work system may be adopted, drawing with the plough light furrows from the main conductor at the top of the field, parallel and horizontal to it, or in diagonal or diamond form, or otherwise, according to the contour of the surface. On level ground the land may be ploughed into beds, and the water introduced in furrows during the growth of the crop: this may be done either by a system of side-irrigation, the soil absorbing the water from the ditches, or by regular flooding.

"In the flat plains of the Rioja," Mr. Roberts* tells us, "a small mound or embankment of clay is formed around each field; and when irrigation is required, the water is admitted from some of the minor channels, of which there is a network on every farm, through an opening in the bank, usually placed at the corner of the field. It is then allowed to flow until the enclosure is completely covered to a depth of about three inches, when the inlet is closed with a sod, and in a few minutes the water is all absorbed by the parched soil.

"In sloping ground the Spanish farmers often level the field into a series of horizontal plots or terraces, that each inclosure may be irrigated in the manner above described. When this is not done, water is admitted at the high side of the field, and allowed to flow over it; and numerous little cuts, like plough tracks, with their corresponding mounds, are made across the enclosure, or at right angles to the direction in which the water flows, so as to check its velocity, and thus facilitate its absorption by the soil."

This system is illustrated in Figs. 18 and 19. The

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* "Irrigation in Spain."

"divisions do not slope on both sides, but incline in one direction, as shown in Fig. 18, at *a b*, *a b*, *a b* ; but are horizontal, in the direction of the arrows in plan,

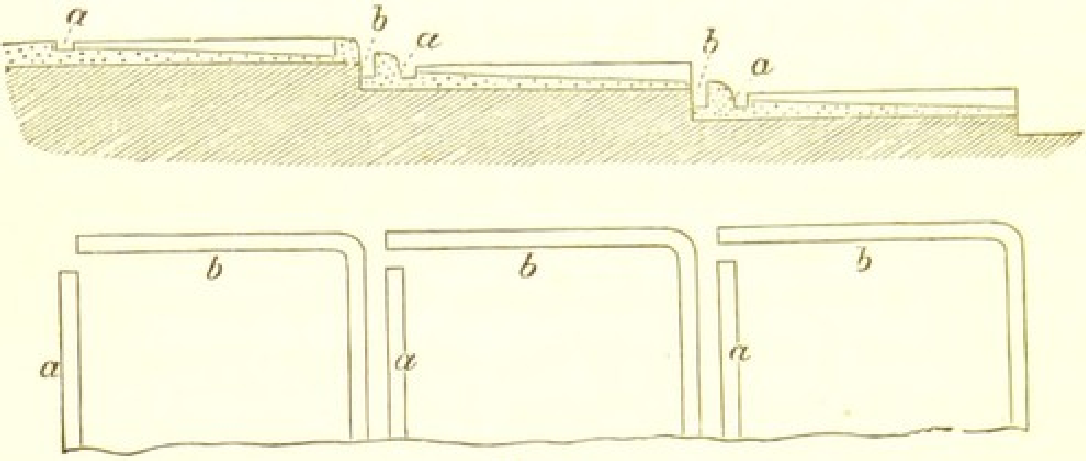

Fig. 18.

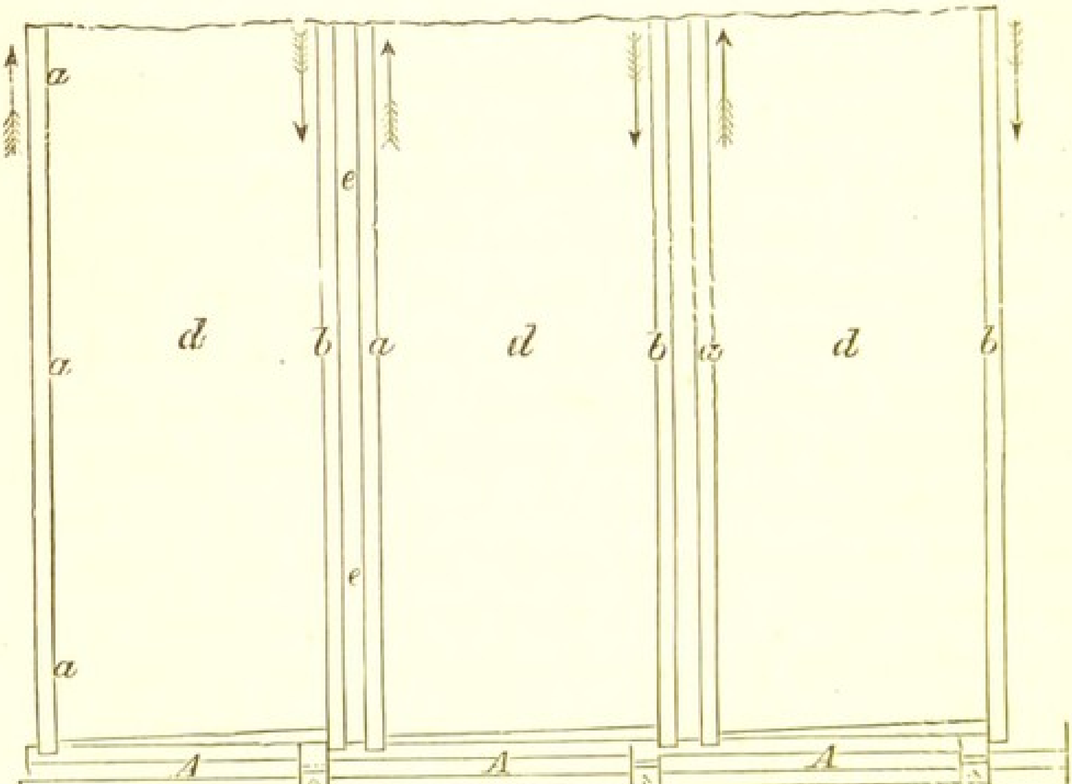

Fig. 19.

Fig. 19. The channel of supply is at *A A*, and sluices are provided at *C C C*, by which the water can be let into or kept out of the channels of distribution (*a a*),

placed at the upper side of the inclined divisions (*d d*). The channels of distribution (*a a*) are divided from each other by small embankments or ridges, as shown in section in Fig. 18. The water, after passing over the surfaces (*d d*) is taken up by the channels (*b b*)."

Mr. Roberts comments on the skilful manner in which the Spanish farmers, when irrigating their lands, conduct the water from one field to another, or from one part to another of the same field on a different level. When all the lower parts are irrigated, they construct temporary dams with the hoe, and by this means raise the level of the water so as to be able to reach the higher parts of the field. A sod or a stone serves the purpose of a hatch, or "stop-off."

Time of Watering.—The evening hours are considered the most favourable time, but this rule is nowhere universally observed.

Application of Water.—Watering should not be deferred until the ground is too dry, as it does not bake so readily afterwards. In dry weather, a moderate watering should be given before sowing or planting, and for a time afterwards the ground should only be kept moist enough to favour germination, and prevent the surface hardening. For the young growing plants, moderate, frequent waterings are best. No rule can be laid down, however, that will be generally applicable. The various field crops which may be brought under irrigation all call for special treatment, and this will vary with the district in which they are grown. The reader may here usefully refer to what has been already said on this point under the heads of crops suited to irrigation, and the number of waterings bestowed on different crops, in Chaps. III. and IV. In the case of nearly every crop, the ground must be allowed to get occasionally dry; for even those crops which require watering most are easily injured if the water is in excess, or is allowed to remain on too long.

Cultivation.—The soil should never be stirred when wet. Tillage and cultural operations "should be timed with reference to the watering, or the watering should be so timed with reference to them, that these operations may be performed when the soil is dry and just before watering."

CHAPTER VIII.

SWAMP IRRIGATION.

SWAMP irrigation is practised more or less on the rice or paddy fields of India, Egypt, Southern Europe, and the Carolinas, and other south-eastern states in America. These crops are generally produced on tide-swamps, or other low-lying grounds, which possess no means of natural drainage; and under this system the land is commonly laid under water for weeks at a time, sometimes, indeed, from the time of sowing till the time of reaping.

The rice plant appears to adapt itself in a very wonderful manner to swamp life. Even here, however, there is doubtless no exception to the general rule, that stagnant water is injurious to the higher forms of vegetation. Where the produce of rice under such treatment appears to be as great as is to be expected from the most skilful and intelligent culture of the plant, it will probably on examination by analysis be found to compare but poorly in nutritive value with that grown under different conditions; otherwise, the presumption is that, though the water was retained on the field during the whole time of the growth of the crop, it was not really stagnant, but constantly undergoing renovation, by percolation or some other means.

Rice irrigation has been well described by the late

Robert Russell, of Kilwhiss, who visited the Carolina rice plantations in 1865, and published an interesting account of them in the *Transactions of the Highland and Agricultural Society* for 1866.

" It is on the tide-swamps of the Savannah, and the numerous other rivers in Georgia and the Carolinas," says Mr. Russell, " that the fine rice known in Europe as the Carolina rice is cultivated. The production of rice for exportation is in a large measure confined to these swamps; and it is further limited to the *fresh* tide water swamps, for where the tides are salt, or even brackish, they are unfit for irrigation.

" Though a considerable quantity of *upland rice* is raised here and there for domestic use, none of it is reckoned sufficiently good in quality for exportation. The rice which grows in the tide-swamps is of much better quality than what grows in dry cultivation. The pickles of the irrigated rice are large and equal in size, and the husk is easily separated from the kernel; whereas the upland rice, being smaller and more unequal, the sample is not only inferior, but there is a great deal more waste and labour in its preparation for market."

Another objection to the culture of rice on the dry upland soils is the great amount of manual labour which is required to keep the crop free from weeds. The lengthened period of hot weather over which its growth is extended, and particularly the circumstance of this crop, like our cereals, either being sown broadcast or in narrow drills which do not admit of horse-hoeing, tend to give great encouragement to weeds, so that its culture demands too much hand labour to be generally profitable.

" The swamps which form the rice grounds were reclaimed by erecting embankments along the sides of the river, and preventing the overflow of the tides.

"Main canals, having sluices on their mouths, are dug from the river to the interior about 20 feet in width; and as they sometimes extend across the whole breadth of the swamp, they are more than 3 miles in length. The rice plantations are subdivided into fields of about 20 acres each. The fields have embankments raised around them, with sluices communicating with the main canal, so as they may be laid dry or under water separately, according as it may be required. Numbers of open ditches are also dug over the grounds, for the purpose of allowing the water to be more easily put on or drawn off.

"From the nature of the works which are required to reclaim the tide-swamps, and render them fit for cultivation, large capitals are invested. A great expenditure of labour is constantly required to maintain the banks in good order, to clean out the drains and canals, as well as to keep the sluices and valves in repair. It would be out of place here to give any detailed estimate of the expenses and profits of rice culture. The fact, however, of the rice grounds being higher in value than any land devoted to any other crop in the south-eastern states, is quite sufficient to attest the profitableness of rice culture. Nor is this so much to be wondered at when it is considered that the land which is capable of raising rice with advantage is comparatively limited, and has been almost all occupied for a considerable time."

In Carolina there is considerable diversity in the mode of cultivating the rice crop. "Some planters plough all the grounds every year. Those who follow this system give a light furrow in the beginning of

January, and afterwards make shallow furrows or drills, 15 inches apart, to receive the seed, which is sown broadcast at the rate of from two to three bushels per acre. A small quantity of water is then admitted for a day or two until the seed sprouts.

"The most approved and general mode of cultivating the rice fields, when free from weeds, is to sow the seed without ploughing. The stubble of the previous crop is burned over in spring, which is easily effected from the large quantity which is left at harvest. A negro then goes into the field, and makes a rut with a hoe between the rice rows of the former crop. This serves as a receptacle for the seed. Sometimes this operation is done by a small drill-plough. The seed is either covered by a rake, or the water is admitted at once, and covers it by washing down the soil.

"In all cases, the water is admitted to the fields as soon as the seed is sown, and when the young shoot appears above ground the water is drawn off. In the course of a week the crop usually receives another watering, which lasts from ten to thirty days, according to the progress which vegetation makes. This watering is chiefly useful for killing the land weeds that make their appearance as soon as the ground becomes dry. But, on the other hand, when the field is under water, aquatic weeds in their turn grow up rapidly, and, to check their growth, the field is once more laid dry, and the crop is then twice hand-hoed. By the 1st of July the rice is well advanced, and water is again admitted and allowed to remain on the fields until the crop is ripe. This usually takes place from the 1st to the 10th of September. The water is drawn off the day previous to the commencement of reaping."

In the Piedmont district, in Italy, where a great deal of rice is cultivated, the ground is first put under water, then worked up into mud, before the rice is sown broadcast over it. The water is then turned off, and the rice is left to germinate in the damp earth before being irrigated again. After this it is left almost constantly under water.*

In some of the paddy-growing districts of India the same course of puddling preparatory to sowing is followed. The land is ploughed several times while under water, and in the operation the soil is worked into a puddle, by the ploughs and by the feet of the cattle. It is then left to stagnate for a few days, after which more water is let on, and the ploughing and puddling repeated. Where vegetable manures are applied, these are trodden into the puddled soil. Before seeding the ground, the surface is smoothed by means of a heavy plank drawn by cattle.

"The rice grounds," Mr. Russell concluded, "are comparatively healthy to white men in winter, but the very reverse in summer and autumn when the crops are growing and ripening. It has been often remarked that the swamps, in their original state, along the southern rivers of the United States were by no means so deleterious to the whites as they are now, when brought under cultivation. This seems to apply, to a certain extent, to all the rich alluvial soils in the river bottoms, but is particularly applicable to the rice grounds that are irrigated by the tides. Indeed, the undrained swamps remain comparatively healthy so long as they are covered with the natural vegetation. The mere stirring of the soil, and the exposing of it to the atmospheric influences of a hot climate, invariably

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* Moncrieff, "Irrigation in Southern Europe."

give rise to malaria. For this reason, the Campagna in Italy became much more unhealthy, as Dr. Arnold states, in his *Roman History*, after its drainage. There is nothing of course deleterious in the mere culture of rice ; it is the mode in which the irrigation is managed. This opinion is confirmed by the fact that the rice grounds at the mouth of the Mississippi, on which the water is not allowed to stagnate, are more healthy to the white inhabitants than either the sugar or cotton grounds of the lower Mississippi that are under dry culture. But the practice adopted on the tide-swamps of Carolina, of laying the fields dry at intervals during summer and autumn, seems to give rise to miasmata of the most deadly character to the white inhabitants, but from which the coloured are exempt. The planters, with their families, invariably leave the rice grounds during the hot season, and remain in a more healthy part of the country until the crops are harvested. And though the negroes are not liable to those diseases which are so fatal to the white inhabitants in summer, yet they do not increase in the rice districts."

The water-cress beds, which are to be found in the neighbourhood of London and all other large cities, afford a more striking example of swamp vegetation than the rice grounds we have been considering. Water-cress is grown on ground entirely under water, but the water is never altogether stagnant. It is a plant that can only be grown where there are running streams, and it also favours a limestone or chalk formation, so that in all but small artificial beds, its cultivation is limited to comparatively few localities.

In some cases it is merely allowed to grow in the natural stream, but those who make a business of growing it, increase the area by making beds at right angles to the stream. The beds are excavated to a depth of about 8 inches, and are usually 5 feet wide, and of a length governed by the level of the land. They should be so constructed that the water from the stream may be directed into them by the use of board dams, and an overflow channel must be provided. Lime or chalk may be added to the bottom of the beds, if the soil is naturally deficient in calcareous matter.

Water-cress is naturalized in many streams, and where it occurs a supply may be secured for stocking the beds. The plant throws off roots at each joint below the surface, and if the stem be made into cuttings, each of these fragments, if set in the soil of the bed, will soon form a vigorous plant. The cuttings may be set a foot apart each way immediately before the water is let into the beds.

Where cuttings cannot be procured, the plants can be readily raised from seeds. If the seeds are sown in a box in good garden soil, and kept very moist, a supply of plants for transplanting will soon be at hand. The starting of beds of water-cress should begin in early spring.

CHAPTER IX.

SEWAGE IRRIGATION AND LIQUID MANURING.

THOUGH there are various ways of utilizing sewage, irrigation is the method which has been most extensively practised, and is the only one which demands notice in this work.

"By sewage irrigation the greatest luxuriance of growth known to English agriculture is obtained. It is adapted to all irrigable crops; but the best results are obtained with rapid-growing succulent plants, such as Lucerne or Italian rye-grass. The sewage is poured on at the rate of 400 tons per acre, equal to a thickness of 4 inches of water, during a few hours, twice in the growth of a single crop or cutting. Drainage, deep cultivation, and subsoiling should accompany the process; these tillage operations being only performed, of course, when the land has been laid-up dry. The drained and deeply-cultivated soil then passes the whole of the rich and fertilizing sewage amongst the fibrous roots of the plants, by which its substance is permeated. By this practice, a cutting of 10 to 20 tons of succulent forage is obtained as the result of not more than a month or five weeks' growth. The land is soaked twice or thrice, at intervals of a fortnight after each cutting; and four or five cuttings are thus obtained from the application of 3,000 to 12,000 tons of sewage in the course of the year. Here, as well as in ordinary irrigation accompanied by land drainage, the result is due to an added temperature, and an addition of plant food, both of which the soil experiences ; and especially to the constant motion and passage of this food beside and amongst the hungry roots of the plants which feed upon it."*

Nearly all the sewage farms in this country are laid out on the "catch-water" system, which consists in floating on large quantities of liquid sewage over a number of successive breadths of land. The objections urged against this system are—(1.) That the bulk of the water escapes by flowing off the surface, and not through the soil to the drains ; and that, therefore, there is no real security that the sewage is purified at all : the fact that it flows off the surface, showing that there is more liquid applied than the land can absorb. (2.) That as the essence of the catch-water system is the pouring of sewage, and of the same particular volume of sewage, over successive areas of land, all the areas of land cannot be equally fertilized, since the sewage cannot be made to flow evenly over all the land.†

These objections apply with even more force to the "Pane-system," which is analogous to the Spanish system of irrigation by water, where rectangular and generally square plots of land are laid out perfectly flat, surrounded by a low bank, and generally on successive levels. The upper plots, in such cases, must evidently retain the whole of the suspended matter which is contained in the liquid sewage, leaving little else than clear water to flow off to the lower levels.

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* "The Soil of the Farm." By John Scott and J. C. Morton.

† W. Hope "On Sewage Irrigation."

The Romford Sewage Farm, in the occupation of Mr. Hope, has been laid out in beds on the ridge-and-furrow system, each bed being 30 feet wide. The ridges are raised up in the centre, with a carriage or gutter along the ridge, over the sides of which the sewage flows, as in some water-meadows. Mr. Hope considers that this system of sewage distribution is the best of all, even for arable lands, and presents no difficulty to horse or steam cultivation; as nothing, in his opinion, is more simple than to form a low ridge, by means either of the horse or of the steam-plough.

On hill-side lands, which do not admit of irrigation by the ridge-and-furrow system, Mr. Hope adopts another plan. The hill-side land is ploughed horizontally with a "turn-wrest" plough, and then with a double-mould-board plough going in the same direction, across the hill, it is thrown into little ridges, as if for potatoes. The sewage is applied to this hill-side from a carrier running along the top, the across-hill furrows effectually preventing the liquid scouring away the earth from the plants. On this system Italian rye-grass, &c., cannot be grown, nor can cereals; but as the slope of the hill-side is far too rapid to permit of the application of any liquid by irrigation, if the surface were left smooth, this is no drawback.

At Edinburgh, where sewage irrigation has been practised with marked success for more than 100 years, about 250 acres of the Craigentinny and Lochend meadows are flooded with crude sewage, at the rate of 2,500,000 gallons every 24 hours. Of this land, 200 acres are in permanent pasture, and 50 acres in Italian rye-grass. The irrigation is carried on in the rudest and cheapest way by the owners of the land adjoining the streams of sewage; no cost having been incurred in providing permanent carriers of any kind. The permanent grass is cut about four times in the season, and yields an aggregate crop of about 40 tons per acre. The Italian rye-grass is cut five times, and yields as much as 60 tons to the acre. The whole produce is sold, by public auction, at the beginning of April in each year, in small allotments, and realises from £20 to £40 per acre. It is eagerly bought up for cow-feeding, by dairymen in and around Edinburgh; who, in addition to the price paid for the plots, cut and remove the grass at their own expense. The annual cost of applying the sewage, and receipts for the produce, are given by Mr. Birch* as follows :—

Receipts.	£	Expenditure.	£
250 acres of grass, at an average of £30 per acre	7,500	Wages of watermen—three in summer and one in winter—and cost of cleaning out carriers .	180
		Estimated rent of land, 250 acres at £2 per acre per annum . . .	500
		Balance . . .	6,822
	£7,500		£7,500

This statement, however, is incomplete. The rent ought to be at least £5 per acre; and nothing is charged for the sewage.

"About 8 acres of the Craigentinny Farm, which is land of excellent natural quality, but too high to be irrigated by gravity, has had sewage pumped on to it by steam power. This land has received about 3,000 tons of sewage per acre in six or eight waterings during the year, and the rye-grass grown upon it has realised from £25 to £36 an acre—prices equal to those obtained at

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* "On Sewage Irrigation by Farmers."

Lochend, where four times the quantity of sewage has been applied."

It is estimated that the yield of land under sewage irrigation, with forage and root crops at least, is fivefold greater than the yield of the common agriculture of England. The quality of sewage-grown crops is also higher. Thus the proportion of cream yielded from sewage-fed grass at Croydon is stated to be about 15 per cent., whilst that obtained from ordinary pastures is only about 10 per cent. The increase of saccharine matter in sewage-grown root crops is so great as to give the crops so grown an entirely new value, in addition to the greater weight produced. On one sewage farm, Mr. E. Chadwick, C.B., tells us the rhubarb grown is so superior that it is used for making a champagne, and a wine of the character of a "still hock."

At the Annual Conference on National Water Supply, Sewage and Health, held in 1879, Mr. Colebrook, as chairman of the Reading sewage farm committee, stated the result of their experience the preceding year, particularly in the growth of mangold under irrigation. The highest weight per acre was 110 tons and the lowest 77 tons; which, he believed, was the heaviest weight ever known to have been grown. There was this peculiarity in the growth of the mangold; it was intended in the spring of the year to irrigate the land while the crop was growing, but the spring was wet and they were not able to hoe the land when they wanted, and when they were able to do so the weeds filled the trenches and they could not get the sewage on to the land while the crop was growing. He pointed out that for this reason he believed it was quite possible to overdose the land with sewage, and the result they obtained was chiefly owing to not having done so. The crop of rye-grass was equally good. They cut six excellent crops during the year of not less than 20 tons per acre each crop, whilst the year before they had seven crops. They had rigidly excluded storm-water, and he attributed a great deal of their success to that.

At Bedford, where the sewage of 20,000 of the population is applied to 180 acres, chiefly of market-garden culture, the weights per acre of the principal crops have been as follows :—

	Tons per acre.
Italian rye-grass, per crop (sometimes cut four or five times a year)	25 to 30
Carrots	24 ,, 30
Onions	12 ,, 16
Potatoes	12 ,, 15

As much as £53 per acre has been realised with a crop of celery, and from £30 to £40 per acre with crops of onions, rhubarb, and asparagus.

In regard to the price which a farmer can afford to pay for liquid sewage, when poured over his land, it has been said that for its use to be profitable the price must not exceed ½d. per ton. At 400 tons per dressing this is equal to 16s. 8d. per acre, and as the land requires in most cases to be dressed six or eight times, that price is clearly prohibitive.

At Cheltenham, where the corporation land under sewage is not sufficient to utilise the whole of the sewage at their disposal, it is applied to neighbouring private lands at a charge of 7s. per acre for each dressing. The corporation lets its sewage-fed land at over £6 an acre, and probably not more than one-third of this rent can be charged to the sewage, as the lands are only dressed on an average about five times a year.

Sewage is best applied to land under tillage, or to grass land that will be mown. If it is not positively dangerous to graze land while under sewage irrigation, it is at any rate objectionable, and should never be practised, unless, indeed, the land has been laid dry for a considerable time. That any ill effects are produced by feeding dairy cows or other stock on sewage-grown crops there is not the least reason to suppose. The soil itself cannot be injured by sewage nor even the crops, unless the dressing of sewage is immoderately large.

"Sewage-sickness," remarks Mr. Birch, "is a term that has become common because it sounds appropriate; but, as a matter of fact, time has no effect in making land sewage sick, for its pores may be filled, as at Edinburgh, year after year, with infinitely more dissolved manure than can be made use of by vegetation, and the land will continue to be as productive and as capable of receiving sewage as ever. A crop may, however, be ruined if it is covered with sewage, even although it may not have had enough for its manurial requirements; or land may be done more harm to than good, temporarily, by one single ill-timed dressing. Experience has proved that over-feeding with sewage has no ill effect, although land may be choked with it in one meal."

Liquid Manuring.—By this term is understood the practice, now seldom adopted except on a very small scale, of applying the drainings from the stables or from the dunghill, direct to the land in the liquid form. The use of liquid manure is no doubt very effective, but it is the extract of the dung-heap, which is afterwards of greatly diminished value. In the majority of cases, therefore, it will be found best to apply the liquid part in conjunction with the dry portion of the farmyard manure.

In order, however, that the liquid manure which flows from the cattle-yards and from the dung-heap may not be lost, it should be collected in tanks. This will be useful whether the practice of liquid manuring is adopted or not, as in the latter case the dry manure may be made to absorb it.

If the dung-heap is made on an impervious bottom, or a small tank or vat is sunk in the ground at the lower end of the pit, the drainage from the manure will flow into it, and, by attaching a small hand-pump to the vat the liquid that there collects can be pumped back again upon the heap, whenever it is deemed desirable to moisten it.

Where liquid manuring is to be practised, the liquid in the tank may be distributed over the lands in various ways and by various means.

On a moderately large scale it will probably answer to lay down pipes above or under ground. Through these the water can be made to flow, by gravitation where practicable, or otherwise by pumping. The hose-and-jet system, which has failed in sewage irrigation from the large quantities of liquid which had then to be dealt with, will answer better here; as, although it will be found more expensive than a system of perforated surface pipes, which are self-working, the hose-and-jet system enables the manure to be directed where it is most wanted. On a smaller scale liquid-manure carts may be used. These will be found not very expensive to begin with, and will do a considerable amount of work. If the land is near by the tank, a man and a boy, with one horse and two carts, will water ten acres a day, at a cost of about a shilling an acre.

Fig. 20 is an illustration of one of Bamford's chain-pumps employed in filling a cart from the liquid-manure tank. For liquid manure and sewage the chain-pump is the best that can be used. It requires a little more power to raise a given quantity of water than a good lift-pump; but it has other advantages. Having no valves it is not easily choked; it seldom gets out of order; and as it is empty when out of use, it is not liable to be injured by frost.

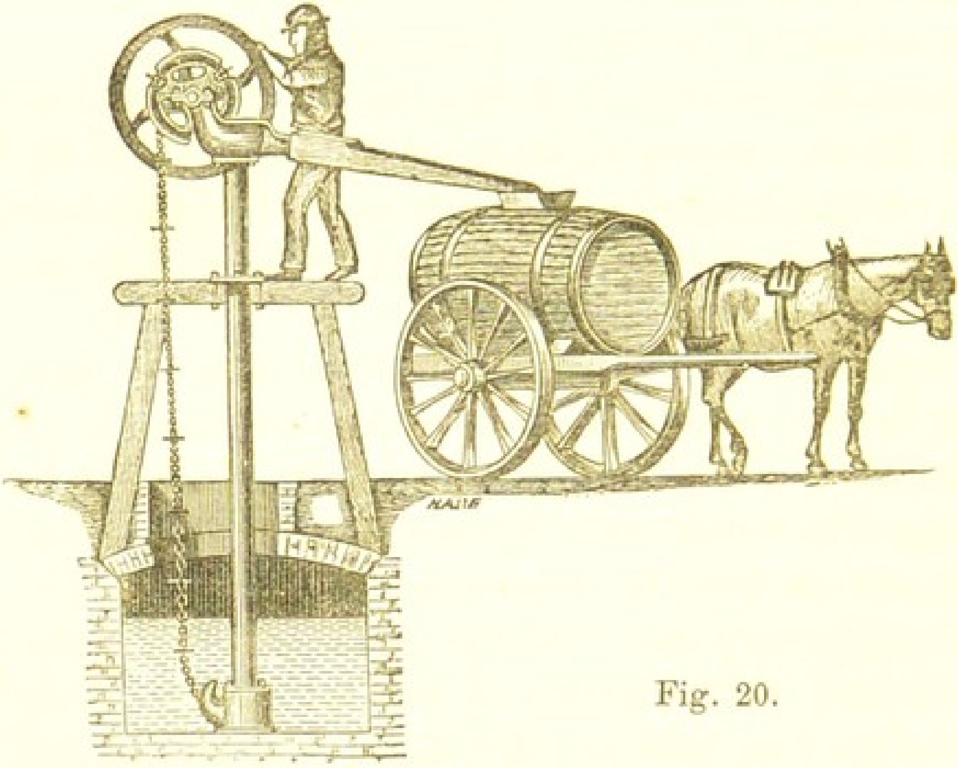

Fig. 20.

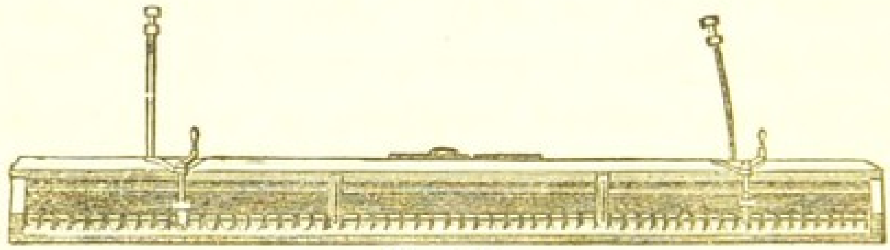

Fig. 21.

Fig. 21 represents a distributor, manufactured by Messrs. S. Owen & Sons, London, for attaching to liquid-manure carts, with braces necessary to fix it. It can be removed at pleasure when the cart is required simply for water only.

For gardens, and other small plots of ground, a hand-barrow or garden-engine, with a small force-pump and a distributing hose and jet attached, similar to that shown in Fig. 22, will serve every purpose.


Fig. 22.

Liquid manure may be applied with great effect to all crops. The quantity to be used will depend on whether it is pure drainings from the stalls and the dung-hill, or has been diluted with rain-water. It is seldom desirable, even where possible, to use it the full strength. Diluted with, say, two-thirds water, it may be applied at the rate of 1,000 to 2,000 gallons per acre each dressing, and the dressings may be repeated as frequently as in sewage irrigation.

"Great advantage has attended the use of the water-drill for sowing turnip and mangold seed in dry seasons. By applying the artificial manures in a liquid state, the germination of the seed and the subsequent brairding can generally be relied on. In a dry climate the water-drill is desirable in any year, if root crops which have to be put in at the driest and hottest seasons are to be successfully cultivated. The same quantity of manure is used as in the dry state, and the quantity of water is regulated by the condition of the land and the dryness of the atmosphere. Superphosphate and guano are the most suitable manures for the water-drill."* Soot is also well adapted for applying in the liquid form, either by means of the water-drill or by flowing on through pipes or otherwise.

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* "Soil of the Farm."

CHAPTER X.

WARPING OR SILTING.

This species of irrigation consists in repeatedly flooding low-lying tidal or river lands, and allowing a succession of sediment to be deposited. Sometimes the object is only to fertilize the land, but more generally it is practised with the double purpose of raising the surface of low and swampy ground.

In either case, warping depends for its effect upon the presence of much suspended alluvial matter in the water used. Being stirred, and kept in motion by the tide, that alluvial matter is, by the process of warping, conveyed over the adjoining lands and there deposited during a period of rest. As soon as this has been done, the clear water is drawn off slowly, so that the new deposit is not disturbed. Another flood is then admitted, and so on until the warp is completed. In this way the thinnest and poorest soils, if favourably situated, may be covered with the richest alluvial to almost any depth.

One tide will leave, on an average, one-eighth of an inch of warp; and in this way 3½ feet of added soil has been obtained in three or four years. Dr. Anderson tells us that in one experiment, where the water used contained 233 grains of mud per gallon, 210 were deposited during the warping.

Warping is effected by a cut or canal from the sea or river, with sluices for the admission and discharge of the water, which is confined to the grounds intended to be warped by surrounding banks raised to the required height. The higher the banks and the deeper the sheet of water that can be impounded the better, as a greater burden of sediment will be deposited; but the height of the bank is, of course, limited by the difference in level between the land surface and the water in the canal.

In these banks there are fewer or more openings to let in and out the water, according to the size of the field to be warped. In general they have only two sluices, one called the flood-gate, to admit, the other called the waste-gate, to let off the water gently. These are enough for 10 or 15 acres. The flood-gates are placed so high as only to let in spring-tides, and the waste-gates are so constructed as to let the water run off between the ebb of one tide and the flow of the next. To avoid the danger of the newly-deposited matter being stirred up and carried off again by the retreating water, the waste-gates may be made to open at the top instead of at the bottom.

Seasons for Warping.—The dry months of summer are considered the best for this work. Land may be warped, however, in any season, provided the water is always muddy; in other cases it should be practised more particularly when the weather is dry and the fresh water in the river very low. When the season is wet, and the river full of fresh water, warping cannot be advantageously executed. The fresh water then mixes with the tide, makes it not half so muddy and thick, and consequently incapable of depositing the same quantity of sediment.

Effects of Warping.—"It is easy to understand the importance of the effects produced by adding to any soil large quantities of fertilizing mud. Herepath has calculated that, in one particular instance, the quantity of phosphoric acid brought by warping upon an acre of land exceeded seven tons. As, moreover, the matters are all in a high state of division, they must exist in a condition peculiarly favourable to the plant. The overflow of the Nile is only an instance of warping on the large scale, with this difference, that it is repeated once only in every year, whereas in this country the operation is repeated at every tide until a deposit of the desired thickness is obtained, after which it is stopped, and the soil brought under ordinary cultivation."*

The fertility of warped lands is so great that they have been known to yield full crops for fifteen or even twenty years in succession without manure. When laid down in grass seed the land is not warped, for the mud would destroy such a crop.

There can be no doubt, however, that the warp of some rivers is much more valuable than that of others. The value must depend on a variety of circumstances, such as the quantity of valuable ingredients contained in the mud, and the proportion of the several ingredients. The presence of any one useful or essential ingredient must add value to the warp, and the greater the proportion of all of them the more valuable will be the deposit.

Mr. Moncrieff † gives an example of this work having been carried on with great success near Avignon, by means of the water of the Crillon canal. M. Thomas, a merchant of that city, having a property composed of

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* Anderson's "Agricultural Chemistry."

† "Irrigation in Southern Europe."

gravel and stones, and fit only for grass crops, laid some of it out in terraces, and obtained the use of 14 cubic feet per second of water from the Crillon canal, which he turned over it for the four winter months of every year. After three years he found he had covered an area of 22·2 acres with a coating of the finest alluvial matter, from 20 to 27 inches thick. The cost of the operation, including a water-rent of 16s., was just £7 per acre. The land, which before had been worth £19 8s. 6d. per acre, was valued after this improvement at £113 7s., and yielded seven or eight crops of wheat without requiring any further manure.

Soils and Situations for Warping.—No land but such as is on a level or below that of spring-tide, or similarly placed for river or canal flooding, can be improved by this process. Of lands so situated there are, however, extensive areas along the shores of the British Empire. In almost every Firth in the three kingdoms, and all along our shores, may be seen extensive tracts of barren sands and mosses which are overflown by spring-tides; and however barren they are, they may be reclaimed and rendered fertile by warping. Cherrycob sands were reclaimed by this means, and are said to be 4 yards thick of warp.

"Some of the marine mosses are so loose and pulpy in the subsoil that if drained they would be reduced to a level sufficiently low for warping, especially if the coarse and useless herbage on the surface were in the first instance pared and burned. If afterwards warped in the manner above described, they would become the most fertile soils in the empire. Besides, it is often more easy to rebank this than any other soil; for if a river or broad ridge, 30 or 40 feet wide along the bank of the river, were left undug and planted with willows, it would serve as an impervious bank to shut out or let in the water at pleasure. While the rest of the surface was dug, and drained, and cropped, and thereby reduced to a low level, this bank, left undug, would not sink in the same proportion, but might serve the purpose at least of an excellent foundation for a more solid bank, even though of itself it might be too light, loose, or low to serve that purpose." *

Cost.—The expense of warping has been variously stated at from 30s. to £10 an acre. In ordinary circumstances it can seldom cost more than the smaller sum, as after the banks and sluices are fixed, which outlay cannot be wholly charged on the warping, the only expense will be the occasional wages of a man to attend the sluices. On the other hand, poor land has been so raised in value by this outlay as in many cases to repay the cost in a single year.

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* "General Report of Scotland."

CHAPTER XI.

COST OF IRRIGATING LAND.

THE cost per acre of irrigating land will, of course, depend on a variety of circumstances. It will vary according to the mode of irrigation adopted, the nature of the work, the configuration of the land, and the natural roughness or smoothness of the surface, the distance from the source of water-supply, and the means by which the required amount of water can be obtained.

Bed-work irrigation is the most expensive; but even here the cost will vary considerably. If the ground is smooth on its surface, or in regular ridges; if the water can be easily brought to the meadow, and neither wear nor conductor is necessary, the cost may not exceed £3 per acre. If, however, the land has a rough and irregular surface; if a long conductor, and a proper wear be required, with hatches both in it and in the feeders, the cost may be £10 per acre.

"Few people unacquainted with the art of irrigation," says Mr. Stephens, "and the regularity of form which the adjustment of water requires, have any idea of the expense of modelling the surface of a field. Where the ground is nearly level, and the surface covered with turf, the turf may be taken up, the ground properly shaped, and the turf replaced for £3 per acre; as was instanced in one case belonging to the late Sir Charles Menteath, of Closeburn, in 1826; whereas, in a case of Mr. Lawson, of Cairnmuir, in Peeblesshire, the cost was £12 per acre. In one field it cost Mr. Simpson, of Glenythan, Aberdeenshire, about £7, and in another field only £1 16s. 9d. per acre. From £7 to £9 may be taken as a fair average of the expense of converting land into water-meadow. Unless, therefore, the advantage to be derived were considerable, such an expense would not be justifiable; but in all cases where meadows have been well managed the yield has at least doubled."

The expense of forming some of the Wiltshire water-meadows has much exceeded £10 or £12 per acre. £20 and even £40 per acre, have, it is said, been expended in the formation of some of these meadows; but the latter sum seems altogether unreasonable, even for the most elaborate work; though no doubt the value of these meadows, which are worth an annual rent of from £5 to £10 per acre, will warrant a large expenditure, so long as it is judiciously made.

Where a new meadow is to be formed on the bed-work plan, and the ground is favourable, the whole of the work within the boundary fence may be done by the plough, except a little final touching-up and shaping out of the channels and gutters, which would have to be done by the spade, and need not cost more than £2 to £2 10s. per acre. The width of the beds or ridges is first set out, then the land is ploughed two or three times, always "gathering" and "splitting" in the same place, to get the necessary rise and round of the beds. After this the ground is well rolled, harrowed, seeded, and rolled again. It then remains to draw out the feeders on the crowns of the ridges, and the furrows in the bottoms between the beds. This is readily done by a single turn of the ridging plough. A man follows with a spade and gives the final touch up, and the work is complete. The expense of outside conductors, dams, and wears will not usually exceed a few shillings per acre.

Catch-work irrigation can be practised at very little expense. The cost of forming the furrows by the plough will not often exceed 5s. per acre, and very little spadework is needed. This is decisive in favour of catch-work, where it can be adopted. It also requires much less water, and is often fully as effective as bed-work irrigation. The furrows need to be but very small, as all that is required of them is to arrest the flow of the water, and cause it to spread out equally again in a thin sheet over the whole surface. The total cost of this system, including the expense of bringing the water to the field, need seldom be more than 10s. per acre.

In the foregoing cases nothing is supposed to be paid for the water itself; but in many countries the water rates are high for irrigating land; and it may also occur that there is considerable expense in raising the water and in bringing it to the land after the right to use it is obtained.

In France, where one cubic foot of water per second is used to irrigate 70 acres of land, as much as £100 is paid per cubic foot per second during the season; and the cost per acre varies from £1 5s. to £1 10s. annually.

" In Spain, the Iberian Irrigation Company makes a charge of about 30s. per acre, for twelve waterings per year, equivalent to a total depth of 33 inches of water over the entire surface irrigated.

"In Italy, the average cost of the water to the farmer is from £150 to £170 per cubic foot per second, equivalent to 11s. 6d. per acre for maize, 31s. 6d. an acre for meadows, and £4 an acre for rice."*

The same writer states that in California, Colorado, and other parts of the United States, the "actual cost" of irrigating land "has been found to range from so small a sum as $1 † per acre upwards. That is, a community of farmers, numbering some hundreds, may construct the necessary dams, canals, sluices, and feed-gates, to irrigate 10,000 to 50,000 acres of land at a total cost not to exceed $5 per acre, where the conditions of water-supply, character of soil, and surface of the land are favourable. . . . . This estimate will allow of substantially constructed works, which will require but little repair or renewal to keep them in permanently good condition. Large tracts of land have been supplied with water for irrigation at a much less cost than this, in some cases even so low as 25 to 50 cents per acre; but this cost covers only the construction of the main supply ditch, and not the interior ditches, which, to be permanent, should be well laid out and properly constructed. It is now sufficiently well known, however, that a supply of water for irrigation can be brought to and spread over a farm upon our dry plains at a total expenditure of capital per acre not any greater than the annual rent paid per acre for irrigating water in European countries."

Where the water used in irrigation has to be raised from wells by pumping, or other means, the working expenses will be much increased. In Behar, where well irrigation is common, and the water is usually

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* Stewart, "Irrigation for the Farm, Garden, and Orchard."

† The American dollar is 100 cents; equivalent to 4s. 2d.

raised by bullocks working a rope and buckets, one pair of bullocks can, in hot weather, irrigate one-tenth of a beegah per day, and in cold weather one-seventh of a beegah (a beegah is about two-thirds of an English acre). This—allowing four annas* per diem, a low rate of hire, for two labourers; pair of bullocks, wear and tear of rope and buckets, &c.—would leave each irrigation to cost, in the hot weather, Rs. 2 8 0† per beegah, and in the cold weather Rs. 1 12 0 per beegah, *i.e.* from 6s. 10d. to 4s. 4d. per acre.

The crops are usually irrigated four or five times, so that, allowing each watering to cost only Rs. 1 8 0 per beegah, there is still, at lowest calculation, Rs. 6 0 0 per beegah, or about 17s. per acre, expended annually in the mere application of the water.

Canal irrigation costs very much less than well irrigation, where, in the latter case, the water has to be raised by artificial means.

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* 1 anna = 1·4d.

† 1 rupee = 22·4d.

CHAPTER XII.

SOURCES OF WATER-SUPPLY.

Rain may be termed the direct source of water-supply, though rain itself is due to the evaporation which goes on from sea and land. The moisture which rises through the air is, in fact, equal to that which falls through it. Every drop of fresh water on the surface of the globe, or within the earth's crust, has been distilled from the atmosphere.

Rainfall.—For drainage works we require to know the maximum fall of rain during storms, but for water supply we must estimate the least quantity of fall.

The comparative quantity of rainfall depends upon the vicinity of mountain ranges, and not upon altitude. The greatest fall occurs in the west of hilly districts. In Great Britain it varies from 15 inches annually, in dry districts in dry years, to 150 inches in wet districts in wet years. In exceptional cases, near the Lake district, as much as 220 inches has fallen in one year. The mean annual rainfall in England is estimated at 32 inches.

Influence of Vegetation on Rainfall.—The fall of rain in any district increases with the increase of vegetation, and especially of forest growth. "Trees and forests," remarks Steinmetz, "contribute to the formation of springs and watercourses, not only by means of the humidity which they produce and the condensation of vapours by refrigeration, but also by reason of the obstacles which they present to the evaporation of the water in the soil itself, and by means of the roots which, by dividing the soil like so many perforations, render it more permeable and facilitate filtration. The clearing of forests, and the consequent drying up or draining of marshes and bogs, have caused a material alteration, not only in the entire face of the country, but in the supply of water to the rivers formerly derived from those reservoirs, and in the periodical amount of rainfall and the regularity of its distribution." In Germany it is considered that, in order to insure a regular and sufficient rainfall in agricultural districts, the proportion of forest or woodland should not be less than 20 per cent.

Springs.—One of the duties of rain-water is to replenish the deep-seated springs. This is done by that portion of the rainfall which escapes evaporation and drainage, and penetrates into the porous strata of the earth. And that it is the rainfall which is the immediate and only source of supply to all the subterranean reservoirs, as well as to all the surface streams and lakes, it would be easy to prove. It may be daily observed that springs increase or decrease in proportion as it does or does not rain; and if a drought occurs, of a few weeks' duration even, many of them go dry altogether. If the drought were protracted for a year or less, there would be scarcely any springs met with in all the land. The absence of rainfall has the very same effect in diminishing the water of lakes, and it tells far sooner in the flow of rivers.

Water-bearing Strata.—Although a considerable portion of the rain-water, perhaps one-fourth of the entire quantity which falls on the surface of the earth, penetrates its porous strata, and is gathered in subterranean recesses, there is no more a general distribution of water in the stratification below the crust of the earth than there is on the surface. Yet many thousands of pounds are annually wasted in fruitless attempts to get water where it does not exist.

Predictions of water being obtainable from subterranean sources at a given point on the surface can never be certain without a very thorough knowledge of the geological position, thickness, porosity, dip, and soundness of the strata over all the area that can have influence upon the flow of the percolating water. There are, of course, water-bearing strata; but though plenty of water may be got by sinking at one point, it may happen that only a few rods distant no water will be obtainable in the same stratum, an intervening *fault* having intercepted the flow and led it off in another direction. In one case, after trying a number of places for water, none was found within 120 feet of the surface, and yet close by water was obtained at 40 feet in depth. Sometimes, by the extension of a heading from a shaft in a water-bearing stratum, to increase an existing supply, a fault is pierced, and the existing supply led off into a new channel.

"The underground flow of water towards wells or springs is limited and controlled, not only by the porosity of the strata which it enters, but also by their inclination, curvature, and continuous extent, and by the imperviousness of the underlying stratum. The chalk and limestone do not admit of free percolation, and are unreliable as conveyors of water from distant gathering surfaces, since their numerous fissures through which the water takes its course are neither continuous nor uniform in direction.

"The mere distance from hills or mountains need not discourage us from sinking wells. Waters are sometimes gathered through inclined strata from very distant water-sheds, and sometimes their course leads under considerable hills of more recent deposit than the stratum in which the water is flowing."*

Commencing with the chalk formation downwards, Professor E. Hull has arranged twelve sets of strata according to their water-bearing quality. Of the twelve seven are permeable, or water-bearing formations, viz.:—(1) Chalk and Upper Greensand; (3) Lower Greensand; (4) Purbeck and Portland beds; (6) Coral Rag and Grit; (8) Oolite and Upper Lias sands; (10) Middle Lias; (12) New Red Sandstone, with a total thickness varying from 1,275 to 5,500 feet; while alternating with the above are five impermeable or dry formations, viz.:—(2) Gault clay; (5) Kimmeridge clay; (7) Oxford clay; (9) Upper Lias clay; (11) Lower Lias and Keuper marls, with a total thickness varying from 2,110 to 5,430 feet vertical.

The water-bearing strata, it is seen, consist of sandstones and limestones of various kinds; the dry formations of clays and shales. Yet the very same "strata that now throw out springs or yield water when pierced would, if occurring at a different level, or if inclined at a suitable angle, become the means of draining water away from other parts than that in which their waters are now collected. This follows as a matter of course, for the conditions would merely be reversed, and the water would pass through the beds

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* Fanning, "On Water Supply."

in another direction, the springs of one locality being in fact but the natural drainage of another."

Effect of Drainage on Water-Supply and Floods.—Every inch of rainfall lost by drainage from every acre of ground represents a loss of 100 tons of water to that acre. The average loss of water by drainage throughout the country is probably half the rainfall, but taking it at 10 inches, then the loss will be 1,000 tons per acre, or 640,000 tons per square mile.

The modern system of drainage clears the land of its surplus water almost as soon as it falls, there being now few of the ancient surface reservoirs, in the shape of bogs and marshes, to receive and retain it for future use. It does not follow, however, that the subterranean reservoirs must suffer, because where there is a porous surface stratum (and it is the porous strata only that feed these underground reservoirs) the rain-water falling upon it will sink as before, until the level of supersaturation rises to the level of the drain-pipe, which will only carry off the surplus water.

The immediate effect of the drainage of higher lands has, however, often been to inundate the lower levels, by causing the watercourses of the district to rise more speedily and to greater height than before. But as the flow of the stream is more rapid, and the total volume of discharge is not augmented, the floods subside sooner.

Artificial Sources of Supply.—The foregoing considerations lead to the conclusion that, in all cases of artificial water-supply, it must be obtained from one of two sources—either from subterranean reservoirs, or from surface drainage—and that geological conditions will determine which of these sources can be made most available. Where water-bearing strata can be tapped, the supply may be obtained by sinking wells; but where the subjacent water-bearing strata lie so deep that the expense of a well would be too great, the supply must be obtained by artificial storage of rain-water and surface-drainage. These different means of obtaining water will be found treated of at length in the succeeding chapters.

The distillation of sea-water is said to be the only means of domestic water-supply in some districts of South America. For agricultural and farm purposes generally, even on the smallest scale, however, the distillation of water would be very far from economical.

Still there are times and places when men cannot afford to disregard any possible means of obtaining even a few drops of water. An Australian recently supplied himself with water in a very novel way, and saved his life by it, while crossing one of the waterless regions of that vast continent. This he did by thrusting the ends of green scrub-wood—"mallec scrub"—into the fire, and catching the sap driven out at the other end in a bark trough. He states that a dozen mallec sticks, 4 feet long and 2 or 3 inches in diameter, would give a pint of water in an hour; and suggests that the same device may possibly be found of vital importance to other bush-rangers and travellers in arid regions.

CHAPTER XIII.

WELLS AND WELL-SINKING.

WELLS are of three kinds:—1. Open Wells. 2. Bored Tube Wells, commonly called "Artesian Wells." 3. Driven Tube Wells, sometimes termed "Abyssinian Tube Wells." One or all of them may be *flowing* wells, or they may not. In the latter case, the water may rise to the surface or near it; but will generally have to be raised some distance by pumping.

Driven Wells, or "Abyssinian Tube Wells."—The newest system of obtaining water from subterranean cavities is by driving a tube into the ground until its perforated end reaches a stratum containing water. When that occurs, the water will immediately flow through the perforations into the pipe; and, if a pump is attached to the upper end of the tube, by pumping for a time, all the particles of sand and fine gravel will be drawn out, and the cavity thus formed around the perforations will remain filled with pure water, as shown in Fig. 23.

Mr. Robert Sutcliff* has given a good account of the process of driving a tube-well:—"In the first place," he says, "the materials used must be of the very best quality, and especially tough and good iron is required for the tubes. The first tube is pointed

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* Annual Conference on National Water Supply, 1879.

and perforated up for a few inches, with holes varying from one-eighth to quarter inch. The point is somewhat bulbous; but only sufficiently so to make clearance for the sockets, by which the tubes are connected together. On the tube a clamp is fastened, provided with steel teeth, so as to grip the tube. This clamp is tightened by means of two bolts. Next, a cast-iron driving-weight, or monkey, is slipped on to the tube, above the clamp. The tube, thus furnished, is stood up perfectly vertical, in the centre of the tripod; ropes are made fast to the monkey, and driving is commenced by two men pulling the ropes, and allowing the monkey to fall on the clamp. It is particularly important that the bolts of the clamp are kept tight, so that no slipping takes place. When the pointed tube has so far penetrated the earth that the clamp reaches the ground, the bolts are slackened, and the clamp raised again some two or three feet. Length after length of the tube is thus driven into the earth, being connected together by socket-joints. It will be noticed that the tube well proper is, therefore, self-boring, and that no core of earth is removed.

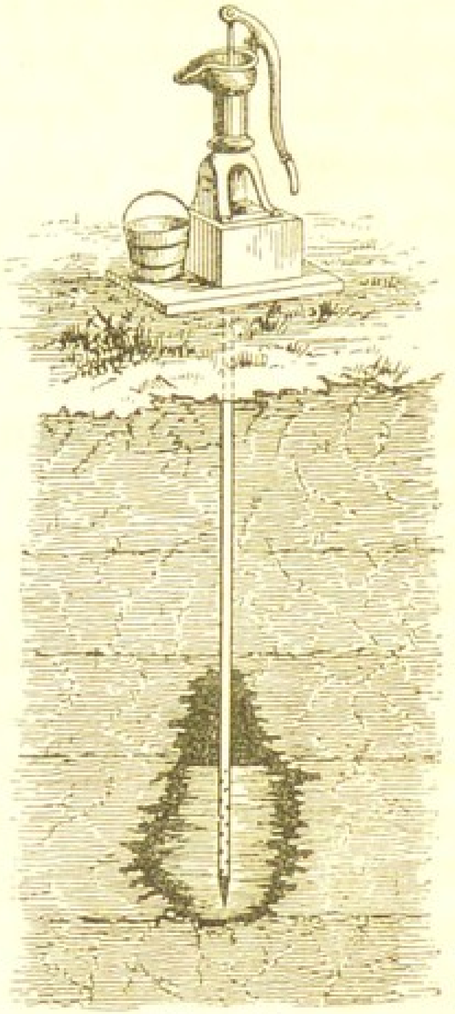


Fig. 23.

"One of the first questions that will suggest itself to a thinking mind is, will not the small perforations be entirely blocked up by being thus forcibly driven through the earth? This was the American's first idea, and he provided a sort of sleeve, in the shape of a sliding-tube, over the perforations, to protect them from the earth. Experience, however, has proved this protection to be quite unnecessary. The perforations are made about four times as numerous as is necessary for obtaining a full flow of water from the tubes. Earth does find its way into the tube wells in pellets, like the casts from a worm; but some of the perforations are always left sufficiently open to allow water to pass into the well; and, if the soil comes rapidly into the tubes, it is easily mixed with water poured down from the surface, and drawn up by ½-inch tubes, to which a pump is attached.

In the Abyssinian and other campaigns, "the wells were only used singly, as one or two were found sufficient to supply the wants of a number of troops. When, however, large supplies for manufactories, towns, and villages were needed, a fresh development in the system took place. Instead of single wells of great diameter, groups of moderate size were driven, and coupled together by horizontal mains; so that powerful steam-pumps could draw from many wells at the same time. The great friction that would be caused by drawing an enormous body of water to a single spot is thus avoided. Wells so coupled draw from a very large area of ground, and the water-level at any one spot is not so readily lowered. The very action of the pump, too, in drawing the water to the wells, opens and maintains channels of communication which help to keep up the level of the water. In putting down plant for a large supply of water, a trench, hundreds of feet in length, and some two or three feet in depth, is dug; and tubes are driven every 20 feet, and coupled by mains as already described.

"It may be interesting to refer to some particular instances, where large supplies of water are thus obtained. At West Thurrock, in Essex, a cement company is pumping from two 5-inch tube wells, about 80 feet deep, 220,000 gallons per day of 10 hours. Another cement works at Northfleet is pumping 60,000 gallons per day. These have been pumped daily for about four years, and still give a constant supply. As expense is an important feature, it may be mentioned that the cost of these did not exceed £60 each. The coupled tube wells are to be found in greatest numbers at the centres of beer manufacture, where abundance of pure and cool water is an absolute necessity. At Burton-on-Trent about two million gallons are pumped daily from these wells.

"When rock, solid stone, or incompressible clay is met with, a tube cannot be driven through it without first making a hole and removing the cores. In some cases, however, there may be many feet of loose earth which can be easily driven through. The tubes, therefore, may be fitted with a temporary hard wooden point, which will allow them to be driven through the soft earth, and when an obstruction that cannot be penetrated is met the point is knocked out, and, being wood and in sections, it floats to the surface of the water and leaves an open-ended tube, through which ordinary boring tools can be passed to chisel and break up the rock. A tube can frequently be driven through gravel and clay to a depth of, say, 70 feet in a single day. To bore to the same depth in a similar stratum frequently takes ten days or a fortnight. The saving that may be effected by driving through the loose stratum can, therefore, be readily appreciated, and what is still more important, the upper part of the tubes are fixed more tightly in the ground than if a boring had been made to receive them. In some cases, however, hard strata come right to the surface, and the boring operations, consequently, cannot be deferred. When this is the case, instead of using a pointed tube, an open-ended steel-shod pipe is driven into the hole as the boring proceeds. As the tools pass down inside the pipe they do not cut so large a hole as the outside circumference, and some little trimming down of the sides is left for the steel shoe to perform.

"In great depths the single tier of pipes with which the work is commenced cannot be forced the whole way. Tubes, therefore, of smaller diameter are inserted; but, as to pump by the tube-well method air-tight joints are absolutely necessary, the final tube is continuous from the deep spring to the surface. In this way tube wells 300 and 400 feet in length are put down, and if the spring, when tapped, rises to the surface, or within, say, 25 feet of it, only an ordinary lift pump is required to obtain the supply. Where the water does not rise to the required height, a deep-well pump can be lowered into the tube well, and worked by rods from the surface."

The latest method of driving tube wells is more particularly applicable to tubes of large size, and is so simple as to merit a brief notice. "An elongated cylindrical weight passes down inside the tube, and the blow, instead of being struck at the surface, is delivered where it is wanted, near the point which penetrates the earth. As water in the tube would impede the force of the blow, the first socket above the perforations is made sufficiently long to admit of a stout iron ring or washer being placed in the centre of it in such a way that the two lengths of tube, when screwed tightly together, butt against it, one on the under, and the other on the upper surface. The interior of this ring is of sufficient size to allow the water to pass freely through it, but it has a screw thread cut throughout its whole length. During the operation of driving, the opening in this ring is closed by a steel plug, which is screwed down into it until its shoulder butts on the ring. The upper surface of the plug forms an anvil, on which the driving weight falls. The plug is readily removed and brought to the surface when the required depth has been reached."

"*Artesian,*" *or Bored Tube Wells.*—Where driven tube wells are not practicable, from the nature of the strata which have to be passed through, artesian wells may be attempted. These are simply open-ended steel-shod pipes, which are driven down after the drill as it bores through the rock, the core of earth at the same time being brought to the surface.

The term "artesian" is only properly applied to wells in which the water rises to or above the surface. But many so-called artesian wells are not "flowing" wells, the water supplied by them having to be raised partly by pumping.

Self-flowing wells and springs are similar in action, and their principle is this: water percolating through pervious strata, such as sand, gravel, or chalk, is finally arrested in its downward course by an impervious stratum of rock or clay, causing it to accumulate in the pervious strata above as in a reservoir, and when the source of supply is higher than the ground at the place where the well is bored, the water will rise to the surface, or even considerably above it.

The process of sinking artesian wells of great depth is attended with considerable difficulty and expense, but in many cases it is not necessary to go very deep. There are cases on record where a couple of men have completed a flowing artesian well in a few hours, and the tools used were carried on their backs. For larger operations a steam driller may be necessary, but smaller sets of the same machinery are made for working by horse, and even by hand power.

Some soils are easier operated in than others, but when the depth is not very great, if no rocks or boulders are met with, there will be no difficulty about the sinking.

In some formations—such as granite, hornblende, and limestone—artesian wells are not generally successful, unless water is reached before touching the solid rock. Where rock has to be passed, the expense is more and water uncertain, unless the geological conditions of the district are well understood.

"Among the causes of the failure of artesian wells," says Mr. Spon, "we may mention those numerous rents and faults which abound in some rocks, and the deep ravines and valleys by which many countries are traversed; for when these natural lines of drainage exist, there remains a small quantity only of water to escape by artificial issues. We are also liable to be baffled by the great thickness either of porous or impervious strata, or by the dip of the beds, which may carry off the waters from adjoining high lands to some trough in an opposite direction—as when the borings are made at the foot of an escarpment where the strata incline inwards, or in a direction opposite to the face of the cliffs."

The artesian well at Passy, for supplying water to Paris, is probably the largest well of the kind yet attempted. It is carried through the chalk into the lower greensands, which were reached at a depth of about 1,900 feet, the bore finishing with a diameter of 2 feet. The first water-bearing strata was reached at a depth of 1,894 feet, but the water did not rise to the surface. At length a true artesian spring was tapped at a depth of 1,923 feet, yielding 5,582,000 gallons per day. The total cost of the well was £40,000. It was laid with solid masonry to a depth of 150 feet, then wood and iron tubing was introduced to 1,804 feet from the surface, and below that there was a length of copper pipe pierced with holes.

There are, however, many deeper wells than that at Passy. The artesian well at Belcher's sugar factory, St. Louis, is 2,197 feet deep. It was finished in thirty-three months, at a cost of 10,000 dols. If report is true, the same American city can probably claim to have the deepest well in the world, for another artesian boring at St. Louis is said to have reached a depth of 3,850 feet, or 3,000 feet below the level of the sea.

Along the lines of the great railroads which now traverse the American continent, from the Atlantic to the Pacific, water is obtained at certain points by means of deep artesian wells for supplying the necessities of the roads. This, though often the only resource in the uninhabited and waterless districts passed through, is not successful at all places, and at hundreds of railway stations on these lines every drop of water they get, even for drinking and culinary purposes, has to be brought long distances by rail on special water-trains, which it is incumbent to run once or twice a day for that purpose.

During the autumn of last year we spent several weeks on the Texas Pacific and the Southern Pacific Railroads, and the lands immediately adjoining them; and, west of the Pecos river, at least, at all the stations along these routes, took notes of what had been done, or was being done, in order to obtain a sufficient water-supply. Thus, at Wild Horse Station, on the Texas and Pacific road, we found two wells had been bored, and plenty of water obtained in both, at a depth of 350 feet. Ten miles farther on, at Van Horn Station, a depth of 750 feet was reached before obtaining water. None of these wells, however, are self-flowing, and pumping-engines of about 35 horse-power, with two men in attendance, were employed at each of them for raising the water.

At Haskell Station, on the Southern Pacific road, and only eight or nine miles south of Van Horn, a boring had been made to the depth of 1,200 feet without finding water. At Sierra Blanca, forty miles farther west, where the two roads unite, water had not been found at a depth of 700 feet. At Finlay Station, twenty-one miles west of Sierra Blanca, the boring had been stopped at 200 feet without any signs of water.

A similar record could be given as the result of borings at more than a dozen other stations on the railways skirting the upper valley of the Rio Grande.

At the time of our visit, the prices being paid for boring were at the rate of $3 per foot for the first 100 feet, increasing half a dollar per foot every 50 feet beyond that depth. The bores were generally 7½ inches in diameter.

Ft.		Ft.		dols.	cts.	
1	to	100	=	3	00	per foot.
100	,,	150	=	3	50	,,
150	,,	200	=	4	00	,,
200	,,	250	=	4	50	,,
250	,,	300	=	5	00	,,
300	,,	350	=	5	50	,,
350	,,	400	=	6	00	,,
400	,,	450	=	6	50	,,
450	,,	500	=	7	00	,,
500	,,	550	=	7	50	,,
550	to	600	=	8	00	per foot.
600	,,	650	=	8	50	,,
650	,,	700	=	9	00	,,
700	,,	750	=	9	50	,,
750	,,	800	=	10	00	,,
800	,,	850	=	10	50	,,
850	,,	900	=	11	00	,,
900	,,	950	=	11	50	,,
950	,,	1000	=	12	00	,,

At the above rates the cost of a well 1,000 feet would be $7,255. These prices, however, only included labour, the railway companies finding tubes, tools, engines, and fuel, &c.; so that the total cost must have been considerably greater. An engineer in charge of the boring at one of the stations told us that, making allowance for accidents, the actual total cost of one of these wells would be nearly double the above sum.

At Chicago, where there are upwards of twenty artesian wells, varying in depth from 1,200 to 1,640 feet, the average cost was found to be $6,000 for a 5½-inch bore, and $5,000 for a 4½-inch bore, in each case 1,200 feet deep.

No doubt, where the bore is less than 100 feet in depth, it can be done at a small outlay. We have heard a practical man say that, in easy working soil, it would then be profitable at $1 a foot; and that the tools and entire outfit for sinking such a well need not cost more than $75. The tubes would cost about 15 cents a foot.

As to the cost of boring artesian wells in England, we will quote Mr. Spon: "Boring," he says, "is usually executed by contract. The approximate average cost in England may be taken at 1s. 3d. a foot for the first 30 feet and 2s. 6d. a foot for the second 30 feet, and continue in arithmetical progression, advancing 1s. 3d. a foot for every additional 30 feet in depth. This does not include the cost of tubing, conveyance of plant and tools, professional superintendence, or working in rock of unusual hardness, such as hard limestone and whinstone."

Open Wells.—All the old domestic wells are of this class, and have been formed by digging or sinking a shaft of several feet in diameter. Owing to the great expense of doing this they are naturally of very limited depth as compared with the tube wells we have previously been discussing, few of them exceeding 60 feet, and the majority of them probably not reaching half that depth.

Very few open wells are now dug. Besides the question of greater expense, there are many objections to them, which the deeper tube wells are free from. In many cases the open wells are merely catch-water tanks, and even where water does rise in them from below, it is liable to be spoilt by the drainage from the surface carrying organic matters into the well.

In sinking a well of this kind the top waters, to a depth of 10 or 12 feet, should be carefully stopped off by solid masonry or hydraulic cement, and means adopted for keeping it free from contamination.

The water is raised in many open wells by pumping, but the old plan, which is still extensively in use in rural districts, was to *draw* water from the well by means of a rope and bucket.

The cost of digging a well in a clay soil, and building a well ring, say 3 feet in diameter, will be about £10 for the first 20 feet in depth, the expense increasing considerably in proportion for every foot of additional depth. This is exclusive of winch or pump, &c.

CHAPTER XIV.

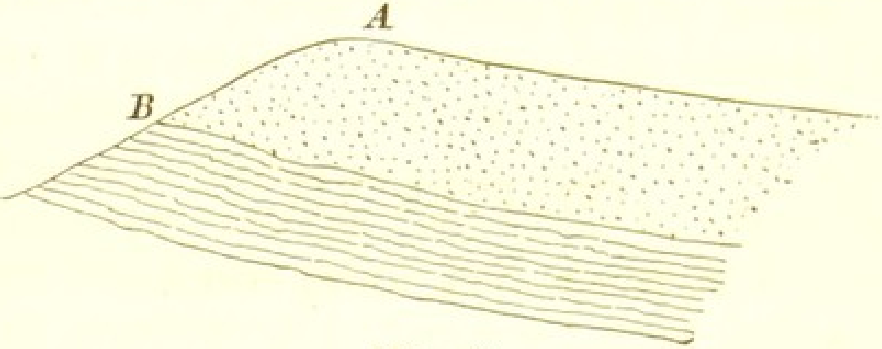
CATCH-WATER RESERVOIRS.

In cases not admitting of supply by means of wells, and where springs do not appear on the surface, the fluctuation of the rainfall, and consequently the flow of streams at different seasons of the year, require almost invariably that there shall be artificial storage of winter rainfall for summer use. When the mean annual requirements, whether for domestic use, for hydraulic power, or for live stock and irrigation purposes, one or all combined, are nearly equal to the mean available rainfall, the question of storage becomes of supreme importance.

Determination of available Rainfall.—For measurement of rainfall two kinds of data are required: (1) drainage-area, catchment-basin, or gathering-ground; (2) depth of rainfall.

Drainage areas are usually bounded by water-shed lines. The water-shed does not always, however, prove the drainage boundary; as, for example, when a porous superstratum overlies an impervious stratum. In such cases the drainage boundary will not be at A but at B (Fig. 24). Artificial watercourses and drains may also lead the water away from its natural course; but while this will diminish the yield of one water-shed, it will add to the natural supply in another place.

Steep rocky surfaces, or clay soils, make the best gathering-grounds, as the rain-water flows rapidly off them and less is lost both by evaporation and absorption than on flat and porous surfaces. Sand, gravel, and chalk, as well as many of the softer sandstones, are all so exceedingly absorbent that the rain is swallowed up as fast as it falls on them.



[Fig. 24

We have, then, only this general rule: Water-shed lines are the boundaries of the basins, but geological features may affect the quantity as already described.

The available rainfall of a district is that part of the total fall which remains to be stored or carried away, after deducting the losses by evaporation, percolation, absorption by plants, and other causes. The proportion which this bears to the total rainfall varies very much, being affected by the distribution of the rainfall, the porosity of the soil, the steepness or flatness of the ground, the nature and quantity of vegetation upon it, the temperature and moisture of the air, and other circumstances. Upon average drainage areas, and including floods and flow of springs, it may ordinarily be taken at about 50 per cent. of the annual rainfall. For different surfaces its ratio is more approximately as follows:—

On primary rocks . . .	nearly 1·
On moorland and hill pasture	·8 to ·6
On cultivated land	·5 ,, ·2
On chalk ditto	0.

Assuming then that half the rainfall can be made available for storage, a fall of 32 inches per annum leaves us 16 inches, or 16·16 tons per acre.

But there are losses incidental to storage which must not be overlooked. Reservoirs constructed on the surface of the ground are seldom perfectly water-tight, and a certain amount of percolation is almost inevitable. More or less evaporation will also take place from the surface of the reservoir. The amount of evaporation from the surface of water has, in England, been found to be 18 inches or more per annum; but the percentage of storage water lost by evaporation will of course depend on the superficial area of the reservoir, and in any case will be comparatively small. If these two losses, however, taken together, amount to 6 or 7 per cent. of the reservoir water, it takes 1 inch off the available rainfall, and leaves us with only 15 inches available for consumption.

When water is impounded in manufacturing districts, it is common to allow from $\frac{1}{4}$ to $\frac{1}{3}$ of the available supply to the riparian owners, leaving $\frac{3}{4}$ or $\frac{2}{3}$ for the impounders.

Site of Reservoir.—This should be carefully chosen in regard to the gathering-ground, the nature of the surrounding and underlying soil, the requirements of live-stock, irrigation, and agriculture in general, as well as the cost of construction. The most favourable site, as affecting cost, is where a comparatively small embankment, thrown across a gorge or valley, will form a large reservoir with the water retained on three sides by the rising ground. An impermeable clay surface is as important as the configuration of the ground, as it not only influences the cost of puddling, but the proportion of the rainfall which can be collected, and also its retention in the reservoir is largely dependent on this feature. The position of the reservoir for supplying grazing stock with water, or for irrigation or other purposes, is of less consequence than obtaining a good storage, unless the reservoir is so distant from the place of consumption that the cost of delivery pipes would defeat the object of storage altogether.

Capacity of Reservoirs.—As a matter of economy, it will always be better to construct one large reservoir than two smaller ones to hold the same amount of water ; but there is of course a practical limit to the height of the dams. Deep open reservoirs, however, are in all cases preferable to shallow ones, for other reasons besides that of first cost ; for where the surface is large in proportion to the capacity of the reservoir, the greater will be the evaporation, and shallow water also encourages the growth and decay of vegetable matter.

Construction of Reservoirs.—Small reservoirs, such as would generally afford sufficient supplies for all agricultural purposes, need entail only a moderate amount of engineering skill and of pecuniary outlay. Where a ravine or gorge can be converted into a storage reservoir, no excavation will be needed, and the only expense will be that of constructing the dam, unless the bottom requires puddling. In such situations, however, the dam must be of great weight and strength as well as height.

The Texas and Pacific Railway Company conceived the idea of obtaining a large water-supply from a reservoir of this kind, near Carisso Pass, where the position was favourable for forming a lake basin of very large area. At a point where the gorge between two mountain ranges narrows to a width of perhaps 60 yards, an embankment, some 75 feet wide at base, 20 feet at top, and 24 feet high, was thrown across it. Riding over the waterless prairie, some miles to the south of this spot, we noticed the artificial mound, and guessing its purpose, was lured out of our way, partly through interest in the scheme, and partly that we might quench our thirst in the cool and pleasant waters of the imaginary lake which was in hiding on the other side. But not a single drop of water was there! The scheme had been carried out regardless of geological conditions, which, on the gigantic surface of the lake (that ought to have been) there had been no attempt to rectify by art. The floods had been there in their season, as was attested by the water-mark on the inner side of the embankment, and the embankment had stayed the torrent of water which had rapidly arisen behind it; but the basin of the reservoir was sandy and porous, and appearances too plainly showed that the whilom lake had vanished underground, when the floods were over and the dry season set in.

In some places a natural hollow exists, which, with very little excavation, can be made to form a capital reservoir. A reservoir on level ground will entail more labour; but it is not always necessary in this case even that the entire capacity of the reservoir should be excavated; for provided water can be led on from higher ground, a small portion of digging need only be done, and the excavated material used for raising the sides, making about two-thirds of the capacity due to embanking, and only about one-third to excavation. The principle of this reservoir is, however, objectionable, owing to the sides being raised so much above the natural level of the ground; so that, even where it could be filled to that raised level, it may be better to excavate to the full extent if necessary.

An excavating scoop, which is manufactured by Messrs. John Fowler and Co., will be found to greatly facilitate and cheapen the construction of these reservoirs. The implement in question was originally designed for making large ponds or reservoirs on Australian sheep farms; but its successful employment for this purpose has led to other application of it, and it is now used for other descriptions of excavating work, and particularly for levelling land and constructing dams. The scoop is worked by drawing it backward and forward between two steam-ploughing engines, in the same way as the implements employed in the double-engine system of steam-ploughing tackle, the engines being placed one on each headland, and the implement being pulled backward and forward between them. The scoop is, however, always filled by one of the engines, the other engine being used only for pulling the loaded scoop to the point where it is required to discharge. By ploughing the ground first, and using the scoop after, an extensive basin can soon be scooped out on the levelest surface; the depth being determined by the number of times the operations of ploughing and scooping are repeated.

Where the bottom of the reservoir is of a porous nature, it should be puddled to make it retain water. Where clay is not available for puddle, all that is necessary is to cover the bottom with loam to the depth of 12 or 18 inches, and then puddle or work this well with water till it will allow none to percolate. This working, or puddling, may be done by turning a flock of sheep or a herd of cattle into the bed of the reservoir to trample it well when wet. A similar practice is followed in India. When it is required to make the bed of a reservoir water-tight, they keep it wet and turn buffaloes into it, as their treading effectually puddles the bottom, and prevents water being lost by percolation.

In the construction of small reservoirs, and certainly of underground tanks, the use of concrete may be advisable. Common lime, properly slaked, and mixed with sand, if faced with cement, will make admirable tanks. Portland cement is a double silicate of lime and alumina, made from the deposits of chalk and alluvial clay on the shores of the rivers Thames and Medway, and possesses the property of setting and hardening under water. One barrel of Portland cement mixed with 16 gallons of water, if laid on half an inch thick, should cover 100 square feet of surface. One barrel of Portland cement and two barrels of clean sharp sand, mixed with 23½ gallons of water, should cover 219 square feet of surface to the same thickness; and one barrel of cement and three barrels of sand, with 28½ gallons of water, should cover 285 square feet of surface. The composition of cement and sand may be used if allowed to set before water is let into the work.

The mode to be employed in filling the reservoir, and the best means of providing for overflow, will be suggested by circumstances.

For drawing off the water from the reservoir, the employment of one or more large syphons will probably be preferable to making an opening in the embankment. On a level surface the water may have to be raised by pump, in order to distribute it by gravitation.

CHAPTER XV.

RAISING WATER BY MECHANICAL MEANS.

In irrigation works of any great extent the question of raising water by artificial means may be dismissed, as too expensive an undertaking for individual enterprise. Where, however, circumstances favour a unified system of irrigation, and the scheme is generally adopted by landowners or occupiers, and carried out as a public work under proper control, it may be otherwise.

In Egypt, for example, where some improvement of the present system is urgently called for, two schemes for improved irrigation by raising water by means of pumping are now under the consideration of the Government. The first of these, presented by the Minister of Public Works, proposes to fill the lesser canals during the dry season. The second proposal, which is favoured by the Public Works Company, is to keep the great summer canals perpetually full and to unify the canal system. The former project would be the less costly, and the amount requisite for it might, perhaps, be met by a slight increase in the land-tax on lands already watered, and a tax on lands expected to be reclaimed. In return, a partial exemption from the *corvée* would compensate the fellaheen from the increased burden. The latter scheme would call for a heavy outlay, but would abolish the *corvée* entirely; and, in the event of a deficit, the Government would endeavour to meet it by an extraordinary budget rather than impose a new water-tax. The experiment of artificially raising water by steam-pumping has already been tried in the province of Behera, with very discouraging results; but this is attributed to the bad quality of the machines. Before sanctioning either scheme, the Government will, probably, cause experiments to be made in one or two provinces.

As already remarked, however, where irrigation is a work of individual enterprise, it cannot be practised with profit on an extensive scale, unless the water is delivered by gravitation from an elevated canal, river, or impounding basin. As there are thousands of situations where the only source of water-supply is below the level of the land to be watered, the effect is practically to prohibit the artificial application of water to such lands on a large scale.

It is different in garden culture, and in market-garden farms, where the area of land under cultivation is comparatively small, and the value of the produce is far greater than in ordinary farming. The difficulties in the way of raising a sufficiency of water for irrigating garden crops in dry weather are not so insurmountable; and the expense will, in most cases, be amply repaid by the increased profits.

For other purposes than irrigation—the wants of live-stock, for feeding engines, and driving machinery, and for domestic purposes—though the need of water is greater, it is required in smaller quantities; and the cost of raising it, when the source of supply is below the level of the place where it is to be used, is then a subsidiary consideration.

As regards the most economical power and machines

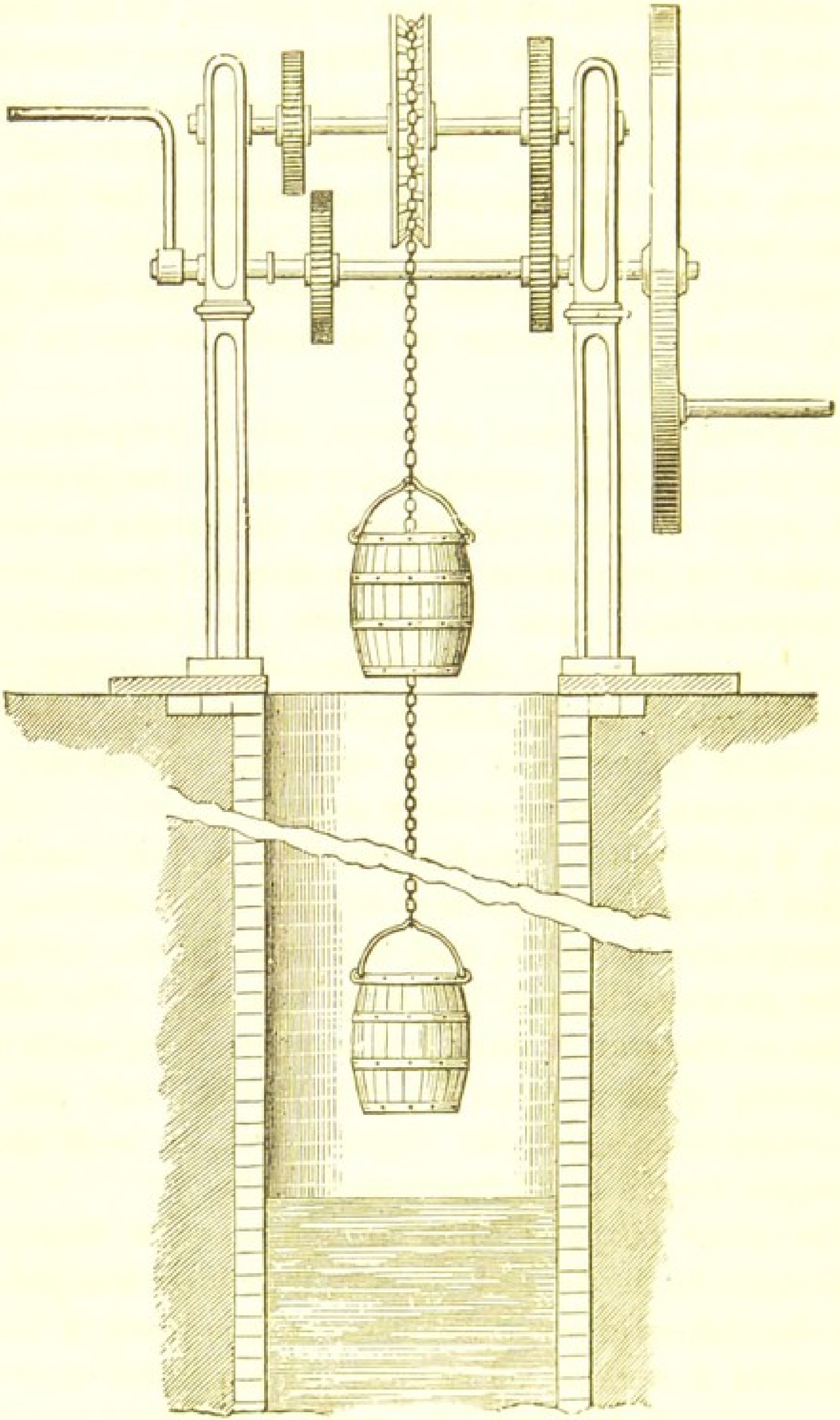


Fig. 25.

for raising water, much will depend on the height of the lift and the quantity to be raised. Hand or animal power, steam, wind, and water, are all employed as motive-powers for this purpose; and the instruments for utilizing the power so used vary from the primitive rope and bucket to the water-ram and the steam-pump.

For raising water from open wells, the rope and bucket is the most simple means. An improvement on the old mode of drawing by bucket is shown in Fig. 25, as designed and manufactured by S. Owen and Sons, London, in which a windlass is erected over the well, and two buckets are in use, one filling while the other is emptying. Where required, a self-tipping apparatus is provided, with a cast or wrought iron trough, into which the buckets discharge themselves as they reach the surface. In Fig. 26, part of a series of troughs is shown connected together by short pieces of flexible or other pipe, so that any number can be filled for watering a large flock of sheep (as required in the Australian colonies, &c.), the man at the wheel keep-

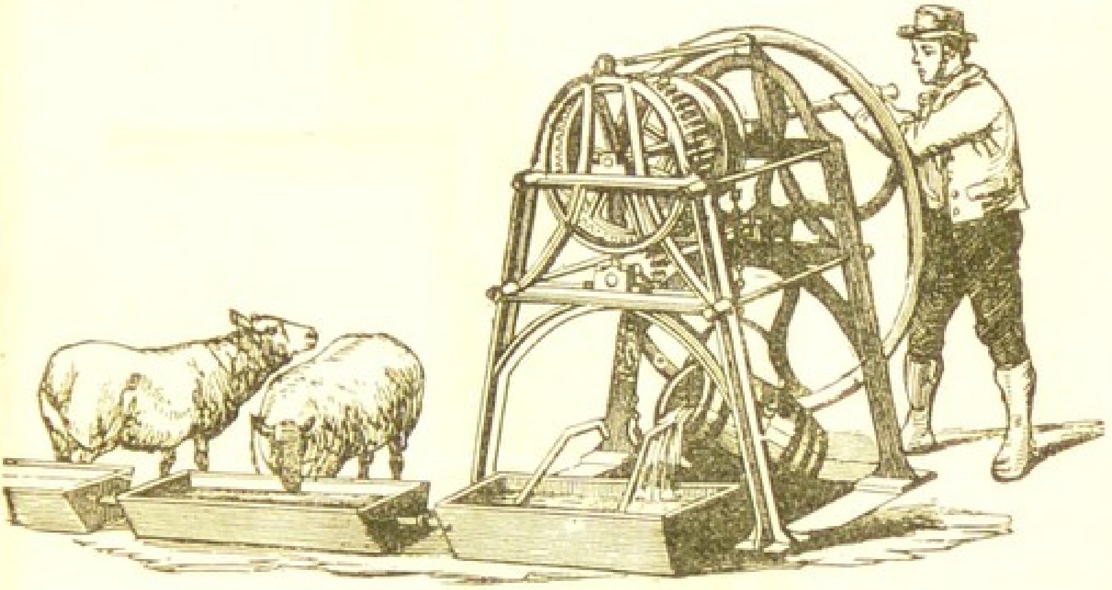


Fig. 26.

ing at his work while the self-acting apparatus fills his troughs. This apparatus for raising water is also largely employed for deep wells in many parts of

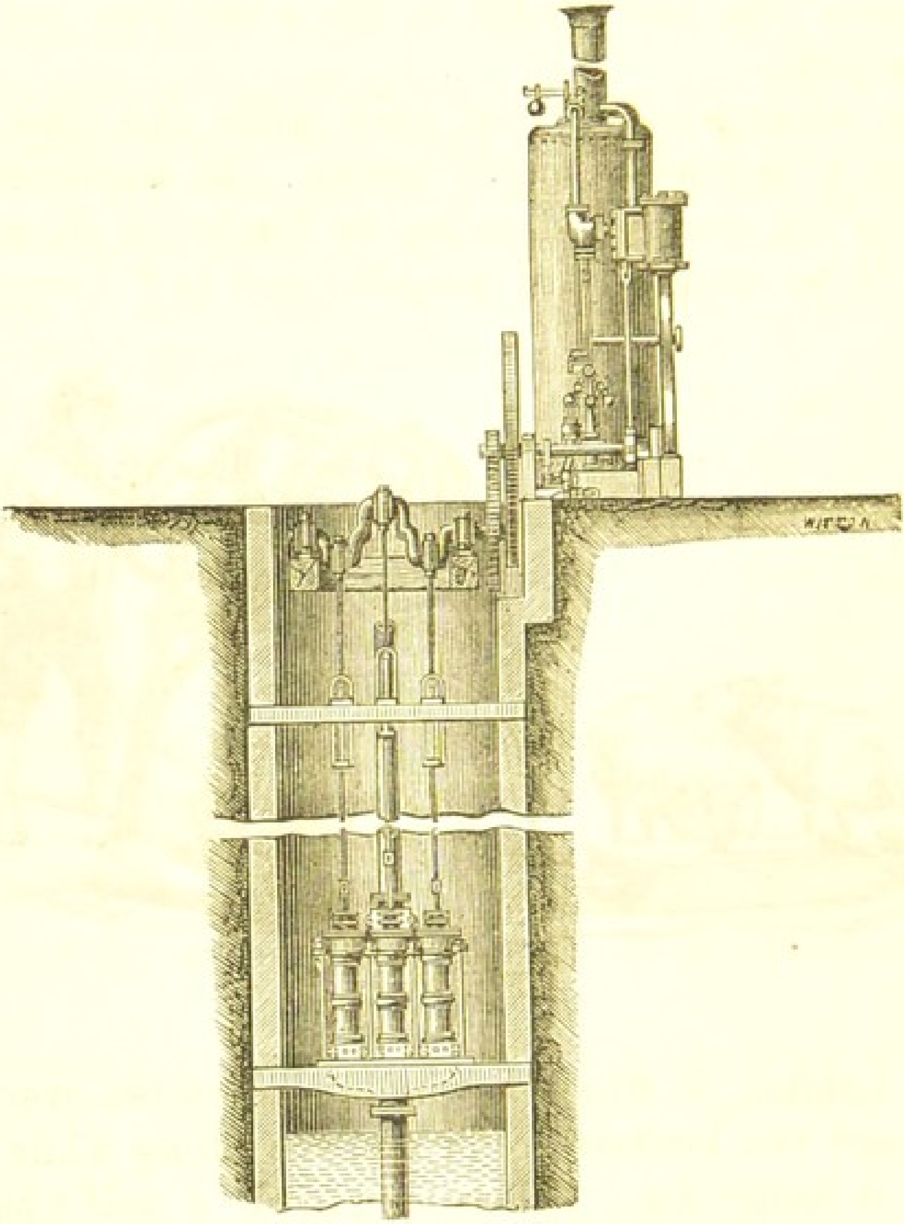


Fig. 27.

England where pumps would be expensive, and the labour required to work them great.

When a large and continuous supply of water has to be raised by this method, a pony or donkey may be employed to hoist the buckets. On the Continent, this mode is practised successfully, and the pony is trained to work without attendance.

Well Pumps.—The pump, however, is a more convenient instrument for raising water from wells than the rope and bucket. For low lifts, under 26 feet, the common suction, or lift pump, is sufficiently powerful; but for deep wells, force-pumps, or suction and forcing pumps, of the treble or double barrelled type, with valves in the buckets, and an additional retaining-valve for lifts over 100 feet, will have to be used. In these pumps the rods pass down inside the rising main pipes, which are of larger diameter than the working barrels, thus allowing of the buckets and valves being drawn up for repair through the pump-head or cover, which is fixed above the highest level to which the water is likely to rise under any circumstances. Without some such provision, access could not be gained to the working barrels and lower valves should they become immersed, or where they are confined in a small bore hole.

Fig. 27 represents a small steam-engine working a set of Warner & Sons' treble-barrelled deep-well pumps. The same class of pumps can be furnished for water, wind, horse, and even for manual power.

Where only small supplies of water are needed, the question of raising it from deep wells by manual power is, however, so difficult to arrange, that small motors, of one or more horse-power, worked by gas or hot air, are commonly employed, especially in country houses. They are more economical than steam, and do not require skilled labour.

Power required to raise Water from Deep Wells.—Appleby gives the following table of power required to raise water from deep wells by pumping:—

Gallons of water raised per hour ...	200	350	500	650	800	1000
Height of lift for one man, in feet	90	51	36	28	22	18
,, ,, ,, donkey ,,	180	102	72	56	45	36
,, ,, ,, horse ,,	630	357	252	196	154	126
,, ,, ,, H.P. steam-engine ,,	990	561	396	308	242	198

A good high-pressure steam-engine should raise 3,300 gallons 1 foot high per minute per nominal horse-power; the friction of the pump being compensated by the excess of the indicated power over the nominal.* The power required depends, of course, on the height to which the water has to be raised.

Rule for finding required Horse-Power.—For calculating the horse-power required to raise a given quantity of water to a given height, we have this general rule: multiply the weight in pounds of water to be lifted in one minute by the vertical height in feet, and divide by 33,000.

Example.—Find the horse-power that will be required to raise 2,000 gallons of water per minute to a height of 100 feet.

A gallon of water weighs 10 lbs. Therefore

$$2{,}000 \times 10 \times 100 \div 33{,}000 = 60{\cdot}60 \text{ H.-P.}$$

Many engineers add one-fifth for friction. This would bring the required horse-power in the example up to 72·72.

Cost of Pumping.—Mr. Fanning gives the following among other examples of the cost of pumping water in various American cities by steam-power and by water-power:—

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* Box, "On Hydraulics."

COST OF PUMPING WATER

Per Million Gallons in various American Cities in 1875.

City.	Power employed.	Lift in feet.	Millions of gallons pumped during year.	Pounds of coal per million gallons.	Cost of coal per million gallons.	Wages of labour per million gallons.	Cost of repairs per million gallons.	Cost of engine-man's stores and supplies per million gallons.	Total cost of pumping one million gallons.	Cost of raising one million gallons 100 feet.	Pounds of coal used to raise one million gallons 100 feet.
Brooklyn, N.Y. .	Steam power .	176·3	9998·00	2703	dols. 8·44	dols. 3·64	dols. 1·45	dols. 1·97	dols. 15·50	dols. 8·79	1533
Jersey City, N.Y.	,, ,,	160	4439·26	—	18·33	—	—	—	18·03	11·27	—
Chicago .	,, ,,	120	10957·25	3095	8·91	1·59	·14	·21	10·81	9·00	2571
Indianapolis, Ind.	,, ,,	117	353·29	1697	14·11	16·01	2·31	3·12	35·55	30·38	1450
Montreal . .	,, ,,	165	1326·47	6204	16·08	7·86	·94	2·30	27·18	16·47	3760
Philadelphia .	Water power .	90 to 115	7670·1	—	—	1·57	·13	·39	2·09	2·15	—
New Haven .	,, ,,	115	1769	—	—	1·00	—	·33	1·33	1·16	—
Manchester . .	,, ,,	113	424	—	—	2·60	·16	1·30	4·06	3·59	—
Montreal . .	,, ,,	165	1879·56	—	—	·76	1·33	1·33	3·42	2·07	—

Centrifugal Pumps.—For raising a large volume of water to a moderate height this class of pump is invaluable. The limit to which it can be economically employed depends upon circumstances which are constantly varying. It is used to raise water to a height of 40 or 50 feet at times, but is best adapted to lifts not exceeding 25 feet.

An advantageous arrangement is to work these pumps by a portable engine, as not only can both the engine and pump be placed in any position most suitable for working, but when not required for raising water the engine can be easily detached, and applied to any work for which portable engines are adapted—such as sawing, threshing, grinding, &c.

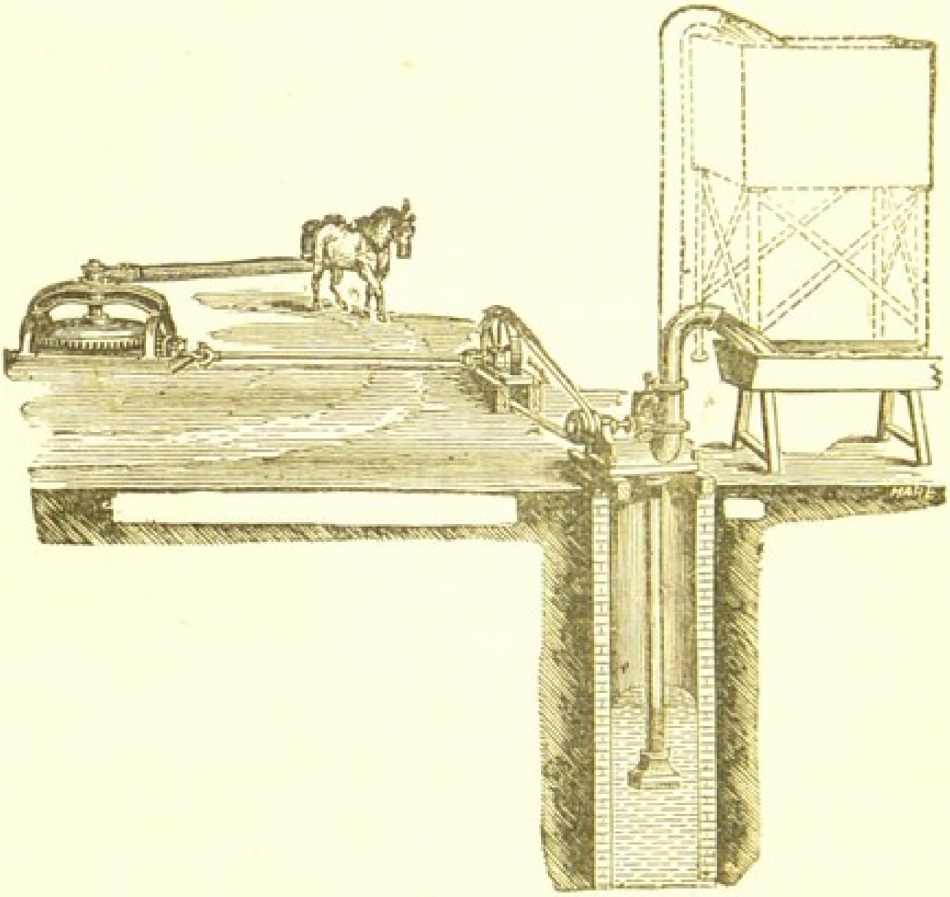

Fig. 28.

On low-lying lands an engine and pump of this class is invaluable for draining, as well as irrigation purposes. The smaller sizes are adapted for being worked by horse-power or by bullocks. Fig. 28 shows a pump of this kind being worked by a horse. It is manufactured by Messrs. Hornsby & Sons, Limited, Grantham.

The following table gives the nominal horse-power required for the discharge of given quantities of water with lifts of 10 and 20 feet:—

Diameter of pipe.	Gallons discharged per minute.	Nominal H.P. required for a 10-foot lift.	Nominal H.P. required for a 20-foot lift.
Inches.			
3	100	1	2
4	200	1½	3
5	350	2	4
6	500	2½	5
7	750	3	6
8	1,000	4	8
10	1,500	6	10
12	2,300	8	14
14	2,800	10	16
15	3,300	12	20
18	6,000	20	35

Wind-Power.—The objection to windmills in drainage works was, that this power was too variable to be relied upon for keeping the water down to a certain level. There can, however, be no such objection when windmills are employed to raise water from wells for irrigation purposes, or for watering live stock, if storage reservoirs are provided equal to, say, a week's supply. By this means the wind can be utilized whenever it blows, and none of the water is wasted. The windmill works night or day, as called upon by the passing breeze; it wastes no water, requires no fuel, and needs no attendance. There are few field-pumps that might not be effectively worked by a small windmill, and a larger one will many times furnish a full water-supply for every purpose on the farm. Where water has to be raised for gardens, a windmill is indispensable. On the dry plains of the far West, too, where deep wells have been sunk, but are not self-flowing, the windmill is the only means of economically bringing the water to the surface, and of enabling stock-grazing to be carried on with success and profit. The wells may be many miles from the homestead, but a windmill-pump will keep up an unfailing supply of water without the daily attention

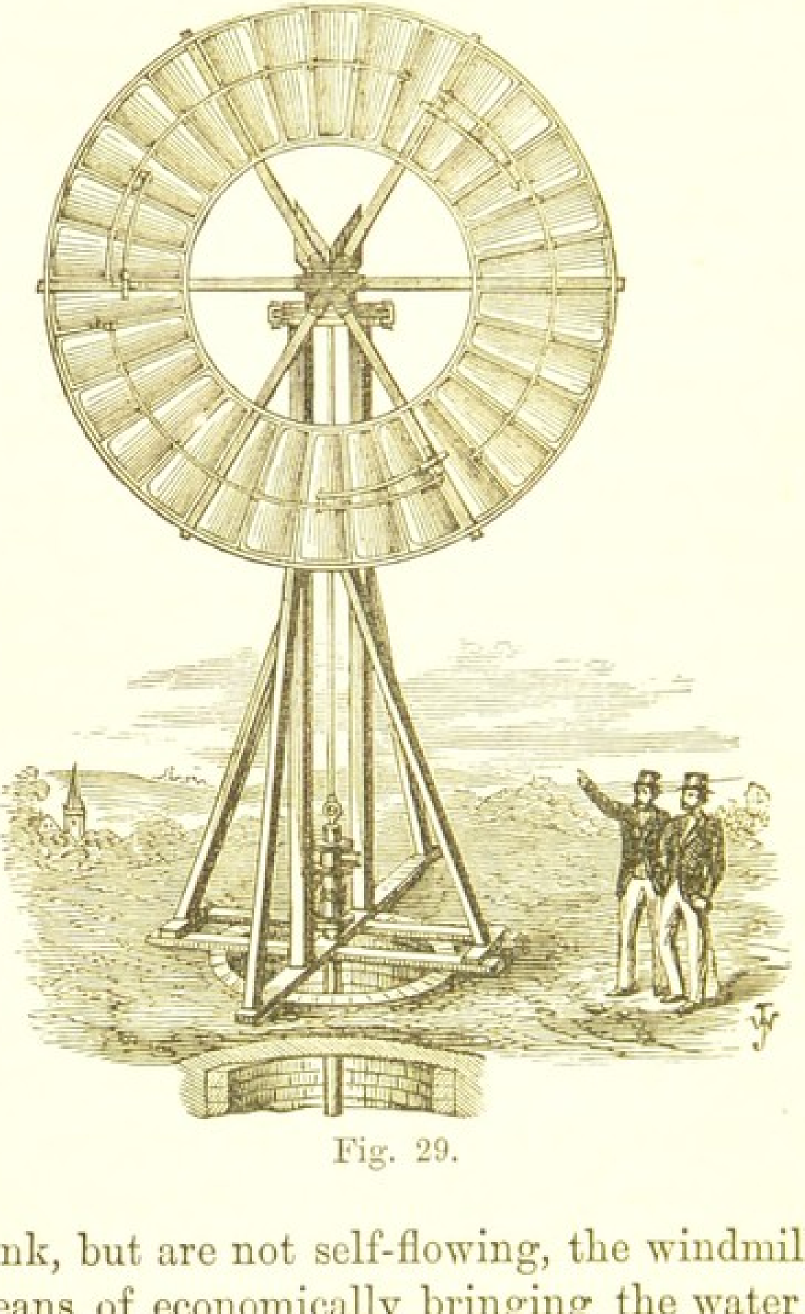

Fig. 29.

of the stockmaster, and at no cost for wages and fuel. Fig. 29 represents a windmill working a well-pump, as erected by J. Warner & Sons, London.

Self-regulating windmills are now made of two kinds. In one kind the circle of fans faces the wind at all times, but their angle to the wind is changed with its force. The other is the "solid wheel," the fans being all fixed, which swings round with its edge against the wind, when it becomes violent, by a self-regulating arrangement, which is partly effected by the centrifugal force of weights, and partly by the direct pressure of the wind. In the former, the self-regulating contrivance is as follows: When the mill begins to run too fast it pumps water rapidly into a chamber or cylinder, and this increase of water moves an arm, which turns the fans edgewise to the wind. When the wind slackens, a reverse movement takes place. By these arrangements the mills are rendered perfectly safe even in a gale of wind. Both these forms are well adapted to farm purposes and pumping water for cattle. They are made of various sizes, and range in price from £10 to £200.

Water-Power.—Water, like wind power, is more economical than steam power for pumping purposes when it can be conveniently employed. Our illustration (Fig. 30) shows an overshot water-wheel, by S. Owen & Sons, London, working a set of treble-barrelled pumps for the supply of a farm, &c., where a large quantity of water is required. In other cases, breast or undershot water-wheels may be employed, and they can be worked with any water that is available. Mr. Wheeler gives an instance of a water-wheel working treble-barrelled pumps, for the supply of pure water for a mansion, homestead, gardens, stables, &c., the motive power being sewage; and in another case, where the water is taken from the duck pond, to pump pure water from the well. The wheels and pumps cost from £76, for supplying 1,700 gallons a day, through 1,200 feet of inch pipes, with 90 feet lift, the fall for working the wheel being only 5 feet; to £133 for supplying 1,200 gallons through 1,600 feet of piping, with 165-feet lift. Mr. Clutton states that the cost of fixing water-wheels 8 feet in diameter, in the neighbourhood of the Cotswold Hills, for the supply of farm premises and cottages, was from £55 to £70.

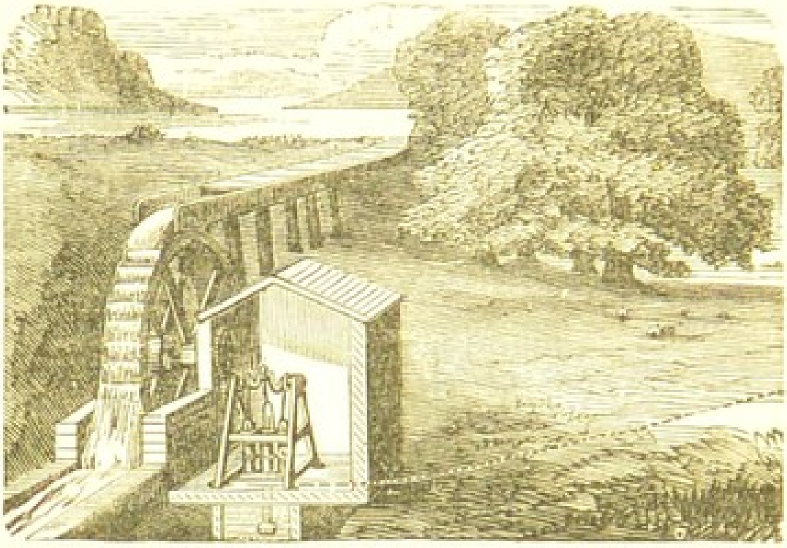

Fig. 30.

Noria, or Persian Wheel.—Markham* thus describes the use of the Noria (Fig. 31) in Eastern Spain, for raising water to irrigate terraced fields on different levels above the canal: "These norias are of extreme antiquity, having been used in one form or another from time immemorial by Eastern nations. A deep channel is cut from the canal, over which a huge timber wheel is placed, upwards of 15 feet in diameter. By its side are two stone pillars supporting a cross-beam,

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* "On Spanish Irrigation."

to the centre of which an upright beam is attached. This upright beam is the axle of a double wheel working horizontally, the two parts being joined by strong battens which lock with cogs in the great wheel. A long pole is fastened to the upper part of the upright beam, to which mules are harnessed and driven round. They move round the horizontal wheel, the battens of which

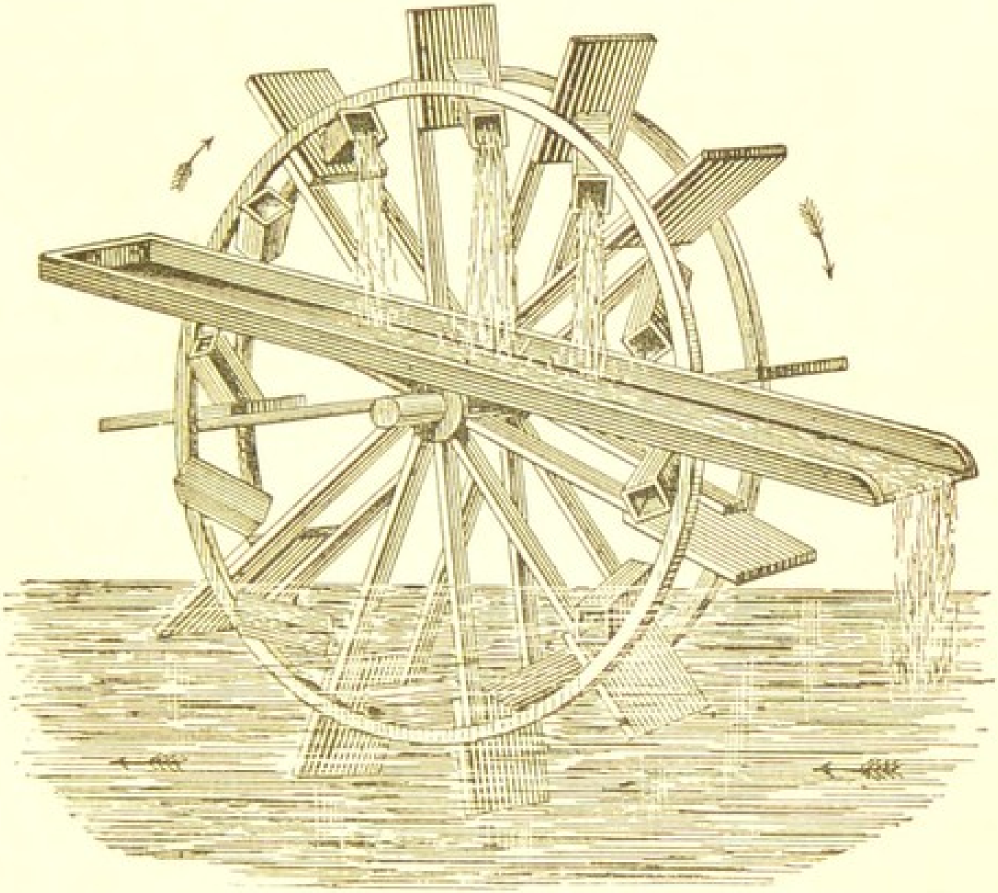

Fig. 31.

lock with the cogs in the great wheel and turn it round. The great wheel is fitted with a succession of boxes round the circumference, which fill when at the lower end of their revolution, bring the water up, and pour it into a trough leading into a channel. Thus the fields up to 15 feet above the level of the mother canal are irrigated. The upper channel brings the surplus water to another large wheel, which raises it in the same way to terraced fields at an elevation of 30 feet above the mother canal. The norias in Algiers and elsewhere are usually fitted with earthenware jars, instead of boxes round their circumference."

Hydraulic Ram.—The improved self-acting hydraulic ram is a highly useful and efficient apparatus, and is now much employed for raising water for such purposes as irrigating lands and supplying farm buildings. Fig. 32 shows its construction and principle of working. "Its principal parts are the reservoir or air-chamber (*a*), the supply pipe (*b*), and the discharge pipe (*c*). The running stream rushes down the supply pipe (*b*), and striking the waste valve (*d*) closes it. The stream being thus suddenly checked, its momentum opens the valve (*e*) upwards, and drives the water into the reservoir (*a*) until the air within being compressed into a smaller space by its elasticity, bears down upon the water, and again closes the valve (*e*). The water in the supply pipe (*b*) has, by this time, expended its momentum and stopped running; therefore the valve (*d*) drops down again, and permits it to escape. It recommences running, until its force again closes the water valve (*d*), and a second portion of water is driven into the reservoir as before—so it repeatedly continues—the great force of the compressed air in the reservoir driving the water up the discharge pipe (*c*)." It works day and night without needing attention, and will raise water to any height or distance, without

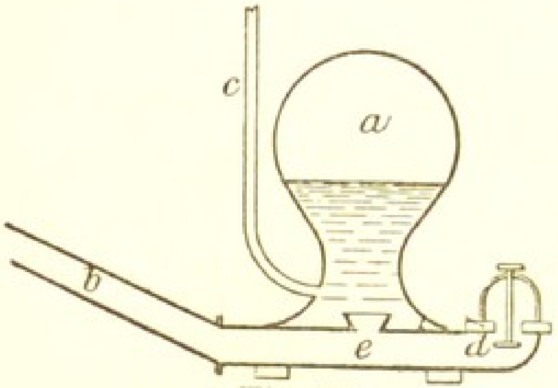

Fig. 32.

cost for labour or motive power, where a few feet fall can be obtained. With the same quantity of water and fall to work it as the water-wheel and pump, the ram will send up double the quantity of water that the wheel will do, and to the same height. The ram is made in sizes to raise from 300 to 100,000 gallons per day, and will force to a height of 1,500 feet. It raises a part of the same water that works it, or will raise pure water from a well or spring, whilst worked from a stream of impure water. Our illustration (Fig. 33) shows a ram, erected by Messrs. S. Owen and Sons, supplied by a fall of water from a lake, and forcing up to a farm at an elevation; the waste water expended in working the ram being carried off to a lower level and into the natural channel which the overflow of the lake finds for itself. It will work when quite immersed; its cost is small to begin with; it occupies but little space; and will work for years without once stopping or needing any repairs.

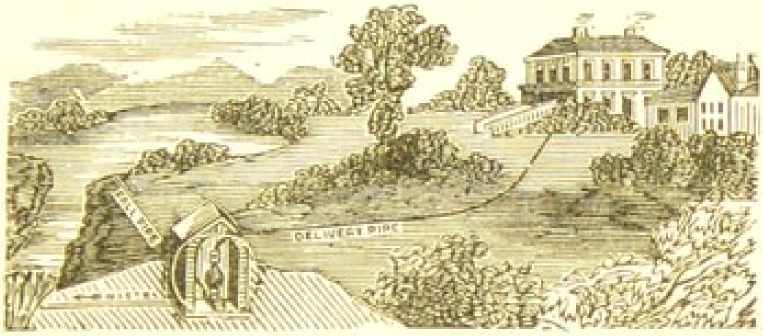

Fig. 33.

The hydraulic ram is applicable where no more than 18 inches fall can be obtained, but the greater the fall the more powerful the action of the machine, and the greater the elevation to which the water can be raised. If at all possible, a fall of 8 or 10 feet should be obtained. At the same time it is not advisable to use a greater fall than is absolutely necessary to raise the required quantity of water to the desired height, as the ram is then subjected to an unnecessary amount of work, the wear and tear of all the parts is increased, and the durability of the whole is proportionately decreased.

The proportion between the water raised and that running to waste depends mainly on the height of the spring or source of supply above the ram, relatively with the height to which the water is delivered. The quantity raised varies in proportion to the height to which it is conveyed with a given fall, and the length of the pipe through which the water is forced; the longer the pipe, the greater is the friction to be overcome. It is, however, not unusual to apply a ram for forcing water to a distance of 1,000 yards or more.

If the ram is fixed at a reasonable distance from the point where the water is to be delivered, the fall necessary to deliver a given quantity is approximately as follows* :—

About one-seventh part of the water will be raised to five times the height of the fall, and so on in the same proportion.

Thus, if the ram be placed under a head or fall of 10 feet, and the stream delivers 50 gallons per minute, about 7 gallons per minute can be raised to a height of 50 feet, or 3½ gallons to a height of 100 feet; or, in other words, an efficiency of 70 per cent. is obtained. Some of the improved forms of ram show, we believe, considerably greater efficiency than this.

The ram should be fixed in a pit 2 or 3 feet deep, sufficient to protect it from frost, and a race should be

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* Appleby, "Handbook of Machinery."

cut to convey the waste water away. The pipes should also be laid at such a depth in the ground that they are out of the reach of the severest frost.

The cost of raising water by means of a hydraulic ram will depend on the quantity of water to be raised, the height to which it has to be forced, and the length of piping. Mr. Wheeler gives particulars of rams fixed for the supply of houses and gardens, varying from £92 10s., with a lift of 200 feet and 1,800 feet of piping, and yielding 1,400 gallons in 24 hours; to £26 for 273 feet of piping and 1,700 gallons.

CHAPTER XVI.

WATER-SUPPLY FOR LIVE STOCK AND FOR AGRICULTURAL MACHINERY.

In the earlier chapters of this work attention has been drawn to the need of water in the economy of plant life and growth, and to its use in irrigating land for the supply of those wants. The amount of water necessary for irrigation works may be greater than the requirements for other agricultural purposes, but assuredly not more important. For the live stock of the farm the need of water is more urgent than for irrigation, and the dependence of live stock on artificial supplies is more incessant. Whether in the fields or in the yards, water is a first necessity in summer, and also in the yards during winter. Only those who have had experience of stock-keeping on a large scale in waterless regions, where there is little or no rainfall during many months of the year, can realise the full importance of this part of our subject. The water-supply for agricultural engines is now only of secondary importance, and water-power for driving threshing or any other machines, if not an absolute necessity, is certainly a very great economy and advantage in many situations.

Water for Stock in the Fields.—A supply of good water for stock during the summer months is an essential requisite in all pasture fields. Horses and cattle require on the average about five gallons each per day, and a sheep about half a gallon per day in dry weather. On waterless formations, therefore, any means of rendering water easily come at does much to enhance the value of the land for grazing purposes.

The plans usually adopted are either to sink deep wells or to form reservoirs or drinking-ponds. If a well is sunk in the corner of a field where two fences cross, one trough may be made to serve for watering the stock in four fields; and if the well has plenty of water, pipes may be laid to carry part of it to other fields, which will be found cheaper than sinking more wells. When a pump is necessary, the water-trough for the stock should not be placed immediately under the pump-spout, but some feet distant, a piece of tubing being employed to convey the water. The pump itself should be fenced off so that cattle and horses cannot reach it.

Millions of acres in Central Australia, which for years have been considered uninhabitable, have been turned into fertile country by the aid of artesian wells and catch-water reservoirs. The country in parts is fairly watered, but wells are everywhere necessary to supplement the supply from the creeks. Those squatters who recognise this fact are doing well. The most valuable run, Tarella station, carries 60,000 sheep, the owner having constructed eight dams, averaging 10,000 cubic yards each, on the Bunker Creek. Not content with this, he sank three artesian wells at different spots, one of which is sufficient for the requirements of 20,000 sheep, whilst each of the others yields 3,000 gallons of water a day. A new artesian well at Sale, with its overflow of 400,000 gallons of water a day, rising 12 feet above the surface, is a great success. The recent sinking of an artesian well by Mr. De

Renzil Wilson, on Tatara Run, near Curriwillinghi, on the New South Wales side of the Queensland boundary, where at the depth of 200 feet a spring was tapped which forced itself to the height of 15 feet above the surface, and at the estimated rate of 500 gallons per minute, is even more successful.

Field ponds answer very well in localities where no other means of coming at water for stock is available. These are simply small reservoirs or receptacles for collecting water, and are dug out of the ground. They are usually made circular in plan, and so situated that they furnish a supply to four fields.

It need never be very difficult to make a pond in a clayey soil, which is itself retentive of water. Where ponds are made in a porous soil, much more care is necessary. The bottom and sides must then be covered with a thick coat of the toughest clay, from a foot to two feet thick, well rammed down. There is the greatest difficulty in finding water in chalky soils, because these are not in themselves very retentive of it, and generally lie in such beds that it is impracticable to dig through them. But even here ponds are easily made by digging into the chalk, and lining them with a coat of clay, as before directed. Some farmers judiciously pave the declivity by which the cattle approach the pond, and this renders it much more lasting than it would be, and preserves the water clean, while others pave the whole pond.

There are different methods of constructing ponds, but the plan adopted is generally this: The ground plan is circular, and usually 40 or 45 feet in diameter, with a centre depth of about 5 feet. This hole being dug out, a layer of clay, sufficiently moistened, is trodden down to the depth of a foot. Upon this a layer of quick-lime, an inch or more in thickness, is spread; and above that another layer of clay, a foot thick, is trodden and rammed as before. The use of the lime is to prevent worms penetrating through the clay in dry weather. A pond of the above dimensions will cost from £8 to £12.

Formerly the price of making a pond 60 feet in diameter was £10. A circle 60 feet in diameter contains an area of 314 square yards; so that each square yard of surface cost at this rate 7½d. And the capacity of such a pond, 6 feet deep in centre, is 209·4 cubic yards, each of which must have cost in the above instance 11½d. Five pounds have been given for a pond 36 feet in diameter, which is 10½d. each square yard of surface; and supposing it 4 feet deep at the centre, 2s. each cubic yard. It is plain from these figures that the larger the pond the less in proportion is the expense.

Water for Stock in the Yards.—Where a supply cannot be drawn from springs or running streams, recourse should be had to deep wells or to rain-water tanks. Ponds and open watering-places about the farmyard are very objectionable, as the water in them is always more or less polluted from yard drainage and from trampling by cattle. In many places driven or bored wells are now erected within the buildings, and even where the supply has to be brought a considerable distance from running springs, the employment of pipes enables water to be laid on to every stall in the yards if necessary, and at a comparatively small cost. The boon of this can only be appreciated by those farmers who have tried it. Not only is less labour entailed in tending the stock, but the animals themselves thrive better than when they are driven out to drink in all sorts of weather, and left standing in the pond, or hanging about the yard-gates to catch a chill.

The roofs of all farm buildings are, or ought to be, spouted; and if the rain-water from the roofs is collected, it will in most cases be found more than sufficient not only for the supply of the farm stock, but also for threshing purposes. Rain-water from the roofs, if stored in cool brick tanks, will keep sweet and fresh for any length of time and in any climate. We have pursued this plan in the tropics for a number of years, and though it was our only supply for domestic use, never had reason to complain of the water. Every 1,000 square feet of roofing, with a rainfall of 32 inches, will yield over 16,000 gallons of water per annum; and as the buildings on an average farm afford at least four times that amount of roof surface, it is evident there need be no lack of water about the farmyard. At the above rate, 4,000 square feet of roofing would supply 64,000 gallons of water per annum, or 175 gallons per day. But the consumption of water at the yards, on an average-sized farm, would be very much less than that. The cattle would be in the pastures all summer, and the horses also, perhaps; so that the summer consumption of water by live stock, in an ordinary farmyard, would never be likely to exceed 50 gallons per day. The brick tanks or cisterns should be large enough to contain a supply for eight months. Rain-water stored in barrels, especially open-headed barrels, is not fit for animals to drink. A plentiful supply of good water for live stock all through the dry summer weather, laid on both to fields and yards by supply pipes, troughs and ball cocks, instead of having to cart it very often from a distance, is so great a boon that no farmer would object to pay 5 per cent. on the necessary outlay.

Water for Agricultural Machinery.—Another reason for a good water supply to every field is the increasing use of steam power in cultivating the soil. Every acre of land cultivated by steam requires about 100 gallons of water for engine use. A 20-acre field requires 2,000 gallons. The convenience, not to say the economy, of having this supply at hand in the field itself is very great. On all recently laid-out farms, where steam cultivation has been introduced, much attention has been given to this point. Where springs, brooks, or drinking ponds are not accessible at every site likely to be occupied by the engines in cultivating an entire farm, tanks or wells should be provided. A tank placed in a corner where four fields meet would usually serve for all the fields, as in the case of a drinking pond so placed.

On the majority of farms, where the fields are tile-drained, the drainage-water may be led into tanks or cisterns and stored in sufficient quantity, not only for the use of the engines employed in steam cultivation, but also for watering the live stock, and sometimes even for working a water-wheel or turbine. Messrs. Howard, on their Bedfordshire farm, have so planned the drainage that it supplies a tank or pond at every point occupied by the engine engaged in tilling any part of the farm; and at the farmyard a reservoir has been excavated in the clay which holds half a million gallons of water. Extensive application of drainage-water has also been made on the estates of Lord Hatherton, in Staffordshire. In this case several ponds are used for storing the water, which is first carried to the farmyard and employed to drive a water-wheel which does all the threshing, &c., in addition to driving a saw-mill. After this, the water is passed to meadows on a lower level, where it is used in extensive and profitable irrigation.

CHAPTER XVII.

WATER-SUPPLY TO DWELLINGS.

IMPORTANT though it is to secure a good supply of water for irrigating crops, for watering live stock, and for driving machinery, the wants of the farmhouse itself, and of the cottages, are, in this respect, still greater. Water is one of the prime necessaries of life, and should be not only abundant but good. It is estimated that an adult consumes, on an average, about half an ounce daily for each pound weight of the body: therefore, a man weighing 150 pounds will require 75 ounces daily; about 50 ounces in drink and the remainder in the food. Unless, at the same time, the water consumed is good, a perfectly healthy condition of the system cannot be maintained; and it is well known that disease, in some of its most dangerous forms, is often introduced through the agency of bad water. Of course large supplies of water must be provided for domestic purposes beyond the quantities actually necessary to be consumed in food and drink.

Quantity required.—"The minimum quantity that is sufficient for the supply of a cottage or small farmhouse, for all ordinary domestic purposes, may be taken at 13¾ gallons per day, allowing 5½ persons as the average number to a house, and 2½ gallons for each person. This, of course, gives no margin for water-closets, baths, or other similar luxuries, which belong only to a larger class of dwelling. This quantity may appear small; but, having made extensive inquiry amongst cottagers and others, I found sufficient evidence to satisfy myself that it was the full quantity that was used when the water had to be baled or pumped from a tank, and not left to run to waste from a tap. Mr. Easton, in his evidence before the Select Committee on the Public Health Amendment Act of 1878, stated that, as the result of his experience and inquiries amongst cottagers in Sussex, he was satisfied that this quantity was sufficient. Colonel Cox put the quantity at 3 gallons a day, and the other witnesses agreed with the estimates of Mr. Easton and Colonel Cox, some even putting it at less. In the Sixth Report of the Rivers Pollution Commissioners is given an instance of four cottages, provided with a tank, in which the rain-water was collected from the roofs—one of the inhabitants being a laundress, who used a large quantity of water, and another feeding a number of pigs. The size of this tank was barely sufficient to give 10 gallons a day to each cottage; yet it is stated that it had never failed to maintain a sufficient supply.

" The large quantity used in towns—varying from 20 to 30 gallons a head—is due partly to manufactories, street watering, and flushing sewers; but, principally, to waste. This is proved by the fact, that towns supplied by meter do not average more than 7 gallons a head; and by the test applied to several streets in Brighton, where it was found that the supply did not average more than $4\frac{3}{4}$ gallons a head, although the number of persons to a house would be above the average, and water-closets and baths be freely used."[*]

Professor Rankine[†] gives as a fair estimate of the daily demand for water, per inhabitant, for different purposes, the following, based upon British water supply and consumption :—

	Imperial gallons per day.		
	Least.	Average.	Greatest.
Used for domestic purposes	7	10	15
Washing streets, extinguishing fires, supplying fountains, &c.	3	3	3
Trade and manufactures	7	7	7
Waste under careful regulations, say .	2	2	2½
Totals	19	22	27½

Sources of Supply.—Water, as ordinarily used for drinking purposes, is obtained from either springs, wells, lakes, or rivers, or from stored rain-water or land drainage. Where none of the other sources are available, the rain-water falling on the roofs of the houses, if collected, filtered, and stored in underground tanks, will furnish an ample and perfectly good supply.

"Granting," says Mr. Wheeler, "that 2½ gallons per head per day is enough for all the ordinary domestic requirements of a cottage, sufficient rain falls on the roof of every house in the course of a year, if properly stored, to yield a full supply. A cottage with its outbuildings covers about 500 square feet of ground. Taking the rainfall at 22 inches per annum, the quantity that may be relied on as an average in the driest districts of the country, a slated roof will yield 5,700 gallons—nearly equal to a daily supply of 15½ gallons, or rather more than 2¾ gallons per head. Tiled roofs

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[*] Mr. Wheeler, C.E., "Universal Conference on National Water-Supply," 1879.

[†] "Civil Engineering."

would yield less than this, being more porous than slates. Thatched roofs may be considered as altogether unsuitable for the collection of rain-water, from their absorbent nature, the difficulty of providing spouting, and the chance of pollution from the organic matter in the decaying straw."

Where rain-water from the roofs is the only supply, the minimum size of the tanks to be provided becomes an important question. It is usually reckoned that the impounding tanks or reservoirs should contain four months' supply in the rainy districts and six months' supply in the dry districts of England. Thus a tank for a cottage, where the daily consumption is 14 gallons, would require to hold from 1,680 to 2,548 gallons.

At the Reading Meeting of the Royal Agricultural Society of England last year, Mr. C. G. Roberts, Haslemere, Surrey, exhibited a very ingenious apparatus for collecting pure rain-water from the roofs of buildings. The apparatus, which is entirely self-acting, consists of a separator, the function of which is to reject the bad and store the good water, by preventing the first portion of the rainfall (which washes and brings down from the roof or gutters all kinds of impurities) from passing into the storage tank. The first water from the roofs when a shower falls is directed into the waste-pipe; then the separator cants, and turns the pure water into the storage tank. An illustration of this apparatus appears in the Journal of the Society, vol. xviii., part 2.

Impurities in Water.—Water may be very good for irrigation purposes and yet utterly unfit for household use. The most wholesome waters, as a rule, are spring water, deep-well water, and upland surface water; and the most dangerous ones are river water, to which sewage gains access, and shallow-well water. Stored rain-water, especially that gathered in large towns and cities, where smoke from innumerable chimneys taints the air, and the surface water from cultivated land, are of "doubtful" quality.

Rain-water is more pure than any other water before its descent, and it is only in large towns or cities where it becomes contaminated by atmospheric impurities, and is rendered unfit for use in the condition in which it falls. It is generally termed *soft*, in contradistinction to spring water, which is considered *hard*. The softness, which consists in a solvent action upon the fatty substance of the skin, is owing to a small amount of carbonate of ammonia, which is formed in the atmosphere and precipitated with the water.

Spring water and deep-well water, when impure, are usually so from the excess of inorganic matter, with which occasionally they rise highly charged. These admixtures are derived from the ground through which the water flows. The incrustations which form in steam boilers are caused by the precipitation of the impurities, in consequence of the concentration of the water in the boiler. They may be effectually removed, no matter what their nature, by boiling charcoal in the water, or by gently heating the water and filtering it through charcoal.

Pond water and shallow-well water is often full of animalcula, sewage, vegetable matter, sediment, &c.

The water from mountain streams and rivulets is always purer than that from low grounds, because the water from high lands runs rapidly, and generally over gravelled beds. River water from low grounds is generally rendered impure by the presence of organic matter generated in sewers and drains, and thence discharged. Almost every gallon of such water contains a quantity of spores, seeds, or ova of vegetable and animal organisms, and if a bottle of it is allowed to stand by for a short time a sediment is thrown down in which a number of creatures will be discovered by the microscope. Water of this sort is unwholesome and dangerous, whether it contains the actual carriers of disease or not.

Filtration.—In all towns where water-works exist the water supplied has already undergone filtration through sand and gravel, which is the only plan available for companies dealing with such immense quantities of water. One square yard of filter-bed should be provided for each 700 gallons required in 24 hours, and the filter-bed should be 6 feet in total depth, composed as follows: 30 inches of fine sand, 6 inches of coarse sand, 6 inches of shells, 30 inches of gravel. Perforated pipes should traverse the bottom of filter-beds to collect the filtered water, and the fine sand forming the top stratum should be frequently renewed.

The sand and gravel filter, however, is not sufficient, nor has it the power to remove a deal of the animalcula and other injurious matters often contained in the water. River water thus filtered may be none the less unwholesome because it is made clearer. Every one knows that the liquid evacuations of both men and animals is often clear, and can be readily passed through a stratum of coarse sand, but the liquid is not less free from sewage after being so passed. This filtration at best can only be looked upon as a means of removing the grosser impurities. It is therefore imperative that the water should undergo another and more complete filtering process before it can be considered fit for drinking, such as passing it through certain media which have the power of thoroughly purifying the water by oxidizing the organic matter and changing chemically the impurities in solution.

The Registrar-General most strongly recommends the adoption of a system of domestic filtration, every consumer employing upon his own premises suitable means to purify the water required for his use. He also recommends that householders should obtain real water purifiers, and not mere strainers. The old-fashioned system of passing water merely through balls or slabs of charcoal, or material which has the appearance of being charcoal, worked into a solid form, is for the most part useless for the proper filtration of water.

The best filters are constructed entirely with pure charcoal, and remove lead, lime, and sewage from water. They are also self-cleansing.

In Fig. 34 we have an illustration of Lipscombe's Self-cleansing Charcoal Cistern Filter. The drawing represents a filter and pure water reservoir inside an ordinary house cistern, but they may be modified to suit any cistern or tank above or under ground. The impure water passes through the inlet into chamber of filter, thence upwards through a plate, usually of porous stone, represented by the dotted line, then through powerful purified charcoal into the pure water reservoir, from which it may be drawn off cold by the pure-water tap, or hot and pure from the boiler.

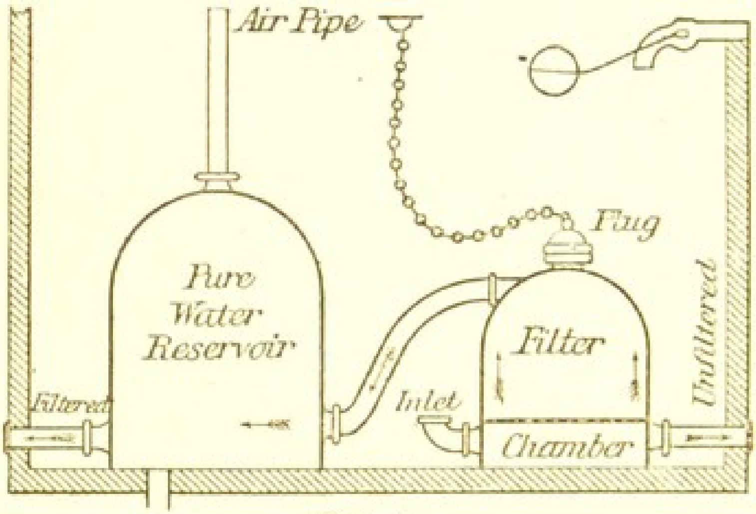

Fig. 34.

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