A brief history of water supply and wastewater management in ancient Greece

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ABSTRACT

The evolution of urban water management in ancient Greece begins in Crete during the Middle Bronze and the beginning of the Late Bronze Ages (ca. 2000–1500 B.C.) when many remarkable developments occurred in several stages as Minoan civilization flourished on the island. One of its salient characteristics was the architectural and hydraulic function of its water supply and sewerage systems in the Minoan Palaces and several other settlements. These technologies, though they do not give a complete picture of water supply and wastewater and storm water technologies in ancient Greece, indicate nevertheless that such technologies have been used in Greece since prehistoric times. Minoan water and wastewater technologies were diffused to the Greek mainland in the subsequent phases of Greek civilization, i.e. in the Mycenaean, Archaic, Classical, Hellenistic and Roman periods. The scope of this article is the presentation of the most characteristic forms of ancient hydraulic works and related technologies and their uses in past Greek civilizations.

Key words | ancient civilizations, aqueducts, Bronze Age, cisterns, drainage, fountains, sewerage systems, water distribution, wells

INTRODUCTION

Water is the beginning of everything. Thales of Miletus (656 – 546 B.C.)

...Ἀρχήν των ύδατων...Θαλῆς: ὑδωρ εἶναι φύσιν (ὅτι ὁ καὶ τὴν γῆν ἐφ᾽ ὑδάτων ἄπορωνται εἰσαί), λαβὼν ἰσος τὴν ὑπολήψιν ταυτίνυ ἐκ τοῦ πάντων ὀραίης τὴν τροφὴν ὑγραίν ὁύσιν...καὶ διὰ τὸ πάντων τὰ σπέρματα τῆς φύσιν ὑγραίν ἔχει, τὸ δὲ ὑδωρ ἀρχήν τῆς φύσεως εἶναι...

...Water is the beginning of life according to Thales: water is the first natural principle (and for that reason he held that the earth rests on water) perhaps from observing that the nutriment of all things contains moisture......and that the seeds of all things possess a moist nature, so water is the origin of nature... (transl. by the authors). (Aristotle, Metaphysics, 983 b)

Unlike the preceding civilizations of Mesopotamia and Egypt which were based on the exploitation of the abundant waters of the large rivers of Tigris, Euphrates and the Nile, civilizations and cultures that flourished in the Greek mainland, the Aegean islands and Crete, have been plagued by limited, often scarce and inadequate natural water resources. This has been reflected on several ancient myths concerning water, including those of the Greek hero Hercules and his struggle with the river god Acheloos. In our times, two millennia later, the symbolism of the myth becomes relevant again: wisdom in management seems to be the solution to the ever-growing global water resources problem rather than engineering development, as was previously suggested. (Angelakis & Koutsoyiannis 2007).

Humans have spent most of their prehistoric past as hunters and food gatherers. Only in the last 9,000 to 10,000 years they have discovered how to grow crops and domesticate animals. This agricultural revolution most likely occurred in Mesopotamia from where it spread to
the Nile and Indus Valleys. During this period permanent human settlements replaced a nomadic existence. About 6,000 to 7,000 years ago, farming villages in the Near and Middle East grew into cities. During the Neolithic age (ca. 5700–3200 B.C.), the first successful efforts to regulate the flow of water were necessitated by agricultural needs (irrigation) and were implemented in Mesopotamia and Egypt. Remains of these prehistoric irrigation canals still exist. Urban hydraulic systems, however, are dated at a later stage, in the Bronze Age (ca. 3200–1100 B.C.). Since the Bronze Age, hydraulic technologies developed further in Greece during several stages of Greek civilization. In fact, more advanced water technologies were invented there, especially in the Hellenistic period following Alexander the Great’s conquests, when Greek ideas and practices spread over a geographical area reaching India to the east and Egypt to the south. The Romans, whose empire replaced Greek rule in most parts of this area, inherited Hellenistic technologies and developed them further, changing their application scale from small to large and implementing them widely throughout the vast realm they possessed. (Mays et al. 2007). Greek and Roman water technologies left us not only a cultural legacy but constituted the underpinning of modern achievements in water engineering and management. The survival of some of these constructions until modern times, and their documentation in surviving scientific written records enabled these technologies to be transmitted to the modern world despite periods of regressions occurring through the centuries, especially in the Dark Ages. A brief description of the main water supply and wastewater systems during the Minoan, Mycenaean, Archaic and Classical, Hellenistic, and Roman periods of Greek civilization follows.

THE MINOAN AND MYCENAEAN CIVILIZATIONS

The southernmost of the Greek islands, Crete, was first inhabited shortly after ca. 6000 B.C. and within three thousand years it had become the largest Neolithic settlement in the Aegean Sea. Here, during the Bronze Age Minoan civilization developed and earned the distinction of becoming the first European cultural center. In the Minoan and Mycenaean settlements (in Crete and mainland Greece, respectively) various water supply and wastewater systems and practices appeared, including collection and storage facilities, wells and groundwater exploitation, aqueducts development, water distribution and use, construction and use of fountains, development of sewer, bathrooms, and other sanitary facilities, and even recreational uses of water (Koutsoyiannis et al. 2008).

Water cisterns

In ancient Crete the technology of surface and rain water storage in cisterns was well developed and continued to be used until modern times. One of the earliest Minoan cisterns was found in the canter of a pre-palatial house complex at Chamaizi and is dated at the turn of the 3rd millennium B.C. (Figure 1a). The house complex is located on the top of a hill and its rooms are set around a small open court with a deep circular rock-cut cistern, 3.5 m deep and 1.5 m in diameter, lined with masonry in its upper part (Davaras 1976). Four of the earliest Minoan structures which may be considered to be large cisterns were built in the first half of the 2nd millennium B.C. (the time of the first Minoan palaces) at Pyrgos-Myrtos (Ierapetra), Archanes, Tylissos and Zakros (Cadogan 2007). The Tylissos cistern is shown in Figure 1b. At the famous Phaistos palace, cisterns were depended on precipitation collected from rooftops and courts; a supplementary system was needed to satisfy the needs of water supply, especially in this particular area where agriculture was widely practiced. Thus, water was probably drawn from wells in a location southwest of the palace which was rich in ground and surface water, and from the Ieropotamos river located to the north, at the foot of the Phaestos hill (Gorokhovich 2005). Also in Malia, at a site lying in a narrow plain between the mountains and the sea, cisterns were found on the high grounds above the palace (Moody 1996). Those cisterns were associated with small canals collecting surface water from rainfall and from mountain streams (Viollet 2003). It appears, therefore, that the use of cisterns preceded canals or aqueducts in supplying the palace and the surrounding community with water.
Groundwater and wells

Knossos, the best known Minoan settlement, had wells since Early Minoan times (Müller 1996). During the period of the first palace (ca. 1900–1700 B.C.), several of them were used for drawing drinking water and at least six have been reported (Evans 1921-1935). Their depth did not exceed 20 m and their diameter was no more than 5 m (Buffet & Evrard 1950). The most important and best known has a depth of about 12.5 m and a diameter of 1.0 m. In the Zakros palace a well-spring is located near the southeast corner of the central Court; steps, now damaged by visitors’ feet, led down into the chamber. The Palekastro community was also depended on groundwater. Here, several wells have been discovered so far with depths ranging from 10 to 15 m (Figure 2a). The sites of Palekastro and Zakros are located in the eastern region of Crete which, unlike other parts of the island, seems to have been rich in groundwater, now sub-saline.

Aqueducts

In ancient Crete the technology of transporting water via aqueducts was facilitated by the mountainous terrain of the island. The Minoan inhabitants of Knossos depended partially on wells but most of their water was supplied by the Kairatos river located east of the low hill of the palace, and by springs. Archaeological evidence suggests that the water supply system of the Knossos palace initially relied on the spring of Mavrokolybos, a limestone spring located 450 m southwest of the palace (Mays et al. 2007). In later periods with the increase of its population other springs from longer distances were used. A second Minoan aqueduct was found at Tylissos. Parts of this masonry aqueduct (Figure 2b), with its main conduit at the entrance of the complex of houses, and other secondary systems led the water to a cistern, namely cistern D, which is dated at ca. 1425–1390.

Water distribution systems

The advanced Minoan water distribution systems were based on the use of pipes. In the Knossos palace, water supply was provided through a network of terracotta piping located beneath the floors in depths that vary from a few cm up to 3 m (Evans 1921-1935). Such pipes are shown in Figure 3.
Similar terracotta pipes were found in other Minoan sites, such as Tylissos which carried water from the spring of Aghios Mamas, where other pipes have also been traced with possible distillers. Terracotta pipes have also been found at Vathypetro, and in the “Caravanserai” (Guest House), south of the Knossos palace while others have been seen scattered in the countryside. Moreover, pipes made of cypress, abundantly grown in the area, must have also been used (Taylor 1983). Wooden pipes were in common use during the Roman period in northern Europe, especially in Germany (Hodge 1992) and their use endured until recently.

**Sewer and drainage systems**

In addition to water distribution, palaces were also equipped with elaborate storm drainage and sewer systems (Figures 4a and 4b). In fact, all palaces had applied effective strategies to dispose water and wastewater (MacDonald & Driessen 1990). Open terracotta and stone conduits were used to convey and remove stormwater and limited quantities of wastewater. Pipes, however, were scarcely used for this purpose. Larger sewers, sometimes large enough for a man to enter and clean them, were used in Minoan palaces at Knossos, Phaistos and Zakro. These sewers may have inspired the conception of the labyrinth, a subterranean structure in the form of a maze that hosted the Minotaur, a hybrid monster. Some Minoan palaces had toilets with flushing systems operated by pouring water in a conduit (Angelakis & Spyridakis 1996; Angelakis et al. 2005). However, the best sample of such an installation was found in the Cycladic island of Thera the modern Santorini (Palyvou). This toilet, the best-preserved of its kind, belongs to the LMIA (ca. 1550 BC) Bronze Age settlement of Akrotiri, which shares the same cultural milieu with Crete.

**Construction and use of fountains**

Another interesting category of Minoan water related techniques is revealed in its fountains. Most of the examples are subterranean structures supplied with water directly or from other springs via ducts. The construction of steps or alternatively shallow basins testify that the water was to be directly taken out with the use of a container. This resembles the type of fountain of the later Classical and Hellenistic period known as arykrene. The most typical of them is that of the Zakro palace. Here, in the southwest corner of the “Hall of the Cistern” an opening led into a small chamber where water was collected and channelled under the floor into the base of a square underground fountain built further south. The dimensions are 3 × 4 m. and it is dated in the LMIA period (ca. 1500 BC). It was built of regular limestone with a staircase of fourteen steps (Figure 5a). This structure was thought to correspond with the fountain mentioned in the Odyssey known as Tykte (Platon 1974). Another fountain similar to the Tykte type was found at the “Guest House” (Caravanserai) of Knossos in the “Spring Chamber” and consists of a rectangular basin of 3 steps with dimensions 2.0 × 1.6 m.; the water comes directly from a spring in the floor of the square (Evans 1921-1935) (Figure 5b). A ritual function of the particular fountains is also suggested, as artefacts of ritual content have also been unearthed. Another fountain category, known in later periods as rookrene, which provided fresh water on a constant basis was also found in Zakro. This type with its two zoomorphic waterspouts was illustrated above as part of the closed/pressured pipe system.

Finally, a remarkable fragment of a fresco composition depicting a fountain of a supposedly Minoan garden, whose existence was also proposed for several palaces, was found in the “House of Frescoes” in Knossos (Platon 1974). This fragment has been restored to what appears to have
been a “jet d’eau” fountain. Although the actual summit of the fresco was not found, the object depicted in the upper part of the field is clearly some type of fountain or “jet d’eau” with the spout of the water made to rise from a forked base (Platon 1974). The lower part of the fragment, with the same forked base and falling drops seems, moreover, to be the base of another column of water drawn in similar conventional manner but with a small section of the contour of the ground projecting an undulating bank beneath it. The background here is white, the central column of water and the falling drops on either side a deep blue, while the drops falling in front of the main jet are painted white, thus becoming quite distinct and visible.

Since no geysers or sulphurous ebullitions, like those of Palici in Sicily exist in Crete, it is highly unlikely that these designs were copied from any natural fountains found on the island. It is to be noted that the first fountains in the form of jets were introduced in the Hellenistic period (Lax & Strasser 1992). This makes the representation quite uncertain. Moreover, another restoration of the fragments argues for a natural gush from the Cretan landscape of the Bronze Age.

Recreational structures

Fountains, aquaria and other water related structures for recreation must have decorated the Minoan palaces, as suggested by several indicators. Among these, perhaps the most remarkable is provided by the fresco fragments from the “House of Frescoes” which seem to depict a “jet d’eau”
Remnants of it are exhibited now in the Archaeological Museum of Iraklion (Koutsoyiannis et al. 2008).

ARCHAIC AND CLASSICAL PERIODS

In the archaic and classical periods of Greek civilization, aqueducts, cisterns, and wells similar to the Minoan and Mycenaean originals were also constructed. However, the scientific and engineering progress of the age made possible the construction of more sophisticated structures. One of the most famous of these is the tunnel of Eupalinos (ca. 530 B.C.) in the island of Samos, the first deep tunnel in history dug from two openings with its two lines of construction meeting at about the middle of the distance. The construction of this tunnel which supplied Samos with water, resulted from the astonishing progress in geometry and geodesy which enabled engineers to dig two independent lines of construction that would meet (Koutsoyiannis et al. 2008).

There are several known aqueducts in Greek cities as the adequate supply of water was a prerequisite for the very survival of any community (Tassios 2006). For safety reasons, aqueducts were always subterranean, built either as tunnels or trenches. At the entrance of the city, aqueducts would branch out and feed cisterns and public fountains in central locations. At the bottom of trenches or tunnels of aqueducts, pipes usually from terracotta were laid, providing protection. One, two or more parallel pipes were used, depending on the flow to be conveyed. The terracotta pipe segments (from 20 to 25 cm in diameter) fit into each other and allow access for cleaning and maintenance by elliptic, terracota covered, openings (Figure 6).

Water transferred by aqueducts typically originated in springs, often formed on karstic geological formations. The existence of natural springs was a definite criterion for the selection of any area to settle. Thus, the Acropolis of Athens which had been settled long before the classical age, in addition to providing defensive capabilities, had also been endowed by nature with an aquifer and a spring. With the subsequent urban development and increase of population the natural springs could not meet its water needs. The increasing demand was then remedied by transferring water from distant springs via aqueducts, digging wells and constructing cisterns for rainwater storage. In Athens all of these alternatives were encountered: the Peisistratean aqueduct, constructed at the end of the sixth century B.C. was followed by numerous wells and later cisterns. Naturally this system with its public and private components was not easy to manage. Therefore, the need for wise and effective management by legislative and institutional means emerged. Thus, since the early years of the sixth century B.C., Athens developed a remarkably sustainable management system which achieved a balance between the public and private sectors (Koutsoyiannis et al. 2008).

Naturally, technologies developed in Greece were diffused to the eastern Greek colonies of Ionia (Asia Minor) and the western world of Magna Graecia in the Italian peninsula, Sicily and the other Mediterranean regions further west which were settled during the archaic period. An excellent illustration of this diffusion is demonstrated in the case of Syracuse in Sicily which was colonized by Corinth ca.734 B.C. Among the many Corinthian cultural traits transplanted to Syracuse such as language, religion, government, and farming was the management of water resources. As Crouch (1993) points out, the transfer of water managing techniques was facilitated by the similarity of geology and climate between the Corinthian metropolis and its Sicilian colony. From the eighth to the first century B.C. the knowledge of locating and collecting water was accompanied by a parallel progress in the techniques of transporting both fresh and used water.

The geology of the site, with earlier and later limestone layers above clay, contained an abundance of water.
The Arethusa spring, located at the edge of the sea, was the first settlement on Ortygia (Crouch 1993). The water supply was drawn from many surface and subsurface openings in the limestone, particularly where it was resting above impermeable strata such as marl. The numerous grottoes above the Greek theatre (Figure 7) were probably a major factor in the development of Syracuse since the early colonists running water flow in this area. As time passed, possibly a couple of centuries later, water followed a new path downhill and in order to cover the increasing demands of a growing population, new supplies to this location were developed, using the same outlets: the Galermi and Ninfeo aqueducts. The elements of Syracuse's original water system were expanded further during Roman times.

HELENISTIC PERIOD

During the succeeding Hellenistic period, impressive accomplishments were achieved in hydraulics, such as in the construction and operation of aqueducts, cisterns, wells, harbours, water supply systems, baths, toilets, and sewerage and drainage systems. At this time major political and economic changes occurred leading to further architectural development and urban beautification in which aqueducts played a major role. The remarkable progress in science during the Hellenistic period also provided the technical expertise required. Hellenistic aqueducts normally used pipes rather than the Roman masonry conduits. Furthermore, following the time honored classical tradition, aqueducts continued to be subterranean for security reasons (inter alia, exposure to enemies in case of war) but also for protection from the endemic earthquakes that plague the region. This practice again contrasts Hellenistic technology with its later Roman counterpart, whose salient characteristic was the use of arches and aqueduct bridges (Mays et al. 2007).

Greek aqueducts generally operated by free surface flow. However, during the Hellenistic period, scientific progress in understanding hydrostatics and water and air

Figure 7 | Water system at Syracuse: (a) Greek theatre in Syracuse along grotto formation in background from where water flowed; (b) view of aqueduct above grottoes; and (c) and (d) outlets of the Galermi and Ninfeo aqueducts inside grotto formation, respectively (Mays et al. 2007).
pressure (due to such luminaries as Archimedes, Hero of Alexandria and others; Koutsoyiannis et al. 2007) allowed the construction of inverted siphons at large scales (lengths of kilometers, hydraulic heads of hundreds of meters). Thus, Hellenistic engineers constructed inverted siphons to convey water across valleys in aqueducts of several cities including Ephesus, Methymna, Magnesia, Philadelphia, both Antiochias, Blaundros, Patara, Smyrna, Prymnnessos, Tralleis, Trapezopolis, Apameia, Akmonia, Laodikeia and Pergamon (Tassios 2006). These siphons were initially built of stone pipes (square stone blocks to which a hole was carved) or terracotta. However, the need for higher pressures naturally led to the use of metal pipes, specifically lead. In fact, one of the aqueducts of Pergamon includes an inverted siphon exceeding 3 km in length with a maximum pressure head of about 180 m, whose pipes were from lead (Tassios 2006).

THE ROMAN SYSTEMS

The Romans built what may be justly called mega water supply systems including many magnificent structures. Water flowed by gravity through enclosed underground conduits (specus or rius), from the source to a terminus or distribution tank (castellum). Aqueducts above ground were built on a raised embankment (substructio) or on an arcade or bridge. Settling tanks (piscinae) were located along the aqueducts to remove sediments and foreign matter. At some locations, secondary lines (vamus) were built along the aqueduct to supply additional water. Also subsidiary or branch lines (ramus) were used. At distribution points water was delivered through pipes (fistulae) made of tile or lead. These pipes were connected to the castellum by a fitting or nozzle (calix) and were placed below ground level along major streets (Mays et al. 2007).

To properly understand the Roman water supply systems we must be aware of the treatises of Vitruvius, De Architectura (Morgan 1914), and Sextus Julius Frontinus, De aquaeductu urbis Romae. The following quote from Vitruvius describes how the aqueduct castellum worked (as presented in Evans 1994). “When it (the water) has reached the city, build a reservoir with a distribution tank in three compartments connected with reservoir to receive the water, and let the reservoir have three pipes, one for each of the connecting tanks, so that when the water runs over from the tanks at the ends, it may run into the one between them.”

The advanced water and wastewater technologies developed in Minoan Crete were expanded and improved during the Roman domination of the Greek world. The achievements of this era which met the hygienic and functional requirements of ancient cities were so advanced that they could only be compared to the modern urban water systems which developed in Europe and North America in the second half of the nineteenth century. It should be noted, moreover, that hydraulic technologies in ancient Greece were not limited to urban water and wastewater systems. The progress in the supply of urban water was even more astonishing, as numerous aqueducts, cisterns, wells, and other water facilities indicate. In Roman Crete there were several aqueducts: in Axos, Chersonesos, Elyros, Fountana, Gortys, Kissamos, Lappa, Minoa (Acrotiri), and Mochlos (Figure 8a). Also, several cisterns from Roman Crete have been found in Archanes, Aptera, Dictynna, Lappa, and Rhizenia (Figure 8b).

RELEVANCE TO PRESENT

To put in perspective the ancient water management principles and practices discussed in this cursory review, it is important to examine their relevance to our times and draw some conclusions. The relevance of ancient works will be viewed in terms of the evolution of technology, technological progress and design principles.

The evolution of technology

An important question to discuss is whether modern water technologies were derived from ancient Greek technological achievements or were Greek achievements totally forgotten (during the Dark Ages) and re-invented in modern times. The latter thesis could be viewed merely as an extension of Crouch’s (1993, p. 123) thinking about the evolution of technologies in ancient times.

The development of science and engineering is not linear but often characterized by discontinuities and
regressions. “Bridges” from the past to the future are always present, albeit oftentimes they are invisible to those who cross them! Thus, in addition to many ancient constructions that have been continuously or intermittently in operation to-date, substantial information from ancient Greek written sources has also been preserved (including such specifics as detailed contracts between the public and constructors of hydraulic works; see Koutsoyiannis & Angelakis 2003).

A characteristic example of survival is provided by the several types of cisterns developed in Minoan and Mycenaean times which are still widely used in many anhydrous Greek islands (Antoniou et al. 2006). A continuous evolution of the engineering of cisterns, which “bridges” several historical periods is clearly indicated here.

The tunnel of Eupalinos and its two lines of construction were also not forgotten for long periods of time. Herodotus (History, Γ, 60) mentions the tunnel calling it “ἄρθροστόμον” or “bi-mouthed”, thus pointing out that it was constructed from two openings. Four centuries after Eupalinos, the mathematician, inventor and physicist Hero (Heron) of Alexandria (Dioptra, II; ca. 1st century B.C.), inspired by this tunnel, studied the problem of how “to dig a mountain on a straight line from two given mouths” (his geometrical Problem #15; see also Apostol 2004). The solution he proposed, based on a route around the mountain, is technologically inferior to that of Eupalinos – but his effort denotes the importance of the problem and the fact that the quest for its solution passed on to succeeding generations and history (Koutsoyiannis et al. 2008).

**Design philosophy**

Currently, engineers typically use a design period of structures of about 40 to 50 years as dictated by economic considerations. Sustainability, as a design principle, has entered the engineering lexicon within the last decade. Naturally, it is difficult to estimate the design principles of ancient engineers but it is notable that several ancient works have operated for very long periods, some until recent times. Thus, wastewater and stormwater drainage systems were functioning in areas of Minoan settlements since the Bronze Age. These include the construction and use of bathrooms and other sanitary and purgatory facilities, as well as wastewater and storm sewer systems. In fact, the hydraulic and architectural function of sewer systems in palaces and cities are regarded as one of the salient characteristics of Minoan civilization. They were so advanced that they can be justly compared with their
modern counterparts. One of the most remarkable Minoan sanitary and storm sewer systems was discovered in Hagia Triadha (close to the south coast of Crete). The Italian writer Angelo Mosso who visited its villa at the beginning of the twentieth century and inspected its storm sewer system noticed that it functioned perfectly and was amazed to see stormwater come out of sewers constructed 4000 years before his time. (Angelakis et al. 2005).

CONCLUSION AND DISCUSSION

Beginning with Minoan Crete, fundamental technologies pertaining to water supply were developed in ancient Greece to a degree unknown in preceding civilizations. (Viollet 2003). Using these technologies, impressive urban water supply systems appear to have been constructed, initially without regard to cost. As a result, they represent the state-of-the-art structures that were technically feasible at that time. Similarly, the aqueduct of ancient Samos is an important hydraulic monument, indicating that it was possible in the ancient world to design and construct technologically advanced water transportation projects on a large scale.

The Athenians, on the other hand, especially during their Golden Age, seem to have fully adapted urban water management principles based on a rather advanced model: it included large scale public works (constructed earlier, during the age of tyranny) but it was mainly concerned with small-scale constructions (cisterns and wells) and non-structural measures (Solon’s laws, institutions such as Superintendent of Fountains). Thus it achieved a remarkable balance of public and private interests. It is evident that the system of democratic Athens must have worked effectively for a long period of time. This model was remarkably advanced, as modern water resource policymakers and hydraulic engineers are presently re-emphasizing the importance of both nonstructural and small-scale structural measures in urban water management (Maksimovic & Tejada-Guibert 2001; Angelakis & Koutsoyiannis 2003).

Excavations at several other ancient Greek sites have brought to light urban water systems as advanced as those previously described. The achievements of ancient Greece in dealing with hygienic and functional requirements, related hydraulic technologies and water management practices can only be compared to modern urban water systems reintroduced in Europe and North America in the second half of the nineteenth century A.D. (Angelakis et al. 2005). It is reasonable to assume then that with a few notable exceptions, the basis on which rests our progress in urban water management today, is clearly of ancient origin.

From the preceding synoptic discussion, certain conclusions might be suggested for further reflection and systematic investigation:

(a) The meaning of sustainability in modern times should be reevaluated in light of ancient public works and management practices.
(b) Technological developments based on sound engineering principles can have extended useful lives.
(c) Securing adequate water resources is of critical importance in the sustainability of a population.
(d) In areas of water shortage, development of an effective water resources management program is essential.

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