Water Supply and Pollution Control

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Preface

Environmental Engineering is of such tremendous scope that it is impossible to write a textbook that will comprehensively cover all of its aspects. It is necessary, therefore, to separate the subject into specific fields, to subdivide these, and to examine the parts individually from various points of view. In doing so, an attempt has been made to examine each of the parts without losing sight of its relation to the whole. This book emphasizes those aspects of Environmental Engineering concerned with the development, transportation, processing, and treatment of water and liquid wastes.

The book is designed as a textbook suitable for either a one- or two-semester course in Sanitary Engineering and Water Resources. For one-semester programs the teacher will not be able to place equal emphasis on all the material covered but will have to select certain topics for accentuation. The book will also serve as a useful reference for graduate students and practicing engineers.

No attempt has been made to treat any aspect of the field exhaustively. Advanced students will find it necessary to consult other books and, particularly, to acquaint themselves with current articles in the technical journals. The book emphasizes an understanding and application of scientific principles. It differs from other introductory books on the same subject in the selection and sequence of topics and in the choice of problems at the end of each chapter. A list of references accompanies each topic presented.

The philosophy of the textbook has been to develop each area of discussion in the most general way, consistent with the capabilities of the upper-division engineering student. The many illustrative problems show in detail how the principles are applied.

Chapter 2, "Legal Considerations," is new to textbooks on water and wastes. It was introduced because water rights play an exceedingly important role in determining the availability and use of water in many parts of the country. The purpose of this chapter is to acquaint the reader with some of the legal problems that may be encountered in water resources engineering. Much of the material in Chapter 3, "Water Requirements and Waste Volumes," is the result of research completed in the past two years. A constantly increasing rate of water use, coupled with the influence of lawn irrigation on peak demands, has resulted in a need for change in past design practices.

Chapters 4, 5, and 6 are presented with the assumption that the student is properly prepared in the areas of fluid mechanics and mathematics. Material of a highly specific nature, such as the design of dams, is completely omitted. It is felt by the authors that the proper treatment of such material is beyond the scope of the text and does not add to an understanding of the overall water problem. Changes in standards brought about by the 1962 U.S. Public Health Service, Drinking Water Standards, and the eleventh edition of *Standard Methods* have necessitated the addition of new information in Chapter 7. A unit operations approach to water and waste problems has been used in Chapters 8 through 12. It is believed that this method will be more useful to the student than a succession of studies of specific systems. This involves an integrating of topic material in fewer lectures, a separation of analysis from design, and a rational approach to design. The objective is to develop creative engineers capable of performing in a changing technology and environment. Chapter 14, "Water Reuse," is considered to be highly important because of the increasing value waste flows are assuming as a potential source for municipal, industrial, agricultural, and recreational water supplies. Chapter 15, "Water Resources Engineering," is included to introduce the student to the broader aspects of water-resources planning and development.

The authors have drawn on many sources for information contained in the book. To these they are deeply indebted. It is hoped that suitable acknowledgment is made in the form of references to these works. In particular the authors would like to thank Professor Russell C. Brinker for his help and editorial assistance, Dr. Nelson L. Nemerow for his constructive reviews, and Mmes. Ralph H. Flowers, James C. Young, and Elton Endebrock for their help in preparing the manuscript.

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Contents

chapter 1

Introduction

Air, water, food, heat, and light constitute the five essentials for human existence. Environmental Engineering concerns itself, to some degree, with all of these. This book is primarily concerned with the development, transportation, processing, and disposal of water and waste.

Water and liquid wastes must be considered simultaneously as there is but a fine line of distinction between them. One community's waste may constitute part of another's water supply. The ultimate goal in water management is the maximum economic use of the total water resource.

1-1. HISTORY

Man's search for pure water began in prehistoric times. Much of his earliest activity is subject to speculation. Some individuals might have led water where they wanted it through trenches dug in the earth. Later, a hollow log was perhaps used as the first water pipe.

Thousands of years must have passed before our more recent ancestors learned to build cities and enjoy the convenience of water piped to the home and drains for water-carried wastes. Our earliest archeological records of central water supply and waste-water disposal date back about five thousand years to Nippur of Sumeria. In the ruins of Nippur there is an arched drain with the stones set in full "voussoir" position, each stone being a wedge tapering downward into place.[1]* Water was drawn from wells and cisterns. An extensive system of drainage conveyed the wastes from the palaces and residential districts of the city.

The earliest recorded knowledge of water treatment is in the Sanskrit medical lore and Egyptian Wall inscriptions.[2] Sanskrit writings dating about 2000 B.C. tell how to purify foul water by boiling in copper vessels, exposing to sunlight, filtering through charcoal, and cooling in an earthen vessel.

There is nothing on water treatment in the sanitary and hygienic code of the early Hebrews in the Old Testament, although three incidents may be cited as examples of the importance of fresh water. At Morah, Moses is said to have sweetened bitter waters by casting into them a tree shown

*Superscript numbers refer to references at the end of the chapter.

him by God.[3] During the wandering in the wilderness, the Lord commanded Moses to bring forth water by smiting a rock.[4] At a much later date, Elisha is said to have "healed unto this day" the spring water of Jericho by casting "salt" into it.[5]

The earliest known apparatus for clarifying liquids was pictured on Egyptian walls in the fifteenth and thirteenth centuries B.C. The first picture, in a tomb of the reign of Amenhotep II (1447–1420 B.C.), represents the siphoning of either water or settled wine. A second picture in the tomb of Rameses II (1300–1223 B.C.), shows the use of wick siphons in an Egyptian kitchen.

The first engineering report on water supply and treatment was made in A.D. 98 by Sextus Julius Frontinus, water commissioner of Rome. He produced two books on the water supply of Rome. In these he described a settling reservoir at the head of one of the aqueducts and pebble catchers built into most of the aqueducts. His writings were first translated into English by the noted hydraulic engineer Clemens Herschel in 1899.[2]

An Arabian alchemist, Geber, of the eighth century A.D. wrote a rather specialized treatise on distillation that included various stills for water and other liquids.

The English philosopher Sir Francis Bacon wrote of his experiments on the purification of water by filtration, boiling, distillation, and clarification by coagulation. This was published in 1627, one year after his death. Bacon also noted that clarifying water tends to improve health and increase the "pleasure of the eye."

The first known illustrated description of sand filters was published in 1685 by Luc Antonio Porzio, an Italian physician. He wrote a book on conserving the health of soldiers in camps, based on his experience in the Austro-Turkish War. This was probably the earliest published work on mass sanitation. He described and illustrated the use of sand filters and sedimentation. Porzio also stated that his filtration was the same as "by those who built the Wells in the Palace of the Doges in Venice and in the Palace of Cardinal Sachett, at Rome."[2]

The oldest known archeological examples of water filtration are in Venice and the colonies she occupied. The ornate heads on the cisterns bear dates, but it is not known when the filters were placed. Venice, built on a series of islands, depended on catching and storing rain water for its principal fresh water supply for over thirteen hundred years. Cisterns were built and many were connected with sand filters. The rainwater ran off the house tops to the streets where it was collected in stone-grated catch basins and then filtered through sand into cisterns (see Fig. 1-1).

A comprehensive article on the water supply of Venice appeared in the *Practical Mechanics Journal* in 1863.[6] The land area of Venice was 12.85 acres and the average yearly rainfall was 32 in. Nearly all of this rainfall was collected in 177 public and 1,900 private cisterns. These

FIG. 1-1. Venetian cistern head located at Dubrovnik, Yugoslavia, showing a stone grating.

cisterns provided a daily average supply of about 4.2 gpcd (gallons per capita per day). This low consumption was due in part to the absence of sewers, the practice of washing clothes in the lagoon, and the universal drinking of wine. The article explained in detail the construction of the cisterns. The cisterns were usually 10 to 12 ft deep. The earth was first excavated to the shape of a truncated inverted pyramid. Well-puddled clay was placed against the sides of the pit. A flat stone was placed in the bottom and a cylindrical wall was built from brick laid with open joints. The space between the clay walls and the central brick cylinder was filled with sand. The stone surfaces of the court yards were sloped toward the cistern, where perforated stone blocks collected the water at the lowest point and discharged it to the filter sand. This water was always fresh and cool with a temperature of about 52° F. These cisterns continued to be the principal water supply of Venice until about the sixteenth century.

Many experiments were conducted in the eighteenth and nineteenth centuries in England, France, Germany, and Russia.

Henry Darcy patented filters in France and England in 1856 and anticipated all aspects of the American rapid sand filter except coagulation. He appears to be the first to apply the laws of hydraulics to filter design.[7]

The first filter to supply water to a whole town was completed at Paisley, Scotland, in 1804 but this water was carted to consumers.[2] In Glasgow, Scotland, in 1807 filtered water was piped to consumers.[8]

In the United States little attention was given to water treatment until after the Civil War. Turbidity was not as urgent a problem as in Europe. The first filters were of the slow sand type similar to British design. About 1890 rapid sand filters were developed in the United States and coagulants were introduced to increase their efficiency. These filters soon evolved to our present rapid sand filters with slight modification.

The drains and sewers of Nippur and Rome are among the great structures of antiquity. These drains were intended primarily to carry away runoff from storms and the flushing of streets. There are specific instances where direct connections were made to private homes and palaces, but these were the exceptions, for most of the houses did not have such connections. The need for regular cleansing of the city and flushing of the sewers was well recognized by commissioner Frontinus of Rome, as indicated in his statement, "I desire that nobody shall conduct away any excess water without having received my permission or that of my representatives, for it is necessary that a part of the supply flowing from the water-castles shall be utilized not only for cleaning our city but also for flushing the sewers."

It is astonishing to note that from the days of Frontinus to the middle of the nineteenth century there was no marked progress in sewerage. In 1842, after a fire destroyed the old section of the city of Hamburg, Germany, it was decided to rebuild this section of the city according to modern ideas of convenience. The work was entrusted to an English engineer, W. Lindley, who was far ahead of his time. He designed an excellent collection system that included many of the ideas presently used. Unfortunately, the ideas of Lindley and their influence on public health were not recognized.

The history of the progress of sanitation in London probably affords a more typical picture of what took place in the middle of the nineteenth century. In 1847 a royal commission was appointed to look into the sanitary conditions of London following an outbreak of cholera in India which had begun to work westward. This royal commission found that one of the major obstacles was the political structure, due to the lack of central authority. The city of London was only a small part of the metropolitan area, comprising approximately 9½ percent of the land area and less than 6 percent of the total population of approximately 2½ million. This lack of central authority made the execution of sewerage works all but impossible. The existing sewers were at different elevations, and in some instances the sewage would have had to flow uphill. Parliament, in 1848, followed the advice of this commission and created the Metropolitan Commission of Sewers. That body and its successors produced reports that clearly showed the need for extensive sewerage works and other sanitary conditions.[9] Cholera appeared in London during the summer of 1848 and 14,600 deaths were recorded during 1849. In 1854 cholera claimed a mortality of 10,675 people in London. The connection was established between a contaminated water supply and spread of the disease, and it was determined that the absence of effective sewerage was a major hindrance in combatting the problem.

In 1855 Parliament passed an act "for the better local management of the metropolis," thereby providing the basis for the Metropolitan Commission of Sewers, which soon after undertook an adequate sewerage system. It will be noted that the sewerage system of London came as a result of the cholera epidemic, as was true of Paris.

The natural remedy for these foul conditions led to the suggestion that human excrement be discharged into the existing storm sewers and that additional collection systems be added. This created the combined sewers of many older metropolitan areas. These storm drains had been constructed to discharge into the nearest watercourse. The addition of sewage to the small streams overtaxed the receiving capacities of the waters and many of them were covered and converted into sewers. Much of the material was carried away from the point of entry into the drains, which in turn overtaxed the receiving waters. First the smaller and then the larger bodies of water began to ferment and create a general health problem, especially during dry, hot weather. The solution has been the varying degrees of treatment as presently practiced, dependent upon the capabilities of the receiving stream or lake to take the load.

The work on sewerage in the United States closely paralleled that of Europe, especially England. Some difficulty was experienced because of the variation in rainfall patterns in America as compared with those of England. The English rains are more frequent but less intense. Our storm drains must be larger for like topographical conditions. The more intense rains tend to have a better cleansing action and in general the receiving streams carry a larger volume of water. This, together with the lower population densities, tends to produce less nuisance than is being experienced in Europe. The density of population in England and the small amount of land suited for sewage farming led to interest in methods of treating sewage before it is discharged into fresh water.

More recent developments in water supply and waste-water disposal are discussed in later chapters under the appropriate headings.

1-2. CURRENT STATUS

Increased demands currently being placed on water supply and waste disposal have necessitated far broader concepts in the application of environmental engineering principles than those originally envisioned.

The average rate of water use for the urban population of the United States is approximately 150 gpcd; peak demands have developed considerably beyond past design practices. The standards for water quality have significantly increased with a marked decrease in raw-water quality available. Considerable research is being directed toward the ultimate use of brackish or sea water for domestic supplies.

Sewage-treatment-plant effluents normally discharge into a stream, lake, ocean, or other body of water. The degree of treatment required is determined by the ability of the receiving waters to assimilate the wastes, and the uses to which the receiving waters are put.

In general practice, large bodies of water or rivers in good condition receive wastes with very limited or no treatment. Expensive treatment is necessary where receiving waters are unable to assimilate additional pollution, or where the body of water is immediately used as a raw-water source for domestic purposes or satisfies extensive recreational demands. Effluent chlorination is usually required where receiving waters are to be used for water supply or bathing.

Land disposal of sewage effluents is practiced in the United States, especially in the semiarid Southwest. Removal of settleable and floating solids is usually required prior to the effluent being distributed over the land. Many state health departments regulate the use of effluents on crops, especially vegetables that might be eaten raw. Some sewage effluents are being used to recharge groundwater reservoirs and to check salt-water intrusion. Sewage-plant effluents are being utilized by industry with varying degrees of treatment.

Surface waters used as a raw-water supply are normally treated by coagulation, filtration, and disinfection. The degree of treatment is determined by the health hazards involved and by the quality of the raw water. Well waters are normally not treated, except for disinfection. Groundwaters are becoming polluted with increasing frequency however, and require additional surveillance.

Water supply and waste-water disposal are interrelated activities of the community. Although they are closely associated, the primary accent has been on providing a safe water supply. The reasons for this are threefold: (1) the effects of an unsatisfactory water supply are usually detectable immediately, (2) the unsafe water supply affects the community served, and (3) water systems are income-producing, while sewage systems normally derive most of their revenue from taxation. Upon the informal recommendations of the state and Federal health services, water systems have been constructed and willingly improved by the community served. The construction and improvement of sewage-treatment facilities have, in many instances, come about because of and after formal complaints and court action.

Public water must be palatable and wholesome. It must be attractive to the senses of sight, taste, and smell and must be hygienically safe.

Liquid waste-disposal systems must collect the wastes from homes and industry and convey those wastes without nuisance to hygienic disposal.

1-3. PROJECTED PROBLEMS

Today, as populations throughout the world multiply at an alarming rate, it is evident that environmental control is a critical factor. Land and water become increasingly important as the population increases. Most European and Asian nations have reached the maximum population that their land areas can bear comfortably. They are faced with the problem of providing for more people than the land will conveniently support.

There are important lessons to be learned from the countries of Europe and Asia—populations increase, but water resources do not. The use and control of our water resources must be nearly perfect to maintain our way of life.

Environmental-engineering needs are far greater than the available supply of trained personnel, and future needs are certain to be even greater. The future potential of any profession is usually determined by the basic factors of demand and/or need. Demand is the less reliable guide because it is subject to change, due both to technological advances and to the instability of social trends. A need is a more dependable guide. It is born of a requirement and thrives when the requirement determines the welfare of a nation.

Environmental engineering will continue to grow in importance because it fills a definite need. The services provided by water-resources engineers are growing in importance in a world staggering under the weight of the greatest population it has even known.

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chapter 2

Legal Considerations

The interrelated and competing uses of water often give rise to varied and complex problems in regions where water supply is inadequate to meet the needs of potential users. The combined development of the water resources of an area is necessary for maximum beneficial use in most drainage basins. Some states in their water laws have recognized an integrated action of all interests, while other states have framed their laws with reference to individual action. Large-scale multiple-purpose projects have created novel problems of reshuffling rights between users and uses, between watersheds, between states, and between countries.

In many areas the virgin opportunities for water development have been largely exhausted. It is becoming increasingly necessary for cities to acquire rights to additional waters needed for their growth through legal action. These additional waters may be available in the local areas, or the water may be conveyed for considerable distance to the places of use. The Feather River project in California proposes to take water from the northern Sierra Nevada and convey it almost to the Mexican Border. This project will cover a distance of several hundred miles down the Sacramento Valley, up the San Joaquin Valley, over a mountain range, and then into Southern California. This is an extreme example but the expansion of water supply and waste-treatment facilities today requires that the engineer have some knowledge of the legal problems involved.

Water rights play an important role in determining the availability and use of water in many parts of the country. Because water law is a complex subject, the purpose of this chapter is to acquaint the reader with some of the legal problems which may be encountered in water-resources engineering.

2-1. LEGAL CLASSIFICATION OF WATER[1]

Legal differences between waters on the surface of the earth and between various classes of groundwaters have been drawn since early times. Some Western states have abolished the distinctions between these waters but in many states they still exist. It is necessary, therefore, to investigate these legal distinctions before discussing water-rights doctrines.