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INLAND WATER SURVEY COMMITTEE

Second Annual Report 1936-37

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INLAND WATER SURVEY COMMITTEE

Second Annual Report, 1936-37

To

The Right Honourable Sir KINGSLEY WOOD, M.P.,
Minister of Health,

and

The Right Honourable WALTER E. ELLIOT, M.C., M.P.,
Secretary of State for Scotland.

GENTLEMEN,

We have the honour to submit the following report on our work for the year 1st April, 1936, to 31st March, 1937:—

1. It is with great regret that we have to record the death during the year of Dr. Bernard Smith, F.R.S., Director of the Geological Survey of Great Britain. Dr. Bernard Smith took a keen interest in the work of the Inland Water Survey and, as one of our Assessors, his great knowledge and experience were always readily available to us. We received valuable advice and assistance from him from the time we were appointed, and we have greatly felt his loss.

2. As was explained in our First Annual Report,* the task laid down in our terms of reference makes it the object of the Survey to collect, to correlate and to encourage the keeping of records of the water resources of Great Britain, and to make these results available for general use. The actual work of gauging and recording is not carried on by us directly, but by various local bodies and organizations, our main task being to examine and co-ordinate the information supplied by these local agencies and so bring them into a form suitable for publication. We are assisted as regards surface water records by the Ministry of Agriculture and Fisheries, the Ministry of Health, and the Departments of Agriculture and Health and the Fishery Board for Scotland; as regards underground water, by the Geological Survey; and in matters relating to rainfall by the Meteorological Office.

Progress of Survey.

3. In order to fulfil a task of such magnitude satisfactorily, a considerable amount of preliminary exploratory work has been found necessary. The replies to our preliminary questionnaire showed that relatively little of the very varied mass of information already in existence was suitable for the purpose of the Survey, and as regards surface water it was evident that an improvement in the methods of recording and gauging of rivers and streams at many existing stations was very desirable and

* First Annual Report of the Inland Water Survey Committee, 1935-36, price 3d., obtainable from H.M. Stationery Office.

also that to make the Survey comprehensive a large number of new stations would be required. During 1936-37 our efforts, which are described later in greater detail, have been directed towards the organization of improved methods of survey on the lines indicated above, and to the examination and rearrangement of existing records suitable for publication in a form which would serve as a model for future extensions of the work of the Survey.

Surface Water.

4. It is generally considered that Catchment Boards are appropriate bodies for gauging the rivers which they control, and that a full knowledge of river flows and their variation is a fundamental necessity for carrying out the Boards' land drainage functions. A number of Catchment Boards are taking active steps towards surveying their rivers, and have appointed technical staff specially qualified for survey work. We wish to emphasize the importance of this work and to express the hope that other Boards will follow their example without delay. At the same time, there are other bodies interested in rivers who could co-operate in this work with the Catchment Boards, or, where no Catchment Board exists, with the County Council as Drainage Authority, or, in Scotland, with the Department of Agriculture for Scotland, in the exercise of analogous functions.

5. In order to assist such bodies and persons in gauging rivers and recording the measurements by methods and in the form that will give results of most value to the Survey, an instructional Memorandum* was prepared and published in October, 1936, containing suggestions for the carrying out of a survey of a river system, and giving details of suitable methods and apparatus and of appropriate arrangements of records and results.

6. During the year we have noted that an increasing interest is being shown in the Survey by many bodies and engineers concerned with rivers in their various aspects. We have, however, encountered some difficulty because bodies interested in taking measurements naturally look only for those parts of a record which are of most use to them in their own work. For instance, Catchment Boards often tend to interest themselves more in periods of high discharge when flooding is likely to occur, and to consider of less importance periods of relatively low discharge. Low discharges, however, often make up as much as 70 or 80 per cent. of the year's records, and may require great care and skill in measurement if accurate results are to be obtained; when measured by exactly the same means as high discharges they cannot always be observed with the precision that is desirable. It is these periods of low discharge

* Inland Water Survey Committee. Memorandum on the Water Survey of a River System (Ministry of Health and Scottish Office, 1936) price 6d., obtainable from H.M. Stationery Office.

which are of most interest to other bodies concerned with rivers, especially pollution prevention and fishery authorities, and they are obviously an important part of any comprehensive survey of a river. Similarly, many water undertakers are interested only in the limited recordings which are required by them for the purpose of their undertaking and regard as superfluous the complete recording of run-off which would be of importance in a comprehensive survey.

We recognise these difficulties and are taking steps to encourage the taking of extensive records which will give as much attention to the accuracy of measurements of low discharges as of high discharges, so as to produce as comprehensive a record of a river basin as possible.

7. Some Catchment Boards who have decided to undertake a comprehensive survey of their area have experienced difficulty in finding a site suitable for a station to measure both high and low discharges of the river. It is, however, not essential that all rates of flow should be measured at precisely the same spot, and it may be that a search would lead to the finding of two sites reasonably close to one another, one convenient for the measurement of low discharges and the other for high discharges, if need be by different methods. Careful local investigation may lead to the discovery of sites and adoption of methods of gauging which involve the minimum of disturbance of the normal condition of the river, thereby reducing the risk of objection from riparian owners and fishery and navigation interests.

We have been able, through the technical staff at our disposal, to give assistance and advice to a number of authorities faced with difficulties in investigating the possibilities of a survey of their area.

Underground Water.

8. For a successful survey of the underground water of an area, and the accurate ascertainment of variations in the level of the water table, reliable information is required of the rest and/or pumping levels of a number of suitably distributed wells and of the geological strata pierced. As has been mentioned above, this branch of the Survey is being carried out with the assistance of the Geological Survey, who have drawn up a programme of operations.

9. In preparation for this work, numerous papers dealing with water supply in this country were examined by the Geological Survey. Underground water has long been the subject of study in Great Britain, and an extensive literature on the subject is in existence. Most of it deals with the provision of public water supplies and consists of the detailed records of wells and borings and other sources of supply. A reorganization of the system of filing records of wells at the Geological Survey was found to be necessary. These have for many years been kept

on a county area basis, but good progress has now been made in transferring them to a new system more suitable for a survey of underground water resources. New records are constantly being received. In the past much valuable information has been lost through the incomplete compilation of borehole journals, particularly when insufficient attention has been given to hydrological data, but with the co-operation of various firms of well-borers, this defect is being remedied where possible.

10. Field work has been begun in the River Nene basin, the district in which preliminary investigations have been conducted, and it is expected to find from a close observation of the fluctuations of the various water tables data from which conclusions of economic importance may be deducible. In this work it is important that measurements of levels should be made periodically over a wide area, and that each set of observations should be taken on the same day, or within the limits of a day or two. It became apparent that comprehensive observations such as were desirable could be carried out only with the assistance of outside bodies. The Head Masters and Geography Masters of various Public, Grammar and Secondary Schools in the area have offered their co-operation, and a survey of wells is now in progress by boys of the following schools: Daventry Grammar School, Fletton County Secondary School, Kettering Grammar School, March Grammar School, Market Harborough Grammar School, Northampton Grammar School, Oundle School, Deacon's School, Peterborough, King's School, Peterborough, Stamford School, Wellingborough School, Wellingborough Grammar School and Wisbech Grammar School. Each school is conducting a survey over a specific district, marking the sites on 6-inch Ordnance Survey maps. Where possible, wells are being plumbed for total depth and all available information is being collected.

Extracts from a memorandum prepared for the assistance of the Masters in charge of this work are given in the Appendix to this report. The survey is proceeding satisfactorily.

11. We wish to take this opportunity of expressing our appreciation of the help which is being afforded us by the Head Masters and Staffs of these schools, and the keenness and willingness they have shown in undertaking this work for the Inland Water Survey.

It is proposed to enlist similar assistance in the survey of underground water in other river basins.

12. As was mentioned in last year's Report, the British Speleological Association offered to assist us by tracing and mapping the course of certain underground streams, and have undertaken to plot information concerning such streams in the limestone areas of the West Riding of Yorkshire, Derbyshire and Somerset on 6-inch Ordnance Survey maps.

Rainfall.

13. In any area where a survey of surface water or underground water is in progress or is contemplated, it is important that the rainfall should be regularly determined at a sufficient number of stations to give an adequate representation of the fall in all parts of the area. Although the average annual rainfall and its seasonal distribution are now known fairly accurately for most areas in the British Isles there are still certain districts for which the information is inadequate for the purposes of the Inland Water Survey. The Meteorological Office (British Rainfall Organization) are in touch with the Engineers of Catchment Boards so as to secure as satisfactory a distribution of rain-gauges as is possible, and wherever practicable arrangements are made for the inspection of existing sites and the selection of sites for new gauges by a representative of the Meteorological Office. It is hoped that it may be possible to extend the inspection work undertaken by the Meteorological Office.

At the same time the work of preparing and revising rainfall maps of river basins is continuing. These include not only maps or annual average rainfall but also current charts of monthly rainfall and will be available for consultation in connection with the published results of the Inland Water Survey.

Finance.

14. In England and Wales grants are available towards the cost of river-gauging installations provided by Catchment Boards as part of proposed improvement works, and where gauging installations are provided by Catchment Boards for the purpose of obtaining information preliminary to the formulation of a scheme of improvement the cost of installation may, if the scheme matures, be included for grant purposes in the cost of the scheme. In Scotland, where only one body resembling a Catchment Board exists, the position is somewhat different and the Department of Agriculture for Scotland, who have general powers comparable with those of the Catchment Boards in England and Wales, were authorized to spend £500 towards the equipment of gauging stations during the year under review. Some 21 level-gauging and 10 level-recording stations have been set up at suitable points on the Clyde and Tay and certain of their tributaries.

15. We understand that a County Council or County Borough Council have power to contribute, under Section 32 of the Land Drainage Act, 1930, a proportion of the cost of installation of a gauging station by a Catchment Board as part of their programme of capital works.

Preliminary Examination of Individual River Basins.

16. As was indicated in our First Annual Report, at an early stage it became clear that a preliminary examination in more

detail of the conditions existing in the various river basins would be necessary before it could be decided whether existing gauging stations for measuring overground water were of any real value, and at what points additional stations were desirable and practicable for the purpose of the Survey. In that report a description was given of the rivers Nene, Thames and Clyde. Below we give the results of preliminary examinations of the Ness basin, the Tay, Ouse (Yorkshire), Severn, Dee (Cheshire), Clyde and Kelvin.

River Ness.

17. The River Ness basin has a drainage area of 692 square miles above the gauging station at Ness Castle Farm, near Inverness. It may be divided into four portions:—

(*a*) the River Moriston basin, including Loch Cluanie and Loch Loyne, with a drainage area at Invermoriston of 151 square miles.

(*b*) the River Garry basin, including Loch Quoich and Loch Garry, with a drainage area at Invergarry of 149 square miles.

(*c*) the River Foyers basin, including Loch Garth, with a drainage area at a point near Foyers of 107 square miles.

(*d*) a valley, Glen More, running north-east towards Inverness, in which lie Loch Oich and Loch Ness, the latter being about 24 miles long, slightly under a mile in mean width and over 550 feet deep for about one half of its area. Through this valley runs the Caledonian Canal.

The behaviour of the river system is strongly influenced by the presence of the several lochs with their considerable storage capacity.

18. The basin has naturally been a subject of interest for those anxious to develop water-power for industrial purposes. The British Aluminium Company has been utilizing the River Foyers since 1895, whilst in 1929 the West Highland Water-Power Scheme was considered by Parliament. Proposals to utilize the River Moriston and the River Garry for power-development were included in the Caledonian Power Bill recently before Parliament.

19. The annual rainfall varies very considerably, from 150 inches at the head of the River Garry to less than 30 inches at Inverness, with a mean for the whole area of the Ness basin of about 66 inches. More than a dozen rainfall stations have been established throughout the basin, despite its sparse and scattered population, and records have been obtained from several of these stations over a considerable period of time.

20. As regards surface-water, records of water-levels at several points on the canal system have been maintained for many years

past by the Ministry of Transport as proprietors of the Caledonian Canal, but the measurement of discharges was not attempted until 1929, when it was undertaken by a private organization, River Flow Records, directed and hitherto almost entirely sustained by Captain W. N. McClean. Thanks to his enterprise automatic water-level recorders have been installed at seven points within the basin and staff-gauges at many other points whilst discharge measurements have been made at numerous stages between ordinary low water and flood level at four points:—Invermoriston, on the River Moriston; Invergarry, on the River Garry; a point near Foyers on the River Foyers, and Ness Castle Farm near Inverness. It should be added that River Flow Records also made measurements of the discharge of the River Garry alone between 1912 and 1913.

We have been much impressed by the public spirit displayed by Captain McClean in founding and directing this organization, whose work has not only had considerable experimental and demonstrational value but has also enabled knowledge to be gained of the resources and behaviour of the rivers and lochs of the Ness basin which would otherwise not have been available when proposals for the utilization of the water resources of the district came before Parliament. The existing stations provide the essential foundations of a survey of the surface water resources of the basin. It is hoped that local authorities and undertakings will assume the task of observing water-levels now performed by River Flow Records. An example in this respect has been set by the British Aluminium Company who observe and record levels at the gauging station near Foyers.

21. Geologically, the Ness basin extends over a wide region of the Central Highlands on both sides of the trough feature, known as the Great Glen, which links Loch Linnhe on the west coast of the country with the Moray Firth on the east. The geological formations present are, in descending order:—superficial recent deposits (marine sand and gravel, fluvioglacial sand and gravel, boulder clay), Middle Old Red Sandstone, metamorphic rocks of pre-Cambrian age. There are also a few masses of intrusive igneous rock. The metamorphic rocks occupy practically the entire area under consideration, while the Old Red Sandstone occupies a relatively small area. In the valley itself superficial deposits obscure these rocks, but an extremely powerful dislocation, the Great Glen Fault, is known to have its course along the trough. From what is visible elsewhere on the course of this fault one may regard it as certain that the strata on either side of the dislocation are exceedingly shattered and broken. The superficial deposits attain a very considerable thickness in the lower part of the valley, a boring at Inverness proving 319 feet of sands, clays and gravels without penetrating bed-rock. No records of underground water resources in this area are available.

River Tay.

22. The non-tidal part of the River Tay above the burgh boundary of Perth drains an area of approximately 1,960 square miles including the basin of the River Almond; the River Earn, which enters the tidal reaches below Perth, is regarded for Survey purposes as a separate river. The main tributaries of the Tay on the right bank are the Almond and the Bran, and on the left bank the Isla, Tummel and Lyon. A characteristic of the Tay is that whilst the tributaries on the right bank consist of small rivers with very minor affluents each of the main tributaries on the left bank is really a small river system with major feeders. The head waters of the River Tay consist of the River Lochy (Perthshire) and the River Dochart discharging into Loch Tay. In the lower regions of the basin, the country is agricultural or pastoral in character, whilst in the middle reaches it is pastoral and peat-covered or afforested; the higher reaches largely consist of peat moors and barren rocks. Within the basin are a number of important lochs including Loch Tay (10·19 square miles); Loch Rannoch (7·37 square miles); Loch Ericht (7·21 square miles); Loch Tummel; Loch Laidon and Loch Garry (Perthshire).

23. The average annual rainfall varies from about 30 inches in the driest parts of the Perth to Blairgowrie district, to about 100 inches on many of the western spurs of the Grampians, parts of which are at an altitude of over 3,000 feet, and even to 120 inches on the slopes of Ben Alder where a considerable proportion of the heavy winter fall is in the form of snow. This very large gathering ground includes considerable areas without houses or population, which are only sparsely represented by rainfall stations; the inhabited valleys are fairly well represented.

24. A considerable proportion of the Tay basin is now controlled, or in process of being controlled, by the operations of the Grampian Electricity Supply Company, who, by the conversion into storage reservoirs of Loch Ericht, Loch Rannoch and Loch Garry, are in a position to manipulate the flow of water according to demands for current. This control affects the River Tummel and the River Tay below the confluence of these rivers. A further complication from a hydrological point of view is the fact that the Power Company are introducing into this basin the flood waters which normally find their way to the River Spey.

25. With the assistance of the Department of Agriculture for Scotland recording gauges have been established at Pitnacree, Caputh Bridge and Stanley on the main river system, at Couttie Bridge on the Isla, and Comrie Bridge on the Lyon. Staff gauges have been erected at Almondbank on the River Almond,

Inver Bridge on the River Bran, and Kenmore at the outlet of Loch Tay. A staff gauge has been maintained for eight years at Stanley by a private fishery interest. This is the lowest point at which the Tay is gauged and gives records in respect of the total run-off of an area of 1,745 square miles.

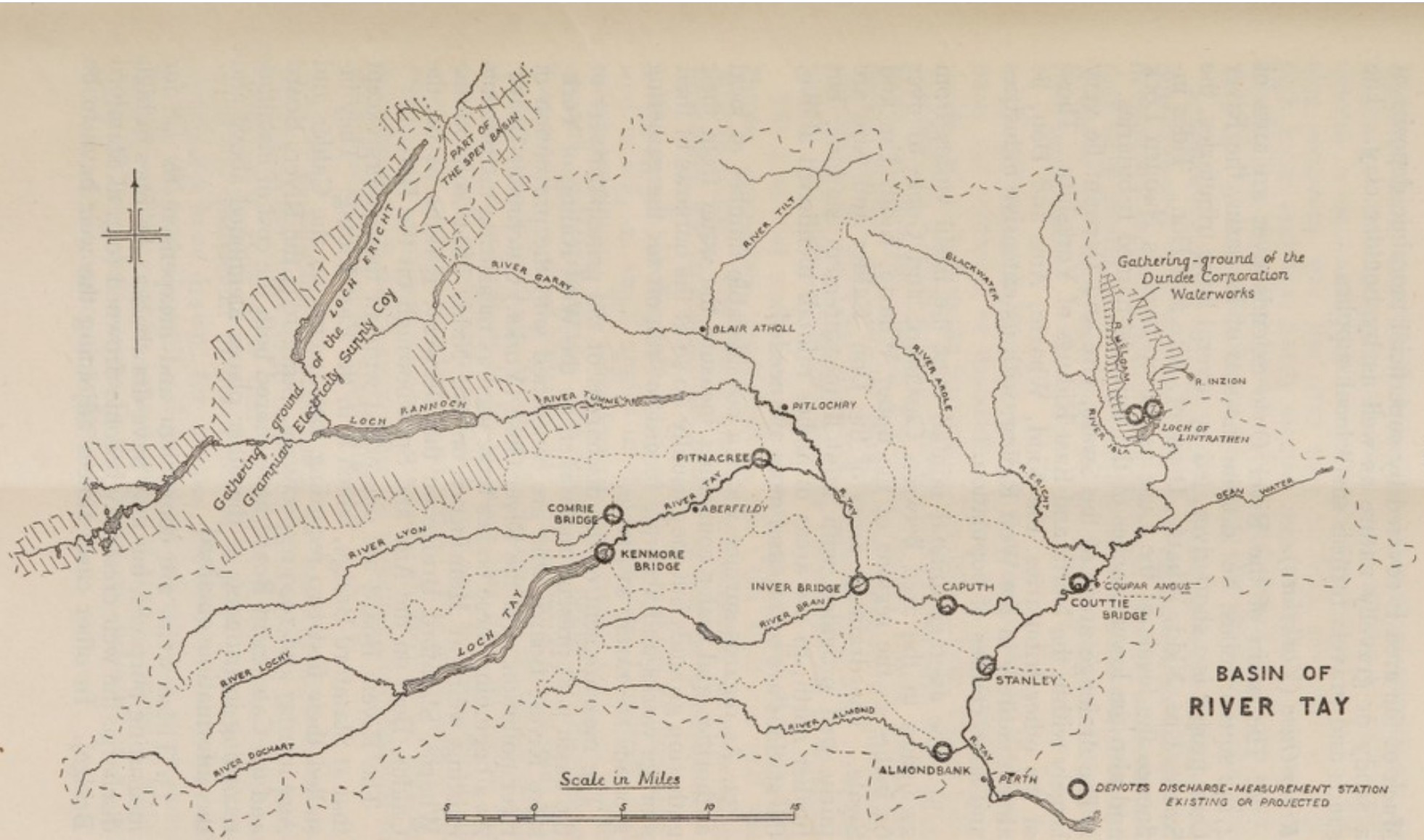
26. Situated within the basin of the Tay, above Stanley, are the towns of Dunkeld, Coupar Angus, Blairgowrie, Pitlochry, Aberfeldy and Blair Atholl, each of which obtains its supply of water from sources within the area; in addition, the works for the water supply of the City of Dundee are situated at Lintrathen Loch on the east side of the basin. This loch is mainly fed by the Melgam and Inzion and the Dundee Corporation have lengthy records which they are making available to us.

27. The geological formations exposed in the Tay basin are, in downward sequence, as follows:—Superficial Deposits (marine sand and clay, morainic sand and gravel, boulder clay), Lower Old Red Sandstone, Highland Border (Cambro-Ordovician) rocks, Dalradian Series; there are, in addition, a number of intrusive igneous masses of which the largest is the Rannoch Moor Granite. The Dalradian succession, and, in a lesser degree, the Highland Border rocks, comprise a metamorphic series of crystalline schists, altered limestones, quartzites, grits and slates. These rocks, and also the igneous intrusions, are all compact and do not retain much water. Where they have been pierced at considerable depth in tunnelling operations, they are dry except for fissure water, and even this is negligible. Much the greater part of the Tay basin lies within the region of the Dalradian Series.

28. The outcrop of the Lower Old Red Sandstone is abruptly demarcated from that of the older rocks by the Highland Boundary Fault. This major dislocation, which extends across the country in a north-east to south-west direction crosses the Tay valley a few miles south-east of Dunkeld. The formation is traversed by the river in the lower 21 miles of its non-tidal course. Two important tributaries, the River Isla from the north-east and the River Almond from the west, also have their courses for many miles in the Old Red Sandstone.

The breadth of this sandstone outcrop across the strike between Perth and the Highland border is about 11 miles. The strata are here disposed in an unsymmetrical syncline whose axis trends parallel to, and about two miles south of, the Highland Border Fault.

29. At the deepest part of the syncline the sedimentary beds should, at a moderate estimate, attain a thickness of at least 10,000 feet. They should also prove to be waterbearing but no records as to their capabilities in this respect are available.


PART OF THE SPEY BASIN
LOCH ERICHT
Gathering-ground of the Grampian Electricity Supply Coy
RIVER GARRY
RIVER TILT
BLACKWATER
Gathering-ground of the Dundee Corporation Waterworks
BLAIR ATHOLL
RIVER ARDLE
R. MELGAM
R. INZION
RIVER ISLA
LOCH OF LINTRATHEN
LOCH RANNOCH
RIVER TUMMEL
PITLOCHRY
PITNACREE
R. ERICHT
OCEAN WATER
COMRIE BRIDGE
RIVER TAY
ABERFELDY
R. TAY
RIVER LYON
KENMORE BRIDGE
INVER BRIDGE
CAPUTH
COUPAR ANGUS
COUTTIE BRIDGE
RIVER BRAN
LOCH TAY
STANLEY
RIVER LOCHY
RIVER ALMOND
RIVER DOCHART
R. TAY
ALMONDBANK
PERTH
Scale in Miles
5 0 5 10 15
DENOTES DISCHARGE-MEASUREMENT STATION EXISTING OR PROJECTED
BASIN OF RIVER TAY

Much of the area is covered by superficial morainic deposits of a sandy or gravelly nature as well as by boulder clay. The sands and gravels furnish small local supplies.

River Ouse (*Yorkshire*).

30. The basin of the River Ouse extends over an area of 4,152 square miles, but despite the size of its basin, the River Ouse proper is a short river, fed by several large tributaries, the Swale, Ure, Nidd, Wharfe, Derwent, Aire and Don. Tides influence the levels of the Ouse as far up-river as Naburn Lock and also the lower reaches of the four last-named tributaries.

The drainage areas of the Swale, Ure and Derwent lie very largely within the North and East Ridings of Yorkshire. Those of the other tributaries, the Nidd, Wharfe, Aire and Don, lie almost entirely in the West Riding, with its extensive industries and large centres of population.

31. The average annual rainfall over the basin varies from 22 inches in the area between Castleford and Goole to over 65 inches in the regions of the upper Wharfe, Nidd, Ure and Swale. The drainage areas of the Don, Calder and Aire are fairly well provided with rainfall measurement stations, but further north, in the areas of higher rainfall mentioned above, the stations are scanty and more are needed.

32. As regards surface water a considerable number of local authorities and water companies measure the water from their gathering grounds but they usually do so at the outflows of their storage works and accurate records of run-off for the gathering grounds are rarely available.

The measurement of the discharges of the principal rivers of the basin is at present undertaken by the West Riding of Yorkshire Rivers Board, who are concerned with the prevention of river pollution, and the River Ouse (Yorks.) Catchment Board. As a beginning these bodies have used as measuring instruments existing weirs at Hunsingore on the Nidd, Flint Mill on the Wharfe, Stamford Bridge on the Derwent, Kirkthorpe on the Calder, Beal on the Aire and Sprotborough on the Don.

The Rivers Board are concerned with all these weirs except that at Stamford Bridge, which is in the East Riding. They installed their first two recording instruments on the Calder and Aire in 1927 and 1929 respectively. Since 1934 the Rivers Board and the Catchment Board have shared both the cost of installing recording instruments at the other places mentioned above and the information obtained.

33. These weirs are convenient and inexpensive to use for measuring purposes, but they have drawbacks. At times of high discharge the weir crest may become drowned (e.g. at Stamford Bridge). In other cases sluices adjoining the weir have to be

operated in a way which hampers accurate measurements of discharge; this happened at Beal weir during at least four months in each of the two water years 1934-5 and 1935-6. On rare occasions, too, the river may outflank the weir at very high levels and thus partly escapes measurement. The weir is usually long as well as broad-crested and, being all at one level, may not be very suitable for measuring the smallest discharges.

It will accordingly be seen that, valuable as is the information now collected, it is very desirable that arrangements should be devised for overcoming any deficiencies of existing stations and that there should be more measuring stations established on the rivers of the basin, especially on the Swale and the Ure with their high rainfall.

34. Of the geological formations that crop out in the Ouse basin the following in descending order, are water-bearing:— sands and gravels in the Superficial Deposits, Chalk, Upper Calcareous Grit, Coralline Oolite, Lower Calcareous Grit, Kellaways Rock, Moor Grit, Middle Estuarine Series, Lower Estuarine Series, Keuper and Bunter Sandstones, Magnesian Limestone, sandstones in the Coal Measures, Millstone Grit and, to some extent, the Yoredale Shales and the Carboniferous Limestone.

The principal water-bearing formations are the Keuper and Bunter sandstones, sandstones in the Coal Measures and the Millstone Grit. The Chalk also is an important water-bearing formation, but its outcrop lies mainly outside the Ouse basin.

The general inclination or dip of the formations is eastwards, and usually at small angles in the Magnesian Limestone and overlying strata. The older formations therefore crop out in the western part of the area. The formations below the Magnesian Limestone (i.e. Coal Measures to Carboniferous Limestone) are much affected by faults or other displacements, which cause the direction of inclination to be variable and tend to divide the rocks up into blocks each of which may act, to some extent, as a separate pound of underground water. The strata above the Magnesian Limestone also are in places affected by or thrown into gentle folds which may cause the direction of inclination to depart locally from the prevailing one.

35. The information concerning the underground water resources of the Ouse Basin embodied in the replies to our questionnaire of 1935 show that records at present available are generally insufficient in detail and in number for any reliable conclusion to be drawn; for instance, the distribution of records giving full hydrological and geological information is approximately one in every 80 square miles. Large amounts of water from underground sources in this basin are, however, used by private and commercial undertakings.

River Severn.

36. The River Severn is joined by the River Avon (Warwickshire) above Tewkesbury, above which point the influence of tide is rarely felt. The areas drained by the two rivers above this point are 2,616 and 1,055 square miles respectively, making a total of 3,671 square miles, which may be compared with that of 3,812 square miles for the Thames above Teddington.

37. The average annual rainfall over the basin of the Severn, including the area drained by the Avon, varies from rather less than 25 inches over a large area near Shrewsbury to over 80 inches in the neighbourhood of Plynlimon and the mountains to the south-west of Lake Vyrnwy.

It has been estimated that the average annual run-off of the area draining to Bewdley on the Severn, which amounts to 1,632 square miles, was, for the 15-year period October, 1921, to September, 1936, 18·9 inches. The average annual run-off of the area draining to Teddington on the Thames, for the same period, is estimated to have been 10·6 inches for a drainage area which is rather more than twice as great as that of Bewdley. In other words, the surface water resources of the area above Bewdley are alone equal to about three-quarters of those of the area draining to Teddington.

38. The area draining to Lake Vyrnwy has a general rainfall of 70 inches and is used for the water supply of Liverpool. The Liverpool Corporation have maintained for many years a valuable series of rainfall records. Further south the mountainous districts are not so well provided with rain-gauges.

39. As regards surface water, various bodies have kept records of water levels for a few stations for long periods, notably the Severn Commission for one point for a whole century, but there has hitherto been little continuous and comprehensive measurement of discharges.

The Liverpool Corporation measure the water leaving the Vyrnwy reservoir area and have water-level observations dating back to 1878 which it may be possible to translate into terms of run-off.

An exceptional case of river measurement is found at Bewdley, where the work, originally begun largely as a study of the methods of measuring and recording discharge, has been executed by staff of the Imperial College of Science and Technology, assisted by funds from the Department of Scientific and Industrial Research. The calibration of the station was effected with current-meters and much investigation of great value for the work of hydrological surveys has been carried out by Professor S. M. Dixon, Dr. M. A. Hogan and Mr. G. Fitzgibbon.

The results of observations during the 15 years 1921-1936 have recently been made available.* The station has now been taken over by the River Severn Catchment Board who are continuing the work.

Below Bewdley the levels of the Severn are affected by a series of weirs which, whilst not necessarily themselves forming precise instruments for the measurement of the smaller and more frequent discharges, tend to hamper such measurement by other means. The Catchment Board are at present engaged in calibrating Diglis Weir at Worcester.

The Avon, like the Severn, is affected as regards levels by the presence of several weirs.

The Rugby Town Council measure the discharge of the uppermost reaches of the river at Welford and the Catchment Board are establishing a gauging station at Evesham, which will be calibrated in the same way as the one at Bewdley.

From the above outline of the present situation it will be seen that much remains to be done before the surface water resources of this very important basin can be considered to be adequately surveyed.

40. The basin of the Severn may be divided geologically into three areas:—

(i) the Welsh area where the river, flowing in a general north-easterly direction from Plynlimon to Welshpool, drains country composed mainly of Silurian shales and sandstones.

(ii) the area of the Shropshire Plain where the river turns eastwards over Triassic sandstones, Coal Measures, Cambrian and Silurian shales to Ironbridge. In this part of its course much of the drainage from the north is over superficial deposits of boulder clay, sand and gravel, while that from the south is over Coal Measures and older Palaeozoic and pre-Cambrian rocks.

(iii) the area from Ironbridge southwards to the Bristol Channel, where the outcrops drained are Liassic clays, Triassic sandstones and marls, Coal Measures and Old Red Sandstone. Superficial deposits are present over parts of this area.

The most important water-bearing rocks are the Triassic sandstones and pebble beds, but supplies are also obtained from sandstones and conglomerates in the Coal Measures, while the Old Red Sandstone yields minor supplies. The Silurian and other older rocks yield negligible amounts of underground water.

Where superficial deposits are present they can often be relied upon for small local supplies.

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* Journal of the Institution of Civil Engineers, June, 1937.

Very large quantities of water are being pumped from the Triassic rocks, especially from the Bunter, as well as from the Upper or Barren Coal Measures, in the eastern part of the basin.

Much detailed knowledge of the underground water resources of this eastern area is held privately, and it is hoped that this, or some of it, may be made available for public use at a later stage.

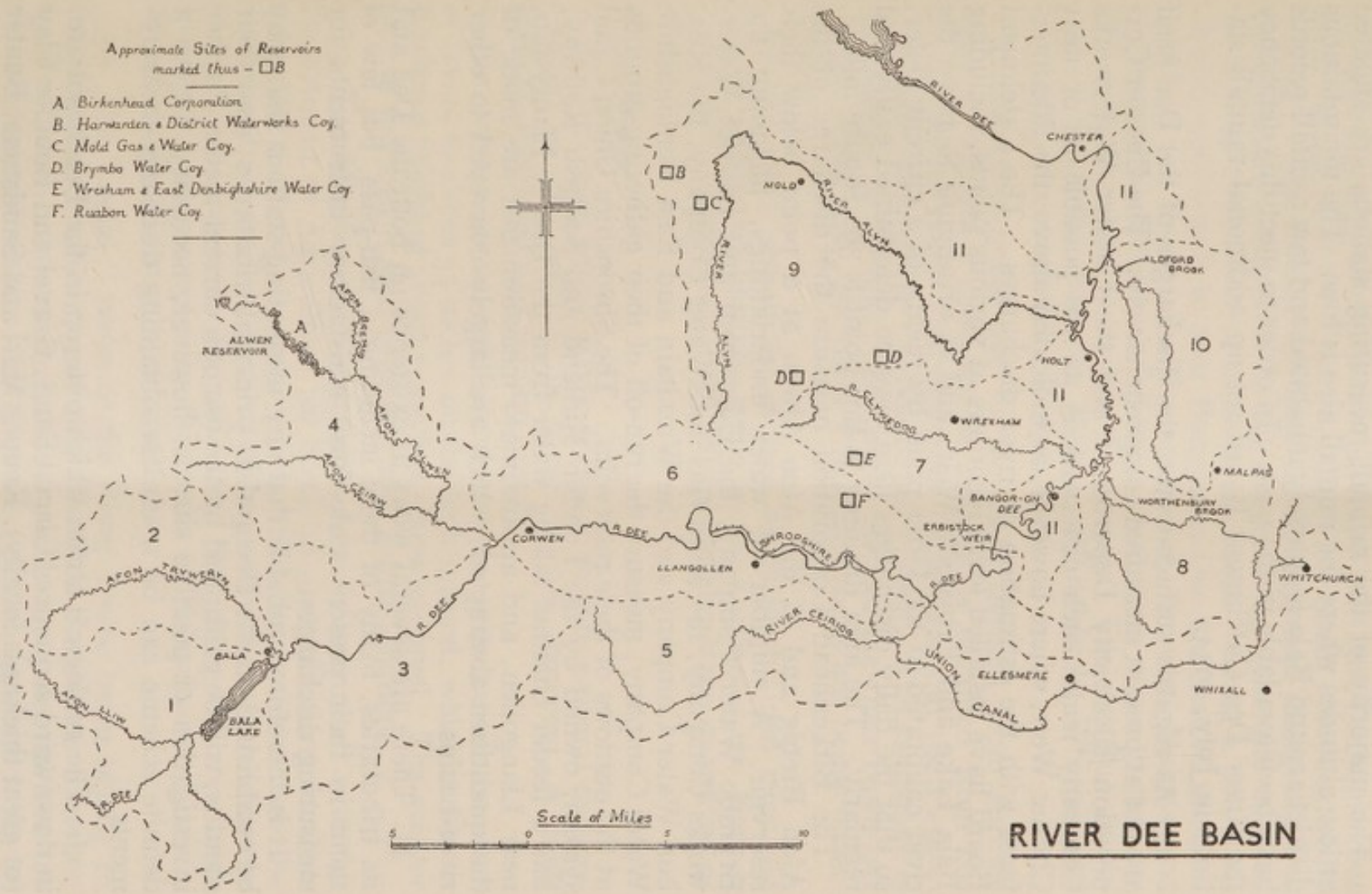
River Dee (*Cheshire*).

41. The River Dee (or Afon Dyfrdwy) has a drainage area of approximately 689 square miles above the weir at Chester. Although this weir raises the river surface considerably, so that at low stages the latter is practically horizontal for a distance of 12 miles above the weir, tides affect the upstream water levels frequently. For example, out of 708 tides during the water year 1935-36 no less than 217 did so.

42. If the river-basin above Chester be considered as divided into drainage compartments in the manner shown in the accompanying map, the sizes of these areas are:—

	Sq. Miles.
1. Upper Dee, above Bala	61·0
2. Afon Tryweryn	41·2
3. Dee, between Afon Tryweryn and Afon Alwen	69·8
4. Afon Alwen	76·5
5. Afon Ceiriog	53·6
6. Dee, between Afon Alwen and Erbistock Weir	93·8
7. River Clywedog	40·0
8. Worthenbury Brook	57·1
9. River Alyn	92·4
10. Aldford Brook	41·4
11. Dee, between Erbistock Weir and Chester Weir	62·3
Total area drained to Chester Weir ...	689·1

43. The average annual rainfall over the basin varies from 25 inches over a large area near Chester to more than 55 inches over the area draining to Bala; in the extreme south-west the rainfall is locally as much as 100 inches. The volume of rainfall over the area above Bala contributes therefore a large proportion of the total over the whole Dee basin. It has been regarded for many years past as a potential source for water supply undertakings. The strata in the western portion of the basin being impermeable, the rate of run-off is rapid and the tributaries feeding the Dee in its upper reaches are consequently of a " flashy " nature, except where they have been regulated


Approximate Sites of Reservoirs marked thus – □B
A. Birkenhead Corporation
B. Harwarden & District Waterworks Coy.
C. Mold Gas & Water Coy.
D. Brymbo Water Coy
E. Wrexham & East Denbighshire Water Coy
F. Ruabon Water Coy
RIVER DEE
CHESTER
MOLD
RIVER ALYN
ALLOWAY BROOK
HOLT
WREXHAM
R. CLYWEDOG
MALPAS
BANGOR-ON-DEE
WORTHENBURY BROOK
ERBISTOCK WEIR
WHITCHURCH
CORWEN
R. DEE
LLANGOLLEN
SHROPSHIRE
RIVER CEIRIOG
UNION CANAL
ELLESMERE
WHIXALL
ALWEN RESERVOIR
ALWEN
AFON TRYWERYN
AFON LLIW
BALA
BALA LAKE
Scale of Miles
RIVER DEE BASIN

by a storage-dam or other works constructed by a water authority (e.g. the Alwen).

The majority of the rainfall measuring stations are situated at low altitudes where the rainfall also is low. The mountainous district around Bala is sparsely inhabited and few rainfall records have been available in the past. In order to meet this deficiency the River Dee Catchment Board set up additional rainfall stations in July, 1934.

44. As regards surface-water, the discharges of the Dee itself are not at present measured comprehensively. The Chester Corporation Electricity Department and the Chester Waterworks Company make such observations as are possible at or near Chester Weir, where however, as indicated above, the tide interferes with the estimation of river discharges. The Catchment Board have installed level recorders at various points, including Bala Lake and Erbistock Weir, and is arranging to have the river calibrated at the latter point by means of a current meter, so that the daily discharges here may be determined easily and regularly. The area draining to this point is 396 square miles.

The Birkenhead Corporation measure the discharge of the Afon Brenig and of the Afon Alwen at a point below their reservoir. A number of water undertakings, including the Brymbo Water Company, the Hawarden and District Waterworks Company, the Mold Gas and Water Company, the Ruabon Water Company and the Wrexham and East Denbighshire Water Company, measure the run-off of their gathering-grounds at the outflows of their reservoirs. The Shropshire Union Canal system, owned by the London Midland and Scottish Railway, has a feeder channel taking water from the Dee at Llantysilio, near Llangollen, and approximate measurements are made of the quantities abstracted, which are largely conveyed to other river-basins.

45. There are several weirs in existence on both the Dee and its tributaries, many of them including a fish-pass, but few of them in their present state form satisfactory instruments for measuring discharges.

It is therefore probable that any measuring-stations that may be established on the Dee and its principal tributaries, near their mouths, will be calibrated by the use of a current-meter. Further investigation of possible sites is, however, necessary, before a definite scheme can be made for obtaining discharge-measurements.

46. The geological strata which outcrop in the Dee basin are, in downward sequence, Glacial Sand, Gravel and Boulder Clay (of great thickness locally), Keuper Marl and Sandstone, Bunter Sandstone and Pebble Beds, Upper and Middle Coal Measures, Millstone Grit, Carboniferous Limestone and Silurian and Ordovician rocks. Of these, only the Keuper and Bunter sandstones,

Millstone Grit and Carboniferous Limestone are of any account as sources of underground water.

The strata dip eastwards off the Welsh hills, the Carboniferous more steeply than the Triassic. Both are much complicated by faulting. The Bunter occupies the low ground along the Dee from Chester southwards to Ellesmere, being generally covered by drift up to 100 feet or more in thickness. Along a belt from Chester southwards to near Bangor-on-Dee the base of the drift is below sea level. To the south-east, between Malpas and Ellesmere, the Bunter and Keuper sandstones come to the surface and are more accessible for boring. The extreme south-east of the basin, between Malpas, Whitchurch, Whixall and Ellesmere, is occupied by Keuper Marl.

47. Water supplies are in the main derived from surface sources, though a considerable amount is obtained from old mining levels in the Carboniferous Limestone and the Cefn-y-fedw Sandstone of the Carboniferous system. The sandstone is also tapped by borings. The upper part of the river basin has surface water only, the older Palaeozoic rocks not being water-bearing.

To the south-east of the estuary water is obtained from old mining levels and borings, while to the north-east the Keuper and Bunter sandstones of the Wirral contain large quantities of water.

River Irvine.

48. The basin of the River Irvine is mainly pastoral or agricultural in character; in its lower reaches, however, it flows through industrial and mining areas.

The average annual rainfall varies from 35 inches on the coast at Irvine to about 55 inches on the high ground, which in places reaches a height of about 1,200 feet above sea level. The greater part of the area is well provided with rainfall stations.

49. The Kilmarnock Corporation have collaborated with the Department of Agriculture for Scotland in establishing at Girtridge Mill a recording gauge which will bring under review the discharge from an area of about 186 square miles, approximately two-thirds of the total drainage area, this being the area from which the water supply for the towns of Kilmarnock, Darvel, Newmilns and Galston is obtained.

50. The " solid " rocks of the River Irvine basin belong to the Permian, Carboniferous and Old Red Sandstone Systems, each of which includes sandstones which are potential sources of underground water. In all three systems igneous rocks of various kinds are present. Numerous faults affect the district, the Inchgotrick Fault being noteworthy. Over much of the area the solid rocks are obscured by drift deposits, usually

boulder clay, but large spreads of fluvioglacial and other gravels are present locally.

A number of reservoirs have been constructed on outcrops of igneous rock on the north-east of the basin. No information regarding local water supplies from wells is available.

River Clyde.

51. A brief description of this river basin was included in our First Annual Report, when it was stated that it was hoped that with the co-operation of the Scottish Departments gauging stations might be installed at an early date. During the year under review the preliminary examination has been continued and we have accordingly deemed it desirable to amplify the details given in the Report for the year 1935-36.

The non-tidal part of the River Clyde, with a drainage area of approximately 1,200 square miles, divides naturally into two portions; the lower from the tidal limit at the weir above Glasgow to the vicinity of New Lanark, is industrialized; above this point it is largely a trout fishing river flowing through agricultural and pastoral country. For the purposes of the Survey the River Kelvin is regarded as a separate basin.

The average annual rainfall varies from about 35 inches to over 70 inches in the upper parts of the drainage area on the Lowther or Leadhills, where it reaches its maximum altitude of 2,300 feet above sea level. Except in the valley of the Duneaton Water the river basin is fairly well provided with rainfall measurement stations.

52. A considerable number of local authorities abstract water from the upper reaches of the Clyde basin, but no records appear to have been kept of the yields of their respective gathering grounds although each authority records the amount of water passed down to their respective districts. Discharge measurements have been made by an industrial firm at Motherwell to show the minimum flow and continuous records were made at Tulliford near Lanark, during the last three months of 1923 and the years 1924 and 1925.

There are no weirs on the upper parts of the river suitable for gauging purposes. During the year a number of recording and staff gauges have been established by the Department of Agriculture for Scotland, with our approval, at Garrion Bridge, Hyndford Bridge, Wolfclyde near Abington and at Watermeetings on the Daer. These will supply data in respect of a total drainage area of about 476 square miles.

53. Rocks cropping out in the Clyde basin include sandstones, limestones, shales, and coals of Carboniferous age; sandstones and conglomerates belonging to the Old Red Sandstone formation; Silurian grits, greywackes and shales; and volcanic igneous

rocks. Some of the Carboniferous rocks, and the upper part of the Old Red Sandstone, may generally be expected to yield supplies of water in greater or less degree, but little water is to be expected from the remainder, except from occasional fissures and along faults, and, in the Silurian rocks, along mineral veins. Certain beds of ash in the volcanic rocks are water-bearing to a small degree.

The lower-lying ground of the basin is largely covered by drift deposits of glacial and river origin, and these give local supplies from shallow wells. Little or no use is, however, made of the underground resources of this area in view of its plentiful surface water resources.

River Kelvin.

54. The Kelvin is a tributary of the Clyde and enters it within the boundaries of the City of Glasgow at a point where the River Clyde is still tidal; a weir situated almost at the confluence of the Kelvin and the Clyde prevents any tidal action in the Kelvin. The last 5¼ miles of its course include nine weirs all of which are in use. The character of the Kelvin Valley changes above the Garscube Weir from a manufacturing to a mining and agricultural area.

The average annual rainfall above Garscube for the Kelvin basin varies from 40 inches in the lowest part to about 55 inches on the slopes of the Campsie and Kilsyth Hills where the basin reaches its maximum altitude of about 1,900 feet above sea level. There is a fairly good distribution of rainfall stations in this area.

55. In its middle reaches the Kelvin is rather a sluggish winding stream and in places flooding is frequent. Water supplies come in the main from reservoirs fed by streams or springs. The valley is traversed by part of the Forth and Clyde Canal, and one of the supply reservoirs for this canal is situated within the area. There is also a compensation reservoir for the benefit of industrial interests. Some small towns such as Kirkintilloch and Kilsyth obtain their water supplies in this area. In connection with an arterial drainage scheme which is being promoted by the Department of Agriculture for Scotland, under the Land Drainage (Scotland) Acts, for the improvement of drainage conditions in this valley, a number of recording and staff gauges have been established, the observations of which will be available for publication in due course. The stations referred to are situated at Garscube Mill, Allander Toll, Milngavie Sewage Works, Gale Bridge, Luggie Bridge, Milton Sewage Works, Inchbelly Bridge and Twechar Bridge. The gaugings will provide information in some detail in respect of a drainage area of about 127 square miles.

56. The rocks of the Kelvin drainage area are generally similar to those of the Clyde, except that the Silurian rocks do not come to the surface. Little or no use is made of underground water resources in the area.

Publication of Data of Surface Water Resources.

57. An indication was given in our First Annual Report of the form which a publication of data collected by the Inland Water Survey might be expected to take. During the year under review we have considered in greater detail the form of publication which we contemplate. The Memorandum on the Water Survey of a River System mentioned above contains information which we hope will be of assistance to engineers and others undertaking the work of river gauging. Appendix II of that Memorandum makes suggestions and sets out various specimen tabular statements in which the data recorded may conveniently be kept in a form which would enable them to be most easily incorporated in a general Survey publication.

58. During the year we have collected from various sources data of records of rivers in different parts of Great Britain which have been gauged consistently for a varying number of years. As recommended in paragraph 30 of our First Annual Report, the technical officers of the Ministry of Health and the Scottish Departments assisting the Inland Water Survey have examined these and inspected field arrangements and are at present engaged in converting, amplifying, correcting, extending and consolidating a selection of them, where necessary, into a form suitable for publication. The results for the year 1st October, 1935, to 30th September, 1936, will shortly be available. The publication will be statistical and will deal with the results from 28 gauging stations in respect of 14 river basins in Great Britain. The publication will relate mainly to the year 1935-36, but in a few cases measurements are available for previous years, and it is proposed to publish these also where practicable.

59. The statistics included in the proposed publication will be illustrative of large, medium-sized and small rivers of different characteristics draining widely differing types of river basin, including rural, industrial and urban areas.

60. The detailed examination of records has been made with the object of discovering what material was available, what was suitable for publication, what problems and difficulties were being met in various parts of the country by those undertaking river measurement, what standards of accuracy were being obtained and how far the available records needed adjustment so as to give as accurate and complete a picture of the conditions and resources measured as possible. In selecting the material

for publication we decided to take as a beginning only that material which best lent itself to publication in a standardized form. It is not expected that detailed revision will or should be always required before the results are in a form adapted for publication in the Survey. It is hoped that the form of publication will serve as a model for the presentation of results in the future by persons and bodies taking measurements and will lead to a greater uniformity of standards, procedure and accuracy, so that gradually the need for recasting the results of those responsible for taking the measurements will disappear.

61. The range of statistics which we contemplate publishing will vary according to the material at our disposal, and will contain for each gauging station some or all of the following items:—description of the station, daily gauge readings (levels), occasional measurements of actual discharges, a rating table based on these, estimated daily discharges for all days of the year, an analysis of these, rainfall tables and frequency tables.

62. It is obviously desirable that the publications of the Inland Water Survey should be based on standard units of measurement and conversion. We have examined this question carefully in conjunction with the National Physical Laboratory and have drawn up a series of equivalent and standard measures which we propose to use in future publications of data. We feel such standards may be of use to engineers and others in taking measurements, and have arranged accordingly that they shall be included in the first publication of Survey records of stream measurements.

We have the honour to be, Gentlemen,

Your obedient Servants,

(Signed) H. G. LYONS (*Chairman*).
CHAS. H. BIRD.
W. S. BOULTON.
GEO. DALLAS.
G. J. GRIFFITHS.
F. HIBBERT.
CLEMENT D. M. HINDLEY.
S. R. HOBDAY.
W. A. MILLAR.
DAVID PAUL.
B. VERITY.

R. F. TYAS (*Secretary*).

23rd July, 1937.

APPENDIX.

Extracts from a memorandum sent to the schools co-operating in the Survey of the Underground Water Resources of the Nene basin.

INLAND WATER SURVEY COMMITTEE.

Geological Survey.

(The Nene basin was divided into fourteen districts, each to be surveyed for wells and springs, and water-levels measured therein, by one or other of fourteen schools in the area. The approximate boundaries for these districts and the schools co-operating in the Water Survey, were shown on an accompanying sketch-map.

A brief outline of researches into Underground Water Resources and of the organization of the Inland Water Survey Committee was given in the full memorandum, followed by a description of the geology of the Nene Basin.)

The survey will be of greatest help to the Inland Water Survey Committee if similar methods are adopted by each school. The following points are suggested with the object of obtaining a uniform system.

(a) *Location and insertion of well-sites.*

Sites should be accurately marked on six-inch Ordnance Survey maps, and subsequently transferred to one-inch Ordnance Survey maps, on which they should be numbered consecutively, treating the School area as a whole, and not (in cases where the School boundary occurs on more than one sheet), commencing a new series of numbers for each one-inch map. A small dot to mark the exact site, surrounded by a small ring in red ink, is the usual indicator for private wells. Wells for public water-supplies, however, should be sited by a dot surrounded by a small square in green ink.

Coincident with marking the sites on six-inch maps, the collection of as much information as possible about each well will be appreciated, including especially the height of the surface above mean sea-level (Ordnance Datum). This should be as accurate as possible, and some indication on the possible error given, e.g. 220 ft. $\pm$ 5. In addition, notes of any points germane to wells and water-supply are desired, such as whether wells are dug or bored, or both; diameter of borehole; whether water is pumped throughout the day or for an hour or two, or whether well is disused; yield of water if any measurements have been made, any abnormality about the water, e.g. whether salt, ferruginous, hard, etc.; date of construction and name of well-sinker who made the well. In some cases the record of geological strata encountered in a well may be obtainable.

It should be stated here that the geological maps of the district were published about the year 1860, and no revision has since been made. It may happen that the maps require correction in some particulars, and any authentic notes on the geology of the district will be valuable.

(b) *Observations of Water Levels and Depths of Wells.*

It is desirable that water-levels be measured at least twice a year, during the first week of March as near to 4th March as possible, and during the week of 4th to 11th October as near 8th October as possible.

The measurement of the total depths of wells from the surface gives valuable information, additional to that obtained by measuring the water-

levels. The depths of the great majority of wells in the Nene basin lie between limits of a few feet and 200 feet. Some are much deeper, but these are unlikely to be plumbed under the present conditions.

Springs.

It would be advantageous if the exact sites of all flowing springs were inserted on a map and the height of the spring above Ordnance Datum level ascertained. Springs should be shown by a small cross, with the letter S alongside in red ink.

Maximum and Minimum Levels of Water in Wells.

The dates in March and October, given above, which are near the dates of maximum and minimum heights of the water-table, are most generally suitable for the biannual measurements, from the point of view of schools taking part in the survey. They may not include, however, the dates of the actual maximum and minimum heights. These latter dates may be obtained if one or two wells, from which but little or no water is drawn, are measured weekly, or more often. It will be understood that measurements from wells constantly in use, e.g. wells for waterworks where pumping takes place throughout the day, will be of less value than from wells where little or no pumping takes place. The water level in a well should not be measured immediately after pumping has taken place.

The results are best shown as graphs, to which greater interest is added if they are correlated with a graph of local rainfall.

Plumb-Lines.

Very accurate measurements of wells are usually made with a tape, constructed largely of metal to obviate contraction when wet. But for general purposes a line composed of good fishing twine, with a sponge rubber ball for a float at one end, is adequate; if the twine is let down slowly over the hand, the moment of contact of the ball with the water is easily perceptible by the "feel." In a line of this type, it is of advantage to tie knots, including in them small bits of coloured ribbon or string, at every 10 feet. This is best done with the twine swung over a high beam, and with a small weight attached to keep the twine reasonably stretched. Plumb-lines of two lengths, 100 ft. and 200 ft. will be found satisfactory.

For measuring the depth of the well, the rubber float is removed, and a lead sinker, about 2 in. × 1 in. × 1 in., attached.

Co-operation with the Geological Survey.

Well-sites marked on one-inch sheets will be copied on a complete set of maps covering the Nene basin retained in the offices of the Geological Survey to which the maps held by Schools should be sent on request.

It is hoped that records of measurements will be forwarded to the Geological Survey as soon as possible after measurements have been completed.

Recording of Information.

(An accompanying tabular statement was suggested as the most convenient method of keeping the records of biannual well measurements.)

Notes may conveniently be kept separately, under the sub-heading of Well No. and Location of Site: for example:—

(*a*) Well No. 4—150 yds. south of Botley's farm, Floore.
Dug well. Well not used.

(*b*) Well No. 27—200 yds. N.E. of Church, Thornhaugh.
Public supply for village. Yield, 1,500 gallons per hour, pumping 8 hours daily. Depression 6 ft., recovering in 2 hours. Bore-hole 6 ins. diameter.

Measures of water-levels in wells for public supplies will usually not be obtainable by direct measurements by boys. Water engineers, however, may be agreeable to giving information on rest-levels, pumping levels, daily yield, and similar details. In many small public schemes, full records may not at present be kept, but the engineers may make fuller observations if requested to do so.

Correlation of Data.

Data collected will in general be correlated by officers of the Geological Survey. Among the work arising out of the survey will be the preparation of maps of the water-bearing formations, contoured maps showing the surface of the water-bearing beds under cover, and contoured maps indicating the water tables at different dates. Geography masters in Schools may wish, however, to formulate their own conclusions on the behaviour of water in their districts. As in the case of notes made during the survey of well-sites, any observations on the results of the well-measurement will be of great use.

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