A survey of ancient Minoan water technologies

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ABSTRACT

A survey is presented of water technologies used by the ancient Minoan civilization during the Bronze Age. This survey considers eleven Minoan settlements on the eastern part of Crete and is based upon a field assessment of the water technologies. While water systems had a monumental role in the life of the Minoans there has been little understanding of these ancient systems. Partially this can be explained by the multiple levels of modifications to the original structures since the demise of the Minoan civilization. In addition, post-excavation activities on archaeological sites obscure and mask features of the ancient structures making it difficult to discern their original purposes. Today, Minoan water technologies can serve as models for sustainable water management and adaptation to climatic fluctuations. Our present day practice of designing water systems in many developed parts of the world has forgotten the more sustainable practices, based upon traditional knowledge, such as rainfall water harvesting, particularly in arid and semi-arid regions. In many developing parts of the world people overlook the technologies and know how that was used thousands of years ago by ancient civilizations, such as the Minoans. How do we overcome these modern day shortcomings and strive for water resources sustainability? Possibly one way is to study the past.

Key words | ancient water technologies, crete, Minoan settlements, traditional knowledge, water resources sustainability

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INTRODUCTION

The literature provides many descriptions of Minoan palaces and the lifestyle of the Minoans but neglects one of the most crucial aspects of sustenance: water. The elaborate Minoan settlements of Crete were endowed with intricate water installations. As the sites went out of use so did the water installations. As archaeologists began to dig into the Cretan soil and expose ancient settlements these installations were brought to light again.

The ancient water technology of Crete is of the utmost importance because the only way these settlements could exist was with a reliable and efficient water system. There is little doubt that water played an important role in the daily lives of the Minoans. Few publications (Angelakis & Spyridakis 1996; Antoniou *et al.* 2006; Mays *et al.* 2007; Viollet 2007; Vuorinen *et al.* 2007) address in a comprehensive manner water related technologies for Minoan settlements. These publications mention water technologies as a part of settlement infrastructure; however, they do not provide a comparison of these technologies on a regional scale. The primary purpose of this paper is to fill this gap and provide a field-based survey of water related technologies in eleven Minoan settlements (see locations in Figure 1) in the eastern part of Crete. The larger settlements are Knossos, Mallia, Palaikastro, Phaistos, Tylissos and Kato Zakros and smaller settlements include Agia Triadha, Chamaizi, Kommos, Myrtos-Pyrgos and Kato Syme.

A second purpose of this paper is to describe Minoan water technologies from engineering and geologic perspectives since Minoan studies are predominantly (or traditionally) archaeological or historical. Engineers and geologists have become engaged in this subject only recently with developing interest for the larger scientific community, specifically with regard to issues of sustainability and climate change.

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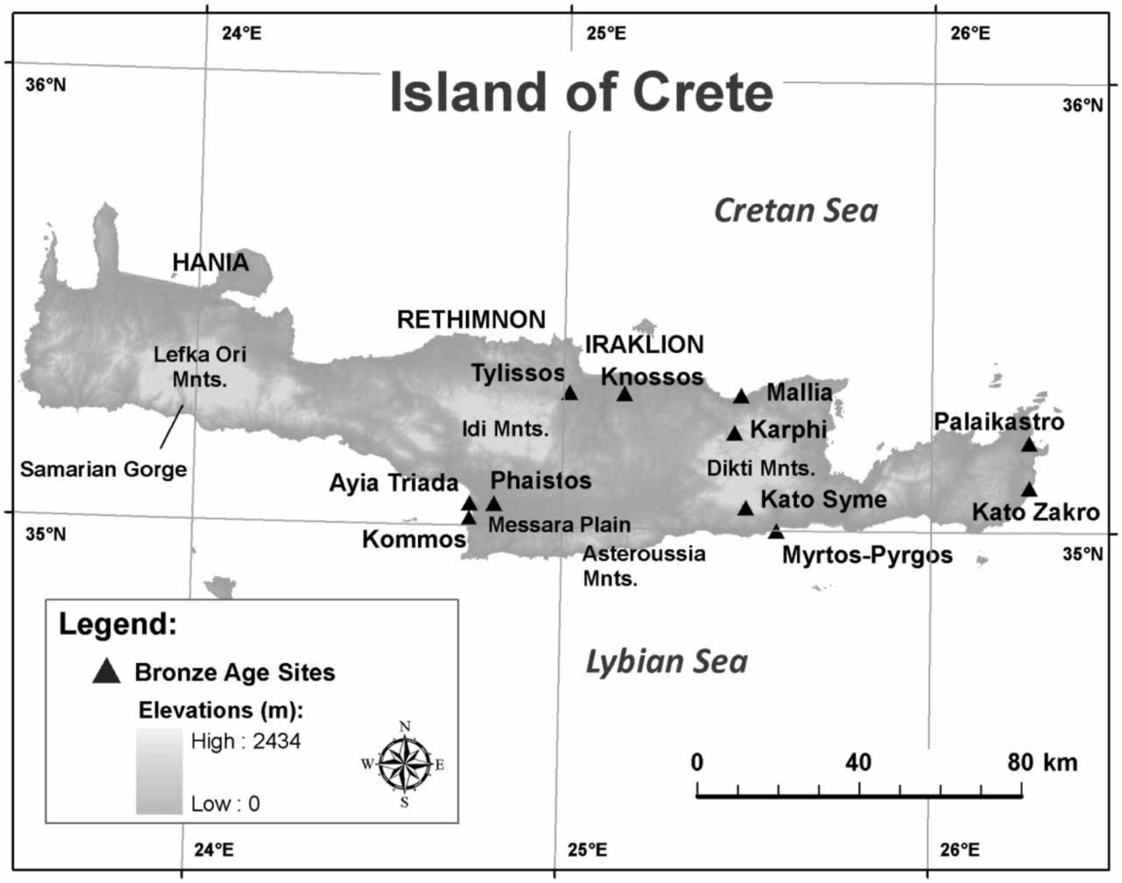

Figure 1 | Location of visited Minoan settlements on Crete.

A third purpose of the paper is to examine the use of traditional knowledge (such as the water technologies of the Minoans) to help solve water resources sustainability issues of the future. In a Newsweek article from 2007 on ancient Chinese water technologies Larry Mays was quoted as saying 'Part of solving the problems we have might be to look at some of these traditional methods instead of building megaprojects' (Newsweek 2007).

Historical overview

The earliest inhabitants of Crete date back to the Neolithic Period, with a scattered population living in caves (Hood 1965). A concentrated population was located at Knossos, which was one of the largest Neolithic settlements in the eastern Mediterranean (Graham 1987). During the early Bronze Age or Early Minoan (E.M.) period, in the third millennium BC (3000–2000 BC), the population increased and spread throughout the island.

The Minoan civilization flourished from around 2800 to 1450 BC. The E.M. period was a pre-palatial period for which little is known about the architecture. Even less is known about its history, government and religion. Graham (1987) points out that the consistent improvement of the quality of pottery during this period indicates general cultural progress. During the beginning of the Middle Minoan (M.M.) period substantial settlements were built. Still very little is known of the history of the M.M. period. The most brilliant and probably the most prosperous period of the Minoan civilization was the Late Minoan (L.M.) period.

The Minoans developed a system of political, economic and social organization centered at a number of major settlements, such as Knossos, Malia, Phaistos, Kato Zakros and others, also referred to in the archaeological literature as palaces. In 1450 BC the palaces were abandoned/destroyed, except for Knossos, which survived longer (possibly another 75 years) under Mycenaean occupation, until it too came to its demise. Knossos was excavated between 1900 and 1932 by Sir Arthur Evans. He published a multi-volume set on his findings entitled *The Palace of Minos at Knossos, Volumes I–IV, 1921–1936*. Evans devised a system of chronology into which he fit his discoveries:

Early Minoan (E.M.)	3000–2000 BC
Middle Minoan (M.M.)	2000–1600 BC
Late Minoan (L.M.)	1600–1200 BC

Environmental conditions

While regional geologic and geographic environments were most likely the same during the Minoan period, climatic conditions were probably different. Earlier studies on this subject belong to Lamb (1968) and Weiss (1982). Broader climatic conditions of the eastern Mediterranean indicate that there was a general warming trend toward 1500 BC that was interrupted and reversed by a cooling effect, returning to dry and warm around 1400 BC, changing back to a cooling phase around 1300 BC (Issar & Zohar 2009).

Research suggests that climatic changes might be related to various stages of evolution of ancient societies causing the decline or flourishing of agricultural activities. This point of view should be taken cautiously since uncertainty in climate proxies (e.g. stalactites, tree rings, pollen data, lake deposits, etc.) and climatic models requires additional independent measurements or agreement between 'separate lines of investigation' (Kuniholm 1990) to support their interpretation. Kuniholm (1990) also raised concern about the cause and effect, providing as an example the possibility of a future archaeologist finding deposits of a 'dust bowl' from the 1930s and linking it with the stock market crash of 1929.

While most chronologic methods and climatic models have uncertainties and lack precision, it is clear that climate changes occurred in the past and could play a role in the evolution pattern of ancient societies. This is especially valid for interdisciplinary studies concerned with environmental issues such as water and wastewater technologies, agricultural development, etc.

Geologic structure

The island of Crete is located in a zone of collision between the African and Aegean tectonic plates. This location experiences intensive crustal (depth >40 km) and subcrustal (depth <40 km) earthquakes (McKenzie 1978) that influenced the Bronze Age settlements on Crete (Monaco & Tortorici 2004). The process of collision between plates formed special geological features on Crete – *nappe*s. *Nappes* are primary features of a continental collision zone and occur when existing folds or basement rocks shear and overturn on themselves, stretching for many kilometers. On Crete this process resulted in complex structures exhibited in all three main mountain ranges.

The important hydrologic implication of Cretan *nappes* is a highly heterogeneous (i.e. rock composition and permeability) structure of the island. In this structure carbonate rocks (primarily limestones) of Neogene cause the development of karst – the process of dissolution of carbonate rocks that forms voids and caverns. Some karstic features such as holes or polje are known on Crete as *katavothri* (Gifford 1992). The heterogeneity of the rock structure provided favorable conditions for perched aquifers – small localized aquifers with limited recharge. Geological heterogeneity makes the karst network a flow-driven heterogeneity (Bakalowicz *et al.* 2003). This means that typical groundwater analysis becomes very complicated.

Tectonic fractures, a karst environment and perched aquifers have a strong influence on the water supply and development of the groundwater conditions on Crete. Surface water penetrates the Cretan landscape and then is stored in underground caves and voids, then flowing along mountainsides, disappearing in fractures and then reappearing in valleys and on the coast. In coastal aquifers salt water penetrates land aquifers and mixes with freshwater (e.g. Almyros Spring on Crete (Burdon & Papakis 1964; Burdon 1967).

OVERVIEW OF TECHNOLOGIES USED FOR WATER SUPPLY, DISTRIBUTION AND DRAINAGE

A systematic evolution of water management in ancient Greece began in Crete during the E.M. period. The Minoans had only one driving force, gravity, at their disposition to move water. In prehistoric Crete rivers and springs provided people with water. During the E.M. period, a variety of technologies such as rainwater harvesting, wells, cisterns, gutters, channels, sedimentation tanks, and aqueducts were used.

Minoan architecture included flat rooftops, light wells, and open courts, which played an important role in water management. The rooftops and open courts acted as catch basins to collect rainwater from which water flowed to storage areas or cisterns (Shaw 2009). Collected information about visible existing features of water related technologies was classified according to their role, such as natural spring, aqueduct, cistern, rainwater collection, well, sedimentation tank, channel or drainage system (Table 1).

A list of technologies used for water supply, distribution and drainage systems for eleven surveyed settlements is shown in Table 1. The most notable feature in them is a cistern. A cistern is a round cylindrical structure similar to a well. The main difference between a cistern and a well is the use of plaster that covered the bottom and sides. While the idea of a well is to tap into an aquifer, the purpose of a cistern is to store water that was added to the repository.

Water could be brought into a cistern from outside or collected from roofs. Except at Palaikastro, which depended on wells, and Kato Syme that used a spring as its primary source of water, all other Minoan settlements have both cisterns and wells. (One cistern in Mallia is probable since it is hard to identify plaster around its walls). Almost half of the settlements have wells. Five settlements have spring feeding systems for water supply, though springs near Knossos and Mallia are also probable. Four settlements have discernable aqueducts represented by disconnected and rearranged channel segments made out of stone and ceramics. Six settlements have drainage systems with channels and canals.

Sources for water supply include springs, rainwater, groundwater and nearby rivers. Most settlements do not presently have a functional water supply and distribution system except for Kato Syme where the spring still supplies water to the excavation site and the nearby village. Some wells in Kato Zakros and Palaikastro still have water, which is hardly suitable for drinking.

The distribution systems usually consist of an infrastructure that collects and distributes water in the settlement. This includes wells, pipes, canals, drains, settlement basins and cisterns. Since all Minoan settlements are now relics they lack the original roofs and supports made out of hay and wood and reveal only walls and foundations of former dwellings. Therefore the only rainfall harvesting structures that can be distinguished are remnants of channels and drains leading to cisterns.

Table 1 | Technologies used for water supply and distribution and for drainage (* probable)

Settlements	Spring	Aqueduct	Cistern(s)	Rainwater collection	Well(s)	Sedimentation tanks	Channels/canals	Drainage
Knossos	X*	X*	X	X	X	X	X	X
Mallia	X*	X*	X*				X	X
Palaikastro					X		X	X
Phaistos			X	X	X		X	X
Tylissos	X	X	X	X		X	X	
Kato Zakros			X		X		X	X
Agia Triadha	X	X	X	X		X	X	X
Chamaizi			X	X	X*			
Kommos			X		X			
Myrtos Pygros			X	X				
Kato Syme	X							

Rainfall harvesting (collection)

Many early civilizations in arid and semi-arid regions have relied on collecting or 'harvesting' surface water from rainfall and storing the water in reservoirs or 'cisterns.' Not only were cisterns used to store rainfall runoff, they were also used to store water from aqueducts. Cisterns during ancient times have ranged from constructions of irregular shaped holes (tanks) dug out of sand and loose rock and then lined with plaster (stucco) for waterproofing, to the construction of rather sophisticated structures.

Rainfall harvesting was accomplished using both rooftop collection and surface collection from larger court areas such as those found in Knossos, Phaistos, Tylissos, Agia Triadha, Chamaizi, Myrtos Pygros and Kato Zakros. Unique hydraulic structures associated with rainfall collection include large stone conduits with branches that were used to supply collected water to cisterns such as those found in Knossos (Figure 2).

Terracotta pipes were also used to convey rainwater to cisterns. Alongside a stairway in Knossos is a small stepped channel consisting of a series of parabolic-shaped step chutes that was used to convey rainwater from terraces down to a sedimentation (desilting) basin. The same components of a rainfall harvesting system, i.e. cistern, channel and sedimentation tank, also existed in other settlements. Figure 3 shows an example from Tyllisos of a sedimentation tank connected by a channel to a cistern.

Rainfall harvesting systems devised by the Minoans, consisted of rainfall collection and storage using cisterns at least 1,000 years before the classical and Helenistic-Greek cities. This system required additional structures (channels) to pass runoff water into cisterns. While cisterns are preserved in archaeological sites, the channels are missing or replaced. Cisterns have been classified as follows:

- Large storage facility of either circular or rectangular shape built with stairs to provide easy access to the water (Phaistos, Tylissos, Kato Zakros). Figure 4 shows an example of such a structure in Kato Zakros.
- Large storage facilities of circular shape without stairs (Knossos, Myrtos-Pyrgos, Mallia). Figure 5 shows an example of such a structure in Myrtos-Pyrgos.
- Smaller storage facilities (Knossos, Agia Triadha).

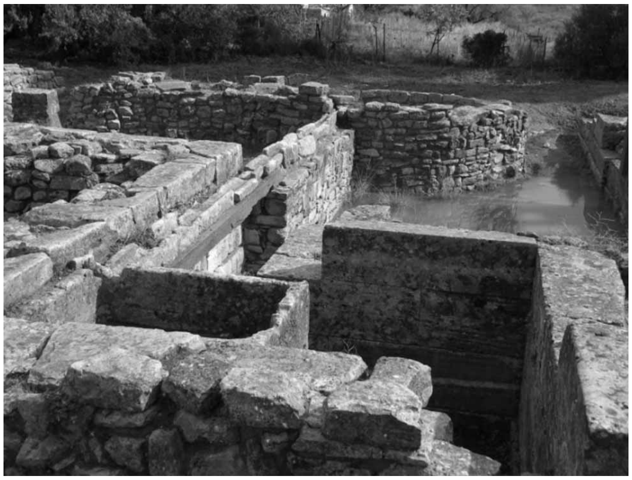

Figure 3 | Sedimentation tank in foreground with stone channel connecting to cistern (Tylissos).

Figure 2 | Carved stone elements of rainfall harvesting system collecting water falling from roof.

Figure 4 | The Hall of the Cistern (Kato Zakros) showing staircase.

Figure 5 | Cistern at Myrtos-Pyrgos.

Figure 6 | Cistern (well?) at Chamaizi.

- Small cistern excavated into bedrock (Chamaizi) that also possibly functioned as a well (Figure 6).

The two earliest large cisterns of Minoan Crete were built in the first half of the 2nd millennium B.C., which was the time of the first Minoan settlement at Myrtos-Pyrgos (Cadogan 2006). These cisterns remain an unusual attribute of the Minoan settlement, as the Myrtos River was able to supply water to the base of the Pyrgos hill. Both cisterns are circular with vertical walls and rounded bottom (Figure 5). The walls and bottom are coated with white lime plaster 1 to 2 cm thick (Cadogan 2006).

Cisterns or granaries?

The round structures that exist at Knossos (4 structures according to Cadogan), Malia (8 structures), and Phaistos (4 or 5 according to Cadogan (2006)) have been referred to as *kouloures*, (a Greek word for something round and hollow). Many have referred to these as granaries. It is interesting to note that the round structures at all three palaces were located in the west courts. The cistern at Tylissos is what we might want to call the standard type of cistern that has water delivered to it from above and then stores the water. This cistern is the only cistern that has a plastered bottom (Cadogan 2006). Steps into the cistern were used to descend down to the various water levels.

According to Cadogan (2006) it is generally agreed that the structures at Malia were used as granaries; however Strasser (1997) argues that they were not granaries. Evans (1935) suggested that at Knossos they were rubbish pits and/or 'blind wells for the disposal of surface waters', but not suitable as cisterns because they were not plastered. Watrous *et al.* (2004) prefers to call them cisterns at Phaistos. At Myrtos Pyrgos the round structures (earliest cisterns in Crete) were plastered and as stated by Cadogan (2006), 'it is clear that having plastered sides is a key factor for positive identification of a cistern although it cannot exclude use as a granary.'

While the interpretation of *kouloures* includes granaries or cistern we can also consider a potential use of them as emergency firefighting water supply. Since roofs were constructed of wood and settlements were subjected to periodic fires from oil spills from lamps during earthquakes it is logical to imagine that Minoan settlers would probably have emergency water supply just for firefighting purposes. This interpretation has not yet been discussed in the available literature and requires further consideration and study.

Aqueducts

Tylissos has an aqueduct that supplied water to the settlement and remains of that aqueduct still exist. The presence of aqueducts is also suggested for Knossos, Mallia, and Agia Triadha where apparent sources of water were in close proximity to springs or streams. The water supply system to Tylissos included an aqueduct from the spring of Agios Mamas (Sklivaniotis & Angelakis 2006). Infiltration devices made of terracotta and filled with charcoal (burnt wood) were found at the spring and are now located at the Archaeological Museum in Heraklion. This infiltration device essentially acted as an activated carbon process.

The water distribution system was constructed of closed pipes and curved stone channels. Secondary conduits were used to convey water to a sediment tank constructed of stone, used to remove sediment and/or suspended sediments. Water then flowed from the sedimentation tank through the small stone-carved channel to the main cistern for water storage.

There are indications that Knossos was initially dependent on the Mavrokolybos spring that is located approximately 0.5 km southeast of Knossos at an elevation 10 m above the palace (Koutsoyiannis *et al.* 2008). Pipes and/or open channels, functioning as an aqueduct, were probably used to transport the spring water to the palace. An aqueduct made of terracotta pipe could have crossed a bridge on a small stream south of the palace, which carried water from a perennial spring on the Gypsadhes hill (Graham 1987).

Graham (1987) noted that Hutchinson (1950) thought that the water-supply of Knossos came from the 'excellent and perennial spring on Gypsadhes,' which served the caravanserai; 'an extension of this conduit could well have been carried along the viaduct across the bridge and so to the southern limits of the palace.' The so-called 'caravanserai' was a building on the other side of the stream, south of the palace, which Evans thought to have been used for lodging travelers and visitors of the palace. He also thought that a strong viaduct existed between the caravanserai and the south entrance of the palace.

It would have been logical to have running water for the caravanserai so that people could have washed themselves and drink water. The aqueduct from the Gypsadhes spring to the caravanserai could have crossed the stream that flows to the Karaitos River on the bridge to supply the palace of Knossos (Viollet 2003). If it did exist then this portion of the aqueduct would have had a siphon effect because the bridge elevation is a few meters lower than the palace (Viollet 2003). This is very interesting because no use of siphons in aqueducts is known until 1,000 years (4th century BC) after the Minoan civilization.

Wells

Wells were used in several locations, particularly at settlements located near the sea, such as Palaikastro, Kommos, Myrtos Pyrgos and Kato Zakros. Wells were also utilized at the inland palaces of Phaistos and Knossos. Table 2 shows well dimensions and their occurrence. Most of them do not exceed 2 m in diameter. Current maximum depth of wells does not exceed 6.3 m. Figure 7 shows an example of a well from Phaistos. The use of wells for water supply is clearly visible at Kato Zakros where the water level is still high. A well with steps is shown in Figure 8 that was supplied with groundwater through infiltration, as the water table was shallow.

Information about well functionality is limited. Excavations of two wells in Palaikastro revealed their intermittent use for water supply and as debris receptacles (Macgillivray *et al.* 2007). This excavation showed that wells stopped functioning during the L.M. III period.

Table 2 | Wells and their dimensions. Where only two dimensions are given, the well is round (* =probable; NA = Not available)

Settlements	Well-dimensions (current depth × diameter × length) meters
Knossos	3.7 × 6.0
Mallia	Spring*/Aqueduct*/Cistern*
Palaikastro	7 × 2
	6.4 × 1.3
	6.6 × 0.9
Phaistos	5.3 × 0.8
	2.7 × 1.0
	5.4 × 0.7
	6.3 × 1.1
	5.6 × 0.9
Tylissos	Cistern/Aqueduct*
Kato Zakros	NA × 1.5 × 2.5
	NA × 2.9 × 5.7
	NA × 5.2
Agia Triadha	Cisterns
Chamaizi	Cistern*
Kommos	0.5 × 4.3
Myrtos Pyrgos	NA × 1
Kato Syme	Spring

Figure 7 | Well at Phaistos.

Figure 8 | Well at Kato Zakros with staircase, filled with water.

Drainage systems

Drainage systems for both storm sewer (excess rainfall) and sanitary (wastewater) sewer purposes were used throughout the Minoan settlements. Components of these systems include both terracotta pipes and drains, and stone carved drainage channels. The terracotta pipes and drains are located under floors. The stone carved channels were located under streets and courts (Figure 9). They connected larger collectors in the downstream direction.

The drainage system at Knossos was complicated. Evans (1921) showed a major drain system as a ring-drain system. Agia Triadha also has some very sophisticated water

Figure 9 | Drainage system at Knossos.

structures including a network of channels that deliver water to the two carved-in-stone open channels (Figure 10) and then into the sedimentation basin.

Recreation/ritual (lustral basins, baths and fountains)

'Lustral Basins,' a term given by Evans, are thought to have been used primarily for ritual purposes. Evans pointed out that they could not have been filled with water since there is no outlet for the dirty water (Cadogan & Clarke 1991). However clay baths could have been placed in the basins as pointed out by Cadogan & Clarke (1991), who referred to these as baths rather than lustral basins. These basins can be seen at Knossos, Gournia, Mallia, Phaistos, Tylissos, and

Figure 10 | Two carved-in-stone open channels in Agia Triadha.

Figure 11 | Lustral basin at Kato Zakros.

Kato Zakros (Figure 11). The idea of bathing seems to be reasonable when one takes into account the location of these features in relation to other rooms within these settlements.

WATER TECHNOLOGIES AND ENVIRONMENTAL FACTORS

The fact that most (9 out of 11) settlements (Table 1) have cisterns clearly indicates that Minoan settlers identified the need to adapt to the climatologic conditions of Crete. Cisterns are used throughout the world to mitigate effects of dry seasons and store excess water. The dimensions and number of cisterns should relate to the size of the population, however we still know little about possible population density in Minoan settlements.

Contemporary geologic conditions on Crete indicate the existence of lithological and stratigraphic heterogeneity due to the nature of limestone bedrock and *nappes* structures. The groundwater sources of water supply for Minoan settlements were springs and wells identified in five locations out of eleven (Table 1). Productivity of wells and springs largely depend on permeability that varies with bedrock conditions. *Nappes* consisting of limestone are perfect for karst development and fractural irregularities that could lead to the formation of perched aquifers and large cavities storing the excess water accumulated during the wet seasons and preserved under the ground during the dry seasons. However, earthquake activity could easily lead to the destruction of cavities and bedrock dislocations thus influencing changes or interruptions of discharges in springs and wells. In addition, climatic conditions could make spring and groundwater flow intermittent. This could explain the fact that cisterns were in large use and demand.

Field investigation of available Minoan sites has shown that due to reconstruction work many original features were modified during the post-Minoan period or during site preservation and restoration. For example, the Agia Triadha complex includes drain channels built later and connected to the Minoan settling basin. This complicates the analysis of 'pure' Minoan technologies. Also, part of the original terrain was modified by excavations and reconstructions of the site. In Agia Triadha the inflow drain channel lacks continuation and apparently was connected to the spring. While the spring bed is barely visible, there is no other source of water that could feed the channel. However, the spring bed can now only be assumed due to the modification of terrain during the reconstruction of the site.

WATER RESOURCES SUSTAINABILITY AND TRADITIONAL KNOWLEDGE

At the beginning of the new millennium we have a water crisis, which threatens human existence in many parts of the world. Water resources sustainability is the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life (Mays 2006). One might ask, how sustainable is it to live in a world where approximately 1.1 billion people lack safe drinking water, approximately 2.6 billion people lack adequate sanitation, and between 2 million and 5 million people die annually from water-related diseases?

UNICEF's *The State of the World's Children 2005: Children Under Threat*, provides an analysis of seven basic 'deprivations' that children feel and that powerfully influence their futures. UNICEF concluded that more than half the children in the developing world are severely deprived of one or more of the necessities essential to childhood: adequate shelter, sanitation, access to safe water, access to information, health care services, school, and food. Of these, three are directly related to water. The overall goal of water resources management for the future must be water resources sustainability.

In 1992 the United Nations organized a World Conference on the Environment and Development, typically referred to as 'The Earth summit', which was aimed at reconciling the dramatic world environmental conditions affecting the development and welfare of people. Three conventions for climate, biodiversity and desertification were considered from development and technology perspectives, with a consideration of traditional knowledge and practices. The United Nations Convention to Combat Desertification (UNCCD) selected a Science and Technology Committee to look at the inventory and classification of traditional knowledge.

A list of 78 techniques and practices were developed by the committee and classified into seven topics: water management for conservation, improvement of soil fertility, protection of vegetation, fight against wind or water erosion, silviculture, social organization, and architecture and energy. Desertification was defined as 'deterioration of the land in the arid, semiarid and semi humid dry areas due to factors including climate changes and human activity.'

'Modern technology aims at an immediate efficiency through a high specialization of knowledge supported by dominant structures able to mobilize resources external to the environment' (Laureano 2001). An example of modern technology would be to dig deep wells and pump to an extent that would harm water supplies for the future, which has been done in so many places particularly in developed parts of the world. Traditional knowledge would have relied on a system for harvesting meteoric water or exploiting run-off areas using the force of gravity or water catchment methods such as rainwater harvesting that would allow replenishment and increase the durability of the resource (Laureano 2001). 'Modern technological methods operate by separating and specializing, whereas traditional knowledge operates by connecting and integrating.'

The looming present day water crisis in many parts of the world must be faced using traditional knowledge and techniques inherited from the past in addition to our present day technological capabilities for more sustainable ways of dealing with water scarcity, particularly in developing parts of the world. Many present day water problems can be solved by using traditional knowledge such as those listed in Table 1 developed by ancient cultures, such as the Minoans.

Rainwater harvesting is certainly one of the technologies of traditional knowledge used by the ancients and could be implemented in both developed and developing parts of the world to strive for water resources sustainability. Oweis *et al.* (1999) pointed out two major features of ancient water harvesting technologies: flexibility and endurance. Flexibility relates to easy integration with other resources and methods by diverse cultures; endurance relates to the ability to persist despite abrupt changes in society. These methods are simple and can be implemented by individuals or small households without intensive labor and expensive technologies. People have forgotten the sustainable ways of the past. In reality highly advanced methods are not required to solve many water problems, particularly in many of the poor and developing parts of the world. A large part of the future will involve living in concert with nature, not trying to defy nature.

SUMMARY AND CONCLUSIONS

An interdisciplinary analysis of water technologies in ancient Minoan settlements shows that later reconstructions and modifications of sites cause significant problems in interpretation and analysis of existing Minoan water technologies. This conclusion was derived from visual assessment of sites where misplacement of engineering elements of water systems, differences in quality and shapes of clay pipes and drains, and modified terrain around sites due to excavations were evident. While these problems hamper interpretation and assessment of Minoan water technologies, it is clear that these technologies were created and adapted to the local geologic and climatic conditions of the island. The Minoan settlement of Kato Syme still has a vital spring that not only continues feeding the site itself but also provides water for the modern village and its agricultural plots below.

The main conclusions are:

1. The geologic and climatic conditions of Crete are favorable for providing both, underground and surface water to feed water related structures in Minoan settlements.

2. Changes in either geologic or climatic conditions would most likely force Minoan people to remodel existing water technologies or integrate them, or abandon settlements and search for new locations with more water.
3. Further studies of Minoan water technologies will require re-analyzing of original excavation documentation and certain other features to establish the original condition and location of wells, cisterns, drains and other water related technologies. For example, to establish differences between wells and cisterns it is necessary to distinguish the absence or presence of plaster around the walls and at the bottom.
4. Minoan water technologies should be considered not as historical artifacts but as potential models for sustainable water technologies.

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