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“The Yield of Catchment-Areas.”

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THERE is at the present time an almost complete absence of direct and systematic observation of the yield of upland drainage-areas, from which so many large waterworks derive their supply. The estimate of the yield usually depends upon a series of assumptions, resting often on a very slender foundation of ascertained fact. In the earlier days of waterworks, 50 or 60 years ago, the proportion of the available yield given to the stream below the works for the benefit of riparian proprietors, as compensation for the abstraction of water, was in some cases very excessive, and part of it had to be bought back by the proprietors of the waterworks, after the experience of subsequent years had shown the unfairness of the apportionment. Since that time general knowledge as to the facts has been largely increased, but there has been little systematic observation and co-ordination of the natural phenomena upon which the design of waterworks should be based, and published accounts of thorough and reliable experiments on the yield of collecting-areas simply do not exist.

Year by year the unappropriated stream- and river-basins suitable for supplying towns with water become fewer. This fact has led to the suggestion that the water-supply of the country is really a national matter, and should be considered as a whole; and that a town should not be allowed to appropriate a particular area unless it can be shown that, in a general survey of available sources of supply, that area can economically, from a water point of view, be allotted to it. At the present time it is usually the case that the only way in which a town can get a *locus standi* to petition against a particular Bill for acquiring a source of supply is by promoting a competing Bill, which would otherwise be premature. As the competition for the remaining areas becomes keener every year, and as the cheaper and more suitable areas are always taken first, it becomes increasingly important that really complete data should be available for forming a reliable judgment as to whether existing areas are economically utilized to the fullest extent, and as to the size and

consequent cost of the works which would be necessary to utilize the less suitable areas which yet remain.

The direct and obviously most satisfactory method of determining the yield of any collecting-area would be to measure the stream or river at the point where it leaves the area. A continuous record of the rate of flow, extending over a sufficiently long period, would in itself show what quantity of water in any season could be made available by the construction of reservoirs, and what the capacity of those reservoirs should be. A reliable opinion could at once be formed as to the most economical quantity of water to take from any particular area, in view of the cost of the impounding-reservoirs of a capacity corresponding with this quantity.

Unfortunately, there are difficulties which prevent the adoption of this method. In order to measure the flow of water from such areas as supply the large towns, it would be necessary to construct in each case a weir and approach-channel of considerable size and consequent cost. These weirs would raise the level of the water behind them, and thus submerge the adjoining land. The necessity for measuring the flow only becomes apparent when a waterworks-authority desires to obtain an increased supply of water, and, therefore, to prove to Parliament the yield of its existing and intended works. Such an authority has no power, except by agreement, to enter upon other people's land for the construction of a weir, or to submerge the land above the weir. And even if this were arranged, the records of a few months only would be valueless.

Again, the weirs would form a barrier to all debris in times of flood, and unless such debris were regularly removed, the approach-channel would be obstructed, and conditions of flow over the weir would arise to which no formula of discharge would apply. The accuracy of such formulas is, of course, strictly limited to the conditions under which the experiments whereon they are based were made. Further, it is difficult, though not impossible, to provide a weir suitable for measuring both the maximum and the minimum flow. The variation of flow in rivers and streams flowing from steep mountain drainage-areas may in this country be as wide as between 1 and 2,500, many of the affluents disappearing in dry weather. The range of depth on a weir for quantities varying between 1 and 2,500 would be between 1 and $(2,500)^{\frac{1}{3}}$, or 1 and 184. In such cases the depth of the minimum flow must be sufficient to allow the water to spring clear of the gauge-plate, and the depth at the maximum flow would consequently be very considerable. Again, the apparatus for automatically recording the depth of water could hardly be relied on to show minute variations accurately over so

wide a range of depth, and yet such minute variations on a necessarily long gauge might represent large volumes of water if continued over a sufficient period of time. All experimental difficulties could, however, be overcome by constant care if the initial obstacle of expense were removed.

In the absence of experimental data, waterworks-engineers are almost invariably obliged to estimate the yield of a drainage-area from records of rainfall only, and, as such records on any particular area are usually inadequate, if not entirely wanting, to estimate even the rainfall itself from the nearest available rain-gauges. When the rainfall has been ascertained or estimated, it is necessary, in order to estimate the yield, to make a series of assumptions as to the quantity lost by evaporation, and as to the equalizing effect of the vegetation and geological strata in modifying the resulting flow under varying conditions of temperature, wind, and rainfall.

This method has at any rate the advantage of being able to take as its basis the work of the British Rainfall Organization. Material can nearly always be found in the annual volumes of that body for estimating with considerable probability of accuracy the average rainfall over a long period in any part of the country, even where there are no rain-gauges on the area in question. It is usual to take the estimated or known average annual rainfall for the driest three consecutive years as a starting-point (although even the orthodox 3-year period is chosen upon an assumption which requires closer examination), and from that figure to deduct the estimated average annual loss by evaporation, the balance being the available rainfall. The latter quantity can be utilized only by the construction of storage-reservoirs to equalize the irregular distribution of the rainfall over the period contemplated; and, as these reservoirs are very expensive, it is of the highest importance that adequate data should exist for estimating the rate at which the available rainfall is yielded, and for determining therefrom the most economical storage-capacity, having regard to the rate of increase in the cost of greater capacity and the rate of increase in the uniform daily quantity of water made available by that increase in cost. It is impossible to make a reliable forecast as to the capacity required in a given case unless at least the rate of rainfall and the rate of loss from evaporation continuously throughout the drought are known. The capacity of reservoirs is usually determined by the use of a formula devised by the late Mr. Thomas Hawksley, Past-President Inst. C.E., which makes the capacity depend on a single element, namely, the available rainfall. The observations upon which this formula was based have, however, not been published: it certainly provides a simple solution of the

problem; but no systematized body of information exists whereby its truth, under the very varying conditions met with, can be tested. These conditions include the quantity, intensity, and frequency of the rainfall, and the declivity and geological character of the catchment-area; and no solution of the problem can be considered entirely satisfactory which leaves these important elements out of account.

Nevertheless, almost every existing waterworks could be converted into an experimental station at which the quantity of rain falling and the resulting yield could be rigorously measured. The only obstacle in the way is the difficulty of providing the funds for carrying on the experiments. It would be necessary to establish such a number of rain-gauges upon the drainage-area as would enable the quantity of rain falling on the whole area to be accurately estimated. A single rain-gauge near the reservoir-embankment is useless for this purpose. Also, all the points at which the water leaves the area must be provided with gauges, and the capacity of the reservoirs at all depths must be determined. This capacity is almost invariably known, but the gauging of the water at the points of outflow is usually very imperfectly done, if done at all. The sources of expense would therefore be the purchase and installation of the rain-gauges, the wages of the rainfall-observer (say £150 a year to one man who could undertake not more than 10,000 acres), the cost of the construction or adaptation of flow-gauges, and the cost of providing recording apparatus and meters where these do not at present exist. It would scarcely be possible to make the experiments on any waterworks which were not in charge of a thoroughly competent engineer, whose supervision would be necessary, and upon whom the reliability of the work would depend.

The towns which are supplied in the manner indicated are the places which would derive the benefit from the experiments, and they should therefore provide the funds. It is, however, unlikely that they would do so unless the matter were very authoritatively brought before them collectively. They would almost certainly refuse to spend the ratepayers' money on any object from which they could see only an indirect and distant advantage—if they saw any advantage at all. The economical use of the water-contributing areas of the country is perhaps a national affair, and, if so, the funds should be provided by a Government grant. This could only be obtained, if obtainable at all, by strong representations from such bodies as the Institution of Civil Engineers, the Royal Society, and the British Association, and no doubt the Local Government Board is the department which is in a position to appreciate the strength of the case for inquiry, and to bring about the desired result.

If the thorough system of observation suggested above could not be initiated in consequence of difficulty in providing the funds, useful information might be collected from existing waterworks which are in charge of engineers, and where the engineering means for making the experiments are adequate. It would be necessary to make preliminary inquiries as to :—

- (1) The acreage of the contributing drainage-area.
- (2) The number and representative character of the rain-gauges on the area.
- (3) The relation between capacity and depth of water in the reservoirs.
- (4) The nature of the gauges for measuring the flow at points where water leaves the area.
- (5) The system of observation and recording adopted.
- (6) The willingness of the engineer in charge to undertake the supervision and tabulation of the records in order to show the relation between rainfall and yield.

If these points, and others arising out of them, were satisfactorily answered, and it were proposed to establish an experimental station at any particular waterworks, details of the physical characteristics of the drainage-area, formulas to be used for estimating the flow at gauges not working under favourable conditions, etc., would have to be ascertained.

The difficulty of obtaining funds for carrying out the experiments in a thorough manner, and in many places, has hitherto formed a complete barrier to the increase of knowledge on this subject. If each town were willing to take its own drainage-area in hand the difficulty would disappear, and the cost in each case would be infinitesimal in proportion to the capital outlay on the works involved.

The amount of public money spent upon this class of waterworks, and the waste of both water and money which inevitably accompanies want of knowledge, should render it obligatory upon all towns, as a condition of their receiving parliamentary powers for the compulsory acquisition of private property, to keep a complete and accurate revenue account, duly audited, of the water which falls on and flows off their drainage-areas. Such an account is just as necessary as the ordinary financial account of a town, as to the necessity for which there is no question ; in fact, it is for economic administration, and, therefore, financial purposes, that it should be kept. Every town receiving from Parliament a share of the national sources of water-supply of the country should be considered as receiving a trust, and should be compelled to render an account of its trust.