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Urban and industrial growth in developing countries has increased the demand for water and the related need for more information on water and sewage treatment. This project, conducted by the University of Oklahoma, focuses on that need by developing a global network of adaptive and innovative technologies based on economic, social, political and cultural factors. A series of detailed reports have been produced that are designed to assist planners in their selection of suitable water and wastewater treatment processes appropriate to the material and manpower resource capabilities of particular countries at particular times.

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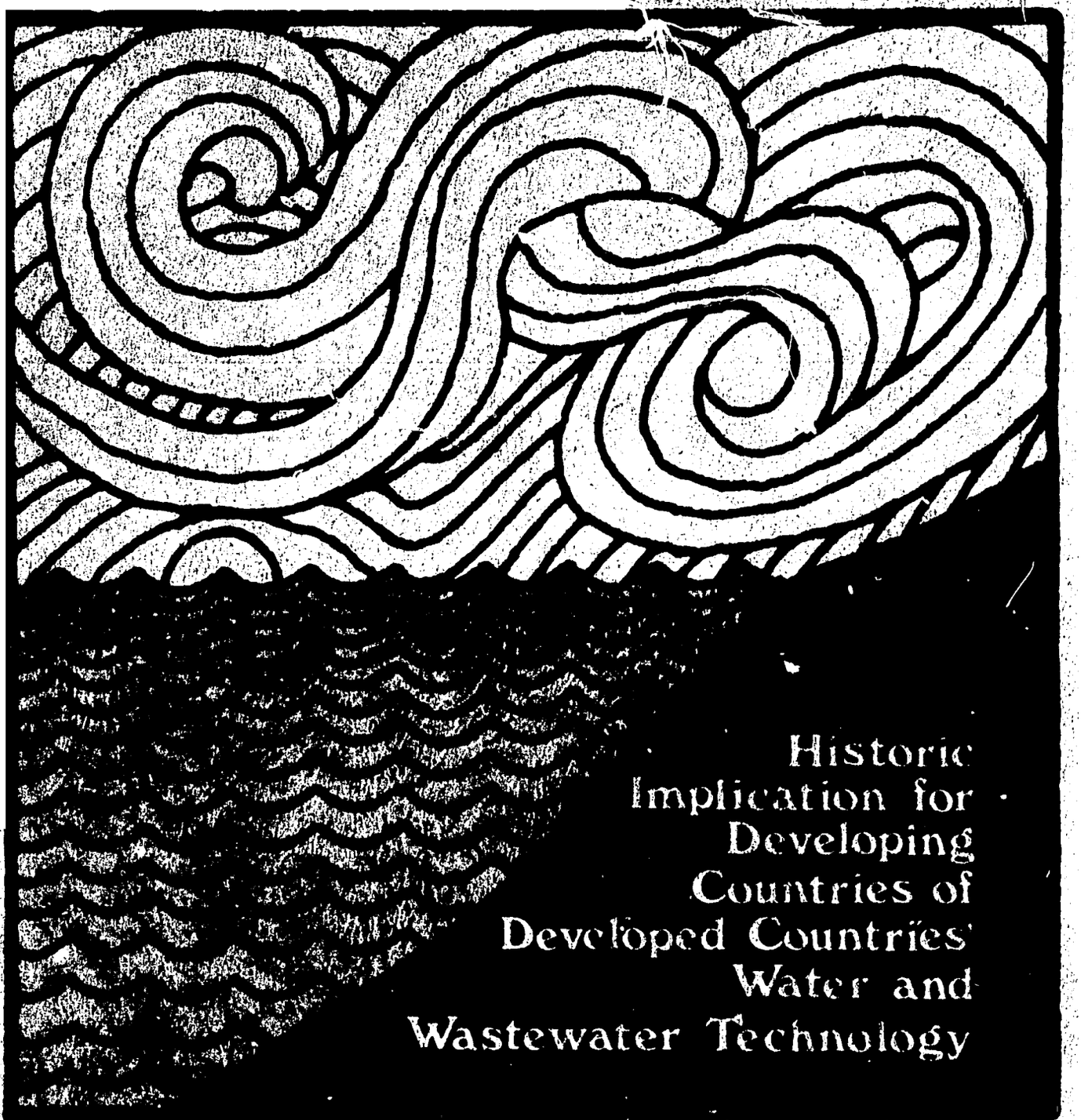

APPROPRIATE METHODS OF TREATING WATER AND WASTEWATER IN DEVELOPING COUNTRIES

THE UNIVERSITY OF OKLAHOMA
BUREAU OF WATER AND ENVIRONMENTAL RESOURCES RESEARCH
Sponsored by: U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D.C.

HISTORIC IMPLICATION FOR DEVELOPING COUNTRIES

OF DEVELOPED COUNTRIES' WATER AND WASTEWATER TECHNOLOGY

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INTRODUCTION

The thought behind this report throughout its preparation was that certain lessons can be learned from past developments in the technology of water handling and usage in developed areas that might be of benefit in accelerating progress in improvements in this field in the developing areas. Information from less developed regions was included in certain instances where it seemed of interest. The general purpose was to show that certain historically used techniques in developed regions may be applicable today in less developed areas. The idea was to find historical evidence of alternatives for those less developed regions.

The first section comprises an inventory of historically used techniques, together with associated health conditions when possible. It should be mentioned in connection with this section that it is difficult in many instances to determine the actual date, place, or originator of an invention, since often successive ideas of only partial success can eventually lead to a successful conclusion. In addition, it should be noted that inventions or patents are often in existence long before the item is actually put into use. The second section contains a description of the chronological development of water usage and handling, first in Great Britain, particularly London, and also in the United States, these being the two areas for which the most complete information was available. In the last section an attempt was made to describe life-style levels as a chronological concept in the developed areas. In addition, levels

of technology were developed as a chronological concept. Finally, an attempt was made to tie historic technology levels to the life-style levels. A time scale was developed for the principal historical regions covered by the inventory. Each regional scale was correlated with the other regional scales as well as with the chronological scales of technology levels and life-style levels.

The rationale behind this report was that there are difficulties involved in transplanting sophisticated and costly technologies from industrial areas to less developed areas. Further, there are implications to be made and comparisons which are possible between present or projected life-style levels in less developed areas, and the various stages of past life-style levels of those countries which are considered as being the most highly developed and leaders in technological innovations. When linked to technological levels, then, this information should provide historical evidence of viable alternatives for developing areas and assist in planning for those regions. Hopefully, this will aid in ascertaining appropriate and reasonable technologies for water-wastewater treatment and handling for less developed areas.

CHAPTER I

INVENTORY OF HISTORICALLY USED TECHNIQUES

Water Supply

Wells

Wells have provided sources of water since the most ancient times.[1] They were perhaps the principal source for urban areas at least up to 500 A.D. It has been suggested that some ancient wells in the region of present-day Somalia were bored to rather great depths through the limestone by means of a process of firing and cooling, a method of rock cutting known to inhabitants of that area. There is evidence of wells in Egypt as early as the fourth millenium B.C. It is said that in Egypt wells were lined with wood where they passed through sand, to a depth of 60 to 90 feet. The lower parts of the wells were narrower and cut through the underlying rock, sometimes to depths of more than 600 feet by the fifth century A.D. The most famous of Egyptian wells was the one known as Joseph's Well in Cairo.

At Chandu-daro there have been found wells of brickwork dated at about 3000 B.C. At Mohenjo-daro there were found wells of about the same period, from two to seven feet in diameter, lined with wedge-shaped bricks.

In the second millenium B.C., many wells were constructed in China, including one of about 1500 feet, the deepest known to exist in ancient times.

In ancient Palestine a phenomenon called cave-well was often found. This type of well sometimes developed when the water table fell, and digging laterally along a fissure was done in order to follow the water. In the case of

fortresses tunnels were provided which would lead from within the walls to the source of water, when it fell at a distance outside the walls. One such device used at Megiddo, has been dated as early as the twelfth century B.C.

The first lined wells in Athens, Greece, belonged to the fourth century B.C. Early lining was by means of terra-cotta drums in section. Greek wells in Troy were lined with stones jointed with clay.

Roman wells were usually lined with wood, stone, or brick, and cement jointing was utilized. To locate groundwater, Vitruvius suggested lying on the ground before sunrise to observe the rise of moisture, as well as noting the type of soil and vegetation present. In the seventeenth century, in certain districts of Italy, wells were dug until water was reached. Then two cylindrical walls were constructed concentric to one another with the space between filled with clay to keep out surface water. Afterwards the well and the inner wall were continued to a lower level.

Wells were the main source of water for Maya and Inca villages and towns.

A feature of the nineteenth century was the development of the artesian well, which took its name from Artois in France, where it is supposed to have originated in 1126. It is possible that this was a Chinese idea transported by Arabs. The nature of this type of well is such that it has a small bore taken to great depths and carries a flow of water with adequate head, to overflow the top of the bore.

Early in the nineteenth century, borings were lined with iron tubes, and since then wells have been taken to increasing depths, reaching thousands of feet in this century, where necessary.

Reservoirs and Dams

In a large reservoir, the water impounded is subjected to a purifying process due to the removal of bacteria, in particular the disease-causing bacteria which do not survive at lower temperatures.

The ancient Egyptians impounded water. One of the earliest impoundments was Lake Maeris of 30,000 acres, adjacent to the Nile.

In Yemen ruins of a masonry structure are thought to be the remains of a water storage dam, the Marib dam, dating back to the tenth century B.C., and apparently failing in the sixth century B.C.

In Aden are the remains of fifty large reservoirs and cisterns, some believed to date from ancient times.

In Mesopotamia with Babylon as the capital, in the first half of the sixth century B.C. Nebuchadnezzar marshalled resources to construct reservoirs and dams.

The Romans constructed many large reservoirs throughout the Empire.

The Mayans collected rainwater in reservoirs cut out of porous limestone and sealed with cementing material. Tikal, the largest Mayan city of the fifth century A.D., obtained its water supply by damming two nearby ravines.

In the 1800's in England, large towns placed dams across shallow valleys to create reservoirs. They built earth dams with a core of puddled clay and flat outer slopes. There were some failures including a dam at the Dale Dike reservoir in 1864.

French engineers built masonry dams, such as the one in 1866 at St. Etienne in the south of France. The first high masonry dam in Britain was built in the 1880's to supply Liverpool.

Dewponds

In the chalk hills in the south of England are found many earthworks with so-called "dewponds" attached. A possible explanation of the origin of these ponds is that they provided a source of water to a neolithic or perhaps less ancient man, who found it necessary to establish permanent settlements in hill-forts located on elevated ground. It has been determined that there is some recruiting agent which keeps the ponds fairly well supplied with water in times of drought when neighboring streams or other ponds at a lower elevation have gone dry.

There are conflicting theories on the method of construction of a "dewpond." One of the most common is as follows:

> The first step is a shallow bowl-shaped hollow excavated in the chalk. This is lined with dry straw or reeds, puddled with clay (which must effectually cover the edge of the straw) and the upper surface of the clay strewn with stones. The reservoir so made then being ready for action, it has been suggested that the pond was "started" with a little water.[2]

The subsequent filling of the pond is also a matter of controversy. Rainfall is suggested as one agent. In addition, it is thought that a significant amount of moisture probably comes from low lying clouds and mists, the water collecting in the pond by gravitation. Probably true dew accounts for very little of the accumulation.

Rain Collection

In early Mesopotamian cities the typical middle-class dwelling had rain water spouts which carried roof drainage to a central cistern or sump.

Some Mayan cities obtained water by storing rainwater runoff from roofs in underground cisterns.

At the Aztec settlement at Gran Quivira, New Mexico, ditches and canals led to reservoirs for storage.

Since the founding of Venice in the fifth century A.D. and for 1300 years thereafter, this city built on many islands depended primarily on catching and storing rainwater in cisterns.

In the past, in some parts of Montenegro and in the arid plains of the Ural provinces of Russia, snow was stored in the winter for water supply.

The troglodytes of Algeria dug "cuvettes" to catch rainwater. A pipe led from the cuvette to a cistern for storage.

In Gibraltar a catchment area was formed by facing a large surface of the eastern slope with galvanized iron sheeting.

Springs

Where available, springs were used as a natural and easily utilized water supply. Sometimes springs were deepened into shallow wells, and these were lined with tree trunks or other materials.

Irrigation Works

These played an important role in domestic supplies for early urban areas in Mesopotamia, Egypt, India, and China, as well as in the Middle East.

Transportation

Localized Supplies vs. Aqueducts and More Distant Supplies

Often, as in ancient Rome, cities have initially taken their water supply from local surface or ground supplies. When these become inadequate, it becomes necessary to transport from distant supplies.

Hangchow in China as early as the eighth century A.D. had for water supply a lake located near the city. Earthenware pipes brought water to cisterns in the city.

In the medieval period London relied on springs, wells, and streams or rivers within the city. In the eleventh century and later aqueducts were built to bring water to London from the Thames, Fleet, and Walbrook rivers. The town of Tiverton made use of an open canal aqueduct built in 1240 which tapped springs outside the city. During the late Middle Ages English towns began bringing water to the cities through lead pipe aqueducts. All British aqueducts of the late Middle Ages were of the gravity flow type, no use being made of the inverted siphon.

Paris came to be Europe's largest city after the decline of Rome. During the Middle Ages Paris depended on the Seine and upon local wells. In the twelfth century two monasteries in Paris constructed aqueducts to bring in water from springs.

Kanats

Kanats originated probably as early as the fourth millenium B.C. They are subterranean aqueducts used to transport groundwater from an underground aquifer to the point of use at ground surface. Structures of this type are still extant in Persia and Syria, where they have been used

primarily for irrigation and urban or village supplies since antiquity. In constructing kanats, a shaft was sunk, perhaps 300 feet, to the water-bearing stratum. A few feet from the bottom of the shaft, a tunnel was placed to connect horizontally with other wells, and hence to carry the water collected to its destination, which could be as much as fifty miles away. The wells were placed at intervals of from thirty to eighty yards. The tunnel was about four feet high and two feet wide, and sometimes unlined or sometimes lined with large oval hoops of baked pottery two inches thick and one foot wide. In later times pipe was used for this purpose. Openings were provided at intervals along the route of the conduit to permit cleaning out of accumulations of settled mud or sand.

Similar channels have been used in Iraq, Yemen, and in North Africa where they were called "foggaras." Cyprus, too, had a kanat-like water system. There soil was removed from the excavations by means of a basket and rope operated by a primitive windlass formed of a cradle of horizontal wooden bars. If valleys lay in the path of the conduit, they were spanned by masonry aqueducts.

There are significant problems associated with the use of a kanat. It is expensive both to construct and maintain. If the tunnels are unlined, there is a heavy loss of water in the system, and the tunnels must be cleaned periodically. Frequently a source dries up or changes take place in the tunnels, necessitating a new kanat.

Aqueducts

Certain early instruments were useful to the construction of aqueducts, to maintain uniform gradients and alignment of tunnel

construction. The dioptra was developed by the Egyptians for levelling. It consisted of a plumb line suspended from the apex of a right angle isosceles triangle. Another form of dioptra used by Hero of Alexandria consisted of a water horizon on a circle marked in divisions. To lay out right angles the ancient Romans made use of an arrangement of plumb lines known as the "groma." Another levelling device used by Romans was the chorobates. This was a table about twenty feet long fitted with a water table and plumb bobs. In most cases Roman aqueducts were constructed with a steeper grade than necessary to allow for error from these instruments.

During the ancient construction of aqueducts, stone masonry was the principal building material; later during the middle ages, lead, wood, or earthenware pipes were preferred; in modern times aqueducts of larger capacity were required, and open channel and stone or brick masonry conduits regained favor, except where high pressures require reinforced concrete or steel.

An inverted siphon was used in the eleventh century B.C. to bring water to Jerusalem. Two aqueducts were fed from springs, one of which was about forty miles in length. Most of the length of the aqueducts was open channel, but some sections were tunnel. The inverted siphon conduit was made of cut stone blocks with a circular opening in each, fitted to form bell and spigot joints sealed with clay mortar.

In Assyria a causeway of stone 900 feet long by 75 feet wide was determined to have been a part of a great aqueduct dating from about 700 B.C., for the supply of water to Nineveh. The bridge crossed

a ravine and was constructed of blocks of ashlar masonry covered by a layer of concrete and a pavement over which the water flowed, between parapets nine feet wide.

A Phoenician aqueduct was found at Sidon which brought in a supply of water from a spring at the southern end of Lebanon.

The Greeks apparently operated aqueducts under pressures as high as 250 to 300 pounds per square inch, making greater use of the inverted siphon than did the Romans. Little remains today since little use was made of masonry structures. They used pipes of wood, metal, or clay tile.

In the sixth century B.C. water was brought to Athens, Greece, in underground conduits. At Olynthus in Greece, excavations dating from the fifth century B.C., yielded evidence of an aqueduct ten miles in length, of terra-cotta pipes jointed with cement in a subterranean tunnel with vertical shafts provided at intervals. In about 200 B.C. at Pergamum in Asia Minor, the Greeks installed an aqueduct on the principle of the inverted siphon. The pipes were laid through rectangular stones pierced with circular holes, standing on their edges at intervals of about four feet apart in a trench. The stones were four to five feet long, twenty-four to twenty-seven inches wide, three to ten inches thick, with holes about one foot in diameter.

Many other examples of water supply from aqueducts could be given. However, it was the Romans who made great strides in the system of aqueducts and organized water supply. The same system as that found at Rome could be found in other parts of the Empire. The aqueduct constructed by the Roman Emperor Hadrian for the city of Athens (134-140 A.D.) was one of the

major tunnelling projects and engineering achievements of ancient times. Rock excavating was by drilling and wedging, or by firing and cooling. Sextus Julius Frontinus, Water Commissioner of the City of Rome (97-104 A. D.), left a very complete account of the water supply of Rome as it stood at that time. His treatise, Two Books on the Water Supply of Rome, was the first known detailed description of works built to improve the quality of a public water supply, and the only contemporary engineering records of such works until after the Christian era.[3]

According to Frontinus, for the first 441 years of the city of Rome, water was supplied by the Tiber and private wells. Then the aqueducts began to be constructed one by one. The nine main aqueducts described by Frontinus are included in the following table. Later four other aqueducts were brought into the city: Trajana, Alexandrina, Septemiana, and Algentia. Some of these ancient aqueducts were still functioning during the first half of this century. In the time of Frontinus, the waters from the various supplies were designated for different functions according to their purity, some being reserved for drinking purposes and some for the meaner uses of the city. It has been estimated that the eleven principal aqueducts serving Rome probably brought in about forty million gallons a day.

According to Vitruvius (Marcus Vitruvius Pollio, an architect and military engineer of the first century A.D.) aqueducts should decline at least one foot in 200. Where closed, underground air vents were placed every 240 feet. Sub-structure or above-ground channels were made of concrete faced with brick. Overhead aqueducts or "bridges" were constructed in masonry, usually reinforced with

TABLE 1

NINE MAIN ROMAN AQUEDUCTS DESCRIBED BY FRONTINUS

Aqueduct	Date B.C.	Distance of Source*	Length of Conduit*		
			Total	Underground	Above Ground
Appia	312	7-8	11	Nearly all	100 yds.
Anio Vetus	272	20	43	Most	¼ mile
Marcia	146-140	36	Nearly 62	54	7½
Tepula	127	10	See Julia		
Julia	33	12	15½	8	7½
Virgo	21	8	14	12 3/4	1¼
Alsietina	Time of Augustus	14	22	Nearly all	About 1/3 of a mile
Claudia	38 A.D.	38	46½	Nearly 37	9½
Anio Novus	50 A.D.	42	58 3/4	49¼	9½

SOURCE: Sextus Julius Frontinus, The Two Books on the Water Supply of the City of Rome of Sextus Julius Frontinus, Water Commissioner of the City of Rome, A.D. 97, explanatory chapters and trans. Clemens Herschel (Boston: Dana Estes & Co., 1899), p. 125.

*Distances are given in Roman miles which can be taken as about 1616 yards long.

walls of concrete faced with brickwork. A mortar was used made of lime, clay, and sand. Elevated channels were troughs of brick or stone lined with cement and covered with a coping, usually arched. Most often water ran directly through the trough. Sometimes it flowed through pipes of lead or terra-cotta which were laid along the trough. Piscanae or settling tanks were located along the route of the aqueduct to remove sediment.

The decline of the Roman Empire brought a halt to these efforts at systematic water supply. In 537 A.D. when the Goths beseiged Rome, they broke the city's conduits. The population dwindled till by the tenth century A.D. Rome again used the Tiber as a water supply. Later, at various times, repairs on the aqueducts were made. For the most part, Europe during the Middle Ages had to rely upon wells and localized supplies of water, until long distance distribution came into practice in the monasteries, this time by means of piping.

Elsewhere, in the Middle East, at the end of the ninth century the Sultan Ahmed of Egypt, in building the new city of Cairo, through the efforts of his engineer, Ibn Katib al Faighani, brought water to the city on an arched viaduct utilizing methods similar to those found in the construction of the Roman aqueducts. A second aqueduct to bring water to Cairo was constructed by Saladin in the twelfth century.

In the western hemisphere, the Incas, Aztecs, Mayas, and cliff dwellers had communal water supplies utilizing aqueducts and reservoirs. An ancient subterranean aqueduct occurs at the Maya site of Palanque. Also, the Inca citadel of Sajsawaman was provided with

a stone subterranean aqueduct, and there are traces elsewhere of Inca aqueducts. They are referred to as stone-lined conduits or open canals following the contours of the ground. The Inca civilization culminated in the Inca Empire of the fifteenth century. The Aztec city of Tenochtitlan (Mexico City) of the fourteenth and fifteenth centuries first utilized local springs. In 1440 the ruler Montezuma I constructed an aqueduct to bring water from springs outside the city. The aqueduct was of stone masonry channels with mortar joints and fed a public fountain in the center of the city. A second aqueduct was built in 1503.

Leats

Leats were open channels following the contours of the land. They were constructed by the Romans without the use of masonry and have been found in Britain. In 1590 Sir Francis Drake constructed a leat at Plymouth. The ditch was six to seven feet wide with concrete floor and granite side slopes. The leat was much used to transport water in the west of England in the 18th century.

Predecessors of the Pump

The history of the raising of water began with irrigation. In Mesopotamia organized irrigation started at a very early date, the earliest example dating from about 4000 B.C. In the various areas where irrigation was practiced, several methods were (and still are) used for this purpose. The simplest method was one in which two men sit one to either side of a channel and swing between them by means of ropes, a flat basket. The basket catches water from the lower channel and raises it to a higher level, perhaps a three foot lift, where it is

deposited as the basket is tipped at the end of the swing. This method is still used in India and China.

A link-chain pump type was used in China from some three thousand years ago. For this an open trough contained pieces of wood fitting the full width, attached to a chain, and pushing the water before them. They were operated by cranks or by treadmills.

In Egypt, as early as the eighteenth dynasty (fourteenth-sixteenth centuries B.C.) and perhaps earlier, the counterpoise principle was used in the shaduf, still in use today. The shaduf consists of a central support across which is balanced another beam with a weight on one end, usually of mud, and a water vessel on the other. "Shadufs" are generally used on lifts from ten to eleven feet. Although the shaduf seems to have originated in the Nile valley, it was or is found in many parts of Europe and Asia. Earliest use may have been 2400-2200 B.C. in Babylonia. In medieval times a device similar to the shaduf was still in use in England. A similar device is the "pirotah" or "kuphar" of India, where one man raises or depresses the water vessel by walking back and forth on the beam while another empties the bucket into the trough for delivery. Another variant found in India is the "spoon" lever, in which a long log of wood is hollowed out like a spoon. The bowl end is depressed into the water source. When it is tipped the other way, the water flows to the other end and is descharged at a higher level.

The saqieh, noria, or Persian wheel was thought to have been introduced into Egypt before Roman domination. Its original form is a vertical wheel on the rim of which water pots are attached to cords. Another smaller vertical wheel with cogs is fixed on the same

axis and engaged with the cogs of a large horizontal wheel turned by an animal walking in a circle, or by water power. The pots dip in the water as they descend, and subsequently are discharged into a trough feeding a channel. The Persian wheel may be found from China to Mexico.

The endless chain or chain of pots another form of noria, was supplied power by a crank or treadmill. Pots attached raised water. This device was still used at Bruges in the 14th century.

Another method of water raising was and is the "taboot" or screw. It is essentially the screw of Archimedes (287-212 B.C.).

A windlass, described by ancient Greek mechanicians, consists of supports and a cylinder rotated by a crank. A rope of light chain winds around the cylinder and raises a water vessel on the other end of the rope.

In Asia and China, toward the tenth century, windmills came into use for irrigation or drainage. Arabs probably introduced windmills to the West. They were initially used only for the grinding of grain.

In 1541 Agricola described a pump with leather-and-horsehair balls. An endless chain to which the balls were attached passed through wooden pipes banded with iron.

Often, instead of raising water for domestic use, by means of some type of pumping device, steps have been provided for the water drawer to descend in order to gain access to the supply.

Pumps and Their Source of Power

The invention of the force pump is attributed to a Greek, Ctesibius, the third century B.C. It is thought the pump was operated by hand only. Robins, in The Story of Water Supply, related a description by Vitruvius of a Roman pump of the first century A.D.

> It was made of bronze; it had at the bottom a pair of cylinders set a short distance apart and a "Y"-shaped pipe connected with both, joining them to a vessel between them. In this vessel were flap valves fitting over the upper vents of the tubes to prevent water forced up to the vessel from returning. Over the vessel was an inverted funnel fastened to it by means of a wedge thrust through a staple to prevent it lifting under pressure of water. Valves were inserted in the cylinders beneath the lower vents of the pipes and over the openings which were in the bottoms of the cylinders. Pistons, which were oiled, worked in the cylinders and, as the valves stopped up the openings, forced the water by repeated pressure and expansion through the vents of the pipes into the central vessel, from which it passed up a pipe at the top of the funnel, so supplying water to a fountain head from the reservoir at a lower level.[4]

The figure which follows illustrates a Roman pump of a type similar to the one described by Vitruvius and which dated from the first century A.D. onwards. This one was found at Silchester, a Romano-British town in England. This pump was a double forcing pump. This pump was operated by hand, and would only work when submerged, being used for domestic water supply. The two barrels were lined with lead tubes, and the body of the pump was cut out of a block of wood. Certain examples found have had pistons of about one inch in diameter and a stroke of from about three to five inches. After the Roman era, there is a lack of evidence of the use of pumps, until the fifteenth century.

In the fifteenth century primitive pumps of the piston or plunger type were developed in central and western Europe and were supplying water to many cities. By the 16th century there were in

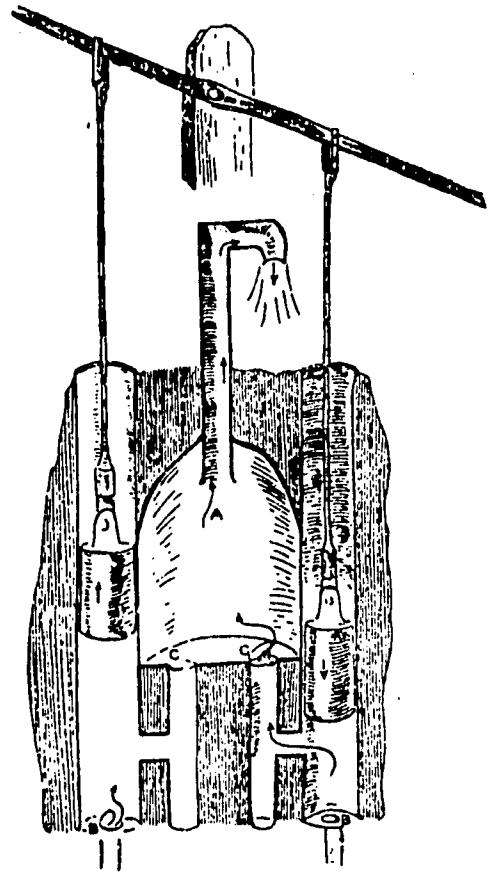

Fig. 1. Roman force pump, Silchester, England

SOURCE: F. W. Robins, The Story of Water Supply (London: Oxford University Press, 1946), p. 78, copyright of Reading Museum.

use single acting and double acting suction and force pumps, as well as a form of centrifugal pump and ball and flap valves. Metal working was limited in its technology. Thus wood was used with few metal parts which were finished by hand. There was no uniformity in size of parts.

From 1582 to 1822 in London there was utilized a waterwheel method of pumping water up from the Thames at London Bridge to supply the eastern end of the city. The design was instituted by Peter Morice or Morris, a Dutchman, the system seemingly having originated in Germany at the beginning of the 16th century. The design used force pumps driven by a wheel which was in turn driven by the current of the river. In most uses of this design, wooden forcers covered with leather and barrels of bronze or wood were used.

The first waterwheel-reciprocal pump installation in Paris was made in 1602 and this type of installation was used till the middle of the 19th century. Rannequin, a French engineer, made use of systems of waterwheels and pumps. At Pont Notre-Dame in Paris three throw pumps were used to raise water into a tank which fed force pumps. In this way the force pumps could be placed above water level and were accessible for maintenance. In 1682 Rannequin carried out a plan to supply the palace, gardens, and fountains at Versailles. This system used fourteen water wheels and 253 pumps, arranged in three lifts. The power was transmitted to the pumps by reciprocating rods and the most distant pumps were more than six hundred yards from the river. This system was less than twenty per cent efficient.

George Scorrold of England developed a modification of the waterwheel which improved their reliability. Scorrold's wheels

were constructed to rise and fall with the level of the stream. In 1693 this principle was patented by John Hadley, one of Scorrold's associates.

The water wheel as a source of power for water supply lasted well into the nineteenth century. However, in 1630 Somerset in London invented a water pumping engine utilizing steam. Later inventors of steam-powered pumps included Thomas Savery of England and Denys Papin in 1690. The Newcomen steam engine (1720) was adopted for water works purposes. Later, the steam engine patents of Smeaton, Watt (1795), and others were adapted to waterworks pumping installations. In the Kensington Area the use of steam replaced a mill turned by horses, and elsewhere the use of windmills was discontinued. In Paris the first steam-powered water pumps were installed in 1776. The first steam-driven pumps in the United States were installed at Bethlehem, Pennsylvania in 1754.

As changes took place in the power source for raising water during the 1700's in England, developments were also taking place in pump manufacture, including the use of metal throughout and the introduction of piston rod glands. Pumps used for water distribution in this period were usually of the sucking and forcing bucket type.

In modern times the plunger pump has been developed into the triple expansion pump, but has been replaced by the rotary and centrifugal pumps. Actually the principle of the rotary pump was described by the Italian Ramelli in 1588. Cheap electrical power sources have enabled municipal plants to operate at economical levels.

Pipe, for Supply and Drainage

According to the Copper Development Association, copper piping covered with gypsum and dating from about 2750 B.C. was discovered at Abusir, Egypt. It was made by hand-hammering a thin sheet of copper and then folding it up.

At Chandu-Daro, Sind, pottery drainpipes dating from the third millenium B. C. of spigot and socket type were found which ante-date water pipes of exactly similar type found in the Mediterranean area.

In Crete terra-cotta pipes with cement joints were found in the Palace of Minos at Knossos (about 2000 B.C.). These pipes thus ante-date similar earthenware pipes used during Roman and medieval time. Two types were found. For one type the sections were tapered, the smaller end of one section fitting into the large end of an adjacent section. The smaller end was provided with a stop flange a few inches from the end. The second type was like the first with one addition. Here the sections were equipped with side loops so that the separate sections could be fastened together. Each section was a little more than seventy centimeters long.

At Sidon the Phoenicians used aqueducts to bring water to the city. Along the route of the aqueduct have been found earthen pipes encased in lead which would take the higher pressures of the inverted siphon which would have occurred at the valley crossing leading to the city.

Excavations at Olynthus in Greece, dating from the fifth century B.C. yielded details of an elaborate water supply in terra-

cotta pipes. The pipes were jointed with cement, and a square elbow of pottery was found. Terra-cotta pipes had also been used for drainage at this site.

In the Roman Empire there were four materials which were usually used for pipes: earthenware, lead, wood, and stone. Concrete was also used. Bronze was used infrequently in pipes, for cases where pressures were high. This material was used commonly for stop-cocks, jets, and spouts. Water outlets were often in the form of animal heads or dolphins. It is interesting to note that the dolphin water outlet is prevalent in Nepal and also found in parts of India, Tibet, and Java. Wood was high in tensile strength, but deteriorated rapidly. Stone, concrete, and terra-cotta were durable, but low in tensile strength. Lead was durable but not resilient, so it was difficult to make the joints water-tight. Vitruvius is said to have expressed a preference for earthenware over lead, because of its being more wholesome and also easier to repair. The earthenware pipes were cylindrical and had joints of the spigot and socket type. Joints were sealed with a mixture of quicklime and oil. Ashes mixed with water were sent through the pipes before first use in order to stop leakage from any imperfect joint. Lead pipes were usually oval, made of sheet lead which was folded into the form of a tube, and soldered along the seam. Sections were normally ten feet in length. The Latin word for lead, plumbum, gave the name to the associated craft of plumbing.

As the Middle Ages began in Europe, stone channels seem to have been more usual in long-distance supplies, while piping was

more characteristic of the fourteenth and fifteenth centuries. Distribution through pipes of wood, earthenware, or lead, seems to have begun in the larger monastic houses. In the Middle East, by contrast, pottery pipes for the distribution of water could be found as early as the eighth century A.D. in a palace of Caliph Hisham which was located in Jordan.

By the early 1600's in London, some domestic supplies were carried in lead pipes of the sheet lead Roman and medieval type. Seventeenth-century pipes of cast lead have been found elsewhere in England.

The mains of the New River Company of London (1613-1904) were first of wood. A description of them found in Robins' book follows:

> Usually they are of elm. They were made from the solid trunk, bored, and laid with the bark left on for external protection. The joints were of the spigot and socket type, the spigot being the smaller tapered end of the log or trunk, which was coated with white lead and driven into the larger end, the latter being reinforced by an iron band driven in. These end bands were of one inch or one and a quarter inch by one and a quarter inch iron, with the inner edges "feathered" to facilitate driving. Y's and T's were at first provided by utilizing the natural forks of the trees. Services were usually of lead. Connexions in case of firs were obtained by the rough and ready method of chopping a hole in the pipe which was afterwards stopped by a plug. As the positions of these plugs were (or should have been) marked to prevent unnecessary additional damage, they became "fireplugs" and gave rise to the term.[5]

Wooden pipes had to be replaced about every fourteen years. Often several lengths were laid together to increase the capacity. At Paisley, Scotland, the first known filter for treatment of a city-wide supply, put into use about 1804, used 200 feet of three inch bore wooden pipe of Scots fir. Wood stave pipes were still in use in some places in the United States as late as 1940, also in Chinese

Turkestan, Scandinavia, Tokyo, and elsewhere. Oak and cedar trunks have been used in addition to elm.

Henry Doulton produced glazed earthenware pipes for house drainage in the 1840's. Carelessness in laying of the pipes sometimes led to problems.

Blast furnaces were first used in Europe in the fourteenth century. This enabled iron to be melted and then cast into molds. Because charcoal was the only fuel, this was difficult and expensive. In the 1700's in England, coke was used and the process became cheap enough to manufacture pipes and cast in molds with a steel bar as a core. Thus a new pipe material, cast iron, made its appearance. First flanged joints were used, later lead, cement, and wooden wedges as jointing materials. The London Bridge Company had 1800 yards of iron pipe main as early as 1745. Cast iron had already been used in mains at Versailles in the last half of the seventeenth century, but this was almost a century before general recognition of the durability of the new material. In 1817, cast iron pipes were introduced in Philadelphia, and bored logs began to be replaced as conduits in the United States. At first iron pipes were not popular with engineers because screw joints were used which suffered from expansion. The Delavaud patent of 1914 introduced a new process of centrifugal spinning of iron pipe which increased its strength and decreased its comparative weight. Ductile iron has also been used in piping.

In 1820 Thomas Burr in England made the first practical machine for manufacturing lead pipe by extrusion.

In 1825 steel tubes were turned out by the butt welding process. In this process the edges of a sheet of steel are brought together by passing through a die. Next was developed the lap-welding method usually employed for steel mains. About 1900, solid drawn steel tubes began to be made from billets pierced and rolled out over a mandrel, and soon these began to be used for water mains.

The temperatures and pressures necessary to manufacture copper pipes by extrusion were reached in 1893. The pipes required a thick wall to allow for a screw thread for jointing. This made them expensive and they were used only in high-quality plumbing work. In the 1920's compression joints were developed, and in 1934 the capillary joint. Copper became a popular plumbing material for smaller diameter connections because it was strong, light, easily manipulated, and would not corrode.

In 1862 an inventor of Birmingham, England, Alexander Parkes, discovered how to make a composition of cellulose nitrate which was soft when hot, but hard and transparent at room temperature. He called it Parkesine. In the United States, John Welsey Hyatt improved Parkes' material and received a patent in 1870 on what he called celluloid. In 1931 PVC (polyvinyl chloride) pipe was developed by German scientists, in 1941 thermoplastic pipe in the United States, and in 1948 PE (polyethylene pipes).

The pitch-fibre pipe was introduced for drainage in 1906 when drains were installed in Orangeburg, New York. These pipes are made of pulped newspapers impregnated with bitumen. In 1942 the pipes were dug up and found in excellent condition.

Asbestos-cement pipe was developed in Europe prior to World War I. This type of pipe resists soil corrosion. In the late 1930's the province of Saskatchewan, Canada, installed its first pipes of this type.

Water Treatment

Introduction to Water Treatment--Methods and Standards

In general, there has been quite a lag between the discovery of principles and techniques for treating water and improving its quality, and the time when those principles and techniques were put to use to any large extent. In presenting a generalized summary of the development of water treatment, the simplest stage would be one in which perhaps no treatment would be attempted, with persons simply moving to a better supply. The use of sedimentation and of filtration through porous vessels would have evolved very naturally, with the knowledge of coagulation coming later. Filtration was known by ancient peoples as well as the use of wick siphons, and distillation. These are basically the methods which were in use for water treatment until the 1890's. Since then other advancements have been made including such things as pH control, softening, as well as some attempts to add elements to the water to make up for deficiencies, iodides and fluorides, for example. From 1923 to 1933 attempts were made to add iodine to the water where it was insufficient to prevent the occurrence of goiters among the populace. The use of fluorine in the water began with plant studies in 1945.

The earliest water standards were based on clarity, taste, and odor. An early means for determining the quality of the water found in a region was suggested by Vitruvius, namely by observing the appearance and health of the inhabitants of that locality. Later methods to determine purity were the determination of the quantity of oxygen or chlorine present, or the presence of nitrites, or of certain

types of bacteria.

The example of Albany, New York, in the 1870's provides an outstanding example of water analysis and standards which resulted in disaster. In 1872 the water commissioners of Albany, New York, engaged Professor Charles F. Chandler of Colombia University to determine the quality of the water in the Hudson River and its suitability as a municipal supply. His report was based on only one sample which was examined for various salts, hardness, and organic and volatile matter. He wrote,

> The suspended impurities which rendered the water turbid being temporary in character were allowed to subside . . . . The organic matter in water really demands the closest scrutiny . . . . [That derived] from sewage, though highly dangerous in certain stages of decomposition, [is] speedily changed by the oxygen held in solution in running water, to forms which are innocuous.[6]

Chandler determined that the Hudson River water was satisfactory in its organic content. Chandler wrote that no sewage of consequence was discharged into the river except at Troy and that the volume at Troy "is so small in comparison with that of the river . . . [that] the most careful examination of the water has failed to reveal anything to sight, taste, smell or analysis which can be considered as throwing the slightest suspicion upon the purity of the Hudson or its fitness for supplying a perfectly wholesome beverage for the city of Albany."[6] With Chandler's report began one of the most tragic incidents in the history of American water works. The supply he approved was to cause thousands of cases and hundreds of deaths from typhoid.

Chandler did not respect the reliability of biological methods of analyzing water which were then being developed. Part of his

second report of 1885 contained the following remarks on bacterial examinations of water:

> Under these circumstances it would appear that counting the number of bacteria that will develop in gelatin, or in the culture media, on the addition of a sample of water, is not a very reliable method of determining the danger of water for domestic purposes, although some enthusiastic microscopists, carried away by their skill in raising bacteria in their microscopic gardens, have said that the days of chemical analysis of water supply are numbered. . . .
>
> When the biologist learns to detect in water "the specific poisons of zymotic diseases," and to distinguish them from harmless organisms that we eat, drink, and breathe with impunity all our lives, then we may set up biological analysis as superior to chemical analysis, for selecting drinking water.[7]

By the time of this report the "gelatin process" of Robert Koch was being used to make bacterial counts on water supplies and since the 1890's bacterial limitations have been probably foremost among the standards for water quality.

Considerations of Health and Developments in Water Treatment

For at least four thousand years, men have known of the important effects water could have on health, and have attempted to either secure healthful supplies or to improve available supplies through treatment. The earliest recorded evidence of concern for treatment dates from a Sanskrit collection of medical lore, the Sus'ruta Samhita whose traditions date from about 2000 B.C. and from wall paintings found in Egyptian tombs which date from as far back as 1450 B.C.

Hippocrates (460-354 B.C.) put much importance on the qualities of water in relation to the health of the inhabitants of a region. He wrote that as the "qualities of the waters differ from one another

in taste and weight, so they differ much in their [other] qualities." One should "consider the waters which the inhabitants use, whether they be marshy and soft, or hard and running from elevated and rocky situations, and then if saltish and unfit for cooking . . . for water contributes much to health."[8]

Great advances in the art of water treatment were made in the eighteenth century, particularly the last half. It was at this time that the first clear-cut expression was found which said that water should be purified if that was required, before it was supplied to large urban areas. William Buchan of Edinburgh wrote that opinion in 1769, saying also that many diseases were caused or made worse through consumption of bad water. He indicated that filtration and aeration were very widely known at that time; yet, in fact, it does not appear that any municipal water supply had been filtered as of that date. The first filtration plant for city-wide supply was installed at Paisley, Scotland about 1804. Two years later a larger plant was opened in Paris on the Quai des Celestins. In the 1820's in London five of the eight water companies distributed raw water from the Thames taken within tidal reach of the stream into which numerous sewers discharged. On March 15, 1827, a pamphlet was published called The Dolphin or Grand Junction Nuisance.[9] A frontispiece engraving showed that the dolphin or water intake of the Grand Junction Water Works Company was located nearby the outlets of a large sewer and several small ones, one of which came from the Chelsea Fever Hospital. The pamphlet spurred on the interest in locating new sources of supply and in providing filtration.

There were some, however, who doubted the wisdom of filtraion of the city's water supply. In 1828 in London, James Simpson, who was at that time developing his slow sand filter, was called to a hearing before the Royal Commission for Metropolitan Water Supply and there met with some skepticism as to the healthfulness of drinking filtered water. He was asked if those who had drunk the water had complained of its "being insalubrious, giving them cholic or any other complaints?" To this, the engineer replied that none of the more than 100 men working on the grounds had complained of filtered water but there had been complaints of the "land spring-water being injurious." [10] Fish, the commission was assured, did not die in the filtered water. Today the sort of skepticism concerning filtered water which was expressed there seems ironic in view of the increasingly poor quality of water supplies which were being delivered by the London water companies at this point in history, and also in light of what we know now to have been the resulting ill effects upon the populace. In 1848 British Parliament required water supplies be pure, safe, and constant, though this condition was not achieved until much later.

It seems that in France a preference for spring water over surface water supplies, and the ability to obtain such supplies, combined with a hostility towards filtration, retarded construction of filters in France until the 1890's, and led to the preference in France of the "natural" filtration basins and galleries. Paris continued to use spring water for domestic purposes and did not turn to filtered water from the Seine and Marne Rivers as the main supply

until the end of the nineteenth century. Marseilles, Tours, Dunkirk, and Nantes were the only cities in France known to have been provided with "artificially" filtered water for the entire city supply before 1890.

As the debates continued over filtration, and as its use spread, more was being discovered concerning the spread of certain diseases by water which was contaminated. In 1874 the Royal Rivers Pollution Commission made a report in which much space was devoted to the "Propagation of Cholera by Water."[11] The conclusions were based on data and facts gathered from the cholera epidemics of 1832, 1849, 1854, and 1866. Data were also presented showing that where slow sand filtration had been installed, there was relatively light incidence of cholera. Typhoid also had been traced to contaminated water. In 1876 in the United States John T. Fanning wrote that water could be a vehicle for the spread of diarrhea, dysentery and typhoid. In 1880 the typhoid bacillus was isolated.

In 1875 Albany, New York, began pumping water from the Hudson, and utilizing this supply without filtration, although it was known that this supply was already subject to a great deal of pollution. In fact, at this time only three cities in the United States had slow sand water filtration plants. Rapid filtration had only two plants which were operating on municipal supplies. Finally in 1899 slow sand filtration was put into use at Albany. Allen Hazen, who had designed the works, reported that Albany had had an abnormally high general death rate and a high incidence of typhoid and

diarrheal disease which when compared with other communities who used filtered water from polluted supplies, was very unfavorable to Albany. In comparing the nine years after filtration was installed with the nine years previous to filtration, the number of typhoid deaths decreased seventy percent. Later there were two outbreaks, one when the filters were flooded, and one when a conduit broke. Opposition to use of the Hudson River continued and in 1932 that source of supply was abandoned.

To each new process of treatment there were always found some who were opposed to its introduction. Certain persons protested rapid filtration and particularly coagulation, as it was developed, notably Dominique Francois Arago of France in 1837, the Massachusetts State Board of Health a half century later, and medical men in the late nineteenth and early twentieth centuries. Arago wrote of coagulation, that "Another more serious objection is that it affects the chemical purity of river water, that it introduces a salt which it did not before contain,--that in supposing this salt wholly inactive in certain proportions, consumers might fear that at times these proportions might be very materially exceeded, and that this might easily happen through the negligence, or mistake, of a workman."[12]

As chlorination developed there were also some who opposed its use. In 1894, Professor Thomas M. Drown pronounced his opposition to the chlorination of city water supplies, as follows:

> Finally, is it desirable in any case to treat a city's water supply with a powerful disinfectant like the hypochlorites? When the question is put in this bald way I cannot think it will receive the approval of engineers and sanitarians . . . in cases where a water supply has got into such a hopelessly bad condition that nothing will render it safe but disinfection by chloride of soda or chloride of lime, it is high time, I think, to

abandon the supply, and in this opinion I feel sure most water works engineers will coincide.[13]

In spite of some opposition here and there to rapid filtration, coagulation, and chlorination, all proved to be invaluable in combatting death and disease which had previously visited large urban areas in frequently recurring waves. One example took place in Hamburg and Altona Germany where a cholera epidemic occurred in 1892. The Hamburg epidemic was the result of contaminated water from the Elbe River. In Altona, water from the same stream was used, and even though all of the sewage from Hamburg was discharged a few miles above Altona, the epidemic in Altona was much less serious. A second example occurred in Louisville, Kentucky, where for the years 1906-1910 the typhoid death rate was 52.7 per 100,000. Rapid filters went into operation in the summer of 1909, but it was not until 1912 that all elements of the system were operating together, that is, filtration, sedimentation, and coagulation, and the typhoid death rate fell to 19.7 for 1911-15. In 1914-15 prechlorination was begun, and the typhoid death rate fell to 9.7 for 1916-20. In 1924 postchlorination was added, and the typhoid death rate fell again to 4.9 for 1921-25 and on down to 0.9 for 1936-40. Along with other typhoid prevention measures, the improvement in water treatment contributed to the decline of typhoid in Louisville, Kentucky.[14] A third and final example was Chicago, where in the early years cholera was prevalent and also typhoid. The rapid decline in typhoid in the twentieth century as shown in the following table was largely due to the use of chlorine.

TABLE 2

TWENTIETH CENTURY DECLINE IN
TYPHOID DEATHS, CHICAGO

Time Period	Deaths/100,000 Population
1833 - 1858	65.5
1859 - 1881	68.6
1882 - 1903	42.8
1904 - 1916	12.4
1917 - 1932	1.02

SOURCE: Jasper Owen Draffin, The Story of Man's Quest for Water (Champaign, Ill.: Garrard Press, 1939), p. 193.

Algae problems in surface reservoirs, without effective control, had created tastes and odors sometimes intolerable to water consumers. Covering of reservoirs remedied the situation in the case of small reservoirs, but for large reservoirs there was not found a really suitable answer until the discovery of copper sulfate as an algicide. There was a history of opposition to the presence or introduction of copper compounds into a drinking water supply, beginning in 1732 with Noel Antoine Plüche.

In 1732 Plüche in his publication, Spectacle de la Nature, mentioned copper cisterns with sand in them "through which by an artificial kind of filtration [the water] clarifies sooner and with equal safety, provided the sand it drains through be often wash'd, and the vessel [be] well tinned within to secure it from verdigrease."[15] This is the first contemporary record of the need for protecting copper containers from verdegris. Verdegris usually was used to refer to the blue and green compounds, various forms of copper acetate, which could be formed by the action of copper, air, and acetic acid sometimes available in the form of vegetable juices. This, like other copper compounds, can be considered poisonous in certain applications.

Joseph Amy from southern France in 1749 was granted the first water filter patent issued by any country. He wrote extensively on what he considered to be the danger of copper poisoning from the filter containers and other household vessels then in wide use in Paris.

There were others who questioned the use of copper sulfate as an algicide, but after reports published in 1904-05 by George T.

Moore and Karl F. Kellerman in the United States, copper sulfate came to be a widely-used and efficient method for the control of algae.

Ultimately it was found that the softening process, besides reducing the usage of soap, had an incidental benefit of bacterial removal. The college town of Oberlin, Ohio, was the first municipality in the United States to build a water softening plant in 1903. Counts which were made showed that softening reduced the bacteria count ninety to ninety-five percent over what it had already been reduced due to storage.

Early Treatment of Water by Filtration

The earliest recorded knowledge of water treatment is found in Sanskrit medical lore and Egyptian inscriptions. The Sus'ruta Samhita is a collection of medical lore in Sanskrit dating from 2000 B.C. In that work the following declaration can be found: "Impure water should be purified by being boiled over a fire, or being heated in the sun, or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool."[16] A picture on the wall of the tomb of Ramses II from the thirteenth century B.C., shows assorted sizes of wick siphons in an Egyptian kitchen. Thus the earliest knowledge of water treatment gave to the process of filtration an important place, and one of the earliest recorded apparatuses for water treatment utilized a process akin to filtration. The time-consuming process of the wick siphon made use of atmospheric pressure and capillary action to move liquid from one vessel to another along a

thread or piece of cloth.

Filtration through porous vessels was known to Aristotle (384-322 B.C.) as the following thought has been attributed to him: "The nutriment which produces flesh is deduced through the veins and pores in the same way as water through earthen vessels not thoroughly baked."[17]

The use of household sand filters in Paris probably dates back to about 1550. By 1757 most of these were probably of sand in copper or pottery vessels covered by and resting on perforated plates.

The first known illustrated description of sand filters was written by Luc Antonio Porzio in 1685. He proposed multiple filtration through sand, preceded by straining and sedimentation.

In 1732 in a work called Spectacle de la Nature the scientist Noel Antoine Plüche provided the first contemporary record of the need for occasional cleansing of sand in filters.

In 1749 Joseph Amy in France was granted the first water filter patent issued by any country. These filters were to be constructed of lead, pewter, or earthenware, with filtering materials of sponge and sand which would be washed in place. The sand would be packed between two perforated plates.

Diderot's Encyclopedie (1757) described stone filters used extensively in Japan.

It seems that commercially filtered water was brought to Paris in 1764 by Montbruel and Ferrand, in 1768 by Compagnie Dufaud, and in 1782 by Charancourt.

In England the first evidence of the manufacture of household filters was a patent granted to Johanna Hempel, a potter of Chelsea,

in 1790.

The first British patent on a process and apparatus for filtration was granted to James Peacock in 1791. To obtain the patent Peacock claimed that the novelty of his invention were filtration by ascent instead of descent, and cleaning of the filter by reverse flow. His use of an air vent and a false bottom were old ideas. Peacock set forth the reasons for placing coarse material at the bottom of a filter with regularly decreasing sizes above it. Interstitial spaces would increase in geometric ratio. Peacock's potential contribution to filtration was significant, but it is not certain how much successors profited from his invention or his ideas.

The first filtration plant for city-wide supply was installed at Paisley, Scotland, in about 1804. The plant utilized a prefilter, sedimentation and double filtration, with lateral flow throughout. Water passed through a roughing filter to a pumpwell. A steam engine lifted the water to the settling basin. The settling basin, main filters, and clear-water basin were arranged concentrically.

Two years after the filters were installed at Paisley, in 1806 a larger plant was installed in Paris on the Quai des Celestins. The water was presettled twelve hours and then prefiltered with sponge prefilters which were renewed every hour. Main filters contained from top to bottom, river sand, clean sand, pounded charcoal and clean Fontainebleau sand. The main filters were "renewed every six hours."[18] Output was about 3.42 mgd per acre. Water from this

plant delivered to different parts of the city made Paris the second city in the world to have a city-wide filtered water supply.

Filter-Cisterns

From the founding of Venice in the fifth century till the eighteenth century, the city depended on water stored in cisterns. Many of these came to be surrounded by a sand filter. The cisterns were usually ten to twelve feet deep while the surrounding filter might be twice that deep. To construct a filter cistern, a cone-shaped excavation was first made. Then a timber form was placed against the wall of the pit and on this was placed well-puddled clay. A flat stone formed the bottom of the cistern and the walls were made of bricks laid with open joints. The space between the cistern and the edge of the excavation with the puddle lining, was filled with sand. At each corner of the filter was a place where water could be fed to the filter, either collected rainwater from roofs and interior courtyards or transported from elsewhere.

Filtration Basins and Galleries

A procedure has been noted among various peoples, whereby water has been obtained from hollows scooped out in the sand along a river or waterhole, even when dry. The water thus obtained has been filtered by passage through the sands. Athenaeus of Attilia in 50 A.D. writing of Alexandria, described channels dug along the sea. These are all examples which may be regarded as prototypes of the infiltration galleries of later centuries.

In Europe and in North America in the nineteenth century, filter basins and galleries were placed in permeable alluvial deposits

along rivers or lakes. The filter basin sometimes consisted only of a shallow open basin with an unpaved bottom. The filter galleries were usually open-jointed conduits of brick, stone, concrete, or pipe, laid in trenches which were then filled in again. Instead of receiving water from the river or lake, most of the actual flow to the filter came from ground water. The first filter gallery on record was built at Glasgow, Scotland, in 1810.

Toulouse became the second city on record to receive its water supply from natural filtration. In 1821 construction on a filtration basin was begun. In the ensuing years of operation problems with algae were experienced. To remedy this an aqueduct of brick was placed in the basin, and this was then covered first with pebbles, then with sand. A second gallery was soon built, and in 1864 a third.

A filter basin was put into operation at Nottingham, England in 1831. This basin was subject to growths of Conferva. They solved their problem by draining the basin and sweeping the bottom with a broom, at three-week intervals in the summer and six-week intervals in the winter.

A rather unusual filter gallery was built in 1880 on an island in the Cumberland River at Nashville, Tennessee. It was constructed in an iron cage, filled with stones. The cage was 152 feet long, and ten feet wide inside. A cover of railroad iron was added and the trench was backfilled to a depth of twenty feet.

The successful operation of a natural filter, depends upon proper studies to determine suitable locations. It is important to ascertain the probable division of yield between the adjacent body

of water and the underflow, and particularly the liability of clogging of the material between the body of water and the gallery or basin. Deposit of sediment will be made on the river bottom, and the extent of scouring should be considered. Studies should be made of the stratum of permeable material, depth and slope of the water table, and characteristics of the surface water and ground water in the area. If conditions appear favorable, it might be worthwhile to consider a natural filter.

Slow Sand Filter

Robert Thom of Scotland and James Simpson of England were outstanding pioneers in the development of filtration. Thom's first municipal filter was installed at Greenock in 1827, and Simpson's at London in 1829. Through experimentation, both men had discovered that the failure of filters due to clogging occurred at or just below the surface, and each developed a method of cleaning, Simpson's method consisted in scraping off the top layer, washing and restoring it, and totally replacing it at suitable intervals. Thom's method of cleaning was the reverse-flow wash which had been called for in the patent for Peacock's filter in 1791. Both men utilized the method of arranging successively finer filter media from bottom to top of the filter, as had also been called for in the British patent granted to Peacock.

Simpson's filter had open-jointed branch drains of brick. Settling reservoirs were operated with their low-water line level with the high-water line of the filter. Output was usually about three million gallons per day (U.S.) per acre. Simpson reported that,

"the silt, . . . renders the interstices between the particles of sand still more minute, and the bed generally produces better water when it is pretty well covered with silt than at any other time. . . . and in cleaning the silt off, it has never been found necessary to scrape any more of the sand off with the silt than the first half-inch depth and sometimes only half that depth was removed."[19] Materials used in the bed were river sand, shells and pebbles, and gravel, with the surface arranged in ridges. The small shells were used to improve the separation of the sand from the gravel and thus maintain the free percolation in the lower layers which would speed up the rate of filtration.

Thom's filter was enclosed by rectangular masonry walls. The filter media was supported on a false bottom of flat tiles with perforations more than 0.1 inch in diameter. Bricks supported the false bottom and formed the underdrains. Media used were gravel, sand, and charcoal. The charcoal, ground to about 1/16 inch diameter, was mixed with the upper layer of sand. Cleaning was by reverse-flow wash aided by stirring with a rake. Output at a filter constructed by Thom at Paisley was given as an average rate of nearly six million gallons per day per acre or double the rate of slow sand filters of that and later dates.

The Simpson type of slow sand filter became the model for slow sand filters throughout the world. Thom's design was used to limited extent, but the elements of reverse-flow wash with the false bottom were principal features of the rapid filter developed in the United States during the 1880's.

In January of 1829 Simpson reported that although the bed of

the filter was covered with five inches of ice, it was still working properly. This is the earliest known report of the effect of ice on filtration. In certain cases of slow sand filtration, climates have been reported such that ice cover for long periods has both prevented cleaning of the bed, and hindered the passage of air and light so as to cut down on the efficiency of the filters. Slow sand filters may be found which have been covered to remedy such situations. In 1876 Colonel John T. Fanning, dean of U. S. hydraulic engineers in the last third of the nineteenth century, wrote a treatise on water wotks in which he emphasized the need for roofing filters to protect their operation against the effects of both low and high temperatures.

In 1857 successful slow sand filters were put into use in Germany, and in 1872 in the United States.

At the Lawrence Experiment Station in Massachusetts, established in 1887, much research was devoted to experiments on the nitrification of organic matter by intermittent sand filtration. Time was to prove that intermittent filtration was not a suitable practice for water treatment. It had been taken over from sewage treatment where a large amount of organic matter often had to be oxidized.

Rapid Filtration

In 1815 Graf von Real patented a force filter for which head was supplied by a reservoir. In 1819 an English patent was issued to Henry Tritton who proposed a partial vacuum within a clear water chamber beneath the filter, which would cause the filter to operate under a negative head. In 1827, J. F. E. Quarnier of Paris took out a French patent on sealed filters working under

pressure supplied by a column of water. Other methods proposed for altering head were pumps or the common siphon.

In the 1830's a half century before development of the rapid filter in the United States, French filter designers made outstanding innovations in the use of high pressure filtration in closed tanks, the advantage of which was that the yield of the filters could be greatly increased. Henri de Fonvielle took out a French patent in 1835 on filtration in a hermetically sealed vessel cleaned by reverse flow. Media used were pebbles on a false bottom, powdered sandstone, iron filings, and crushed charcoal. Perforated zinc plates were placed above and below the filter bed. Above the upper zinc plate, sponges were placed in inverted troughs to remove sediment, and air venting was provided. The Frenchman Henry Darcy patented a filter in 1856 which encompassed all the elements of the future American rapid filter, save one, coagulation. Most aspects of Darcy's system had been developed previously, but the particular combination he devised was new. It was proposed to use increased pressure or negative pressure and only about one foot of sand and one-third to two-thirds foot of gravel. Reverse-flow wash was to be used at intervals, as well as scraping. In addition new methods of keeping the filter clean were proposed, namely sweeping the surface with a mechanically driven revolving broom, and discharging to waste suspended matter within twenty inches of the surface of the sand, without stopping filtration. (Raw water was introduced horizontally to the filtration tank one meter above the filter bed.)

In the 1880's and early 1890's the rapid filter was developed in the United States and put on a sound engineering basis. Principal methods of cleaning used were jets of water directed on or just below the surface, reverse-flow wash, and agitators which loosened the media from top to bottom. (The first appearance of mechanical sand agitators in patent claims was in a letter of 1858 from William Clark to the British patent office.) Egg crates or compartments were situated in the gravel layer. These were vertical partitions from the filter floor to the base of the sand which prevented wash water from disrupting the gravel bed. The rapid filters developed were usually operated under significant head.

No coagulant was used in various of the antecedents of the American rapid filter, or in instances of the later rapid filters. However, in general, coagulation came to be regarded as an important element of most rapid filtration units. In 1884, Isaiah Hyatt obtained a patent on simultaneous coagulation-filtration. This method proved not as sound as precoagulation and sedimentation, but was much used nevertheless in rapid filtration for many years. Later precoagulation and presedimentation came to be seen as essential elements in the rapid filtration process, especially in the treatment of highly turbid water.

Among names which stand out in the development of the American rapid filter, is that of the National Water Purifying Company of New York City, which was established to promote a filter patented by William M. Deutsch in 1886. Claims for the company's filters included horizontal perforated wash pipes at two levels, one at the

bottom of the filter bed, and one located near the top. The pipe at the bottom also served as an underdrain. Sectional washing was made possible by partitions which extended from the bottom to the top of the filter. The advantage in the upper wash pipe was to have been the breaking up of the surface layer where most of the sediment would have accumulated. Strainers were tapped in the underdrainage pipes.

The firm of O. H. Jewell & Sons was formed in 1890 at Chicago. Among many patents granted to Omar H. Jewell were several for strainers or screens for underdrain washing systems, revolving sand agitators, a settling chamber below the filter, and a process apparatus for maintaining negative head in filtration. The type of strainer usually used was a perforated aluminum-bronze plate, placed across a cup screwed into the underdrain and wash pipe. Between the plate and the bottom of the cup was a deflector which deflected the wash water. The sand agitators were horizontal arms from which many rods extended to the bottom of the filter.

The Continental Filter Company gained prominence in the early 1890's. In 1892 a patent was issued to an engineer of the company, David Williamson, for a centrifugal filter.

The East Jersey Water Company placed into service in 1902 at Little Falls, filters which were rectangular in shape rather than cylindrical tanks as previous rapid filters had been. Designs already in use at Continental plants were adopted and enlarged to provide new features, namely a structure of reinforced concrete rather than of wood or iron, application of the coagulant at the point where the treated water entered a detention basin, and an aid to cleansing by agitation

with compressed air introduced underneath the filter before reverse-flow wash rather than stirring with rakes.

Drifting-Sand Rapid Filters

The basic principle of this type of rapid filter is the ejection of sand from the bottom to the top of a filter to aid in washing. In the Hyatt sand-transfer wash filter developed in the United States pipes led from the bottom of the filter to the top. When valves were opened at the upper end, and water under pressure was introduced throughout the underdrains, sand was carried to the top of the filter, where dirty water was wasted and the clean sand was returned to the top of the filter bed. This washing system was first used for a municipal supply in 1885 in an installation for the Somerville and Raritan Water Company in New Jersey. Patent specifications of John W. Hyatt described apparatus which anticipated sand-transfer methods of later inventors.

In 1913 a British patent was granted to William Gore and Martin Deacon engineers of Westminster, England, for a drifting-sand filter. A plant was put into use with this type of filter at Toronto in 1918. At the bottom of this type of filter there is a collection point called a sand ejector. Water to be filtered passes through this area and then up through a central pipe to be distributed at the top of the filter for treatment. Sand to be cleaned passes to the ejector through many small tubes leading from points on the outer edge of the filter bed near the bottom. Washing is done in the ejector, and then the dirty water is wasted from the top of the ejector. The cleaned sand then passes up through the

central pipe and is deposited at the top of the filter. This sand transfer process is carried on constantly without stopping the process of filtration. Reverse flow wash is used when needed.

From 1934 to 1939 seventeen water works in France had installed drifting-sand rapid filters with the trade name "Trailigaz," provided by Société Traitement des Liquides et des Gaz, Paris. These filters were cleaned by reverse-flow wash, as well as by forcing the sand to the top of the bed by an ejector.

Multiple Filtration

In 1685 Luc Antonio Porzio, an Italian physician, proposed multiple filtration through sand, preceded by straining and sedimentation. After 1685 multiple filtration was proposed from time to time and had been used in Scotland, England, and other places. At the close of the nineteenth century Paris adopted multiple filtration consisting of two or more roughing filters of gravel, a prefilter and a final filter of the slow sand type. This system subsequently became widely used in France, more than in other parts of the world.

The Paris filters of 1899 were installed by Armand Puech, who had taken out a British patent on multiple filters in 1898. From filter to filter in the series, the filtering material decreased successively in size as did the unit rate of filtration. In these early days of the Puech filters, there was generally no presedimentation, coagulation, or disinfection. Later, in the development of this system, the roughing filters and prefilters were converted into what were actually rapid filters. After installation of the Paris

filters, Puech was joined by H. Chabal and by 1935 the Puech-Chabal system of filtration was more widely used in France than any other means of water purification.

Non-Submerged Filter

This type of filter was developed in France beginning in the early 1890's. Water was to be showered upon the filter at such a rate that it would not stand on or in the sand, and really involved the same operation as that found in the sewage trickling filter which was being perfected in the 1890's in England. The composition of the filter was much the same as the composition of English slow sand filters. Output was about 2.2 million gallons per day per acre. M. Marboutin in a paper presented in 1909, attributed to this type of filtration a greater reduction in bacteria than that achieved with the ordinary sand filter. The only known installation of this type of filter was at the small community of Chateaudun on the River Loire in 1907.

Filtering Media

Numerous types of media and various combinations of them have been employed in filtration. The most used, of course, have been various grades of sand and gravel. In fact, the earliest recorded knowledge of water treatment in Sanskrit included filtration by sand and gravel. Allen Hazen, Chief Chemist at the Lawrence Experiment Station in Massachusetts did much to promote the efficient operation of filtration in the twentieth century through his studies on the effective size and uniformity coefficients of sand grains and of frictional resistance to the passage of water through sand and gravel.

Charcoal was also used very early and widely in the history of water filtration. In 1790 Johann Tobias Lowitz, a Dutch chemist, presented a paper before the Economics Society of St. Petersburg, Russia, in which he stated his experimental finding that powdered charcoal prevented tastes and odors in waters, and aided incidentally in clarification. Partly on the strength of Lowitz' findings charcoal was frequently used as a filter medium from the 1790's until later when sand alone was adopted for slow and rapid filtration.

Filtration through porous or earthenware vessels was known at least since the time of Aristotle (384-322 B.C.) in various parts of the world. Some more unusual media have been used or proposed from time to time and place to place. In France sponge was promoted from 1745 onward, and wool for a short period in the 1840's. These media were often used in combination with each other or in combination with sand, crushed sandstone, or gravel, either mixed together or in layers. In the early 1800's James Simpson recommended the use of shells in his English slow sand filters. A filter patented in 1835 by Louis-Charles-Henri de Fonvielle contained among other things, the innovation of a layer of iron filings placed near the top of the filter bed. In 1877 Caesar Gerson of Hamburg, Germany, took out a British patent and in 1878 a United States patent for double filtration in which a rather unusual combination of materials was used in the filter bed. The water was to travel "upward through layers of sponge and powdered pumice stone or gravel, each impregnated with insoluble iron salts, and downward through a mass of Swedish iron ore and layers of sand, powdered glass and wool shearings, all impregnated with iron salts."[20]

Changing Concepts of Filtration

At the beginning of the 1800's removal of turbidity was the chief objective of filtration. Some attention was given to organic matter. By the middle of the century it was generally felt that organic matter present in the water might possibly be harmful when the water was intended for drinking or cooking, and it was proved that filtration with or without charcoal reduced the content of organic matter.

For a long time, and still at the beginning of the nineteenth century, filtration was widely regarded as just a straining process whose efficiency depended on the size of the interstices between the filter media. This mistaken concept encouraged the popular but misguided proposals for upward-flow filtration during the nineteenth century. The media still were arranged in layers graded, from bottom to top, from coarse to fine. Gravity, it was supposed, would carry suspended matter to the bottom of the filter, particularly from the coarser layers, so that much material would not even reach upper layers of the filter. It was also supposed that gravity would act to draw material from the interstices in the filter media down to the bottom of the filter. Larger interstices at the bottom were supposed to aid in carrying dirt below in the process of reverse-flow washing. The error of this concept of filtration resided in the idea that filtration was simply a process of straining. In assessing the results of his research on ascending filtration, James Simpson of England wrote,

> All the modifications of lateral and ascending filters proved disadvantageous; difficulties were encountered in preserving the

> various strata in their assigned position, according to the sizes of their component particles; and effectual cleaning could not be accomplished without the removal of the whole mass of the filtering medium. All devices by currents, reactions of water, and other means, also proved either inefficient or inconvenient and expensive.[21]

A pioneer in broader concepts of filtration was Dr. Angus Smith who wrote in 1848 for the British Association for the Advancement of Science that nitrates and also oxidized carbon resulted from the purification of water from organic material. Thus he stated that, "a filter . . . as an oxidizing agent, acts in proportion to its cubic contents."[22] In 1867 Thomas Hawksley, then Vice President of the Institution of Civil Engineers in Britain, reaffirmed the opinion that as well as mechanically, filters operated chemically, in a process that was dependent on the admission of free atmospheric oxygen. He also made an important additional point that "the minute particles of matter suspended in it [the water] were attracted and held by the facets of the sand and adhered there . . . ."[23] At about the same time report was made of remarks of Edwin Chadwick, that for filters to operate properly, the presence of "vegetation" was necessary. It had been noticed that when a filter bed had been relaid, it took several days for it to work efficiently. A German chemist discovered that sterilized sand was not effective when used in a filter bed. It was later proved that in the proper operation of the slow sand filters in operation in the nineteenth century the action of organisms was essential, through biological activity and through production of what was called "schmützdecke." This term was applied to the layer of organisms which covered the filter sand and was attributed with the ability to entangle materials carried in the water

through the action of elements such as flagella or a gelatinous-like envelope surrounding some of the organisms present.

As concepts changed concerning the mechanisms involved in the operation of slow sand filtration, discoveries were also being made concerning water and the "germ theory" of the transmission of certain diseases which caused turbidity to be replaced as a primary objective of filtration. In 1874 in the sixth report of the Great Britain Rivers Pollution Commission, a report was included on the propagation of cholera by water. Data were presented on the epidemics of 1832, 1849, 1854, and 1866, as well as on instances where the incidence of cholera had declined after the introduction of slow sand filtration. Elsewhere outbreaks of typhoid had been traced to contaminated water. In 1886 in London before a meeting of the Institution of Civil Engineers, Percy F. Frankland stated that filtration removed most of the bacteria from water. His studies had been made possible by the "gelatin process" of Robert Koch which had been recently developed. The importance and magnitude of the changes in concepts of filtration and hygiene which were taking place during this period are reflected in the portion of Frankland's report which follows:

> Thus for the first time a definite conception has been obtained of the effect of sand-filtration upon these lower forms of life. Hitherto those who were acquainted with the size of these minute microscopic organisms on the one hand, and with the dimensions of the pores in a sand filter on the other, have believed that little or no barrier could be offered to these organisms by the comparatively spacious pores of the filter . . . .[24]

In completing this section on changing concepts of slow sand filtration in the nineteenth century, it is of some interest to note experimentation with rapid filtration which was conducted in

the United States at Louisville at the turn of the century. The highly turbid waters at Louisville could not be successfully clarified by slow sand filtration. Therefore, it was determined to use rapid filters, and several companies were invited to conduct experiments to show what its filter could do. The results of the experiments emphasized the importance of presedimentation and precoagulation in the operation of rapid filters when treating highly turbid waters. In addition, the figures which follow show the percentage of work done in removing turbidity and bacteria by filtration in the process at Louisville, for selected years after permanent installation of rapid filters. On an average for the years 1910-1933 rapid filtration was responsible for ten percent of the reduction in turbidity which occurred in the Louisville plant, and 9.6 percent of the reduction in bacteria. This is a small percentage while the larger portion of the reductions were due to presedimentation and precoagulation. Figures for the single year 1930 are included in the table to demonstrate the possibilities of wide fluctuation in the percentage distribution of work done by the main elements of the process depending upon changes in turbidities or bacterial counts of the raw water. In the drought of 1930 the raw water turbidity at the plant dropped to only 60 ppm, and the percentage removal of bacteria due to filtration was triple the overall average. The importance of presedimentation and precoagulation dropped correspondingly.

Sedimentation

The earliest known apparatus for clarifying liquids has been found pictured on the wall of the tomb of Amenhotep II at Thebes, 1450 B.C. It is presumed by some to be a picture of Egyptians siphoning off water

TABLE 3

REDUCTION OF TURBIDITY AND BACTERIA BY FILTRATION, AS PERCENTAGE OF TOTAL REDUCTION, LOUISVILLE RAPID FILTRATION PLANT

	Average of 1910-1933 Averages	1930 Average
Turbidity	10	13
Bacteria	9.6	30.9

SOURCE: W. H. Lovejoy, personal letter, Louisville, Ky. (August 26, 1942), cited by M. N. Baker, The Quest for Pure Water: The History of Water Purification from the Earliest Records to the Twentieth Century (New York: American Water Works Association, 1949), pp. 242-243.

or wine clarified by sedimentation.

Around 260 B.C. Antiochus Theos built an aqueduct at Laodicea, Syria, with two chambers at the terminus which are presumed to have been settling reservoirs.

In 47 B.C. when Caesar began taking possession of Alexandria, he found the more prominent families provided with cisterns in which the water supplied from the Nile became clarified by sedimentation.

Vitruvius (15 B.C.), according to Roman records, recommended that cisterns be constructed with more than one compartment so that water in one compartment could settle while water from another compartment was being used.

Sextus Julius Frontinus, who in 97 A.D. became water commissioner of Rome, in his treatise on public water supply, Two Books on the Water Supply of Rome, described a settling reservoir at the head of one of the aqueducts supplying Rome and also the "piscanae," which were built into most of the aqueducts. Clemens Herschel, a U.S. hydraulic engineer who translated Frontinus' treatise, saw the piscanae as covered catch-basins designed to intercept small stones.

Two many-chanbered vaulted reservoirs were found in the remains of ancient Carthage. There is some question as to their date of construction, but the general agreement is that they date from at least as far back as 138 A.D. It has been suggested that the cisterns were built in compartments so as to provide "progressive sedimentation."

In the first known illustrated description of sand filters, Luc Antonio Porzio, an Italian physician in 1685 proposed multiple filtration preceded by straining and sedimentation.

The earliest baffled settling reservoir to be described was apparently built late in the seventeenth century along a Swiss stream, and was reported in 1804 by Henry C. Engelfield as having a series of under-and-over baffles.

In 1732 Noel Antoine Plüche gave the first clear-cut recognition recorded of the slowness of sedimentation compared with filtration.

At York in England even in the nineteenth century, the public water supply was taken from the river and not filtered. Most houses let the water used, stand first in pots to settle for a day or two before use, thus practicing a form of home treatment.

The first known filter to supply an entire city with water was completed at Paisley, Scotland, in 1804 with lateral flow through units in the form of rings, one inside the other. After passing a roughing filter and before entering the main filters, the water passed through a settling basin.

The first American settling reservoir on record was a part of the water works completed in 1829 at Lynchburg, Virginia.

In 1837 Dominique François Arago reported to the French Academy of Sciences concerning the limitations of sedimentation. His opinion was that while larger particles subside very quickly, the finest particles require an indefinite amount of time. For a large supply, an exceedingly large settling area would be required to settle all particles and during the long settling period required, the water might become contaminated or otherwise lessened in quality. Therefore sedimentation should be considered as one important method for getting rid of the grosser particles only.

James P. Kirkwood, an eminent water works engineer of Brooklyn, New York, reported in 1869 that the sediment of muddy waters which would subside in twenty-four hours could be more economically removed by sedimentation than by filtration. In fact, it was his opinion that successful slow sand filtration required presedimentation. He proposed that four basins be provided for sedimentation, one for filling, one for settling, one for decanting and one for cleaning.

In 1904 Allen Hazen wrote an important paper on sedimentation. Parts of the introduction and summary follow:

> It has been found in St. Louis that continuous operation, that is to say, a continuous flow of water into, through and out of the basin, gives quite as good results as the intermittent operation. . . . The use of baffles has also been learned, and it has been shown clearly that a well-baffled basin will do as much work as a much larger basin without baffles. . . .
>
> The fundamental propositions [of sedimentation] may be very concisely expressed. They are: first, that the results obtained are dependent upon the area of bottom surface exposed to receive sedimentation, and that they are entirely independent of the depth of the basin; and second, that the best results are obtained when the basins are arranged so that the incoming water containing the maximum quantity of sediment is kept from mixing with water which is partially clarified. In other words . . . practically accomplished by dividing the basins into consecutive apartments by baffling or otherwise.[25]

Coagulation

Coagulation as an aid to sedimentation has been practiced since ancient times. The Sus'ruta Samhita said to date from 2000 B.C. suggested using the seed Strychnos potatorum or "Gomedaka," a kind of stone, to purify water.

Prospero Alpino, Italian botanist and physician, reported in 1592 that powdered almonds were rubbed on the inside of jars containing Nile water as an aid to sedimentation in Egypt. It is likely that

this was the same practice which had been followed in those regions since ancient times.

The use of alum for small-scale water clarification in China was an ancient practice. The use of coca is also mentioned for the same purpose.

Viruvius wrote about 15 B.C. that if water in cisterns did not clear without taste or smell, it would be necessary "to clear it by adding salt."[26] Pliny about 77 A.D. made mention of lime and aluminous earth as precipitants.

In 1767 Dr. William Heberden stated that the common people of England used two or three grains of alum dissolved in muddy water to make the dirt flocculate and precipitate. Then the water was filtered. This is the earliest suggestion found for coagulation followed by filtration, but this was referring to domestic treatment.

In 1827 in London, Dr. John Bostock reported the use of alum and iron sulfate to aid in coagulation.

In 1838 Felix D'Arcet, a French chemist, wrote that in certain parts of the Sudan people used beans for coagulation, broad, kidney, or castor oil, but that they did not cause the water to become completely clear.

The earliest use of alum to clarify a town water supply occurred in 1879 in Groningen, Holland.

In the 1880's appeared the so-called "Anderson Process," merely an apparatus for producing by attrition finely divided particles of metallic iron which were to be dropped into water flowing to a slow sand filter.

The Somerville & Raritan, New Jersey Water Company in 1885 began the use of coagulation on a public water supply in the United States. From that time it has been nearly always an integral part of the rapid filtration process.

The agent most used as a coagulant is aluminum sulfate, or alum. Lime is sometimes employed. Iron has been used in comminuted metallic form but more generally as an iron salt, such as ferric chloride or ferrous sulfate. An alum dosing apparatus was patented in 1890 by Professor Henry Carmichael of Massachusetts. It was a pump with curved tubes attached to a hollow hub which was driven by a propellor in the raw water main. Greater velocity and therefore volume of the raw water increased the speed of the pump. Sometimes around-the-end baffled mixing chambers have been used for mixing the chemicals introduced for coagulation.

Originally plain sedimentation had for its objective the removal of turbidity. Later, especially with the use of rapid filtration, coagulation and sedimentation have as objectives, in addition to the removal of turbidity, the removal of color and bacteria.

Straining

Avicenna, an early eleventh century Persian physician of the Arabian school, writing of means for water purification, advised straining drinking water through cloth.

In 1685 Luc Antonio Porzio, an Italian physician proposed straining and sedimentation to precede multiple filtration.

In 1767, Jean Bertrand, pastor at Orbe, Switzerland, discussing detention of water in ponds, suggested that chalky and viscous waters could be improved by passing through green branches of fir trees placed at the outlet of the pond.

In the United States after 1849 there were installed various rapid, granular, straining devices, some in the form of cribs and trenches.

Disinfection

Methods of disinfection have been used to treat drinking water for millenia, at times without detailed scientific knowledge of the actual mechanisms involved, but rather as practices developed from previous experience.

Heat. A passage from the Sus'ruta Samhita, written in Sanskrit and whose traditions date from 2000 B.C., has been cited previously, and is also of interest in a discussion of methods of disinfection, particularly in this instance as the earliest recorded knowledge of boiling as a water treatment. It stated that, "Impure water should be purified by being boiled over a fire, or being heated in the sun, or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool."[27]

It was reported that Cyrus the Great, King of Persia in the sixth century B.C., when traveling with his army, took with him water from a particular river, Choaspes, which was boiled and stored in flagons of silver.

Hippocrates in perhaps the fifth century B.C. stated that if rain water was not boiled and strained, it would acquire a "bad smell" and cause "hoarseness and thickness of voice to those who drink them."[28]

Many other instances have been found of the recommendation that drinking water be boiled first: Pliny, about 77 A.D.; Paulus Aegineta late in the seventh century A.D.; Rhazes, an important Mohammedan physician of the ninth century; and Avicenna, an early eleventh century Persian physician.

Hermann Boerhaave (1668-1738) wrote, "But when the Water has thus spontaneously grown putrid, it may easily be rendered wholesome again,

and may be drank without being offensive; for if you give it only one boil on the Fire, the Animals that are in it will be destroyed, which with the rest of the impurities, will subside to the bottom. . . ."[29]

In Philadelphia in 1835 Robley Dunglinson stated that "Whenever water is unusually contaminated, it may be boiled, filtered and agitated . . . .There are many valetudinarians, and some whole nations--as the Chinese--who never drink water that has not been boiled."[30]

In general use of heat for large supplies proved too costly a method of treatment, though after discovery of the principles and properties of heat transference, apparatuses were applied in a few special cases beginning about 1888 by Charles Herscher. Later developed were a Vaillard - Desmoraux apparatus and in the United States, the Waterhouse-Forbes apparatus (1898).

Copper. Copper has been widely used for water containers and cooking utensils through millenia. In some cases this may have had some germicidal value. However, it is probable that they were not used for that purpose but rather because of the availability of the metal, the ease with which it could be worked, cleaned, and polished. After studies in 1904 by George Thomas Moore and Karl F. Kellerman in the United States, copper sulfate was accepted as an effective germicide and algaecide.

Silver. It was determined that small quantities of silver in water would destroy some macro-and micro-organisms. Forerunner in these investigations was Carl von Nageli, a Swiss botanist, in 1880. Some limited applications were found in the twentieth century for swimming pools in the United States and England.

Chlorine. Avicenna, an early eleventh century Persian physician indicated that acid added to rainwater preserved the quality of water and made it safe for drinking.

The first proposal to chlorinate water recorded, has been found in Dr. Robley Dunglinson's Human Health, published in 1835 at Philadelphia. He wrote that to make "the water of marshes potable, it has been proposed to add a small quantity of chlorine, or one of the chlorides; but a quantity sufficient to destroy the foulness of the fluid can hardly fail to communicate a taste and smell, disagreeable to most individuals."[31] This proposal predates scientific knowledge of water-carried disease germs. The earliest British patents involving some type of chlorination dated from about 1840.

Before 1900 several patents, both in the United States and in Britain, has been issued for water treatment by electrolysis. In each case the electrolytic methods produced a chlorinating or oxidizing agent that could be applied to the water. In the United States the first patent on chlorination of water was granted in 1888 to Albert R. Leeds, on an electrolytic apparatus. The apparatus was a tank containing acid solution of hydrochloric, nitric, phosphoric, chromic, or sulfuric acid or salts of the acids, singly or in a mixture. Leeds reported that best results were achieved with the use of hydrochloric acid. Electrodes in the solution tank produced a gas, which was carried to a contact chamber for treatment of the raw water.

Chlorination with bleaching powder was used in 1896 to stop a typhoid epidemic at Pola on the Adriatic Sea (one-time chief naval station of Austria-Hungary.) Sodium sulfite was used to neutralize the excess chlorine.

At the Louisville, Kentucky, testing station in 1896 William M. Jewell applied chlorine gas to the effluent from the Jewell rapid filter. It was operated about ten days, and applied chlorine at the rate of 0.25 ppm. This was probably the first use of chlorine gas on the effluent from a working-scale water filter, to reduce the bacterial count.

The first permanent water chlorination plant was installed at Middelkerke, Belgium, in 1902. Before passing through gravity filters, chloride of lime and perchloride of iron (0.2 and 8 ppm) were introduced through drip cocks.

The first permanent chlorination of a municipal water supply was in Lincoln in 1905 using a solution of sodium hypochlorite containing about ten per cent available chlorine.

At Poughkeepsie, New York, in 1908 a drought caused a failure in the treatment by sedimentation, coagulation, and slow sand filtration to render the Hudson River supply potable. On the recommendation of George C. Whipple, chloride of lime came to be regularly introduced by coagulant apparatus at the inlet to the sedimentation basin.

In 1909 use of hypochlorite was begun at the treatment plant at Albany, New York. Also, in 1909 liquid chlorine was first produced commercially in the United States and in 1910 was used experimentally for water disinfection at Fort Myer, Virginia.

In 1912 Dr. George Ornstein developed the process in which chlorine gas is first dissolved in a stream of water before introduction into water to be treated.

Chlorination has also been used in combating algae growths, and

improvements in methods have aided in combatting odor and taste problems. A discussion of those methods may be found in the sections dealing with those topics.

In the United States and Canada disinfection with chlorine to a large degree is responsible for the confidence placed in single filtration, generally of the rapid type. There has been almost a complete lack of multiple filtration in those countries. In France, where chlorination was met with less enthusiasm, multiple filtration was widely adopted.

Ozonation. Ozonation for water treatment began at about the same time as chlorination did. It has been used more extensively in France than in perhaps any other country. As a process ozonation has been more expensive and complicated to install and operate. One advantage of ozonation is that it does not aggravate taste and odor problems as chlorination sometimes does.

In 1873, C. J. Fox reported that ozone destroyed bacteria in fluids. In 1874 E. H. C. Monckton was granted a British patent for ozonation by the passage of an electric current through the water in "tubes or channels of special construction." In 1884 Albert R. Leeds was granted a United States process patent for purifying water by "saturating it with oxygen or ozone by causing the water to come in contact, while under artificial pressure and in motion, with compressed air."

In 1896 a British patent was granted to J. Y. Johnson for the production of ozone "by passing oxygen from a reservoir through a cooling vessel into space between two connecting cylindrical vessels, across which there was a brush discharge of electric current."[32]

In the development of ozonation in the United States a small pilot plant was operated at Whiting, Indiana, in 1938-39, and a 3.5 mgd ozonation plant was installed there in 1940. The pre-ozonating plant included: an electrostatic air filter, air dryer, air compressors, ozonators, (for production of the ozone), meters, and two ozonizers (for introduction of the ozone-filled air through porous tubes into the supply to be treated).

Ultraviolet Rays. The earliest reported statements of the bactericidal action of ultraviolet rays was made in 1877 by two English scientists, Downs and Blunt.

The earliest experimental plant was operated at Marseilles, France, beginning in 1909 or 1910. The first known installation on a municipal supply in the United States was in 1916 at Henderson, Kentucky, but was later discontinued in 1923 or 1924.

In general this mode of treatment has proved too expensive for municipal installations. The process found limited adoption for some ships, industrial concerns, and swimming pools.

Algae Control

In 1676 the Dutch naturalist Antony van Leeuwenhoek observed living creatures in rainwater which he called animalcula. In 1693 Dr. Edward King observed that a small amount of sulfuric acid introduced into water containing "some hundreds of these animalcula . . . very nimbly frisking about causes them to spread themselves, and tumble down seemingly dead."[33] In 1757 Dr. John Rutty of England reported five drops of hydrochloric acid would destroy the animalcules.

James Peacock who in 1791 was granted the first British patent on a process and apparatus for water filtration designed a process in which

the raw water vessel discharged into a bag or strainer which collected "innumerable green filaments" which "coalesce and form a tough mucus" causing "disagreeable effects."[34] Peacock stated that this phenomenon did not occur unless the water was exposed to the sun.

In 1821 Toulouse, France, constructed a filtration basin in which problems were experienced with "aquatic plants." These "plants, these animals, died and putrefied in a water lukewarm, making it very bad."[35] It was not possible to cover the basin because of its size; thus it was converted into a filtration gallery after which there were no further problems. Toulouse was the first large-scale example of difficulty in a public water supply from tastes and odors and of the solution by excluding light and air.

Another filter basin put into use in Nottingham, England in 1831, likewise experienced growths of algae. The problem was handled there by pumping out the water and sweeping the bottom with a broom at three-week intervals in the summer and six-week intervals in the winter.

To avoid the occurrence of "vegetation" Edwin Chadwick suggested that where water was gathered from areas underlaid with granite or like material, the overlying vegetable matter should be stripped. This anticipated stripping of the sites of large storage reservoirs practiced in the United States a few decades later.

In 1896 Charles P. Allen, Chief Engineer of the Denver Union Water Company experimented with different linings of reservoirs, concrete, asphalt, and earth. The various linings made little difference in algae growths.

When problems were experienced at the Ludlow Reservoir in Springfield, Massachusetts, in the summer of 1899, the water was not potable for a

period of time. Mud and other material had accumulated to depths of from about twenty to forty-six feet. One possible solution would have been to cover the basin floor with sand and convert it into two compartments so that one could be emptied annually. This would have diminished the storage capacity, however, and finally a new source of supply was sought instead.

George T. Moore and Karl F. Kellerman reported in 1904-05 on studies which had begun in 1901, that copper sulfate was an efficient algicide. Within a few years algae control was effected by application of copper sulfate from boats by spraying or by filling bags and immersing them in the water. In 1935 the Los Angeles Bureau of Water Supply introduced the broadcasting of copper sulfate crystals. By using crystals of various sizes, the chemical would reach the surface as well as lower layers.

In 1924 at Huntington, West Virginia, artificially created turbidity was introduced as a treatment for algae. The turbidity provided a nucleus for flocculation and sedimentation of the organisms.

Prechlorination of water before slow sand filtration was introduced by Ilion, New York, in 1929, to prevent algae growth on the filters. Chlorination rates of 20 to 30 pounds per million gallons were used.

Taste and Odor Control

The first attempts at taste and odor control date from prehistory and involved boiling the water. Hippocrates suggested boiling to prevent odors, in the fifth century B.C.

Paxamus in the first century A.D. proposed immersing a bag containing pounded coral or barley, in water to cure taste due to mineral salts.

Aeration has been used for taste and odor removal or prevention for millenia, with the first-known apparatus for artificial aeration appearing in 1755 as described by Hales. At about the same time James Lind, a British Naval surgeon and hygienist, described a method of dropping water into air. Various types of cascade, jet, and other open-air aerators were developed. Pan aerators with or without coke fillings were used at Winchester, Kentucky in 1901 or 1902.

Use of charcoal for taste improvement is also lost in prehistory. In 1790 Johann Tobias Lowitz, a Dutch chemist, announced that powdered charcoal aided in preventing or removing bad tastes and odors. In 1807 Cavallo, Italian, proposed adding powdered charcoal to water, agitating, and then filtering. Since the 1920's activated carbon has been used.

Algae and other organisms can produce tastes and odors. Methods for control of algae are discussed in a separate section.

Chlorination for disinfection sometimes produced an odor problem. An increased odor problem arose when chlorine was added to water supplies containing phenols as chlorophenols were produced which are highly odorous compounds. Joseph Race at Ottawa in 1917 applied ammonia with chlorine to reduce end tastes, and it was later determined that this combination also prevented end tastes or odors occurring as a result of the presence of phenolic compounds.

In 1926 Toronto began what was called superchlorination. It was found that if enough chlorine was added so that practically all of the residual chlorine was "free" instead of "combined" end odors would be destroyed. In 1928 R. D. Scott reported the phenomenon which is the principle behind this type of chlorination, and which gave the method

the name, "break-point" chlorination. It was found that, while constantly adding more and more chlorine, the residual chlorine at first increased, then decreased, and then once again began to increase. The idea with superchlorination was to add sufficient chlorine to pass beyond the breakpoint in the curve, to the side where the residual once again began to increase.

In 1930 and 1932 ozonation was applied to taste and odor control at Hobart and Long Beach, Indiana, and at Whiting, Indiana, in 1940.

Aeration

The value of aeration as a method of water treatment has been known, and aeration has been practiced since very ancient times. The first experiments on artificial aeration were reported by Dr. Stephen Hales in 1755. The objective was to remedy odors by forcing air through a perforated tin pipe at the bottom of the water tank. About the same time James Lind, a British naval surgeon and hygienist proposed to remove hydrosulphuric acid and volatile organics by passing water through a perforated plate so that it would fall through the air in finely divided streams.

The earliest known cascade aerator working in series was installed in 1848 near Glasgow, Scotland. The water treatment system consisted of five units, the settling reservoir, three filters, and the clear-water reservoir, all arranged in stair-step fashion. Between each unit there was a cascade down to the next unit.

The first known aerator on an American water supply was installed at Elmira, New York in 1860-61. It was of the fountain jet type. In 1876 in Rochester, New York, installation was made of the earliest of the multiple-jet fountain aerators in the United States.

Professor Albert R. Leeds in 1884 was granted U.S. patents on saturating water with oxygen or ozone by introducing air under pressure into water under pressure and in motion. The object in using pressure was to force the oxygen into solution in order to restore oxygen stored in reservoirs or when covered by ice, as in a stream. The method shown in the patent was the introduction of the air into the lower end of a pump line delivering water into a reservoir through a submerged opening.

John W. Hyatt was granted a U.S. patent in 1885 on a device for sucking air into and mixing it with water in its downward passage through a group of tubes.

Beginning at Brownsville, Texas, in 1931, porous tubes or plates for air diffusion have been used at a few water works.

As developed in the twentieth century, aeration continued to have as objective the removal of odors plus an additional objective of aiding in iron and manganese removal. A previously held objective, the removal of organic matter, was given up in the case of drinking water treatment.

Other methods which have been used besides those previously mentioned include weirs, pans with or without coke, and many spray nozzles discharging not far above the surface of a reservoir.

Distillation

Ancient writers recorded that the vapors which rose from bodies of water were purer than the original bodies of water themselves. Rainwater, regarded as condensed vapors, was thus a preferred supply. Aristotle (384-322 B.C.) wrote that when sea water was evaporated, the vapors obtained were purer than their source.

Jabir Ibn Hayyan, an Arabian alchemist of the eighth century A.D. wrote the first treatise on distillation. He described various apparatus, and defined distillation as "an elevation of aqueous 'Vapours' in their 'Vessel'," some by means of fire and some without use of fire. He wrote that the objective of distillation,

> . . . which is made by ascent into the Alembeck, is the desire of acquiring Water Pure without "Earth" . . . for the "Imbition" of "Spirits," and clean Medicines. When We need Imbition, We must have pure Water, which leaves no "Feces" after its "Resolution"; by which "Feculency," Our Medicines and cleansed "Spirits" might be infected and corrupted.[36]

In the late sixteenth century the British patent office first began to issue patents for distillation, mainly for salt water aboard ships.

In 1767 Dr. William Heberden of England wrote that to improve the taste of distilled water, it could either be allowed to stand or boiled in an open container, or air could be forced into it. This was done in order to replenish the oxygen which had been lost in the process of distillation.

During the last half of the nineteenth century the use of distillation continued to be limited mainly to ships and naval bases. When the Suez Canal was opened the British installed plants along the canal for the distillation of sea water.

Softening

On a small scale, if not by name, softening has been practiced through the centuries ever since soap came into use. In 1756 Francis Home, a Scotch physician, published a book on his studies on water softening. They appear to have been the first scientific experiments

on water softening, and he seems to have been the first to suggest that water softening be applied to municipal supplies. The softening agents he proposed were alkaline salts. His measure of the softness of a water sample was its soap curdling point.

One of the pioneers in the field of water softening was John Rutty of England. In 1757 he wrote that one method of softening was to introduce an alkaline compound into the water to be treated, and he mentioned pearlash as one such compound. Other means of applying alkaline salts to water were the use of "the ashes of green ash or beech burnt to a whiteness."[37] In 1767 William Heberden in England wrote that water could be softened by boiling.

The first softening of water for public use which has been discovered was practiced at Black Rock, near Cork, Ireland, in 1810 or before. Potash of soda was used.

In 1830 Abraham Booth, in Britain wrote a treatise on softening and related topics in which he stated that "Simple boiling will soften waters whose hardness consists of the carbonates of lime and magnesia . . . for as the carbonic acid is expelled . . . the earth subsides, . . . [but this] will not remove sulphate of lime, and, as this is almost constantly present in water, boiling is but a partial mode of purification. . . ."[38]

In 1841, Thomas Clark, Professor of Chemistry in Aberdeen University, Scotland, announced what was called the Clark lime process and was granted a British patent. He claimed that his excess lime method would also work to purify the water. His patent covered

the use of lime as a precipitant followed by sedimentation or by sedimentation and filtration. The method was for removal of what was called "temporary" hardness.

The first plant for softening of a municipal supply was completed at Plumstead, England, at the end of 1854. The ratio of slaked lime to untreated water was one to eight or one to nine. The lime sludge was sold to bristle manufacturers.

John Henderson Porter, a London civil engineer took out a British patent in 1876 which proposed to use the precipitate resulting from the Clark process as the medium of filtration by retaining it on filter cloths.

A. Ashby was granted a British patent in 1878 which claimed removal of "permanent hardness" from water which had already been subjected to Clark's process. The method in the patent proposed to add enough sodium carbonate or potash to precipitate the ions of calcium, magnesium, and iron which had remained in the water after the Clark process in the form of soluble compounds. In 1891 William Lawrence took out a British patent which included the antecedent of upward-flow reaction and sedimentation, a notable development when applied to water softening practice.

In 1897 at the water works of Swadlincote and Ashby softened water was recarbonated by means of coke to remedy the problems associated with excess causticity. Later, practically all softening plants were equipped with recarbonation devices.

In 1903 Robert Gans was granted a German patent for what was to be called the zeolite process of water softening. His invention

was "a form of artificial zeolites" created by fusing "clays and soda ash, and hydrating them."[39]

Iron and Manganese Removal

In 1820 when a filter gallery was put into use at Glasgow, Scotland, the water obtained was so heavily concentrated with iron that it could not be used in the textile industry and consumers found it unpleasant for domestic use. This is the first instance found in the literature of problems arising from iron in ground water.

In 1868 B. Salbach in Germany stated that "certain ground waters could be freed from iron by aeration followed by filtration through gravel and sand."[40] The aeration was to oxidize the iron and manganese compounds to form insoluble compounds which could then be removed by filtration.

Charlottenburg, Germany, was the first city to build an iron-removal plant, in 1874. In 1942 a plant in Etobicoke in Canada was using zeolite for both softening and iron removal. In Saigon and Chalon in 1933-35 a design was developed to "combine in a single closed tank: (a) contact aeration by passing water downward and compressed air upward through a layer of broken lava at the top of the tank and (b) filtration in the lower part of the tank."[41]

Ion exchange has also been used for manganese removal, as well as for iron.

Desalinization

Various forms of distillation have been used, as well as electrodialysis, freezing, reverse osmosis and ion exchange.

Storage

Water Vessels

Before the advent of pottery in Europe a basket lined with clay was used. Woven wicker buckets have been used in China and jars of plaited willow pitched inside and out were reported to have been used in Mesopotamia.

Cisterns

Water stored in cisterns benefits from the sedimentation process, whether by design or by accident. In Palestine and Syria there were numerous cisterns which received activity from early times in the conservation of water supplies. Most of the cisterns in Jerusalem were of four types:

> (a) small cisterns each consisting of a long shaft cut through the rock, with a bottle-shaped excavation to collect the water at the bottom--a type, up to twenty feet or so in depth, attached to houses or groups of houses in Palestine even in Canaanite times, (b) large excavations beneath the surface, roofed with the natural rock, some measuring up to forty feet from floor to ceiling, (c) cisterns of Herodian or later date where the rock has been cut down perpendicularly and an arch, or roof of masonry, built over the excavation, and (d) cisterns of more modern construction dug out of the rubbish and lined with masonry, which are supplied by rain collected on the roofs and terraces of the houses.[42]

The best known of "Phoenician" water [illegible]s were those of the city of Carthage, where two groups of [illegible]sterns were constructed to catch and hold rain water. The con[illegible]ruction was of rubble lined with cement. The first group is 139 meters long and 37 meters wide, barrel vaulted and divided into eighteen compartments, in parallel rows opening on to a common "corridor." The compartments are each nearly 100 feet long by 20 feet wide, and 27½ feet high. The other group was larger.

From the fifth century to the eighteenth century Venice depended on water stored in hundreds of cisterns. Large storage reservoirs such as those found at Carthage were not possible due to the situation of the city on islands.

At Byzantium, Justinian in the sixth century, had two great underground cisterns built. One, the "Hall of a Thousand and One Columns" was built in 528 A.D. The structure is in two stories, and the domed roof is supported by sixteen rows of fourteen columns each. The other, Yeri Batan Serai still held the water supply of Constantinople in the middle of the twentieth century. Like the other, it is filled with decorated columns and gives the appearance of a cathedral filled with water, rather than a reservoir.

The construction for Mayan villages of underground cisterns to store rainwater runoff is regarded as a noteworthy engineering achievement of ancient times.

Distribution Within Municipalities

Water Carrying, Piping, and Distribution By Open Ditch

In many large urban areas, the distribution of water which was carried out was done by means of porters or carts before the later introduction of piping. In Cairo, during the Middle Ages the number of water carriers was once estimated to be 100,000. In London the water carriers formed themselves into the Company of Water Tankard Bearers, which had a membership of four thousand by the end of the fifteenth century. The use of water carts had begun in England by the sixteenth century.

When the first known filter for city-wide supply was installed at Paisley, Scotland in about 1804, the filtered water was taken from the clear-water basin and placed in large casks. Two carts loaded with these casks, making seven trips a day through the town, delivered about 6,700 gallons a day. The cost to the consumer was one or one and one-half cents per gallon and was said to provide benefits to him in time and labor saved. In 1838 water from another filter designed by Robert Thom began to be piped through the streets of Paisley. In 1807 Glasgow, Scotland, became the third city to have a filtered water supply, after Paisley and Paris. Here, however, the supply was piped from the beginning.

In 1806 in Paris a filter plant was installed on the Quai des Celestins in Paris. As of 1823 these filters were supplying 52,840 gallons per day, or about one percent of the total supply to the city of Paris from all sources. This was delivered by 130 men

using 75 casks and 109 horses, making two or three trips each day to different parts of the city. The charge to consumers was about half a cent for five gallons. Up to the end of the nineteenth century most of the filtered water in Paris was distributed by licensed porters or was sold at the filtration plant by consumers who carried it away themselves, with only a little being piped. Paris has had a dual supply, one of potable water, the other of water for street washing and fire-fighting. At Nantes in France Souchon filters were installed in 1855. The product of those filters was piped through one distribution system, while raw water was piped through another.

In Cincinnati in 1797 water from wells was carried through the streets. Soon after, water from the Ohio River was distributed by sled and cart. In 1821 piping was introduced.

In urban centers in Iran, until fairly recent times, distribution in urban centers such as Teheran was by means of open ditch.

Supply to Private Homes Vs. Public Fountains, Continuous Flow Vs. Intermittent Flow

Where public water supply systems were found prior to Roman times, the distribution of the water was generally only to a few public fountains or conduits. Where distribution was made to private homes, in Rome or before, the practice was quite limited. An inscription on the Mabite Stone refers to an effort by King Mesha in the tenth century B.C., to provide in the city of Karcha, a form of water distribution system:

> Mesha built two conduits, and since no cisterns were in the city, Karcha, Moab, he ordered the inhabitants of the city to place a cistern in each house. He then had a conduit constructed by the Israelitish prisoners to supply water to the cisterns.[43]

The water supplied by means of the Roman aqueducts generally fed fountains for public use, which flowed continuously. Also, in Europe during the Middle Ages, the water outlets in the monasteries, as well as public fountains usually ran continuously. In some cities the public conduits were plugged during the night, and later on, some conduits were provided with taps.

In Europe in the Middle Ages townspeople usually obtained water from a public fountain or cistern or purchased water from carriers. However, in the thirteenth century Dublin had a water supply with pipe connected to private homes.

In England before the seventeenth century, private water services were rare. During the seventeenth century private services increased, although the poorer people continued to obtain their water from public fountains and supplies. With private supply, generally the water was stored in cisterns in the basements of houses and then pumped to cisterns in the upper part of the house, in order to provide head. Where the flow was intermittent, there were problems for those who had to wait at the public tap. There was great difficulty for them in obtaining and storing sufficient amounts for their needs. In 1848 British Parliament required that supplies be constant. However, intermittent supplies continued in Britain for many years. By 1890 most British towns had constant supplies.

In 1849 the first Medical Officer of Health of the City of London reported:

> I consider the system of intermittent water supply to be radically bad; not only because it is a system of stint in what ought to be lavishly bestowed, but also because of the necessity which it creates that large and extensive receptacles should be provided, and because of the liability to contamination incurred by water which has to be retained often during a considerable period. In inspecting the courts and alleys of the City, one constantly sees butts for the reception of water, either public, or in the open yards of the house, or sometimes in their cellars; and these butts, dirty, mouldering and coverless, receiving soot and all other impurities from the air; absorbing stench from the adjacent cesspool; inviting filth from insects, vermin, sparrows cats and children; their contents often augmented through a rain pipe by the washings of thereof, and every hour becoming fustier and more offensive. Nothing can be less like water should be than the fluid obtained under such circumstances.[44]

In 1553 in France the public fountains at Nantes served a population of 2600. In 1866 water from public fountains was available only from four to eight p.m.

In the United States in the early 1800's Philadelphia replaced the public standpipes with underground tanks and handpumps in order to save water.

Quantities Available and Consumption

People in villages and cities of ancient times probably did not use over three to five gallons per day per person. However, Clemens Herschel estimated that the average quantity of water delivered to Rome by the aqueducts was in A.D. 97, about thirty-eight million gallons per day or thirty-eight gallons per capita day.[45]

In Paris in the middle of the sixteenth century the amount of water available to the public was only one quart per capita. At this time the supply was from the Seine and local wells. At the end of the seventeenth century there was available just over two and one-half quarts per capita.

In 1850 New York used 78 gallons per capita per day, and in 1890, 96 gallons per capita per day. In 1900 New York City received 115 gallons per capita per day.[46]

In the last part of the nineteenth century, increased water demand occurred where there was increasing use of bath tubs, water closets, and public bath houses. In the twentieth century a further increase occurred because of the use of washing machines, dishwashers, garbage disposals, air conditioners and lawn sprinklers.

Metering

In Rome in the days of Frontinus, the charges were made according to the diameter of pipe which was inserted for the flow to pass to the user.

In 1835 a metering device was being used which consisted of a hollow drum or wheel divided into sections. As the wheel rotated each compartment would fill water and then be subsequently emptied. The number of revolutions was recorded through a system of gears. This is much like the modern water meters, except that the wheel rotated in a vertical rather than horizontal plane. Metering helped to cut down on the amounts of water wasted. Other ways of charging which did not have the benefit of encouraging conservation were charging by the number of faucets present in the house, or charging according to the appearance of the house, the more prosperous looking residences being charged a greater amount.

Household and Community Use

Baths

Bath and shower facilities are dependent on constant pressure water supply and sewerage facilities.

The remains have been discovered of a square bath at Gaza dated at about 3100 B.C., also palace bathrooms at Mari, Syria, of about 2000 B.C., and an elaborate swimming bath of the Sassanian kings at Kish in Iraq, of the fifth century B.C.

At Mohenjo-daro in West Pakistan (about 2500 B.C.) there was a large public bath, and nearly every private dwelling had a bathroom connected to the drainage system.

In ancient Mesopotamia only the wealthy had private bathing facilities. In place of soap a mixture of oil, ashes, and clay was used. By the third millennium B.C. sanitary facilities were comparable to contemporary cities in the Indus Valley.

The earliest form of bathtubs yet discovered date from 1700 B.C. and were made of earthenware, found in the Palace at Knossos in Crete.

Crude stone shower baths were used at Tell-el-Amarna from 1350 B.C., and in Greek cities of the first century B.C.

Houses in the Greek town of Olynthus (fifth century B.C.) had bathrooms, cisterns, lavatories, and washbasins, with a waste pipe running through the outside wall to the street.

There were six large bathing establishments in the City of Rome during the time of Frontinus, and the Baths of Diocletian would accomodate more than 2,000 bathers at a time. During the reign of Constantine (324-337 A.D.) Rome had eleven great thermae and 926 public baths. The large establishments were complete recreation centers.

The common source of water for the public was an outlet discharging over a stone tank placed against a wall in a public street. These baths became necessary because so many people lived in tenement-like dwellings, and charges were within the reach of everyone.

In Alexandria in Egypt, in 640 A.D., every dwelling had its own bathroom. In the Moslem city (seventh to thirteenth centuries) the bath played a social and hygienic role of primary importance.

Communal steam baths were a common feature of early Mayan culture. The Incas had constructed baths, and also the priests of the temple at Teotihuacan (Toltec). The subterranean rooms of the latter included a chamber with a deep recess to which water was conveyed by an oval conduct and then flowed onto the bather through an opening at the top of the recess.

In the Middle Ages in Europe, bathing was infrequent and lacking in privacy. Monasteries were the only establishments with private bathing facilities.

By the end of the thirteenth century, Italy began to have bathrooms in private dwellings, and public baths appeared in Northern European cities.

By the year 1800 in Britain a bath was not used very often. When one was used, it consisted of a portable bath in the bedroom which would be filled and emptied by one of the servants. London's first public bathhouses were established in the 1840's.

In 1840 in the United States copper or iron boilers were connected with the bath to supply hot running water. In 1870 in New York hot water was supplied to homes from a central plant in the home. In 1890 in Berlin was developed the manually operated gas water heater and in 1910 in the U.S. the automatic waterheater.

By 1900 Tokyo had around 1000 public bathing facilities and most major cities in Europe had systems of public baths, while in the United States the practice did not gain much popularity.

In 1894 in the United States 83-98 percent of the residences were without bath facilities. In 1970 residences with private baths were 88 percent of the total in the United States, 75 percent in Great Britain, 64 percent in Germany, and 49 percent in France.[47]

Latrines and Closets

Around 2500 B.C. in the Indus Valley (now West Pakistan) at Mohenjo-daro, one of the largest towns of that time, every house had a latrine.

The Minoan civilization (2500-1400 B.C.) had water flushed latrines in the Palace of Minos at Knossos.

In Egypt around 1350 B.C. there were latrines which employed earthenware jars as receptacles.

Many larger Greek towns of the first century B.C. had public and private lavatories with water flushing facilities. This was usually a channel with a continuous flow of water.

In Rome in the fourth century A.D. water flushing of latrines became prevalent and much use was made of waste water from the public baths. In 315 A.D. Rome is reported to have had 144 public latrines, or about one for every 5,000 persons. A continuous flow of water in channels was used.

In Europe during the Middle Ages, monasteries designed latrines to accomodate large numbers of people, and provided water flushing by diverting a natural stream of water into an artificial channel beneath the latrine. The moats surrounding castles disposed of wastes from latrines built into the walls of the castles.

In London during the middle ages, public latrines were built which were flushed by water courses. Toward the end of the thirteenth century private latrines became common, constructed along water courses. When the number increased, the disposal was diverted from open water courses to privy vaults and cesspools.

By 1500 in England, a townhouse would have had a privy in the yard consisting only of an open pit under a wooden seat in a little shack.

A type of water closet was first described in 1596, in a poem published by Sir John Harrington. Water closets later came into general use in the eighteenth century. In the early years of their use, it was not permitted to use municipal supplies of water for the operation of water closets.

By 1700 the wealthier class in Britain made use of a "close-stool" which was kept in the bedroom. This was a box fitted with a padded seat and enclosing a pot which was emptied by the servants.

The first types of water closets included the long hopper, and the pan closet. The latter originated in London in 1852. The plunger closet received a U.S. patent in 1857. This was the first patent in the United States for a water closet. In 1775 a watchmaker, Alexander Cumming, took out a British patent for a valve closet, consisting of a cast-iron bowl with a valve at the base which could be opened by a plunger to release the contents through an inverted siphon. The water for flushing came from a cistern overhead, while the effluent was discharged into a cesspool under the basement or in the yard of the house. In 1778 Joseph Bramah took out another patent for a valve closet with a different design. By 1815 this was the accepted type. As late as 1937 the valve closet was recommended by some for situations in which no flushing cistern was required. Other

earlier types of water closets included the short hopper and the washout closet. In 1782 in London, a trap was devised using a water-seal. In 1852 Josiah G. Jennings made the first wash-down closet. The siphon closet was developed and perfected in the United States.

In 1701 in Boston, a leader in the U.S. in positioning of privies, a by-law required no privy be located within forty feet of a public street, shop, or well. In 1826 Baltimore required privies within a certain distance of wells to be constructed of impervious materials.

Sewage Removal and Treatment

Introduction

Throughout history, the typical urban environment has been in general quite unsanitary, and progress in correcting the situation has been very slow. Urban sanitation in the more highly industrialized countries has experienced most of its advances only since the middle of the nineteenth century. Beofre this time, the problems of sanitation in urban areas increased enormously with growing populations. By the seventeenth century in Europe, the larger urban areas were already experiencing a necessity for some type of improvements, while in the colonial United States the relatively small size of the communities created a different situation. The second half of the eighteenth century saw greater industrialization and the urbanized areas became decidedly unhealthful places in which to live. By the middle of the nineteenth century the major cities of the United States were overcrowded and unsanitary, and there were frequent epidemics of yellow fever, cholera, and typhoid in the middle years of that century.

Aside from land application by some Greek cities, no treatment was given urban drainage in ancient times. It was generally discharged directly into a receiving stream. A small portion of the population had access to drainage facilities. Most waste was carted out of the city periodically.

Virtually all the conventional types of sewage treatment used in developed areas today, were introduced within the last one hundred years. Sewers existed in many localities for thousands of years, but there was generally no attempt at treatment until quite recent times. The effluent

was usually deposited unchanged, in lakes, rivers, the sea, or on land, usually without any controls.

In 1860 the sewered cities in the United States disposed of the effluent by dilution without prior treatment. In the United States from the 1870's, treatment plants came to be provided for increasing numbers of cities, using chemical precipitation and biological processes. In 1900, ninety-six percent of sewered cities used dilution without prior treatment. In 1935 seventy percent of sewered cities had some form of treatment, and in 1955, two-thirds of sewage flow received artificial treatment. In 1962, of the sewage flow in the United States, twelve percent received no treatment, thirty-five percent partial treatment and fifty-three percent secondary treatment.[48]

Standards

In 1912 in Britain the Royal Commission on Sewage Disposal proposed standards for sewage effluents in its Ninth Report. When effluents were to be discharged into rivers where dilution would be greater than eight to one, the Commission recommended that in the effluent, "(1) suspended solids should not exceed thirty parts per million, and (2) not more than twenty parts per million of dissolved oxygen should be absorbed in five days at 65° F."[49] The later restriction refers to the test for "biochemical oxygen demand" or BOD test.

Considerations of Health and Demands for Sewage Disposal and Treatment

In 1875 Albany, New York, began using water form the Hudson

River to supplement the municipal supply. The river was dangerously polluted with sewage from other cities on the river. As a result Albany experienced difficulties of the sort which were common to other municipalities as well. Professor Albert R. Leeds was engaged as a consulting chemist. In a report filed in 1885, he stated that the people of Albany were,

> . . . drinking a residual portion of the sewage of Troy and a part of their own sewage. . . . A human and wise public opinion [should compel communities] to reclaim their sewage before emptying the purified effluent into a flowing stream. . . . Simple, economical and completely effectual methods of doing this are known and practiced by sanitary engineers.[50]

These ideas were ahead of their time. Although methods were available, in 1885 there was no concerted public demand for such compelling legislation, and no city in the United States was treating its sewage effectively. Thus it may be seen that when proper precautions have not been taken in more modern cities, this lapse into generally poor methods of waste disposal can contribute to a return to the devastation of typhoid, cholera, and other plagues.

Solid Waste Collection by Private Contractors

The traditional Chinese practice was to collect all urban domestic sewage including that from privies and cesspools and use it as fertilizer.

In Mesopotamia and the Middle East the early cities deposited sewage and solid waste in streets and open spaces.

In Pre-Colombian America there is evidence that collection was used by the Aztecs.

In the 1800's and earlier throughout the Middle Ages in England and the rest of Europe, solid waste including sewage was heaped up in piles in the streets, paved or unpaved, and around the homes of city dwellers. Some was sold for agricultural purposes. In the wealthier parts of towns private contractors collected the refuse periodically. In the early fourteenth century London was the first European city to set up an organized scavenging system.

Composting

Composting is an ancient method of dealing with the problem of sewage removal and treatment, but at least one modern-day application may be mentioned. On the island of Jersey in the English Channel, in 1957 a composting plant was built. It consisted of a tower of six floors. Aeration occurred as the refuse and sludge fell slowly down through the floors, and aerobes assisted in decomposing the mixture. The finished product was used as fertilizer.

Cesspools

At the close of the Middle Ages in Britain much of the human wastes were being directed to privy vaults or cesspools, and thence percolated into the porous layer contaminating well water. By 1775 in Britain the effluent from water closets was being discharged into cesspools under the basements or in the yards of the houses.

Septic Tanks

Septic tanks were first introduced in France about 1869, and the United States in 1884. In England in 1896 Donald Cameron, city surveyor of Exeter, announced his discovery that sewage could be held in an

airtight tank for a day or so and that this reduced the organic content. He called this a septic tank.

The process in the septic tank utilized the action of anaerobic bacteria. Disposal of effluent from this unit is now usually accomplished by cesspool or soil percolation through open-jointed clay pipes.

Drains and Sewers

The subject of drains and sewers may be supplemented with information from the paragraphs on piping located elsewhere in this inventory. There are really two types of processes involved here, one the transportation of stormwater, and secondly the transportation of sanitary flow. In general, it may be said that sewage systems using water work well in urban areas with high density population where there is an abundant and constant supply of cheap water, and where there is enough wealth in the community to pay the costs of installation and upkeep.

In Mesopotamia in the fourth millennium B.C. open ditch and rough stone-lined channels drained stormwater.

At Chandu-daro, Sind (third millennium B.C.), as well as at Mohenjo-daro and Harappa there were found excellent sanitary systems to which an adequate water supply would have been essential. In the fourth century B.C. similar drainage systems again came into use in the same geographic area.

On the island of Crete the Minoan Civilization (3000 B.C.-1200 B.C.) produced the royal palace of Minos with water and drainage systems quite well developed.

Drainage systems as old as 2500 B.C. were known to exist in Egypt.

The cities of Babylon and Jerusalem had sewers cut in rock or built of masonry dating back to the eleventh century B.C. Cylindrical sewer pipes were in use in the seventh century B.C. at Babylon and Ninevah.

The Greek city of Olynthus, planned in the Macedonian Period (380-130 B.C.), was provided with a central paved alley five feet wide in each city block to provide drainage. Covered brick masonry drains were in each street. Each house was connected with a small sump chamber of brick masonry on each house connection to collect sedimental material. Lime-mud mortar was used. A channel in the floor was for dry weather flow. Similar systems were present in the City of Ur and other contemporary cities of Mesopotamia. Although some cities of ancient Greece had drainage systems into which private houses were connected, Athens was an urban center which showed lack of planning in the matter of sanitation and water supply. There seems to have been no drainage systems or sewer networks. Many systems were installed in Greece later during the Roman period.

Sewers were common in the time of Rome. The famous sewer of ancient Rome called the cloaca maxima was built about 588 B.C. Only wealthy people had private sewer connections. No drainage systems

rivaled those of Rome until the nineteenth century.

Urban centers in the Mayan civilization had systems of gutters, troughs, drains, and pipes.

In medieval Europe the larger monastic houses usually had underground sewers flushed by a flowing stream of water. Drainage from bathrooms usually flowed to a fish pond and from there for the flushing of latrines. In cities of Europe during the Middle Ages and later, the narrow lanes found in the cities often had a drainage ditch in the center which carried all sorts of refuse and wastewaters. In most urban areas in Europe in the Middle Ages the drainage systems were often clogged because of refuse and lack of water to provide flushing. By 1800 in cities in Europe as well as in the United States, it was becoming common to discharge domestic wastes to storm sewers. This was the "combined' sewer system. In Paris in 1833 shallow drains discharged directly into the Seine River. In that year storm sewers were begun, but no sanitary sewage was allowed to enter those drains until 1880.

By 1841 in London there was no over-all planning in the construction of sewers, and most were square brick tunnels with flat bottoms and no fall. One medical officer wrote: "The sewer in Friar Street has a most curious quality, that of flowing either way equally well."[51] Such sewers were really elongated cesspools. Little water was used; thus the sewers were made quite large so that cleaners could enter them. Subsequent to the period described here John Roe designed the egg-shaped sewer.

In the middle of the nineteenth century came the concept of a separate sewerage system to carry only water-borne human wastes. This was a major advance in urban sanitation. In Hamburg, Germany, was introduced the first complete sewer system which was flushed thoroughly with water every week. The first large modern sewers were at Hamburg (1844-48) and London (1854-65). In London the pumps used were steam-driven double-acting beam engines, driving ram or plunger pumps. The last of these sewage pumps was not replaced until 1952. In England in 1856 Joseph Balzagette proposed a plan of sewer construction including interceptor sewers with pumping stations to discharge into the Thames Estuary downstream from the city.

In the United States, meanwhile, at Boston toward the end of the seventeenth century, there was constructed a system of sewers in which each houseowner paid a proportional part of the cost of construction. New York had only two public sewers before 1720. Street drainage was usually by means of a ditch along the center of the street. In 1860 there were only ten sewered cities in the United States; in 1900, 950; in 1935, 6,800. In 1962 about two-thirds the population were served by sewerage systems.[52]

Colonel George E. Waring was an advocate of separate systems for sanitary and storm sewerage in the United States. However, well into the twentieth century, the combined system was more prevalent. In 1880 Pullman, Illinois, and Memphis, Tennessee, were the first U.S. cities to install separate sewer systems. Many English towns had adopted the separate systems earlier than this.

In Russia in 1912 there were only seventeen cities with sewer systems.

Sewage Farms and Land Application of Sewage

In ancient Greece, cities which had drainage systems often apread the effluent over wide areas of ground for irrigation.

Following recommendations of the Health of Towns Act in 1888, in the second half of the nineteenth century, some towns in Britain were operating sewage farms, growing grass, mangolds, cabbage, and willow. The produce from these farms was generally unpopular in the vegetable markets.

The land application of sewage has been used in other parts of the world also. The sewage of Paris and Berlin has been disposed of by land application, and the method has been used in some parts of the United States.

Land application may not be used during winter months, when the sewage might need to be stored for spraying on fields during warmer weather. This is economical in terms of usage of energy or chemicals, but requires large areas of land. If a drainage system is used, salt build-up and waterlogging of soil can be prevented.

Chlorination and Ozonation of Sewage

Experimental application of chloride of lime was made to London sewage in 1854 and 1884.

On January 27, 1887, Webster received a British patent on an electrolytic method of purifying sewage. The electrolytic processes which were developed each operated on the principle of producing a chlorinating or oxidizing agent which could then be applied to the sewage.

On May 10, 1887, the first United States patent on chlorination

of sewage was granted to J. J. Powers. His apparatus was to generate gaseous chlorine from manganese dioxide, sodium chloride and sulfuric acid. Powers built six sewage works in New York state.

In 1893 electrozone produced from salt brine by an apparatus designed by Albert E. Woolf, was added to the sewage of the village of Brewster, New York. This plant continued to operate until it was destroyed by fire in 1911, after which time bleaching powder was used. It was said that this plant was similar to the one used by M. H. Hermite at Rouen, France, in 1889.

Coagulation

In spite of the developing science of bacteriology arising out of Pasteur's discoveries of the 1850's, the principles of that science were not applied until later in the treatment of sewage. The British first experimented with filtration as a purely mechanical process and with chemicals such as lime or alum which would cause suspended matter in sewage to coagulate and precipitate. London began treating its sewage by chemical precipitation in 1882. In 1885 manganate of soda was used for London's sewage and in 1887 chloride of lime. By 1898 in Britain there were 500 patents for chemical precipitants.

The first chemical precipitation plant in the United States was at Worcester, Massachusetts, in 1889.

Contact Beds

This type of treatment appeared in the 1880's. Crushed rock or slag is placed in watertight tanks. The beds are operated by the fill and draw method and require removal of accumulated solids. This process is aerobic.

Sewage Trickling Filter

In 1871 in Wales the first intermittent sand filtration process was placed in operation. William Joseph Dibdin, a London Chemist, in 1882 gave evidence to the Royal Commission on Metropolitan Sewage Disposal that bacteria were important in sewage treatment. He was one of the first to suspect and promote this idea.

In 1887 the State Board of Health of Massachusetts at the Lawrence Experiment Station experimented with Dibdin's idea. Two years later the board reported that "the mechanical separation of any part of the sewage by straining through sand is but an incident . . . [while] the essential conditions are very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact."[53] However, even the coarsest sand became clogged and useless in a short time.

Dibdin continued experimentation using different media. In 1896 he wrote of his own experiments explaining that a very coarse medium was needed into which air could pass freely over the slimy deposits of aerobic bacteria which fed on the organic matter in the sewage.

Before the date of Dibdin's publication, about 1893, at Salford, England, one of the earliest of the trickling filters was installed. The first trickling filter treatment plants in the United States were introduced in 1894. By 1940 there were about 1600 trickling filter plants in the United States, representing about sixty percent of all sewage treatment plants in the country.[54]

Trickling filters are self-cleaning units from which settleable solids pass out with the effluent to settling tanks.

Activated Sludge Process

In 1912, Dr. Gilbert Fowler, employed by the Manchester Rivers Department, and his assistants discovered what is now known as the "activated sludge" process. They aerated sewage in bottles for a period of time, withdrawing at the end a clear liquid and leaving the brown deposit. When raw sewage was replaced in the bottles with the deposit, the liquid became clear in a shorter time than before. In this process aerobic bacteria were at work, making their home on the particles of sludge. Two processes came to be used to provide air for the bacteria, the diffused air process, which forced air into the bottom of the tank, and surface aeration which introduced air by moving paddles at the surface.

In the 1940's refinements were tapered aeration and step aeration which made better use of oxygen throughout the aeration period, and better distribution of aeration tank volumes in multiple pass plants. Other refinements have been high-rate aeration, bioabsorption, and extended aeration. Extended aeration lowers the rate of sludge production.

Sewage Lagoons or Stabilization Ponds

This form of treatment has been widely adopted in recent years. These lagoons can be anaerobic or aerobic. Artificial aeration can be utilized, and this type of unit is closely related to the oxidation ditch.

Garchey System--Modified Water Carriage System

A French Engineer, Louis Antoine Garchey designed a system in which a three-gallon cast-iron container was fitted beneath a sink,

with an eight-inch outlet covered by a removable disc. Refuse dropped down the hole in the sink and mixed with waste water. The container was similar to a valve closet and by pulling a plug the contents could be flushed into a six-inch vertical pipe resembling a soil-pipe.

An eight-inch earthenware drain led to collecting chambers Finally the refuse was partially dried by rotating it in extractors like large spin-driers. The water passed to the sewer and the solid refuse was incinerated.[55]

The system was first installed in a housing development near Paris. The first British Garchey system was installed in 1935.

Establishment and Administration of Public Water Supply Systems

The Greek philosopher Plato (427-347 B.C.) suggested that a city water supply be administered by a group of water commissioners representing individual districts. He also recommended regulation for water use and penalties.

Frontinus, as water commissioner of the City of Rome around 97-104 A.D., headed an organization run by the government, and one which was quite well developed. Of great importance in the growth and maintenance of these systems and of those found throughout the Empire, were the funds provided by the Roman governments and Emperors.

In the Middle Ages in Europe, the decline in urban populations decreased tax revenues, and monasteries came to be leaders in providing water supply, and sanitation facilities. Late in the Middle Ages cities again began to grow and local municipalities took over leadership from the monasteries.

In Europe after the Middle Ages and up to the eighteenth century, with rare exceptions the costs of water supply were borne by the Church or by burgesses of the municipality. In seventeenth century England, only wealthy homes could afford a private water supply system. In the eighteenth century private enterprise began to enter the field of urban water supply. By 1800 London, Paris and Rome were nearly the extent of water supply facilities in Europe at that time.

In modern times Great Britain and the United States have played a leading role in the development of public water supplies. However, the pace of development of urban water supply facilities did not pick up in Europe and the United States until the nineteenth century.

By 1810 there were several private companies serving London. In that year they decided to divide the areas served between them and to increase the rates, which aroused complaints of monopolistic practices. Later, complaints and difficulties arising from the poor quality of water supplied led to successive hearings and attempts at certain reforms. Among these were the Waterworks Clauses Act of 1847, and that of 1863, which introduced the principle of compulsory supply. In 1867 the water used in London was supplied by nine companies. It was not until 1902 that the Metropolitan Water Act authorized the Metropolitan Water Board and directed that London's water finally come under public control, a matter which was accomplished in 1904.

In 1800 Boston, Philadelphia, and New York were nearly the extent of public water supply facilities in the United States at that time. In the United States at the end of 1830 there were only forty-four cities with public water supplies. Most of them were small gravity water works, and none included filtration. As public water supplies in the United States developed, public ownership became the norm.

Importance of Water Supply and Social Organization

Among earlier men, and sometimes today in certain parts of the world, a supply of pure water, whether a spring, river or pool, has been considered a holy place, if not actually the home of a god. This process carries with it the additional benefit of protecting the water supply from interference or pollution.

Because the distribution of water for irrigation in ancient Egypt required that the water pass by the holdings of different farmers in succession, a sense of cooperation was necessary, "and the ethical precepts of the Egyptians concerned themselves markedly with one's duty to one's neighbour in the matter. One of the 'confessions' to be made by the soul of the deceased before the Judges in the Underworld, for instance, was a declaration that he had not cut off or interfered with his neighbour's water supply."[56]

In the Islamic religion as well as others, there has been an influence from the religion leading to a greater acceptance of the habits of bathing and cleanliness.

Previously, and also today, in areas of India where the caste system has been in force, a problem has been created concerning the use of wells. This has led to the system of multiple wells, each well set aside for the members of various caste groups, or else, arrangements being made for lower castes to use the wells at designated times, with the aid of someone from a suitable caste to draw the water and distribute it to them.

Women are very often the drawers of water in Africa and the East, and in most small communities in developing regions of the world.

In a community where the domestic supply of water must be visited by a family member in order to obtain the supply for daily activities, the place of supply becomes a rendezvous for gossip and other social undertakings, whether it be a spring, pool, well, or fountain. In desert areas, wells situated along caravan routes provided places for meeting and trade. In a larger dimension, the plentiful and dependable supply of potable water is a necessary attribute to extensive and permanent settlements.

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CHAPTER II

BRIEF SUMMARY OF HISTORICAL DEVELOPMENT IN GREAT BRITAIN (EMPHASIS ON LONDON) AND THE UNITED STATES

Great Britain

Britain, and particularly London, were especially selected for a summarized developmental survey because it is there where may be found the oldest of the modern systems for which there is a rather well-known history throughout.

The earliest civilizations in the world were found in Egypt, Crete, Persia, northern India or Pakistan, and China. All at some point, attempted to provide for water supplies and drainage systems. After the decline of the Roman civilization, principles of town sanitation were widely ignored in Europe. Beginning in the twelfth century, towns began to increase in Europe. At that time liquid wastes from the towns were being drained into ditches and moats, while solid wastes were piled in the streets, and sometimes sold for agricultural purposes.

A house in a British town in the year 1500 or thereabouts would have had no water pipes and no drainage. In the yard was located a privy consisting of a large pot under a wooden seat in a little shack.

In 1578 London was one of the largest towns in Europe, with a population of about 100,000. Sources of water at that time included

the river, public conduits supplied by springs, and water sold by porters. In 1580 Peter Morice, a Dutch engineer, built two wooden force pumps under London Bridge driven by a water wheel. The river water was pumped through a wooden pipe which could be tapped by lead pipes to run water to the yards of some private homes.

In 1596 Sir John Harrington, a poet, published a book containing a poem in which was described something which we would now call a valve water closet. It was presented by him and treated at that time as something of a joke.

By 1700 in an English townhouse of the upper classes, the owner and his family no longer used a privy in the yard, but rather a "close-stool" which was kept in the bedroom. This was a box with a padded seat and a pot inside the contents of which were emptied by the servants.

In 1775 a watchmaker, Alexander Cumming, invented a type of valve closet, consisting of a cast-iron bowl with a valve at the base which could be opened by a plunger to release the contents. The water for flushing came from a cistern overhead, while the effluent was discharged into a cesspool under the basement or in the yard of the house. In 1778 Joseph Bramah took out another patent for a valve closet with a different design.

About this time was culminating a change in life-style in Britain, a movement from the country to the city, and from the farm to industry. Before 1780, most people in Britain worked in agriculture, on the land. Water power limited the size of industries; pack horses were used to distribute goods; and since the introduction in Europe of blast furnaces in the fourteenth century, small amounts of iron were smelted with

charcoal. In 1711 in Shropshire, coke began to be used by Abraham Darly and his son to smelt iron (from about 1750 cast-iron pipes began to replace wooden pipes for water mains); in 1712, Thomas Newcomen pumped water from a coal mine with the use of a steam engine; in 1759 a canal was built; and in 1781 James Watt improved the steam engine to supply rotative power. Industry and towns began to grow rapidly after 1780.

London's population increased from 1.5 million to 2.5 million between 1831 and 1851. With growth in the towns, and the beginning of the popularity of water-closets in the early 1800's, more sewage, besides other wastes, were dumped into rivers from which water supplies were subsequently drawn. Solid waste was still left piled in streets and yards and was collected in wealthier parts of town by private contractors. Before 1815 in London and 1880 in Paris, laws prohibited the discharge of any waste other than kitchen waste into drains. Not until 1848 in Britain did it become compulsory to discharge town sewage into drains. Where privy vaults or cesspools were built or manufactured improperly, they often created a hazard to health.

Early water mains supplied water only intermittently. In 1800 better homes received piped water for storage in a lead-lined cistern and subsequent use. However, in some poorer areas, one well pump and one privy would serve many houses. The poorer classes had great difficulty to wait at the public standpipes at the appointed hours to obtain the water and then to store it, so that they most often did not have sufficient supply. Sometimes a great number of people had to provide themselves water from taps which flowed for less than an hour

each day and not at all on some days.

In the year 1800 a bath was not often used in Britain. When it was used, it consisted of a portable bath set up in the bedroom which was filled and emptied by the servants.

In 1804 John Gibb, owner of a cotton mill in Paisley, Scotland, began selling water from a sand filter he built to clean water used for bleaching. The water was delivered in carts for a half-penny per gallon. The first town with a piped supply of filtered water was Glasgow, in 1807. These sand filters were never completely successful because a satisfactory method of cleaning was not then known by the operators. In 1827 a Scottish engineer and mill owner, Robert Thom, built a slow sand filter cleaned by reverse flow wash. In 1829 James Simpson devised a slow sand filter which was cleaned by scraping the surface of the sand with spades. It was thought at this time that filtration was simply a straining process. A German chemist later discovered sterilized sand was not effective. By the end of the century, it was concluded that the slimy film covering the sand contained microscopic organisms which produced the bacteria in the water. These discoveries in filtration were too late to be of use during the first epidemic of cholera to sweep Britain, but in the three epidemics which followed, doctors noted that those areas served by filtered water suffered fewer cases of cholera.

Before 1817, there had been occasional outbreaks of cholera in India, but in that year, it began spreading across the world. In October 1831 cholera reached Britain and produced the first epidemic there killing thousands of people. Besides cholera, bacterial diseases were also the cause of thousands of deaths every year. Three more cholera

epidemics were to occur later in Britain, in 1848-1849, 1853-1854, and 1866.

In general, living in town was much less healthy than living in the country. Whereas today about ten persons out of 1000 die in Britain each year, in 1831, the figure was over twenty, as high as thirty or forty per 1000 in some towns.[1] In 1831, no one knew how to prevent cholera. Now it is known that no epidemics of that disease have ever occurred where there was a good water supply.

Edwin Chadwick, prominent among forerunners in urban hygiene, reported in 1842: "The great preventives, drainage, street and house cleaning by means of supplies of water and improved sewerage, and especially the introduction of cheaper and more efficient modes of removing all noxious refuse from towns, are operations for which aid must be sought from the science of the civil engineer, not from the physician."[2] Civil engineering was a new profession, and the word civil was used to make the distinction, since in those days an "engineer" was a military man. Reporting for the Poor Law Commission in 1842, Chadwick recommended measures which may be summarized in part as follows:

(1) Every town should have a system of pipe sewers with pipe sizes restricted and grades of sufficient slope to give self cleansing velocities. . . . Thus every town and city would have a system of sewers that would afford an efficient means of conveyance, rather than a depository for sanitary sewage.
(2) Every house should be directly connected to the system of sanitary sewers, and every house should be served by a constant pressure public water supply system.
(3) Sanitary sewer systems and public water supply systems should be publicly owned. Such systems should be designed by competent civil engineers and should be operated under the direction of appointed water and sewer commissioners supported by adequate administrative and technical staff.[3]

Subsequently, John Roe, engineer to the Holborn and Finsbury Commission of Sewers, designed the egg-shaped sewer to replace the square ones in use, and Henry Doulton produced glazed earthenware pipes for house drainage.

In 1835 after the first cholera epidemic in 1831, a committee appointed by Parliament reported on conditions arising from the fact that the Thames was used both for the disposal of sewage from the City of London as well as for the municipal water supply.

> The Thames, to this day, receives the excrementitious matter from nearly a million and a half of human beings; the washings of their foul linen; the filth and refuse of many hundred manufactories; the offal and decomposing vegetable substances from the markets; the foul and gory liquid from slaughterhouses, and the purulent abominations from hospitals and dissecting rooms, too disgusting to detail.
>
> Thus that most noble river, which has been given to us by Providence for our health, recreation and beneficial use, is converted into the Common Sewer of London, and the sickening mixture it contains daily pumped up with water as a common beverage for the inhabitants of the most civilized capital in Europe.[4]

In 1848 the second epidemic of cholera began in Britain, involving almost every urban region. In London alone there were 15,000 deaths and as many more who fell ill but recovered. It was during this epidemic that a 36-year-old physician, Dr. John Snow, discovered that cholera was communicated by the mixture of water contaminated by cholera victims with supplies of water used for drinking or cooking. His findings were published in 1849, but were not accepted by the majority of medical men, who still believed in the miasmatic theory of communication of diseases. According to this theory, disease was a fever which was brought by special disease-producing airs or vapors.

Parliament enacted in 1848 "that water supplies must be pure, safe, and constant. . . ."[5] However, there continued to be intermittent supplies for many years.

In 1848 most municipal water supplies were privately owned and were not operating or improving their services sufficiently. Efforts were begun by municipal governments in Britain to buy up the companies. However, the eight London water companies did not come under public control until 1902.

The wash-down closet was first made in 1852. A Metropolitan Water Act of 1852 required that all domestic water from the Thames be filtered, but the London water companies were often in violation. A third epidemic of cholera occurred in 1853-54.

In 1858 Louis Pasteur, a French chemist, published his finding of living microscopic beings which required air, calling them aerobes. In 1860 he described miscropic beings which lived in the absence of air, calling them anaerobes.

By the 1860's large towns in England tried to increase their supplies by creating reservoirs with dams of puddled clay. There were some failures of this type. The first high masonry dam in Britain was built in the 1880's.

Scarlet fever killed many people in Britain, especially children, from 1830 to 1863, and diptheria also beginning in the 1860's until the mid-twentieth century: sore throat is a symptom of both. The Victorians believed in the miasmatic origin of disease and worked to improve plumbing so as to avoid gases from drains passing up into their homes. In fact, these diseases are spread through person-to-person contact and on food.

By the second half of the nineteenth century, some towns in Britain were operating sewage farms for sewage disposal. Generally, a bacterial process was not considered in the experiments with treatment of sewage.

Instead, experiments were conducted on filtration of sewage as a purely mechanical process, and on the use of chemicals to precipitate the suspended matter in sewage. Manganate of soda was used on London's sewage in 1885, and chloride of lime in 1887.

The Public Health Act of 1872 required cities of over 25,000 to appoint a medical health officer and inspectors. As a result many wells were condemned because of contamination by sewage, and significantly reduced urban death rates in England.

Beginning in 1875, the number of cases of typhoid fever began to decline until 1900. Few cases were spotted in the twentieth century.

In 1882, William Joseph Dibdin, a London chemist, was among the first to indicate that bacteria were important in sewage treatment; later he discovered with some assistance from results of the Lawrence Experiment Station in Massachusetts, the principles of operation, of what later came to be known as the trickling filter. One of the earliest of the trickling filters installed was in 1893 at Salford, England. By 1890 most British towns had constant supplies of water. There were still regular cases of typhoid. In 1897 a vaccine was first produced.

In 1893 pressures and temperatures necessary to manufacture copper pipe by extrusion were reached and copper pipes were used in high-quality plumbing.

In 1896, Donald Cameron, city surveyor of Exeter, discovered the principles of operation of what he called the septic tank.

In 1897, at Maidstone in Kent bleaching powder was put in the water mains to stop an outbreak of typhoid. The use of chlorine for disinfection of a public water supply was a big step in the hygiene of water. The first permanent chlorination of a municipal supply was in

Lincoln in 1905 using a solution of sodium hypochlorite. Chlorination was slow to find adoption in Britain. In London, chlorination was not begun until 1916 and then only to avoid the necessity of undergoing sedimentation before filtration. Bleaching powder was used first and then liquid chlorine in 1917. Ozonation was introduced at about the same time as chlorination, but never received widespread acceptance in Britain.

Although water carriage of sewage was widely accepted by the end of the nineteenth century, less than ten percent of the residences in the principal cities of England had that facility at that time.

In 1912, Dr. Gilbert Fowler and assistants in the Manchester Rivers Department, discovered what is now known as the "activated sludge" process for treatment of sewage. In that same year the Royal Commission on Sewage Disposal proposed standards for sewage effluents. Where discharge was to be made into rivers where dilution was greater than eight to one, no more than thirty ppm suspended solids would be allowed in the effluent, and not more than twenty ppm 5-day BOD would be allowed.

In the 1920's compression joints for piping developed and in 1934 the capillary joint. Copper piping came into wide use.

In 1862 Alexander Parkes of Birmingham had discovered how to make a plastic-like material out of cellulose nitrate. Later the plastic industry developed and plastic waste pipes were introduced in 1944 and water pipes in 1953. Problems were encountered with brittleness in the first attempts.

In 1957 on the island of Jersey in the English Channel a composting plant was built utilizing the action of aerobes, with the product being used as fertilizer.

United States

The history of the development of water supply in the United States will be briefly given as well as an indication of the differences this development has had on the public health and the society as a whole. As well as in Britain, developments in the United States have represented a leading force in modern systems of water handling.

In colonial America before steam powered water pumping systems were developed, municipal water supplies were ordinarily taken from public wells equipped with hand pumps. As late as 1799, New York obtained its water supply from a well by means of a horse-powered pump.

The earliest public water supplies in the United States were in Boston in 1652; Schaefferstown, Pennsylvania, in 1732; and at Bethlehem, Pennsylvania, in 1761. By 1800 there were seventeen utilities, in 1850 more than one hundred, and in 1885 more than one thousand. In 1895 there were about 3000, in 1924 more than 9000 and in the 1960's more than 18,000 systems. In 1890 about one-third of the systems were privately owned. The later trend was toward publicly-owned systems, and in 1960 more than three-quarters of the people were served by publicly owned systems.[6]

Some of the early public supplies were originally installed primarily for the purposes of street washing rather than for domestic supplies. The treatment of the earliest supplies in the United States was primarily directed toward the removal of turbidity, and the ability to perform tests for purity predated their use. The greatest advances in improvement of quality have been made in the last century. In the 1870's the first filtration systems in the United States were installed when slow sand filters were built at Poughkeepsie and Hudson, New York. In the late 1880's the

earliest rapid sand filtration units were in operation. Chlorination for bacterial disinfection was introduced in 1908. In 1945 three communities were supplied with fluoridated water, and in 1959 over one thousand communities.

One hundred years ago, wastewater was often simply poured into street gutters. Cesspools and privy vaults were in common use. By 1957 more than 7500 sewage treatment plants were in operation. An additional 3000 communities had sewerage, but were discharging without treatment.

The diseases which may be waterborn range from typhoid fever, amebic dysentery, infectious hepatitis, and schistosomiasis, to others which are too numerous to mention. All of these diseases were prevalent in the United States in the not too distant past. Water purification is one of the measures which has brought them under control in that area. In 1900 in the United States, deaths from typhoid fever were 35.8 per 100,000 population. By 1936 the figure was 2.5, and later dimished to practically zero. It is significant also that in large cities of more than about 100,000 population the rates have been lower than for the nation as a whole.[7] Safe water as well as pasteurization of milk would have played major roles in this development. In some of the developing countries, the mortality rates from enteric diseases are in the same range as that which was true in North America in the last period of the nineteenth century.

[1]Read, p. 3.

[2]Ibid., p. 7.

[3]Small, pp. 193-194.

[4]Read, pp. 21-22.

[5]Ibid., p. 37.

[6]Abel Wolman and Herbert M. Bosch, "U.S. Water Supply Lessons Applicable to Developing Countries," Water, Health and Society, ed. Gilbert F. White (Bloomington: Indiana University Press, 1969), p. 220; reprinted from Journal American Water Works Association 55, no. 8 (August 1963).

[7]Ibid., p. 225.

CHAPTER III

SUMMARY AND CONCLUSIONS

Water Supply

Wells were perhaps the principal source for urban areas at least up to 500 A.D. Often cities initially took their water supply from local surface or ground supplies, and when these became inadequate, it became necessary to transport from more distant supplies.

The Romans made great strides in the system of aqueducts and organized water supply. Certain early instruments were used in the construction of aqueducts to maintain uniform gradients and alignment of tunnel construction. A steeper grade than necessary was often used by the Romans to allow for error.

Once again in Europe during the Middle Ages, the first supplies for towns were usually wells and rivers, localized supplies. Population increases brought long-distance supplies, and monasteries were leaders in this effort in Europe.

In ancient aqueduct construction, stone masonry was the principal material; in the Middle Ages, lead, wood or earthenware pipes; in modern times larger capacities required open channel stone or brick masonry conduits, and high pressures required reinforced concrete or steel.

In modern times Great Britain and the United States have played leading roles in the development of public water supplies. Most of the development in those areas occurred beginning in the nineteenth century.

Pumps and Power

The history of the raising of water began with irrigation. Early methods of pumping were often powered by cranks, treadmills, and water or wind power.

After the Roman era, there is a lack of evidence of the use of pumps till the fifteenth century in Europe. The first systems there were of wood and operated by hand. From about 1500 to 1850 the waterwheel was widely used as a source of power. In the 1700's steam was introduced as a source of power, and metal came to be used throughout pump construction. Cheap electrical power has been available in modern times.

Water Treatment and Standards

In general, there has been a considerable lag between the development of techniques for treating water and their actual use. In the development of treatment, sedimentation and filtration through porous vessels probably came first, followed by coagulation. These methods plus filtration, wick siphons, and distillation were basically the total of methods used till the 1890's. Among the more recent developments were pH control, softening, and addition of iodides and fluorides.

Great advances in the art of water treatment were made in the eighteenth century, particularly the last half. However, to each new process of treatment, there were, as usual, always some who were opposed to its introduction.

About 1800 the objective of filtration was removal of turbidity, and filtration was viewed as a straining process. From about 1850 removal of organic matter became more important, and filtration was viewed increasingly as a chemical and biological process. By the late 1800's filtration was viewed as a means to remove bacteria and combat cholera, typhoid, and other diseases. Chlorination has been largely responsible for the reliance

on single-pass rapid filtration in the United States, whereas in France, where chlorination was not widely adopted, multiple filtration has prevailed.

Early standards of water quality were based on clarity, taste, odor, and the health of users. Later tests measured the amount of oxygen, chlorine, nitrites, or certain types of bacteria.

Distribution and Use

In many urban areas, the distribution of water has been carried out by means of porters or carts before the later introduction of piping. Where public water supply systems were found prior to Roman times, the distribution was generally only to a few public fountains. Even in the Roman Empire, distribution to private homes was quite limited. In Europe in the Middle Ages water was usually obtained from public fountains or carriers, and not until the 1600's did piped private supplies begin to be introduced.

In the late 1800's water demands began to increase due to increased use of bathtubs, water closets, and public bathhouses. In the 1900's further increases in demand occurred where use was made of washing machines, dishwashers, garbage disposals, air conditioners, and lawn sprinklers. Where metering has been used, it has encouraged conservation of water.

Bath and shower facilities are dependent on constant pressure water supplies and sewerage facilities. Public baths and latrines have been useful in areas such as ancient Rome where many people lived in tenement-like dwellings and charges for the facilities were kept within the reach of all.

Sewage Removal and Treatment

Throughout history the urban environment has been in general quite unsanitary, and progress in correcting the situation has been very slow.

In industrialized areas, problems increased with growing populations. By the seventeenth century in Europe improvements were needed, and by the second half of the eighteenth century some urbanized areas became decidedly unhealthful places. In the United States the major cities by the middle of the nineteenth century were overcrowded and unsanitary, and there were frequent epidemics of yellow fever, cholera, and typhoid in the middle years of that century. In some of the developing countries, the mortality rates from enteric diseases are in the same range as that which was true in North America in the last period of the nineteenth century. Virtually all the conventional types of sewage treatment used in developed areas today, were introduced within the last one hundred years. Before that the effluent from cities was usually deposited unchanged in lakes, rivers, the sea, or on land.

Methods were available for the treatment of sewage long before their actual use. When proper precautions have not been taken, poor methods of waste disposal have contributed to a return to the plagues of typhoid, cholera, and other diseases, even in more developed areas.

In general, it may be said that sewage systems using water work well in urban areas with high density populations where there is an abundant and constant supply of cheap water, and where there is enough wealth in the community to pay the costs of installation and upkeep.

Life-style Levels and Technology Levels As a Chronological Concept

In taking an over-all view of the material of this report it was possible to organize it in such a way as to ascertain chronological developments in technological levels as well as in life-style levels. The first stage in this process involved an arranging by geographical area, and in chronological order, the data presented in the remainder of the report. Areas covered in the tables

included Egypt and Mesopotamia as representative of developments in the Middle East in ancient and medieval times. The ancient Indian subcontinent was also represented. Europe was divided into two main divisions, Europe in ancient times and Europe in medieval and modern times. Ancient Europe included subdivisions on the Minoan Civilization in Crete, as well as the ancient Greek and Roman civilizations. Medieval and modern Europe contained sections on Europe in general as well as on France, Britain, Holland, Germany, and two major cities in particular, Paris and London.

With the aid of this type of organization of data, it was possible to ascertain different levels of technology developing chronologically in the various geographic areas. Six levels were detected, and the main aspects of the classification have been included in a table for easy reference. It should be noted with respect to this classification process, that inventions which are listed in the inventory were not put into use immediately. There was usually a certain lag-time between the discovery of a technology and its application. Also, these technology levels are not closed units, each separate from the others. As new ways of handling water or sewage came into practice, the old ways very often continued to exist along with the new, and the appearance of a new level of technology was often a gradual process, with first one element appearing, to be followed later by others of the same level.

In addition to technology levels, life-style levels could be discerned as a chronological concept. Four levels were defined and the principal aspects of this classification have been included in a table which follows. There can be no doubt that technological progress is linked to demographic expansion, and important as well to the transitions from one life-style stage to another are the processes of urbanization and industrialization.

TABLE 4

CHRONOLOGICAL SUMMARY OF HISTORICAL DATA--MIDDLE EAST (ANCIENT AND MEDIEVAL), INDIAN SUBCONTINENT (ANCIENT), EUROPE (ANCIENT)

Date	Middle East (Ancient and Medieval)		Indian Subcontinent (Ancient)	Europe (Ancient)		
	Egypt	Mesopotamia		(Crete) Palace of Minos at Knossos	Greeks	Rome
4th millennium B.C.	Evidence of wells.	Open ditches and rough stone-lined channels drained stormwater.				
3rd millennium B.C.			(Chandu-daro and/or Mohenjo-daro) wells of brickwork; public baths; bathroom and latrine in each private dwelling; excellent sanitary systems; pottery drainpipes.			
2750 B.C.	Copper piping.					
2500 B.C.	Drainage systems.					
2500-1200 B.C.				Terra-cotta pipes with cement joints; earliest form of bathtub discovered (earthenware); water-flushed latrines.		
2400 B.C.		(Babylonia) possibly earliest use of shaduf.				

TABLE 4--Continued

Date	Middle East (Ancient and Medieval)		Indian Subcontinent (Ancient)	Europe (Ancient)		
	Egypt	Mesopotamia		(Crete) Palace of Minos at Knossos	Greeks	Rome
early times		Typical middle-class dwelling stored rain-water in a cistern; irrigation works used as domestic supply; private bathing facilities for the wealthy; sewage and solid waste deposited in streets and open spaces.				
about 2000 B.C.			(Sanskrit) Early evidence of water treatment: boiling, sunlight, heated iron, filtration through sand and course gravel, coagulation.			
16th century B.C. or earlier	Shaduf.					
1450 B.C.	Early evidence of water treatment.					
1350 B.C.	Latrines with earthenware jars as receptacles. (Tell-el Amarna) crude stone shower baths.					
13th century B.C.	Wick siphons.					

TABLE 4--Continued

Date	Middle East (Ancient and Medieval)		Indian Subcontinent (Ancient)	Europe (Ancient)		
	Egypt	Mesopotamia		(Crete) Palace of Minos at Knossos	Greeks	Rome
11th century B.C.		(Babylon) sewers cut in rock or built of masonry.				
ancient times (?)					Land application of of urban drainage.	
about 750 B.C.						Founding of Rome; water supply from Tiber and private wells.
600 - 550 B.C.		Construction of reservoirs by Nebuchadnezzar.				
6th century B.C.					(Athens) aqueduct constructed, although the city never acquired a well-developed system of water supply, drainage system, or sewer networks.	
588 B.C.						Construction of Cloaca Maxima.
5th century B.C.					(Olynthus) aqueduct of terra-cotta pipes; houses with bathrooms, cisterns, lavatories, and a waste pipe running through the outside wall to the street; central alley in each block for drainage; covered brick masonry drains. Hippocrates advocated boiling for disinfection and prevention of odors.	

TABLE 4--Continued

Date	Middle East (Ancient and Medieval)		Indian Subcontinent (Ancient)	Europe (Ancient)		
	Egypt	Mesopotamia		(Crete) Palace of Minos at Knossos	Greeks	Rome
about 400 B.C.					Plato recommended city water supply administered by a group of water commissioners.	
400-100 B.C.		Drainage served each house.				
about 350 B.C.					Aristotle mentioned filtration through porous vessels and distillation to purify water.	
312 B.C.						Construction of the first of the main aqueducts.
3rd century B.C.					Ctesibius invented force pump, operated by hand.	
about 250 B.C.					Screw of Archimedes.	
about 200 B.C.					(Pergamum, Asia Minor) aqueduct with inverted siphon constructed of stones with holes.	
1st century B.C.					Crude stone shower baths; public and private lavatories with water flushing facilities.	
47 B.C.	(Alexandria) prominent families provided with cisterns.					

TABLE 4--Continued

Date	Middle East (Ancient and Medieval)		Indian Subcontinent (Ancient)	Europe (Ancient)		
	Egypt	Mesopotamia		(Crete) Palace of Minos at Knossos	Greeks	Rome
15 B.C.						Use of coagulation.
50 A.D.	(Alexandria) prototype of infiltration galleries.					
97-104 A.D.						Sextus Julius Frontinus, Water Commissioner of the City of Rome, wrote first contemporary engineering record of works to improve public water supply; included description of piscinae or settling tanks along aqueducts. Water Commission was government-operated, funded by Roman government and emperors. Most of the supply from the aqueducts fed continuously-flowing public fountains. Herschel estimated the supply by 100 A.D. at 50 gallons/capita/day. Population of Rome about 1 million. Six large public bathing establishments.
4th century A.D.						Eleven great thermae and 926 public baths; water-flushing public latrines. These cheap and accessible public facilities were necessary because a large population inhabited tenement-like dwellings.
537 A.D.						Goths broke conduits at Rome; the population dwindled.

TABLE 4--Continued

Date	Middle East (Ancient and Medieval)		Indian Subcontinent (Ancient)	Europe (Ancient)		
	Egypt	Mesopotamia		(Crete) Palace of Minos at Knossos	Greeks	Rome
640 A.D.	(Alexandria) each dwelling with a bathroom.					
Middle Ages	(Cairo) number of water carriers estimated to be 100,000.					
end of 9th century	(Cairo) arched viaduct similar to Roman aqueducts.					
10th century A.D.						Tiber again used as supply.

TABLE 5

CHRONOLOGICAL SUMMARY OF HISTORICAL DATA--EUROPE
(MEDIEVAL AND MODERN) AND THE UNITED STATES

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
iddle Ages	Urban population declined along with tax revenues, and monasteries became leaders in supplying water supply and sanitation facilities. Wells and localized supplies, or stone channels for long-distance supplies. Delivery at public conduits or by porters. Bathing infrequent and lacking in privacy except in monasteries; monasteries provided latrines with water flushing and underground sewers, while cities usually had drainage ditches in the middle of the street.		Largest city in Europe after the decline of Rome. Seine and local wells used as water supply.		Supply from springs, wells, streams, and rivers within the city.		
dle Ages to 0's				Solid waste and sewage heaped in piles in the streets; collection in wealthier parts of town.			
h century					Aqueducts transported water from distant supplies.		

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
late middle ages	Cities began to grow, and municipalities began to take the lead from monasteries in the provision of water supply and sanitation facilities.			Lead pipe aqueducts of the gravity-flow type; use of privy vaults and cesspools.			
1100's	Liquid wastes drained to ditches and moats; solid wastes piled in the streets and sometimes sold for agricultural purposes.		First aqueducts to city.				
1105		First recorded windmill in Europe.					
1126		Development of artesian well (possibly a Chinese idea).					
about 1300	(Northern Europe) Public baths appeared.				Private latrines situated along watercourses.		
early 1300's					First European city with an organized scavenging system for sewage and solid waste; public latrines with water flushing.		
1300's	Introduction of blast furnaces to smelt iron with charcoal.						

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
15th century	Primitive pumps of piston or plunger type supplying water to many cities.						
about 1500				Houses without water pipes or drainage.	Company of Water Tankard Bearers numbered 4000.	(Germany) Origin of waterwheel method of pumping (force pumps driven by wheel; wooden construction).	
16th century	Single acting and double acting suction and force pumps, also centrifugal pump and ball and flap valves; use of wood rather than metal.						
1500-1700	Cost of water supply borne by church or burgesses of municipality.						
about 1550			Supply an average of one quart/capita/day; household filters in use.				
1553		Public fountains at Nantes (pop. 2600).					
1578					One of the largest cities in Europe (pop. 100,000). Sources included rivers, springs supplying public fountains and porters.		

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1580					Peter Morice designed first mechanical public water supply, waterwheel-driven pumps under London Bridge to serve some private homes with piped water (wooden construction).		
1596				Watercloset described by Sir John Harrington.			
before 1600				Private water services rare.			
1600	Large urban areas needing improvements in sanitation.						
early 1600's					Sheet-lead pipes; wooden mains of New River Company.		
1600's				Cast-lead pipes; private services increased, but only for the wealthy.			
colonial times							Smaller communities meant there were relatively few problems with sanitation. Water supplies were usually public wells equipped with hand pumps.

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1602-1850's			Waterwheel-reciprocal pump system.				
1630					Somerset invented water-pumping engine utilizing steam.		
1652							(Boston) earliest public water supply in the United States.
1676						(Holland) Leeuwenhoek observed living creatures in rainwater.	
1682		(Versailles) cast-iron mains, waterwheel and pump system.					
about 1700			Supplied 2½ quarts/capita/day.	Upper classes used "close-stool."			(Boston) construction of sewer system.
1700's	Private enterprise entered field of water supply.			Coke used in blast furnaces, to manufacture cast-iron pipes, use of leats in western England; metal introduced to pump manufacture; waterclosets in general use.			
1720					Newcomen steam engine.		(New York) only two public sewers; drainage ditches in center of street.

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1745					Iron pipe mains measuring 1800 yards.		
1749		Joseph Amy granted first water filter patent in any country.					
1750				Beginning of "Industrial Revolution."			
1750-1800							Industrialization and growth of cities.
1754							First steam-driven pumps in U.S., at Bethlehem, Pennsylvania.
about 1755				Description of aeration by dropping water into air.			
1756				(Scotland) first scientific experiments on water softening.			
1757				Proposal to soften water with alkaline compounds; hydrochloric acid observed to destroy living creatures in water.			
1764			First commercially filtered water in Paris.				

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1767				Description of softening by boiling; alum used in home treatment by coagulation.			
1775				Effluent from water-closets discharged to cesspools: patent for valve closet.			
1776			First steam-powered pump in Paris.				
1778				Bramah valve closet (accepted design 1815-1937).			
1780				Shift to urbanization and industrialization from agriculture.			
1782					Water-seal trap for closet.		
1790				Johanna Hempel, first patent for household filters in England.		(Holland) Johann Tobias Lowitz, paper on powdered charcoal to prevent tastes and odors.	
1791				First British patent on a process and apparatus for filtration.			
1797							(Cincinnati) water porters.
1799							(New York) supplied by well and horse-powered pump.

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
about 1800	"Combined" sewer systems; only London, Paris, and Rome, in Europe, had water supply facilities.			Infrequent bathing in portable baths.	Intermittent supply; some homes with piped supply but poorer areas served with a central pump and one central privy for many families; bathing infrequent in portable baths.		Only public water supplies in U.S. located at Boston, Philadelphia, and New York. "Combined" sewer system.
early 1800's					Popularity of water closets; waste still piped in streets and collected in wealthier areas by private contractors.		(Philadelphia) public standpipes replaced with underground tanks and handpumps.
1800's	Filter basins and galleries.			(York) unfiltered river water subjected to home treatment by sedimentation.			Filter-basins and galleries.
1804				(Paisley, Scotland) first water filter for city-wide supply (delivery by cart).			
1806			Second city with city-wide filtered water supply.				
1810				(Glasgow, Scotland) first filter gallery on record; water was piped.	Private companies supplied London's water.		
1815					Sanitary sewage permitted in drains.		

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1817							(Philadelphia) cast-iron pipes introduced.
1818				(Ireland) first known softening of water for public use (potash of soda).			
1819				Patent for filter with negative head.			
1820's		(Toulouse) first large-scale example of difficulty in a public water supply from tastes and odors and of the solution of excluding light and air.			Water supply being taken from sewer outfall.		
1827		Patent on pressure filter.		(Scotland) Robert Thom's first municipal filter installed, having principal features of rapid filter.			
1829				Simpson's first slow sand filter.	James Simpson's first municipal filter installed (model for slow sand filter).		(Lynchburg, Va.) first U.S. settling reservoir.
1831-1851					London grew from 1.5 to 2.5 million.		
1832				Cholera epidemic.			
1833			Storm sewers begun.				

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1835		Fonvielle patent for reverse-flow wash.					(Philadelphia) first proposal recorded, to chlorinate water supply.
1838				(Paisley, Scotland) Filtered water was piped.			
1840							Boilers supplied hot water to the bath.
1840's				Earliest British patents on chlorination. Henry Doulton, glazed earthenware pipe.	London's first public bathhouses.		
1841				(Scotland) Clark lime process of softening.	No over-all planning in construction of sewers; little water used.		
1842				Chadwick's General Report.	Edwin Chadwick's report on water supply and sewerage; John Roe subsequently designed egg-shaped sewer to replace square ones.		
1844-48						(Germany) Construction of first modern complete sewer system; flushed with water every week.	

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1848				(Scotland) Earliest-known cascade aerator working in series; British Parliament required water supplies to be pure, safe, and constant (not in fact accomplished until later).	Compulsory to discharge sanitary sewage to drains; Snow discovered that cholera is communicated by contaminated water.		
mid-1800's							Cities crowded and unsanitary; epidemics of yellow fever, cholera, and typhoid. (New York) supplied 78 gallons/capita/day.
1850–1900				Use of distillation for ships and naval bases.			
1850's							Waste water poured in street gutters; cesspools and privy vaults common.
1852					Wash-down closet; pan closet.		
1853				Third cholera outbreak.			
1854					Chloride of lime applied to sewage.		

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1854-65					Construction of modern sewer system.		
1856		Darcy patent, forerunner of rapid filtration (coagulation not included).					
1857						(Germany) slow sand filters introduced.	Patent for plunger closet (first U.S. patent for water closet).
1858		Pasteur published findings on "aerobes."					
1860		Pasteur described "anaerobes."					Ten sewered cities in U.S.; disposal of sewage by dilution.
1860-61							(Elmira, N.Y.) first known aerator on a U.S. water supply.
1862				Invention of plastic-like Parkesine.			
1863						(Germany) proposal to remove iron and manganese by aeration and filtration.	
1866		Masonry dam at St. Etienne.		Last cholera outbreak in Britain.			
1869		Septic tanks.					

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1870							(N.Y.) hot water supplied from central plant in home. John Wesley Hyatt, patent for celluloid.
1870's							(Poughkeepsie and Hudson, N.Y.) first U.S. filtration system installed, slow sand filters.
1870's and 1880's							(Albany, N.Y.) no filtration of river-supply and resulting deaths from typhoid.
1870's and after							Increasing number of sewage treatment plants using chemical precipitation and biological processes.
1871				(Wales) first intermittent sand filtration of sewage.			
1874				"Propagation of Cholera by Water"; British patent for ozonation.		(Germany) First municipal iron removal plant.	
1875-1900					Cases of typhoid fever decreased.		
1876							(Rochester, N.Y.) earliest U.S. multiple-jet fountain aerators. John Fanning, statements on water as vehicle for diarrhea, dysentery, typhoid.

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1877				Earliest statements on bactericidal action of ultraviolet rays.			
1878				Patent on softening with sodium carbonate.			
1879						(Holland) earliest use of alum to clarify an urban water supply.	
before 1880				Adoption of separate sewerage systems.			
1880			Sanitary sewage allowed in storm sewers.				
1880's				First high masonry dam in Britain, at Liverpool.			Earliest rapid sand filter units; first cities to install separate sewer systems.
1882				Evidence of importance of bacteria in sewage treatment.	Treatment of sewage by chemical precipitation.		
1884							Process patent for ozonation; septic tanks; Hyatt patent on simultaneous coagulation-filtration.
1885							(New Jersey) Hyatt drifting-sand rapid filter first installed; no city in U.S. treating

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
							sewage effectively; coagulation became integral part of rapid filtration process.
1887					Patent on electrolytic method of purifying sewage.		Lawrence Experiment Station established in Massachusetts (studies included intermittent sand filtration). (Worcester, Mass.) patent on chlorination of sewage.
1888				Health of Towns Act, operation of sewage farms.			First patent on chlorination of water.
1889							First plant in U.S. for chemical precipitation of sewage.
1890						(Germany) Manually operated gas water heater.	(New York) Ninety gal./cap/day supplied.
1890's		Shift to artificially filtered water supplies.		Sewage trickling filter perfected; most British towns with constant supplies.			
1892						(Germany) Hamburg-Altona cholera outbreak emphasized protection of filtration.	

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1894							First trickling filter plants in the U.S.
1896				Septic tanks.			(Louisville, Ky.) chlorine gas applied to effluent from working-scale filter to reduce bacterial count.
1897				First recarbonation of softened water, and chlorination of public supply.			
1899							(Albany, N.Y.) slow sand filtration decreased incidence of typhoid.
about 1900	Public baths in most major cities.		Shift from spring water to filtered river water and piped supply.	Less than 10% of residences in principal cities had water carriage of sewage.			In U.S., 950 sewered cities; deaths from typhoid were 35.5/100,000. (New York) supplied 950 gal/cap/day.
after 1900		Multiple filtration came into wide use.					
1901-02							(Kentucky) pan aeration with or without coke filling.
1902	First permanent water chlorination plant.						
1903						(Germany) patent for zeolite process of water softening.	

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1904					London's water supply came under public control.		George Thomas Moore and Karl F. Kellerman, studies on copper sulfate as algicide and germicide.
1905							First permanent chlorination of U.S. municipal water supply.
1906							Pitch-fiber pipe introduced.
1906-10							(Louisville, Ky.) Annual typhoid death rate 52.7/100,000.
1907							Liquid chlorine first commercially produced in the U.S.
1910							Automatic water heater.
1912				Discovery of "activated sludge" sewage treatment; standards for sewage effluent.			(Louisville, Ky.) filtration, sedimentation, and coagulation decreased annual typhoid death-rate to 19.7/100,000. Process whereby chlorine gas is dissolved in stream of water prior to introduction to water to be treated.

TABLE 5--Continued

Date	Europe (Medieval and Modern)						United States
	Europe in General	France	Paris, France	Britain	London, England	Holland and Germany	
1910							
1916-20					Chlorination begun.		
							(Louisville, Ky.) prechlorination decreased annual typhoid death-rate to 9.7/100,000.
1924							
							(Virginia) artificially-created turbidity used as treatment for algae.
1929							
							(Ilion, N.Y.) prechlorination used to prevent algae growth on slow sand filters.
1931							
						(Germany) Development of polyvinylchloride pipe.	(Brownsville, Tex.) porous tubes or plates for air diffusion at a water works.
1935							
							In U.S., 6800 sewered cities.
after 1936							
							Deaths from typhoid practically zero.
1936-40							
							(Louisville, Ky.) post-chlorination decreased annual typhoid death-rate to 0.9/100,000.
1941							
							Development of thermoplastic pipe.
1945							
							Fluoridation.
1948							
							Development of polyethylene pipes.

TABLE 6

CLASSIFICATION OF WATER TECHNOLOGY LEVELS

Level	Water	Sewage
I	Dug wells, springs, or rivers (all local supplies); transport by water carriers. Disease as result of improper handling. Use level, about 1-2 liters/capita/day.	Scavenging system for sewage and solid waste, sometimes for use as fertilizer.
II	Aqueducts, canals (more distant supplies); village hydrants, fountains. Disease as result of improper handling. About 10-20 l/c/d.	Privy vaults, public latrines with water flushing; drainage systems.
III	Pumps, piped water, lead plumbing, fire control. Typhoid, dysentery, sewage problems. About 30-40 g/c/d.	Privy vaults, "close stools," some water closets; cesspools.
IV	Inside plumbing, slow sand filters, municipal/industrial water-need ratio of 1/2, growth of industrial need and need for growing supply. Cholera, typhoid. About 60-80 g/c/d.	Water closets; combined sewers; dilution as disposal method.
V	Rapid filtration, chlorination, ozonation, water-softening, aeration, municipal/industrial need ratio of 1/10. Typhoid fever and other water-borne diseases decreased. About 100-150 g/c/d.	Separate sewerage systems; trickling filters, activated sludge treatment.
VI	Fluoridation, recarbonation, advanced treatment systems, concepts of water conservation, recycling and multiple use. Death from typhoid practically zero.	Reuse, sewage farms.

TABLE 7

CLASSIFICATION OF LIFE-STYLE LEVELS

Level	Characteristics
I	Agricultural civilization, peasant and herdsman the most important members of the community
II	Balance between agriculture and hand-craft industry with a close connection to agriculture. (Implements are economically cheap and technically crude, most made of wood; power source is irregular and often water.)
III	Industrialization. (Implements are cheap and uniform, much use being made of iron; power source is coal and the steam engine.)
IV	Industrialization and automation. (Much use is made of alloyed metals; power source is often electricity.)

SOURCE: Some elements of this classification presented in Lewis Mumford, Technics and Civilization (New York: Harcourt, Brace & Co., 1934).

TABLE 8

TIME SCALE, DEVELOPED REGIONS--HISTORICAL

Rome			Europe, Medieval and Modern			United States		
Life-Style Level	Technology Level	Time Span	Life-Style Level	Technology Level	Time Span	Life-Style Level	Technology Level	Time Span
I	I	750 B.C.-588 B.C.						
II	II	588 B.C.-100 B.C.						
	III	100 B.C.-537 A.D. (Population about one million.)						
I	I	537 A.D.-1000 A.D. (Population dwindled.)	I	I	500 A.D.-1000 A.D. (Population declined.)			
			II	II	1000-1600 (Cities grew.)			
						I	I	1600-1700 (Communities small.)
				III	1600-1800 (Industrial Revolution begins, 1750.)	II	II	1700-1750
							III	1750-1800 (Industrialization and growth of cities.)
			III	IV	1800-1870	III	IV	1800-1870
				V	1870-1950		V	1870-1930
			IV	VI	1950-	IV	VI	1930-

The same process of blurring between levels occurs with the life-style levels as was the case with the technological levels, and interrelationships are evident between the two classifications, life-style and technological.

Subsequent to the previous steps in arriving at life-style and technology levels, an attempt was made to tie historic technology levels to the life-style levels. A time scale was developed for three historical regions covered by the inventory. The three regions chosen were Rome, Europe (medieval and modern) and the United States. These regions were selected because information concerning them was more complete, and because these areas had been forerunners in the economic and technological development of interest here. For each region, the time scales were correlated with the other regional scales. Corresponding technology levels and life-style levels were also indicated. The results of these comparisons is shown in a table which follows.

From the table it may be seen that the progression to higher stages of life-style level or technological level corresponds to periods of population increases. This phenomenon may be seen from two points of view, first, that smaller urban areas could solve their problems of water supply and sanitation with simpler means, but also that larger populations might provide a larger base for tax or other revenues with which to pay for improvements. The greater urbanization, in addition, was accompanied by industrial advances which contributed to progress in technological development. In connection with this last observation, it can be seen that life-style level I corresponds to technology level I, life-style level II to technology levels II and III, life-style level III to technology levels IV and V, and life-style level IV to technology level VI. This proved to be the case in all three of the regions included in the Time Scale display. The United States began its process of

development at a much later date than was the case in Europe, so that the early life-style and technology levels are telescoped into a shorter time span.

In conclusion, it was felt that past developments in the technology of water handling and usage in developed areas could be of benefit in accelerating progress in this field in developing areas and that this report could provide background information for planning in these areas. There are implications to be made and comparisons which are possible between present or projected life-style levels, technological levels, or other aspects of the situation in less developed areas, and the various historical stages of those countries which are considered as having been leaders in the field of water supply and sanitation. The information in this report provides historical evidence of viable alternatives for developing areas and assistance in planning for those regions, as something may be learned from the past successes as well as the failures. Hopefully, this will aid in ascertaining apporopiate and reasonable technologies for water-wastewater treatment and handling for less developed areas.

APPENDIX

Fig. 2. View down tunnel to source of water at Gibeon, Palestine

SOURCE: James B. Pritchard, The Water System of Gibeon, Museum Monographs (Philadelphia: University Museum, University of Pennsylvania, 1961), fig. 11.

NOTE: See "Wells," p. 3 above.

Fig. 3. Pool at Gibeon, Palestine

SOURCE: James B. Pritchard, The Water System of Gibeon, Museum Monographs (Philadelphia: University Museum, University of Pennsylvania, 1961), fig. 3.

NOTE: See "Wells," p. 3 above.

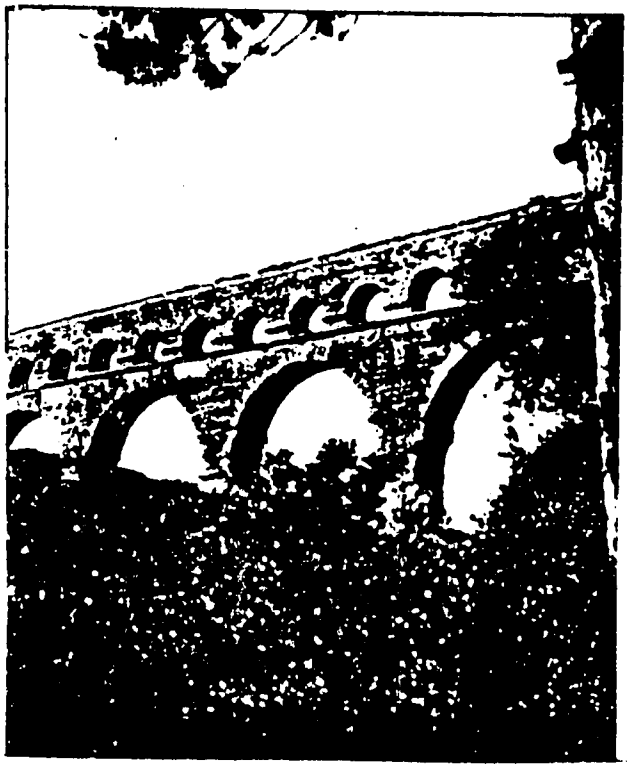

Fig. 4. Roman aqueduct, Pont du Gard, Nîmes, France

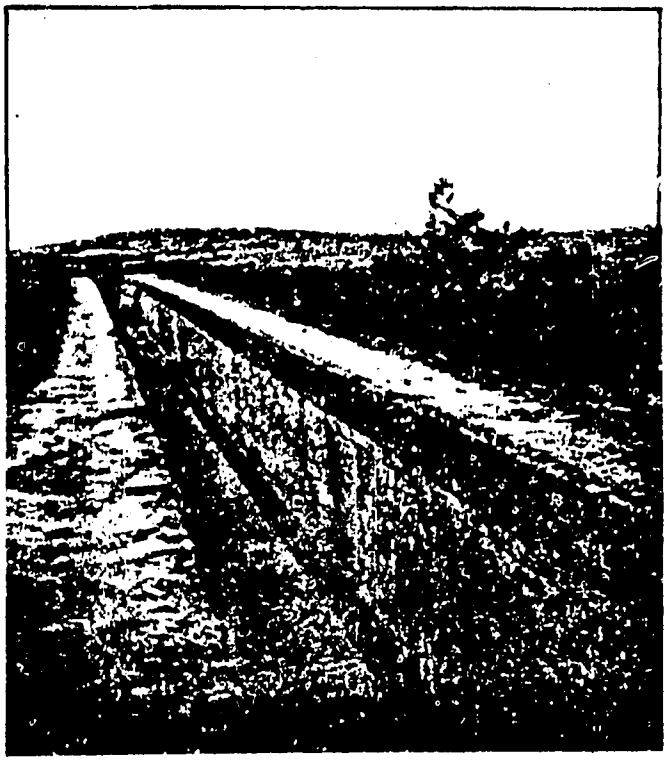

Fig. 5. Water channel, Pont du Gard

SOURCE: F. W. Robins, The Story of Water Supply (London: Oxford University Press, 1946), plate 4.

NOTE: See "Aqueducts," p. 9 above.

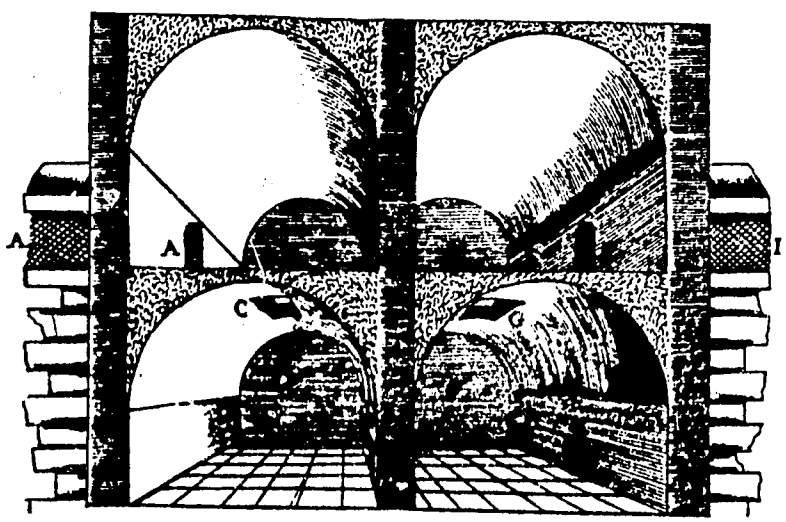

Fig. 6. Piscana on Roman aqueduct Virgo. Water enters from aqueduct at A, proceeds following the sequence of letters and returns to the aqueduct at I. Sedimental material passes through K to a cloaca.

SOURCE: Rapha Fabretti, De Aquis et Aquaeductibus Veteris Romae. Dissertationes Tres (Rome: I. B. Bufsotti, 1680), presented by M. N. Baker, The Quest for Pure Water: The History of Water Purification from the Earliest Records to the Twentieth Century (New York: American Water Works Association, 1949), p. 291.

NOTE: See "Aqueducts," p. 9 and "Sedimentation," p. 56 above.

Fig. 7. Medieval leat, Britain

SOURCE: F. W. Robins, The Story of Water Supply (London: Oxford University Press, 1946), plate 11.

NOTE: See "Leats," p. 15 above.

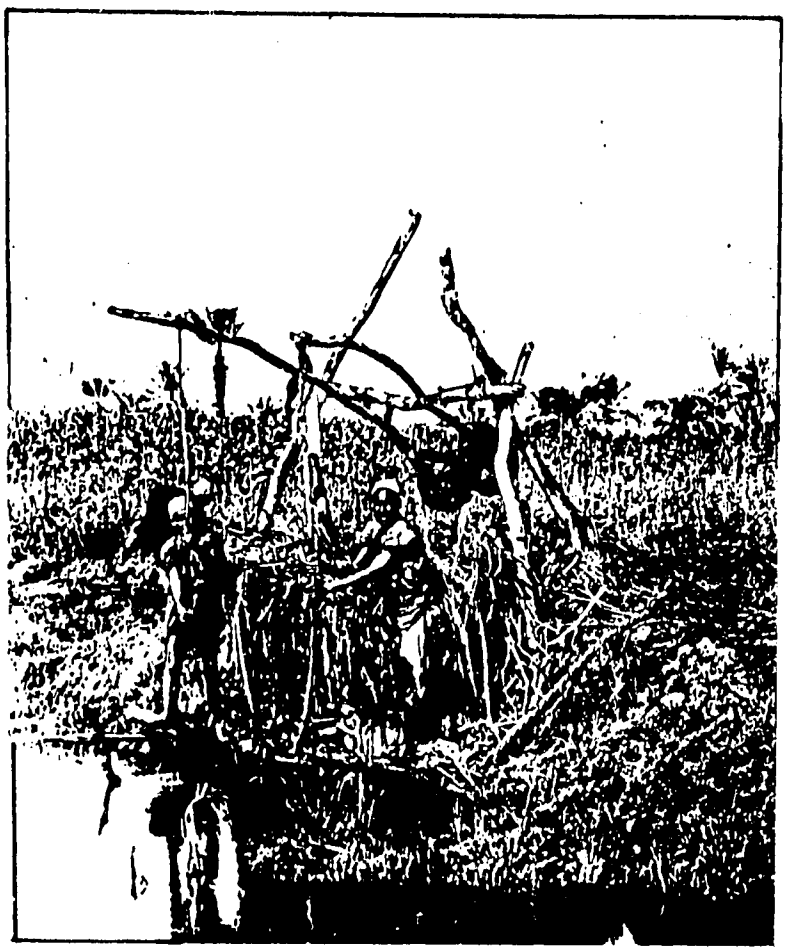

Fig. 8. Modern Egyptian shaduf

SOURCE: F. W. Robins, The Story of Water Supply (London: Oxford University Press, 1946), plate 2, presenting Crown copyright photo, Science Museum, South Kensington.

NOTE: See "Predecessors of the Pump," p. 15 above.

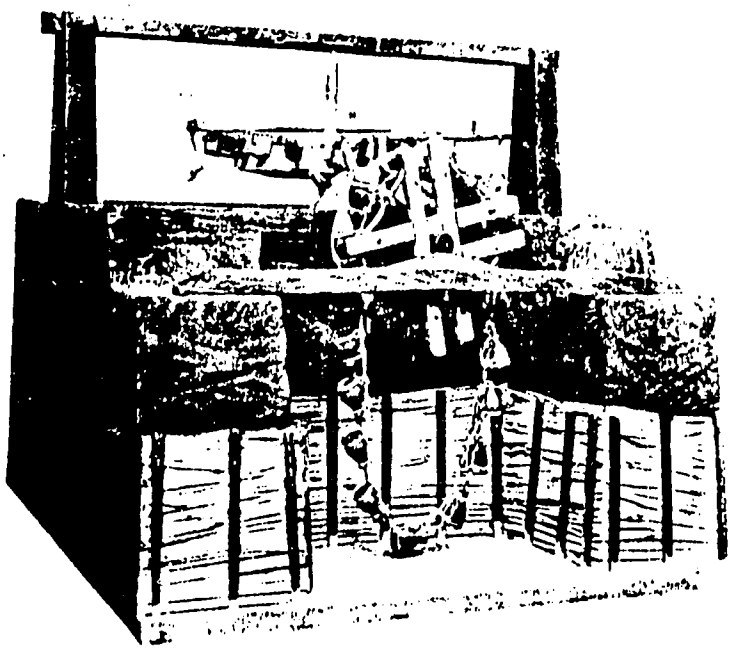

Fig. 9. Animal-powered chain of pots, a type of noria

SOURCE: F. W. Robins, The Story of Water Supply (London: Oxford University Press, 1946), plate 3, presenting Crown copyright photo, Science Museum, South Kensington.

NOTE: See "Predecessors of the Pump," p. 15 above.

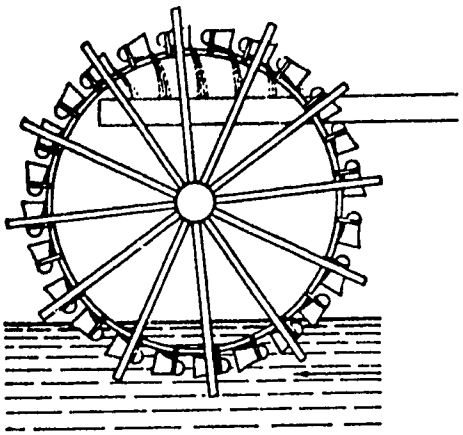

Fig. 10. Paddle wheel for raising water, a type of noria

SOURCE: Maurice Daumas, ed., A History of Technology and Invention: Progress Through the Ages, vol. 1: The Origins of Technological Civilization, trans. Eileen B. Hennessy (New York: Crown Publishers, 1969), p. 106.

NOTE: See "Predecessors of the Pump," p. 15 above.

Fig. 11. Form of Archimedes' screw

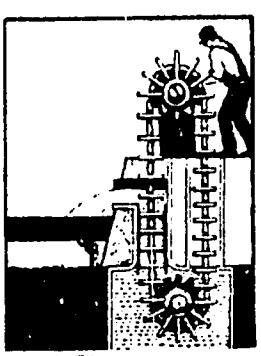

Fig. 12. Chain pump

SOURCE: Compton's Pictured Encyclopedia and Fact-Index, 1952 ed., s.v. "Water."

NOTE: See "Predecessors of the Pump, p. 15 above.

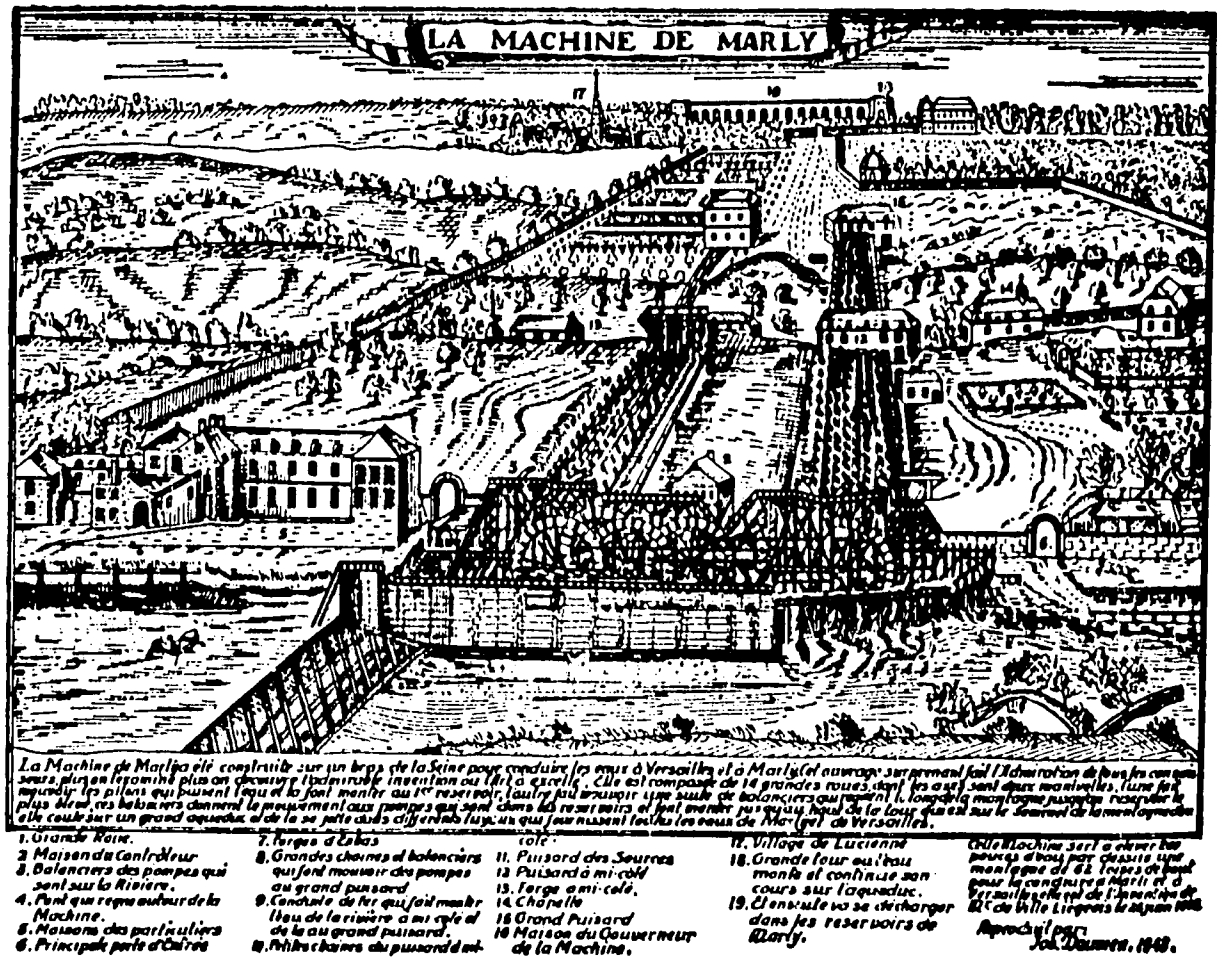

Fig. 13. Machine at Marly
to supply water to Versailles and the castle of Marly,
France, seventeenth century

SOURCE: Maurice Daumas, ed., A History of Technology and Invention: Progress Through the Ages, vol. 2: The First Stages of Mechanization, trans. Eileen B. Hennessy (New York: Crown Publishers, 1969), p. 524.

NOTE: See "Pumps and Their Source of Power," p. 18 above.

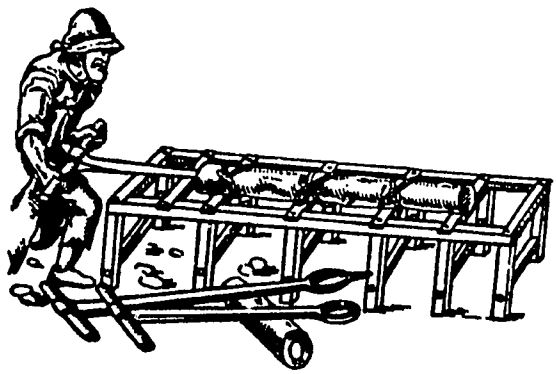

Fig. 14. Boring a wooden pipe by hand, Europe, early sixteenth century

SOURCE: Maurice Daumas, ed., A History of Technology and Invention: Progress Through the Ages, vol 2: The First Stages of Mechanization, trans. Eileen B. Hennessy (New York: Crown Publishers, 1969), p. 255, presenting Georgius Agricola, De Re Metallica (1556), trans. Herbert C. Hoover and Lou Henry Hoover (London: n.p., 1912; reprint ed., New York: n.p., 1950).

NOTE: See "Pipe, for Supply and Drainage," p. 22 above.

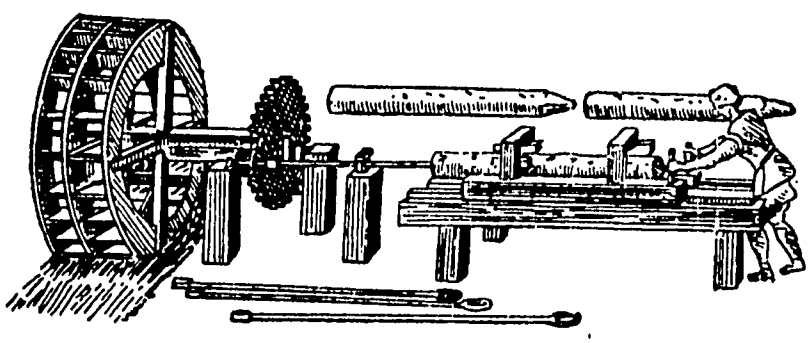

Fig. 15. Machine for boring wooden pipes, Europe, eighteenth century

SOURCE: Daumas, vol. 2, p. 517.

NOTE: See "Pipe, for Supply and Drainage," p. 22 above.

Fig. 16. Egyptians siphoning off
liquid clarified by sedimentation.
Picture from wall of tomb of Amenhotep II at Thebes, 1450 B.C.

SOURCE: John Gardner Wilkinson, The Manners and Customs of the Ancient Egyptians, rev. S. Birch (London: J. Murray, 1879), presented by M. N. Baker, The Quest for Pure Water: The History of Water Purification from the Earliest Records to the Twentieth Century (New York: American Water Works Association, 1949), p. 2.

NOTE: See "Sedimentation," p. 56 above.

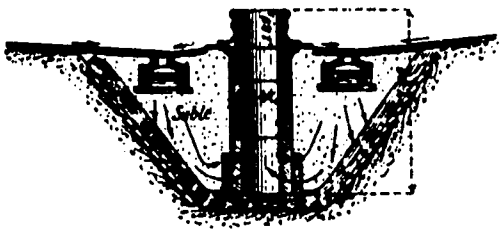

Fig 17. Cross section of Venetian filter-cistern

SOURCE: Edouard Imbeaux, L'Alimentation en Eaux (n.p., 1902), presented by M. N. Baker, The Quest for Pure Water: The History of Water Purification from the Earliest Records to the Twentieth Century (New York: American Water Works Association, 1949), p. 15.

NOTE: See "Filter Cistern," p. 41 above.

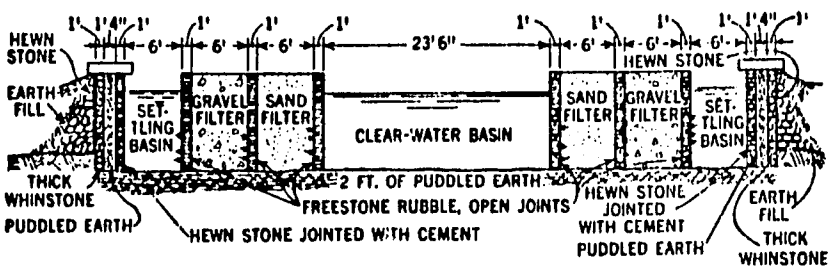

Fig. 18. First known filter to supply an entire city with water, Paisley, Scotland, 1804

SOURCE: John Sinclair, The Code of Health and Longevity (Edinburgh: A. Constable & Co., 1807), presented by Baker, p. 78.

NOTE: See "Early Treatment of Water by Filtration," p. 38 above.

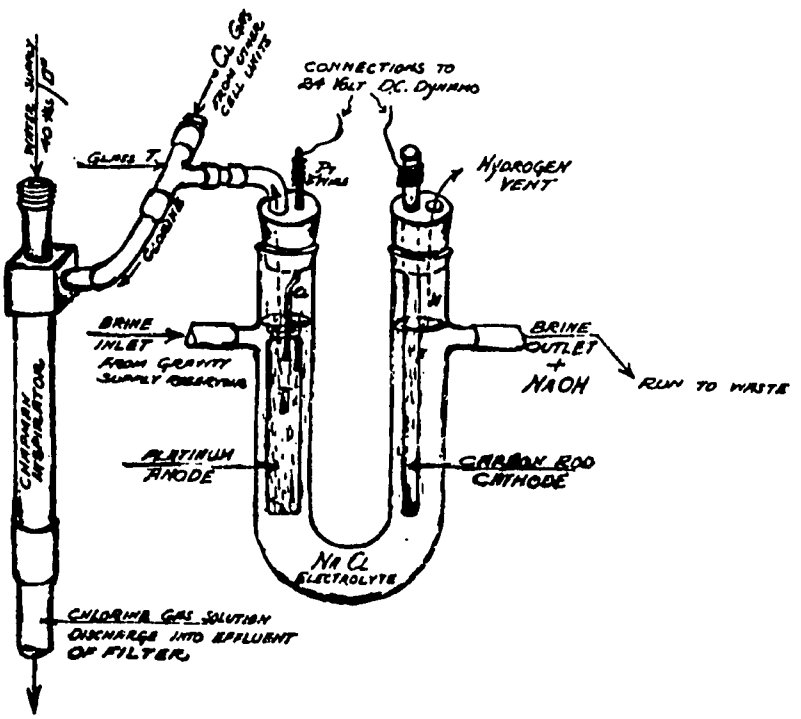

Fig. 19. Jewell chlorine gas generator, Louisville, 1896

SOURCE: Reproduction of sketch made by William M. Jewell, presented by M. N. Baker, The Quest for Pure Water: The History of Water Purification from the Earliest Records to the Twentieth Century (New York: American Water Works Association, 1949), p. 333.

NOTE: See "Chlorine," p. 65 above.

Fig. 20. Lining up at the public conduit, Britain, 1832

SOURCE: Brian Read, Healthy Cities: A Study of Urban Hygiene, Topics in Modern History Series, gen. ed. Ivor D. Astley (Glasgow: Blackie, 1970), p. 36.

NOTE: See "Supply to Private Homes Vs. Public Fountains, Continuous Flow Vs. Intermittent Flow" p. 81 above.

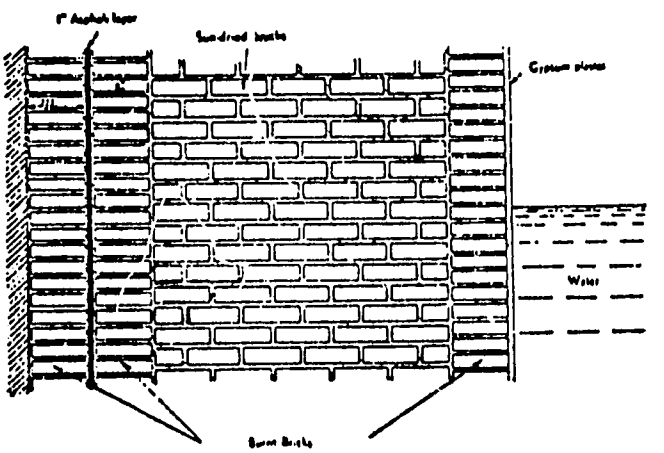

Fig. 21. Sectional view through wall of ritualistic bathing tank showing asphalt waterproofing membrane, Mohenjo Daro, c. 2500 B.C.

SOURCE: T. L. Small, The Influent and the Effluent: The History of Urban Water Supply and Sanitation (Manitoba, Canada: Underwood McLellan and Associates, Modern Press, 1974), p. 163.

NOTE: See "Baths," p. 85 above.

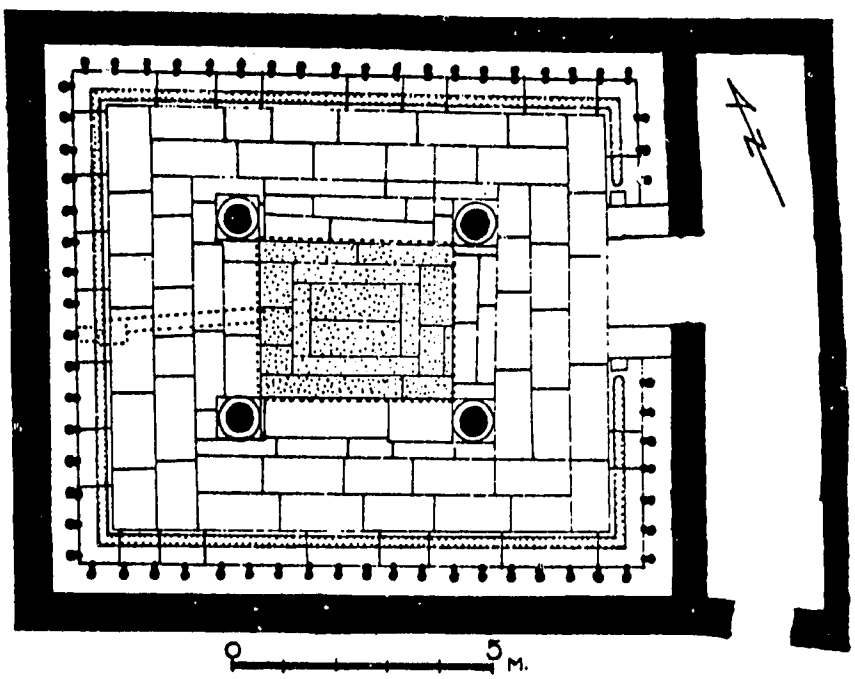

Fig. 22. Plan of latrine, market square Athens (under Roman occupation)

SOURCE: T. L. Small, The Influent and the Effluent: The History of Urban Water Supply and Sanitation (Manitoba, Canada: Underwood McLellan and Associates, Modern Press, 1974), p. 169, permission of American School of Classical Studies at Athens.

NOTE: See "Latrines and Closets," p. 87 above.

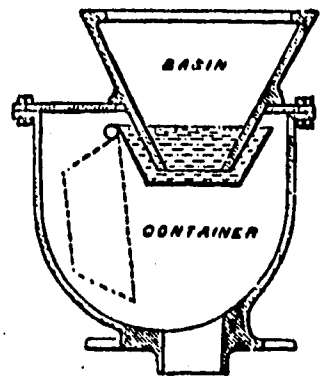

Fig. 23. Pan closet

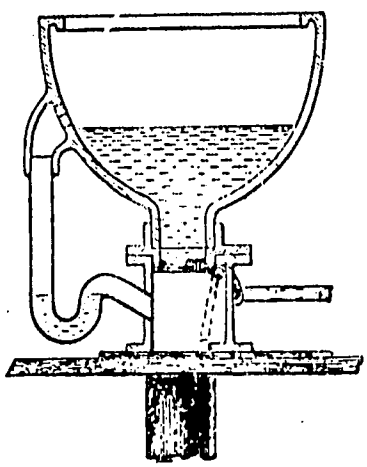

Fig. 24. Valve closet

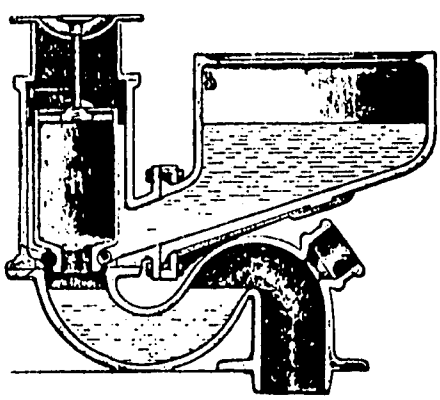

Fig. 25. Plunger closet

SOURCE: Thomas S. Ainge, The Sanitary Sewerage of Buildings (Chicago: Domestic Engineering, 1907), pp. 102, 104, 105.

NOTE: See "Latrines and Closets," p. 87 above.

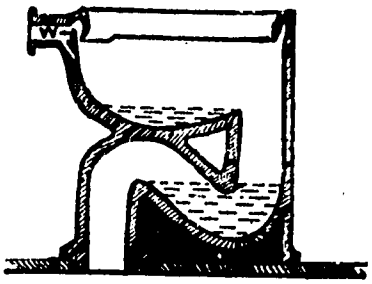

Fig. 26. Wash out closet

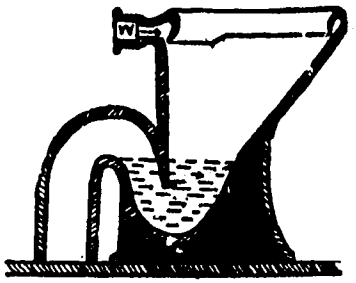

Fig. 27. Wash down closet

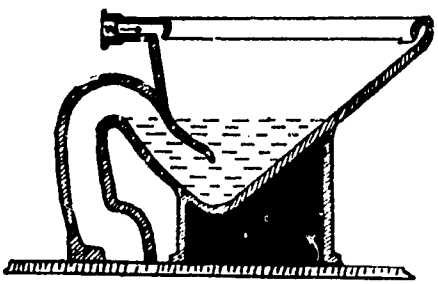

Fig. 28. Siphon closet

SOURCE: Jean Broadhurst, Home and Community Hygiene: A Text-Book of Personal and Public Health, 4th ed. rev. and enl., Lippincott's Home Manuals, ed. Benjamin R. Andrews (Philadelphia: J. B. Lippincott Co., 1929), pp. 240, 241.

NOTE: See "Latrines and Closets" p. 87 above.

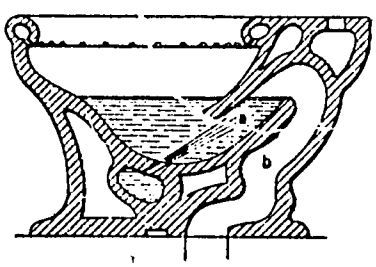

Fig. 29. Siphon jet closet

SOURCE: Charles Merrick Gay and Charles De van Fawcett, Mechanical and Electrical Equipment for Buildings (New York: John Wiley & Sons, 1935), p. 84.

NOTE: See "Latrines and Closets," p. 87 above.

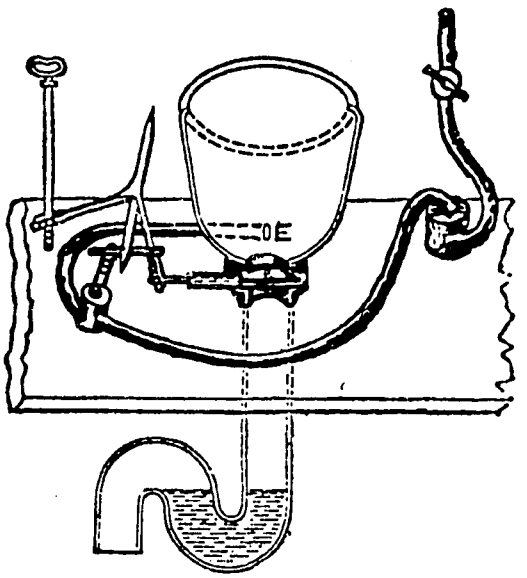

Fig. 30. Cumming's valve closet, 1775

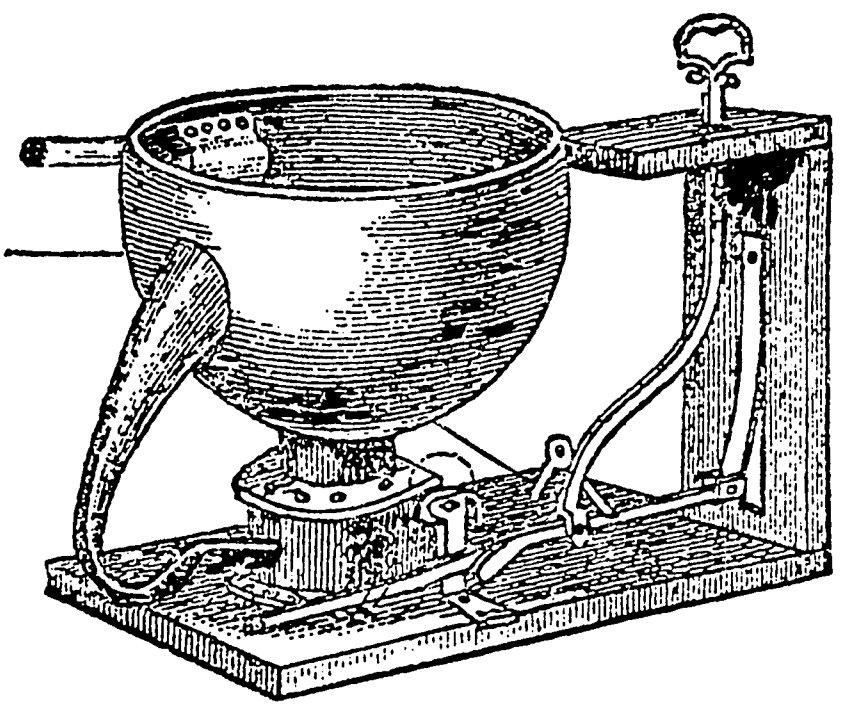

Fig. 31. Bramah's valve closet, 1778

SOURCE: T. L. Small, The Influent and the Effluent: The History of Urban Water Supply and Sanitation (Manitoba, Canada: Underwoood McLellan and Associates, Modern Press, 1974), pp. 198, 199.

NOTE: See "Latrines and Closets," p. 87 above.

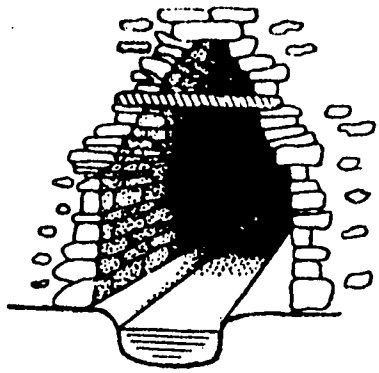

Fig. 32. Maya sewer at Palenque, showing drainage gutter

SOURCE: Maurice Daumas, ed., A History of Technology and Invention: Progress Through the Ages, vol. 1: The Origins of Technological Civilization, trans. Eileen B. Hennessy (New York: Crown Publishers, 1969), p. 399.

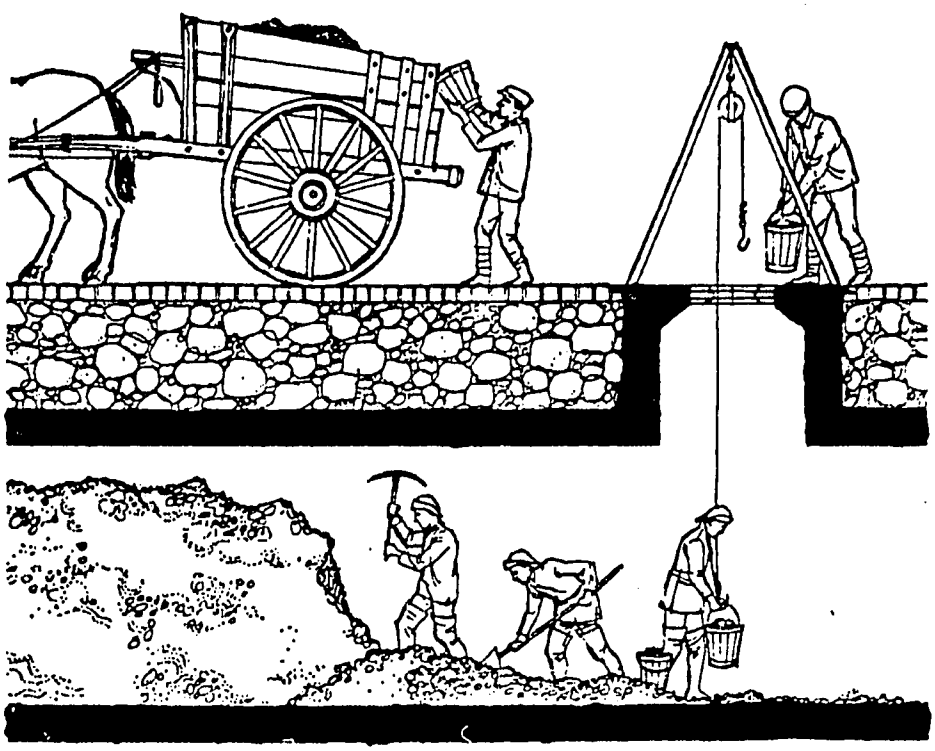

Fig. 33. Cleaners working on square brick sewer, London, 1830

SOURCE: Brian Read, Healthy Cities: A Study of Urban Hygiene, Topics in Modern History Series, gen. ed. Ivor D. Asbley (Glasgow: Blackie, 1970), p. 10, from History of Technology (Oxford University Press, 1958).

NOTE: See "Drains and Sewers," p. 94 above.

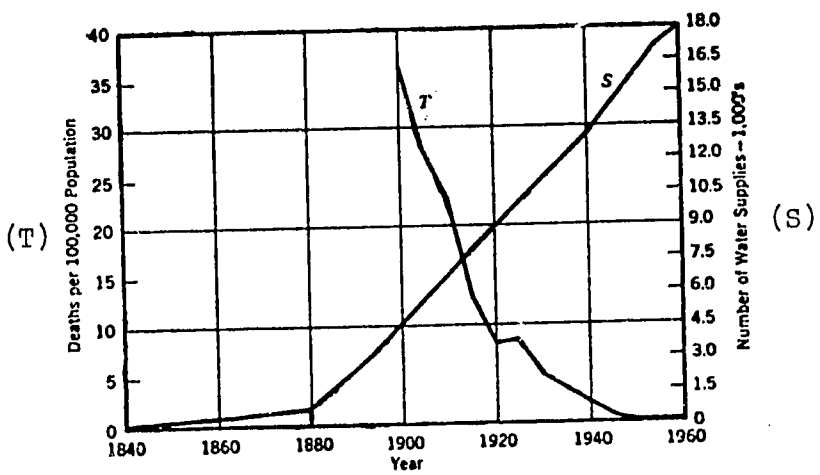

Fig. 34. Simultaneous decline in typhoid fever death rate and rise in number of community water supplies in the United States

SOURCE: Abel Wolman and Herbert M. Bosch, "U. S. Water Supply Lessons Applicable to Developing Countries," Water, Health and Society, ed. Gilbert F. White (Bloomington: Indiana University Press, 1969), p. 225.

NOTE: See "Establishment and Administration of Public Water Supply Systems," p. 103 above.

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