



Historical Water Schemes in Turkey

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ABSTRACT Turkey has been at the crossroads of many civilizations, which have, during the last 4000 years, left remarkable remains of waterworks, and new discoveries add to their richness. These pipes, canals, tunnels, inverted siphons, aqueducts, reservoirs, cisterns and dams convey a fine sense of the hydraulic technology of their times.

Introduction

Turkey is one of the foremost open-air museums of the world with respect to ancient waterworks. A great variety of hydraulic structures were implemented during the last 4000 years on Anatolian soil, which was at the crossroads of civilizations.

There are remains of several waterworks from the second millenium BC. Hittite period (Figure 1) in Central Anatolia; from the first half of the first millenium BC Urartu period (Figure 2) in Eastern Anatolia; from the second half of the first millenium BC to the first half of the first millenium AD. Hellenistic, Roman, Byzantine periods (Figures 3 to 5) in Western and Southern Anatolia; from the second millenium AD Seldjukide and Ottoman periods (Figures 6 to 8) throughout Turkey.

The Şamram irrigation canal in the Van region from the 8th century BC, the water conveyance systems and aqueducts of Taşlımüsellim-Edirne and Kirkçeşme-Istanbul constructed by the great architect Sinan in the 16th century AD, the Istanbul water supply dams of the 17th to 19th centuries, as well as some other hydraulic systems, are still partly or completely in use.

Although archeologists, historians and occasionally civil engineers prepared a limited number of publications until the second half of the 20th century on ancient waterworks, they attracted growing interest after the 1950s, especially with increasing contribution from civil engineers. Major publications are given in the bibliography at the end of the paper.

All these works (Figure 9) reflect the several thousand years old water engineering tradition of Turkey, constructing universally important modern waterworks, which will also be appraised in the future. It is anticipated that both national and international interest in the ancient waterworks of Turkey, from the Hittite, Urartu, Hellenistic, Roman, Byzantine, Seldjukide and Ottoman periods, some still in use, will continue to increase.

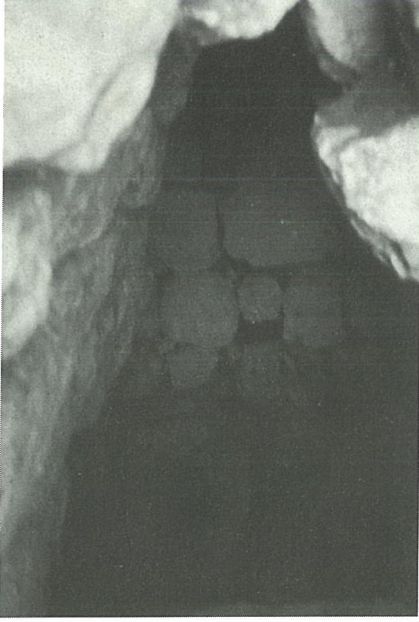


Figure 1. Entrance to the spring-water collection chamber in the Hittite capital Hattuşa (Boğazkale), from the second millenium BC.

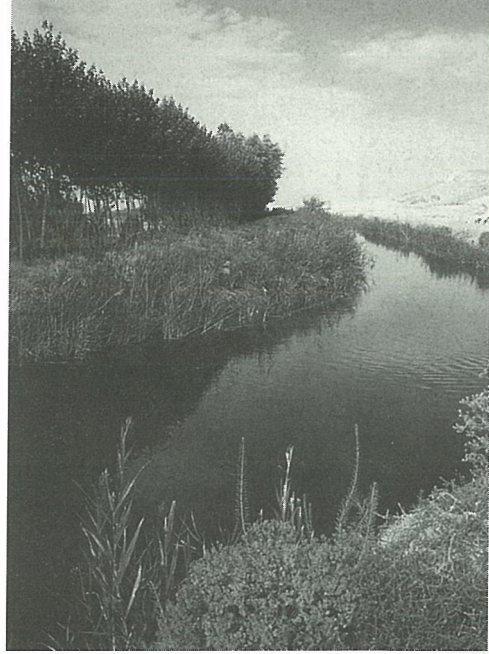


Figure 2. The 56 km long Şamram canal, conveying water to the Urartian capital Tuşpa (Vankale), from 800 BC.

Historical Waterworks in Central Anatolia in the Hittite Period

Karakuyu Dam

It is believed that the most ancient dam in Anatolia is the Karakuyu dam, constructed by Hittites towards the end of the second millenium BC for the irrigation of Uzunyayla. The U-shaped crest of the dam has a total length of 400 m, the central part being 200 m long (Figure 10); the upstream slope of the dam appears to be covered with a stone pavement.

The embankment of the 8 m high Karakuyu dam probably collapsed in its first year, due to seepage along the bottom outlet in the form of a masonry gallery, located at the deepest point of the cross-section. The Gölpinar dam near Alaca-höyük and the Köylütolu dam near Ilgin date probably from the Hittite period.

Boğazkale (Hattuşa) Springwater Collection Chamber

The most interesting water work in Boğazköy is a spring collection chamber, in the form of a 2.6 m high by 1.4 m wide masonry gallery. This underground collection work, ending with a pond 1.8 m long and 1.1 m in depth, can be reached by descending stairs.



Figure 3. A stone (trachyte) anchor block of the lead pipe inverted siphon of Pergamon, from the 2nd century BC, resisting a maximal pressure of 190 m and supplying the acropolis; and the later aqueduct, from the 1st century BC/AD, supplying less elevated parts.

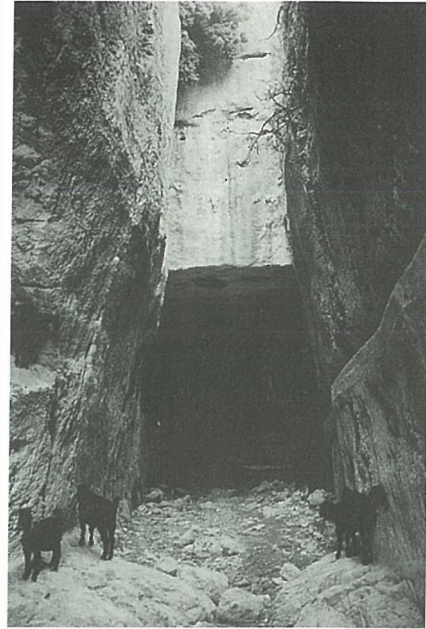


Figure 5. The exit of the second part of the Çevlik tunnel, with variable (horseshoe/trapezoidal) cross-section of about 5.8–6.9 m diameter / side lengths, diverting the creek to protect the port of Seleuceia Pieria, from 1st–2nd centuries AD.



Figure 4. The 16 m high Sextilius-Pollio aqueduct on the Marnas water conveyance system to Ephesos, from 4–14 AD.

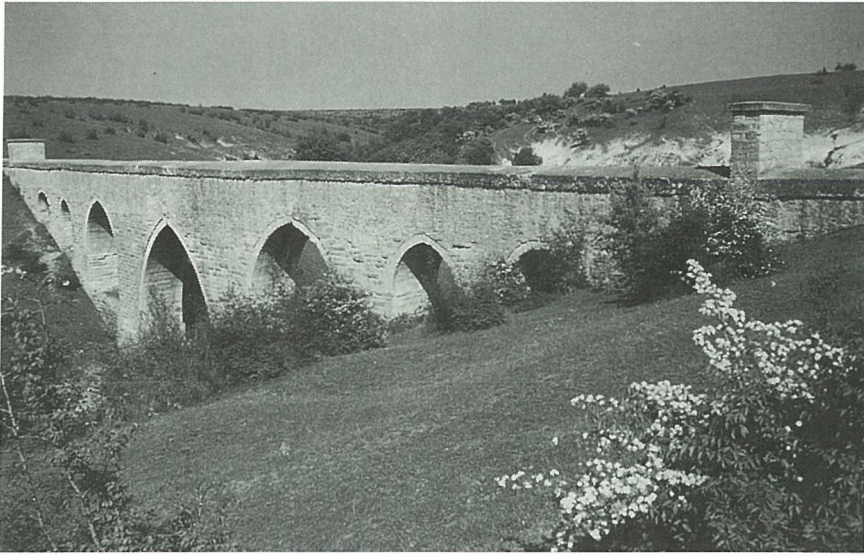


Figure 6. The 20 m high Yedigözü aqueduct on the Taşlımüsellim water conveyance system to Edirne, from 1530.



Figure 7. The 35 m high Mağlova aqueduct on the Kırkçeşme water conveyance system to Istanbul, constructed by the Architect Sinan in 1564.

Conduits at Korucutepe

A canal passing through a house as well as a water gallery, also believed to be a secret underground passage, were found in Korucutepe impounded by the Keban reservoir. There are also the remains of some canals at Alacahöyük.

Levee at Eflatunpınar

The levee forming a small pond at Eflatunpınar near Beyşehir is also regarded

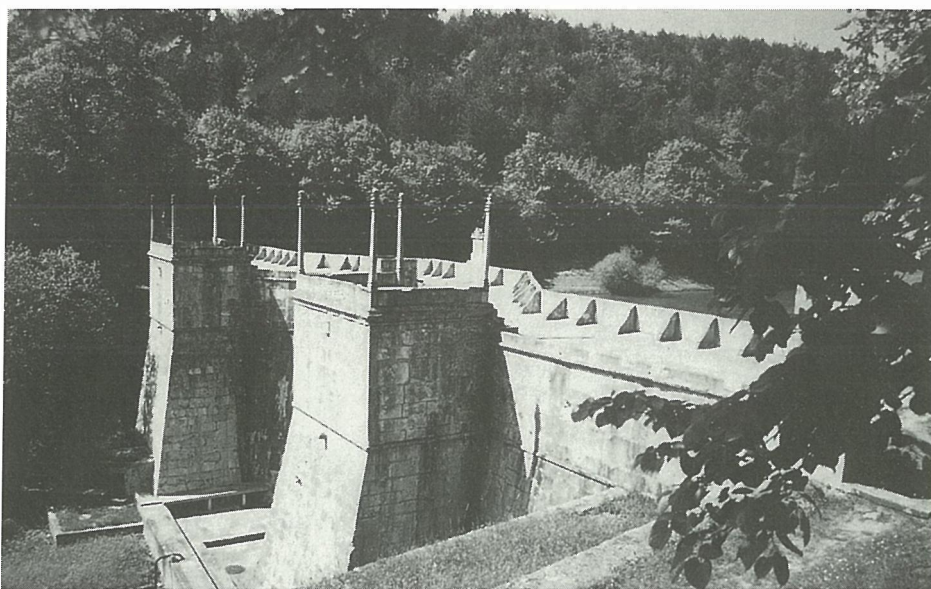


Figure 8. The 16 m high Topuzlu dam with a crest length of 81 m, supplying the Taksim water conveyance system to Istanbul, from 1750.

as dating from the Hittite period, in view of the carving technique of the stone spillway sill. The springwaters at Yalburt near Ilgin were collected by a small reservoir formed by walls of ashlar masonry.

Historical Waterworks in Eastern Antolia in the Urartu Period

Şamram Canal

The Urartians developed very important water systems during the first half of the first millenium BC in Eastern Antolia, especially in the Van area (Figure 11).

The most important waterwork of the Urartu period is the 56 km long Şamram (Semiramis, Menua) irrigation canal, dating from 800 BC and conveying 2–3 m³/s of water collected from the Engil creek springs south of Van to the then capital city Tuşpa (Vankale); this canal is still in use as part of a system irrigating about 2000 ha.

Small Dams

There were two dams to increase the volume of the Rusa (Keşiş) lake for water supply to the later capital Rusahinili (Toprakkale) and her environment. Two of the three dams, still in use, at Doni lake and the downstream dam on Engizer creek for additional irrigation water to Tuspa (Vankale) and its surroundings, probably date from the Urartu period. Furthermore, the second dam downstream of the Sultan lake appears to date from the same period.

Galleries

The long-distance underground conveyance and distribution of water by means of masonry-lined tunnels with an egg-shaped cross-section, like that of the



Figure 9. Location of major historical water schemes in Turkey.

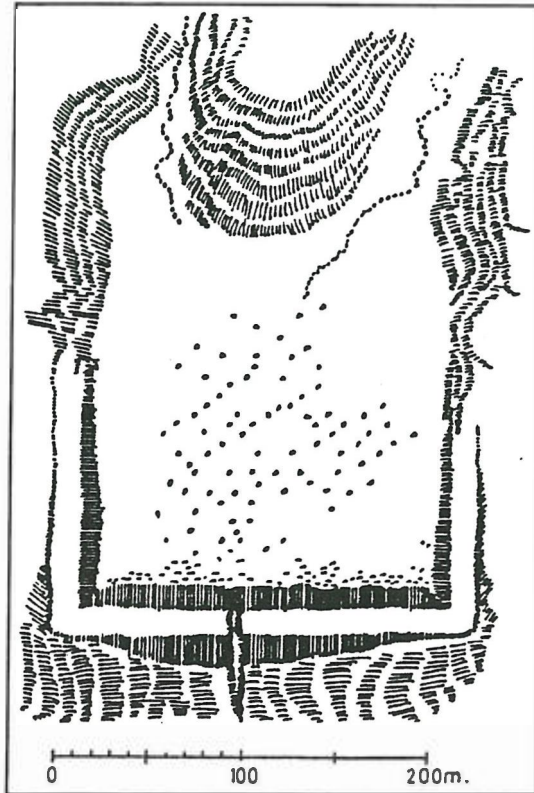


Figure 10. Layout of the Karakuyu dam near Uzunyayla. Sources: Osten, Martin & Morrison, 1933; Schnitter, 1979; Emre, 1993.

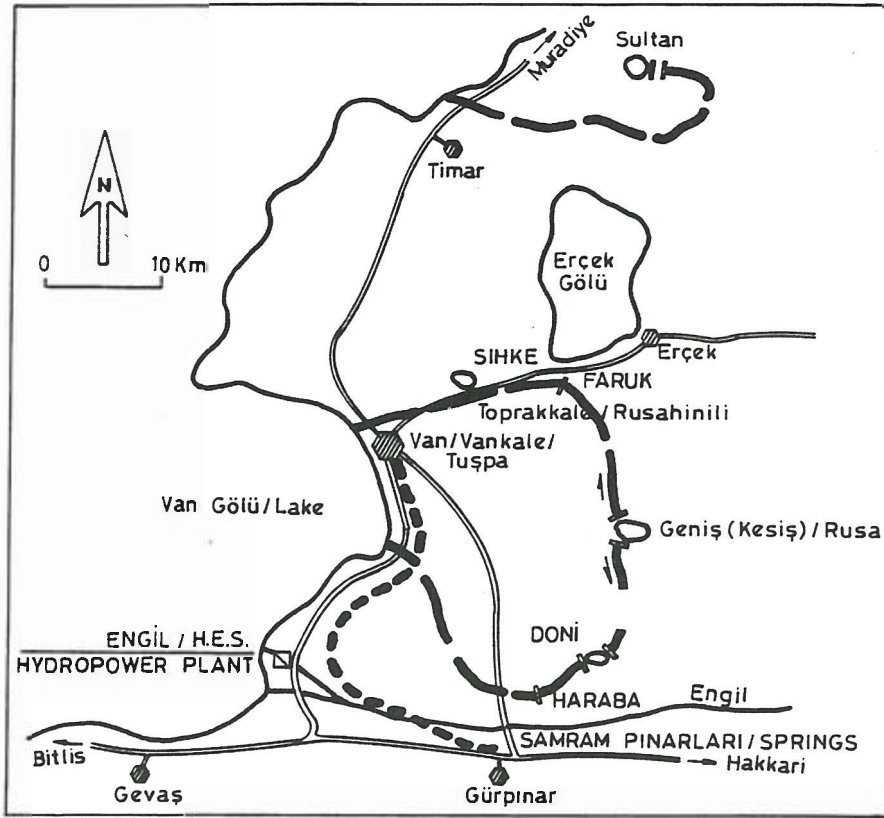


Figure 11. Ancient waterworks from the Urartu period in the Van region.
Sources: Ögün, 1970; Garbrecht, 1975–79; Baykan, field notes.

spring collection chamber in Boğazköy, and which were later well known as the qanats of the Iran, were first used by Urartians. Some of such galleries, still used around Van, are believed to date from the Urartians.

Historical Waterworks in Western Anatolia and Thrace in the Hellenistic, Roman and Byzantine Periods

Water Conveyance to Istanbul

Remains of a water conveyance system are encountered at certain locations along the southern slopes of the Istranca mountains, from Pınarhisar to Istanbul (Figure 12). This system, with a length of over 200 km, is the longest water conveyance system of the Roman period. Its construction might have started when Constantin I made Istanbul the new capital of the Roman Empire during the first half of the 4th century AD.

There are two aqueducts from the second half of the 4th century AD, serving this and later other systems conveying water from the Halkali area to Istanbul, like certain Ottoman systems. One of these aqueducts, the two-storey Ma'zul (Mazlum), located outside the ancient city walls, is 19 m high and 110 m long. It was thoroughly repaired in 758 AD. The other, the two-storey Bozdoğan, located inside the walls very close to the centre of the city, is 23 m high and 970 m long. It was constructed by Valens in 368 AD.

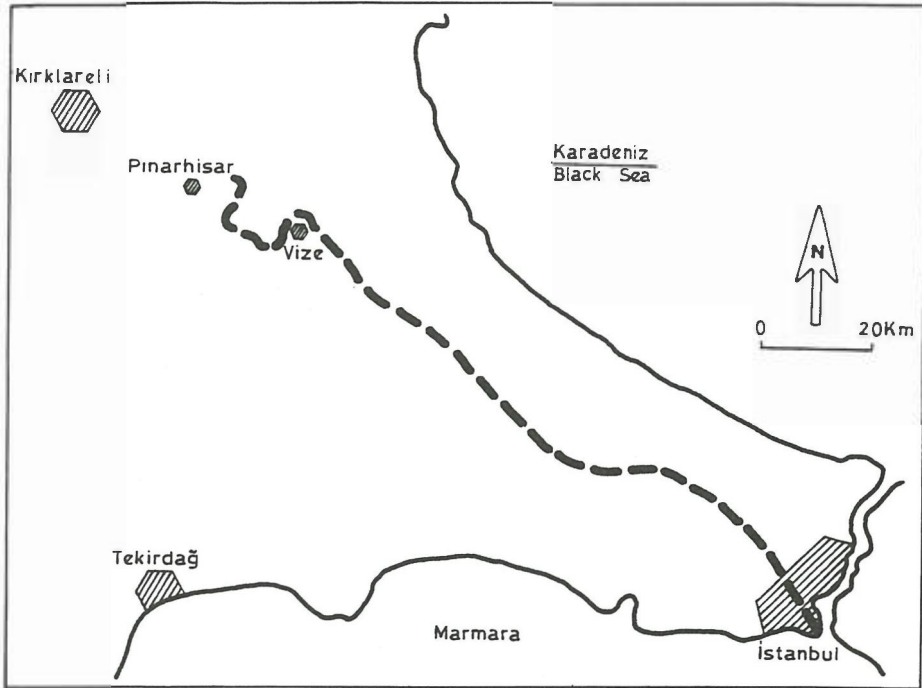


Figure 12. Location of the antique water conveyance system from the Pınarhisar region to Istanbul. *Source:* Çeçen, 1994.

Cisterns of Istanbul

Besides the long-distance water conveyance systems in Istanbul, the first large cistern, Binbirdirek, with a covered ceiling of $64 \text{ m} \times 56 \text{ m}$, supported by $16 \times 24 = 234$ columns, was constructed in the 4th century AD, primarily as a heightening substructure for the residence located above it.

During the 5th century AD, uncovered pond-like large cisterns, such as the 13 m deep Aetius near Edirnekapi with an area of $244 \text{ m} \times 85 \text{ m}$, the 11 m deep Aspar near Sultanselim with an area of $152 \text{ m} \times 152 \text{ m}$ and the 11 m deep Mokios near Altimermer with an area of $170 \text{ m} \times 145 \text{ m}$, served in the accumulation and regulation of waters conveyed to Istanbul. Another large, 11 m deep cistern, Filhane near Bakirköy covered an area of $125 \text{ m} \times 67 \text{ m}$, is believed to have been constructed in the 8th century.

The largest of the over 60 covered cisterns in Istanbul, with a total volume of about $1\,000\,000 \text{ m}^3$, is the Basilica (Yerebatan) cistern near Hagia Sophia, constructed in the 6th century AD by Justinianus, with a vaulted ceiling of $140 \text{ m} \times 70 \text{ m}$, supported by $12 \times 28 = 336$ columns of 8 m height.

Water Conveyance to Pergamon

Water conveyance systems from Selinus valley. Water from the eastern slope of the Selinus (Bergama) river valley was transported to Pergamon by two clay pipe systems of about 20 km length (Figure 13), the early 2nd century BC of the Hellenistic period; one of the conveyance systems, with a 3 l/s capacity,

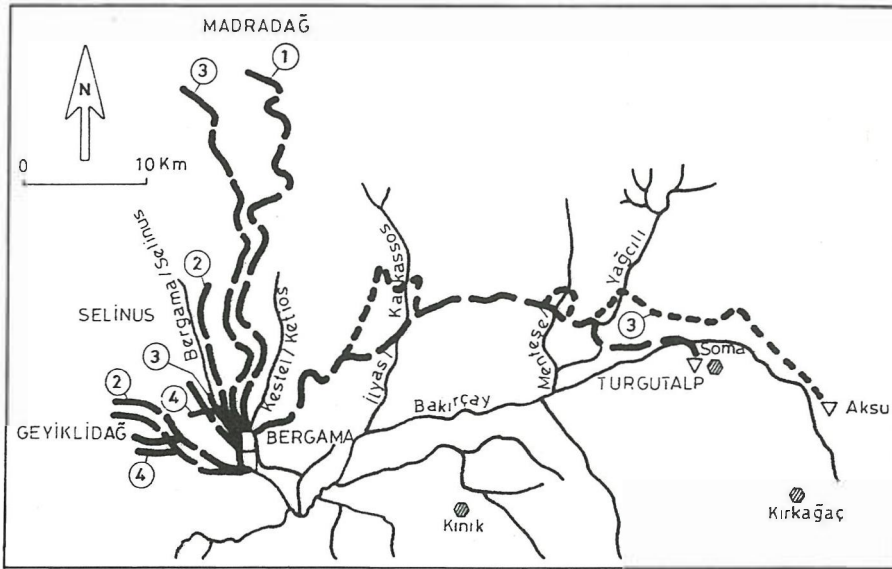


Figure 13. Locations of ancient water conveyance system to Pergamon: (1) Hellenistic; (2) Hellenistic–Roman; (3) Roman; (4) Roman–Byzantine–Turkish.
Source: Garbrecht, *et al.*, 1973–87.

consisted of a single pipeline, the other, with 27 l/s capacity, of two parallel pipelines. Both systems crossed the valley before reaching Pergamon by clay pipe inverted siphons, under a water load of 25–30 m, where the pipe joints are accomplished by means of stone blocks of 50 cm side length. The clay pipes had 10 cm inner diameter and a 5 cm wall thickness in the first system; 18 cm and 7 cm respectively in the second.

There are also remains of five more clay pipe systems, two Hellenistic and one Roman on the western slopes of the Selinus valley, and two Ottoman systems, one on either slope.

Water conveyance systems from Madradağ. In the first half of the 2nd century BC, water was brought from three springs at an elevation of 1150 m on Madra mountain north of Pergamon, by a 44 km long water conveyance system, consisting of three parallel baked clay pipes, each for one spring, but following the same alignment. After flowing through a settling basin with two compartments of 1.2 m × 3.6 m area at an elevation of 376 m, serving also as a forebay, water was conveyed to the acropolis at 330 m elevation by means of an inverted siphon of single-line lead pipes under a water load of 190 m.

Each pipe passed through a stone block of 0.2–0.3 m thick trachyte, was of 1.2–1.5 m width, 0.6–0.7 m height, and had a 0.3 m diameter hole, serving as anchorage and laid at 1.2 m intervals. The pipes were bedded on flat trachyte plates, with the exception of joints. Although not a single lead pipe has been found, the difference in lead concentration in the soil, being almost 50 times greater along the alignment of the inverted siphon compared with the ambient soil, led to the conclusion that lead pipes were used. It is estimated that the pipe thickness was about 4–4.5 cm so that the inner diameter was in the order of 21–22 cm.

The conveyance system included near Yoğurtdöken, at the 20th km, a tunnel section. The clay pipes of this conveyance system have an inner diameter in the order of 16–19 cm, wall thicknesses of 3–4 cm and lengths of 50–70 cm. The average slope is 0.7%, the minimum slope 0.4%, and with a Manning friction coefficient of $n = 0.030$, this slope results in a maximum velocity of $v = 0.73$ m/s, hence the total discharge equals about 45 l/s. The 200 000 pipe elements of this conveyance system are fabricated by oven-baking of natural clayey material; the watertightness of joints was assured by the use of a special sand-slit-clay mixture.

In the Roman period, water was also brought from Madradağ to Pergamon almost along the same alignment but by means of a masonry gallery with vaulted roof, of 50–55 cm width and 85–105 cm height. However, instead of the inverted siphon as used in the Hellenistic system, this conveyance system crossed the lower parts of the valley above a long arched aqueduct, and supplied water to the newly developing middle parts of the city.

Water conveyance systems from the springs of the Kaikos river. To satisfy the increasing water need of the growing city in Roman times, especially spreading over the lower plain, water from the Turgutalp springs near Soma in Kaikos (Bakırçay) river basin was conveyed by a 53 km long conduit, including 40 aqueducts and six tunnel sections. The masonry gallery with vaulted roof has an average width of 90 cm, height of 140 cm, a slope of 0.31‰. Assuming a water depth of 90 cm and a Strickler friction coefficient of $k = 75$, the discharge capacity is estimated as 450 l/s; due to diminished cross-section caused by significant encrustation, this should have decreased to about 225 l/s.

The completely ruined aqueduct over the Karkassos (Ilyas) river, just upstream of the aqueduct over the Ketios (Kestel) river with only one arch still remaining, was perhaps the most interesting element of this water conveyance system. It should have had a height of 40 m and a length of 550 m according to the topography, and hence should be considered as one of the most noteworthy aqueducts in the world.

The catastrophic earthquake of Izmir in 178 AD greatly damaged the water supply system of Pergamon. An inverted siphon like that at Aspendos was set up above the remaining lower arch row of the aqueduct of the Madradağ system. The high aqueducts of the Kaikos system were heavily destroyed, so that the alignment was changed to cross the valleys at more interior locations with lower aqueducts, and to bring water from the 10 km farther Aksu springs on the right bank of the Kaikos instead of the previously used Turgutalp springs on the left bank. These measures resulted in significant decreases of the conduit's slope to 0.21‰ in the section near Mentese creek, 0.12‰ near Karkassos tributary, and the discharge capacity dropped to below 100 l/s.

A tunnel section in the extended part of the system was constructed by using flat baked clay plates as lost form lining, so that the upper section of the tunnel had a trapezoidal, instead of the usual semi-circular shape.

Water conveyance systems from Geyiklidağ. The Asklepeion near Pergamon was set up in the 4th century BC. It was one of the foremost health centres of its time, reaching its climax during the 2nd century AD. The somewhat radioactive water was used both for drinking and for bathing, and noteworthy remains of related waterworks still exist.

Two water conveyance systems have been found, probably one from antiquity, the other from the Ottoman period, bringing water from two locations in Geyikli mountain. The Ottoman conduit begins with baked clay pipes of 25 cm diameter, and continues after the junction of two arms as a covered masonry canal of about 40 cm width and 80 cm height.

Twin Tunnels on Selinus River

Another interesting waterwork in Pergamon is the covered conduit like a twin tunnel, one arm 196 m and the other 183 m in length, enabling the flow of the Selinus river under the 'red' courtyard of the Serapis temple, constructed around 130 AD. In fact the river still flows through these conduits.

These conduits have simple horseshoe cross-sections of 7.5 m height and 9 m width, a slope of 0.6%, and with a friction factor of $n=0.020$, the discharge capacity of each is calculated as 360 m³/s. The comparison of this capacity with flood peak discharges from the 101 km² drainage area, estimated by modern synthetic unit hydrograph methods, showed that the total capacity corresponds to a peak flood discharge with an average recurrence interval of about 700 years.

Water Conveyance to Phoea

The water conveyance system to Phoea (Figure 14), most likely fed from the Gökusu springs near Manisa, has an alignment similar to the modern Izmir 1. Stage water supply project, along its first 19 km. The alignment is then similar to that of the modern Menemen right-bank irrigation canal for the next 48 km; and finally it follows most probably the contour lines along the coastal slopes for the last 33 km, in order to reach Phoea, so that the entire length of the system should be about 100 km.

The conduit consists of simple horseshoe-shaped masonry galleries in some sections, of rock-cut tunnels in other sections, and open channels in some others, with bottom widths of 40–70 cm and longitudinal slopes of 0.15–0.3‰, so that the discharge capacity may vary from 125 to 865 l/s, when a water depth of 2.0 m is assumed.

Water Conveyance to Ephesus

Şirince system from the east. The groundwater from the hills of the village Şirince east of Selçuk was collected by means of a main and three lateral galleries of 3.5 m length and 0.45 m width, conveyed by an 8 km long system (Figure 15), of baked clay pipes of 12–22 cm outer and 10–16 cm inner diameter.

This system probably supplied the Artemis temple and its vicinity, entering its foundation by lead pipes, seven of which still remaining *in situ*, dating from about the 6th century BC. These pipes have an inner diameter of 8 cm, wall thickness of 4.5 cm, length of 60 cm; the joints were set up by marmor elements of 13 cm inner diameter, 35 cm outer diameter and length also. A lead pipe with marmor joint elements is displayed at the Ephesus museum in Selçuk.

There are also stone block pipe elements of 35–45 cm side lengths with an inner diameter of 15 cm, which may resist a pressure of about 50 m as parts of an inverted siphon. However, it has not yet been clarified to which conveyance system these blocks belonged.

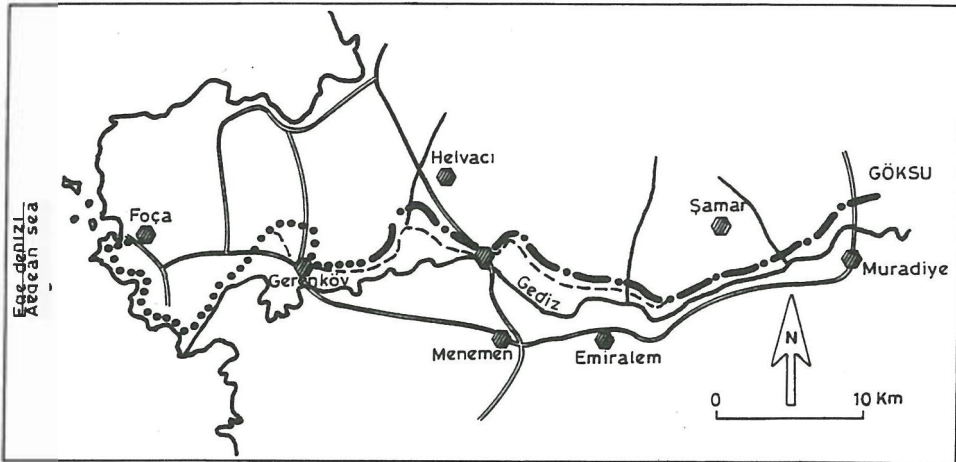


Figure 14. Location of the ancient water conveyance system to Phoece. Sources: Önen, Özyurt & Yağci, 1979; Öziş, 1994.

Derbentdere system from the south-east. The 6 km long Derbentdere (also called Marnas) water conveyance system might originally date from the 3rd century BC. The location of the diversion site displays a variety of elements including a low dam, so that this source should have been used during different periods. The system passed later over the Sextilius Pollio aqueduct constructed in 4–14 AD, as well as over the two smaller ones, and has been called 'aqua-troessitica'.

The Pollio aqueduct has a maximum height of 16 m, with three arches of 5.2 m span at its lower tier, six arches of 2.75 m span at its upper tier, and is the oldest Roman aqueduct in Turkey. The Derbentdere system consists of three parallel lines of baked clay pipes of different diameters, laid partly on rock-cut terraces, and reaches the city near the Magnesia gate.

Değirmendere system from the south-west. The 43 km long water conveyance system, called also Kenchrios, dating probably from the 1st century AD and named 'aqua iulia', brought to Ephesus the Değirmendere springs east of Kuşadası with 60 l/s discharge and the Keltepe springs north of it with 18 l/s discharge. The waters of Değirmendere springs were conveyed to Kuşadası in Ottoman times, crossing the last valley by a long aqueduct.

The Roman system to Ephesus crossed the valleys by means of 15 aqueducts. Among them the heavily ruined Bahçecik was the highest at 20 m, Arvalya the longest at 400 m. It encompassed also certain tunnel sections; the major one between Başkemer and Bahçecik aqueducts was constructed by kanat technique.

The conduit is basically a masonry canal, of 80 cm width and 90 cm height. However, a parallel smaller one, of 65 cm width and 45 cm height, exists between the 25th and 30th km of the alignment, also shown on the Kiepert atlas, and the valleys are crossed by adjacent aqueducts.

Kayapınar system from the north-east. The water of the Kayapınar springs near the village of Kurşak was brought to Ephesus by a 40 km long water conveyance system, also called the Kaystros system. In the last 10 km it received the waters from the Pranga springs too. The conduit was a masonry canal, of about 0.9 m

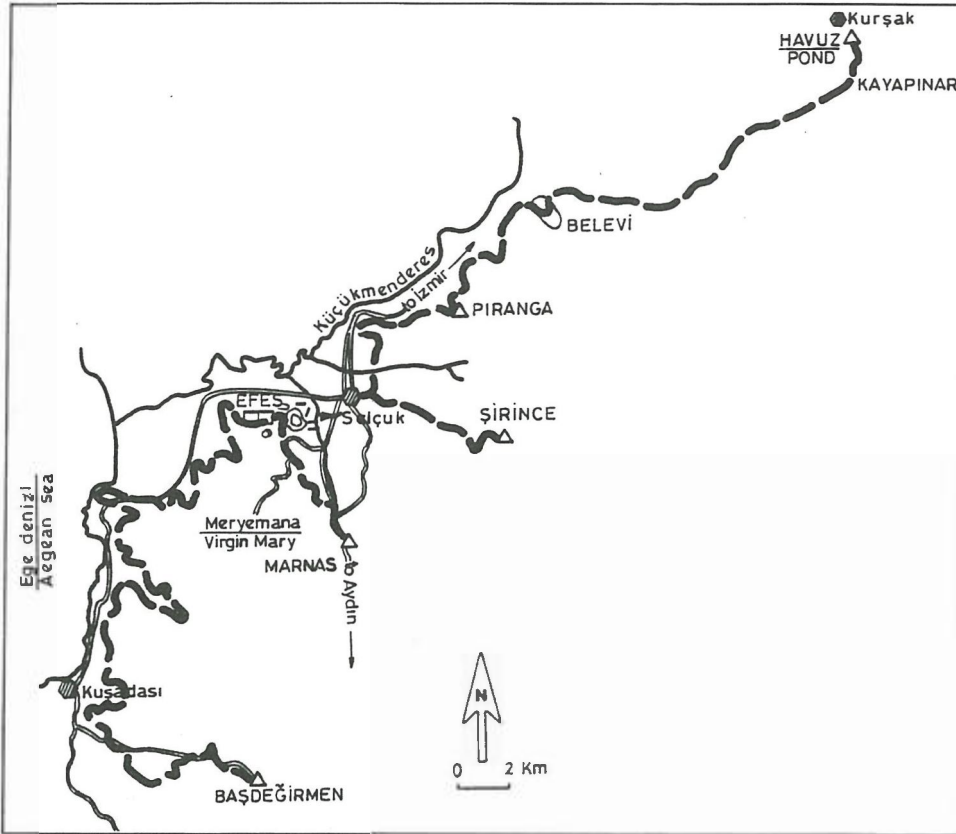


Figure 15. Locations of the ancient water conveyance systems to Ephesus. Sources: Linguri, Tulgar & Şamlı, 1974; Ersöz & Arat, 1977; Baltalı & Büyükbeci, 1977; Öziş, 1978; Öziş & Atalay, 1995.

width and 1.3 m height, in the form of a cut-and-cover gallery or laid on rock-cut terraces, crossing the valleys along the alignment by means of shallow aqueducts.

After Pranga, six single-arched aqueducts, with span widths of 3 to 4 m, still exist. The long shallow aqueduct over the Kirkinci valley is heavily ruined. No trace is left of the long one crossing the Selenus and Marnas valleys in the Selçuk plain, although the conduit passes along the north-eastern slopes of the Pion (Panayir) mountain and enters the city near the stadium.

The Kayapınar system was probably built in the 2nd century AD. It was extended to Ayasuluk hill in the 6th century by means of a 650 m long aqueduct with 125 arches, the remains of which can still be seen at three locations in Selçuk. The row of water towers parallel to this aqueduct are elements of the baked clay pipe system from the Ottoman period.

The system was extended in the opposite direction, towards the Magnesia gate, along the slopes of the Pion mountain during the same period, as witnessed by the remains of small aqueducts.

Water distribution and sewerage systems. The water supplied by these conveyance

systems was distributed in Ephesus with a dense network of baked clay pipes, a large number of which still remain in their original position. There was also a sewerage network under the main streets of Ephesus, discharging to the port, which is today 5 km distant from the sea. Of particular note are the sections near the Celsus library, under the marmor road and the main road leading to the port.

Water Conveyance to Priene

Water conveyance system. The ancient water works in Priene are typical examples of the Hellenistic period. Springs issuing at an elevation of 900 m are diverted by means of 1.5 km long masonry canals or clay pipes laid on bedding channels as evidenced at some locations. They are then branched at a division chamber into two arms, one leading to the Acropolis at an elevation of 400 m, the other to the reservoirs of the proper city at an elevation of 144 m (Figure 16).

According to approximate hydraulic computations, the amount of water conveyed to the city was in the order of 30 l/s. The springs, which once probably fed Priene, now flow through Güllübahçe before reaching the plain, and there are some ancient water mills along the creek.

Water distribution and sewerage systems. The water distribution system, consisting of baked clay pipes, is fed from two reservoirs, one having two chambers, the other a single one, and constructed probably at two different times. Furthermore, fountains, water outlets and wash-basins at the end of the distribution system, as well as the sewerage system, collecting both excess and used waters, and discharging outside the city, are noteworthy and display well-preserved sections at several locations.

Water Conveyance to Miletus

It is stated that water was brought to Miletus from springs located at Kalabak hill to the south-west and at the mountain range between Akköy and Yeniköy farther south. Wells also provided water to some extent. The system, with some remains visible today, can be dated back to the Roman period, since it supplied water to the monumental fountain, Nymphaeum, and large baths were also constructed in this period. However, some of the numerous clay pipe conduits may probably date from earlier periods.

Water Conveyance to Iassos

The remains of an almost 200 m long aqueduct exist in Iassos, with arches of 3.1 m span widths supporting a baked clay pipe conduit of 0.7–0.9% slope. The aqueduct begins near a well, and it is assumed that water was taken from this well and raised by a height of at least 3 m to supply the conveyance system. Furthermore, there are several clay pipe lines and masonry canals in the city.

Water Conveyance to Alabanda and Gerga

Water collected from the springs located in the south-east was brought to Alabanda (Araphisar) by a 21.4 km long water conveyance system (Figure 17),

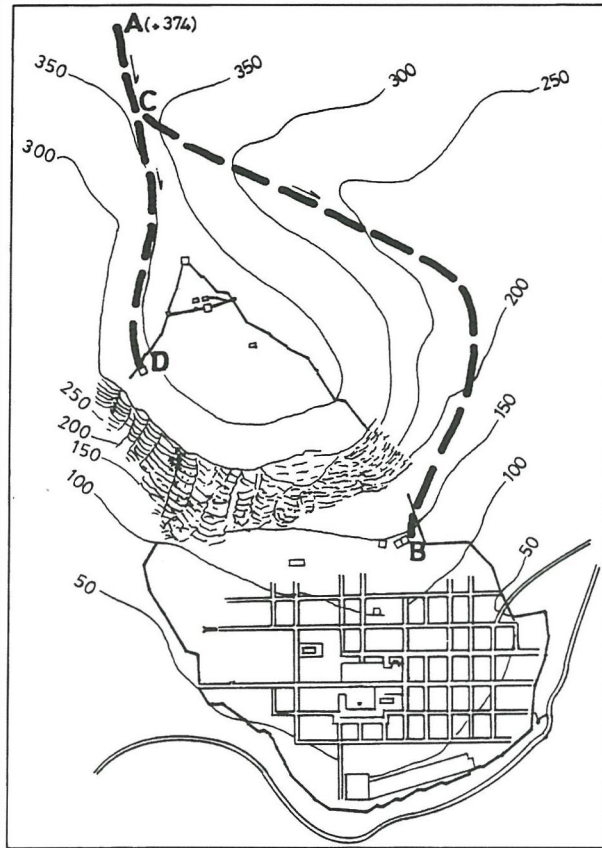


Figure 16. Location of the ancient water conveyance system to Priene. *Sources:* Wiegand & Schrader, 1904; Tanrıöver, 1974; Özis, 1994.

consisting basically of a canal with rectangular cross-section. The width of the canal is generally 90 cm; the height is 65 cm after the first group of springs and 160 cm after the second group. The canal has a mortar lining, and in contrast with other conduits in this area, displays virtually no encrustation.

The slope of the canal is 2.2% in the first and 0.74% in the second part, resulting in a capacity of 400 to 800 l/s. The city covered an area of 75 ha as evidenced by the remains of surrounding walls; hence this capacity appears to be quite high for domestic consumption, and would probably have been used for other purposes such as irrigation.

Moreover, the positions of Incekemer on the Çine river and the stone pipe elements spread around in the vicinity of the road to Milas do not allow it to be established in which direction water flowed, so it is assumed that they served to convey water to Gerga on the other bank of the Çine river. It is even worth considering that both Alabanda and Gerga water conveyance systems had branched from a conduit supplied from springs located farther southwards.

The Alabanda water conveyance system, with elements such as the five springwater collection chambers, settling basins, masonry conduit sections, rock-cut channel sections, supporting walls, aqueducts and the observation

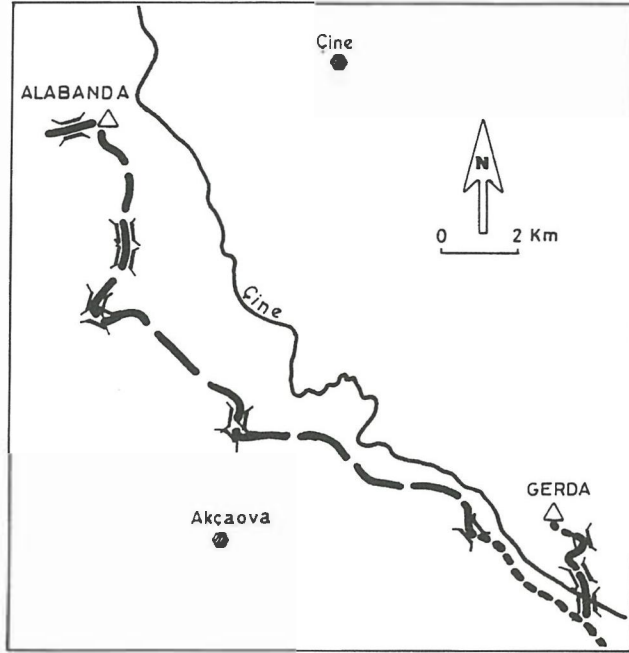


Figure 17. Location of the ancient water conveyance system to Alabanda and Gerga. Sources: Utku & Haşal 1978; Öziş, *et al.*, 1979; Öziş, 1991.

tower, as well as the Gerga system with elements such as the remains of stone pipe inverted siphons and surge chambers, give very special importance to this region with regard to the great variety of ancient waterworks.

Water Conveyance to Nysa

According to the remains of the diversion work and aqueducts, it is believed that water was brought to Nysa from the Tekkecik (Malkoç) creek, 1 km to the north. Although the water conveyance system has not duly been clarified, there is a very interesting water reservoir north of the city. This reservoir has a depth of 4.4 m and covers an area of 40 m × 50 m, so that the resulting 8800 m³ volume appears to have also served for a long-range regulation. Baked clay pipes for water distribution were found in the city.

Tunnel in Nysa

The Tekkecik creek flows through a covered, tunnel-like conduit and was conveyed to the stadium of Nysa with seat rows along both banks of the creek. The conduit has a broken alignment and a simple horseshoe cross-section.

The upstream part has a width of 7.0 m, height of 5.7 m and length of 25.5 m. After changing direction, the downstream part has a width of 5.7 m, height of 5.9 m and length of 50 m. Thus the total length of the tunnel amounts to 75 m and the slope is in the order of 3.3%. Moreover, the structure located 10 m

downstream of the tunnel, and defined as a bridge until recently, is basically another part of the tunnel; hence the total length should have exceeded 100 m.

There is an inscription within the tunnel. The lower part of the tunnel walls are of ashlar masonry, the upper parts of rubble masonry, and by taking into account the change in direction of the alignment, a friction factor of $n = 0.025$ is assumed, resulting in $290 \text{ m}^3/\text{s}$ as the tunnel discharge capacity.

The comparison of this capacity to flood peak discharges from the 4 km^2 drainage area, estimated by modern synthetic unit hydrograph methods, showed that this capacity corresponds to peak flood discharges with recurrence intervals of about 7500 to 13 000 years, or even more.

Water Conveyance to Aphrodisias

Water was brought to Aphrodisias by two conveyance systems, one from the Işıklar creek to the north, the other from the springs between Işıklar and Palamutçuk villages to the north-east. The conduit of the Işıklar creek system is a canal of square cross-section with 50 cm side lengths; a branch of it probably supplied irrigation water to the Damdere plain westwards. The conduit from the springs discharges into a water reservoir, 1.5 km north of the city, with a depth of 3 m and covering an area of $60 \text{ m} \times 40 \text{ m}$, hence having a volume of 7200 m^3 . Furthermore, there are several baked clay pipe lines and sewerage channels within the city.

Tunnel in the Tavas Area

There is a tunnel with an outlet to the Büyük Menderes basin near Geyre from a closed basin, a karst *polje* in the Tavas area. It has still not been investigated in detail as to whether it was intended as a flood control work for the drainage of the closed basin or was part of another water conveyance system to Aphrodisias.

Water Conveyance to Laodicea

Water was brought to Laodicea by a 7 km long conveyance system from Baspınar springs with about 50 l/s discharge, located southwards at an elevation of 442 m near Denizli. The conduit is a masonry canal of 60 cm width and 80 cm height. The alignment encompassed two aqueducts, and continues to the surge chamber at an elevation of 316 m by an inverted siphon of almost 1 km length, formed by two parallel rows of stone blocks, to the city's distribution tower at an elevation of 262 m.

The stone block pipe elements are 50–60 cm long, have an almost square cross-section of 70–95 cm side lengths and an inner hole diameter of 30 cm, heavily diminished by strong lime encrustation. From the distribution tower, which displays an actual height of 5 m but should have probably had a height of 8–9 m, water was conveyed to the reservoir as well as to other places such as the adjacent building and fountains.

The thickness and form of the lime crust in the stone pipe elements of the inverted siphon, caused by the quite hard water, and the large number of clay pipes in the water tower can still be seen *in situ* and are of great interest.

Water Conveyance to Hierapolis

Water was brought to the city reservoir of Hierapolis at an elevation of 475 m probably from Cevizli springs located 4 km north-east at an elevation of 910 m. Clay pipes, which might date from the Hellenistic period, as well as covered canals from the Roman period were found along the same alignment. The discharge of about 8 l/s from the Cevizli springs is not sufficient for a city like Hierapolis, and the capacity of the conveyance line is far larger than this. There are also the traces of another water conveyance system from the north-west.

The reservoir of Hierapolis is relatively well preserved. It covers an area of 12 m × 18 m and has a depth of about 2.5 m. The outflow openings in the walls show that besides the lockstone pipe element for the outflow and the bottom outlet, two water supply outlets and another bottom outlet have been constructed at a later period on a higher elevation.

It would be worth investigating whether Frontinus, who was proconsul for Asia in the years 82–83 AD and constructed some edifices such as the Domitian gate in Hierapolis, had dealt with the water works of Hierapolis before those of Rome. The sewers under the main road leading to this gate are also interesting.

Water Conveyance to Patara

The water conveyance system to Patara brings the water of the springs near Islamlar village (Figure 18). It consists of baked clay pipe at some sections and masonry canals at others, has a total length of 21 km and a slope varying between 1% and 8%, resulting in a discharge capacity in the order of 100–150 l/s. The most interesting element of the system is the 200 m long inverted siphon under 20 m water load, consisting of stone pipe elements of 35–55 cm thickness and 75–85 cm side lengths of the almost square cross-section with 30 cm inner hole diameter.

There is a water reservoir of 6 m × 5 m area and 2 m height on Doğucasari hill, at the end of the conveyance system.

Water Conveyance to Perge

Water conveyance systems. Besides some cisterns and five springwater collection works close to the city, water was brought to Perge by two conveyance systems of large capacity. The system from the west begins at Düdenbaşı, where the underground river reappears, has 400–500 l/s capacity and a length of almost 23 km and passes over an aqueduct with a central arch of 10 m span. The system from the north-west is of 200–300 l/s capacity, has a length of about 10 km and passes over two aqueducts with arches of 11 m span width.

Sewerage of used waters. There are several remains of large-sized sewers in Perge, evidencing a sewerage system for the disposal of various used waters, primarily those from the baths.

Water Conveyance to Aspendos

Water was brought to Aspendos from the Gökçe springs to the north-west by a 17 km long conveyance system, consisting of an 80 cm wide canal with 60 cm

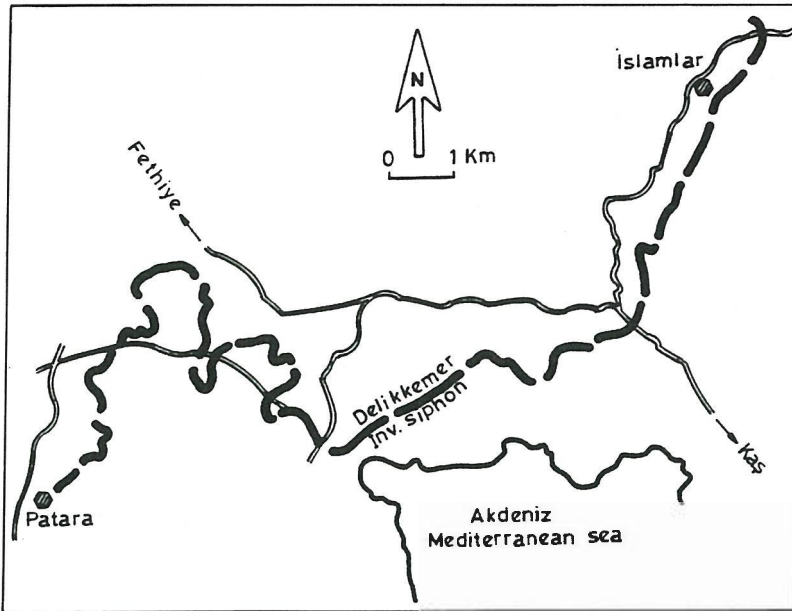


Figure 18. Location of the ancient water conveyance system to Patara. *Sources:* Kocakaya & Alkaya, 1993; Özis, 1994.

maximal height, ending with a 1.4 km long inverted siphon over an arched aqueduct-like substructure leading to the acropolis of Aspendos. The inverted siphon is formed by stone pipes of 50 to 85 cm side lengths with about 30 cm inner hole diameter. The aqueduct-like substructure is single-storey for the most part with a height of up to 17.6 m from the valley bottom. However, at both ends of the valley this substructure includes two multi-storey water towers of 30 m height, 924 m distant from each other, with ascending and descending ramps for the conduit.

Although there is actually no stone pipe over this substructure, the existence of these two towers and the general alignment of the arches show that, instead of constructing a 50 m high aqueduct, about 2 atmospheres of the pressure have been controlled by the arched substructure, 2–3 atmospheres by the stone pipe inverted siphon.

This scheme with two water towers primarily served to eliminate bending forces due to the changes in the direction of alignment being 12° at the first and 55° at the second tower. The upstream one would also have served to allow escape of the air sucked into the siphon.

Several stone pipe blocks were later used in the repair of the superstructure and the reinforcement of the piers of the Seldjukide bridge, located downstream on Eurymedon (Köprüçay) river.

It is anticipated that water brought to Aspendos was distributed to various regions and buildings of the city by clay pipes from the monumental fountain with a regulation basin, like the Nymphaeum in Side, which is better preserved. Moreover, some wells, small springs and several cisterns were found within the city.

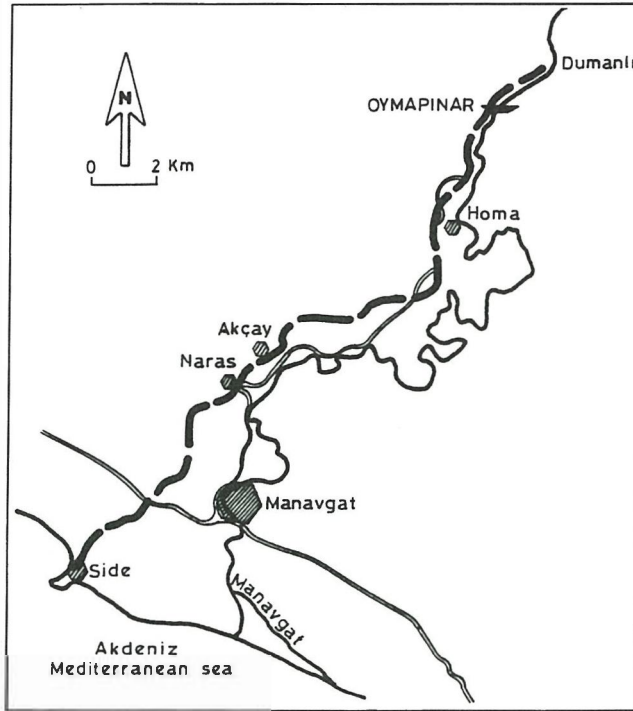


Figure 19. Location of the ancient water conveyance system to Side. Source: Izmiriligil, 1979.

Water Conveyance to Side

Water for Side was diverted by a simple lateral intake from the Melas (Manavgat) river, in the vicinity of Sevinç village or directly after the effluence of karst springs. The most important is Dumanlı spring, which is one of the most noteworthy springs in the world with $50 \text{ m}^3/\text{s}$ average discharge from a single orifice.

The 25.3 km long water conveyance system (Figure 19) includes 24 aqueducts and several tunnel sections. The flow diverted from Manavgat river appears to be in the order of 400–500 l/s. Tunnels have widths of 2.05–2.7 m and heights of 1.85–2.05 m. Covered canals at the beginning have widths of 1.1–1.3 m. The width of the aqueducts is 4.5 m, that of the canal on top of them 1.2–2.1 m, with a depth over 1.5 m. The slope of the conduit is around 1.0‰.

Dumanlı spring, the primary source of the system, and the first few kilometres of the conveyance channel are actually impounded by the reservoir of Oymapınar dam. Among the 24 aqueducts of the system, the Şihlar village–Akçay aqueduct is two-storey; others are single-storey.

The 340 m long Homa village–Kemeraltı aqueduct with all of its 40 arches well preserved, though the channel above it has been destroyed, is noteworthy. In some publications, the water conveyance system to Side has also been mentioned as the Homa aqueduct.

Water for the irrigation of a certain area was provided by a canal branching from the conveyance system at the 19th km, just before the Şihlar village–Naras

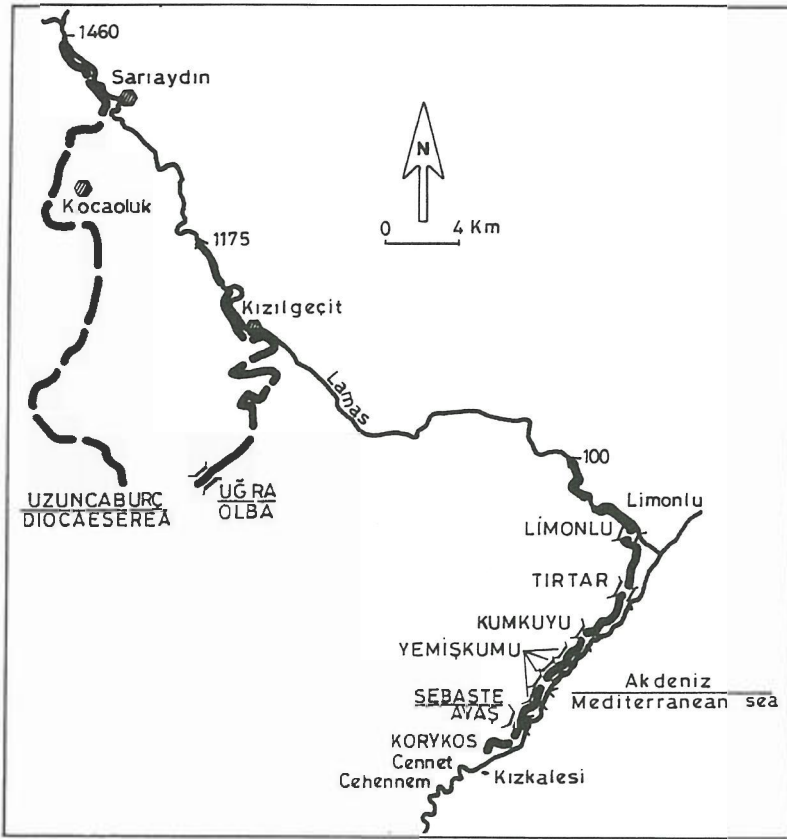


Figure 20. Locations of the ancient water conveyance systems to Diocaeserea, Olba and Elaiussa Sebaste in Lamas basin. Source: Arisoy, Öziş & Kaya, 1987.

aqueduct. The conveyance system branched again before entering Side. One arm supplied the monumental fountainhouse Nymphaeum, the other arm continued to the centre of the city and distributed water to various buildings.

Water Conveyance to Diocaeserea

Water diverted by a simple lateral intake from Lamas river at an elevation of 1460 m downstream of Sariaydin village was brought to Diocaeserea (Uzuncaburç) by a 36 km long conveyance system (Figure 20). This consisted mainly of a rock-cut canal, but including short tunnel sections and especially a qanat-like underground section crossing the upper plain at a depth reaching almost 10 m.

The consideration of structural elements of the conveyance system and of the historical development of the site leads to the assumption that the water conveyance system to Diocaeserea was built in the 3rd to 2nd centuries BC and used for several centuries during the Roman period.

Water Conveyance to Olba

Water diverted by a simple lateral intake from Lamas river at an elevation of 1175 m downstream of Kizilgeçit village was brought to Olba (Uğra) by a 20 km long conveyance system (Figure 20), consisting mainly of a rock-cut canal along the steep karstic right bank of Lamas river. The system includes some tunnel sections and an important aqueduct close to the city.

The water conveyance system to Olba dates from the Roman period and was probably constructed between the middle of the 1st century and the end of the 2nd century AD.

Water Conveyance to Elaiussa Sebaste and Korykos

Water was diverted by an ingenious lateral intake from Lamas river at an elevation of 100 m upstream of the Limonlu village, conveyed till the coastal zone on the steep right bank in a rock-cut canal, then followed the contour lines along the coast and crossed the small valleys over seven aqueducts, those in the upstream sections being taller and then gradually becoming lower. The 25 km long conveyance system (Figure 20) reaches first Elaiussa Sebaste (Ayaş), then appears to end in a pond in Korykos near Kizkalesi, and might have even continued beyond it.

It can be said that the water conveyance system to Elaiussa Sebaste was constructed during the Roman period, probably between 140 and 260 AD, later underwent several repairs and was extended to Korykos no later than in the 4th century.

Tunnel System to Seleuceia Pieria

A tunnel system, diverting the creek to prevent the siltation of the antique harbour of Seleuceia Pieria (Çevlik), is located to the north west of the lower city. The construction began in the 1st century AD during the reign of Vespasianus (69–79 AD), continued under his son Titus (79–81 AD) and was completed in the 2nd century AD during the reign of another Roman emperor, Antoninus Pius. A rock-carved inscription at the entrance of the first tunnel bears the names Vespasianus and Titus; another inscription in the downstream channel is that of Antoninus.

The creek flowing to the harbour has been diverted to the tunnel (Figure 21) at an elevation of 40 m by a dam of 15 m height, 4.5 m width and 175 m crest length. The system displays a broken alignment, beginning with a 55 m long approach channel, leading to the entrance of the 90 m long first tunnel section with simple horseshoe cross-section of 6.3 m width and 5.8 m height.

The cross-section changes to an almost rectangular shape 3 m after the entrance, being 6.9 m wide and 6.5 m high at the outlet. The width of the open channel between the first and second tunnel sections decreases to 5.5 m. Due to former karst solution channels, the height of this 64 m long channel reaches 25–30 m and becomes narrower close to the surface.

The entrance of the second tunnel has a rectangular cross-section of 7.3 m width and 7.2 m height; the outlet of this 31 m long tunnel section is trapezoidal and of 5.5 m width and 7.0 m height. Hence the total length of the two tunnels amounts to 121 m. There is a small rock-cut springwater conveyance channel of 0.4 m width and 0.3 m height on the left wall of the tunnels.

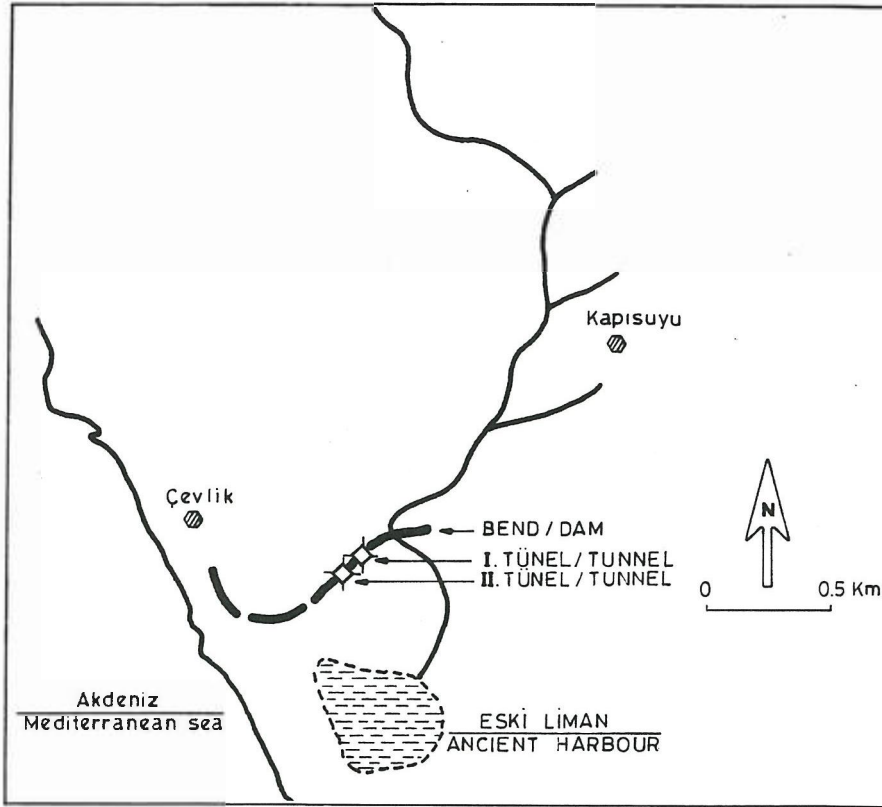


Figure 21. Location of the ancient Çevlik tunnel diversion system. Sources: Alkan, 1988; Alkan & Özis, 1991.

There is an arch of a bridge of 4.5 m height and 5.5 m span width after the outlet of the second tunnel. The open channel part following the second tunnel displays widths from 3.8 to 7.2 m, heights from 3.7 to 15 m, and is 635 m long, so that the total length of the diversion system is around 875 m.

The tunnel capacity is computed as $150 \text{ m}^3/\text{s}$ under the assumption of a friction factor of $n = 0.050$, taking into account that the conduit is excavated in rock. The comparison of this capacity with flood peak discharges from the 13 km^2 drainage area, estimated by modern synthetic unit hydrograph methods, showed that it corresponds to a peak flood discharge with average recurrence interval of 1200 years. The capacity of the open channel section is computed as $75 \text{ m}^3/\text{s}$, so that this corresponds to a peak flood discharge with average recurrence interval of only 250 years.

Water Conveyance to Samosata

The 40 km long water conveyance system to Samosata (Figure 22) collects springwater on the right bank of the Kahta river to the north-east, and continues on the western, right bank of the Euphrates. The system consists basically of a masonry canal, includes some rock-cut tunnel sections, and crosses the valleys encountered over 15 aqueducts of different sizes.

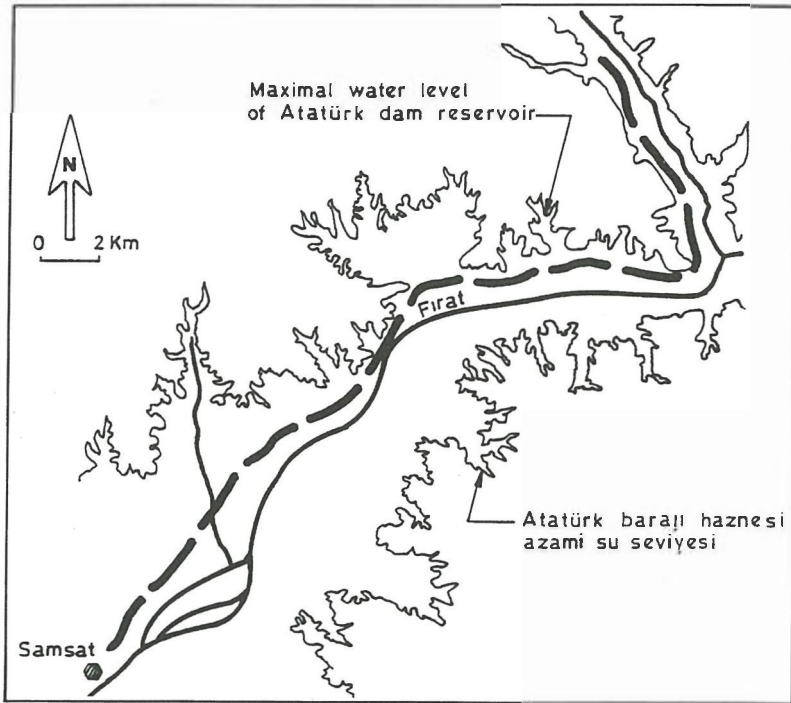


Figure 22. Location of the ancient water conveyance system to Samosata.
Source: Izmiriligil, 1983.

This water conveyance system was probably built in 200 AD during the reign of Septimus Severus. According to an inscription carved on the rock at the entrance of a tunnel, it was still used at the end of the 5th and early 6th centuries. Later completely ruined, the Samosata water conveyance system now lies entirely in the reservoir of the Atatürk dam.

Water Conveyance to Other Cities

There are interesting remains of waterworks dating from this period in various cities. These include the baked clay pipes of Troy, the fountainhouse from the middle of the first millenium BC in Bayrakli settlement of ancient Smyrna and the aqueducts crossing the Melas (Melez) river, the baked clay pipes of Teos, the water conveyance system to Lycia's capital Xanthos, the aqueduct and rock-cut canals of the Carian city Alinda, the inverted siphon of Oinoanda, the water conveyance system to Tralles, rock-cut canals of Antiochia and Amaseia, pipes of Ankara, aqueducts of Phaselis, Anemurium, Dörttyol, Edessa and cisterns of Termessos.

Dams

Çavdarhisar dam near Kütahya was probably built to protect the nearby city of Aizanoi from floods. It has a height of 10 m and the 80 m long crest is slightly curved in layout.

Örükaya dam near Çorum, of 16 m height and 40 m crest length, was probably built for irrigation purposes. Both dams were constructed by earth-filling the 4.5–5.5 m wide space between upstream and downstream walls, which were made of rectangular stone blocks of 1 m length and square cross-section with 60–70 cm side lengths.

Böget dam near Niğde was built for water supply to the city of Mustilla (Misli), with a weir of 4 m height and 300 m crest length. The structure, with a total crest width of 2.5 m, consists of an embankment between two stone walls, further supported both on the upstream and downstream faces by embankments of 1 to 1.5:10 slope.

It is anticipated that all these dams were built in the Roman period, especially in the 1st and 2nd centuries AD, although the timely sequence of their construction is still unclarified.

The first of the three Dara dams near Mardin, constructed during the reign of Justinianus (527–565), is one of the most ancient arch dams in the world.

Löştüğün embankment dam near Amaseia, consisting of two parts of 30 m and 70 m crest lengths, of 12 m height and 20 m crest width, may date from the Byzantine or Ottoman periods. The first dam on the outflowing creek from Sultan lake, the last dam downstream of Doni lake, and the ancient Sihke dam, all in the Van region, date probably from the Middle Ages.

It is still undecided as to whether the masonry Faruk dam near Van dates back to the Urartu period or to the 10th to 14th centuries AD like the dams in Iran.

Historical Waterworks in Central and Eastern Anatolia in the Seljukide Period

Water Conveyance to a Mill in Çermik

The most interesting waterwork of this period is a canal still supplying a water mill, and passing under an asymmetrical arched span at the left bank of a three-span bridge, constructed in 1179 over the Haburman tributary of the Euphrates near Çermik.

Konya Irrigation

An irrigation network constructed by Sahip Ata is among the irrigation facilities fed from Meram springs. This irrigation canal, called also the Sahip river, is actually still in use, providing water to upper parts of Meram vineyards.

Historical Waterworks in Thrace and Anatolia in the Ottoman Period

Halkali Water Conveyance to Istanbul

General description of Halkali water conveyance systems. Large repair and reconstruction works on the Halkali water system, which was the first group of three systems supplying the European part of Istanbul, began under the reign of Sultan Mehmet the Conqueror. These efforts continued until the middle of the 18th century, resulting from 16 different water lines with a total length of 130 km, and with some coincidences in their alignments.

The Halkali water systems, with a total capacity of 600 masura (Ottoman discharge capacity units: 1 lüle = 4 kamaş = 8 masura = 32 çuvaldiz = 64 hilal = 0.6 l/s), encompass the following water conveyance works: (1) Fatih (1453–

81); (2) Turunçlu (1453–81); (3) Mahmutpaşa (1453–73) and Laleli (1754–74); (4) Bayazıt (1481–1512); (5) Kocamustafapaşa (1511–12); (6) Süleymaniye (<1557); (7) Mihirmah (<1565); (8) Ebusssuut (1545–74); (9) Cerrahpaşa (1598–99); (10) Sultan Ahmet (1603–17); (11) Saray fountains (1623–40); (12) Köprültü (1656–61); (13) Miri/Beylik (1730–54); (14) Hekimoğlu Alipaşa (1732–50); (15) Kasımağa (?); (16) Nuruosmaniye (1748–55).

Süleymaniye water conveyance system. Süleymaniye water conveyance system (Figure 23), the second of the large systems by Sinan the Architect, conveys the waters of two regions through two lines called Aypah and Çınarlı. After their junction in Cicoz chamber near Taşlıtarla, the system reaches the Süleymaniye mosque with some intermediate distributions.

The maximal single-line length of the Süleymaniye system is 26 km. The total length becomes about 50 km, when several additional supplies, such as that of Ayşe Sultan to the Aypah branch near Mazul aqueduct, are also taken into account.

The system made use of the Byzantine Mazul and Bozdoğan aqueducts and includes several new ones, Avasköy being the largest. It terminates at the distribution chamber in the courtyard of the Süleymaniye mosque, flowing from the roof of the chamber towards the bottom.

Bozdoğan aqueduct, over which several lines of the Halkali water conveyance systems passed, was almost 1 km long. Later, as drawn on ancient sketch-like maps, the section after 625 m was either destroyed by earthquakes, or torn down by Sinan in order to free the sight line between Şehzade and Süleymaniye mosques, and thus partly transformed into an inverted siphon.

The Süleymaniye water conveyance system was constructed at the latest in 1557, since the construction of the Süleymaniye mosque by Sinan the Architect, for Sultan Süleyman the Magnificent, began in 1550 and finished in 1557.

Taşlimüsellim Water Conveyance to Edirne

Among the various ancient systems that brought water to Edirne, it is believed that the one from the Taşlimüsellim sources in the north-east, is the work of Sinan the Architect. This system (Figure 24) begins with two arms, one from the south of Taşlimüsellim village, the other from Sinanköy (Pravadi). After the junction to the north-east of Küçük Döllük village, the system reaches the water distribution chamber in Taşlık.

A large portion of this conveyance system is still in use. Its alignment was largely identified on the occasion of repair work carried out in the 1960s. The length of the Sinanköy arm is 6 km, that of the Taşlimüsellim 15 km, the length after the junction 20 km. The total length of the Taşlimüsellim water conveyance system amounts to about 50 km when numerous secondary feeders added later to both arms are also considered.

The system includes five tunnel sections with a total length of 3.8 km and 12 aqueducts, 20 m to 105 m in length. The total amount of water supplied is in the order of 35 l/s, whereas 10 l/s are originating from Taşlimüsellim springs, 7 l/s from Sinanköy, and the remaining part from later additions.

It has always been stated that the Taşlimüsellim water conveyance system was constructed by Sinan the Architect. However, it is not mentioned in 'Tezkiret-ül

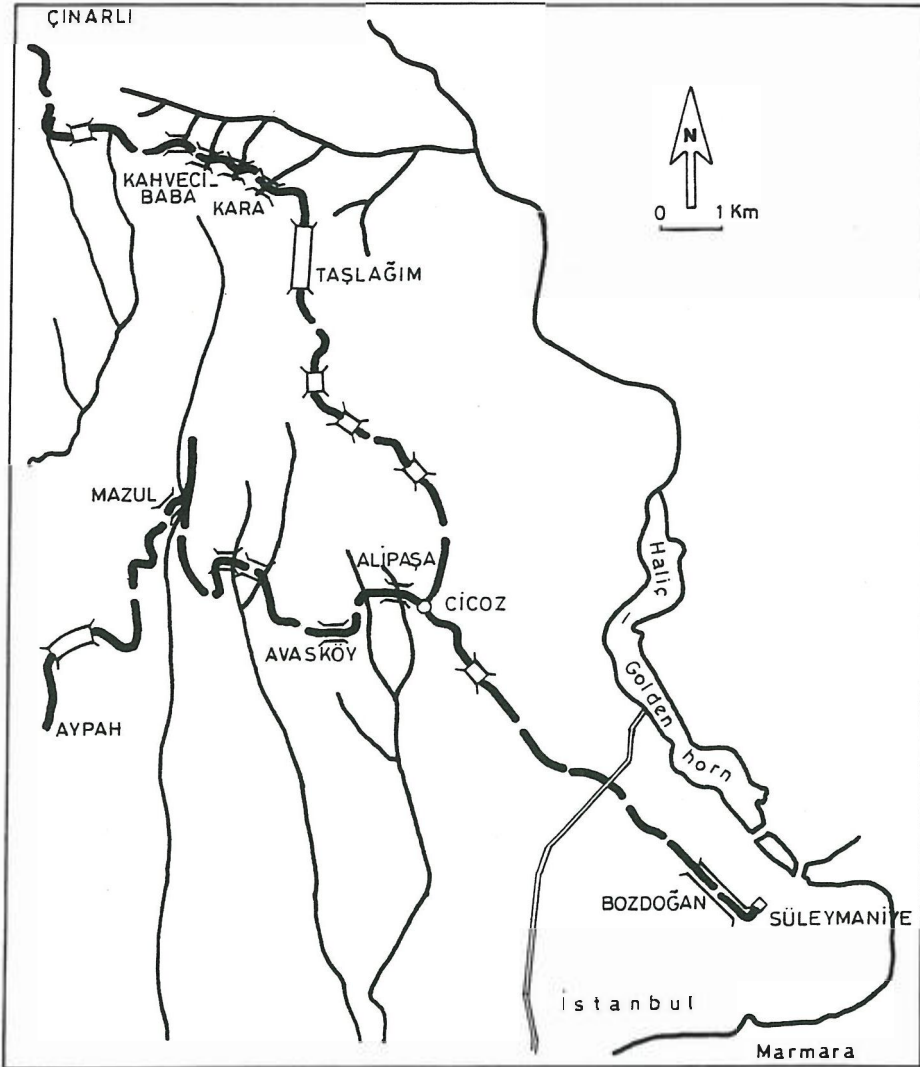


Figure 23. Location of the ancient Süleymaniye water conveyance system to Istanbul. Source: Çeçen, 1979–91.

Ebniye' and other similar manuscripts of his own dictates. On the other hand, in the manuscript of the earliest description of Edirne's water lines by Badi in 1890, it is stated that the system was constructed in the year 936 of Hegire (= 1530), and through reference to the histories of Peçevi and Ata, by Sinan during the reign of Sultan Süleyman the Magnificent for his wife Haseki Hürrem Sultan.

Kirkçeşme Water Conveyance to Istanbul

The second of the three large systems supplying water to the European part of Istanbul in the Ottoman period is the Kirkçeşme water conveyance system



Figure 24. Location of the ancient Taşlımüsellim water conveyance system to Edirne. Sources: Akmandor, 1968; Öziş & Arisoy 1986–88.

(Figure 25), collecting a part of the water sources to the north of the city. The Kirkçeşme water conveyance system is mostly still in use, contributing a modest $10\,000\text{ m}^3/\text{day}$ to Istanbul, and attracts great interest. The maximal single-line length of the system is 35 km, the total length 55 km.

The alignment includes dozens of aqueducts, among them four magnificent ones: the 26 m high and 710 m long Uzun, 35 m high and (with broken axis) 342 m long Eğri, 35 m high and 258 m long Mağlova, 32 m high and 165 m long Güzelce.

The construction of the Kirkçeşme water conveyance system in order to relieve the water shortage of Istanbul, was begun in 1554 and completed in 1560. An extremely severe flood destroyed some of the aqueducts, and the system definitely entered into service in 1564.

Topuz, Büyük and Kirazlı dams were added to the Kağıthane arm and Ayvat dam to the other arm of the Kirkçeşme water conveyance system in the period 1620–1818, to ensure the seasonal regulation of flows.

As stated, a large part of the Kirkçeşme water conveyance system, till the

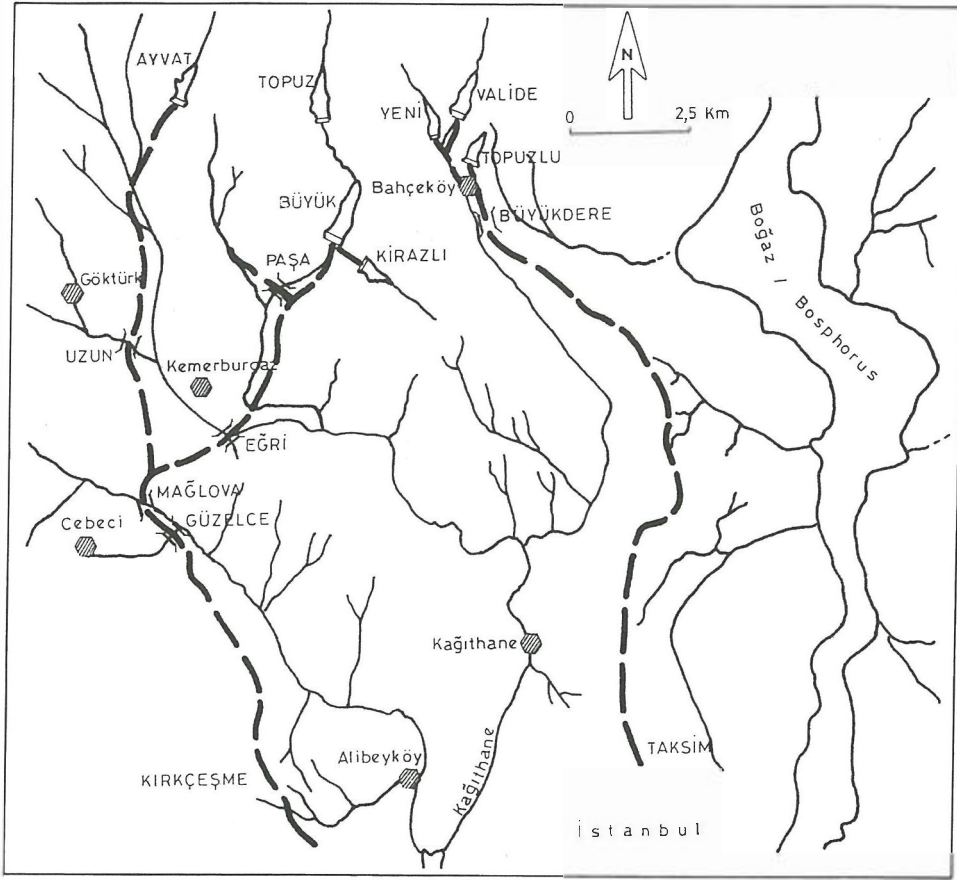


Figure 25. Locations of the Kirkçeşme and Taksim water conveyance systems to Istanbul, of dams and major aqueducts. Sources: DSI 1967; Öziş, 1977.

confluence with Keçe water-line before entering the treatment plant, is still in use. The lower parts of Mağlova and Güzelce aqueducts are temporarily threatened by the impoundment of the Alibey dam's reservoir.

Üsküdar Water Conveyance to Istanbul

There are interesting water conveyance systems in the Anatolian part of Istanbul, emphasizing the use of water balance towers as evidenced from ancient sketch-like maps, called the Üsküdar water conveyance systems. These were constructed during a period from the end of the 16th century to the beginning of the 19th century.

Taksim Water Conveyance to Istanbul

The Taksim water conveyance system (Figure 25), with a total length of 23 km, was constructed in 1731 under the reign of Sultan Mahmut I. The main conduit is a masonry gallery of 0.6–0.7 m width and 1.2–1.4 m height. The system

includes the 400 m long Büyükdere aqueduct, of 20 m height at the two-storey part over the creek and maximal 11 m at the valley slopes, as well as the 330 m long Derbent inverted siphon and several water towers.

Topuzlu, Valide and Yeni dams were constructed in the period 1750–1839 in order to regulate the water supplied to the Taksim water conveyance system.

Later on in the 19th century a new system, called the Hamidiye water conveyance, was constructed, primarily for drinking water.

Dams of Istanbul Area

The most important dams of the Ottoman period are those added to the Kirkçeşme and Taksim water conveyance systems to Istanbul (Figure 25). Among the dams serving the Kirkçeşme system, the 10 m high Topuz with a crest length of 65 m was constructed in 1620, the 15 m high Büyük with a crest length of 85 m in 1724, the 15 m high Ayvat with a crest length of 66 m in 1765, the 13 m high Kirazlı with a crest length of 60 m in 1818. Büyük dam failed in the meantime and was reconstructed in 1748 and heightened in 1900.

Of the dams supplying water to the Taksim system, the 16 m high Topuzlu with a crest length of 81 m was constructed in 1750, the 13.5 m high Valide with a crest length of 104 m in 1796 and the 17 m high Yeni with a crest length of 102 m in 1839. Topuzlu was heightened in 1786. There is also a fourth, small dam downstream of the three dams supplying the Taksim system.

The majority of dams constructed in the world until recent centuries were embankment dams. The rather rare masonry dams were generally gravity dams with straight axis and quite a few were arch dams. Hence, following two Roman buttressed dams in Spain, Topuz can be considered as one of the earliest hollow gravity buttress dams.

Topuzlu dam is a more developed one and with its central polygonal-axis part heralds the later multiple-arch buttress dams. Ayvat dam, with a polygonal axis, appears to be close to the arch dam type. Valide dam displays a type of its own, owing to the position of the buttresses along the polygonal crest.

Büyük and Kirazlı are common gravity dams; Yeni is an arched gravity dam. The crest length to height ratio of Yeni is 6 and was the largest in its time.

The investigation of the spillway capacities of these seven dams shows that, compared with others, that of Topuz appeared to be small and that of Valide large, although the flood inflow hydrographs do not require these differences. However, the spillway capacities of all dams appear to be underdesigned in view of the routed peak flood discharges, so that overflows with a couple of dm water load over the entire crest of dams might have occurred in the past.

Investigation of the reservoir operation features of Topuzlu dam indicates that the dam height was suitably selected and the heightening by 3 m in 1786 was adequate.

Other dams constructed in the last century of the Ottoman period are the 10 m high Şamlar dam from 1826 for the Azatlı gun powder manufacture near Küçükçekmece in Istanbul; a 23 m high dam with a crest length of 34 m over Maden creek in Sakarya basin, dating from the middle of the same century, probably for water supply to a lead mine; and the Elmalı I dam near Anadoluhisari for water supply to the Anatolian part of Istanbul, constructed in 1893 as an embankment dam, thoroughly repaired and heightened to 20 m as a gravity dam in 1926.

Other Waterworks of the Ottoman Period

Sinan the Architect, worked in 1583 with some of his collaborators on a very important project to divert the Sakarya river over the Sapanca lake to the Marmara Sea by a 25 km long canal, for various purposes such as flood control, water power (mills), river navigation and setting up an arsenal in Sapanca. This project, however, was not implemented.

Traces of the 100 km long Roman water conveyance system to Phocaea are not evident near the city but there are the remains of aqueducts of the Ottoman system, which brought water from shorter distances.

Although used in Roman water supply systems like that of Pompei, water balance towers were extensively used in Ottoman water supply systems. These towers, set up in baked clay pipe water lines, avoided especially unnecessary high pressures, acting like modern pressure relief chambers, besides serving other purposes such as changes in direction, branching of lines, ejecting the air entrained in the pipelines and control of non-functioning sections.

Other interesting waterworks include a diversion canal for irrigation from the vicinity of Gaziantep to Aleppo; water conveyance systems to Izmir in the early 19th century; first attempts at the Sürğü irrigation canal; the change of the river bed of Gediz towards the end of that century; the construction of the Beyşehir weir and the Çumra irrigation system in the early 20th century; and the implementation of Tarsus hydroelectric scheme in 1902. These are all projects of the last century of the Ottoman period, partly with contributions of foreign experts.

Fountains, as the last point of water distribution systems, displayed during the Seljukide and especially Ottoman periods a fine combination of architectural art beyond their usual functions, as evidenced in a large number of highly interesting examples.

Cisterns, which were of importance for water supply to the cities during the Byzantine period, continued to serve in certain regions. Furthermore, they found an interesting application for military water supply along the campaign routes of the army in the Ottoman period.

Conclusion

Various waterworks, dating from the Hittite period in Central Anatolia, from the Urartu period in Eastern Anatolia, from the Hellenistic–Roman–Byzantine periods in Western and Southern Anatolia, from the Seljukide and Ottoman periods in different parts of Anatolia, some still in use after several centuries, even millenia, make Turkey one of the most outstanding open-air museums of the world in this respect. Moreover, based on a four-millenia-long tradition of hydraulics technology and engineering, Turkey is actually constructing large-scale waterworks to irrigate 8.5 million ha of land and to generate 130 billion KWh/yr by means of over 600 dams and 500 hydroelectric power plants.

These include schemes such as the South-east Anatolian Project to irrigate 1.8 million ha of land and generate 27 billion KWh/yr of energy; the Atatürk dam of 85 million m³ embankment and 2400 MW installed capacity; the 207 m high Keban, 200 m high Berke, 195 m high Altinkaya dams and some proposed dams on Çoruh river with heights above 250 m; the Karakaya dam and power plant

generating 7.5 billion KWh/yr; the Şanlıurfa twin tunnels, each 26.4 km in length and 7.6 m in diameter, and various large long-distance water conveyance systems to supply water to cities with several million inhabitants.

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