out that the present Thames system not only robs the other towns of the Thames Valley for the benefit of London, but subjects them to a heavy expense in treating their sewage.

The average daily supply from the Thames during November, 1895, was about 123,000,000 gallons; from the Lea, 45,000,000; from springs and wells, 42,000,000: being in the proportions of fifty-nine Thames, twenty-one Lea, and twenty from springs and wells.

The amount of solid matter carried down by rivers is frequently enormous. The Mississippi has been calculated to carry down 400,000,000 tons of suspended matter yearly; the Ganges over 6,000,000; the Thames about 2,000,000.

CHAPTER VI.

STORAGE—FILTRATION.

It has been already stated that all the varieties of water on the earth's surface have originally fallen as rain. The fluctuations of seasons affect the volume of rivers and of every spring that is not fed by a large underground "pocket" of water, or a system of extensive fissures, as in the chalk. Storage of water then becomes necessary. In some localities nature has effected this by means of lakes, sometimes of vast extent, as in Canada and Central Africa. Where fed by mountain streams they have the character of upland surface water, as described on page 61, with the further advantage, when the lake is large, that it has undergone a long subsequent purification by subsidence and oxidation, so that it often attains a high degree of clearness and of organic purity. Most of the chief towns in the North of England derive at least part of their supply from mountain lakes, either natural or artificial. On account of their distance from contamination, and of their great depth permitting the solid particles to subside beyond the reach of disturbance, such water is fit for consumption without filtration, the only precaution being to keep the long aqueducts watertight and free from organic life. As has been already mentioned (p. 43), the germs of disease, which are rapidly enfeebled or even killed by such an impure water as that of the Thames, multiply with extraordinary rapidity in a pure liquid like the water of Loch Katrine; while the conditions are also favourable for other minute plants, other infusoria or animalcules which live on these plants, and microbes, which consume both plants and infusoria after their death, to freely develop. This fact, which has actually been advanced as an argument against a mountain supply for cities, only proves that when pure water has been obtained the greatest care should be taken to protect it from pollution. That any one should continue to drink an impure or doubtful fluid when a better one is attainable, will not be seriously contended, as, although disease may not be directly or obviously communicated, the effect of a bad water, even when perfectly filtered, has been shown to be distinctly lowering to the constitution, and to pave the way towards the reception of further injurious influences on health.

Loch Katrine is about forty miles from Glasgow. The water is brought to the city by a closed conduit, and is very clear and bright. It contains in 100,000 parts, 3·28 of total solids, 0·256 of organic carbon, (p. 247), ·008 of organic nitrogen, ·031 of nitrogen as nitrates and nitrites, 0·36 of calcium carbonate, 0·25 of chlorine, ·002 of free ammonia, and has a hardness of about half a grain per gallon. The colour is faintly brownish. It will thus be seen that it is an exceedingly soft water, the high relation of carbon to nitrogen showing that the organic matter is of a vegetable nature. Its only fault is that it acts rapidly on lead, of which we shall speak further. It is said that Glasgow saves in soap, since using Loch Katrine water, £36,000 annually. For manufacturers the softness of the water is of great value. Bala Lake, one of the sources proposed for London, Thirlmere, which supplies Manchester, and other lakes of Westmoreland, are of similar character.

An example of the effect of depth and stillness in attaining clarification is furnished by the River Rhone, which enters the Lake of Geneva full of suspended matter, but emerges clear and bright.

To increase the storage capacity of a natural reservoir such as a lake, and also to form one where the sides of the valley through which a stream flows are sufficiently impervious, an embankment is built across the outlet. Reservoirs of the kind are very common in the United States, where small lakes are plentiful. Manchester is also supplied from Longerdale valley by six storage reservoirs, arranged in steps, with dams seventy to 100 feet high. The Bolton embankment at Entwistle is 120 feet deep, while one at Villar Madrid, in Spain, is 158 feet, and another at St. Etienne, in France, 164 feet. The new waterworks of the Bradford Corporation include a reservoir at Gouthwaite, covering 330 acres, which is the same area as Thirlmere. It is over two miles in length, holds more than 1,500 million gallons of water, and is said to add considerably to the beauty of the valley.

Before proceeding to the selection of a site for a reservoir, it is necessary to make an accurate and continuous observation on the flow of the streams that may feed it and the amount of rainfall. Where there is considerable storage accommodation, the ill-effect of a dry season is not felt to its full extent during the drought, but ensues some time after the rains have begun again. It is not uncommon to lose a large proportion of the first rains by their rapid flow over parched or frozen ground. The greater number of watersheds of England are already appropriated by towns, even beyond their present needs, "to make provision against future increase of population." Towns like Middlesbrough and Barrow, which have suddenly grown up from small beginnings to considerable magnitude, are threatened under the present haphazard system with having either to remain content with insufficient or possibly unwholesome supplies, or to buy watersheds at fancy prices from the forestalling neighbours.

Here is a case when it is the province of the State to apportion the upland water sources according to the needs of the populations, and to see that "private ownership" does not offer such hindrance as it has frequently done to local enterprise. It

is hardly necessary to mention that high cultivation with manuring should not be permitted on the lands providing water for storage reservoirs.

The selection of a source from which to obtain a water supply depends principally on the following considerations:—

1. Purity, volume, and permanency of the supply.
2. Its elevation and distance.
3. Nature of the intervening ground.
4. Purchase of water rights and easements.

English law has decided that the property in water in a river or stream flowing in its natural course belongs to no one, but the use of it to every one having the right of access. Thus a local sanitary authority must first come to terms with the owner of the land whereon the spring rises, or the riparian owners at or below the point at which the water is sought to be taken. Sometimes "compensation reservoirs" have to be constructed to store the flood water (see p. 63), which is then allowed to flow as required, so as to minimise the interference with the stream. An "easement" is the right to lay pipes or tunnels through private property, and to have access to them for repairs. (For further details, see *Rural Water Supply*, by Greenwell and Curry: Lockwood, 1896.)

Where the source is elevated, water descends by gravitation, but in other cases pumping has to be resorted to. The former generally involves a larger first outlay, but a heavy annual expense is avoided

Where, as is usual, the natural supply varies in amount, "impounding reservoirs" must be constructed to remedy the irregularity, their size and number depending on the population of the district, and its scattered or dense distribution. The amount of water to be provided is generally reckoned at twenty gallons per head per day for non-manufacturing towns and thirty gallons for manufacturing towns : but this quantity is not at all necessary if reasonable economy be practised.

The construction of storage reservoirs involves an examination of the ground for the foundations, and the subsequent erection of an embankment, which are subjects for the geologist and engineer. Suffice it to say, that springs and porous beds of rock are frequent sources of trouble, and that well-remembered calamities have occurred from want of proper construction at first and of efficient supervision afterwards. The slightest leakage, if neglected, as it notably was in the case of the Johnstown reservoir, U.S.A., permits the water to gradually wear a passage, until a section is loosened, and then suddenly the whole gives way. The embankment of the Holmfirth reservoir, which burst in 1852, was constructed on fissured sandstone, through which water leaked till the barrier was undermined; then a flood completed the destruction.

The scheme for supplying London with pure upland water from Wales, as elaborated by Mr. Binnie,

engineer to the London County Council, proposes to collect the head waters of the Usk, Wye, and Towy in five large reservoirs, from which the water would flow by gravity to London through two aqueducts of masonry and concrete 150 and 175 miles long. Two tunnels would occur in the course, a siphon pipe 13½ miles long under the Severn, and several bridges of iron pipes across the valleys. The service reservoirs would be at Elstree and at Banstead Downs, at a height of 312 feet above sea level, from which the water would flow by gravity to all parts of London. The impounding reservoir near Llanynis would contain 31,000,000,000 gallons; its dam, of masonry, would be 166 feet high. The rocks over which the head waters flow are of Silurian and Old Red Sandstone, and the water is similar in purity to that of Loch Katrine. The rainfall varies from forty-five to seventy-five inches per annum, or about three times that of the Thames valley, and is usually very regular. It is estimated that 415,000,000 gallons could be supplied per day to London, which is sufficient for the probable increase of London in the next fifty years.* But, as previously mentioned, it would be neither necessary nor advisable to take so large a supply, and risk incommoding the local populations.

The winter of 1895 proved that the present distributing mains are not laid deep enough for protection from

* In the London Water Companies' Bills of 1896 it was proposed to take a total of 149 million gallons from the Thames daily.

frost; they have also frequently been injured by heavy loads passing over them. Whilst repairing, a second set of mains could be laid, so as to provide Thames water for common purposes, and the purer mountain water exclusively for drinking. Frankfort-on-the-Maine has already a double water supply, where spring water is supplemented from river and ground sources. Vienna has also successfully carried out a dual plan.

The improvement of water in reservoirs is largely due to the deposition of suspended mineral matter and bacteria, but, in addition, open storage favours the beneficial action of aeration and light. It would seem at first sight desirable that service reservoirs should be open to light and air, as by such means the brown colour of moorland water would be bleached, matters derived from sewage oxidised to ammonia and nitrates, and the bacteria antagonised. This would be the case if the water could be kept free from algæ or water-weeds, but unfortunately these are favoured as much by light as the lower organisms are enfeebled. The minute algæ which render the water green (Scenedesmus, Closterium and others related to the Desmids, are specially active), also cause an unpleasant fishy odour and taste, which, though not poisonous, gives rise to complaints from the consumers. Many attempts have been made to remedy this evil by fountains, circulation, and scouring, but the algæ grow so rapidly when supplied with fresh water, that it has been found

impracticable to suppress them at certain seasons, especially in hot countries. The Massachusetts Board, after lengthened experiments, concluded that while surface waters were generally improved by storing in open reservoirs or tanks, ground or subsoil waters underwent rapid deterioration from algæ unless kept in the dark. They also conclude that "the colour of water exposed to the sun in open reservoirs is reduced by storage; but it must be stored for several months to cause any material reduction of colour, and from six months to a year to remove practically all of it."*

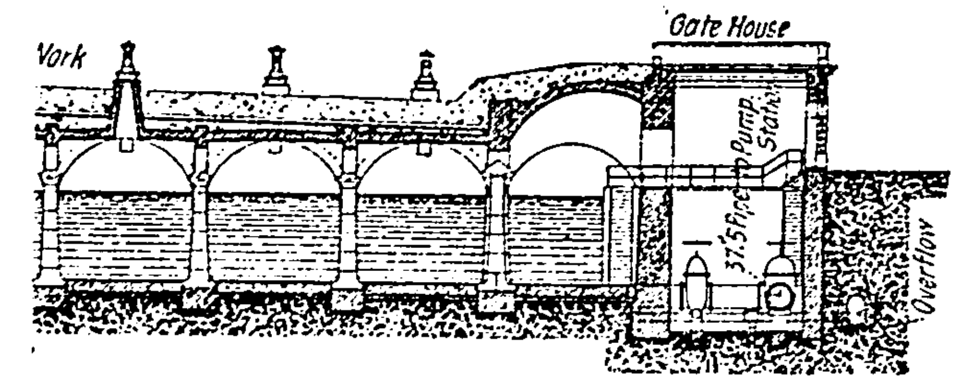
The main distributing reservoir at Vienna is in three sections, lined with smooth Portland cement and covered with a roof supported by granite pillars. Conical glazed openings and ventilators supply light and air to the interior (Fig. 28). The capacity of the third extension is 10,470,000 gallons.

Deep well waters are not improved by storage, but are better delivered as pumped, provided they are clear, which is almost always the case after the well has been worked for some time. It has already been pointed out that pathogenic and other bacteria multiply in them with great rapidity. At their source they do not usually contain more than two or three bacteria per

* G. Bertrand is investigating certain soluble ferments termed "oxydases," which possess the power of bleaching and precipitating the organic colouring matter with absorption of oxygen (*Comptes Rendus*, cxxii. 1215).

cubic centimetre, and these have probably got in mainly by accident. But on exposure for a few hours in any vessel, there will be hundreds of bacteria, and perhaps millions in two or three days, after which time they will diminish by mutual exhaustion and destruction. Surface water on the other hand does not show any such multiplication, this change having taken place to its fullest extent during the previous history of the water.

It may be summed up that the only waters which deteriorate on storage in properly prepared reservoirs are those which are filtered or taken from subterranean sources. When they must be stored, they should be kept in closed reservoirs arched over like those of the Kent Company at Deptford. But surface waters are never injured by *proper* storage; on the contrary, in the great majority of cases they are very materially improved, and the poorer the quality of the water and the greater the amount of organic matter in process of change, the more conspicuous is the benefit of the action of light and air. Even the green algæ and other water plants, as Dr. Bokorny has shown, can use up as a nutriment many of the organic impurities that are drained into waters. And yet the recurrence of the offensive results of these algæ may compel the adoption of covered reservoirs, relying on subsequent filtration for the removal of bacteria, crenothrix (p. 140), and fungi which are encouraged by the dark. The depth of open reservoirs should



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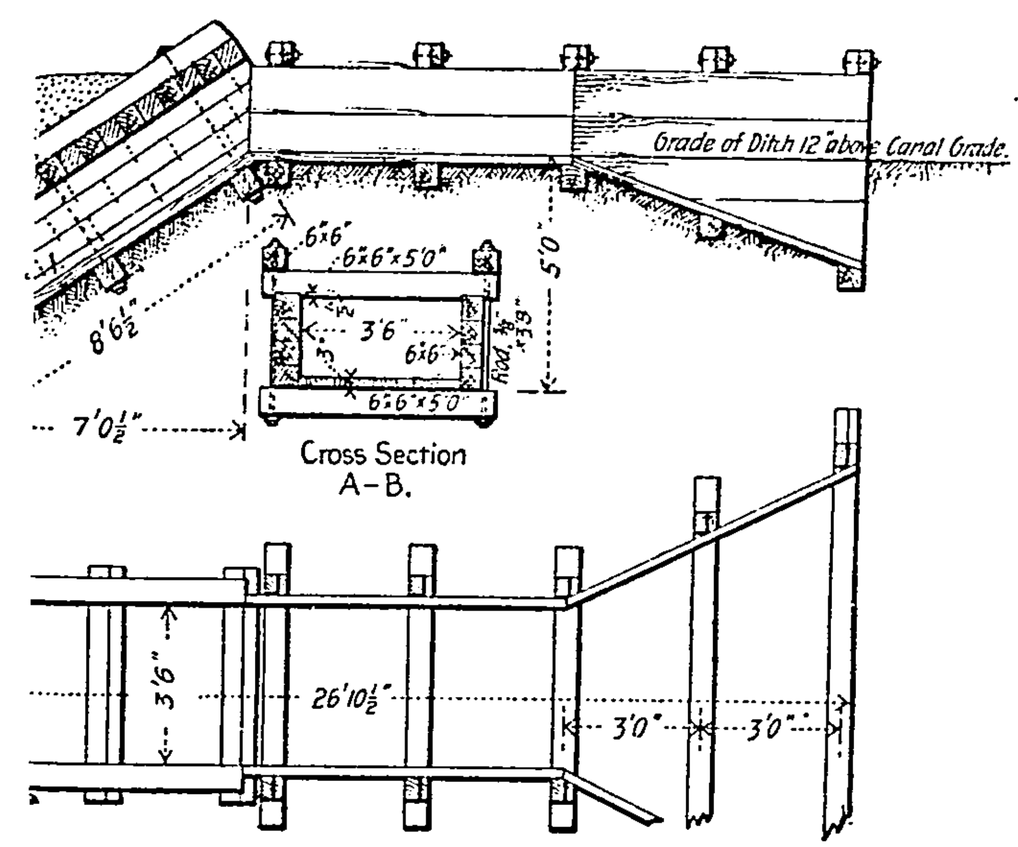

River, Utah.

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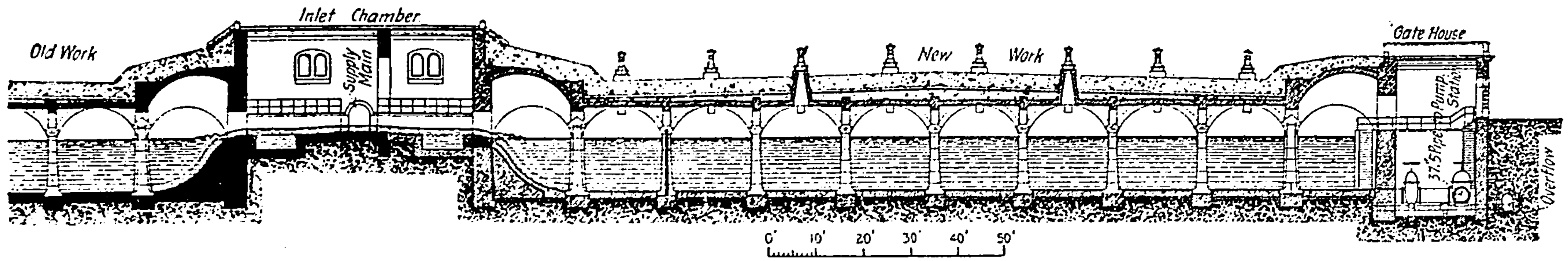

Fig. 28. New Extension of Vienna Reservoir.

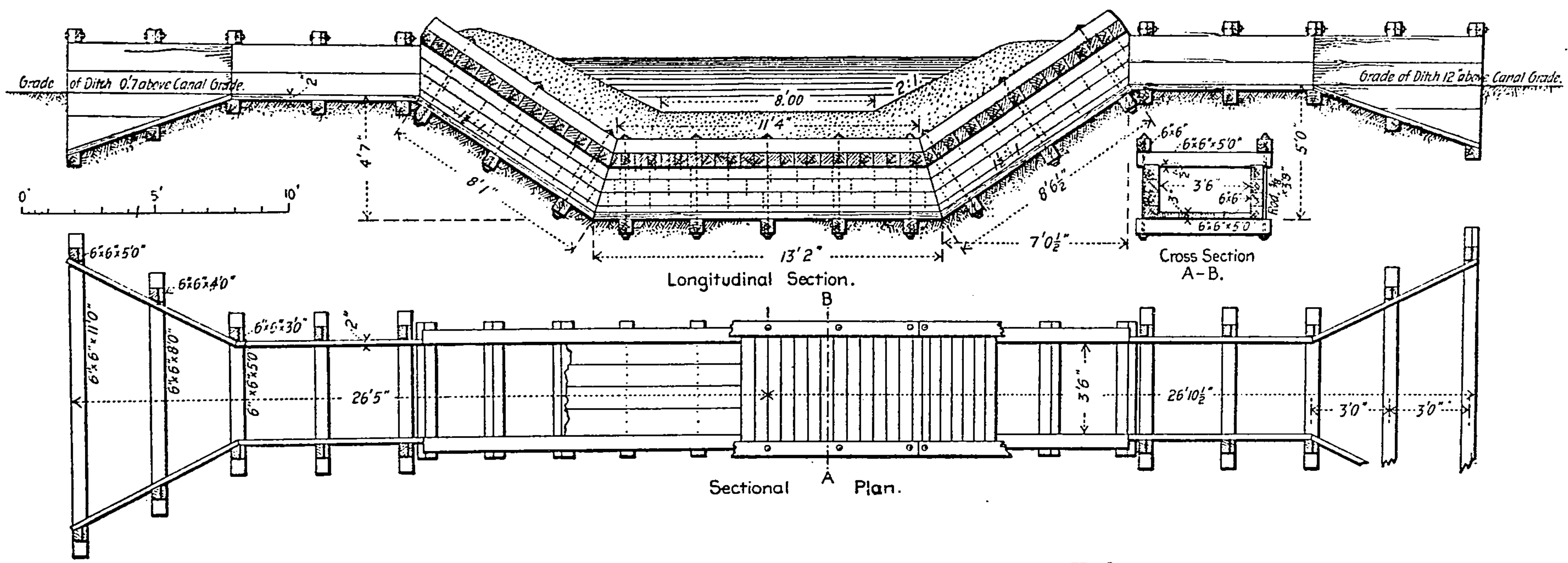

Fig. 29. Inverted Siphon for passing old canal, Bear River, Utah.

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not be under ten feet, and preferably rather more, as an increase of depth hinders the growth. Covered reservoirs should have about two feet of earth above the roof to keep the water cool in summer, and ventilators should be placed at intervals. A reservoir must of course be covered when close to a town or factories, especially after the water is filtered.

The sides of open reservoirs should be well protected, sodded, and kept free from animals, &c. There are recorded cases of dead bodies having lain for a long time in reservoirs, and intestinal parasites may easily be derived from such carcases.

At Southampton and other places, an ingenious electrical apparatus, worked by a float, signals the depth of water in a distant reservoir to the pumping station.

The average cost (and hardness) of different classes of supply is said to be:—

Surface	4 degrees	total hardness,	4*d*.	per	1,000 gallons.
River	13	,,	,, 9*d*.	,,	,,
Spring	20	,,	,, 1/-	,,	,,

But this of course must vary immensely with circumstances.

Private storage in cisterns will be considered under "Distribution," in the next chapter.