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A Brief History of Urban Water Management in Ancient Greece

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10.1 Introduction

It is commonly accepted that technologies and infrastructures related to use of water were developed as early as the 6th millennium BC in Egypt and Mesopotamia. In Greece, such technologies first appeared in the Minoan Crete and the Mycenaean Mainland Greece during the 3rd and 2^{nd} millennium BC, respectively. The end of the Mycenaean civilization (around 1100 BC) is followed be the Dark Ages (*ca*. 1100 - 700 BC) a period characterized by the decrease of the population and the disruption of the cities. Under a general lack of archaeological data for this period, no evidence for hydraulic works has been found so far. At about 700 BC a new period, known as archaic Greek antiquity, starts, which is characterized by urbanization, spread of the colonization, and emerging of city-states. The first urban water infrastructures are developed under a political system known as tyranny.

Evolution of water systems continued in later periods, in the Classical and Hellenistic antiquity (*ca*. 500-67 BC). Exceptional examples of advanced water infrastructures and management practices of these periods are found in Athens, Aegean islands and Asia Minor. The infrastructures impress not only for their scale, but for their integration even by today standards. Some of the infrastructures are still in use, demonstrating how far sustainability can go.

Although the archaeological and technological documentation on ancient Greek water systems and management practices is extensive (mainly following an object-oriented approach), the following aspects need further investigation:

(a) What are the conditions that led societies or city states to construct and operate complex and costly infrastructures?
(b) How the developments in the form, the structure and the scale of the city of the past interrelate with the contemporaneous developments on water resource technology and management?
(c) How water management and legislation interrelate with technology of urban water systems?

Previous works (Koutsoyiannis *et al*., 2008) shed light on the management frame of urban water management in the city of Athens. The basic conclusion of this analysis was that water infrastructures were combined by non-structural measures, including support by legislation (e.g. Solon's laws). Here we further explore the above questions using several examples. The interested reader can find more information on these examples at the *Web Based Information System for the Inspection of the Hydraulic Works in Ancient Greece* (http://itia.ntua.gr/ahw/works/; see also Mamassis and Koutsoyiannis, 2010), which contains data for almost 100 important hydraulic works from the Minoan era up to the Roman period.

10.2 Prehistoric Greece

The hydraulic technological frame of the ancient Greece was formed very early, during of the Minoan/Cycladic and Mycenaean era. There is a difference of scale between Minoan and Mycenaean water systems. The former were mainly focused on domestic water use at the palatial scale whereas the latter targeted agricultural water use (irrigation and drainage) and were larger-scale systems.

The technologies and practices developed in Minoan Crete, at the scale of the palace, include (Angelakis *et al*., 2005):

- *potable water systems*, like the network of terracotta piping located beneath the palace floors in Knossos;
- *wastewater and storm water sewage systems*, like those found at Knossos, Zakros and Phaistos palaces;
- *hygienic water use systems*, like bathrooms with flushing toilets.

The study of those elaborate infrastructures has revealed a degree of development that presupposes a good understanding of water flow. Similar urban sewer systems have also been found in the island of Thera (Santorini) and other prehistoric sites of the Aegean civilization (*ca.* 3200 - 1100 BC).

Mycenaean civilization depended on agricultural production. In order to cover the increased water needs for agriculture (even in modern Greece, about 85% of total water consumption is used for irrigation), Mycenaeans chose closed river basins for their settlements and developed large scale flood control and drainage infrastructures, for the first time in Greek territory (Koutsoyiannis et al., in press). The prosperity of areas like the Arcadian and Boeotian Orchomenos is directly connected to the successful operation of these projects.

10.3 Archaic Greece: the formation of the city-state and the impact of tyranny

10.3.1 Urbanization: the model of the city–state

In archaic Greek antiquity, a new political and societal model starts to form: the city-state. Additionally, spread of the colonization occurs. An explanation of the emerging of the city-state model has been given by Doxiadis (1964):

> *"Greece is divided by mountains into small plains. It is in these plains that the major part of land cultivation takes place and we can roughly say that these do not exceed 20% of the ancient Greek peninsula. The physical boundaries of the small plains form the boundaries of the city-state. These areas range from fairly small states with an area of 100 km^2 such as the state of Aegina, to fairly large states, such as the states of Arcadia and Laconia which spread over an area of about 5 000 km^2. Diagrammatically, we can thus visualize the ancient Greek states as squares of 10 by 10 km, which could be crossed from end to end in 2 hours or so, to squares of 70 by 70 km, which need 14 hours to cross on foot."*

During that period, cities depended on trade, rather than on agricultural production, which triggered new criteria for city siting. The locations of the new cities tended to appear in dry places, at a distance from rivers or lakes, but attention was paid to water adequacy in the event of war. In addition, the core of the city moved from the palace or the Acropolis to the Agora. As Agora gradually became the centre of political, social and commercial activities, hygienic technologies were gradually implemented at a larger scale, the scale of the Agora. The cities grew considerably and the first large-scale urban water infrastructures were developed. At the political level, institutional progress led to tyranny.

10.3.2 City siting

Observation of the most important cities of the Greek antiquity leads to the conclusion that they are mainly located in dry climates (with annual precipitation of about 500 mm/year or less). City siting in dry places, must have been primarily driven by the laws of the natural selection with the populations established in dry climates having larger probability to survive, as they were protected from water-born diseases. In the centuries that followed, Greeks must have progressively assimilated the fact that dry climates are generally more convenient to live and healthier. As a result, most major Greek cities during the several phases of the Greek civilization that lasted for millennia were established in those areas that had the minimal rainfall across the continental and insular Greece.

As the model of city-state starts to dominate, the economy moves from agriculture- to trade-based. This change of the societal model gradually reduces the dependence of the economy on water, allowing the relocation of the centre of human activity at a distance from large water bodies (rivers and lakes). Thus, contrary to Mycenaeans who used to settle close to flood plains of rivers, that is, the most fertile areas, no major city in flood-prone areas existed in the Classical Greek antiquity. The importance of city siting can be inferred from Aristotle's Politics (VII, X, 4):

> *"The site of the city itself we must pray that fortune itself may place on slopping ground, having regard to four considerations: first, as a thing essential, the consideration of health (for cities whose sites slopes east or towards the breezes that blow from the sunrise are more healthy, and in the second degree those that face away form the north wind, for these are milder in winter); and among the remaining considerations, a slopping site is favorable both for political and for military purposes"* (translation by Doxiadis, 1964, p. 346 - 364).

However, the above criteria have not been applied for cultural and places, many of which (e.g. Delphi, Olympia, and Dodone) are situated in areas with adequate water resources, e.g. close to springs or inside groves, and if this was not practical, great efforts were made to transfer water and plant the area (Camp, 2004, p.113).

10.3.3 Safety of water supply

Safety in the event of war imposed city development around a natural rock (e.g., the Acropolis of Athens or the Acrocorinth). Even if there was enough water to the wider area around the town, additionally, there should be enough water within the walls of the acropolis, in case of siege. According to Aristotle the driving force behind the development of small-scale constructions (such as cisterns) was ensuring adequacy of water in the event of war:

> *"There should be a natural abundance of springs and fountains in the town, or, if there is a deficiency of them, great reservoirs may be established for the collection of rainwater, such as will not fail when the inhabitants are cut off from the country by war"* (Aristotle, Politics, 7, XI, translation by Benjamin Jowett; http://classics.mit.edu/Aristotle/politics.7.seven.html).

Figure 10.1. Area of Klepshydra spring.

Thus, water adequacy was primarily ensured by natural springs and/or wells. In the case of the Acropolis of Athens, the Klepshydra spring, which is believed to have been discovered in the second half of the 13th century BC during the fortification works, ensured water adequacy (Figure 10.1). In addition beneath the Parthenon, on the southern cliffs of the Acropolis, is a sacred spring in a small cave. While details of its earliest use are lost, it is known that the spring became the focal point of a sanctuary to the healing god Asklepios by the 5th century BC. (http://www.hydriaproject.net/en/cases/athens/acropolis_hill_/water_works.html). Also, several cisterns from the sixth century BC have been found inside the Acropolis wall to the left of the Propylaea. Dug into the rock of the surface, with rock-cut drainage channels, they were capable of holding several months' supply of water, which could be used for drinking if necessary, but usually was used for bathing and cleaning (Crouch, 1993).

10.3.4 Economic growth, institutional progress and the tyranny

The model of city-state is followed by institutional progress, with the governance following a transition from kingdom to aristocracy and then tyranny. While in modern thinking tyranny is regarded the result of a coup, during the Archaic Greece it seems to be a parenthesis intended by the people in order to impose the judicial and social order (Lezine - Velissaropoulou, 2002). The tyrants appear on the political scene of the Greek cities, on the 7^{th} and 6^{th} century BC, in times of population growth. In the case of Athens, significant spatial expansion appears as early as the period of the tyrant Hippias (527-510 BC) Hippias considered that any expansion of property as violation of public property and obliged the owners of the property to pay a sum in order to maintain their properties (Lezine-Velissaropoulou, 2002).

As population grew, the pressure on water resources was significant. Tyrants, in order to increase their popularity financed large scale civil infrastructures, mainly aqueducts.

10.3.5 Typical water projects during tyranny

10.3.5.1 Athens

In the Athenian Agora, archaeological evidence from wells and graves reveals and increase of the city population between 1000 and 700 BC. Paradoxically, in the end of the 8^{th} century, a sudden discontinuance occurs. Around 700 BC, a total of sixteen wells dating in the last third of the century are abandoned. The simultaneous abandonment of almost all of the wells in use at that time indicates a period of serious and prolonged drought (Camp, 2004).

During the 7^{th} century BC, many city-states of the continental and insular Greece created new colonies across the Mediterranean. Athens showed an unusual inertia during that period. The inability of Athens to follow that trend is possibly linked to this prolonged drought (Camp, 2004). The recovery of the city of Athens took place during the 6^{th} century BC, leading to a gradual increase in water demand. In response to the increasing pressure on water resources, the number of the wells increased significant. Solon, the Athenian statesman and poet of the late seventh and early sixth century BC, made a law for the way the water from the wells should be handled (Koutsoyiannis *et al*., 2008). Most of his laws were later described by Plutarch (47–127 AD), from whom we learn:

> *Since the country was not supplied with water by everflowing rivers, or lakes, or copious springs, but most of the inhabitants used wells which had been dug, he made a law that where there was a public well within a "hippikon," a distance of four stadia (4 furlongs, 740 m), that should be used, but where the distance was greater than this, people must try to get water of their own; if, however, after digging to a depth of ten fathoms (18.3 m) on their own land, they could not get water, then they might take it from a neighbor's well, filling a six choae (20 L) jar twice a day; for he thought it his duty to aid the needy, not to provision the idle* (Plutarch, Solon, 23; Translation adapted from Bernadotte Perrin; http://hydra.perseus.tufts.edu/).

The tyrant Peisistratus seized power in 546 BC and ruled until his death in 527 BC. His reign was characterized by large public works projects, the first in Athens for centuries. The increasing pressure on water resources and the inability of springs and wells to meet the demand, must have led Peisistratus in the construction of an aqueduct, named after him, which carried water from the foothill of the Hymettus mountain, to the centre of the city near Acropolis (Figure 10.2). He also converted the natural spring Kallirhoe, into an elaborate fountain house, Enneakrounos.

Figure 10.2. Terracotta pipes of the Peisistratean aqueduct in public display at Athens metro station of Evangelismos

10.3.5.2 Samos

In Samos during the rule of tyrant Polykrates (second half of the 6th centrury BC), impressive civil infrastructures were constructed. The advancement of urban water technology and management is illustrated through the extraordinary example of the water supply of the island of Samos. The most amazing part of the water supply system of ancient Samos (located at the site of the modern-day village of Pythagoreio) is the "Eupalinean digging," more widely known as the Tunnel of Eupalinos, named after the engineer from Megara who designed and constructed it. The aqueduct includes the 1 036 m long tunnel and two additional parts, so that its total length exceeds 2,800 m. Its construction started in 530 BC and lasted 10 years. From Herodotus (484-425 BC), the "Father of History", we learn:

> *I have dwelt the longer on the affairs of the Samians, because three of the greatest works in all Greece were made by them. One is a tunnel, under a hill one hundred and fifty fathoms high, carried entirely through the base of the hill, with a mouth at either end. The length of the cutting is seven furlongs- the height and width are each eight feet. Along the whole course there is a second cutting, twenty cubits deep and three feet broad, whereby water is brought, through pipes, from an abundant source into the city. The architect of this tunnel was Eupalinus, son of Naustrophus, a Megarian. Such is the first of their great works; the second is a mole in the sea, which goes all round the harbour, near twenty fathoms deep, and in length above two furlongs. The third is a temple; the largest of all the temples known to us, whereof Rhoecus, son of Phileus, a Samian, was first architect. Because of these works I have dwelt the longer on the affairs of Samos* (Herodotus, Histories, III, translation by George Rawlinson; http://classics.mit.edu/Herodotus/history.3.iii.html).

The tunnel was in operation until the fifth century AD. It is certain that the tunnel Eupalinos constructed was not the only solution to the problem of conveying water to Samos. A simple alternative solution could have been the construction of a chain of open channels and tunnels at shallow depths with shafts, following a route around the mountain. This solution, already well known (cf. Peisistratean aqueduct), would certainly have been easier technically, faster, and less expensive. The reasons that led to the construction of such a costly structure are not obvious. Probably Eupalinos and the tyrant Polycrates preferred this unorthodox and breakthrough solution because they wished to build a monument of technology rather than simply solving a specific water transportation problem.

10.3.5.3 Naxos

In a recent excavation, the remnants of an ancient aqueduct conducting water from Melanes, a fertile place in inland Naxos to the littoral ancient town of Naxos were investigated (V. Lambrinoudakis, personal communication). The original phase of the aqueduct construction is dated to the late 6^{th} century BC, either during the tyranny of Lygdamis or during the succeeding brief interval of democracy in the island. The aqueduct run over 11 km on hillsides at the upper limit of fertile land and consisted of socket-jointed clay pipes of a diameter of about 0.30 m buried in a ditch of a depth of about 1 m (Figure 10.3). Its slope varied from 1 to 4%. The aqueduct contained a tunnel, hewn in the heights to the north of the Melanes basin, which allowed the aqueduct on the one hand to pass by another spring and to secure a supplementary resource, and on the other to irrigate, before entering the plain, a small fertile valley named Cambones. This tunnel was 220 m long, 1.60 m high and 0.80 m wide. Its entrance and its exit, well preserved behind reconstructions of the Roman Period, were recently investigated at lengths 3 to 5 m inside. Parts of the series of pipes are sometimes well preserved and other times blocked, as indicated by by-pass series of pipes found along the route of the aqueduct. The original phase of the aqueduct is of the same type with the Peisistratian and Eupalinos aqueducts. Sometime in the Roman imperial period the aqueduct was reconstructed on the traces of the ancient pipeline. The Roman aqueduct ended in the ancient city of Naxos in a vaulted fountain, whose interior is totally preserved until today under a modern superstructure. According to finds in the bottom of the pits at the entrance and the exit of the tunnel, the aqueduct remained in function until the 8th century AD. Presumably it was abandoned during the raids of Arabs who ravaged Cyclades at that time.

Figure 10.3. Naxos aqueduct, clay pipes

10.4 Classical Greece: the contribution of democracy

The Classical Greek antiquity is not characterized by marked developments on water technologies—although aqueducts were constructed in various cities. However, significant progress has been made in water management practices, mainly in Athens. In addition, the introduction of Hippodameian system in city planning is a significant novelty, which later, during Hellenistic period and up to modern time, influenced urban water systems markedly.

10.4.1 Athenian urban water management

Shortly after the death of Peisistratos, the Athenian society invented democracy. Athens grew, as well as its needs in potable water. Contrary to what one would expect from a period that created several monuments like the Parthenon in Acropolis, it seems that no major hydraulic works have been implemented. A possible explanation of this inaction is that allocation of public funds to water projects is more difficult when decisions are made under democracy. Another possible scenario connects the lack of large-scale infrastructures to city's sustainability in the event of war. According to Thucydides, the cause of the Great Plague of Athens, during the Peloponnesian war, might have been the poisoning of the water resources of Piraeus:

> *It first began, it is said, in the parts of Ethiopia above Egypt, and thence descended into Egypt and Libya and into most of the King's country. Suddenly falling upon Athens, it first attacked the population in Piraeus- which was the occasion of their saying that the Peloponnesians had poisoned the reservoirs, there being as yet no wells there- and afterwards appeared in the upper city, when the deaths became much more frequent. All speculation as to its origin and its causes, if causes can be found adequate to produce so great a disturbance, I leave to other writers, whether lay or professional; for myself, I shall simply set down its nature, and explain the symptoms by which perhaps it may be recognized by the student, if it should ever break out again. This I can the better do, as I had the disease myself, and watched its operation in the case of others* (Thucydides, The History of the Peloponnesian War, 2, VII, translation by Richard Crawley; http://classics.mit.edu/Thucydides/pelopwar.2.second.html).

Small scale infrastructures, such as wells and cisterns are regarded more resilient in war conditions. Most of the cisterns found in the Athenian Agora date from the 4th to the 1st centuries BC. The storm-water cisterns, whose maintenance in ancient Athens must have been obligatory for citizens, is an appropriate provision for the maximization of system stability and safety. In addition to providing a source of water for private use and enhancing the security of the overall system, cisterns, still in wide use today in anhydrous Greek islands, also reduce the amount of storm water to be discharged (Koutsoyiannis *et al.,* 2008).

10.4.1.1 Potable and sub-potable water quality

Rainwater, collected from the roofs and stored in cisterns was normally used for washing whereas well water was used for drinking (Lang, 1968). The distinction between potable and non-potable water is also reflected by Aristotle:

> *Special care should be taken of the health of the inhabitants, which will depend chiefly on the healthiness of the locality and of the quarter to which they are exposed, and secondly, on the use of pure water; this latter point is by no means a secondary consideration. For the elements which we use most and oftenest for the support of the body contribute most to health, and among these are water and air. Wherefore, in all wise states, if there is a want of pure water, and the supply is not all equally good, the drinking water ought to be separated from that which is used for other purposes.* (Aristotle, Politics, 7, XI, translation by Benjamin Jowett; http://classics.mit.edu/Aristotle/politics.7.seven.html).

10.4.1.2 Water administrators

From Plutarch's Life of Themistocles (XXXI,I), it is known that there was at least one public official concerned with waterworks even in the early fifth century BC, named "κρουνῶν επιμελητής" (superintendent of fountains). He was appointed to operate and maintain the city water system, to monitor enforcement of the regulation, and to ensure the fair distribution of water (Koutsoyiannis *et al.*, 2008). The superintendent of fountains was one of the most important public officials. According to Aristotle:

> *All the magistrates that are concerned with the ordinary routine of administration are elected by lot, except the Military Treasurer, the Commissioners of the Theoric fund, and the Superintendent of Springs. These are elected by vote, and hold office from one Panathenaic festival to the next.* (Aristotle, The Athenian Constitution, Section 2, Part 43, translation by Sir Frederic G. Kenyon; http://classics.mit.edu/Aristotle/athenian_const.2.2.html).

10.4.1.3 Public and private works

Water resource management of the city of Athens has not always been based on public financing. In periods where democracy had troubles in finding its own financial resources, development was driven by the private sector. In the 5th century BC hydraulic benefactors of Athens included two statesmen, Pericles and Kimon, and an astronomer, Meton. Specifically, according to Lang (1968) Meton provided a fountain on Kolonos Agoraios and Pericles (495-429 BC) generously offered to restore a springhouse. Also, according to Plutarch, Kimon made a grove by bringing in water in the Academy:

> *"And the place where they built them being soft and marshy ground, they were forced to sink great weights of stone and rubble to secure the foundation, and did all this out of the money Kimon supplied them with. It was he, likewise, who first embellished the upper city with those fine and ornamental places of exercise and resort, which they afterwards so much frequented and delighted in. He set the market-place with plane-trees; and the Academy, which was before a bare, dry, and dirty spot, he converted into a well-watered grove, with shady alleys to walk in, and open courses for races"* (Plutarch, Kimon, XIII, 8, translation by John Dryden; http://classics.mit.edu/Plurarch/cimon.html).

10.4.2 The contribution of Hippodamos on city planning and its effects on water infrastructures

Ancient Greek cities are divided in two categories: those formed through natural growth (e.g. like Athens or Corinth) and those created on the Hippodameian system, named after Hippodamos the Milesian (498-408 BC). The choice of building a city on the Hippodameian system is based on the benefits of the parallel streets fording a grid, and is dictated by functional reasons. According to Aristotle, Hippodamos was the first architect to design a city in the form of a grid:

> *"His system was for a city with a population of ten thousands, divided into three classes; for he made one class of artisans, one of farmers and the third the class that fought for the state in war and was the armed class. He divided the land into three parts, one sacred, one public and one private: sacred land to supply the customary offerings to the gods, common land to provide the warrior class with food, and private land to be owned by the farmers" (Aristotle*, Politics, II, V, 2, translation by Doxiadis, 1964, p. 346-364).

Despite their differences, the concept hidden behind both building processes was the same: To take advantage of the natural landscape and to create both public and private spaces according to rational and functional considerations with man at the centre (Doxiadis, 1968).

The Piraeus peninsula was uninhabited when Themistocles decided that the port of Athens had to be relocated from Phalero to a more appropriate and safer area. The Piraeus port was designed from scratch by Hippodamos in 470-460 BC and is considered to be the first city designed under the Hippodamian system. Hippodamos introduced a series of innovations that established Piraeus as a design standard throughout antiquity. More specifically Zissimou (2007) reported the following:

(a) He separated the function of each part of the city, creating three separate zones: public, private and sacred.
(b) He divided the city in equal building blocks, each of which contained the same number of houses. Each block had dimensions of 140×160 ft^2 (40.37×47.40 m^2) and contained 8 properties of 40×70 ft^2 (11.87×20.31 m^2 = 241 m^2).
(c) He enrolled the Pythagorean theory of numbers in the design of roads creating a harmony that effected citizens. There were three categories of roads: the *culs de sac* in simple blocks with a width of 14 ft (about 5 m), roads connecting the settlements with a width of 20 ft (about 8.20 m) and "wide roads", connecting the ports, the market and the entrances of the city with a width of 45 ft (about 15 m).

The most famous example of an Hippodamian city is Priene in Western Anatolia (Figure 10.4).

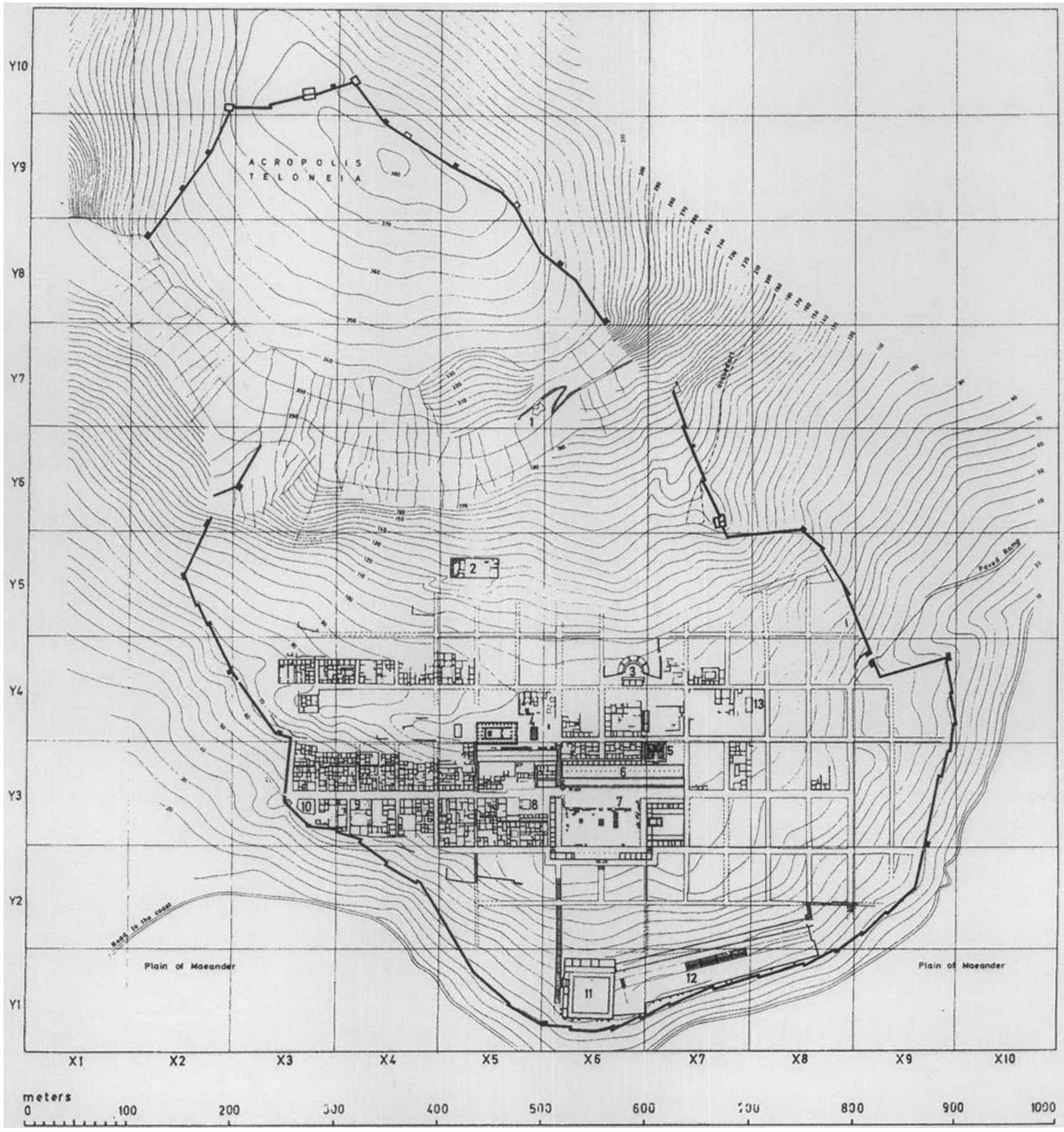

Figure 10.4. Plan of Priene (by Doxiadis (1972), based on Th. Wiegand and H. Schrader, Priene 1904 Stadt plan)

The consequences on urban management from the "pre-designed" urban space are:

(a) The scale of the city changes, requiring bigger infrastructures.
(b) The location of all public infrastructures (agora, temples, public baths etc.) is pre-defined

The benefits on water management from the "pre-designed" urban space are:

(a) The organized city-planning and the regularity of the grid allow engineers to optimize design and construction of hydraulic infrastructures, similar to modern ones.
(b) The construction and maintenance of infrastructures are easier

Although the Hippodamian city is an invention of classical Greece, the benefits of the predesigned urban space became clear mainly during the Hellenistic period (*ca*. 323-67 BC), as most of the cities of that period were designed under the Hippodamian system.

10.5 The evolution during the Hellenistic period

After a period of wars and conflicts, a large period of peace was established in Greece during the Hellenistic period. Destroyed cities were rebuilt, usually in the same site with their predecessors. In most cases, the Hippodamian system of city planning is followed. This period is characterized by significant scientific progress accompanied with the construction of large scale public works. These include aqueducts, which led to water adequacy. As a result, hygienic use of water in public baths and lavatories became feasible and gave access to "luxurious" water usage to all citizens. On the other hand, some principles of sound water management, as implemented in classical Greek antiquity, tend to get forgotten. In Athens, for example, during the Hellenistic Period of the city, the way water was treated changed completely. This can be inferred from the way the overflow of the fountain was dealt. The information for the above is mainly acquired from the waste conduits that belong to two periods. In the first period, we have a smaller line, carefully jointed with lids in place. It seems that at that time period, the overflow water was not just disposed of but kept for some secondary purpose. In the second period, the original line was given up in favour of larger pipes. It seems that the new aqueduct not only brought in more water, which required larger overflow pipes but also that the increased supply of water in the Agora may has obviated the need for the overflow. At the same time, private installations like wells and cisterns tended to be abandoned (Lang, 1968).

In the Hellenistic world, the prevalence of the Hippodameian system resulted in reduced importance of security in city planning. This had been predicted and cautioned by Aristotle, who made the following comment:

> *"The arrangement of the private dwellings is thought to be more agreeable and more convenient for general purposes if they are laid out in straight streets, after the modern fashion, that is, the one introduced by Hippodamus; but is more suitable for security in war if it is on the contrary plan, as cites used to be in ancient times; for that arrangement is difficult for foreign troops to enter and to find their way about in when attacking. Hence, it is well to combine the advantages of both plans, and not to lay out the whole city in straight streets, but only certain parts and districts, for in this way it will combine security with beauty"* (Aristotle, Politics, VII, X, 4, translation from Doxiadis, 1964, p. 346-364).

Technological innovations of this period include the construction of pipelines under pressure. A prominent example is the water supply of the Hellenistic city of Pergamon in Western Anatolia. At about 200 BC, the system of cisterns could not meet the demand of a growing population. One of the three aqueducts constructed transferred water from Madragad Mountain passing a valley by an inverted siphon of length exceeding 3 km and with a maximum pressure head of about 180 m. The inverted siphon was made of lead and anchored with big stone constructions (Koutsoyiannis *et al.,* 2008).

In the centuries that followed, the ancient Greek city-state was replaced by the powerful Roman Empire. The enforcement of "Roman Peace" throughout the Mediterranean reduced the importance for the protection of water in the event of war and ensured the reliability of water supply through the massive construction of large scale aqueducts. Paradoxically, the Roman technology made little use of the flow under pressure, replacing siphons with water bridges, which became characteristic a mark of the Roman aqueducts. The explanation for the preference of free surface flow over pressurized flow is explained by Vitruvius (VIII, 6, 10):

> *"Water supply by earthenware pipes has these advantages. First, if any fault occurs in the work, anybody can repair it. Again, water is much more wholesome from earthenware pipes than from lead pipes. For it seems to be made injurious by lead, because white lead is produced by it; and this is said to be harmful to the human body"* (translation adapted from Lang, 1968).

This is correct, of course, but on the other hand it is a technological regression. Without pressurized pipes, the modern urban water systems would be impossible. But these had to wait for the industrial revolution, to replace the lead pipes with iron (cast iron, steal) pipes (more recently with plastic pipes) which are not harmful to health.

10.6 Discussion and conclusions

Sound know-how about urban water systems existed in Greece from the Minoan times. The strong technological base of Minoan and Mycenaean period has been the base of the advanced technological progress and water management of the centuries that followed.

The stagnancy during the Dark Ages was followed by significant progress in the Archaic Greek antiquity. During that period, city-states were formed and urbanization occurred. As cities depended on trade and not on agricultural production, they tended to be located at dry places, at a distance from rivers or lakes. Under tyranny, cities grew significantly and the first large scale urban water infrastructures were developed.

The period of democracy that followed, with its small-scale structures and its non-structural measures is a lesson of sustainable management and marks the importance of the institutional progress in water management.

During the Hellenistic period, urban city planning acquires a new dimension in the form of the Hippodamian city, which implemented a different design philosophy. The evolution of the "designed city" is mainly reflected on the scale of the projects, which results in water adequacy and more widespread hygienic water use.

Obviously, the scale of the city today is much greater than in antiquity. This is also reflected on the scale of water infrastructures. As a result, a direct comparison is not possible. Nevertheless, we can assume that the following elements of ancient Greek water management should be re-considered:

(a) City planning has to include urban water criteria; protection from floods should be a major consideration.
(b) The use of small-scale infrastructures, in parallel to the large-scale ones, is a big step towards sustainability and resilience. The principles and practices of sustainable water use should not be forgotten even in periods of water adequacy.
(c) Safety and security of water supply in emergency situations, including turbulent and war periods, should be kept in mind in our designs of urban water systems.

Acknowledgements

Special thanks are due to Dr. V. Lambrinoudakis, Emeritus Professor at the University of Athens, Greece for the information he provided on the ancient aqueduct in Naxos.

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