

WATER SUPPLY ENGINEERING

By

HAROLD E. BABBITT, M.S.

*Professor of Sanitary Engineering
University of Illinois*

and

JAMES J. DOLAND, M.S., C.E., D.Sc.

*Professor of Hydraulic Engineering,
University of Illinois*

FOURTH ~~EDITION~~
THIRD IMPRESSION

NEW YORK TORONTO LONDON

McGRAW-HILL BOOK COMPANY, INC.

1949

WATER SUPPLY ENGINEERING

Copyright, 1929, 1931, 1939, 1949, by the McGraw-Hill Book Company, Inc.
Printed in the United States of America. All rights reserved. This book, or parts
thereof, may not be reproduced in any form without permission of the publishers.

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE TO THE FOURTH EDITION

In preparing the text for the fourth edition the conflicting demands to make the text brief, to retain everything of value already in the text, and to add recent valuable contributions to waterworks knowledge presented a problem difficult to solve with satisfaction. The authors' dilemma lay in choosing between an encyclopedia and a primer, neither of which would be satisfactory. A solution has been attempted in the emphasis of functional rather than structural procedure and practical applications rather than theoretical design. The discussion of theories available in more theoretical textbooks has, in general, been removed. These omissions include much of the theoretical development of formulas in the mathematics of finances, of the hydraulics of the flow of water, of steam and reciprocating pumping machinery, of electricity, and of the epidemiology of water-borne diseases. In their place appear applications of such theories to practice in finances, hydraulics, pumping machinery, electrical equipment, and water purification. The aim, in general, has been to apply theories and fundamentals to practice in the waterworks field. Revisions and additions have been made to emphasize the timeliness and utility of the information presented.

HAROLD E. BABBITT
JAMES J. DOLAND

URBANA, ILL.
March, 1949

PREFACE TO THE FIRST EDITION

This book is intended primarily as a textbook for use in civil engineering courses as presented in many engineering college curricula. The authors have had the opportunity of presenting portions of the manuscript to their classes at the University of Illinois. In this presentation the need for a comprehensive and up-to-date text has been felt for years. The literature of waterworks is rich, and available textbooks covering such fundamentals as history, finances, hydraulics, etc., are unsurpassed. The use of such books for the teaching of fundamentals, supplemented by references to current literature, is laborious to the instructor, time consuming for the student, and unsatisfactory to all concerned. A textbook on waterworks, to be of continued value, must receive frequent revisions to keep pace with the rapid changes in practice. In preparing this book the authors have tried to combine both fundamentals and practical procedure in a single volume within the limitations of space and cost customary in engineering college texts in specialized professional courses.

Limitations of space have prevented the exhaustive treatment of all the subjects mentioned in the book. An exhaustive treatment of the subject of almost any chapter of the book would require a volume as large as or larger than this entire book. The design of dams is one subject worthy of greater space than is allotted to it. But few, if any, earlier textbooks on waterworks devote space to the subject of electrical equipment. Knowledge of the application of electricity to waterworks practice is not easily acquired by civil engineers. It is felt, therefore, that this subject should be presented for their benefit. The chapter on The Utilization of Electricity has been presented for students who have completed a study of the subject of electricity and magnetism in college physics and who have some acquaintance with the subject of electrical engineering. The space devoted to the subject is inadequate, but it has been filled with the idea that half a loaf is better than none. The textbook is not intended as a comprehensive treatise on waterworks or as a handbook. Such volumes are of little value as textbooks. In this book the student is introduced to the subject, fundamentals are stated, practice is explained, and, where desirable, references are made to articles of value on the subject. The problems presented in Appendix II should be found helpful to the teacher.

The value of a textbook in professional subjects is measured partly by its value to the engineer practicing in the same field. No book which treats the subject in an exclusively academic manner can be successful as a textbook. In this book an attempt has been made to illustrate fundamentals with practical applications thereof. Where recognized practice is based on empiricism, the procedure is explained and practical illustrations are presented.

An attempt has been made to give credit to all sources from which material has been taken. The authors apologize for any omissions of this character which may, unknowingly, have occurred. Thanks are due to the American Water Works Association, to the *Engineering News-Record*, and to others for their permission to quote from their publications.

The authors are greatly indebted to W. D. P. Warren and to Alex Van Praag, Jr., of the firm of Warren & Van Praag, consulting engineers of Decatur, Illinois, for their comprehensive and exhaustive review of the manuscript and for their valuable suggestions and contributions. Thanks are due to Prof. A. R. Knight, assistant professor of electrical engineering at the University of Illinois, for his review of the chapter on The Utilization of Electricity, and to W. N. Espy, associate in mechanical engineering at the University of Illinois, for his review of the chapters pertaining to mechanical engineering. The permission given by Dr. Elwood Mead, Commissioner of the United States Bureau of Reclamation, to reproduce the information taken from the standards of engineering practice in the Bureau is gratefully acknowledged.

HAROLD E. BABBITT
JAMES J. DOLAND

URBANA, ILL.
December, 1929

CONTENTS

PREFACE TO THE FOURTH EDITION.	v
PREFACE TO THE FIRST EDITION.	vii
CHAPTER I. INTRODUCTION.	1
Historical—Development of Water Purification—Importance of Waterworks—Reliability of Waterworks—Governmental Regulation—Legal Rights and Liabilities—Legal Rights to Sources of Supply—The Parts of a Waterworks System—The Business of Supplying Water—Appearance of Waterworks Properties—Public Relations—Waterworks Management and the Engineer—Starting a Waterworks— <i>Finances</i> —Financial Principles—Methods of Raising Money—Direct Taxation—Special Assessments—Bonds—Governmental Grants and Loans—Water Districts, Sanitary Districts, and Miscellaneous—Financing Extensions—Free Water—Fire-hydrant Service—Water Rates.	
CHAPTER II. HYDRAULICS.	21
Problems Involved—Intensity of Pressure—Total Pressure on Plane Surface—Components of Total Pressure on a Curved Surface—Center of Pressure—Flow through Orifices and Nozzles—Discharge under Falling Head—Discharge over Measuring Weirs—Broad-crested Weirs—Ogee Spillway Crests—Velocity Meters—Other Methods of Measuring Rates of Flow—Measuring Flumes—Salt-velocity Method of Measurement—Flow in Channels—Flow Formulas—Hazen and Williams Formula—Effect of Temperature on Pressure and Flow—Minor Losses of Head—Hydraulic Grade Line—Equivalent Pipes and Compound Pipes—Crossover Systems—Fire Streams.	
CHAPTER III. DEMAND FOR WATER	46
Estimates of Demand—Population and Rate of Demand—Prediction of Population—Population Trends and Growths—Rates of Water Usage—Use of Water for Specific Purposes—Fire Demand—Fluctuations in Rates of Demand—Conditions Affecting Rate of Demand—Population and Living Standards—Location and Climate—Character of District—Pressure and Quality—Intermittent Pumping—Air Conditioning—Sewers—Cost of Water—Effect of Meters on Demand—Policy of Metering.	
CHAPTER IV. GROUND WATER	64
Occurrence of Ground Water—Water-bearing Formations—Springs—Velocity of Underground Flow—Types of Wells—Well Problems—Conditions of Flow into Gravity Wells—Physical Laws of Underground Flow—Capacity of a Gravity Well—The Free-surface Curve—Relation between Q , $h_c - h_w$, and r_c —Partial Penetration—Area of Influence—Drawdown and	

Recovery Curves—Dupuit's Formula for Flow into a Gallery—Dupuit's Formula for Flow into a Pressure Well—Rate of Recovery in a Pressure Well—Interference between Wells—Examples.

CHAPTER V. LOCATION, CONSTRUCTION, AND MAINTENANCE OF WELLS	84
Location of Wells—Grouping of Wells—Legal Restrictions on Well Construction—Types of Well Construction—Dug, Bored, and Driven Wells—Drilled Wells—The Standard Method—Jetting Methods—Core-drill Method—Hydraulic Rotary Drilling—Difficulties in Drilling—Deviation from the Vertical—Depth of Well—Diameter of Wells—Log of a Well—Well Casing—Screens—Corrosion of Screens—Incrustation of Screens—Gravel-wall Wells—Finishing a Well—Protection from Contamination—Sealing a Well—Chlorinating a Well—Performance Requirements—Well Tests—Measurement of Water Level in a Well—Maintenance of Wells—Developing Wells—Blasting Wells—Surging—Acidizing and Chlorinating—Pumping Sand.	
CHAPTER VI. RAINFALL AND RUNOFF	112
Hydrology—Source of Water Supply—Precipitation—Measurement and Records—Amount of Rainfall—Distribution of Rainfall—Rate and Frequency of Intense Rainfall—Rate of Rainfall on a Drainage Area—Disposal of Precipitation—Evaporation from Water Surface—Evaporation from Land Surface—Transpiration, Consumptive use, and Interception—Infiltration—Rainfall-runoff Relations—Graphical Presentation of Runoff Data—Droughts—Runoff Records—Flood-flow Estimates.	
CHAPTER VII. DAMS.	132
Purposes—Types—Dam Sites—Porous Foundations— <i>Earth Dams</i> —Earth Dams—Hydraulic-fill Dams—Embankment Slopes—Slope Protection—Top Width—Freeboard—Berms—Classification of Materials—Core Walls and Cutoff Walls—Blankets—Safety of Earth Dams— <i>Masonry Dams</i> —Masonry Dams—Other Dams— <i>Forces on Dams</i> —Forces Acting on Dams—Water Pressure—Flotation and Uplift—Sliding and Shear—Ice Pressure—Foundation Reaction—Earthquake Shocks—Other Forces— <i>Spillways</i> —Functions—Location—Types—Overflow Spillways—Spillway Channels—Siphon Spillways—Shaft Spillways—Flashboards and Tilting Gates—Outlet Works—Logways and Fishways.	
CHAPTER VIII. INTAKES.	156
Types of Intakes—Location of Intakes—Design of Intakes—Screens—Difficulties with Ice—Intake Conduit and Intake Well.	
CHAPTER IX. AQUEDUCTS.	165
Definition—Canals—Pipe Lines—Diameter of Pipe through Which Water Is Pumped—Diameter of a Pipe through Which Water Flows by Gravity—Tunnels—Cross Sections of Aqueducts—Surge.	
CHAPTER X. STRESSES IN PIPE.	177
Loads and Stresses—Internal Bursting Pressure—Temperature Stresses—Flow around Bends—Flexural Stresses—External Loads on Buried Pipes—	

Water Hammer—Causes and Prevention of Water Hammer—Surge-tower Design.

CHAPTER XI. IMPOUNDING RESERVOIRS. 184

Function—Site Characteristics—Preparation of Site—Requisite Capacity—Losses from Reservoirs—Measurement of Capacity—Siltling of Reservoirs—Reservoir Problems—Routing of Floods.

CHAPTER XII. PUMPING STATIONS 191

Buildings—Location—Choice of Power—Classification of Pumps—Capacity of Pumps—Selection of Pumps—Piping—Surge Control—Suction Lift—Operating Schedules—Auxiliary Pumping Stations—Cost of Water and of Pumping.

CHAPTER XIII. STEAM AND RECIPROCATING PUMPING MACHINERY 201

Pumping-station Equipment—Steam Pumping Engines—Steam Turbines—Water Rates and Duties—High-pressure and Superheated Steam—Overload and Underload—Compensators—Waterworks Type of Condenser—Steam-pump Auxiliaries—Pistons and Plungers—Speed and Stroke of Pumps—Water Valves—Foot Valves—Air Chambers—Setting of Reciprocating Pumps—Steam Fire Pumps

CHAPTER XIV. ELECTRICAL EQUIPMENT. 213

Electric Power—Electrical Equipment—Electric Current—Voltages—Frequencies—Phases and Circuit—Characteristics of Electric Motors—Induction Motors—Squirrel-cage Motors—Phase-wound, or Slip-ring, Motors—Synchronous Motors—Starting Alternating-current Motors—Motor Speeds—Variable Speeds—Speed Control—Speed-reducing Devices—Special-duty Motors—Rating of Electrical Equipment—Operating Hazards for Polyphase Induction Motors—Protection of Motors and Operators—Setting of Motors—Transformers—Relays and Circuit Breakers—Switchboards—Installation of Electrical Equipment—Automatic Pumping Stations.

CHAPTER XV. CENTRIFUGAL PUMPS 227

Description—Status and Performance—Cost—Theory—Relationships of Characteristics—Centrifugal Pump Series—Characteristic Curves—Types—Selection of Size of Pump—Parts—Setting—Cavitation—Operation.

CHAPTER XVI. WELL PUMPS. 242

Types—Single-stroke Pumps—Two-stroke Pumps—Differential-plunger Pumps—Double-acting Cylinder Pumps—Power Heads for Reciprocating Pumps—Jet Pumps—Revolving Vertical-shaft Pumps—Selection of Turbine Pumps—Air-lift Pumps—Design of an Air Lift—Air-lift Boosters.

CHAPTER XVII. MISCELLANEOUS ENGINES AND PUMPS. 256

Internal-combustion Engines—Gas or Gasoline Engines—Diesel Engines—Diesel Auxiliaries—Fuel Oil—Water Power and Wind Power—Power Pumps—Jet Pumps—Rotary Pumps—Miscellaneous Pumps.

CHAPTER XVIII. MATERIALS FOR AND THE DESIGN OF PIPES.	263
Materials—Cast-iron Pipe—Manufacture of Cast-iron Pipe—Thickness of Cast-iron Pipe—Length of Cast-iron Pipes—Cast-iron Pipe Fittings—Joints for Cast-iron Pipe—Joint Materials—Poured Joints—Wrought Pipe and Fittings—Steel Pipe—Design of Plate Steel Pipe—Wood Pipe—Design of Wood Pipe—Concrete Pipe—Design of Reinforced-concrete Pipe—Asbestos-cement Pipe—Service-pipe Connections—Materials for Service Pipes—Plastics.	
CHAPTER XIX. VALVES, GATES, HYDRANTS, AND METERS	296
Valves—Gate Valves—Globe Valves—Check Valves—Check-valve Slam—Air-relief Valves—Balanced Valves—Pressure-regulating Valves—Pressure-relief Valves—Altitude Valves—Needle Valves—Ground-key Valves—Mud Valves—Sluice Gates and Other Gates—Butterfly Valves—Other Valves—Operation of Valves—Hydrants—Meters—Size of Water Meters.	
CHAPTER XX. METALLIC CORROSION.	315
<i>Theories of Corrosion</i> —Explanations—Galvanic, or Bimetallic, Corrosion—Hydrogenation—Electrolysis—Chemical Reaction—Direct Oxidation—Biological Action—Natural Protective Coating and Tuberculation—Cavitation—Selective Corrosion of Alloys—Grounding of Electric Circuits to Water Pipes— <i>Methods of Retarding Corrosion</i> —Methods—Cathodic Protection—Care in Manufacture—Alloys and Resistant Materials—Coatings and Linings—Bituminous Coatings and Linings—Resins and Lacquers—Paints—Vitreous Coatings—Zinc Coatings and Galvanizing—Metallic Plating—Metallizing—Linings—Cement Lining.	
CHAPTER XXI. DISTRIBUTING RESERVOIRS	327
Purposes of Reservoirs—Classification—Capacity—Storage to Equalize Flow—Location—Types—Depth—Foundations— <i>Earth Reservoirs</i> —Walls—Core Walls—Clay Blankets—Protection of Outlet Pipes—Linings— <i>Masonry Reservoirs</i> —Walls—Floors—Roofs— <i>Elevated Reservoirs</i> —Types—Standpipes—Materials for Standpipes—Steel Standpipes—Cylindrical Concrete Tanks—Reinforced-concrete Standpipes—Elevated Tanks—Elevated Tanks of Steel—Appurtenances for Steel Tanks—Architectural Treatment.	
CHAPTER XXII. DESIGN OF DISTRIBUTION SYSTEMS	352
Description of Distribution Systems—Design of a Distribution System—Selection of Pipe Sizes—Analyses of Pressures in Distribution Systems—Hardy-Cross Method of Analysis—Assumptions of Rates of Flow—Pressure Contours—Service Pressures—Fire Pressures—Location of Valves, Tees, and Specials—Location of Fire Hydrants—Fire Streams—Studies of Existing Systems.	
CHAPTER XXIII. CONSTRUCTION AND MAINTENANCE OF DISTRIBUTION SYSTEMS	367
Safe Practice—Work Involved in Construction—Raising and Lowering Water Mains—Disinfection of Water Mains—Work Involved in Maintenance—Records—Scraping Water Mains—Cleaning with Acids—Emptying Water Mains—Flushing Dead Ends—Air Locks—Cleaning Service Pipes—	

Cleaning and Disinfecting Reservoirs—Waste Surveys and Control—Illegal Use of Water—Finding Pipes—Finding Leaks—Electrical Sound Magnification—Permissible Leakage—Pressure Tests—Freezing of Water in Pipes—Thawing Frozen Pipes—Care of Hydrants.

CHAPTER XXIV. QUALITY OF WATER SUPPLIES 384

Considerations of Quality—Quality of Natural Waters—Calcium, Magnesium, and Sodium Salts—Hardness—Alkalinity and Salinity—Chloride—Iron and Manganese—Lead, Copper, Zinc, and Tin—Other Minerals—Methane and Carbon Dioxide—Ionic Concentration—Organic Life in Water—Bacteria in Water—Water-borne Organisms Causing Disease—Iron and Sulphur Bacteria—Microscopic Organisms—Macroscopic Organisms—Limnology—Rheology—Factors Affecting Organic Life in Water—Temperature—Stratification and Circulation Due to Temperature—Currents—Density and Viscosity—Light—Food Supply—Dissolved Gases—Eiologic Growth—Protection of Sources—Deterioration in Quality—Effect of Storage—Standards of Quality—Governmental Control over Water Quality—Purposes and Methods of Water Purification—Water and the Public Health—Diseases Borne by Water—Other Diseases Due to Water—Cross Connections.

CHAPTER XXV. INTERPRETATION OF WATER ANALYSES 411

Purposes of Analysis—Sanitary Survey—Physical Characteristics—Temperature—Color—Turbidity—Odors and Tastes—Chemical Analysis—Oxygen—Nitrogen—Chlorine and Chlorides—Alkalinity and Acidity—Hydrogen-ion Concentration and pH—Illustrations of pH Computations—Relation of pH and Acidity—Practical Applications of pH—Bacteriological Analysis—The *E. coli* Index—The Most Probable Number (M.P.N.) of *E. coli*—Microscopical Analysis—Mineral Analysis—Industrial Water Analysis—Colloids.

CHAPTER XXVI. PLAIN SEDIMENTATION. 428

Process—Sedimentation-basin Design—Theory and Practice—Depth—Period of Retention—Capacity and Number of Basins—Circular Settling Basins—Velocity of Flow—Surface Area—Relation of Length to Width—Baffles—Inlet and Outlet Devices—Covers—Sludge Storage—Draining and Cleaning—Continuous Sludge Removal.

CHAPTER XXVII. COAGULATION. 438

Sedimentation with Coagulation—Control of Coagulation—Coagulants—Coagulation with Alum—Practical Considerations in the Use of Alum—Difficulties with Alum—Residual Aluminum Compounds—Commercial Alum—Coagulation with Ferrous Sulphate—Reactions with Ferrous Sulphate—Amount of Iron and Lime Required—Sodium Aluminate—Ferric Coagulation—Ferric Chloride—Chlorinated Copperas—Handling Ferric Coagulants—Coagulation with Clay—Lime Treatment—Costs and Weights of Chemicals—Handling and Storing Chemicals—Preparation of Solutions—Storing Chemical Solutions—Stirring—Chemical Feed—Solution-feed Devices—Pipes for Chemical Solutions—Dry-feed Apparatus—Factors Affecting Coagulation—Mixing, Conditioning, or Flocculation—Measurement of Floc—Mixing Devices—Baffled Mixing Basins—Spiral-flow or

Tangential-flow Basins—Mechanical Flocculators—Agitation with Air—Coagulating Basins—Upward-flow Coagulation.

CHAPTER XXVIII. SAND FILTRATION. 460

Theory of Filtration—Types of Sand Filter—Comparison of Slow Sand and Rapid Sand Filtration—Cost of Filtration—The Parts of a Slow Sand Filtration Plant—Results of Slow Sand Filtration—Details of a Slow Sand Filter—The Parts of a Rapid Sand Filter—Design of a Rapid Sand-filter Plant—Plans and Specifications—Capacity of Plant—Filter Buildings—The Filter—Rate of Filtration—Capacity of Filter Unit—Length and Width of the Filter Unit—Wash-water Gutters—Quality of Filtering Materials—Size and Depth of Filtering Material—Filter Gravel—Underdrainage Systems—Perforated-pipe Underdrains—Pipe-and-strainer Underdrains—Ridge-and-valley Underdrains—Miscellaneous Underdrainage Systems—Air Distribution—Depth of Filter Box—Negative Head—The Loss of Head in Filter Operation—Control of Water Level on Filter—Rate Control—Manual Rate Control—Automatic Rate Control—Pipe Gallery—Washing of Filters—Surface Wash—Sand Expansion—Amount of Washing—Wash-water Pressure—Capacity of Wash-water Equipment—Wash-air Equipment—Operating Tables and Equipment—Loss-of-head Gages—Sampling Devices—Clear-water Basin—Operation of a Rapid Sand Filter Plant—Mud Balls—Cracking and Clogging of Filter Bed—Cleaning Rapid Sand Filters—Maintaining Filter Runs—Loss of Sand—Growth of Size of Sand Particles—Displacement of Gravel—Results of Rapid Sand Filtration—Permissible Loads on Filters—Pressure Filters—Double Filtration.

CHAPTER XXIX. WATER SOFTENING 504

Purposes—Results Desired—Methods of Softening Water—The Lime-soda Process—Chemistry of the Lime-soda Process—Chemicals Used—Sedimentation Basins—Recarbonation—Disposal of Sludge—Operating Expedients—A Softening Plant—*Softening with Zeolites*—Characteristics of Zeolites—Hydrogen Exchangers—Cation and Anion Exchangers—Softening with Sodium Zeolites—Limitations of Zeolite Softening Process—Zeolite Water Softeners—Size of Zeolite Softeners—Regeneration with Salt—Loss of Softening Capacity—Washing Equipment—Control of Municipal Zeolite Softening—Comparison of Lime-soda and Zeolite Processes—Synthetic Organic Detergents—Other Substances Used.

CHAPTER XXX. DISINFECTION 523

Purpose and Methods—Chlorination—Effect of Chlorine on *E. histolytica*—Amount of Chlorine Required—Leaching Powder and Quicklime—Handling Chlorine—Application of Chlorine—Application of Liquid Chlorine—Liquid Chlorinators—Determination of Residual Chlorine—Tastes and Odors Due to Chlorine—Prechlorination, Double Chlorination, and Superchlorination—Dechlorination—Break-point Chlorination—Chlorine-ammonia Treatment—Handling Ammonia—Chlorine Dioxide—Ozone—Ultraviolet Ray—Oligodynamic Action of Metals—Excess Lime—Control of Microscopic Organisms—Use of Copper Sulphate—Chlorine as an Algicide—Control of Weeds—Control of Small Animal Life.

CHAPTER XXXI. MISCELLANEOUS METHODS OF WATER PURIFICATION 544

Purposes and Methods—Iron Removal—Manganese and Its Removal—Removal of Silica—Removal of Fluorides—Removal of Certain Dissolved Metals—Removal of Color—Removal of Taste and Odor—Removal of Dissolved Gases—Aeration—Deaeration—Activated Carbon—Use of Activated Carbon—Magnetite Sand Filters—Puech-Chabal and Drifting-sand Filters—Diatomite Filters—Chemical Control of Metallic Corrosion—Threshold Treatment—Carbonate Balance—Langelier's Index of Carbonate Balance—Ryznar's Stability Index—McLaughlin's Method—Chemical Adjustment of pH—Chemical Formation of Carbonate Coatings—Chlorination to Control Corrosion—Corrosion by Hot Water—Effect of pH Correction on Zinc and Copper.

APPENDIX I. OUTLINE OF REPORT ON WATERWORKS DESIGN . 563

APPENDIX II. PROBLEMS 566

INDEX 595

CHAPTER I

INTRODUCTION

1. Historical.¹ A knowledge of the history of the development of waterworks is desirable to emphasize changes in practice and the relatively recent development of present-day waterworks methods and equipment. The history of waterworks is as ancient as the history of man. Waterworks structures are found in the excavation of prehistoric ruins. The remains of Lake Moeris, in Egypt, indicate its construction about 2000 B.C. It was the largest of the reservoirs of the Nile Valley, which supported 20,000,000 people—four times the present-day population.

In ancient times the valleys of the Euphrates and Tigris, now almost a desert, were densely populated. Four thousand years ago the rulers of Assyria had converted these sterile plains and valleys into gardens of extreme productiveness by the construction of immense artificial lakes for the conservation of the flood waters of the river, and great distributing canals for irrigation. One of these canals, the Nahrawan Canal, supplied by the Tigris, was over four hundred miles long and from two hundred to four hundred feet broad, with sufficient depth for the navigation of vessels of that time.

In India, tanks, reservoirs and irrigating canals were constructed many centuries before the Christian Era and a great part of that country was kept in the highest state of cultivation. Some of the tanks or artificial lakes covered many square miles and were often fifty feet or more in depth.

Evidences exist in New Mexico and Arizona that in prehistoric times a race, now extinct, had extensive irrigation works and cultivated large areas.

Biblical references to waterworks are frequent. For example, in II Kings 20:20:

And the rest of the acts of Hezekiah, and all his might, and how he made a pool, and a conduit, and brought water into the city, are they not written in the book of the chronicles of the kings of Judah?

And the reference to Elisha's purification of water with a coagulant which is stated in II Kings 2: 19-22.

The water supply for the city of Rome is one of the marvels of ancient times. The water was brought from surrounding hills in aqueducts totaling about 381 miles in length. The first aqueduct, the Appia, was

¹ See also BAKER, M. N., "The Quest for Water," American Water Works Association, 1948.

10 miles long and was built in 312 B.C. The Claudia Aqueduct is illustrated in Fig. 1. All these aqueducts were constructed along the hydraulic grade line in order to avoid the necessity for building pressure conduits. Iron pipe was unknown at the time. Lead was the only material available to carry water under pressure. As lead was not suitable for high pressures, it was necessary to convey water in aqueducts at atmospheric pressure.



FIG. 1.—A Roman aqueduct. Claudia of dimension stone, and Novus of brick and concrete. (From "*Frontinus and the Water Supply of Rome*," by Clemens Herschel.)

Much detail concerning the history of the water supply of Rome is presented in "*Frontinus and the Water Supply of Rome*," translated by Clemens Herschel. Frontinus was water commissioner for the city of Rome about A.D. 100 under the Emperor Nerva. His records are a most human document, revealing the intimacies of the life of the people of Rome and relating his difficulties with human nature which was prone to err then as it is today. He had considerable difficulty with persons who stole water from the aqueducts:

The cause for this is the fraud of the water-men whom we have detected diverting water from the public conduits for private use; but a large number of proprietors of land also, whose fields border on the aqueducts, tap the conduits; whence it comes that the public water courses are brought to a standstill by private citizens, yea, for the water of their gardens.

The baths constructed by the Romans are among the outstanding features of their era. The baths of Bath, England, illustrated in Fig. 2, are in an excellent state of preservation. Natural hot water still flows through the original pool. It is supposed that these baths were constructed during the first century A.D., possibly when Frontinus was governor of Britain, probably before his position as water commissioner of Rome.

Evidences of ancient waterworks that were constructed in the Western Hemisphere are to be found in Arizona, New Mexico, Central America, and the northern parts of South America. The Cenote, or Great Pool of

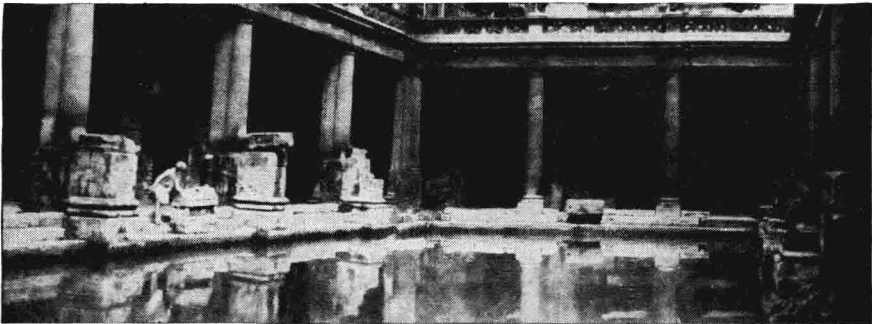


FIG. 2.—Roman baths at Bath, England.

Sacrifice, was constructed at Chichen Itzá, Yucatán, Mexico. No legible record has been left by the people who constructed this pool. It is possible that much of the work of the prehistoric races in Central America was done during the Christian Era, but proof to that effect is not certain. The aqueduct of Zempola, in Mexico, was constructed about A.D. 1560. It was about 28 miles long and supplied the city of Otumba.

During the Middle Ages in Europe there was more destruction than construction. It is probable that the use of polluted water was the cause of many of the epidemics that swept the continent. All was not destruction, however, as some aqueducts were constructed in Spain by the Moors during the ninth century, and the Roman aqueduct at Seville was repaired in 1172. London and Paris increased the capacity of the public water supplies. A small aqueduct was constructed in Paris in 1183, and water was brought to London from the outlying districts by means of lead pipes and masonry conduits in 1235. Cast-iron pipe was laid in France during the reign of Louis XIV to supply water to the fountain at Versailles.

The modern renaissance in waterworks construction is marked at the start of the nineteenth century by the appearance of steam-driven pumping machinery and of cast iron. Previous to the appearance of these

features, a general public water supply with a service connection to each house was unknown. Wood and lead were the only materials available for pipes, and, as then constructed, the pipes would withstand but little internal pressure. The first steam-driven pumping engine is said to have been installed in London in 1787.¹ Previous to this, pumps driven by the river current had been used. The first steam pumping engine in the United States was installed in Philadelphia in 1800. Cast-iron pipe was laid in Philadelphia in 1804 and in London, England, in 1807. "Public water supplies in the United States date from 1652 at Boston, about 1732 at Schaefferstown, Pa., and 1761 at Bethlehem, Pa."²

2. Development of Water Purification. The first steps in water purification were probably taken in China and India thousands of years ago. For centuries it has been the practice of the Chinese to put alum in tubs of water to clarify it. The same thing was done in Egypt:³

In the "Ousruta Sanghita"—a collection of medical lore in Sanskrit, probable date 2000 B.C., Chap. XIV, verse 15—appears this instruction: "It is good to keep water in copper vessels, to expose it to sunlight, and filter through charcoal." In the "Neghrund Bhusan"—a collection of medical maxims from the "Ayura Veda," the earliest Sanskrit work on medicine extant, of about the same date—in the chapter on water, in the last sloka but two, it is directed to treat foul water by boiling and exposing to sunlight and by dipping seven times into it a piece of hot copper, then to filter and cool in an earthen vessel.

An early reference to water purification occurs in the Bible, as follows:⁴

19. And the men of the city said unto Elisha, Behold, I pray thee, the situation of this city is pleasant, as my lord seeth; but the water is naught, and the ground barren.

20. And he said, Bring me a new cruse, and put salt therein. And they brought it to him.

21. And he went forth unto the spring of the waters, and cast the salt in there, and said, Thus saith the Lord, I have healed these waters; there shall not be from thence any more death or barren land.

22. So the waters were healed unto this day, according to the saying of Elisha which he spake.

There are but few records of advance in water purification up to the introduction of the slow sand filter or the "English system," which dates back to A.D. 1829. The first filter was constructed during this year by

¹ KIRBY, R. S., and P. G. LAURSON, "Modern Civil Engineering," p. 191, Yale University Press, New Haven, 1932.

² "Water Works Practice," p. 3, American Water Works Association, 1925.

³ *Water*, Aug. 15, 1905.

⁴ II Kings 2: 19-22.