ANCIENT WATER SUPPLIES

Thesis for the Degree of B. S.

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THESIS

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INTRODUCTION

The subject of water supply is an extremely interesting one entirely aside from its purely technical aspects. Its importance in the development of ancient civilizations makes it a subject of more general interest than most branches of engineering. One might say, with little fear of exaggeration, that water supply was the most important single factor influencing the life of the ancients, determining, in most cases, whether that life be nomadic, agricultural, or commercial. The subject has the added historical interest to engineers in that the first members of the profession were doubtless hydraulic engineers. Certain it is that wells were sunk and lands irrigated before roads were built or engines of war developed.

In a study of this sort, we have only two sources of information--structural ruins, and written records. Unfortunately, most of the writings that have come down to us were written by non-technical writers whose knowledge of engineering was all too slight. Particularly is this so of the more ancient civilizations, where we are further handicapped by the paucity of structural remains. When one adds to this the exaggeration found in many of the records, the difficulty of study will, I think, be apparent. Of course, when we come down to the period of the Roman Enpire, the conditions are much more favorable for a detailed study. Both ruins and written records exist in moderate profusion and may be used to check each other on many salient points.

Thus much of the first of this paper is devoted to ancient superstitions and beliefs about water, and to casual allusions to wells and springs. While it may be objected that this is not engineering, it should be remembered that, in the main, it is all that we know of the earlier water supplies.

While no comprehensive survey of the subject has been possible in this brief space, I have endeavored to present a broad account of these ancient works and give some idea of their magnitude and importance.

PART I

"The chief thing is water"
Pindar.

In early ages water was reverenced as the vivefying principal of which all things were made. Later it was thought by Greek philosophers that different combinations of four elements: earth, fire, air, and water, produced all the infinite variety found in the universe. Hence we find that rivers, fountains, and wells have been worshiped from time immemorial, with most nations, today, retaining some relics of these superstitions.

Even the practical Romans were exceedingly superstitious about wells and springs. Frontinus, speaking of the early water supply of Rome, has this to say: "Springs have held, down to the present day, the name of holy things, and are objects of veneration, having the repute of healing the sick; as for example the springs of the Prophetic Nymphs (Camenae) of Apollo, and of Juturna."

This belief in the miraculous powers of certain springs is a common one even today. In ancient times it was universally accepted. Pliny has much to say about the healing effects of different waters; they reputedly offered cures for everything from lunacy to barrenness (Nat. Hist. XXXI. 2). Vitruvius says that alum springs will cure paralysis, and that bitumen springs will remedy "interior defects". The springs at Paphlagonia caused inebriety; those of Chtor in Arcadia caused abstemiousness. An inscription at the spring reads: "Shun my vine-hating spring; here Melampus restored to sense the daughters of Proetus from their frenzy." There was a spring in the island of Chios, the waters of which dulled the wits of those drinking there. "Sweet is the flow of cooling drink which rises in a fountain, but he who drinks of it is turned to stone in his mind." At Susa, capitol city of Persia, there was a small spring with this inscription:

> Waters from the rock you see, stranger, from which it is safe for men to take to wash their hands;
>
> But if you take of the fair water of the leafy cave, and touch it but with the tip of your lips,
>
> Forthwith those banquet grinders, your teeth, fall on the ground and leave empty the sockets in your jaw.

Because of their sacred nature, springs and wells were worshiped and special celebrations were held in their honor. Among the ancient Peruvians, certain Indians were appointed to sacrifice "to fountains, springs, and rivers." The Mexicans had their God of water, Tlaloc. In Egypt, water was identified with Osiris; Thales of Miletus (one of the Seven Wise Men), who affirmed that the principle of all things is water, is said to have been inspired by Egyptian priests. The Fontinalia of the Romans were religious festivals held in October in honor of the Nymphs of Wells and Fountains. The Celts venerated lakes, rivers, and fountains, into which they threw gold; as did the Britons and the Picts.

At what period in man's history he first had recourse to wells, we can only conjecture; certain it is that it was in very primitive times indeed. When man first penetrated the earth in the search for water his wells were doubtless

mere shallow basins into which water would slowly percolate. Examples of this elementary type of well can be found that are in use today by primitive peoples.

It is quite probable that the art of constructing wells was mastered before any other. The physical character of Central Asia, its almost universal deficiency of water, its swarms of inhabitants, would naturally contribute ot that result. Thus we find many very ancient wells dug to remarkable depths, wholly through rock, and indicating highly advanced knowledge concerning their construction and location. In penetrating through loose soils or quicksands for example, a curb was first constructed, of stone or brick, which settled as the excavation proceeded.

Many of the most ancient wells were dedicated to the use of travelers and the general public. These public wells are often m entioned in history. At one of these Hagar rested and refreshed himself, when she fled from the ill treatment of Sarah. And it was by way of this well that Isaac was going when he met Rebecca and where he subsequently took up his abode. A common custom in those days of congregating around wells, often made them the neuclei of ancient villages and cities. "Palmyra, one of the most splendid cities of the old world, was built by Solomon in the Syrian desert, and its location was determined by springs and wells which were found at that place only." Most of Sicilian cities took their names from the fountains they were near or the rivers they bordered upon. A deep well in Italy gave its name, Lilybe, both to the cape and to the town near it. The numerous place

names in Palestine beginning with En or Ain, meaning spring, point to the water supply as the determining factor in locating a town or village. Bath in England derives its name from adjacent springs. It was named Caer-Badon, or place of baths, before the Roman invasion. Similarly the city or Wells was named. The Trojans are said to have given the name Xanthus, or Chestnut, to the river which flows through the plains of Troy because it was believed that the cattle in the neighborhood, which were of a reddish color, had taken their hue from the water (Vitru vius VIII 3.14). "Thus the property of liquid when it enters the body produces the kind of quality with which it is tinctured."

Conditions in Palestine and Syria favored individual rather than community water supply. "Drink waters out of thine own cistern, and running waters out of thine own well," says the Hebrew proverb. The coastal plain of Palestine and Syria was supplied by springs along the base of the Judean and Lebanon highlands, and by wells. In the plains of Philistine, the ground water level was high and furnished the ample springs of Gaza and Ashdod, but on the steep coast of Lebanon, with its rapid run-off, the ancient Phoenicians probably depended mainly on mountain streams and springs. However, the Phoenicians were famous as hydraulic engineers. Stabo tells of the water works of the island city of Arudus. Rain water from the roofs was collected in cisterns, and in addition a great inverted funnel, with hose attached, was placed over a submarine spring that bubbled up in the sea a few hundred yards from port.

In Rephidim there was but scanty water (Exod. 17-1 Num. 33-14). Amalek fought with the envading Israelites to defend the good water supply of Wady Fieran, the most fertile oasis of all the penninsula. Wells sunk in the dry wady beds were private possessions fought over by the herdsmen of Abraham and the neighboring king of Gerar. The extraordinary preservation of sandstone sculptures in this region would indicate no greater rainfall since 5000 B.C. (Petrie. Researches in Sinai). It is therefore extremely probable that the population never greatly exceeded that of the present. There is an ancient Egyptian well at Maghareh, two miles distant from the town, that is sunk eight feet in granite at the foot of a mountain. If the ground water level had been any higher than that at present this well would have been unnecessary.

Numerous wells of extreme antiquity are still to be found inside the pyramids. The immediate successors of the Pharoah who patronized Joseph erected stations to protect the ancient wells at Wady Jasous. These wells still supply the port of Philoteras or Aennum as they did four thousand years ago. In Karnak, the house plan was very similar to that of the Romans, and each house was generally supplied with a round well and an oblong cistern.

The practice of building stations to protect wells was a common one; often the roads were guarded near them. Many of the ancient wells were left without curbs so they could be more easily concealed, and thus guarded against destruction or poisoning.

Like her neighbors, Greece was well supplied with springs and wells. Many of them sacred to Apollo and Demeter, suggest their utilization for agricultural purposes. Other springs arose in sacred groves and grottos. City springs are met with in Homer, in the fountain of Hyperia in Pegasae on the Gulf of Volo, by the roadside in the city of Alcinous, and in the fountain of Arethusa in the capitol of Ithica. Plutarch preserved some of the laws of Solon respecting wells. Persons living within four furlongs of a public well had liberty to use it. Others had to dig their own, and they must be dug at least six feet from their neighbors land. According to Pliny, Danaus sunk the first wells in Greece. Plutarch says the Athenians taught the rest of the Greeks how to sow corn, how to construct wells, and the use of fire, indicating that wells were among mans first inventions. In mythologic ages the daughters of Danaus were punished for the murder of their husbands by being forced to raise water out of deep wells.

Phoenicia, Carthaginia, and Persia were apparently well supplied with private as well as public wells. At Arar, are wells excavated through sandstone of a considerable depth. The celebrated Fountain of the Sun of the ancients was a well eight feet square and sixty feet deep. Well and fountain were terms often used synonymously. The Chinese used wells to water their land. Many of the largest were lined with marble and were of extraordinary depth. (M. Arago, in his Essay on Artesian Wells, observes that the Chinese have sunk wells to a depth of eighteen hundred feet.) The Egyptians irrigated the borders of the desert above the reach of the Nile from wells. When taken by the British, 50,000 wells were counted in one district of Hindustan, many of them being of great antiquity.

The ancients constructed many large tanks for the purpose of collecting water for irrigation. In the Carnatic, some were eight miles in length and three in breadth. In the plains of Arabia water was drawn from wells and carried to the fields. Watering the land with pots carried in yokes was one of the labours of the Israelites in Egypt. "I removed his shoulder from the burden, his hands were delivered from the pots." (Psalms 81.6).

In India, as elsewhere, the rich often donated public wells for the use of their less fortunate brethern. A good sized well cost about two-thousand dollars and a celebration was held at its dedication. During the ceremony a Brahmin in the name of the donor would exclaim, "I offer this pond of water to quench the thirst of mankind." Ferose, monarch of India in the fourteenth century, built fifty sluices to irrigate the land and over 150 wells. Near the village of Futtehpore is a large well ninety feet in circumference and thirty feet to the water surface.

The wells of Asia were generally of considerable depth. In Guzzerat they are from eighty to one hundred feet deep. In the adjoining province of Mulwah, they are frequently three hundred in depth; in Ajmeer, from one to two hundred; Cabaul has one well three hundred forty-five feet deep and only about three feet in diameter; a well of ancient Tyre was two hundred sixteen feet deep. A tribe of Kabyles is said to have sunk wells to a depth of two hundred fathoms.

Jacobs well near Sychar on the road to Jeruselem has been in use for 3600 years. It is one hundred five feet deep nine feet in diameter, with about fifteen feet of water. It was excavated through solid rock.

The well Zemzem at Mecca is considered by Mohametans one of three holiest things in the world, and as the source where the great progenitor of the Arabs refreshed himself when he and his mother left his fathers house. The Caaba was built around the well, possibly by Abraham or Ishmael. In 979 A.D. the Karmatians slew 17,000 pilgrims within the Caaba and filled the well with bodies. The well itself was two hundred ten feet deep, fifty-six feet to the water surface. It had a curb of white marble five feet high, seven feet, eight inches in diameter.

A Roman well was discovered in Britain in the seventeenth century near a road to Carlisle. It was lined with large pine casks, six feet in length. The well was covered with oak planking nine inches thick. In it were found urns, drinking cups, sandals and shoes, the soles of which were stitched and nailed.

Joseph's well at Cairo is two hundred ninety-seven feet deep and one of the most remarkable wells ever constructed. It is rectangular in shape, twenty-four by eighteen feet, and, is excavated through solid rock one hundred sixty-five feet to a capacious chamber, at the bottom of which is formed a basin or reservoir to receive the water raised from below. On one side of the reservoir, is another shaft fifteen by nine feet, which penetrates down another one hundred thirty feet where it emerges into a bed of gravel. Water was first raised

into the reservoir by means of machinery propelled by horses or oxen within the chamber. The well is surrounded by a spiral passage-way to the chamber with a gentle descent. The passage is six feet four inches wide and seven feet two inches high. The partition between the passage and the shaft is only about six inches thick and is of astonishingly uniform thickness throughout. The passage is lighted by occasional openings or windows to the shaft proper. In the lower shaft a perilous passage-way is cut around the periphery of the shaft to the bottom. Wheels at the top of each shaft carried endless ropes to which earthenware vases were secured--the "Chain of Pots".

Before the building of the aqueducts, Rome was chiefly supplied from springs and wells, some of which are still in use. The springs of the Camenae in the Egerian valley were said, by Vitruvius to furnish the best of water. Equally famous springs were the Fons Apollinis and the Fons Juturnae near the Lake of Curtius. The control and administration of the wells and springs was under a different set of officials than the aqueducts. Roman wells are found in every country where that people conquered. Their armies often depended upon them, the battles often going to the side with the best water supply.

In 1711, while digging a well, a workman in Italy uncovered what proved to be the site of ancient Hurculaneum, which had been buried by Vesuvius in 79 A.D. It was one of the most important archaeological finds ever made. When the ashes were removed, one of its public wells was found, which had been protected by an arch and a curb. It still contains excellent water. During excavations in 1832, a well was found near the gates of the Pantheon that was one hundred sixteen feet deep and contained fifteen feet of water.

It is interesting to note how the Romans located their wells and springs. Vitruvius gives considerable information on this point. "Those who look out for water must also observe the nature of the ground; for there are certain places where it rises. In clay the supply is thin and scanty and near the surface; this will not be of the best flavour. In loose gravel the supply is scanty but it is to be found lower down; this water will be muddy and unpleasant. In black earth, moisture and small drops are found; when these gather after the winter rains and settle in hard solid receptacles, they have an excellent flavour .....In coarse gravel, common sand and red sand,[1] the supply is more certain and this is of good flavour. The waters from red rock are copious and good, if they do not disperse through the interstices and melt away. At the foot of mountains[2] and in flinty rocks water flows more copiously; and this is more cool and wholesome." (De Architectura II,VIII 1. 2)

After a favorable location was found, a hole was dug,"not less than three feet square and five feet deep". At sunset an inverted basin was placed in the bottom and covered with

[1]The pebble beds and New Red Sandstone of the Triassic series supply abundant water.

[2]Cretaceous formations containing water are found all along the Apennines.

leaves and earth. If drops of water and moisture were found on the oiled inside of the basin, water was indicated. The water was sought in mountain regions because it was "of sweeter quality, more wholesome and abundant". When deep wells were being dug, the air was tested with a lighted lamp, and, if the lamp was extinguished, air-shafts were dug on each side of the well to enable the work to proceed safely.

Where the locality was unfavorable for the location of wells or springs concrete cisterns were built. The instructions for making the concrete were as follows: "First let the purest and roughest sand be provided; then rubble is to be made of broken flint, no piece weighing more than one pound; the strongest lime is to be mixed in the trough, five parts of sand to two of lime." The trench was rammed down with wooden rams shod with iron. The same concrete was used to cover the floor. Several cistern were often placed in series, to be used as settling basins. Sometimes salt was added to purify the water.

As to methods of testing water as to quality after the spring had been in use, the people that had been drinking of it were examined. If they were healthy, the water was considered good. Also if fresh water from the spring was poured over a vessel of Corinthian[1] and did not tarnish it, the water was considered good. The Romans also used a rough test for turbidity in determining the quality of the water.

[1] Alloy of gold, silver, and copper.

PART II

"Large reservoirs may be established for the collection of rain water, such as will not fail......"

Aristotle

The growth of large and populous cities became possible only after the development of extended systems of water supply, utilizing not only water from local sources, but also, bringing it in from distant rivers, lakes, and springs. No very extended or accurate information of the earliest of these water-works is extant, our knowledge of them being confined largely to the lands surrounding the Mediterranean. It isn't until the period of the Roman Empire, as a matter of fact, that we can call our information anything but extremely fragmentary. Certain it is, however, that extended systems of water supply existed long before the time of Romulus.
All ancient literatures reflect the concern of the Mediterranean peoples in securing a safe and adequate supply. Aristotle says, "There should be a natural abundance of springs and fountains in the town; or lacking these, large reservoirs may be established for the collection of rain water, such as will not fail when the inhabitants are cut off from their country by war......if the water supply is not all equally good, the drinking water ought to be separated from that used for other purposes."

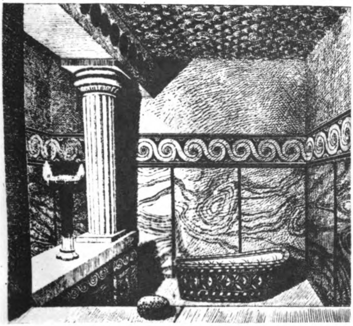
One of the most remarkable works of the ancients was the construction of Lake Moeris, by the Egyptians. Heroditus gives its circumference as 3600 stades, or 430 miles, and a maximum depth of 240 feet, (these figures are fairly well authenticated by more recent investigations). It was excavated by hand and connected to the Nile by a canal. During low water the reservoir supplied water to the Nile and the Nile in turn supplied the lake during high water. The lake was also connected to the interior to the west by an underground tunnel into Libya. An undertaking which indicates the high degree of engineering science possessed by the Egyptians was the removal of the Nile itself. In the reign of Menes (about 5000 B.C.) it swept along the Libyan chain of mountains, i.e. on the west side of the valley that constitutes Egypt. In order to make it equally beneficial to both sides a new channel was formed running down the center.

During the reign of Khufu, or Cheops, at the time of the building of the Great Pyramid at Gizeh, Ptah-hotep, Chief of Artificers, established a flood gauge on upper Nile so as to determine the mean flow and, if possible, predict the future.

Babylonia, like most of her neighbors, suffered from a acarcity of water and depended on wells and irrigation. There was only about enough water to sprout corn, after which irrigation was necessary. The river does not, as in Egypt, overflow banks of its own accord, but it is spread into fields by hand or engine[1]. "Whole of Babylonia is, like Egypt, intersected with canals. The largest of them all, which runs toward the winter sun, and is impassable except in boats[2], is

[1]This engine seems to have been the common hand-swipe which was essentially a bucket on one end of a weighted lever, which could thus be easily raised by hand.

[2]This probably refers to the original Nahr Malcha, the great work of Nebuchadnezzar, Felugia and entered the Tigris in the vicinity of the Gyndes (Dujalah).



A Bathroom of Ancient Crete

[Sir Arthur Evans, *The Palace of Minos*, Macmillan, London, 1930]

Early Cretan Libation Vessel of Black Steatite and Crystal

[J. A. Hammerton, *Wonders of the Past*, G. P. Putnam & Son, New York, 1924] carried from the Euphrates into another stream, called the Tigris." (Heroditus. Clio, Chap. 193)

These canals in Babylonia and Assyria were five to twenty feet deep and thirty or more feet wide. They were many miles in length, interlacing among themselves and intersecting both the Tigris and Euphrates. Acurious feature was their occasional arrangement in paralled groups of two or three, separated only by embankments. These canals served the entire Euphrates-Tigris valley from the Persian Gulf to Modern Baghdad and possibly to ancient Nineveh. Later on, during one of his victorious expeditions through this country, Alexander found masonry dams in the Tigris that blocked his ships, (between 356 and 322 B.C.) These dams had been built to furnish the irrigating canals with water and had, like those of Egypt, regulating devices such as sluices and gates.

Perhaps the most elaborate system of water supply and distribution of any of the ancient peoples, down to the time of the Romans, was possessed by Crete, a thousand years before the time of the Greek tyrants. The water supply was piped from deep wells in the hillsides and from springs in the higher gorges through pipes of stone and terracotta. Homes were furnished with hot and cold running water. The bathrooms and lavatories of the palaces were probably the most beautiful and well equipt the world has ever seen. An interesting commentary on the workmanship of the ancient inhabitants of Crete is furnished by a comparison of the pipes successively made by the Cretans, Romans, Venetians, Turks,

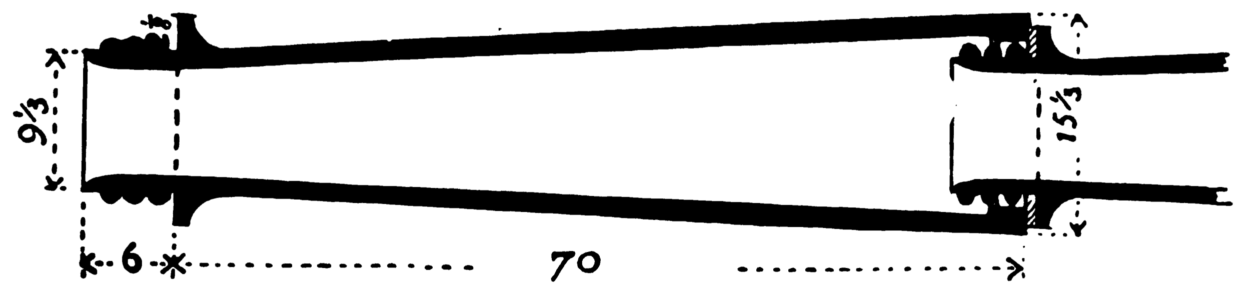


FIG. 50.—MYCENÆAN PIPE OF TERRACOTTA FOR THE DRINKING WATER SUPPLY.

and the present municipality of Candia. The pipes were continually made of greater size, but the fineness of the clay, the quality of cement, and exactness of shape gradually deteriorated.

The Greek Tyrants justified their beneficent despotisms by improving the water supplies of their capitols. Pisistratus (605-527 B.C.) built, around the chief spring of Athens, a hall of nine columns giving it the name of Enneacrunis, or fount of nine mouths. Water was brought for it by two conduits from the upper course of the river Ilissus, one of them passing underground out to the Piraeus. Other aqueducts, one from Mt. Hymettus and two from Lycabettus, contributed to the water supply of Athens, while a system of canals from the Cephissus were used to irrigate the neighboring olive groves and gardens. These Greek conduits were generally subterranean channels out of natural rock with shafts sunk at regular intervals. At the entrance to Athens the aqueducts discharged into large rock settling basins.

Megara was furnished with a long canal, built by the Tyrant Theagenes in 620 B.C., which brought water from the mountains to a beautiful and famous fountain in the market place. Polycrates of Samos, about 530 B.C., employed an engineer from Megara to supply Samos with water. Samos was built on a small island with a high mountain core. The mountain was pierced by a tunnel nearly a mile long to reach the springs of Mt. Ampelus. Corinth had the most famous city fountain of all Greece, the upper spring of which was said to be the gift of the river god Asopus.

The finest Greek aqueducts were the underground conduits of Syracuse, which were destroyed by the besieging Athenians in 413 B.C.

The ancient city of Laodicea in Phrygia is supposed to have been founded by Antiochus II (261-246 B.C.) The water supply was probably of Grecian origin and was obtained from the river Caprus. Conduit commenced about 225 feet above the highest part of the city and three miles south of it. The total length of the aqueduct was over four miles. Water was first conveyed in a masonry conduit across the plain of Denizla, then across two short viaducts into a settling basin composed of two chambers, 42' by 42', and 14' by 14'. From the smaller chamber an inverted siphon led across a valley and to the city. The siphon was formed by two lines of stone pipe two feet apart. Pipes were made of limestone blocks about two and one-half feet in length and two feet wide, that had bored out. The pressure at the bottom of the siphon was about sixty pounds per square inch.

One of the most impressive examples of works for distributing and storing water for a large city is to be found on the site of ancient Carthage. Built more than 2,500 years ago, parts of the ancient aqueducts and reservoirs are still in use.

We must remember that Carthage flourished over seven hundred years before its destruction by the Romans about 150 B.C. and then rose again to be one of the most magnificent cities in the world for seven hundred years under Roman rule. It was destroyed again and taken apart piecemeal for a thousand years. Thus most of the remains left are of Roman origin.

The great reservoir of Maalaka, in Carthage, was half mile from the sea. The Arabian work Maalaka means "connected together" and typifies the collection of vaulted communicating chambers, which covered a space of about 750' by 500', and served to collect and store the rainwater from the marble paved area around the reservoir, and the streets of the city. It was of excellent workmanship and was made of concrete and rubble masonry.

All over the ancient site, similar cisterns are found. There was another reservoir near the sea, 400' by 110', vaulted, with eighteen compartments--two for filters or settling basins, and the rest for the storage of settled water. These reservoirs have been restored and are now used for the water supply of the towns of Goletta and Marsa, water being brought to them from the hills of Zaghouan, some forty miles distant, utilizing for a part of the way the magnificent aqueduct built by the Emporer Hadrian in 221 A.D.

The conduit of this aqueduct was carried for over five miles on piers from seventy to eighty feet high. It still is used for its original purpose. The piers are twelve feet by fifteen feet, with a foundation of cut stone on which is built the column of pise,or earth, from the vicinity, mixed with lime and thoroughly rammed in cubicle blocks about three and one-half feet each way. The horizontal joints were made by embedding laths of olive wood in the freshly laid pise, covering them with a bed of lime mortar and wood ashes, and driving through the mortar and lath wooden pegs about six inches long. On this the next course of pise was laid.

The voussoirs are of cut stone, and there is a band of cut stone at the spring of the arches. The conduit, on top, is about five feet high, arched, built of pise and lined with cement.

The cities of Palestine, with their concentrated populations, felt the need of exploiting all local resources to assure their water supply. The city provided public pools or reservoirs by damming valley streams, and often supplemented these by aqueducts from distant springs. Jeruselem had the pools of Siloam and Bethesda, the Upper Pool, the Lower Pool, the King's Pool, Old Pool, and Hezekiah's Pool. Josephus also mentions four others as existing at the time of the Roman conquest. The Pools of Solomon may be seen today, eight miles beyond Bethlehem. They are still in use. "These reservoirs are really worthy of Solomon.........they are three in number, the smallest being between four and five hundred feet in length." (Lindsay. Travel Lect.) The pools are in series and the water is conveyed to the city by an ancient conduit which tunnels the hill of Bethlehem. The Pool of Siloam was fed in part by a tunnel conduit which brought water from the Fountain of the Virgin, and which must date from the eighth century B.C. or even earlier. King Hezekiah dammed the upper water course of Gihon and ran a conduit to his pool on the west side of the city of David. The channels were mainly hewn in rock and were covered with stone slabs. On the arid eastern escarpment of the Judean plateau, tanks and aqueducts fed by limestone springs supplied water to cities like Jericho and Bethsham.

There was a water tunnel at Gezer in Palestine that was built during the XII Dynasty in Egypt. It ran from a spring in a natural cave ninety feet below the courtyard of the palace. It was an arched passage in solid rock, twenty-three feet wide and twelve feet high, at a slope of thirty degrees.

On the westward facing escarpment of the Arabian plateau, conservation of water was necessary wherever towns grew up. Ruins of a tank at Heshbon show it to have been 191 feet long, 139 feet wide, and 10 feet deep. Madeba had a reservoir or pool nearly three acres in extent. Aden, Arabia, had a splendid system of water tanks for the collection of water. The town is situated at the base of the Shumshum mountains on the floor of the crater of an extinct volcano. The sides of the crater are entirely of lavas, breccias, and gypsum, and entirely devoid of any vegetation. The tanks were built in a deep cleft in the sidewall of the crater. The date of its construction is doubtful; probably about 600 B.C. The tanks are artificial pockets in the narrow gorge, no two of which are alike. There were originally fifty of them. When the British captured Aden in 1839 they restored fourteen of them at a cost of $180,000, with a capacity of over thirty-six million gallons. The construction of these tanks is most interesting. The lava sides and bottom of the gorge were lined or covered with a most peculiar cement. When examined closely it resembles old ivory, but from a distance it appears translucent. Beginning far up the gorge, the tanks increase in size as they approach the bottom. The capacity of the bottom tank being 5,574,330 gallons. Dikes were run out at salient angles diagonally down the sides of the gorge walls. During a rain a number of small aqueducts along the side of the gorge emptied into the tanks. Some of these tanks were eighty feet deep and very narrow; others were wide and fairly shoal.

The remains of all the highland cities of eastern Syria show the ruins of Roman aqueducts, baths, reservoirs, and occasionally a naumachia, or naval pool, like that at Gerasa. The Romans built a thirty mile aqueduct to supply Gadara.

On this side of the Atlantic, the Peruvians had probably the most extended system of supply of any of the ancient Americans. The people were allotted square fields which they surrounded with walls of stone. They irrigated these fields by open canals, called Rarccac, and subterranean conduits, called Pinchas. The Spaniards destroyed these channels; the land has been arid ever since. Many of the underground conduits contained pipes of gold. The largest space of these canals which has been preserved entire is found in the valley of Nosca, which owes its rare fertility to the water brought by the canals of the ancients. The subterranean aqueducts were paved with flagstones closely joined, from four to six feet long and about three feet wide, and had an inside height of six to eight feet.

Garcilasso de la Vega speaks of two aqueducts: one made by the Inca Viracocha ran from the heights of the Sierras for a distance of more than one hundred twenty leagues; another

ran north more than one hundred fifty leagues along the top of the steepest Sierras. "We may compare these canals to the greatest works which the world has seen, and give them the first place, considering the lofty Sierras over which they are carried, the large stones which they broke without instruments of iron or steel, and which were broke with other stones by mere force of arms; we must remember too that they knew not how to make scaffoldings with which to build the arches of bridges and span the chasms and small rivers. If they had to cross any deep river they headed its sources, thus encircling all the Sierras which presented themselves before them."

PART III

"Why should I mention the aqueducts, sustained upon lofty arches, to which Iris could scarcely lift the waters of the clouds? One might say these were mountains that had grown skyward.......Rivers are intercepted and hidden in thy walls." (Pinder)

"But if any one will note the abundance of water skillfully brought into the city, for public uses,...... for baths, for houses,......suburban gardens,.....;if he will note the high aqueducts,...... the mountains which had to be pierced......, and the valleys it was necessary to fill up, he will conclude that the whole terrestrial orb offers nothing more marvelous."

As was mentioned at the beginning of this paper, the water supply of ancient Rome is the only one of which we have fairly complete knowledge. There is a comparative profuseness of both structural remains and written records that enables us to follow, with comparative accuracy, the development of Rome's supply almost from the founding of the City. While in some ways not the finest, the supply of Rome was certainly the most extensive of any of the ancient supplies and was such as to inspire wonder and admiration even today. Surely we can agree with Frontinus when he asks "Will anybody compare the idle pyramids, or those other useless though much renouned works of the Greeks, with these aqueducts with their indispensable structures?"

The presence of an ample water supply undoubtedly influenced the Romans in the location of the City. Cicero says: "He (Romulus) choose a place abounding in springs" (De Rep II 6). The City is located among a group of detached hills and spurs and was originally about eight miles from the sea. It is interesting to note that the sea has been receding at the rate of thirty feet a year. The Campagna is a rolling plain resembling the prairies of Iowa or Illinois. There is a marked ridge across the prairie which many of the aqueducts naturally followed.

We are indebted principally to two sources for our knowledge of the Roman water supply, Frontinus and Vitruvius. Sextus Julius Frontinus may be properly called a Roman engineer, although he was a man of many public affairs. Besides filling the post of water commissioner (Curator Aquerum) of the city, he was three times consul and was governor of Britain (under Vespasian) besides various and sundry other accomplishments. He wrote at least seven books, "A Treatise on Surveying", "Art of War", "Shategematics", "Essays on Farming", "Treatise on Boundaries, Roads, Etc.", "A Work on Roman Colonies", and his account of the water works of Rome, "De Aquis". His book, "De Aqueductibus Vrbia Romae" is a sort of official report on the water supply of Rome in the reign of Tvajan. The translation of this work from the Latin was made from the "Montecassino Manuscript" by Clemens Herschel in his entertaining and valuable work, "Frontinus, and the Water Supply of the City of Rome".

Much interesting information is given by Vitruvius in his book, "De Architectura". He goes much more into practical details than does Frontinus with regard to the construction of aqueducts, cisterns, filters, lead pipes and the like, while Frontinus gives figures as to the lengths of the aqueducts and their discharge into the city.

There were three means of supplying water to the city, viz, aqueducts with channels of stone or concrete (canales structiles), lead pipes (fistulae plumbeae) and clay pipes (tubuli fictiles), used mainly for agricultural purposes. Pottery pipes (tubuli) were also in use as rainwater and overflow pipes.

Before we consider the supply system of the Romans it would be well to see how extended their knowledge was of hydraulics. They knew that water seeks its own level but were handicapped by having no accurate conception of rates of flow. The capacities of pipes were measured in quinariae, which were essentially units of area. The fact that the discharge depended also on velocity was taken no cognizance of by the Romans although the Greeks before them had understood it. Hero of Alexandria, at about this period, wrote, "Observe always that it does not suffice to determine the section of flow to know the quantity of water furnished...... It is necessary to find the velocity of its current for the more rapid the flow the greater will the discharge be". He recommended that the discharge of a pipe be measured by discharging it into a small reservoir and measuring the quantity discharged in one hour. Thus the Roman quinaria as a measurement of flow is to be taken with a good deal of salt, as it were. It apparently ranged from about 2,850 g.p.d. to 9,250 g.p.d. with an average value of five or six thousand gallons per day.

Pipes of different "capacity" had different names, such as quinaria, senaria, septenaria, etc. According to Vitruvius they were named from the width of the plate before it was rolled into a tube. Frontinus, however, thought it more probable that the names were taken from the finished diameters. The method used to measure the supply through these

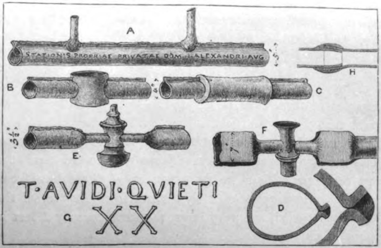


Fig. 97.

Lead Pipes and Turncocks.

A. Main pipe with two service branch pipes, inscribed with the name of Severus Alexander.
B. Fourway pipe.
C. Junction formed by enlarged lead cylinder.
D. Section of pipe and soldered joint to larger scale.
E, F. Stopcocks, *Epistomia adplumbata.*
G. Owner's name and capacity of pipe (20 *quinariae*) inscribed in raised letters.
H. Method of joining two lengths of pipe.

pipes and to prevent fraud is interesting: The juncture of the public main and a private supply was made with a bronze adjtage (calix) with its diameter stamped upon it. They varied in diameter from .907 to 8.964 inches and were originally made of lead. The Romans were evidently familiar with the action of a Venturi Tube, because the ajutages were required to be at least nine inches long and must be without any type of flange on the intake end. Also the pipe below the calix was required to be of the same diameter for at least fifty feet.

The pipe distribution in the city itself was very complete and compares favorably in its extent with modern systems. Street mains were laid in practically all streets supplying houses and fountains along the way. In the more important streets the Romans ran their mains through tunnels so they could be repaired without tearing up the pavement. The pipes were completely fitted with valves, turncocks, stopcocks and junctions.

The Romans were perfectly familiar with the construction of inverted siphons. Vitruvius describes quite in detail how they should be designed. They were usually made of lead pipes although earthenware pipes were occasionally used. The pipes were carried down one slope, across the valley, and up the other side, the bottom of the "U" being called the "venter". All elbows were guarded by using a single piece of stone into which the pipes were inserted from each direction. The pipe sections were ten feet in length. Standpipes were connected at the "venter" to allow air to escape. Water was admitted in a gradual manner and ashes were thrown in when the siphon was first used to close up any existing leaks.

Ancient lead pipe siphons of Roman origin, 12 to 18 inches in diameter and one inch thick, have been found at Lyons, France, that were built to withstand a 200 foot head. A drain pipe siphon with masonry reinforcement was built at Alatri, Italy about 125 B.C. to carry water under a head of 340 feet. Some of the inverted siphons were constructed of lead pipe imbedded in concrete.

The aqueducts leading into the city itself were constructed along the hydraulic grade line because of the expense and difficulty of making lead pipes that would withstand much pressure. Bronze was even more expensive. Another excellent reason for constructing stone and concrete conduits lies in the extreme hardness of the water brought into Rome. The large stone conduits offered a comparatively easy access for cleaning out the deposited carbonate, where lead pipes would have been extremely difficult, if not impossible to keep clean. Vitruvius, speaking of aqueducts says the "structure must be on a very solid foundation", and gives a minimum grade of six inches per hundred feet or about .042%. They had to be "arched over to protect the water from the sun."

In the earliest aqueducts, both the supporting arches and the covered channel (specus) were made of large blocks of tufa (mixture of volcanic ash and sand). The channels were lined with a hard mortar made of lime, pozzolana, and pounded pottery or brick. Later aqueducts were built of concrete faced on the outside with brick. In some cases the roof of the specus was formed by two large tiles (tegulae bipedales) set leaning together and supporting the mass of concrete that was poured in above (Middleton p. 322). At intervals of a few yards blow holes (spiramina) were made for imprisoned air to escape and for ventilation when workmen were repairing the channel.

Many of the conduits were in good part subterranean, only emerging at or above the surface at a few points. Air shafts (putei) were built at intervals of one actus (120 feet).

At the end of a conduit in the city there was a large distributing reservoir (castellum aquarusn) from which the district was supplied. Also there were a number of small reservoirs throughout each district. Aqua Marcia had over fifty of these. The main distributing reservoir was divided into from three to seven separate compartments, each with a separate main supplying a certain classification such as fountains, private houses, public baths, etc. Some of these reservoirs were very magnificent. They were lined with rich marbles and decorated with statues and large public fountains. These were at the time of Frontinus, 247 delivery tanks or small reservoirs, about one-sixth of the supply being consumed by 39 ornamental fountains and 591 water-basins. (Burr, p. 44).

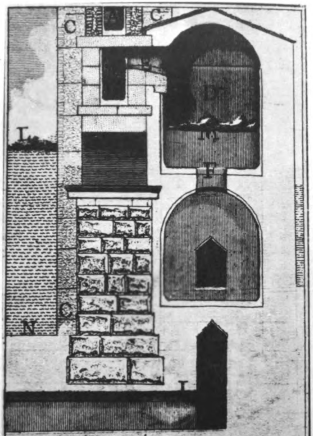


Fig. II *Sezione del Bottino che riceveva parte della Marcia per tramandarla nel rivo Erculaneo e che si nota in pianta al num. 22.* A. *Speco della Tepula.* B. *Speco della Marcia.* C. *Investitura del condotto riferita ai num. 117, 118, 119, e 120 dell'Indice generale.* D. *Bottino.* E. *Imbocco di una parte della Marcia nel Bottino* F. *Discesa dell'acqua nel ricettacolo sottoposto al Bottino.* G. *Altro imbocco corrispondente allo sgorgo* H *per dove l'acqua entrava nel rivo Erculaneo* I. L. *Piano moderno di Roma.* M *Rovine che ingombr.^no il Bottino.* N. *Piano ant.^co di Roma*

Water Tower of the Rivus Herculaneus

The constructing of the aqueducts was carried out by public contractors (redemptores operum publicorum) and done with slave labour. The building material used (tufa, peperino, pozzolana, and clay for bricks) were state property. The Aqua Caludia and Anio Novus, both started by Caligula and completed by Claudius in 50 A.D. are stated by Frontinus to have cost only 55½ million sesterces - about $2,800,000.

Much care was taken to insure wholesome and potable water. At the intakes of a number of the aqueducts reservoirs or basins were constructed which acted as settling or sedimentatia basins (picinae). Similar basins were constructed at different points along the aqueducts to act both as settling basins and storage reservoirs in case part of the aqueduct had to be repaired. These basins were constructed in a number of compartments in a two storied arrangement, the water flowing from one compartment to another. In some cases salt was used for clarifying.

These aqueducts were subject to serious leakage and large forces of workmen were constantly employed in maintaining and repairing them. A thirty foot strip was reserved along the courses of the channels of all the aqueducts on which no encroaching was allowed. Along the three older aqueducts, the margin of the strip was marked with boundry stones (cippi jugerales) set at intervals of two actus, or 120 feet, to indicate the distance from Rome.

Until the last century of the Republic, the Censors had charge of all the aqueducts and subterranean channels (vivi subterranae); and then for a short time they were under Quaestors and Aediles. Augustus instituted a new system. The supply system was directed by the Curator Aquarum, or water commissioner, who was appointed for life. It was an office of great dignity. The Curator was surrounded by a number of minor officials and personal attendants (apparitores), such as secretaries (scribae librarii), three public slaves (servi publici), and several engineers (architecti), and many others. There were several classes of artisans: Aquarii, who made and laid the lead pipes; Libratores, who measured the water levels; Castellarii, who kept the reservoirs in order; Silicarii, who tore up and relaid the lava (silex) pavements; besides bricklayers, masons, and crushers of pottery with which to line the channels.

As would be expected, Rome had a well developed code of water law. Water grants were for life only, and had to be renewed by each subsequent owner. This of course did not apply to bathing and other public establishments. In the case of synidcates, the water grants were good until the last member dissolved his interest in the estate.

The power of eminent domain was well established, the lands being appraised and paid for much as at present. The fine for polluting the waters was 10,000 sesterces ($500), and when water was illegally used for irrigation, the land was confiscated. In the time of the Emperor Nerva, thirty days notice was given before the water was shut off.

THE AQUEDUCTS OF ROME

In the time of Frontinus, water commissioner from 97 to 106 A.D., there were nine aqueducts supplying Rome.

I. The AQUA APPIA was built at the same time that the Via Appia was constructed by the Censor Appius Claudius Caecus in the year 313 B.C. The source has been discovered in some ancient quarries, now called "latomie della rustica" about 50 feet below the level of the ground. The Aqua Appia is mostly an underground waterway, only about 300 feet of it being carried on masonry arches. Its cross section was 2½ feet wide by 5 feet high. The subterranean "specus" is well preserved for a long distance and is accessible at some points. The termination of the viaduct was near the Tiber, close by the Marmoratum. The elevation of its water surface in Rome was probably about 60 feet above sea level. Additional springs were brought to the Aqua Appia by a branch added by Augustus, which was called the Aqua Appia Augusta. Its discharge into the city was over four million gallons per day.

II. The ANIO VETUS was begun in 272 B.C., forty years later than the Appia, by the Censor Manius Curiui Dentetus out of the spoils won from Pyrrhus, and was completed in 269 B.C. by M. Fulvius Flaccus (Frontinus 80). It was 43 miles in length; it took its water from the river Anio and pursued an extremely circuitous route to the city. About 1100 feet were above ground on an artificial structure. It too, was a low level aqueduct, its elevation in Rome being about 150 feet above sea level. Where the specus was above ground, it was built of massive blocks of peperino, laid in cement. Its channel was about 3.7 feet wide by 8 feet high.

At one point there is preserved a curious inspection shaft (puteres). It stands above the excavated ground level like a small circular tower, about 12 feet high and 10 feet in diameter. It is built of massive blocks of tufa and travertine. Augustus built a branch subdividing the waters of the Anio Vetus into two parts, starting about two miles from its termination in Rome. The discharage of the Anio Vetus was nearly ten million g.p.d.

III. The AQUA MARCIA was built by the Praetor Q. Marcius Rex in 144 B.C., by the order of the Senati at the same time that the two earlier aqueducts were restored. About $9,000,000 were voted to build this aqueduct. Its source is about 38 miles from Rome. About seven-eighths of its length was subterranean but the last six miles was on massive peperino arches. It is nearly 58 miles long and its channel at the head of the aqueduct was 5-7/8 feet by 8-3/10 feet, but farther down the channel was reduced to 3 feet by 5-7/10 feet. The water was of a most excellent quality and was brought into Rome at an elevation of about 195 feet above sea level (Burr, p. 40). Discharge was about 11,600,000 g.p.d.

A short branch, called the Aqua Augusta, was added by Augustus, and this doubled the original supply of water. The Marcian water is still brought to Rome under the name

Name	Date of Construction	Length Carried Above Ground	Total Length	Name of Builder
Aqua Appia	312 B.C.	300'	9½ mi.	Appius Claudius Caecus
Avis Vetus	272-269 "	1,100'	43 "	M. Fulvius Flaccus
Marcia	144-140 "	32,000'	58 "	Q. Marcius Rex
Tepula	125 "		11 "	
Julia	33 "	37,000'	14 "	Agrippa
Virgo	19 "	5,000'	13 "	Agrippa
Alsietina	10 A.D.	1,600'	22 "	Augustus
Claudia	38-52 "	53,000'	45 "	Caligula Claudius
Anio Novus	38-52 "		62 "	Caligula Claudius

Aqua Pia, a restoration completed in 1870.

The Marcian aqueduct, like its two predecessors, was built of dimension stone, 18 inches by 18 inches by 42 inches, or larger, laid in cement; but concrete and brick were used in the later aqueducts, with the exception of Claudia.

IV. The aqueduct called the AQUA TEPULA, about 11 miles in length, and completed about 125 B.C., was built to bring into Rome the slightly warm waters from the volcanic springs on the Monte Albani southeast of Rome. The temperature of these springs is about 63°F. Its discharge was less than three million gallons per day. Cross section of the channel was 2.7' by 3.3'.

V. The AQUA JULIA was built by Agrippa in 33 B.C. from some springs about a mile from the monastery of Grotta ferrata up in the same valley from whence the Aqua Tepula started. Its water was considerably cooler than that of Tepula. It was about 14 miles long with about half of its course subterranean. The Julia, Tepula, and Marcia, were for a long distance carried on the same row of arches, one above the other with Julia the highest. (The Julia was the third highest of all the aqueducts; the first was the Anio Novus, and the second was the Aqua Claudia.) Restorations were carried out by Augustus in 5 B.C., by Severus in 196 A.D., and by Cavacalla in 212 A.D. In Rome itself the three separated and carried in different directions. The water from the Aqua Julia entered Rome at an elevation of 212 feet,

The Terminal Fountain of the Aqua Julia

Name	Size of Channel	Discharge Elevation	Discharge in Quinaria	Discharge in m.g.d.
Appia	2½' x 5'	60'	704	4.2
Anio Vetus	3-7/10 x 8'	150'	1,610	9.7
Marica	5-7/8 x 8-3/10 3 x 5-7/10	195'	1,935	11.6
Tepula	2-7/10 x 3-3/10	201'	445	2.7
Julia	2-3/10 x 4-6/10	212'	803	4.8
Virgo	1-6/10 x 6-6/10	67'	2,504	15.0
Alsietina	2-8/10 x 2-9/10	55'	392	2.3
Claudia	3-3/10 x 6-6/10	185'	2,812	16.9
Anio Novus	3-3/10 x 9		2,813	16.9
		Total Discharge	14,018	84.1

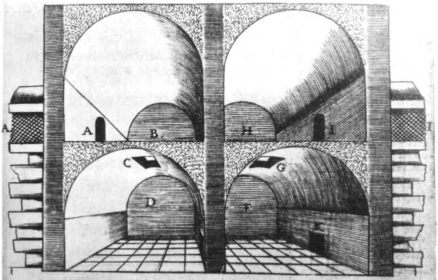
that of Aqua Tepula at about 201 feet above sea level.

Julia had a channel of 2.3 feet by 4.6 feet and a discharge of slightly under five millions gallons per day.

VI. The VIRGO AQUEDUCT - "See how the aqueducts of Rome contribute to her ornamentation. Virgo's stream is so pure that the name, according to common opinion, is derived from the fact that those waters are never sullied; since, while all others give evicence of the violence of rainstorms by the turbidity of their waters, Virgo alone ever maintains her purity."

Virgo was begun by Agrippa in 35 B.C. and completed in 19 B.C. (Pliny. Nat. Hist. 31, 42). In the same year (33 B.C.) Agrippa is said to have constructed for public use no less than 700 basins or pools, 500 fountains, and 130 reservoirs, many of them richly decorated with fountains and statues. Three hundred statues of marble and bronze were used in these works, as were 400 marble columns. (Middleton II, p. 342.)

The main object of Virgo was to supply the Thermae (baths) of Agrippa. It took water from springs about 8 miles from Rome and 80 feet above sea level, but the length of the channel was about 13 miles. It discharged into the city at an elevation of 67 feet. The channel cross-section was 1.6 feet by 6.6 feet. About one-thirteenth of its length was above ground. The waters of this aqueduct were distributed from eighteen reservoirs. Virgo has been restored and now supplies a large number of fountains and streets in Rome. Its



A.A Ductus Aquæ Virginis, se exonerans in receptaculum B
C.Ostium, per quod Aqua descendit in cellam subterraneam D
E.Porta, ex quâ Aqua defertur in aliud Receptaculum subterraneum F
G.Ostium, per quod Aqua iterum assurgit ad Receptaculum H, & Ductui I I se restituit
K.Porta cataracta, ex quâ limum, & purgamenta in Cloacam emittebantur.

FABRETTI 168

Reservoir of the Virgo near the Spanish Steps discharge was over fifteen million gallons per day.

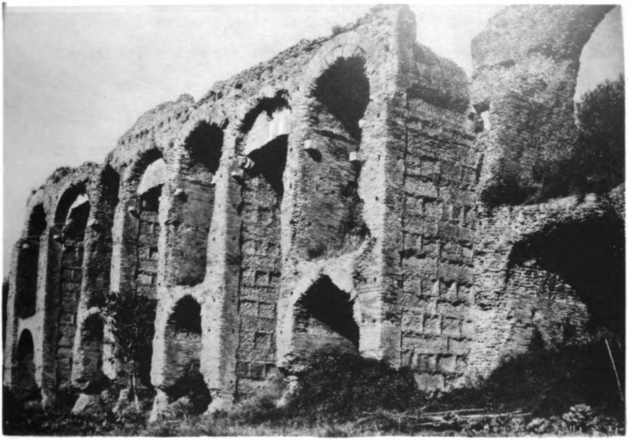
VII. AQUA ALSIETINA - The preceding aqueducts were all located on the left or easterly side of the Tiber, but the Aqua Alsietina was on the right. It was constructed by Augustus in 10 A.D. mainly to supply his great Naumachia or show naval fights.

"I gave the people the spectacle of a naval combat beyond the Tiber where is now Caesar's grave; and for the purpose I caused the ground to be excavated for 1800 feet in length and 1200 feet in width. Thirty beaked triremes and quadriremes were engaged in this fight. Besides the rowers, 3000 men fought on these fleets." (Paragraph 23, Aucyrean Inscript).

Its source is a small lake (now called Lago de Martiguano) about 20 miles from Rome. The elevation of this lake is 680 feet, and the water was delivered at about 55 feet above sea level. The water was of a very poor quality and discharged something over two million gallons per day.

VIII. The AQUA CLAUDIA - "But how much more beautiful (than the Nile) it is to see Claudia at Rome, carrying to the baths and domiciles, across the arid summits of the hills (Mt. Aventine) the waters that discharge from its productive channels."

Because of the increasing public needs and the growing demands of private luxury, Caligula began, in 38 A.D., the construction of the two most magnificent of the aqueducts, the Claudia and the Anio Novùs. Upon Caligula's death, the



Remains of the Claudia of the Time of Hadrian remainder of the work was completed by Claudius, his successor, in 52 A.D.

At the time of Frontinus, the sources of the Claudia were four in number, consisting of the two original springs, the fons Caeruleus and the fons Curtius, the nearby fons Albudinus, and, as a supplementary source in time of need, a part of the system of the Marcia known as the Aqua Augusta. Originally the conduit had but a single channel and a clearing tank near Capannelle. In the time of Hadrian, however, a supplementary channel was built in its upper stretches. From the terminal reservoir in the city, the water, which was there mixed with that of the Anio Novus, was distributed through 92 smaller reservoirs to all the fourteen regions of the city.

Despite the time and money spent in its construction, the aqueduct clearly revealed, with the passage of the years, the worthless materials and careless methods too often employed by its builders. It seems to have been in almost constant need of repair, the restoration of Vespasion in 71 A.D. being followed ten years later by another restoration by Titus. Fifty years later the aqueduct was again threatened with collapse and was restored, together with several other aqueducts, by the architect-emperor Hadrian. Still another restoration was made in the last great period of building activity in Rome - that of the Severans.

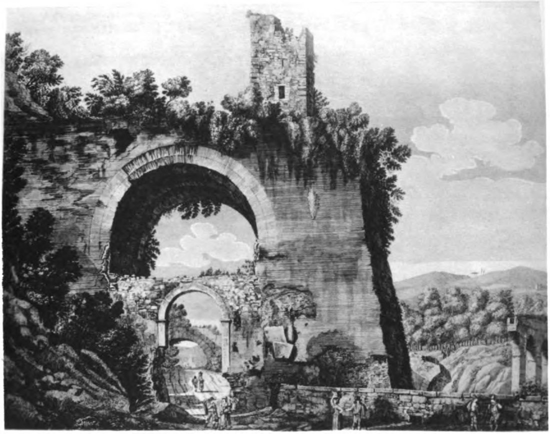
The arches of this aqueduct had clear spans of 18 to 20 feet with thickness at the crown of about 3 feet. The channel was 3.3 feet by 6.6 feet, and it delivered water at the Palatine 185 feet above sea level. The total length of this aqueduct was over 45 miles, with 9½ miles on lofty arches, and about 3000 feet on solid masonry.

IX. ANIO NOVUS - "All previous aqueducts yield in rank to the one commenced by Caligula and finished by Claudius. The waters.....were brought 40 miles to Rome in manner such as to rise up on all the hills of the city. 55,500,000 Sesterces were spent on this work." (Pliny. Nat. Hist. 36, 24).

This aqueduct, together with the Aqua Claudia, belong to the highest type of Roman hydraulic engineering, and were greatly esteemed by the Roman people. The combined cost was nearly $3,000,000, or about $6.00 per lineal foot for the two.

The Anio Novus was 62 miles long, with 9½ miles carried on arches. Some of the arches were as much as 109 feet high. It joined the Aqua Claudia about 3 miles outside Rome from which point both were carried on the same arches. Within the city the two waters were mixed. Its channel was 3.3 feet by 9 feet. The structure was built of brick masonry lined with concrete. Anio Novus discharged nearly seventeen million gallons per day into the city.

Whever Roman colonies were watered vast sums were spent in the construction of aqueducts, such constructions being found at many points in Spain, France, and other countries



The Anio Novus and the Marcia at Ponte degli Arci that were once under the wing of Rome. It is estimated that the remains of 200 or more of these aqueducts are still extant in different parts of the world.

One of the prominent ancient aqueducts is the Pont du Gard at Nimes in the south of France. It is supposed to have been built between the years 31 B.C. and 18 A.D. (by Agrippa?). It has three tiers of arches with a single channel on top. The greatest height above the river Gardon is nearly 180 feet and its length along the second tier of arches is 885 feet. The arches in the lowest tier are 51 feet, 63 feet, and 80.5 feet in span, while the arches in the top tier have a span of 15 feet 9 inches. The thickness from face to face at the top is 11 feet 9 inches, at the middle tier of arches 15 feet, and 20 feet 9 inches at the lower tier of arches. The largest arch has a depth of keystone of 5 feet 3 inches as compared to a keystone depth of 5 feet in the other arches of the lower tier. The depth of ring stone of the upper arches is 2 feet 7 inches. The lower tier is made up of four separate arch-rings placed side by side, the middle tier of three archrings, but the top masonry in the top tier is continuous from face to face. These parallel series of arches in the middle and bottom tiers are in no way bonded or connected with each other. There is no cementing material in any of the arch-rings, but cement mortar was used in rubble masonry around the water channel above the top row or arches. The velocity of flow was about one foot per second.

The aqueduct at Segovia in Spain was built by the Emperor Trojan about A.D. 109. It was built without mortar, and has 109 arches, 30 of them being modern reproduction of the old. It is 2700 feet long and in places nearly 100 feet high. It was still in use at the beginning of the twentieth century. The old Tarragona aqueduct is built with two series of arches, twenty-five in the upper and eleven in the lower. It is 876 feet long and 80 feet in maximum height. At mayence there are ruins of an aqueduct about 16,000 feet long. Near Metz are found the remains of a large old Roman aqueduct with a single row of arches. The aqueduct at Antioch, although of crude construction, had a height of 200 feet and a length of 700 feet. A solid wall, with the exception of two openings, made up its lower portion and a single row of arches extended on top of this to make up the upper portion. Similar ruins are found in Dacia, Africa, and Greece.

The aqueduct of Pyrogos, near Constantinopa, was built not earlier than the tenth century. It consists of two branches at right angles to each other. The greater branch is 670 feet long with a maximum height of 106 feet, the lesser branch is 300 feet long and was built with twelve semicircular arches. At the longer branch there are three tiers of arches, the lowest of Gothic and the two upper of semicircular outline, the length of span increasing from the lowest to the upper tier, thus making the top tier the lightest. The lowest row of piers is reinforced by buttresses.

The thickness varies uniformly from 11 feet at the top to 21 feet at the bottom.

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