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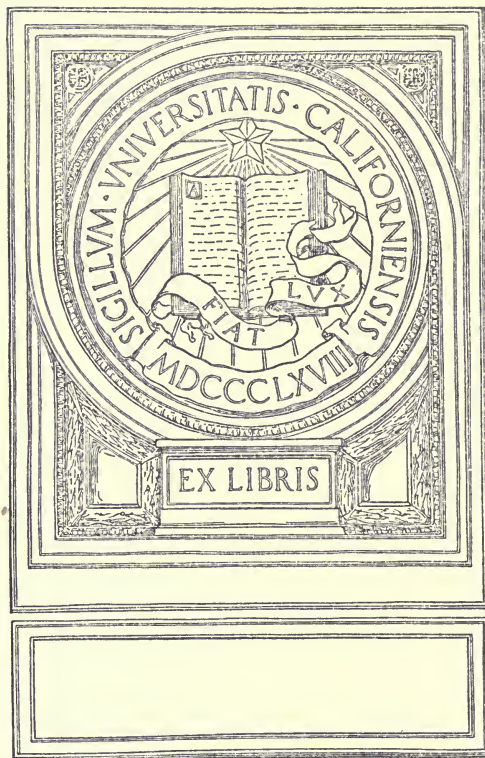
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SOME OF THE EARLY METHODS OF  
COLLECTING, STORING AND  
DISTRIBUTING WATER.

BY

WILLIAM R. HILL.



# SOME OF THE EARLY METHODS OF COLLECTING, STORING AND DISTRIBUTING WATER.



Read before the American Water Works Association,  
at Buffalo, N. Y., June 14th, 1898.

BY

WILLIAM R. HILL,

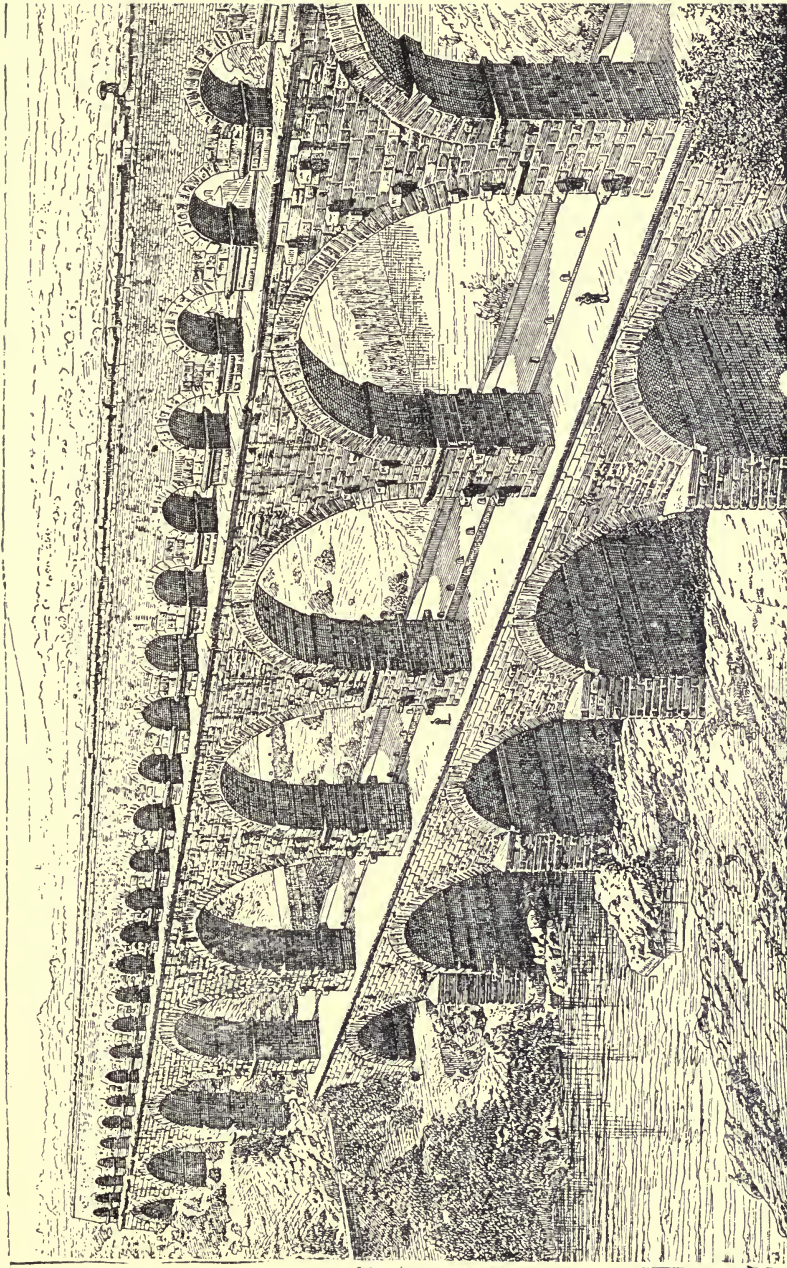
Civil Engineer, Syracuse, N. Y.

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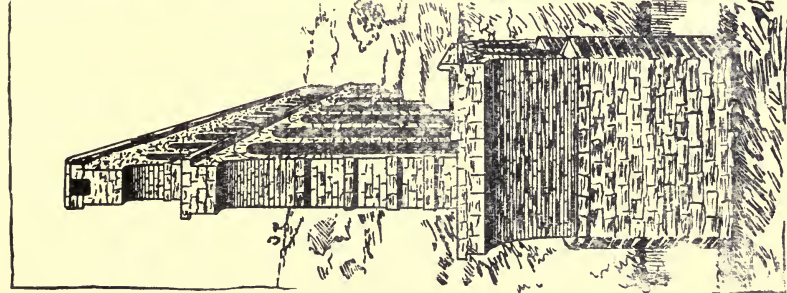
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The Pont Du Gard Aqueduct over the River Gardon, near Nîmes, France. It is 180 feet high and 873 feet long. The channel is about five feet high and two feet wide. Supposed to have been built 19 B. C.



This section made from the accompanying view by Thomas McE, Vickers, C. E.





Water is in many respects the most important substance in the world. It covers the greater part of the earth's surface, permeates its interior, and is the substance of the clouds above us. In the early ages it was venerated as a substance of which all things in creation were supposed to be made. Hence, wells, fountains and rivers were worshipped and religious feasts and ceremonies were established in honor of them or of the holy spirits that were believed to be hovering over them. The ancient Syracusans held great annual festivals at the fountain of Arethusa and sacrificed black bulls to Pluto at the fountain of Cyane. The ancient Romans celebrated the "Festival of Fontanalia," when wells and fountains were adorned with flowers and wreaths were cast upon the running streams. The early Egyptians worshipped the River Nile as the God of Fertility and Abundance, and to that deity they made human sacrifices. As late as in the twelfth century the custom of worshipping water was so general that kings and bishops issued regulations strictly forbidding it. Our ancient fathers worshipped water because they knew that it is the world's great natural stimulant and the first necessity of their lives. Without it all vegetation would perish, the earth would be shorn of its beauty and would become one vast burning desert. There would be no clouds in the heavens to protect man from the scorching rays of the sun and his existence would be impossible.

Before attempting to review any of man's work in the art of collecting, storing and distributing water, it would be well humbly to bow to our Creator and acknowledge that all human contrivances are but faint imitations of

nature's most wonderful and magnificent machinery. We find nature performing the duties of an immense hydraulic engine, requiring neither wheels, nor cranks, nor rods, nor pistons, continually converting water into vapor and pumping it into the atmosphere. In the night the dew gently settles over the surface of the earth and gives a sweet and refreshing drink to all the vegetable kingdom. At the dawn of day the sun's rays burst forth and silently and invisibly pump the water in perfect purity up to the distributing reservoirs, the clouds in the heavens, which are grand and beautiful in their formation, presenting the appearance of gigantic mountains crowned with snow, tinted with gold and silver, and emblematic of purity in their whiteness. At other times they present an angry aspect. They cast dark shadows over the earth and seem to be engaged in a great conflict, cannonading each other with electric fire, accompanied by vivid flashes of light followed by the loud reports of the discharge of their artillery. The winds distribute them in the heavens and affected by the temperature they fall in the form of rain, hail and snow to refresh the earth, to give drink to man, to give life to vegetation, and to form streams, lakes and rivers, the natural conduits that convey the water to the great storage reservoir, the ocean.

The subterranean boiler's water is heated by Pluto's blue sulphur flames, generating steam and producing power to operate nature's marvelous pumping machinery which discharges water from the bowels of the earth with a pressure sufficient to produce nature's amazing fountains, the geysers.

Water is purified by passing through natural filter beds, the subterranean strata of sand and gravel, and leading therefrom we find small service pipes conveying the clear, cold and sparkling water to nature's fonts, the

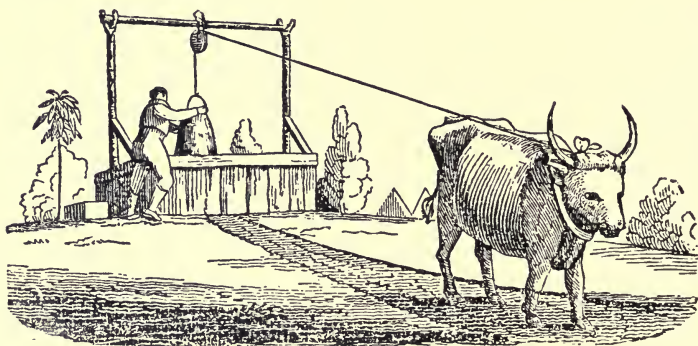
springs. Every tree and every plant is performing the services of a pump drawing up the water from the ground through their tubes to the top of the highest tree in the forest, even to the end of the smallest blade of grass in the meadow.

In constructing water works, man also imitates his own vascular system. The heart of every human being is a pump, the arteries are force mains, and the veins are suction pipes. At every contraction of the heart the fluid is conveyed through the force mains to the extremities of the system; at every expansion the fluid is drawn to the pump through the suction pipes. The duty of this pump, its strokes per minute, is indicated by the pulsations in the force main. In the vigor of youth, when the machinery is new, the strokes are strong and regular. When affected by the wear of old age they become weak and irregular, and at last when the pump fails to perform its duty the hydraulic system in man is ruined and, like a piece of worn-out machinery, his days of activity cease forever.

There can be scarcely a doubt that man first employed his skill in the art of procuring water. In the primeval ages he undoubtedly imitated the lower animals and lying on the ground drank directly from the running streams, and when it became inconvenient to reach the water in that manner, he then used the first vessel, which was the hollow of his hand.

The earliest work was perhaps the construction of wells. These at first were shallow, with steps or inclinations leading down to the water so that it could be reached with the hand. When the wells were made deeper several methods of lifting the water from them were employed, such as in vessels, by cords, chains, poles, pulleys, windlasses, treadmills, capstans and swapes, and by chains of pots, wheels, screws, chain pumps and numerous other

devices. In southern India water was obtained from wells by means of a vessel called a "mot." It was made of an entire ox-hide, bound on a wooden ring to form an opening. It was raised by animal power by a cord on a pulley fixed over the well.



The ancient inhabitants of the island of Aradus (now called Ruad) obtained their water supply from a spring in the bottom of the Mediterranean Sea at a depth of about eighty-five feet. The island is about three-quarters of a mile in circumference and is situated about two and one-half miles off the coast of the southern portion of Turkey in Asia. In ancient times it was very populous. The water was obtained by sinking over the spring a wide-mouthed funnel of lead to which was attached a long pipe of leather. The water was discharged in vessels in boats and conveyed to the city. This spring is known as "Abraham's Fountain." It is located between the island and the mainland. The inhabitants of modern Ruad still tap it in the ancient fashion.

Hezekiah, King of Judah, who reigned in the years 688 to 717 B. C., was a pioneer in constructing a system of water works, bringing water into the city of Jerusalem. In the Holy Book we read: "He made the pool and the

conduit and brought the water into the city, stopping the upper part of Gihon, and bringing it straight by an underground way." "He stopped the upper water course of Gihon and brought it straight down to the west side of the city of David, and Hezekiah prospered in all his works." From the "Pools of Solomon," near Bethlehem, water was conveyed to Jerusalem, a distance of six or seven miles, through a conduit of earthen pipe about ten inches in diameter. The pipe was encased within two stones hewn out to fit it, then covered over with rough stone cemented together.

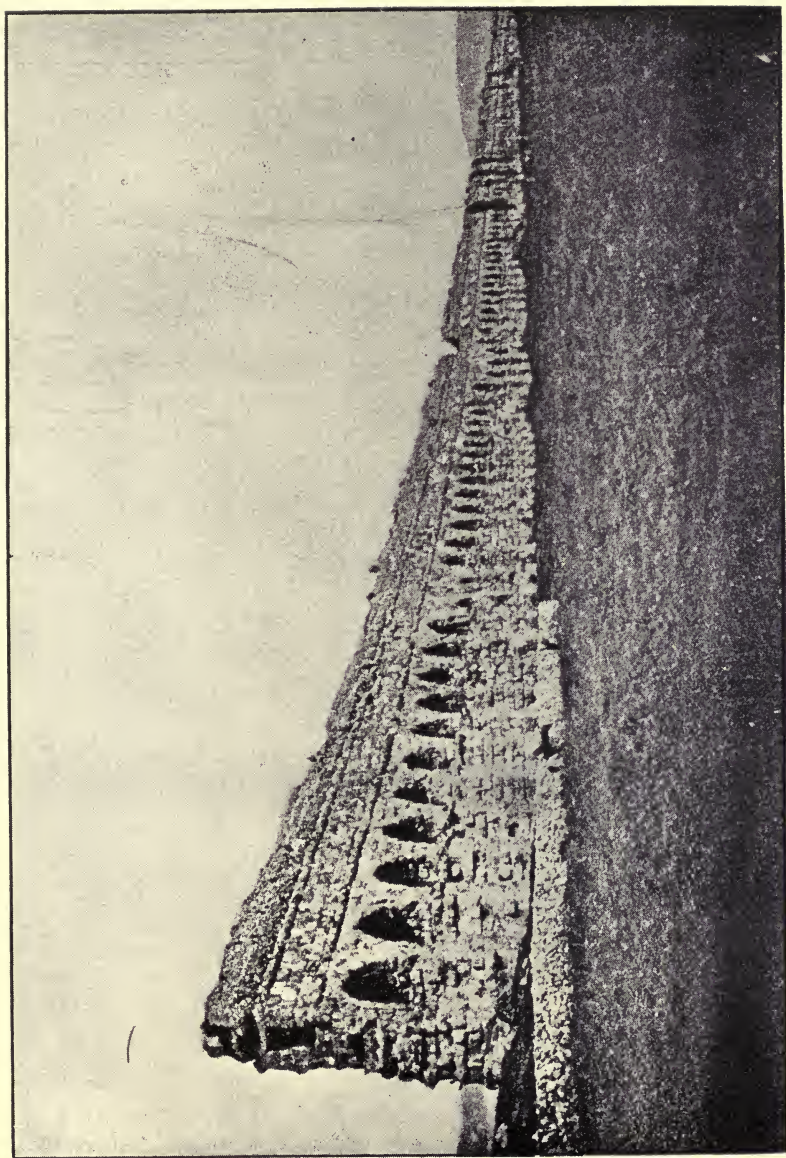
The remains of aqueducts in many parts of the world give evidence that the ancients were well provided with water. - The supply was generally discharged into fountains placed in different parts of the cities and then conveyed by the water-carriers to the dwellings or to wherever it was to be used. The aqueducts of the Greeks were open or subterranean channels. They apparently never constructed any aqueduct bridges, hence they left no conspicuous monuments of their works. They were unlike the Romans, who performed work with a disdain to obstacles, building immense structures of masonry to conduct water across deep valleys. Many of the bridges still existing, though in ruins, excite our admiration and astonishment.

In the year 312 B. C. water was for the first time conveyed to Rome from a distance. At that time Appius Claudius the Censor constructed the Aqua Appia aqueduct from the Alban Mountains, a distance of eleven miles. The channel was underground the entire distance with the exception of about 100 yards. In the first century, at the time of Emperor Nero, Rome was supplied with water by nine aqueducts, the aggregate length of which was 255 miles, with a capacity of over 200,000,000 gallons per day. After the construction of other aqueducts the capac-

ity was increased to about 375,000,000 gallons per day. At the time of Constantine there were in Rome 926 public baths, 247 reservoirs and 1,212 public fountains. Many of the fountains were rich in works of art and were of a monumental character, and were dedicated to some god who was supposed to keep the water pure and undefiled.

France had many notable aqueducts. In the first century, in the time of Emperor Claudius Cæsar, there was constructed a conduit from Mount Pila to Lyons. It crossed thirteen valleys on aqueducts and three valleys by inverted syphons. The first syphon was laid in a valley about 2,600 feet wide and 217 feet deep. The second in a valley 3,458 feet wide and 325 feet deep. The third was of considerably less importance.

The water was admitted on the upper side of the first syphon into a reservoir of masonry, in the walls of which were inserted, at about ten inches from the floor, nine lead pipes eight and three-quarter inches in diameter and one and one-twelfth inches in thickness. These pipes were carried down the side of the valley on a species of substructure, arched in some places so as to preserve a regular inclination; they were of the same diameter as at the commencement for a distance of eighty-one feet, and they then each divided into two pipes of six inches diameter. The eighteen smaller pipes were continued to the bottom of the syphon; but instead of descending quite to the lowest part of the valley they were carried across an irregular depression of the latter on an aqueduct of about eighty feet maximum height, so that in fact the descending limb of the syphon was only about 164 feet in vertical height and the ascending limb was about 142 feet. Midway in the ascending limb the two six-inch pipes were reunited into nine-inch ones, and the latter poured the waters they conveyed into a small reservoir corresponding with the one on the de-



The Aqueducts Claudia and Anio Novus, about four miles from Rome. Constructed 38 to 52 A. D.  
The upper channel is the Anio Novus.



scending side. The descending limb of the second syphon was 282 feet.

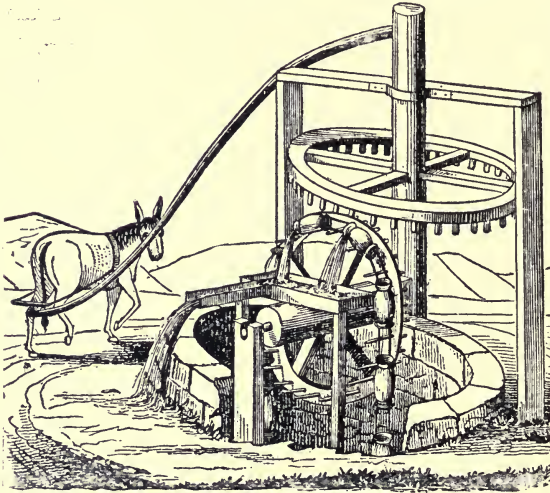
The famous Bridge of Maintenon which was constructed in the seventeenth century, during the reign of Louis XIV., to convey water to Versailles is, without doubt, in point of magnitude and height, the most magnificent structure of the kind in the world. The bridge was about 4,400 feet long and over 200 feet high. It consisted of three tiers of arches, one above the other, of fifty-foot spans.

On the 29th day of September, 1613, water was for the first time conveyed to London from a distance. An open channel about eighteen feet wide and five feet deep was constructed from various springs near Ware and Amwell to the metropolis. Although the distance in a straight line was not more than twenty miles, yet the conduit by its circuitous route was forty miles in length. This length was preferred in order to obtain a fall of three inches per mile throughout its entire course. Later on the channel was shortened to a length of twenty-eight miles. The valleys were in most cases crossed by timber aqueducts, the water ways on which were lined with lead. These timber aqueducts were replaced with embankments about the year 1785.

The canal that supplies the City of Marseilles with water was constructed during the years 1839 to 1847. It is among the boldest undertakings of the kind in Europe in modern days. It has a capacity of 285,000,000 gallons per day. The water is conveyed about sixty miles through forty-five tunnels of an aggregate length of eight and one-half miles, and across many valleys by aqueducts, the largest of which, that over the ravine of the River Arc, is 1,287 feet long and 262 feet high.

In the northwestern part of Arabia there is a well

which the Arabs claim to be the work of pre-Islamic times. It is five feet in diameter at the top and gradually enlarging until it reaches the water at a depth of nearly 200 feet. It is lined with hewn stone throughout. However, the most remarkable well in the world is Joseph's Well at Cairo, Egypt. Its shaft was excavated through solid rock to a depth of 165 feet, at which depth it was enlarged on one side to form a chamber, in the bottom of which a reservoir was made immediately under the shaft. At one side of this reservoir another shaft was excavated through rock to a bed of gravel where water was found.



The lower shaft was 130 feet deep, making the total depth 295 feet. The upper shaft was rectangular, twenty-four by eighteen feet. The lower shaft was fifteen by nine feet. Winding around the well a spiral passageway six feet four inches wide by seven feet two inches high was cut with great care from the surface of the ground down to the chamber. Between the well and the passageway a wall of rock was left. Horses and oxen descended the

passageway to the chamber where they propelled machinery to raise the water in pots attached to a chain from the lower shaft to the reservoir in the chamber, whence it was again raised by machinery operated by power on the surface. In the lower shaft a path was cut in its sides so that a descent could be made to the water. There was no wall between the path and the well. This work is said to have been constructed by Saladin, who lived in the years 1137 to 1193. Some writers do not mention this and say that the date of the construction is lost in antiquity.

Through small holes bored in the ground water is often raised above the surface by natural hydrostatic pressure. In Europe this mode of obtaining water was first practised in the French province of Artois, anciently called Artesium, hence the name artesian is derived. At Aire, in that province, there is a well from which the water has continued to flow steadily to a height of eleven feet above the ground for more than a century. There is a flowing artesian well within the old Carthusian convent at Lillers that has been in steady operation since the year 1126. Unmistakable traces of much more ancient bored wells appear in Asia Minor, Persia, China, Egypt, and even in the great desert of Sahara. At Grenello, in the vicinity of Paris, there is an artesian well which is 1,798 feet deep. It discharges water at the rate of about 850,000 gallons per day and at a temperature of 82° Fahr. The boring of this well commenced in the year 1834 and was completed in the year 1841. Previous to the latter date no well had reached a depth of 1,000 feet. The well at Passy, near Paris, is 1,923 feet deep. At its bottom it is two feet and four inches in diameter. It throws a continuous stream of water, at the rate of about 5,500,000 gallons per day, to a height of about fifty feet above the ground. At Bourne, England, there is an artesian well ninety-five feet deep

which yields over half a million gallons per day, with a pressure sufficient to supply the town and to force the water to the tops of the highest houses.

The older cities of Germany were the first to use pumps to raise water for public purposes. There they were quite commonly used in the year 1550, operated by water-wheels. We have no information in detail of their construction. Pumping engines were first used in London in the year 1582. Water was raised from the Thames river to an elevation of 120 feet by sixteen force pumps. The pumps were operated by two undershot water-wheels placed under the arches of the London Bridge. The wheels were twenty feet in diameter and were turned by the current during the rise and fall of the tide. When the water flowed rapidly the wheels made six revolutions per minute. The plungers of the pump were seven inches in diameter and had a stroke of thirty inches, and for every revolution of the wheels they made two and one-fifth strokes. The pumps had a total capacity of 2,500,000 gallons per day. About the year 1757 one of Newcomen's steam engines was erected to raise the water at ebb tide when the water-wheels were not in operation. A water company, incorporated in London in the year 1691 to supply water from the Thames river, used a Newcomen's engine but soon laid it aside and worked their pumps by horses. In earlier days the supply was obtained by the City Company of Water Bearers, who brought water from the adjacent rivers in leather panniers slung on the backs of horses.

The atmospheric or sucking pump was invented in the year 1641. It was a mystery at that time why the pump would not raise the water higher than thirty-two or thirty-three feet. Two years later Torricelli discovered that the water was raised in the barrel of the pump by air pressure on the surface of the water.

The most complicated machinery ever constructed for raising water was erected and set in operation at Marli, near Paris, in the year 1682. The pumps were divided into three groups. The first set contained sixty-four sucking and forcing pumps, raising the water 160 feet directly from the Seine river, through an iron pipe, to a cistern 600 feet from the river. The second set, seventy-nine pumps, were placed at this cistern and raised the water 185 feet to a second cistern 1,344 feet from the first. The third set, eighty-two pumps, were placed at the second cistern and raised the water 188 feet in a distance of about 2,000 feet to a reservoir. Therefore, the water was raised 533 feet in a distance of nearly 4,000 feet.

The pumps were operated by water power from the Seine river, which was divided into fourteen distinct water courses, in each of which an undershot wheel was erected. The first set of pumps was operated by six wheels, while the remaining wheels transmitted power to vibrating levers and through these to the piston rods of the second and third set of pumps. Therefore, the upper set of pumps was stationed 345 feet above and 1,944 feet distant from the power that operated them.

The feasibility of raising the water directly from the river to the reservoir was demonstrated by an attempt made in 1738, but owing to the inability of the machine to stand the strain they were operated as before until the year 1775, when a trial was made to dispense with the first cistern but the pipes burst and the old plan was resorted to until Napoleon ordered a steam engine of sixty-four horse power to replace the water-wheels. Consequently these pumps were in use and operated by water power for a period of at least 100 years. The hammering, rattling and creaking noise of the working of this machinery has been described as something hideous. It would be

well to note the advancement made in the method of transmitting power in the last two hundred years by comparing the operating of these pumps with the noiseless and invisible movement of transmitting power by electricity.

The first water works of Philadelphia, Pa., were put into operation January 27, 1801. An engine was placed at the corner of Schuylkill, Front and Chestnut streets. The water was pumped from the Schuylkill river into a brick aqueduct which was six feet in diameter and 3,144 feet long, leading to the Center Square engine-house at the crossing of Broad and Market streets. Here another engine pumped the water into two wooden tanks set in the top of the building fifty feet above the bottom of the brick tunnel. The tanks were ten and fourteen feet in diameter and twelve feet deep. The engine could not fill them in less than twenty-five minutes. The pumps were double-acting force pumps. They were made of wood and lined with sheet copper to prevent leakage. The steam cylinder of the Central Square engine was cast in two pieces, united by copper. The joint was secured by a cast iron sleeve eighteen inches wide. The cylinder was thirty-six inches in diameter and six feet six inches long. Nearly four months were spent in boring it. The steam boilers were made of five-inch white pine plank. They were boxes nine feet high, nine feet wide and fifteen feet long. They were securely bolted and braced. Inside of each was a wrought iron fire-box with vertical cast iron flues. The lever-beams, shafts, fly-wheels, etc., were also made of wood. The water was distributed through the city in pipes of bored logs six inches and four and one-half inches in diameter. Construction of the works commenced in the year 1799.

In contrast with these early contrivances it is interesting to note that there is perhaps no engine in the world

which has a capacity equal to that of the pumping engine "Michigan," which was built from designs of Mr. E. D. Leavitt. It has a capacity of 60,000,000 gallons in twenty-four hours against an average head of fifty-one feet. It is located at the Calumet and Hecla Stamp Mills, Lake Linden, Michigan. It was constructed and erected by the T. P. Morris Company in the year 1891.

The first person who is known to have raised water by a water ram was Mr. Whitehurst, of Derby, England, in 1772. He conveyed water through a one and a half-inch pipe a distance of about 600 feet with a fall of sixteen feet to furnish water directly to the lower part of a building. When a faucet in the building was opened the water in the pipe was set in motion and as soon as the faucet was closed the momentum of the long column of water opened the check valve and part of the water after passing through an air chamber rushed up a vertical pipe higher than the spring to a tank in the upper part of the building. This effect took place every time the faucet was opened and closed. The self-acting water ram was invented by a Frenchman in the year 1796. By using two or more rams and connecting their ascension tubes into one, water has been raised at Marly, in France, to a height of 187 feet.

The origin of the syphon is lost in antiquity. It was, however, used in Egypt as early at least as 1450 years before Christ. In the tomb of Amunoph II., who reigned in that period, there is a delineation which represents the syphon apparently in operation drawing liquid from one vessel to another. A syphon of extraordinary size was built for the Quindaro water supply of Kansas City. It leads from the intake crib to the pump wells, a distance of 745 feet. It is forty-two inches in diameter; its rise is ten feet above low water, and its capacity is about 50,000,000 gallons per day.

A conduit discovered near Patara was formed of stone blocks about three feet square, through which a tube about thirteen inches in diameter was cut. On one end of each block there was a projection which fitted into a recess three inches deep in the face of the adjoining stone, forming a socket and spigot joint which was filled with cement. The blocks were secured together by iron clamps run with lead. The date of the construction of this conduit is lost.

Great and important advances in the science of engineering in the methods of distributing water have been made through the manufacture of pipes. The ancients, so far as we know, made only a limited use of pipe. Although the Romans carried their systems to a high degree of perfection, they preferred brick or stone conduits to lead pipe, which was the only metal conduit they had at their disposal, excepting a bronze pipe which was difficult to manufacture. These lead pipes were made in lengths of ten feet by bending sheet lead upon a cylindrical form and soldering the edges. Thus they were ill-adapted for the conveyance of water under pressure. Earthenware pipes were also used. Some were made to screw into each other. Most of the great houses or palaces were supplied with water which flowed constantly into basins of stone or marble. Water was rarely carried by pipes to the upper stories. A lead pipe of great antiquity was recently found under the street in Rome. The pipe was not less than two feet in diameter. It was re-enforced in ancient brick masonry.

A conduit with an inverted syphon of cast iron pipe was constructed in the year 1782 to supply Genoa with water. I have been unable to find any record of cast iron pipe having been used prior to this date. Pipes formed of stone artificially hollowed out were laid down in considerable quantity in London and in Manchester in the early

part of the present century. The result in each case was a disastrous failure.

In the early days of London's water supply the distributing mains were made of bored trunks of elm trees, and in most cases they were six or seven inches in diameter. Owing to their small capacity it was necessary in many cases to lay additional lines. In the year 1810 there were nine lines laid side by side in one street. At the end of the last century they commenced to use cast iron pipe. About twenty miles of wooden pipe were removed annually until the year 1820, when all the mains of the New River Water Company, about 400 miles, were replaced by others of iron, of diameters from one to three feet. The cast iron pipes were screwed together at the joints. This prevented their free expansion and contraction, and often caused them to be broken by the varied temperature of the water, rendering them very defective in the winter season. Cylindrical socket joints were then introduced. They were accurately turned in a lathe. No stuffing was used other than a little whiting and tallow. The pipes were driven up in the joints. They were made in lengths of nine feet. The service connections were made by flanged joints cast with the pipe.

Until about the year 1850, or a little later, London and many of the principal cities and towns in England were supplied by the intermittent method, the water being turned on and off in the mains once or twice a day, or once in two or three days, as the case may have been, to fill tanks in the houses. Liverpool had an intermittent supply until the year 1873.

The first improvement on the ancient method of making lead pipe was in the year 1539 in England. It was then cast in an upright position in short lengths. The lengths were united in a mould by pouring hot metal over

the ends until they were run together. Later on lead pipes were made by casting them in moulds laid in a horizontal position. After a short piece was cast it was almost entirely drawn from the mould. The mould was then refilled with hot metal which fused with the first piece and increased its length. It was then partly withdrawn and more metal poured, increasing the length as before, and so on until the pipe was made the required length. The present method of making lead pipe was patented in England in the year 1820.

The process of making wrought iron tubes was invented and patented in England in the year 1824. These have been extensively used as service pipes, but in many cases, owing to the nature of the water, they have soon corroded and leaked. In other cases oxidation and incrustations have seriously diminished the capacity of the pipes. Many experiments of coating the pipe have been made from time to time with view of preventing its deterioration. The most durable and effective coating appears to be a lead lining. The lead lined iron pipe was first made about ten years ago. The method of making it is as follows: A reamer is run through the iron pipe making it smooth and true. It is then heated. The outer surface of the lead pipe is covered with a cement and then drawn into the iron pipe, followed by an expander which runs through the pipe its entire length. Wrought iron pipes are lined with tin in the same manner.

The water meter was first patented in England in the year 1825, and in America in the year 1848. Where it is used it restrains a great wastage of water. Many cities have erroneously demanded an unnecessarily large supply of water and have unduly increased their works by building reservoirs, conduits, pumping stations, etc., while, if all their services were metered, they would find that the

supply first available would serve a population two and three times as large. The meter is a great economizer. It saves many thousands of dollars in the cost of pumping. It is an honest arbitrator between the supplier and consumer, and it is a better inspector than the most competent man.

In conclusion, it is my hope that this and future generations may enjoy many improvements in the art of collecting, storing and distributing that beverage which is provided by our Creator to cherish and invigorate his creatures and to beautify the world.





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