water

Review

Evolution of Water Technologies and Corresponding Philosophy and Sciences Focusing on the Hellenic World through the Millennia

Andreas N. Angelakis [1,2,*], **Jens Krasilnikoff** [3] **and Vasileios A. Tzanakakis** [4]

[1] Institute of Crete, National Foundation for Agricultural Research (N.AG.RE.F.), 71307 Iraklion, Greece
[2] Hellenic Union of Municipal Enterprises for Water Supply and Sewerage, 41500 Larissa, Greece
[3] Department of History and Classical Studies, School of Culture and Society, Aarhus University, 8000 Aarhus, Denmark
[4] Department of Agriculture, School of Agricultural Science, Hellenic Mediterranean University, 71410 Iraklion, Greece
* Correspondence: info@a-angelakis.gr

Abstract: In this review, hydro-technological advancements in the Hellenic world throughout the millennia are considered in relation to the scientific developments and perceptions of the natural world articulated by Greek thinkers. Starting with the advanced hydro technologies of the Minoan civilization, this review presents the state-of-the-art evaluation of the hydro technologies in Greek historical contexts. More precisely, this review focus on how, when, and where modern hydro technologies developed based on ancient technological achievements, and subsequently when technological achievements were totally forgotten in specific periods, such as the Iron Age (ca 1200–800 BC), only to be reinvented or rediscovered in subsequent periods. In most cases, information has been collected from different sources and was cross-matched with each other. The results observed from the literature and material evidence are compiled and presented in the form of a critical review study. With a few examples, comparisons to hydrologic and hydraulic developments in other civilizations are considered and discussed.

Keywords: cisterns; dark ages; drainage; sewerage systems; irrigation; aqueducts; dams; water supply

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1. Introduction

. . . .ὅμοια γὰρ ὡς ἐπὶ τὸ πολὺ τὰ μέλλοντα τοῖς γεγονόσιν.

Most of what will be done in the future are the same as what has been done. Aristotle (384–322 BC).

Science and technology have historically been the main currencies for exchange and dialogue among human societies and sovereign nations. The provision of water has been a major enterprise in human history. By using, inventing, adapting, and adopting hydro technologies ancient civilizations influenced other civilizations. Hydro technologies played significant roles in different civilizations and the evidence demonstrates that many basic principles of water technologies emerged alongside the development of human societies. Thus, the ancient world was significantly influenced, with technologies and strategies still serving their original purposes in our present. As a result, water supply has been a major achievement in human history. Significant characteristics of the different civilizations originated in their ability to engage unique environments with durable technologies. During the Bronze Age, the Minoan and the Mycenaean cultures, dominating the Eastern Mediterranean, and the Indus Valley civilization, appear to have developed in balance with the environment and at the same time pioneered technological developments, especially those related to water resources. This included paradigms of water supply, such as fountains, storage of rainwater in cisterns and exploitation of spring water, construction of dams, wells, aqueducts, toilets, baths, water use for recreation, drainage, and sewerage systems, treatment of water and wastewater, irrigation and drainage of agricultural land. Moreover, the civilizations implemented numerous vital paradigms on water resources technologies, such as wastewater and storm water management.

Sciences, such as mathematics (geometry), astronomy (predicted the eclipse), geophysics, and in particular, hydrology, were initiated later on in the archaic period in ancient Ionia by Thales of Miletus (ca 624/23–548/45 BC) and his successors Anaximander (ca 610–547 BC) and Anaxagoras of Clazomenae (ca 500–428 BC), who developed the principles of Thales. Anaxagoras brought scientific traditions from Ionia to mainland Greece, taught in Athens for about 30 years, and thus disseminated the ideas of the Ionian philosophers to his students. Political leaders, dramatists, and historians, such as Pericles (ca 495-429 BC), Euripides (480–406 BC), Sophocles (ca 497/6–406/5 BC), and Herodotus (ca 480-430 BC) subscribed to this fundamental scientific approach to the study of the natural world [1].

To our knowledge, the close relationship between the development of science and philosophy was first condensated in the work and life of Pythagoras (ca 582–500 BC). The Ionian philosopher and mathematician Pythagoras was the eponymous founder of Pythagoreanism. Apart from his influence in mainland Greece, his political and religious teachings flourished with the western Greeks in Magna Graecia referred to the coastal areas of southern Italy, by which the philosophies of Plato and Aristotle and through them western philosophy was influenced (Diogenes Laertius, 8.1.). Later members of Plato's Academy developed some of the ideas of the later Pythagoreans, resulting in the fruitful continuation of Pythagoreanism [2].

Moreover, Plato (ca 427–347 BC), a student of Socrates (470–399 BC) and the teacher of Aristotle (384–322 BC), founded the Academy. Recently, Brinckhouse and Smith pointed out that of all of Plato's works, *Timaeus* provides the most detailed conjectures in the areas we now regard as the natural sciences: physics, astronomy, chemistry, and biology [3]. In other parts of his extensive literary production, Plato speculated on how to organize the ideal Greek society or city. Especially in *The Laws*, Plato formulated extensive juridical stipulations of how to regulate water rights and how societies should oversee these regulations [4]. Although the empiric approach to scientific research was central to the pupils of Plato, such as Aristotle and Theophrastus, Price and Back [5] perhaps not quite adequately summarize Plato's and his followers' somewhat inconsistent perception of this as follows:

> *"Today, our version of the hydrological cycle seems so logical and obvious that it is difficult to [1] believe that it did not gain widespread acceptance until the 17th century. This was caused in large part by the tendency of the philosophers of Ancient Greece to distrust observations and by the tendency of later philosophers to accept the opinions of the Greeks almost without question. Plato advocated the search for truth by reasoning. He and his followers appear to have attached little importance to observations and measurements. Thus Aristotle, Plato's most famous pupil, was reportedly able to teach that men have more teeth than women, when simple observation would have dispelled this idea. From a hydrological viewpoint, however, he had a more serious misconception—he believed that rainfall alone was inadequate to sustain the flow of rivers".*

Moreover, Todd and Mays [6] pointed to basic challenges with ancient hydrological perceptions: *"As late as the seventeenth century it was generally assumed that water emerging from springs could not be derived from rainfall, for it was believed that the quantity was inadequate and the Earth too impervious to permit penetration of rainwater far below the surface. Thus, early Greek philosophers such as Homer, Thales, and Plato hypothesized that springs were formed by seawater conducted through subterranean channels below the mountains, then purified and raised to the surface. Aristotle suggested that air enters cold dark caverns under the mountains where it condenses into water and contributes to springs".* However, not all ancient natural world and geography authorities shared these impressionistic views. This included the ca first century AD geographer Strabo (6.2.5), who firmly rejected these hypotheses.

Another relevant quote from Price and Back [5] addressing this complexity, is: *"The first person to make a forthright and unequivocal statement that rivers and springs originate entirely* *from rainfall appears to have been a Frenchman called Bernard Palissy, who put forward this proposition in 1580. Despite this, in the early 17th century many workers were still in essence following the Greeks in believing that sea water was drawn into vast caverns in the interior of the Earth, and raised up to the level of the mountains by fanciful processes usually involving evaporation and condensation. The water was then released through crevices in the rocks to flow into the rivers and so back to the sea"*. So, as these examples demonstrate the views of Greek and others' perceptions of hydrology varied enormously throughout history and actualized the clarifications of the field's central paradigms.

Hence, this review aims to present a survey of the advances and changing paradigms of Greek water management from the earliest periods to the 21st century. It includes clarifications of how the Greeks created new innovative strategies for water management and how they—potentially—adopted and adapted technologies and strategies from other parts of the world. This includes some adjustments in time and space because "the Greek world" changed in the cause of time. In antiquity, the Greeks expanded throughout the Mediterranean region from the archaic through to the Classical period. The Greek world greatly expanded following the conquest of the Persian Empire by Alexander the Great [7]. When the Roman expansion in the ca 3rd–1st century BC came to include mainland Greece and the Aegean islands, the two cultures' water management principles merged. The Romans, partially inspired by Greek water technology, provided new arrays of communal water technology by adapting and further elaborating on the aqueduct concept. The collapse of the Roman Empire and the emergence of medieval European west and east invoked a new concept of urban life and thus called for new consultation of older proven technologies for water management.

This review focus on hydro technologies from the prehistorical through the Modern periods. It includes the long chronology of prehistory; the Bronze Age (ca 3200–1150 BC); the Iron Age (ca 1150–700 BC); Archaic, Classical, and Hellenistic Antiquity (ca 700–31 BC); Roman times (ca 31 BC–476 AD); medieval times (ca 476–1400 AD); early modern and present times (ca 1400–present). The main aim is to present advances in hydro technology design and construction systems of past Greek civilizations concerning its use for domestic and agricultural purposes, its impact on different civilizations and societal developments, and comparison to current technological achievements. In addition, the review points to emerging trends and future perspectives of technological advances. According to the ancient Chinese philosopher Confucius (551–479 BC), "*Study the past before planning anything for the future*".

Based on this, this review paper is organized as follows: Section 1, the introduction, presents the theme and elements of the review followed by Sections 2–4. Here, the authors explain the distinct histories of water sciences and technologies from the prehistoric era to the present time in a geographical and chronological view, including various types of technology used and the quality of water. Section 5 includes the innovative technologies in the water sector and current issues and future challenges, and Section 6 is the epilogue (conclusions) that includes conclusive remarks and highlights. Finally, an Appendix A on major achievements in the history of the water sciences and technology in Greece through the millennia is included.

2. Prehistoric to Medieval Times (ca BC 3200–1400 AD)

2.1. Prehistoric Times

Societal developments of the prehistoric period and especially the Bronze Age (ca 3200–1150 BC) presumably sparked what to us seems to have been the first systematic technological induced thinking. During the Minoan period and especially the Neopalatial period (ca 1750–1450 BC), in Crete, the Aegean islands, and the western coast of Turkey, the material evidence of the Minoans points towards advances in culture, trade, and, of course, technology. Apparently, not until the end of the Neopalatial period, around 1450 BC, did Minoan civilization develop balanced strategies for the exploitation of natural resources and the environment [8]. At that time, there was a "cultural explosion" that had no precedent in the long history of southeastern Greece. This, among other things, included advances in shipbuilding, architecture, water resource management, and the arts, including pottery, weaving, stamping, and expansion of trade networks (see [9]).

Regarding the type of government prevailing in Minoan communities, contemporary evidence is inconclusive, although later classic tradition maintained a monarchical type of government (the fifth-century historian Thucydides mentions King Minos). However, recent scholarship suggests that elite corporate groups or "houses" controlled and governed Minoan societies through competition related to the central religious sites at Knossos and Khrainia [10]. Thus, in all probability, the competitive nature of the Minoan elite was not epitomized in military-induced ideologies, as was the case of the Mycenaean societies of mainland Greece. It is possible to find what seems to be egalitarian elements in Minoan society, reflected in its technological advances, including water management.

Scholarly perceptions of the nature of Minoan culture and society have changed throughout the recent century. First, Evans [11] saw the Minoans as a stable and mainly peacekeeping presence in the wider region, imitating neighboring and modern civilizations (e.g., Egyptians and Mycenaeans), and saw the palaces as administrative and economic centers of its kings. In the list of wars and/or conflicts worldwide, before ca 1000 BC and especially during the Bronze Age, one can observe that most occurred in the eastern Mediterranean region, where the Minoans dominated for almost two millennia, but apparently without taking part in conflicts [12].

The Minoans constructed advanced hydraulic works (e.g., aqueducts, water supplies, and sewerage systems) from an early date, stored rainwater and spring water in cisterns, and subsequently conveyed it to urban areas by using aqueducts [13]. Typically, Minoan cisterns were circular structures (e.g., Zakros palace) assembled amid rocks beneath the Earth's exterior, with a capacity of up to 100 m^3 (Figure 1a) [14].


(**a**) (**b**)

Figure 1. Rainwater harvesting technologies: (**a**) Minoan circular cistern (photo: A.N. Angelakis) and (**b**) Indus Valley Reservoir at Dholavira [15].

In addition, the sewage and drainage systems were extensive, and the dimensions of sewers and drains allowed people to enter for maintenance. Some sewers were closed for long distances, and manholes were constructed for maintenance and cleaning [15]. Airshafts at equal distances were provided for aerating the sewerage and drainage systems [16]. Similar systems were found in several other Minoan sites, of which the most significant is the excavation in the Hagia Triadha, located on the south places of the central island of Crete. Part of the central sewerage and drainage system in that place is shown in Figure 2a [17].

Concurrently with the development of the Minoan civilization, a Bronze Age civilization in the Indus River Valley on the India–Pakistan border developed from around 3300 to 1300 BC, with its zenith mainly around 2600–1900 BC. The cities of this Indus Valley culture displayed complex urban planning, including brick houses, elaborate drainage systems, water supply systems, clusters of large non-residential buildings, and new techniques in handicraft. The Minoan and the Ancient Indians display similar technological achievements, although their sizes and scales differ, sharing several fundamental principles. The reconstruction of India's early history rests on some written scriptures and archaeological evidence. Excavations of Harappan era sites display urban entities with populations living in brick houses in towns with excellent drainage facilities. One of the oldest scriptures in the world is the four-volume Veda, which many regards as the repository of national thoughts that anticipated later scientific discoveries.

One of the unique hydraulic systems is in Dholavira, which is characterized by massive reservoirs used for collecting and storing rainwater [18]. It is one of the oldest prehistoric sites with hydro technology systems worldwide. However, only three such systems have been found in excavations. First, it is entirely made from boulders [15]. One of the dry channels in the north–south course of the reservoir was found at many places used for collecting and storing rainwater (Figure 1b). Additionally, the prehistoric Indus Valley people developed similar hydro-technology systems on a larger scale (Figure 2b).

Several early scientists revered the sewage and drainage system, such as the American H.F. Gray [18] who stated:

> *We frequently hear people speak of modern hygiene as if it something rather recently developed, and there appears to be a prevalent idea that municipal sewerage is a very modern thing that began some time about the middle of the last (19th) century. Perhaps these ideas do something to support a somewhat wobbly pride of the modern civilization [. . .], but when examined in the light of history that is far from new or recent. Indeed, in the light of history, it is surprising, if not bitterness, the fact that man has gone so poorly, if at all, in about 4000 years [. . .]. Archaeologists researchers this [Minoan and Indus] space give us the image that people have come a long way towards a comfortable and hygienic living, with a considerable degree of beauty and luxury [. . .]. And this was about 4000 years ago.* [18]

Many visitors also admire the sewage and drainage system nowadays. Several visitors in the 20th century prized the sewage and drainage systems of the Minoans as well. The Italian writer A. Mosso [19], who visited Hagia Triadha and Phaistos at the beginning of the last century, noticed how perfect the sewerage and drainage system operated during heavy rainfall and proclaimed: "*I doubt if there is other case of stormwater drainage system that works 4000 years after its construction*" [14].


(**a**) (**b**)

Figure 2. Sewerage and drainage systems: (**a**) Minoan (photo: A.N. Angelakis) and (**b**) Indus Valley [15,20].

In neighboring Egypt, during the long history of the 31 dynasties from ca 3300 to 330 BC, the monarchs placed even more importance on developing water technologies and strategies, especially those concerned with the exploitation of the Nile River. Moreover, after the conquest of Egypt by Alexander the Great in 332 BC and the consolidation of the royal house of the Ptolemies, the development of research milieus (notably the Bibliotheca and the Museum) paved the way for further advances in water technologies. Thus, Egyptian knowledge of essential water technologies of its deep past merged with the scientific traditions of Classical Greece [21].

A king, the Wanax, probably ruled in all Mycenaean societies, and his power base rested on his ability to regulate the redistribution of goods and services within the limits of his kingdom. The army leadership may have been the responsibility of another senior official, the "leader of the people", who appears second in the hierarchy (see further [10]). During that period, massive hydraulic works were built, including polders, dams, and artificial reservoirs for floodwater retention and storage [22,23]. Houses in several settlements, especially the luxurious ones, were equipped with a water supply, sewerage, drainage systems, bathrooms, and in some cases, bathtubs. Regarding the technological achievements of the Mycenaeans, these could be described as a continuation of those of Minoans. However, contrary to the Minoan palaces and other urban settlements, all the Mycenaean palaces and settlements in mainland Greece (e.g., Gla, Mycenae, and Tiryns), were surrounded by massive walls. In some of these sites, the underground cistern system allowed the Mycenae citadels unlimited and secure water supply (see Figure 3a). The steep passage tunnel to the water cistern, paved with stones, is wide enough for two people to stand side by side. The water cistern was located 18 m below the citadel's ground and connected to a nearby natural spring outside the citadel. Additionally, a large open sewer was located parallel just inside the citadel's outer wall and probably part of the central sewerage and drainage system, leading waste and rainfall water down the steep hillside of the outer wall (see Figure 3b).


(**a**) (**b**)

Figure 3. Remnants of water supply and sewerage system in Mycenae: (**a**) the underground cistern in Mycenae is an impressive engineering feat that allowed the citadel unlimited and secure water supply and (**b**) part of the central sewer/drain hillside outside of the Mycenae citadel (photos: A.N. Angelakis).

Although this is beyond the scope of this review, it is essential to distinguish between how civilizations emerge according to modern scholars (anthropologists, historians, etc.), and to distinguish this from how civilizations themselves explain their emergence in the past. One example of how these two approaches merged into one vexed field is Harari's recent [24] subscription to the older observations by Dodds [25]. Harari contended that: (a) legend and myth are often used to explain the advancement of hydro technologies through the direct meddling or gifts from deities. One example would be the immortal benefactor Prometheus who, in the version by the Boeotian poet Hesiod, secured fire from Zeus and thus remained a most beneficent deity towards humans. (b) The natural phenomenon is a method by which human beings could be obtained advancements in their hydro technologies. Nature is mainly personified in some of the sources and leads to a more scientific consideration of the advances of human beings. (c) The third method could be the theory of natural evolution. Humanity is made up of unique species with unique abilities, and she is compelled by necessity or guided by her intelligence and wishes to improve her lot. Thus, Hariri's ponderings traverse the vexed field of mythical historicity and the apparent fact that human successes were in all probability originated in our intelligence but ignore the importance of our ability to act coherently in social contexts. Moreover, for obvious reasons, all water management strategies of the past derived from human interaction with the natural environment and the need for water in the many above-mentioned forms. However, the human ability to solve problems is always associated with the ability to learn from previous generations, preserve knowledge, and invest this knowledge in practical projects for the future. This, however, is not always a straightforward process.

During the Iron Age (ca 1150–700 BC), from the end of the Mycenaean period to the beginning of the Archaic period, very little information exists and technological development is considered to have been minimal. However, the Minoan technological achievements were somehow adopted or adapted by the Mycenaean societies. It seems as if the physical remains of the Bronze Age civilizations had an afterlife and inspired Archaic and Classical Greeks to use and further develop the technologies of the second-millennium Bronze Age civilizations. Thus, some technological achievements were preserved throughout the Iron Age in a state, which allowed them to inspire and even reemerge in the restored condition in subsequent periods. One example of this is the drainage works at the Lake Kopaïs, originating in the Mycenaean times and subsequently revitalized in the Classical and Hellenistic periods [26,27]. Characteristic examples of survival are provided by the several hydro technologies developed in the Minoan and Mycenaean periods, which in principle are similar to those found in later historic periods. The quality of Minoan water resource projects impresses by their excellent design and adaptability to the environment. The basic principles and rules for designing and constructing hydraulic works, such as water, drainage, and sewerage systems that first developed in the Minoan era, were increased in scale and improved in subsequent civilizations, especially in the Classical and Hellenistic periods. Moreover, similar "bridges" through other neighboring civilizations (e.g., Etruscan and Egyptian) have probably been built [28].

2.2. Historical Times

The Archaic Period (ca 700–480 BC)

Neolithic Chinese civilizations originated from cultural centers along the Yellow and Yangtze Rivers. These civilizations arose millennia before the Shang dynasty (ca 1600–1046 BC). China has a long and continuous history and is considered one of the world's oldest civilizations and one of the cradles of world civilization. The Zhou dynasty (ca 1046–256 BC) supplanted the Shang and introduced the concept of the Mandate of Heaven to justify their rule [29]. The majority of the population subsided on diverse forms of agriculture. The dominant form of government was monarchical regimes, most clearly exemplified by the dynasties of Shang and Zhou. Ever since the beginning of state formation, water availability became a primary concern and a pivotal criterion for the selection of the sites where to find the first human societies in East Asia [30]. Apparently, other criteria such as the protection of the site, the nature of the physical environment, and the soil quality were of secondary concern.

In Archaic Greece (ca 700–480 BC), Peisistratus attempted three times to become a tyrant of Athens and finally succeeded in establishing a lasting power base in 546 BC and remained in power until his death. He forbade the exiled opponents to access rural land, which he redistributed to landless people, redeveloped rural land, and restricted urbanism, which the early sixth-century Athenian reformist Solon did not dare to do [31]. After his death, Peisistratus' son Hippias succeeded, and his youngest son Hipparchus ruled until the regime's abolition in 510 BC [32]. In addition to agricultural reforms, Peisistratus' construction of the Peisistratean aqueduct significantly improved Athens's water supply. Additionally, Thucydides (2.15.5) attributed alterations to the fountain Enneacrounos, or the "Nine pipes" to "the tyrants". The famous fountain would later be known under the name of the nymph Callirrhoe—"Fairwater" [33]. The aqueduct saw further improvements into the fifth century and had a length of 10 km (with the terminal section) from its beginning at Mount Hymettus to the center of Athens. Numerous wells and a tunnel to a maximum depth of 14 m are attributed to the period. Peisistratus' aqueduct, together with the improvements to the city's water supply by Emperor Hadrian, constructed with the same technology seven centuries later, was used to supply water for Athens until the end of the 1920s when the Marathon dam was implemented and the lake Marathon became the primary source for fresh water for Athens.

3. The Development of Ancient Water Sciences

Several sciences have their roots in Ionia. The so-called Ionian School was allegedly founded by Thales of Miletus (ca 624/23–548/45 BC), one of the Seven Greek Sages and considered to be the father of natural philosophy and science. Many of his colleagues and students and others, most notably Aristotle, regarded him as the first philosopher in Greek history. In addition, his contributions extend to: (a) mathematics (geometry); (b) astronomy (predicted eclipse on 28 May 585 BC); (c) geophysics and in particular hydrology. In that context, Thales (i) formulated the so-called Nile paradox as a scientific problem, and (ii) diverted the Halys River when Croesus sent his army into the Persian territory and thus stopped by the unbridged river [34].

Anaximander (ca 610–547 BC), a successor to Thales, was the first to write a book "On Nature" and to reject the mythological interpretations of natural phenomena. It helped to understand the relationship between evaporation and rainfall, stating that: *Rains are generated from the evaporation (atmis) that is sent up from the earth toward under the sun (Hippolytus Ref. I 6, 1-7—D. 559 W. 10)* [35].

After that, Anaximenes of Miletus (ca 586–526 BC) devised reasonable explanations for the formation of winds, clouds, rain, and hail. In addition, Xenophanes (ca 570–480 BC) conceived, expressed, and explained basic concepts of the hydrological cycle and the role that the sea plays in it. Moreover, Pythagoras (ca 582–500 BC), the most famous student of Thales, stated that forms and ideas are governed by numbers. This is confirmed by the following logical connection: *Everything in the universe is governed by mathematical rules and reasons* (i.e., the forms are governed by numbers). *So if we understand the arithmetic and mathematical relations, then we will understand the structure of the universe and mathematics is basic model for philosophical thought* (i.e., ideas are governed by numbers) [36].

After Pythagoras returned to Samos, he made a short journey to Crete to study the system of laws there. Back in Samos, he founded a school called the "*semicircle*". Iamblichus (245–325 AD) in the ca third century AD, reported that: *he formed a school in the* city [of Samos], *the 'semicircle' of Pythagoras, which is known by that name even today, in which the Samians hold political meetings. They do this because they think one should discuss questions about goodness, justice and expediency in this place which was founded by the man who made all these subjects his business. Outside the city he made a cave the private site of his own philosophical teaching, spending most of the night and daytime there and doing research into the uses of mathematics*... [37].

When Pythagoras arrived in Crotone in southern Italy, he made an impression on the locals with his speeches, and people from neighboring countries flocked to hear him. Allegedly, more than 2000 people attended his first public speech. Fascinated by his speeches, those first listeners decided not to return to their particular homelands, but send for their wives and children. They built a large house building for teaching, which they named *Omakoeion* [38,39]. Many prominent members of Pythagoras' school were women and some up-to-date scholars sympathize with his idea that women should be taught philosophy similarly to men [40].

After accepting specific laws and orders related to Pythagoras, without which they did nothing, they remained in unity with all the disciples, cheering and welcomed by those around them. They put their property in common use (shared by friends) and included Pythagoras among the gods. The first medical schools were founded in Greece and Magna Graecia (south Italy), namely in Sicily and Crotone in Calabria [41], and the most important school was the Pythagorean [42]. Pythagoras was an advisor to the elites in Crotone and gave them frequent lessons and advice [43]. Thereafter, biographers highlighted the results and effects of his eloquent speeches in leading the people of Crotone to abandon their luxurious and corrupt way of life and devote themselves to the purer system, which he introduced (Figure 4).

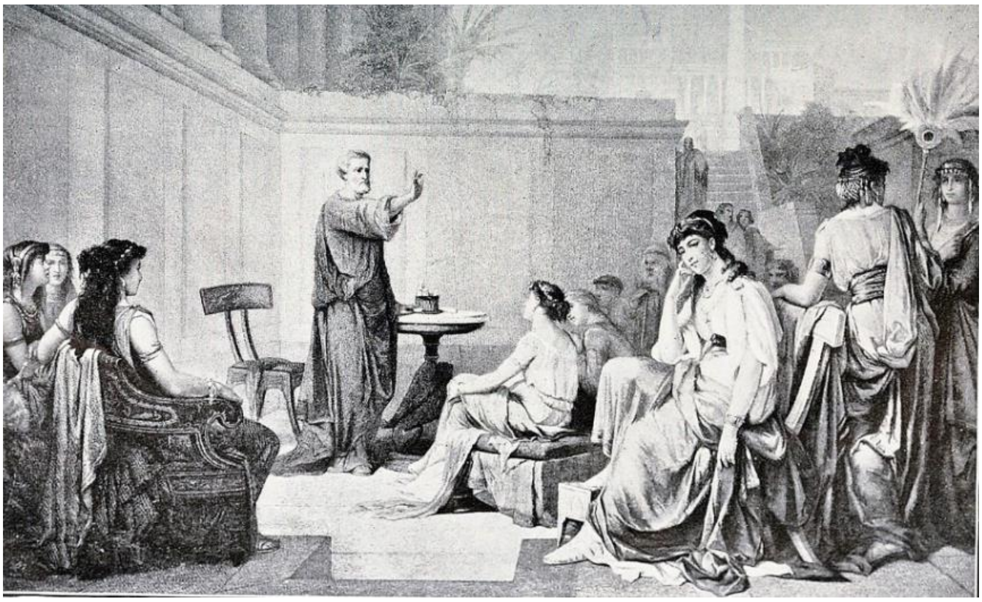


Figure 4. Illustration from 1913 showing Pythagoras teaching a class of women [40].

Finally, a lot of evidence indicates that Pythagoras was charismatic and quickly acquired great political influence in his new environment. Moreover, the concept of a spherical world is also attributed to Pythagoras. His disciple Parmenides of Elea (ca 540–460 BC) stipulated five zones on the surface of this spherical world (one torrid, two temperate, and two frigid) and stated that the central torrid zone was uninhabitable because of the heat from the direct rays of the Sun [44]. Not all Greek intellectuals shared this belief. Nonetheless, the explanations of several meteorological phenomena were based on Pythagoras' findings.

Philolaus the Crotonian (470–385 BC) from Crotone or Taranto, a coastal city in southern Italy, was a contemporary of Socrates (ca 470–399 BC) and is considered the founder of the "theory of numbers" of the Pythagorean philosophy (Diogenes Laertius, 8.1). He later became a teacher and follower of the Pythagorean fraternity. Philolaus (470–385 BC) delivered some books of the later Pythagoreans to Dion, a student of Plato, resulting in the fruitful continuation of Pythagoreanism through the Platonic Academy. The Pythagorean schools and societies died out in the ca 4th century BC. However, Pythagorean philosophers continued to practice in the centuries to follow [45].

In addition, Pythagoras influenced thereafter philosophers such as Plato (ca 427–347 BC) with his teachings. His teachings influenced the middle Platonists of the first century BC and gave rise to Neopythagoreanism [46]. Moreover, Pythagoras influenced philosophers and scientists throughout the medieval period.

Anaxagoras of Clazomenae (ca 500–428 BC) a pre-Socratic Greek philosopher, from Ionia, brought the science of technology from Ionia to Athens. He lived and taught in Athens for about 30 years and introduced the ideas of the Ionian philosophers to the Athenians. Among his students were Pericles (ca 495–429 BC), Euripides (480–406 BC), Sophocles (ca 497/6–406/5 BC), and Herodotus (ca 480–430 BC). His philosophy was based on the principle of "*ἐν παντὶ παντὸς μοῖρα ἔνεστι*", i.e., in everything there is part of everything. Anaxagoras considered the Sun to be a giant stone and stars similar to the Sun, and he proposed a correct explanation for eclipses [42]. Despite his main occupation with astronomy, he also contributed to the contemporary understanding of basic principles of hydrology, including clarification of elements of the water cycle:

> *"The rivers receive their substance from the rains and from the waters of the earth; for the earth is hollow and has water in the cavities"*. [43]

"*Rain is created from the vapours which rise from earth by the sun*" (Hippolytus of Rome, Refutation of All Heresies, I, 5; https://books.google.gr/books?id=9HCOCwAAQBAJ, assessed on 1 September 2022) [47].

Thales of Miletus (624/23–548/45 BC), the founder of the Ionian School of Philosophy, formulated the theory that water was the basic substance of the world. Then his student and successor, Anaximander (ca 610–547 BC), was the first who dared to write a book ("*On Nature*"), which was not based on theocracy or religion, which unfortunately has been lost. As mentioned above, he understood the relationship between rainfall and evaporation, and he tried to explain the genesis of winds, lightning, and other meteorological phenomena [35].

3.1. Classical and Hellenistic Periods (ca 480–31 BC)

In the Classical and Hellenistic periods, direct or no-representative democracy as a constitution appeared in ancient Athens [48]. In the fifth century, basic views of the Ionian philosophers were adapted by Athenian philosophers, such as Socrates (ca 470–399 BC), who did not produce writings of his own, but his views were disseminated in the writings of Plato (ca 427–347 BC), founder of the Platonic Academy. Plato's dependence on Pythagorean thinking is apparent but debated among modern scholars [49].

Critias (460–403 BC), an oligarchic and fierce enemy of the democratic regime, was born in Athens into an aristocratic family and was a relative of Plato. He was involved in the oligarchic coup of 411 BC and after the restoration of the democratic government, he lived in exile until the Athenian defeat in the Peloponnesian War in 404 BC. Critias stated that: "*The land reaps the benefits of the annual rain, not only by directly letting the water flowing from the bare land into the sea be lost, but by keeping an abundant supply in all places, and receiving it within it and it hoards it in the dense clay soil . . . offering abundant springs and rivers everywhere*" [50].

As was previously referred to, Plato developed the ideas of Pythagoras and in that sense, he was a Pythagorean. Horky [49] disagrees with that, but he knows the question is not simple. It depends on what one makes of the term Pythagorean and how one reads Plato. Since neither of these factors is self-evident, the relation between the two is very difficult to determine. In general, we could say that Horky's [51] case is in good order. The work itself is divided between the two factors, approached in the right order and with due scholarly caution.

At the beginning of the ca 4th century BC, democratic ideas spread further throughout the Mediterranean (Hansen, 2006). Later in the fourth century, Aristotle (384–322 BC) pondered the ideal state and included the sharing of a "constitution", a "*politeia*" as the preferred type of government: "*The opinion of majority takes precedence over the opinion of the minority and is for the general interest and not for the interests of the rulers*". The earliest mention of "democracy" in an Athenian context is from around 420 BC, in a speech of Antiphon (6.45); visualizations of Athenian democracy came later in the fourth century BC [51].

At the same time, the scientific milieus in Athens and elsewhere in the Greek world developed scientific principles and used them to create advanced water management unprecedented in the history of humankind. These included all areas of social life such as diet and resources (land reclamation projects), trade (shipbuilding), quality of life (medicine, architecture, urban planning, water supply, and sewerage and drainage), industry (metallurgy, ceramics, textiles, and automation), innovations, and the arts. It also included measuring instruments (type differences, odometer, and nautical rotors), pumps, astronomical instruments, and automation (automatic crater with a counterweight, the magical fountain of Heron, self-controlled water heater, Hephaestus' tripods, and Heron's mobile automatic theater). In addition, technological advances included lifting machinery, defense and war machines, shipbuilding instruments and machinery, medical instruments and medicines, musical instruments, and, of course, the enigmatic mechanical device from Anti-Kythira, which is now exhibited at the Archaeological Museum of Athens.

Many of the principles of hydro technologies discovered by previous thinkers were adapted and reformulated by members of the Peripatetic School of Aristotle (384–328 BC) whose theories were also influenced by the Ionians, and he formulated the hydrological cycle correctly. Understanding the water phase changes, and the energy exchange required for it, he stated that: " ... *the Sun causes the humidity to rise; this is similar to what happens when water heats up in a fire* ... " (Meteorologica, II.2, 355a 15). The steam that is cooled, due to lack of heat in the area where it is located, condenses and is converted from gas to water; and after the water is created in this way, it falls down to the Earth again. "*The 'evaporation' of water is steam and the condensation of air into water is a cloud". He also acknowledged the principle of conservation of mass in the hydrological cycle: "Consequently, the sea will never dry up; since the water that has risen first will return to it; repeated appearance of". "Even if the same quantity is not returned every year or in a given area, however in a certain period of time the total quantity removed will return*" (ibid, II.2, 355a 26) [32].

Apart from observation, Aristotle also took to experiments in order to prove his observations. Thus, he understood by experiment that salt contained in water is not evaporated, stating that:

> *"Salt water when it turns into vapour becomes drinkable [freshwater] and the vapour does not form salt water when it condenses again; this I know by experiment".*

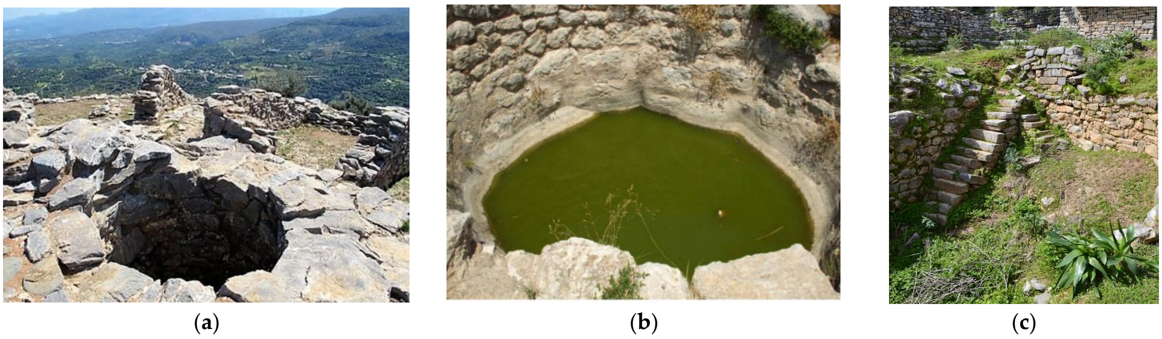
(Meteorologica II 3; Translated by E. W. Webster [52]; (see also http://classics.mit.edu/Aristotle/meteorology.2.ii.html, assessed on 1 September 2022).

Archaeological excavations and historical evidence show that these technological innovations and adaptations occurred in Greece from the beginning of the Classical period (ca 480–336 BC). These included various disciplines of hydro technologies such as aqueducts, dams, water supply networks, especially those in urban areas, and recovery and use of surface resources. Hygienic concerns resulted in the construction of baths and other sanitary structures, sewerage, and drainage systems including disposal structures. Land rehabilitation projects and agricultural land irrigation and drainage had a direct impact on the economies of the city-states, where water works were incorporated into the landscape architecture of cities for recreational purposes. The advancement of hydro technology and management is demonstrated with a plethora of hydraulic works in several archaeological sites (e.g., Miletus, Athens, Crete, Delos, Pella, Naxos, and Samos). An extraordinary example is that of the water supply of the island of Samos.

The water supply system in the inland of Samos, located at the site of the modern-day village of Pythagoreio, was highly valued in antiquity and today [24]. The great part of the water supply system is the "Eupalinean digging", known as the Eupalino tunnel. It was named so due to Eupalinos, an engineer from Megara who designed and constructed it. The total length of the aqueduct exceeds 2.80 km, with a 1.0 km long section within the tunnel (see Figure 5). The tunnel's construction began in 530 BC, during the tyranny of Polycrates, and was completed in 10 years. It remained in good maintenance and operation until the fifth century AD.

Figure 5. A view of the Eupalinos tunnel with the aqueduct channel on the right-hand side of the picture (with permission of K. Voudouris).

In addition, ancient Greeks constructed water cisterns similar to those implemented by the Minoan and Mycenaean several centuries earlier. A comparison of hydraulic works developed in prehistoric times with those in Classical and Hellenistic periods display many apparent similarities (Figure 6). Thus, in all probability, "bridges" disseminating knowledge from the past to the future are open, albeit sometimes invisible in the present [28].



(**a**) (**b**) (**c**)

Figure 6. Comparison of Minoan and Mycenaean cisterns with those in Classical times: (**a**) Cistern in the Hamezi Minoan village in eastern Crete, (**b**) cistern in Mycenae, and (**c**) cistern in Classical Dreros in the eastern Crete (photos: A. N. Angelakis).

During the Hellenistic period, the hydraulic screw of Archimedes (287–212 BC) (Figure 7) was discovered, and it is widely used today [53]. It has been mainly used to raise irrigation and drainage water in agricultural land, often powered by people or animals. Additionally, this device, besides its simple construction, is able to move water that contains mud, sand, or gravel and its basic principle is still used today because it is capable of lifting water from rivers to higher places [54,55]. In addition, it is widely used today to transport untreated wastewater to treatment plants, which are usually located in higher places than the sewerage systems.

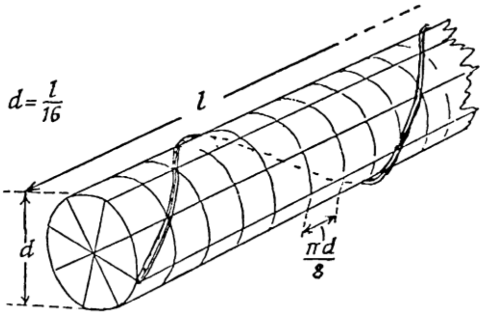


Figure 7. The endless screw of Archimedes based on the description of Vitruvius [54,55].

Athenaeus, a Greek rhetorician and grammarian (ca 2nd–3rd century AD) stated [56]: "*As far as the ship constructed by Ieron the Syracussian is concerned, which was overseen by Archimedes as the overseeing geometrician, I think that I should not omit mentioning the writing of someone named Moschion. He mentions: Archimedes the engineer alone succeeded this with little help. Through the construction of a helix, he managed to bring down such a ship to the sea. Archimedes was the first to invent this construction of the helix*".

Additionally, Hero has referred to a rocket-like reaction engine, and the first-recorded steam engine described the construction of the aeolipile (a version of which is known as Hero's engine) (Figure 8). It was constructed about two millennia before the Industrial Revolution (see further Heron of Alexandria, 1889). It is the first steam water pump ever and the aeolipile was mechanically combined with the Ktesibius pump [54].

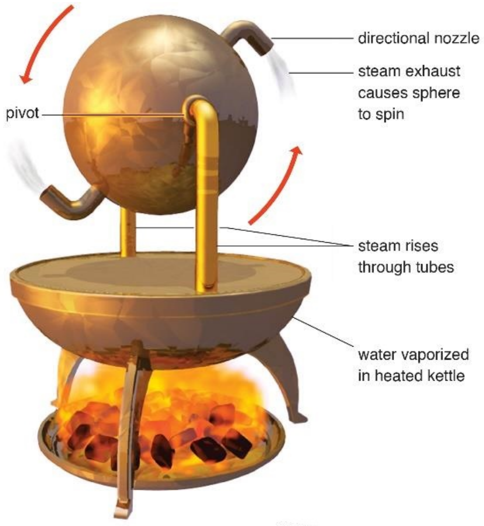


Figure 8. Hero's aeolipile [54].

Alexandria remained the leading center of Greek philosophy and the dominant center of intellectual culture well into the Roman period. In addition, apart from being the geographical location where the three continents join, it also became the battle place of religious unrest and a hotspot of religions confrontation with philosophical principles [57].

The history of Alexandria began with its founding by Alexander the Great in 331 BC [58,59]. After conquering Egypt, Alexander trusted one of his generals, Ptolemy Lagus, with the task of completing the founding of Alexandria. The streets were based on the ideal plans of Hippodamus of Miletos (498–408 BC), an architect and urban planner, and were continued by Aristotle and others. They were oriented southwest to provide shelter from the north wind and to have the advantage of the weak air. They placed the Daughter Library next to the sanctuary of Serapis, the Serapeum [60]. The Museion, the first public research institution, was located in the center of the city, which, together with the Great Library, said to contain 700,000 scrolls, represented Alexandria's primary scientific assets (Figure 9). The Museum and the Library were exclusively reserved for scholars who studied various aspects of philology, mathematics, and astronomy [61]. However, the famous Library of Alexandria, the largest and most complete in the world, the one that contained all the recorded wisdom of humankind, began as part of the Museum. Eratosthenes, the first director of the Library, calculated the circumference of the Earth, and the school of mathematics was founded and led by Euclid in the fourth century BC.

Figure 9. The Library of Alexandria based on some archaeological evidence [7].

Additionally, in Hellenistic times, the "School of Mechanics" was founded in Alexandria. Some prominent representatives of the mechanics were Archimedes from Syracuse (287–212 BC), Ctesibius (285–222 BC), Philon from Byzantium (260–180 BC), and Biton Takticus (150–80 BC), Heron from Alexandria (ca 10–70 AD). Athenaeus Mechanicus (first century BC), who was active in Rome and elsewhere, argued to be a Cilician ex-statesman living in Rome in the 20s BC, and Pappus of Alexandria (ca 290 AD–350 AD) should also be added to the list of prominent members of the community. Some of their innovations are mentioned by ancient writers and referred to in Egyptian papyruses as well [7,62].

3.2. Roman Period (ca 31 BC–476 AD)

As the chapters above demonstrate, from the early phases of human history in the Fertile Crescent and the Mediterranean region to the end of antiquity, the exploitation of hydropower was an essential strategy for successful societal developments. The expansion of Alexander the Great brought Greeks and Macedonians in contact with the rich technological traditions of the Ancient Near East, a heritage later continued and refined by the Romans. The invention of the watermill presumably took place in Alexandria in the 3rd century BC by Philo of Byzantium (ca 280–220 BC), and its invention included both the water wheel and gear technology, described in his technical treatises *Pneumatica* and *Parasceuastica* [57]. The mill used water to feed the wheel, which subsequently grounded grains. This allowed the production of a large amount of flour, which revolutionized the food production of that time. The invention and transfer of this powerful technology of Greek origin were documented by Vitruvius (ca 80–15 BC) and Strabo (ca 64 BC–24 AD), and it was further developed by them and thus acquiring an "industrial form", which included both quantitative and qualitative improvements. The mechanism of the watermill was based on two parts: the kinetic with the impeller and the executive with the millstones and the operating components [63].

During the Roman Empire, Hellenistic technologies expanded in terms of the purpose served and, of course, their size. Civic authorities focused on enlarging public buildings with fine mosaics and artwork, and special attention was directed towards improving public baths and toilets. Thus, many cities made an effort to improve hydraulic works, including the water supply, sewerage, and drainage systems. Moreover, additional public works added to the positive effects of these endeavors, such as aqueducts with large-scale tanks, and necessary infrastructure necessary for maintenance was added as well [64]. However, the original Greek hydro-technological knowledge continued to dominate the Roman approach to water technology, and they added only minor improvements to the overall technological paradigms of the Classical and Hellenistic periods. The Romans, nonetheless, took the scale (size) of their water infrastructure to new heights as they were greatly expanded [60]. However, some new technologies, such as concrete, the so-called "opus caementitium", were invented during this period, which allowed the construction of even larger structures such as pipelines, aqueducts, bridges, and even tunnels in appropriate geological formations [12]. This also included the ubiquitous aqueducts so intimately associated with Roman technological architecture. The typical aqueduct consisted of a buried canal with a four-sided inner profile and an arced vault (Figure 10).

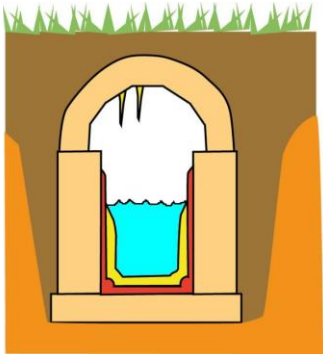


Figure 10. Cross-section of a Roman aqueduct channel constructed with bricks below the Earth's surface. The inside of the channel was covered with reddish waterproof cement (*opus signinum*—in red), with a distinctive seal on the edges. Some channels have carbonate deposits (yellow) due to the hard water transported by aqueducts in some regions [60,65].

Gortyn, a major city-state in the Classical and Hellenist periods, was created as the capital of Roman Crete, and the Law Code of the mid-fifth century BC was reused and re-erected on the site of the Odeon, built in the period of Trajan (98–117 AD) [66]. The Odeon was a circular building erected in the first years of the Roman period on the site of a square structure. The walls have been conserved, rainwater drainage works have been implemented and, finally, the arches of the passageways behind the cave have been supported (Figure 11). Moreover, the so-called Second Law Code of Gortyn survived with regulations for water extraction from the river Litheos. In all probability, the water from the river was intended for households and fields [67,68]. What is more, two inscriptions from the later fouth century Gortyn stipulate how to deal with water-related conflicts and how the damage caused by leading drainage water into the neighboring field must be avoided (ICret IV 73 A, ICret IV 52 A and 52 B, 1–6 [27]). In a mid-fourth century speech, the Athenian politician and orator Demosthenes (*Dem*. 55, *Against Callicles*) addressed a similar situation, only this time as a controversy between neighbors ending in the courtroom.

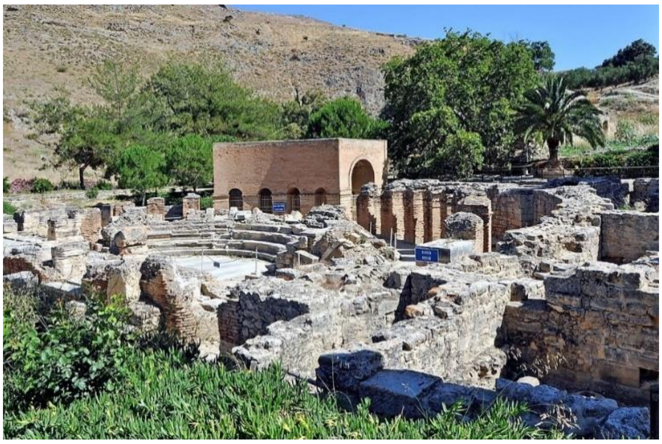


Figure 11. Roman Gortyn with a view of Trajan's Odeon (photo: A. N. Angelakis).

The Romans widely expanded hydropower in the centuries following the conquest in the second century BC. One of the major agents in this development was the new political order of Roman Greece, where the old political borders between city-states no longer prevented the expansion of hydrological technology. In addition, the water mill now caught the attention of Vitruvius (80–15 BC), and Plinius the Elder (23/24–79 AD) recognized it as a new device [69] (Figure 12). Moreover, the Romans widely adopted the water mill and continued to be so throughout the European medieval period [70,71]. Indisputably, Heron of Alexandria played an essential part in introducing this device and, as implied above, was probably also the inventor. However, the basic technological paradigm of the mill attributed to Heron needed more time and refinement to become a primary mover. In that respect, the history of the water mill should also include its development in the Roman and Medieval periods [69].

Figure 12. Reconstruction of a grain-mill following the principles of Vitruvius (ca 80–15 BC). The undershot waterwheel powered the gear mechanism (lower floor) and thus induced the millstone (upper floor) to function (https://en.wikipedia.org/wiki/Public_domain, assessed on 1 September 2022).

It should be mentioned that the role of the Library at Alexandria in technological advancements could hardly be exaggerated. Hence, the destruction of the Library and the Museum was undoubtedly a major drawback to the afterlife of Greek and Roman technological innovation. During the siege of the city by Julius Caesar in 47 BC, the major part of the Library of Alexandria was burned. What remained was destroyed twice by Caracalla (in 211 and 213 AD), then by Valerian (253 AD), and finally by Aurelian (AD 273). A disastrous passage of Zenobia, queen of Palmyra (269 AD) had also intervened. Nevertheless, all that remained of manuscripts after the disasters were gathered in the Serapeum, the temple of Serapis, and the Library continued to function. The finishing blow was delivered during the clash between Romans and the local Christians [72]. When the last emperor of the Western Roman Empire, Theodosius I, with a decree issued in 391 AD, ordered the closure of all pagan temples, including the Library located within the broader complex of the temple of Serapis, much knowledge and research were lost.

Finally, the Neoplatonist philosophers Porphyry of Tyre (ca 234–305 AD) and Iamblichus (245–325 AD), which were partially considered to be against the rise of Christianity, wrote two late biographies. After that, sources are longer and more significant in descriptions of Pythagoras's role. Porphyry and Iamblichus used written information from those that were lost from students of Aristotle and these manuscripts are considered the most reliable.

3.3. Medieval Period (ca 476–1400 AD)

Earlier perceptions of the medieval period between the fall of the Western Roman Empire in the fifth century and the Renaissance often focus on its alleged intellectual darkness. This statement is, of course, a matter of perspective and is not in tune with what took place during the many centuries. However, hydro-technology development only made little progress in central and western Europe. During this period, the warring states of Europe invested considerable resources in warfare and compared to the Romans before them, were less interested in advancing the infrastructure of cities. As a result, outbreaks of maleficent diseases (cholera, plague, and others) and epidemics became ordinary in both cities and the country. In addition, very high death rates scourged European populations almost at regular intervals [73]. Gradually and not surprisingly, as populations expanded, the disposal of human feces became an issue in large cities during the medieval ages, a challenge that took centuries to solve.

Despite these setbacks, water sciences and technological education progressed during the medieval period. The opening of several medieval universities, especially in the 11th through the 13th centuries, significantly contributed to advancing the field. By ca 1500, the institution had spread throughout most of Europe and played a crucial role in maintaining a scientific momentum, which gradually developed into the educational concepts and institutions, which are now globally adopted [74].

4. Early and Mid-Modern Times (ca 1400–1900 AD)

From the ca mid-14th century to the 17th century or the Renaissance, numerous inventions were based on the rediscovery of Classical Greek philosophy and science, including that of the pre-Socratic Greek philosopher Protagoras (ca 490–420 BC), famously cited for the dictum: "*Man is the measure of all things*" [75]. As stated above, this new thinking became apparent in the Classical period in the development of political systems, such as democracy, art, architecture, and science and technology.

During the Venetian period (ca 1205–1669 AD), water technology became widely distributed and applied in the southern parts of Greece and the Aegean Sea's isles. As we have seen to be the case in previous centuries, urban and rural communities in the region exploited energy taken from watercourses and transferred its mechanical energy in order to grind wheat into flour. In the following century, during the 1700s, mechanical waterpower expanded to become widely used for milling and pumping to support drainage and mainly irrigation-required needs [54].

The first hydroelectric power plant was constructed in Cragside, England, in 1870, and thus initiated the modern period of waterpower development. As was the case with the earlier versions of waterpower, the energy it provides originates from fast-running or falling water subsequently harvested for different purposes. Since antiquity, waterpower has been applied as a valuable renewable energy source mainly used for irrigation and the operation of various mechanical devices. Whereas the exploitation of water power in antiquity was primarily used to prepare food, especially grain, later centuries saw widespread use, e.g., to provide energy for textile mills, sawmills, trip and stamp hammers, and dock cranes [76]. At that time, the knowledge of how to make concrete was widely distributed. Da Vinci's contributions during this period include designing machines and experiments on controlling water flow and hydrogeology. In addition, the development of the trompe made it possible to use compressed air from falling water to power other machinery, and towards the end of the 19th century, waterpower became a source for producing electricity.

When canal building in the United States gained momentum in the 1830s, waterpower delivered the energy to support barge traffic across the hilly country by inclined plane railroads. In the 19th century, the expansion of the railway system rendered the canal system for transport obsolete. Instead, the modification of the extensive system of canals allowed the development of new hydropower systems; there is a classic example from

Lowell, Massachusetts [77]. Here and elsewhere, the combination of waterpower and entrepreneurship sparked industrialization and new commercial development.

In Greece, on the island of Aegina, survive numerous examples of a distinctive rural open rainwater cistern called "*Mpourdechtis*" [78]. The name is a colloquial transformation of "*omvrodechtis*" (water collector), which means that it accepts rainwater (Figure 13).

Figure 13. The cistern in the island of Aegina at Mpourdechtis area (photo: G. Antoniou).

They are situated at a relatively high altitude and combine rainwater harvesting and occasionally spring flow in cases where a high underground water table exists. Many such structures are adjusted to pre-existing natural cavities. Therefore, their shape is irregular. In many cases, some, impromptu or not, artificial constructions—ditches, sloping surfaces, etc.—increased the amount of water gathered in the cisterns. The semi-formed parts of their construction were carved from natural rock, and as a result, they have been preserved relatively well up to nowadays. The most exciting aspect of this cistern type is that many are still in use in remote areas, mainly for stockbreeding purposes.

5. In Contemporary Times (1900 AD–Present)

The emergence of the independent Greek state in the 1820s was followed by the development of the first industrial enterprises in the new country. In this new political and economic reality, hydro technologies were introduced in all parts of the country [79]. Again, past technologies and new inventions emerged, including the development of deep wells, new standards for pumps, pipes, and adjacent technology. On the one hand, although Greece experienced substantial benefits from introducing new technology, other problems followed initial successes. One challenge was to exploit the technology to expand agricultural production, which was necessary due to a rapid rise in population numbers. Another challenge was practically implementing the new technology in steep landscapes, which also dramatically increased the price of projects [22]. At the same time, urban water supplies faced similar problems due to demographic pressure. Thus, several urban areas in southeastern Greece continued to collect, store, and use water until the middle of the 20th century; this practice continues to provide water for stockbreeding (Figure 14). Moreover, several old and proven techniques and materials continued to be used in the 19th through the early 20th centuries, modern materials and techniques were implemented to strengthen ancient methods and strategies for rainwater harvesting. An example is the rainwater runoff surfaces and reinforced concrete tanks on the island of Ithaki [79,80].

The early 20th-century implementation of wastewater treatment plants capable of handling large volumes of wastewater meant that the problem could now be solved by discharge into waterways or directly into the ocean. This significant advance in technological and scientific innovation created new challenges. In Athens, the first water treatment plan (WTP) opened in 1931 at Galatsi, a location 159 m above sea level. From the very start at Galatsi, the strategy was to apply disinfection to reduce pollution. After this initial success, civic authorities created enterprises in most cities all over the country, prioritizing water treatment plans with chlorine to eliminate infectious threats. However, this development meant that interest in reclaiming nutrients and organic matter to fertilize and improve soil characteristics diminished [81]. Municipal authorities and the public have increased their interest in the reclamation and reuse of water in the latter part of the 20th and the beginning of the 21st century. As in other parts of the world, the growing attention to these matters is sparked by urbanization and population growth. Moreover, the growing demand for methods to improve water reclamation has fostered technologies able to produce water of different qualities. This includes demands for water quality equal to or even higher than drinking water and reuse of treated wastewater effluent for irrigation throughout this period, especially in the southeaster region of Greece. However, during the 21st century, this practice has not highly increased in Greece as well as in most European countries compared with many other developed countries.

Figure 14. A cistern near Neapolis in eastern Crete which is still in use (photo: A. N. Angelakis) [82].

The rising attention to water resource sustainability worldwide has accentuated desalination technology as a potent and fast-growing avenue to secure future demands. The mounting challenges of the future caused by limited resources have made this technology popular and a critical factor in the struggle for a positive future. The worldwide operating capacity for desalination of sea and brackish water is over 100 million m^3/d and has multiplied over the last 30 years [35]. Last but not least, seawater intrusion has become a rising challenge, especially in some of the island states of the Pacific region are the first countries to experience the harsh consequences of global warming and rising sea levels. Other regions are beginning to notice the rising threat, including countries in North Africa and the Middle East (especially Saudi Arabia and the UAE), but also countries facing the Mediterranean, such as Israel, Italy, Spain, Greece, Malta, Cyprus, and Turkey. A number of research studies on the future effects of seawater intrusion in coastal areas have been conducted, and simulated seawater intrusion along the Adriatic coast of Emilia-Romagna in Italy as well [83].

For Greece, implementing desalination strategies could be the obvious and sustainable choice to counter the endemic problem of water scarcity in the “waterless” islands of the

Aegean Sea. The growing number of tourists in the summer often triggers critical situations and thus threatens the vital tourist industry of Greece. The alternative to desalination would be constructing expensive pipelines for water transport from the mainland. The most typical way of acquiring water in many semi-arid islands before was to transfer it at the cost of between 4.91 and 8.32 EUR/m^3 [84]. An additional advantage of choosing the desalination strategy is the concurrent prospect of building redundant renewable energy storage capacity in renewable energy source installations.

Some authors suggest that the increase in life expectancy from 30 years to over 85 in the last century is mainly due to improvements in water quality [85,86]. Although there is much truth in this statement, as we believe there is and have pointed to throughout this paper, the major advances in medical sciences, biology, etc. have also contributed dramatically to the increase in the number of humans with an increased life expectancy on this planet. We know that for several millennia (since prehistory), the life expectancy was about 30 years, and about the same level in Greece, during the Minoan era (ca 5000–3000 years ago) and in the Classic and Hellenistic periods (ca 2500–2100 years ago) it was just over 30 years. In 1947 it had risen to 45 years and in 2020 the life expectancy increased over 82.50 years. The significant increase in the life expectancy immediately after the Second World War is probably due to the improvement of the potable water quality and hygiene conditions, which is only possible to achieve with the combination of science (medical and biological) and applied technology and engineering for the development of sustainable water management strategies [85].

6. Innovative Technologies in Water Sector and Current Issues and Future Emergenges

Advances in water technology have an essential role in addressing current and future critical water issues worldwide. The introduction of new technologies in (waste) water and reuse (mentioned above) within the highly promoted circular economy concept, efficient water management associated with water delivery, control and monitoring, water decision applications, remote sensing technologies, and improved modeling to address future challenges, and new strategies technologies and practices increasing water use efficiency (WUE) by different users (i.e., domestic, agriculture, and industry) should be of concern and supported by governance and water policy in order to protect water resources and increase water availability on a spatial and temporal scale.

Non-conventional water resources, such as the treated wastewater from wastewater treatment plants (WWTPs), seem ideal in areas suffering from water scarcity and prone to climate change (e.g., the Mediterranean Basin). Mainly, reclaimed wastewater can satisfy the increasing water demands in agriculture (accounting for more than 80% of water consumption), mitigating the pressure on freshwater resources. To increase the use of non-conventional water resources, future work should focus on improved tertiary wastewater treatment to eliminate several pollutants and contaminants [86], such as pharmaceuticals, antibiotics, antibiotic resistance genes (ARGs) [87], and microplastics [88,89] to minimize the risk for public health and biodiversity and the quality of resources [90,91]. In addition, technological innovation and methodologies are necessary to improve the monitoring and traceability of emerging pollutants/contaminants in various environments and humans. Such innovations should be accompanied by new policies and regulatory actions to set criteria and control pollutants/contaminants' spreading into the environment, animals, and humans [86,92].

Rainwater harvesting (RH) poses a cost-effective alternative to saving water in many areas of the planet [93–98]. It is a flexible technology involving different collection systems and economic sectors. However, new developments are still needed to improve technology [93,99], planning [96,100], and prevent public health from undesirable effects [99]. In regards to desalination, it is believed that optimization of the current technologies, the use of small-scale desalination plants as an alternative option, energy recovery, and combined use of seawater with brackish water [101,102] will further boost the systems in the future.

Water and energy are mutually dependent. Water is required during energy generation in hydropower dams and fuel and energy manufacturing sectors. In the same way, energy consumption is required in water extraction (groundwater pumping), (waste) water collection, treatment and reuse, desalination, and water transfer and supply to water users, i.e., agriculture, domestic, and industry [103]. Given the vast flows of both energy and water in the water–energy nexus, innovations in renewable and/or non-renewable energy source technologies and the use of water/wastewater sources (e.g., in the water sector, (waste) water management, use of smart water supply networks, sophisticated control, and monitoring, application of artificial intelligence-modeling) are pertinent to achieve high water/energy use efficiency by the users and reduce economic costs [103–106].

Improved WUE is needed to control water consumption by the primary users (mainly domestic and agriculture). As the largest consumer of water, agriculture should incorporate technological innovations that reduce freshwater consumption and improve and increase WUE by crops, an option that is compatible with adaptation to climate change and mitigation of caused impacts. Such methods and technologies may include deficit irrigation and improved soil moisture monitoring [12,107].

Finally, new advances in modeling projections in the domains of climate, environment, and hydrology are necessary to validate projections that so far are prone to inherent deficiencies and uncertainties arising from the included assumptions and downscaling procedure [102,108]. For example, in the climate change domain, we need new approaches to project the changes in precipitation patterns and hydrological characteristics of an area and the spreading pattern of specific pollutants/contaminants caused by intensified rainfall and flooding events (see [107] and references in it).

7. Conclusions

Further technological development is necessary to reduce global mortality and enhance sustainable food production while protecting the quality of natural resources. In other words, it is necessary to maintain sustainable well-being, which, on the one hand, will contribute to meeting basic human needs and, on the other hand, will achieve specific economic development goals, such as sufficient productivity, the development of new or improved products and services, reduced production costs, and rational use of natural resources [109].

Modern technologies and water science principles have roots from more than three and half thousand years ago. People then had advanced scientific knowledge and could design and construct extraordinary hydraulic works, such as the construction of tunnels from two openings and the transportation of water through open or closed conduits. Such technological developments are based on the need for efficient use of natural water resources in order for civilizations to improve their quality of life and be resilient against potential natural disasters. As a result, some civilizations developed a comfortable and healthy way of life, as evidenced by the construction of public and private baths and toilets, similar to the modern constructions developed in Europe and North America at the beginning of the last century [110]. In addition, civilizations, such as those of the Indus Valley and prehistoric Greek civilizations (e.g., Minoan and Mycenaean), were able to develop innovations in the various fields of military infrastructure, engineering, and architecture.

It is unknown whether technological achievements were forgotten entirely during some periods (e.g., the Greek Iron Age) only to reemerge at a later time or had to be reinvented. Regarding ancient Greek hydro technologies, the evidence seems to suggest that the development of science and engineering is not linear but instead characterized by discontinuities and regressions. On the other hand, it is not "Markovian" in the sense that only the present, i.e., the state at a certain point in time, and not the past, i.e., the entire history, affects the future [23].

Prehistoric technologies, developed by different cultures such as the Assyrians, the Minoans, the Mycenaeans, and other civilizations, such as those of the Indus Valley, were transferred to neighboring cultures in the Mediterranean region, such as the Egyptians, Etruscans, and Greeks. Later, these people's expertise, experience, and knowledge were found in Archaic and Classical Greece [28]. The classical and prehistoric Greeks further developed Minoan and Mycenaean technologies by occasionally expanding their scale of application mainly to urban areas. Minoan technologies, especially hydro technologies, were further developed and spread throughout Greece during the Classical and Hellenistic periods [111]. Based on these and other reports concerning the historical development of technologies related to water resources and wastewater management, we could conclude that:

(a) The Minoans and Indus River cultures developed in what appears to be good balances with their physical environments.
(b) Since then, no fundamental changes have been observed in the design and construction of waterworks, referring mainly to changes in construction scale.
(c) The development of technology was occasionally preceded by the development of relevant science.
(d) Hydraulic technology was developed initially during Minoan Greece and Indus Valley civilizations and improved further in ancient Ionia during the Archaic times (e.g., Thales Miletus), took off in Classical Athens (e.g., Pythagoras, Anaxagoras, Plato, and Aristotle), and continued during the Hellenistic times in Athens and Alexandria (e.g., Alexander the Great).
(e) It should be pointed out that the ancient philosophers and scientists, Pythagoras in particular, influenced the following civilizations mainly with their bibliographies, dialogues, and teachings.
(f) Greek hydraulic technology had two fundamental characteristics: safety in extraordinary conditions (e.g., wars) and long-term durability and sustainability.
(g) Greek hydraulic technology serviced integrated water resources management to equalize the water supply with the current and future water requirements.
(h) Current hydro technologies share the same principles as the past ones developed in Minoan and Indus Valley locations.
(i) Life expectancy, except for water quality, is driven by several other factors, such as nutrition, environmental risks, lifestyle, and diseases.

Overall, this study highlights the evolution of hydro technologies showing the outstanding knowledge and experience of ancient civilizations regarding water management water. This knowledge is still the base for the current developments and applications by hydro-technologists and is available to new scientists dealing with critical issues in water management, such as water transportation, groundwater and surface water exploitation, preservation of water quality, water and wastewater treatment, the development and application of water use efficient practices, and water reuse.

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Appendix A

Major steps in the Greek history of the water sciences and technology through the millennia.

Time	Technological Achievements	Comments
Before ca 33000 BC	*Homo neanderthalensis*	
ca 33000–8700 BC	*Homo sapiens*. Nomadic culture [112]	
Stone Age (ca 8700–3200 BC)	People lived in permanent settlements applying technologies and tools for their survival. Water was managed by nature, while human excrement was covered by soil.	
Mesopotamia (ca 3500–700 BC)	The architecture was developed by civilizations of Mesopotamia, such as the Babylonians, Assyrians, and Sumerians. Additionally, Babylonians developed and applied technologies to transfer and irrigate fields. They also developed drainage systems.	Shaduf, water wheel
Bronze Age (ca 3200–1150 BC)	Copper retrieved from the surface was used before copper smelting was known. Terracotta pipes and ceramic technology were used. Minoans, Indus Valley, and Mycenaeans civilizations developed water hydro technologies to support water supply and sanitation [113].	Shaduf, water distribution
Egyptian (ca 3200–330 BC)	Pyramids were built by simple machines moving vast numbers of limestone blocks. They also made writing paper from papyrus. In addition, they developed water technologies and devices similar to the Greeks [7].	
Iron Age (1150–700 BC)	Iron smelting technology was developed. The Iron Age showed limited technological development (apart from the use of iron, of course!)	
Classical and Hellenistic Periods (ca 480–31 BC)	The most advanced progress occurred in this period in the context of the Ionian School, Omakoeion, Plato's Academy, the Peripatetic School, and the institutions at Alexandria. Thales Miletus, Pythagoras, Plato, Aristotle, and Alexander the Great advanced technology. Water supply and sewerage systems and practical water management were highly improved. Additionally, mathematics, philosophy, architecture, theater technology, and hydro technologies were further developed. At that time, water supply and sanitation technologies were developed and applied. The screw of Archimedes and Ktesibius' force pump was discovered and used. Hero's aeolipile was mechanically combined with the Ktesibius [54]. Finally, at that time, much practical water management developed among farmers in rural contexts, trying to cope with local challenges, e.g., on Delos and in the Greek west (Metaponto, Herakleia, and others).	
Chinese (Xia–Han dynasties)	From 220 BC–220 AD, the Chinese introduced important developments, such as drilling deep wells. During the Han Dynasty, they could lift water with the Lúlu for domestic and agricultural use.	
Roman (31 BC–476 AD)	Many significant Pythagorean sources are also from Roman times [114]. In addition, during this period, water and sanitation technologies (aqueducts, cisterns, dams, sewerage, and drainage systems) increased in scale [64]. Roman and other civilizations, mainly Mesopotamians, adopted the practice of hydraulic works from Greek examples. However, Romans and other civilizations increased their scale.	
Inca, Maya, and Aztec (1800 BC–1500 AD)	Inca and Maya developed advances in water engineering, such as irrigation canals, drainage systems, and even hydroponics; their agricultural technology was still soil-based. Additionally, Aztec-developed *chinampas* consist of growing crops on small artificial islands [115].	
Medieval (476–1400 AD)	Pythagoras' teachings influenced the rise of Neopythagoreanism in the medieval period. Additionally, he was regarded as a significant philosopher at that time, and his philosophy greatly impacted philosophers and scientists [114]. In addition, economies were developed where water and wind power were significant. Mills or other technologies exploited this kind of power in many countries.	
Renaissance time (ca 14th–17th century)	Water-powered mechanical devices were developed, such as stamping mills, pumps, and hammers.	
Industrial Revolution (1760–the 1830s)	Coal was the primary source of cheap energy in the form of coal, produced in ever-increasing amounts from the abundant resources of Britain. In addition, the steam engine was applied to the iron, copper, and lead industries.	
Second Industrial Revolution (the 1860s–1914)	In Europe, developments in the manufacturing, transportation, and construction domains. Additionally, steam-powered factories became widespread.	
20th century	Production of automobiles, electronic computing, radiotelephony, and jet engines are among the most significant achievements. Increase in life expectancy after the second World War.	

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