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Water supply of Rome in antiquity and today

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Abstract In ancient Rome, water was considered a deity to be worshipped and most of all utilized in health and art. The availability of huge water supplies was considered a symbol of opulence and therefore an expression of power. The countryside around Rome offered a spectacular view: it was adorned with an incalculable number of monuments, temples, and villas, and it was crossed by sturdy aqueducts with magnificent arcades. The aqueduct as a superelevated monumental work is a typical concept of the Roman engineering, although it is possible to recognize that the inspiration and the basic ideas came from Etruscan technology. The Etruscans did not construct real aqueducts, even though they built hydraulic works as irrigation channels, drainage systems, dams, etc. The Greeks had also built similar hydraulic structures, before the Roman influence. Interesting aqueduct remains are in Rome, Segovia (Spain), Nimes (France), and Cologne (Germany), among other places.

Key words Water supply · Rome · Antiquity · Present

Ancient water supply of Rome (700 BC–500 AD)

Rome initially used the water from the Tiber River, and wells and many small springs existed inside its town area, such as Acque Lautole, Acque Tulliane, Fonte Giuturna, and Fonte Lupercale. Since the 4th century BC, Rome gradually built aqueducts. The aqueducts conveyed water originating many kilometers away from Rome. Through underground tunnels and huge arched bridges, necessary to keep the slope of the flow, they reached the outskirts of Rome where "water castles" distributed the water for public (baths and fountains) and private uses (Fig. 1). Most aqueducts were located in the area east of Rome, except one located in the north. Water from all eastern aqueducts was collected in the Porta Maggiore area, called by Romans "ad Spem Veterem" (Figs. 2, 3).

The first aqueduct was built in 312 BC. During the subsequent 600 years, ten more aqueducts were built. The last one was completed in the 3rd century AD. With completion of construction, there were Aqua Applia, Anio Vetus, Aqua Marcia, Aqua Tepula, Aqua Julia, Aqua Virgo, Acqua Alsietina, Aqua Claudia, Anio Nowus, Aqua Traiana, and Aqua Alexandriana.

Aqua Applia

No remains are left of the first great Roman aqueduct constructed in 323 BC. It was entirely underground because of the war against the Sannites. Therefore its route is almost unknown. Appius Claudius Crassus (later called Caecus) and Caius Plautius (called Venox) identified the springs. The aqueduct and the coeval consular road were named after Appius and called Applia.

The aqueduct was 16.5 km long, and three main restoration works were carried out by: Quinto Marcio in 144 BC to eliminate unauthorized connections by citizens, Agrippa in 33 BC, and Augusto in 11–4 BC. The latter ordered collection of water from more springs and built a new aqueduct 9.4 km long called the Applia Augusta. The original catchment area has not yet been exactly located. The area is east of Rome, in the northern slope of Albano Volcano near Pantano Borghese, the ancient lake Regillo.

Total discharge recorded by Frontino [Sextus Jiulius Frontinus "curator aquarum," i.e., head of Roman aqueducts or water magistrate, lived at the time of Emperors Domitiano, Nerva, and Traiano. He wrote a fundamental treaty on Roman aqueducts in imperial times to which we often refer ("De Aquaeductu Urbis Romae" 97–103 AD). Quinaria: a Roman discharge unit equal to 41,472 $m^3\ d^{-1}$ ($0.48\ l\ s^{-1}$)] at the main reservoir near Rome (ad Spem Veterem) was 75,686 $m^3\ d^{-1}$ ($876\ l\ s^{-1}$).

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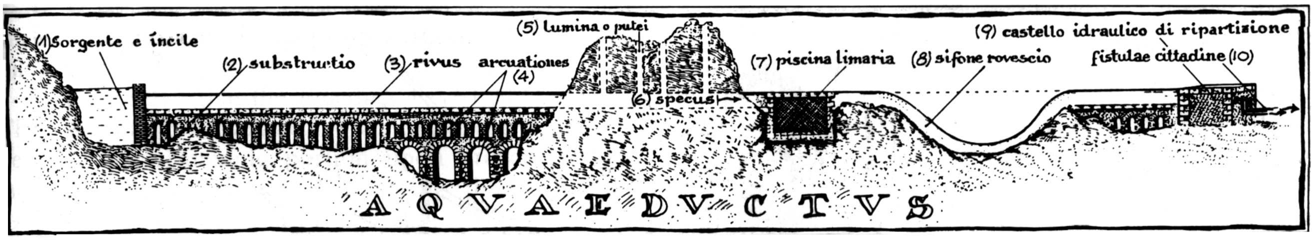


Fig. 1 Section of a Roman aqueduct: (1) spring and inlet; (2) bearing wall; (3) open channel; (4) arcades; (5) shafts; (6) underground channel; (7) settling basin; (8) reverse siphon; (9) main reservoir; (10) water pipes

Anio Vetus

Frontino dates the beginning of work for the Anio Vetus aqueduct to 272 BC. It was built by M. Curio Dentato and L. Papirio Cursore with the plunder obtained from the victory over Pirro (Punic Wars). The springs have not been located but must be karst springs. They were located east of Rome, along the Aniene (Anio) river, not far from Agosta springs collected later in the Anio Novus aqueduct.

The Anio Vetus aqueduct is 64 km long, mainly underground. It has many lumina (shafts), and it develops along the left bank of the Aniene river up to Rome. According to Frontino the aqueduct was restored by Quinto Marcio Re 127 years after its construction, by Menenio Agrippa in 33 BC, and by Augusto, who provided it with mileage stones. The spring discharge was 182,394 $m^3\ d^{-1}$ (2.11 $m^3\ s^{-1}$) according to Frontino.

Fig. 2 Outline of Roman aqueducts near the city (dotted area). Only the 14th district of Rome (Regio XIV) is located along the right bank of Tiber river

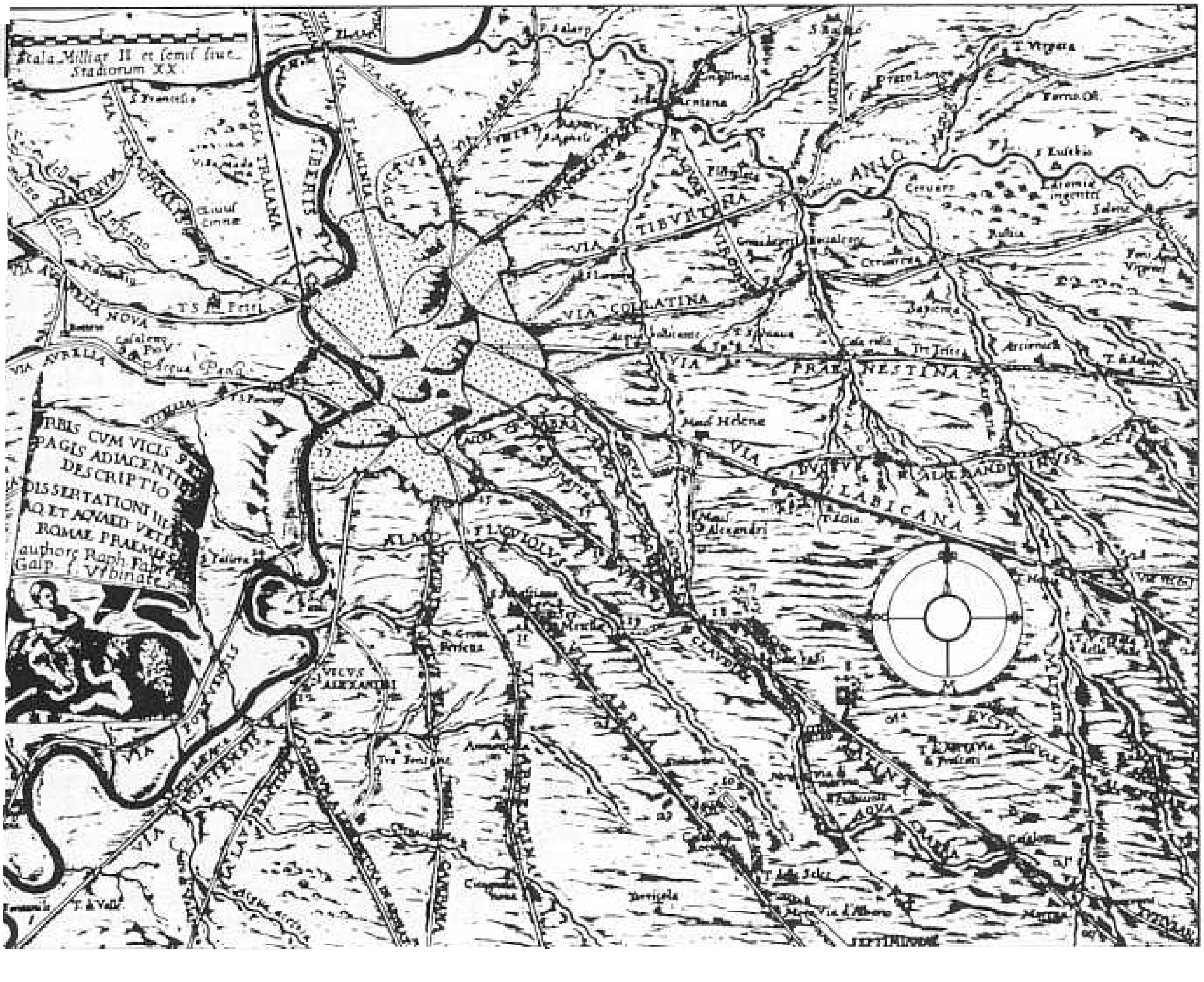


Fig. 3 Urban course of aqueducts and location of terminals in ancient Rome: (1) underground aqueduct; (2) arcade aqueduct; (3) terminal (main town reservoir)

Aqua Marcia

In 144 BC, the Roman Senate charged Praetor Quinto Marcio Re to restore the Anio Vetus and Aqua Appia in order to prevent undue connections by unauthorized citizens. In the meantime the population of Rome had grown and water requirements were constantly increasing. Q. Marcio Re was charged therefore with building a new aqueduct to ensure more water of good quality. The new aqueduct was supplied by karst springs located in the valley of the Aniene river. The quality of its water has been greatly praised by ancient authors such as Plinio the Old for being fresh and healthy.

The aqueduct worked perfectly for over one century. In 33 BC, Agrippa carried out the first of many repair works. In 11–4 BC, Augusto modified the aqueduct structures by collecting more springs, thus doubling the water discharge. In 79 AD Tito and later Adriano and Severi restored and kept the aqueduct working. In 212–213 AD, Caracalla collected new springs (Aqua Antoniniana) to increase the discharge as needed by huge thermal baths. Diocleziano was ordered to collect new karst springs, promoting the renewal of the entire structure of the aqueduct and its terminal part. More restoration work occurred during the time of Arcadio, Onorio, and Popes Adriano I, Sergio II, and Nicola I.

Frontino states that the aqueduct was 91.330 km long. The water was conveyed 80.280 km in underground tunnels and the remaining portion upon arched bridges (aquae pensiles) (Fig. 5). The spring discharge was 194,504 $m^3\ d^{-1}$ (2.25 $m^3\ s^{-1}$) although 30% of it was lost before reaching Rome in part due to unauthorized connections.

Aqua Tepula and Aqua Julia

Consuls C. Servilio Cepione and L. Cassio Longino in 125 BC promoted the catchment of Aqua Tepula. The springs were located in the Albano volcanic area near Marino–Castel Savelli. The quality of the water was poor due to its temperature of 16–17°C according to Frontino. In fact, its name tepula means lukewarm. The water from many small springs was also collected by a subsidiary aqueduct.

In 35 BC, during Agrippa's rule, new springs were identified near Grottaferrata while aqueduct restoration were carried out. Such water resources were mixed with the Aqua Tepula to improve its taste and physical characteristics. There was a piscina limaria (settling basin) downstream for the mixing of the water from the two groups of springs. Water was then channeled in two different pipes, which were underground and at the surface. About 10 km from Rome, the water was conveyed on the Marcia arched bridges.

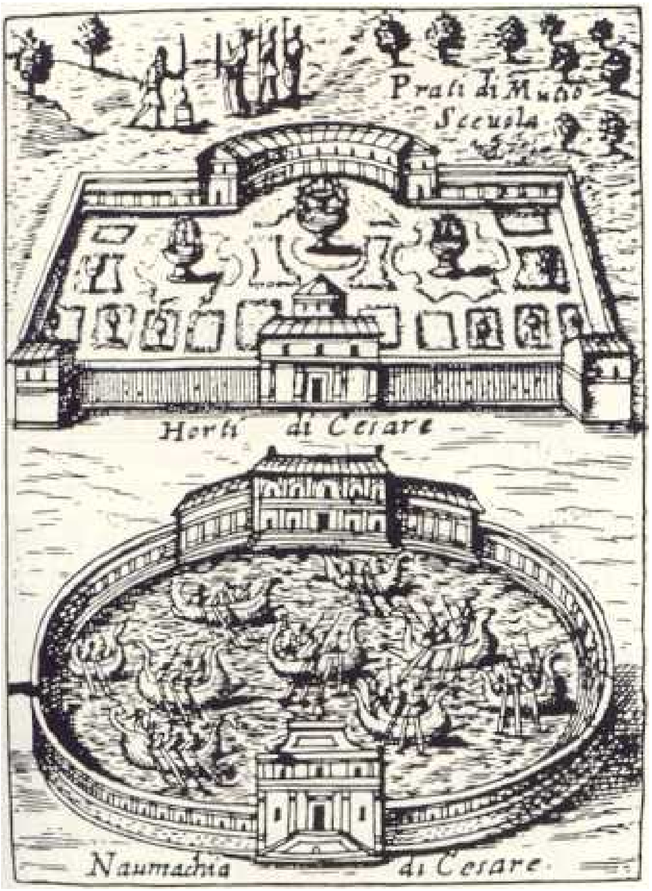


Fig. 4 Emperor Augusto's naumachia (naval battle basin)

The distance of Tepula springs to Porta Maggiore (ad Spem Veterem) was about 17.8 km. Frontino states that Tepula discharge was 7550 $m^3\ d^{-1}$ (87 $l\ s^{-1}$) supplemented *with 10,108* $m^3\ d^{-1}$ *(117* $l\ s^{-1}$*)* drawn from Aqua Marcia and Anio Novus aqueducts. The total discharge of the Julia–Tepula springs at the settling pool was 47,952 $m\ d^{-1}$ (555 $l\ s^{-1}$) according to Frontino. Before reaching Rome, the Julio aqueduct received about 75 $l\ s^{-1}$ from Aqua Claudia.

Aqua Virgo

Frontino and Plinio the Old wrote a story about a young girl (virgo) who showed the location of some springs to Roman soldiers. Therefore the aqueduct was named after her. More probably the name of virgin is due to the purity of the water, which was praised by the poet Marziale. The Virgo aqueduct is the only one that operated from the time of Augusto up to the present. The aqueduct was constructed underground in volcanic rocks. It reached Agrippa's thermal baths, where at present the Trevi and Navona square fountains are located and fed by the Aqua Virgo.

The construction of the aqueduct was ordered by Agrippa and its inauguration took place on 9 June 19 BC. It was mainly supplied by the Salone springs and its discharge was 99,519 $m^3\ d^{-1}$ (1,150 $l\ s^{-1}$) according to Frontino. Along its route lateral drainage tunnels branch off from the main one at lower altitude, adding from the aquifer 210 $l\ s^{-1}$ to the total discharge. The springs were located at the northern border of the Albano volcano, east of Rome, in a marshy area near the Aniene river. Restoration works were carried out during the time of Emperor Tiberio, 36–37 AD; Claudio, 46–47 AD; and Constantino at the beginning of the 4th century. The slope of the tunnel is 4.2 m over a distance of 19 km (0.22%).

Aqua Alsietina

The quality of this water was poor. At the time there was no option to supply the 14th district of the city since that district (Trastevere) is located on the right bank of the Tiber river, opposite the terminal of the major aqueducts of the town. The water was conveyed to Rome in 2 BC mainly to supply the monuments built by Augusto near the Gianicolo. The surplus water was used to supply the imperial and private gardens and Trastevere fountains (Fontino).

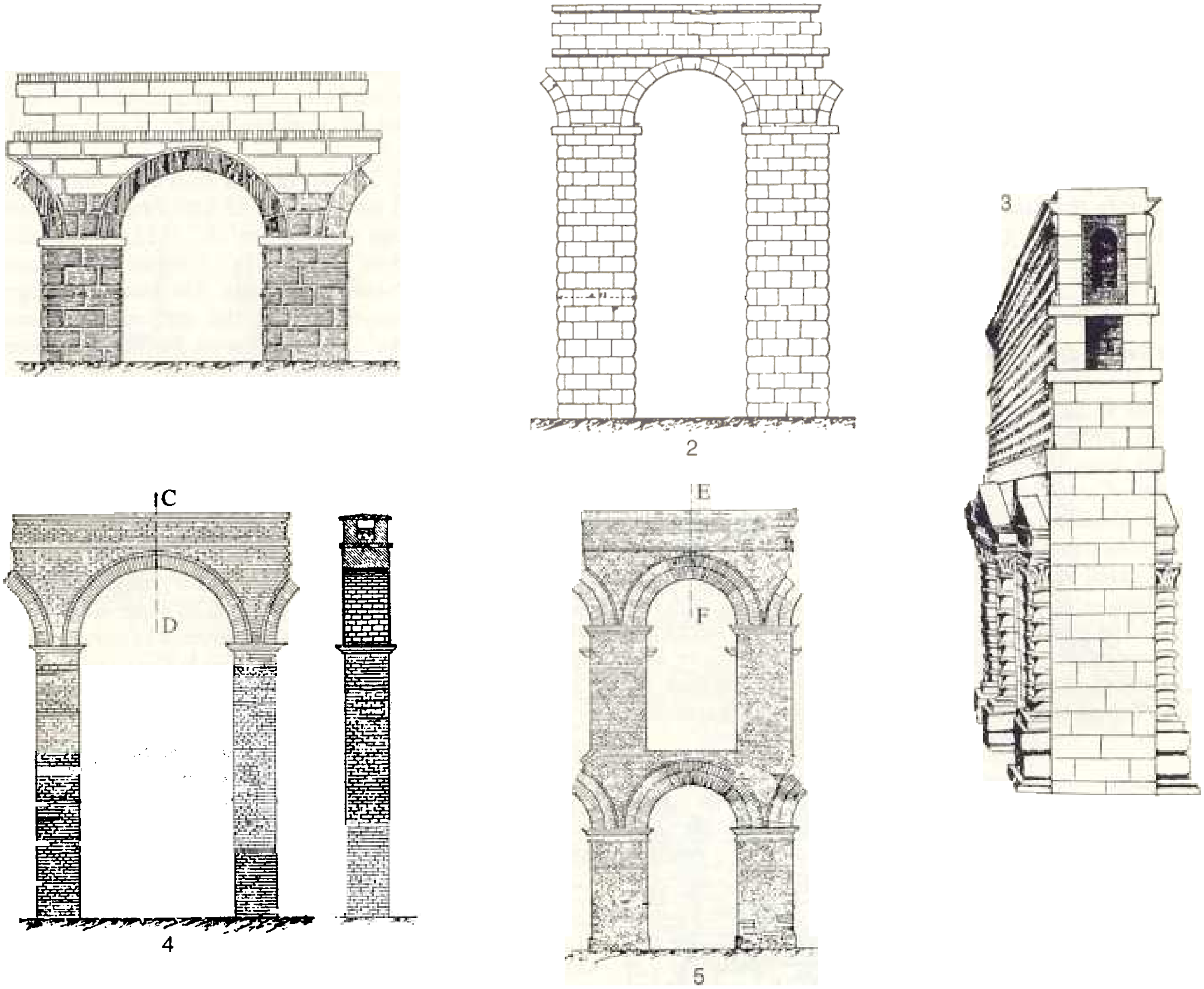


Fig. 5 Roman aqueduct arcades (arcuationes) were first built in volcanic tuff (tophus) or in travertine squared blocks (opus quadratum) (1–3). Later on during the time of Emperor Silla, the technology was improved by means of brick tiles, which were used to curtain the wall (opus latericium) and to strengthen the arches (4 and 5).

Naval battles or shows (naumachia) were performed in a large pool supplied by the Alsietino aqueduct and located in a huge park area where a monumental complex was also built (Fig. 4). The elliptical basin (whose axis were 533 and 355 m long) was 1.5 m deep with a storage capacity of 200,000 m^3 of water.

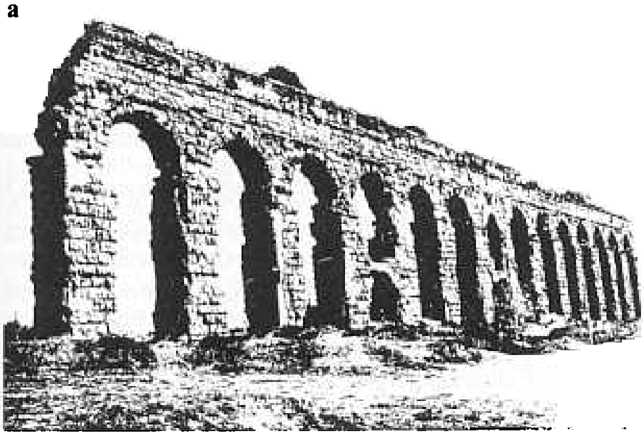
The spring catchment area was located in the volcanic area of the Sabatini Mountains at the border of Martignano lake (Lacus Alsietinus), north of Rome. The water of a lake was diverted by a tunnel at an altitude of 207 m. Probably Augusto ordered that catchment to ensure the regular level of the lake. To keep the discharge of the aqueduct constant (16,257 $m^3\ d^{-1}$), water from Bracciano lake was collected as well (Frontino). The aqueduct was 32,770 km long built mainly as a tunnel through volcanic rocks. The water was conveyed only 529 m on arcades. It underwent great restoration work and structural modification in the time of Traiano (109 AD) and in 18th century during the time of Pope Benedetto XIV.

Aqua Claudia

Caligola started work on two new aqueducts in 38 AD: Aqua Claudia and Anio Novus. Work was ended in 52 AD by Claudio (Fig. 6). Historical writings (Tacito) indicate that in 47 AD, Aqua Claudia was already distributing water in Rome. Anio Novus is supposed to have been finished five years later.

Structural modifications and maintenance work are due to Vespasiano (71 AD), Tito (81 AD), and Domiziano, while several works of consolidation are due to Adriano, Settimio Severo and Diocleziano. During the Gothic War (537 AD), the aqueduct was seriously damaged and thereafter restored during Belisario's time. Pope Adriano I in 776 AD again repaired the aqueduct but its previous discharge had been considerably reduced.

a



b

Fig. 6 **a** Anio Novus aqueduct near Rome, **b** Emperor Claudio's aqueduct near Rome

The springs of Aqua Claudia were all karst springs (fons Caeruleus, fons Curtius, fons Albudinus, Aqua Augusta) located along the right bank of the Aniene river, east of Rome not far from the Marcio aqueduct inlet. Frontino records the spring discharge at the catchment area at 191,190 $m^3\ d^{-1}$ (2213 $l\ s^{-1}$) while at Spem Veterem, in Rome, it was reduced to 1341 $l\ s^{-1}$ due to unauthorized connections existing along the aqueduct. Both Aqua Claudia and Anio Novus reached Porta Maggiore (Rome).

From the main reservoir (castellum aquae), the water from the two aqueducts was distributed to all 14 districts of Rome (called Augusto regions) through 92 subsidiary reservoirs (Frontino). The Aqua Claudia aqueduct was 69.750 km long, of which 54.500 km of tunnels and 15.200 km trough arcades were originally built in tuff (tophus).

Anio Novus

The construction of the Anio Novus aqueduct was started by Caligola in 38 AD and completed by Claudio about 50 AD. Historically, the Anio Novus and Aqua Claudia aqueducts are closely related. Important modifications to both aqueducts were made by Traiano (109 AD), while several maintenance and restoration projects are recorded up to the 4th century.

According to Frontino, Anio Novus was built in opus reticolatum (tuff wall) and opus latericium (brick wall). The catchment area was located near the Aqua Claudia springs along the Aniene river, from which the aqueduct collected part of its natural discharge, mainly represented by karst groundwater. A large settling basin (piscina limaria) was built near the banks of the river since the surface water was muddy during major floods.

In order to improve the resource quality, some springs of Rivus Hercolanus were collected and conveyed to the same aqueduct. In fact, Frontino states that the water quality had the same standard as the celebrated Aqua Marcia. Total discharge of Anio Novus was 196,490 $m^3\ d^{-1}$ (2274 $l\ s^{-1}$); the aqueduct was 86.876 km long, 73 km of which was in tunnels.

Aqua Traiana

The aqueduct was built by Traiano in 109–110 AD in order to supply the 14th district of Rome (Trastevere) with good, drinkable water. Actually the district was previously supplied by the poor-quality water of Aqua Alsientina, being that area located on the right bank of Tiber river opposite the terminal of the main aqueducts of the City. Few data are available about Aqua Traiana because Frontino died and the following civil servants in charge (curatores aquarum) were not so ambitious in registering data concerning new aqueducts.

Many springs were collected to supply the aqueduct. They were scattered in a wide volcanic area north of Bracciano lake, northeast of Rome. Although many of the springs have not yet been located, it is believed that they are those that appear in an 18th century map century showing the aqueduct of Pope Paolo V. The Aqua Traiana aqueduct was 32.500 km long. Most of it was underground and partially on arcades. It supplies mainly the Trastevere area and Traiano baths on Colle Oppio. The aqueduct was partially utilized by Pope Paolo V in 1608 and its name was changed to Aqua Paola.

Aqua Alexandriana

Emperor Alessandro Severo (222–235 AD) decided to build the aqueduct named after him during the last years of his reign. It was the last great aqueduct built in Rome in ancient times. The emperor intended to supply water to the Campo Marzio baths built by Nerone in 6 AD and restored in 227 AD. The catchment area is located in the volcanic area east of Rome near ancient Gabi, not far from Aqua Appia springs. During the Gothic War (537 AD) the aqueduct was destroyed in order to cut the water supply of besieged Romans. In 1585 the springs were collected anew to supply the Felice aqueduct built by Pope Sisto V. The aqueduct was 22 km long, 8 km in tunnels and 14 km on arcades. Repair works are recorded up to 500 AD. The Alexandriana and Vergine aqueducts were kept in use during the Middle Age.

Water potential and use in antiquity

Aqua Virgo and Aqua Traiana-Paola are the aqueducts built during Roman times that are still in use. Total discharge of the ancient aqueducts (excluding Aqua Traiana and Aqua Alexandriana, whose data are missing) was 24,360 quinariae [1,010,258 $m^3 d^{-1}$ (11.69 $m^3 s^{-1}$)]. The population of Rome at the end of the 1st century AD was about 500,000; consequently, a mean of 1550 $l\,d^{-1}$ per capita was available (Fig. 7).

At the beginning of the 4th Century AD, the large monuments of Rome supplied by aqueducts are estimated to include: 11 large baths, 856 public baths, 15 monumental fountains, 1352 fountains (nimpheos) and basins, and 2 naumachiae (naval battle basins). According to Frontino, water consumption included: 17.2% by the emperor; 38.6% by citizens; and 44.2% by public services. Today Rome is supplied with 1,987,200 $m^3 d^{-1}$ (23 $m^3 s^{-1}$) of groundwater mainly from karst aquifers. Its population is 3.5 million, with a per-capita water availability of 500 $l\,d^{-1}$ including industrial uses.

Decline and revival of Roman aqueducts (500–1800 AD)

The siege of Rome by Vitige, the king of Goths in 537 AD, marks the decline of the water supply system built by Romans. The Goths destroyed the aqueducts to cut water supplies to the besieged city. After a short restoration period by the Byzantine governments, Rome underwent political and economic decay. The aqueducts were neither reconstructed nor maintained and most of the arcades collapsed.

By the end of the Middle Ages, only Aqua Virgo was still in operation. Although the population had decreased considerably, the available water supply was insufficient. Therefore, people had to use water from the Tiber river and from wells drilled in the urban area. During this time a great number of Roman buildings, villas, and monuments were torn down to recover bricks and materials for new construction. This practice went on until the beginning of modern times.

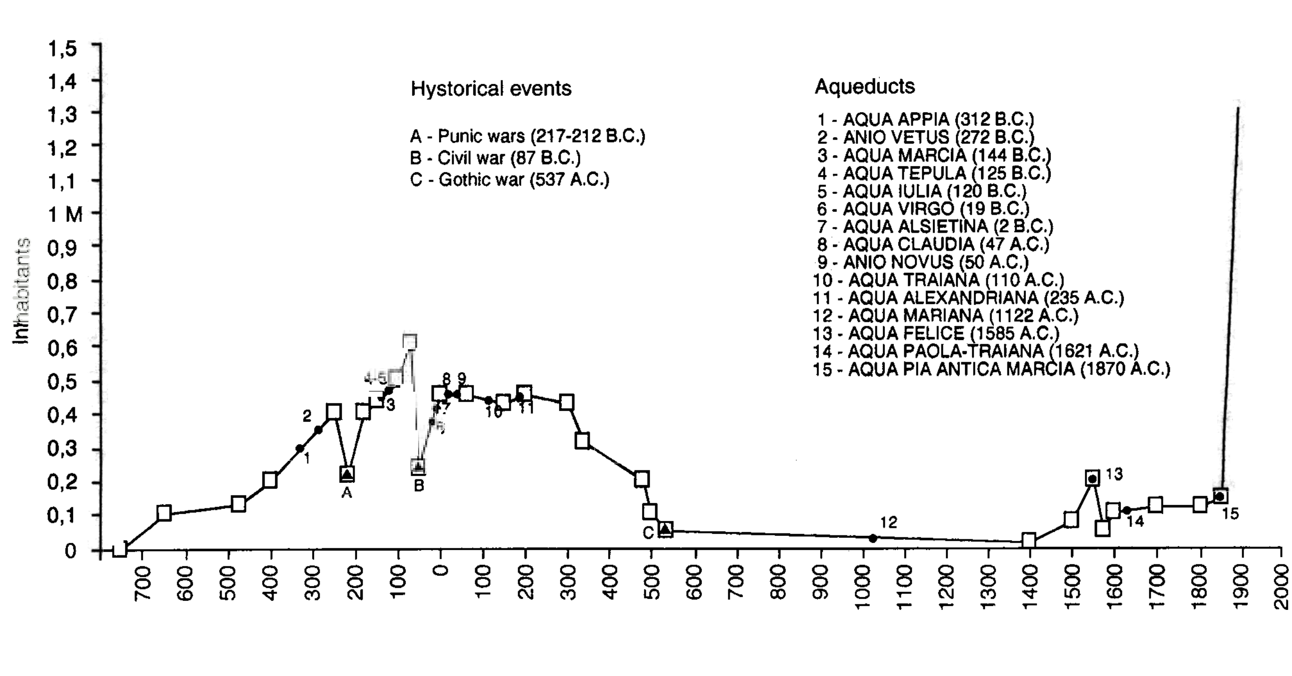
In 1122 Pope Callisto II planned to build the aqueduct Mariano, recovering ancient Roman catchment areas (Aqua Julia and Aqua Tepula). The new water line cannot be compared to the magnificence of the Roman aqueducts. However, many windmills and workshops were located along its country and urban routes; therefore it had economic importance from the Middle Ages to modern times.

In 1570 Pope Pio V restored Aqua Virgo. Pope Sisto V in 1585–1590 collected Aqua Alexandriana's springs to build the Felice aqueduct, while in 1607 Pope Paolo V Borghese restored Aqua Traiana (later called the Paolo aqueduct). In 1870, Pio IX completed the construction of the Pio aqueduct collecting some of the springs of the ancient Aqua Marcia.

Modern water supply of Rome

From the end of the papal rule (1870) to 1938, the water supply of the city was administered by the Municipality of Rome. By then, ACEA, which was established during the Fascist period as an electricity production company,

Fig. 7 Demographic trend of Rome and chronology of aqueducts



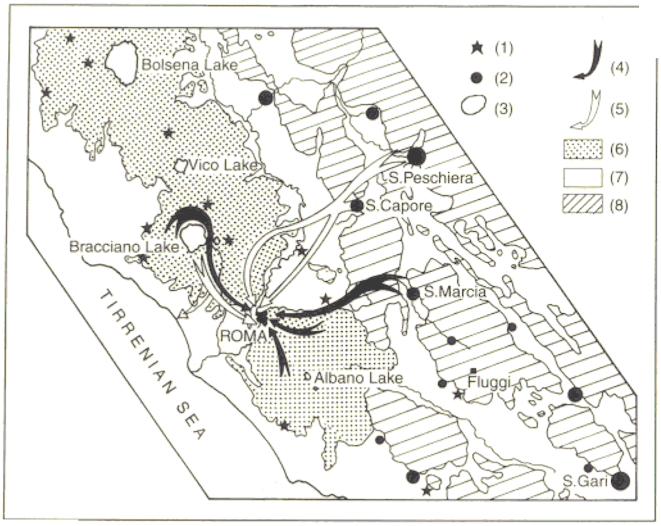


Fig. 8 Schematic hydrogeological map of central Italy: (1) thermal spring; (2) major karstic spring; (3) lake; (4) Roman aqueducts today integrated in the supply water scheme of Rome (ACEA); (5) New ACEA aqueducts; (6) volcanic area (Quaternary); (7) terrigenous cover (Upper Miocene–Quaternary); (8) karstic area (Mesozoic)

took over the management of the water supply of Rome and continues to do so (Fig. 8). In 1964 the ACEA was given responsibility for the water supply of all communities belonging to Rome Municipality. The total water supply at present is about 23 $m^3 s^{-1}$, 86% of which is from karstic springs. It is interesting to note that the water quality standard does not require any chemical treatment for human consumption except for chlorination as a preventive measure of organic pollution (Table 1).

Marcio Aqueduct

The aqueduct conveys springwater of the ancient Anio Vetus, Aqua Marcia, Aqua Claudia, and Anio Novus destroyed by Goths in 537 AD. At the time of Pio IX, a new aqueduct was inaugurated in 1870 and named Aqua Pia Antica Marcia. Different in technical conception and layout, it carries to Rome only some of the springs collected during Roman times.

The population of Rome gradually increased after 1970 by about 2.5% to 3.5 million, so more springs had to provide water to meet the increased demand. The mean discharge of springs that supply the Marcio aqueduct today is 5.0 $m^3 s^{-1}$ while Roman aqueducts produced from the same area about 8.8 $m^3 s^{-1}$. The springs are related to the karst system of the Simbruini Mountains, which has its base level in the Aniene river (321–327 m asl). The springs are located along the riverbed (linear springs) and along the contact between the karst aquifer and an impervious belt of sandstone deposits (upper Miocene flysch).

The water chemistry of all the springs is uniform and constant in accordance with the homogeneity of the karst

Table 1 Aqueducts of Rome: mean discharge and chemistry of spring waters[a]

	Peschiera-Capore			Marcio				Paolo-Traiano	
Reference	1 + 2			3	4	Nuovo Vergine	Appio-Alessandrino		
Mean discharge, Q ($m^3 s^{-1}$)	13.75	9	5.0	5.0	0.95	0.8	1.2	8 (max)	
Temperature (°C)	11	11	12	10	15	15.5	16	10	15
pH	7.2	7.2	7.3	7.3	6.7	7.3	7.25	8.02	8.0
Conductivity 25°C (μS/cm)	590	640	580	540	1460	650	550	540	270
TDS (110°C)	370	410	375	320	1030	460	360	354	230
Hardness (°F)	32.5	34.8	29.5	31	74.2	25.5	21.8	11.5	8
Alkalinity ($CaCO_3$)	315	340	270	300	510	275	240	164	112
Organic compounds (O_2)	0.25	0.2	0.25	0.3	0.5	0.35	0.45	0.8	0.5
NH_4									
Ca	110	115	95	87.5	234	78	74	32	15.5
Mg	12.5	15	11.5	21.1	38	18	7.7	8.4	10
Na	4.5	2.5	10	2.51	52.5	31.8	16	43.5	23
K	1.55	2	1.3	0.7	3	36.5	20	39.4	19
NO_2									
NO_3	3.3	2.3	4.3	2	3.5	20.6	14.5	0.7	9
Cl	4.6	3.8	7	5	80	20.5	14.3	45.9	15.9
SO_4	14.5	9.9	27	4.5	215	48	16	40	8.7
P	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
F	0.1	0.07	0.11	0.1	0.25	1.1	1	1.7	1.9
HCO_3	385	415	165	360	622	335	293	200	138
Si	4.5	3	8.2	4.5	10.5	45.5	48	1.5	50
CO_2	14.5	23	12	20.9	210	22	n.d.	2	3.5
O_2	12	7	13.5	10.9	3.5	7.3	n.d.	9.5	13.7

[a] ACEA data: (1) Peschiera springs; (2) Capore springs; (3) Acqua Marcia springs; (4) Acquoria springs; (5) Bracciano lake; (6) Acqua Traiana springs.

aquifer and its regime. The mean annual effective infiltration is about 910 mm.

New Vergine Aqueduct

The ancient Aqua Virgo reached Rome at a low elevation and therefore hydraulic constraints did not allow its use extensively as a drinking water supply. In 1901 and 1930 a lifting plant and a new aqueduct 12.7 km long were planned. The springs (25 m asl) are located at the northern slope of the volcanic area of Albano, southeast of Rome. Their mean discharge is 1.1 $m^3 s^{-1}$, 0.3 of which are conveyed to the ancient Vergine aqueduct and 0.8 to the New Vergine aqueduct. The groundwater chemistry is not uniform in the catchment area. Each spring has a different composition and mineral content. The variability is due to the heterogeneity of the aquifer and to the upwelling of hydrothermal fluids.

Peschiera-Capore Aqueduct

The aqueduct supplies Rome with about 14 $m^3 s^{-1}$. Its construction started in 1935 when the population of Rome was one million. It collects groundwater from two groups of springs: Peschiera (9.0 $m^3 s^{-1}$) and Capore (5.0 $m^3 s^{-1}$) belonging to different hydrogeological units of the central Apenines range. The aqueduct layout has an X shape, where the Peschiera and Capore springs are located at two ends. The pipes converge at the Salisano hydroelectric plant, and from there two separate aqueducts run along the two banks of the Tiber river up to Rome.

Peschiera Springs

They are located along Velino river with an altitude of 410 m. The mean discharge is 18 $m^3 s^{-1}$, with a very regular regime. The springs are related to a homogeneous karst aquifer that discharges a total of 26 $m^3 s^{-1}$ partially directly into the river (linear springs). The water chemistry of the springs is uniform and constant according to the extension of the recharge area (about 1000 km^2) and to the regularity of the aquifer discharge. The mean annual effective infiltration is about 980 mm.

Capore Springs

The springs are located along the bed of Farfa river at the altitude of 246 m. Their mean discharge is 5 $m^3 s^{-1}$ with a remarkably steady regime. Recharge area is about 280 km^2, while the mean annual effective infiltration is about 570 mm.

Appio-Alessandrino Aqueduct

The new aqueduct obtained groundwater from Roman catchments (drainage tunnels) related to Aqua Appia and Aqua Alexandriana and from recently drilled wells. The catchment areas are located along the foothills of the volcano Albano at Pantano Borghese, Finocchi, Torre Angela and have a total discharge of 1200 $l s^{-1}$. Different piezometric potentials in the catchment area account for a heterogeneous reservoir with groundwater flow in perched aquifers partially connected as could be expected in a volcano strato. Structural conditions reflect a wide variability of groundwater chemistries related also to several hydrothermal gaseous sources recognized in the area.

Paolo-Traiano Aqueduct

In the early 1600s the population of the Trastevere urban area had no option other than to use the water of the Tiber, while the inhabitants of the areas located on the left bank of the river could benefit from good quality water after the Vergine and Felice aqueducts were rebuilt. Pope Paolo V Borghese (1605–1621) therefore ordered the reconstruction of Aqua Traiana imperial aqueduct by then fallen into neglect. In 1946 Pope Innocenzo X Pamphili promoted the development of an aqueduct with the catchment of more springs located in the Anguillara volcanic area and later on diverting the outlet of the Bracciano volcanic lake (Arrone river).

At present ACEA's management has further increased the discharge of the Paolo-Traiano aqueduct by pumping water from Bracciano lake up to a yield of about 1 $m^3 s^{-1}$. In case of emergency due to the breakdown of Roman aqueducts, a temporary additional discharge of 8 $m^3 s^{-1}$ will be possible by drawing the water from Bracciano lake to the almost completed Bracciano aqueduct. To reduce the fluorine content of the water, Paolo-Traiano aqueduct converges in a mixing plant supplied by karst water of the Peschiera-Capore-aqueduct.

Water wells

The increasing population on the outskirts of Rome, new residential settlements, and more agricultural and industrial water demand resulted in the drilling of many private wells. The wells are up to 200 m deep and top aquifers in volcanic terrains whose base level is represented by the Tevere (Tiber) and Aniene rivers. In this area, the so-called mineral water is a commercial activity with several bottling plants and brands. The pH of the water ranges between 6.7 and 7.2, salinity between 0.3 and 0.6 $g l^{-1}$, and the temperature between 14 and 18°C.