Water systems and urbanization in Africa and beyond
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Water control in the Greek cities

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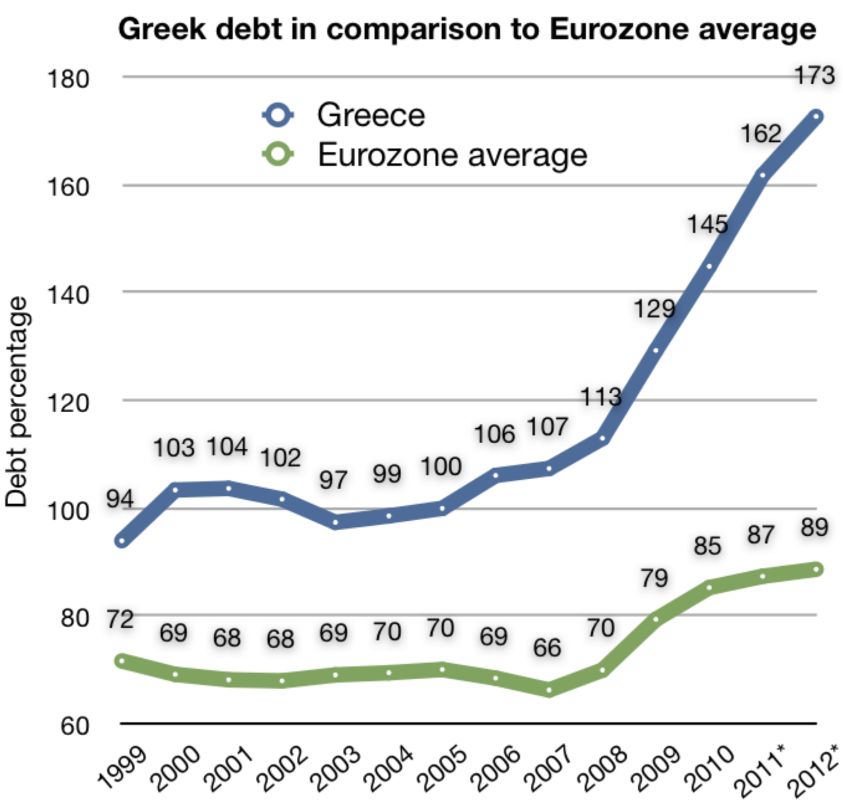
Presentation available online: itia.ntua.gr/1195/

Control in Greek cities? A joke?

Images from:
http://crisisphotostories.blogspot.com/2012/02/1202.html
http://www.dailymail.co.uk/news/article-2099230/Greece-Riot-police-flames-protesters-armed-petrol-bombs-rampage-Athens.html
http://www.international.to/index.php?option=com_content&view=article&id=5081
http://www.thenewstribune.com/2012/02/13/2024158/obstacles-remain-for-greek-bailout.html

What went wrong in Greece?



*estimate
Source: Eurostat

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The Big Fat Greek Gravy Train: A special investigation into the EU-funded culture of greed, tax evasion and scandalous waste

BBC Mobile

NEWS BUSINESS

What went wrong in Greece?

Greece went on a big, debt-funded spending spree, including paying for high-profile projects such as the 2004 Athens Olympics, which went well over its budget.

Sources:
http://www.bbc.co.uk/news/business-13798000
http://www.dailymail.co.uk/news/article-2007949/The-Big-Fat-Greek-Gravy.html
http://upload.wikimedia.org/wikipedia/commons/2/29/Greece_public_debt_1999-2010.svg

What went wrong in Greece in terms of water?

Hydrological Sciences Journal – Journal des Sciences Hydrologiques, **56**(4) 2011

Scale of water resources development and sustainability: small is beautiful, large is great

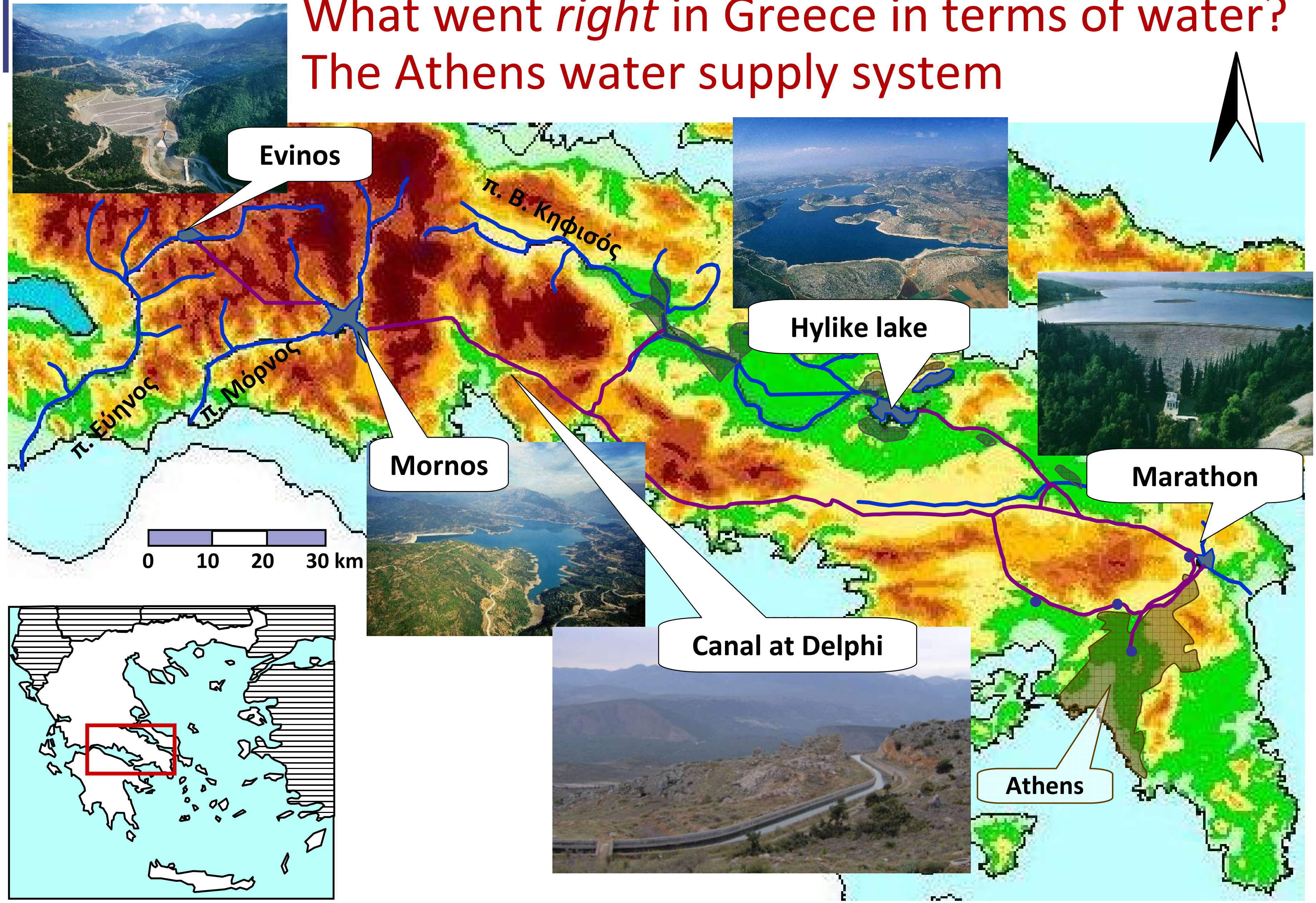
Demetris Koutsoyiannis

Table 4 Virtual water trade balance of Greece (hm³/year; Source: Roson & Sartori, 2010).

Trading country	Exports	Imports	Balance
Albania	83.4	4.7	+78.7
Croatia	16.7	3.0	+13.7
Cyprus	52.0	5.3	+46.7
Egypt	5.4	91.4	−86.0
France	45.0	541.9	−496.9
Italy	242.3	171.3	+71.0
Morocco	0.9	4.9	−4.0
Spain	36.1	121.6	−85.5
Tunisia	1.1	4.2	−3.1
Turkey	30.9	143.1	−112.2
Rest Europe	1662.3	890.5	+771.8
Rest MENA	49.5	42.7	+6.8
Rest World	165.3	2337.5	−2172.2
Total	2390.9	4362.0	−1971.1

Why has Greece's hydroelectric production been stagnant? The answer to this question should be sought in the mimetism—at the ideological rather than the pragmatic level—of Greek society and politics for European stereotypes, that did not enable water resources development in recent decades. This mimetism is very strong in the Greek "green" groups, which fanatically oppose water infrastructure projects. (Recently, private energy companies may have been added to the opponents of hydropower projects, whose operation pushes energy prices down during water-rich periods; www.energypress.gr/portal/resource/contentObject/id/bd4974a8-00b8-47ea-9472-eb64388ae09f.) The most impressive example, with the dimensions of a Greek tragedy, is the Mesochora project (170 MW, 340 GWh/year, investment 500 M€; shown in Fig. 12) in the Upper Acheloos River (Koutsoyiannis, 1996; Stefanakos, 2008). The dam and the hydropower plant have been constructed and have been, in effect, ready for use since 2001. However, they have not been put into operation, thus causing a loss of 25 M€/year to the national economy (assuming the lowest price of renewable energy, i.e. 73 €/MWh imposed by decree in Greece—see below).

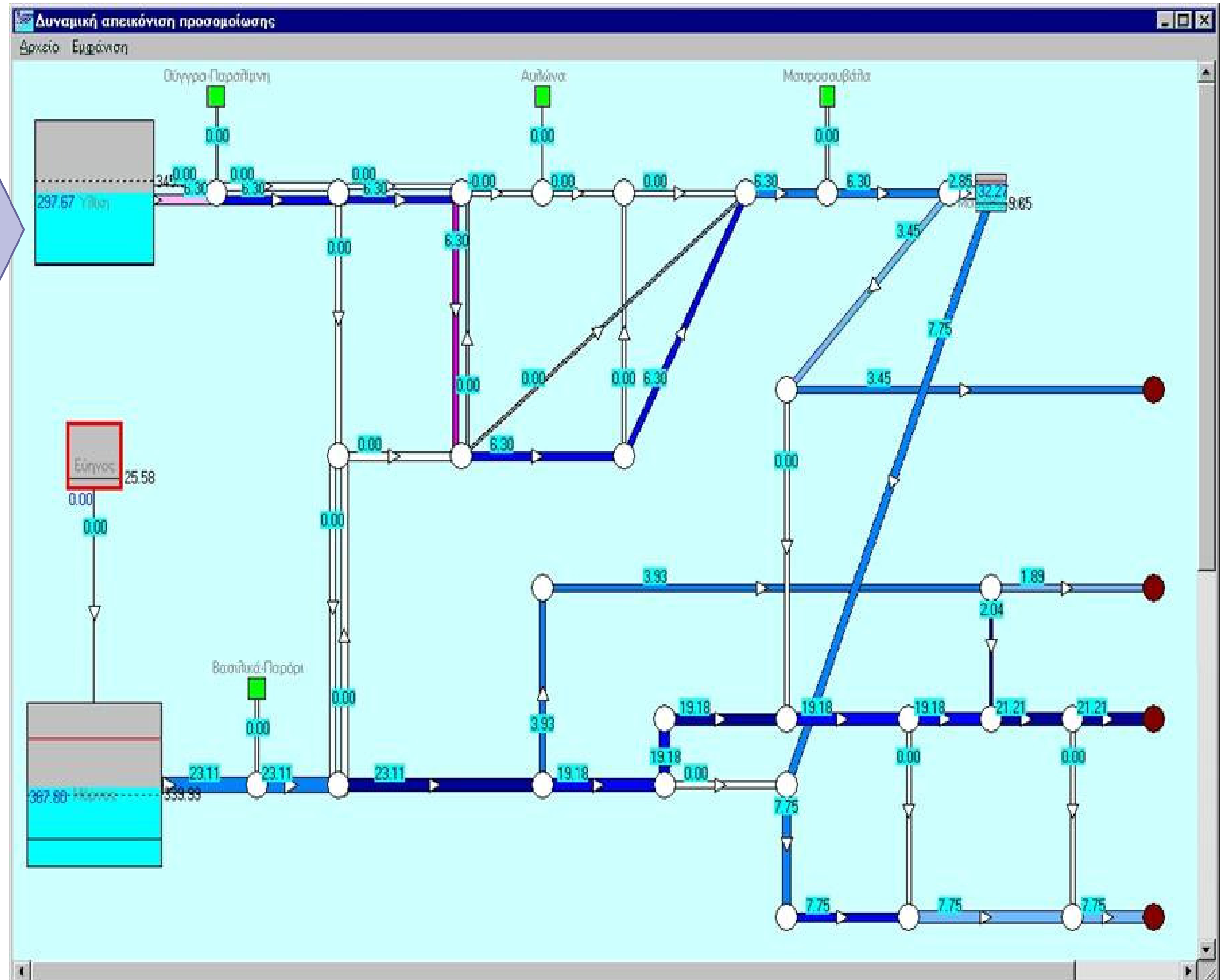
What went *right* in Greece in terms of water?
The Athens water supply system



A state-of-the-art decision support tool for the control of the Athens water supply system

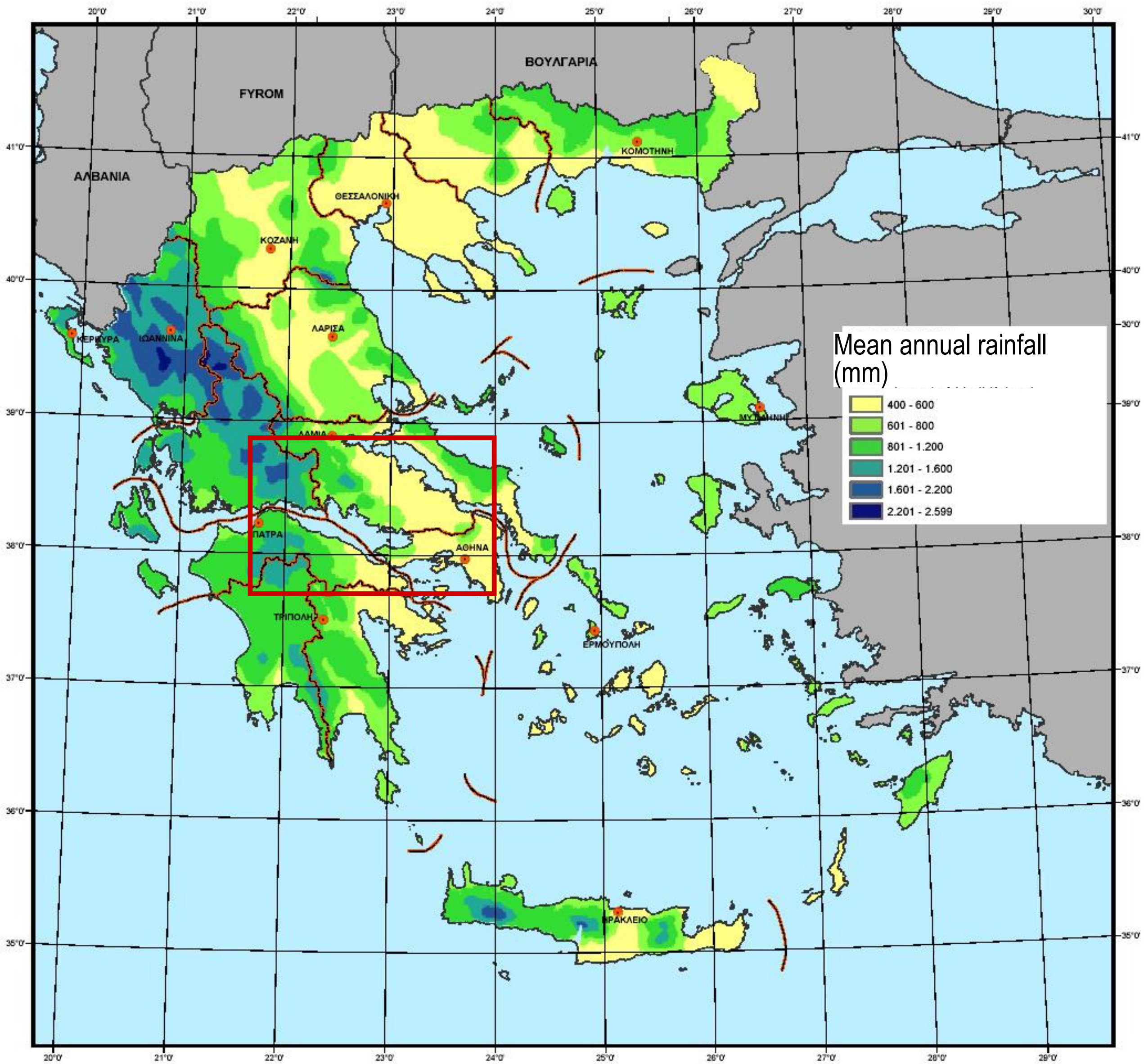
Hydronomeas: A decision support tool implementing a new methodology termed *parameterization-simulation-optimization*

See theoretical and practical justification of the approach in Koutsoyiannis and Economou (2003); Koutsoyiannis et al. (2002, 2003); and Efstratiadis et al. (2004)



Why the Athens water supply system is so big?

- **Population dynamics**: Current (2011) population of Greater Athens: 3 812 000 (35% of the Greek population)
- **Climate**: Annual rainfall in Athens: 400 mm (among the driest places of Greece) → insufficient water resources

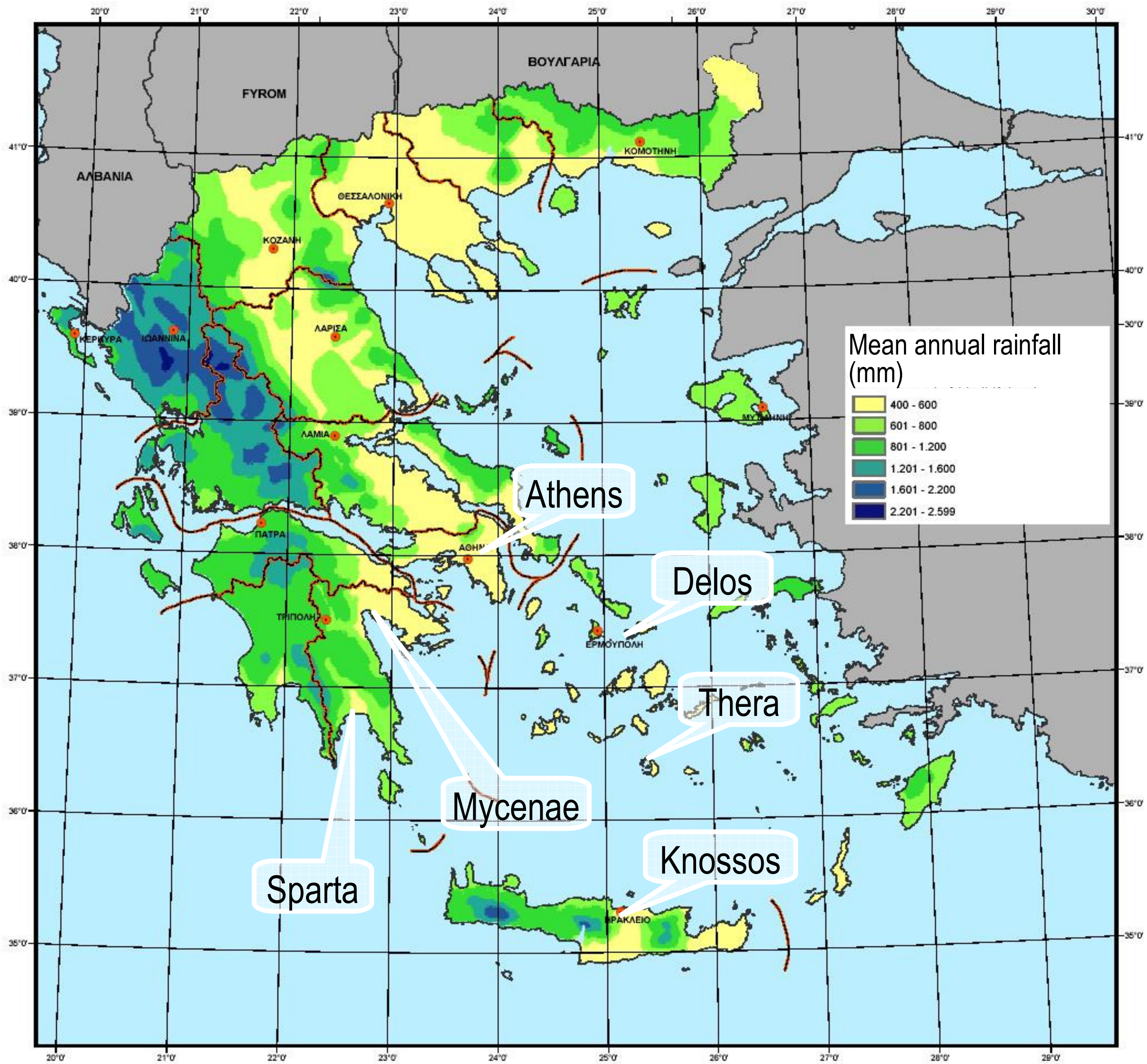


Back in time: Climate and the ancient Greek civilization

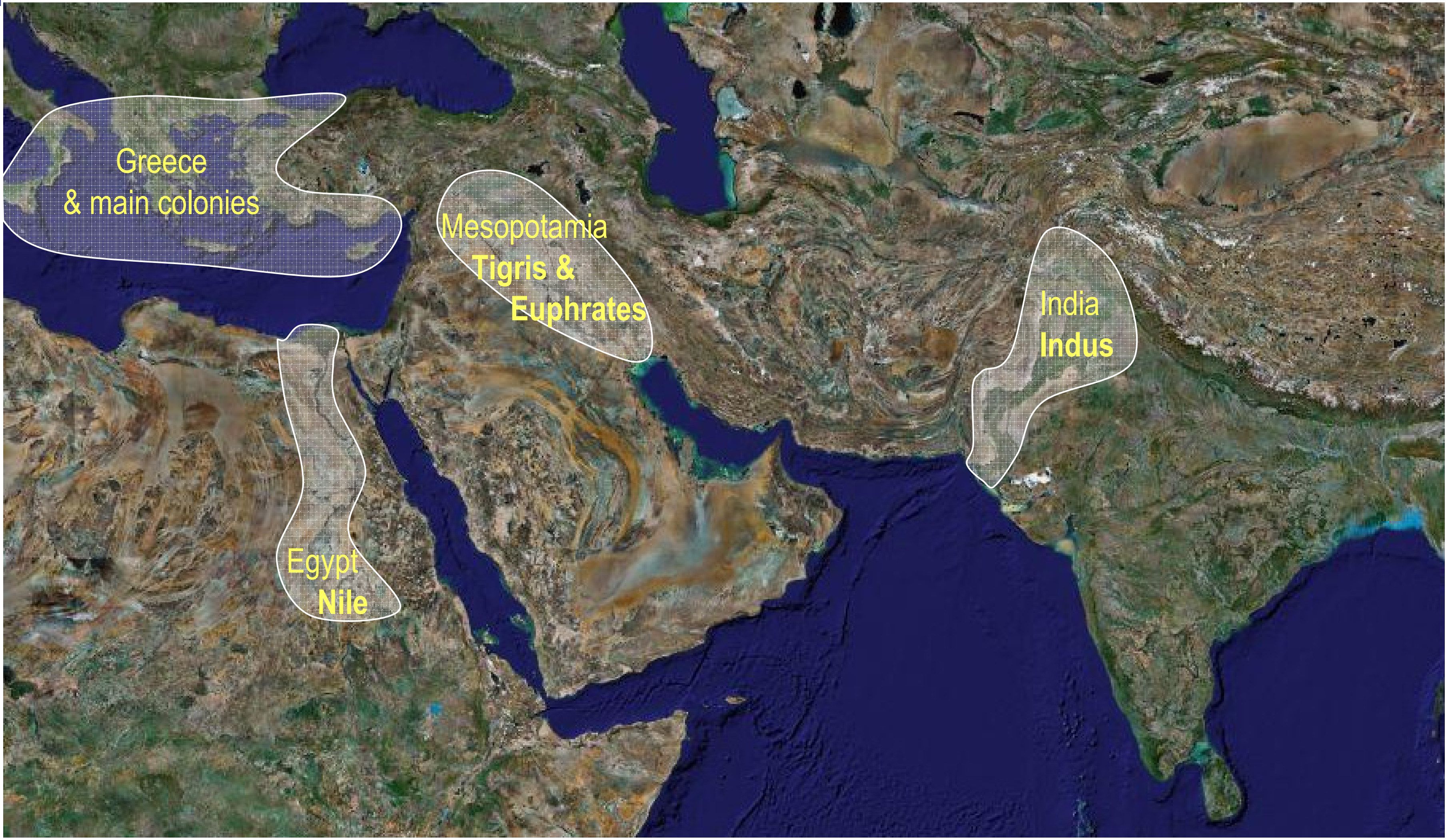
- Why ancient Greeks chose the driest places for their cities?

Or

- Why the settlements on driest places were the most flourishing?
  - (Life in dry climate is more convenient and healthier?)
- What are the consequences/impacts of water scarcity on cultural progress?
  - (Can scarcity trigger progress in technology and management?)

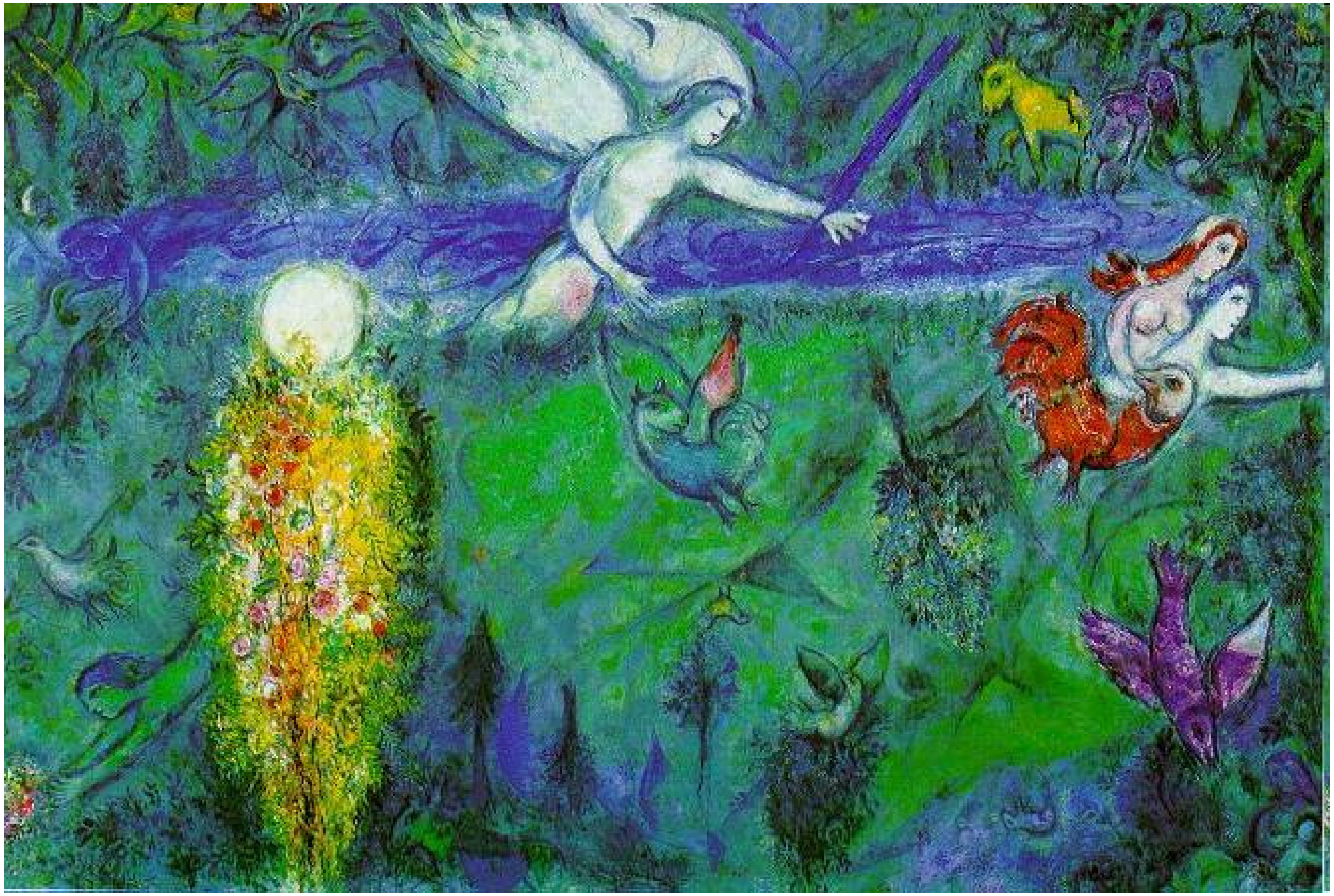


Ancient Greek civilization vs. preceding ones



- Most earlier civilizations bloomed in large river valleys (water abundance)
- Greece does not have large rivers (water scarcity)

Is abundance a paradise?



- In Paradise (Eden), Adam and Eve enjoyed abundance of everything – including **water**
- However, they were expelled from this nice place; this was a punishment because Eve could not resist to the goods of the **knowledge** tree

Adam and Eve expelled from Paradise - Marc Chagall, 1961, France
http://www.wikipaintings.org/en/marc-chagall/adam-and-eve-expelled-from-paradise-1961-6

An opposite view: The myth of the competition of Athena and Poseidon

- To choose their patron god, Athenians organized a competition for two candidates: Athena (goddess of wisdom) and Poseidon (god of waters)
- Poseidon offered **abundant** spring **water**
- Athena offered the olive tree and an explanation why it would be wiser to choose her gift
- Athenians opted for **wisdom**
- Scarcity may not be a punishment (as in the biblical story) – but a **choice**
- **Wisdom** may be more powerful than **abundance**

What is paradise?

- Abundance
  (no effort required)

Or

- Scarcity
  (triggering knowledge/wisdom and progress)

Stages of cultural and technological progress in Greece

- Technology based on empirical knowledge
- Social organization and institutions
- Philosophy and science
- Technology based on scientific knowledge

Technology based on empirical knowledge: some examples

Main periods of Greek antiquity

- **Minoan**: Island of Crete, *ca.* 3500 - 1450 BC (mostly known from large houses and luxurious palaces, e.g. Knossos, Zakros, Mallia, Gortys, Phaestos)
- **Cycladic**: Islands of the Aegean, *ca.* 3100 - 1600 BC
- **Mycenaean**: Mainland Greece, *ca.* 1550 - 1150 BC
- **Greek Dark Age** (a misnomer) also known as **Geometric** or Homeric Age: *ca.* 1200 - 800 BC
- **Archaic**: *ca.* 800 - 500 BC
- **Classical**: 500 BC - 336 BC
- **Hellenistic**: 323 BC (death of Alexander the Great) - 146 BC (annexation by Rome)

Note: chronologies not generally agreed

Minoan civilization: Water resources development

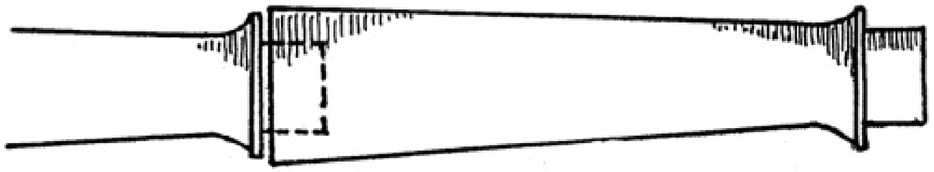
- Groundwater exploitation (Knossos, Zakros, Palekastro)
  - Springs combined with aqueducts and/or cisterns
  - Wells
- Rainwater collection (Phaestos, Chamaizi)
  - Cisterns

Well used for water supply at Palekastro

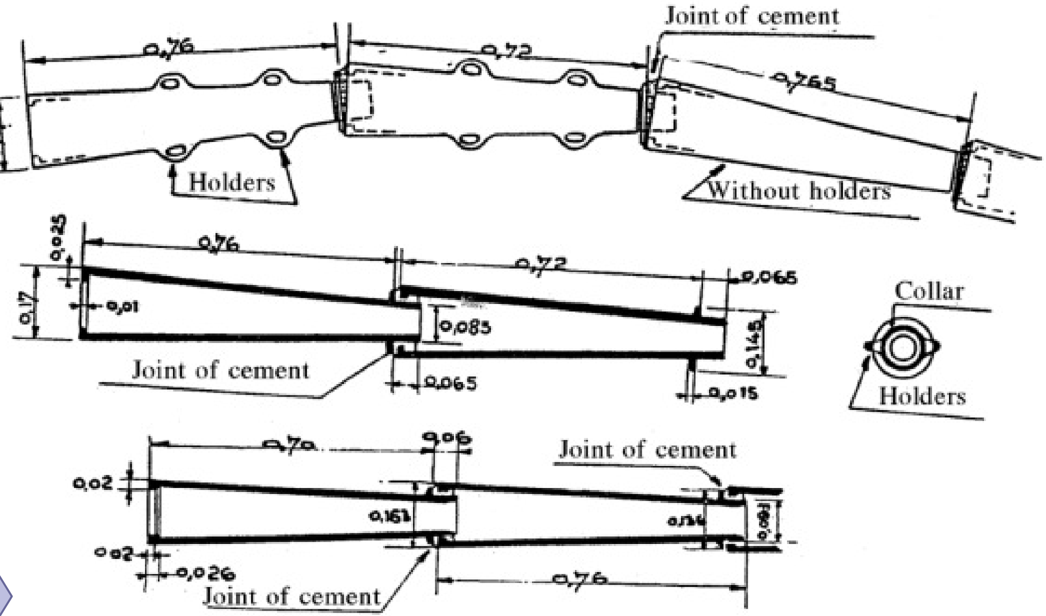
Cistern at the pre-palatial house complex in the vicinity of the village Chamaizi, near the town of Seteia dated in the turn from the 3rd to the 2nd millennium BC

Minoan water supply systems

In the Knossos Palace, water was conveyed from springs at distances 700 m – 5 km using terracotta pipes



(a)



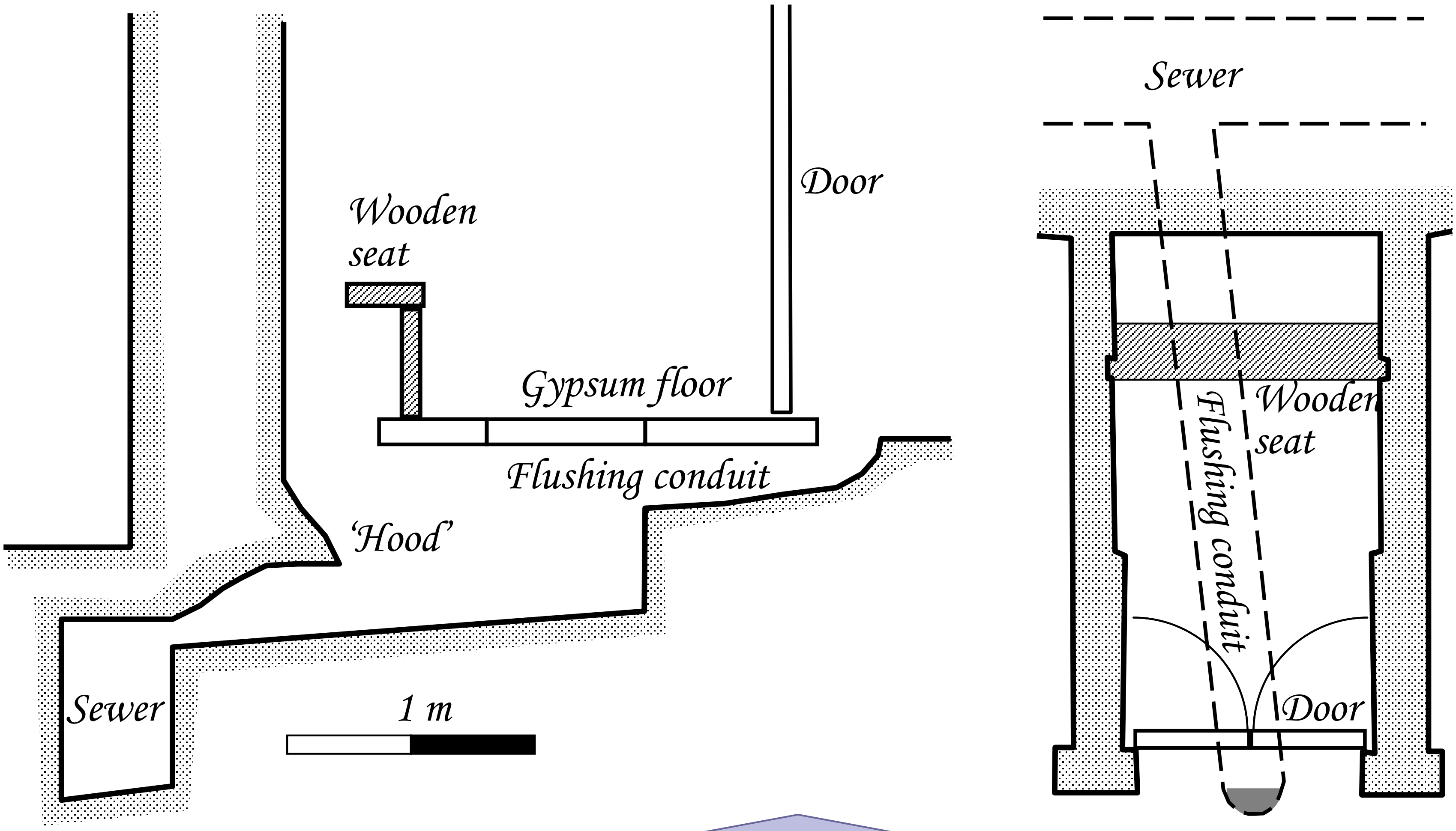
(b)

Terracotta pipe sections (Buffet and Evrard, 1950)

Modern research with due respect for our ancestors’ technology

An ongoing experiment in the Applied Hydraulics Laboratory (NTUA) to investigate the hydraulic behaviour of the ceramic Minoan pipes; the research is made using replicas of the original pipes (same geometry and material) by Panos Papanicolaou and Menelaos Xirouchakis

Minoan flushing toilets



Section and plan of ground-floor toilet in the residential quarter of Palace of Minos (Angelakis et al., 2005)

Minoan sanitary and storm sewers

Part of restored stairway with parabolic runnels in Knossos Palace (Angelakis et al., 2005)

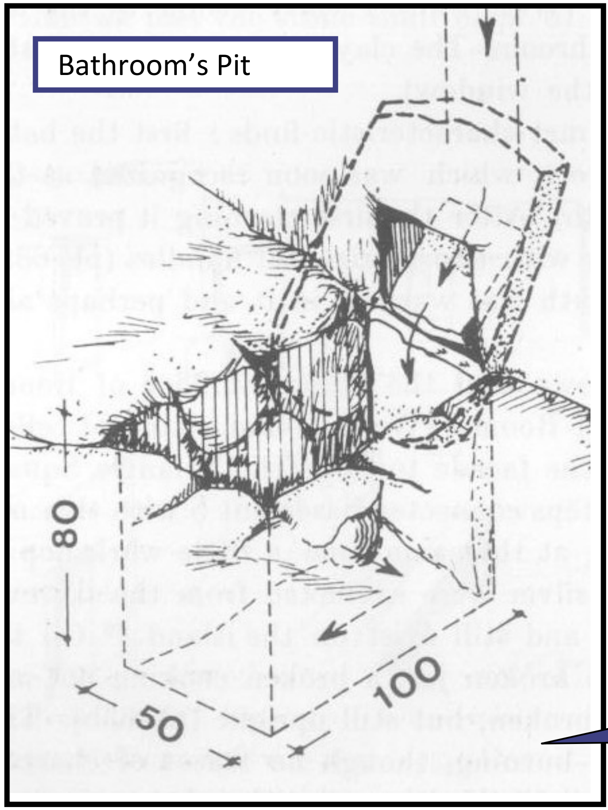
Parts of the sanitary and storm sewer systems in Agia Triadha (Angelakis et al., 2005)

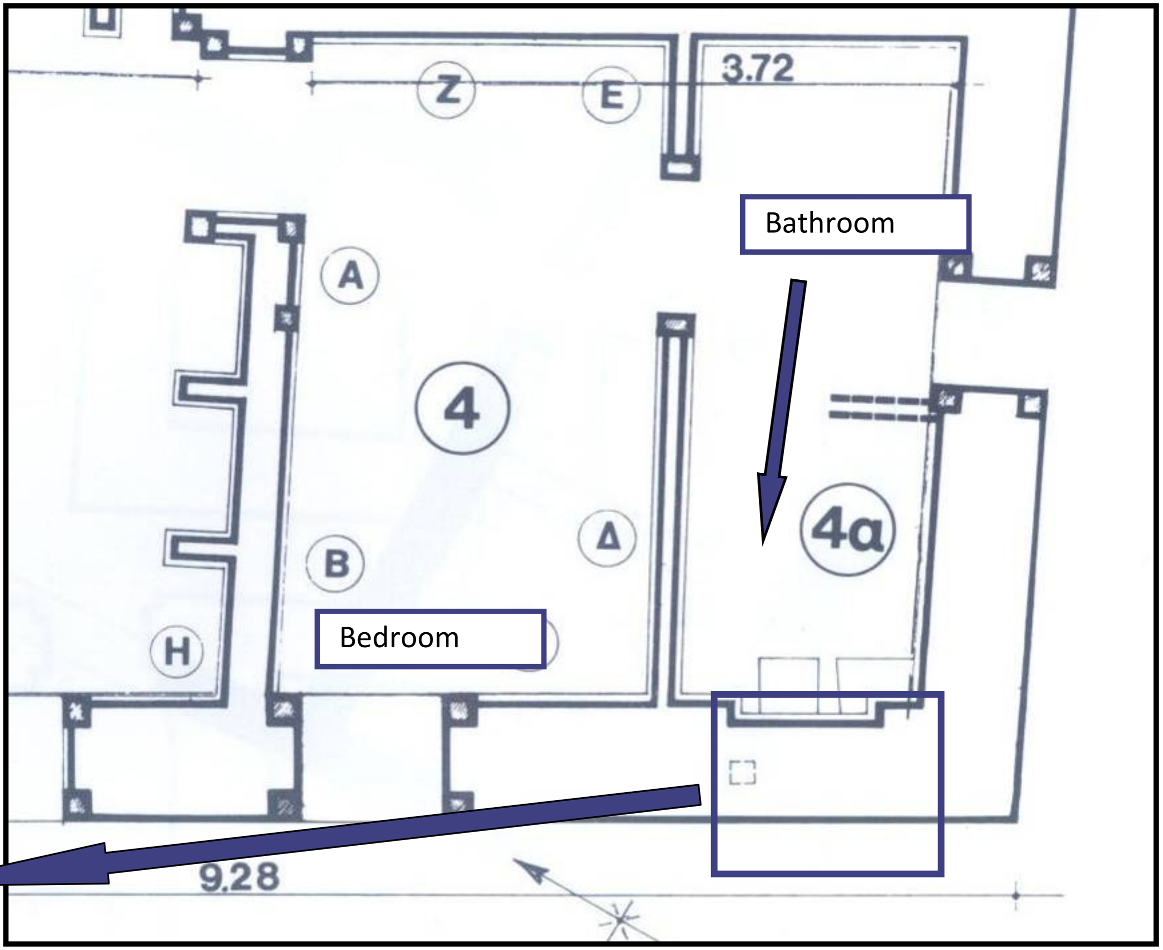
"One day, after a heavy downpour of rain, I was interested to find that all the drains [of the Villa Hagia Triada] acted perfectly, and I saw the water flow from the sewers through which a man could walk upright. I doubt if there is any other instance of a drainage system acting after 4000 years."

Angelo Mosso from his visit in Aghia Triada (Escursioni nel Mediterraneo e gli scavi di Creta, Treves, Milano, 1907)

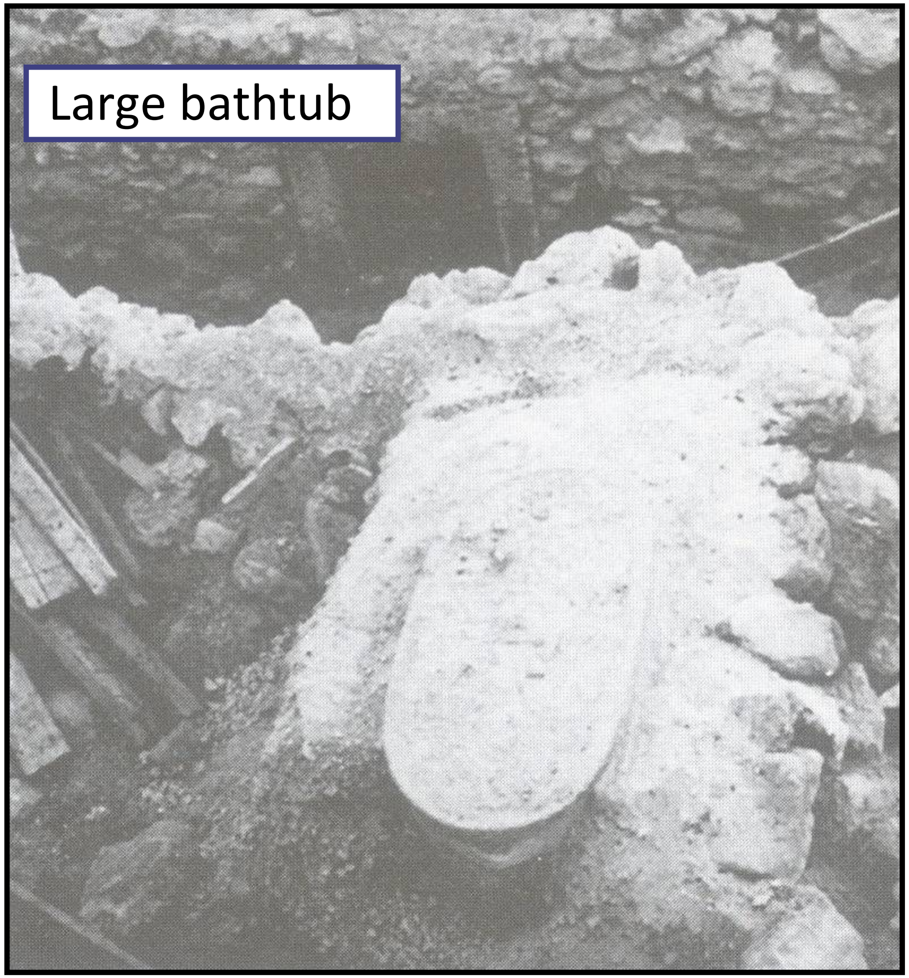
Cycladic bathrooms in the Island of Thera

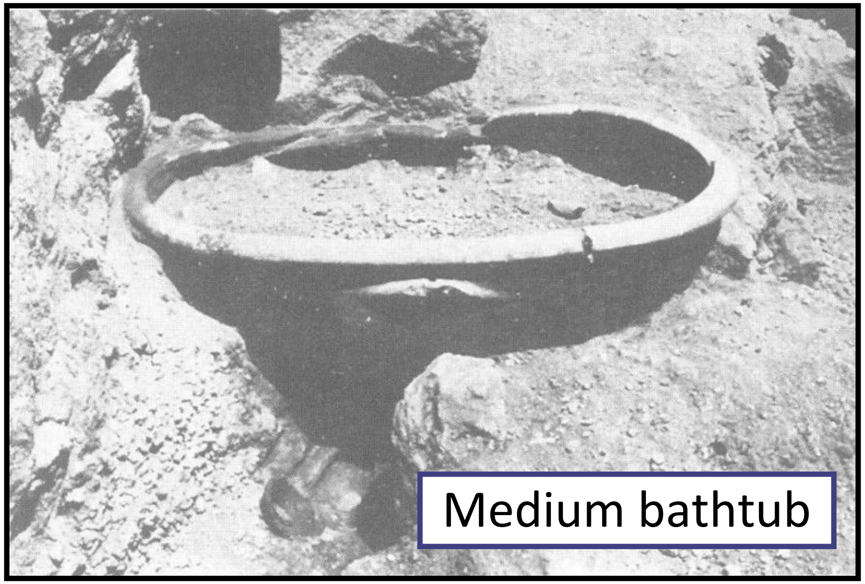
West House, Bathroom at Room 4a with a sewer made of clay pipes of size 20 cm discharging to a pit built externally near the foundation; from Marinatos (1999)

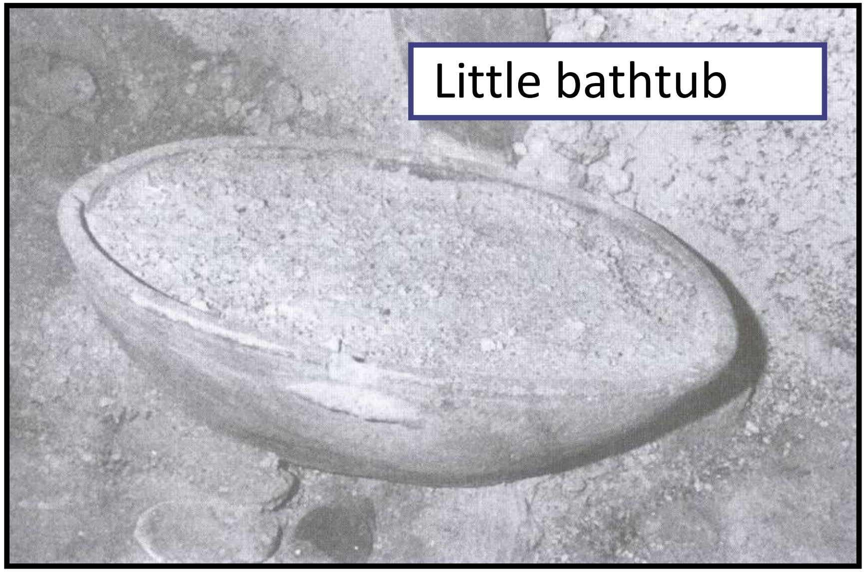




Cycladic terracotta bathtubs in the Island of Thera



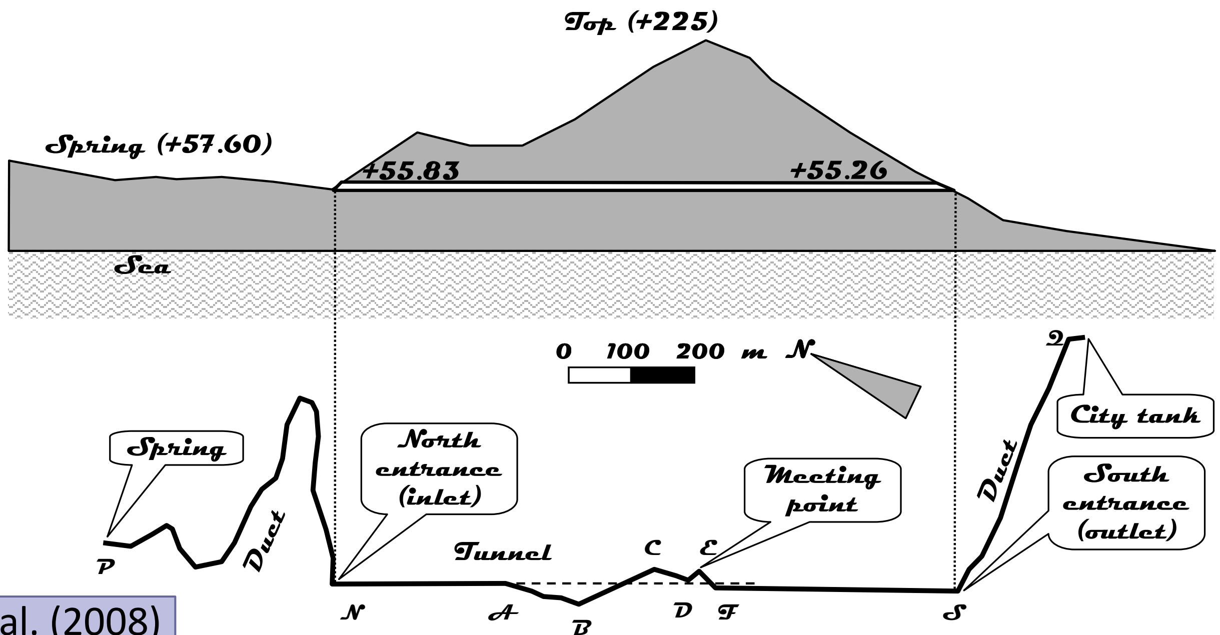




A set of bathtubs with various sizes; photos from Marinatos (1999)

Classical era: The water supply of Samos and the tunnel of Eupalinos

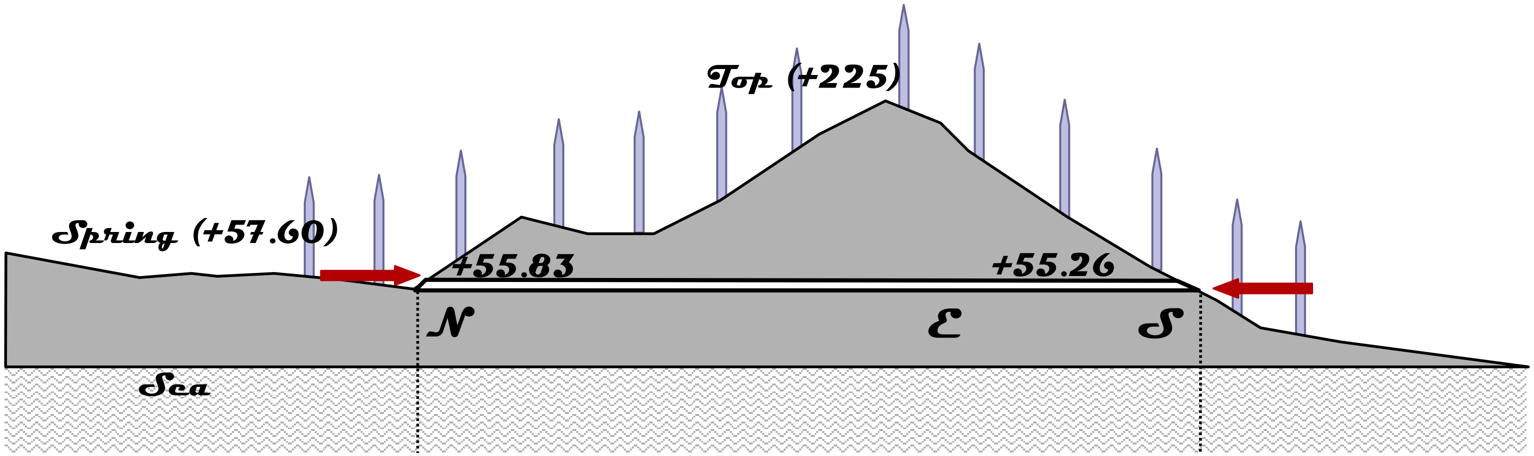
- The most famous hydraulic work of ancient Greece was the aqueduct of ancient Samos, which was admired both in antiquity (e.g. Herodotus) and in modern times
- The most amazing part of the aqueduct is the «Εὐπαλίνειον ὄρυγμα», or "Eupaninean digging", after Eupalinos, an engineer from Megara: a 1036 m long tunnel dug from two openings
- Its construction started in 530 BC, during the tyranny of Polycrates, and took ten years
- Owing to the text of Herodotus, the entrance of the aqueduct was uncovered in 1856; only ninety years later, between 1971 and 1973, the German Archaeological Institute of Athens uncovered the entire tunnel



Sketch from Koutsoyiannis et al. (2008)

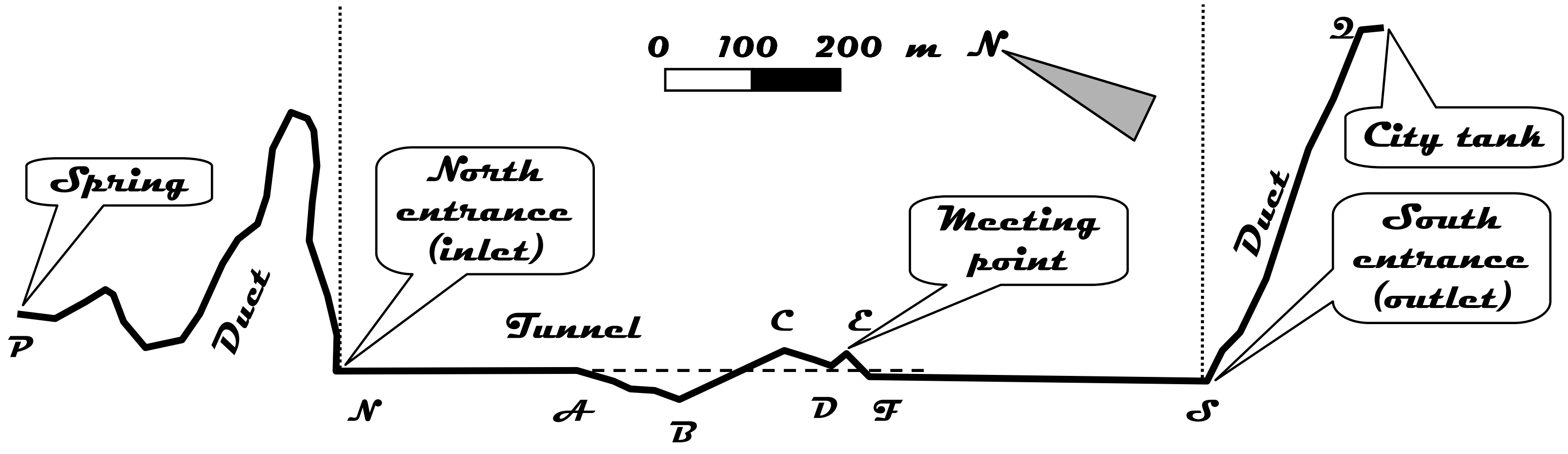
The great achievements of Eupalinos

- He constructed the first known deep tunnel in history; shallow tunnels are much easier to construct (qanat technology)
- Like in modern construction practice, he started from two openings (N and S); the point E where the two construction lines met is known
- To carve segments of the same straight line from two openings in a mountainous terrain, he must have had a good working knowledge of geometry and geodesy
- There is evidence that Eupalinos solved the problem with simple means and in an accurate manner by putting poles up over the mountain along the path in a straight line (a simple method used even today in engineering geodesy, but for simpler problems – not for the construction of tunnels); then he lined up the workers in the tunnel segments with these poles



The great achievements of Eupalinos (2)

- He showed that from an engineering point of view a straight line may not necessarily be the best path; thus, at point A he left the straight line NA and followed the direction AB, a plausible explanation for this being that he found a natural fracture or rift and broadening this he was able to proceed faster
- He found a clever geometrical way to eliminate the impact of uncertainty in position and direction (magnified due to already abandoning of the straight line route) and ensure the intersection of the two construction lines: by deliberately abandoning the straight line routes at points D and F and changing direction to the left and right, respectively, made it mathematically certain that the two lines would intersect

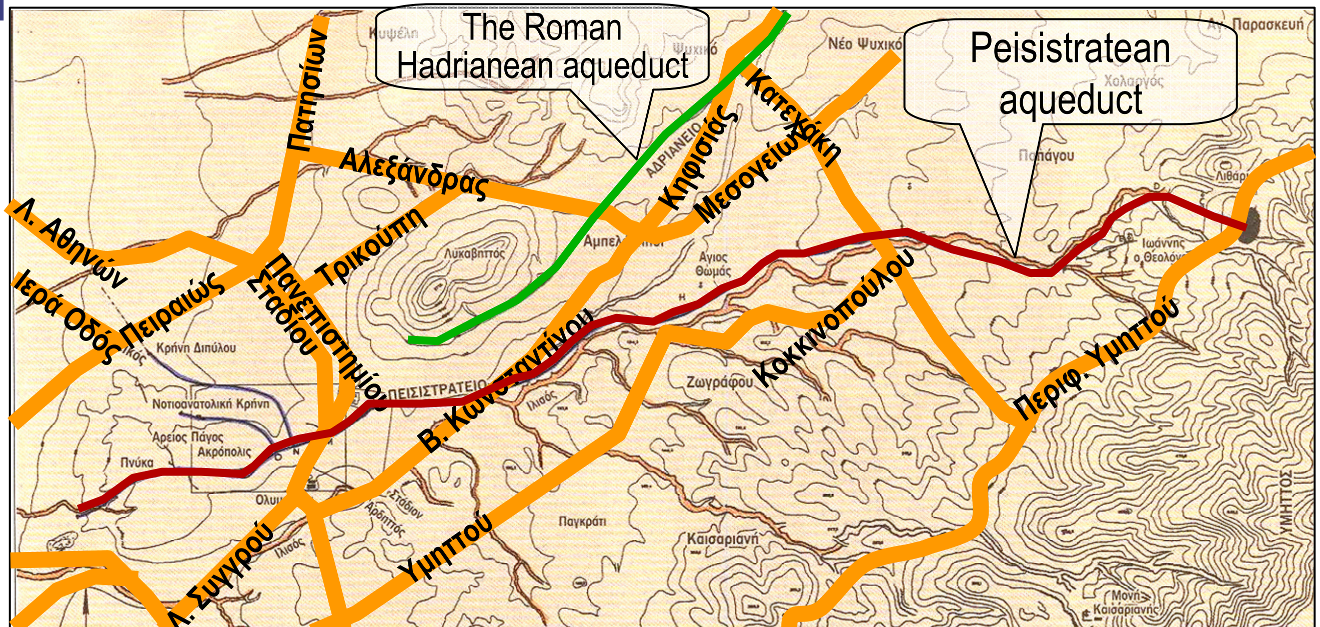


The great achievements of Eupalinos (3)

- He devised an especially smart engineering solution to balance the construction needs with the physical properties of water flow
- On the one hand, the choice of a **horizontal** main tunnel was dictated by the technological means of the time, while a sloping one would be impossible to construct from two sides; note that the accumulation of groundwater in the upper (viz. down-sloping) segment would not allow its construction
- On the other hand he was aware of the hydraulic principle that water needs a **gradient** to flow
- In the horizontal tunnel he achieved the necessary gradient by excavating a slopping channel along one side of the floor; in places where due to slope the depth of the channel would be very high, a second small tunnel below the main tunnel was built

Image source: http://www.swan.ac.uk/grst/images/tunnelatitsbest.jpg

The Peisistratean aqueduct in Athens



- The first major hydraulic project in Athens was constructed under the tyrant Peisistratos (in power between 546-527 BC) and his sons
- The greatest part of the aqueduct was carved as a tunnel at depth reaching 14 m

Image from Panagoulia and Zarris (2009)

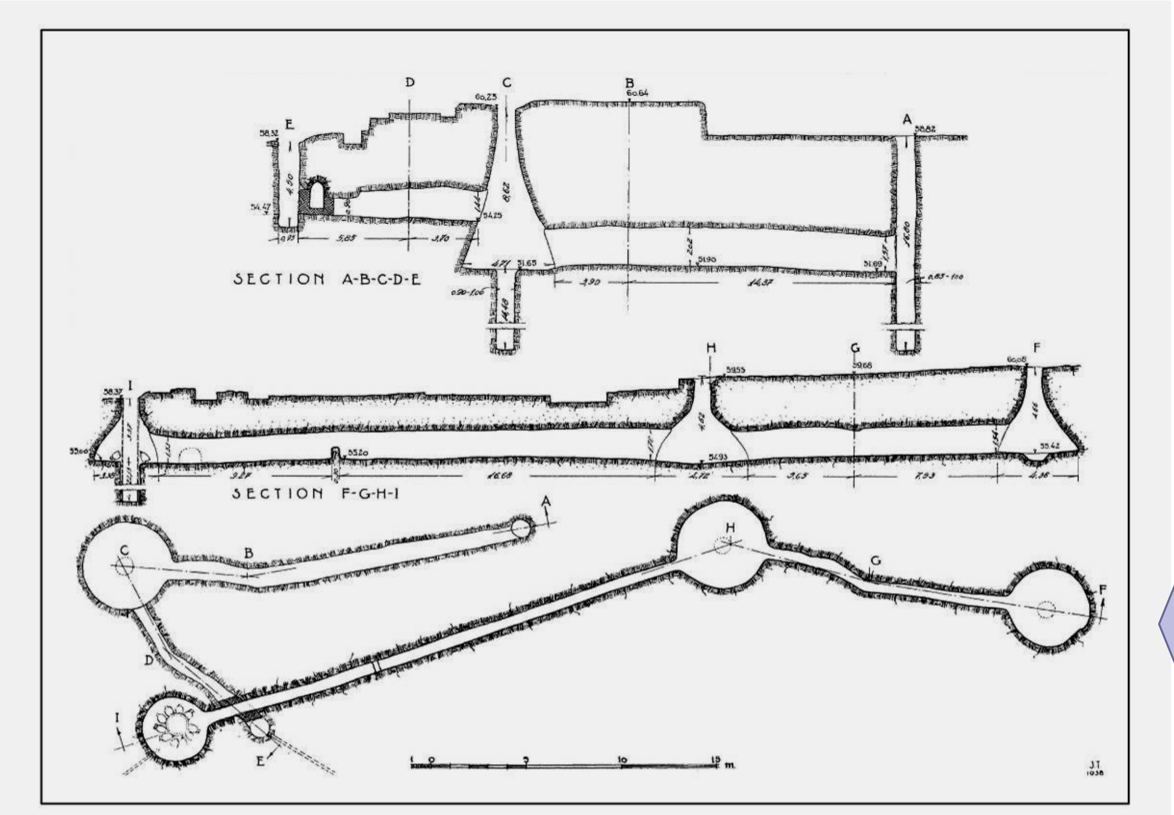
- Other aqueducts were also constructed with similar technologies in several phases forming a network of pipelines; one of them, the Hymettus aqueduct, follows a route parallel to the Peisistratean; the last and longest one (25 km), the Hadrianean aqueduct, was constructed in Roman times
- One aqueduct (Peisistratian or Hymettus?) is still in operation providing irrigation water to the National Garden (!!!); the Hadrianean aqueduct used to provide drinking water up to the mid 20th century

The Peisistratean aqueduct in Athens (2)

- Greek hydraulic constructions were mostly underground for security reasons (not no be exposed to aliens, e.g. in case of war)
- For cleaning and maintenance, in their upper part the pipes had elliptic openings covered by ceramic covers

Small scale water constructions in Athens

- In addition to large-scale aqueducts, Athens had numerous small scale constructions, such as wells for groundwater exploitation and cisterns receiving rainwater from roofs
- In several cases, such small-scale constructions were interconnected forming complex systems storing groundwater and rainwater



Plan and sections of a system of interconnected cisterns near the Hephaisteion in Athenian Agora (Thompson 1940; Chiotis and Chioti, 2012)

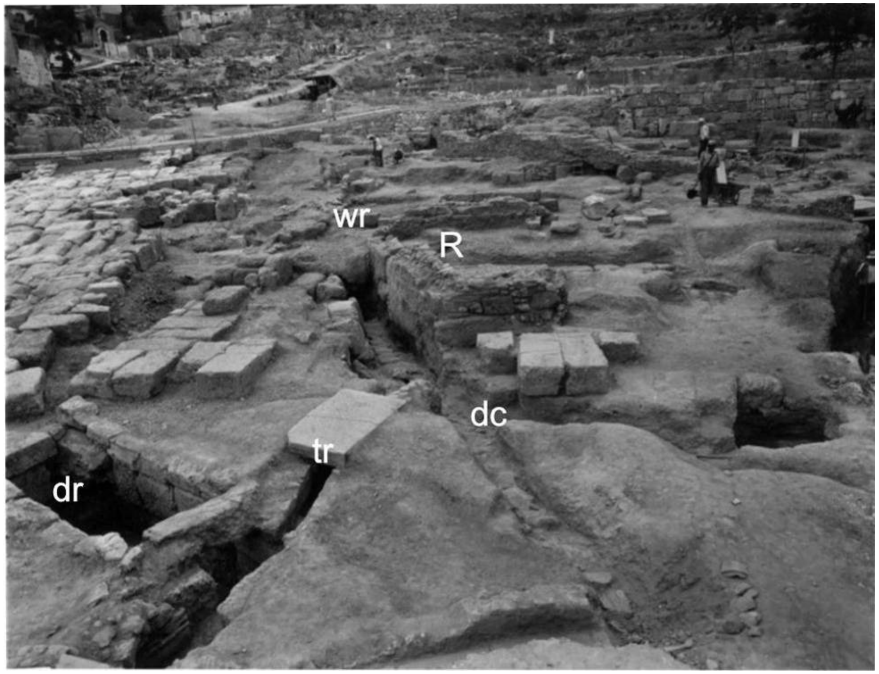
Survival of small-scale technologies up to present date

These pictures are from a 300-year old cottage in the Cephalonia island, which still implements a traditional water supply system (for drinking water and garden irrigation) comprising a couple of cisterns; the only modern adaptation is the replacement of the bucket with a pump (photos by author)

Hydraulic systems for flood control and energy utilization

The Great Drain of the Athenian Agora; it was made in the early fifth century BC and still drains the Agora today (Chiotis and Chioti, 2012)

Remnants of a watermill in the Athenian Agora: wr: wheel-race, R: mill room remnants, tr: tail-race, dc: diversion channel, dr: drainage pit (Chiotis and Chioti, 2012)



The Alyzia dam (Western Greece)

The dam (most likely built in the classical period to protect the downstream plain from floods and sediments) is in perfect condition 2500 years after its construction

The stone-carved spillway has formed an irregular shape by erosion through centuries

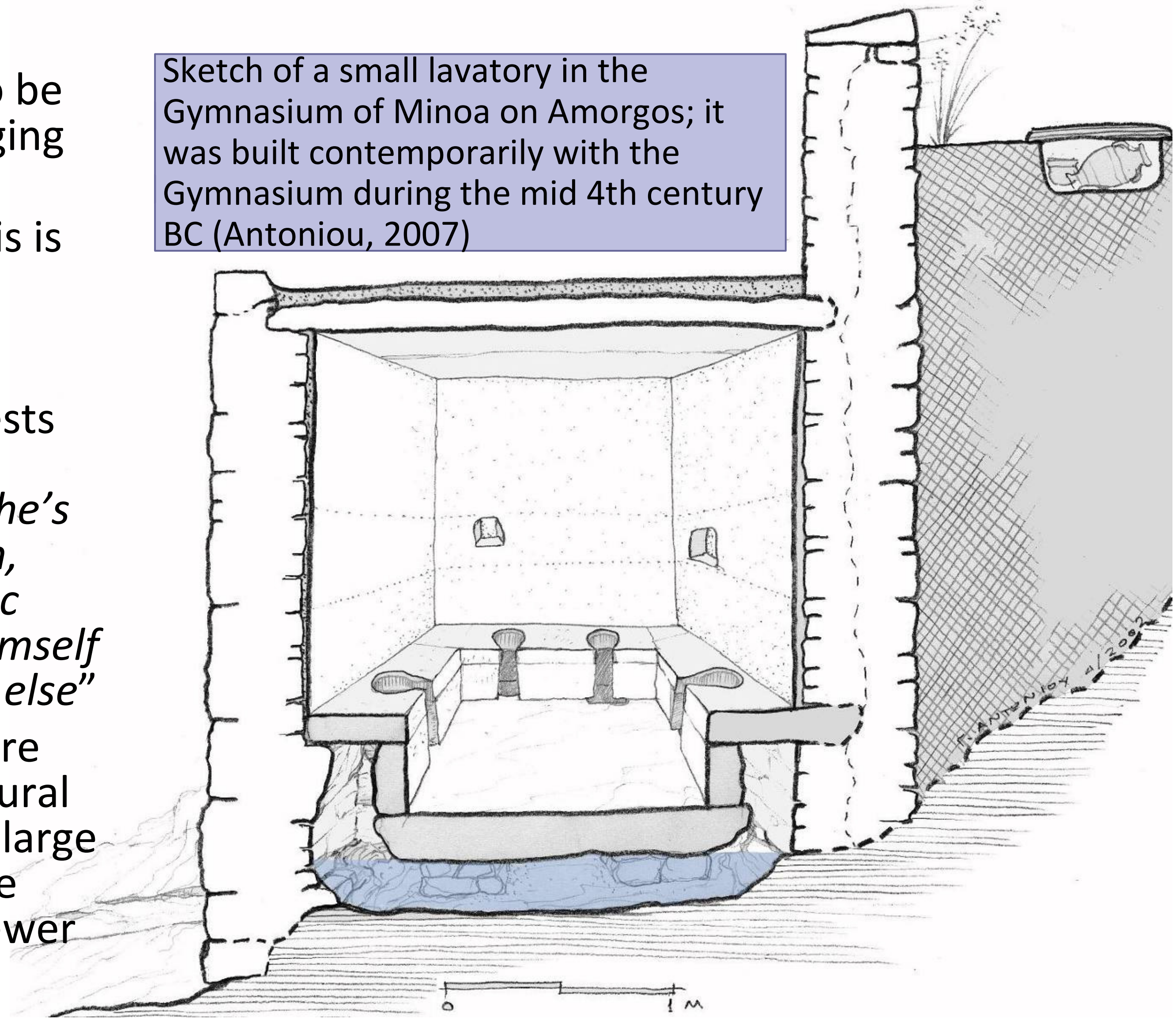
The spillway in operation

Photos by N. Zarkadoulas from Koutsoyiannis et al. (2008)

Hygienic systems: Lavatory at Amorgos island

- Ancient Greek lavatories used to be public—discouraging privacy
- The reason for this is not obvious (humility?); note though that Antiphanes suggests that: *“whoever thinks he’s more than human, going to the public latrine, will see himself just like everyone else”*
- The lavatories were supplied with natural running water by large conduits and were connected to a sewer

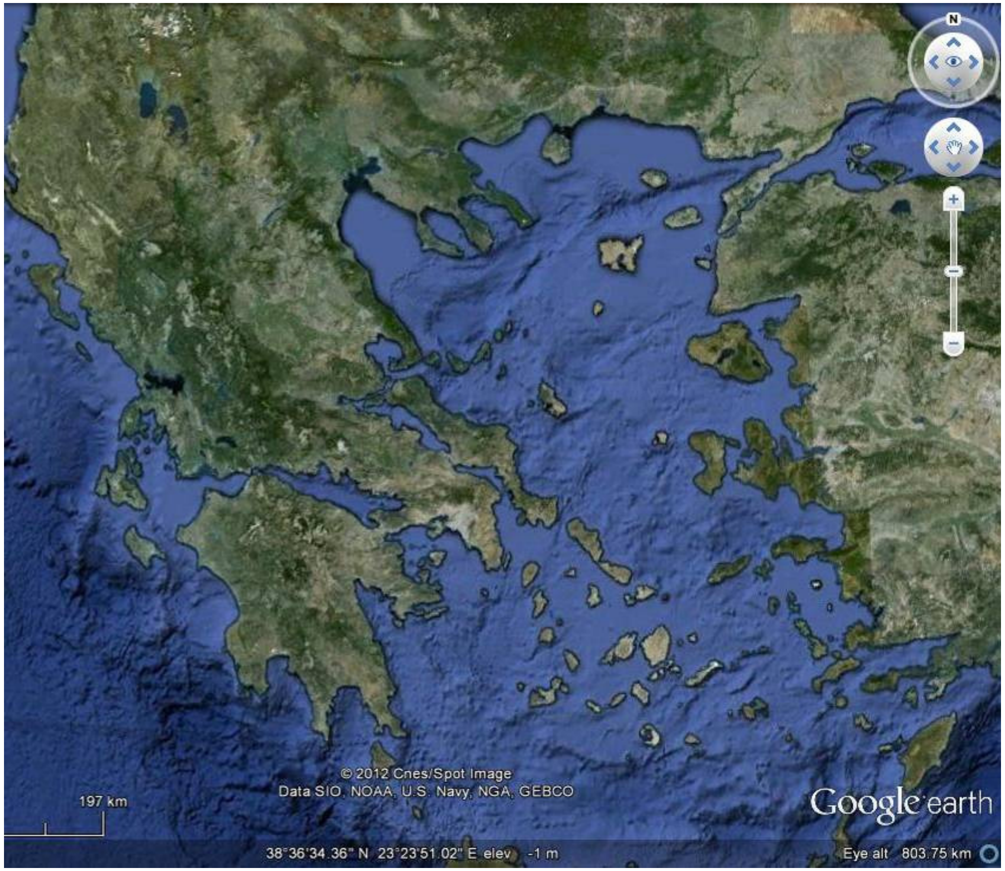
Sketch of a small lavatory in the Gymnasium of Minoa on Amorgos; it was built contemporarily with the Gymnasium during the mid 4th century BC (Antoniou, 2007)



Social organization and institutions: some examples

Background information: geophysical characteristics and social organization

- *'Greece is divided by mountains into small plains; it is in these plains that the major part of land cultivation takes place and we can roughly say that these do not exceed 20% of the ancient Greek peninsula*
- *The physical boundaries of the small plains form the boundaries of the city-state; these areas range from fairly small states with an area of 100 km² …, to fairly large states, … which spread over an area of about 5000 km²*
- *Diagrammatically, we can thus visualise the ancient Greek states as squares of 10 by 10 km, which could be crossed from end to end in 2 hours or so, to squares of 70 by 70 km, which need 14 hours to cross on foot'* (Doxiadis, 1964)



Timeline of Greek states organization as reflected in the history of the Athenian city-state

- Eupatrid Oligarchy (700-600)
- Solon (600 - 561)
- Tyranny of the Peisistratids (561-510)
- Foundation of democracy (Democracy of Cleisthenes, Persian Wars, Delian League and post-war re-building) (510-462)
- Radical Democracy of Pericles (462-431)
- Peloponnesian War and Oligarchy (431-403)
- Post-Peloponnesian War Radical Democracy (403-322)
- Macedonian and Roman Domination (322-146)

Legislation for water

- Apart from the structural solutions for the water supply and sewerage of Athens, the Athenian city-state (and other ones) developed a framework of laws and institutions for water management
- The first known regulations were made by Solon, the Athenian statesman and poet of the late seventh and early sixth century BC, who was elected archon in 594 and shaped a legal system by which he reformed the economy and politics of Athens; most of his laws have been later described by Plutarch (47-127 AD), from whom we learn:

  "*Since the area is not sufficiently supplied with water, either from continuous flow rivers, or lakes or rich springs, but most people used artificial wells, Solon made a law, that, where there was a public well within a hippicon, that is, four stadia (4 furlongs, 710 m), all should use that; but when it was farther off, they should try and procure water of their own; and if they had dug ten fathoms (18.3 m) deep and could find no water, they had liberty to fetch a hydria (pitcher) of six choae (20 litres) twice a day from their neighbours; for he thought it prudent to make provision against need, but not to supply laziness*" *(Plutarch, Solon, 23)*
- The spirit of this law which, among other targets, aimed to balance the public and private interests for the construction and operation of wells, seems to have been kept during the whole history of the Athenian city-state

Legislation for water (2)

- **Water supply safety**: In addition to large-scale public works (mainly aqueducts and fountains), private installations like wells and cisterns were necessary, particularly in times of war and crisis; it is thus hypothesized that there were regulations forcing people to maintain the wells at a good condition and ready to use
- This hypothesis is supported (cf. Koutsoyiannis et al., 2008) by the following passage from Aristotle (Politics, III, I330b; translation from http://hydra.perseus.tufts.edu/) "*…and* [the city] *must possess if possible a plentiful natural supply of pools and springs, but failing this, a mode has been invented of supplying water by means of constructing an abundance of large reservoirs for rainwater, so that a supply may never fail the citizens when they are debarred from their territory by war*"
- **Flood damages**: From Demosthenes' speech *Against Kallikles*, which refers to property damage after heavy rain and flooding, we can infer that there was a law penalizing anyone responsible for a man-made obstruction to natural flow of water, which caused damage to someone else's property (penalty 1000 drachmas or else forfeit of the land on which the obstruction stood; MacDowell, 1986; Krasilnikoff, 2002)
- **Protection from pollution**: An epigraph of about 440 or 420 BC contains the "law for tanners", according to which no one '*was to soak skins in the Ilissos above the precinct of Herakles, nor to dress hides, nor to* [throw rubbish?] *into the river* (MacDowell, 1986)
- **Minimum (environmental?) river flow**: A good example survives owing to 5th century BC epigraphic evidence (Davies, 1996): '*Gods. If anyone makes the flow of the river run from the middle of the river towards his own [property], it is without penalty for the person so doing. [He is] to leave the flow as wide as the bridge at the agora holds, or more, but not less*'

Θιοί· τô ποταμô αἴ κα κατὰ τὸ
μέττον τὰν ῥοὰν θιθῆι ῥῆν (κ-
ατὰ τὸ Ϝὸν αὐτô, θιθεμένōι ἄ-
πατον ἤμην. τὰν δὲ ῥοὰν λείπ-
εν ὅττον κατέκει ἀ ἐπ' ἀγορâ-
ι δέπυρα ἢ πλίον, μεῖον δὲ μή.

Institutions

- In Athens a distinguished public administrator, called «κρουνῶν ἐπιμελητής», (Superintendent of Fountains), was appointed to operate and maintain the city's water system, to monitor enforcement of the regulations and to ensure the fair distribution of water
- From Aristotle (Athenaion Politeia, 43.1) we learn that this officer was one of the few that were elected by vote whereas most other officers were chosen by lot; an interpretation is that this position was particularly important within the governance system of Athens
- Themistocles himself ("the man most instrumental in achieving the salvation of Greece" from the Persian threat, as Plutarch describes him; cf. the Battle of Salamis) had served in this position
- In 333 BC the Athenians awarded a gold wreath to the Superintendent of Fountains Pytheus because he restored and maintained several fountains and aqueducts
- Generally, private sponsoring of public hydraulic systems was encouraged
- The entire regulatory and management system of water in Athens must have worked very well and approached what today we call sustainable water management
- Present day water resource policymakers and hydraulic engineers have emphasized the usefulness of nonstructural measures in urban water management and the importance of small-scale structural measures like domestic cisterns, which reduce the amount of stormwater to be discharged and provide a source of water for private use (like watering of gardens)

Institutions for building public hydraulic works

- It was a common practice in ancient Greece that competition announcements, project specifications and project contracts were written on marble steles erected in public sites so that everyone would have known all project details and, simultaneously, the breach of contract would be difficult
- An interesting example (see Koutsoyiannis and Angelakis, 2007) is the contract for draining and exploitation of the lake Ptechae (probably identified with the Dystos Lake in Southern Euboea), which is between the Eretrians and the engineer-contractor Chairephanes (2nd half of 4th century BC); the stele was revealed in Chalkis (1860) and is kept in the Athens Archaeological Museum

Image from Tassios (2006)

- The project is what we call today BOT – Build, Operate, Transfer; the rather wordy (like construction contracts of present day) contract is written on a Pentelian marble stele
- On the surface relief sculptures show the Gods that were worshiped in the region, Apollo, Artemis and Leto; a carved scripture in 66 verses signed by more than 150 people contains the construction contract
- The first 35 verses are the main contract and followed by two resolutions of the parliament, by which (a) asylum is granted to Chairephanes and his collaborators for the whole duration of the contract and (b) the keeping of the contract is confirmed by oath to Apollo and Artemis; against misdemeanors moral and material sanctions (penalty for breach of contract) are foreseen such as the confiscation of their property and the dedication of it to Artemis

Institutions for building public hydraulic works (2)

A summary of the main contract for draining of the lake Ptechae (Koutsoyiannis and Angelakis, 2007)

1. Between the city of the Eretrians representing the 31 municipalities of the Eretrian region and the contractor Chairephanes a contract is made concerning the draining of the Ptechae Lake
2. The draining works include the construction of drainage canals, sewers, and wells for the drainage of water to natural underground holes or cracks, and miscellaneous protection works including wooden or metallic railings
3. In addition, irrigation works, such as the construction of a reservoir with side length up to 2 stadia (360 m) for storing irrigation water, and sluice gates, are included in the contract
4. It is agreed a 4-year construction period that could be extended in case of war
5. The contractor is granted the right to exploit the dried fields for 10 years (extended in case of war), starting by the finishing of the drying works
6. The contractor is granted the privilege of custom free import of materials (stones and wood)
7. The contractor is obliged (a) to pay all labour costs without any charge for the people Eretria; (b) to pay the amount of 30 talents in monthly instalments as a rental for the permission to exploit the lake for 10 years; (c) to maintain all works for the exploitation period, in order to be in good condition after the finishing of the contract; (d) to compensate the land owners by one drachma per foot of land area that is to be the expropriated for the construction of works; and (e) to avoid harm on private property as much as possible by locating the works in non cultivated areas
8. In case of death of the contractor, his heirs and collaborators will substitute him in the relations to the city
9. Penalties are enforced against any person trying to annul the contract
10. The contractor is obliged to submit a good construction guarantee up to the amount of 30 talents

From mythology to philosophy and science: some examples

Mythological views

Attic red figure vase,
6th century BC depicting the battle of Hercules against Acheloos, in which Hercules won (image from British Museum)

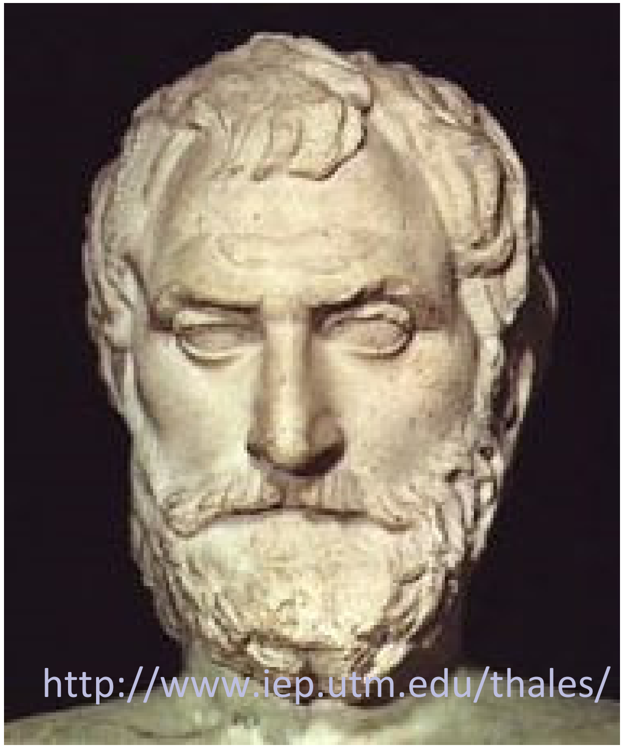
Acheloos is the greatest in discharge river of Greece

As demystified by the historian **Diodorus Siculus (ca. 90-30 BC**) and the geographer **Strabo** (**ca. 64 BC-24 AD**), the meaning of the victory is related to the channel excavation and the construction of dikes to confine the shifting bed of Acheloos (see also Koutsoyiannis et al., 2007)

The emergence and development of philosophy and science

- A phenomenon perhaps unique in history, which occurred around 600 BC in Ancient Greece (mainly in Ionia), is that technological needs triggered physical explanations of natural phenomena, thus leading to the foundation of philosophy and science; the new approach to understanding Nature rejected myths and intervention of supernatural powers, and sought physical explanations for natural phenomena
- The study of hydrometeorogical phenomena (evaporation, creation of clouds, rain, hail and snow, river flow and, more generally, the hydrological cycle) had a major role in the development of science
- Many of the theories are erroneous (as happens with modern theories) but there are many impressive elements in Greek exegeses of hydrometeorological processes
- During the 5th and 4th centuries BC, philosophy and science were developed further in classical Athens forming a body of knowledge that would be dominant for about 2000 years
- During the Hellenistic period (4th-1st centuries BC) there was significant progress in mathematics, physics, and technology; the scientific views were advanced and close to modern ones (see also Koutsoyiannis et al., 2007)

Thales of Miletus (640-546 BC)



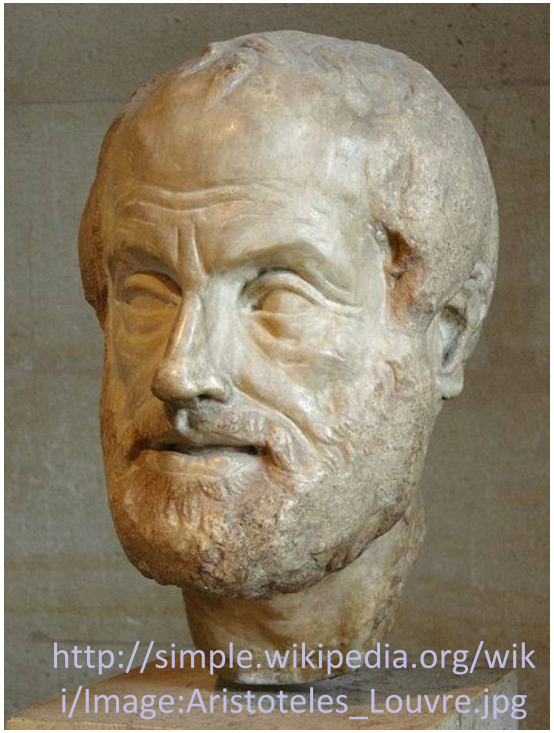
- He was the founder of the Ionic philosophy (according to many, the father of philosophy and of science)
- He proclaimed water as the fundamental substance of the world
- He accomplished the diversion of Halys River (thus emphasizing the link of technology and philosophy at the first steps of the latter)
- He proposed a physical exegesis for the "Nile puzzle" (the fact that the Nile floods occur at the summertime when rainfall in Egypt is minimal), thus emphasizing the importance of hydrology for the birth of science
- This explanation was based on the regime of winds and was blatant wrong, but the important thing is that a natural phenomenon was described and studied on physical grounds (see also Koutsoyiannis et al., 2007)

Aristotle (384-328 BC)

- He was a student of Plato but his theories were influenced by Ionic philosophers
- His treatise *Meteorologica* is a great contribution to the explanation of hydrometeorogical phenomena:

  *"the **sun** causes the **moisture to rise**; this is similar to what happens when water is heated by fire"*

  *"the **vapour that is cooled**, because of 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**"* (see also Koutsoyiannis et al., 2007)



http://simple.wikipedia.org/wiki/Image:Aristoteles_Louvre.jpg

Aristotle (continued…)

- He recognized the principle of mass conservation within hydrological cycle:

  *“Thus, the **sea will never dry up**; for the **water** that has **gone** up beforehand will **return** to it; and if this has happened once we must admit its **recurrence**”*

  *“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**”*

- He understood “change” perhaps better than we do today:

  “The same parts of the earth are not always wet or dry, but they change depending on the formation or the disappearance of rivers”

  *“But if **rivers are formed and disappear** and the same places were not always covered by water, the sea must change correspondingly”*

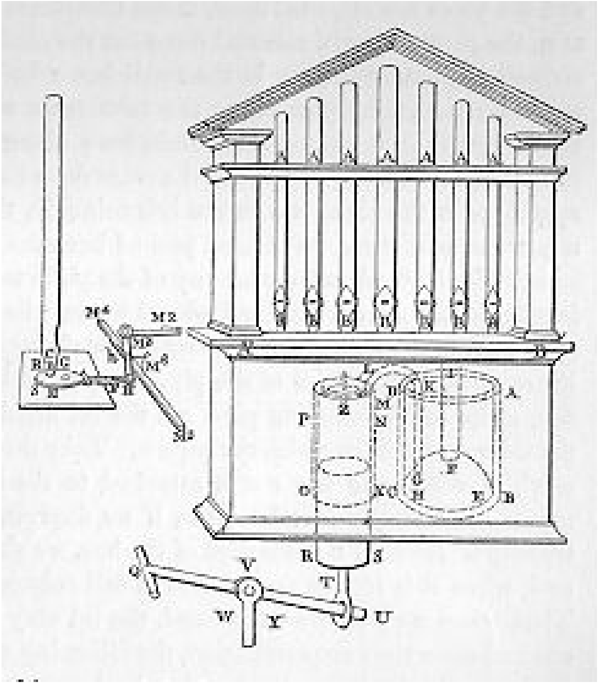
  *“And if the sea is receding in one place and advancing in another it is clear that the **same parts of the whole earth are not always either sea or land,** but that **all changes in course of time*** (see also Koutsoyiannis et al., 2007)

Hero (Heron) of Alexandria (~ 150 BC)

He is mostly known as an engineer, but his comprehension of physics is very advanced, as evidenced from his treatise *Pneumatica*:

> *"Vessels which seem to most men empty are not empty, as they suppose, but full of air. Now the **air**, as those who have treated of physics are agreed, is **composed of particles** minute and light, and for the most part invisible. If, then, we pour water into an apparently empty vessel, air will leave the vessel proportioned in quantity to the water which enters it. This may be seen from the following **experiment**. Let the vessel which seems to be empty be inverted, and, being carefully kept upright, pressed down into water; the water will not enter it even though it be entirely immersed: so that it is manifest that the **air, being matter**, and having itself **filled all the space** in the vessel, does not allow the water to enter. Now, if we bore the bottom of the vessel, the water will enter through the mouth, but the air will escape through the hole."* (English translation by Bennet Woodcroft; see also Koutsoyiannis et al., 2007)

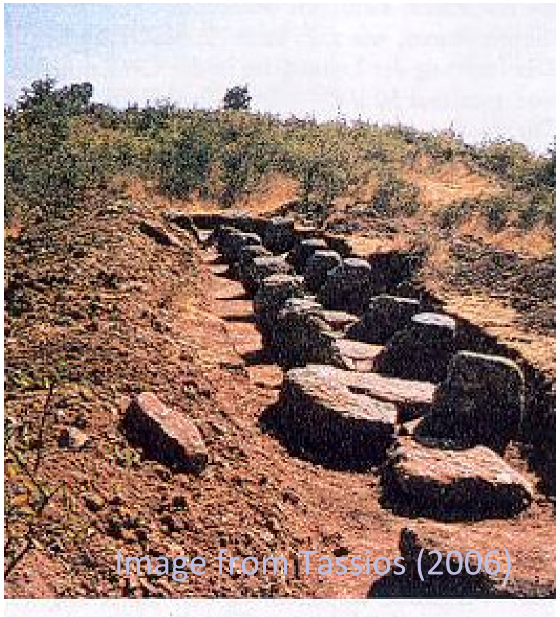
Hero's *Pneumatica* (continued…)

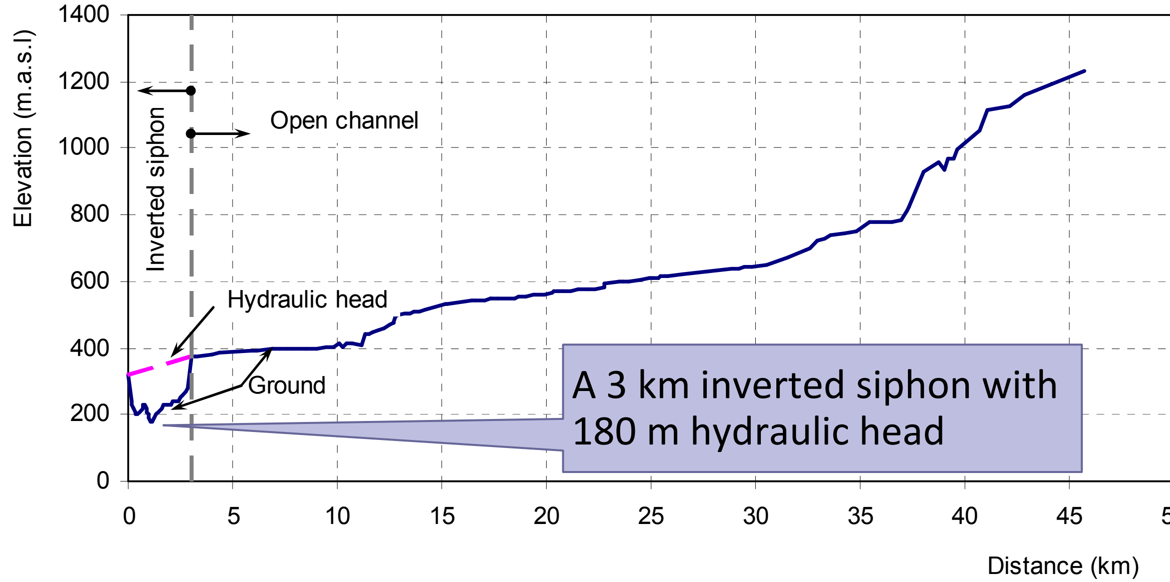


*"Hence it must be assumed that the air is matter. The air when set in motion becomes wind (for **wind** is nothing else but **air in motion**), and if, when the bottom of the vessel has been pierced and the water is entering, we place the hand over the hole, we shall **feel the wind** escaping from the vessel; and this is nothing else but the air which is being driven out by the water. It is not then to be supposed that there exists in nature a distinct and continuous **vacuum**, but that it is distributed in small measures through air and liquid and all other bodies. […] Winds are produced from excessive exhalation, whereby the air is disturbed and rarefied, and sets in motion the air in immediate contact with it. This movement of the air, however, is not everywhere of **uniform velocity**: it is more violent in the neighbourhood of the exhalation, where the motion began."* (English translation by Bennet Woodcroft; see also Koutsoyiannis et al., 2007)

Technology based on scientific knowledge: some examples

Pressurized flow and the Pergammon aqueduct



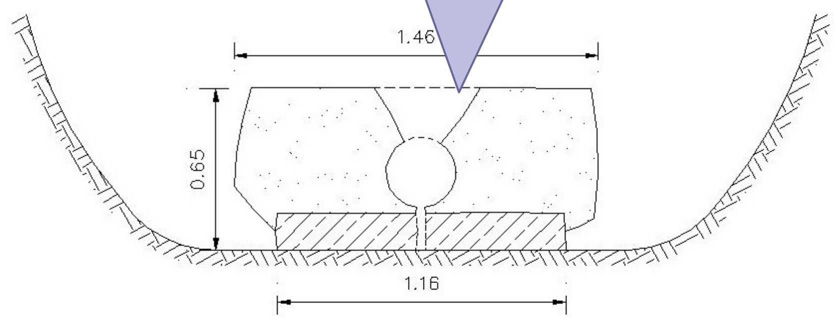


A 3 km inverted siphon with 180 m hydraulic head

The scientific progress in Hellenistic period allowed, for first time in history, application of the pressurized flow on large technological scale for water conveyance

In the city of Pergamon (located on top of a hill, 30 km inland from the Aegean Sea, in Western Anatolia, Turkey), one aqueduct (Madradag) included an inverted siphon made of metal (lead) and anchored with big stone constructions (Figures from Koutsoyiannis et al., 2008)

An anchor stone of the leaden pressure pipe



Hydraulic mechanisms and pumping devices

- Although in antiquity several devices were in use to lift water to a higher elevation, the first pump with the modern meaning is Archimedes's helix or water-screw
- Archimedes was a Syracusian mathematician and engineer (287-212 BC) considered by many to be the greatest mathematician of antiquity or even of the entire history; the invention of the water screw is tied to the study of the spiral, for which Archimedes wrote a treatise entitled *On Spirals*, in 225 BC
- This pump is an ingenious device functioning in a simple and elegant manner by rotating an inclined cylinder bearing helical blades around its axis whose bottom is immersed in the water to be pumped; as the screw turns, water is trapped between the helical blades and the walls, thus rises up the length of the screw and drains out at the top

Archimedes's water screw in its original form as depicted in an Italian stamp along with a bust of Archimedes (from https://www.cs.drexel.edu/~crorres/Archimedes/Stamps/screw_stamp.jpg)

Archimedes's water screw in its modern form, as implemented in the wastewater treatment plant of Athens (1 of 5 screws that pump 1 million m^3 per day).

Desalination

- Desalination (removal of salt from sea water) has its roots in Aristotle, who understood that the salt is not evaporated:
  "*Salt water when it turns into vapour becomes sweet* [freshwater], *and the vapour does not form salt water when it condenses again; this I know by experiment*" (Meteorologica II 3; Translated by E. W. Webster; http://classics.mit.edu/Aristotle/meteorology.2.ii.html)
- We learn from the commentary on Aristotle's Meteorologica II, written by Olympiodorus, the peripatetic philosopher who lived in the 5th century 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 in Forbes, 1970)

Conclusions

- Abundance may make us feel happy and leisured but scarcity, and problems springing form it, trigger knowledge discovery, progress and evolution
- Study of history is also a good advisor for problem solving; in this respect ancient Greek water control practices provide useful lessons such as the following
- City planning has to include urban water criteria including water supply, pollution and wastewater control, and protection from floods
- The principles and practices of sustainable water use should not be forgotten even in periods of water adequacy
- The use of small-scale infrastructures, in parallel to the large-scale ones, is a big step towards sustainability and resilience
- Harmonization of public and private interests and functions may perhaps represent an optimal policy for water control
- Safety and security of water supply in emergency situations, including turbulent and war periods, should be kept in mind in our designs of urban water systems
- Scientific progress is an important agent for water control but it seems to be neither a necessary nor a sufficient condition; perhaps common sense and a functional social organization are more important than scientific knowledge

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> *"Excepting machinery, there is hardly anything secular in our culture that does not come from Greece*"
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> Will Durant, The Life of Greece (The Story of Civilization, Part II) (New York: Simon & Shuster) 1939: Introduction, pp vii- viii.