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The water supply of Athens through the centuries

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Presentation available online: www.itia.ntua.gr/1543/

The importance of hydrology and climate: Athens within the big picture of early civilizations

Locations of earliest civilizations

American civilizations, AD

7. Arizona

8. Mexico

9. Andes

1. Fertile Crescent *(early agricultural areas, 9000 BC)*

From 6th to 3th millennium BC

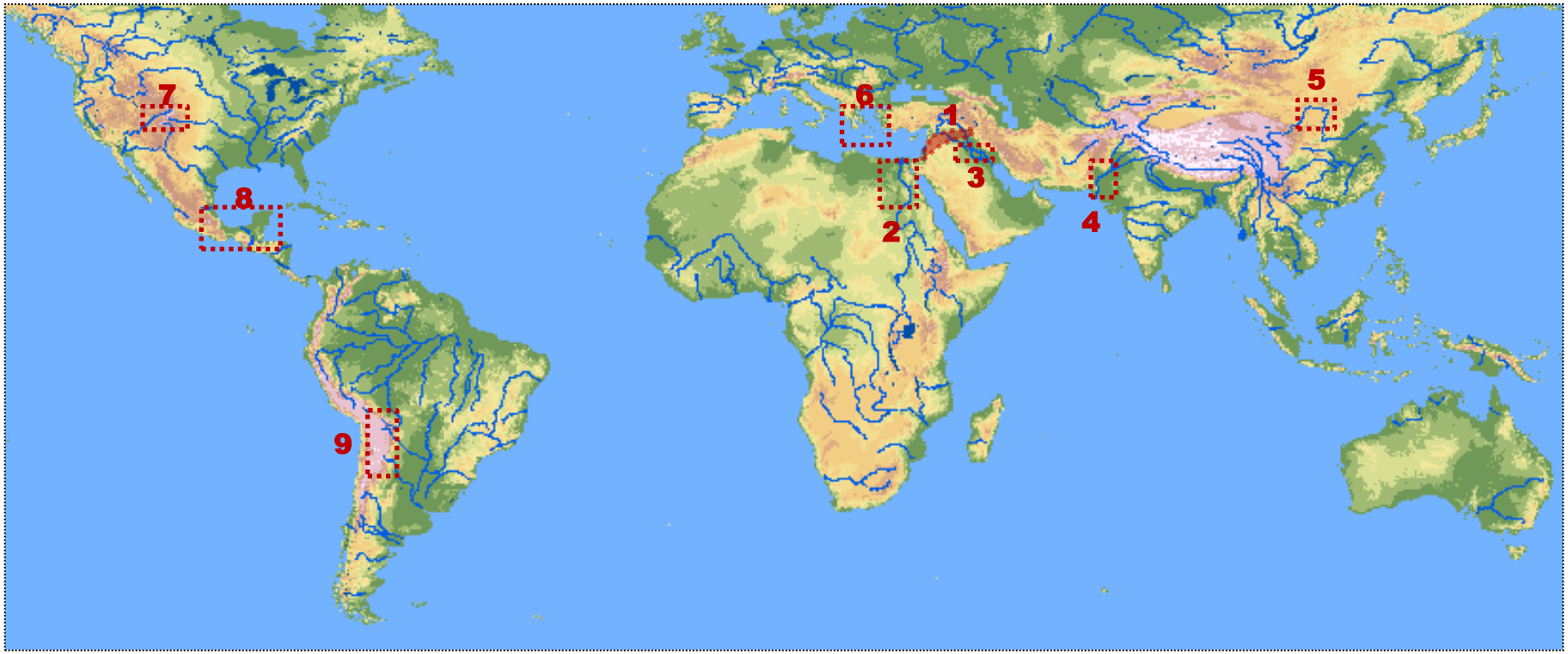
2. Nile valley

3. Mesopotamia (Tigris-Euphrates)

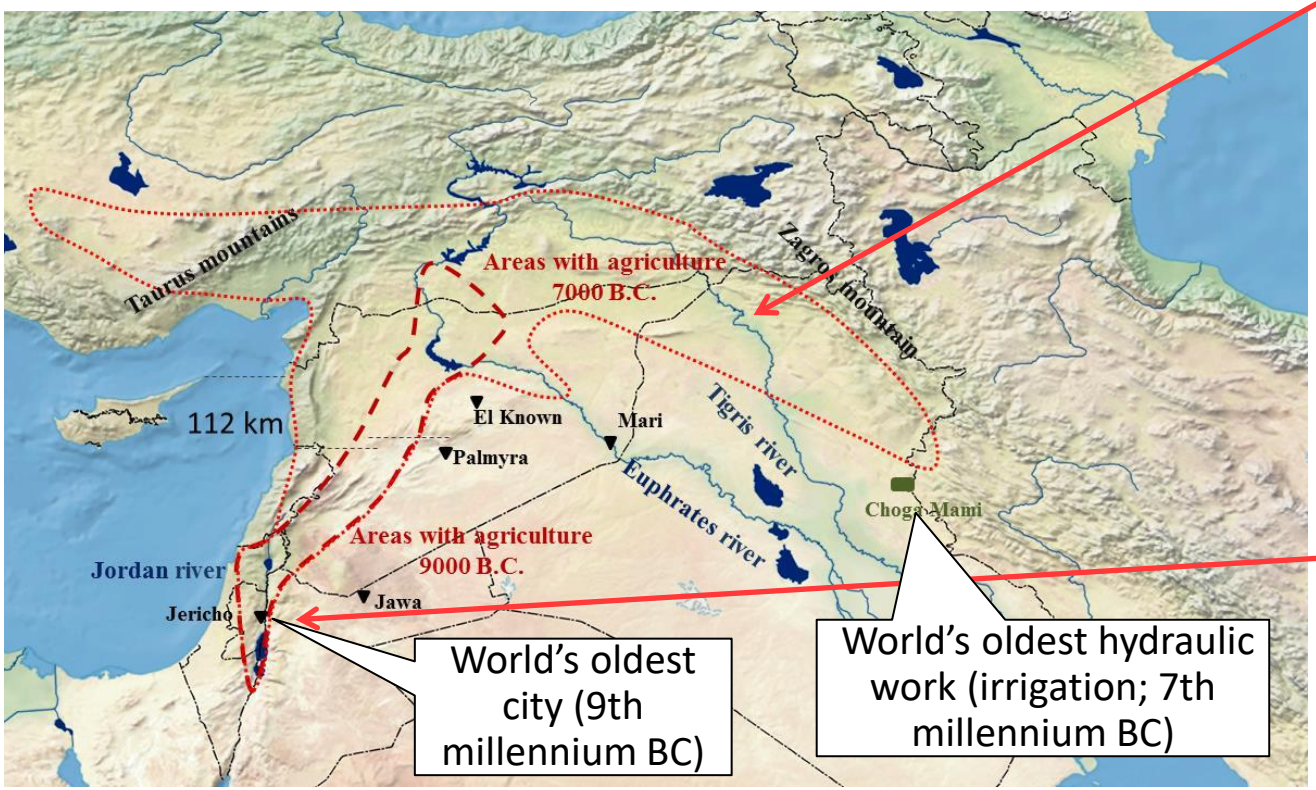
4. Indus valley

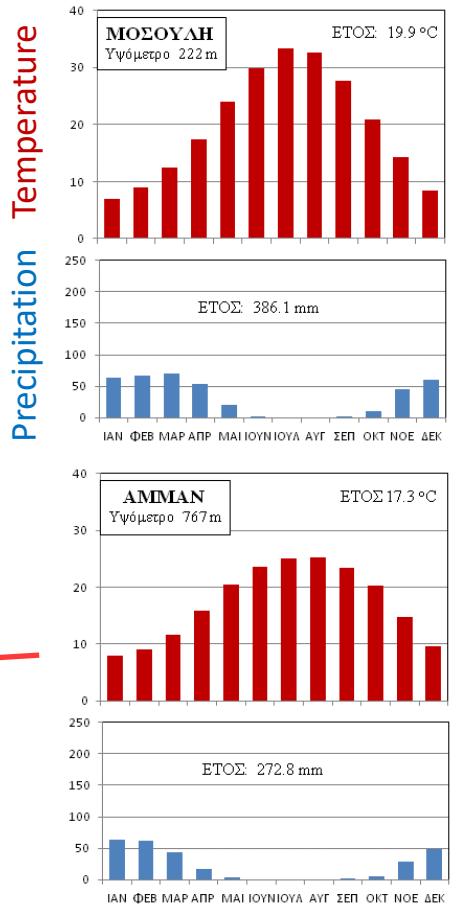
5. Yellow river valley

6. Greek civilizations *(from 3th millennium BC)*



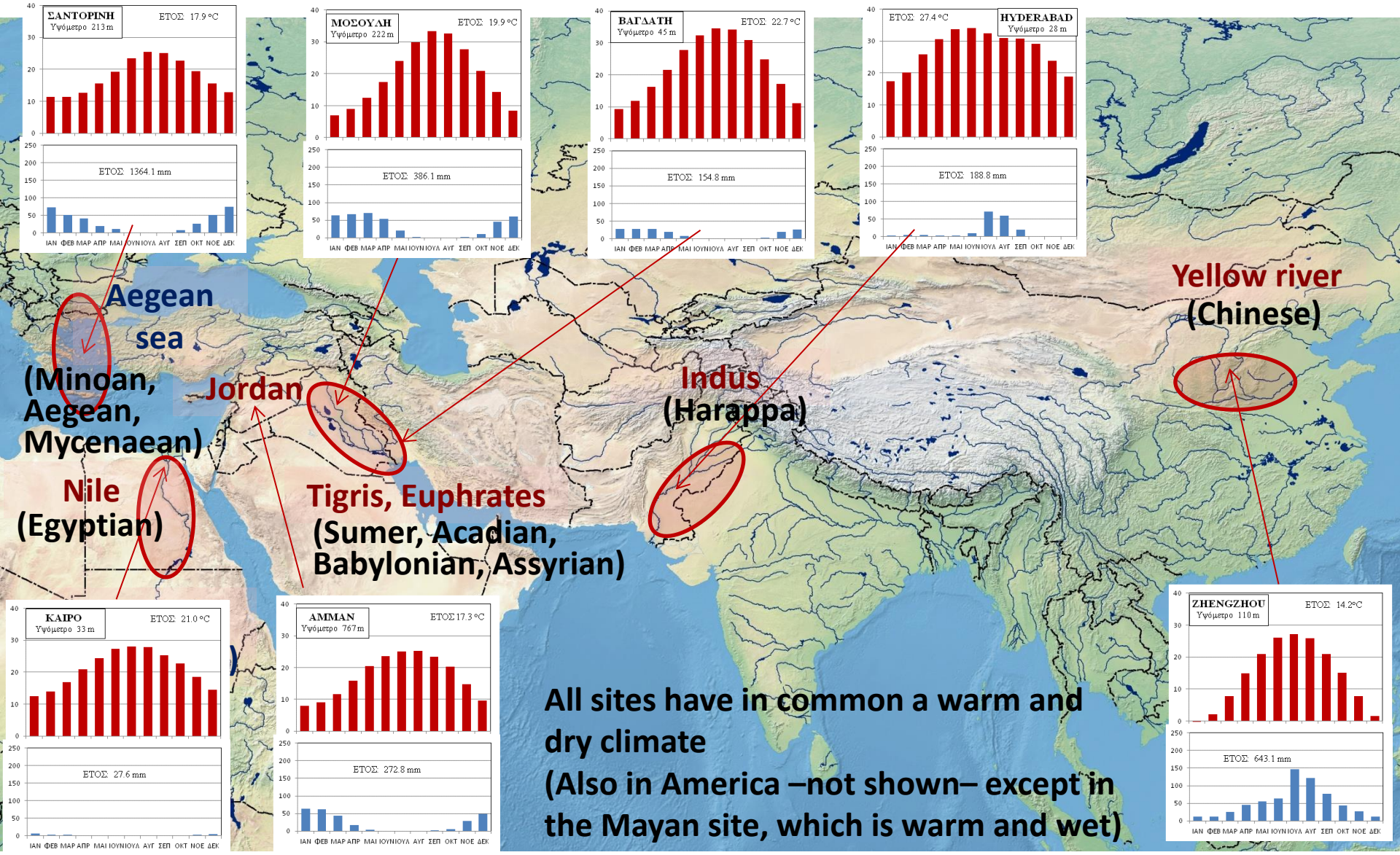
Conditions in the Fertile Crescent



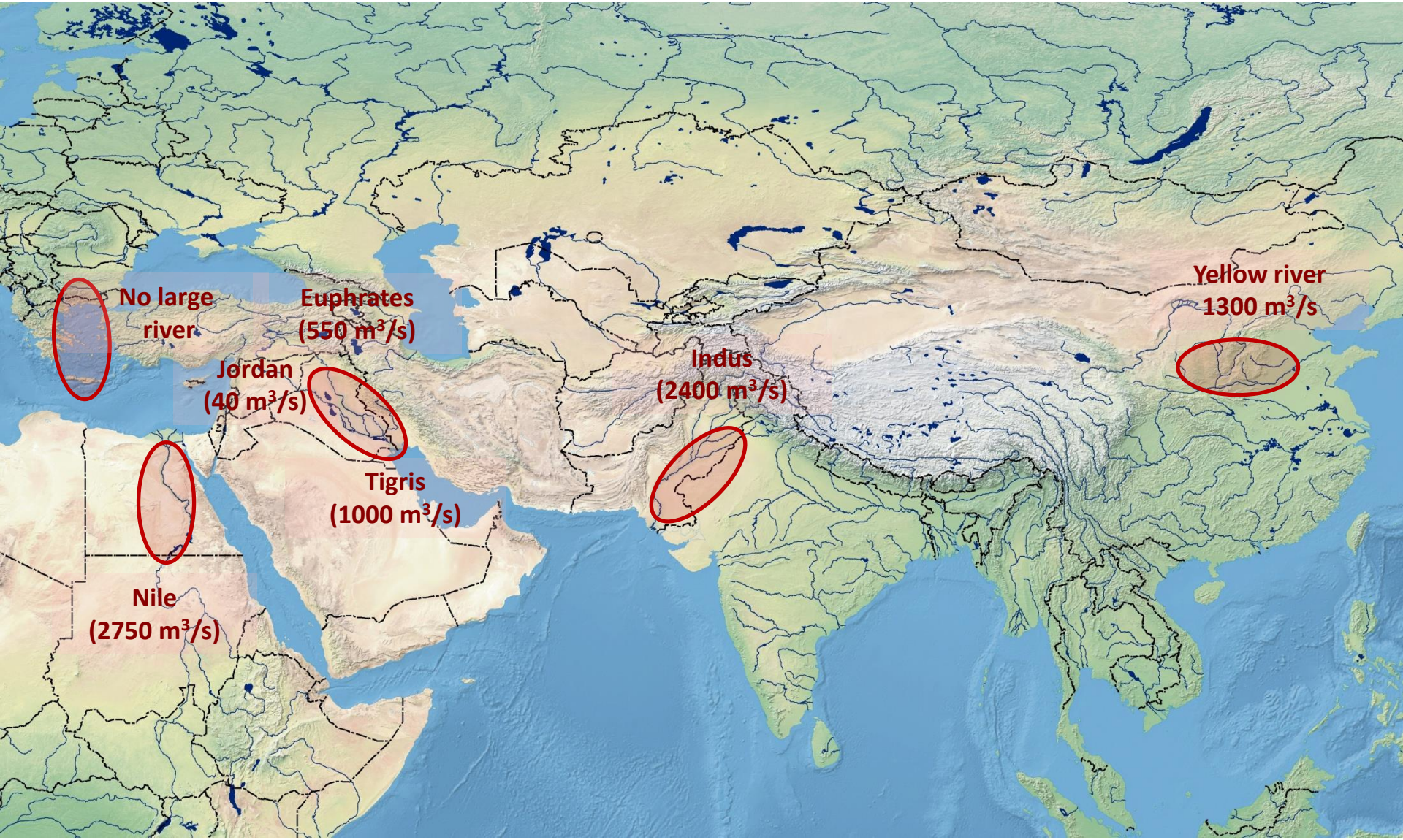


- **Neolithic period (after the last Glacial Age)**: groups of people concentrated at a zone of hills extended from Syria-Palestine to the foot of Taurus and Zagros mountains, where the winter rainfalls favoured the natural growth of wild grains, such as barley and wheat.
- **About 9000 BC (stabilized climate)**: these communities developed the first agricultural methods and animal domestication, and constructed the first small hydraulic works.
- **7500 to 4500 BC (Neolithic revolution)**: increased population was spread to nearby alluvial valleys of large rivers.

Climatological conditions in other ancient sites



Hydrological conditions in ancient sites



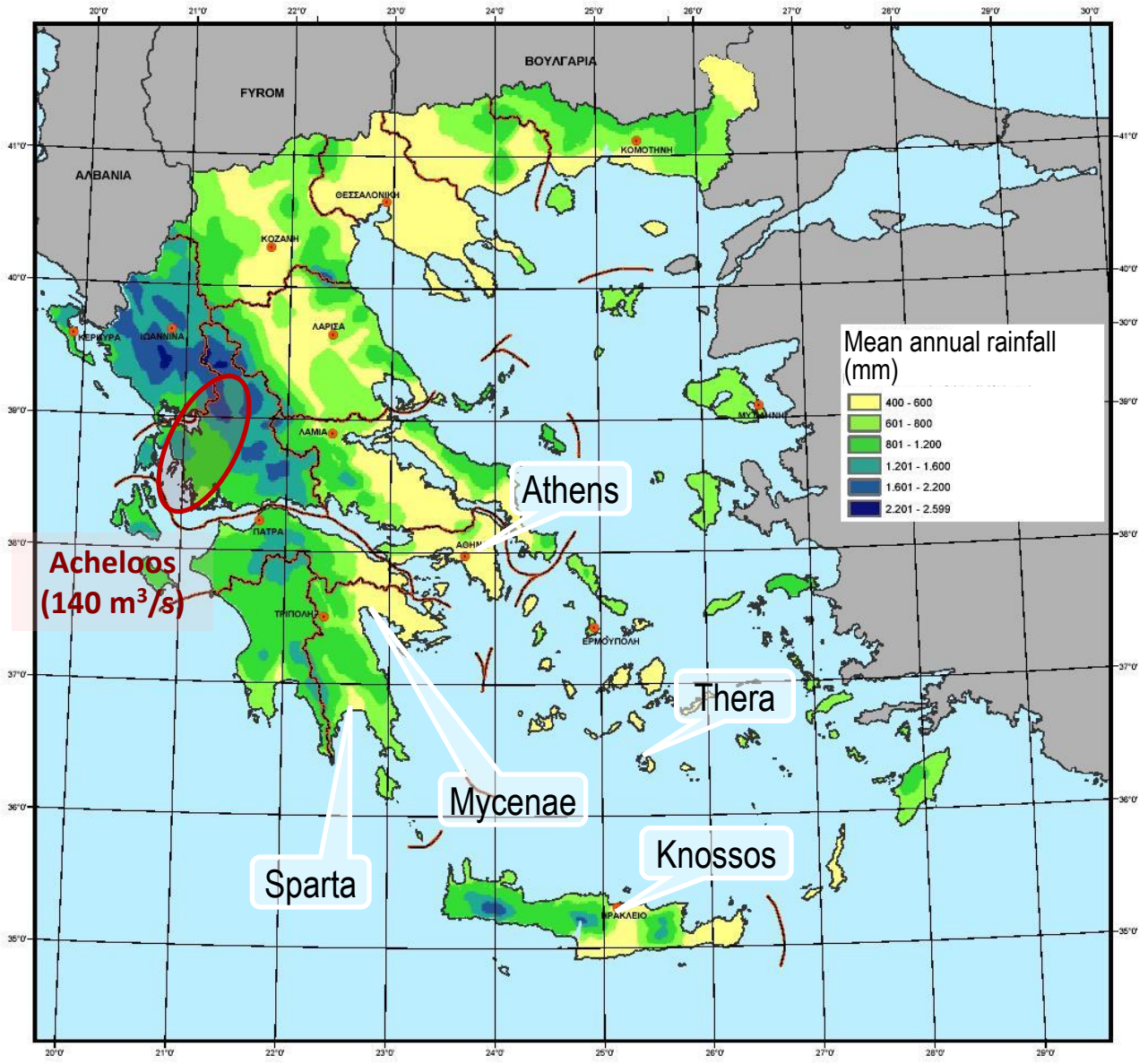
Hydroclimatic conditions and the ancient Greek civilizations

- Why ancient Greeks chose water-deficient places for their cities?

Or

- Why the settlements on water-deficient places were the most flourishing?
- What are the impacts of water scarcity on cultural progress?

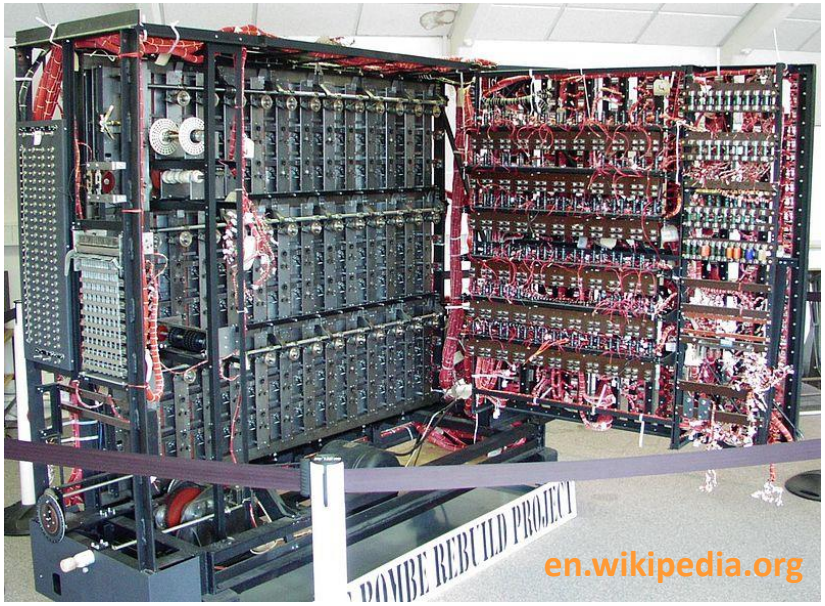
  (Can scarcity trigger progress in technology and management?)



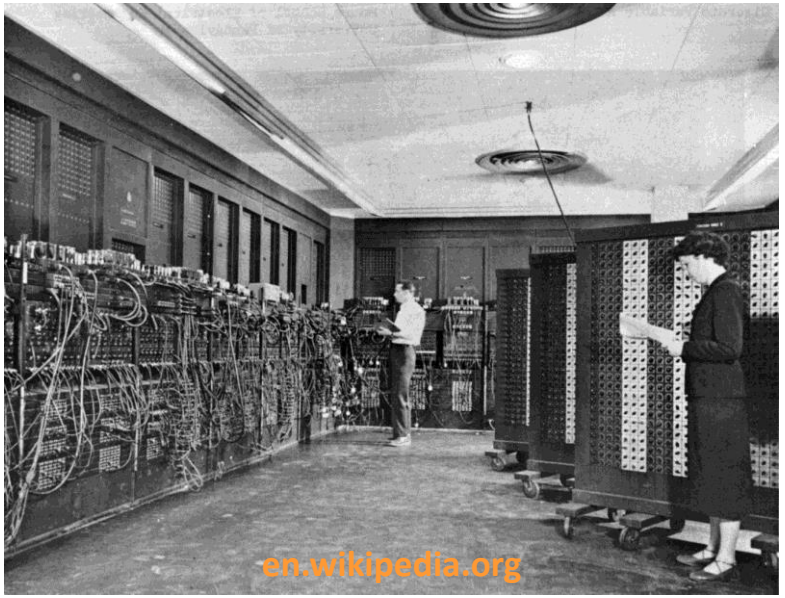
“Need is the mother of creativity” (“Necessity is the mother of invention”)

ἴϑι δή, ἦν δ᾽ ἐγώ, τῷ λόγῳ ἐξ ἀρχῆς ποιῶμεν πόλιν: ***ποιήσει δὲ αὐτήν****, ὡς ἔοικεν, ἡ* ***ἡμετέρα χρεία****.*
(Come, then, let us create a city from the beginning, in our theory. ***Its real creator****, as it appears, will be* ***our needs)****.*

Plato, Republic, 2.369c



A working replica of the electro-mechanical computer built by Alan Turing and other British cryptologists to decipher German Enigma-machine-encrypted messages during World War II.



ENIAC, the first Turing-complete electronic device, that performed ballistics trajectory calculations for the United States Army.

Scarcity and poverty triggers progress in Athens

μάλιστα δὲ τῆς γῆς ἡ ἀρίστη αἰεὶ τὰς μεταβολὰς τῶν οἰκητόρων εἶχεν, *ἥ τε νῦν* ***Θεσσαλία*** *καλουμένη καὶ* ***Βοιωτία Πελοποννήσου*** *τε τὰ πολλὰ πλὴν Ἀρκαδίας, τῆς τε ἄλλης ὅσα ἦν κράτιστα.* ***διὰ γὰρ ἀρετὴν γῆς*** *αἵ τε δυνάμεις τισὶ μείζους ἐγγιγνόμεναι στάσεις ἐνεποίουν* ***ἐξ ὧν ἐφθείροντο, καὶ ἅμα ὑπὸ ἀλλοφύλων μᾶλλον ἐπεβουλεύοντο. τὴν γοῦν Ἀττικὴν ἐκ τοῦ ἐπὶ πλεῖστον διὰ τὸ λεπτόγεων ἀστασίαστον οὖσαν ἄνθρωποι ᾤκουν οἱ αὐτοὶ αἰεί****. καὶ παράδειγμα τόδε τοῦ λόγου οὐκ ἐλάχιστόν ἐστι διὰ τὰς μετοικίας ἐς τὰ ἄλλα μὴ ὁμοίως αὐξηθῆναι:* ***ἐκ γὰρ τῆς ἄλλης Ἑλλάδος οἱ πολέμῳ ἢ στάσει ἐκπίπτοντες παρ᾽ Ἀθηναίους οἱ δυνατώτατοι ὡς βέβαιον ὂν ἀνεχώρουν,*** *καὶ πολῖται γιγνόμενοι εὐθὺς ἀπὸ παλαιοῦ μείζω ἔτι ἐποίησαν πλήθει ἀνθρώπων τὴν πόλιν, ὥστε καὶ ἐς Ἰωνίαν ὕστερον ὡς οὐχ ἱκανῆς οὔσης τῆς Ἀττικῆς ἀποικίας ἐξέπεμψαν.*

The richest soils were always most subject to this change of masters*; such as the district now called* ***Thessaly, Boeotia, most of the Peloponnese,*** *Arcadia excepted, and the most fertile parts of the rest of Hellas.* ***The goodness of the land f****avoured the aggrandizement of particular individuals, and thus* ***created faction which proved a fertile source of ruin. It also invited invasion. Accordingly Attica, from the poverty of its soil enjoying from a very remote period freedom from faction****, never changed its inhabitants. And here is no inconsiderable exemplification of my assertion that the migrations were the cause of there being no correspondent growth in other parts. The most* ***powerful victims of war or faction from the rest of Hellas took refuge with the Athenians as a safe retreat****; and at an early period, becoming naturalized, swelled the already large population of the city to such a height that Attica became at last too small to hold them, and they had to send out colonies to Ionia.*

Thucydides, The Peloponnesian War, 1.2.3-6

Reflection from mythology on water scarcity: 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 – but a **choice**.
- **Wisdom** may be more powerful than **abundance**.

Water supply in ancient Athens

Wisdom in early water legislation in Athens

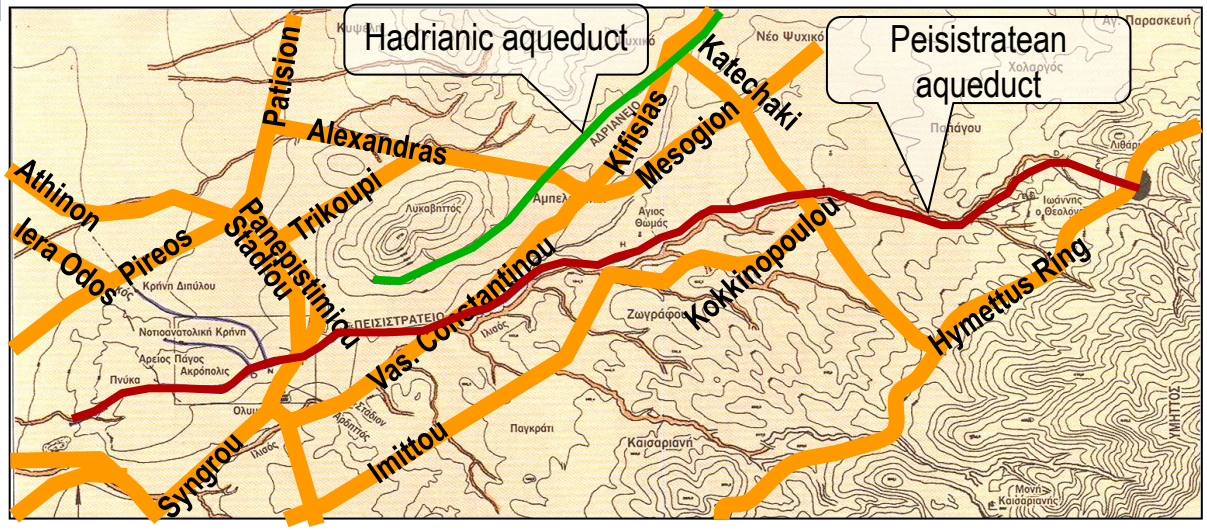
- *ἐπεὶ δὲ πρὸς ὕδωρ οὔτε ποταμοῖς ἐστιν ἀενάοις οὔτε λίμναις τισὶν οὔτ᾽ ἀφθόνοις πηγαῖς ἡ χώρα διαρκής, ἀλλ᾽ οἱ πλεῖστοι φρέασι ποιητοῖς ἐχρῶντο, νόμον ἔγραψεν, ὅπου μέν ἐστι δημόσιον φρέαρ ἐντὸς ἱππικοῦ, χρῆσθαι τούτῳ: τὸ δ᾽ ἱππικὸν διάστημα τεσσάρων ἦν σταδίων: ὅπου δὲ πλεῖον ἀπέχει, ζητεῖν ὕδωρ ἴδιον: ἐὰν δὲ ὀρύξαντες ὀργυιῶν δέκα βάθος παρ᾽ ἑαυτοῖς μὴ εὕρωσι, τότε λαμβάνειν παρὰ τοῦ γείτονος ἑξάχουν ὑδρίαν δὶς ἑκάστης ἡμέρας πληροῦντας: ἀπορίᾳ γὰρ ᾤετο δεῖν βοηθεῖν, οὐκ ἀργίαν ἐφοδιάζειν*

  (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 [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 L] *twice a day from their neighbours; for he thought it prudent to make provision against need, but not to supply laziness.)*

  Plutarch, Solon, 23

- Important elements of this law are:
  - the priority of public wells and their protection;
  - the balance of the public and private interests for the construction and operation of wells;
  - the regulation of relationships among individuals in order to cover water needs of all citizens;
  - the provision against need, while discouraging laziness.

Technological advances: aqueducts




Syntagma Square

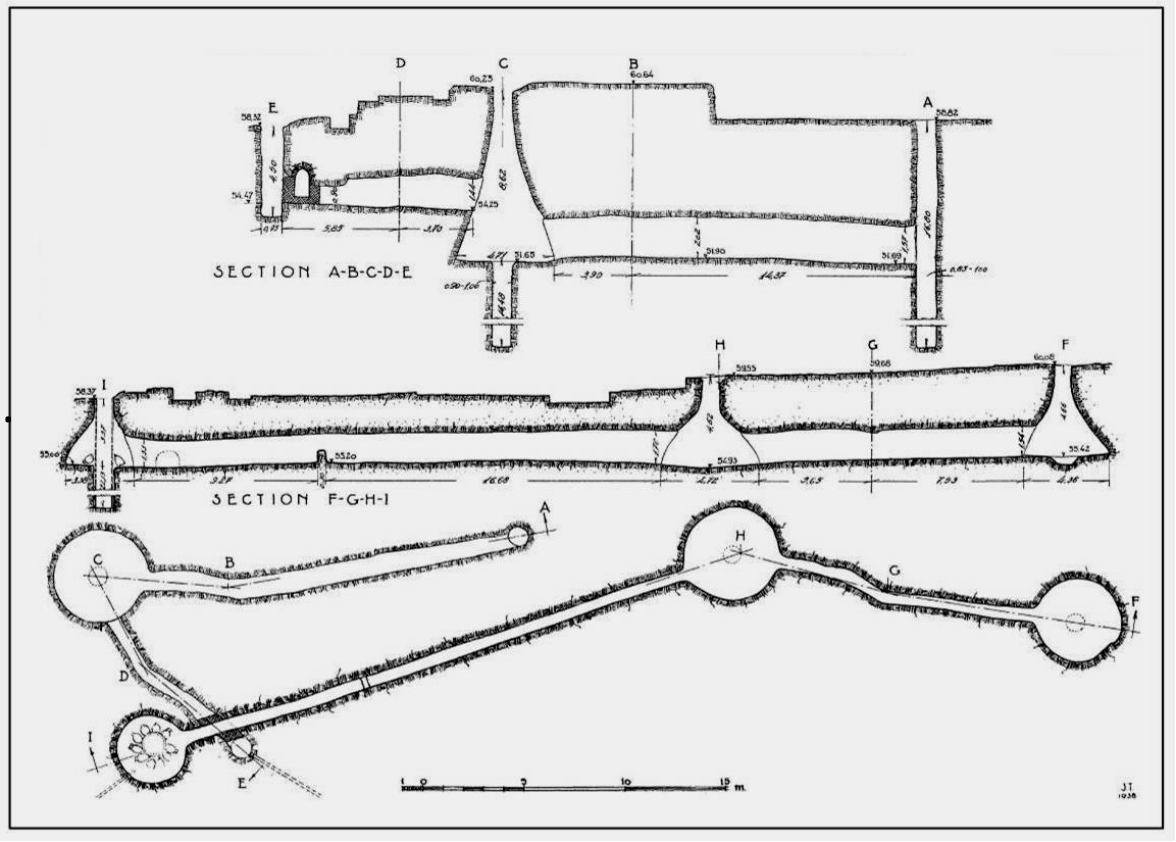

Evangelismos Metro station

For cleaning and maintenance, in their upper part the pipes had elliptic openings covered by ceramic covers.

- The first major hydraulic project in Athens was constructed under the tyrant Peisistratos (in power between 546-527 BC) and his sons.
- The largest part of the aqueduct was carved as a tunnel at depth reaching 14 m.
- Other aqueducts were also constructed in several phases forming a network of pipelines; one of them, the Hymettus aqueduct, follows a route parallel to the Peisistratean.
- Greek hydraulic constructions were mostly underground for security reasons (e.g. in case of war; Koutsoyiannis et al., 2008).

Small scale water constructions

- In addition to wells and large-scale aqueducts, Athenians developed a technology of storing rainwater from roofs in underground cisterns.
- In several cases, small-scale constructions, i.e. wells and cisterns, were interconnected forming complex systems storing ground- and rain-water.
- The rationale behind such connections must have been:
  - to recharge aquifers with excess rainwater;
  - to use the tunnels as extra storage;
  - to facilitate water distribution exploiting principles of hydraulics.



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

Rationale behind the complex Athens water supply system

- Using many sources of water, i.e. ground-, rain- and spring-water, makes the system more reliable than relying on a single source.
- Using and maintaining large-scale public works (aqueducts) can provide more water at lower cost.
- However, the private small-scale constructions (wells and cisterns), provide security and safety, particularly in times of war and crisis:

  ὑδάτων τε καὶ ναμάτων μάλιστα μὲν ὑπάρχειν πλῆθος οἰκεῖον, εἰ δὲ μή, τοῦτό γε εὕρηται διὰ τοῦ ***κατασκευάζειν ὑποδοχὰς ὀμβρίοις ὕδασιν ἀφθόνους*** *καὶ μεγάλας, ὥστε* ***μηδέποτε ὑπολείπειν εἰργομένους τῆς χώρας διὰ πόλεμον****.*

  (*…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****.*)

  Aristotle, Politics, 7, 1330b

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.
- This officer was one of the few that were elected by vote whereas other officers were chosen by lot:

  τὰς δ᾽ ἀρχὰς τὰς περὶ τὴν ἐγκύκλιον διοίκησιν ἁπάσας ποιοῦσι κληρωτάς, πλὴν ταμίου στρατιωτικῶν καὶ τῶν ἐπὶ τὸ θεωρικὸν καὶ τοῦ τῶν ***κρηνῶν ἐπιμελητοῦ. ταύτας δὲ χειροτονοῦσιν****, καὶ οἱ χειροτονηθέντες ἄρχουσιν ἐκ Παναθηναίων εἰς Παναθήναια.* ***χειροτονοῦσι δὲ καὶ τὰς πρὸς τὸν πόλεμον ἁπάσας****.*

  (*All the officials concerned with the regular administration are appointed by lot, except a Treasurer of Military Funds, the Controllers of the Spectacle Fund, and the* ***Superintendent of Fountains; these officers are elected by show of hands****, and their term of office runs from one Panathenaic Festival to the next.* ***All military officers also are elected by show of hands***.)

  Aristotle, Athenaion Politeia, 43.1
- This must be related to the high importance of this particular position, in which even Themistocles had served.
- Generally, private sponsoring of public hydraulic systems was encouraged; e.g. in 333 BC the Athenians awarded a gold wreath to the Superintendent of Fountains Pytheus because he restored and maintained several fountains and aqueducts.

The Hadrianic aqueduct in Athens

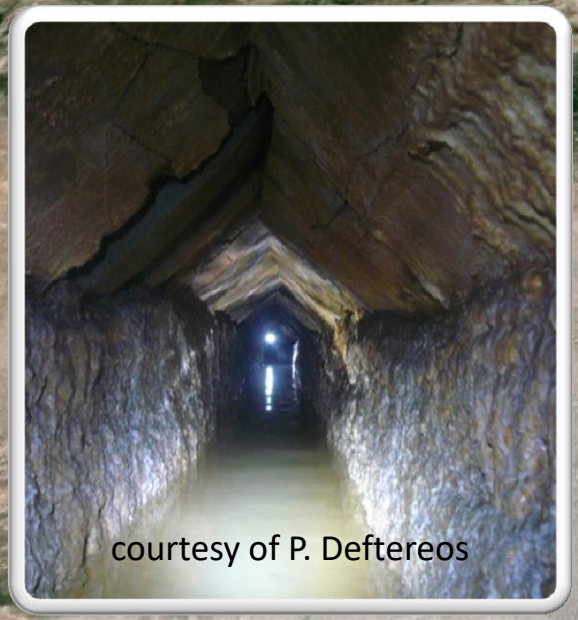
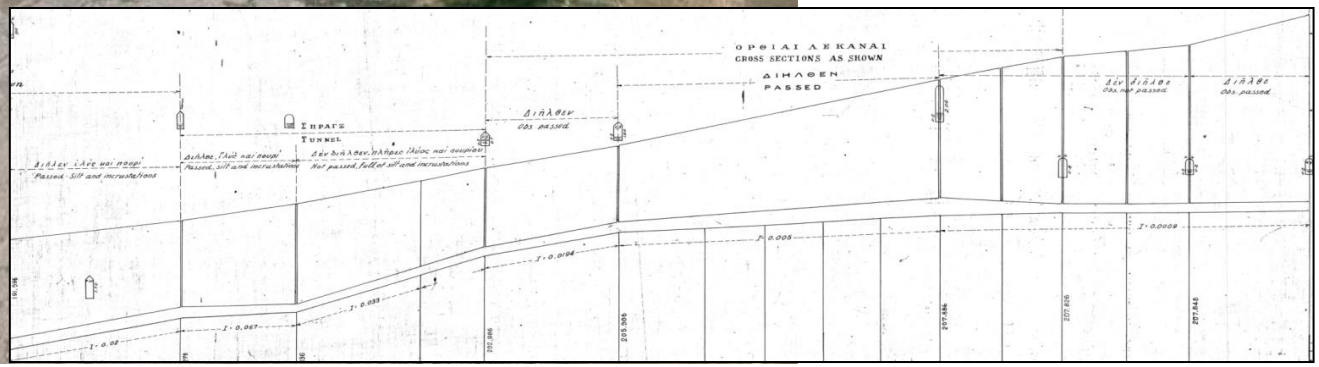

courtesy of P. Deftereos

Image from Google Earth

- The last and longest ancient aqueduct, the Hadrianic aqueduct, was constructed during Roman times.
- Its length is 25 km and, as all earlier ones, it is subterranean at typical depths of 20-30 m.



The Hadrianic aqueduct

Some cross-sections

Main tunnel with inflows through the walls

Lateral inflows through small works

Photos by P. Deftereos

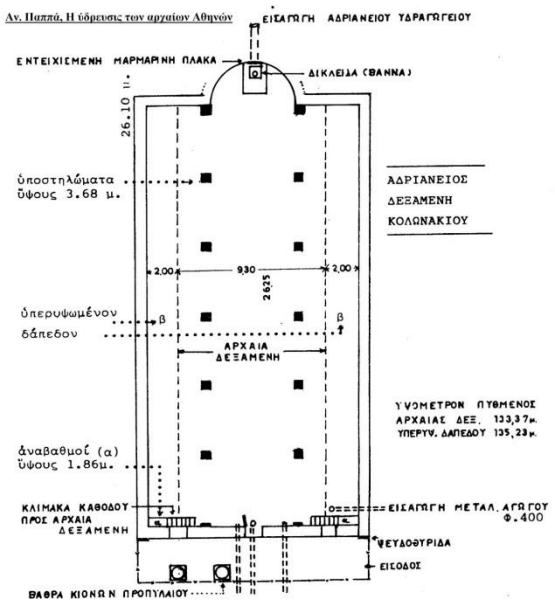
The modern water supply system and its links to the past

Ancient Greek inheritance to the modern Athens water system

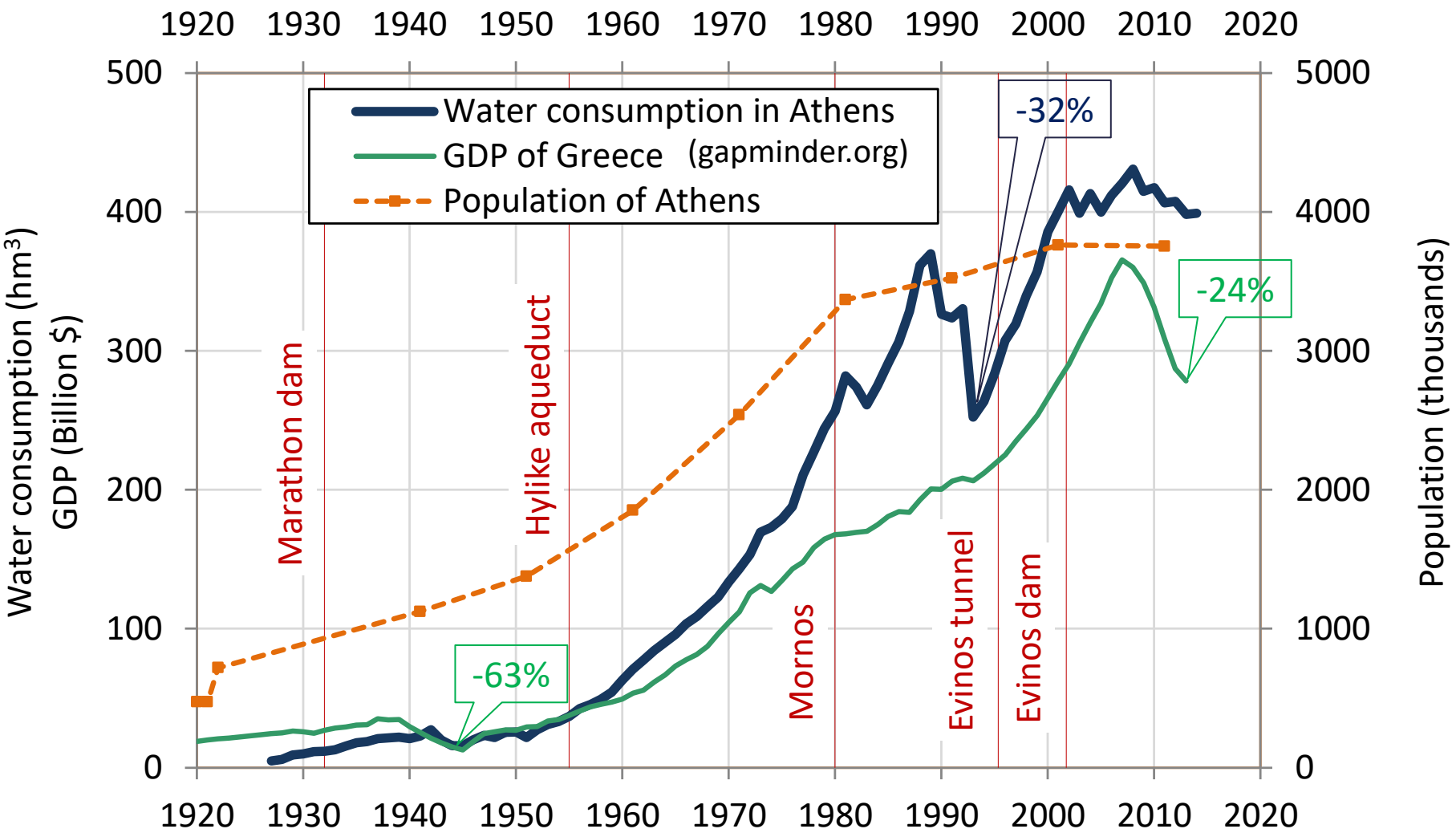
- One ancient aqueduct (Peisistratian or Hymettus?) is still in operation providing irrigation water to the National Garden.
- In 1870 the Hadrianic aqueduct was repaired and its cistern in Lycabettus was reconstructed.
- The Hadrianic system used to provide drinking water up to the mid-20th century.


Irrigation in the Athens National Garden
Image from Panagoulia and Zarris (2009)

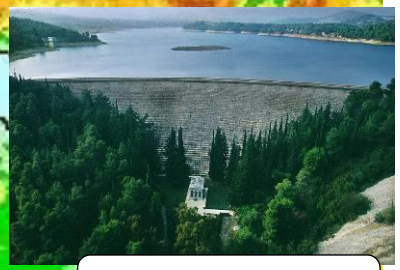

courtesy of P. Deftereos

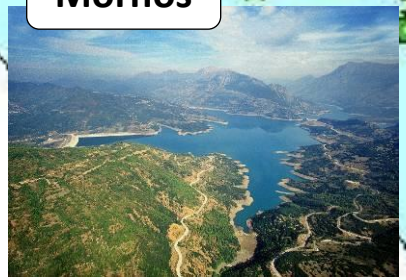


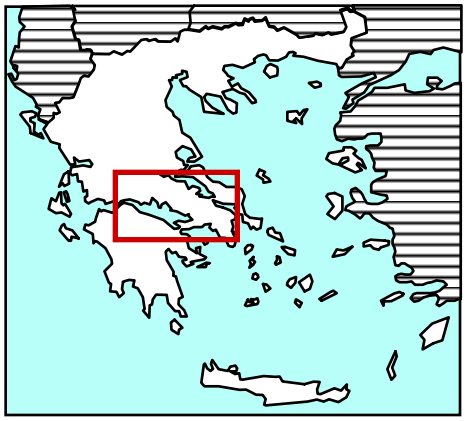
Evolution of water consumption in modern Athens



The modern Athens water supply system







Evinos

Canal at Delphi

Hylike lake

Marathon

Mornos

Athens

Evinos R.

Mornos R.

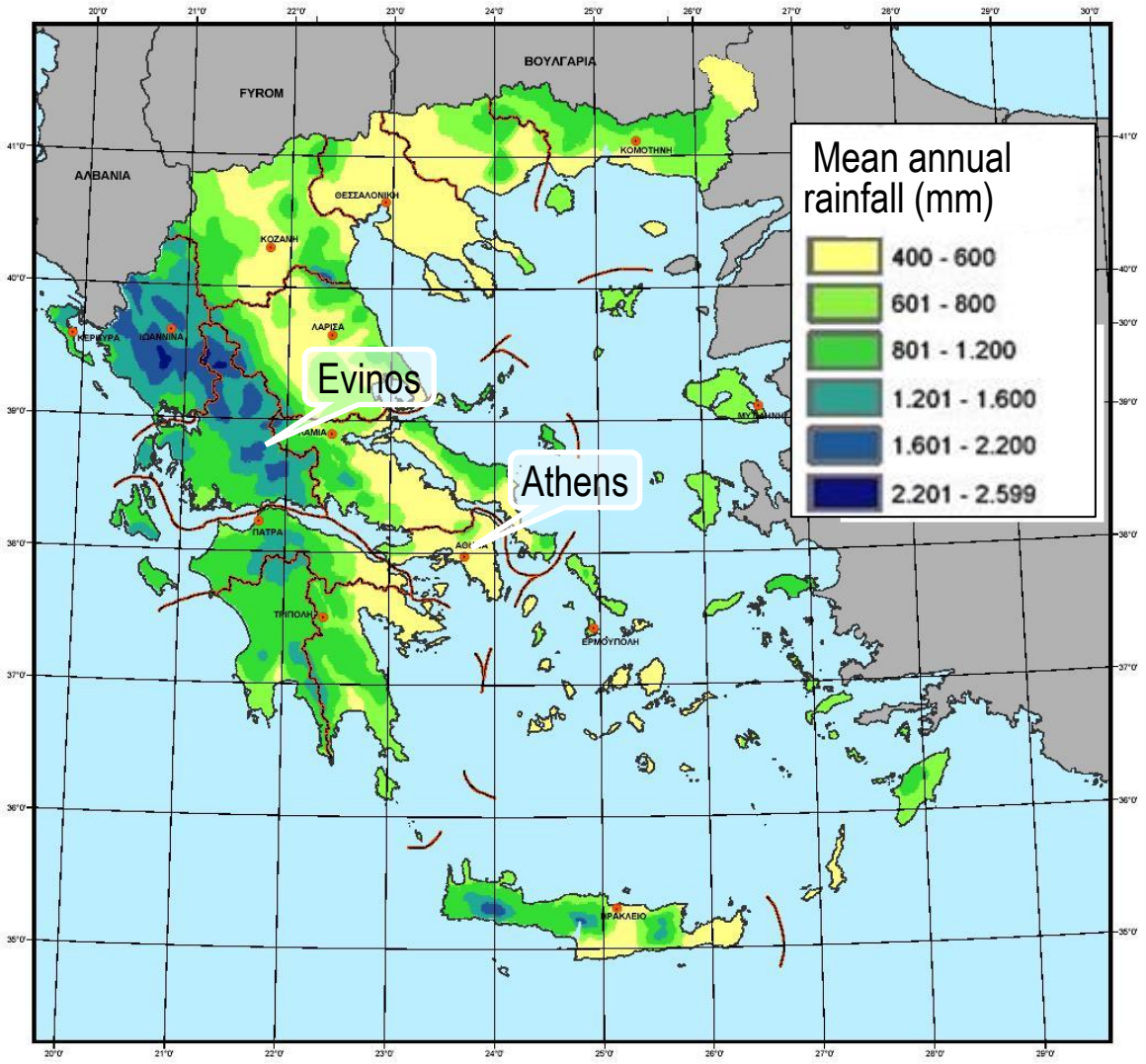
0 10 20 30 km

The Athens aqueducts compared to some of the world's most famous aqueducts

- Longest path of the Athens water supply system: 217 km from Evinos to Athens (Acharnae WRP), not counting the path across the Mornos reservoir.
- Los Angeles First Aqueduct: 375 km.
- Los Angeles Second Aqueduct: 220 km.
- Delaware Aqueduct, New York: 137 km (the world's longest continuous underground tunnel).
- Croton Aqueduct, New York : 66 km.
- Quabbin Aqueduct, Massachusetts: 40 km (tunnel).
- Chicopee Valley Aqueduct, Massachusetts: 21 km.
- Sooke Flowline, City Of Victoria (Vancouver Island, Canada): 44 km.
- Päijänne Water Tunnel, Helsinki: 120 km (underground aqueduct).
- Thirlmere Aqueduct, Manchester: 154.3 km.
- National Water Carrier of Israel: 130 km (a system to transfer water from the Sea of Galilee in the north of the country to the highly populated center and arid south).

Why modern Athenians needed to convey water from so far west?

- The reason is the same that led their ancestors to build elaborate (and very long for the era) aqueducts: **Annual rainfall 400 mm**.
- Modern Athenians, were able to combine:
  - The convenient and healthy way of living in dry climate;
  - The water sufficiency of the wet western part of Greece.



Links to the past: Marathon dam

The first modern project for Athens water supply was constructed between 1926 and 1929 by Ulen & Co. from New York.

The project included:

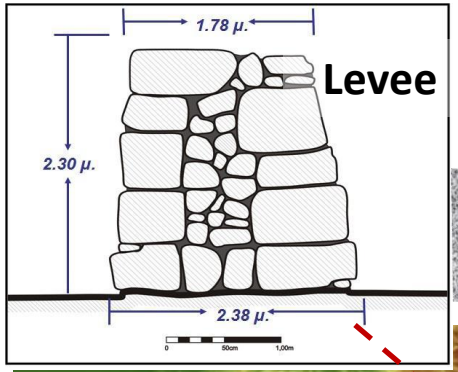
- a 54 m tall concrete dam, the only in the world with a marble coating;
- a 21.5 km aqueduct (with a tunnel);
- a water treatment plant.

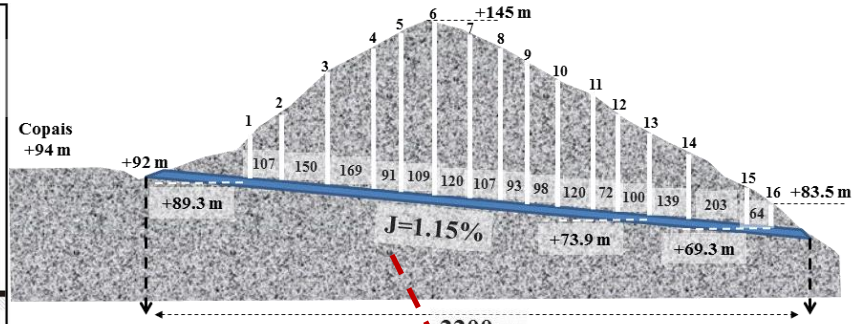
The structure at the end of the bottom outlet is a replica of the Athenian Treasury at Delphi that was build for the victory in the Battle of Marathon (490 BC).

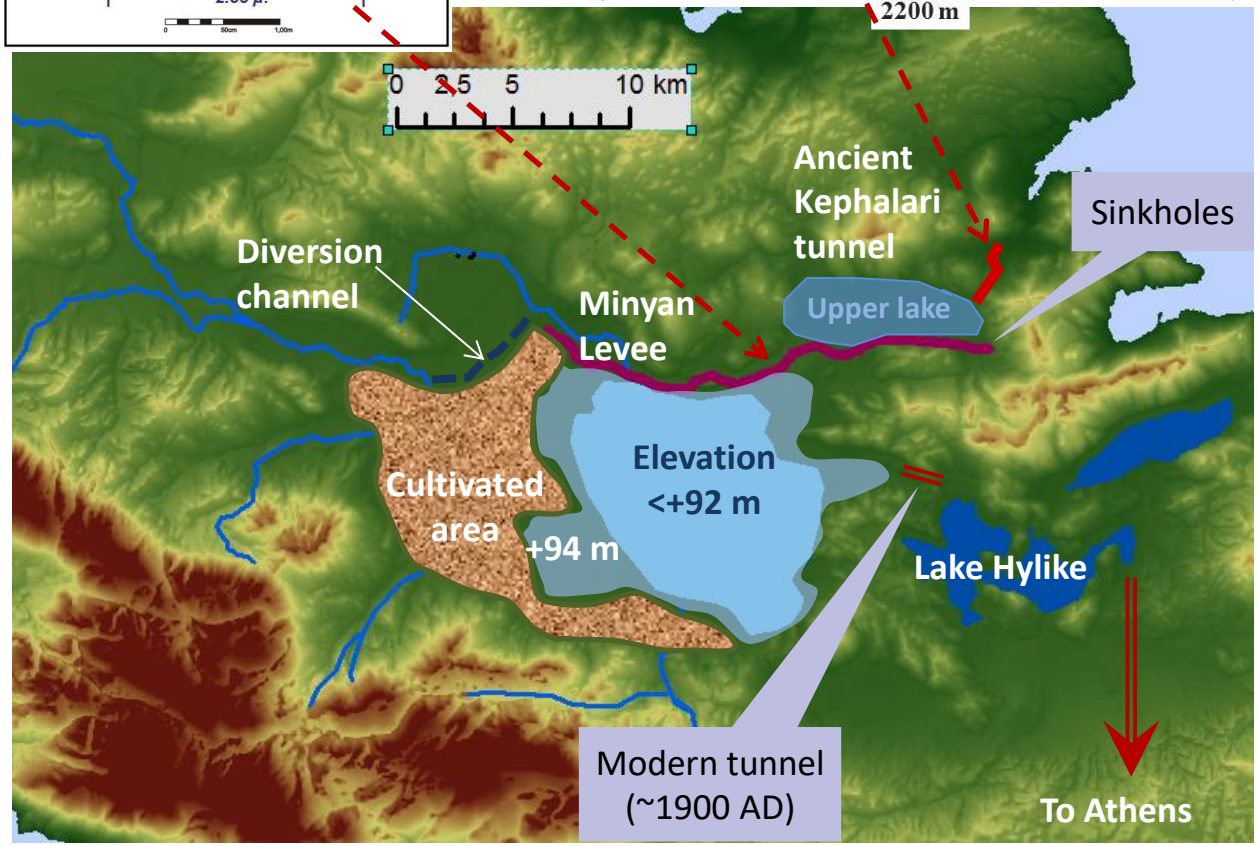
The replica symbolizes the victory of modern Athenians against drought.

Links to the past: Lake Hylike & former Lake Copais

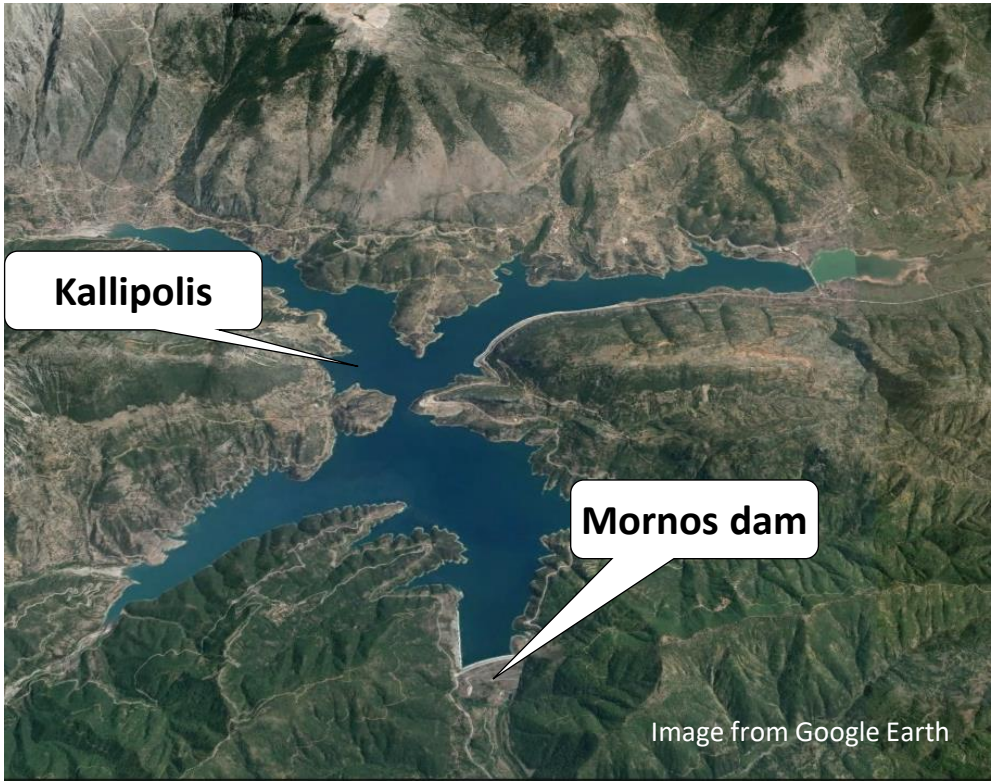
- The Lake Hylike (part of the Athens WSS) receives waters from the former lake Copais, which was drained at ~1900 AD.
- During the Mycenaean period (12th century BC), the Minyans drained part of the lake Copais and reclaimed land for agriculture.
- A channel and a levee diverted two rivers to natural sinkholes (Mamassis et al., 2015).
- Later, a drainage tunnel was attempted but never completed.





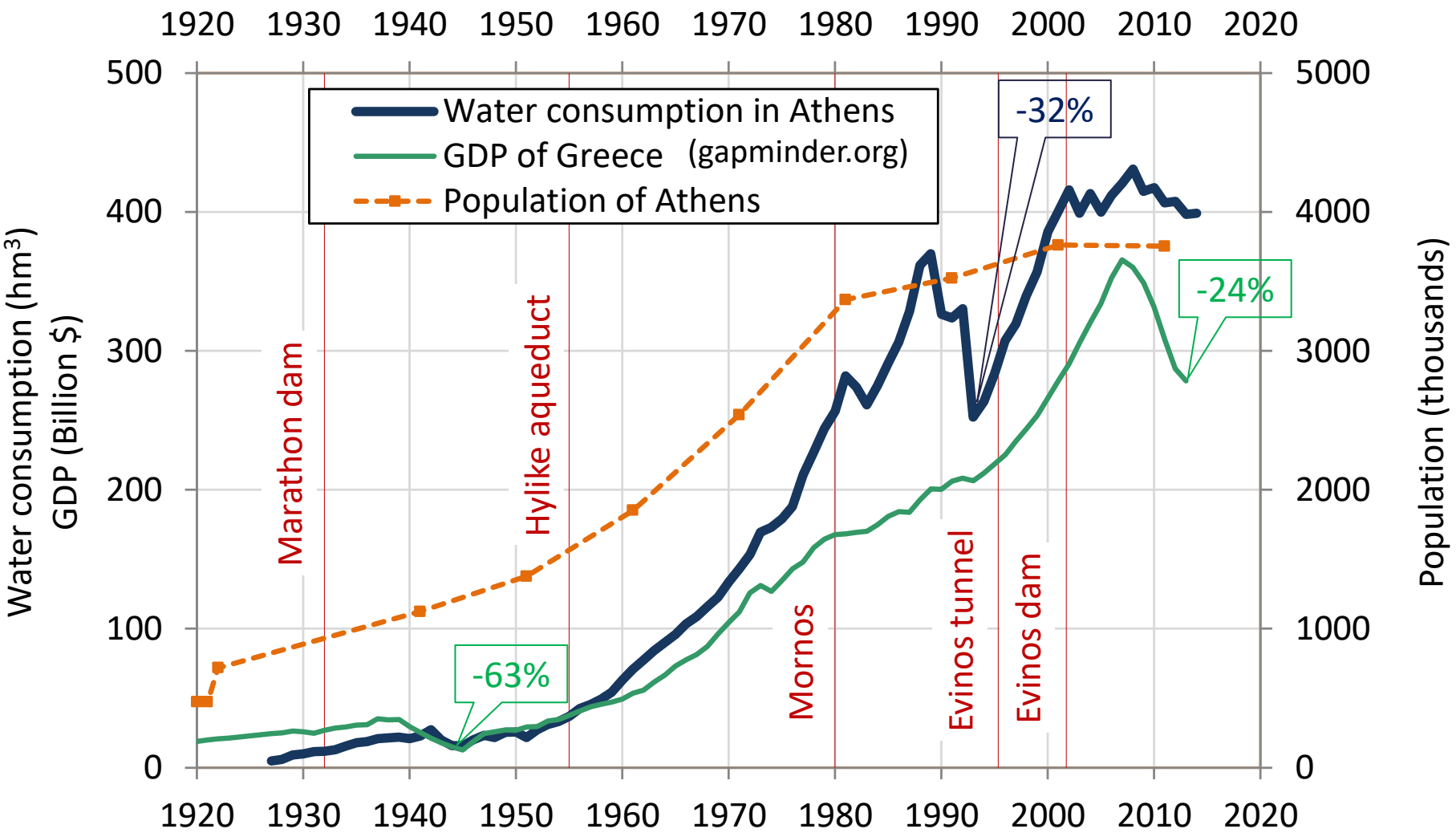


Links to the past: Mornos dam



- To exploit the water of the Mornos River, the ancient city of Kallipolis was sacrificed, along with the modern village of Kallion.
- They are now submerged in the Mornos reservoir.

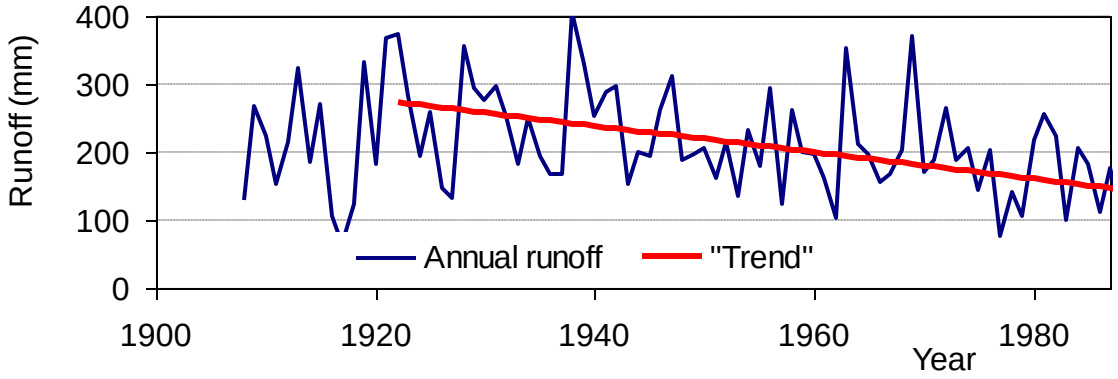
The water crisis in Athens in 1988-94



Hydrological conditions leading to the crisis

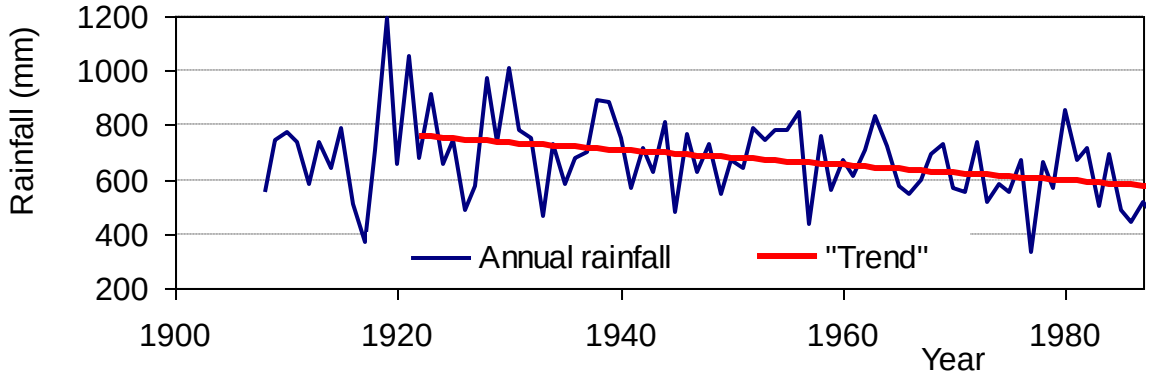
The historical time series of Boeoticos Kephisos runoff (Hydrological years 1907/08-1986/87)

A multi-year «trend» is observed



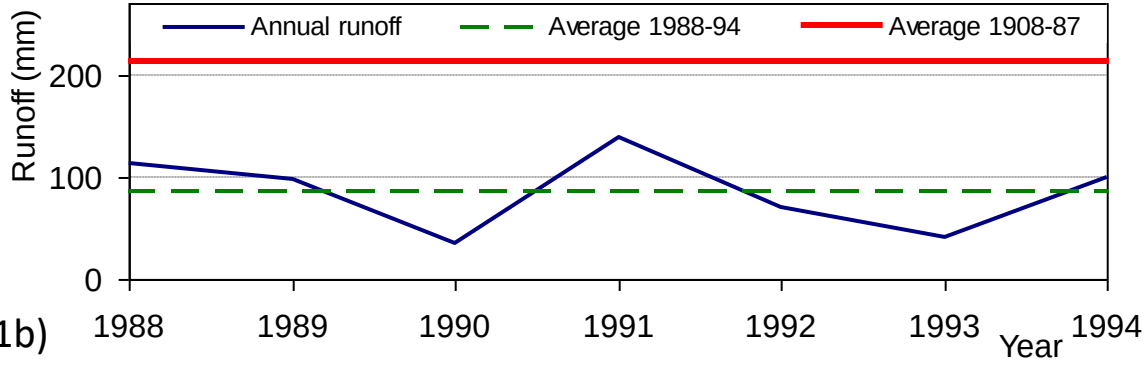
A similar «trend» in the rainfall time series

Explains the «trend» in runoff



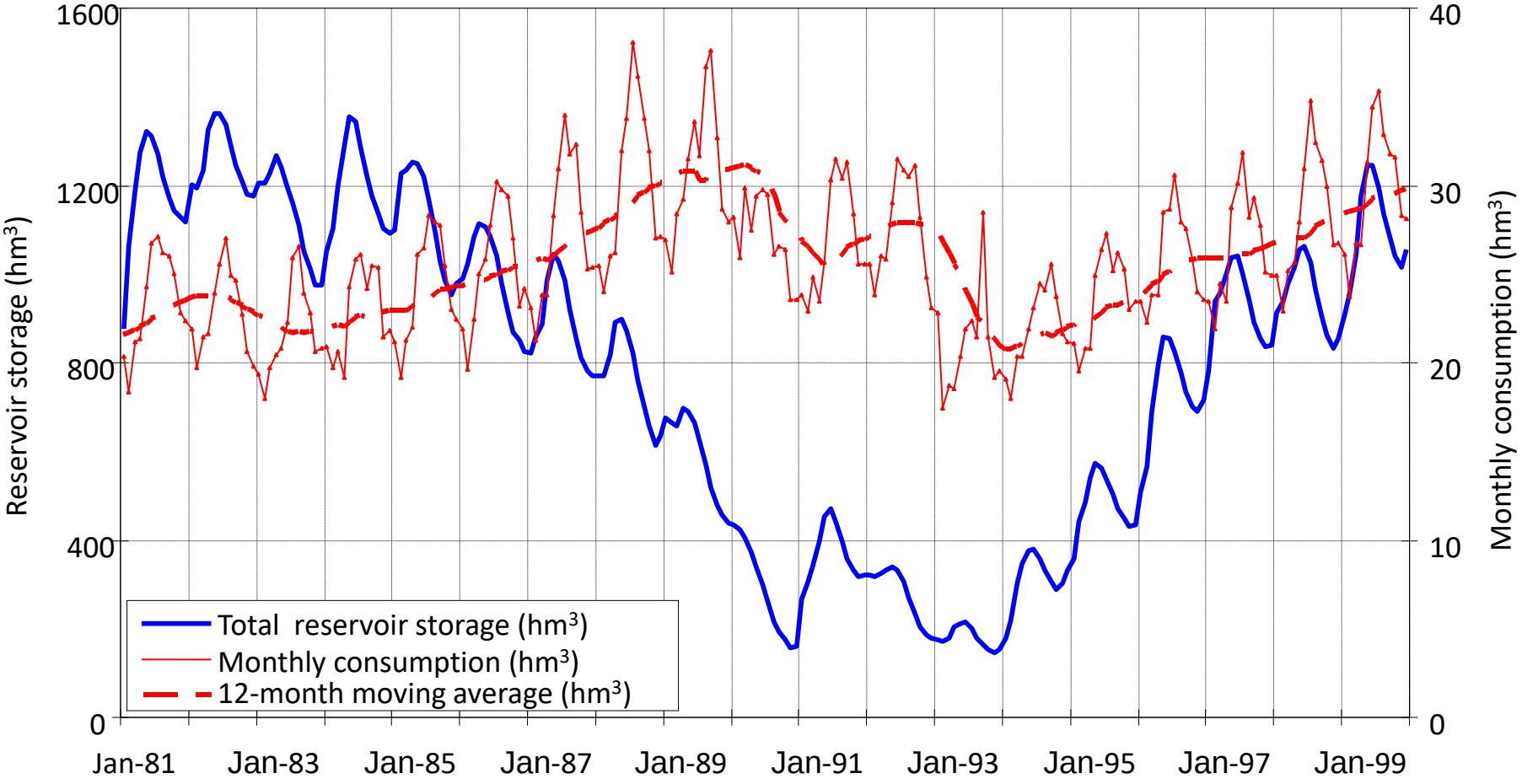
Next was a shocking drought

Intense and persistent: Mean flow less than half compared to historical average, duration 7 years

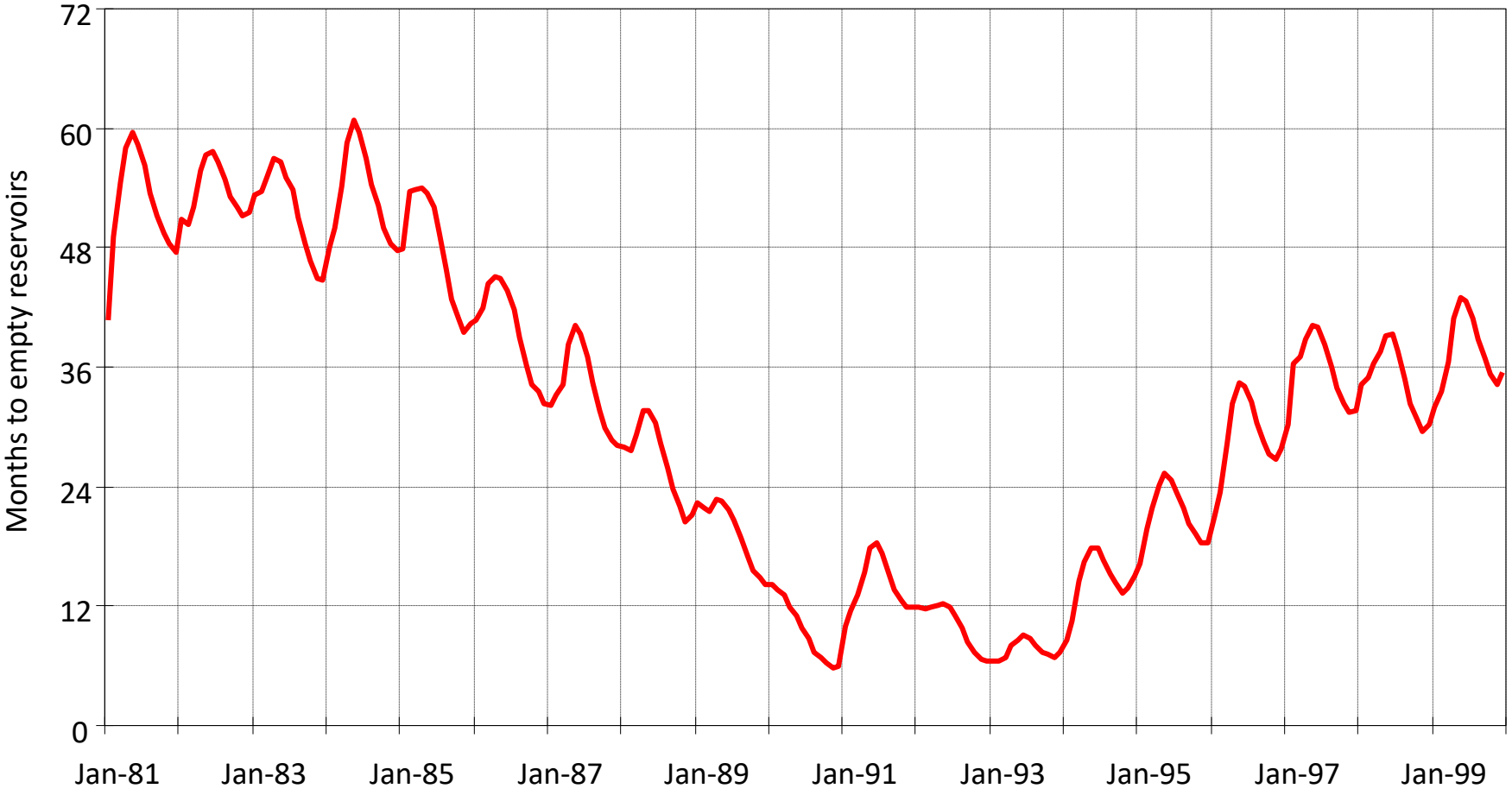


(See details in Koutsoyiannis, 2011b)

Temporal evolution of water storage and consumption



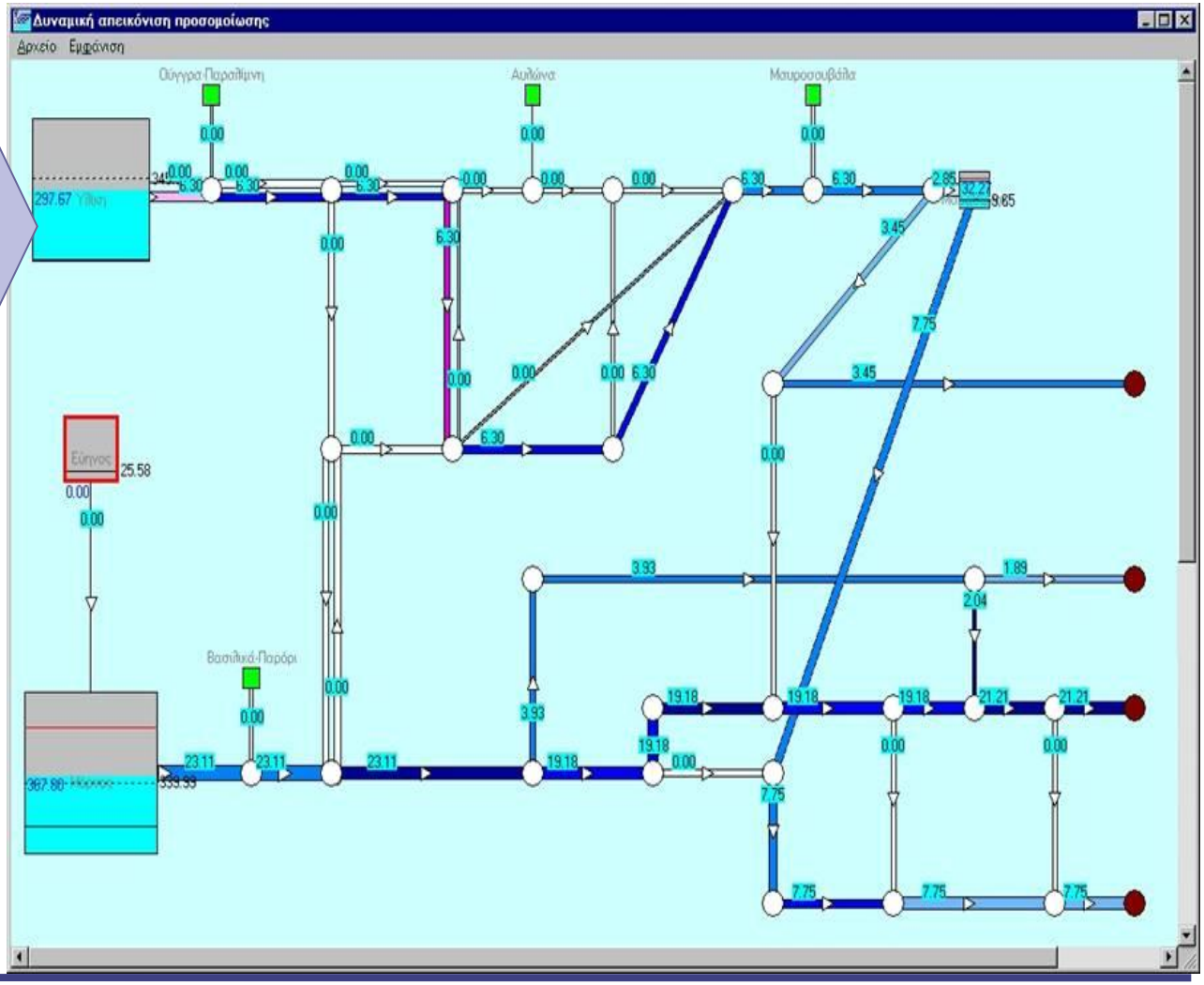
Temporal evolution of storage expressed as the number of months to come for which water suffices



How we dealt with the persistent drought: Development of an innovative decision support tool

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

See theoretical and practical justification of the approach in Nalbantis and Koutsoyiannis (1992, 1997); Koutsoyiannis and Economou (2003); Koutsoyiannis et al. (2002, 2003); and Efstratiadis et al. (2004)



How we dealt with the persistent drought: Structural measures

- New large-scale works, namely the Evinos dam and tunnel, were studied and constructed; the tunnel was completed in record short time (< 3 years).
- Aquifers were intensively exploited with new boreholes and pumping stations.
- Individuals and municipalities searched for alternative local water sources, mostly groundwater from lower quality local aquifers, to irrigate private and public gardens, to wash roads and cars and to use in industry.

How we dealt with the persistent drought: Water demand control

- Two drastic increases in water price, with increasing-block tariffs and discount for significant water conservation.
- Severe restrictive regulations, including:
  - prohibiting and fining the use of treated water for irrigation, car and road wash, and swimming pools;
  - restricting private consumption to an upper limit (70-100% of the consumption of the previous year), and fining heavily the exceedance of this limit.
- A massive public information campaign (via press, TV, internet, school programmes) so that:
  - all people be aware of the problem and its real causes;
  - all people actively participate to the problem solution.

More info: Xenos et al., 2002

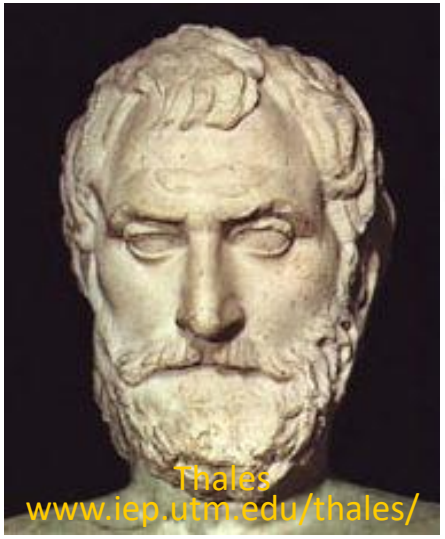
The most important Ancient Greek legacies and their usefulness to solutions of modern problems (1)

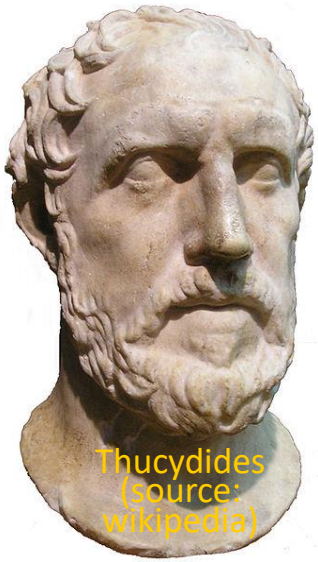
- Creation of philosophy and episteme (i.e. science), explaining nature and history based on reason).
  - Thales of Miletus (640-546 BC) was the father of philosophy and of science.
  - Thucydides was the father of *scientific history* (= based on evidence and analysis in terms of cause and effect)
- Conception of the principle of Orthos Logos (Recta Ratio, or Right Reason) in guiding human decisions and actions.
  - Aristotle (384-328 BC) was perhaps the first to formulate this principle:

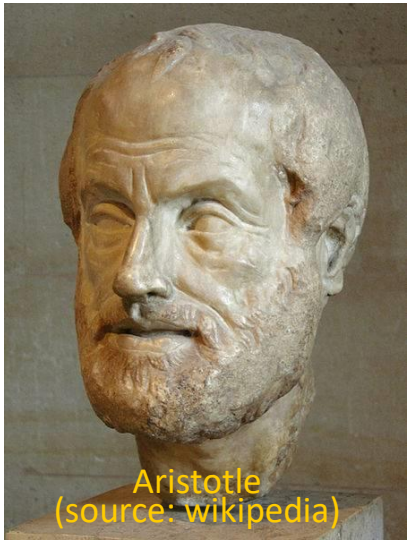
    τὸ μὲν οὖν κατὰ τὸν ὀρθὸν λόγον πράττειν κοινὸν καὶ ὑποκείσθω.

    (*It is a common principle which must be accepted that we must act in accord with orthos logos*.)

    Aristotle, Nicomachean Ethics 1103b

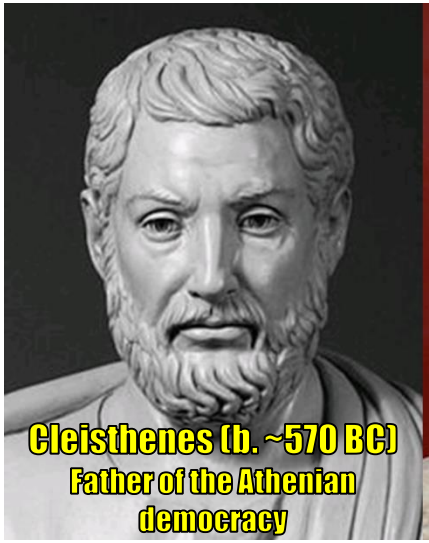

Thales
www.iep.utm.edu/thales/

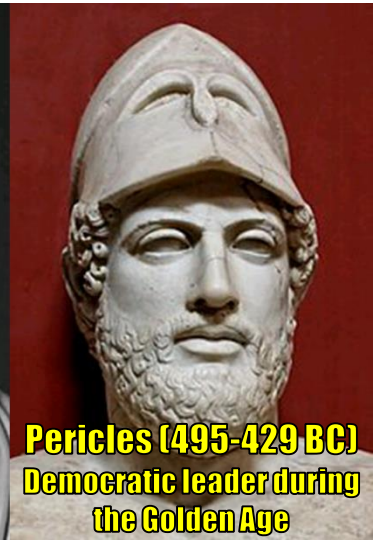

Thucydides
(source: wikipedia)


Aristotle
(source: wikipedia)

The most important Ancient Greek legacies and their usefulness to solutions of modern problems (2)

- Creation of democracy, the system of government in which all people are equally involved in taking decisions and actions.


Cleisthenes (b. ~570 BC)
Father of the Athenian democracy


Pericles (495-429 BC)
Democratic leader during the Golden Age

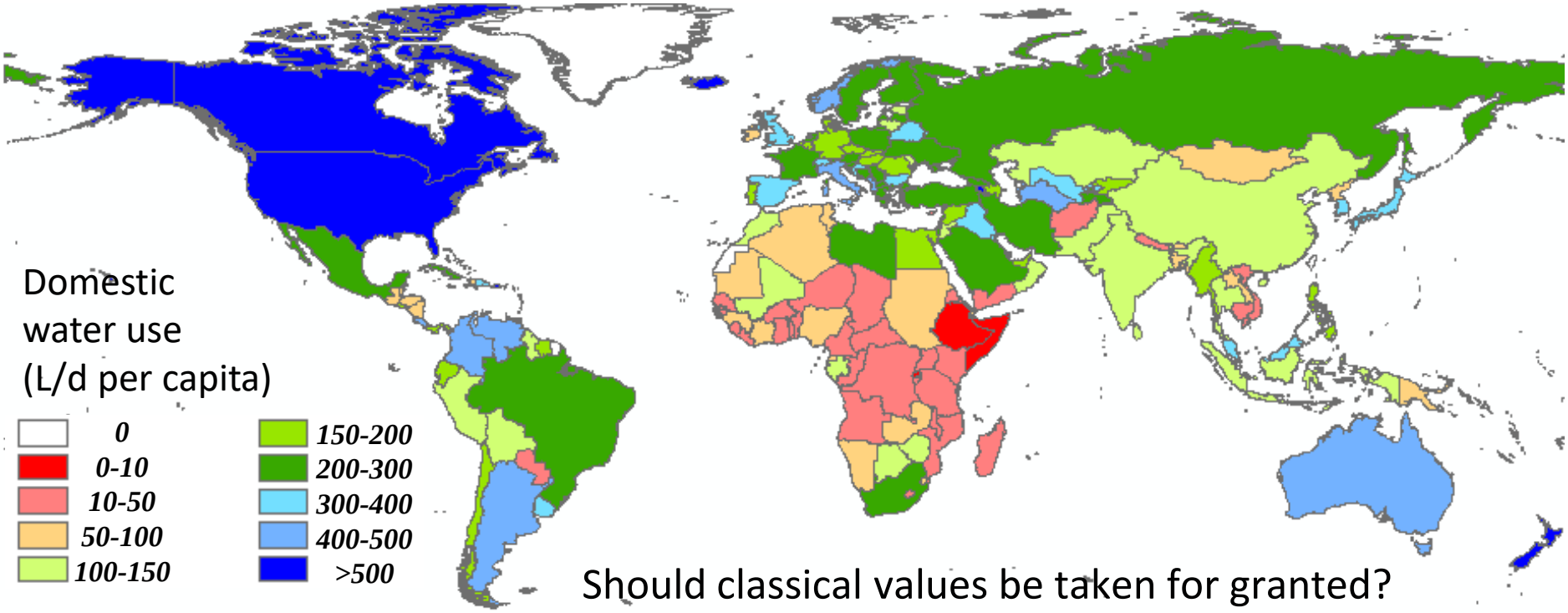
…καὶ ὄνομα μὲν διὰ τὸ μὴ ἐς ὀλίγους ἀλλ' ἐς πλείονας οἰκεῖν ***δημοκρατία*** *κέκληται· μέτεστι δὲ κατὰ μὲν τοὺς νόμους πρὸς τὰ ἴδια διάφορα* ***πᾶσι τὸ ἴσον****, κατὰ δὲ τὴν ἀξίωσιν, ὡς ἕκαστος ἔν τῳ εὐδοκιμεῖ,* ***οὐκ ἀπὸ μέρους τὸ πλέον ἐς τὰ κοινὰ ἢ ἀπ' ἀρετῆς προτιμᾶται****…»*

[The Athenian] administration favors the many instead of the few; this is why it is called a ***democracy****. If we look to the laws, they afford* ***equal justice to all*** *in their private differences; if to social standing, advancement in public life falls to reputation for capacity,* ***class considerations not being allowed to interfere with merit****.*

Pericles's Epitaph, from Thucydides, The Peloponnesian War, 2.37


Thrasybulus (440 – 388 BC)
Leader of the democratic resistance against the Thirty Tyrants regime

Currently there are a lot of problems to solve: In Athens, in Greece, in the world



In a significant part of the world the current water supply level is inferior than that in ancient Athens (Koutsoyiannis, 2011a)

Should classical values be taken for granted?

- Science-based propaganda instead of scientific inquiry…
- Doctrines and stereotypes instead of orthos logos…
- Oligarchy instead of democracy…
  - Oligarchy + high technology = locked cockpit…

Concluding remarks

- Study of history is a good advisor for problem solving.
  - This applies to water problems too.
- Technology developing is guided by necessity.
  - Technology can modify poor natural conditions.
- Technology is not enough.
  - It should be combined by episteme (science), orthologism (rationalism) and democracy.
- Technology, episteme, orthologism and democracy are all legacies of our Athenian ancestors.
- Modern Athenians do not claim exclusiveness of these legacies:
  - Sharing material things may sometimes be *division*.
  - Sharing intellectual values is always *multiplication*.

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