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PUBLIC WATER-SUPPLIES.

CHAPTER I.

INTRODUCTION.

HISTORICAL SKETCH.

1. **Water-supplies in Ancient Times.**—The earliest method of artificially obtaining a water-supply was doubtless by the digging of wells. These were naturally at first mere shallow cavities scooped out of the ground in moist places, such as are used at the present time by savage tribes; but as necessity arose and the use of implements developed, these wells were gradually deepened.

The digging of wells dates from a very early period. In the vicinity of the pyramids there still exist wells which were in use when those great works were constructed. Joseph's well at Cairo is perhaps the most famous of all ancient wells. It is a remarkable work and exhibits in a high degree the skill of the people of ancient Egypt in matters pertaining to construction. It is excavated in solid rock to a depth of 297 feet and consists of two stories or lifts. The upper shaft is 18 by 24 feet, and 165 feet deep; the lower is 9 by 15 feet and reaches to a further depth of 130 feet. Water is raised in two lifts by means of buckets on endless chains, those for the lower level being operated by mules in a chamber at the bottom of the upper shaft, to which access is had by means of a spiral pathway winding about the well.*

Frequent mention is made by the old historians of important wells in ancient Greece, and remains of such works are numerous in Assyria, Persia, and India. Probably the deepest wells were dug by the Chinese, depths of 1500 feet or more being reached by methods almost identical with those now in common use.

* Ewbank's Hydraulics, p. 45.

Besides the digging of wells, the ancients executed many works for the storage and conveyance of water. In Jerusalem underground cisterns were built for the storage of rain-water; and other reservoirs were constructed near the city to store the water which was brought thither in masonry conduits. Aqueducts were also built in ancient Greece, one mentioned by Herodotus as built to supply the city of Samos being still in good preservation. Some of these ancient aqueducts included inverted siphons of cut-stone blocks. Ruins of extensive underground reservoirs are to be found on the site of ancient Carthage, which it is believed were constructed prior to the capture of the city by the Romans. Works for irrigation in Egypt, Assyria, and India were established on an immense scale, one reservoir in Egypt, Lake Maeris, having had, it is said, an area of 30,000 acres. In the Presidency of Madras, India, the English found at the time of their occupation about 50,000 reservoirs for irrigation purposes, the construction of which had involved the building of 30,000 miles of earth embankment. Many of these reservoirs were doubtless of ancient construction.

2. **Water-works of the Romans.**—Among ancient systems of water-supply the works of no other nation equaled those of the Romans, either in point of size or number; and no city in the Roman Empire was more abundantly supplied than the city of Rome itself. Previous to about 312 B.C. Rome obtained its water from the Tiber and from springs and wells in the immediate vicinity, but this water finally became so badly polluted that a purer supply was sought from distant sources.

3. *Aqueducts.*—The conveyance of water from these new sources necessitated the construction of long conduits or aqueducts. These were often led through hills in tunnels, or carried over valleys on long lines of arches that are to this day the object of our wonder and admiration. The Romans, and indeed the Greeks, well understood the principle of the inverted siphon, and used it on occasion; as, for example, in the works of Lyons, France, where they constructed a siphon consisting of nine miles of lead pipe from 12 to 18 inches in diameter, working under a 200-foot head. The only materials, however, which could be used for this purpose were stone, lead, and pottery, iron pipes being unknown; and the engineers of that time adopted what was doubtless the most economical method of crossing depressions, that is, by carrying the conduit on arches.

The first aqueduct built to supply Rome was called the Aqua Appia, after its builder, Appius Claudius. It was constructed about

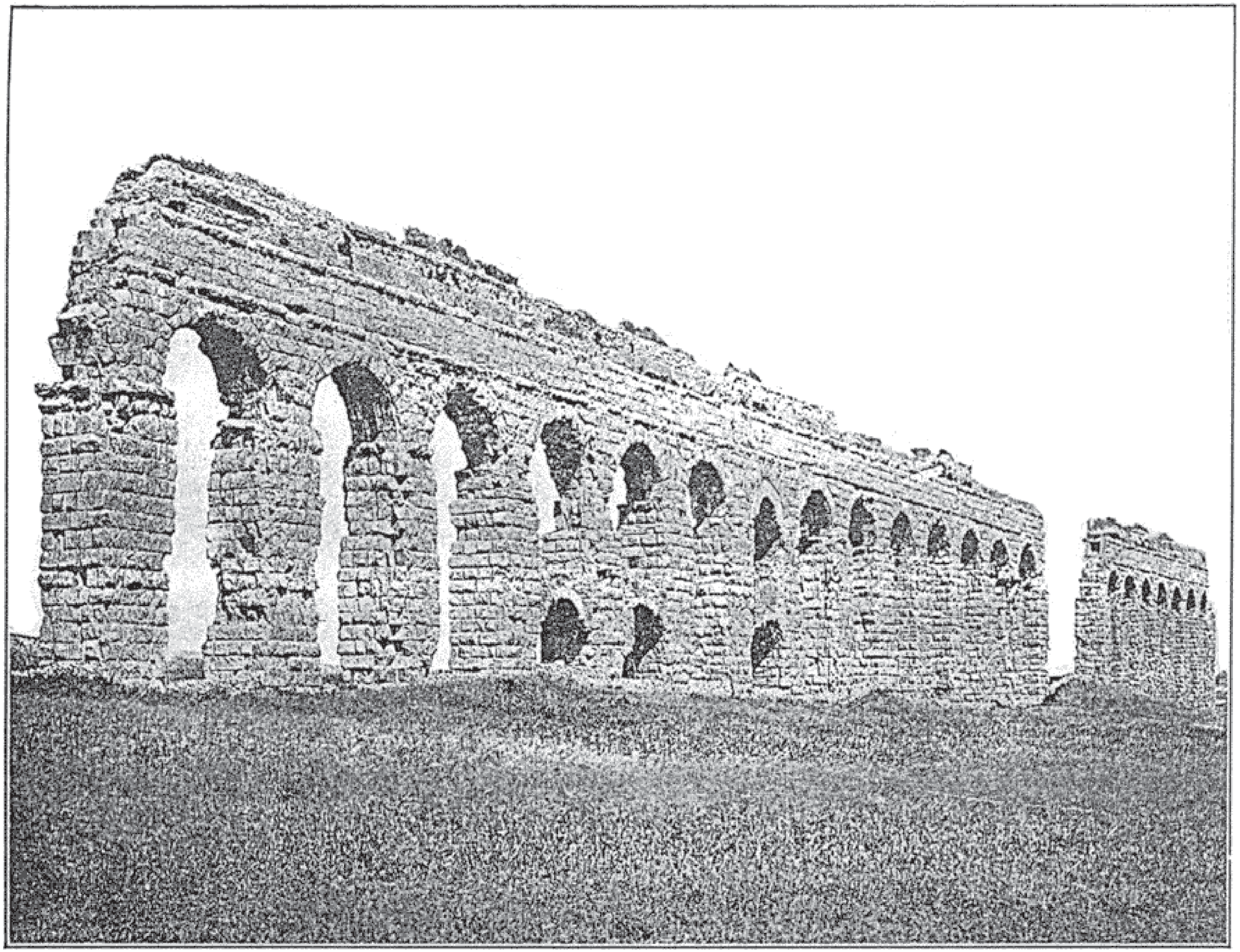

FIG. 1.—ROMAN AQUEDUCTS CLAUDIA AND ANIO NOVUS; 38–52 A.D. (HERSCHEL.)
(Anio Novus is built on the top of Claudia.)

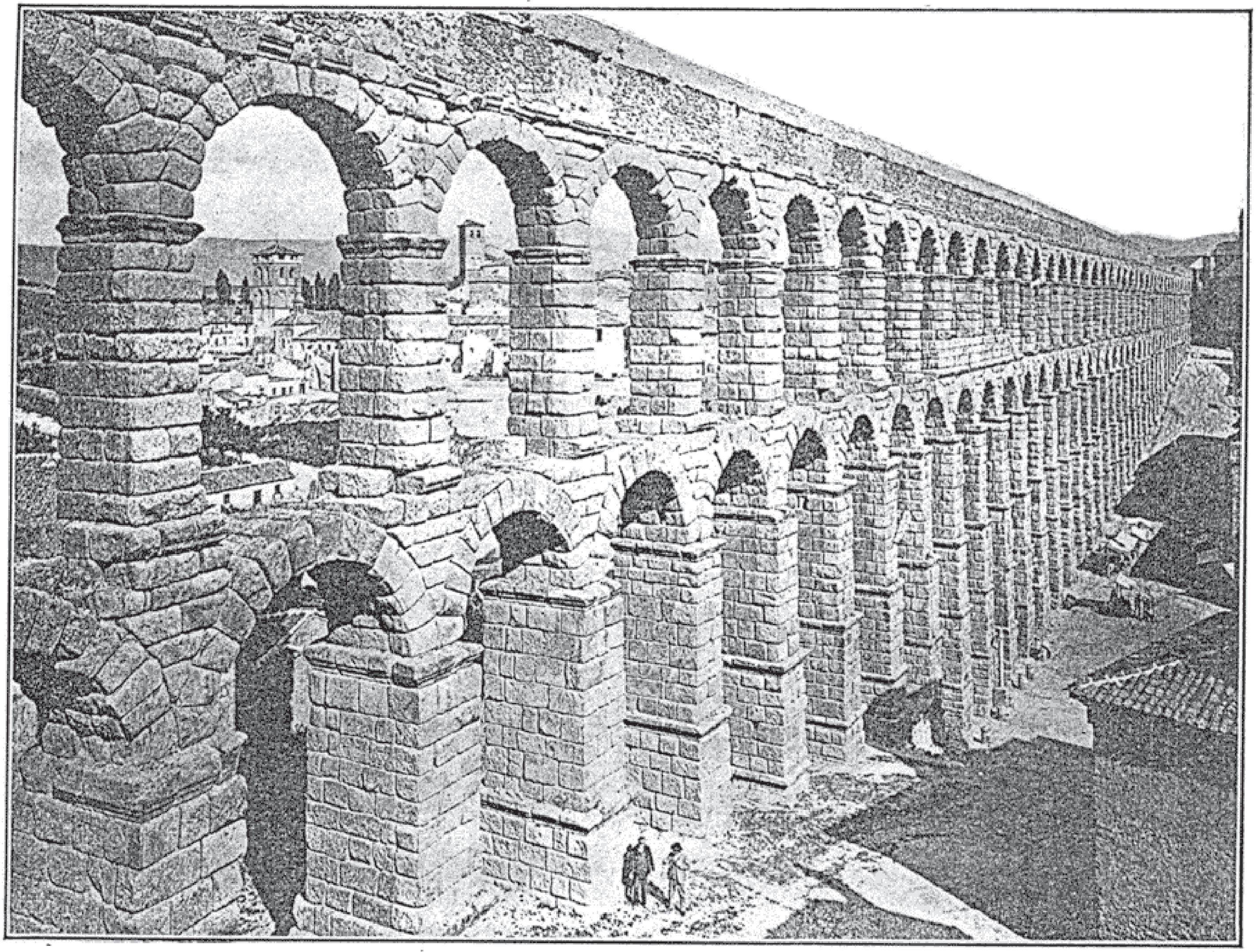

FIG. 2.—AQUEDUCT OF SEGOVIA IN SPAIN. (HERSCHEL.)
Built about 109 A.D and still in use.

312 B.C. and had a length of about 11 miles. A second was built about 270 B.C. with a length of 39.5 miles, 1080 feet of which was supported on arches. Others were constructed from time to time until, with the completion of the Anio Novus about 52 A.D., there were nine aqueducts furnishing water to the city of Rome. These are described in detail by Frontinus, a Roman surveyor and water commissioner, in a work written A.D. 97,* in which he also gives much interesting information concerning the various matters coming within his official duties. Five more aqueducts were constructed after the time of Frontinus, the last dating about 305 A.D. The aggregate length of the fourteen was 359 miles; and aggregate length of arches, 50 miles. In cross-section the aqueducts of Rome varied from 3 to 8 feet in height by 2½ to 5 feet in width, and were built with vertical sides and flat or arched roofs. The interior was finished with great care to secure imperviousness, but in spite of this they were constantly getting out of repair.

The Romans not only built works for supplying their chief city, but also executed many works of great importance in all parts of the Empire, as at Paris and Lyons in France, Metz in Germany, and Segovia and Seville in Spain. One-half of the aqueduct at Metz is still in use, although built in the year 130 A.D. That at Nimes, France, is famous for its great aqueduct bridge, the Pont du Gard, where three tiers of arches rise to a maximum height of 158 feet.

4. *Distribution System.*—The distribution of water in this age was by no means general. In Rome the water from the aqueducts first passed into large cisterns, and from these was distributed through lead pipes to other cisterns, and to the fountains, baths, and various public buildings, and to private consumers. The last class was very limited in number, most of the people being obliged to get their supply from the public fountains. Each service required a separate pipe leading from the distributing cistern, and the amount of water to which the consumer was entitled was measured by means of a short tube of specified diameter. At the time of Constantine there were in Rome 11 great thermæ, 926 public baths, 1212 public fountains, and 247 reservoirs.†

5. *Quantity of Water Supplied.*—The amount of water supplied to ancient Rome was very liberal. It has been estimated as high as 400 million gallons per day at the time of Frontinus, but after a careful study of the evidence, and allowing for the fact that usually some of

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* See reference (13), p. 14.

† Lanciani. The Ruins and Excavations of Ancient Rome (1897), p. 56.

the aqueducts were out of repair, Mr. Herschel estimates the probable quantity delivered within the city at about 50 million gallons daily, or about 50 gallons per capita. Even at the latter figure the supply must be considered as very liberal.

6. *Quality of Water.*—The ancients had some clear notions concerning the quality of water-supplies. In his time, Hippocrates knew something of the danger of drinking water which had passed through lead pipes, and even recommended the boiling and filtering of polluted water. At Rome the different aqueducts brought waters of quite different qualities. The best was used for domestic purposes and the other for baths and various public purposes, the water from one aqueduct being of such poor quality that as a rule it was used only for irrigation and for supplying the basin of a marine circus. In some cases water was passed through artificial reservoirs to purify it by sedimentation.

7. The Middle Ages.—The fall of Rome brought with it the destruction of the aqueducts and the general neglect of the entire subject of water-supply. The Popes maintained with various interruptions a supply to the city of Rome, and a few other important cities were scantily provided with water. In other places, however, the supplies entirely ceased; and it is said that in some cases the inhabitants even forgot the use to which the old works had been put.

The terrible ravages of pestilence during the Middle Ages were doubtless due in large measure to the use of grossly polluted water, and it was not until about the end of the sixteenth century that general improvement began to be made in sanitary matters. However, as exceptions to this there should be mentioned the construction of a few important works in Spain by the Moors, such as those at Cordova in the ninth century, and the repair of the Roman aqueduct at Seville in 1172.

Paris depended entirely on the river Seine for its water-supply until a small aqueduct was constructed in 1183, but as late as 1550 the supply amounted to only one quart per head per day. In London small quantities of spring-water were brought to the city as early as 1235 by means of lead pipes and masonry conduits. The first pump was erected on the old London bridge in 1582 for the purpose of supplying the city through lead pipes. In Germany water-works were constructed as early as 1412, and pumps were introduced in Hanover in 1527. Mention should here be made also of the aqueduct of Zempola in Mexico, constructed by a Franciscan monk between 1553 and 1570, which for two centuries served to convey water from Zempola to

Otumba. It had a length of 27.8 miles and included three arch bridges of a maximum height of 124 feet.*

8. **Development of Modern Water-works in Europe.**—During the seventeenth and eighteenth centuries progress was slow, and confined mainly to the cities of Paris and London. Pumps operated by water-power were erected in Paris in 1608. The aqueduct of Arcueil was completed in 1624 and delivered about 200,000 gallons per day, but at the end of the seventeenth century the supply to Paris was as yet only 2½ quarts per head. In London various pumps were erected on the bridge from time to time which drew their supply from the river and were operated by the current. In 1619 the New River Company was incorporated and laid its pipes throughout the city. It received its supply from the New River, and for the first time the general principle was adopted of supplying each house with water. This company still supplies a part of London.

The application of steam to water-pumping in the eighteenth century gave a great impetus to the development of water-works. Probably the first use of steam for this purpose was in London in 1761. A steam-pump was also erected in Paris in 1781 and another in 1783, and a second in London in 1787. In all these instances the supplies were taken directly from the adjacent rivers.

Since 1800 the supplies of both London and Paris have been greatly augmented from various sources. Some of the works are very noteworthy, as, for example, the two aqueducts, of respectively 81.5 and 108 miles in length, constructed to bring spring-water to the city of Paris.

In 1890 the supply of Paris was about 65 gallons per capita, of which about three-fourths was drawn from rivers and used for street-washing and other public purposes, while only one-fourth, or about 16 gallons per capita, was drawn from springs and used for domestic purposes. The latter quantity having been found inadequate, an additional supply of about 30 million gallons was brought to the city in 1892 by means of another aqueduct 63 miles long, thus giving an additional supply of about 12 gallons per head. A still further addition of some 15 million gallons has recently been provided for.

The water-supply of London was brought under municipal management in 1904, previous to which time the city was supplied by eight separate companies. About 55 per cent of the supply is from the Thames, 25 per cent from the Lea, and 20 per cent from springs and wells in the chalk. All river-water is filtered. The total population

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* *Eng. News*, 1888, xx. p. 2.

supplied is about 6,000,000, and the rate of consumption is about 40 gallons per capita daily.

Notwithstanding the early existence of public water-supplies in a few cities, the general development of water-works was very slow in the first half of this century; for example, as late as 1864 there had been constructed in Germany but twenty-four water-works. During the last thirty years, however, the development in all civilized countries has been very great, and the rate of growth has constantly increased.

9. For many years the larger pipes were usually of wood, made by boring out logs to a diameter of 6 or 7 inches. Cast-iron pipes came into general use about 1800; and in 1820 the New River Company of London replaced its wooden mains with cast-iron ones at a cost of $1,500,000. At one time this company had about 400 miles of wooden pipe in use, and often as many as ten lines of pipe were laid side by side to form a single main.

When water first began to be supplied to each house it was thought quite impracticable to furnish a continuous supply. Instead, the water was turned on for only a few hours in the twenty-four, at which time the consumers were obliged to lay in their supply for the day. For sanitary reasons, and as a matter of convenience, the constant-supply system came into general use in spite of the many arguments against it. It was introduced in London in 1873, but as late as 1891, 35 per cent of the total supply was still on the intermittent system.

In Europe the question of quality has received as much attention as that of quantity. Great expense is borne to secure, if possible, water from springs or mountain streams, but where this is impracticable, efficient purification works are established. In the early part of this century some use was made in Paris of artificial filters for purifying the water from the Seine; but filtration on a large scale was first inaugurated by the Chelsea Company in London, which in 1829 started the first large sand filter similar to those now in such extensive use. In the last twenty-five or thirty years the use of such filters has rapidly extended until now it is a rare exception to find a European city using unfiltered surface-water.

10. **Development of Water-works in the United States.**—*Early Works.*—The first works in America for the supply of water to towns were those of Boston. They were built in 1652 and served to bring water by gravity from springs. The first instance where machinery was used was at Bethlehem, Pa., the works of which were put into operation June 20, 1754. In this case also the water was from a

spring, which is still in use as a water-supply. It was forced by a pump of lignum vitæ of 5-inch bore through hemlock logs into a wooden reservoir. Eight years later the builder of these works, Hans Christ. Christiansen, replaced the wooden pump by three iron ones of 4-inch bore and 18-inch stroke which were in use for seventeen years. The next works constructed were probably those at Providence, R. I., in 1772; and the next, those at Morristown, N. J., put into operation in 1791, and which still furnish water to the town.

The first use of the steam-engine was at Philadelphia in 1800. These curious engines were constructed largely of wood, even the boiler being partly of this material. The duty was 4,790,000 foot-pounds per 100 pounds of coal.* Steam was applied to New York's water-supply in 1804, these works having been inaugurated in 1799.

In the United States, as in Europe, wooden pipes were at first used, but it is stated by Chanute† that cast-iron pipes were used in Philadelphia as early as 1804, thus antedating by a few years their use in London.

Besides the works above mentioned some others were constructed at an early date, the total number in 1800 being 16. Important steps in advance were made by the construction, in 1822, of the enlarged works at Philadelphia and, somewhat later, of the gravity works of New York and Boston.

11. *Progress since 1850.*—The principal development in this country has taken place since 1850, and the improvements made have been very marked. Among these have been the perfection of cast-iron pipe; the improvements of pumping machinery, whereby a duty is now obtained greatly in excess of what was considered possible twenty-five years ago; the manufacture of the smaller pumps on a commercial scale, thus greatly reducing the cost to small towns; the adoption of direct-pumping systems for small towns, thus also in many cases greatly reducing first cost; and the development of the ground and artesian water-supplies in the Western States. The public water-supply has now come to be so much of a necessity that it is rare to find a village of 2000 inhabitants without its public supply.

The growth in the number of water-works since 1850 is shown by the following table taken from the "Manual of American Water-works" for 1891 and 1897. It gives the total number of water-works in existence at the end of various years, and the number built in each period.

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*Illustrated description in *Eng. News*, 1887, XVII. p. 247.

†Trans. Am. Soc. C. E., 1880, IX. p. 220.

Year.	Number of Works.	Number of Works Built in each Period.	Year.	Number of Works.	Number of Works Built in each Period.
1850	83	....	1875	422	179
1855	106	23	1880	598	176
1860	136	30	1885	1013	415
1865	162	26	1890	1878	865
1870	243	81	1896	3196	1318

The new works built between 1890 and 1896 were of course mainly for small towns, but a large amount of work has also been done each year in increasing the supplies for the larger cities. In 1880 the total population supplied was 11,809,231, while in 1890 it was 22,814,061, nearly one-half of the increase being due to the increase in population of cities already supplied in 1880. The total estimated cost of the works up to 1891 was $543,000,000; number of miles of mains 32,400, taps 2,213,000, and hydrants 220,000.

12. *Present Conditions and Necessities.*—As regards the improvement in the quality of water supplied not so much progress has been made as in increasing the quantity, and in this respect this country is far behind Europe. A large proportion of our largest cities use water taken directly from streams more or less polluted by sewage, and as yet few of these supplies are subjected to any purification process The problem here is rendered especially difficult by reason of the enormous quantities of water used by American cities as compared with those of other countries.

From this statement of present conditions it is evident that the engineering work of the future lies principally in the development of new and better sources of supply, in providing increased quantities for our rapidly growing cities, and especially in the improvement of the quality of existing supplies. In the management of water-works, also, much needs to be done in the direction of waste prevention, both to reduce the immediate cost of operation and in many places to render it possible to install purification works at a reasonable expense.

VALUE AND IMPORTANCE OF A PUBLIC WATER-SUPPLY.

13. **Domestic Use.**—The most important use of a public water-supply is that of furnishing a suitable water for domestic purposes. The absolute necessity of a supply of some sort for such purposes in a large city is well appreciated, but the value of purity is, by many, not rated as high as it should be. The transmission of certain diseases

such as cholera and typhoid fever by polluted water is now universally recognized, and the value to a city of a pure supply when compared to one constantly polluted by sewage can scarcely be overestimated. Many examples of the benefits arising from the introduction of new or improved supplies are given in Chapter X.

A public supply of pure water is of great value not only in large cities, but in the smaller towns and villages. Too often a supply for a village is designed with almost exclusive reference to fire-protection, and little attention is paid to the quality of the water, the people expecting to depend on wells as before. As a rule, however, a good pure water is quite as much to be desired in this case as for a city supply, and, if provided, will in many cases be quite as fully utilized.

Another highly important function of a water-supply is that of furnishing the necessary flushing-water for a sanitary system of drainage. The most satisfactory and economical method yet found for disposing of the organic wastes of a community is by the water-carriage system. Such a sewerage system is manifestly of but slight value to the public at large without the coexistence of a public water-supply, as otherwise the necessary water for the flushing of closets—the most important function of a sewerage system—can be afforded by but few.

Besides furnishing an improved supply from the sanitary standpoint, a public works may often be made to furnish a water which for other reasons will be of greatly increased value to the domestic consumer; such as a soft water in place of a hard well-water—a point of very considerable importance to both domestic and commercial users.

14. **Commercial Uses.**—The commercial value of a good water-supply is appreciated when one considers the large number of manufacturing interests which require for their operation large quantities of suitable water. Such establishments as sugar-refineries, starch-factories, bleaching and dyeing houses, breweries, chemical works, and various other factories require an abundant water-supply, and in some cases a water of a high degree of purity. The question of water-supply indeed often determines the location of such factories. Large quantities are also used for operating elevators, for boiler purposes, and for many other uses that may be classed as commercial.

15. **Public Uses.**—The most important public use of a water-supply is perhaps in extinguishing fires. The economic value of a good fire-protection system is directly shown in the reduced rates of insurance which follow its introduction or improvement. Instead of distributing

a heavy fire-loss among the people of a community through high rates of insurance it is assuredly much better economy to contribute to the maintenance of a public water-works, which at the same time provides a suitable water for other purposes. To permit of the establishment of certain classes of factories it is absolutely essential that an efficient fire-protection be furnished.

Other important public uses of a water-supply are in street-sprinkling and sewer-flushing, in furnishing water for public buildings, and for drinking and ornamental fountains. A real value exists in the improved appearance which may be given a city by the use of water in fountains and for lawns and public parks; and indeed all the benefits accruing from a good water-supply act indirectly to increase the desirability of a town for many purposes and to enhance the value of the property therein.

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