Reports of the 2nd International Seminar on Water Culture

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From Thales to Aristotle and Heron of Alexandria: The development of hydrology in the Greek antiquity and its relevance to modern times

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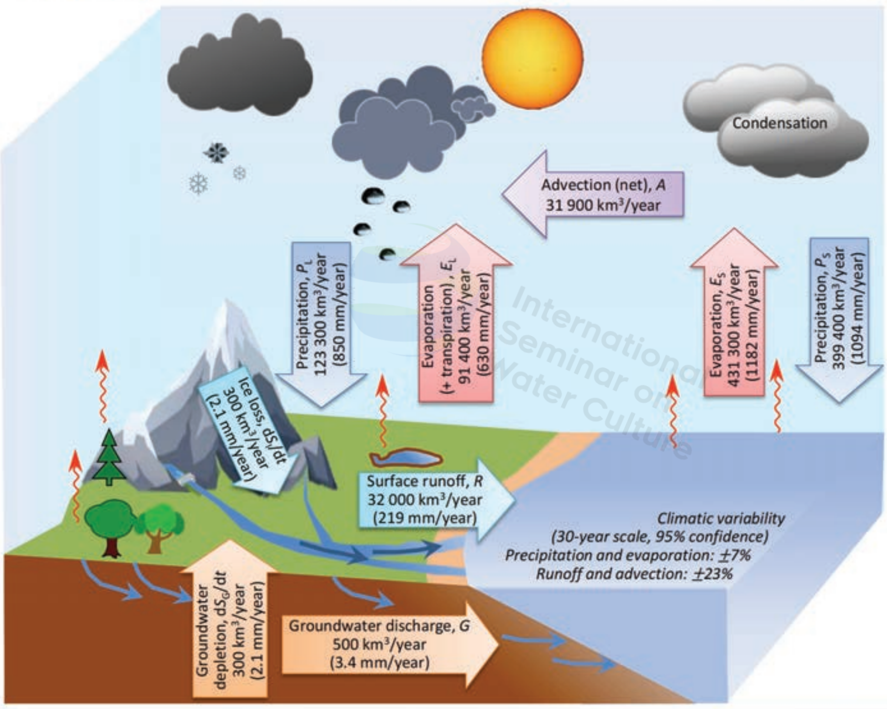
Presentation available online: http://www.itia.ntua.gr/2261/

The hydrological cycle as we know it today



This is the current knowledge (with quantification) about the hydrological cycle (see detailed calculations and results in Koutsoyiannis, 2020).

What did ancient Greeks think about the hydrological cycle and the hydrological processes?

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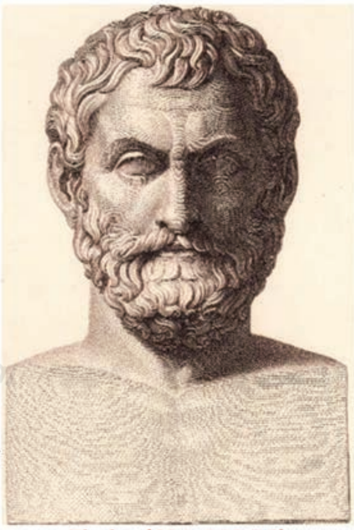
Thales and the birth of science

Thales of Miletus, one of the Seven Sages of Greece, is regarded as the **father of natural philosophy and science**. His contributions cover several fields:

- **Mathematics**. He introduced deduction through theorems; he proved several theorems in geometry, including those bearing his name: the Thales' angle theorem and intercept theorem.
- **Astronomy**. He predicted the solar eclipse in 28 May 585 BC.
- **Physics**. He studied static electricity by experimenting on amber (in Greek ήλεκτρον—electron) as well as magnetism.
- **Surveying engineering**. He measured the heights of pyramids and the distance of ships from the shore.
- **Hydraulic engineering**. He made a diversion of the river Halys for military purposes.



Thales (624–548 BC)
Image source: Visconti (1817)

In addition to his scientific achievements on geometry and astronomy, he dealt with the paradox of the Nile (will be examined below), thus highlighting the importance of hydrology in the birth of science.

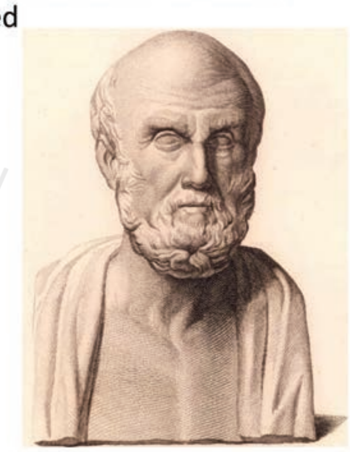
Thales' successors and the foundation of hydrological cycle

Anaximander of Miletus (610–546 BC) understood the relationship or **rainfall and evaporation**.

Anaximenes of Miletus devised logical explanations for the formation of **wind, clouds, rain and hail**.

Xenophanes of Colophon (570–478 BC) understood the presence of fossilized marine organisms at three island locations and developed a theory of alternating periods of flood and drought. He proclaimed the **sea as the source of clouds, rain water and river flow**.

Hippocrates of Kos (460 – c. 370 BC), the philosopher and most outstanding figure in the history of medicine, studied the relationship of **water and health**. He also contributed to hydrology through his treatise *Airs, Waters, Places*, where he **clearly described the hydrological cycle**, including the fact that the **salt contained in sea water is not evaporated**.



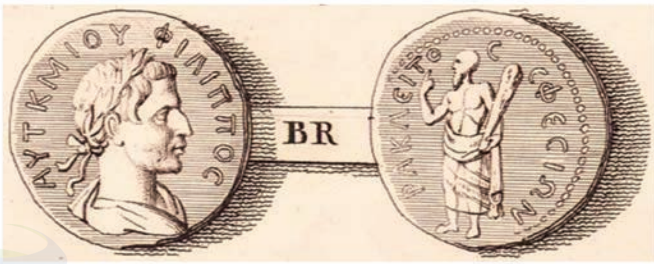
Hippocrates (460 – 370 BC)
Image source: Visconti (1817)

See details in Koutsoyiannis and Mamassis (2021)

Hydrology is the science of change and randomness; Heraclitus described the nature of each in a few words

Heraclitus of Ephesus (535 – 475 BC) was another Ionic philosopher, father of dialectics.

He emphasized the **dominance of change and randomness in Nature**.



Heraclitus of Ephesus (535 –475 BC) depicted in the back facet of a coin whose front facet shows Philip
Image source: Visconti (1817)

«Πάντα ῥεῖ»
"Everything flows"
(Heraclitus; quoted in Plato's Cratylus, 339-340)

«Αἰών παῖς ἐστι παίζων πεσσεύων»
"Time is a child playing, throwing dice"
(Heraclitus; Fragment 52)

«Τὸ ἀντίξουν συμφέρον καὶ ἐκ τῶν διαφερόντων καλλίστην ἁρμονίαν καὶ πάντα κατ' ἔριν γίνεσθαι»
"Opposition unites, the finest harmony springs from difference, and all comes about by strife"
(Heraclitus, Fragment B 8)

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Aristotle and the phase change of water

Aristotle (384 – 322 BC) taught mostly in Athens, but his theories were influenced by Ionic philosophers. They expand to all aspects of knowledge; in particular his treatise ***Meteorologica*** **offers a great contribution to the explanation of hydrometeorological phenomena**:

«ἔτι δ' ἡ ὑπὸ τοῦ ἡλίου ἀναγωγὴ τοῦ ὑγροῦ ὁμοία τοῖς θερμαινομένοις ἐστὶν ὕδασιν ὑπὸ πυρός» (Μετεωρολογικά, Β2)

"the sun causes the moisture to rise; this is similar to what happens when water is heated by fire" (Meteorologica, II.2, 355a 15)

Aristotle (384 – 322 BC)
Image source: Visconti (1817)

«συνίσταται πάλιν ἡ ἀτμὶς ψυχομένη διά τε τὴν ἀπόλειψιν τοῦ θερμοῦ καὶ τὸν τόπον, καὶ γίγνεται ὕδωρ ἐξ ἀέρος· γενόμενον δὲ πάλιν φέρεται πρὸς τὴν γῆν. ἔστι δ' ἡ μὲν ἐξ ὕδατος ἀναθυμίασις ἀτμίς, ἡ δ' ἐξ ἀέρος εἰς ὕδωρ νέφος»

"the vapour that is cooled, for lack of heat in the area where it lies, condenses and turns from air into water; and after the water has formed in this way it falls down again to the earth; the exhalation of water is vapour; air condensing into water is cloud" (ibid., I.9, 346b 30).

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Aristotle and mass conservation

Aristotle recognized **the principle of mass conservation** within the hydrological cycle:

«ὥστε [τὴν θάλατταν] *οὐδέποτε ξηρανεῖται· πάλιν γὰρ ἐκεῖνο φθήσεται καταβὰν εἰς τὴν αὐτὴν τὸ προανελθόν».*

"Thus, [the sea] *will never dry up; for* [the water] *that has gone up beforehand will return to it"* (ibid., II.3, 356b 26).

«κἂν μὴ κατ' ἐνιαυτὸν ἀποδιδῷ καὶ καθ' ἑκάστην ὁμοίως χώραν, ἀλλ' ἔν γέ τισιν τεταγμένοις χρόνοις ἀποδίδωσι πᾶν τὸ ληφθέν».

"Even if the same amount does not come back every year or in a given place, yet in a certain period all quantity that has been abstracted is returned" (ibid., II.2, 355a 26).

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Aristotle and Change

Aristotle penetrated into the concept of *change*. He was fully aware that the landscape changes through the ages and that **rivers are formed and disappear in the course of time**:

«ἀλλὰ μὴν εἴπερ καὶ οἱ ποταμοὶ γίγνονται καὶ φθείρονται καὶ μὴ ἀεὶ οἱ αὐτοὶ τόποι τῆς γῆς ἔνυδροι, καὶ τὴν θάλατταν ἀνάγκη μεταβάλλειν ὁμοίως. τῆς δὲ θαλάττης τὰ μὲν ἀπολειπούσης τὰ δ' ἐπιούσης ἀεὶ φανερὸν ὅτι τῆς πάσης γῆς οὐκ ἀεὶ τὰ αὐτὰ τὰ μέν ἐστιν θάλαττα τὰ δ' ἤπειρος, ἀλλὰ μεταβάλλει τῷ χρόνῳ πάντα».

"But if rivers are formed and disappear and the same places were not always covered by water, the sea must change correspondingly. And if the sea is receding in one place and advancing in another it is clear that the same parts of the whole earth are not always either sea or land, but that all changes in course of time" (ibid., I.14, 353a 16).

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Aristotle and experimentation

Aristotle also understood **by experiment that salt contained in water is not evaporated**:

«ὅτι δὲ γίγνεται ἀτμίζουσα πότιμος καὶ οὐκ εἰς θάλατταν συγκρίνεται τὸ ἀτμίζον, ὅταν συνιστῆται πάλιν, πεπειραμένοι λέγωμεν»

"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****"* (ibid., II.3, 358b).

This has certainly found technological application in desalination (removal of salt from sea water), useful in a country with scarcity of fresh water and many shores and islands. Thus, we learn from a commentary on Aristotle's Meteorologica II, written by Olympiodorus (the peripatetic philosopher, 495 – 570 AD), that:

"Sailors, when they labour under a scarcity of fresh water at sea, boil the sea-water, and suspend large sponges from the mouth of a brazen vessel, to imbibe what is evaporated, and in drawing this off from the sponges, they find it to be sweet [fresh] *water"* (Morewood 1838; see also quotation by Alexander of Aphrodisias, peripatetic philosopher, fl. 200 AD, in Forbes, 1970).

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Aristotle and the solution of the "Nile paradox"

Most of ancient Greek texts have been lost and information on them is indirectly obtained from references in other books.

An example is Patriarch Photius's (c. 810/820 – 893) Myriobiblon or Biblioteheca, composed of 279 reviews of books which he had read. This book, perhaps **the first in history collection of book-reviews**, written in Greek, was printed in 1611 with Latin translation.

This gives important information about **Aristotle's decisive contribution in solving the Nile paradox**.

1611

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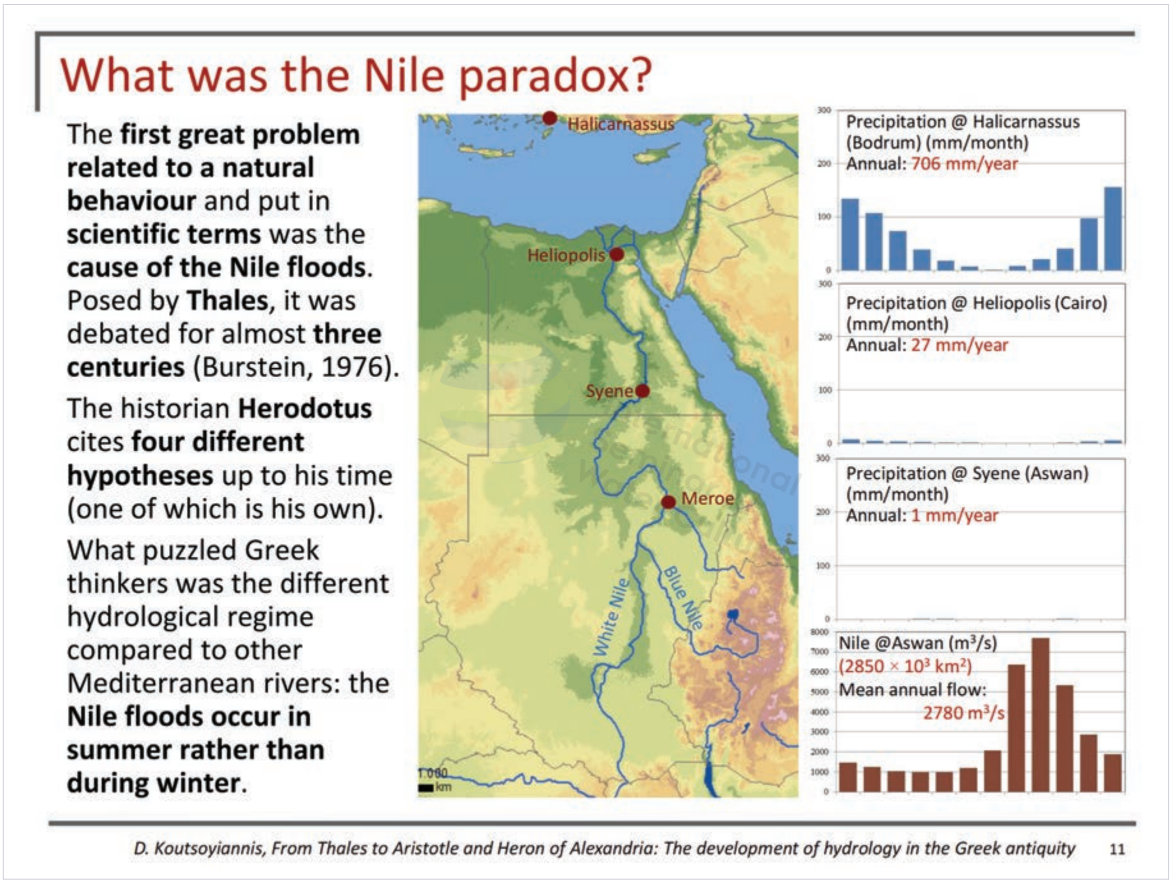
What was the Nile paradox?
The first great problem related to a natural behaviour and put in scientific terms was the cause of the Nile floods. Posed by Thales, it was debated for almost three centuries (Burstein, 1976).
The historian Herodotus cites four different hypotheses up to his time (one of which is his own).
What puzzled Greek thinkers was the different hydrological regime compared to other Mediterranean rivers: the Nile floods occur in summer rather than during winter.
Halicarnassus
Heliopolis
Syene
Meroe
White Nile
Blue Nile
1.000 km
Precipitation @ Halicarnassus (Bodrum) (mm/month)
Annual: 706 mm/year
Precipitation @ Heliopolis (Cairo) (mm/month)
Annual: 27 mm/year
Precipitation @ Syene (Aswan) (mm/month)
Annual: 1 mm/year
Nile @Aswan (m³/s)
(2850 × 10³ km²)
Mean annual flow:
2780 m³/s
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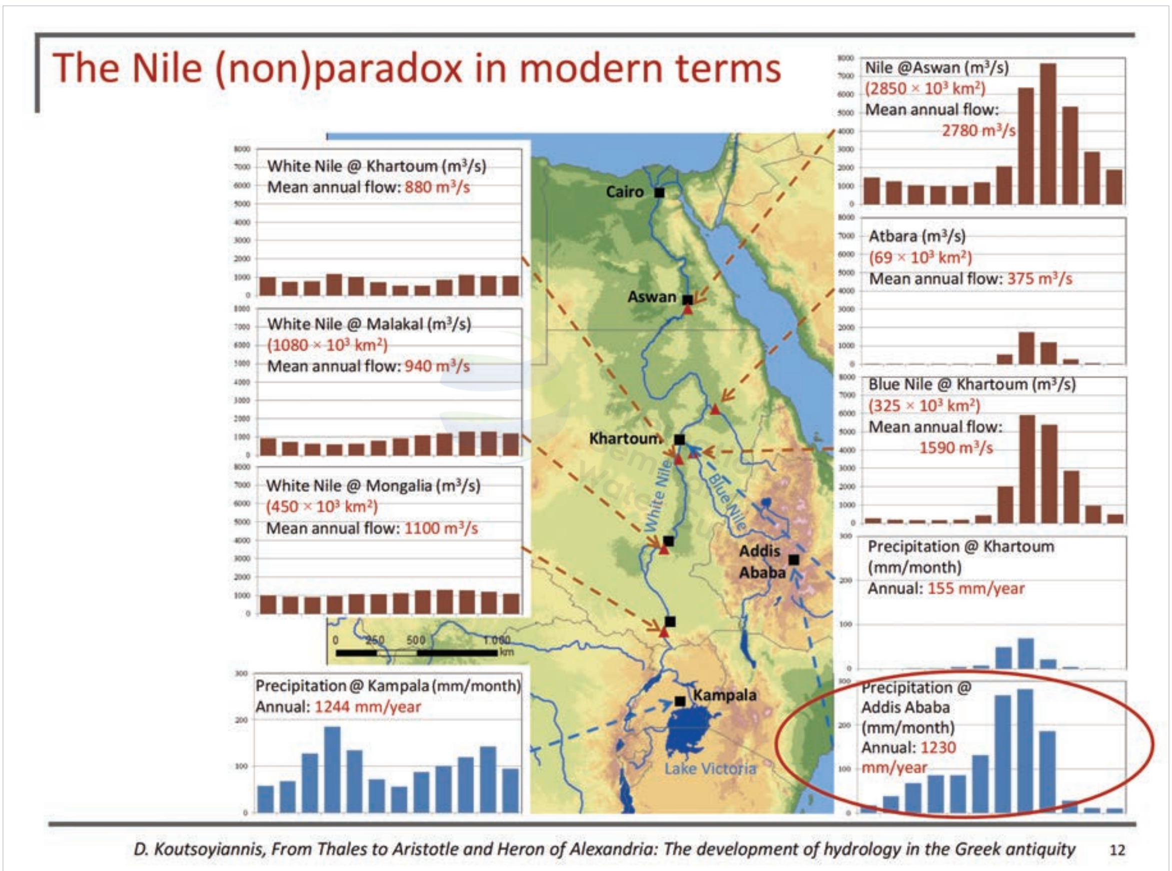
The Nile (non)paradox in modern terms
Nile @Aswan (m³/s)
(2850 × 10³ km²)
Mean annual flow:
2780 m³/s
White Nile @ Khartoum (m³/s)
Mean annual flow: 880 m³/s
White Nile @ Malakal (m³/s)
(1080 × 10³ km²)
Mean annual flow: 940 m³/s
White Nile @ Mongalia (m³/s)
(450 × 10³ km²)
Mean annual flow: 1100 m³/s
Precipitation @ Kampala (mm/month)
Annual: 1244 mm/year
Cairo
Aswan
Khartoum
White Nile
Blue Nile
Addis Ababa
Kampala
Lake Victoria
0 250 500 1.000 km
Atbara (m³/s)
(69 × 10³ km²)
Mean annual flow: 375 m³/s
Blue Nile @ Khartoum (m³/s)
(325 × 10³ km²)
Mean annual flow:
1590 m³/s
Precipitation @ Khartoum (mm/month)
Annual: 155 mm/year
Precipitation @ Addis Ababa (mm/month)
Annual: 1230 mm/year
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The solution of the paradox by Aristotle

*«Ὅτι οἱ ἐτήσιαι πνέουσι κατὰ τὸν καιρὸν τοῦ ἀκμαιοτάτου θέρους δι᾽ αἰτίαν τοιαύτην. Ὁ ἥλιος μετεωρότερος καὶ ἀπὸ τῶν μεσημβρινῶν τόπων ἀρκτικώτερος γινόμενος λύει τὰ ὑγρὰ τὰ ἐν ταῖς ἄρκτοις· λυόμενα δὲ ταῦτα ἐξαεροῦται, ἐξαερούμενα δὲ πνευματοῦται, καὶ ἐκ τούτων γίνονται οἱ ἐτήσιαι ἄνεμοι [...]. Ἐκεῖ δὴ ταῦτα ἐκφερόμενα προσπίπτει τοῖς ὑψηλοτάτοις ὄρεσι τῆς Αἰθιοπίας, καὶ πολλὰ καὶ ἀθρόα γινόμενα ἀπεργάζεται ὑετούς· καὶ ἐκ τῶν ὑετῶν τούτων ὁ Νεῖλος πλημμυρεῖ τοῦ θέρους, ἀπὸ τῶν μεσημβρινῶν καὶ ξηρῶν τόπων ῥέων. Καὶ τοῦτο Ἀριστοτέλης ἐπραγματεύσατο· **αὐτὸς γὰρ ἀπὸ τῆς φύσεως ἔργῳ κατενόησεν, ἀξιώσας πέμψαι Ἀλέξανδρον τὸν Μακεδόνα εἰς ἐκείνους τοὺς τόπους καὶ ὄψει τὴν αἰτίαν τῆς τοῦ Νείλου αὐξήσεως παραλαβεῖν. Διό φησιν ὡς τοῦτο οὐκέτι πρόβλημά ἐστιν· ὤφθη γὰρ φανερῶς ὅτι ἐξ ὑετῶν αὔξει.** Καὶ <λύεται> τὸ παράδοξον, <ὅτι> ἐν τοῖς ξηροτάτοις τόποις τῆς Αἰθιοπίας, ἐν οἷς οὔτε χειμὼν οὔτε ὕδωρ ἐστί, ξυμβαίνει τοῦ θέρους πλείστους ὑετοὺς γίνεσθαι»* (Ανώνυμος, Βίος Πυθαγόρου, στο Φωτίου, *Μυριόβιβλον*, Anon, https://el.wikisource.org/wiki/Μαρτυρίαι_(Αριστοτέλης).

"*The Etesian winds* [i.e., monsoons] *blow during the peak of the summer for this reason. The sun, at the zenith passing from south to north, disintegrates the moisture from the arctics and once this moisture is disintegrated, it evaporates and gives rise to monsoons* [...] *When they reach the high mountains of Ethiopia and concentrate there, they produce rains. These rains in full summer cause the flood of the Nile and make it overflow, while it flows at the northern arid regions.* ***This was analysed by Aristotle, who, by the superiority of his mind, understood it. He demanded to send Alexander of Macedonia to these regions, and to find, by sight, the cause of the flooding of the Nile. That's why they say there is not a problem anymore.*** *It became apparent by sight that the flow is increased by these rains. And this solved the paradox that in the driest Ethiopian [i.e. African] places where there is no winter nor rain, it happens that in the summer strong rainfalls occur*" (Photios, *Bibliotheca*, Comments on Anonymus, *Life of Pythagoras*, http://remacle.org/bloodwolf/erudits/photius/pythagore.htm)

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Aristotle, Alexander and the Hellenistic World

Aristotle, in addition to his many scholarly achievements, was tutor of **Alexander the Great**.

Alexander, during his campaign, in which he conquered big parts of Asia and Africa, was exchanging letters with his tutor (and his mother Olympias), addressing his as professor (καθηγητὴν).

The respect of the student to his mentor* resulted in the **first scientific expedition in history in order to confirm a scientific hypothesis**.

The Hellenistic period, which starts with the death of Alexander in 323 BC and ends with the emergence of the Roman Empire in 31 BC, is marked by the **wide dissemination of the Greek civilization and the flourishing of science**.

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*Note that such respect is not the rule in history: Remarkable counterexample is the conspiration of Kolmogorov, Alexandrov and other students of Luzin, to convict their mentor likely to death—an attempt which was prevented by intervention of Kapitsa and ultimately by a decision of Stalin (Graham and Kantor, 2009).

Aristotle (384 – 322 BC)

Alexander of Macedonia / the Great (356–323 BC)

Source of images: Visconti (1817)

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When was Aristotle's theory accepted?

The **mythological views are more charming than scientific** and, hence, they continued to be popular **during the Roman times**. The Roman epicurean philosopher **Lucretius** (c. 99 – c. 55 BC) and the stoic philosopher **Seneca** (4 BC –65 AD), both of whom wrote about Nile, did not rely on Aristotle's scientific explanation. Rather, they **were fascinated by the Nile for its mystery, not its demystification**. An excellent summary of the reasons is contained in the following quotation by Merrills (2017):

> *The metaphysical qualities of the Nile—a river that replicated each year the origins of the world, and which overspilled its banks even into the bathhouses and taverns of Pompeii—were essential to its resonance in the Roman world.*

The reference to Pompei encapsulates the archaeological evidence of sacred objects and iconographies for Nile and its waters.

And what about modern times? Were the mythical views abandoned after the first quantification of the hydrological cycle in the 17th century? This question is studied in detail in Koutsoyiannis and Mamassis (2021).

In brief, **the surprising answer is that a new mythology was developed around a "theory" of the "nitre" which was a mythical element that presumably caused the flooding of the Nile**, while rainfall in Ethiopia had a minor role, if any.

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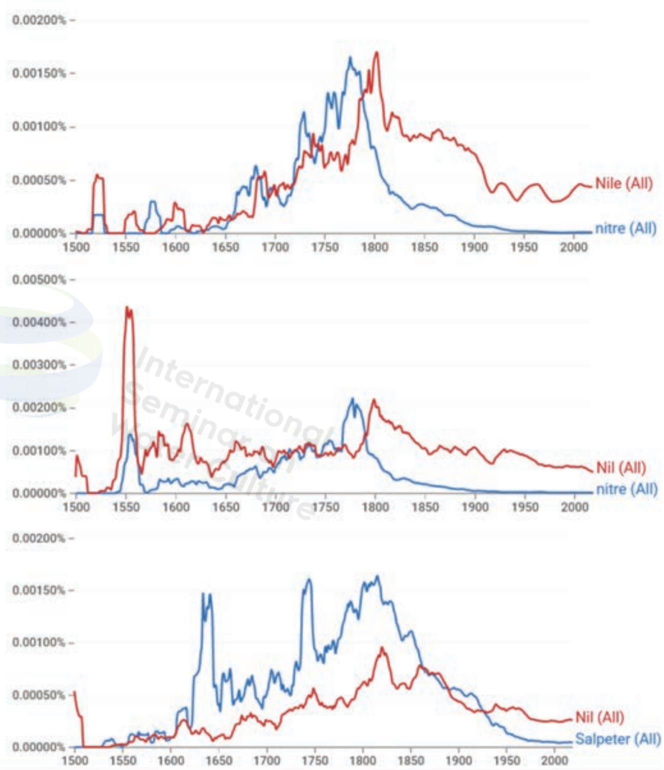
Why Aristotle's Nile theory was unpopular?

It took the visit to the origins of the Blue Nile of the Scottish traveller James Bruce and the publication of his book (Bruce, 1813) for the modern mythical theory to cease.

Question (food for thought):

Why Aristotle's incorrect geocentric system was so popular while his correct explanation of the Nile was unpopular?



Frequency of appearance of the indicated words in books hosted in the Google books platform in three languages: (upper) English; (middle) French; (lower) German.

Source: Koutsoyiannis and Mamassis (2021)

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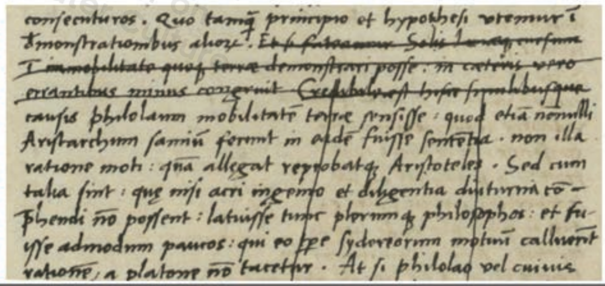
Prominent scientists of the Hellenistic period: Aristarchus

Aristarchus of Samos (310 – 230 BC; mathematician and astronomer), **introduced the heliocentric model for the solar system 1800 years before Copernicus**. He also said that the stars were distant suns and made calculations on the relative sizes of the Sun, Earth and Moon. Notably, before him also the Pythagorean philosopher Philolaus (470 – 385 BC) had moved the Earth from the center of the cosmos and made it a planet, but in Philolaus's system Earth does not orbit the Sun but rather a central fire.

Interestingly, **Copernicus in the manuscript of his book *De revolutionibus* included a citation to Philolaus and Aristarchus but he crossed it out before publication**. The point that was crossed out, translated in English (Gingerich, 1973, 1985), reads:

> [...] *It is credible that for these and similar causes (and not because of the reasons that Aristotle mentions and rejects), Philolaus believed in the mobility of the Earth and some even say that Aristarchus of Samos was of that opinion. But since such things could not be comprehended except by a keen intellect and continuing diligence, Plato does not conceal the fact that there were very few philosophers in that time who mastered the study of celestial motions.*



Part of page 22 of Book 1 of Copernicus's manuscript showing the references to Philolaus, Aristarchus and the Greek cosmology, which he crossed out before publication of his book De revolutionibus

Source: http://copernicus.torun.pl/en/archives/De_revolutionibus/1/?view=gallery&file=1&page=22

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Prominent scientists of the Hellenistic period: Eratosthenes

Eratosthenes (276 – 195 BC; head of the Library at Alexandria, following the windings of the Nile, calculated the distances between several points on the Nile up to Meroe (Strabo, Geography, 17.1.2; Rawlins, 1982). Perhaps because of this, he is often credited by several authors for solving the paradox of the Nile.

However, in view of the information provided here (in particular by Proclus), his achievement seems to be no more than a further verification of Aristotle's theory. He also seems to have been aware of the earlier expedition to the Nile sources for the purpose of proving Aristotle's theory (Burstein, 1976).

One of his biggest achievements was to **calculate, with remarkable accuracy (<2.5%), the Earth's circumference** by measuring, at the noon of the day of summer solstice, the shadow cast by a gnomon at Alexandria and the distance between and Alexandria and Syene, where the latter is situated close to the Tropic of Cancer.

Despite the advancements in geography during the Hellenistic period, the achieved geographical representation of the Earth was rather poor.

Map of the World according to Eratosthenes
Reproduced by Rhys (1912)

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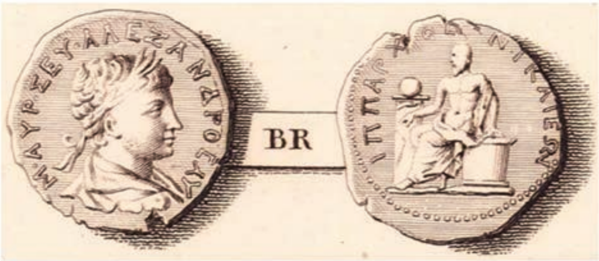
Prominent scientists of the Hellenistic period: Hipparchus

Hipparchus, the Greek astronomer, geographer and mathematician, and founder of trigonometry **introduced the term climate** (κλίμα, pl. κλίματα). Its etymology from the verb κλίνειν (= to incline) expresses the dependence of climate on the seasonal pattern of inclination angles of the incoming sunbeams.

Note that the **notion of climate had been studied earlier by Aristotle, who used another term, crasis** (κρᾶσις = mixture, blend) (see also Koutsoyiannis, 2021,2022).

Perhaps Hipparchus's most remarkable achievement is the **discovery of the precession of the equinoxes, one of the cycles in Earth's motion, with period of about 21 000 years, that determine the long-term changes of the climate. This constitutes one of the several now called Milankovitch cycles.**



Hipparchus of Nicaea (190 – 120 BC), depicted in the back facet of a coin whose front facet shows the Roman emperor Severus Alexander (M. AYP. ΣΕΥ. ΑΛΕΞΑΝΔΡΟΣ ΑΥ = Marcus Aurelius Alexandros Augustus)
Image source: Visconti (1817)

Prominent scientists of the Hellenistic period: Archimedes

Archimedes (287 – 212 BC) was the leading scientist (mathematician, physicist, engineer, inventor and astronomer) of the Hellenistic world, and is regarded to be perhaps the greatest mathematician of all time. While Aristarchus's heliocentric system was contrary to "consensus theory" for 1800 years, it is important to notice that it was adopted by Archimedes. In fact, he provides the most precious information about Aristarchus's ideas:

> *It is hypothesized* [by Aristarchus of Samos] *that the fixed stars and the Sun remain unmoved and the Earth revolves about the Sun in the circumference of a circle, with the Sun lying in the middle of the orbit and the sphere of the fixed stars, situated about the same centre as the Sun, is so great that the circle in which the Earth is hypothesized to revolve, bears such a proportion to the distance of the fixed stars as the centre of the sphere bears to its surface* (Archimedes, The Sand Reckoner).

It is well known that Archimedes offered several **important contributions in mathematics, including the concept of infinitesimals and a first version of integral calculus**. From the hydrological perspective, important is the principle named after him and the **foundation of hydrostatics**. From his inventions most relevant to hydrology is **Archimedes' screw, which is still in wide use for pumping**.

The Fields Medal (regarded as the highest honour for mathematicians) depicts Archimedes. The head of Archimedes in the medal is synthesized by the imagination of the artist (Tropp, 1976), as there is no original sign about it, neither in sculpture nor in coins
Image source: https://en.wikipedia.org/wiki/Fields_Medal

Prominent scientists of the Hellenistic period: Heron

The scientist of the Hellenistic period with the greatest contribution to hydrology is **Heron (Hero) of Alexandria** (mathematician and engineer who most likely lived in the 1st century BC or the 1st AD; see Woodcroft, 1851). He studied the notion of pressure and pneumatics and invented a steam machine. He introduced the term hydraulic (organ) for a musical instrument operated by hydraulics (ὑδραυλικὸν ὄργανον), which he describes in his book Pneumatica (Πνευματικὰ; Schmidt, 1899, p. 192, "Ὑδραυλικοῦ ὀργάνου κατασκευὴ"; Woodcroft, 1851, p. 105). **His contribution to hydrology is that he introduced the concept of discharge and its measurement**. Here is the relevant passage from his book Dioptra (Διόπτρα):

Πηγῆς ὑπαρχούσης ἐπισκέψασθαι τὴν ἀπόρρυσιν αὐτῆς, τουτέστι τὴν ἀνάβλυσιν, ὅση ἐστίν. εἰδέναι μέντοι χρὴ ὅτι οὐκ ἀεὶ ἡ ἀνάβλυσις ἡ αὐτὴ διαμένει. ὄμβρων μὲν γὰρ ὄντων ἐπιτείνεται διὰ τὸ ἐπὶ τῶν ὀρῶν τὸ ὕδωρ πλεονάζον βιαιότερον ἐκθλίβεσθαι, αὐχμῶν δὲ ὄντων ἀπολήγει ἡ ῥύσις διὰ τὸ μὴ ἐπιφέρεσθαι πλέον ὕδωρ. αἱ μέντοι γενναῖαι πηγαὶ οὐ παρὰ πολὺ τὴν ἀνάβλυσιν ἴσχουσιν. δεῖ οὖν περιλαβόντα τὸ πᾶν τῆς πηγῆς ὕδωρ, ὥστε μηδαμόθεν ἀπορρεῖν, σωλῆνα τετράγωνον μολιβοῦν ποιῆσαι, στοχασάμενον μᾶλλον μείζονα πολλῷ τῆς ἀποθύσεως· εἶτα δι' ἑνὸς τόπου ἐναρμόσαι αὐτὸν ὥστε δι' αὐτοῦ τὸ ἐν τῇ πηγῇ ὕδωρ ἀπορρεῖν. δεῖ δὲ αὐτὸν κεῖσθαι εἰς τὸν ταπεινότερον τῆς πηγῆς τόπον, ὥστε ἔχειν αὐτὴν ἀπόρρυσιν. τὸν δὲ ταπεινότερον ἐπιγνωσόμεθα τῆς πηγῆς τόπον διὰ τῆς διόπτρας. ἀπολήψεται οὖν τὸ ἀπορρέον διὰ τοῦ σωλῆνος ὕδωρ ἐν τῷ περιστομίῳ τοῦ σωλῆνος· οἷον ἀπολαμβάνει[ν] δακτύλους β· ἐχέτω δὲ καὶ τὸ πλάτος τοῦ περιστομίου τοῦ σωλῆνος δακτύλους ς· ἑξάκις δύο γίνονται ιβ· <ἀποφανούμεθα δὴ τὴν ἀνάβλυσιν τῆς πηγῆς δακτύλων ιβ>. εἰδέναι δὲ χρὴ ὅτι οὐκ ἔστιν αὔταρκες πρὸς τὸ ἐπιγνῶναι, πόσον χορηγεῖ ὕδωρ ἡ πηγή, [ἢ] τὸ εὑρεῖν τὸν ὄγκον τοῦ ῥεύματος, ὃν λέγομεν εἶναι δακτύλων ιβ, ἀλλὰ καὶ τὸ τάχος αὐτοῦ· ταχυτέρας μὲν γὰρ οὔσης τῆς ῥύσεως πλέον ἐπιχορηγεῖ τὸ ὕδωρ, βραδυτέρας δὲ μεῖον. διὸ δεῖ ὑπὸ τὴν τῆς πηγῆς ῥύσιν ὀρύξαντα τάφρον τηρῆσαι ἐξ ἡλιακοῦ ὡροσκοπίου, ἐν τινὶ ὥρᾳ πόσον ἀπορρεῖ ὕδωρ ἐν τῇ τάφρῳ, καὶ οὕτως στοχάσασθαι τὸ ἐπιχορηγούμενον ὕδωρ ἐν τῇ ἡμέρᾳ πόσον ἐστὶν, ὥστ᾽ οὐδὲ ἀναγκαῖόν ἐστι τὸν ὄγκον τῆς ῥύσεως τηρεῖν· διὰ γὰρ τοῦ χρόνου δήλη ἐστὶν ἡ χορηγία. (Ηρων ο Αλεξανδρεύς, Διόπτρα, Schoenne, 1976)

Prominent scientists of the Hellenistic period: Heron (2)

Translation of the Greek text:

Given a spring, to determine its flow, that is, the quantity of water which it delivers. One must, however, note that the flow does not always remain the same. Thus, when there are rains the flow is increased, for the water on the hills being in excess is more violently squeezed out. But in times of dryness the flow subsides because no additional supply of water comes to the spring. In the case of the best springs, however, the amount of flow does not contract very much. Now it is necessary to block in all the water of the spring so that none of it runs of at any point, and to construct a lead pipe of rectangular cross section. Care should be taken to make the dimensions of the pipe considerably greater than those of the stream of water. The pipe should then be inserted at a place such that the water in the spring will flow out through it. That is, the pipe should be placed at a point below the spring so that it will receive the entire low of water. Such a place below the spring will be determined by means of the dioptra. Now the water that flows through the pipe will cover a portion of the cross-section of the pipe at its mouth. Let this portion be, for example, 2 digits [in height]. *Now suppose that the width of the opening of the pipe is 6 digits. 6 × 2=12. Thus, the flow of the spring is 12* [square] *digits. It is to be noted that in order to know how much water the spring supplies it does not suffice to find the arca of the cross section of the flow which in this case we say is 12 square digits. It is necessary also to find the speed of flow, for the swifter is the flow, the more water the spring supplies, and the slower it is, the less. One should therefore dig a reservoir under the stream and note with the help of a sundial how much water flows into the reservoir in a given time, and thus calculate how much will flow in a day. It is therefore unnecessary to measure the arca of the cross section of the stream. For the amount of water delivered will be clear from the measure of the time.* (Hero, Dioptra, 31, English translation by Cohen, 1958)

Recapitulation and relevance to modern science

1. **Posing scientific questions** (e.g., the Nile paradox) **and seeking scientific explanations** was a crucial historical development, which did not prevail in earlier civilizations, as exemplified by Herodotus's contrast between Greek philosophers and Ancient Egyptian intellectuals (and priests).
2. Science and philosophy were not only invented but also defined, with their meaning clarified to be the **genuine pursuit of truth, independently of other (e.g. economic) interests**.
3. **Science, then called natural philosophy, was developed as part of philosophy**, with other parts thereof, i.e., metaphysics, epistemology, logic and axiology (ethics, aesthetics), being equally developed.
4. The development of (Aristotelian) **logic** offered a powerful instrument for science to distinguish sense from nonsense as well as deduction from induction, and the relative validity of the inference based on each of these two methods.
5. The gradual development of the **scientific method,** which constitutes part of philosophy, by incorporation of observation, experience and, at a later stage, experiment, provided a solid foundation of science.
6. Central in Ancient Greek thought was **reasoning as the main tool for the search for truth**. By no means does this imply that the philosophers of Ancient Greece tended to distrust observations, as incorrectly asserted by some modern scholars (where samples are given in the Introduction). Obviously, if this happened, it would contradict reasoning per se (it is totally unreasonable to dismiss observations).

D. Koutsoyiannis, From Thales to Aristotle and Heron of Alexandria: The development of hydrology in the Greek antiquity 23

Recapitulation and relevance to modern science (2)

7. **Clarity (σαφήνεια)** was also a desideratum so strong that Aristotle identified it with truth. This is also related to the accurate accounting of the phenomena and the attainment of accurate scientific knowledge (Lesher, 2010). The introduction of terminology, i.e., of sophisticated terms whose meaning may not be identical to the colloquial one, and their definitions, is another reflection of the clarity desideratum.
8. Formulation of a **plurality of ideas** by different scholars, as well as their **debate**, were vital for the development of science. It is clear from the quotations given above that Ancient Greek scholars cite and discuss each other's ideas and theories, mostly with proper respect and sometimes with moderate irony. Thanks to these discussions, today we are aware of opinions of philosophers whose original works are totally lost.
9. The **plurality of ideas and diversity of opinions**, some of which necessarily were better than other, resulted in an evolutionary process which in turn enabled **scientific progress**. It appears that such recently promoted ideas as that of a "settled science" did not have a place in the ancient environment of scientific inquiry.
10. An important development that expedited scientific progress was the **creation of Philosophical Schools**, functioning as centres of higher-level education and research, similar to modern universities. Plato's Academy, Aristotle's Lyceum (or Peripatetic School), Epicurus's Kepos (meaning garden), Zeno's Stoa (meaning arcade) were some of the most famous. After nine centuries of continuous operation, they were massively closed in 529 AD by an infamous emperor Justinian's edict, which marked a societal paradigm shift and a millennium-long regression in scientific inquiry.

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Recapitulation and relevance to modern science (3)

11. The **communication of ideas among philosophers and to the public was organized in the form of books**. Within this practice, a writing style or code was developed, characterized by critical literature review and expression of own thoughts, using a sophisticated language. This writing style is more or less followed even in present day, as can be inferred by inspecting several extracts from Ancient Greek texts given above.
12. According to Plato and Aristotle the motivation of philosophers is their curiosity to explain Nature, but according to Herodotus, it is their ambition to achieve reputation for wisdom. Noting that even this latter does not look an unethical incentive, we may assert that the **development of science complies with the development of axiology and of ethical values, including the promotion of the truth as an ethical value and the modesty of those seeking it. Even the term *philosophy* (*φιλοσοφία*) reflects this modesty**. Notably, the term *philosopher* (*φιλόσοφος*) replaced the earlier term *sophos* (*σοφός*, translated in English as *sage* or *wise*, as in the expression "Seven Sages"). According to an Heraclitian aphorism, *wise is only one* (*ἓν τὸ σοφὸν*, meaning something supernatural, i.e. God) and henceforth Pythagoras introduced the term *philosopher*, meaning *lover* (or *friend*) of *wisdom* (*φίλος σοφίας*). This is clarified in the following quotation:

Φιλοσοφίαν δὲ πρῶτος ὠνόμασε Πυθαγόρας καὶ ἑαυτὸν φιλόσοφον [...]· *μηδένα γὰρ εἶναι σοφὸν [ἄνθρωπον] ἀλλ' ἢ θεόν* (Διογένης Λαέρτιος, *Βίοι καὶ γνῶμαι τῶν ἐν φιλοσοφίᾳ εὐδοκιμησάντων*, Α.12).

Pythagoras was the first to name it philosophy and himself a philosopher [...] *for no man is wise, but God alone.* (Diogenes Laertius, Lives of the Philosophers, 1.12)

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Back to Aristotle: importance of seeking the truth

«*φίλος μέν Σωκράτης, ἀλλά φιλτάτη ή ἀλήθεια*»
(Latin version: "*Amicus Socrates, sed magis amica veritas*")
"*Socrates is dear* (friend)*, but truth is dearest*"
(Ammonius, Life of Aristotle)

Aristotle (384 – 322 BC)
Image source: Visconti (1817)

«*δόξειε δ᾽ ἂν ἴσως βέλτιον εἶναι καὶ δεῖν ἐπὶ σωτηρίᾳ γε τῆς ἀληθείας καὶ τὰ οἰκεῖα ἀναιρεῖν, ἄλλως τε καὶ φιλοσόφους ὄντας: ἀμφοῖν γὰρ ὄντοιν φίλοιν ὅσιον προτιμᾶν τὴν ἀλήθειαν*»

"*Still perhaps it would appear desirable, and indeed it would seem to be obligatory, especially for a philosopher, to sacrifice even one's closest personal ties in defense of the truth. Both are dear to us, yet it is our duty to prefer the truth*" (Aristotle, Nicomachean Ethics 1096a11).

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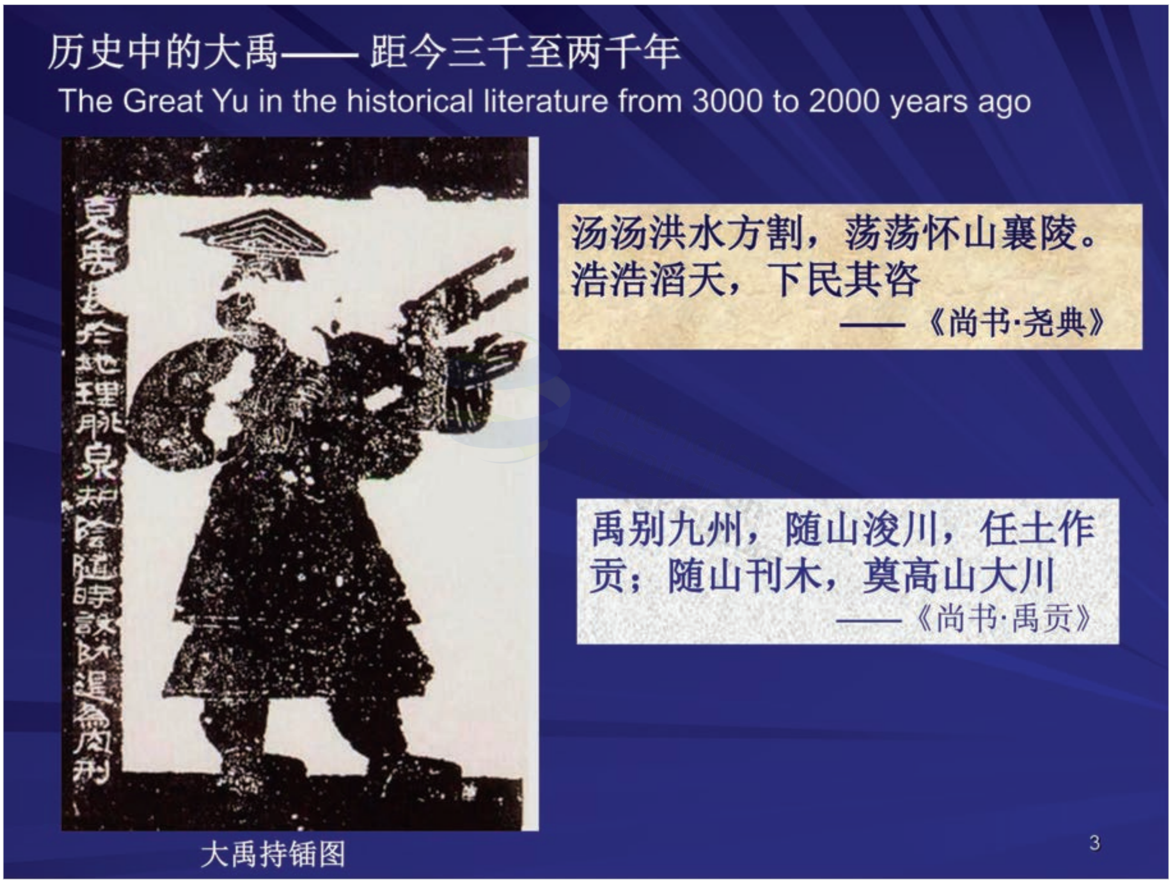
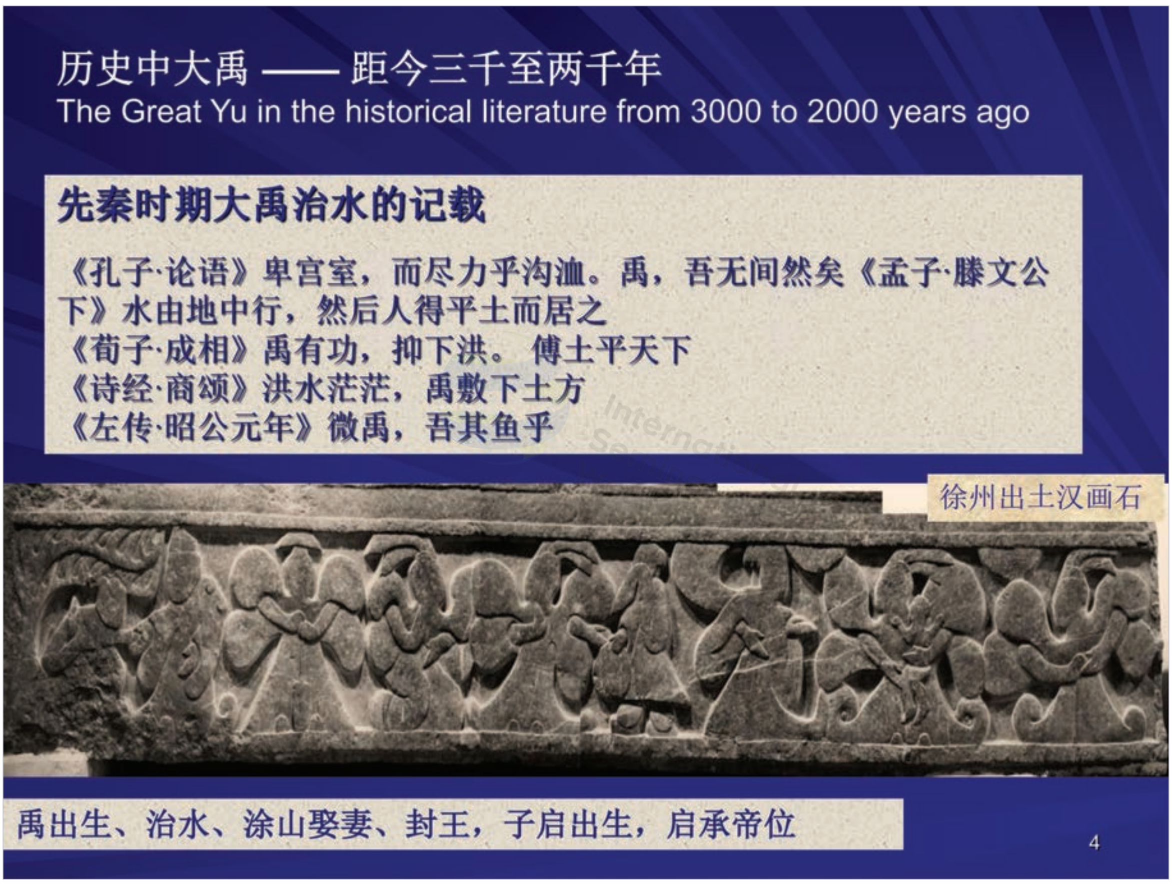
禹迹问史：中华民族的创世纪
Yu's Trace and History: the Creation of the Chinese Nation
中国水利水电科学研究院
谭徐明
1


前序
Preface
何以为中国？
Formation of China?
何以为中华文明？
What is the Origin of Chinese Nation
• 禹迹的历史
History of Yu's Trace
•大禹治水的文化价值
Cultural Value of Yu's Flood Control
2


历史中的大禹—— 距今三千至两千年
The Great Yu in the historical literature from 3000 to 2000 years ago
汤汤洪水方割，荡荡怀山襄陵。
浩浩滔天，下民其咨
——《尚书·尧典》
禹别九州，随山浚川，任土作
贡；随山刊木，奠高山大川
——《尚书·禹贡》
大禹持锸图
3


历史中大禹 —— 距今三千至两千年
The Great Yu in the historical literature from 3000 to 2000 years ago
先秦时期大禹治水的记载
《孔子·论语》卑宫室，而尽力乎沟洫。禹，吾无间然矣《孟子·滕文公下》水由地中行，然后人得平土而居之
《荀子·成相》禹有功，抑下洪。 傅土平天下
《诗经·商颂》洪水茫茫，禹敷下土方
《左传·昭公元年》微禹，吾其鱼乎
徐州出土汉画石
禹出生、治水、涂山娶妻、封王，子启出生，启承帝位
4


历史中的大禹 —— 距今1500-1000年
The Great Yu in the historical literatures from 1500 to 1000 years ago
禹的世系的记载
Documents of Yu's Lineage
夏禹姓姒氏黃帝玄孫
父鯀母有莘氏女初堯
時洪水滔天禹嗣父職
以司空治水開九州通
九道陂九澤度九山告
厥成功舜嘉之禪位焉


大禹治水技术的记载
Documents of Yu's Flood Control Technology
禹乃与益、后稷奉帝命。命诸侯、百姓兴人徒以傅土。行山表木，定高山大川。… 左准绳、右规矩，载四时
——《史记·夏本纪》
禹之决渎也，因水以为师
——（西汉）刘安《淮南子·原道训》
禹治水的传说
黄河西来决昆仑，咆哮万里触龙门。波滔天，尧咨嗟。大禹理百川，儿啼不窥家。杀湍堙洪水，九州始蚕麻
——（唐）李白
（明代）尤求，大禹治水图
6

1.大禹治水是史实，但不是文明起源而是文明转折

Yu's flood control is a historical fact, not the origin but a turning point of civilization

寻找文明的源头：大洪水前的时代，上溯三千年

The Source of Civilization: The Age Before the Great Flood, Going back 3000 Years

黄河流域仰韶文化至龙山文化时期（距今7000至4000年）
聚落和城邑遗址发现大量粟、黍、水稻遗存

7

中国是世界粟的发祥地

China is the Birthplace of Millets

- 以黍、稷、粟为主的旱作农业发生于距今8000年左右，主要分布在海河下游、黄河的支流二级及三级台地
- Dry farming occurred about 8000 years ago, mainly distributed in the lower reaches of the Haihe River and the 2nd and 3rd platforms of the tributaries of the Yellow River

仰韶文化

- 河北武安磁山遗址发现了距今8000年的88处粟遗存的窖穴，粟灰堆积层0.3—2米，总量10万公斤
磁山地处太行山东麓山洺河北岸，遗址区为山前台地，保水性较好的红黄土壤，多年平均降雨量700毫米

- 西安半坡遗址中发现了200多个窖穴，6处陶窑遗址，距今6000－6700年的粟壳保存完好

- 西自甘肃，东至辽宁陆续发现的距今7000至4000年文化遗址中都有粟、黍的遗存

8

- 中国是稻作农业的发祥地

China is the Birthplace of Rice Farming

新石器至青铜器早期稻作农业遗址

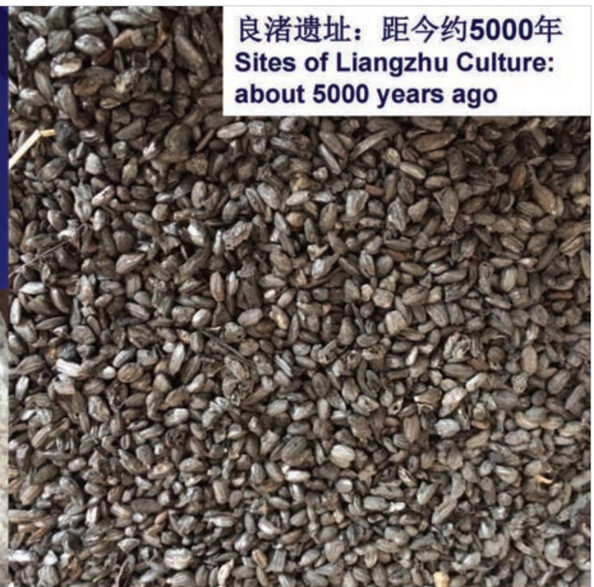
区域		新石器中期 约公元前7000- 前5000年	新石器晚期 约公元前5000- 前3000年	青铜器早期 约公元前3000- 前2000年
长江	中游	10	25	28
	下游		20	24
淮河	上游	1	9	9
珠江	三角洲			2

至迟在公元前4000年左右旱作和稻作农业涵盖了黄淮海平原。这些都是传说时代夏、淮夷、三苗、唐虞等部落活动的区域，也最早华夏部落联盟的区域

Dry farming and Rice farming spreads all over the Plains of The yellow River, Huaihe River and Haihe River no later than about 4000.

9

- 约公元前5000 部落氏族社会进入部落联盟的邦国或称方国时期



良渚遗址：距今约5000年

Sites of Liangzhu Culture: about 5000 years ago

上山文化（距今约10000年）红陶碳化稻

Sites of Shangshan Culture (about 10000 years ago) Red pottery carbonized rice

10

河姆渡井塘（距今7000至5000年）
Well pond in Hemudu culture site (7000 to 5000 years ago)

• 水利设施诞生

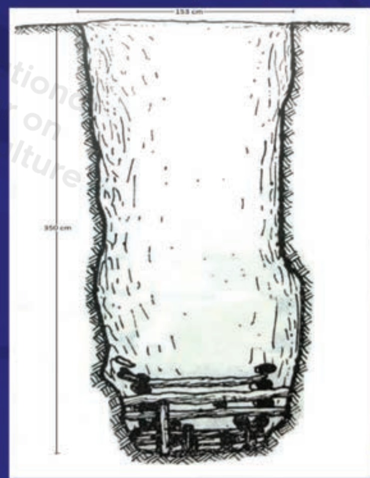
Water Resources Facilities were born

人类社会文明进程的里程碑

Milestones in the process of human civilization

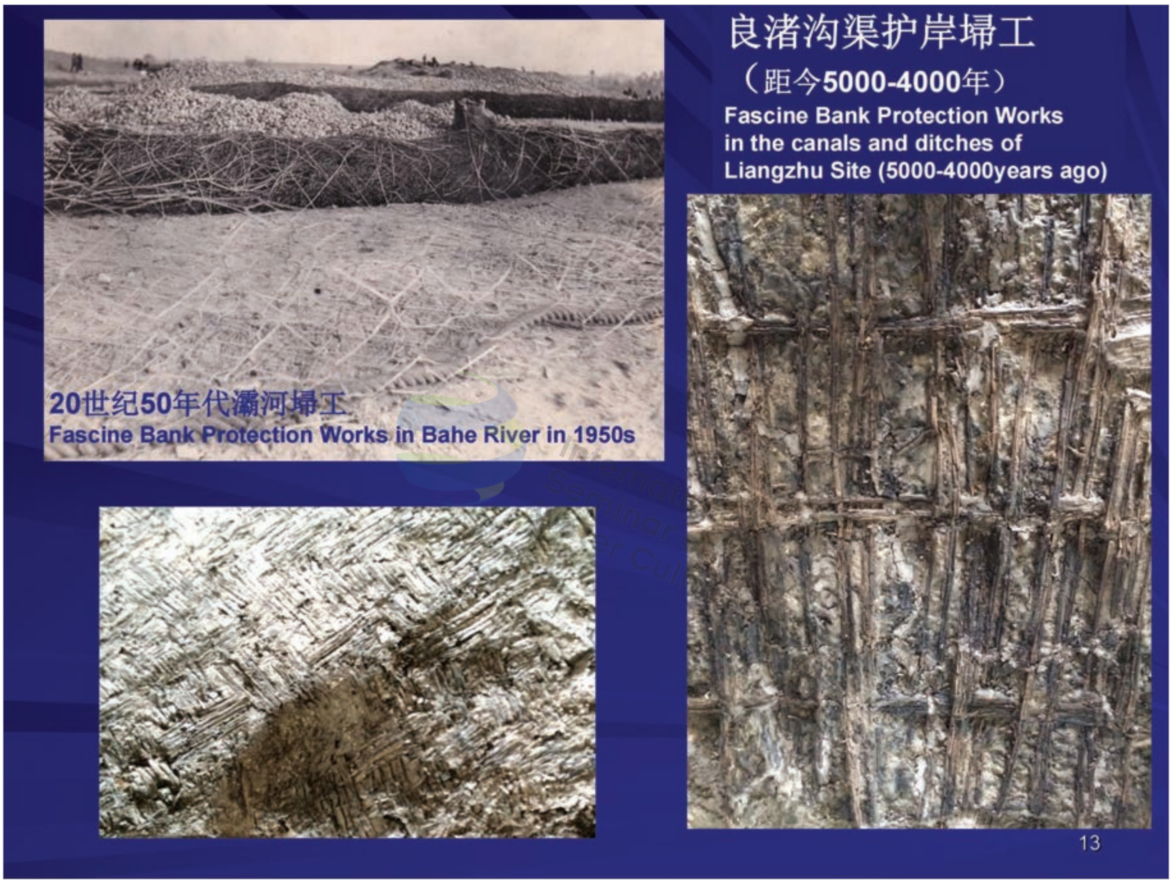
（元）王桢《农书》记载的井灌工程
Well Irrigation Works Documented in Agricultural Book by Wang Zhen (Yuan Dynasty)

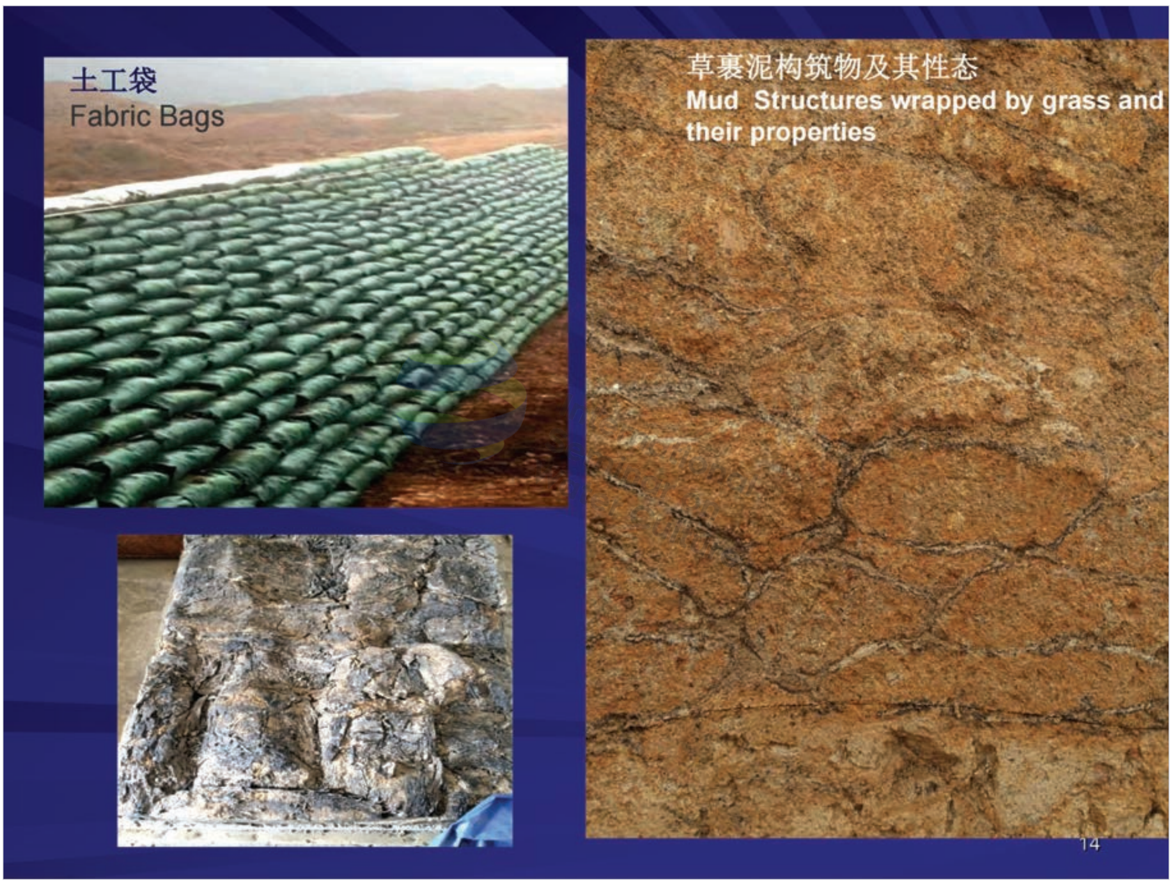
河北藁城商井（距今约3000年）
Well in the Gaocheng County of Hebei Province (3000 years ago)



11

良渚沟渠木桩护岸工程（距今5000-4000年）
Bank Protection Works with wooden stake in the canals and ditches of Liangzhu Site (5000-4000 years ago)


良渚沟渠护岸埽工
（距今5000-4000年）
Fascine Bank Protection Works
in the canals and ditches of
Liangzhu Site (5000-4000years ago)
20世纪50年代灞河埽工
Fascine Bank Protection Works in Bahe River in 1950s
13


土工袋
Fabric Bags
草裹泥构筑物及其性态
Mud Structures wrapped by grass and
their properties
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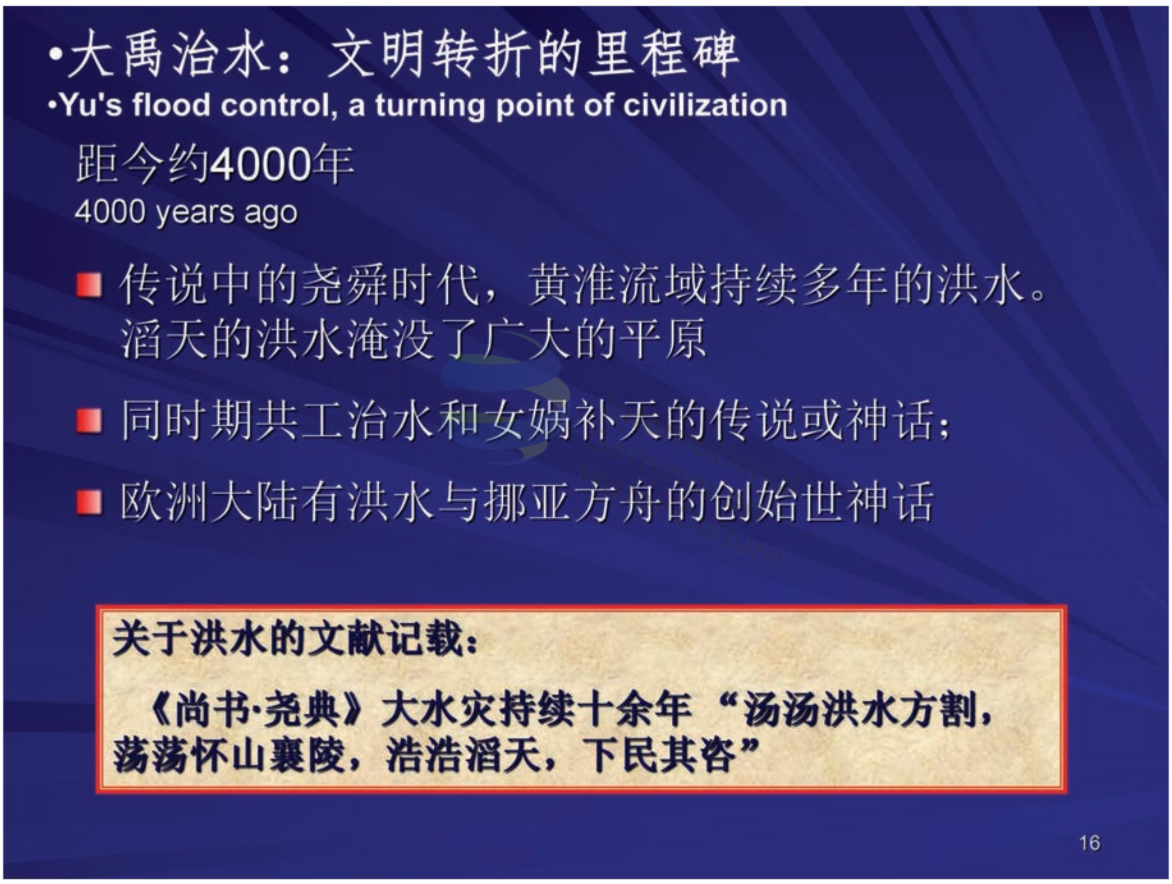
历史学的大禹的时代
距今约5000——4000年左右
The Great Yu Age in History
华夏五帝 ——夏
黄帝、颛顼、帝喾、尧、舜 → 禹
邦国林立—东夷、三苗、戎狄、氐羌、百越…
戎
狄
华夏诸部
东夷
氐 羌
三苗
百
越
• 大禹的时代（龙山文化晚期距今5000年前）
The Great Yu Age 5000 years ago
邦国林立的部族社会，黄河流域的中原地区，长江上中下游和太湖平原多个地域政治经济中心形成
Political and Economic center began to shape in tribes distributed over the central plains of the Yellow River basin,the upper, middle and lower reaches of the Yangtze River
古史时代各文化集团的分布


•大禹治水：文明转折的里程碑
•Yu's flood control, a turning point of civilization
距今约4000年
4000 years ago
传说中的尧舜时代，黄淮流域持续多年的洪水。滔天的洪水淹没了广大的平原
同时期共工治水和女娲补天的传说或神话；
欧洲大陆有洪水与挪亚方舟的创始世神话
关于洪水的文献记载：
《尚书·尧典》大水灾持续十余年 “汤汤洪水方割，荡荡怀山襄陵，浩浩滔天，下民其咨”
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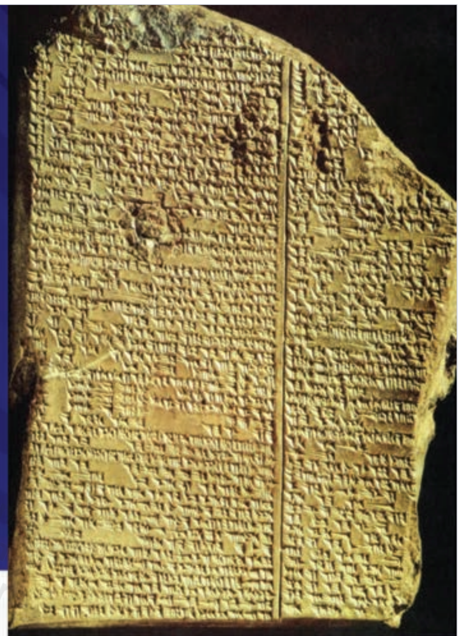
文明起源多学科研究

Multi-disciplinary Research on Origin of Civilization

夏商周断代工程

The Xia-Shang-Zhou Dynasty Chronology Project



古天文学、古气象大洪水的考据

- 依据五星汇聚 、仲康日食 、禹征三苗日食天象记录；
- 极地、热带—亚热带山地冰芯 、湖泊地层、石笋、木化石，重构古气象灾变事件

古气候重大灾变事件重构认为：

- 史前大洪水是全球性大灾变。大洪水对世界许多地区早期文明发展进程产生了重大影响
- 大洪水历时约150年，禹治水在灾变后期即距今4000年

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西周遂公盨与《禹贡》

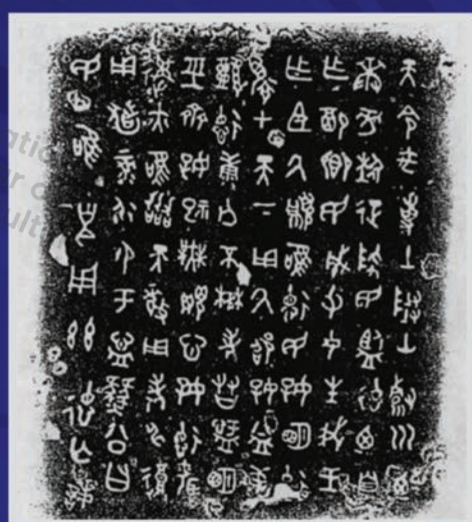
- **2002年发现了距今约2900年前铸造的记载禹绩的青铜鼎——遂公盨。遂公盨将禹治水的记载从春秋提前了300年**

A bronze Ding with the record of Yu's flood control. The bronze Ding was an cooking vessel 2900 years ago

盨铭：天命禹敷土，随山浚川，迺差地设征

《尚书·禹贡》的记载

禹敷土，随山刊木，奠高山大川
禹别九州，随山浚川，任土作贡



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3. 大禹治水的文化影响
Cultural Influence of Yu's Flood Control

- 大禹治水是水利的国家行为，以威权制衡上下游左右岸的利益的文化表达

Yu's flood control is the national activities.

- 大禹是水利作为兴利除害的文化标识和政府官员为官的道德约束

- Yu is the cultural symbol of water resources for beneficial development and eliminating disasters and the moral restraint of government officials

- 大禹治水是历史时期自然观的治水策略的依据

- Yu's flood control is the basis of natural concept of flood control strategy in the historical periods

➢ 世以己治水，而禹以水治水也。

➢ 以己治水者，己与水交战，决东而西溢，堤南而北圮，治于此而彼败，纷万绪之俱起；

➢ 以水治水者，内不见己，外不见水，惟理之视。避其怒、导其驶。引之为江为河为济为淮，汇之为潭为渊为沼为沚。盖蓄于性之所安，而行乎势之不得已

——陆游《禹庙赋》

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大禹：国家治水的图腾
Great Yu: the Totem of Nation Flood Control

➢ 禹何人?斯崇之者以为神，否其为神者则并否有其人。…均非可以为训也。夫禹之德行，孔氏、墨氏言之至矣

➢ 思天下大业非一二人所可为力，必众擎乃易举。必有一极高尚之人格，其德业可以为全国万世之所共同崇仰而不渝者以为师表，始可以合千万人而一之。

➢吾华民族每一行业，必有其所祀之神，尚在乎斯。亘古人格容有过于大禹者乎？则在吾众，众俱以禹为宗，则千万人者一人也，四千年者旦暮也

李仪祉，1934年

Dear distinguished presenters, friends, and all event attendees - Warm Greetings! I am Daniela Bemfica, the Director of Strategic Programmes and Engagement at the International Water Association.

On behalf of our Association, I would like to welcome you to the 2nd International Webinar on Water Culture, which theme is *Water and Environment in Ancient Civilizations: Culture, Technology, and Traditions*.

Thank you very much to the China Institute of Water Resources and Hydropower Research and the Dujiangyan Water Resources Development Center for organizing this event about such an interesting discussion topic.

Water underpins every aspect of human and environmental existence. The global water sector is currently facing multiple serious challenges, which require an unprecedented global response. Although water and sanitation for all has been an integral part of the international agenda for several years, still around 2.2 billion people lack access to safe drinking water and more than 4 billion people do not have safely managed sanitation services. Achieving Sustainable Development Goals 6.1 and 6.2 by 2030 is essential, but also extremely difficult.

In addition to these challenges, the world is now facing severe consequences of climate change impacting our living environment. The impact of climate change on urban water management is potentially huge, affecting the capacity of utilities to deliver safe water for all, ensure water resources quality, and protect people and assets from flooding. On the other hand, we cannot ignore that the urban water sector is also a driver of climate change, as utilities are responsible for up to 5% of global greenhouse gas emissions, related to its high energy consumption, and to wastewater handling.

To overcome these challenges, it is crucial for us to work together internationally, cross-disciplinarily, and cross-sectorally. The International Water Association, as the most influential professional water network, supplies a unique platform to enable such kind of global collaboration and knowledge sharing to contribute to accelerate actions towards achieving the SDGs.

Our Association brings together over 8,000 members from around 140 countries, representing universities, research institutes, utilities, NGOs, international agencies, engineering and consulting companies, technology providers, among others. Our members organize themselves in 50 Specialist Groups, covering all areas of water related technology and water management. These Specialist Groups provide an opportunity for experts from different geographies to network and collaborate, organising conferences, online events, and co-developing publications.

The International Water Association also hosts two major global events, the World Water Congress and the Water Development Congress, and publishes 19 journals, including Water Research, which is number 1 journal on water science. Also, through IWA Strategic Programmes we develop projects and initiatives aiming at establishing change agendas on key water-related themes, contributing to develop and promote sustainable urban- and basin-related water solutions.

The International Water Association acknowledges that ancient hydro-technologies – most of which were decentralized, cost-effective, friendly to the environment, and highly sustainable – can be an inspiration for today's water professionals. We believe that understanding those technologies and making them visible to the wider water community can contribute to the development of wise, sustainable, and efficient water management systems for the present and future generations. In this context, the International Water Association and the International Water History Society jointly established, years ago, the Water in Ancient Civilizations Specialist Group. This is a very active specialist group, that has already organized 5 International Symposiums on Water, Wastewater and Environment in Ancient Civilizations, and has published multiple papers and books describing and evaluating ancient water-related technologies applied around the world.

The event today is totally aligned with IWA's vision that the wisdom of ancient water science and technology can still be used in the present. And I am sure that our audience today also shares this perspective. With this is mind, I invite you all to enjoy this fantastic knowledge sharing and network opportunity and wish the event a great success! Thank you very much!

Roman lead pipes impacts on environment and human health

Jure Margeta

University of Split, Split, Croatia

**2nd International Seminar on Water Culture,
Dujiangyan City, Sichuan province, Beijing, China**

INTRODUCTION

- Lead pipes were a standard element of Roman urban water supply systems, and wooden pipes, pipes of baked clay and stone were also used, but significantly less.
- Roman lead pipes very slightly increased lead levels in tap water but effect was „unlikely to have been truly harmful".
- We believe that lead pipes has very important role in sustaining life – water in the ancient Roman towns.
- Inscriptions on lead pipes found in Rome indicate that lead pipes began to be used before 11 BC. However, soil tests and lead concentrations in the soil around Rome indicate that the use began earlier around 140 BC.
- In order to get a more complete insight into the use of lead pipes, a pressure test of the pipes found in Salona a capital of the Roman Province of Dalmatia, which are about 2000 years old, was organized.
- We believe that our experiment is the first attempt in the world, so the results of the performed test are of great importance for a more complete understanding of the sustainability of Roman water supply networks.

The paper analyzed and present:

- The Roman lead pipe characteristics, production and use in Roman urban water distribution system.
- A pressure test of a lead pipe excavated in Roman town Salona (Croatia).

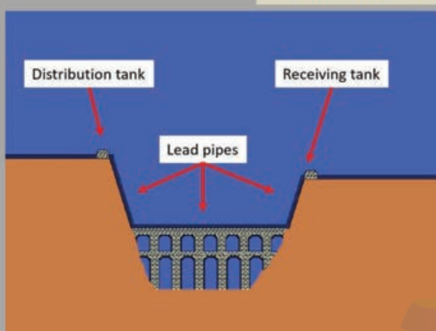
Objectives of the paper are:

1. Present impact of lead pipe features on the planning and design of the Roman urban water distribution system, environment and human health;

2. Present practice and rules for the use, construction and maintenance of lead pipe in the Roman inner-city water distribution system once it arrived in city.

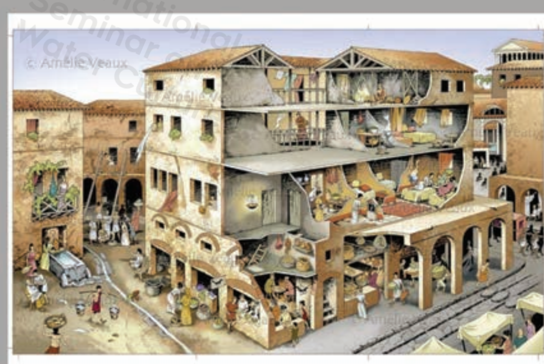
3. Pressure test experiment of a Roman lead pipe, and the influence of the obtained results on a more complete understanding of the performance of the Roman urban water supply system.

MAIN APPLICATIONS OF LEAD PIPES



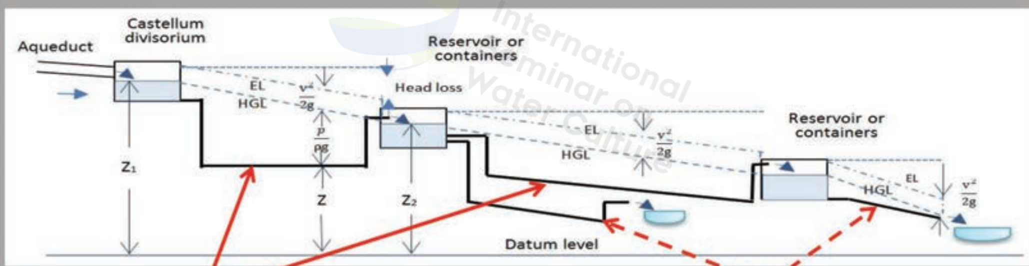
(I) WATER DELIVERY SYSTEM ;
A MULTIPLE LEAD PIPES SIPHON AT AQUEDUCT

(II) WATER DISTRIBUTION SYSTEM;
A LEAD PIPES IN THE CITY WATER DISTRIBUTION SYSTEM



WATER SUPPLY SYSTEM

- The concept of Roman water supply system was simple and relied on gravity for water transport and distribution and had serpentine paths similar to rivers.
- In addition to a network of interconnecting pipes, water distribution systems today as well as in ancient time normally include storage facilities, valves, fire hydrants, service connections to user facilities, and perhaps pumping facilities.
- Water continuously flowed through the system from the intake to the point of use (say fountains). Constant flow 24 hours a day is a very important technological feature, because the constant flow of water in the system ensures fresh and healthy water, and free water availability to residents. Short contact time period of water with lead and external temperature!

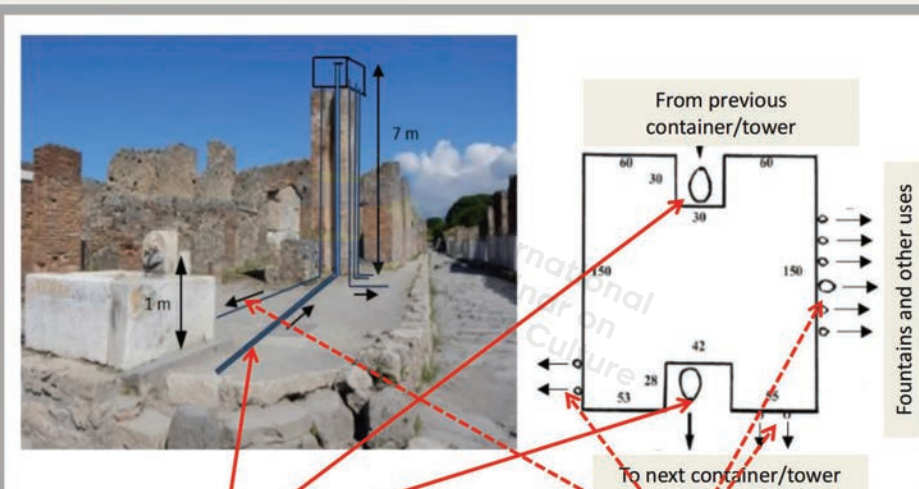


Main pipes
– connect reservoirs

Distribution pipes
– connect reservoir and users

WATER TOWER AND PIPES ARRANGEMENT

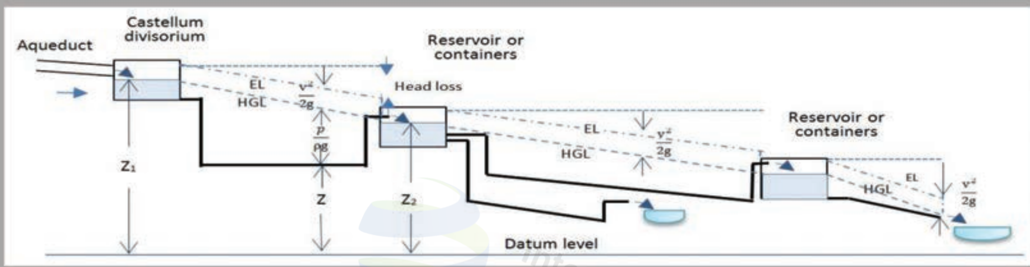
From smaller storage tanks at water towers, the water would continue through lead pipe to reach public fountains, latrines and baths, and next lower head storage tanks at water towers distributed throughout the city like a web.



Main pipes – connect storage tanks at towers

Distribution pipes – connect storage tanks and users/final destinations

WATER DISTRIBUTION SYSTEM HYDRAULIC



Roman reservoir/water towers were lower than **8 m**, so the vertical difference between the height of the water in the reservoir/container and the lowest elevation of the pipe axis is generally less than 8 m, so **the water pressure in the pipe is also less than 8 m**.

This does not apply to pipes used for siphon construction on the aqueduct where the water pressures were significantly higher.

The inflow and outflow from the castellum were regulated by choosing the pressure head, size of the pipe, length of the pipe, and calix/nozzle dimensions at the connection of the pipe and container (Frontinous, 1899, 35-36).

LEAD CHARACTERISTICS AND IMPACTS

- In the Roman Empire, lead was **readily available and cheap**, and was mostly obtained as a **by-product of silver smelting**.
- It is a natural metal that is obtained from galena ores, is easy to process, and is **resistant to water corrosion**. The inner and outer surface of the pipe is relatively smooth, according to Crapper et al. (2022) about 0.9 mm, so major head losses are small.
- **Lead is poisonous to humans**, which was known to the Romans (Vitruvius VIII.6.10-11; XXXIV.47. 212. Prolonged exposure to lead results in health impairment, and the greatest risk is for children under 6 years of age and pregnant women. That is why since 1970, lead pipes have not been used in water supply.
- The yield strength of lead is 5.5 MPa, while the ultimate tensile strength is 17 MPa.
- **Lead is soft and prone to creep/deformation** especially at higher temperature.

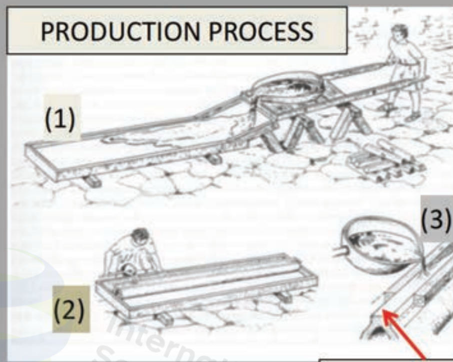
Therefore, the limiting factor for the use of lead as a building material was susceptibility to creep, not its tensile strength.

LEAD PIPE PRODUCTION AND CHARACTERISTICS

The pipes are produced by first: **(1)** heating and melting the lead, and then pouring it into a mold that forms a flat piece of metal about 3 m long (10 feet, where 1 foot = 29.6 cm),

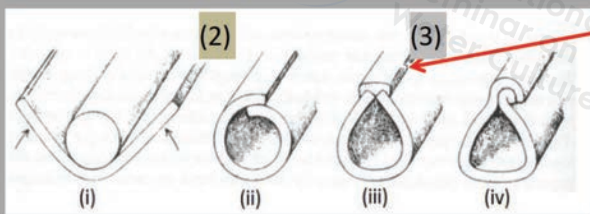
then **(2)** bent around a wood cylinder to form the pipe,

and **(3)** soldered together along the long side of the bent pipe, thus providing the pipe with a **pear-shaped cross-section**.



LONGITUDINAL JOINT

PEAR-SHAPED CROSS SECTION



The longitudinal joint of the plate (continuous seam) was made in several ways depending on the size of the pipe, wall thickness and required strength.

DIMENSIONS AND CHARACTERISTICS

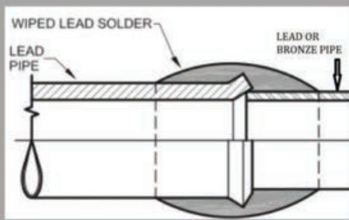
- The size of the pipe was determined by the width of the flat piece of the lead for manufacturing it. The size of the pipes given in ***digiti*** corresponds to the circumference of the pipe, or somewhat less.
- Vitruvius provided a Roman standard for water pipes, with **eight standard sizes** based on the circumference of the pipe in *digiti* (1 *digitus* = 1.85 cm). In 11 BC, another system for pipe dimensions with **25 standard sizes**, but in practice **only 15 sizes are generally used.**
- He also mentioned the length of the plate to be used to manufacture the pipe **in *feet*** (where 1 *foot* = 29.6 cm), and its weight in *pounds*, where 1 *pounds* = 0.45 kg.
- The **lightest pipe** was the ***fives*** weighing 60 *pounds* (**27 kg**), with a circumference of 9.25 cm (Ø 2.94 cm), and the largest ***hundreds*** weighing 1200 *pounds* (**540 kg**), with a circumference of 185 cm (Ø 58.89 cm).

The **weights** presented by Vitruvius demonstrate that, in his opinion, all the lead plates had the same thickness (**approximately 1 cm**) irrespective of the size of the pipe. **It follows that all lead pipes, regardless of the width of the plate and thus the size of the pipe, have the same wall thickness, which is not theoretically correct.**

The reason why he the proposed thickness of 1 cm we believe is **related to the construction and the additional load that occurs in the pipe network, and not only the internal pressure**, which is small and did not have a major impact on the required wall thickness.

PIPE JOINTS CHARACTERISTICS

A WIPED JOINT - is a form of soldered joint used to join lead pipework.

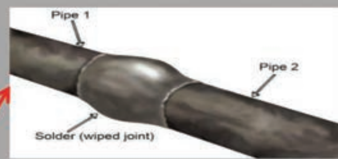


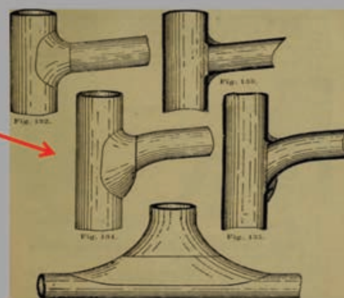
PIPE IN SALONA

- QULITY OF JOINTS IS VERY IMPORTANT FOR PIPE SYSTEM FUNCTIONS AND CHARACTERISTICS.
- IT IS TRADITIONALLY A WEEK POINT OF THE SYSTEM – WATER LOSS.

TODAY: Joints in lead pipe or fittings, or between lead pipe or fittings and brass or copper pipe, shall be full wiped joints. Wiped joints shall have an exposed surface on each side of a joint not less than 3/4 inch and at least as thick as the material being jointed. Wall or floor flange lead-wiped joints shall be made by using a lead ring or flange placed behind the joints at wall or floor. Joints between lead pipe and cast-iron, steel, or wrought iron shall be made by means of a caulking ferrule, soldering nipple, or bushing.

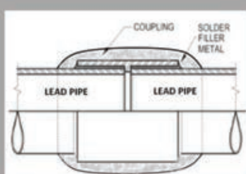
ROMANS USE VERY SIMILAR TECHNOLOGY.



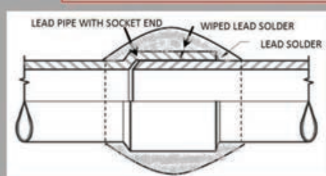


PIPE JOINTS CHARACTERISTICS

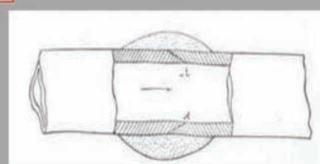
OTHER TYPES OF JOINT



a) Couple joint



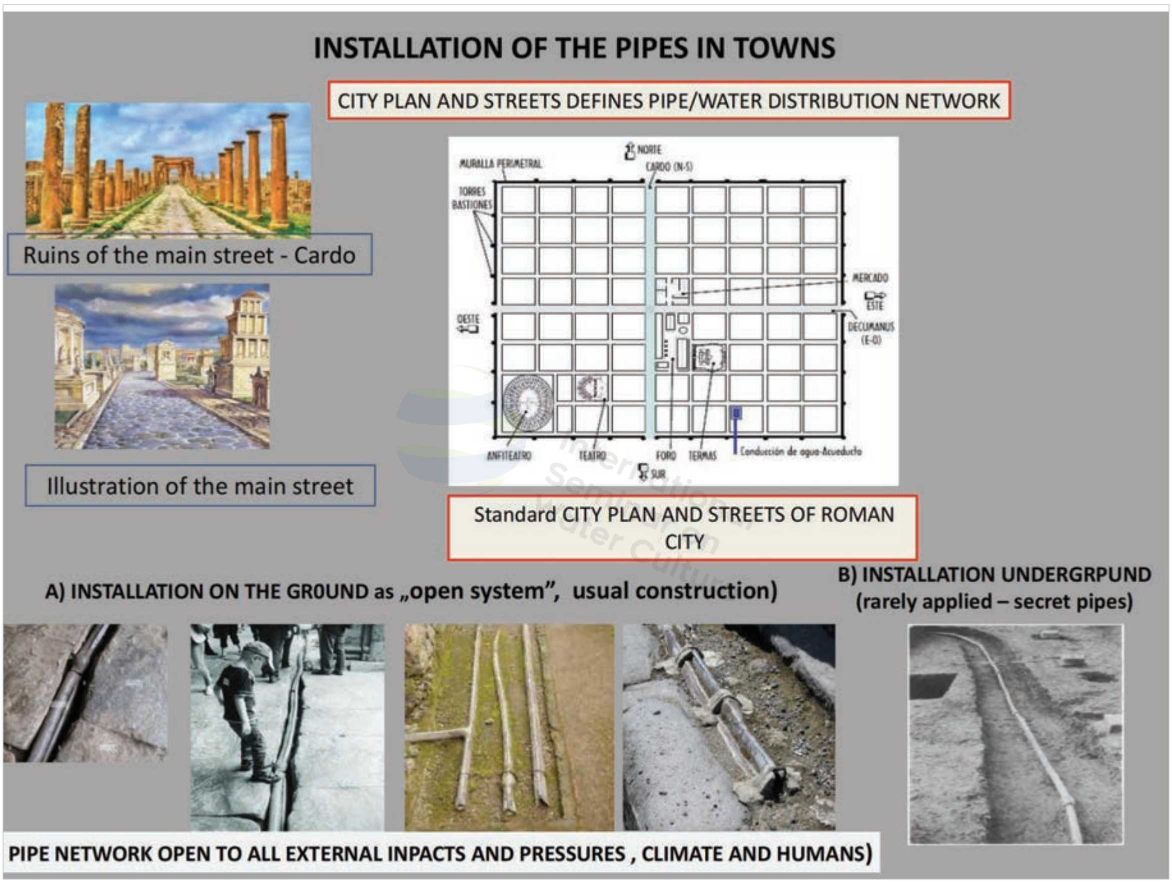
b) Spigot and socket joint

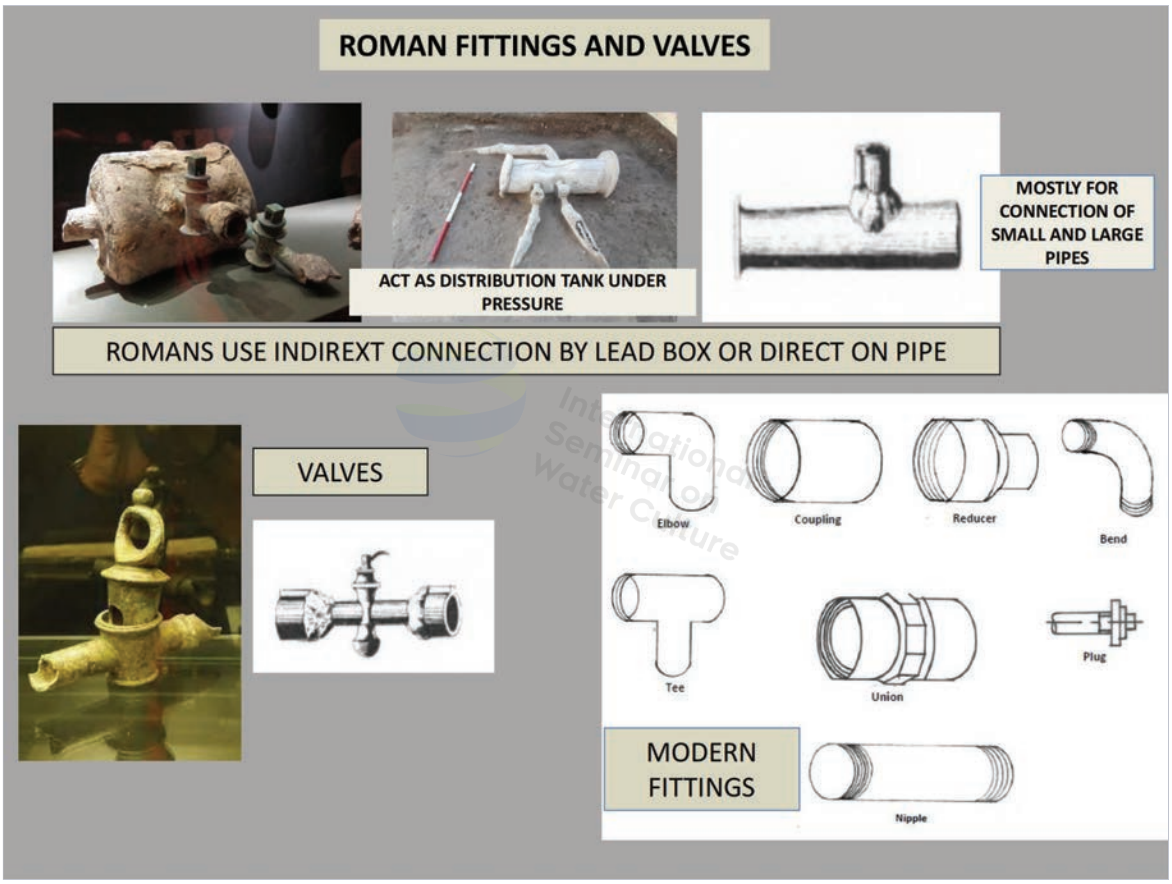


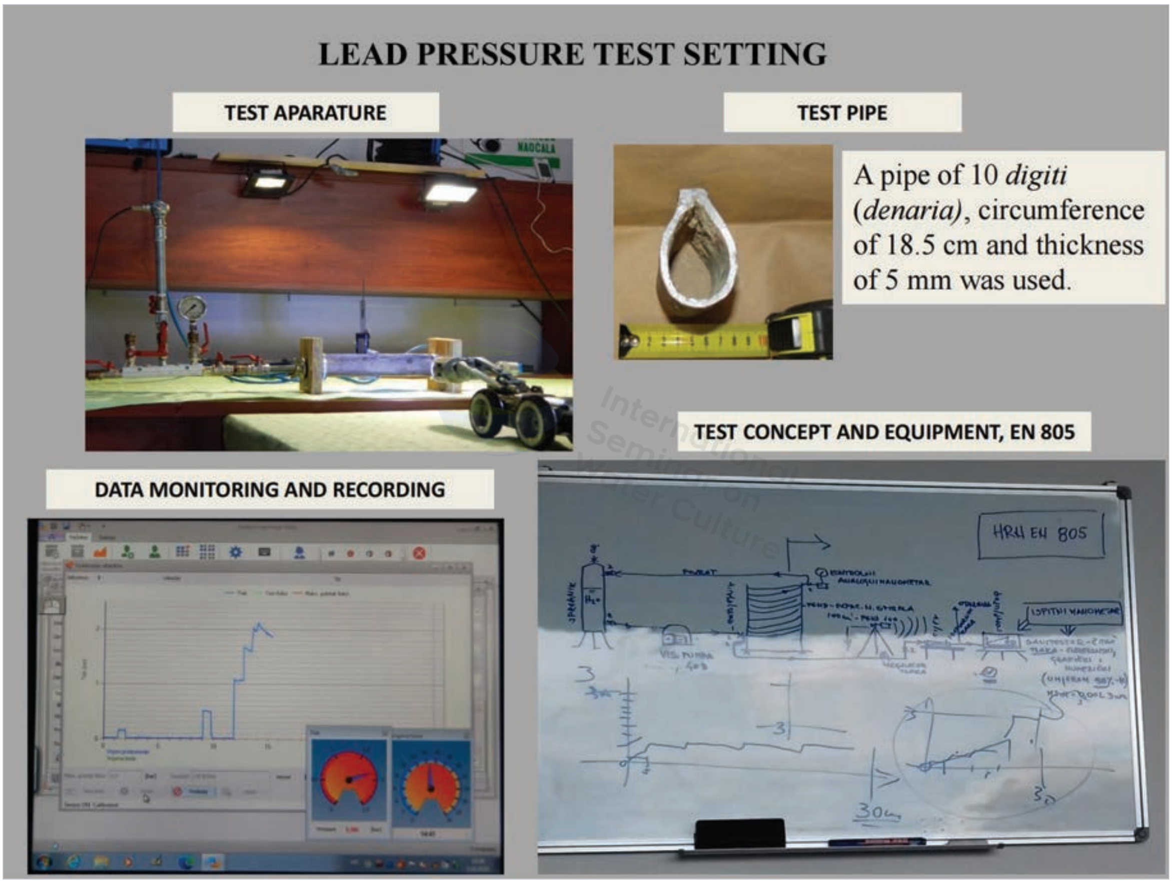
c) Direct joint

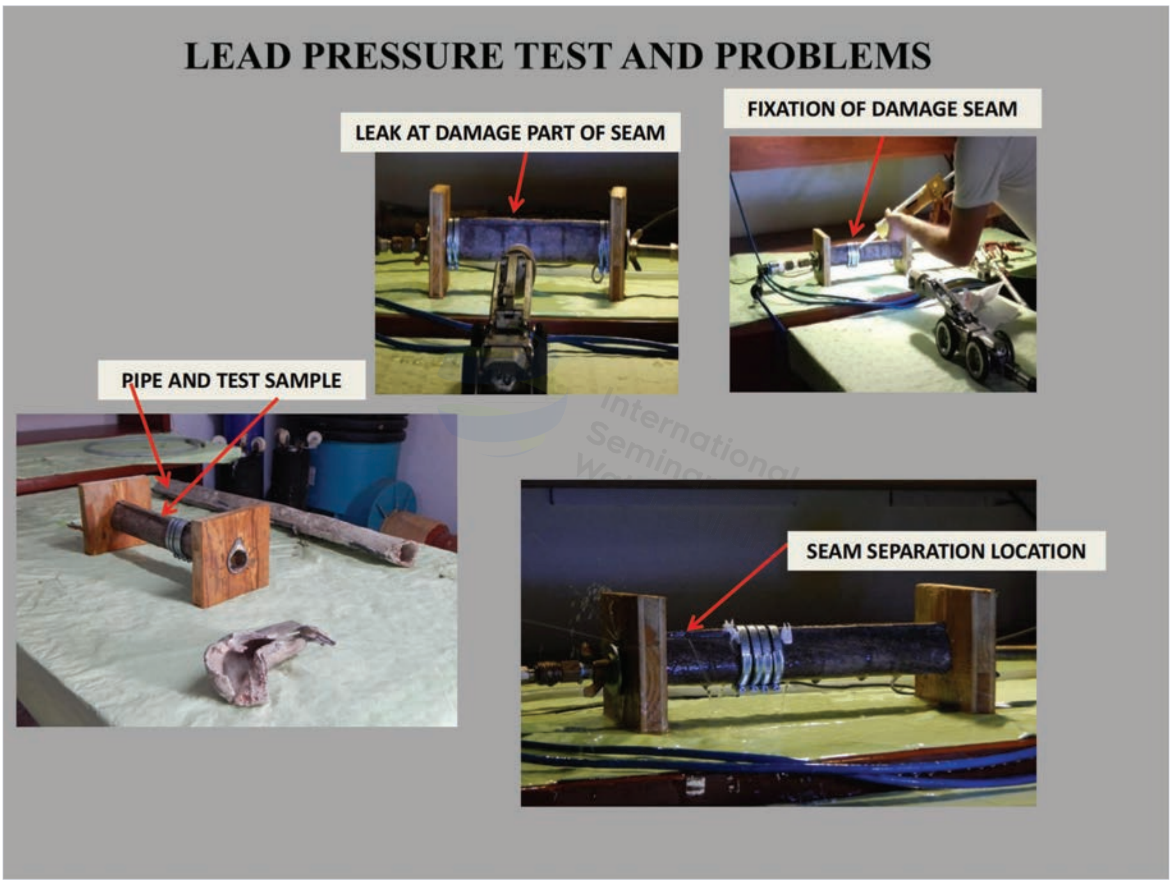
Connecting lead pipes with a nail driven through both ends and covering the joint with soldered lead sheet.

In general, the pipe joints were no weak points in the water network due to the superior soldering techniques of the Romans! Such conduits may be regarded as being made of a homogenous material.

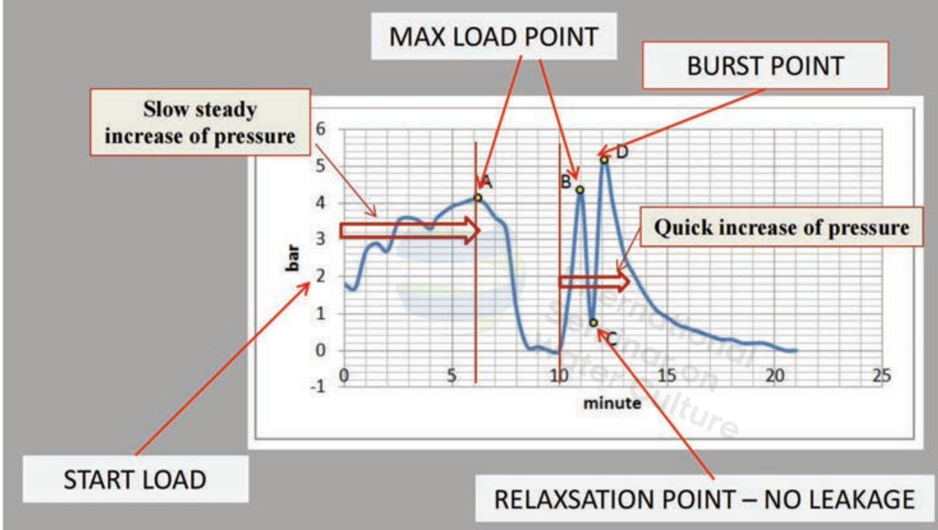

INSTALLATION OF THE PIPES IN TOWNS
CITY PLAN AND STREETS DEFINES PIPE/WATER DISTRIBUTION NETWORK
Ruins of the main street - Cardo
Illustration of the main street
MURALLA PERIMETRAL
NORTE
CARDO (N-S)
TORRES BASTIONES
MERCADO
ESTE
DECUMANUS (E-O)
OESTE
ANFITEATRO
TEATRO
FORO
TERMAS
SUR
Conducción de agua-Acueducto
Standard CITY PLAN AND STREETS OF ROMAN CITY
A) INSTALLATION ON THE GROUND as „open system", usual construction)
B) INSTALLATION UNDERGRPUND (rarely applied – secret pipes)
PIPE NETWORK OPEN TO ALL EXTERNAL INPACTS AND PRESSURES , CLIMATE AND HUMANS)


ROMAN FITTINGS AND VALVES
ACT AS DISTRIBUTION TANK UNDER PRESSURE
MOSTLY FOR CONNECTION OF SMALL AND LARGE PIPES
ROMANS USE INDIREXT CONNECTION BY LEAD BOX OR DIRECT ON PIPE
VALVES
Elbow
Coupling
Reducer
Bend
Tee
Union
Plug
MODERN FITTINGS
Nipple


LEAD PRESSURE TEST SETTING
TEST APARATURE
TEST PIPE
A pipe of 10 *digiti* (*denaria)*, circumference of 18.5 cm and thickness of 5 mm was used.
TEST CONCEPT AND EQUIPMENT, EN 805
DATA MONITORING AND RECORDING
HRN EN 805


LEAD PRESSURE TEST AND PROBLEMS
LEAK AT DAMAGE PART OF SEAM
FIXATION OF DAMAGE SEAM
PIPE AND TEST SAMPLE
SEAM SEPARATION LOCATION

RESULTS



SUMMERY

of lead pipe characteristics in a application of Roman water networks taking into consideration design parameters, local experience, environmental conditions, construction, operation, maintenance, and financial evaluation.

General design parameters

Indicator	Evaluation	Comment
Diameter	Good choice of dimensions	25 types
Pressure resistance	Sufficient	High safety factor.
Local experience	Relevant	A high knowledge of engineers and workers.
The price of the material	Low	Lead is a by-product of silver production.
The price of the pipes	Acceptable	Significantly lower compared to bronze.
Construction costs	Not relevant	The only available and acceptable building material.

Structural Properties

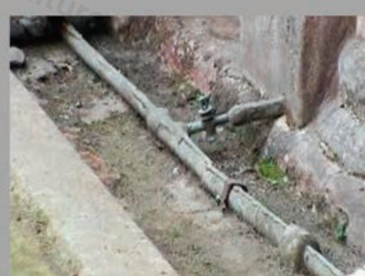
Indicator	Evaluation	Comment
Lifetime	More than 100 years	Salona pipe 2000 years old.
Resistance to internal pressure	Relevant	Fully satisfy system working pressure.
Resistance to external pressure	Weak	Especially at higher temperatures
Resistance to shock load	Sufficient	High safety factor in relation to possible working shocks load.

Environmental Conditions

Indicator	Evaluation	Comment
Resistance to internal corrosion	Very high	Internal roughness very stable for hundreds of years.
Resistance to soil corrosion	Very high	No changes for hundreds of years.
Resistance to groundwater corrosion	Very high	No changes for hundreds of years.
Resistance to stray currents corrosion	Not relevant	

Construction, Operation, and Maintenance

Indicator	Evaluation	Comment
Weight	Very heavy	lead density 11.34 g/cm^3
Ease of jointing	Moderate	Sensitive pipe connection.
Route width	Small	Diameter + 20 cm
Need for specific bedding	Yes	Protection against external loading is required.
Need for thrust blocks	No, except for vertically laid pipes (high weight)	The pressure in the system is low, < 1 bar.
Ease of leakage detection	Yes	Pipe mostly easily visible.
Ease of repair	Yes	Pipes readily available.



Human health impact

Indicator	Evaluation	Comment
Toxicity of piping system and materials	Significant	Lead dissolves in water and pollutes water, soil and the bio environment.
Duration of negative impacts	Very long	Lead remains in the soil for a long time period, more than 100 years.
Environmental contamination process	Complex	Through natural processes in the environment, lead accumulates in soil and water and transported through the non-living and living environment (plant) and finally uptake by humans.
Toxicity of waste material	Significant	The same as in the case of lead pipes.
Special conditions	Different	Higher temperatures generate greater dissolution of lead; soft or acidic water generate higher dissolution of lead to water.

Environmental impacts

Indicator	Evaluation	Comment
Material toxicity	Very significant	Lead is a highly poisonous metal.
Water toxicity in pipes	Low	Due to short contact time of material and water, less than 30 minutes.
Toxicity to builders	Significant	Inhalation of lead dust and toxic gases, skin absorption and ingestion when making joints, repairs, etc.
Toxicity during production	Significant	Lead smelting, casting and plate joining generate toxic gases and lead dust.
Toxicity during pipeline dismantling	Significant	Cutting and tearing creates lead dust that is inhaled and introduced into the body, and through contact and ingestion.

CONCLUSIONS

1. Pipes, jointing, and continuous seams in Roman pipes, as well as lead piping, are efficient and satisfactory techniques for Urban Water Distribution System (UWDS) design.
2. The pipes had a high safety factor related to the water pressure in the pipes used for UWDS construction, and satisfactory in relation to the total loads arising from the performance of the pipe network.
3. The test pipe was prone to bursting along the continuous seam.
4. Lead contamination of water in the network was not significant due to water short contact time with pipes, especially not in the case of hard water. The constant flow of water 24 hour per day in the system ensured reliable access to clean water and protected the water from pollution.
5. Lead pipes were safe and reliable, and enabled the long-term functioning of the water supply system with healthy drinking water, which significantly contributed to the improvement of health conditions and living standards.
6. It can be concluded that the pipes were functional, reliable and very durable for the water supply concept used by the Romans. The same cannot be said for their application in modern systems.
7. These results provide a useful basis for future research in Roman hydraulic engineering.

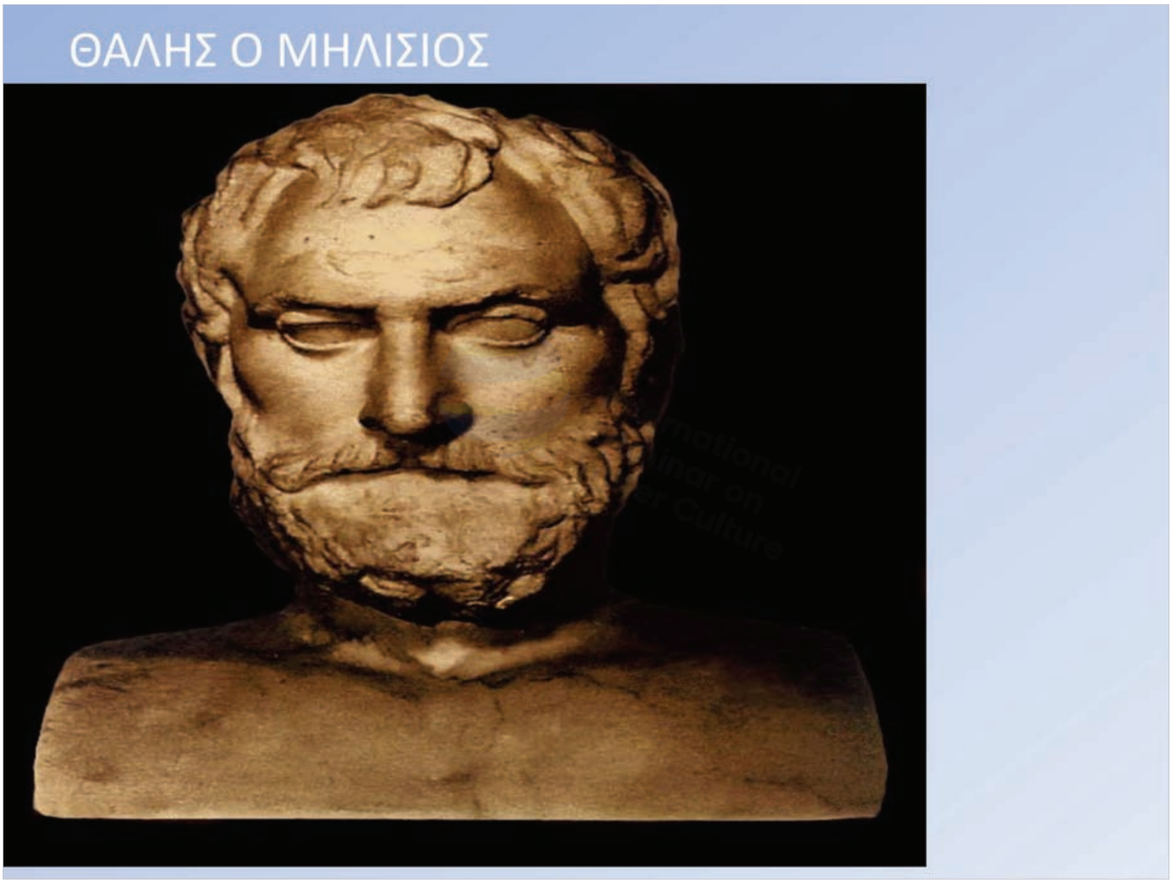

Thank you
for your attention!

In Greece, have found systematically organized wastewater drain networks since 3000 BC.

Minoans and Indians are considered the precursors of designing and constructing wastewater disposal networks.

In later times Greeks and Romans further improved the technology of the wastewater management

The ancient Greeks, considered the water as being a "divine gift" of Gods.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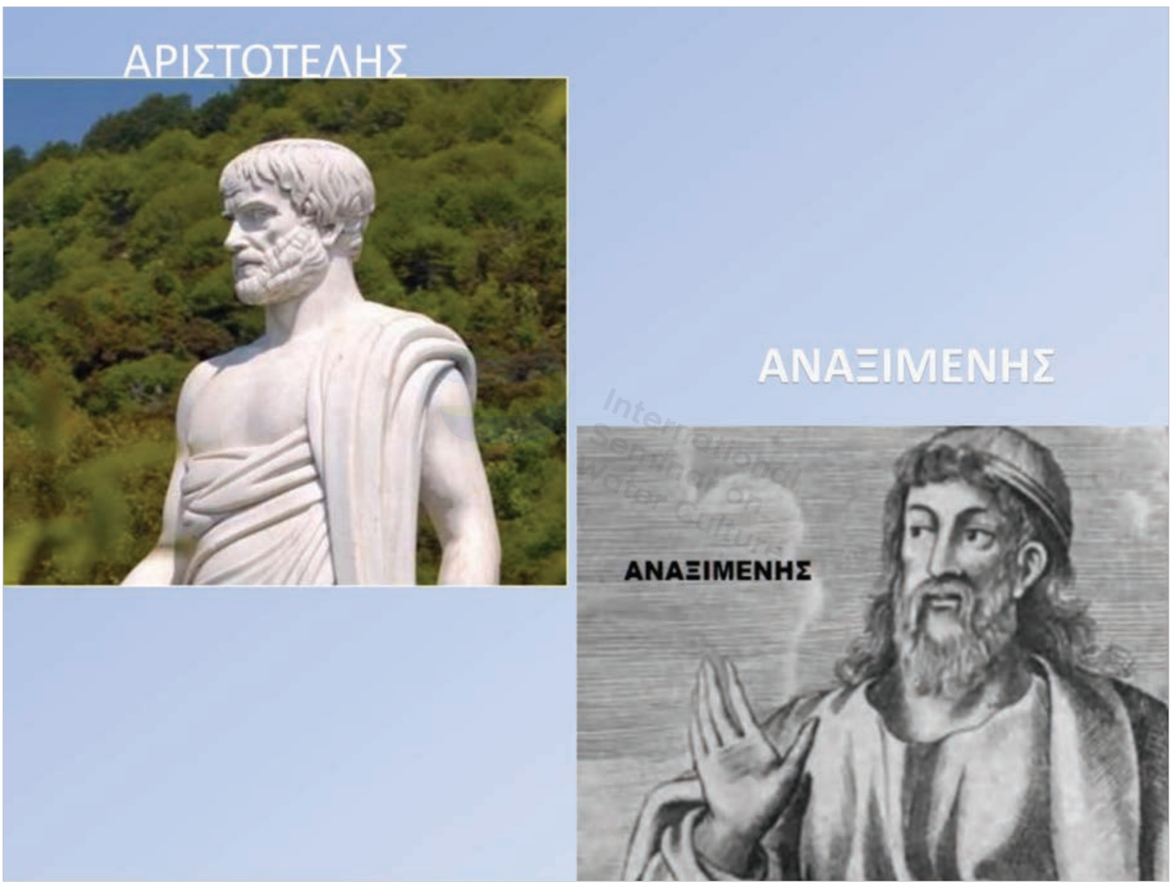
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ΑΝΑΞΑΓΟΡΑΣ


Acheloos River
Acheloos,
the Father of all waters


The fight of Acheloos
and
Hercules for Deianera
Hercules breaks one
of Acheloos's
horns and wins

The hydrological know-how in ancient Greece

The first effort to manage the water use in crop irrigation was made in Mesopotamia and Egypt during the Neolithic era i.e. 6000 to 7000 years ago

The first constructions for the transfer of potable water were made in Palmyra of Syria and in Eastern Crete, during the Neolithic era.

Apart from construction of small cisterns for maintaining the water quality by means of settlement of suspended particles, the Minoans of Knossos were using filters from loam or special structures filled with charcoal. Such filters were found in Aghios Mamas in Crete.

In the Minoan Crete the rainwater was collected and stored in special cisterns (hydrological constructions: aqueducts, water collection systems, rain water cleaning and storing constructions, deep wells, cisterns and fountain).

In Crete, due to the dry climate the water management included a wide system of rain water collection.

The hydrological know-how in ancient Greece

Rain water system in Saint Triad (A.N. Angelakis, with permission).

Rain water system in Knossos (A.N. Angelakis, with permission).

The hydrological know-how in ancient Greece

The engineers of the Minoan Crete knew very well the principle of the "communicating vessels" and they were applying this principle during the construction of the water distribution and transfer networks.

In Knossos, the water was transferred by means of underground tunnel during the Roman times, with a length of 1150m.

Such tunnels were found in Malia having a length of 1900m and being used for water transfer, also in ancient Tylisos an underground tunnel with a length of 1400m.

The technological knowledge for the water transfer by means of tunnels was also applied in other parts of Greece as well. This knowledge allowed also the construction of small dams, canals, pipe ducts, and cisterns in the Aegean islands during the Cycladic period (3100-1600 BC). Similarly technologies are also applied in the continental Greece during the Mycenaean period (1600-1100 BC).

The Mycenaean Civilization

Persea Dam Mycenean

Cistern in the Acropolis of Mycenean (A.N. Angelakis, with permission).

The hydrological know-how in ancient Greece

An important hydraulic structure of this period was the construction of the underground cistern in the Acropolis of Mycenae, which supplied the networks with water through a huge rock. This was indeed a miraculous structure before 33 centuries, which could be compared with modern systems of water supply of cities.

The Athenians also constructed a cistern within a rock of Acropolis for water storage.

In Athens the archaeologists found a pelagic aqueduct, which was constructed most probably before the appearance of Theseus. The aqueduct was made of closed cyclic ducts, and it was extending along a large distance from Kesariani to the side of Philopapou hill.

Another old aqueduct of Athens was that of Theseus which was constructed in 3090 BC and transferred the water up to the western side of the mount Pendelis.

The hydrological know-how in ancient Greece

During the Mycenaean period dams were constructed with a height of 2-5 meters and 250m to 5000m of length. The volume of water that could be stored was about 2-250 million m^3. This water was used for the irrigation of agriculture crops.

After 700 BC the evolution of commerce created favorable conditions which led to the rapid development of Athens, and consequently the hydraulic works started expanding. Thus deep wells, cisterns, fountains and canals were constructed and public networks for water distribution were made including deep wells, water sources, and many private structures leading to optimum water management.

The hydrological know-how in ancient Greece

During the Archaic period (750-480 BC) and the classical period (480-333 BC) in inland Greece hydraulic structures similar to those of the Minoan period, such as the Pissistratio aqueduct in Athens (510 BC), which had a length of 2800 m, of which 270 m were within a dome.

Also, within the city of Athens many hydraulic structures were constructed such as fountains, water transfer networks, wastewater drain networks, fountains, aqueducts.
Laws were passed by the tyrant Solon for the effective management of water resources.

Pissistratio aqueduct, Athens, (510 BC) (N. Mamasis, with permission).

Parnithas aqueduct in Athens

Andrianion aqueduct in Athens

Andrianion aqueduct in Athens

The hydrological know-how in ancient Greece

Some basic principles which were applied by the ancient Greeks in relation to constructing the hydraulic structures were:

1.The economy in regard to the use of the material destined for construction

2.The means used for accomplishing the aim set forth. Their main scope was to exploit the rain water as effectively as possible.

3.The methods used were friendly to the environment.

4.The structures made, must be enforced so as to resist the effect of time and to last as many years as possible.

5.The construction of the structures ought to be friendly towards the environment and to be long lasting, contrary to the modern hydraulic structures which last only 50 years.

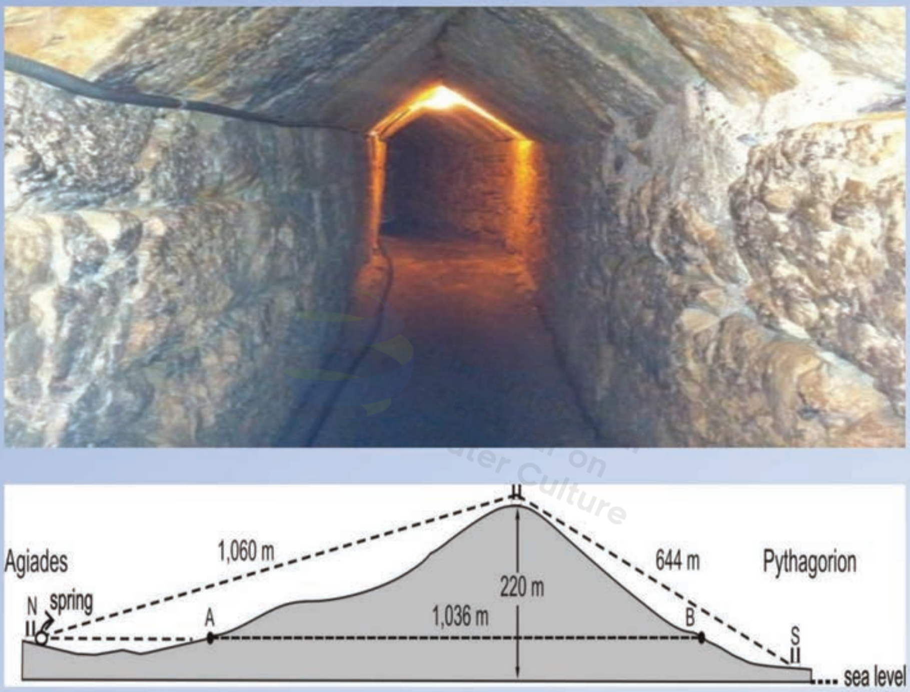
The hydrological know-how in ancient Greece

During this period the well-known Eufpallian was constructed in the island of Samos. In fact this was the first deep tunnel ever made in history. It construction started from the two ends (edges) of a hill and the tunnels made, were joint with mathematical accuracy. This connection was made at the center of the hill. The technology used was based on the Euclidian geometry.

At the Hellenistic period i.e. from 323 to 146 BC, as well as in the Roman period, the famous open ducts were constructed which transferred the water to large distances.

A general rule which was applied at this period for the water transfer was that the ducts must have a slope of oil -2% so that the water to be moving and transferred by means of the effect of gravity.

Also the technology of siphons was used to transfer the water upward, i.e. to higher heights via closed pipes.



Eupalinos tunnel in Samos Island (Voudouris, 2012).

The hydrological know-how in ancient Greece

Characteristic aqueduct is that of Nikopolis, which had a length of 50 km. It was made to cover the water needs of this town by transferring the water to Nikopolis from the water sources of St. George in 30 BC, located 50 km away from Nikopolis.

The aqueduct was a complex structure of 50 km including an aerial system for water transfer in order to overcome a canyon of Louros and continued by a tunnel through hill, and the aqueduct continued up to the village Archangelos crossing the village Samsuda and Kanali of Preveza and finally transferring the water to Nikopolis.

The hydrological know-how in ancient Greece

Another long aqueduct was constructed during this period in the island of Lesvos (Mytilini) in having a length of 22 km.

Similarly, significant hydraulic structure of this period is the "Andrianion Aqueduct" of 500 m3 capacity and length of 25 km. This aqueduct is underground throughout it length. It transfers the water from the mountain of Parnitha.

The Andrianion Tunnel

The hydrological know-how in ancient Greece

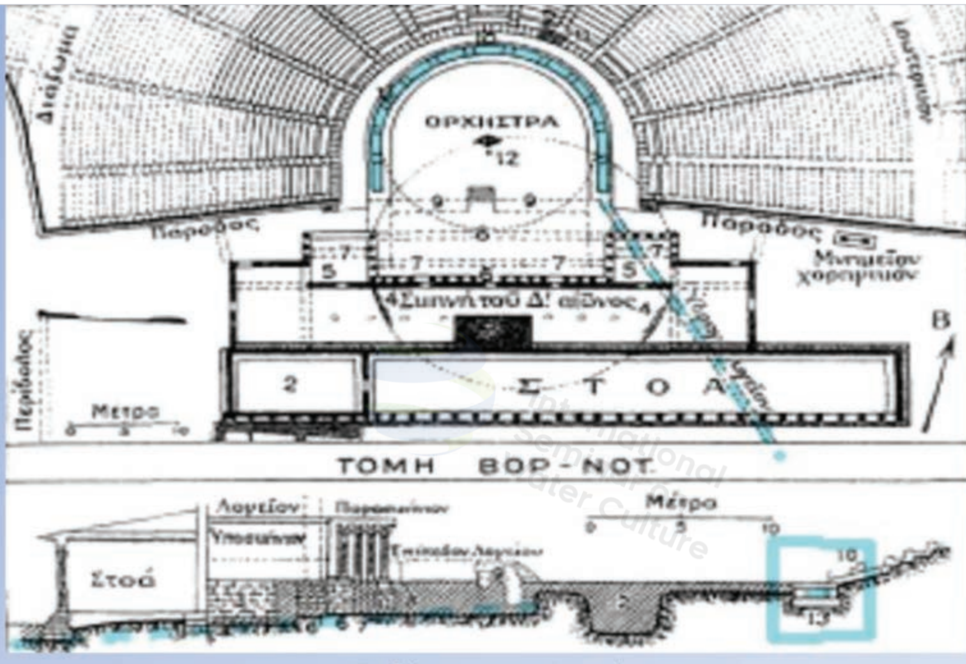
An important aqueduct was also constructed in the town of Philippi of Kavala with 8 km length. It was made with clay flagstones. The wails and the bottom were covered by lime stones mortar, which was also covered by hydraulic stucco. The dimensions of the tunnel were 0.96m width and 1.35m height. The cross section of the duct was square.



Ancient Makyneia, Aitoloakarnanias, photo of the stone drain system (Kollyropoulos et al., 2017)




Dionysus theater; details of drainage channel (images by K. Kollyropoulos): (a) view next to orchestra; (b) view of channel exit under stage of
theater; (c) view of downwards flow of channel
(Kollyropoulos et al., 2015)



Το θέατρο του Διονύσου.
Με μπλε γραμμή παρουσιάζεται το αποχετευτικό.
Με διακεκομμένη μπλε φαίνεται το σκεπασμένο τμήμα του δικτύου
(Kollyropoulos et al., 2014).

Drain systems during the Roman Period

In the Roman Period the drain discharge systems were further improved. The houses had perpendicular drains incorporated into the walls, via which the wastewater was transferred into the central drain system which was underground and led the wastewater into the sea.

The rain water during the Roman time was collected along with the surplus of the water of fountains, and was used for the irrigation of urban gardens or it was removed via the drain system, while at the same time it cleaned the drain ducts, thus protecting human health from diseases.

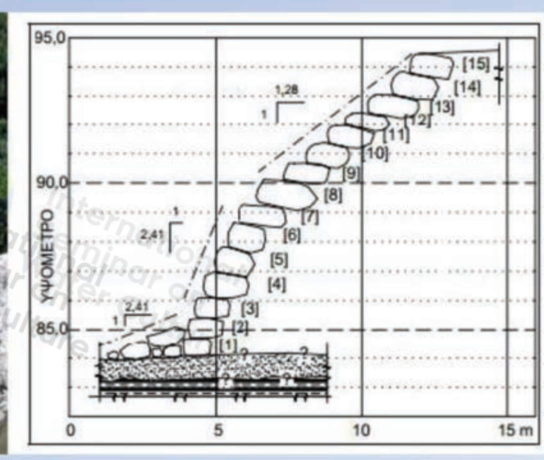
In Patras during the Roman time the domestic wastewaters were crossing underground central roads via built ducts or clay pipes, discharging the wastewater into the sea. Even today there are sections of the drain network, which are still in function. Also, at the same time, public toilets were constructed to serve peoples' needs.

Patras Roman aqueduct

Ancient Pleurona, Aitoloakarnania : The Great Cistern (Diamanti and Kalavrouziotis, 2013)

Water reservoir in Makyneia, Aitoloakarnanias, (Kollyropoulos e al., 2017)

Ancient Dam Alezis, Aitoloakarnanias.



Toilets and drain systems

The public toilets were constructed in such a way so as to have four or more seats (places) as shown in the toilet of Amorgos. There was a ditch for the removal of the wastewaters, which was connected to the main canal being constructed parallel to the South wall of the toilet.

Public toilets have been found in many places such as, in the island of Delos, in Athens, in roman markets (Agora), in the drain of Attalos, in island of Kos, in Philippoi and in Epidaurus.

Other characteristic structures were the drain systems of theaters.

The theater of Dionysos, which had a drain system where the rain water was being collected, coming from the seat rows, and from orchestra, and was discharged into southeast side of the Acropolis rocks, ending finally into the Illysos River. It was constructed of limestone, transferring the rain water to the coast of Patras where it was been discharged. Characteristic structure was also the theater of Orchomenos in Arkadia since the 4th Century B.C.

Hellenistic Period

During this period great progress took place in relation to the knowledge of technology, to the technical possibility for the construction of hydraulic structures, and the improvement of hygienic bathrooms and toilets.
A characteristic example of theater was that of the island of Delos which was constructed in 314 BC.

It has a perimetric drain ditch, stone made, which collected the rain water.

Generally the ancient theaters of Greece were constructed in such a way so as to include a drain system for the collection of rain water and its effective management.

The ancient theater of Delos with the part of sewage (Kollyropoulos et al., 2014).

Ancient Greek and present world water technology

Based on the above mentioned, an important question may arise regarding the relation between the ancient Greek and the present world water technology.
Is it worth to study the ancient water technology?

The comparison of the ancient Greek civilization hydraulic technology with the contemporary world technological achievements provides an excellent example of motivation for environmental and conservation issues of our present time.

A number of Greek ancient technological developments are still in use. Similarly, such developments accomplished in other regions of the world are still in practice in Africa, India, Iran, Jordan etc.

Ancient Greek and present world water technology

Considering the ingenuity of the Greek Technology related to the solution of hydraulic problems, Greeks apart from the cisterns,clay pipes, drainage systems open and underground, fountains, aqueducts toilet and sanitary systems, rain harvesting and similar developments, along with other civilizations of the ancient world, they especially invented many hydraulic devices, making easier the handling of the water and of the fluids.

Ancient Greek and present world water technology

The hydraulic devices the ancient Greek ingenuity has produced some important devices for water lifting (pumps) being used in some countries until the present time. Some examples of representative hydraulic devices are given below

a- The Kilonion (Shantur): An ancient system for water pumping (invented by in Mesopotamia and reproduced by the Greeks).

b- The hydraulic endless screw of Archimedes: A mechanism for pumping water with small difference in height, still used today for transposting fluids and granular material.

c- The hydraulic wheel of perahora: A machine used in the 3rd century for pumping water, discovered in the Village of perahora , Korinthow, Greece. (Its considered the most ancient water pumping device).

d- The subdivided wheel of Philon: A water pumping machine (device) of slmall difference in height.

Ancient Greek and present world water technology

e- The sub-divided wheel of Philon (variation of Polykadia)

f- The chain pump of Philon A popular machine for water pumping of large differences in height used until recently.

g- The piston force pump of Ktersibios: A force piston pump used for fluids, invented by Ktesibios in the 3rd century and its use till the present time extensive innovated in various ways.

h- The fire pump of Heron: A twin suction fotce piston pump for continuou water flow that was used in firefighting and continued to be used till recently identically.

g- The hydraulic bellow: An ingenious machine for water pumping.

Ancient Greek and present world water technology

As it has been pointed out, the ancient technological developments have been considered as the underpinning of modern achievements.
Yet, this high technology had been for a long time forgotten, subjected to maturation, and it was only during the last two centuries that the contemporary technology revived it.

The western Technology however revived the Greek technology extending from robot servant of Philon to the cinema of Heron, and from the automatic clock of Ktesibios to the analog computer of Antikythera. This relation shows undouptedly the real influence of the ancient water technology on the modern one.

Figure 13:Artificial lake Kremasta (G. Fatouros with permission)

Artificial lake Kastraki (G. Fatouros with permission)

Artificial lake of Stratos (G. Fatouros with permission)

Conclusion

The study of the ancient water technology is of outmost importance because the inventions and innovations of the ancient Greeks as well as of other ancient civilizations contistitute the underpinning of the modern technological achievements.


Thank you for your attention!

Water Quality: From Ancient to Modern Times and the Future

A. N. Angelakis, Joint IWA/IWHA SG on Water history

2nd International Seminar on Water Culture, Beijing, China, 01/12/2022

Prolegomena

The history of water is equivalent to the history of the world and the history of water quality is equivalent to the history of life.

Andreas N. Angelakis

It will review and consider the history of water treatment and quality and the life expectancy in parallel courses

It is focusing on emerging trends and the current and future issues and challenges.

Finally it is ended with conclusive remarks highlights, and the used major bibliographic sources.

Prehistoric time, i.e. Minoan Era (ca 3200-1100 BC)

An astonishing paradox about this civilization is:
A great power without a military aristocracy; a "palace" that was not a royal residence and neither the king was glorified; a religion with no greatness, while women were equal to men and free (Muge and Loucanicas, 2013).

In addition this period of ascendancy was called the *Pax Minoica* or "*Minoan peace*"; time when cities needed no walls by Arthur Evans (1921-1935).

Phaistos without walls

Theocracy

The Minoans were pantocrators in the Eastern Mediterranean but also very peaceful people. The Minoans were considered Thalassócrates (i. e. people that are dominant to the sea). Also Krasilnikoff and Angelakis (2019) state that the Minoans dominated the Mediterranean, particularly the Eastern Mediterranean for nearly two millennia, living in harmony with the environment.

The oldest Minoan shipwreck which was reconstructed

Possible reasons for the conical shape:

(a) The construction of the pipes was easier with conical than cylindrical ones.
(b) The conical shape serves better the connection.
(c) The pressure could be easier controled on rough terrain.
(d) The design of the network was easier in the case of curved walkways. And
(e) The pricipitation and deposition of sediments on the walls of the pipes, particularly in the case of water with high pH, could be avoided

Constructed identical cylindrical pipes.

Fountains and others

View of the Minoan Tykte fountain in the "palace" of Zakros

View of the Tykte fountain in Caravansary of the "palace" of Knossos

Minoan Water treatment systems

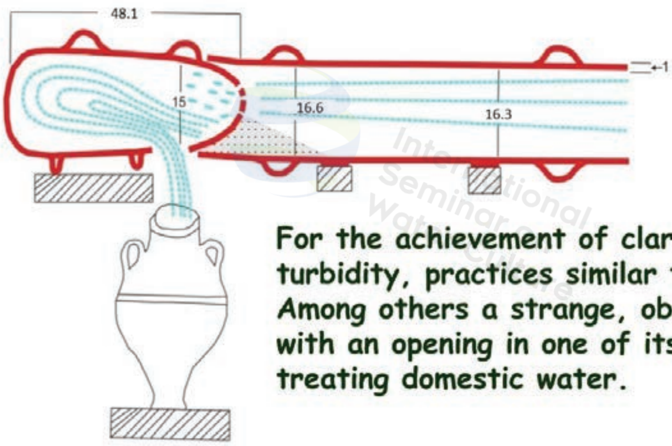
Cistern with sand filter in the "palace" of Phaistos

Clay made devices possibly used for treatment of potable water

Sedimentation tank in the aqueduct of Tylisos

A sedimentation tank allows suspended particles to settle out of water as it flows slowly through the tank, thereby providing some degree of purification.

Minoan water ceramic filter (units are in cm) (Angelakis *et al.*, 2020).



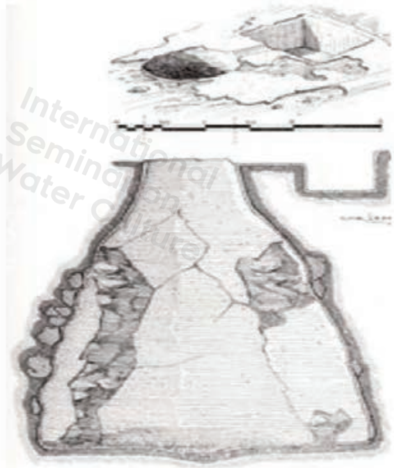
For the achievement of clarity and/or avoiding turbidity, practices similar to today were used. Among others a strange, oblong ceramic device with an opening in one of its ends was used for treating domestic water.

Historical time, i.e. Archaic, Classical and Hellenistic periods (ca 750-31 BC)

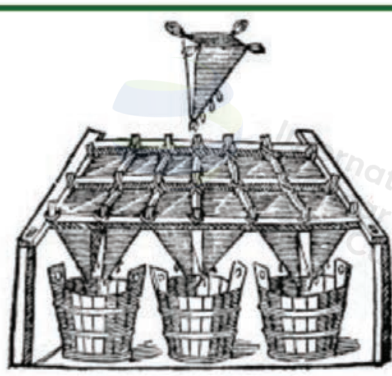
During the Archaic period, Pythagoras (ca 570-495 BC), philosopher and Alcmaeon of Croton (in ancient Greek: Αλκμαίων του Κρότονα), probably a student of Pythagoras, the first physician and physiologist in the pre-Hippocratic medicine, were the first to consider the possibility that water quality may affect human health (Aëtius, at Opinion of the philosophers V. 30.1) (Angelakis *et al.*, 2020b).

Hippocrates is one of the most outstanding figures in the history of medicine.

During the Classical period Olynthus bottle-shaped cistern with a small tank for pretreatment, including the capture of debris and sediment: (a) plan and (b) cross section (Klingborg and Finné, 2018).



Hippocrates (ca 460-370 BC) invented and used the first water filtering system, in the form of a cloth bag, in about 400 BC, known today as the Hippocrates' Sleeve.



Hippocrates began to conduct his own experiments in water purification with Hippocrates' Sleeve (Mays, 2013). Also more than 400 Asclepieia (i.e., Ancient Hospitals) were operated.

Cistern and ceramic water filters in the Asclepieion in the Hellenistic city of Emporiae, which is located in the northwestern coastal area of Catalonia, Spain (Angelakis *et al.*, 2020b).

Roman period (ca 31 BC-476 AD)

- Roman times improved the hydro-technologies of the Classical and Hellenistic periods, mainly by increasing their scale.
- Aqueducts were usually the most common technology of water supply in Roman period mainly in cities.
- Moreover, other technologies such as springs, percolation wells, dams, and weirs on streams were also developed in that time.

Roman times model (reconstruction) of the settling tanks (piscina limaria) on the aqueduct Virgo at the Pincian Hill in Rome, which is located in the Roman Civilization Museum in Rome (Angelakis *et al.*, 2020a).

Medieval Times (ca 476-1400 AD)

Little progress was made in water treatment and sanitation and their connection to public health field. During this time, also known as the Dark Ages, technological development, especially that related to water quality, was minimal due to the lack of scientific innovations and experiences (Enzler, 1998). Water supply was extracted from rivers or wells, which became highly polluted due to the discharges of wastes and others. To face that problem, people started to bring water from unpolluted rivers located outside the cities.

Venetian times (ca 1204-1668 AD). At that time various hydro-structures were constructed. Also the Venetians increased the size of structures and their quality (photos by A. N. Angelakis).

Cistern (of rectangular cross section) in the Palaiokastron in eastern Iraklion used mainly for water supply

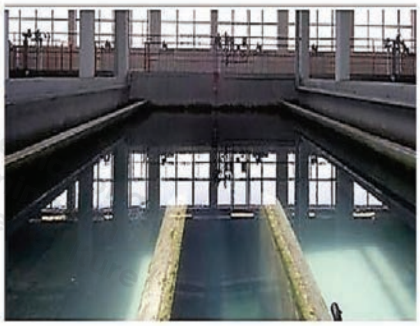
Central cistern of two linked chambers in the Arsenal Nuovi (close to the Venetian port) in Iraklion city

Ottoman times Times (ca 1400-1900 AD)

This period is more or less a continuation of Medieval Times. At this time very little progress was made in water treatment and sanitation and their connection to public health field. During that time, known as well as the Dark Ages, technological development, especially that related to water quality, was minimal due to the lack of scientific innovations and experiences (Enzler, 1998).

Greek WTPs

In Galatsi of Athens in 1931 (Photo G. Stefanakou, EYDAP, Athens)



Thessaloniki Water Treatment Facility (Refinery) after the 2o WW (Photo from www.eyath.gr)

Describing the current situation based on a report of WHO (2022),

(a) 2.1 billion people globally do not have access to clean and safe drinking water.

(b) 3.4 million people die each year due to contaminated and scarce water sources.

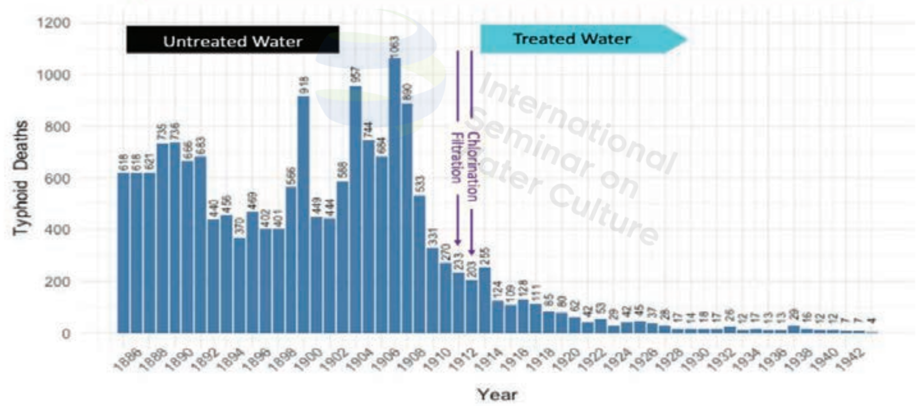
(c) Millions of women and children spend 3-6 h each day in order to collect water from distant polluted sources. And

(d) Half of the world's hospital beds are constantly occupied by patients who suffer from diseases associated with the lack of access to clean water.

Water quality highly affects life expectancy

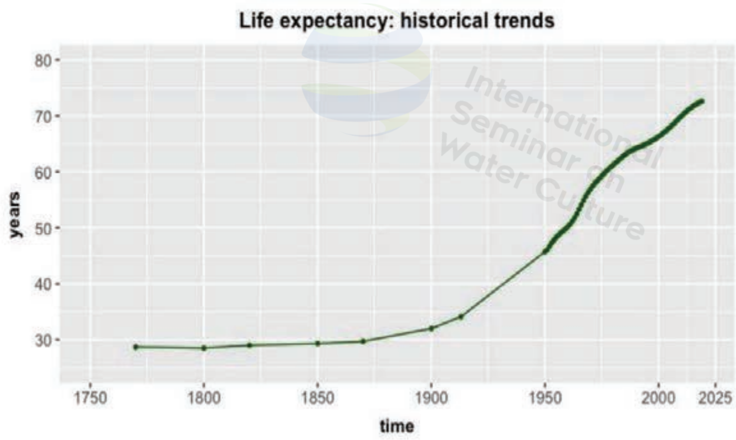
- During the early contemporary times, historical data showed that life expectancy was shortened due to several infectious diseases, such as pneumonia, tuberculosis, meningitis, etc.
- Historical data shown a significant increase of the expectancy life in the developed world since the beginning of the last century (Office for National Statistics, 2015).

It is due that the number of typhoid deaths in Philadelphia were drastically reduced following the city-wide water filtration (1912) and chlorination (1913) system.



Data from the Philadelphia Water Department (Kramek and Loh, 2007).

Historical trends of life expectancy for the entire world (Angelakis *et al.*, 2021).



In the last century Water quality was highly affecting life expectancy in Greece

- In Greece, life expectancy in 1920—25 was 45 years, mainly due to the low quality of available water supply. However, in most developed countries of the world, the quality of drinking water improved significantly after the 1st World War. In Greece, the life expectancy reached 83 years in 2021. However, there has been a small decrease in the last years due to the pandemic of COVID-19 (Angelakis *et al.*, 2022).
- In Greece and other countries, a dramatic increase in life expectancy mainly after the 2nd World War is probably due to the improvement of potable water quality and hygiene conditions.

The Future of Water Treatment Technology

The future water purification technologies are surely expected to increase maninly in solar technology, water desalination, high-tech filtration and nanotechnology.

(a) Solar Technology. Using sunlight to generate clean water goes back well over two thousand years. Recently, scientists discovered that black carbon-dipped paper with sunlight, can expedite the water purifying process.

(b) Nanotechnology. The use of nanotech biosensors in water sanitation is a new process and it works by detecting pesticides and heavy metals in water.

(c) Desalination. Recent discovery by scientists and UK engineers is the use of ultrasound waves to desalinate and to purify ocean water.

(d) High-tech filtration. Different filters are developing (e.g. technology that converts cow manure into filtered water).

Example

Non-reverse osmosis (RO) alternatives are now a hot topic across the USA and some states are leading the charge on alternative treatment approaches for DPR. An alternative approach now days developing in USA is Carbon-Based Advanced Treatment (CBAT) approach, essentially consisting of ozone, biological activated carbon (BAC) for filtration, and then granulated activated carbon (GAC),

Conclusions

- The "Water Resources Engineering" in the ancient Greece practiced hydraulics, sustainability, and hygiene, since the Minoan time.
- The basic principles and rules of Minoan hydraulic works were improved in Historic times and especially during the Classical and Hellenistic period.
- Water quality is highly influenced the life expectancy. In Greece life expectancy increased from about 30 years in Minoan times to about 35 in Classical and Hellenistic times to 45 years in 1930 and about doubled in the last years. This mainly is due to highly improved water quality in the developed world after the 1st WW.
- It should be revisited and recognized the chronological evolution of hydro-technologies as an essential guarantee against water quality and life preservation through the ages.
- In the last years there is significant extent and planning of water reuse in developed countries, e.g.in Los Angeles and Hampton Roads region of Virginia, USA are planning to recycle 100 % of its water supplies
- Also new hydro-technologies for updating the current water and wastewater treatment practices should be considered.
- Measures focus on identifying the sources of vulnerability to implement mitigation and adaptation actions to the droughts.
- Must think of water and wastewater differently (i.e. as a source) and the profession must speak with a unified vocabulary.

TAKE HOME MESSAGES

1. Further improvement water quality mainly filtration and disinfection is required.
2. In the future urbanized world DPR will be highly practiced,

Finally many thanks are due to
China Institute of Water Resources and Hydropower Research (IWHR)

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中國水利學會水利史與水利遺產專委會
2022學術年會暨成立四十周年學術研討會
雜談水利法規的歷史演變與不變
簡報人：李方中 博士
2022年12月1日
臺灣大學 水工試驗所


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■ 中國歷史上的國際水法

- 春秋時期（公元前 651 年），葵丘之會
- 《孟子·告子下》：“五霸，桓公為盛。葵丘之會，諸侯...五命曰：‘無曲防’...曰：‘凡我同盟之人，既盟之後，言歸于好’”
- 朱熹《四書集注》：“無曲防，不得曲為隄防，壅泉激水，以專小利，病鄰國也。”

■ 《防洪法》

- 第十一条　编制防洪规划，应当遵循确保重点、兼顾一般，以及防汛和抗旱相结合、工程措施和非工程措施相结合的原则，充分考虑洪涝规律和上下游、左右岸的关系以及国民经济对防洪的要求，并与国土规划和土地利用总体规划相协调。

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■ 現代國際水協定

- 中俄間、中哈間《关于合理利用和保护跨界水的协定》，強調聯繫及合作(上下游、左右岸的关系)

■ 國際水法的內國化

- 歐盟《水框架指令》基本原則：

“(21)欧共体及其成员国是各种国际协议的缔约方…”

“(23)需要制定共同原则以便协调各成员国在水量与水质方面保护和改善欧共体境内的水体，促进水的可持续利用，控制跨界水问题，…”

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■ 《水利法》(1942)

- 第六十條　主管機關得於水道防護範圍內，執行警察職權。防汛期間，主管機關於必要時，得商調防區內之軍警協同防護。
- 第六十一條　防汛緊急時，主管機關為緊急處置，得就地徵用關於搶護必需之物料、人工，並得拆毀妨礙水流之障礙物。

　　前項徵用之物料、人工、及拆毀之物，主管機關應於事後酌給相當之補償。

■ 《防洪法》(1998)

- 第四十二条(II)　在紧急防汛期，国家防汛指挥机构或者其授权的流域、省、自治区、直辖市防汛指挥机构有权对壅水、阻水严重的桥梁、引道、码头和其他跨河工程设施作出紧急处置。
- 第四十三条(II)　中国人民解放军、中国人民武装警察部队和民兵应当执行国家赋予的抗洪抢险任务。

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■ 《防洪法》(1998)

- 第四十五条　在紧急防汛期，防汛指挥机构根据防汛抗洪的需要，有权在其管辖范围内调用物资、设备、交通运输工具和人力，决定采取取土占地、砍伐林木、清除阻水障碍物和其他必要的紧急措施；必要时，公安、交通等有关部门按照防汛指挥机构的决定，依法实施陆地和水面交通管制。

　依照前款规定调用的物资、设备、交通运输工具等，在汛期结束后应当及时归还；造成损坏或者无法归还的，按照国务院有关规定给予适当补偿或者作其他处理。取土占地、砍伐林木的，在汛期结束后依法向有关部门补办手续；有关地方人民政府对取土后的土地组织复垦，对砍伐的林木组织补种。

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■ 《河川法》(1896)

- 第二十三條(I)　洪水危急時，地方行政官廳或受委任之官吏，為當場防禦之必要，得使用土地，使用或徵收土砂、竹木、其他材料、車馬、及其他搬運器具及器具，並可動員現場人員，即拆除有關房屋或其他障礙物。

■ 《河川法》(1964)

- 第二十二條(I)　洪水及高潮位緊急情況下，必需採取防災及減災緊急措施時，河川管理者得在現場徵用必要之土地，土石、樹木及其他必要物資，亦得徵用車輛等運輸工具或器具，以及處置建築物及其他障礙物。
- (II)河川管理者在採取第1項規定之緊急措施時，亦得徵召居住於附近的住民或現場人員投入搶險工作。
- (III)河川管理者根據第1項的規定徵用、使用或處置措施，而致所有者受損時，必須對受損者之損失給予賠償。

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■ 《防洪法》(1896)

- 第十一条(II)　防洪规划应当确定防护对象、治理目标和任务、防洪措施和实施方案，划定洪泛区、蓄滞洪区和防洪保护区的范围，规定蓄滞洪区的使用原则。

■ 《水利法》(2018)

- 第 七 章之一 逕流分擔與出流管制

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■ **用水次序**

- 唐代《水部式》殘卷即有用水次序的規定
- 《明史·職官志》：“碾硙者不得與灌田者爭利，灌田者不得與轉漕爭利。”明白規定著漕運→灌溉→碾硙的用水次序

■ **水資源開發的權利概念與用水爭議**

- 清代，康熙帝取台灣後，陸續開墾台灣，是當時中國少有的新領域(新疆)，有大量、持續的土地開發及水資源開發行為
- 清政府對水資源開發的態度，認為是民事行為，官府協助。
- 清代水爭議判決，水量不足時採等比例分配。

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- 周鍾瑄
- 貴州貴筑人
- 1719年任臺灣府諸羅縣(今嘉義)知縣
- 1722年轉任臺灣縣(今台南)知縣
- 嘉義城隍廟奉祀

圖像來源：嘉義市政府文化局

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《水利法》(1942)

- 第十五條(I) 用水標的之順序如左：

一 家用及公共給水。
二 農業用水。
三 工業用水。
四 水運。
五 其他用途。

- 沿用用水次序的概念，但

1.反轉次序：灌溉→水碓(水力)→水運
2.在灌溉之前增加家用及公共給水標的
3.缺水優先權採登記優先，非等比例分配

- 1963年在台灣改採順序優先權
- 第十四條 團體公司或人民，因每一標的取得水權，其用水量，應以其事業所必需者為限。

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《水法》(1988)

- 第十四条 开发利用水资源，应当首先满足城乡居民生活用水，统筹兼顾农业、工业用水和航运需要。
- 第三十二条 国家对直接從地下或者江河、湖泊取水的，实行取水许可制度。...

《水法》(2002)

- 第二十一条 开发、利用水资源，应当首先满足城乡居民生活用水，并兼顾农业、工业、生态环境用水以及航运等需要。
- 第七条 国家对水资源依法实行取水许可制度和有偿使用制度。...
- 由公司管理水庫

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■ 水權制度的重要性轉變

- 以色列的故事。早期水權制度，重視避免水源枯竭。2000年，大量開發海水淡化及農業大量使用再生水(85%)，滿足水安全，水資源制度重點往水廠管理傾斜，水權重要性降低。
- 台灣的實踐。2020年，台灣的農田水利會轉變為政府機關→超過90%的水權登記在政府或國營企業，《水利法》水權制度從量變到質變→計畫供水?

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- 成立至立法之間?

■ 《水利法》(1942)

- 第一條 水利行政之處理及水利事業之興辦，悉依本法行之。但地方習慣與本法不相牴觸者，得從其習慣。

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- 水資源部分的水法原則較會隨著社會經濟的變化而變化
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- 以色列水法(李方中譯)。
- 日本河川法(吳憲雄譯)。

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結語

- 戰後的機遇，經由石門水庫的興建，臺灣工程師直接地由經驗極豐富的美國工程師學習到了最先進及最安全的土石壩(堆填壩)技術，也保障了多強颱烈震的臺灣的壩工安全
- Mr. Clarence O. Duster對於水庫人才榮枯的看法
- 興建石門水庫時沒有學到的?

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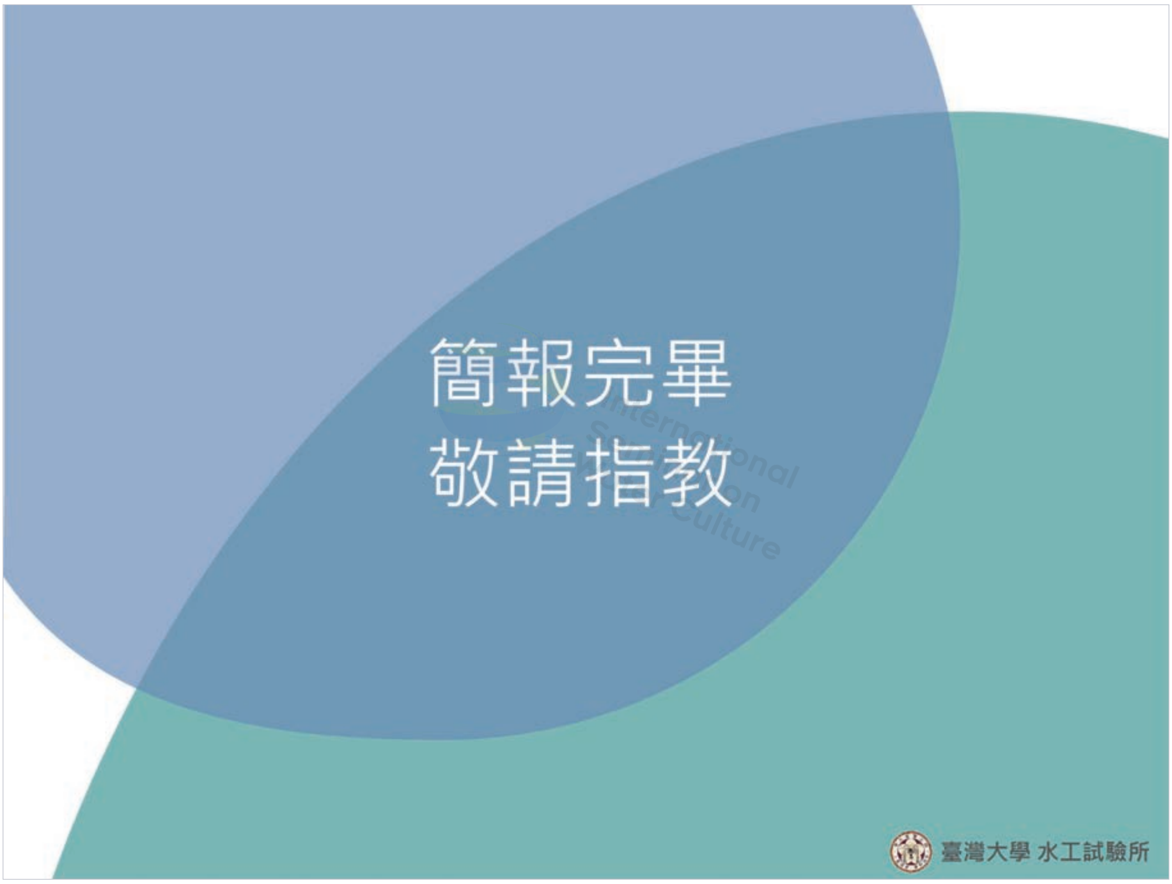
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