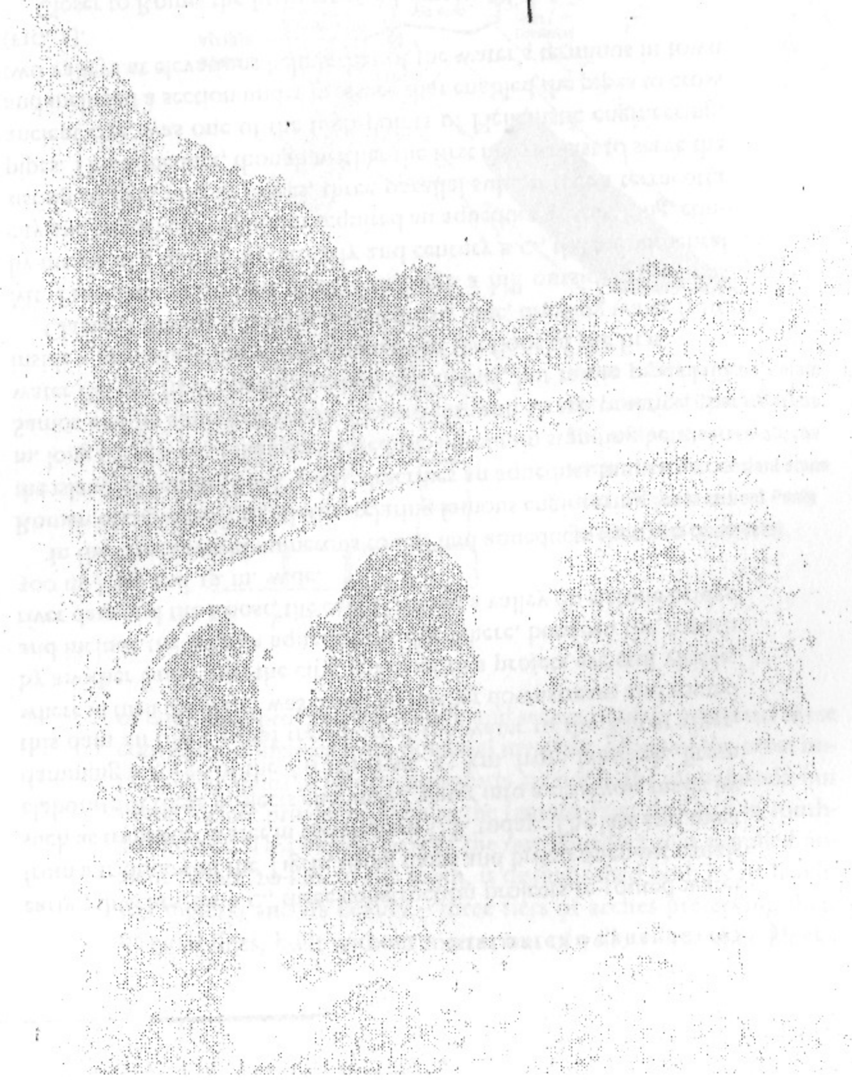
Aicher
Guide to the Aqueducts
of Ancient Rome

PART ONE

The Roman Aqueduct

p 3-21



A. Historical Perspective

Although the Romans took aqueduct building to new heights, they were not the first ancient people to channel water long distances. The Assyrians developed and widely exploited a technique of tunneling that continues to be used today in the Iranian plateau and supplies much of modern Teheran's water. These tunnels, called qanats, roughly 1 1/2 m. wide and 3 m. tall, tap underground aquifers and drain the water out to the side of a hill. Such water could either be used locally, or taken by canal to a further destination (FIG. 1). Vertical well-like shafts connect the qanat with the surface at regular intervals. (For the function of these shafts in both the qanat and Roman aqueduct, see p.12).

The technique of building qanats was spread by the Assyrian ruler Sargon II in the 8th century B.C. His engineers may have learned the art of qanat-building when military campaigns took the Assyrians to the mining regions of Armenia in western Turkey and northern Iran, where qanat-like techniques were used both in mining the ore and in draining water away from mines. The qanat later supplied the ancient cities of the Medes and Persians with water, and the technique subsequently spread not only historically into present times, but geographically through North Africa to Spain and from Spain to the Americas. Two aqueducts of Rome, the Appia and the Virgo, bear a resemblance to the qanat construction: they tap underground streams or aquifers and lead the water to a hillside exit by means of a tunnel, which is connected to the surface at regular intervals with vertical shafts. These Roman projects, however, had their model in Etruscan techniques of drainage, such as can be found in valleys near ancient Veii.

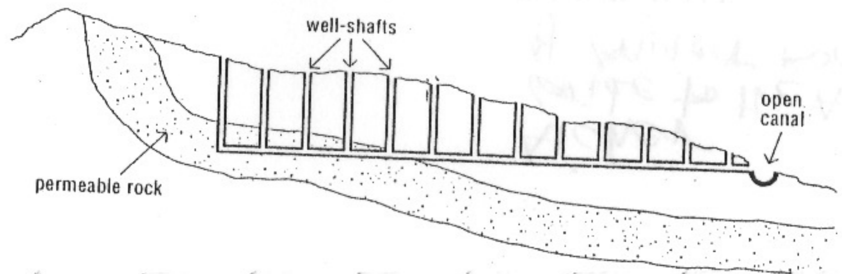
A different system supplied the Assyrian capital of Nineveh (on the Tigris, about 300 kms. upstream of Baghdad). In the late 8th and early 7th centuries B.C., three construction projects re-routed water from a tributary of the Tigris, using dams and broad open-air canals such as transport water in the western U.S. today. The last and most elaborate of these projects channeled water into a reservoir made by damming a gorge of the Atrush river, 55 km. from Nineveh. From this dam an older canal transported the water to the Khosr river, where in turn the water was dammed further downstream and routed by another canal into the city. Ruins of this project are still visible, and include the Jerwan aqueduct bridge where, between the Atrush river dam and the Khosr, the canal crossed a valley on a stone bridge 300 m. long and 12 m. wide.

In the Greek world numerous towns had aqueducts that pre-date Roman occupation. Herodotus, relating famous engineering feats on the island of Samos (Book 3.60), describes an aqueduct tunnel 1,100 m. long (c. 530 B.C.) that perforated the mountain standing between Samos and its source of water. Consistent with Greek practice, the water did not flow openly through this tunnel, but ran in pipes laid inside a secondary tunnel cut down from the floor of the first.

Classical Athens had several aqueducts. One, drawing water from Mt. Pentelicus, also had to pass through a hill outside of Athens by means of a tunnel. In the early 2nd century B.C., the monumental city and citadel of Pergamum acquired an aqueduct 42 km. long, consisting of two, and at places, three parallel subterranean terracotta pipes. This aqueduct, though neither the first nor the last to serve the ancient city, was one of the high-points of Hellenistic engineering, and included a section under pressure that enabled the pipes to cross two valleys at elevations below that of the water's terminus in town (FIG. 2).

Closer to Rome, the Etruscans had developed techniques of land-drainage and water-supply which involved tunneling through the soft volcanic rock of the region. Etruscan kings are also credited with Rome's first notable hydraulic project. At the beginning of the 6th

Figure 1. Cut-away of a qanat.



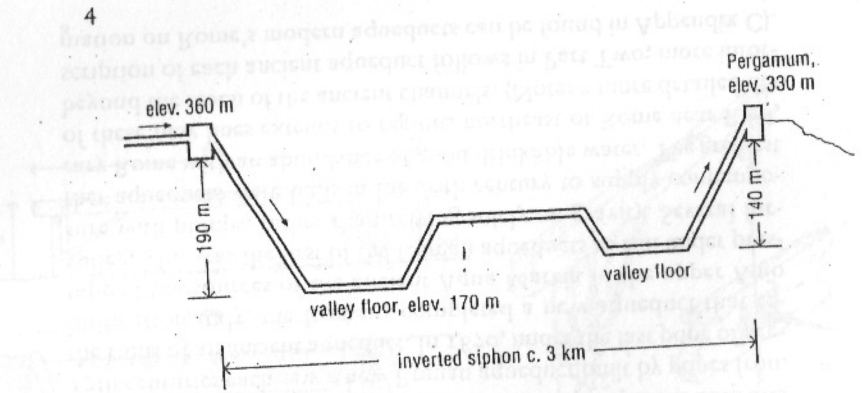
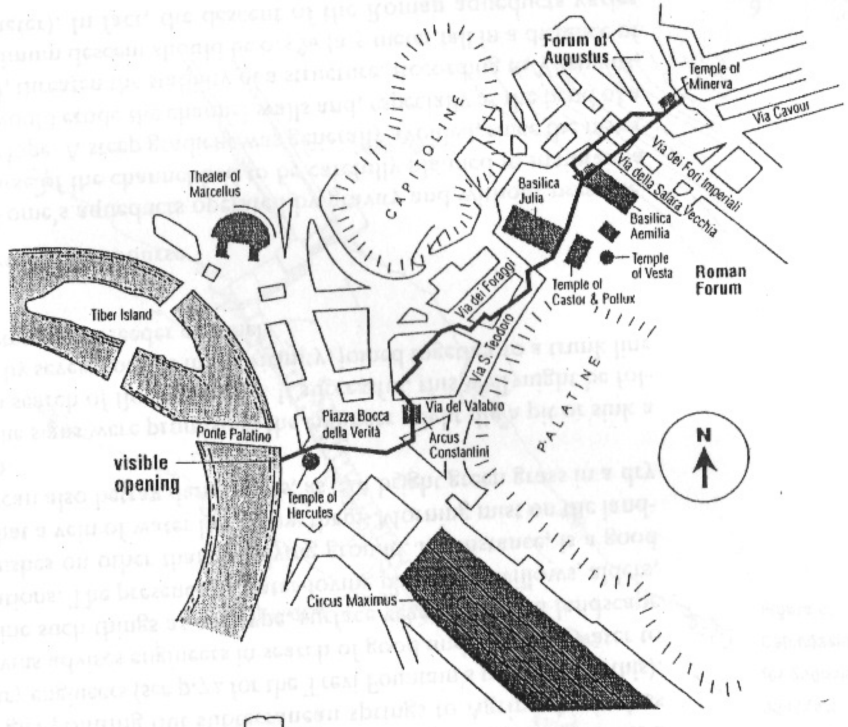


Figure 2. Hellenistic siphon at Pergamum (after Landels).

century B.C., in the reign of the Etruscan king Tarquinius Priscus, the Romans drained low-lying areas in Rome with a system of canals. The trunk-line, running from the Subura through the middle of what, subsequent to the drainage, became the Forum, was called the Cloaca Maxima, "the Main Sewer" (FIG. 3). This drain, which collected water from a larger network of feeder drains, was vaulted over in the 2nd century B.C., and this same sturdy channel of cut stone still carries run-off water to the Tiber today. The mouth of the tunnel is visible in the left bank of the river just downstream of Tiber Island and Ponte Palatino, where the travertine embankment is interrupted for a space to accommodate the effluence of the ancient canal. Rome's sewer system was the hidden half of the city's famous water system, and some ancient writers with good noses and an appreciation of hygiene equated the drainage system with the aqueducts and the famous roads of Rome as the most impressive accomplishments of the imperial city (Strabo, *Geog.* 5.3.8. Cassiodorus, with fulsome praise for the sewers of the capital, testifies to their continued upkeep under the Gothic king Theodoric in the 6th century A.D.: *Var.* 3.30). The aqueducts were valued not only because they provided water for sustenance, recreation, and adornment, but also because they continuously flushed refuse from the city into the Tiber.

The earliest aqueducts of Rome were primarily the underground channels similar in construction to the drainage techniques of the Etruscans. As Roman power spread, so did the construction of aqueducts, which became quite common throughout Italy and in towns from England to Africa. In the lands where Rome's power, in Virgilian formula, kept the peace and suppressed local warfare, aqueducts began to include the sizeable arcades that attract the most attention today. Not only did Roman economy and society (the system of patronage and the love of baths) encourage the undertaking



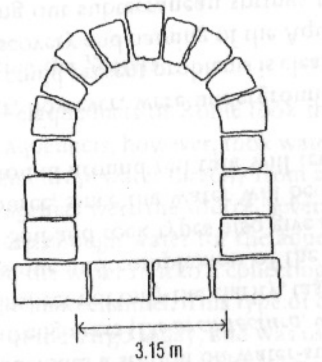


Figure 3. Ancient Rome's main sewer line, the Cloaca Maxima. Still used for street run-off, the sewer's terminus, ancient stone intact, can be seen from Ponte Palatino (after Lamprecht).

of large civic projects, but distant and secure borders protected these conspicuous lifelines from potential invaders. Many of the most impressive remains of Roman aqueducts are not in the capital itself, but in the former provinces, such as the famous Pont du Gard in southern France. This bridge, part of the one aqueduct that supplied ancient Nîmes 20 km. to the south, is distinguished both by its height (49 meters) and its beauty – three tiers of arches preserving their original lines, built without mortar out of yellow limestone blocks quarried locally. Another Roman aqueduct bridge of architectural distinction, almost as high as the Pont du Gard, can be found in central Spain near Madrid. Here in downtown Segovia some of the city's water is still carried on a structure that dates back to the reign of Claudius, 800 m. of tall narrow arches built from gray granite blocks without mortar. In the Roman province of lower Germany, an aqueduct 90 km. long supplied the colony of Cologne, and Carthage under Roman rule was served by an Antonine aqueduct of over 100 km.

The uniqueness of the city of Rome with regard to aqueducts lay primarily in the size and complexity of the hydraulic system as a whole. The renown of these urban aqueducts is also due in part to the existence of a detailed report on Rome's water system left by Frontinus, a Roman senator appointed the city's water commissioner in A.D. 97. Rome acquired its first aqueduct in 312 B.C., before which time the inhabitants managed with water from wells, cisterns, and the Tiber River. During the next 500 years ten more aqueducts were built and linked to an increasingly extensive network of distribution. The eleventh and last ancient aqueduct was built by A.D. 226. Altogether, the length of the aqueducts was over 450 km., less than 70 km. of which, however, were carried above ground on arches.

Even before the eleventh aqueduct was built, the fortunes and the population of the city were declining, making further construction neither necessary nor feasible; the existing channels, however, were periodically renovated. In a siege of Rome in A.D. 537, the Ostrogoths cut the waterlines supplying the city (see on-site description, p.90), but the victorious imperial forces under Belisarius quickly repaired them, and several continued to function into at least the tenth century. Only the Aqua Virgo stayed in use throughout the Middle Ages, and continued, though in diminished capacity, to supply a city that had shrunk from a million inhabitants in Augustus' day to 25,000 people by the 14th century. The more prosperous 16th and 17th centuries each saw a new Roman aqueduct built by popes from the ruins of an ancient aqueduct. In 1870, under the last pope of pre-unification Italy, the Romans completed a new aqueduct that re-tapped the sources of the ancient Aqua Marcia in the upper Anio valley. This was the first of the Roman aqueducts to run under pressure with pumps, rather than relying solely on gravity. Several further aqueducts were built in the 20th century to supply contemporary Rome with an abundance of good drinkable water. The greatest of these new lines extends to regions northeast of Rome near Rieti, beyond the reach of the ancient channels. (Note: a more detailed description of each ancient aqueduct follows in Part Two; more information on Rome's modern aqueducts can be found in Appendix C).

B. Parts of the Ancient Aqueduct

1. Locating the Source

The source of wholesome, plenteous and constant water was not always obvious, and the search for it developed into something of a science. Where the source of the water was apparent (open springs, streams, lakes), the engineer simply had to determine its quality. Vitruvius, who includes a section on water-supply in his handbook for architects and engineers (*De architectura,* written c. 30 B.C.), tells the engineer to inspect not only the clarity, taste and flow of the water but the physique and complexion of the locals who regularly drink it (8.1.1). Soil and rock types also give clues: clay soil is generally a poor source, since the water will be scarce and unsavory, whereas water found around red tufa will tend to be copious and pure.

Many springs, however, were underground and had first to be found. That this could present problems is clear from one of the stories about the discovery and naming of the Aqua Virgo, which has a local girl pointing out subterranean springs to Agrippa's clueless military engineers (see p.72 for the Trevi Fountain's portrayal of this). Vitruvius advises engineers in search of good underground water to examine such things as soil type, surface vegetation, and landscape formations. The presence of water-loving plants like willows, alders, and rushes on other than low-lying ground, for instance, is a good sign that a vein of water lies below them. Morning mist on the landscape can also betray damp spots, as can bright green grass in a dry season.

If the signs were promising, the engineer might dig a pit or sink a well in search of flowing water. If successful, this well might be followed by several others in the vicinity, joined together to a trunk line by subterranean feeder channels.

2. Surveying the Course

Since Rome's aqueducts operated by gravity and without pressure, the course of the channel had to be carefully planned to maintain a steady slope. A steep gradient was generally avoided, since the faster water would erode the channel walls and, especially at the bend of a channel, threaten the stability of a structure. According to Vitruvius, the minimum descent should be 0.5% (a 5 meter fall in a distance of 1 kilometer). In fact, the descent of the Roman aqueducts varies

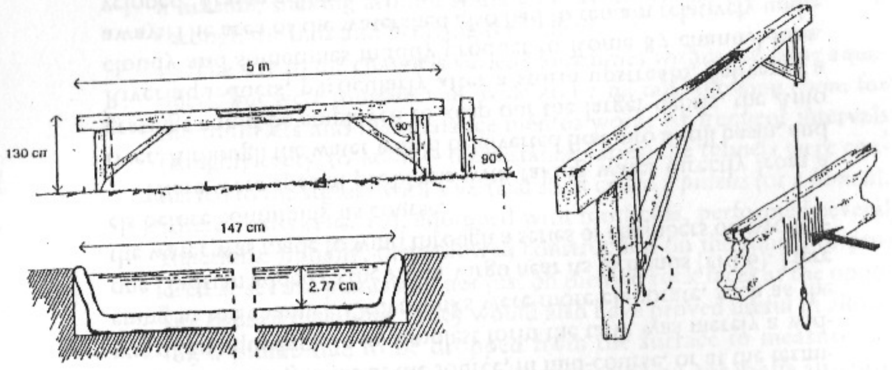


Figure 4. The chorobates (after Pace).

greatly, even within the course of the same aqueduct, and many gradients have been documented both above and below Vitruvius' figure. The average gradient usually lay between 0.15% and 0.3%, with the aqueducts of the capital averaging closer to the steeper descent. The smallest declination has been found in the Nimes aqueduct, in the underground stretch just downstream of the Pont du Gard bridge, where the channel drops on the average only 7 mm. every 100 m. This, though a fine piece of engineering, comes perilously close to being level, and must have reduced the speed and hence the volume of water reaching Nimes. Such a gradual descent, however, was demanded by the small drop in elevation between the Pont du Gard and Nimes.

The Roman engineer had several surveying instruments available to him which had been developed by the Greeks. Vitruvius recommends the *chorobates* as the most accurate (FIG. 4). This is a long builder's level consisting of a horizontal beam 6 m. long supported by legs and cross-braces. Water placed in a trough cut in the top of the beam formed the level; the surveyor then adjusted the beam to this level, and could project a horizontal line to a marker placed in the distance. Alternately, if there was not a wind, plumb lines could be checked against markings on the braces. In tunnels, where the *chorobates* would be impractical, a simple water-level might be used. Since the tunnels were connected to the surface with vertical shafts at frequent intervals, it was generally not difficult to keep the tunnel straight (for an exception, see below under "Tunnels"). The line of the shafts could be laid out straight with the aid of markers on the surface, and then a plumb line could both measure the tunnel's depth below the surface and ensure that the shaft descended vertically.

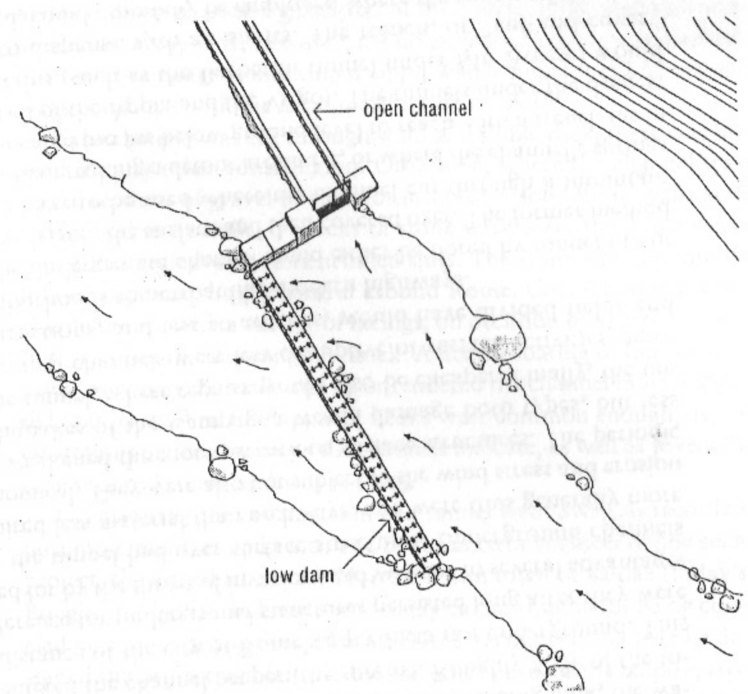


Figure 5. Catchbasin for Segovia aqueduct

3. Collecting the Waters

Most of the aqueducts of Rome took their water from springs. The two Anio aqueducts, however, took water directly from the river, and the Alsietina drew water directly from a lake.

When springs were the source, several feeder branches were necessary to tap enough water for the aqueduct. These feeder branches would lead the water first to a collecting basin, where the water then entered the main channel. This type of collection system still gathers the water of the Virgo today, and was used as well for the ancient and modern Marcia aqueducts. The numerous spring houses covering today's sources of the Marcia Pia are visible at Rosoline Springs, downstream from Subiaco (see p.159). Nothing has survived of the collecting basins for the Anio River aqueducts, but they had to be sophisticated enough to control the intake when the river flooded, since the aqueducts were not designed to run full or especially fast. Repairs and maintenance of the channel would also require a convenient way to shut off the water. On a smaller scale than the Anio aqueducts, there is an old Roman catchbasin on a stream above Segovia, renovated but still functioning in its ancient form, that illustrates one of the techniques for taking water from a stream (FIG. 5).

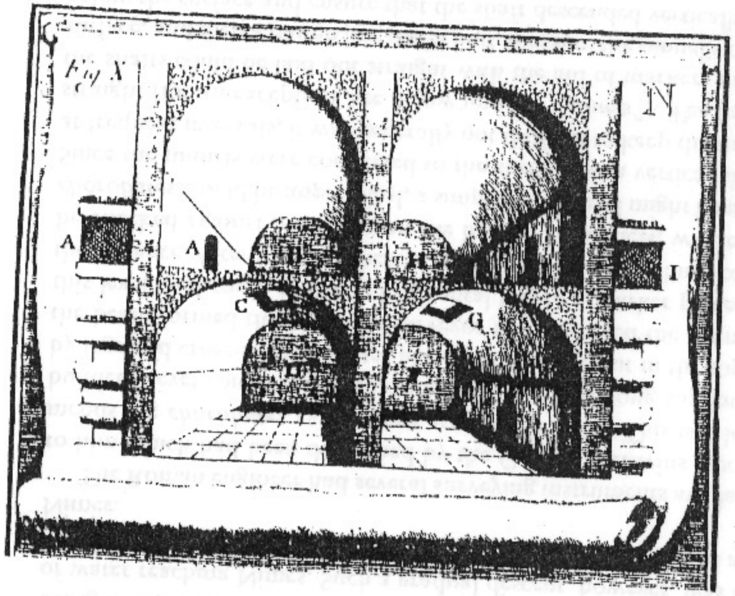


Figure 6. The *piscina limaria* (settling tank) of the Aqua Virgo (by Poleni). This used to lie against the Pincian hill near the entrance today of the Piazza di Spagna subway stop.

4. Water Treatment

The sizeable impurities borne by the water could be removed by a settling-tank (*piscina limaria)* anywhere along the line. This tank's basic purpose was to slow the flow of water so that the load of sand and rock carried along by the current would drop out of the water and collect at the bottom of the tank. Periodically the water of the aqueduct would be shut off or diverted to allow a crew to shovel out the sediments. There was no consistent location for these tanks, which in some instances were dispensed with altogether. There is evidence for settling tanks at the source, in mid-course, or at the terminus of an aqueduct. In its simplest form the tank was merely a widening in the channel. Other tanks were more elaborate, such as the one Hadrian added to the Aqua Virgo near its terminus (FIG.6). Here the water was made to wind through a series of chambers on two levels before continuing its course.

There were special problems with taking water directly from a river. Although the water would be diverted first into a still basin, and gratings could be employed to keep out the larger debris, the Anio River aqueducts, particularly after a storm upstream, delivered a cloudy and sometimes muddy product to Rome 87 channel-kms. away. The area of the watershed also had to remain relatively undeveloped. Trajan addressed both of these pollution problems when he

moved the source of the Anio Novus upstream to a pre-existing dam above Subiaco (See p.163). The watershed here was more pristine, and the artificial lake behind Nero's dam functioned as a giant settling tank.

Also contributing to the purity of Roman water was the aeration it underwent in its course and at some of the fountains in the city, where something similar to the "cascade aeration" of modern systems would have occurred. Although there is no evidence that the Romans knew that the water's exposure to air improved its quality, enabling it to breathe off odors and precipitate some of its minerals, the Roman practice of transporting water in large unfilled conduits also allowed more exposure to the air than the common Greek practice of enclosing the water in smaller pipes (though in general these pipes did not run full). Even in the underground sections frequent vertical shafts, though built for other reasons discussed in the next section, exposed the running water to fresh air.

5. Tunnels and Trenches

Leaving the collecting basin and the (optional) settling tank, the water entered the channel proper (the *specus*). Roughly 80% of the total distance of the city of Rome's aqueducts ran underground. This preference for underground structures persisted long after they were called for by the threat of invasion, and was due to several advantages that the tunnel had over surface structures. Underground channels required less material than archways, and were thus generally more economical. They were also not subject to the wind stress and erosion that weakened the more precarious surface structures. The periodic earthquakes of the Campagna would damage both types, but less so the tunnel, where repairs would also be cheaper. Finally, the underground channels were less disruptive of surface activities, since substructions, and less so arcades, would have divided fields and neighborhoods somewhat like modern highways.

The underground channel could either be bored by tunnel or cut by trench from the surface and then covered over. The former method would have to be used where the channel cut through a mountain rather than making a detour around it, or where the channel's springs were located too far below ground level to reach with a trench (as in the cases of the Appia and the Virgo). The tunnels under the deepest mountains (such as the Barberini tunnel under Mt. Arcese) would have to dispense with air-shafts. The trench, or "cut-and-cover" method, could especially be employed where the course of the channel followed along a river bed, or approximated a contour line on a hillside, snaking around spurs and ravines rather than tunneling through the hills and bridging the valleys.

The size of the channels varied (sometimes within the same aqueduct), but were roughly 1 m. wide and 2 m. tall, allowing room for the tunnelers and maintenance men to work. At frequent intervals (roughly every 30-60 m. – the distance varies) the tunnels were connected to the surface with a vertical shaft called a *puteus* (or a *lumen*). These shafts (FIG. 27), equipped with footholds, performed several functions. Initially, they allowed construction on the tunnel to proceed at several points and not just on the two rock faces at the opposite ends of the tunnel. They would also have proved useful in allowing a plumb line to be dropped from the surface to measure the tunnel's descent. Once the aqueduct was running, the shafts also provided for air circulation, and for access during maintenance. Many of the shafts to the aqueducts have collapsed over the centuries, but others remain hidden in the underbrush. Some can still be seen at Ponte S. Gregorio and near Ponte Amato on the Via Prenestina (p.126 and p.115). Originally the holes were covered with lids of stone or wood.

The entire channel, whether above or below ground, was subject to the incrustations of minerals, which would gradually choke the channel if not periodically removed. This eventually happened during the long and gradual decline of Rome's aqueducts, several of which ran well into the Middle Ages. Distilled like accretions in caves, this deposit of calcium carbonate, sometimes called "sinter" after the German name for it, accumulated at the rate of about one-half foot a century. The water from the upper Anio region is especially rich in this mineral, having trickled down and percolated through the limestone rock of Mt. Autore. After being chipped away from the channel walls and floor, these calcareous deposits were hauled to the surface through the shafts used in constructing the channel. It was piles of these mineral deposits on the surface that allowed archaeologists

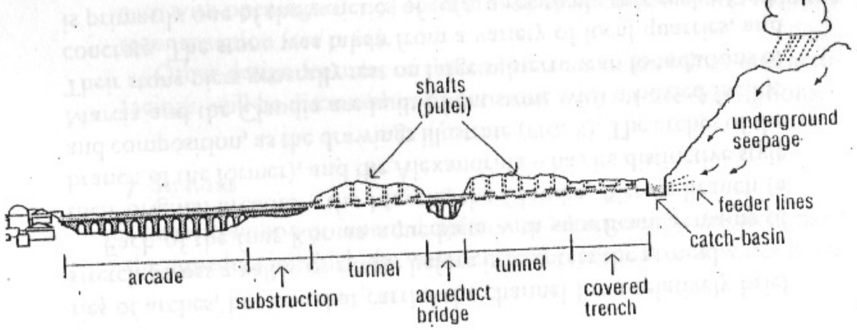


Figure 7. Schematic drawing of ancient Roman aqueduct.

in this century to trace a good part of the course of the underground aqueducts. Originally, however, the underground course was marked out with boundary stones called *cippi*, which sometimes but not always coincided with the location of a vertical shaft.

If the channel was cut through solid and stable rock, there was no need for any other construction. Otherwise, where the channel traversed sections of gravel or clay, for instance, a solid floor, walls and ceiling had to be built. If blocks of stone were used, the joints were sometimes sealed with cement-filled slots. The stone was commonly tufa or peperino, both plentiful around Rome. Concrete walls were also common, with a variety of facings, on occasion *opus reticulatum* (FIG. 11), but more commonly brick. A liberal coating of fine mortar (*opus signinum*) on walls and floor rendered the channel more watertight, at least when first applied. Leaks were common enough, as incrustations on the outside of the channels indicate, as well as Juvenal's reference to leaking archways (3.11).

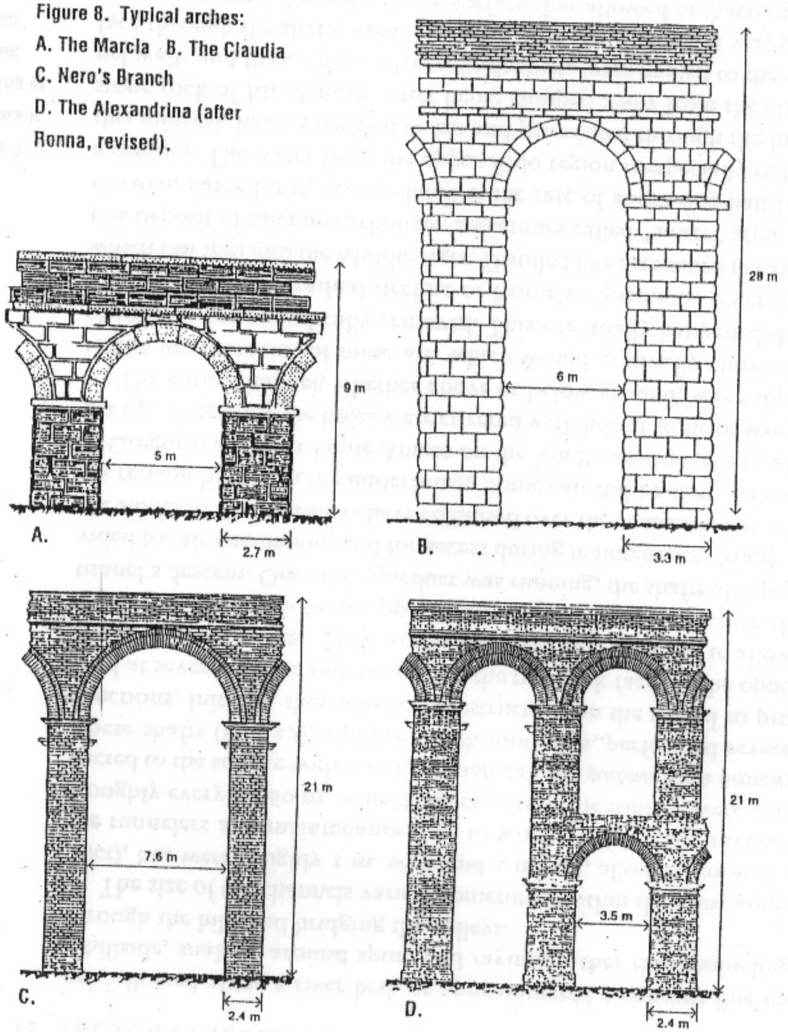
Occasionally the construction of a tunnel went awry, as recorded on a monument set up in A.D. 152 by the ancient engineer of one such project, the aqueduct for the North African town of Saldae (today's Bougie, in Algeria). In Latin surprisingly circumstantial for being chiseled on stone, the engineer, Nonius Datus, recounts how, after he designed the project and left the site for other parts of the empire, two crews began digging at the opposite sides of a mountain. However, they swerved off the course he set for them, a problem noted when the crews had not met up after the combined distance of their tunnels exceeded the width of the mountain. The emperor summoned Nonius Datus back to the town to correct the problem. On his journey back to Saldae, he was robbed, badly beaten, and stripped of his clothes by highway brigands, but he eventually arrived and was able to direct the two crews to a successful rendezvous in the heart of the mountain. (For the inscription, see *CIL* 8.2728.)

6. Substructions, Arcades & Aqueduct Bridges (FIG. 7)

When a valley or depression forced the engineer to abandon tunnels and trenches for elevated sections of channel, he could support it with either a solid wall (*substructio*) or a series of arches (*arcuationes*, "arcades"). The substruction was chiefly used in leading up to the arcade, carrying the channel where it emerged from the ground to a height of two meters. Anything taller called for arches, which had the advantage of using less material than a solid wall and were less disruptive of drainage and traffic than a wall would be. The aqueduct bridge (a loosely-used English term without a Latin counterpart) is also a series of arches, but one that carries the channel for a relatively brief stretch across a valley or ravine before it re-enters the ground.

Each of the four Roman aqueducts with significant remains of their original arcades – the Marcia, the Claudia, Nero's Branch (a branch of the former), and the Alexandrina – has its distinctive style and composition, as the drawings illustrate (FIG. 8). The arches of the Marcia and the Claudia are built of cut stone with a bossed facing. Their stone piers generally rest on large subterranean foundations of concrete. The stone was taken from a variety of local quarries, and is primarily one of the varieties of tufa, a relatively soft rock of vol-

Figure 8. Typical arches:
A. The Marcia B. The Claudia
C. Nero's Branch
D. The Alexandrina (after Ronna, revised).



canic origin. Sometimes a thin layer of mortar helped give solidity to the structure, and in places a spline of cement or lead might be used to hold stones in line (e.g., in the channel wall of the Aqua Marcia, p.100–1. A groove is cut down the side of a stone, which is placed against another stone with a similar groove, into which cement or lead is then poured.)

The arches of the Neronian arcade and the Alexandrina have concrete cores faced with brick, a construction technique (*opus caementicium*) which grew increasingly popular in imperial Rome, especially after the innovations of Nero's reign. The method of construction for brick-faced concrete structures was as follows (FIG. 9). The bricks themselves were pressed initially in large tile-like squares, which when cut yielded a triangular brick that was thinner and longer than today's brick (FIG. 10). A wooden frame was built as a form for the bricks, which were laid at first as separate parallel walls. The bricks were bonded together with a layer of cement made up of sand and lime. As the exterior walls arose, the interior would be filled with irregular fist-sized rocks (generally tufa) laid loosely in courses and surrounded liberally with cement. (Modern concrete construction differs mainly in the smaller size of the rock it incorporates, which also allows the mix of rock and cement to be poured; in the ancient method, workers laid rock and cement as separate components.)

On occasion the surface of the concrete was given a facing of small cut stones instead of brick. When laid in a net-like pattern, this stone facing is called *opus reticulatum* ("net-work"). The facing is square, but the hidden part of the stone extending into the cement is pyramidal (FIG. 11). Bands of *opus reticulatum* distinguished the otherwise brick-faced exterior walls of the channels of the Anio Novus

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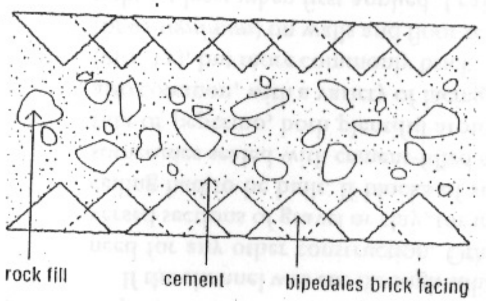

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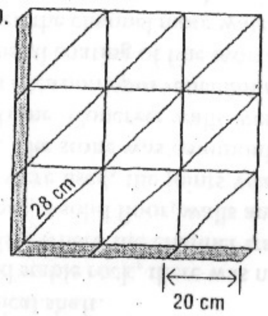

Figure 9. Wall or pier of brick-faced concrete, viewed from above.

Figure 10. Ancient brick-tile. The brick was generally thinner and longer than today's brick, and cut from a large plate of tile.

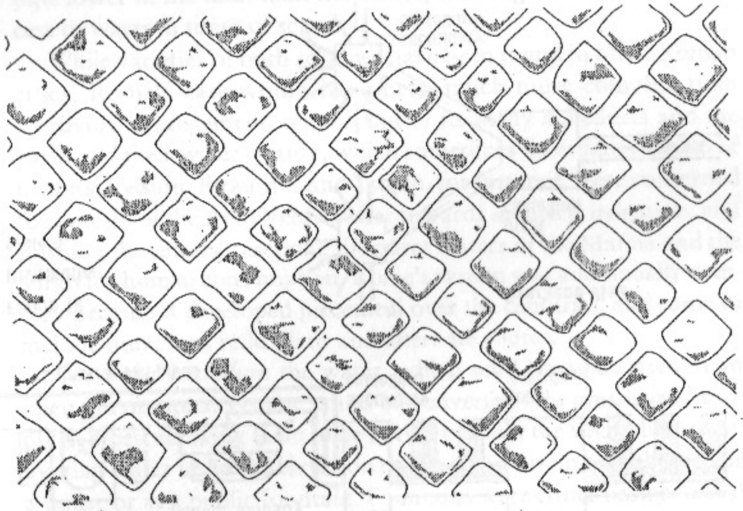

Figure 11. Opus reticulatum.

(p.98) and Traiana (p.78). During Augustus' reign *opus reticulatum* was used in renovations of subterranean sections of the Aqua Virgo (some of them in use today: see Quilici 1968) and repairs on Ponte Lupo (p.121).

The many various types and proportions of brick and cement used in different periods of Roman construction have allowed archaeologists, led in aqueduct studies by Esther Van Deman, to date the numerous renovations of the aqueducts with some precision, generally to the emperor ruling at the time.

The illustrations show that the proportions of the structures differ characteristically as well as the materials, depending on the height of the arch, its load, and the architect's confidence in his material. The Marcia is unique in that the piers of its arches vary in length from 2 to 3.3 meters, depending on the height of the arcade; the span of the arch remains nearly constant at a little over 5 meters. The graceful proportions of the Neronian arches (piers 2.3 meters wide alternate with openings of 7.7) soon proved to be unstable, and required reconstruction (see p.64).

Other design features of the arches, such as moldings and arch-facings, will be discussed in conjunction with on-site descriptions.

7. Siphons

The term siphon or inverted siphon has been given to the sections of the aqueduct in which the water entered pipes that took water down one side of a valley and up the other to an elevation nearly equal to its starting point (by the principle of "communicating vases" rather than by siphoning proper). An alternative to an aqueduct bridge, an inverted siphon was generally used when the valley to be crossed was over 50 m. below the channel level, requiring otherwise a massive and sometimes unstable arcade of numerous stories. The Pont du Gard reaches this maximum height. The Beaunant siphon of the Gier aqueduct serving Lyon, however, had a drop of 123 meters and was 2.6 km. long. On occasion, the siphon would cross the lowest portion of the valley on a bridge, whether to reduce the water pressure that increased with the vertical drop of the pipe, or to form a level and sturdy bed.

In an aqueduct siphon, the water that the channels carry in an open-air gravity system fills a basin and, converted into an airtight pressurized system, descends to the valley floor in pipes (FIG. 2). Forced up the hillside on the opposite side of the valley by the pressure of the water on the descending side, the water fills another basin just below the elevation of the starting basin (the water would find its own original level, but the friction of the pipe crossing would back the water up if the receiving tank were the same elevation as the header tank). From here the water can proceed once again in an open-air unpressurized channel.

The pipes of a siphon were generally made of lead, and usually ran in a series to accommodate the large flow of Roman channels. The Gier aqueduct just mentioned, for instance, converted the channel water into nine pipes laid side by side. The prohibitive factor in building siphons was not primarily a technical one – the lead pipes of the Romans could withstand greater pressures than they were required to – but a matter of economics. Huge quantities of lead were needed to make these pipes, and while lead was in plentiful supply in the empire, it was not always near the aqueduct, and had to be carted at great expense. Stone for bridges, on the other hand, was generally at hand. Soldering the thousands of 10 ft. pipes that went into some of the siphons would also have been a time-consuming job, though it is not clear how they heated up the pipe to take the solder; perhaps portable braziers were positioned beneath the joint. Another disadvantage of the siphon is the accumulation of deposits, which are more difficult to remove from a siphon than from a channel. Nonetheless, siphons were used throughout the empire to great effect. The aqueduct supplying Arles actually crossed underneath the Rhone river with an inverted siphon, and the 50 km. Gier aqueduct employed several siphons in succession.

Although no traces of inverted siphons exist in Rome, it is likely that at least one of them was used in the ancient capital. One may have run between the Quirinal and Capitoline Hills, the latter being one of the termini of the Aqua Marcia. No remains have been found of the massive arcade that would have been needed for the job in place of a siphon. A siphon may also have been used in conjunction with an arcade to deliver water to the Palatine Hill (see p.68). There is no evidence that siphons were employed outside the city in the remainder of the 500 km. system of Rome's aqueducts – a sign, some have thought, that the tradition of engineering in the capital may have been more hide-bound and less experimental than in the provinces. In Pergamum, however, the Romans replaced a Greek-built aqueduct of closed pipes and siphons with a more massively constructed open-channel system, which they clearly preferred throughout the empire, given the option.

8. The Distribution System

Water could be diverted from the main line of the aqueduct anywhere along its route for irrigation or to supply a villa. Frontinus says that 30% of the water was delivered outside the city. The rest of the water arrived in town at a main water tower, in some cases 24 hours after entering the channel at the source. Some towns in the empire

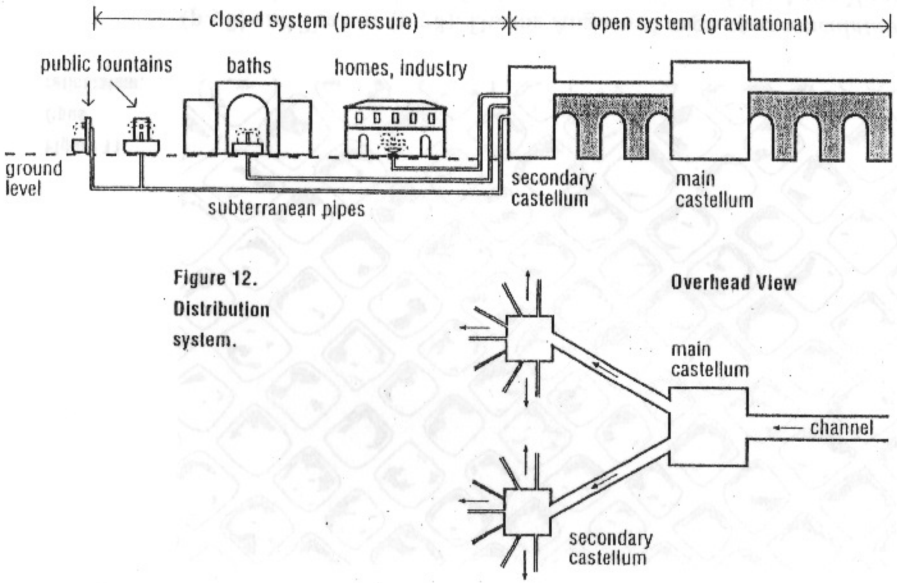

Figure 12. Distribution system.

were furnished with reservoirs or giant cisterns to store the water (such as the Piscina Mirabilis at the end of an aqueduct in Misenum), but water tower or water tank is a better term than reservoir to translate the word *castellum* given by the Romans to these distribution tanks (see p.55). The word is military in origin, and refers to the look of a defense post on a wall, which is sometimes where a water tower was conveniently placed. Juvenal (3.11) and Martial (3.47.1) refer to a dripping Capena Gate (in the Servian Wall at the start of the Via Appia), which may have supported a *castellum* of the Aqua Marcia, known to have crossed the valley near here on its way to the Aventine (Frontinus 5 and 87). The largest of the *castella* no doubt did hold a large volume of water, but their main function was to divide the water while holding it high enough for maximum distribution under pressure. Rome was apparently so well supplied with water of reliable source that large public reservoirs could be dispensed with. In emergencies, the Romans could revert to water from wells, cisterns, and the Tiber.

Little remains of the distribution system in Rome, but statements by Frontinus and Vitruvius as well as the archaeological remains in other cities provide a general picture of how it worked. There would be a main *castellum* at a high point in the general area to receive the water. Some of the aqueducts split into several large branches inside the city, each of them in turn having some such structure at the terminus of the branch. A broad division of the water occurred in the initial *castellum*. From here large conduits led the water to a secondary *castellum*, where the water would be distributed in the smaller pipes that led to the individual users and local fountains (FIG. 12). This mediation of *castella* was necessary to avoid having numerous pipes tap the channel wall itself, thereby weakening it. They were also useful in decreasing the water pressure in areas significantly lower than the primary *castellum*. In Frontinus' time (c. A.D. 100) there were 247 such distribution towers in the city of Rome.

Vitruvius provides a textbook case of how a *castellum* worked. His model divides water to three separate compartments designated for private users, the baths, and the public fountains respectively. His design gives priority to the public fountains, where the majority of the population would go for its daily needs (private plumbing being the exception). Public waters should be derived from the central compartment of the *castellum*; on either side, the compartments for the other two sectors should be designed to overflow into the middle one, so that any excess from these would supplement the public supply. Another scheme to privilege certain consumers is to place the privileged pipe lower in the tank than the others, insuring that it had [illegible] ac-

corroborate his caution, he cites the sickly look of the men who cast the lead-pipes. Lead, nonetheless, was often used. Two factors tended to limit the ill effects of using lead pipes. Although a variety of taps were manufactured which could stop the flow of water, they were not widely used, and the water therefore seldom rested in pipes, which is when it would gather lead particles in harmful concentration. Secondly, the minerals in Rome's hard waters soon coated not only the channels but the pipes as well with a deposit that kept the water from contact with the lead. Recently a theory that lead-poisoning (whether from pipes, utensils, or a lead-additive found in some of the cheaper wines) led to the decline of Rome's ruling class gained some publicity, but is refuted by the features just mentioned, and by the general aristocratic tendency to avoid cheap wine.

Lead pipes came in about ten standard sizes, ranging from an internal diameter of about 1.3 cm (.5 in.) to 57.4 cm. (22.6 in.). They were made by pouring molten lead into a trough 10 Roman-ft. long (3 m.) with a base of sand or stone. The thickness of the sheet could be varied, as could its width. Inscriptions were added to many of the pipes by pressing letters into the sand mold, or by securing movable type to the stone mold. When cool, the sheet was bent around a log-like mold. The opposites sides were then overlapped or folded together, and the tube thus created soldered with a lead-tin alloy along its length. Clay pipes were made on a potter's wheel, limiting their length to little over a meter. They were tapered at one end, which Vitruvius recommends should be coated with a putty-like mixture of quicklime and oil to seal the joint. The Greeks had developed clay pipes with a more elaborate joint, but the Romans preferred a simpler model, which required less skilled labor to manufacture and thus allowed for mass production.

Though water in an ancient Roman city generally flowed without the restraint of taps, they were used on occasion, both for re-routing water and at the end of a line. The type of tap in use was a simple rotary plug with a hole through it. A turn of 90 degrees would align the hole with the pipe and allow water to pass through the plug. The main problem was that the plug was not fastened down to its housing and so could burst upward under pressure.

9. The Drainage System

Rome's drainage system rivaled its aqueducts in attracting ancient praise. Originally the city had a reputation in the ancient world for the foul smell caused by poor drainage. Over the centuries the Romans connected an elaborate artificial network of drains to the larger natural watercourses, which they eventually transformed into subterranean canals (FIG. 3). The same system served for both rainwater and waste, the former useful in washing away the latter. Since rains could be infrequent in this city of a million, the Romans also relied on the water from the aqueducts to wash waste into the river. Some of this swilling water came straight from the *castella* as overflow, water which Frontinus calls *aqua caduca*. In effect, it was water from the pipe or opening placed highest in the distribution tank. This insured that only water unneeded elsewhere was consigned to drainage before serving any other purpose. Most of the water, however, ran through fountains, mills, or baths before being relegated to sanitation, although the constant overflow of local fountains must have been considerable. (In late antiquity we know of public lavatories at the original basilica of St. Peter's flushed by fountain water from a newly refurbished Aqua Traiana). Large latrines were often connected to the public baths, which would have enough water at hand, perhaps used bath-water, to flush them with a constant stream. The free-flow of largely unstopped water of the Roman aqueduct, which suggests a cavalier disregard for the conservation of water and a conspicuous luxury, was thus connected with the sanitation of the city. Day and night the aqueducts delivered their constant volume of water to the hills of Rome, and what was not consumed by the individual went to industry, irrigation, and sanitation, put to some use even when it streamed straight to the Tiber. Some conservation of water may also have been exercised in the filling of cisterns at night, which would increase the flow available at the peak hours of the day.

In the case of some individual dwellings and private establishments, gates built into the wall of a trench along the street could be opened and shut to route flushing water aside under the building; this would occur at regulated intervals each day. Most homes, however, and the apartment buildings had no such arrangement. Some homes and apartments had cesspits, which could be emptied by a manure merchant and carted out of the city to fertilize outlying fields. Apartment dwellers apparently resorted to pots at home, or availed themselves of public latrines on the streets and in the baths. There were other options, as two bits of graffiti in Pompeii testify: *Cacator Cave Malum!* reads one standard sign, and more cleverly: *Cacator sic valeas ut tu hoc locum transeas* (loosely, "may you prosper, by shitting elsewhere"). Critics of ancient urban Rome, such as Lewis Mumford, who paints a crowded, dark, stinking world of high-rise apartments housing most of Rome's population, overlook that life in ancient Rome was primarily lived outdoors, and that many of the private amenities we find at home the ancient Roman could enjoy in the public establishments of the baths. The "squalor" of the crowded apartments and the "luxury" of the spacious baths should thus not be seen as polar opposites but as connected accommodations.

C. Administration

1. Republican Rome

In Republican times (from the building of the Appia in 312 B.C. up to Augustus' rule, c. 30 B.C.) the censors were primarily responsible for Rome's aqueducts, and built three of Rome's four Republican aqueducts (the Appia, the Anio Vetus, and the Tepula; a praetor was in charge of the building of the Marcia). The censors had to contract out (*locatio*) the work required, and to inspect it (*probatio*) once it was finished; this second task might be delegated to an aedile, who also oversaw the distribution of the water in town, and deputized two locals on each street to police their neighborhood fountain. The *cura aquarum* (the administration of the water-supply) also involved the quaestors, in their capacity as treasurers. During the periodic vacancy of the censorship, questions of jurisdiction sometimes fell to a praetor to decide.

2. Imperial Rome

Both Augustus and Agrippa, in accordance with Rome's fabled mission to bring civic amenities to the lands she conquered (there was a spate of aqueduct building throughout the empire under Augustus), devoted a good deal of their considerable energy to improving the physical fabric of the city of Rome as well, and they revolutionized the administration of its water supply. Agrippa acquired the office of the aedileship in part to give his intervention in the water-supply some constitutional precedence. Once out of office he retained his position as the chief supervisor of the aqueducts, in effect becoming Rome's first *curator aquarum*, a new office that the Senate created (or acknowledged) with legislation in 11 B.C. a year after Agrippa's death. Included in the vast amount of wealth Agrippa bequeathed to his emperor was a private crew of 240 slaves that had been employed in the maintenance of the city's aqueducts. Augustus handed these workers over to the state, and the Senate's legislation organized them into a *familia publica* – a slave gang supported by public funds, and under the direction of the curator.

The Emperor Claudius (d. A.D. 54) introduced some reforms that were in line with his general policy of concentrating authority in a civil service under direct imperial control. He created a *procurator* post, to which the emperor appointed imperial freedmen and, after the time of Trajan, an occasional equestrian. Claudius also added another 460 slaves to the previous number of 240 *aquarii* established by Agrippa. The procurator was in charge of this new crew (called the *familia Caesaris*) and controlled the funds designated for their livelihood and other maintenance costs, paid out of the imperial fiscus.

3. The Curator and His Staff

Ashby calls the curatorship of the Roman aqueducts the most prestigious non-political office in ancient Rome. Its holders (listed by Frontinus down to his own day) were generally senators, and held distinguished positions both before and after their term as curator. Frontinus himself held the consulship several times. A curator received many of the honors extended to other high offices of the state, including certain immunities of office and the right to wear the *toga praetexta*.

The curator was appointed by the emperor, in accordance with the Senate's legislation of 11 B.C., and served for an indeterminate period that ranged from a few months to many years. There may also have been times when the post was left unfilled, and other times when two men held the position simultaneously. The qualifications and commitment of the appointed official must also have varied. In his concern to master all aspects of the water supply after his appointment to the post, Frontinus appears to have been an unusually conscientious curator. He would be ashamed, he writes, to rely solely on assistants in a matter that concerned the welfare of millions. Ashby sees a political dimension in Frontinus' diligence on the job, which he attributes to a concern that the responsibilities of the senatorial class remain vital rather than perfunctory; negligence on the curator's part would simply concentrate more power in the imperial court.

The post of curator was never meant to be a full-time occupation. A resolution by the senate as quoted by Frontinus (101) prescribes that the curators devote one-quarter of the year to their public office. Besides being the highest official insuring that the water supply remained as constant as possible in all the public fountains, the curator had to adjudicate over right-of-way disputes and cases of water-law violations.

Besides the curator, there were two *adiutores* (assistants, likewise of the senatorial class), and a personal staff that included record keepers and an architect. To lend him authority for his judgments outside of the city, the senate allowed two lictors to accompany him in the field. The (generally slave) labor of the construction workers (*aquarii*, "water-men") was specialized, and included pipefitters, masons, and line-walkers. Some common routine tasks of maintenance included cleaning out the settling tanks and recoating the channel walls with waterproof cement.

The physical location of the water-office in Rome (the *statio aquarum*), if indeed there was one, is not known. At the end of the second century A.D. the title *curator aquarum et Minuciae* appears, indicating that the same official oversaw both the water-supply and the distribution of free grain; the latter occurred from the Porticus Minucia, which was probably located in the Campus Martius east of the four Republican temples in Largo Argentina. The *statio aquarum* may have stood nearby in between Temple A and B of the four Republican temples at Largo Argentina. Inscriptions from Constantine's reign found in some rooms near the spring and temple of the water-goddess Juturna in the Forum have led some to speculate that the administrative office of the water utility was relocated to the Forum in the 4th century. Bruun, however, in a recent administrative study of the aqueducts, doubts the existence of any special headquarters for the water administration.

4. Regulations and Fines

Reforms legislated in 11 B.C. made the maintenance of the aqueducts easier for the state. A law was passed requiring a clear space of 15 Roman feet (4.5 m.) to be maintained on each side of arcades and substructions, and 5 feet (1.5 m.) on each side of a subterranean channel. This was to ensure ready access to the line, and to avoid damage to the structures from tree roots. Tombs and other edifices were also prohibited from encroaching on this space above conduits, which was to be marked with boundary stones (*cippi*). A second law required that owners of land adjacent to the aqueduct furnish construction materials (such as stone and sand) at a fair price, and that they allow the repair crews a right-of-way to the channel.

A law from Republican times stipulated a stiff fine of 10,000 sesterces for anyone who polluted a public fountain (by bathing, watering animals, washing clothes, etc.). The aediles were responsible for appointing two men on each street as caretakers and watchmen of the fountains. The legislation under Augustus imposed another 10,000 sesterce fine on those who planted trees or shrubs in the clear zone described above; 5,000 of this went into the state coffers, and the other half to the person whose information led to a conviction. More serious imperilment of Rome's water, such as the willful destruction of an aqueduct structure, drew a fine of 100,000 sesterces.

D. Financing

The money for Rome's aqueducts came primarily from war-booty, and from the patronage of wealthy individuals who in many instances had acquired their fortunes from the spoils of war. The sudden income of pillage was ideal to meet the large outlay of money needed for an aqueduct. The state would also gain more gradual income from the taxes imposed on the conquered people as payment for incorporation into a pacified realm of plenty. The city of Rome, as the center of the empire, benefited the most from conquest, and its inhabitants gradually became specialized in their role as the receivers of patronage. They formed a vital part of the equation of Roman glory, comprising the audience required for the great performances of their leaders. Payment for services had no place in this relationship. As a result, the aqueducts and many other services in Rome were never expected to pay for themselves.

Vitruvius' model for an aqueduct has private customers paying for their water, and this was the case in most towns. As mentioned, however, Rome's situation was special. In Republican times, the private use of aqueduct water was not prevalent, and only the overflow water was sold to private users. In Imperial times, with the rapid addition of several new aqueducts, more water became available for private consumers, and much of it was free, available in grants from the Emperor. He would determine the amount (one of the standard *calix* sizes), and send a letter of authorization to the curator, who gave the job of installation to the procurator and his men. The user was responsible for the costs of installation and piping. The grant was only valid for its specific recipient; if he died or sold the property, the water reverted to imperial discretion (though sometimes not before alert *aquarii* surreptitiously sold the water in the interim for their own profit).

Pipe inscriptions reveal that about half of the private users who were granted water belonged to the senatorial class. That these were

precisely the people who could most afford to buy it is a standard feature of Roman patronage.

Some users continued to pay in Imperial times as they had in Republican. Frontinus records a yearly income of 250,000 sesterces from the sale of aqueduct water, but he doesn't identify the paying customers – perhaps industrial users, or the owners of the numerous privately-owned bathhouses.

E. Aqueducts and Baths

The popularity of the large baths or *thermae* in ancient Rome created a great demand for the water to supply them. Many of the baths were huge, costly structures, lavishly appointed with art and engineered with the most advanced technology of the time. Their function for the inhabitants of the city, however, included what we would consider some very basic amenities. They of course contributed to cleanliness and hygiene, and were places of exercise as well. Since most of Rome's inhabitants lived without piped water and toilets, the continuously flushed latrines of the baths may also have been one of their attractions. The nobler faculties of the clientele could also be exercised in the libraries, lecture halls and gardens of the larger baths.

Several of the monumental public baths in Rome required an extension of the aqueduct-system to offset the bath's new demand for water. Agrippa, in keeping with his active interest in other aspects of Rome's water, built the first of the large baths (though it only became public after his death), located in the Campus Martius at the terminus of one of the aqueducts he built, the Aqua Virgo. Together, the bath and the aqueduct did a good deal to urbanize this open area that Augustus had targeted for development. (see p.73)

In A.D. 212 Caracalla added a new spring (the Fons Antoninianus) to the sources of the Aqua Marcia. This was in compensation for the water he diverted from the main line at the urban end to supply the giant new baths (the Thermae Antoninianae, or Baths of Caracalla) that he built on the edge of the city at the beginning of the Appian Way. Remains of this branch aqueduct, called the Aqua Antoniniana, can be seen where it crossed over the Via Appia near the later Aurelian Wall (p.75).

In the next decade Alexander Severus extensively renovated the Baths of Nero located in the area between today's Piazza Navona (the ancient Stadium of Domitian) and the Pantheon. Although Nero had carried out some improvements in the water supply to the Caelian and Aventine Hills, he had made no provisions for extra water to supply his baths in the Campus Martius. Alexander Severus added the last of Rome's ancient aqueducts to the city, the Aqua Alexandrina, which probably replaced the purer waters of the Aqua Virgo as the new supplier of these refurbished baths. Little remains of these baths, and nothing of the urban section of Alexander's aqueduct.

At the end of the 4th century Diocletian carried out further renovations of the Marcia, adding still another source to it with a feeder branch (called the Forma Iovia in late antiquity). This augmentation was probably in conjunction with the construction of the largest of all the Roman baths, the Thermae Diocletianae, in the uncrowded zone of estates northeast of the Forum on the Quirinal Hill. A great deal of Diocletian's Baths can still be seen, but the remains of the Aqua Marcia that supplied it, as well as the large reservoir that stored its water, have been covered over or obliterated by construction in the area (in front of the Termini train station) since the late 1800s.

These and several other public baths were open to the public (including men and women, free and slave) at little or no charge. In this too the people of Rome had an advantage over most of the other cities with baths in the Empire, where the fees were generally more substantial. There were, however, numerous privately-owned public bathhouses in the city which cost money to enter. The fee would range widely, depending on the bathhouse services, its surroundings and its clientele. Some of these private baths could be as lavishly appointed as the imperial *thermae*, with their statues, columns, and plunge pools carved from the colored marbles and granites quarried in the far reaches of the empire. At the other end of the social ladder were baths crowded in with shops on the ground floor of four-story apartment buildings.

A regionary description of Rome compiled about A.D. 400 (the *Curiosum Urbis*) records 856 public baths, not counting the eleven grand *thermae*.

F. Aqueducts in Christian Antiquity

It was more Rome's gradual removal from the centers of imperial power than the empire's conversion to Christianity that had a significant effect on the condition of Rome's water supply. Constantine continued in the long-standing patterns of secular patronage. He built a new bath on the Quirinal and restored the Aqua Virgo and the

Baths of Agrippa. The secular government of the city carried out major repairs to the aqueducts as late as the 6th century, when Belisarius restored several of the aqueducts that had been destroyed in the Gothic siege of Rome. At the end of the 6th century, Pope Gregory the Great refers to a *comes formarum*, indicating that the office of the *curator*, though now called a *comes*, still existed, as did the aqueducts, called, as often in the Middle Ages, *formae*. But by this time there was little money in the city government's coffers, and little arriving in the way of patronage from the Emperor in Constantinople. In the case of the aqueducts, however, unlike other defining institutions of the city such as the games and the temples, the church took up the slack when the tradition of secular patronage ceased, and renovations of the aqueducts continued into the Middle Ages under the Popes.

Pope Hadrian I carried out several restorations of aqueducts in the late 8th century. His restoration of the Aqua Traiana supplied the Trastevere region again, with its watermills on the Janiculum Hill. St. Peter's Basilica was also an important recipient of this water, which, with the fountains, baptismal fonts and the baths that Hadrian built for pilgrims and the poor, played an important role in the religious life of the region. Pope Hadrian likewise restored the Claudia, Nero's Branch of which ran adjacent to the other major center of the Church in Rome at that time, St. John of the Lateran (hence the medieval name for the Neronian Branch, the *Forma Lateranensis*). Besides insuring the supply to these religious centers, Hadrian also renovated the Aqua Virgo for the Campus Martius, as well as the Aqua Marcia.

References to working aqueducts dwindle in the following centuries, and although we have no dates for when any of them decisively ceased to function, it is safe to say that by the beginning of the 2nd millennium most regions of the city were getting their water from wells and streams once more. The Traiana was repaired as late as the 9th century; nothing more is heard of it until Pope Paul V incorporated parts of it into a new 17th century aqueduct. Both the Aqua Claudia and the Anio Novus were out of commission by the 12th century, when an open-air water-ditch, the Marrana Mariana, was built to supply the Lateran region. Like most of Rome's physical ruin, the process of losing both water and sanitation was a gradual one, worked by the agencies of invasion, erosion, earthquake, and sedimentation. Only the Aqua Virgo continued to deliver water throughout the Middle Ages, though it too lost much of its capacity as its collection system of multiple sources deteriorated and its distribution net collapsed.