Minoan Aqueducts: A Pioneering Technology

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Abstract: In this paper several archaeological, historical and other aspects of aqueducts in Minoan era are reviewed. During the Middle Bronze Age a "cultural explosion", unparalleled in the history of other ancient civilizations, occurred on the island of Crete. One of the salient characteristics of that cultural development was the architectural and hydraulic function of aqueducts used for water supply in "palaces" and cities. In the entire structures of most Minoan "palaces" and cities, nothing is more remarkable than their elaborate water supply systems. The Minoan hydrologists and engineers were aware of some of the basic principles of what we call today principles and practices of water sciences with emphasis on the construction and operation of aqueducts. The description of several of the Minoan aqueducts could justify that Minoans could be considered as pioneers in those technologies.

Key words Aqueducts; Crete; Knossos; Malia; Minoan civilization; Tylissos; Water resources.

Prolegomena

The rainfall regime and consequently the water availability over Greece vary substantially in space. In general, climate is affected during the summer by a subtropical high pressure belt, which results in hot and rainless weather conditions. During winter, the region is dominated by the mid-latitudinal depressions, connected with the westerlies regime, which brings cold weather and rainfall. In Crete the three main mountains (White, Ida, and Dikti mountains) play important role in rainfall and runoff regimes of the Island. Thus, the mean annual rainfall exceeds 1,800 mm in the mountainous areas of western Crete whereas in the eastern regions of the Island it may be as low as 300 mm. It is of interest to point out that the most advanced cultural activities in ancient Greece are located in semiarid areas with the lowest rainfall and thus the poorest water resources; i.e., Knossos, Gortys, Zakros, and Phaestos on Crete with annual rainfall less than 500 mm. The potential evapotranspiration exceeds 2,000 mm all over Crete, with the highest rates in summer months. Thus, irrigation of cultivated areas during summer is absolutely necessary and becomes the most demanding water use.

The above figures apply to the nowadays climatic conditions. Several studies have attempted to reconstruct past climate of the eastern Mediterranean (Issar, 1995; Issar and Makover-Levin, 1996). They concluded on the existence of long cold and humid periods followed by warm and dry ones (Angelakis et al., 2005). For example, Middle Bronze times are characterized by cold and humid conditions. Also, archaeological and other evidence indicate that during the Middle Bronze Age a "cultural explosion", unparalleled in the history of other ancient civilizations, occurred on the island of Crete. However, not only did Minoan Crete establish the critical foundations for almost all modern technological achievements,
including water resources technologies (aqueducts, cisterns, wells etc.), but their approaches were remarkably advanced.

It is evident that during the Bronze Age extensive systems and elaborate structures for water supply and sewerage systems, irrigation, and navigation were planned, designed and built to supply the growing population with water for the cities and villages, commerce, and for the irrigated agriculture. Thus, it not by chance that the main technical and hydraulic operations of capture, conveyance, raising and measurement have been practiced in varying forms since ca. 3,500 B.C. (Fig. 1). In the Minoan Crete various fundamental technologies such as aqueducts, wells, cisterns, and closed water distribution systems for water supply to the “palaces”, cities and villages were very well developed, as did techniques relevant to the recreational use of water.

![Figure 1](image.png)

**Figure 1** Historical development of water sciences technologies.

Commercial relationships have been known between the Minoans and continental Greece, Egypt, and Syria. There is no doubt that skills in hydraulic and water management had been transferred from Mesopotamia and Syria to Crete by that time. The Minoans not only applied these skills but also they developed them further, especially in urban hydraulics, in the “palaces”, the cities and the villages, to a level that was never reached before (Viollet, 2003). In most of Minoan settlements the potable water was dependent on surface springs, rivers, wells and cisterns. The normal reasons an aqueduct was build was to supply the baths (Hodge, 2002). The achievements of this period in dealing with the hygienic and the functional requirements, toilets and baths, and wastewater and urban drainage systems of “palaces” and cities, are supporting this statement (Angelakis et al., 2005). However, the water was also used for other purposes, ranging from gardens irrigation to aquatic shows and decorative fountains. A possible second reason for Minoans to build an aqueduct was the civic pride. It seems likely that these technologies had been transferred to continental Greece and then to other European countries by the Minyans, another prehistoric civilization, by ca. 1900-1600 B.C., and had since created the so-called Mycenaean civilization. (Angelakis and Spyridakis, 1996a).

The scope of this article is not the exhaustive presentation of what is known today about aqueducts, related technologies and their uses in Minoan Crete. Rather, some characteristic examples in selected fields that chronologically extend from the early Minoan civilization through the end of that era are presented. These examples may justify that Minoans could be considered as the pioneers in the technological development of aqueducts.

**Major Aqueducts**

In ancient Crete the technology of transporting water to “palaces”, cities and villages by aqueducts was very well developed due to the mountainous terrain as early as at the Early Minoan era. Several aqueducts of the Minoan era have been identified so far by Angelakis
and Savvakis (unpublished data). Water was transported through the aqueducts by closed or opened pipes (teracotta) and/or opened or covered channels of various dimensions and sections. The main of these aqueducts are in Gournia, Karfi, Knossos (Mavrokolympos), Malia, Mochlos, Minoa, and Tylissos. These technologies were further developed during the Hellenistic and Roman periods in Crete, and were transferred to the continental Greece and other Mediterranean and Near East countries.

**Aqueduct of Knossos (Mavrokolymbos)**

Minoan hydraulic engineers apparently were concerned with the solution of some water engineering problems and were able to provide cities and “palaces” with complete water supply systems. On the basis of their accomplishments it can be assumed that they were, in a sense, aware of the basic hydrostatic law, known today as the *principle of communicating vessels*. It is manifested in the water supply of the Knossos «palace» through pipes and conduits fed by springs; this is supported by the discovery of the Minoan conduit heading towards the Knossos «palace» from Mavrokolymbos which suggests a descending and subsequently ascending channel (Evans, 1921-1935; Hutchinson, 1950). However, it appears that Minoans had only a vague understanding of the relationship between flow and friction.

Present knowledge of how Minoan cities were supplied with potable water is mainly acquired from the «palace» of Knossos. The «palace», which was surrounded by a town (with 80,000 inhabitants), lies on the gently sloping banks of the Kairatos river, close to its confluence with a small brook (Viollet, 2003). Evidences for advanced hydraulic structures are apparent in many areas of the “palaces”. However, the sources of water and the methods used for supplying the «palace» are only partially understood. Several wells have been discovered in the «palace» area itself, and a single well slightly to the northwest of the Little «palace». The latter, restored to its original depth of about 12.5 m and 1.0 m diameter, continues to furnish an excellent supply of potable water (Evans, 1921-1935).

The Knossos «palace», however, did not solely depend on the water of the wells. There are indications that the water supply system of the «palace» of Minos at Knossos, was initially dependent on the spring water of Mavrokolymbos and later on the *Fontana* and the Mt. Juctas (Karidaki and Paradisi) springs. *Fontana* aqueduct, including the Scalani tunnel (1150 m in length), was constructed during the Roman period. Mavrokolymbos, a pure limestone spring, is located at a distance of 0.5 km south of the «palace» at an elevation of about 100 m, whereas Knossos lies at an elevation of about 90 m from sea level. The water from the spring of Mavrokolymbos was transported to the Knossos «palace» through pipes and conduits. That aqueduct is running along the western edge of the Vlikhia ravine (Evans, 1921-1935). The possible passage of the Mavrokolymbos aqueduct is shown in Figure 2. Due to the small distance from the «palace» to the spring, it is possible that a sloping cannel was used as suggested Evans (1921-1935) and Hutchinson (1950).

Water supply in the «palace» was provided through a network of terracotta piping located beneath the «palace» floors. The pipes were constructed in sections of about 60 to 75 cm each. These pipes with their expertly shaped, tightly interlocked sections date from the earliest days of the building and are quite up to modern standards. They imply a practical knowledge of the hydraulic principle that water seeks its own level. The sections of the clay pipes resemble those used in Greece in classical times, though Evans considered the Minoan to have been designed more efficiently; each section was rather strongly tapped toward one end with the objective of increasing the rate of water flow, thus helping to flush any sediment through the pipe (Buffet and Evrard, 1950).
Aqueduct of Tylissos

The aqueduct of Tylissos was also developed in the Minoan period. The remnants suggest that part of the aqueduct was constructed from closed pipes and part of it was as curved channel (Fig. 3). Parts of the Tylissos aqueduct are shown in Figure 4; the main conduit at the entrance of the house C (Fig. 4a) and secondary conduits and two cisterns (Fig. 4b). A stone made tank was used for pretreatment of water, mainly for the removal of sediments and/or suspended solids and the main cistern of cylindrical-shaped was used for the storage of water. Finally, a possible layout of the Tylissos aqueduct of a total length of 1.4 km, is shown in Figure 5.

Aqueduct of Malia

The Minoan aqueduct was probably using the water of a spring located west of the hilly area of Profitis Elias ‘Holly Hillock’. Water was supplied to the «palace» by closed pipes (terracotta pipes) or opened channels. A possible plan of the aqueduct is shown in Figure 6. The total length of the aqueduct up to point B is estimated to be 0.85 and 1.15 km with closed and opened conduit, respectively. A total length of 2.4 km is estimated when the water...
supply of House A located north of the «palace» and the port of Agia Varvara located northwest of the «palace» is included.

![Figure 4](image1.png)  ![Figure 4](image2.png)

Figure 4 Parts of the Tylissos aqueduct: (a) central conduit located at the entrance of the three villas and before the little cistern and (b) secondary conduit, small lithic cistern used for the removal of suspended solids of water before its storage into the main cistern.

![Figure 5](image3.png)

Figure 5 Possible layout of the Tylissos aqueduct (A spring of Agios Mamas).

**Epilogue**

Crete became the cradle of one of the most important civilizations of mankind and the first major civilization in Europe. One of the major achievements of the Minoans was the advanced water management techniques practised in Crete at that time. The advanced water
distribution systems in various Minoan “palaces” and settlements is remarkable, because no aqueducts are known before the Minoan era, whilst strong evidence suggests that this technology was developed by Minoans. Thereafter, aqueducts were used by the Mycenaeans in continental Greece. In the Minoan «palace» of Knossos terracotta pipes for water distribution have been identified, suggesting that some aqueduct systems should exist. Similar terracotta pipes were found in some other Minoan settlements such as Tilissos, Gournia, and Vathypetro, as well as in Malia.

Figure 6 Possible plan of the Malia aqueduct.

Minoan technological developments in water management principles and practices are not known as well as other achievements of the Minoan civilization, such as poetry, philosophy, sciences, politics and visual arts. To put in perspective the ancient water aqueducts discussed in this paper, it is important to examine their relevance to modern times and to harvest some lessons learned. The relevance of ancient works will be examined in terms of the evolution of technology, the technological advances, homeland security, and management principles. The achievements of Minoans in dealing with the aqueducts and functional requirements of water distribution systems can only be compared to modern urban water systems, re-established in Europe and North America from the second half of the 19th century A.D. (Koutsoyiannis et al., 2006) until present day. Thus, with a few exceptions, the basis for present day progress in water transfer is clearly not a recent development, but an extension and refinement of the past.

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References


