Chapter 2
Water Works of Ancient Civilizations

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Abstract Turkey is renowned for her outstanding remnants of ancient water works and is thus one of the foremost open-air museums of the world with regard to hydraulic structures in the world. Numerous ancient water works from a four-millenia-long period are still in operation after several centuries or even several millennia. These historical works are rich in kind to encompass dams, irrigation canals, masonry conduits, aqueduct-bridges, tunnels, water collection works, water conveyance systems, pipes, inverted siphons and water mills. Geographically, they extend all over the country, indicating the various civilizations who realized them. They date back to the second millenium BC, the Hittite civilization in Central Anatolia; to the first half of the first millenium BC, the Urartu civilization in Eastern Anatolia; to the second half of the first millenium BC and the first millenium AD, the Hellenistic, Roman and Byzantine civilizations in Western and Southern Anatolia; to the eleventh up to the fourteenth centuries, the Seljukide civilization in Central and Eastern Anatolia; to the fourteenth up to the early twentieth centuries, the Ottoman civilization in Turkey. Some of these ancient water works were given as interesting examples in relevant books; several of them were dealt with more detail in other specific publications, journals and proceedings.

Keywords Turkey · Civilization · Ancient · Water · Hydraulic · Dam · Conduit · Tunnel · Aqueduct · Bridge · Canal · Pipe

2.1 Introduction

Turkey is one of the foremost open-air museums of the world with regard to historical water works for the last 4000 years (Fig. 2.1). Numerous ancient water works from this four-millenia-long period are still in operation after several centuries or even several millennia.

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Fig. 2.1 Location of major historical water schemes in Turkey (Ozis & Arisoy)

The ancient hydraulic works in Turkey encompass dams, irrigation canals, masonry conduits, aqueduct-bridges, tunnels, water collection works, water conveyance systems, pipes, inverted siphons, and water mills.

They date back to the second millenium BC, the Hittite civilization in Central Anatolia; to the first half of the first millenium BC, the Urartu civilization in Eastern Anatolia; to the second half of the first millenium BC and the first millenium AD, the Hellenistic, Roman and Byzantine civilizations in Western and Southern Anatolia; to the eleventh up to the fourteenth centuries, the Seljukide civilization in Central and Eastern Anatolia; and to the fourteenth up to the early twentieth centuries, the Ottoman civilization in Turkey (Ozis and Benzeden 1977; Ozis 1981b, 1984a, 1994a, b, c, 1995, 1996, 1998, 1999, 2015a, b, 2017; Bildirici 1994, 2004; Buyukyildirim 1994a, 2017; Ozis et al. 2006, 2009, 2014a; DSI 2008; Unutmaz 2013, Baykan and Baykan 2015).

Some of these ancient water works were presented as interesting examples in relevant international books (Garbrecht 1985, 1987a, 1991, 1995; Fahlbusch 1987a; Tolle-Kastenbein 1990; Hodge 1992; Grewe 1998, 2010a; Viollet 2000; Crouch 2004; Wiplinger 2006a, 2013a, 2014, 2016; Nikolic 2008; Mays 2010; IWA 2012; Wiplinger and Letzner 2018). Several of them were dealt with more detail in other international specific publications, journals, and proceedings, as cited in the subsequent sections.

This chapter summarizes the principal sites and main features of ancient water works in Turkey. Further details can be found in more specific literature given in the lengthy list of references at the end of the chapter.

2.2 Hittite Water Works

2.2.1 Dams

The most ancient hydraulic works in Turkey date back to the second millenium BC, remaining from the Hittite civilization in Central Anatolia. Certain indices indicate that some wells and canals may even date back to the sixth millenium BC (Emre 1993; Bildirici 1994, 2004; Ozis 1994a, 1999; Cinaroglu 2007; DSI 2008; Inal 2009; Grewe 2010b; Strobel 2013).

The 8 m high Karakuyu dam in Uzunyayla, with a total crest length of 400 m, is a remarkable example. The restituted Golpinar dam near Alacahoyuk is thus the most ancient dam actually in use. Eflatunpinar dam near Beysehir lake, Koylutolu and Yalburt dams near Ilgin, and Guneykale dam near Bogazkale are other dam remains from the Hittite Period.

2.2.2 Water Supply

The spring-water collection chamber in Hattusha (Bogazkale) (Fig. 2.2), formed by rubble stones, has an almost triangular cross-section of about 1.4 m width and 2.6 m height (Neve 1969/70).

Fig. 2.2 The springwater collection chamber in the Hittite capital Hattusha (Bogazkale). (Photo by U. Ozis)

2.2.3 Irrigation

There are remains of several water conduits in ancient Hittite settlements and irrigation systems in Central Anatolia (Bildirici 1994, 2004; Bildirici and Bildirici 1996; DSI 2008).

2.3 Urartu Water Works

2.3.1 Dams

There are several small dams from the first half of the first millenium BC, belonging to the Urartu civilization in Eastern Anatolia. These are located mostly on various watercourses flowing to Lake Van. Some of them, like the 7 m high dam raising the level of the Kesis Lake and those on Doni creek, are still in use. Kircagol dam near Adilcevaz, Suphan and Argit dams near Muradiye, and several small dams between Van and Hakkari are other remains (Garbrecht 1987a; Belli 1996; Ozis 1999; Bildirici 2004; DSI 2008; Hepbostanci et al. 2015).

2.3.2 Water Supply & Irrigation

2.3.2.1 Samram Canal

The 56 km long Samram canal (Fig. 2.3) supplied the Urartu capital Tushpa (Vankale). This canal dates back to 800 BC and is one of the oldest canals still in use. The Samram canal irrigates, with very few modifications, about 2000 ha of land (Ogun 1970; Burney 1972; Garbrecht 1975; Ozis 1994a; Belli 1997; Bildirici 2004; DSI 2008; Grewe 2010b; Hepbostanci et al. 2015).

2.3.2.2 Ferhat Canal

Remains of the Ferhat canal, conveying water from Lake Balikli towards the western edge of the Igdir plain, and some other irrigation systems in the Van area, might also date back to the Urartu period (Bildirici 2004; DSI 2008).

Fig. 2.3 The Samram Canal near the Urartu capital Tushpa (Van). (Photo by U.Ozis)

2.3.2.3 Qanats Near Van

Some of the underground water conduits of Van, still partly in use, might also date back to this period and can be considered as predecessors of the later qanats. Certain cisterns in this region appear to be of Urartu origin (Bildirici 2004; DSI 2008).

2.4 Hellenistic, Roman and Byzantine Water Works

2.4.1 Water Supply & Conveyance Schemes

2.4.1.1 General Remarks

Long-distance water supply schemes in Western and Southern Turkey, from the Hellenistic, Roman and Byzantine civilizations, date back to the second half of the first millenium BC and the first half of the first millenium AD.

The long-distance water conveyances in the Aegean and Mediterranean regions of Turkey are very numerous and new discoveries add to the rich variety of them (Weber 1904, 1905; Ozis 1981b, 1994a, 1995, 1996, 1998, 2015a, b; Fahlbusch 1982, 1987a; Garbrecht 1985, 1995; Tolle-Kastenbein 1990; Hodge 1992; Buyukyildirim 1994a; Cecen 1996a, b; Grewe 1998, 2010a, 2014; Viollet 2000; Wiplinger 2006a, 2013a, 2016; Ozis et al. 2007, 2009, 2014a, 2018a; DSI 2008; Turk et al. 2010; IWA 2012; Baykan and Baykan 2015).

These systems include spring-water collection chambers; lead-, stone-, clay-pipes of various sizes; rock-cut and masonry canals; tunnels of over 2 m height; inverted siphons under up to 190 m water pressure with lead-pipes and to 155 m water pressure with stone-pipes; and aqueduct-bridges of up to 40 m height.

The water conveyance to Constantinopolis (Istanbul) with a length of 242 km is the longest Roman water conveyance in the world, and that to Phoceia (Foca) with 100 km length ranks among the longest Roman conveyance systems. The multiple water conveyance systems to Pergamon (Bergama), Smyrna (Izmir), and to Ephesus (Efes) make these cities, besides Rome, Lyon and few others, among the most interesting examples of multiple urban water supply schemes in the antique world. The water conveyance systems to Perge, Hierapolis, Tralleis, Antiochia/Orontes are other, somewhat shorter multiple water conveyance systems in Anatolia.

The lead-pipe inverted siphon of the Madradag water conveyance to Pergamon resists up to 190 m water pressure, and the 3.3 km long stone-pipe inverted siphon of the Karapinar water conveyance to Smyrna resists up to 155 m water pressure. These were siphons operating under respective largest pressures in the antique world, dating back to the late centuries of the first millenium BC, the Hellenistic period.

With a length of about 1.7 km, the stone-pipe inverted siphon of Aspendos is the longest one on arches in Turkey. The ruined aqueduct-bridge over Karkassos (Ilyas), a tributary of Kaikos (Bakircay), on the Soma conveyance to Pergamon, had probably a height of 40 m, being the second highest Roman aqueduct after the Pont-du-Gard of Nîmes.

Various important sites are summarized below in an approximately counterclockwise geographical sequence.

2.4.1.2 Constantinopolis (Istanbul)

This city served as the capital of three empires in the course of 16 centuries: of the Roman Empire from 330 to 395, of the Byzantine Empire from the year 395 to 1453, and of the Ottoman Empire from 1453 to 1922.

Istanbul was supplied by water during the Roman and early Byzantine times through important long-distance conveyance systems (Forchheimer 1890; Forchheimer and Strzygowski 1893; Dalman 1933; Eyice 1979; Fahlbusch 1982; ISKI 1983; Tolle-Kastenbein 1990; Cecen 1994, 1996a, b; Ozis 1987, 1994a, 1995, 1996, 2001; Unutmaz 2013; Ozis et al. 2018a). These systems were heavily damaged in the course of numerous sieges of the city, during the second half of the first millenium and the first half of the second millenium, until her fall in 1453 to the Ottoman Empire.

The first major water conveyance system to Istanbul dates probably back to the Roman emperor Hadrian's time (117–138 AD). The remains of a water conduit, found roughly 220 m south of the Mihrimah Mosque in Edirnekapi, indicate that this

Fig. 2.4 Valens (Bozdogan) Aqueduct-bridge in Constantinople (Istanbul). (Photo by U.Ozis)

conduit transported water from the westwards Halkali area to the city. The conveyance continued over the 23 m high and 970 m long Bozdogan aqueduct-bridge (Fig. 2.4), which has been earlier called as the Hadrian aqueduct-bridge. It is later called Valens-aqueduct-bridge, who reigned during 364–378 AD and thoroughly repaired it in the context of the very long water conveyance from Thrace.

The 242 km long water conveyance system to Istanbul, along the southwestern slopes of the Istranca mountains in Thrace, was constructed for the new capital of the late Roman Empire in the fourth century AD, when emperor Constantinus I shifted the capital from Rome to Istanbul in 330 AD. This was by far the longest water conveyance system of ancient times (Cecen 1996a, b). The conveyance passes over 40 aqueduct-bridges, whereby the 33 m high Kursunlugerme is the highest.

Two aqueduct-bridges of this system, the already mentioned Bozdogan and the 19 m high and 110 m long Mazul, were later used by several Ottoman systems (some of the Halkali water conveyances, including the Suleymaniye water conveyance built by the great Architect Sinan in the sixteenth century).

A long-distance water conveyance from the north, the Belgrade Forest area close to the Blacksea, date probably back to the reign of Valens or of Theodosius I, the latter of whom reigned in the period of 379–395 AD, being the last emperor of the entire empire before the split in 395 AD. This conveyance was laid at an altitude significantly higher than that of the later Ottoman Kirkcesme water conveyance to Istanbul, which is one of the masterworks of the Architect Sinan in the middle of the sixteenth century. Only the lowest row (four arches) of the three-storey Egri (Kovuk) aqueduct-bridge, with a broken alignment, might belong to another Roman system.

2.4.1.3 Parion (Kemerkoy)

A ruined aqueduct-bridge, along with various baked clay and marmor pipe elements, exist at the ancient city of Parion on the southern shore of the Marmara Sea, near the village Kemerkoy northwest of Biga. It is presumed that water was conveyed from the vicinity of the village Cataltepe, southwest of Kemerkoy, so that the length of the water conveyance may be estimated to be in the order of 20 km (Wiplinger 2016).

2.4.1.4 Troia – Ilion (Truva)

A water conveyance of probably 25 km length brought the water of the springs near the village of Camlica to Troia-Illion (Truva), located to the east of the city. The most interesting element of this conveyance is the aqueduct-bridge at the village of Kemerkoy, with an arch of 16 m span width, located 27.5 m higher than the creek underneath (Kayan 2000; Aylward et al. 2002; Wiplinger 2006a; Unutmaz 2013; Ozis et al. 2018a).

2.4.1.5 Pergamon (Bergama)

Pergamon was supplied by several long-distance water conveyances dating back to Hellenistic and Roman periods, from the north-western Selinus (Bergama) valley, from the northern Madradag area, and from the eastern Kaikos (Bakircay) basin (Garbrecht and Holtorff 1973; Garbrecht and Fahlbusch 1975, 1978; Fahlbusch 1982, 1987a, e; Hecht 1975, 1976, 1978, 1979, 1983; Garbrecht 1976, 1985, 1987b, 1995; Tolle-Kastenbein 1990; Ozis 1994a, 1995, 1996; Grewe 1998; Viollet 2000; Nikolic 2008; Mays 2010; Alkan et al. 2014; Ozis et al. 2018a).

The 44 km long Madradag water conveyance system, consisting of three baked clay pipe conduits, crossed the last valley by means of a lead pipe inverted siphon under a maximal water pressure of 190 m, the highest pressure in antiquity, to reach the Akropolis area. This system was later replaced by a masonry conduit in the Roman period and crossed the same valley over an arched aqueduct-bridge (Fig. 2.5), to supply the blooming middle-level part of Pergamon.

Also in Roman times, a 53 km long conveyance brought the water of Turgutalp springs, located to the east of Pergamon in the Kaikos (Bakircay) river valley, through six tunnel stretches and over 40 aqueducts-bridges. The completely ruined aqueduct-bridge over the Karkassos (Ilyas) tributary likely had a length of 550 m and a height of 40 m. This conveyance is later extended by 10 km eastwards in order to harness the water of the Aksu springs.

Fig. 2.5 The Roman Aqueduct-bridge of the Madradag Water Conveyance crossing the last valley before Pergamon. (Photo by U.Ozis)

Fig. 2.6 Rock-cut canal of the water conveyance to Phocea. (Photo by U.Ozis)

2.4.1.6 Phoceia (Foca)

The roughly 100 km long water conveyance to Phocea was most likely fed from the Goksu springs near Manisa. It has an alignment similar to the modern first stage water supply project of Izmir along its first 19 km. The alignment is quite close to that of the modern Menemen right bank irrigation canal for the next 48 km. It follows most probably with a gentle gradient the contour lines along the coastal slopes for the last 33 km in order to reach Phocea (Ozis 1994a, 1995, 1996; DSI 2008; Wiplinger 2016; Ozis et al. 2018a).

The conduit displays stretches of open channels (Fig. 2.6), simple horse-shoe shaped masonry galleries, rock-cut canals, and rock-cut tunnels. The bottom widths are in the order of 0.4–0.7 m, and the longitudinal slopes vary between 0.15 and 0.3‰. Remains of any significant aqueduct-bridges have not been encountered.

2.4.1.7 Sardis (Sart)

The almost 16 km long water conveyance system to Sardis was fed from the Kocapinar springs issuing on the slopes of Bozdag to the south of the city. Another spring is connected at km 6. The conveyance includes stretches of masonry galleries, tunnels, clay pipes, and small aqueduct-bridges up to 8 m height. The conduit bifurcates in Teknetas at km 10; one branch reaches the Artemis temple after 1.5 km, and the other continues for 5 km until it reaches the baths and the gymnasium (DSI 2008; Wiplinger 2016; Ozis et al. 2018a).

Fig. 2.7 Aqueduct-bridges over the Melas (Melez) creek in Izmir. (Photo by Y.Ozdemir)

2.4.1.8 Smyrna (Izmir)

The 30 km long Karapinar water conveyance from the east is the longest of the seven water conveyance systems supplying Izmir in the past (Weber 1899; Fahlbusch 1982; Tolle-Kastenbein 1990; Hodge 1992; Ozis 1994a, 1995, 1996; Ozis et al. 1999, 2018a; DSI 2008; Nikolic 2008; Pinar 2011; Unutmaz 2013; Alkan et al. 2014; Wiplinger 2016). This clay pipe conduit may date back to the Hellenistic period. It includes a 3.3 km long stone-pipe inverted siphon crossing the Melas (Melez) river under a remarkable water pressure of 155 m.

The 27 km long Akpinar water conveyance from the south is the second longest one and may date back to the Roman period. The conduit is basically a covered masonry canal, crossing the small creeks along the alignment over heavily damaged modest aqueduct-bridges.

The probably 20 km long conveyance from the vicinity of Buca in the southwest crosses the Melas (Melez) river by means of two aqueduct-bridges (Fig. 2.7). The downstream one with masonry channel is 21 m high and dates probably back to the Roman period. The other aqueduct-bridge, roughly 100 m upstream of it, with a conduit of clay pipes, appear to be constructed later as a bypass to the former one and dates probably back to Byzantine or Ottoman periods.

2.4.1.9 Metropolis (Yenikoy)

Metropolis (Yenikoy) was supplied by a 21 km long water conveyance which carried the water of a spring northwest of the city. The elevation of the spring limited the water supply to only the lower half of the city. The conduit is a masonry channel and crosses a valley over an aqueduct-bridge (Weber 1904; DSI 2008; Ozis et al. 2018a).

2.4.1.10 Ephesus (Efes)

Ephesus was supplied by at least four water conveyances in antiquity: the 8 km long Selenus (Sirince) system from the east; the 7 km long Marnas (Derbentdere) system from the southeast; the 37 km long Kenchrios (Degirmendere) system from the south; and the 42 km long Kaystros (Kayapinar) system from the northeast (Forchheimer 1923; Wilberg 1923; Ozis and Harmancioglu 1980; Fahlbusch 1982; Alzinger 1987; Tolle-Kastenbein 1990; Hodge 1992; Ozis 1994a, 1995, 1996; Ozis and Atalay 1999; Ozis et al. 1998, 2005a, b, 2014b, 2018a; Ortloff and Crouch 2001; Crouch 2004; Wiplinger 2006a, b, 2008, 2010, 2013b, c, 2016; DSI 2008; IWA 2012; Unutmaz 2013; Alkan et al. 2014).

The Sirince conveyance, fed by groundwater collected near the village, supplied water to the area around the Artemis temple and may date back to the fifth century BC. The main conduit consists of conical baked clay pipes and ends with lead pipes under the altar of the temple, joined by marmor elements. This conveyance was probably diverted to the Ayasuluk hill in Selcuk in the sixth century AD, over the 625 m long Selcuk aqueduct-bridge of up to 15 m height, and served as the venter of a stone-pipe inverted siphon. The remains of water-balance towers parallel to this aqueduct-bridge are elements of a baked clay pipe conduit supplying the fourteenth century Isabey mosque and baths in its vicinity.

The Derbentdere system displays several baked clay pipe conduits, which probably had been subject to various repairs and bypasses. The system lay partly on rock-cut terraces and reaches the castellum near the Magnesia gate of Ephesus. The conveyance passes over the 15 m high two-storey Sextilius Pollio aqueduct-bridge (Fig. 2.8), replacing probably a clay- or stone-pipe inverted siphon. It then extends over two smaller, single-arch aqueduct-bridges (Becerik I & II).

The Degirmendere water conveyance carries the water of the Degirmendere and Keltepe springs by means of a cut-and-cover masonry conduit, passes through half a dozen tunnels, crosses the creeks by two dozens aqueduct-bridges, and reaches Ephesus at the southwestern hill slopes. The longest aqueduct-bridge was Arvalya with 400 m and the longest tunnel Atalay with 815 m. The system was initially constructed in Hadrian's time, early decades of the second century AD. However, an earthquake in the year 159 AD caused a sink of 3 m at the fault by km 18 and disrupted the function of the conveyance. A second larger and almost parallel channel had to be built in order to reach the city. This conveyance, with almost parallel aqueduct-bridges, was established during the later decades of the second century and reached Ephesus at an 8 m higher elevation.

The Kayapinar conveyance carried the springwater of the village Kursak near Belevi to Ephesus, receiving also the water of the Pranga springs at km 23. The conduit is basically a cut-and-cover masonry channel, crossing the creeks over small aqueduct-bridges. It reaches the antique stadium at km 40, passes then under the central seat row of the theater's upper tier, and dicharges into the Traian fountain, constructed in 114 AD by Claudius Aristion. The conduit continues under the marble road and supplies water also to the slope-houses quarter.

Fig. 2.8 The Sextilius Pollio Aqueduct-bridge on the Derbentdere Water Conveyance to Ephesus. (Photo by U.Ozis)

2.4.1.11 Magnesia/Meandros (Ortaklar)

Three relatively short water conveyances supplied water to Magnesia ad Meandros. The 7.5 km long Naipli conveyance from the northwest passes over the almost 1 km long Ortaklar aqueduct-bridge. The 6 km long Tekinkoy conveyance from the north consists mainly of a masonry channel. The 8 km long Arguvanli conveyance consists of baked clay pipes (Baykan et al. 2001a; DSI 2008; Ozis et al. 2018a).

2.4.1.12 Tralleis (Aydin)

The northwestern branch of the Tralleis water conveyance extends from the Caykavustugu springs to the Taskemer aqueduct-bridge and is 8.6 km long. The northern branch from the Olmez spring to the same bridge is 2.5 km long. The conveyance continues for 4.5 km to reach the Kizlarkulesi tower. A third, north-eastern branch from the Kocabag spring to the same tower is 10.4 km long. The final stretch, from the tower to the Ucgozler aqueduct-bridge in Tralleis, is 1.5 km long (Weber 1904; Wiplinger 2006a; DSI 2008; Ozis et al. 2018a).

2.4.1.13 Nysa (Sultanhisar)

Remains of an eventual diversion work and of some aqueduct-bridges led to the assumption that water was brought to Nysa, near Sultanhisar, from the Tekkecik (Malkoc) creek, 1 km to the north. Moreover, a very interesting water reservoir exists to the north of the city, covering an area of 40 m × 50 m (Ozis 1984a, 1994a). More recent investigations indicated a 5.5 km long water conveyance from Malgacemir area in the north, consisting of clay pipes (DSI 2008). Baked clay pipes for water distribution were also found in the city.

2.4.1.14 Tripolis (Yenicekent)

The 22 km long water conveyance carried the water of the Karsipinar spring, in the northeast, to Tripolis between Buldan and Yenicekent. The interesting springwater collection work still serves to supply water to the city Guney (DSI 2008; Ozis et al. 2018a).

2.4.1.15 Eumenia (Isikli)

A roughly 6 km long conveyance carried the water of Ortadag springs from the north to Eumenia, at the village Isikli of the county Civril. The conduit consists of baked clay pipes. The remains of a water tower exist in Eumenia (DSI 2008).

2.4.1.16 Hierapolis (Pamukkale)

Three relatively short water conveyances supplied Hierapolis: the 5.4 km long Karahayit conveyance from the north, the 6.4 km long Kocapinar conveyance from the northeast, and the 4.8 km long Mustak conveyance from the east (Weber 1904; Ozis and Harmancioglu 1980; Fahlbusch 1982; Ozis 1994a, 1995, 1996; Baykan 1999; Baykan et al. 2001b; Wiplinger 2006a; DSI 2008; Grewe 2014; Ozis et al. 2018a).

Remains of masonry channels and aqueduct-bridges indicate that the Karahayit conveyance dates back to the Roman period. Remains of baked clay pipes are encountered elsewhere. The most interesting water work is the water reservoir (Fig. 2.9), a ‘castellum aquae’ close to the city, with 11 × 12 m inner area and roughly 2.5 m height.

2.4.1.17 Laodicea (Eskihisar)

Water was brought to Laodicea by a 7 km long conveyance system from Baspinar springs, located southwards near Denizli. The initial conduit consisted of two parallel rows of baked clay pipes, dating back to the Hellenistic period. Later, in the Roman period, it was replaced by a masonry channel which extended partly over aqueduct-bridges, reaching the stone-pipe inverted siphon (Weber 1898; Ozis 1994a; Baykan 1999; Baykan et al. 2001b; Wiplinger 2006a; DSI 2008; Unutmaz 2013).

Fig. 2.9 Water reservoir at Hierapolis. (Photo by U.Ozis)

The inverted siphon is 820 m long, crosses the 40 m deep valley by two parallel rows of stone blocks (Fig. 2.10) and reaches the city's first distribution tower. From this tower, which has an actual height of around 5 m, but which probably had a height of 8–9 m, water was conveyed for 430 m to a second distribution chamber to supply other parts of the city.

The archeological excavation team under the leadership of Celal Simsek discovered in 2015 at Laodicea a water-related inscription from 114 AD, reflecting the ancient regulations of water use in the city.

2.4.1.18 Attuda (Hisarkoy) and Trapezopolis (Bekirler)

A roughly 5 km long conveyance from the southwest supplied Attuda, at Hisarkoy near Babadag, with the water of the Ikizce spring. A roughly 10 km long conveyance from the south supplied Trapezopolis, at Bekirler near Babadag, with the water of the springs on western slopes of the Salnakos mountain. The conduits consisted probably of baked clay pipes in both cases (Weber 1904; DSI 2008).

2.4.1.19 Sebastapolis (Kizilca)

A roughly 6 km long conveyance from the northeast supplied Sebastapolis, near Kizilca to the southeast of Tavas, with the water of the Caylak spring (DSI 2008).

Fig. 2.10 Stone-pipe inverted Siphon of the water conveyance to Laodicea. (Photo by U.Ozis)

2.4.1.20 Aphrodisias (Geyre)

Several water conveyance systems supplied Aphrodisias in ancient times (Weber 1904; Ozis 1994a; DSI 2008; Commito and Rojas 2010; Wiplinger 2016; Ozis et al. 2018a). The 25 km long Timeles (Yenidere) system from the southeast carries the water of two springs near the Guzelkoy village, located in the adjacent Tavas closed basin. The conduit is basically a cut-and-cover masonry channel (Fig. 2.11), passing through tunnels of several km length before the villlage Karapinar. The springs and the initial part of the conveyance is actually submerged in the reservoir of the Yenidere dam.

A 10 km long water conveyance from the north carried the water of a spring, located near the village Isiklar, to Aphrodisias. There are traces of a probably 9 km long water conveyance near the village Seki. An aqueduct-bridge of this conveyance was used as a bridge in Ottoman times.

2.4.1.21 Alinda (Karpuzlu)

An up to 7 m high and roughly 85 m long aqueduct-bridge (Fig. 2.12) crosses the last valley before Alinda near Karpuzlu. Parts of a canal formed by stone plates are still in situ on top of this bridge. Remains of a ruined masonry canal exist southwest of the bridge. A 12 km long water conveyance, with baked clay pipes, carry water from of a spring located to the northeast of the city towards the aqueduct (DSI 2008; Grewe 2014; Ozis et al. 2018a).

Fig. 2.11 Remains of the Timeles water conveyance to Aphrodisias. (Photo by A.Alkan)

2.4.1.22 Alabanda (Doganyurt)

Alabanda was supplied with water by an at least 22 km long conveyance system from the south (Ozis et al. 1979a, 2018a; Ozis 1991, 1994a, 1995, 1996; DSI 2008). The conveyance was fed from five springwater collection chambers (Fig. 2.13) at hill slopes along the left bank of Cine river. The conduit is basically a masonry channel with rock-cut stretches, passes over seven aqueduct-bridges, and ends in the city's water reservoir, which is actually totally silted.

About 5 km further to the south of the first water collection chamber is the Incekemer aqueduct-bridge over the river Cine, which served as a 'venter' for a stone-pipe inverted siphon. Road construction activities left no trace of any water conveyance between these two locations. Remains of a much smaller inverted siphon were found on a creek at the right bank of Cine river.

Initially, it was believed that Incekemer belonged to another water conveyance in the direction of Gerga on the right bank. However, the large elevation difference between Incekemer and the several hundred meters higher Gerga led later to the assumption that Incekemer should belong to a conveyance to Alabanda to eventually constitute an upstream element of the actual system, increasing its length to about 30 km. This part is actually submerged in the reservoir of Cine Adnan-Menderes dam.

Fig. 2.12 The last Aqueduct-bridge of the water conveyance to Alinda. (Photo by U.Ozis)

Fig. 2.13 A springwater collection chamber of the water conveyance to Alabanda. (Photo by U. Ozis)

2.4.1.23 Priene (Gullubahce)

The water of the springs on hill slopes to the north of the city is carried to two locations of Priene. The conveyance consists of baked clay pipes, laid on the ground or in masonry canals. The conveyance bifurcates after 125 m: a 290 m long branch discharges in the water reservoir at the acropolis northwest of Priene, and the other 1140 m long branch into water reservoirs to the east of the city (Crouch 1993, 1996, 2004; Ozis 1994a, 1995, 1996; Crouch et al. 1997; Ortloff and Crouch 1998; Alkan et al. 1999; Wiplinger 2006a; DSI 2008).

2.4.1.24 Miletus (Balat)

The roughly 4 km long conveyance carried water from the spring at the Stefania-Plateau to the south between the villages Akkoy and Yenikoy. It supplied the nympheum and the northeastern part of Miletus. The conduit consists of baked clay pipes at the beginning, then continues as a masonry channel, and reaches the nympheum with an aqueduct-bridge, of which only two arches remain. The almost 2 km long other conveyance carried water from the spring at the Jeralex area in the south between Balat and Akkoy, reached the Holy Gate, and supplied the smaller southwestern part of Miletus (Ozis 1994a; Tuttahs 1998, 2001, 2007; Crouch 2004; Ozis et al. 2018a).

2.4.1.25 Iasos (Gulluk)

The remains of an almost 490 m long aqueduct-bridge exist in Iasos (Fig. 2.14). It begins near a well, and it is assumed that water was taken out from this well and heightened at least 3 m to supply the conveyance system. Furthermore, there are several clay pipe lines and masonry canals in the city (Tomasello 1991; Ozis 1994a; Ozis et al. 2018a).

2.4.1.26 Mylasa (Milas)

The 7.4 km long water conveyance from the northeast was fed from a spring near the creek Saricay. It passes over six modest aqueduct-bridges upstream of the Akgedik dam and reaches Mylasa on a highly interesting, but partly damaged, 2.3 km long, so far the longest aqueduct-bridge in Turkey (Fig. 2.15) (DSI 2008; Mays 2010; Alkan 2015; Wiplinger 2016; Ozis et al. 2018a).

2.4.1.27 Keramos (Oren)

The roughly 6 km long water conveyance from the northeast carried the water of five springs to Keramos at northern shore of the Gokova bay. One of these springs, Sucikan, still supplies Oren. The conduit passes over several partly ruined aqueduct-bridges, discharges into pools, which might have served as silting basins, and then to a cistern (Wiplinger 2006a; DSI 2008; Ozis et al. 2018a).

Fig. 2.14 The Aqueduct-bridge in Iasos. (Phot by U.Ozis)

Fig. 2.15 The 2.3 km long Aqueduct-bridge in Mylasa. (Photo by A.Alkan)

2.4.1.28 Knidos (Datca)

A roughly 7 km long conveyance carried the water of the springs in cape Kalamis, from the east to Knidos at the western end of the Datca peninsula between the Gokova and the Hisaronu bays. The conduit consisted of baked clay pipes (DSI 2008).

2.4.1.29 Kibyra (Golhisar) and Oenoanda (Incealiler)

The water conveyance system to Kibyra near Golhisar is 2.3 km long and includes a 400 m long stone-pipe inverted siphon. The water conveyance system to Oenoanda, near Incealiler, is 3.5 km long and includes a 500 m long stone-pipe inverted siphon (Stenton and Coulton 1986; Coulton 1987; Baykan and Cantilav 1997; DSI 2008; Turk et al. 2010; Alkan et al. 2014). These two antique cities, together with Bubon and Balbura in between, formed the Kibyratis Union.

2.4.1.30 Xanthos (Kinik)

The water of the Inpinar spring was brought to Xanthos near Kinik by a roughly 9 km long conveyance from the east. The conduit is basically a masonry channel, rock-cut at some stretches, and passes over modest aqueduct-bridges (Buyukyildirim 1994a; Burdy and Lebouteiller 1998; Ozis et al. 2018a).

2.4.1.31 Patara (Gelemis)

The 22 km long conveyance carries the water of the Islamlar spring from the northeast. The conduit is basically a masonry channel with some rock-cut stretches and even displays a baked clay pipe stretch. It passes over several modest aqueduct-bridges and through an interesting stone-pipe inverted siphon. The length of the siphon is about 500 m and that of the masonry venter 190 m, curved in alignment and in elevation; stone pipes are under a maximal water pressure of about 20 m (Buyukyildirim 1994a; Ozis 1994a, 1995, 1996; Baykan et al. 1997; Baykan and Iskan 2011; Iskan and Baykan 2013; Unutmaz 2013; Sahin 2016; Wiplinger 2016; Ozis et al. 2018a).

2.4.1.32 Pinara (Minare)

A roughly 7 km long water conveyance from the west brought the water of the spring Ericek to the upper part of Pinara near the village Minare southwest of Fethiye. A shorter conveyance from the south brought the water of the spring Muargoz to the lower part of the city (DSI 2008; Turk et al. 2010).

2.4.1.33 Arykanda (Arif)

An almost 4 km long conveyance from the northwest carried the water of Baskoz springs to Arykanda, near the Arif village north of Finike. The conduit was mainly a rock-cut channel along the mountain slopes. A short conveyance from the southeast carrying the water of the Badil spring also supplied the city (Buyukyildirim 1994a; DSI 2008; Turk et al. 2010).

2.4.1.34 Phaselis (Tekirova)

A long, partly damaged aqueduct-bridge (Fig. 2.16) exists in Phaselis near Tekirova. It appears probable that an almost 10 km long conveyance from the north brought the water of a spring at the hill slopes (Buyukyildirim 1994a; Kurkcu 2015b; Ozis et al. 2018a).

2.4.1.35 Perge (Aksu)

Besides some cisterns and five springwater collection works close to the city, water was brought to Perge by two conveyance systems of large capacities (Fahlbusch 1987c; Baykan and Dag 1994; Buyukyildirim 1994a, 1997; Ozis 1994a, 1995, 1996; Ozis et al. 2018a).

The 11 km long conveyance from the north carried the water of the Gelindusen spring, 2.5 km to the north of the Kursunlu waterfall, to supply Perge. The conduit is partly rock-cut and partly cut-and-cover masonry gallery. It passes over a few aqueduct-bridges, such as the 11 m high Egridere and 16 m high Ahmetali.

The 22 km long conveyance from the northwest carried the water of Dudenbasi springs, which originate, in turn, from the karstic Kirkgozler springs. The conduit begins as a tunnel, then continues as a masonry channel, and passes over some aqueduct-bridges, like the 10 m high Sogucaksu.

Fig. 2.16 The Aqueduct-bridge in Phaselis. (Photo by U.Ozis)

2.4.1.36 Selge (Zerk)

The ancient city Selge (Zerk), located in the mountainous upper Koprucay basin, northwest of Beskonak, was supplied by two rather short water conveyances. The 5 km long conveyance from northwest passes over a 10 m high, partly damaged aqueduct-bridge; the conduit consists of a stone plate canal on the ground, but a baked clay pipe conduit exists in the ground underneath. The 6 km long conveyance from southwest consists of semi-cylindrical or U-shaped baked clay elements (Buyukyildirim 1994a, b; Ozis et al. 2018a).

2.4.1.37 Aspendos (Belkis)

The 17 km long water conveyance to Aspendos is fed by springwater and crosses the Koprucay valley, the last one before the city, by a 1.7 km long stone-pipe inverted siphon (Fig. 2.17) (Ward-Perkins 1955; Garbrecht 1977; Ozis and Harmancioglu 1980; Fahlbusch 1982, 1987a, b; Garbrecht 1985, 1995; Tolle-Kastenbein 1990; Hodge 1992; Buyukyildirim 1994a; Ozis 1994a, 1995, 1996; Kessener and Piras 1997; Grewe 1998, 2014; Kessener 2001; Piras 2001; Ortloff and Kassinos 2003; Nikolic 2008; Unutmaz 2013; Alkan et al. 2014; Wiplinger 2016; Ozis et al. 2018a).

The venter of the inverted siphon is an up to 18 m high aqueduct-bridge and displays two partly damaged water balance towers, which probably had 38 m and 30 m heights. This structure can be considered as three consecutive inverted siphons. The length of the upstream part between the inlet surge chamber and the upstream tower is about 600 m; the length of the middle part between the two towers 950 m; and the length of the downstream part, between the second tower and the outlet

Fig. 2.17 The Stone-pipe inverted Siphon of Aspendos, on Arched bridge as Venter. (Photo by U. Ozis)

chamber is 150 m. The alignment of the aqueduct-bridge displays two changes of direction, 16° at the first tower and 55° at the second one.

The hydraulic capacity of the siphon is calculated as 65 l/s. The two towers assure the safe functioning of the system under air displacements and dynamic pressure changes (Kessener 2001; Ortloff and Kassinos 2003; Nikolic 2008; Wiplinger 2016). Moreover, the second tower avoids the horizontal bending forces due to change in direction, which otherwise might damage the pipe system and interrupt the water flow (Garbrecht 1977; Ozis 1994a, 1995, 1996; Alkan et al. 2014; Ozis et al. 2018a).

2.4.1.38 Side (Side)

The 25 km long conveyance to Side diverts a small part of the Manavgat river flow on the right bank, at the location where the Dumanli spring discharges into Manavgat on the left bank. The karstic Dumanli spring has an average discharge around 50 m^3/s flowing out from a single orifice. The spring and the initial 5 km of the water conveyance to Side are submerged in the reservoir of Oymapinar dam.

The conduit passes through several rock-cut channels (Fig. 2.18), tunnels and over 24 aqueduct-bridges. The longest is the 340 m long Homa (or Kirkgozler) aqueduct-bridge, situated 2 km downstream of the Oymapinar dam (Izmirligil 1979; Ozis and Harmancioglu 1980; Fahlbusch 1982, 1987d; Tolle-Kastenbein 1990; Hodge 1992; Buyukyildirim 1994a; Grewe 1994, 1998, 2010a, 2014; Ozis 1994a, 1995, 1996; Ozis et al. 2018a).

2.4.1.39 Sagalassos (Aglasun)

A 24 km long conveyance collected the water of several springs, from the east to the west, along the slopes of the mountain in the north, and supplied Sagalassos near Aglasun with water. Some remains of rock-cut or masonry conduits are encountered (Wiplinger 2006a, 2016; Ozis et al. 2018a).

2.4.1.40 Antiochia/Pisidia (Yalvac)

A probably 11 km long conveyance from the north supplied water to Antiochia ad Pisidia. The conduit is basically a masonry channel, ends over a 300 m long partly ruined aqueduct-bridge of curved alignment and crosses the last valley with a stone-pipe inverted siphon (Weber 1904; Bildirici 1994; Burdy and Taslialan 1997; Ozis et al. 2018a).

Fig. 2.18 Rock-cut channel of the water conveyance to Side and, in the background, the Modern Oymapinar Arch Dam on Manavgat river. (Photo by U.Ozis)

2.4.1.41 Antiochia/Cragum (Guney)

Several drainage channels, a ruined part of a masonry gallery, and the remains of a large Roman bath were found at Antiochia ad Cragum, located near the village Guney, southeast of Gazipasa at the Mediterranean sea. These elements indicate a relevant water conveyance from the eastern area (Wiplinger 2016).

2.4.1.42 Anemurium (Anamur)

Remains of a significant aqueduct-bridge indicate an interesting water supply for the antique city of Anemurium (Weber 1904; DSI 2008).

2.4.1.43 Sbede (Yukari Caglar)

A 4 km long water conveyance carries the water of the spring Boncukcayiri to Sbede, near the village Yukari Caglar, northeast of Ermenek. Besides a short baked clay pipe stretch, the conduit is a rock-carved channel, partly in the karstic underground. A stretch of this conduit is obtained by an horizontal qanat system with horizontal lateral tunnels instead of vertical shafts (Bildirici 2014).

2.4.1.44 Diocaeserea (Uzuncaburc)

Three antique settlements, Diocaeserea (Uzuncaburc), Olba (Ugra), and Elaiussa Sebaste (Ayas), were supplied by the water of the Lamas (Limonlu) river, which flows into the Mediterranean sea near Erdemli. The 36 km long water conveyance to Diocaeserea consists of masonry and rock-cut channels and some tunnel stretches, the longest of them constructed by the qanat technique. The water conveyance to Diocaeserea dates probably back to the first century AD (Arisoy et al. 1987; Tolle-Kastenbein 1990; Bildirici 1994; Ozis 1994a, 1995, 1996; Ozbay 1998; DSI 2008; Unutmaz 2013; Wiplinger 2016; Ozis et al. 2018a).

2.4.1.45 Olba (Ugra)

The 18 km long water conveyance to Olba consists of masonry and rock-cut channels and numerous tunnel stretches; the total length of the tunnel stretches is 3.7 km. Furthermore, there is also an almost 18 m high aqueduct-bridge in Olba. The water conveyance to Olba dates probably back to the middle of the first century AD or latest to the end of the second century (Arisoy et al. 1987; Tolle-Kastenbein 1990; Bildirici 1994; Cangiri and Akpinar 1994; Ozis 1994a, 1995, 1996; Ozbay 1998; DSI 2008; Unutmaz 2013; Ozis et al. 2018a).

2.4.1.46 Elaiussa Sebaste (Ayas)

The water conveyance to Elaiussa Sebaste (Ayas) is 25 km long and extended by 3 km to Korykos (Kizkalesi). The conduit consists of rock-cut or masonry channels and passes over eight aqueduct-bridges (Fig. 2.19) (Limonlu, Tirtar, Kumkuyu, Yemiskumu A to D, Ayas). The extension to Korykos ends in a large cistern. The water conveyance to Elaiussa Sebaste was probably constructed between 140 and 260 AD and extended to Korykos at the end of the fifth or early sixth century AD (Arisoy et al. 1987; Bildirici 1994; Ozis 1994a, 1995, 1996; Grewe 1998; Ozbay 2001; DSI 2008; Murphy 2013; Unutmaz 2013; Ozis et al. 2018a).

2.4.1.47 Antiochia/Orontes (Antakya)

Four water conveyance systems supplied Antiochia ad Orontes in ancient times. The 4 km long Kuruyer conveyance from the east and the 5 km long Dursunlu conveyance from the south are the shorter ones. The longer conveyances of 12 km and

Fig. 2.19 Kumkuyu Aqueduct-bridge of the water conveyance to Elaiussa Sebaste. (Photo by U. Ozis)

14 km are fed from the Defne springs farther to the south (Lassus 1983; Doring 2012; Pamir and Yamac 2012; Ozis et al. 2018a).

The quite ruined Kantara aqueduct-bridge, 35 m high and 160 m long, appears to be the largest of the system. The Demirkapi aqueduct-bridge was very close to the city gate; it was heightened by an arched gravity dam in the sixth century and transformed into a dam, but collapsed later.

2.4.1.48 Edessa (Sanliurfa)

The Karakoyun water conveyance supplying Edessa (Sanliurfa), evidenced by the remains between Samsat and Millet bridges over the Karakoyun creek, is also called Justinian's aqueduct-bridge, so that it might date back to the early Byzantine period (Kurkcuoglu 1992; Gerger and Kurkcuoglu 1997; IWA 2012; Yenigun et al. 2013).

2.4.1.49 Samosata (Samsat)

Samosata was supplied by a 40 km long water conveyance from the northeast. The conduit was partly rock-cut and partly masonry channel and passed over 15 aqueduct-bridges, which are ruined to a great extent. The city and the entire conveyance are submerged by the reservoir of the Ataturk dam (Izmirligil 1983; Ozis 1994a, 1995, 1996; Ozis et al. 2018a).

Fig. 2.20 Rock-cut Canal of the water conveyance to Amaseia. (Photo by U.Ozis)

2.4.1.50 Amaseia (Amasya)

A 24 km long water conveyance from the south supplied Amaseia. It had an alignment mostly parallel to the river Yesilirmak along the foot of the mountain range on the right bank. The conduit includes impressive rock-cut stretches (Fig. 2.20) (DSI 1994, 2008; Unutmaz 2013; Ozis et al. 2018a).

2.4.1.51 Ankyra (Ankara)

Considering the alignment of the last stretch, a water conveyance from the Elmadag area in the southwest is assumed to supply Ankyra (Firatli 1951). Such a conveyance probably had a length of around 30 km. The conduit consisted probably of baked clay pipes. Numerous remains of stone pipes are encountered in the area, and a large number of stone pipes are used in the construction of the castle's walls. A significant stone-pipe inverted siphon, eventually in double rows, probably have crossed the last large valley near the city.

2.4.2 Water Distribution and Sewerage

Water distribution and wastewater collection systems of certain Hellenistic-Roman-Byzantine cities in Anatolia deserve also special attention, such as Priene, Miletus, Ephesus, Hierapolis, and Istanbul (Bildirici 2002; Crouch 2004; Ortloff and Crouch 1998, 2001; Wiplinger 2006b; Tuttahs 2007; Strobel 2013; Uytterhoeven 2013).

2.4.3 Cisterns

Covered and open cisterns in Istanbul, dating back to the fourth and up to the sixth centuries AD, are extraordinary examples of antique cisterns, totalling a volume of roughly 1,000,000 m^3. They were the largest of their kinds, with side lengths up to 150–250 m. Noteworthy are the covered cisterns Yerebatan with 336 (Fig. 2.21) and Binbirdirek with 234 columns (Forchheimer and Strzygowski 1893; Eyice 1979; Ozis 1982; IWA 2012).

There are also other sites with important cisterns, like Termessos to the northwest of Antalya (Kurkcu 2014), Assos near Behramkale, Pergamon (IWA 2012), Aigai near Yuntdag (DSI 2008), Keramos (Wiplinger 2006a), Sagalassos (Wiplinger 2006a), Patara (Wiplinger 2016), Arykanda (DSI 2008), Rhodiapolis to the north of Kumluca (Wiplinger 2006a), and Ariassos near Bucak (Wiplinger 2006a; Kurkcu 2015a).

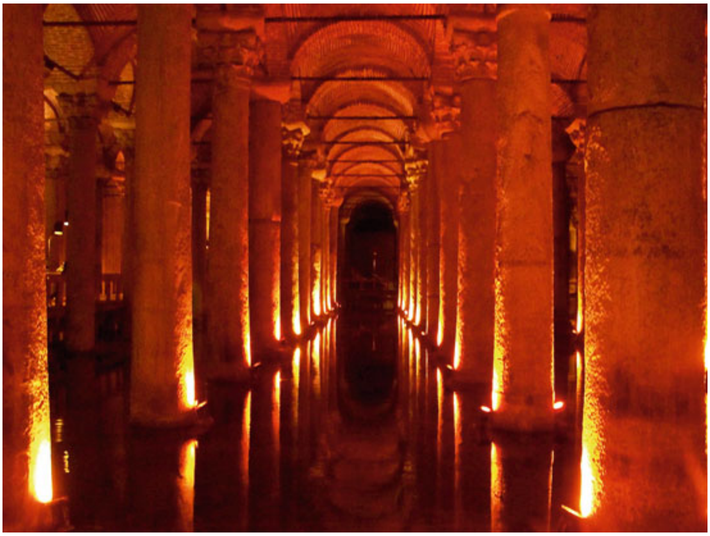

Fig. 2.21 The Yerebatan Cistern in Istanbul. (Photo by Y.Ozdemir)

2.4.4 Tunnels

2.4.4.1 Seleuceia Piera (Cevlik)

The tunnel and river diversion system at Cevlik dates back to the Roman period. The construction began in the first and ended in the second century AD. It was aimed to prevent the silting of the harbor of Seleucia Pieria to the northwest of Samandag near Antakya.

The 875 m long system has a capacity of 70 m^3/s. It encompasses two tunnel stretches of 90 m and 30 m in length. The cross sections are of simple horseshoe or trapezoidal, with dimensions in the order of 6–7 m, being the largest of its time (Fig. 2.22) (Alkan and Ozis 1991a, b, 2013; Garbrecht 1991; Grewe 1998, 2010a; DSI 2008; Grewe et al. 2010; Ozis et al. 2010; Baykan et al. 2011).

2.4.4.2 Bezirgan Near Kalkan

The 250 m long Bezirgan tunnel near Kalkan, with 1.1 m width and 2.2 m height, serves as flood water emissary of the karst polje (Genc et al. 2010; Ozis et al. 2010; Baykan et al. 2011, 2013; Wiplinger 2016).

Fig. 2.22 Inlet of the first tunnel stretch in Cevlik. (Photo by U.Ozis)

2.4.4.3 Underground Conduits of Amaseia (Amasya)

There are some water channels, dating back to the fourth and the third centuries BC, at the Amasya castle, located on the mountain overlooking the city (DSI 2008).

2.4.4.4 Tunnels of Water Conveyances

Several water conveyances to ancient settlements include tunnel stretches, as dealt with in Sect. 2.4.1; most of these tunnels have widths in the order of 1 m, heights in the order of 2 m.

2.4.5 Structures Covering Water Courses

2.4.5.1 Pergamon (Bergama)

The tunnel-like twin structures from the Roman period, covering the Bergama creek, date back to the early second century AD. They were the largest of their kind with 7.5 m height and 9 m width each. They have a total capacity of 720 m^3/s and are still in situ (Fig. 2.23) (Ozis et al. 1979b, 2010; Grewe et al. 1994; Ozis 1994a, 1995, 1996; DSI 2008; Baykan et al. 2011).

Fig. 2.23 Inlet of the twin structures covering the Bergama Creek. (Photo by U.Ozis)

2.4.5.2 Nysa (Sultanhisar)

The tunnel-like structure covering the Tekkecik creek in Nysa has dimensions close to 6 m and a capacity of 290 m^3/s (Ozis et al. 1979b, 2010; Grewe et al. 1994; Ozis 1994a, 1995, 1996; DSI 2008; Baykan et al. 2011).

2.4.5.3 Acarlar Near Ephesus

The tunnel-like structure covering the creek in Acarlar near Ephesus has dimensions of 3.3–4.9 m and a capacity of 70 m^3/s (Ozis et al. 2010; Baykan et al. 2011).

2.4.6 Dams

Several dams in Central Anatolia, dating back to the early centuries of the first millenium AD, like the 16 m high Orukaya dam near Corum (Fig. 2.24), 16 m high Cevlik dam near Antakya, 10 m high Cavdarhisar near Kutahya, 4 m high Boget dam near Nigde, and others dating back to the sixth century AD, like the Dara dams near Mardin in Southeastern Anatolia, are interesting remains from these periods. The Ildir dam near Cesme and the Lostugun dam near Amasya date probably back to the second half of the first millenium AD. Sultan and Sihke dams near Van, with some Urartu origins, might also date back to the same period (Schnitter 1979; Garbrecht 1991; Ozis 1999; Hepbostanci et al. 2015). A structure over the creek up in Termessos appear to be a dam (IWA 2012).

2.4.7 Water Power

There are numerous remains of water mills in Turkey; it is hard to conclude that some of them date back to this period. It is believed, however, that the first water wheel was constructed in the fourth century BC in Cabeira (Niksar) (IWA 2012).

Several water mills are encountered in the upstream part of the Degirmendere water conveyance to Ephesus and of the Anaia (Kadikalesi) water conveyance near Kusadasi (Kreiner 2013). Remains of Roman water-powered stone saws were found at certain locations in Anatolia (Wiplinger 2006a; Grewe and Kessener 2007).

Fig. 2.24 The bottom outlet of the Orukaya Dam. (Photo by U.Ozis)

2.5 Seljukide Water Works

2.5.1 Dams

A few dams in Turkey date back to the eleventh up to the fourteenth centuries, the Seljukide period in Central and Eastern Anatolia. The remains of some dams have been submerged in the reservoirs of modern dams like Altinapa and Sille; others are damaged by outside effects.

An interesting example is the 12 m high Faruk dam near Van, with a crest length of 30 m; however, the left half collapsed in 1988. The estimates for the construction date of the Faruk dam varies from the Urartu to the Ottoman periods, but the appropriate dating appears to be Seljukide (Schnitter 1979; Cecen 1987; Garbrecht 1991; Ozis 1999; Bildirici 2004; Ozis et al. 2007; DSI 2008).

2.5.2 Water Supply & Conveyance Schemes

Certain remains of the water supply system in Sanliurfa date back to the Seljukide period (Kurkcuoglu 1992; Gerger and Kurkcuoglu 1997; IWA 2012; Yenigun et al. 2013).

2.5.3 Cisterns

The cisterns, especially in western and southern regions of Turkey are quite interesting (Ozis 1982; IWA 2012).

2.5.4 Irrigation

The Sahip Ata irrigation canals in Konya date back to the thirteenth century. The irrigation systems in Eregli and at other places in Central Anatolia, some of them with probable Hittite origins, date also back to the Seljukide period; a few of them are still in operation (Bildirici 1994, 2004; Bildirici and Bildirici 1996).

2.5.5 Water Power

The supply canal of a water-mill at Cermik passes through an asymmetrical opening of the Seljukide Haburman masonry bridge belonging to the twelfth century (Fig. 2.25). This is apparently one of the most ancient water power schemes in Anatolia still in operation (Ozis et al. 2007; DSI 2008).

Some ancient water-mills encountered in the upstream part of the Degirmendere water conveyance to Ephesus and of the Anaia (Kadikalesi) water conveyance near Kusadasi may eventually date back to the Seljukide period (Kreiner 2013).

2.5.6 Hydromechanics

The book by Ebul-feyz El Cezeri, who was named after the town Cizre in Southeastern Anatolia, is a twelfth century masterwork on ingenuous hydro-mechanical devices (Cezeri 1196; Hill 1974; Cecen 1979a; IWA 2012).

Fig. 2.25 A Canal, supplying a water Mill, through the Seljukide Haburman Bridge in Cermik. (Photo by U.Ozis)

2.6 Ottoman Water Works

2.6.1 Water Supply & Conveyance Schemes

2.6.1.1 General Remarks

The use of water during the Seljukide and Ottoman periods was relatively more modest, compared to the abundant water use in the Roman period. Water was very appreciated by the Ottomans, and adequate measures were utilized for water safety and wastewater removal (Cecen 1999; IWA 2012).

The basic discharge unit during the Ottoman period was "lule" (a word used also for 'orifice') (Fig. 2.26), equivalent to 36 liters per minute. 1 lule is the discharge flowing through a circular orifice of 26 mm inner diameter, under a water pressure of 96 mm over the center of the orifice. The subunits of lule are: 'kamis' (= 1/4 lule), 'masura' (= 1/8 lule), 'cuvaldiz' (= 1/32 lule), 'hilal' (= 1/64 lule) (Cecen 1988, 1991a, b, 1999, 2000; Ozis and Arisoy 1987, 1996; Ozis 1994a; IWA 2012).

2.6.1.2 Suleymaniye and the Other Halkali Water Conveyances to Istanbul

The Halkali water conveyance systems to Istanbul were constructed in the period of 1450's to 1750's. They consist of 16 systems with a total length of 130 km, including the 50 km long Suleymaniye water conveyance by the great engineer and architect Sinan in the 1550's. The conduits are basically baked clay pipes, with certain tunnel sections, and passing over some aqueduct-bridges. The Suleymaniye system even made use of the fourth century Mazul and Bozdogan aqueduct-bridges (Cecen 1979b, 1984, 1986a, b, 1988, 1990, 1991a, 1999, 2000; Ozis 1984b, 2001; Ozis and Arisoy 1987, 1996, 2000, 2003; Ozis et al. 2007, 2016, 2018b; Acar 2010; IWA 2012).

Fig. 2.26 The Orifices (lule) in the operation chamber of the Yeni Dam. (Photo by Y.Ozdemir)

Fig. 2.27 Yedigoz Aqueduct-bridge on the Taslimüsellim Water Conveyance to Edirne. (Photo by U.Ozis)

2.6.1.3 Taslimusellim Water Conveyance to Edirne

The 50 km long Taslimusellim water conveyance system to Edirne is also considered as a work of Sinan, dating back to the 1530's and expanded some decades later. The conduit is a masonry gallery; the alignment passes over several aqueduct-bridges and includes certain tunnel sections. The system is for the large part still in operation (Fig. 2.27) (Akmandor 1968; Ozis and Arisoy 1986, 1987, 1996, 2000, 2003; Ozis et al. 2007, 2016, 2018b; DSI 2008).

Fig. 2.28 Maglova Aqueduct-bridge on the Kirkcesme Water Conveyance to Istanbul. (Photo by U.Ozis)

2.6.1.4 Kirkcesme Water Conveyance to Istanbul

The 55 km long Kirkcesme water conveyance system to Istanbul in the 1560's is one of the masterworks of Sinan, with four major aqueduct-bridges (Uzun, Egri, Maglova, Guzelce). The system includes more than thirty aqueduct-bridges of various sizes. The conduit is a masonry gallery and is for the large part still in operation (Ozand 1968; Cecen 1979b, 1984, 1986b, 1988, 1990, 1999, 2000; Ozis 1984b, 1987, 2001; Schnitter 1990; Ozis and Arisoy 1987, 1996, 2000, 2003; Ozis et al. 2007, 2016, 2018b; DSI 2008; IWA 2012).

Sinan's schemes are the most important long-distance water conveyance systems since Roman times. The aqueduct-bridges Uzun, Egri, Maglova, Guzelce of the Kirkcesme system, with heights up to 35 m and lengths up to 700 m, rank among the largest of their kinds in all times (Fig. 2.28).

2.6.1.5 Uskudar Water Conveyances to Istanbul's Asian side

The Uskudar water conveyance systems, to the east of Bosphorus in Istanbul, date back to the sixteenth up to the nineteenth centuries. The conduits are mostly baked clay pipes; noteworthy are the water balance towers for pressure control and distribution (Fig. 2.29) (Cecen 1979b, 1991b; Ozis et al. 2007; Dinckal 2001; IWA 2012).

2.6.1.6 Taksim Water Conveyance to Istanbul

The 23 km long Taksim water conveyance to Istanbul dates back to the 1730's and is still for the large part in operation. The conduit is a masonry gallery; it includes a

400 m long aqueduct-bridge over Buyukdere and initially an interesting inverted siphon. A new system for drinking water purpose, the Hamidiye water conveyance, collecting water from the same area, was constructed in the nineteenth century (Yungul 1957; Cecen 1979b, 1984, 1986b, 1992; Ozis 2001; Ozis et al. 2007; IWA 2012).

2.6.1.7 Kilyos Water Conveyance Near Istanbul

The short Kilyos water conveyance near Istanbul is interesting with regard to the water balance towers (Bildirici 2008).

Fig. 2.29 A water balance tower of the Uskudar Water Conveyances. (Photo by U. Ozis)

2.6.1.8 Other Ottoman Water Conveyances

The water supply systems of Sanliurfa, having roots in the Seljukide period (Kurkcuoglu 1992; Gerger and Kurkcuoglu 1997; IWA 2012; Yenigun et al. 2013); of Bursa (IWA 2012), of Corum (IWA 2012), and of Safranbolu (IWA 2012) are some other interesting systems.

Some of the Ottoman water conveyances to Izmir (Ozis et al. 1999; DSI 2008) and the Pasasuyu water conveyance to Izmit (Unal 2001) have roots in ancient periods. The diversion and conveyance of Ephesus' Degirmendere waters to Kusadasi (Ozis and Atalay 1999; Ozis et al. 1998, 2005b) and a water conveyance with aqueduct-bridges to Foca (Ozis 1994a, 1995, 1996) date back to the Ottoman times.

2.6.2 Water Distribution and Sewerage

Beyond the water conveyances, the water distribution and wastewater collection systems of Istanbul deserve also special interest (Sarikaya et al. 2001; Bildirici 2002; Dinckal 2005; IWA 2012). Besides the traditional baked clay pipes and cut-and-cover masonry channels, traditional kharizes are used for clean water collection and transport as well as wastewater collection (IWA 2012).

2.6.3 Cisterns

Several cisterns in the western and southern regions of Turkey date also back to the Ottoman period (Ozis 1982; Commito and Rojas 2010).

2.6.4 Dams

2.6.4.1 Istanbul Dams

In the period of 1620–1839, the Kirkcesme system was supplemented by four (Topuz, Buyuk, Ayvat, and Kirazli) and the Taksim system by three (Topuzlu, Valide, and Yeni) masonry dams, with heights up to 17 m and crest lengths up to 104 m. All these dams, located at the Belgrad forest to the north of Istanbul, are still in operation (Figs. 2.30 and 2.31) (Yungul 1957; Cecen 1968, 1979b, 1984, 1986b, 1987, 1988, 1990; Ozis 1977, 1981a, 1984b, 1999; Tutuncuoglu and Benzeden 1979; Schnitter 1994; Ozis et al. 2007; DSI 2008; Acar 2010).

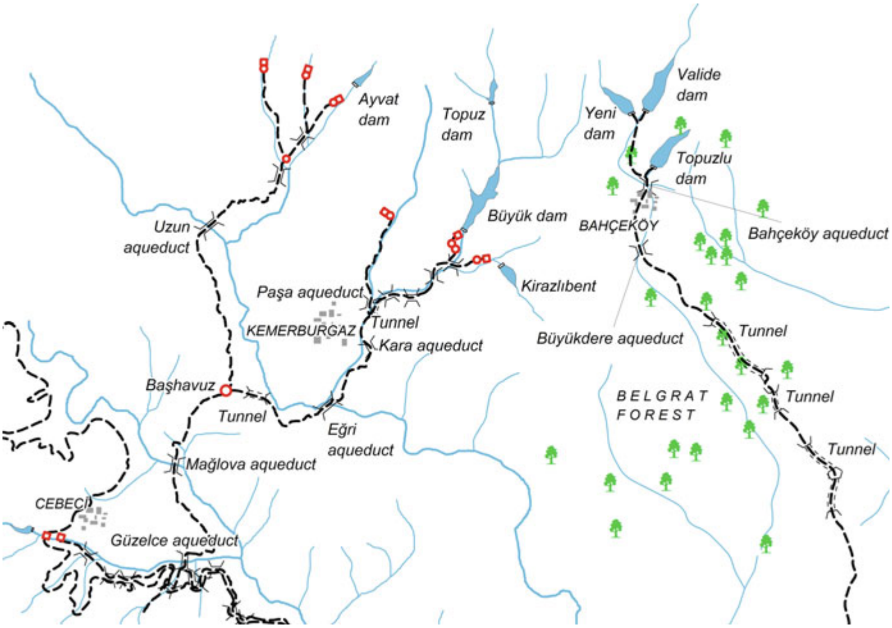

Fig. 2.30 Location of the Historical Istanbul Dams with the upper parts of the Kirkcesme and Taksim Water Conveyances. (U.Ozis and Y.Arisoy)

Fig. 2.31 Yeni Dam supplying the Taksim system. (Photo by Y.Ozdemir)

The majority of dams constructed until these centuries were embankment dams, so that the masonry dams of Istanbul deserve a special place with regard to the historical development of dams.

2.6.4.2 Other Ottoman Dams

There are also some newer dams of the nineteenth century like Samlar and Elmali I dams around Istanbul (Cecen 1987; Ozis 1999), and the 23 m high Maden dam near Karasu. The Semali embankment dam near Amasya is considered as an Ottoman dam. It is mentioned in certain sources that the imperviousness of the dam was achieved by covering the upstream face with ox-skins (Ozis 1999).

2.6.5 River Diversion

2.6.5.1 Sakarya – Sapanca Diversion

The engineer and architect Sinan planned in 1583 the diversion of the Sakarya river to the Marmara sea over Lake Sapanca for flood control, water power (mills), and river navigation purposes. This idea had roots in the sixth century but could not yet be realized until present times (Cecen 1981).

2.6.5.2 Gediz Diversion

The Gediz river was diverted to the outer bay in the late nineteenth century in order to prevent the closure of the Izmir Bay (Ozis 1994a; Buyukyildirim 2017).

2.6.6 Irrigation

Various irrigation systems under actual operation have their roots in Ottoman times, like the Surgu irrigation near Malatya from nineteenth century, and the Beysehir-Cumra irrigation south of Konya from early twentieth century (Bildirici 1994; Ozis 1994a; Ozis et al. 2009; Buyukyildirim 2017).

2.6.7 Water Power

The first electricity was generated in Turkey in 1902 in the Tarsus hydroelectric scheme (Ozis 1994a; Ozis et al. 2009, 2014a). The scheme used the elevation difference of the Berdan River at Tarsus falls.

2.7 Conclusion

Ancient hydraulic works, dating back to various civilizations of her last 4000 year long history, make Turkey one of the world's foremost open-air museums in this respect. Some of them are, with very few repairs or modifications, still in operation after several centuries or even millenia. Based on this tradition, Turkey has continued to harness her water resources during the Republican period.

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This text summarizes the studies and field investigations of the first author for more than 40 years, often in cooperation with several colleagues and students. The authors wish to thank their close colleague civil engineers for their contributions, many of them being also former students of the first author, whose names often appearing as co-authors of publications cited in the lists of references, especially to the late Prof. Dr. Orhan Baykan. The present text is an updated version of several previous publications of the authors, given in the list of references.

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