CHAPTER VI.

ON THE SELECTION OF THE SOURCE OF SUPPLY.

Introductory—Estimation of Quantity required; Population; Consumption per head for different purposes; Waste; Constant and Intermittent Systems of Supply; Consumption in London; Trade and Public Purposes—Quality of the Water—Delivery of Water under Pressure—Various Sources—Gravitation Schemes; Catchment Area; Mean and available Rainfall; Gauging Streams; Compensation; Storage Capacity in Relation to Drainage Area; Illustrations; Purification and Distribution—River Schemes: Flow from large Districts; Measurement of the Flow of Rivers; Necessity for Pumping; Intakes; Chicago—Springs—Well Schemes—Miscellaneous.

IN the present chapter it is proposed, firstly, to regard some of the chief considerations which influence the choice of a source; and, secondly, to view different systems of water supply, leaving to succeeding chapters the treatment in greater detail of the separate and more prominent parts of such systems.

Water is found under various conditions, and it is continually passing in a complete circuit from one of these stages to another. From its great reservoir, the ocean, it is drawn by the sun in perfect purity; solar heat regenerates it, as it were, to follow its career of usefulness once again. Hence, in a vaporous state, it is borne by the winds to the land, and, descending in the form of rain, becomes available for the varied necessities of man; not, indeed, for necessities alone, but for his pleasure and delight as well. There is a temptation to wander from the province of this work and to muse on the Intelligence which has ordained that even in its passage from the ocean to the land water should lend its aid to the beauty of the landscape in the form of clouds, now silvery, now golden, by the light of the sun which gave them birth. It is for us here, however, to regard water in the beauty of its utility alone; and in the form of descended rain, water first becomes available for the supply of cities and towns.

Reservoirs may be formed for impounding the water flowing down the streamlets on the hills, and storing it from times of flood to times of drought. Works for water supply having their sources thus are known more generally as gravitation than as impounding or catchment schemes, because in most cases the supply may be distributed in the town by gravitation alone—that is to say, without the aid of pumping power. But there are impounding works which are not gravitation works in the above sense; and those at Cropstone, from which part of the supply of Leicester is derived, are an instance; for the water, after being impounded, is pumped by engine power into reservoirs more elevated than the source. These cases are, however, exceptional. If, now, one of these elevated valleys in which the impounded streamlet is flowing be conceived as filled up in the upper part with some material such as sand, gravel, or chalk, through which the rainfall could descend, our streamlet would no longer be known as such, but would issue as a spring, whose waters thus, perhaps, naturally freed from impurities gathered on the surface of the ground, might be conveyed at once, by gravitation, for human consumption in the town. Elevated valleys are sometimes formed naturally into reservoirs or mountain lakes, from which the necessary supply may be at once derived by gravitation.

The streams from the hills, the high springs, and the mountain lakes, unite with others and form the river; and the next class of waterworks is that in which the supply is derived from rivers when these are too large to be impounded as in the former class, a part only of the flow, therefore, being abstracted. Pumping power is almost always necessary in these cases, when, as is most proper, the river selected is that in the basin of which the town to be supplied lies. Large supplies are sometimes derived from springs issuing from the foot of hills; but a much more general source is some deep water-bearing stratum of the earth's crust, into which the rainfall has descended and been stored, and from which it is drawn by means of wells.

The conditions which influence the selection of a source of water for the supply of a city or town are, first, the *quantity* to be provided. The natural base of an estimate of the required quantity is the population of the district, which we will suppose is known with sufficient accuracy for the purpose. Guided by observed or carefully assumed rates of increase, it will be necessary in most cases to calculate upon the probable population of some years hence; how many will be influenced partly by the time which will be occupied in completing the works, and bringing them into thorough operation, partly by the greater or less facilities for the economical extension of the works as a matter of construction, and partly by the relation between the immediate and the prospective financial conditions of the undertaking. Of these considerations, perhaps the most important is that relating to the facilities for extension; for to some parts of the works—such as wells, reservoirs, filters, pumping machinery—additions may be made with great facility, while others—long conduits, for instance—may offer serious, or at least considerable difficulties, if useless expenditure is to be avoided. So much is this the case that but very rarely are the several parts of a carefully-studied system of waterworks perfectly harmonious at the outset.

Of the gross population, it is not always that the whole will take water. The proportion of non-consumers to consumers will depend upon many circumstances—facilities for independent private supplies, such as from wells, the position of the undertakers with regard to the town—that is, whether they are a simple trading company, or the local authority itself, legally competent to make bye-laws concerning the use of water and to levy general rates for the same. (*See* Chapter XV.) The circumstances are, however, rare under which it could be deemed wise to lay out a system of waterworks without a view to the whole population being ultimately included amongst the consumers, even if the profits for some years to come are estimated upon the supposition of only a partial patronage.

The average quantity of water actually consumed, per head of population, varies from 14 to 15 gallons per day (of which the city of Norwich is an example) to more than 50 gallons (of which a notable instance is found in the case of Glasgow). These quantities include water for domestic purposes, trade purposes, street-watering, flushing sewers, and extinction of fires. It may be readily perceived that this enormous difference cannot be attributed to corresponding peculiarities in the habits of the population; nor can it be due to relative demands for manufacturing purposes; the difference in the trade consumption is not more than from 4 to 5 gallons per head per day in the two cities above named. It will be well to consider the elements of consumption separately, commencing with the quantity required for domestic purposes. It would appear that for cooking, drinking, washing (including an average for baths, as bathing is now indulged in), and water-closets, 10 gallons are more than sufficient. Inquiries instituted in the metropolis by Mr. Haywood and Mr. Simon in 1850 went to show that in first-class houses of from 12 to 20 rooms, and with every convenience, an average of 12·87 gallons per head was taken; in second-class houses, but still having water-closets, the consumption was 7·41, gallons per head; in houses of the poorer class only about 3 gallons were used; model lodging-houses, with every necessary accommodation, required 6½ gallons. Making some allowance for the greater number of smaller houses, these results would seem to show an average of about 7 gallons. Of late years, however, the use of water has become more liberal, and the average result would now be somewhat higher. Nevertheless, judging even from the most recent experience, 10 gallons may be regarded as a full net allowance for domestic purposes, including water-closets, but of course disregarding waste, of which notice will be taken directly.

Concerning the influence of water-closets upon the general consumption, it is obvious that we should regard, not the proportionate number of water-closets to the number of inhabitants, but the proportion of the population having access to water-closets. The consumption in water-closets depends principally upon the mechanical contrivances which regulate the flow of water in them; an allowance of 3 gallons per head, per day, however, would seem to be ample, if properly disposed for flushing the pan, and where waste-preventing apparatus is employed. (*See* Chapter XIV.) Where no such contrivance is used, the waste will reach an almost incredible amount; indeed, it is principally to water-closets that the great difference between the gross consumption and the quantity actually utilised is due.

Such, then, may be considered the actual requirements of domestic purposes; but only under unusual conditions can these limits be maintained in practice. Unless special preventive measures be adopted, the consumption will be enormously increased by waste. Waste may be partly due to the wilfulness or negligence of the consumer, and partly to the house-fittings—bib-cocks, ball-taps &c.—being of imperfect construction, or suffered to be out of repair. Principally with a view to reduce the waste of water is the system of supply adopted known as the *intermittent or cistern system.* The consumption is thus limited to the contents of the cistern, and the quantity used or wasted in the short time each day during which the cistern is being filled from the mains. Where the *constant or direct system* is followed, it is absolutely necessary that strict attention be paid to the construction and condition of the house-fittings, or the unlimited waste would be ruinous to the parties supplying the water. With due preventive measures, however, the gross domestic consumption may be reduced to a quantity very much smaller than that to which the intermittent system has hitherto been brought, as will be seen in Chapter 16.

In London, under the intermittent system, the supply for domestic purposes ranges from 20 gallons, in the district of the East London Company (comprising Bethnal Green, Stepney, the Docks, and Stratford), to 36 gallons in the district of the Chelsea Company (comprising the most aristocratic part of London—Buckingham and Kensington Palaces, Belgravia, and Pimlico), the average being very nearly 26 gallons.

The New River Company, supplying the City proper, Clerkenwell, Kentish Town, and Stoke Newington, follows the East London, with 23½ gallons.

The Southwark and Vauxhall Company (which, besides the district giving it its name, supplies Rotherhithe, Battersea, Wandsworth, and also Kew and Richmond), delivers 25 gallons.

The Kent Company, with Deptford, Greenwich, Woolwich, Lewisham, Blackheath, and Eltham, shows a consumption of 27 gallons.

The West Middlesex Company, with Regent's Park, the district north-west of that locality, and that between Kensington and Kew, is 28.

The Lambeth Company, whose district is far more extensive than the place from which its name is taken, extending, as it does, from Kingston on the west to Beckenham on the east, delivers 33 gallons.

The Grand Junction Company, reaching from Pall Mall, through Brentford and Twickenham, to Hampton, also supplies 33 gallons.

These figures are interesting when viewed in relation to the different classes of people and property characterising the different districts: as the grade of society is higher, the water consumed for domestic purposes is greater, and almost, it would seem, in regular proportion.* For intermittent-service towns generally, the average domestic consumption may be set down at from 20 to 25 gallons per head. For constant-service towns the two widest extremes that can be cited have already been mentioned—Norwich, with 10·8 gallons, and Glasgow, with about 45 gallons. Of the latter quantity there can hardly be a doubt that nearly two-thirds are wasted, one way or another. The case of Norwich shows how effectually waste can be checked by attention to the details of the works, and by stringent regulations concerning the use and misuse of the water. (*See* Chapter XVI.) Not more, however, than about one-fourth of the inhabitants of Norwich have access to water-closets. Taking this fact into consideration, it would seem that even in this city nearly 10 gallons are consumed for domestic concerns other than water-closets.

This question of the quantity of water which is, and the quantity which ought to be, consumed for domestic purposes is too generally regarded in its commercial aspect; inasmuch as the virtue of a water supply is mostly measured by the smallness of the consumption. The principle is correct so long as the efforts for reduced consumption are directed solely against *waste*; but it is wrong if it operates against the more extended *use* of water. Notwithstanding the apparent large quantities of water now brought into our cities and towns, twice the quantity at present consumed would not be too much for the legitimate uses of a people paying rightful attention to their bodies. Waste ought to be curtailed, but it is a far higher duty to encourage the use of water than to increase the dividends of water companies.

Water is required for street-watering, fire extinction, and in some cases—chiefly where water-closets are few—for flushing sewers. For these general public purposes the consumption is never more than a small fraction of that for domestic purposes; it may be considered to average about 1 gallon per head per day.

With regard to street-watering, it is found that of macadamised roads 400 square yards, and of paved roads 600 square yards, may be effectively watered—i.e. sufficiently so to lay the dust—by one ton of water. The average number of days on which this operation has to be performed in this country is about 120.

For trade and manufacturing purposes the quantity of water consumed, as might very well be supposed varies considerably in different towns, say from 1 gallon to 8 or 9 gallons per head of the population. It is customary, however, to divide the gross consumption into, first, that for ordinary domestic, and, secondly, that for manufacturing purposes, trade, and general purposes taken collectively; and in the table on the following page particulars of the water actually consumed in various towns are given according to this classification.

Having formed an idea of the quantity which must be provided to meet the demand of the population, the selection of the source will turn upon the *quality* of the water. In a former chapter, the leading characteristics of waters derived from different sources have been described, and it is not necessary to repeat the arguments still keenly advanced for and against the rival virtues of rivers, springs, and mountain basins. On these questions prejudices run very strong, and it would be vain to dogmatise concerning them. The point is generally settled by

* The association of the Lambeth Company with the Grand Junction Company may at first sight appear strange, but it should be remembered that the district from which the former derives its name is only a small constituent of the area supplied by it, while the remainder includes such places as Piccadilly, Kensington, Hammersmith, Turnham Green, Kew, Brentford, Richmond, Twickenham and Hampton, Brixton Hill, Crystal Palace, Norwood, Croydon, Streatham, and Wandsworth.

considerations of cost, although on a matter of such importance this should not be. If it be satisfactorily determined that one water is, on the whole, better than another, but chiefly so as far as the public health is concerned, then we can scarcely pay too dearly in obtaining it. But as with the quantity to be supplied, so with the quality—it is mostly a question of dividend rather than of what is really best for the consumers.

Name of Town or District	Population	Consumption per head per day		
		Domestic	Trade and General	Total
		Gallons	Gallons	Gallons
INTERMITTENT SERVICE.				
London: District supplied by—				
New River Company	800,000	23·5	5·5	29·0
East London Company	750,000	20·0	6·5	26·5
Grand Junction Company	288,000	33·0	3·8	36·8
Chelsea Company	200,000	36·0	3·25	38·25
West Middlesex Company	290,000	28·0	2·3	30·3
Southwark and Vauxhall Company	480,000	25·0	7·3	32·3
Lambeth Company	290,000	33·0	2·5	35·5
Kent Company	280,000	27·0	·88	27·88
Average	3,378,000	26·0	5·0	31·0
Liverpool	625,000	21·5	2·6	24·1
Birkenhead	40,000			42·5
Chester*	33,000			45 45
Exeter (City)	37,000			25·0
Exeter (St. Thomas's)	5,000			30·0
Chelmsford	8,000			18·75
Bath	53,000			19·0
Berwick	10,000			18·0
Gosport	22,000			10·01
St. Helens†	40,000			17·5
Hastings	20,000 to 25,000			21·0
Huddersfield	40,000			10·0
Shrewsbury	26,000			19·22
Windsor‡ (including Eton and Clewer)	14,000			46·42
Warwick	11,000			22·72
CONSTANT SERVICE.				
Manchester	685,000	14·0	7·0	21·0
Glasgow	511,000	45·0	8·0	53·0
Leeds	225,000	18·5	4·5	23·0
Edinburgh	206,000	30·0	6·0	36·0
Newcastle	200,000	21·0	7·0	28·0
Sunderland	150,000	13·0	6·5	19·5
Nottingham	130,000	13·0	5·5	18·5
Bristol	116,000	16·66	2·0	18·66
Preston	82,000	18·5	6·0	24·5
Norwich	57,500	10·8	3·7	14·5
Leicester	53,000	14·0	7·0	21·0
Derby	38,000	15·0	5·0	20·0
Cambridge	30,000			18·0
Sheffield	225,000	26·0	3·0	29·0
The following are now Constant Service:				
Chester*	35,000	28·5	1·71	30·21
St. Helens†	45,000	12·0	14·0	26·0
Windsor‡ (including Eton and Clewer)	14,000	37·5		37·5

Some waters, which in their natural state are scarcely fit for human consumption, may be rendered so by one or other process of artificial purification, a subject which will be treated of in a following chapter. The only processes practicable on a large scale are aeration, subsidence, precipitation, and filtration; the applicability of one or all of these must be duly weighed when comparing the eligibility of one source with that of another. The reader may here be reminded, in passing, that a process of precipitation applied to water from the chalk formation has succeeded in producing a water for which no praise can be too high; indeed, it is very doubtful whether in any other natural or artificial water all the same virtues are to be found. On the questions both of original purity and of artificial purification reliance will have to be placed largely upon the searching power of chemistry and the microscope; but, as we have already seen, the elements of danger which in a potable water have most to be feared are minute particles of organic matter, which even modern science can hardly discern. The safest course to pursue is to avoid waters which have been in any way exposed to the introduction of these dangerous elements. Rivers which drain large areas of cultivated land, and into which the sewage of the towns on its banks must sooner or later, and in either a crude or modified form, find its way, are always open to suspicion. Due regard has been paid in a former chapter to the theory that organic matter in river water undergoes a process of transformation into innocuous inorganic elements by the free oxygen with which it is brought into contact; but this process requires time to complete. As far as this country is concerned, the Rivers Pollution Commissioners, who devoted prominent attention to this subject, gave it as their opinion that 'there is no river in Great Britain long enough to effect the destruction of sewage matter by oxidation.' This sounds like a severe verdict, especially when it is known that a large proportion of the inhabitants of London drink water drawn from a part of the Thames above which there is received the drainage of towns and villages with, together, more than 800,000 inhabitants; nevertheless, it cannot be doubted that navigable rivers draining populous districts are not the purest sources from which to draw water for domestic consumption.

When comparing different sources on the ground of purity, note must be taken of the possibility of contamination at future periods, such as by mineral workings in mountain districts, or by the cultivation of the land, or the increase of population in the district. Of all sources, deep wells are least liable to have the quality of their water injured by such causes, because of the great depths of natural filtration which the waters undergo. The water from deep wells partakes rather of the character of the stratum from which it is derived than of its original source; indeed, great depths of certain geological strata—more particularly the chalk and the new red sandstone—seem to be capable of freeing water from some of the vilest impurities, and replacing them by a small and almost constant proportion of harmless mineral compounds. Organic matters are quite lost as such before they have gone very far into these cleansing media.

The foregoing remarks concerning purity have reference, of course, only to water for human consumption. The minute particles and organism, which would be sufficient to condemn a water if intended for certain domestic uses would be inappreciable in most manufacturing concerns, and obviously so in the general public purposes of street-watering, sewer-flushing, fire extinction, ornamentation, &c. At the same time, there are constituents of certain waters—salts of lime, for example—which render them objectionable to the manufacturer, but more pleasant to the taste, without being at all injurious to health. These considerations would seem to suggest, for certain favourable cases, two sources, or at least two qualities of water as supplied to the consumer, even if the difference be effected in the course of the artificial purification. The cost of such an arrangement is, however, its chief objection, and the practical result is, as will be presently seen, to rely upon only one source, or, more correctly, only one distribution, for two or more sources may be combined. It is obviously redundant to highly filter ordinary river water, for instance, that is afterwards to be used for baths, flushing closets, house-cleaning, and general public purposes. But it is a rare case in which it would be less expensive to provide two distinct means of distributing the water than to purify the whole quantity of water supplied. And the balance will also be found on the side of the latter expedient, if compared with the purification of water by each establishment or household for its own cooking and drinking purposes, although such a method would be capable of a refinement hardly practicable on the larger scale; it would, at the same time, however, be exposed to great abuses.

Where it is proposed to bring water into a town without the assistance of pumping, the source selected must not only yield water ample in quantity and of reasonable purity, but must be at an elevation that will ensure the delivery of a sufficient volume without requiring the aid of a conduit of unusually large dimensions. The effective pressure in the town should be such that the highest storeys of the houses in the most distant parts may be supplied, and, further, that the roofs may be commanded by jets from the mains without the assistance of fire-engines. As far as these objects are concerned, the value of the water increases with its pressure; while there are applications in which it will be of value even for its pressure alone, if this be sufficiently great for it to be used with economy in water-power machinery of one kind or another. With an effective pressure of 100 feet, each 1,000 gallons of water represents 1,000,000 foot-pounds of work. Suppose, then, for instance, that such water be used in a machine developing 75 per cent. of its theoretical value, and suppose, further, that the price of the water is 6*d*. per 1,000 gallons, then for one penny we may have 125,000 foot-pounds of work. With 200-feet pressure, the price remaining constant, 250,000 foot-pounds of work could be had for one penny, and so on directly with the pressure. On the other hand, as the pressure is greater, so must the pipes and fittings be made stronger, and the extra outlay thereby incurred must be set against the corresponding advantages, when forming a true estimate of the value of pressure. It should be remembered, however, that excessive pressure due to a very elevated source can always be reduced and kept in check by means of very inexpensive contrivances, whereas deficiency of pressure can be compensated only by the employment of engine power, with its necessary attendant expense.

It is not imperative that a town should be dependent upon one source alone; many places have their supply

from two or more different, and sometimes very opposite, sources. The demands of an increasing population will often exceed the greatest supply obtainable from the original source, and thus compel resort to another and yet another. But it is very rarely that a scheme to procure water from two sources, opposite in character, and perhaps in position, will be originally laid out, for the advantages of such a proceeding will generally be outweighed by the disadvantages. It is true that in many cases water suitable for road-watering, sewer-flushing, fire extinction, and indeed many manufacturing and even some domestic purposes, might be obtained close at hand from the river upon which the town is situate, whilst none fit for cooking and drinking can be found in sufficient quantity within a very long distance. Supposing the remote source to be ample in quantity for the entire wants of the community, it then becomes a question between the cost of conveying the additional quantity from the distant source, or from the near source, but coupled in the latter case with the cost of additional and independent means of distribution—an item which will generally turn the scale in favour of the single source. But if the waters from both the sources are fit for all domestic purposes, or can be readily made so, the case is a much more promising one.

In selecting a source for the supply of a town or district, attention should be, and in most cases is, confined in the first place to the hydrographical basin to which that town or district belongs. It is but natural and proper so to do, for otherwise the water drawn from the neighbouring basin may be before long required for the rightful use of the population springing up within it. In thinly peopled districts this principle is not difficult to follow, but in populous countries there is a strong temptation to wander far afield for eligible sources before having fully utilised those which nature has assigned. The sites of towns have, no doubt, in most cases been originally determined with reference to a supply of water; and in a country's early days the requirements of a small community are readily accommodated by the river or stream upon which it has settled. In a little while, however, civilisation, with its accompaniments of drainage and manufactures, fouls those sources which it should have been its first duty to preserve in purity. And only now is the true philosophy dawning upon us, and the irrational slovenliness of fouling our streams and rivers for the sake of finding an easy riddance of our filth is at last being duly recognised. Thus both the difficulties with which many of our existing water supplies have been threatened, and the contingences of subsequent impurification which would otherwise have to be estimated in selecting new sources for towns, promise before long to be removed. As a consequence, it will be found that, even in the face of the rapid increase of population and the growth of manufactures, there will be a better opportunity for observing the principle that towns should look first for their supply of water to their own natural basin, and not abandon it for any but the most patent considerations—a principle prominently urged in the report of the Royal Commission on the Water Supply of the Metropolis.

Often—indeed, far too often—the most influential consideration in selecting a source of water supply is the cost. Far too frequently is it preferred to swallow the impurities, and make shift with the scantiness of the existing supply, than to favour a liberal scheme. As remarked in a former chapter, we are far behind the ancients in our estimate of the value of water for personal use; and so mercenary have become our notions in the pursuit of 'economy,' that even in the paramount question of health and comfort, the purse is supreme. The truest economy will mostly be found in selecting that source which will secure a liberal quantity of water of unimpeachable quality at almost any cost.

We will now refer more particularly to the design and construction of waterworks of different kinds, and, first, as to *Gravitation Works.*

The source of supply in gravitation works is the rainfall upon the gathering-ground or catchment basin, a tract of land more or less completely bounded by ridge lines, or, more properly, watershed lines. This latter distinction is necessary, because the hydrographical basin is not necessarily coincident with that traced from surface contours. Valleys of denudation on an anticlinal axis, for instance, where permeable strata are superimposed, would show from surface contours a gathering-ground larger than the drainage area really available for the impounding of water, and *vice versâ.* In impervious or rocky districts the case is simplified to one of surface observations.

The gathering-ground having been determined, and its area ascertained, an estimate has to be formed of the available rainfall upon that area. The available fall is a quantity more or less short of the mean fall—how much so remains to be seen. The mean rainfall is determined by rain gauges, some varieties of which have been described in a former chapter, where will also be found some of the rules to be observed in the establishment of new gauges, and in the comparison of their returns with those from old-established ones. The first deduction from the mean annual fall is one rendered necessary by the variations in the amount of fall. The extent of these variations, as already stated, is found to be about two-thirds of the mean fall—that is, one-third in excess, and one-third in defect. Were the whole of the rainfall (neglecting for a moment the loss by evaporation) to be impounded, and an uniform quantity, equal to the mean fall, to be discharged from the reservoir, the storage

capacity of the reservoir would have to be far greater in proportion to the supply than has hitherto been found economical. The greater the mean supply (rainfall) compared with the mean demand, the less will be the storage capacity required to ensure the demand being regularly met ; and it is now the practice to consider as available no more than the mean fall for three consecutive dry years, and to secure a gathering-ground correspondingly large. Where an extension of catchment area presents difficulties, and an increase of storage capacity unusual facilities, a modification of this practice may be advantageous. The mean fall in three consecutive dry years is found to be, with remarkable regularity, one-sixth less than the mean fall, and this deduction is therefore always made; the one-sixth passes away in floods which the reservoir is not large enough to impound.

The next deduction is for the loss by evaporation and absorption. The remarks on this head in a former chapter need not here be repeated ; suffice it to say that the loss from these causes varies in this country from about 9 to about 19 inches per annum, and that an estimate of it for any case can be formed only from careful observation and by experienced judgment. The actual loss for a particular period may be found by comparing the gaugings of the stream or streams fed from the drainage ground with the returns from the rain gauges for the same period. The difference will, of course, give the loss for that period. If the period of stream gauging be one in which the rainfall has proved to be less than the mean annual fall, the proportionate loss shown by the gaugings will be greater than the proportionate mean loss, and *vice versâ*. Gaugings for short periods require to be treated with the greatest caution, and in inexperienced hands would be almost sure to lead to erroneous conclusions.

The flow of water in small streams is usually gauged by means of a notch-board. The board must be made to act as a water-tight dam, serving to retain a pond of still water, the level of which may be accurately ascertained. If the water above the notch-board be not still, but have a sensible velocity of approach towards the notch, this velocity must be regarded in calculating the quantity of water passing over. The notch should present to the stream a thin edge formed by chamfering the board on the down-stream side, as shown in Fig. 20. The height of still water above the cill of the notch may be ascertained from a scale previously adjusted on a stake driven in the bed of the stream above the dam. The notch should be nearly of the full width of the stream, the better to allow for the passage of larger volumes of water, and there should be a clear run away from the notch-board, to prevent the tail-water rising and 'drowning' the notch. Great care must be taken also to prevent leakage round the end or under the bottom of the board. Observations should be taken never less frequently than once a day, and at shorter intervals as the drainage area is smaller and more precipitous, for the falls of rain are then more quickly felt and pass sooner away. The most satisfactory, because the only correct, method of ascertaining the flow is to make it with its variations self-recording. This may be accomplished by any means which will register the variations in the level of the still water above the notch upon a revolving drum actuated by clockwork. The width of the notch, the head of water, and the time for which that head has been maintained being all known, the quantity discharged during that time may be ascertained by a simple calculation. Messrs. John Bailey & Co., of the Albion Works, Salford, have for some time manufactured complete instruments applicable to this and other similar uses connected with waterworks.

In catchment or gravitation schemes an allowance should be made for the evaporation from the water surface of the reservoirs. This will have to be calculated on an assumed area. There are cases in which this area is about one-tenth of that of the gathering-ground, while, on the other hand, there are instances in which it is as little as one-seventieth. The average for this country appears to be about one-twentieth; and setting the annual loss by evaporation at 20 inches, this would show a loss equal to one inch per annum over all the gathering-ground, in addition to the other elements of loss.

In systems of waterworks where the supply is derived by impounding streams there are generally existing interests which will be affected by the diversion of the water, and which must, of course, be regarded. The most important are those of millowners; and the kind and amount of compensation to be given in such cases is one of the most difficult questions connected with the subject of water supply. If water compensation be agreed upon, an important addition is made to the demand, which addition must, of course, be provided for in the supply. Mills are never designed to utilise the whole of the water flowing down the stream ; by far the larger portion runs to waste, partly in times of excessive rain, and partly when the mills are not at work. The proportion of water utilised necessarily varies in different cases, and it is upon this point that most of the contention between the promoters of waterworks and the owners of mills arises. It must not be forgotten that the one-sixth already shown to be a necessary deduction from the total supply should be struck off before fixing the amount of compensation water, for the simple reason that, coming when there is already a superabundance of water, it is as useless to the one party as to the other. Of the five-sixths remaining, it is ordinarily found that mills are capable of using only from one-fourth to one-third, and one or other of these proportions—mostly the

from two or more different, and sometimes very opposite, sources. The demands of an increasing population will often exceed the greatest supply obtainable from the original source, and thus compel resort to another and yet another. But it is very rarely that a scheme to procure water from two sources, opposite in character, and perhaps in position, will be originally laid out, for the advantages of such a proceeding will generally be outweighed by the disadvantages. It is true that in many cases water suitable for road-watering, sewer-flushing, fire extinction, and indeed many manufacturing and even some domestic purposes, might be obtained close at hand from the river upon which the town is situate, whilst none fit for cooking and drinking can be found in sufficient quantity within a very long distance. Supposing the remote source to be ample in quantity for the entire wants of the community, it then becomes a question between the cost of conveying the additional quantity from the distant source, or from the near source, but coupled in the latter case with the cost of additional and independent means of distribution—an item which will generally turn the scale in favour of the single source. But if the waters from both the sources are fit for all domestic purposes, or can be readily made so, the case is a much more promising one.

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If the drainage area first examined be found not to yield a supply sufficient for all purposes, a neighbouring basin may sometimes be united with it by means of a conduit or tunnel.

Should it be found desirable to impound the water of a stream at a point where the mean available supply would be greater than required for all purposes—that is, including an addition to the town demand of say 50 per cent. for compensation—it will mostly be advisable not to impound the whole stream, and incur the increased liabilities which such an act would entail, but to divide the stream by a tongue, in such a manner that only the correct proportion should be impounded. Then, if the catchment area yields say 1,000,000 gallons per day, and 200,000 gallons be required for the town, add one-half for compensation, and then rather less than one-third of the total stream will be required, and only 100,000 gallons will have to be delivered from the reservoir as compensation water. If, however, the whole stream be impounded, a reservoir will have to be formed large enough to ensure the regular delivery of 200,000 + $\frac{1000000}{3}$ = say 533,000 gallons per day, of which 333,000 would be for compensation.

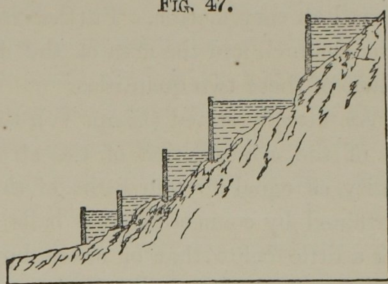
Setting aside for a moment the legal liabilities, as just instanced, which attend the control of excessively large drainage areas, it may be seen that the daily delivery of a quantity of water sufficient for the requirements of a town may be guaranteed by any measure which lies between the two following extremes, viz., on the one hand, the selection of a gathering-ground the mean supply from which—without deductions for excesses of flood or drought—is just equal to the mean demand, and, on the other hand, the selection of a gathering-ground from which the least supply taken for short periods—days at the longest—is sufficient to meet the greatest possible demand for any such period. In the former case the area of the gathering-ground is at the minimum, and the storage room necessary to equilibriate the very varying supply and the tolerably uniform demand is at a maximum. In the latter case the gathering-ground is at the maximum, and the storage room at the minimum. The practice in this and most thickly populated countries tends towards the first extreme, partly because land is dear and partly because the gathering-grounds available are scarce and small compared with the number and size of the towns which have to look to them for their supplies of water. But this practice will not necessarily be the best when these circumstances are reversed, and where, it may be, there are but scarce facilities for the construction of adequate storage reservoirs.

To illustrate these different cases, let us suppose a mean annual fall of 40 inches, and an estimated loss by evaporation and absorption of 12 inches. If the whole of the water be impounded and utilised, none being allowed to run to waste in time of flood, 28 inches per annum will be available, and $11\frac{1}{2}$ acres of catchment will be required for every thousand consumers, taking the consumption at 20 gallons per head per day. Under these circumstances, however, the supply could not be deemed reliable if there were less than twelve months' storage room, to equalise the irregularities of annual rainfall over long series of years. Thus $7\frac{1}{3}$ million gallons storage per thousand consumers would be required, equivalent in this case to more than 100,000 cubic feet per acre of catchment. To pass now to the other extreme, and reduce the storage room to the minimum at the expense of the catchment area, or, in other words, to do away altogether with storage reservoirs, let us suppose a minimum flow of half a cubic foot per second per thousand acres of catchment. There would then be required 74 acres per thousand consumers, or an area six and a half times that of the previous case. If, now, with these extremes the usual practice be compared, there will have to be deducted from the mean annual fall of 40 inches one-sixth of this quantity, or $6\frac{2}{3}$ inches, for losses at flood times due to want of storage room. This will leave $33\frac{1}{3}$ inches, from which, again, the 12 inches for evaporation and absorption will have to be deducted, leaving $21\frac{1}{3}$ inches per annum as the net quantity available. This involves but 15 acres of catchment per thousand consumers; but, at the same time, allowing six months' storage, which would be about the right amount in this case, $3\frac{1}{2}$ million gallons storage would be required for every thousand consumers, equivalent to 38,000 cubic feet per acre.

Storage reservoirs for impounding schemes are mostly formed by damming across the valleys of the streams in a manner hereafter to be described. On Plate 16 is shown the general plan of the gravitation works by which the town of Bideford is supplied. In this case only one catchment basin is at present appropriated, and one storage reservoir formed. Frequently two or more basins are combined in one scheme, sometimes with a common storage reservoir and sometimes with separate ones. In the case of Bideford, just referred to, it is proposed ultimately to lead into the existing reservoir the waters from the adjacent catchment areas, shown in Fig. 1 by different methods of shading. This will be accomplished by driving a short tunnel through one of the dividing ridges, and carrying thence a catchment drain. There are frequently two or more reservoirs to one catchment basin. The Manchester Works, amongst numerous others, are of this kind; and the accompanying figure is a section down the valley line, showing the relative positions of the reservoirs.

The water impounded for purposes of town supplies is sometimes filtered before delivery, but in many cases no further purification is deemed necessary than that which the water undergoes in the large reservoirs, by the subsidence of the suspended matters, and the atmospheric oxidation of some of the organic impurities which may have been brought down from the gathering-ground. Water impounded from moorland is frequently discoloured by peat, but this discolouration in great part vanishes in the reservoir.

FIG. 47.



Horizontal scale $\frac{1}{3}$ inch per mile.
Vertical scale 250 feet to an inch.

Natural lakes are occasionally utilised for town supplies, instead of artificial reservoirs. The Loch Katrine Works, supplying Glasgow, are a famous example of this system.

From the reservoirs (Chap. VIII.) or filter beds (Chap. IX.), as the case may be, the water is led by a conduit (Chap. XII.) generally into one or more service reservoirs, situated near the town, whence, again, the town mains (Chap. XIII.) are directly led. Advantage may sometimes be taken of small basins near the line of conduit, in which water may be impounded, to act as an auxiliary to the main supply. Into the Shaws Water Conduit of the Greenock Works waters are led from no less than six auxiliary reservoirs, formed at different points along the line of route. As service reservoirs are common to all varieties of waterworks, the description of their uses will be reserved for a subsequent and separate notice (Chap. VIII.).

The next kind of works to which reference will be made is that in which the water is pumped from a river or stream whose flow is generally greatly in excess of the quantity to be abstracted. This excess makes one of the chief differences between river schemes and impounding or gravitation schemes; inasmuch as, in the latter, storage reservoirs, to equalise the supply and demand, are essential, whereas, in the former, reservoirs for such purposes are, except in very rare cases, quite unnecessary. It is sufficient that the smallest dry-weather flow of the river is so large as not to be injuriously affected by the withdrawal of the quantity required for the works. The great experience and careful observation necessary for the success of gravitation works may be here largely dispensed with—that is, as far as ensuring an abundant supply is concerned. The larger the stream, the smaller, proportionately, will be the variations in its flow at different seasons. The greater extent of the drainage area will alone be a moderator of the effects of irregularities in rainfall; and even more so will be the existence in that drainage area of absorbent strata serving to retain the rainwater only to yield it again in the form of perennial springs. And thus it is that droughts which would threaten the complete failure of impounding works need scarcely be regarded in connection with river schemes.

The following particulars of the summer discharges of rivers, taken from Mr. Beardmore's well-known manual, are of value in connection with this subject, as showing the powerful influence of *retentiveness* in the geological character of the drainage ground, acting even in opposition to the moderating effect of *extent*.

Rivers	Drainage Area	Summer Discharge				Mean Annual Rainfall
		Total	Per sq. mile	Per 1,000 acres	Equivalent Annual Rainfall	
	sq. miles	c. ft. per min.	c. ft. per. min.	c. ft. per sec.	inches	inches
Nene, at Peterborough—Oolites, Oxford clay, and lias	620	5,000	8·45	·22	1·88	23·1
Thames, at Staines—Chalk, greensand, Oxford clay, oolites, &c.	3,086	40,000	12·98	·338	2·93	24·5
Loddon (Feb. 1850)—Greensand . . .	222	3,000	13·53	·352	3·01	25·4
Mimram, at Panshanger—Chalk . . .	50	1,200	24·0	·625	5·5	26·6
Wandle, below Carshalton—Chalk . .	41	1,800	43·9	1·147	9·93	24·0

The flow of streams or rivers which are too large to admit of a gauge-weir being erected across them may be estimated either by means of floats, having the same velocity or nearly the same velocity as the current of water, or by instruments held stationary, and arranged to indicate the velocity of that part of the current which acts upon their mechanism.

When the first-named method is pursued, it is necessary to select a part of the river where its course is tolerably straight and its cross-section uniform. Near each end of such length two poles should be set up, marking points in an imaginary line intersecting the river at right angles to its course. The measurement by a chronometer of the time occupied by the passage of a float from one of these imaginary lines to the other is thus rendered an easy matter. Further requirements are to ascertain the mean velocity of the current along this part of the channel, and the area of the mean cross-section of the latter; the discharge or flow will obviously be the product of these two quantities.

As already stated (Chap. V.), the surface velocity at mid-stream is always greater than that at any other part of the cross-section of the stream. For rough estimates it will generally suffice to consider the mean velocity as equal to four-fifths of the maximum surface velocity. The mean velocity may be more correctly ascertained by connecting two balls of equal diameter, but with specific gravities one a little above and the other a little below that of water, but such that the mean shall be less than that of water. The length of the connecting-cord shall be such that, while the upper ball floats just below the surface, the large one shall move along near the river bed. To ensure more accurate results other balls, with specific gravities adjusted so as to equal that of water, may be attached to the cord at intermediate points. The apparatus should be placed in the stream some distance above the first point of observation, in order that before reaching the latter it may have acquired the proper velocity.

Sometimes a tube or hollow rod is used, open only at one end, and so adjusted by means of water ballast or shot that it will float upright with its bottom near the bed of the stream.

Amongst the second class of instruments, those ordinarily used are the pitôt tube and some form of screw fan. The former consists essentially of two vertical tubes, of which short lengths at the bottom are bent horizontally, these horizontal arms being made to point in opposite directions. The tubes are immersed in the current whose velocity is to be determined, the horizontal arms being held strictly in the line of the current.

In the tube whose arm is presented up stream the water rises above the level of the surrounding water, and in the other tube the water rises only to a point which is below that level. The difference of level $(h-h')$ of the water in the two tubes thus becomes a measure of the velocity of the current—

$$V=\mu \sqrt{2g\,(h-h')}$$

μ being a coefficient which is constant for each instrument.

The screw fan has been made to indicate and record the velocities of currents of water by acting on a train of suitable mechanism. Like the funnel of the pitôt tube, the apparatus can be lowered to any point in the stream, and the number of revolutions which the screw makes in a given time may be ascertained. To know to what actual velocity this number corresponds previous experiments must have been conducted by moving the instrument with different velocities through a body of still water.

The chief characteristic of river works is that, as the source is generally below the level of the points to be supplied, the water has to be raised by artificial means. The current of the river itself would, at first sight, appear to be very generally eligible for this purpose, and in many cases it is so employed with success, especially in France, Switzerland, Germany, and the United States of America. Various hydraulic machines are used, according to the peculiar circumstances of the case. As described in a former chapter, London itself derived part of its supply from the London Bridge Works, the pumping machinery of which was worked by undershot wheels, actuated by the strong current which ran through the arches of the bridge. Advantages for the employment of water power are afforded by a dam across the stream, forming a reservoir of comparatively still water. Thus the waters of the stream are placed more directly under control, and, further, a chance is given for much of the suspended impurity to subside. Where no such dam exists, opportunities for the economical utilisation of water power will mostly be confined to small or unnavigable streams, unless the rivers, if navigable, be wide enough and have sufficient velocity to allow the employment of undershot or stream wheels. In this country, where coal is plentiful, steam power is almost universally used.

The high service of the Aberdeen supply is provided for by an ingenious hydraulic arrangement, which may be thus described. From a point on the line of the aqueduct where the latter is 150 feet above and about 500 yards distant from the river Dee, an 18-inch pipe is led to a water-pressure engine, situated near the river. A million and a half gallons of water per day are passed down this pipe to the engine, and of this quantity about 30 per cent is pumped through a 9-inch pipe, more than a mile in length, into a large service reservoir, the remainder flowing into the Dee. The elevation of the reservoir above the river is nearly 400 feet, as may be seen from Plate 36 where the arrangements are illustrated.

The *intake* should be situated at some point of the river where a good stream of deep water is constantly running ; stagnant and shallow parts should be avoided, for obvious reasons. The water should be abstracted at not less than about five feet below the lowest summer level, on account of the higher temperature of the water at and near the surface ; and provision should be made, either by fine gratings or by rough filters of coarse gravel, or the like, for excluding grosser suspended matters. Double screens are sometimes used, sliding one in front of the other, so that one may remain in operation while the other is being cleaned.

On Plate 33 will be found details of the river intake of the Aberdeen Waterworks, constructed from the designs of the late Mr. James Simpson. The water is admitted from the river, through two sluices, into a chamber which contains an iron pipe. This pipe is connected with the main conduit by a movable joint, (Fig. 8), its free extremity being supported by floats, and enlarged (Figs. 7 and 10) so as to admit the water as it were over a weir. The arrangements are such that the depth of water flowing over this weir, and consequently the quantity flowing into the conduit, shall be pretty nearly constant, whatever the height of the water in the river.

Where the water is to be taken from the river, not by gravitation, but by direct pumping, the cost of executing work much below the summer level of the river—that is, where the foundation is permeable—may be avoided by carrying the suction-pipe from the engine to the river above summer level, and then, by means of a bend, dropping the foot of the suction pipe to the required depth below the surface. In such cases the lower part of the pipe would contain a valve, opening upwards, and serving to retain the water in the suction-pipe when the engines are not at work.

From the river the water is most generally led into subsiding reservoirs, specially constructed for the purpose, but in some instances it is passed directly to the filter-beds without such preliminary purification. The omission of this process as a separate one need not interfere with the ultimate purity of the water, if the filtration be conducted accordingly, as will be seen more particularly from a succeeding chapter.

Favourable advantages are presented where river lakes are eligible as sources of supply, provided that stagnant and shallow spots be avoided. The diminished velocity through the lake permits the depositing process to take place, and the water may be at once filtered, or, perhaps, even at once be distributed for consumption. A remarkable work has been executed in connection with the water supply of Chicago from Lake Michigan, upon the borders of which that town is situated. To avoid the polluted marginal waters a tunnel, 5 feet in diameter, has been carried for a distance of two miles under the bed of the lake, and having at its extremity an intake shaft, containing a vertical iron pipe 9 feet diameter, into which the water is admitted at different levels, according to requirement.

We have now to deal with works drawing their supplies entirely from subterranean sources; and, first, as to the utilisation of springs. But rarely, indeed, are springs found with a flow of more than two or three million gallons per day, and seldom even as much as this. The more ordinary flow of large springs is 'from 100,000 to 500,000 gallons per diem, with a fluctuation between the maximum and minimum period of from 1·0 to ·4.' * The Chadwell Spring, one of the sources of the New River Company, is said to yield 4½ million gallons per day.

Long-continued observation is the only safe guide for ascertaining the relationship which subsists between the flow of a spring and the rainfall upon the area from which the water is drawn. Springs may more frequently be utilised as contributing to a supply than as the sole source. Sometimes, however, two or more springs, too small independently for the demand to be met, may be led into a common reservoir, serving also, perhaps, as a service or town reservoir. One advantage to be drawn from the joint utilisation of waters from different springs is, that probably their least separate discharges will not occur at precisely the same season of the year. Difference in the extent, nature, situation, elevation, and distance of their respective drainage grounds, and also difference in the lithological characters, *massif*, and inclination of the respective strata, may bring this about, but always with the advantageous result that the periodical diminution of flow in either one spring will be more or less neutralised by the more liberal flow from the others.

The selection of a site for a Well should no doubt be left, in the first instance, entirely to geological considerations, as the question of the probable yield is the most difficult that will have to be solved. The verdict of the analyst and the requirements of constructive engineering are then to be regarded. As the subject of wells and their construction will be separately treated in the next chapter, it will be necessary to regard them here only as parts of complete systems of water supply. In the first place, it will be seen that, except where the disposition of the permeable and impermeable strata is peculiarly favourable, pumping power will necessarily have to be employed. Such favourable conditions, however, are not unknown, and, in illustration, reference may be made to the town of Bourne, in Lincolnshire, which is supplied, under the direction of Mr. Pilbrow, from an artesian well without the assistance of pumping. On Plate 11, Figs. 1 and 2 show the arrangement for connecting the pipe leading from the well with the supply main. The pressure is sufficient to effect a satisfactory distribution in the town. To ensure success in cases of this kind, it is very necessary to be careful in making a sound water-tight joint between the rising-pipe and the impermeable stratum which thus holds down the water under pressure.

* Beardmore's Hydrology.

Service reservoirs are very necessary adjuncts to all pumping schemes, especially where the pumping arrangements are not in duplicate, for then there are additional liabilities to stoppage. They are of great value also as summit reservoirs in equilibriating the pressure in the mains. Districts are sometimes supplied without this important auxiliary, the pressure being maintained and adjusted solely by the power of the engine. Though this method has been practised with success, it is essentially attended with greater risk than where there is a summit reservoir. In such cases the mains themselves collectively act the part of a reservoir, to a certain extent. Without an elevated service reservoir, however, or some equivalent thereto, the higher parts of the district could not be considered safe against conflagration. It is often very difficult to find a suitable site for a service reservoir. Beside the elevation, the distance from the district to be supplied becomes an important consideration as regards the cost of the connecting main. It is sometimes found cheaper to erect a tower for the support of an elevated reservoir or tank than to lay a long length of pipe to the nearest high ground.

Supplies of water for towns are sometimes derived by a method intermediate between well and river schemes, though more properly belonging to the latter. Where the bed of the river is permeable, a heading or tunnel is sometimes driven alongside, or even partly under, the stream, and the river water which filters into it is pumped out. It is generally in such cases the professed object to obtain river water naturally filtered ; but it is only reasonable to suppose that a part of the water drawn from the subterranean cavities must be 'spring' water from the porous stratum, intercepted on its way to the river, its natural outlet. Windsor is supplied from perforated cylinders sunk in the gravel on an ait or islet in the river Thames. Oxford is somewhat similarly supplied, namely by pumping from a lake near the river, into which the river water filtrates through the stratum of gravel.

An ingenious proposal for supplying London, made by Mr. Bailey Denton, should be referred to here. The efficiency of chalk as a filtering medium has been already remarked; indeed, the almost universal freedom of chalk well water from all but slight inorganic impurities is sufficiently well known. The stumbling-block to a more extended use of chalk water in the metropolis has chiefly been the notion that the gradual depression of the line of saturation in the chalk demands a comparatively low estimate of its greatest possible yield of water. To eliminate such doubts, Mr. Denton proposes to let Thames water pass down to the chalk through the London clay by means of wells sunk or bored expressly for the purpose. The practical difficulty in working such a scheme would be to prevent the action of the wells becoming choked by the accumulation of impurities. The difficulty does not, however, appear to be insurmountable.