WATER SUPPLY and SEWERAGE

Water Supply and Sewerage

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Preface

The fields of water supply and sewerage have developed to the extent that many volumes would be needed to cover them exhaustively. The teacher of sanitary engineering must, however, adapt his courses to the time available in the crowded civil engineering curriculum and accordingly requires a text that will provide the essentials in a limited space. This book is an attempt to present, for engineering students, those principles and present-day practices necessary to solution of the problems of water supply and sewerage. It is hoped that it is also sufficiently practical to be of value to operators of waterworks and sewerage works, city engineers, practicing engineers, and others who have more or less contact with the problems of sanitary engineering.

The author foresees several criticisms that may be expressed as to the contents of the book and takes this opportunity to answer them in advance. Teachers may consider that some important matters have been omitted or that some of the material included is unimportant. To this objection the author states apologetically that he used his own judgment as to subject matter, and it is a certainty that opinions will differ. Another well-founded accusation may be that the problems are few in number. The answer to this objection is that it was considered advisable to avoid a bulky volume. Consequently the problems included are intended only to illustrate some point in the text or to indicate to the instructor the possibilities in problem construction. Where obvious opportunities for problem making exist, as in Chapter 6, none are included.

It is assumed that the student has a knowledge of hydraulics; therefore, only formulas, charts, and diagrams especially applicable to sanitary engineering design are included. Wherever possible, subjects common to water supply and sewerage, or closely allied to both, were treated together. For example, discussion of the amount of water consumed in a city leads to estimation of the amount of sanitary sewage produced; consequently both of these subjects are included in Chapter 2. On the other hand, the amount of storm sewage that must be disposed of has no relation to water supply and is, therefore, placed in the portion of the book devoted to sewerage. Similar treatment was given to self-purification of streams and sewage disposal by dilution, the former being treated under water supply and the latter under sewerage. Such arrangements have prevented duplications and aided in keeping the book within moderate size.

Advancements in the fields of waterworks and sewerage works have made a fourth edition of this book necessary. In the presentation of material the same plan has been followed as in the former editions, and an attempt has been made to strike the same balance between theory and practice. This aim has necessitated both inclusion of new material and rewriting of other portions of the book.

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Ernest W. Steel

List of Abbreviations*

amp.—ampere
ave.—average
b.hp.—brake horsepower
B.O.D.—biochemical oxygen demand
B.t.u.—British thermal unit
C.—Centigrade degree
c.f.m.—cubic foot per minute
c.f.s.—cubic feet per second
cu. ft.—cubic foot
cu. yd.—cubic yard
F.—Fahrenheit degree
f.p.s.—feet per second
ft.—foot
gal.—gallon
gm.—gram
g.p.a.d.—gallons per acre per day
g.p.c.d.—gallons per capita per day
g.p.d.—gallons per day
g.p.g.—grains per gallon
g.p.m.—gallons per minute
hp.—horsepower
hr.—hour
in.—inch
lb.—pound
mg.—milligram
m.g.—million gallons
m.g.a.d.—million gallons per acre per day
m.g.d.—million gallons per day
mg./l.—milligrams per liter (parts per million)
mi.—mile
min.—minute
ml.—milliliter
mm.—millimeter
M.P.C.—maximum permissible concentration
M.P.N.—most probable number
μ—micron
μc.—microcurie
No.—number
oz.—ounce
p.p.b.—parts per billion
p.p.m.—parts per million
p.s.i.—pounds per square inch
p.s.i.g.—pounds per square inch gage
r.p.m.—revolutions per minute
sec.—second
sec.$^{-1}$—feet per second per foot
sec.-ft.—cubic feet per second
sq. ft.—square foot

* There is no differentiation between singular and plural forms except where indicated.

Contents

CHAPTER 1

Introduction

1-1. Work of the Sanitary Engineer. The development of sanitary engineering has paralleled and contributed to the growth of cities. Without an adequate supply of safe water, the great city could not exist, and life in it would be both unpleasant and dangerous unless human and other wastes were promptly removed. The concentration of population in relatively small areas has made the task of the sanitary engineer more complex. Ground-water supplies are frequently inadequate to the huge demands; and surface waters, polluted by cities, towns, and villages thickly scattered on watersheds, must be treated more and more elaborately as the population density increases. Industry is also demanding more and better water from all available sources. The rivers are receiving ever-increasing amounts of sewage and industrial wastes, thus requiring more attention to the problems of sewage treatment and its relationship to stream pollution and the complicated phenomena of self-purification.

The design, construction, and operation of water and sewage works are treated in this book, but the field of sanitary engineering extends beyond these limits. To the sanitary engineer the public looks for assistance in such matters as the control of malaria by mosquito control, the eradication of other dangerous insects, rodent control, collection and disposal of municipal refuse, air conditioning, industrial hygiene, and the sanitation of housing and swimming pools. The activities just given, which are likely to be under the local or state health departments, are sometimes known as public health engineering, a term which, while descriptive, is not accepted by all engineers. The term, however, is indicative of the important place the engineer holds in the field of public health and in the prevention of diseases.

1-2. Water Supply. During all the ages large cities have been concerned with their water supplies. Even the important ancient cities soon found that the local sources of supply—shallow wells, springs, and brooks—were inadequate to meet the very modest sanitary demands of the day, and the inhabitants were constrained to build aqueducts[1] which would bring water from distant sources. It cannot be said, however, that such supply systems could compare with modern types, for only a few of the wealthier citizens had private outlets in their homes or gardens, and most citizens carried water in vessels to their homes from a few fountains or public outlets. The medieval cities were smaller than the ancient cities, and public water supplies were practically nonexistent. The existing aqueducts of ancient Athens, Rome, and the Roman provincial cities fell into disuse, and their purposes were even forgotten.

The water works engineer of ancient times labored under the severe handicap of having no type of pipe that would withstand even moderate pressures. He used pipe of clay, lead, and bored wood in small sizes, but even with these, as with his masonry aqueducts[1] and tunnels, he followed the hydraulic grade line and rarely placed his conduits under pressure. It was in the seventeenth century that the first experiments were made with cast-iron pipe. They were successful; but it was not until the middle of the eighteenth century that cast-iron pipes were cheap enough for wide use, although bored logs were installed as water mains in the United States as late as 1800. The durability of cast iron and its freedom from breaks and leakages soon made its use almost universal, although steel and other materials were also used. This forward stride, together with the development of pumping methods, made it economically possible for all but the smallest villages to obtain water supplies and to deliver the water into the homes of the citizens.

Although some cities were able to collect safe water from uninhabited regions and thereby reduce water-borne disease to a low level, many others found that their supplies were dangerously polluted and that the danger was increasing as population increased upon watersheds. Accordingly treatment methods were developed that, when properly applied, have eliminated the hazard. The efficiency of water filtration was recognized by engineers early in the nineteenth century, but city councils were slow to be convinced of the necessity for spending money to save lives, and water treatment was not widely adopted until about 1900. The effects of treatment are graphically shown by Fig. 1-1. Philadelphia's water supply came, without treatment of any kind, from increasingly polluted rivers until 1906, when slow sand filters were completed. An immediate reduction in typhoid fever followed over a period of 7 years. A tendency to increase, possibly caused by further increases in the pollution of the untreated water, was checked by disinfection of the filtered water with chlorine. A still greater decrease was accomplished after 1920 by careful control over infected persons who had become carriers.

1-3. Sewerage. Remains of sanitary sewers are to be found in the ruins of the prehistoric cities of Crete and the ancient cities of Assyria. Rome also had sewers, but they were primarily drains to carry away storm water. It was the practice to deposit all sorts of refuse in the streets, and accordingly the storm sewers also carried much organic matter at times. Sewerage was practically unknown during the Middle Ages, and not until modern times was construction of sewers resumed. At first, however, they were storm sewers not designed to carry domestic sewage. As late as 1850, the discharge of household wastes into the sewers of London was forbidden. The water courses in or near towns apparently were used as convenient places of refuse disposal, for many writers comment upon the offensive condition of the London brooks, with their burden of dead dogs and filth* of all sorts. In the course of time it was recognized that sanitation would best be served by permitting the use of sewers to convey human excreta away from dwellings as promptly as possible, and the original storm drains became combined sewers which carried both storm-water runoff and the liquid wastes from occupied buildings. The development of water supplies, of course, played a large part in the

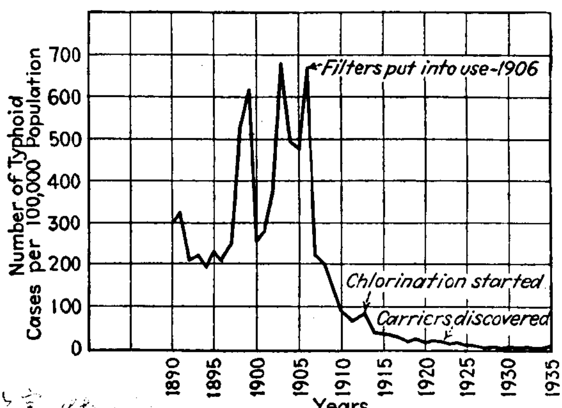

FIG. 1-1. Typhoid fever cases per 100,000 population from 1890 to 1935, Philadelphia, Pa.

greater use of plumbing systems with water-flush toilets. The commonly used vault toilets, which frequently overflowed and always produced odors, were soon legislated out of existence in the larger cities in favor of the water-carried system. This improvement together with safer water supplies caused a sharp decline in the urban death rate.

Providing sewers for the cities was not a complete solution of the problem of excreta disposal. The offensive and dangerous materials were discharged into the streams where they decomposed to cause discomfort and danger to rural populations or to cities located downstream. Most cities,

* Queen Elizabeth I once decreed that the rushes which were used as floor coverings in many homes were not to be disposed of by dumping into streams, as the practice was polluting the drinking water of Her Majesty's subjects. History does not record how well the decree was enforced.

therefore, soon found it necessary to treat the sewage before releasing it. Even those cities which are located along the ocean are in many cases obliged to protect bathing beaches or shellfish beds. Some, however, are able to discharge their sewage untreated into very large bodies of water or into streams that traverse relatively uninhabited regions. Still others are indifferent to the needs for sewage treatment and in the absence of laws or proper enforcement spoil the beauty of streams, make them unusable for recreative purposes, and endanger lives. A later development of this sanitary problem is the pollution of streams by industrial plants located not only in cities but in previously unspoiled rural sections. Streams have been spoiled for fishing, camping, and swimming by the putrescible and toxic wastes of industrial plants.

When the problem of sewage treatment first attracted attention, a difference of opinion existed among engineers as to the completeness of treatment that should be given to sewage before discharge into a body of water. Some engineers maintained that the public interest required the most complete treatment possible. Others held the opinion that treatment should be based upon local conditions and that no more treatment need be provided than would give reasonable assurance, with a factor of safety, that danger and nuisance would not exist. So far as safety of water supplies is concerned, this viewpoint places upon the water works authorities some of the burden of safeguarding and treating their raw water. When it is considered that water of streams and lakes may often be polluted or made unsuitable for use otherwise than by city sewage, it is obviously inequitable to require all cities to produce a sewage treatment plant effluent even approximately equal to drinking water. Therefore, sewage treatment is based upon local conditions rather than idealistic standards.

1-4. Effects of Sanitary Engineering upon City Life. The bills of mortality of London in the seventeenth century, which were the vital statistics of the day, indicate that the death rate in large cities at that time was greater than the birth rate. Cities, therefore, grew slowly and only by migration from country to city. This condition can be ascribed to the prevailing insanitary conditions combined with the crowding of people into a small area and the resulting prevalence of communicable disease. The first municipal sanitary improvement both in England and elsewhere was the construction of water supplies which, in the large cities, was soon followed by sewerage. The small cities and towns have also been installing water works and sewerage systems during the last few decades until, at the present time, there are few communities of more than 2,500 population that do not have a public water supply and in most cases a sewer system, while an increasing proportion of even smaller towns are also constructing them.

The effect of these improvements upon the typhoid death rate has been striking. During the period 1901–1905, the average annual death rate from typhoid fever in the cities of the Registration Area of over 8,000 population was 34.6 per 100,000. In some cities it not infrequently rose to over 100 per 100,000. By 1915, the rate in all the Registration Area cities, as reported by the Bureau of the Census, had fallen to 11.6; in 1930, it was 2.9; in 1940, it was only 0.8, while in 1948, it had fallen to only 0.1. It is of interest also that rural areas have typhoid death rates twice as great as urban areas. It should be noted that rural areas, as defined by the Bureau of the Census, also include towns and villages having populations under 2,500 where, in many instances, close proximity of dwellings is not offset by adequate water supplies or sewer systems. Some of the decrease in typhoid fever is due, of course, to improved methods of treating the disease, immunization, and better general sanitation.

The important effects of water works and sewerage upon cities are not confined to safeguarding of health. Safety of life and property against fire has been obtained. Street cleaning and flushing are possible. Swimming pools, fountains, and other ornamental and recreational uses of water are now commonplace. Industries will locate in cities where they are assured of an ample supply of water and where there are sewers to remove their liquid wastes. Some industries, and this should be recognized by municipal authorities, may make unreasonably high demands for water or may produce wastes which are unsuitable for joint treatment and disposal. Storm sewers protect property from damage by storm water. Sanitary sewers are largely instrumental in preventing the disagreeable odors which are still characteristic of large oriental cities.

The unthinking citizen, accustomed to the comforts of civilization, has little conception of the significance of the stream of water that he obtains when he turns on a tap and even less of the vast network of underground conduits available to receive that water as it escapes into the drainpipe. To the student, this book, brief as it is, will convey some idea of the investigation, planning, accumulated experience, and plain hard work behind the water works and sewerage works that give our citizen water in the amounts that he wants when he wants it and then conduct it away when it has served his purpose.

1-5. Magnitude of the Problem. Supply of water to the cities of the United States is a huge engineering problem. According to the U.S. Department of Commerce,[2] the cities of the United States, with a total population of 110,000,000 in 1955, produced and distributed 17 billion gal. of water daily to their domestic, commercial, and industrial consumers. Of this, 12.88 billion gal. were from surface water sources which usually require elaborate treatment. Of the 4.18 billion gal. from ground sources a small proportion would require treatment. Large as these figures are, they are increasing yearly. It is estimated that in 1975 public supply requirements will be about 30 billion gal. daily, of which 23 billion gal. will be from surface sources.

Water supply is only a part of the task. Nearly all the water will become sewage that must be collected and disposed of after such treatment as the local situation may require. A third problem is the collection and disposal of the storm sewage resulting from the rainfall upon cities growing in area as well as population.

Water use is not confined to cities. In 1955, industrial users and such miscellaneous users as motels, resorts, army installations, and mines, all self-supplied, consumed 60 billion gal. daily, and this use is estimated as reaching 115 billion gal. in 1975. Much of this water requires treatment, and much of it becomes sewage or industrial wastes that will require treatment.

A large amount of capital is required to construct adequate works for a city. Such works will include a source, which may be wells, impounding reservoirs or some natural body of water as a lake or river, pumping

TABLE 1-1. STATISTICS OF WATER DISTRIBUTION SYSTEMS[3]

Population range	Average population	No. of cities studied	Miles of main per 1,000 population	Valves per mi. of main	Fire hydrants per mi. of main
0–10,000	3,600	33	5	9	6
10,000–25,000	17,200	26	3	10	7
25,000–100,000	46,500	28	3	16	7
100,000–500,000	202,000	13	2	16	7
500,000 plus	1,560,000	6	1.5	17	8.5

equipment, treatment plant, if necessary, and the distribution system, which will include the storage reservoirs, system of pipes or mains, and such appurtenances as valves and fire hydrants. The total per capita investment will vary according to local conditions as to source, whether elaborate water treatment is needed, and the topography. The time of construction will also be important, since present construction costs are high as compared with those of past decades. Total capital investment, less depreciation, will vary from $40 to $80 per capita for the older systems. The miles of mains, etc., as required by cities of various sizes are as shown in Table 1-1, which is based upon data compiled by the American Water Works Association.[3] In addition to physical plant a large force of employees is needed to operate and maintain the system, read the meters, send and collect bills. The total cost of water varies from