Chapter 6
A Web Based Information System for the Inspection of the Hydraulic Works in Ancient Greece

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6.1 Introduction

Most ancient civilizations exploited water resources constructing hydraulic works, in order to support the everyday water needs. Ancient societies that flourished on the Greek territory since 3000 B.C. except their great contribution to philosophy, politics, sciences and arts, constructed several technical works. Many of these structures were related with water use. Using hydraulic technologies combined with understanding of processes, ancient Greeks supported several needs such as water supply, drainage of the lands and the cities, flood protection, sanitary facilities and even water use for recreational purposes. Their familiarity with water use is depicted in the hydria of the 6th century B.C. (Fig. 6.1), where young men take baths in a public installation.

The Ancient Greek societies held an exceptional position to the use and management of water recourses as testified by: (a) the advanced technologies they applied in the construction of several hydraulic works; (b) the sustainable water management practices they adopted; (c) the high living standards related to water use they developed; and (d) the explanations about the natural hydrometeorological phenomena they devised.

As a result of thousands of years of creative activity, several simple hydraulic structures (cisterns, lavatories, wells, aqueducts) or more advanced ones (dams, tunnels, siphons) are spread all over the wider ancient Greek territory. These works supported several water uses as listed above. Their presence reveals that ancient Greeks wisely resolved several problems concerning water that modern societies still have to face. Also in the ancient Greek literature there is a plethora of references about: (a) sustainable water management practices, (b) hydraulic works that are not preserved to date and (c) impressive exegeses about hydrometeorological

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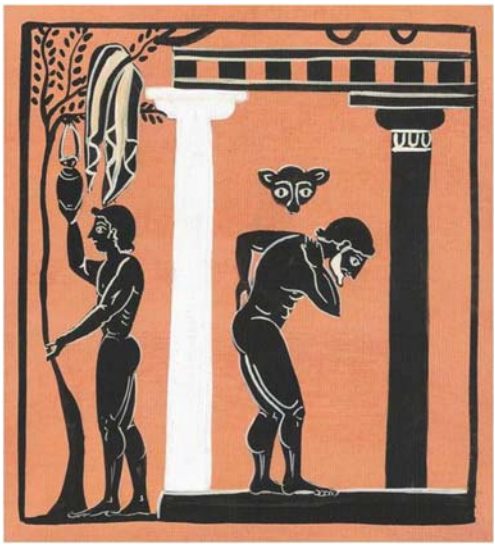


Fig. 6.1 Young men are bathing (6th century B.C.; drawing by V. Kordoni based on a theme of a black-figured hydria kept in Leiden, National Museum of Antiquities)

processes (e.g. evaporation, condensation, hail, snow, rain). During the last decade, hydraulic works and water management practices developed in ancient Greece have been revisited with an increased interest. Several researchers originating from different scientific fields (archaeologists, engineers) studied the (relatively unknown) water technologies, hydraulic works and water practices developed in ancient Greece (Angelakis et al., 2005; Koutsoyiannis et al., 2008; Mays et al., 2007). The Greek philosophers' explanations about the related natural phenomena have also been studied (Koutsoyiannis et al., 2007). At this time a considerable amount of this knowledge can be found in papers published in scientific journals and conference proceedings.

To facilitate the inspection of available information about the hydraulics works in Ancient Greece a web based application has been developed. The application includes the necessary informatics tools to manipulate and analyze the various information types and make the information available on the Internet. Information includes geographical location, technical characteristics of the structures, drawings, maps, texts, papers, studies, photos, videos etc.

The main purposes of this application are: (a) gathering and archiving of all available information which is characterized by lack of homogeneity, (b) codification of the above information, (c) facilitation of its analysis using informatics tools to perform queries or to make maps and (d) an easy access from the general public and researchers to all available information.

The aim of this system is not to develop sophisticated informatics tools, but mainly to create a basic information pool concerning ancient Greek water knowledge. In order to serve this task continuously, the system must be enriched and be extended gradually, incorporating new findings.

6.2 Information System

The web based information system (http://www.itia.ntua.gr/ahw/works/) includes the necessary informatics tools to manipulate and analyze the various information types and also make the processed information available on the Internet. Open source technologies were used for the development of the various applications. The operating system is Debian GNU/Linux running in an Apache web server, the database is PostgreSQL, the programming language is Python and the web application framework is Django.

The general scheme of the information system is presented in Fig. 6.2. The system consists of a Database (DB), a Geographical Information System (GIS), a Digital Library (DL) and a Website that integrates the entire system. Also there are two separate levels of access through the web. At this time the application under development, although it already contains rich information as detailed below.

The GIS includes the geographical location of each structure and is related to the DB to perform queries and make maps. Using this, the researcher can have a wider perception of the ancient hydraulic works. The distribution of the structures in space can be combined with other characteristics such as the construction period, the type of the structure and the specific sociological and political characteristics of the society in the period of construction. In Fig. 6.3a the geographical distribution of all hydraulic works with respect to the construction period, is presented. Obviously the areal distribution of the hydraulic works is strongly related to the region where each civilization flourished. The structures are concentrated in three specific areas: Crete Island, Peloponnesus and Athens, the cradles of Minoan, Mycenaean and classical Greek civilizations, respectively. In Fig. 6.3b the sites of aqueducts have been extracted and are presented. The locations of the aqueducts are relatively dispersed from the birth places of Greek civilizations, but later Romans built them in every place of their empire, which included the Greek territory.

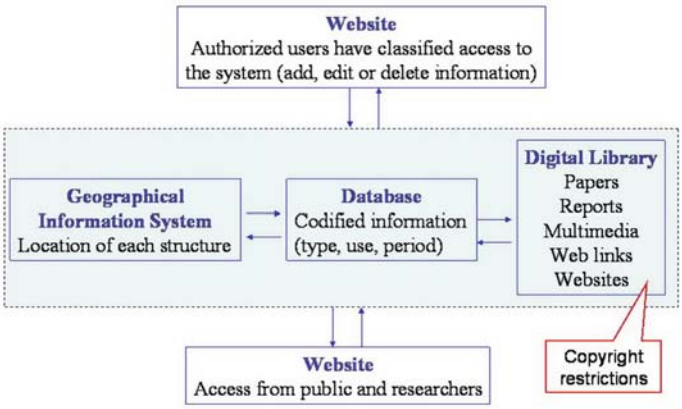
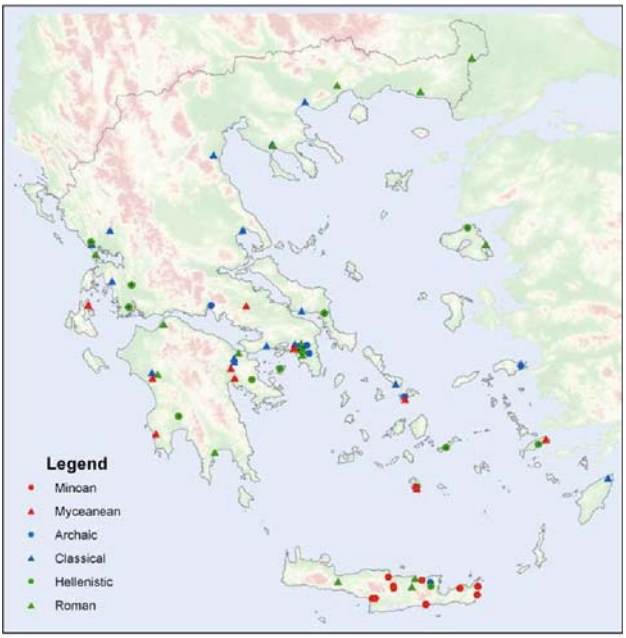
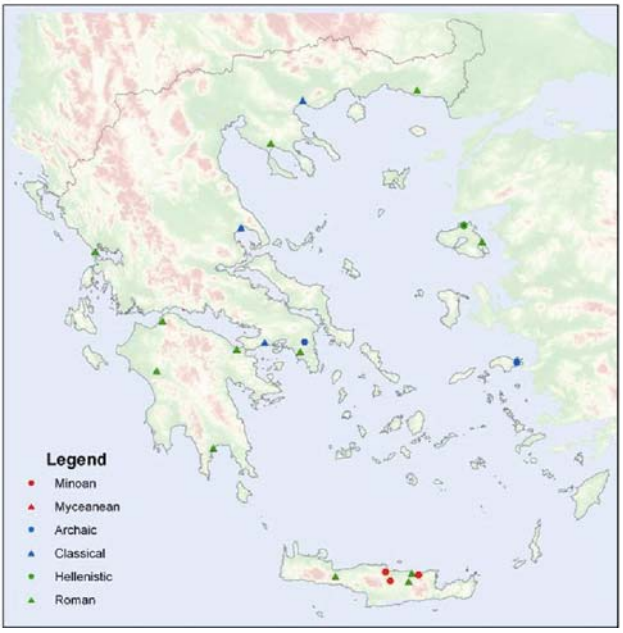


Fig. 6.2 General scheme of the application



(a)



(b)

Fig. 6.3 Examples of maps constructed by the system: (**a**) Hydraulic works classified by construction period, (**b**) aqueducts classified by construction period

In the DB the organized information about each hydraulic work is stored. The main table of the DB contains fields such as: (1) name, (2) region, (3) type (main – secondary), (4) use (main – secondary), (5) period of construction, (6) name of hydrosystem, (7) brief description, (8) today's condition of the structure, (9) remarks and (10) related documents.

The region includes the name of the site and the Greek area. The types of the hydraulic works (main or secondary) can be: aqueducts, dams, tunnels, cisterns, lavatories, canals, siphons, river control works, fountains, sewers, agricultural drainage works and urban drainage works. The use of the hydraulic work (main or secondary) can be: urban or agricultural water supply, urban or land drainage, flood prevention and urban sewerage. The construction period of each work can be: Minoan and Cycladic (3500–1200 B.C.), Mycenaean (1600–1100 B.C.), Archaic (about 800–500 B.C.), Classical (500–336 B.C.), Hellenistic (323–146 B.C.) and Roman (146 B.C.–323 A.D.). An extension to the Byzantine period (323–1453) has been planned. Also another 'virtual period' (Mythology) has been created to include several hydraulics works described in myths. These myths come from the prehistoric period and exist in ancient Greek literature. Most of them refer to the labours of Heracles (Hercules) and describe several river regulation works, including river diversion, and land reclamation. There is a specific field for the name of the hydrosystem that the structure belongs. This field is very essential for the inspection of different structures that worked together. Also there are fields with a brief presentation of the structure and its current condition. Finally the most essential field is the connection with the digital library where all related documents with the structure are gathered.

Today the information system contains information about 100 hydraulic works and 20 important hydrosystems (still there are other sites under study) but the database is being enriched continuously. The distribution of the registered hydraulic works and hydrosystems through different time periods is presented in Table 6.1.

Table 6.1 Time distribution of hydraulic works and hydrosystems registered

Period	Hydraulic works	Important hydrosystems
Minoan	28	Knossos, Phaistos, Mallia, Zakros, Akrotiri
Mycenaean	11	Mycenae, Tyrins, Pylos, Copais, Olympia
Archaic	7	Athens, Samos, Archaic Thera
Classical	21	Amphipolis, Megara
Hellenistic	16	Pergamos, Messene
Roman	14	Corinth, Patras, Mytilene, Nicopolis, Olynthus, Palaiopolis
Total	97	

Currently the database contains important hydraulic works, but lacks information related to smaller and more usual structures like wells, cisterns and fountains. On the other hand almost all important hydrosystems of the Greek ancient world are represented in the database by a number of structures. Through the centuries many of these hydrosystems displayed a continuous transformation or upgrading as the local

society changed its priorities, perceptions and values. The hydrosystem of Athens is such an example because of its continuous operation until the 20th century.

In the DL the large amount of information (in several formats) that is related with each structure, is stored and managed. This information includes: (1) scientific papers (or their web links), (2) reports with technical characteristics, (3) drawings and maps, (4) multimedia (photos, videos, movies), (5) related web sites, (6) references of the structure from classical texts and (7) references of the structure from scientific papers. Using a web browser the researcher can access the other three subsystems (Database, GIS, DL). Part of the information in DL is under the Copyright Law, so at this time this part is not visible through web pages to the general public.

Currently the application does not include features such as the following, which however are scheduled for incorporation in a future expansion of the system:

- Harbours, for which exists the application Limenoscope, (Theodulu and Memos, 2007). This is a database operated through the web (http://www.limenoscope.ntua.gr/) with main aim the dissemination of harbour related information.
- Water management practices that were applied in several Greek cities. Their descriptions can be found in the classical literature, and in many cases in text related to the legislation.
- Explanations of natural phenomena and physical theories that had a relationship with the hydraulic works, because they triggered the advancement of technology. These include the foundation of hydraulics, by Archimedes and Hero (Heron) of Alexandria.
- Hydraulic mechanisms that were invented in the Greek antiquity. An exceptional example is the pump (screw) of Archimedes, a device that is still in use up today.

6.3 Historical Evolution of Hydraulic Works

The information collected so far allows us to summarize the history of the Greek hydraulic technologies, which started from Bronze Age and after over 2,000 years of development, were inherited to the Romans. The evolution of hydraulic works in Ancient Greece is strongly connected with the different characteristics of Greek civilizations. The small scale hydrosystems of the Minoan villas and Mycenaean fortified palaces were gradually ruined and replaced by larger systems during the Archaic and Classical periods. The structures of Hellenistic and Roman period incorporated new advanced water technologies and construction techniques, resulting in hydraulic works that in many cases are still in use. Romans who conquered Greece at the end of the second century B.C., respected the local culture and science and improved the current technology in order to support their vast empire with a variety of technical works.

Reviewing the material of the database we can summarize some special characteristics of each period, related with the scale, the type, the use and the visibility of the structures

The majority of the recorded structures of the Minoan and Cycladic periods are located in the four palaces of Crete (Knossos, Phaistos, Mallia, Zakros). In these

well organized sites several small scale hydraulic works (aqueducts, cisterns, wells) operated to ensure the water supply and drainage of their dwellers. Also small scale facilities (lavatories, bathtubs, recreational fountains) ensured a luxury way of life that can be compared with the modern one. During this period small scale hydraulic works can be also found in other places of Crete (Archanes, Chamaizi, Hagia Triadha, Palecastro, Pyrgos, Tylissos), in the islands of Thera and Cyprus, and in Asia Minor.

The water facilities of the peaceful Minoan civilization were also followed by the Mycenaean warriors. The fortified palaces of the Mycenaean period (Mycenae, Tyrins, Pylos) in mainland Greece are also places that hydraulic technologies were applied. During that period the larger scale water management for agricultural purposes (irrigation, drainage) led to the construction of hydraulic structures that control larger water quantities. A great example of such a work is the drainage of the Lake Copais located in Boeotia. The water of the Boeotic Kephisos River that fed the lake, were directed through a 25 km canal to natural sinkholes in the karst subsurface. The constructors (Mynians) protected the reclaimed land with dykes and used it for cultivation but also for building a palace in a former small island of the lake. The project was in operation until the collapse of the Mycenaean civilization. Other drainage systems of this period are those of Tiryns and Olympia with the first system to include a 10 m high dam in its structures. The dam was used to divert waters from one stream to another, perhaps to protect the city of Tiryns from floods.

During the Archaic period hydraulic works similar with those of previous periods were constructed. The higher populations of the cities increased the need of transferring water from distant sources, in addition to local water resources (wells, cisterns, springs). During this period the engineering experience of the past matured, enabling the construction of more advanced technical works. Two very important aqueducts, the Peisistratean and the Eupalinean, are the main contribution of the Archaic period to the water technology. The Peisistratean aqueduct that transported water to the city of Athens was a huge technical achievement. The main part of its 7.5 km route was constructed as a 14 m deep tunnel (for security reasons), in which a ceramic pipeline was laid.The Eupalinean aqueduct, that transported water in the city of Samos, comprised the fist deep tunnel in history dug from two openings. The tunnel was constructed around 530 B.C. with a length of about 1,050 m. Eupalinos had a great knowledge of engineering, which enabled the digging of the tunnel from two openings, a practice followed also today. He used advanced geometrical techniques to eliminate the impact of uncertainty in position in the tunnel excavation and ensure the hydraulic gradient to sustain flow in the aqueduct (Koutsoyiannis et al., 2008).

During the Classical period a vast variety of hydraulics works were constructed to serve the urban water supply and sewerage of the prosperous Greek cities. In many cases smaller structures (cisterns, fountains, wells) supplemented larger hydraulic works (aqueducts), augmenting the water management possibilities and forming the concept of a large scale hydrosystem. During this period Athens, the most important city of the Greek antiquity, had a population of more than 200,000 and an extended hydrosystem. This was based mainly on the Peisistratean aqueduct, two rivers with ephemeral flow, natural springs, and wells and cisterns supplied by storm water.

Other important hydraulic works of this period were a dam in Alysia (western Greece) and an aqueduct that carried water in a water tank in the city of Megara, near Athens. The dam of Alysia is preserved in good condition (Fig. 6.4) and is characterized by its masonry body and the spillway that operates still today.

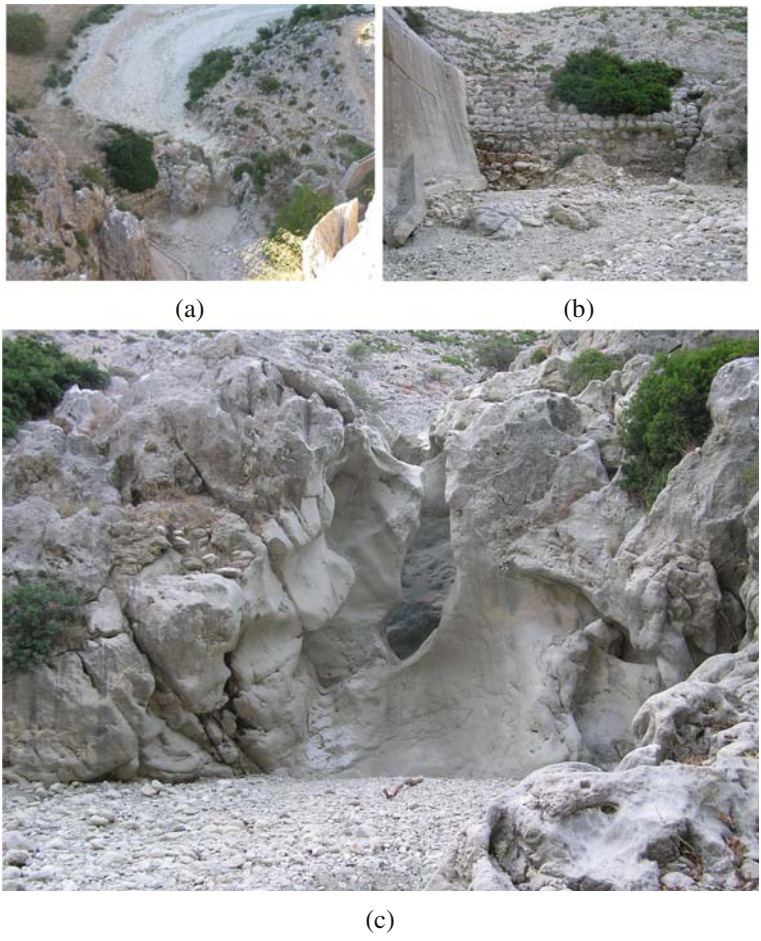


Fig. 6.4 Alysia dam: (**a**) General view (**b**) masonry (**c**) spillway. Color version available in Appendix

The structures that were constructed during the Hellenistic period could be connected with two unrelated (and probably opposed) to each other characteristics of the Hellenistic world: (a) the growth of the scientific and technological knowledge that permitted more sophisticated solutions in water management, and (b) the turn of the societies to a more luxurious way of life that included the embellishment of the cities and the people thereof. The inventions of Archimedes and Alexandrians and the primitive formulation of fluid mechanics led to the application of advanced

hydraulic technology to the Hellenistic cities. Several (inverted) siphons that were parts of aqueducts are the more impressive examples of advanced engineering during this period (Viollet, 2005). The largest of them that belongs to the Pergamon aqueduct and constitutes a miracle of fluid mechanics for that period. It was constructed around 200 B.C. with length that exceeds 3,000 m and it is the first large scale application where water was transported under pressure. On the other hand the raised sanitary and living standards resulted in widespread expansion of private and public baths and lavatories. Their construction was attained to perfection during that period and today their remnants can be found everywhere in Greece (Athens, Delos, Amorgos, Epidaurus, Kos, Philippoi, Thera; Antoniou, 2007). The installation for the cleaning of the young men, at the Gymnasium of Priene (Fig. 6.5) is a well preserved structure of this period.

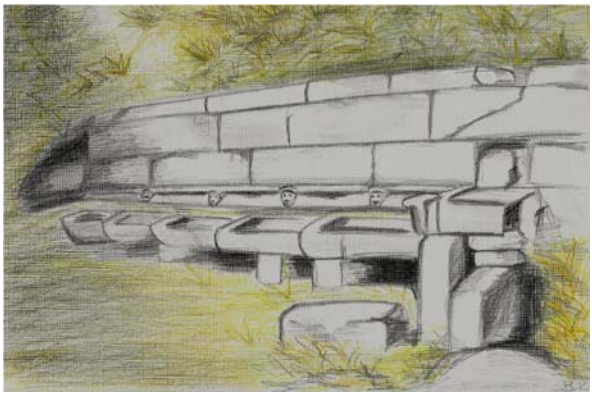


Fig. 6.5 Installation for the cleaning of the young men, at the Hellenistic Gymnasium of Priene (drawing by V. Kordoni)

The Roman period is characterized by the larger scale of hydraulic works (mainly water supply systems) that include many admirable components. The Roman engineers incorporated the technologies of the previous periods to their experience, and constructed advanced structures such as water bridges, siphons, tunnels, cisterns and urban distribution pipes for the water supply of the cities of Roman Empire. The large number of Roman aqueducts situated everywhere in Mediterranean basin are benchmarks of this ancient technology. Parts of them are preserved in good condition in several sites in Greece (Athens, Corinth, Lappa, Lictos, Mytilene, Nicopolis, Olynthus, Palaiopolis, Patras, Strymi). Finally, after 3000 years of activity, during Roman period the hydraulic knowledge integrated, the structures were spread in every site of the empire and the society was familiarized with the sustainable use of water. In Fig. 6.6, the plan of a Roman residence in the city of Ancient Thera, is presented. Inside the residence there is lavatory and the impluvium a sunken part of the atrium that captured rainwater from the roof. In the same site, a roofed cistern that still stores water is presented in Fig. 6.7.

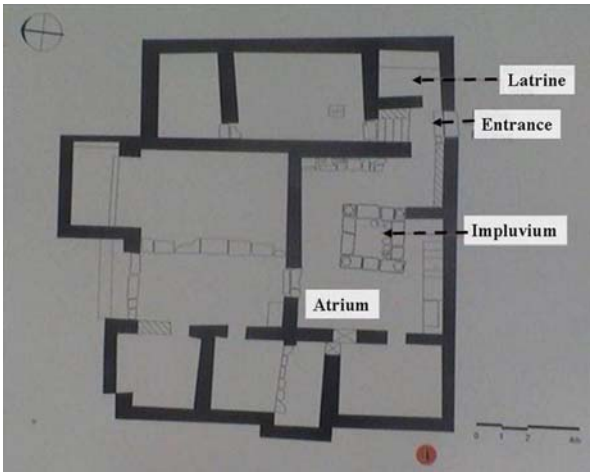


Fig. 6.6 Plan of a Roman residence (city of Ancient Thera). The sites of lavatory and impluvium are visible

Fig. 6.7 Roofed cistern (city of Ancient Thera). Color version available in Appendix

6.4 Discussion

The review of all this information about hydraulic works in ancient Greece reveals several issues that can be also approached from different, non-technical, points of view. Three issues are chosen for further discussion:

a. the cooperation of small- and large-scale structures as a hydrosystem;
b. the relation of the implemented technology with socio-economical characteristics of the societies; and
c. the small-scale facilities that improved the quality of life.

Small-scale hydraulic structures existed in all periods of the Greek antiquity. Urban water supply was not based on a central system, as happens today, but on several structures distributed all over the area. In many important sites, all these structures such as wells, cisterns, fountains, small water distribution systems and aqueducts operated as a hydrosystem. From the small hydrosystems that served the water facilities of the Minoan and Mycenaean palaces gradually Greeks passed to the creation of larger hydrosystems that supported the everyday life of the glorious cities of the Classical period. The operation of the new complex hydrosystems was strongly supported by legislation, institutions and public awareness about water. The Minoan palace sites (Knossos, Zakros, Mallia, etc.) and the city of Athens from Archaic to the Roman period are remarkable examples of such distributed small and large hydrosystems.

The size and character of the projects are related to the socio-economical characteristics of the societies. During oligarchic periods, the political situation favoured the construction of large public works. Those aimed to reflect the society's wealth or the power of the sovereign. For example in the case of the Eupalinos tunnel, even though cheaper works could be easily constructed to serve the same purpose, this breakthrough and expensive engineering solution was chosen perhaps due to an ambition of the local tyrant Polycrates to create a monument of technology (Koutsoyiannis et al., 2008). On the other hand, during the period of democracy in Athens, smaller constructions were preferred, such as cisterns collecting storm water. An advanced institutional framework for the water use that engaged the citizens to sustainable water management, was an important part of the hydrosystem management.

Several small scale facilities, related to water use, improved the quality of life in antiquity. In many cases, these can easily be compared with the modern ones. Lavatories, bathtubs and recreational fountains have been in use since the Minoan period (e.g. the toilets of the Knossos palace had seats and flushing equipment, and were connected to sewers; Angelakis et al., 2005) but they were shaped into an advanced form during the Hellenistic period.

6.5 Summary and Conclusion

Recently ancient water technologies and management practices are being revisited with an increased interest. Motivated from this, an information system is developed to support the scientific research about ancient Greek engineering practices and to disseminate this knowledge to the public.

A quick view of the gathered information reveals that ancient Greeks effectively tackled several water problems that modern societies still have to face up. The lower level of technological means (construction equipment in particular), in comparison to modern standards, did not hinder the design of marvellous hydrosystems with long duration structures that we encounter today everywhere in Greece. Studying these systems of that distant era is worth even today to discover (a) the sustainability that characterizes several management practices and hydraulic works (some of

the latter are still functioning to date), (b) the complementary character of projects with different types and sizes, and their relation to the specific socio-economical conditions and (c) the design principles of the engineering solutions that had been applied.

Up to this moment the information system contains data about 100 important hydraulic works from the Minoan era up to the Roman period. It is scheduled that the database will be completed in the future. Also a classification of water management practices and hydraulic devices will be included. Finally, the information will be expanded in space (to other parts of the Ancient Greek world) and time (through the Byzantine period).

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