Drainage and Sewerage Systems at Ancient Athens, Greece

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Evolution of Sanitation and Wastewater Technologies through the Centuries

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Edited by

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Prolegomena: *Probing the past and facing the future*

'Ομοια γάρ ως επί το πολύ τα μέλλοντα τοις γεγονόσι.
Most future facts are based on those in the past.
Euripides, 480–406 BC, Ancient Greek Tragic

It is well documented that most of the technological developments relevant to water supply and wastewater are not achievements of present-day engineers but date back to more than five thousand years ago. Already during the Bronze Age such. developments were driven by the necessities to make efficient use of natural resources, to make civilizations more resistant to destructive natural elements, and to improve the standards of life, both at the public and private level. With respect to the latter, Minoans in the island of Crete (*ca*. 3200–1100 BC) and an unknown civilization (*ca*. 2600–1900 BC) in Indus valley at Mohenjo-Daro, Harappa, and Lothal developed advanced, comfortable, and hygienic lifestyles, as manifested by efficient sewerage systems, bathrooms and flushing toilets, which can be compared to the modern wastewater system of today, re-established in Europe and North America only a century and half ago. The amazing evolution and development of structures for bathing, sanitary and other purgatory installations can be traced from the Minoan palaces and houses at Mohenjo-Daro, Harappa, and Lothal up to the cities of Ancient Egypt, of the Hellenistic period, of the Chinese Dynasties and Empires to the facilities built during the Roman period. It is interesting that very unsanitary conditions and overcrowding were widespread throughout Europe and Asia during the Middle Ages, resulting periodically in cataclysmic pandemics such as the Plague of Justinian (541–542AD) and the Black Death (1347–1351AD), which killed tens of millions of people and radically altered societies.

The book 'Evolution of Sanitation and Wastewater Technologies Through the Centurie' presents the major achievements in the scientific fields of sanitation throughout the millennia from a wide geographic perspective. It provides valuable insights into ancient wastewater technologies and management with their apparent characteristics of durability, adaptability to the environment, and sustainability. A comparison of the water technological developments in several civilizations is undertaken. These technologies are the underpinning of modern achievements in sanitary engineering and wastewater management practices. It is the best proof that 'the past is the key for the future.'

A timeline of historical developments associated with sanitation and wastewater management worldwide through the last 5500 years of humankind´s history is considered. A chronological order is followed with emphasis to the major periods and the corresponding worldwide civilizations.

Rapid technological progress in the twentieth century created a disregard for past water technologies that were considered to be far behind the present state of knowledge and engineering. There is a great deal of unresolved problems, still, related to the wastewater management principles, such as decentralization of treatment processes, durability of the water projects, cost effectiveness, and sustainability issues such as protection from floods and droughts. In the developing world, such problems were intensified to an unprecedented degree.

Moreover, new problems have arisen such as the contamination of surface and groundwater. Naturally, intensification of unresolved problems led societies to revisit the past and to reinvestigate the successful past achievements. To their surprise, those who attempted this retrospect, based on archaeological, historical, and technical evidence were impressed by two things: the similarity of principles with present ones and the advanced level of wastewater engineering and management practices in the past.

Most likely urbanization will continue to increase. The proportion of people living urban areas might rise to 80–90% of the global population. This means that innovative sanitation technologies must be developed to regulate and manage municipal wastewater and stormwater. Many of these technologies will be based on decentralized principles, will serve different sizes of buildings from single-family homes to high-rise buildings, public or commercial buildings. Treated water might be readily reused locally for various purposes such as toilet flushing, watering gardens or car washing. Sludge from decentralized plants can be used as fertilizer as demonstrated in the past at various locations in the world. Also, measures and technologies for harvesting rainwater in order to reduce the flood risk and increase water availability need to be further developed.

There is much we can learn from past technologies and practices that were implemented. This includes for example design philosophy, adaptation to the environment, and decentralization management of water and wastewater projects, architectural tied to operation aspects, and sustainability as a design principle. It is time to think about managing the complete water cycle, to do so with impunity we look towards *probing the past, forging the future.*

70 authors and or co-authors from several disciplines and regions of the planet developed the chapters in this book. The disciplines include Archaeology, History, Engineering, Life sciences, Health sciences, History of Medicine, Environmental sciences, Biology and Geosciences. The geographical coverage is very wide, with prominence in the Mediterranean world. However, several other civilizations from other parts of the world, such as Asia (Iran, India, China, and Korea), Central Europe, and South America are also covered. The themes of the Chapters included are from prehistoric to medieval and even modern times. All Chapters submitted were peer-reviewed by at least two reviewers and the Editors.

The book is organized in six parts. The first three chapters in the first Part are introductory mainly referring to pre historical civilizations. The eleven chapters in the second Part refer to historical civilizations (including Archaic, Classical, Hellenistic and Roman) over the globe. The six chapters in the third Part, should be considered as case studies; major cities with long histories are included. The following two Chapters in the fourth Part address the history of water borne diseases. The final four chapters in the fifth Part mainly deal with cases in the modern times. The last chapter (sixth Part), summarizes and synthesizes the conclusions, comparison, and lessons learned with some commentary on the future.

We appreciate the efforts and contributions of the authors who have written a compilation of the labours of humankind to bring sanitation to the people and cities. We are particularly grateful to Dr. Peter A.

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Chapter 15

Drainage and Sewerage Systems at Ancient Athens, Greece

E.D. Chiotis and L.E. Chioti

15.1 INTRODUCTION

Urban wastewater and stormwater technologies in Greece have already been reviewed by Angelakis et al. (2005), with a brief reference to ancient Athens. The present study focuses on Athens in particular and relies extensively on published archaeological evidence extending from the Classical to the Late Roman period[1].

The city walls shown in Figure 15.1, adapted from Theocharaki's study (2011), are a good marker of the urban area occupied by the ancient city of Athens; the figure displays also a general plan of the terrain, the natural drainage network of streams and rivers and the mountains of Parnitha (Pa), Penteli (Pe), Hymettus (Hy) and Aegalaio (Ae) surrounding the Kifissos plain.

Modern urbanization has covered up most of the natural drainage network. Despite that, the streams at elevations above fifty meters can be reliably delineated on detailed topographic maps, especially if in addition maps of the 19th century are taken into account; this combination was actually applied for the compilation of the Figure 15.1.

Torrential rains cause significant natural disaster in the Mediterranean region and Greece in particular. The evaluation of precipitation in Athens for a long period of time (1891-2000) has revealed that extreme daily precipitation of more than 10 mm occurs statistically in 3 to 24 days per year and more than 20 mm in 0 to 11 days (Paliatsos et al. 2005). Thus, torrential rainfalls represent a significant fraction of the average annual precipitation of 400 mm in Athens and this necessitates an effective drainage system. Furthermore, local geology favours surface run-off of rainwater since the broader area is covered by schists and only about 5% of the precipitation penetrates the ground. Only the tops of the hills are covered by limestones which are good water reservoirs, of limited areal extent and capacity though.

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[1] The following historical periods are often mentioned below: Classical (480-323 BC, from the first Persian war to the death of Alexander the Great), Hellenistic (323 BC–146 BC, i.e. up to the control of Greece by the Romans), Roman (146 BC-267 AD, i.e. up to the Herulians' invasion) and Late Roman period, roughly up to late 4th / early 5th century AD.

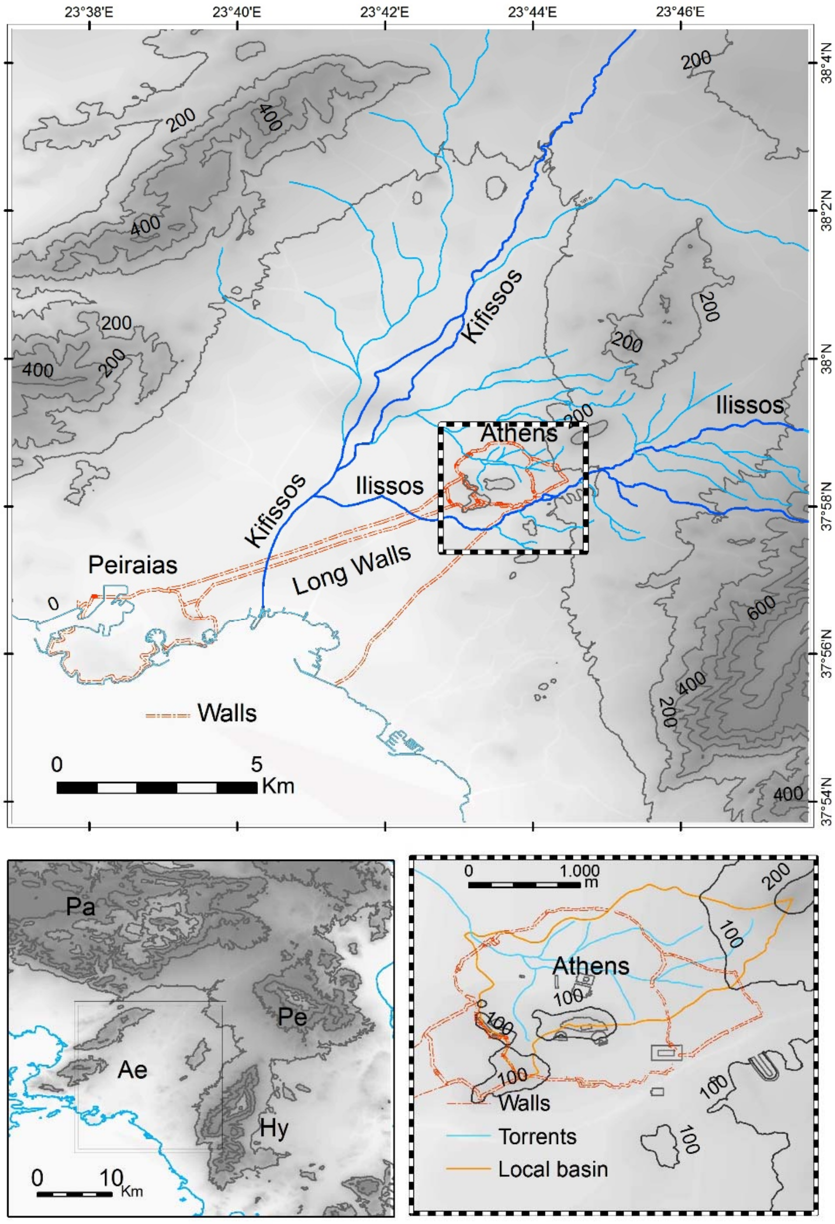

Figure 15.1 Rivers and streams surrounding the area of study (top); western Attica and the adjacent mountains (lower left); the area of study (lower right). Inset frames delineate magnified areas.

Two hydrologic domains can be distinguished in Athens, separated by the east-west trending watershed passing through the Acropolis hill: a) the steeper southern slopes of the Acropolis hill and b) the rather flat domain north of the Acropolis hill, which is drained by a network of streams, as shown in the Figure 15.2.

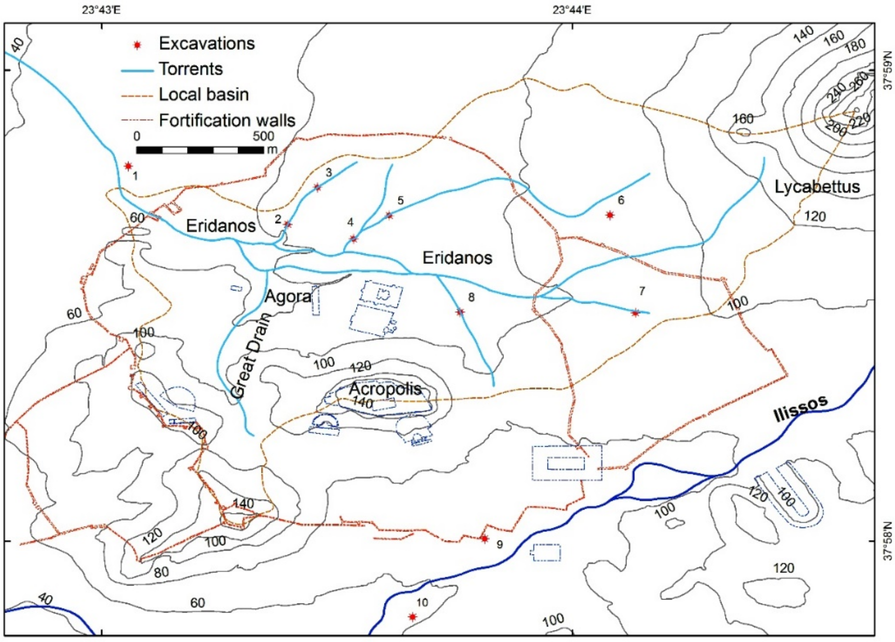

Figure 15.2 The network of streams of the local hydrologic basin of ancient Athens.

In the northern domain the streams were modified into artificial drainage channels. In the late 6th or early 5th century BC, the so called Great Drain (Figure 15.2) was the first stream transformed into an artificial drainage channel at the western side of the Agora, which was the political centre of the city. This made possible the establishment of public buildings in an area previously occupied by swamps. The Great Drain was built with heavy walls of polygonal-shaped stone blocks covered with stone plates to serve as a street. It is very well preserved and measures internally 1x1 m. It has served as the prototype of drainage channels that followed in the next centuries. As public buildings expanded in the Agora, additional stone-built channels were progressively constructed which discharged into the Great Drain, as described by Chiotis and Chioti (2012, Figure 16.22). The Great Drain continues to drain the Agora today. The images http://agora.ascsa.net/id/agora/image/2000.03.0008, http://agora.ascsa.net/id/agora/image/1997.04.0260 and http://agora.ascsa.net/id/agora/image/1997.04.0289 at http://www.agathe.gr of ASCSA (American School of the Classical Studies at Athens) are representative pictures of the Great Drain. In the southern domain Underground pipelines, usually along the streets, were used as sewers, due to the lack of natural runoff courses. Drainage control is aggravated by the steep dip of the terrain and the dense occupation of the area during the Classical-Roman times. In addition, the Ilissos valley was dotted with sanctuaries and public buildings; therefore restrictions were implemented to prevent pollution of the river and the adjacent sanctuaries from tanning, as implied from the inscription IG I^3 257 (Karouzos 1923).

An additional major feature of the city's drainage system was the trench surrounding the circuit walls.

15.2 TYPES OF DRAINAGE AND SEWERAGE STRUCTURES: PIPELINES, CHANNELS AND GALLERIES

The same structures were used both for wastewater and rainwater at Athens during the studied period. Various types of terracotta pipes (http://agora.ascsa.net/id/agora/image/1997.09.0382) were used depending on the particular application. Special terracotta pipes were used in the Peisistratean aqueduct late in the 6th century BC (http://agora.ascsa.net/id/agora/image/1997.04.0152); they were tightly connected with lime mortar. A hole closed by a lid was available for the placement of the mortar and perhaps for cleaning the calcite deposits. The pipes were placed in trenches with the hole closer to the end of the previously laid pipe section (Lang 1968; ASCSA: http://agora.ascsa.net/id/agora/image/2004.01.1571).

Rectangular sections were commonly applied either to transfer waste from the buildings into larger pipes or to serve as gutters for the flow of rainwater along the streets. When placed in the ground they were covered with terracotta plates or tiles originally used for other applications, such as tiles for the lining of wells (http://agora.ascsa.net/id/agora/image/2004.01.1091); occasionally, they were covered with pieces of U-shaped tiles.

The U-shaped tiles were extensively used in couples for the construction of elliptical pipelines for drainage or water supply. The pipes were composed of two symmetrically placed parts 0.45x0.45 m, up to 5 cm thick (http://agora.ascsa.net/id/agora/image/1997.09.0397); manholes were also constructed at intervals (http://agora.ascsa.net/id/agora/image/1997.09.0393). U-shaped tiles were used in the 4th century BC in the Acharnian aqueduct which was designed for the water supply from the springs at the foothills of Parnitha Mountain to the city of Athens (Vanderpool 1965).

Elliptical pipes laid in trenches became very common in underground drainage lines along the streets in the Hellenistic and the Roman times; amphorae were usually placed on top to reduce, as believed, the overburden. Burying amphorae layers in drainage ditches was a technique applied also in the 1st century BC in Rome in land improvement projects (Wilson, 2000b, p. 316). It is therefore suggested that amphorae, commonly placed in Athens on top of U-shaped pipe lines in trenches, would also contribute to the drainage of rainwater from the surface of the streets, as the voids between the amphorae provide a horizontal way of flow of easier circulation.

Underground channels built of bricks were developed in Roman times, particularly in great buildings, like the Hadrian's Library, to drain the rainwater from large open spaces (Tigginaga 2008). Channels made of cast concrete were also introduced in the Roman times.

In nearly flat areas or in swamps drainage was accomplished by means of dipping underground galleries carved in soft rock; a section of a 33 m long drainage gallery was studied by Axioti (2009) in an excavation at the centre of Piraeus, about 100 meters NW of the ancient theatre. The shallow gallery, trending NW-SE, was uncovered beneath the axis of a street heading towards the harbour of Zea; it was dug in the soft rock, 0.55 m wide and 1.10 m high. It is emphasized that drainage galleries were conveniently accommodated in the rectangular Hippodamean urban plan of Piraeus. Rainwater was collected in the galleries through a system of shafts and trenches. The cisterns which accumulated and stored the rainwater from the roofs of the adjacent houses were dug in the yards, the location of which was generally anticipated in the city-plan (Axioti 2009).

A similar drainage gallery, 1.70 m high and 0.50 m wide, was excavated over a length of 65 m at the Kerameikos cemetery, beneath a mass burial, located in the middle of a swampy area (Baziotopoulou-Valavani and Tsirigoti-Drakotou 2000).

It is summarized that the commonest principal structures of drainage and sewerage can be classified into three main types: a) pipelines, most commonly elliptical, buried in trenches along streets b) stone masonry channels along streams or streets and c) unlined galleries hewn in soft bedrock. The close connection of the drainage networks with the streets is emphasized.

As Costaki (2006) notes, water supply and drainage systems installed beneath the streets was rather elaborate, ranging from great drains and aqueducts in public areas to drain pipes piercing walls of individual houses and emptying into street drains.

Water pipes and sewers in parallel lines along streets are described below at the excavation for the Acropolis Museum (section 15.3.2.2). A unique case of drainage and water flow in opposite directions is described by Camp (2007) along the north-south street west of the Painted Stoa, at the Agora's NW corner, where water in pressure pipes was directed uphill and waste in elliptical tile pipes southwards emptying into the so called Eridanos River by gravity flow.

The function of roads not only as conduits for people, goods, and wheeled traffic but also for water and waste management is perfectly demonstrated at a Roman road at ancient Corinth recently studied by Palinkas and Herbst (2011). It is impressive that the road in the Panayia Field of the Roman forum at Corinth "contains 31 successive lines of pipes and drains that represent solutions to water supply and sewage management within the city" over a period of six centuries.

15.3 DRAINAGE OF REPRESENTATIVE AREAS

Drainage structures are described below in two representative areas of ancient Athens, i.e. the local hydrologic basin and the southern slopes of the Acropolis hill.

15.3.1 Drainage in the hydrologic basin north of the Acropolis hill

Archaeological excavations reveal the function of streams in the drainage of the buildings and confirm at the same time the geometry of the network of streams as drawn in the Figure 15.2.

Excavations at the site No 5 (Figure 15.2) uncovered a sanctuary of Zeus and Athena along an ancient road passing over a channel (Kyparisses and Thompson 1938). The walls of the channel were made of large blocks of limestone and conglomerate and were spanned by a carefully constructed flat vault of bricks. The top of the vault was approximately at the level of the road. The walls of the channel are dated to the Hellenistic and the brickwork to the Roman period. The channel is located along a stream (Figure 15.2, site No 5) and the vault served actually as a bridge. The excavators noted that the marked topographic irregularity, of five meters difference in elevation across the street would certainly not have been suspected from the present level surface of the region; it is expected though between the bank and the bottom of a stream. Similar bridges over streams were also uncovered across the so called Eridanos River at the Sacred Gate, NW of the Agora and at the Monastiraki square at the recent excavation for the Metro station.

A similar drain channel was excavated at the location No 4 (Alexandri 1967a); the walls, made again of large stone blocks, are spanned by a vaulted roof of bricks; the structure is dated to the times of the Roman Emperor Hadrian (117-138 AD).

At the site No 2, an elliptical tile pipeline set below a Roman street drains towards the adjacent stream (C΄Archaeol. District 1964); the roof of the pipe is covered with amphorae to reduce the overburden. At another excavation (Alexandri 1973), some fifty meters N-NE from the site No 2, another channel built of brick-walls and floor of square terracotta plates conveyed rain water and domestic waste to the same stream. Furthermore, a channel of monumental size was uncovered some 50 meters NW from the site No 2 next to hypocausts for baths. It is enclosed in a rectangular structure made of Roman concrete (opus caementitium) with external dimensions 2.80x2.45 m (Alexandri 1975). Waste was emptied directly into the same stream by rectangular tile pipes at the site No 3 (Stavropoullos 1965a).

Streams of the local hydrologic basin of Athens were also excavated at the sites No 6 and No 7. It is suggested that archaeological excavations with fluvial or torrential sediments should not be correlated in space as points arranged linearly, but through the dendrogramme of the Figure 15.2.

Another interesting drainage pattern was excavated some fifty meters west of the site No 4 (Alexandri 1967b), where the local drainage lines are arranged along the streets. This solution seems to be preferable in areas closer to a street than a stream. The channels, enclosed between the retaining walls of the streets, are dated in the beginning of the 4th century BC. They collected the waste directly from the houses by means of terra cotta pipes placed below the floor of the buildings. Houses were being erected here over a long period, from the beginning of the 4th century BC till the Late Roman times and the drainage structure was maintained in use over this period.

The artificial drainage system interlaced with the network of streams was developed continuously through the Classical to the late Roman times with remarkable technical improvements, such as the construction of bridges with vaulted roofs and drainage channels of cast concrete in the Roman and Late Roman times.

The drainage works described in this section can be classified into categories similar to those suggested by Wilson (p. 152, 2000a). The first order drainage from the buildings is connected to the second order drain along streets which in turn empties into the third order drain of the natural streams. Finally, the Eridanos River collects all streams and represents the fourth order drainage. Naturally, buildings close to a stream drain directly to it.

15.3.2 Drainage at the southern slopes of the Acropolis hill

Drainage and sewerage will be commented in two extensive excavated areas south of the Acropolis: the area "A", south of the Roman Odeion of Herodes Atticus and the area "B", south of the Theatre of Dionysos (Figure 15.3).

Figure 15.3 General plan of the southern slopes of the Acropolis hill projected on KTIMATOLOGIO air photo, where the areas A and B are delineated (top); the cisterns C1 and C2 south of the Odeion of Herodes Atticus are also shown (bottom).

15.3.2.1 Area south of the Odeion of Herodes Atticus

The area south of the Odeion of Herodes Atticus (area A in Figure 15.3) is of special historical importance due to the almost continuous occupation in the last millennia and the wealthy residences during the Roman period (Dontas 1962a and 1962b). New buildings were erected on the ruins of older ones and the remains are therefore rather fragmentary; however the drainage system (Dr), shown in Figure 15.3 (top), has been preserved in good condition, as it was constructed in the ground.

The oldest recognizable drainage network is dated to the middle of the 2nd century BC. It was composed of a main gallery hewn in the schists with lateral branches and manholes. The gallery was later opened and terracotta pipes were used instead, a measure which would protect ground water from pollution.

Elliptical tile pipes were used in the Roman period and the drainage network was extended with more lateral branches and tile-lined manholes; baths and a private latrine are dated in this period. Majestic baths were built around 400 AD. The route of the main drainage (Dr) is shown in the Figure 15.3 (top); the pipeline was placed in a trench in schists and extended over a length of 80 meters at least.

This drainage pattern became the standard practice in the Roman times. A central sewer dipping downhill was made of couples of U-shaped tiles and collected the waste from lateral sub-horizontal branches. Tile-lined manholes provided access for cleaning of the central drainage line.

The central line in the area A was placed below the foundation of the buildings with a slope about 10%. The drainage lines are in general arranged along streets where the terrain is gentler, dipping not more than 5%, as in the area B uncovered in the excavation for the foundation of the New Acropolis Museum.

The well preserved Roman cisterns C1 and C2 were essential for the water supply of the area at elevations above the 84 meters, since the aqueducts could not reach so high by gravity flow, as explained below. Drainage of the Odeion of Herodes Atticus was performed through a tile pipeline, the route of which is partly shown west of the cistern C1. The routes of the pipes supplying water to the cistern, adapted from Brouskari (2002), are also shown in the Figure 15.3.

15. 3.2.2 Excavation for the New Acropolis Museum and the Metro Station

The excavation for the New Acropolis Museum and the adjacent Metro station (area B in the figure 15.3) covered an area of 10,000 sq.m. and disclosed a complete part of the ancient city; continuity in the habitation of the area extended from the Late Neolithic to the Middle Byzantine times (Eleutheratou 2008).

The area emerged in the classical times as a thriving quarter of houses with yards, wells and cisterns. Urban partitioning of the area was already shaped in the last decades of the 5th century BC and was only marginally changed up to the 3rd century AD. The character of this densely occupied district changed from residential to manufacturing after Sulla's sack of Athens in 86 BC, when pottery, marble and steel workshops were developed. New and prosperous dwellings with private baths and lavatories were built in the 2nd and 3rd century AD, to suffer a new destruction during the Herulian invasion in 267 AD. Two baths existed in the Roman period and a third was added in the Late Roman times

The drainage network during the 2nd and 3rd centuries AD is shown in the Figure 15.4, adapted and simplified from Eleutheratou (2008). The triangular sector delimited between the main streets was occupied by houses with wells for drinking water in the yards and lavatories arranged close to the main street. A drainage network made of elliptical terracotta pipes existed along the streets which collected both rainwater and domestic waste, whereas the waste of the lavatories was accumulated in pits along the streets.

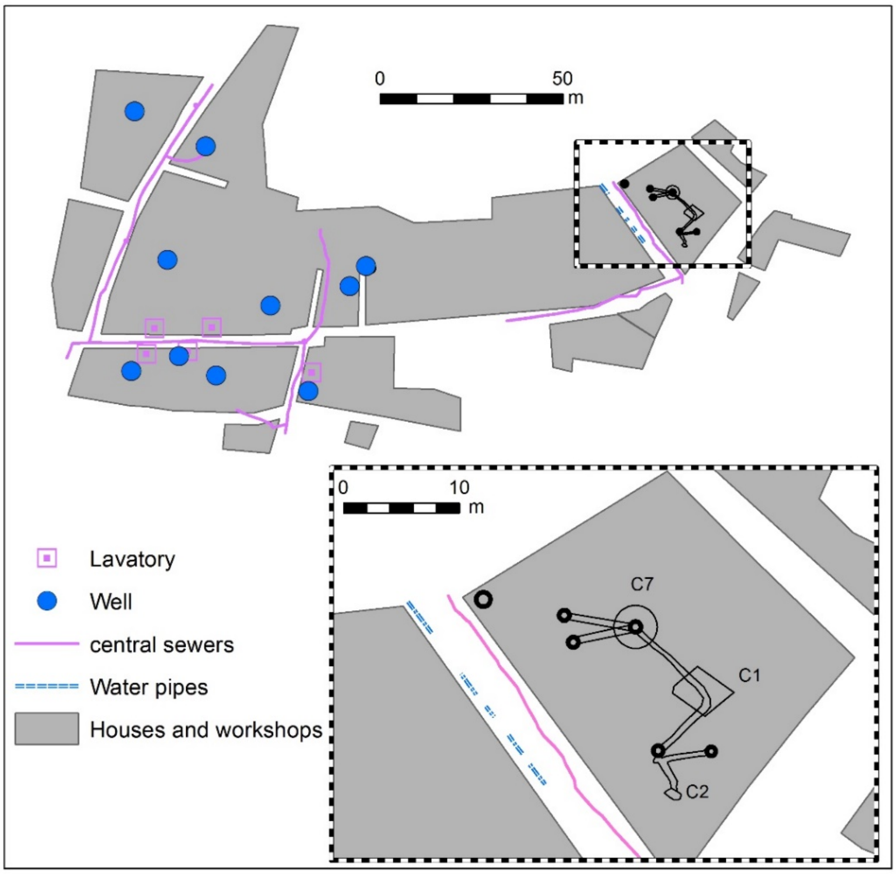

Figure 15.4 Hydraulic features of the excavation for the New Acropolis Museum, adapted from Eleutheratou (2008): the excavation area, “B”, is delineated in the Figure 15.3 (top).

Water pipes are also shown in the above figure which are dated to the second half of the 5th century BC and are considered to belong to an extension of the older Peisistratean aqueduct (Eleutheratou 2006).

15.4 UNDERGROUND STRUCTURES OF DOUBTFUL INTERPRETATION

Underground works for aqueducts and sewers are often of similar construction and as a result they are occasionally misinterpreted. Some of them deserve further investigation and are therefore summarized below.

A case of misinterpretation is believed to be that at the site No 8 in the Figure 15.2. A surface channel hewn in the bedrock has been interpreted as the Hadrianic Aqueduct (Stavropoullos 1965b). The channel was spanned with marble plates; there are no built or lined walls and the site of the excavation falls along a local stream of the basin of Athens; it should therefore be reinterpreted as a typical drain channel.

A significant structure of disputed interpretation is the gallery excavated in the National Garden close to the Valerian Wall; it was built in a shallow trench in the Athenian Schists. Its outline measured 2.05 m wide and 1-1.50 m high, the walls were 0.55 to 0.60 m thick, the roof was vaulted and the floor was paved with stones; it was inclined towards the city and was ascribed to the Hadrianic Aqueduct (Spathari and Chatzioti 1983). Another section of the same gallery was excavated in the extension of the previous one and was interpreted as a central sewer (Zachariadou 2000). The total excavated length is about seventy meters and this indicates for sure a significant work.

A gallery, almost identical in structure to the previous one, dated most likely in the 3rd century AD, was excavated near the Ilissos River (No 9 in Figure 15.2); it was built of stones and mortar with a vaulted roof and measured 2 m wide and 1.5 m high, including the walls, which were 0.45 m thick; it was founded on solid rock and its roof was 1.3 m below the surface (Alexandri 1968, Chatzipouliou 1988). The gallery (G) was situated near the city walls as shown in the Figure 15.5. It is suggested that this type of vaulted gallery (No 9) of heavy and waterproof construction does not correspond to any of the types of sewers previously reviewed in section 15.2. It was described by the excavators as a conduit and it is suggested by the authors that the possibility of connection with a sally port of the circuit wall cannot not be excluded.

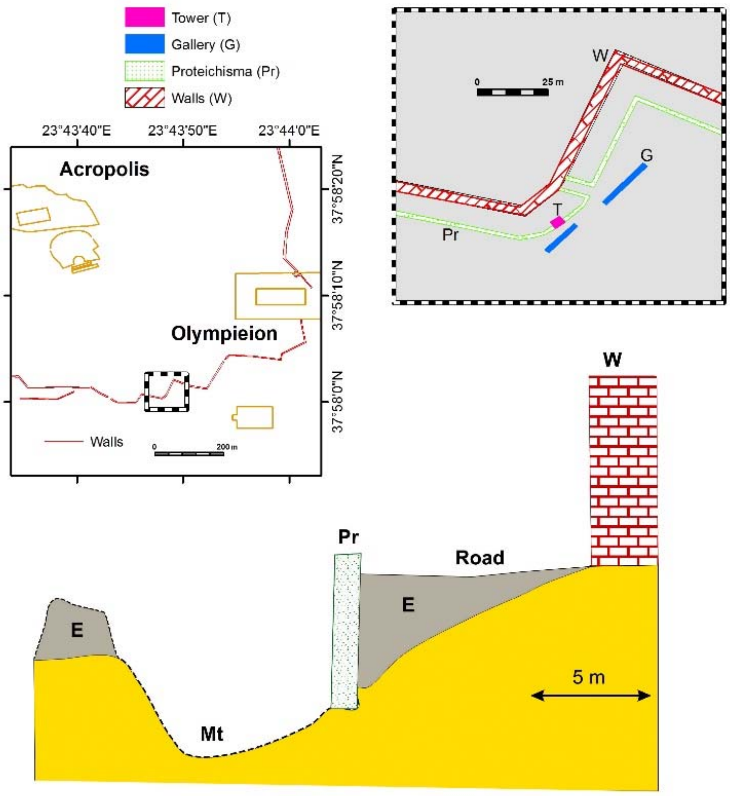

Figure 15.5 The fortification walls near the Olympieion (left), location map of a gallery sections G (top right) and schematic section through the wall (W), the ring road on earth pile (E), the proteichisma (Pr) and the moat trench (Mt) (bottom).

The excavations provided also good evidence on the walls at this site, which is summarized in the following in order to illuminate the function of the moat as a peripheral feature in the drainage of the city. The fortification system consisted of the circuit wall (W), the first defensive line or “proteichisma” (Pr), the trench of the water-filled moat (Mt), a ring street between the circuit wall and the proteichisma partially constructed on earth pile (E) (Figure 15.5). It is noted that in the 1st century AD, the ancient fortification moat was filled in with earth and the area was used for burials or constructions, such as channels, buildings and cisterns (Alexandri 1967c, Theocharaki 2011).

A gallery carved in soft rock, 0.6 m wide, 1.3 m high and about 10 m long, was excavated at the site No 10 (Figure 15.2). The site is projected on the Map of Kaupert (1878) close to a “Felsrinne”, i.e. a gallery hewn in the rock. Furthermore, limestone lenses either intercalated or thrust over the schists occur in this area according to the geological map; these data combined suggest that the particular gallery might be a work for water capturing.

Another excavation, No 1 in the Figure 15.2, with significant underground works is described along the Demosion Sema, the street connecting Athens with the Academy (Karagiorga 1978); a pipeline of elliptical tiles 5.60 m long and a manhole have been brought to light 5.60 m below the surface. The tiles were placed in a trench hewn in the schists in the Late Hellenistic times. They were covered with amphorae in two layers, according to the common practice for overburden reduction. In the 2nd century AD, the street seems to be abandoned and a “sewer” was constructed at the same place, founded 3.40 m below the surface. This “sewer” made of Roman concrete measured 4.90 m wide, the walls were 0.85 m thick and the roof was vaulted. Evidently, the dimensions of this structure correspond to a cistern.

15.5 LAVATORIES AND LATRINES

Lavatories in private houses existed in Athens since the 5th century BC. They were located inside the house close to the street and were connected to pits along the street below the ground level, where the waste was accumulated by gravity. The pits were emptied periodically and only household sewage was disposed in the drainage network, with the exception of latrines. The characteristics of lavatories in antiquity in the Greek territories as well as the ancient written sources on the subject are extensively reviewed by Antoniou (2010).

Thompson (1959) excavated a group of private houses on the gently sloping ground between the northern foot of the Areopagus and the east-to-west roadway that bordered the south side of the Agora. The houses were presumably established in the second quarter of the 5th century BC. As Thompson notes, a feature that would seem to be characteristic of these houses is a rectangular stone-lined pit set down below ground level, along the street; the pits were considered most probably as cesspits which were connected by means of a short length of drain with lavatories immediately inside the house (http://agora.ascsa.net/id/agora/image/1997.18.0089).

A similar pattern of lavatories and pits along the streets is also suggested by Steinhauer (2009) in Piraeus, in Classical building blocks of the Hippodamean urban design.

The most illuminating description of lavatories in private houses is due to the excavation at the New Acropolis Museum (Figure 15.4). The lavatories measured a few square meters in plan and their pit was about one meter deep and about half a sq. m. in plan. They were placed close to the main streets (Eleutheratou 2008).

Sanitation rules were adapted, the application of which was supervised by pertinent officers. As noted by Thompson (1959), a decree of 320/19 BC appears to prohibit cesspits in the streets of the Piraeus (IG II^2 380, lines 34-40). The waste of the lavatories was removed by the so called Koprologoi under the command of the Astynomoi, five for Athens and five for Piraeus (Steinhauer 2009).

Owens (1983) points out that although the collection of garbage was supervised by the state, a large part of the operation may have been in the hands of private entrepreneurs, the Koprologoi, who were able to turn a profit first by collecting waste material and then by recycling and reselling it as fertilizer. In addition, Owens stresses that it was the duty of the Astynomoi to ensure that the Koprologoi deposited the kopros at least 10 stades from the city. Further discussion on the function of Koprologoi is given by Papadopoulos (2006).

As Owens concludes "at Athens in the fifth and fourth centuries BC there existed a well-organised municipal service for the collection and disposal of sewage and waste. Citizens were forbidden to foul the streets and were obliged to empty waste and sewage into statutory dumps, which were periodically cleaned by the so called Koprologoi. The Koprologoi carried out a private service and collected the waste and then dump it beyond the permitted minimum distance from the city".

It seems that the same approach was practiced also in other Greek cities. Ault (1999) reexamined sizable stone-lined pits, sunk into the surface of the courtyard, in a number of houses of the 4th century BC excavated at Halieis in the southern Argolid. They were originally considered as cellars, but Ault reinterpreted them as cesspits. Furthermore, Ault accepted Owens's views on the organization of urban refuse disposal in Classical Athens and suggested that cesspits at Halieis were used as a source of fertilizers for the cultivation of olive trees.

Only two public latrines of the Roman period are known in Athens, the larger one close to the Roman market (Orlandos 1940) and the other one in the NW part of the Agora.

The latrine in the Agora was recognized close to the NW corner of the Poikile Stoa (Shear 1997); the channel under the latrine was flushed out with water at the NE corner and the waste flowed below the Panathenaic Way into the Eridanos River. The site of the latrine was occupied later in the Roman times by part of an enormous bathing establishment. A slab of Pentelic marble, preserving the characteristic keyhole-shaped opening of a communal latrine seat block, found in recent excavations of the ASCSA, should be associated with the above mentioned latrine (Camp 2007).

15.6 POSSIBLE SANITATION PROBLEMS

Shortcomings of Athens' public sanitation under extreme conditions are examined below to investigate potential drawbacks when normal life is disorganized, as in the case of war. The excavation of the New Acropolis Museum is taken as an urban model, since this quarter of the city is adequately known.

15.6.1 Sanitation and water supply at the excavation for the New Acropolis Museum

The regular water supply from aqueducts could easily be interrupted by enemies, since the water resources were beyond the city walls and the underground works of the aqueducts were accessible through noticeable wells or manholes; perhaps the Peisistratean aqueduct was less obvious. Thus, Athenians under siege, when enemies ravaged the countryside, would have to rely largely on the few springs around Acropolis, on wells and cisterns.

According to Eleutheratou (2006) the fact that the number of wells has increased significantly since the 2nd century AD is interpreted as an indication that even the aqueduct donated to the city of Athens by the Emperor Hadrian could not supply sufficient water. This is a reasonable assumption for the area of the New Acropolis Museum, although the Hadrianic aqueduct or any other aqueduct approaching Acropolis from the east could not supply water by gravity flow at elevations higher than 83.9 m because of topographic limitations. Both the Hadrianic and the Peisistratean aqueducts should pass through a narrow saddle at the elevation of 83.9 m in order to reach the slopes of Acropolis from east to west (Figure 15.6). Therefore, a waterbridge or a siphon would be required for the water to reach at higher elevations; there is, however, no such evidence in the area. Thus, the springs around Acropolis, groundwater from wells and the rainwater stored in cisterns were the only sources of water at the higher garland surrounding Acropolis. An indirect indication for that is the presence of the two spacious Roman cisterns near the Odeion of Herodes Atticus (Figure 15.3, top).

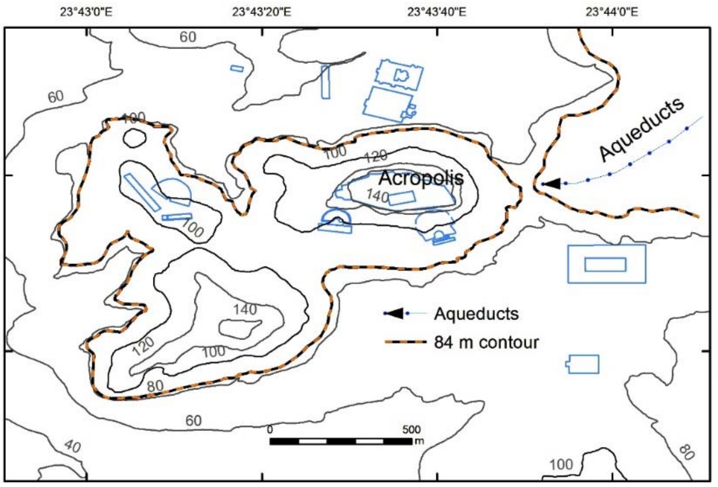

Figure 15.6 Potential route of aqueducts approaching the hill of Acropolis and the contour of 84 meters.

Figure 15.7 The area of the theatre of Dionysos projected on the Ktimatologio air photos, the drainage channel and the aqueduct after Dörpfeld and Reisch (1896).

A stone built channel (Figure 15.7) constructed for the drainage of the Dionysos Theatre was revealed in excavations (Dörpfeld und Reisch 1896); wasting this source of water would be extravagant for the water shortage of this particular area, but no associated cistern is known nearby. The pipelines described by Dörpfeld und Reisch at the theatre of Dionysos were uncovered at elevations higher than 84 m and cannot therefore be related to the Peisistratean aqueduct, as suggested by them.

The steep limestone hill of Acropolis is surrounded by a flyschoid formation, composed of schists with intercalations of sandstones and limestones. In the absence of better water reservoirs, this formation was the only local source of underground water and was therefore intensively exploited by means of wells and galleries. The wells were normally lined with especially designed tiles and this should reduce the pollution near the surface of the ground; however, the water bearing sections at the bottom of the wells would be unlined, exposed to potential pollution.

The proximity of sewers to water supply systems aggravates the danger of pollution in some densely populated areas of the city, like the one excavated for the New Acropolis Museum. Thus, 37 wells ranging in depth from 5.2 to 26.4 m and seven cisterns were uncovered at the excavation of the Acropolis Metro station within an area of 2500 sq. m. (Eleutheratou 1997). Based on these figures, the average distance between adjacent wells is estimated to 16 m.

No doubt, the sanitation conditions of water supply network through tile pipes along the street close to the network of sewers would be subject to pollution (Figure 15.4). Not only because of the proximity of the sewer at the other side of the street, but also due to the outlets of the domestic waste pipes which pass on top of the water pipeline. In addition, pollution would be possible through the elliptical opening of the water pipe sections (Marinakis 2000). It is noted that this pipeline (Figure 15.4), found below 84 m, is considered as a branch of the Peisistratean aqueduct and is dated to the second half of the 5th century BC (Eleutheratou 2006), which means that it might have been in operation during the Plague of the Peloponnesian War. Cisterns were lined with waterproof mortar and would be therefore less vulnerable to pollution: the water of the cisterns would normally be reserved for domestic use.

A rather sophisticated water system in the same area functioned during the Late Roman - Early Christian period (Kalligas 2000)[2]; it is a combination of old cisterns and wells with the addition of new cisterns (inset map of Figure 15.4). The system was composed of the cisterns C1, C2 and C7 which were connected through galleries and wells lined with waterproof plaster. The cistern C1, dated in Late Roman - Early Christian period, was built of tiles bound with mortar (Eleutheratou 1997). It is assumed by the excavators that this system collected rain water; it is envisaged though that it should not be excluded that the water could be supplied from a branch of the Late Roman aqueduct (Chiotis and Chioti 2011).

As mentioned earlier, lavatories were close to wells and constituted, therefore, an additional source of pollution. The waste would be normally disposed outside the city; if however the drainage lines were used instead of the sewers, pollution might have caused serious diseases. Furthermore, the statutory dumps of waste mentioned above by Owens would be a permanent source of pollution, also if the law was upheld. The experience from the beginning of the 20th century is mentioned for comparison: the use of sewage for the irrigation of cultivated fields from the stream of Prophet Daniel in Athens, in the Kifissos plain, has caused many diseases including typhus, dysentery, amoebae and other intestinal diseases (EYDAP at http://www.eydap.gr/index.asp?a_id=164).

A similar hazard might be likely in the ancient Piraeus in case of siege and civil disorder; it seems that city planning by Hippodamus around 460 BC accommodated a net of galleries for rainstorm drainage. If however lavatories were emptied into these galleries due to negligence of the Koprologoi, this could cause pollution of the wells.

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[2] According to the excavator this period includes the 4th, 5th and 6th century AD (Kalligas, p. 37, 2000)

15.6.2 The Plague during the Peloponnesian war

An impressive mass burial was excavated recently at the Kerameikos cemetery (Baziotopoulou-Valavani and Tsirigoti-Drakotou 2000; Baziotopoulou-Valavani 2002), dated approximately in 430 BC. It was therefore associated with the spread of the Plague in Athens during the first years of the Peloponnesian War (Baziotopoulou-Valavani 2002).

The cause of the Plague is a subject of longstanding controversy (Morens and Littman 1992). Based on molecular evidence, resulting from investigation and analysis of ancient DNA, typhoid fever was considered as a likely cause of the epidemic (Papagrigorakis et al. 2006); this conclusion, however, has been disputed (Shapiro et al. 2006).

The Peloponnesian War between the Athenians and Peloponnesians and their allies started in 431 BC when the Spartans invaded Attica and ended in 404 BC with the victory of the Spartans. The historian Thucydides in his History of the Peloponnesian War described also the Plague of Athens, a terrible epidemic which occurred first in 430 BC. Thucydides himself suffered the illness and survived.

As described by Thucydides in the second Book (2.52), "An aggravation of the existing calamity was the influx from the country into the city, and this was especially felt by the new arrivals. As there were no houses to receive them, they had to be lodged at the hot season of the year in stifling cabins, where the mortality raged without restraint. The bodies of dying men lay one upon another and half-dead creatures reeled about the streets and gathered round all the fountains in their longing for water. The sacred places also in which they had quartered themselves were full of corpses of persons that had died there, just as they were; for as the disaster passed all bounds, men, not knowing what was to become of them, became utterly careless of everything, whether sacred or profane". Under such conditions of disintegration "Fear of gods or law of man there was none to restrain them (2.53)" (translation by Crawley, 1950). Refugees in Piraeus in particular occupied the fortified space between the walls (Conwell 2008).

Under these conditions, sanitation problems in water supply and sewage disposal at Athens would be inescapable. This would obviously facilitate the dispersion of the epidemic and cause intestinal diseases even to those not infected by the epidemic itself.

15.7 CONCLUSIONS

A well organised infrastructure for water supply, rain water drainage and sewers, as well as a municipal service for the collection and disposal of lavatory waste existed in Athens since the 5th century BC. Drainage and sewerage works were adapted to the topography, the natural network of streams and rivers, the streets and the moat trench of the fortification.

The local drainage basin of ancient Athens is delineated on modern maps and the natural streams are traced and confirmed on the basis of archaeological evidence. It is also documented that these streams were gradually developed into the backbone of an artificial drainage network. Rainwater drainage was of great concern due to the climatic peculiarity of sudden rainstorms which can flood flat areas at once.

The so called Great Drain in the Athenian Agora was the first torrent transformed into a stone built channel in the early 5th century BC, designed mainly to drain rainwater in the flat area of the Agora, the political centre of Athens; the channel was covered with stone plates and served as a street too. More or less, all streams of the flat terrain north of the Acropolis within the city walls were gradually incorporated into an integrated drainage network.

Houses and workshops were drained through tile pipes which transferred the sewage into bigger U-shaped pipelines along the streets or directly into stone-built channels arranged along streams. Alternatively, drainage galleries were excavated at shallow depth in the soft basement rock to drain flat or swampy areas. The development of the drainage network all over the city and the application of rather standardized techniques are noted.

The drainage pattern of the buildings at the rather steep slopes south of the Acropolis hill was based on artificial drainage lines, either below the foundation and the retaining walls or along the streets.

Since the 5th century BC collection and disposal of waste and sewage was well organized in Athens; lavatories built close to the streets were established as a standard feature of the houses. In addition, municipal officers supervised the fulfilment of sanitation rules and restrictions.

However, the proximity of water wells, lavatories and sewers could cause water pollution if the sanitation rules were neglected, as in the case of war; the outbreak of the Plague in the first years of the Peloponnesian war would further aggravate the situation. Therefore under these conditions water pollution and consequent diseases should be considered as a very likely eventuality. Since, "it is conceivable that the Plague was a combination of diseases" (Salway and Dell 1955), it is suggested that symptoms associated with water pollution should be differentiated from those of the Plague itself.

City-planning of Piraeus by Hippodamos provided the space both for the accommodation of rainwater drainage galleries along the streets and for underground cisterns at the yards of the houses.

By comparison of the drainage and sewerage techniques at ancient Athens to the elaborated prehistoric drainage systems in Mesopotamia, the Indus Valley and Knossos, a couple of millennia BC, Wilson's conclusion (p.178, 2000a) is justified, that "the individual elements of drainage systems appear relatively early and remain largely unmodified until the Middle Ages.

The remarkable point with the well organized infrastructure of drainage and sewerage of Athens is, in the authors' opinion, the social structure which supported the regular operation of the system. The "cheaply built" houses of Athens in the Hellenistic times, in the opinion of the traveller Heraclides Creticus, made use of the same sanitation infrastructure with the "few houses of higher standard". In addition, all citizens enjoyed "the most beautiful sites on earth: a large and impressive theatre, a magnificent temple of Athena, something out of this world and worth seeing" (Austin, p.151, 1981).

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