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HISTORIC REVIEW OF THE DEVELOPMENT OF SANITARY ENGINEERING IN THE UNITED STATES DURING THE PAST ONE HUNDRED AND FIFTY YEARS

A SYMPOSIUM*

With Discussion by Messrs. James W. Armstrong, J. W. Ellms, Caleb Mills Saville, M. M. O'Shaughnessy, Morris Knowles, George H. Fenkell, Harry G. Payrow, W. Kiersted, John H. Gregory, Karl Imhoff, Kenneth Allen, George S. Webster, L. L. Tribus, N. T. Veatch, Jr., Arthur E. Morgan, Arthur M. Shaw, W. B. Gregory, R. A. Hart, L. L. Hidinger, Roy N. Towl, E. R. Jones, H. F. Gray, James E. Brooks, W. G. Stromquist, Thornton Lewis, Samuel R. Lewis, Leonard Greenburg, George W. Fuller, Harrison P. Eddy, S. H. McCrory, J. A. LePrince, and George Truman Palmer.

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HISTORIC REVIEW OF THE DEVELOPMENT OF SANITARY ENGINEERING IN THE UNITED STATES DURING THE PAST ONE HUNDRED AND FIFTY YEARS

INTRODUCTION

By Harrison P. Eddy,* M. Am. Soc. C. E.

One hundred and fifty years ago the inhabited part of the United States consisted principally of the area east of the Allegheny Mountains and between the St. Lawrence River and the Spanish Province of Florida. The first census (1790) of the new Republic showed a population slightly less than 4 000 000.

Westward migration began during the Revolution and has continued with the extension of boundaries. Naturally, the course of migration was along the river valleys where ease of traveling was obtainable. Towns sprang up around border trading posts and forts, such as Pittsburgh, Cincinnati, Detroit, St. Louis, and Chicago.

The living conditions of the great mass of the people were extremely simple. Houses were of logs or of loose unpainted clapboards. Cooking was before open fires or in brick ovens. Lighting by night was by tallow candles, the sperm-oil lamp, or by the open wood fire. The friction match had not been invented, and flints and steel and tinder were the means for procuring fire. Clothing was chiefly homespun manufactured in the household with spinning wheels and hand looms. Few public water supplies and no public sewerage systems existed. Plumbing was practically unknown. Primitive methods for the removal and disposal of household waste and excretal matters prevailed.

At the time of the first census, only four municipalities had populations in excess of 10 000—New York, N. Y., 33 131; Philadelphia, Pa., 28 522; Boston, Mass., 18 320; and Baltimore, Md., 13 503. The remaining population was living under rural or semi-rural conditions.

The development of water supply and water purification, of sewerage systems and sewage treatment, and of refuse collection and disposal, has been coincident with the growth of cities. Land drainage has followed westward migration and the establishment of farms in the level areas of the western river valleys. Until the end of the Nineteenth Century the part played by the mosquito in the transmission of malaria and yellow fever was unknown, but, in the last two or three decades, an extraordinarily successful campaign has been waged against the mosquitoes conveying these diseases. In the early days the problem of ventilation was non-existent but, to-day, with large gatherings of individuals in halls, schools, and theatres, the problem has become acute.

During the 150-year period there has been an unprecedented utilization of science and engineering for the amelioration and control of man's environment. The papers which follow, outline the progress in those branches of engineering which have done so much to promote human health and comfort.

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WATER-WORKS

By George W. Fuller,* M. Am. Soc. C. E.

Prior to 1870 the history of water-works in the United States presents a picture of isolated and spasmodic community efforts to obtain supplies, then, for about a generation, increased activity due largely to the enterprise of business men making water-works equipment, and then a continuous and fairly active growth caused by the rapid increase in urban population, culminating in the general recognition—since 1900—that the design and operation of modern water-works offer opportunities for research, engineering, and administrative skill of the highest grade.

The few water-works of the Colonies were crude affairs, frequently consisting of a bored log pipe line leading from a masonry walled hillside spring to a trough in the center of the town, as exemplified by the plant built at Schaefferstown, Pa., in 1730. As a rule, however, these early community works were large wells, from which the householders carried water, as is done in little European hamlets to-day. According to Mr. M. N. Baker, there were seventeen water-works in the United States at the close of 1800, all but one privately owned. It seems probable that public wells used by communities would increase this number, but the now unknown instances of such works can be discovered only as a by-product of more important historical research, through old newspapers and local records, in diaries, and in books of travel.

The early Seventies was the period of the great fires in Chicago, Ill., and Boston, Mass., and there has been a tendency to attribute the increased rate of water-works construction during this decade, from 243 plants in 1870 to 598 in 1880, to a better appreciation of the importance of public water-works as a fire-protection resource and an increased standard of living that demanded running water in homes. The facts, however, seem to be that the most important influences were furnished by promoters working for manufacturers of water-works equipment. The late J. James R. Croes, Past-President, Am. Soc. C. E., explained† the situation as follows:

"The rapid increase in the number of water works constructed within the last sixteen years is mainly due to the competition of enterprising business men. About the year 1870 Mr. Birdsill Holly, of Lockport, N. Y., a builder of pumping engines, began an active canvass of the towns which had no water supply, with the view of furnishing a type of engine and pump manufactured by him by which the pressure was pumped directly into the mains without the use of a reservoir, and at any desired pressure variable at will of the engineer, thus enabling the whole pipe system to be used as a fire engine if necessary. By organizing a private corporation to build works and asking from the public only a certain fixed annual subsidy based on the number of fire hydrants furnished and guaranteed to deliver on demand a fire stream under 100 pounds pressure, the Holly Company were able to induce many towns to allow water-works to be built.

* Cons. Engr. (Fuller & McClintock), New York, N. Y.

† In the preface to the Third (1887) Edition of his "Statistical Tables of American Water Works."

"The practicability of the scheme being proved, and the financial success of several such enterprises having been demonstrated, other pump builders followed the example of the pioneer, and with such success that competition has compelled all parties to build better pumping machinery than ever before and to increase their guaranties of efficiency, durability and economy of operation."

Table 1 shows the available data on growth and ownership of water-works used for public supply in the United States. These data are taken from the "Manual on American Water Works Practice," published in 1925, by the American Water Works Association. When it is realized that more than five years' work, with the help of more than 300 collaborators, resulted in a volume of more than 800 printed pages to tell what is good water-works practice, it will be appreciated how meager must be the historic outline which can be set forth in the limited space here available.

TABLE 1.—Growth of Water-Works in the United States, and Changes in Character of Their Ownership.

Year.	Total. plants.	Public plants.	Private plants.	Ownership unknown.	Percentage of Total. Public.	Private.	Unknown.
1800	16*	1	15*	....	6.3*	93.7*	....
1810	26	5	21	....	19.2	80.8	....
1820	30	5	25	....	16.6	83.4	....
1830	44	9	35	....	20.5	79.5	....
1840	64	23	41	....	35.9	64.1	....
1850	83	33	50	....	39.7	60.3	....
1860	136	57	79	....	41.9	58.1	....
1870	243	116	127	....	47.7	52.3	....
1880	598	293	305	....	49.0	51.0	....
1890	1 878	806	1 072	....	42.9	57.1	....
1896	3 196	1 690	1 489	17	52.9	46.6	0.5
1924†	9 850†	6 900†	2 950†	....	70.0	30.0	....

* Since this table was compiled, another private water-works, built prior to 1800, has been discovered.

† Estimated.

Two supplementary comments are needed, to indicate:

First.—That although the proportion of privately-owned water companies is less than previously, the hit-or-miss type of franchise, or contract both as to quality of service and rates of charges, has largely disappeared. In its place have come State regulatory commissions which, under the provisions of the police powers of the State, now supervise rates of charges and in many States the quality of service, with or without the co-operation of State health commissions.

Second.—That the water-works industry is more extensive than is indicated by the number of plants used wholly or in part in supplying water to the public. The water-works for the exclusive use of many of the large industrial plants are both extensive and important. Water for condensing purposes is highly important, although the subject is clearly outside the scope of this paper.

Distributing Systems

There is little positive information about the distributing systems leading from the primitive collecting works in American communities. In Great Britain, where it was customary to supply water to each consumer for only a short time during each day, cisterns were constructed in the attics of buildings and connected by lead pipes to the street mains. A man (called a "turncock") went around every day, turned a cock on the service pipe and filled the cistern. If it did not hold enough water to meet the requirements for the next 24 hours, the occupants either did without water or procured some from outside the building.

The scheme of intermittent supply never gained a foothold in the United States, but house cisterns were used, on account of low street pressures They served a useful purpose, during periods of scanty supply, by making available, during the day hours of heavy draft and consequent low pressure, water which slowly filled them during the night.

The early pipes were practically all bored logs, sometimes with a ring of iron shrunk on each end to prevent splitting. Such pipes had long been used in Europe, and were not a makeshift adopted on account of the exigencies of construction in a new country, as is sometimes stated. As a matter of fact, bored wood pipe are still made and used to a considerable extent, chiefly for mine drainage in the East and for water-works on the Pacific Coast. The manufacture of such pipe, and of banded stave pipe was greatly improved about 1850 by Wyckoff, of Elmira, N. Y. The banded type was the forerunner of the large banded wood-stave aqueduct pipes used to-day in the West for irrigation, hydro-electric plants, and water-works.

About 1800 cast-iron pipe began to supplant wood pipe in England. Such pipe, with flanged joints, had been tried by the Chelsea Water Company, of London, about 1746, but without much success on account of difficulty with the joints. After studying the causes of the trouble, Thomas Simpson, the Company's engineer, about 1785, designed the first successful bell and spigot pipe with a lead joint. It was quickly adopted, but the facilities for manufacture restricted its introduction for some time. Such pipe, imported from Great Britain in 1807 and laid in Philadelphia, inaugurated the use of cast-iron water mains in the United States.

It was soon found, however, that, in some cities, the interior of uncoated pipe carrying water became tuberculated, and that the carrying capacity was much inferior to that of new pipe. The problem of preventing tuberculation was solved by Dr. Angus Smith, who in 1848 produced the coating that has since borne his name. Although this tar product, which rapidly came into general use, did not prevent tuberculation entirely, it was an excellent and inexpensive deterrent when made of the materials and prepared and applied as he recommended. After the success of this coating was proved, cast-iron pipe had no serious rival for water-works, except in localities where transportation charges made it preferable to use materials which were less expensive although they might not be so durable.

Quite recently a desire for a still better coating for cast-iron pipe, has developed, and the subject is again one of the live topics of discussion in water-works circles.

As the demand for cast-iron pipe began to increase, there was a corresponding increase in the range of thicknesses adopted for pipe walls, and in the shapes of the bells, spigots, and special castings. This complexity at last became intolerable, and in 1902 a standard set of specifications for pipe and specials was adopted by the New England Water Works Association. In 1908 the specifications of the American Water Works Association were adopted, and have since been the standard in America. Although they may need revision to-day (1926), as to coatings and quality of material, and perhaps in other respects, they have been invaluable alike to pipe purchasers and makers.

Wrought-iron pipe appeared in the Forties as a material for distribution mains and service pipes. The pipe was used as a shell, being lined with cement mortar and coated on the outside with some form of preservative. These cement-lined pipes had a decided vogue, particularly in New England, for about twenty-five years, but finally were adjudged less economical than cast-iron pipe in the long run. Owing to recent changes in commercial conditions, they are again back on the market.

In the Fifties, when hydraulic mining in California was becoming a notable industry, large quantities of water had to be dealt with. Although open flumes served as conduits in most places, there were occasional dips below the hydraulic grade where pipe of some sort had to be provided. Cast iron was out of the question on account of cost and transportation difficulties; wrought iron had to be used. When the late Hermann F. A. Schussler, M. Am. Soc. C. E., began the construction of the San Francisco Water-Works, in the Sixties, his knowledge of the satisfactory service of wrought-iron pipe in mining led him to use it for the larger mains of those works As a consequence of the early satisfactory experience in San Francisco, wrought-iron and steel water pipe gained a foothold on the Pacific Coast from which they have never been dislodged.

The first important riveted wrought-iron pipe in the East was laid in Rochester, N. Y., in 1873-75, but it was not until after steel had replaced wrought iron to a great extent that the construction of riveted pipe was considered seriously in this part of the country. Exterior protective coating and the lining of riveted and similar plate pipes have recently received much attention, and some of these methods are so encouraging that, even in the East, steel has become a strong competitor of cast iron in the larger sizes. Both materials, however, are relying, more than ever before, on coatings and linings to preserve their inherent advantages.

In this commercial struggle, active competition has arisen from reinforced concrete pipe, for places where the pressure is not too great. It has been used for aqueducts and other pressure lines for little more than a decade, but in this brief period has shown encouraging results as to low first cost, freedom from leakage, and maintenance of discharging capacity.

Not until about 1875 or 1885 was any general attention paid to what might be called distribution economics. The early distribution systems, after a time, did not deliver the theoretical quantity of water they should, at different parts of a city. This seems to have been one of the reasons for the attention paid to service reservoirs and stand-pipes long before any serious study was made of the hydraulics of distribution systems as a whole.

In some cities attempts were made to improve the distribution of water by partly closing the gates of mains that fed districts where the pressure was highest. When serious fires made an ample supply necessary in a section fed by one of these throttled mains, it was found that the practice was a hazardous makeshift. Engineers finally undertook a careful study of the subject, and an early result was a paper, presented in 1892 to the New England Water Works Association by John R. Freeman, Past-President, Am. Soc. C. E., which attracted wide-spread atttention.

Many years prior to this, one cause of low street pressures was known to be the leakage of water through defective plumbing fixtures, services, and street mains. The leakage inside buildings was attacked by metering the services, but progress was very slow for years, except in some of the thrifty New England cities. Where metering was impracticable, attempts were made to inspect the plumbing, but this also met with violent objection in many cities. To-day, it is difficult for anybody unfamiliar with the facts to realize the bitterness of the opposition to metering as late as the Eighties, and it is fitting in this general discussion to mention the long and forceful campaign for metering conducted a generation ago by Henry C. Meyer, F. Am. Soc. C. E., in his paper* and in other ways.

The opposition to metering service pipes on dwellings was so strong that the method of detecting waste, by dividing a city into districts and then searching for all instances of leakage in one district after another, was developed. In its most elaborate form, due to Mr. G. F. Deacon, of the Liverpool Water-Works, the water delivered to each district was measured by a continuously recording meter. By inspection of plumbing and by using early forms of what is now called the aquaphone, most of the serious leaks and cases of waste in a district were detected and remedied. After that, the district meter register indicated any material increase in waste. The system was tried in only one city of the United States—Boston. It was successful technically, but was so expensive that it was finally abandoned.

When Clemens Herschel, Past-President, Am. Soc. C. E., invented the Venturi meter, in the Eighties, he furnished the first reliable device for measuring large quantities of water supplied through pipes from reservoirs and pumping stations; for the actual discharge of pumps in those days was affected to such an extent by the unknown slip in the pump valves that the only sure thing about the discharge was that it was much less than the reading of the pump counters. Then, in the late Nineties, E. S. Cole, M. Am. Soc. C. E., developed the pitometer, by which the discharge of any pipe can

* *The Sanitary Engineer.*

be determined. With these devices, everything formerly accomplished by the Deacon district system can be done at much less cost.

Obtaining Water Supplies—Sources

With the early water-works there was rarely any difficulty in finding near at hand ample supplies which seemed to be of satisfactory quality. In Philadelphia, for example, after the early wells were deemed inadequate, an unlimited supply could be obtained by pumping from the Schuylkill River.

In New York, the case was unusual. Public water-works began with public wells, the first dug by the Dutch in 1658. Many others were dug later, and those in each ward were placed in charge of its alderman and councilmen. The wells in the heart of the town became so polluted and the water so offensive that it was little used. Just before the Revolution, a private company, under the direction of Christopher Colles, sunk a large well near the present site of the Tombs Prison, from which a less objectionable supply was pumped, by a Newcomen engine, to a small reservoir and then delivered by gravity through log pipes. The enterprise was soon abandoned on account of the war.

Next came Aaron Burr's water-works, built by the Manhattan Company in 1799, under an Act of the Legislature. The works consisted of a large well, two pumps, and the reservoir built by Colles. The Company made hardly more than a nominal attempt to furnish water, as its real object was to conduct a bank, permitted by an innocent looking clause, in its perpetual charter, regarding the investment of its surplus funds. In 1823, it had 23 miles of pipe, nearly all wood, two small steam pumps, and a masonry reservoir holding 550 000 gal. This plant and many wells furnishing water of very inferior quality supplied the city until 1830, when a well, 16 ft. in diameter and 112 ft. deep, was sunk at 13th Street and Broadway, most of it in rock. The water was too hard for domestic purposes, and was used chiefly for fire protection. A small steam pump raised the water to a large cast-iron tank, and the supply was delivered through about 9 miles of cast-iron pipe, from 6 to 12 in. in diameter. This was the first municipal plant in New York.

By 1832 the supply furnished in the city by the Manhattan Company and by the public and private wells was so offensive that all who could afford to do so purchased water brought in hogsheads from unpolluted wells in the northern part of the island. About 600 hogsheads were furnished daily in this way at $1.25 per hogshead. A very bad outbreak of cholera during that year was followed by an increase in the already strong demand for an adequate public supply. It was at first thought that water could be obtained from the Bronx River, but later it was shown that the nearest available supply was from the Croton water-shed. In 1835 the Croton project was approved by the citizens at a special election, bids for construction were opened in 1837, and Croton water, practically the first fit to drink after the days of Dutch control, was delivered in 1842, when the city had attained a population of more than 300 000.

Intakes.—The construction of intakes, by which water was drawn from rivers and ponds, developed so slowly and by such small advances that it is hardly possible at this time to give credit for significant improvements in design, except in one respect. The first public water supply in Chicago was established in 1831; it was merely a public well. The municipal water-works were begun in 1851. After the sewerage system of the city was built and the sewage was carried out into Lake Michigan by the Chicago River, apprehension was felt that the water about the intake in the lake would become dangerously polluted. The extension of the intake pipe farther out into the lake, beyond the area of pollution, was the remedy most favored. The City Engineer, the late E. S. Chesbrough, Past-President, Am. Soc. C. E., opposed this vigorously and insisted that only a supply drawn through a tunnel in the lake bed would be free from serious danger of interruption of service. Such a subaqueous tunnel was then an engineering feat of the first order, but it was at last built in 1867, establishing a practice followed in many cities, not only on the Great Lakes, but also on some of the larger rivers.

Dams and Reservoirs.—Turning to those works for which a supply is obtained by impounding surface waters, one naturally recalls first the dams which form the reservoirs. The development of the details of gravity dams has been slow but continuous. The outstanding novelties have been of a different nature, and of rather limited availability. First there is the hydraulic-fill dam, a form of construction first used by the late James D. Schuyler, M. Am. Soc. C. E., in making railway embankments in Western Canada; then the rock-fill dam, with an impervious covering on the back; and the arched dam, particularly suited for high, narrow gorges. Somewhat later the hollow dam was introduced, for the purpose of saving part of the cost of gravity dams. It has developed into two types, both having transverse parallel buttresses supporting the up-stream back. In one type the back, of reinforced concrete slabs, slopes gently upward to the crest, and the weight of the water on it contributes to its stability. In the other type, nearly vertical arches between the buttresses form the back. Although only bare mention can be made of these types, the general interest in them has resulted in a large volume of printed information regarding their relative merits.

Hydrology.—One of those features of the development of water-works practice that has had a profound influence is inextricably tied up with the gradual increase in the knowledge of hydraulics and hydrology. For a long time so much water was available that there was no shortage except what was due to lack of ordinary common sense in procuring a supply. Little by little, however, there were shortages that could not be explained by the engineering knowledge of those times, and so water-works engineers began to search for their causes. Later, the necessities of irrigation and hydraulic power development increased the interest in this group of subjects, culminating in the interesting utilization of the mathematics of probability, under the leadership of Allen Hazen, M. Am. Soc. C. E.

So far as the co-ordination and direct utilization of this kind of knowledge is concerned, it should be mentioned that in the Nineties the late F. P. Stearns, Past-President, Am. Soc. C. E., in investigations for the Massachusetts State Board of Health, and C. C. Vermeule, M. Am. Soc. C. E., in studies of the water supplies of New Jersey, for the Geological Survey of that State, developed general methods of adjusting reservoir capacities to the run-off from a water-shed. Just before that time there had been in the West, a few cases of expensive irrigation reservoirs, which could not be filled. The economical maximum capacity of reservoirs to utilize the run-off of a water-shed was, therefore, manifestly more than an academic topic.

Underground Water.—Underground water supplies are more numerous than surface supplies, although their total yield is not so great. It is unfortunate, therefore, that nobody has yet undertaken to gather and digest all the existing definite information regarding the engineering aspects of underground supplies, as has been done with surface supplies.

PUMPING WATER

The Keystone State not only holds the record for the first public water supply, but also for the first public supply furnished by pumping. In 1754 Hans Cristopher Christiansen, a Danish millwright, began the construction of the first water-works of Bethlehem after the general method already in use in several places in Europe. His pump, constructed of lignum-vitæ and driven by an over-shot water-wheel, raised water from a spring to tanks on the hillside above the village.

The first steam pumps in America were used for draining New Jersey mines. They were built in England, of the Newcomen type as improved by Smeaton. The first Newcomen pump used for town supply was erected in New York just before the Revolutionary War by a short-lived private company.

The first steam pumping plant in Pennsylvania was put in operation in 1801, in Philadelphia, where a low-lift pump, on the Schuykill River at the foot of Chestnut Street, raised the water to an open basin, from which it flowed by gravity through a conduit in Chestnut Street to Centre Square, now the site of the City Hall. There, at another station, the water was elevated about 50 ft. to wooden tanks, of about 17 000 gal. capacity, on top of the building.

The boilers at both plants were wooden boxes, 9 ft. high, 9 ft. wide, and 15 ft. long, of 5-in. white pine plank thoroughly bolted and braced. The fire-box, constructed of wrought-iron plates with vertical cast-iron flues, was inside. The engines were the Watt vertical, double-acting type attached to a Cornish pump. The pump of each was of wood lined with copper. The steam cylinder was of cast iron.

It had been recognized, from the days of Savery and Newcomen, that the load on pumps is pre-eminently adapted for being carried by a steam engine. It is steady and always accompanied by enough water for condensing purposes. As a consequence, the early history of the development of the steam engine is largely that of the development of pumping engines. The condition is just the opposite, however, with boilers which furnish the steam to the pumps. The early pumping stations had boilers carrying very low pressure, and, when more pumping capacity was added, the low pressure was retained in order that the old boilers could still be used. This condition kept station efficiency low, in spite of efficient pumping engines. As a matter of record of an important feature of pumping station development, the following statement, prepared by the late Charles A. Hague, M. Am. Soc. C. E., shows the maximum steam pressures in such stations:

Year	1800	1830	1850	1875	1900	1906
Steam pressure, in pounds.	5	20	50	75	125	175

There was a period of quiescence in the field of pumping machinery, down to the Sixties, due chiefly to patent conditions. Small pumps were usually direct-acting, and the larger pumps were improvements on the Bull-Cornish or Watt-Cornish types. In the Sixties the late Henry R. Worthington, M. Am. Soc. C. E., brought out the duplex, direct-acting pump, and other inventors followed soon with other devices for utilizing the duplex principle. At about the same time the Holly quadruplex crank-and-flywheel pump was introduced, and thus began a business competition between the two types of pumping engines that resulted in great improvements in each and a substantial reduction in their cost.

In England another type of pumping engine was developing, the Simpson compound engine, first used there in 1848, and in the United States in Philadelphia in 1872. Others were erected in a number of cities of the United States, the largest plant being that of the West Side Pumping Station in Chicago.

A few pumping engines used in the United States at that time were designed by consulting engineers, among whom the late E. D. Leavitt, M. Am. Soc. C. E., was prominent, but nearly all were designed by the builders. Competition was severe. It was necessary, not only to meet constantly rising guaranties, but also to reduce manufacturing costs, and naturally the improvements were in details rather than in general types. Finally, the experience with the Simpson type seemed so certain to establish it as the single standard for handling large volumes of water that the Worthington high-duty attachment, for the duplex engine, was brought out, and the Holly-Gaskill crank-and-flywheel engine was designed to improve the economy of the Holly quadruplex, crank-and-flywheel type.

In the Eighties, the Reynolds triple-expansion pump was designed, the first being built at Milwaukee in 1886; this soon became the standard high-duty, large-capacity, American pumping engine.

By 1900, earlier experience and commercial competition had rather definitely established certain types of pumping engines for the different kinds of service, and those interested in the subject will find them described by Irving H. Reynolds, M. Am. Soc. C. E.*

About 1900 the centrifugal pump became a really strong candidate for favor for water-works use. It was largely the development of reliable steam turbines and reduction gears that established such pumps in the favor they now hold in water-works practice. Originally, such pumps were used only

* *Transactions*, Am. Soc. C. E., Vol. LIV (1905), Part D, p. 513.

for low-lift service, but the field has gradually widened as the methods of design have been improved, and electrically driven centrifugal pumps are now operated against very high heads. This development has brought about one interesting change in pumping-station practice.

In the early plants these turbo-centrifugal units were generally placed in an old pumping station, where it was desired to handle the largest possible quantity of water with pumps occupying a definite space. The steam pressure was low, and other conditions were unfavorable for economy, but when turbo-centrifugal pumps were put in service under better conditions, using superheated steam at pressures most suitable for turbines, their economy rose very favorably, just as it did in the early days of turbines in industrial power plants and central stations. It became very evident then that station economy, rather than prime-mover economy, was the real measure of the success of the design.

Electrically operated centrifugal pumps, when the motors and pumps are suitably designed for the loads carried, are now standardized equipment. The chief drawback to their use is the possible unreliability of the current supply from outside sources. This is a serious matter where only a small quantity of water is stored in tanks or reservoirs.

The danger of interruption of current supply for motor-operated pumps, both centrifugal and reciprocating, has been met in many small pumping stations by adding a high-speed gasoline engine to help out in emergencies. Although the gasoline engine is cheap, its fuel is much more expensive than the oil used in Diesel engines. These were introduced about 1895, and have been improved steadily ever since, until to-day they are capable of satisfactory operation for a considerable range of speed, although, like all internal combustion engines, they must not be given overloads. Two considerations seem to be chiefly influential in determining their use. The first is the present and probable future price of fuel oil and its availability at any place; the second is the length of satisfactory service of these engines. Concerning the second point, there is difference of opinion which probably cannot be reconciled until after longer experience with them.

The reciprocating well pump has been slowly improved, but, usually, it is not economical. The shocks and vibrations attending its operation and its relatively complicated construction make its maintenance high in comparison with the quantity of water it delivers. Attempts to avoid these drawbacks have taken two forms, both successful and widely used: The air-lift and the centrifugal well pump, which deserve more than this brief mention.

Quality of Supplies

Presumably, this branch of the topic is the most important to develop in historic outline at present. Its consideration relates to the development of the modern germ theory of disease, particularly regarding the transmission of water-borne disease. In a strict technical sense, modern views as to the relation between the quality of a water and the health of the communities using such water date from the early or middle Eighties. Such matters, however, were then under discussion for the most part by highly trained scientists in a few of the larger cities, and the general mass of water consumers, even including those well informed on educational topics in general, did not give much recognition to the significance of water-borne diseases until after the terrific outbreak of Asiatic cholera in Hamburg, Germany, in 1892-93.

The best index of the successful fight waged against water-borne disease in America is the decrease in the typhoid fever death rate, shown by Table 2. Although the pasteurization of milk, fly suppression, and the education of the public in the rules of sanitation and hygiene have contributed to this decrease, the improvement in the quality of water supplies has been the chief cause.

Prior to the development of modern views as to transmission of disease, there was a well-recognized belief that a public water supply should not be obtained from a filthy source. This theory, originating in England, had much to do in explaining the progressive changes made by numerous cities and towns in efforts to get water from clean sources. Most of the rivers of Western and Central Europe are only of moderate turbidity, and can be clarified suitably on sand beds such as were first constructed at London in 1829. The idea of these sand beds spread quite rapidly to various places in England and on the Continent.

Kirkwood's Report.—In 1866-68, the late James G. Kirkwood, Past-President, Am. Soc. C. E., then Chief Engineer of the St. Louis, Mo., Water-Works, made a thorough-going study of the methods used in filtering European supplies. It was a most admirable report, and its merit was well recognized by its translation into German and its becoming a standard work of reference in several European countries. On account of the unusually heavy turbidity or muddiness of the local rivers at St. Louis, Mr. Kirkwood did not recommend sand beds for the local supply, and this report was followed by no activities in the adoption of European filtration practice other than the two small sand filter beds which he built for Poughkeepsie and Hudson, N. Y., in the early Seventies.

Conditions in the Early Nineties.—It is difficult for the younger engineers to realize the extent to which the United States suffered from the scourge of sewage-polluted waters, which caused severe epidemics and in many places continuous or endemic conditions as to typhoid fever. The explanation is simple enough when one considers the close proximity of sewer outlets and water-works intakes. No wonder typhoid fever records were frequently from ten to twenty times higher than ordinarily found at present. The scourge was particularly severe in the manufacturing cities of Massachusetts and in the steel districts of Western Pennsylvania, where many of the population paid little or no attention to warning notices against drinking public water supplies. One of the sad features of the Columbian Exposition at Chicago in 1893 was the number of visiting engineers who contracted typhoid fever while there.

TABLE 2.—ANNUAL TYPHOID FEVER DEATH RATES PER 100 000 POPULATION FOR SOME AMERICAN CITIES.

Year.	Philadelphia, Pa.	Chicago, Ill.	Milwaukee, Wis.	Detroit, Mich.	Cleveland, Ohio.	Buffalo, N. Y.	Boston, Mass.	New York, N. Y.	Manhattan and The Bronx New York, N. Y.	Jersey City, N. J.	Baltimore, Md.	Washington, D. C.	Pittsburgh, Pa.	Cincinnati, Ohio.	Louisville, Ky.	New Orleans, La.	Minneapolis, Minn.	St. Louis, Mo.	Kansas City, Mo.	San Francisco, Calif.
1880	58	34	87	....	44	....	42	25	....	24	59	54	185	70	....	24	......	40	......	84
1881	74	105	47	....	99	67	56	88	....	68	58	46	151	71	....	80	......	58	......	87
1882	73	82	82	....	68	69	57	82	....	121	47	66	158	55	....	88	......	45	......	61
1883	64	62	25	....	65	84	52	82	....	49	85	62	107	51	....	28	......	41	......	04
1884	71	56	81	....	60	42	56	29	....	84	42	76	70	56	....	25	......	42	......	58
1885	64	75	28	....	84	28	40	27	....	71	42	65	76	42	....	17	......	81	......	44
1886	64	69	80	89	56	28	84	26	....	60	89	71	68	54	....	18	......	80	......	49
1887	68	50	81	65	52	84	44	26	....	54	41	78	128	142	....	15	......	28	......	28
1888	78	47	42	46	47	29	40	23	....	74	42	87	87	70	....	19	......	81	......	88
1889	71	48	28	81	74	80	48	24	....	83	47	94	95	49	....	17	......	93	......	55
1890	64	92	41	19	69	40	85	22	28	98	59	112	132	69	....	21	41	81	52	44
1891	64	174	88	84	50	51	84	28	25	100	85	82	101	62	....	24	55	29	42	42
1892	40	124	80	94	59	84	29	22	25	72	44	89	100	40	....	20	44	93	88	82
1893	41	54§	85	42	52	87	81	21	28	66	49	86	111	44	....	15	76	44	89	82
1894	88	88	25	28	29	59	29	17	19	53	47	91	56	55	....	29	56	84	26	87
1895	40	38	26	24	85	26	88	17	18	95	86	86	78	89	....	44	48	31	27	84
1896	34	58	18	23	48	20	81	16	16	84	88	58	62	52	....	88	82	20	28	26
1897	88	29	12	15	28	20	88	16	16	20	87	48	64	83	....	52	78	28	28	19
1898	46	41	17	22	84	27	84	21	20	40	86	71	73	83	....	66	44	17	87	41
1899	75	27	17	18	82	24	80	16	15	19	29	78	111	37	....	55	86	23	86	22
1900	35	20‡	17	27	54	26	26	21	18	21	85	78	144	89	64	40	89	29	40	18
1901	34	29	23	21	86	27	25	20	19	16	27	60	125	55	46	48	59	84	44	22
1902	44¶	45	15	24	88	33	24	21	18	20	42	78	134	62	61	45	27	37	36	27
1903	70	32	17	20	114	35	20	17	16	15	36	48	134	42	61	39	42	47	74	24
1904	53	20	14	20	48	23	23	17	18	19	37	47	142	79	68	36	42	36	39	27
1905	48	17	23	21	15§	23	20	16	18	19	36	48	99	40	51	32	25	20‖	58	24

TABLE 2—(*Continued.*)

Year.	Philadelphia, Pa.	Chicago, Ill.	Milwaukee, Wis.	Detroit, Mich.	Cleveland, Ohio.	Buffalo, N. Y.	Boston, Mass.	New York, N. Y.	Manhattan and The Bronx New York, N. Y.	Jersey City, N. J.	Baltimore, Md.	Washington, D. C.	Pittsburgh, Pa.	Cincinnati, Ohio.	Louisville, Ky.	New Orleans, La.	Minneapolis, Minn.	St. Louis, Mo.	Kansas City, Mo.	San Francisco, Calif.
1906	74	19	31	24	20	23	20	15	15	20	35	50*	180	70	71	30	34	17	32	58
1907	61	18	26	35	19	28	10	17	16	14	41	35	125	45	71	55	27	15	33	30
1908	35**	16	17	23	18	20	25	12	11	9§§	33	37	45	18*	47	33	19	14	29	19
1909	22††	18	28	23	18	23	14	12	12	9	25	33	23*	13	45	29*	21‖	16	30	14
1910	17†	14	45	20	19	20	12	12	11†	7	42†	23	28†	6†	32*	32	....	18	....	....
1911	14‡‡	11	20	15	14	25§	9	11	10	8	27§§	23	26	12	24	31	12	16	30§§	15
1912	18*	7	26	15	7†	12	8	10	7	8	24	22	13	8	22	14	12	11	12	14
1913	16§§ ‖	10†	12§§	25§§	14	15	9	7‡‡	7	11	22	16	20§§	7	24	17	12*	17§§	22	16
1914	8	7	8	11	8	16	9	7	6	8	21	11	15	7	27§§	22	18	12	16	18
1915	7	5	5	10	8	10§§	6	6	5	6	19	11	11	8	14	21	8	7*	10	9
1916	8	5	16	11	5	11	4	4	4	8	16*	12	9	8	14	23	6	10	13	8
1917	6	2§§	6	13	7	10	3	4	4	4	13	12	12	4	16	24	7	8	12	5
1918	5	2	6	8	5	7	3	4	4	5	10	11	10	5	15	20	9	8	15	4
1919	5	1	4	5	3	7	2	2	....	2	9	4†	4	3§§	6	18	3	6	11	3
1920	3.4	1.1	2.2	5.1	3.9	5.1	1.5	2.4	2.1	3.7	4.7	6.6	2.7	2.7	5.5	7.0	2	2.7	7.4	3.1
1921	2.2	1.1	1.9	5.8	3.5	3.5	3.2	2.4	2.1	3.7	5.5	6.4	3.2	3.7	4.7	9.8	1.3	3.8	11.5	4.0
1922	2.8	1.1	2.5	5.3	2.2	3.6	1.4	2.2	1.9	1.6	3.9	5.1	3.3	3.0	7.2	5.7	1.8	4.4	4.6	4.3
1923	1.5	1.9	0.8	4.0*	1.9	4.1	1.3	2.4	2.5	1.6	4.1	6.0	2.1	3.0	4.1	4.0	1.5	4.2	4.8	2.6†
1924	2.2	1.6	1.0	3.0	1.2	2.8	2.1	3.1§§	....	2.6	2.8	4.3	3.9	2.5	1.9	10.0	2.1	3.7	3.6	2.6
1925	2.3	1.5	1.4	2.7	1.5	4.5	3.5	3.3	....	4.1	3.6	5.0	3.2	4.2	5.8	19.8	3.3	3.9	1.9	2.2

* Filtration effective for city.
† Sterilization of water supply begun.
‡ Drainage canal in service.
§ New intake.
‖ Coagulation introduced.
¶ One per cent. of water supply filtered.
** Fifty per cent. of water supply filtered.
†† Ninety per cent. of water supply filtered.
‡‡ Sterilization of 66% of water supply.
§§ Sterilization of entire water supply.
‖‖ Coagulant applied during periods of high turbidity.

Lawrence Filter.—When the Massachusetts State Board of Health was re-organized in 1886, one of its most important steps was the establishment of the Experiment Station at Lawrence where, since that date, a vast fund of information has been developed on the subject of purifying water and sewage. One of the outstanding characteristics of these investigations, under the direction of the late Hiram F. Mills, Hon. M. Am. Soc. C. E., was that it embodied data of an engineering, chemical, and biological nature. Such thorough-going and unusually well co-ordinated data have had much to do with the development of sanitary engineering during the past forty years. In 1891-92, one of the most important pieces of work at Lawrence was an investigation of the ability of ordinary sand filters to remove typhoid fever germs, a matter of more than usual importance in the Merrimac Valley, where the Lawrence water-supply intake is only eight miles below the Lowell sewers.

In the late summer of 1892 Asiatic cholera appeared on vessels quarantined in New York Harbor, and, under these circumstances, it was not difficult for Mr. Mills to obtain from the City Council of Lawrence, authorization for the construction of the Lawrence filter. This filter was completed in September, 1893, and embodied in its design the application of many of the data derived under Mr. Mills' direction at the State Experiment Station. The success of this filter, in reducing typhoid fever in that city, was so notable that it became a landmark in the train of developments which characterized the improvements in the quality of water supplies in America.

Louisville Investigations.—What the Lawrence experiments were to the development of slow sand filters, the results of the investigations at Louisville, Ky., were in respect to rapid or mechanical filters. The late Charles Hermany, Past-President, Am. Soc. C. E., found, as did Mr. Kirkwood at St. Louis, that the muddy Ohio River water was not susceptible to filtration in a practical way through sand beds, as used in Europe and later adopted with some modifications at Lawrence. In 1895 he began investigations, continuing for nearly two years, on various ways of coagulating and filtering muddy Ohio River water, the writer being in immediate charge of the work. Prior to that period mechanical filters had been in use at a few mills, for removing coarse material, but had obtained practically no standing for municipal supplies. They had been studied shortly before by the late E. B. Weston, M. Am. Soc. C. E., at Providence, R. I., and extensive investigations immediately followed those at Louisville, one set being conducted at Cincinnati, Ohio, by the writer and the other at Pittsburgh, Pa., by Mr. Hazen. In those days mechanical filters were contained within wooden tubs or metal cylinders, and it happened that their status became largely enhanced through the development of reinforced concrete for the filter units such as first adopted at Little Falls, N. J., in 1901. Since that date there have been marked developments in mechanical equipment for the efficient control of various filter arrangements.

Filtration Practice.—At present (1926) there are approximately 635 filter plants, having capacities in excess of 1 000 000 gal., serving about 23 750 000 people, and having a total daily rated capacity of 5 000 000 000 gal. There are 47 slow sand filters and 588 mechanical filters, having a rated daily aggregate capacity of 915 000 000 and 4 085 000 000 gal., respectively.

Algæcides.—One aspect of the quality of water has been the tastes and odors associated with the growth and decay of various forms of microscopic life. The late George W. Rafter, M. Am. Soc. C. E., began a painstaking study of this matter, at Rochester, N. Y., and, later, at Boston, Mass., with the aid of the late George C. Whipple, M. Am. Soc. C. E., who for about fifteen years conducted thorough-going investigations into the various factors related to tastes and odors in surface water supplies at Boston and New York. To the engineer, perhaps, it may be of most interest to indicate that by the use of copper sulfate or other algæcides much can be done toward controlling these tastes and odors by killing the organisms producing them.

Aeration.—Stored waters frequently stagnate, with the result that water in the lower parts of deep reservoirs becomes offensive to sight and smell. Aeration will restore the depletion of atmospheric oxygen, lessen the free carbonic acid, and offset the products of decomposition found in the deep parts of large reservoirs. Advantageous use of aeration is to be found in the works of the Catskill project for New York City.

Chlorination.—One of the results of the cholera epidemic at Hamburg was the development of the fact that bleaching powder was an efficient sterilizing agent, although in Europe the idea was to apply it in cases of emergency only. Beginning in 1908, with the Boonton Reservoir supply of Jersey City, N. J., the regular use of chlorine was adopted for the purpose of destroying objectionable bacteria. This practice has become general in America, and it is estimated that there are in service now more than 3 200 chlorinating plants, capable of supplying about 4 000 000 000 gal. of water daily.

Iodizing.—Beginning in 1922 at Rochester, N. Y., there recently has been added to public water supplies intermittent small doses of sodium iodide, for the purpose of supplying the deficiency of iodine. This deficiency in some water supplies is believed to be an important factor in the causation of common goiter.

Methods of Analysis.—The quality and composition of waters in various parts of the United States vary greatly, and the methods of analysis suitable in Western Europe and in New England are quite inadequate for many of the waters of the Southern and Western States. It is of importance to record an unusual amount of good team work in America in improving and unifying methods of analysis. The first edition of "Standard Methods of Water Analysis" appeared in 1905, under the auspices of the American Public Health Association, and, in 1925, its sixth edition appeared under the joint auspices of that Association and the American Water Works Association. It is of interest to note that the standard methods in use in America are to be translated into French and German, under the sponsorship of the Health Section of the League of Nations. It is to be hoped that the co-operative work, carried on in America for thirty years, may assume a wider scope under the guidance of an international committee.

Iron Removal Plants.—Many ground-water supplies contain objectionable quantities of iron and manganese, so that, on exposure to the air, objectionable deposits and discolorations are formed. It is thoroughly practicable to remove these objectionable constituents by aeration and filtration. Chemicals are sometimes used—and in a few instances iron settling basins—for the removal of the deposit, rather than filters.

Removal of Carbonic Acid.—Some water supplies, particularly those derived from deep underground sources, contain large quantities of free carbonic acid, and this is of much significance in connection with the correction of corrosion of metals. It is thoroughly feasible, by aeration and filtration, and, if need be, with the aid of quicklime, to reduce the carbonic acid content to practical limits for safe use. A plant for removing such corrosive properties has been established for the new deep well supply at Memphis, Tenn.

Water Softening.—There are a few well-known water-softening plants in America. The most comprehensive data have come from Columbus, Ohio, in a paper by John H. Gregory, M. Am. Soc. C. E.* Some supplies of hard water undoubtedly should be softened, but views have not been well crystallized as to where to draw the line separating a hard water justifying softening from one where it is not worth while to pay the cost of such softening. This view, however, for public supplies, does not relate to the opinions held by those in charge of the water supplies of many industrial and power plants. What is said of softening also applies to the removal of carbonic acid and other corrosive properties.

Filter Loading.—Engineers are faced to-day with one problem that very soon must receive more attention than has been accorded to it hitherto. Sources of water supply are being contaminated by industrial wastes to a serious degree in some sections, and the pollution due to the discharge of sewage into such waters after little or no treatment is causing apprehension in well-informed circles. The time is fast approaching when the loads thrown on some water purification plants will be unreasonably heavy, and engineers should consider carefully the advisability of abandoning the old attitude that, except in unusual instances, it is a matter of indifference as to purification of sewage so long as public water supplies derived from a polluted source are purified. In twenty-five years cities have grown rapidly, and the industries discharging objectionable wastes have grown even more rapidly. Rivers and lakes have about the same volume of water now as they had a century ago. What was good practice in 1900 is no longer such in many cities, because of the changes that have taken place. This view is adopted in the treaty between the United States and Great Britain, ratified in 1909, in which it is stated that boundary waters between the United States and Canada should not be polluted on one side of the river so as to be injurious to those living on the other side. These matters were interpreted to deal with filter loading, after the International Joint Commission, to which these matters were referred, had conducted extensive investigations and inquiries.

* *Transactions*, Am. Soc. C. E., Vol. LXVII (1910), pp. 235 *et seq.*