Nexus Summer School

Water systems under pressure
Land use change and impacts on the Water-Food-Energy Nexus

30/8/2014
Technical University of Munich

Water control through history



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Presentation is available at: http://www.itia.ntua.gr/el/docinfo/1487/

Main topics

- Introduction to water resources and needs
- Where early civilizations were developed? Climatologic and hydrologic regime of first organized communities
- Evolution of hydraulic works and water related issues (legislation, environmental issues, ethics, management practices)
- Science and technology in ancient world
- The water problems today. Temporal and spatial evolution of water needs and water resources exploitation.
- Water and energy
- Philosophical aspects on hydrological modeling and hydrosystem management
- Design, operation and optimization of complex hydrosystems

Part of the material is coming from presentations that are available in the digital library of ITIA (www.itia.ntua.gr)



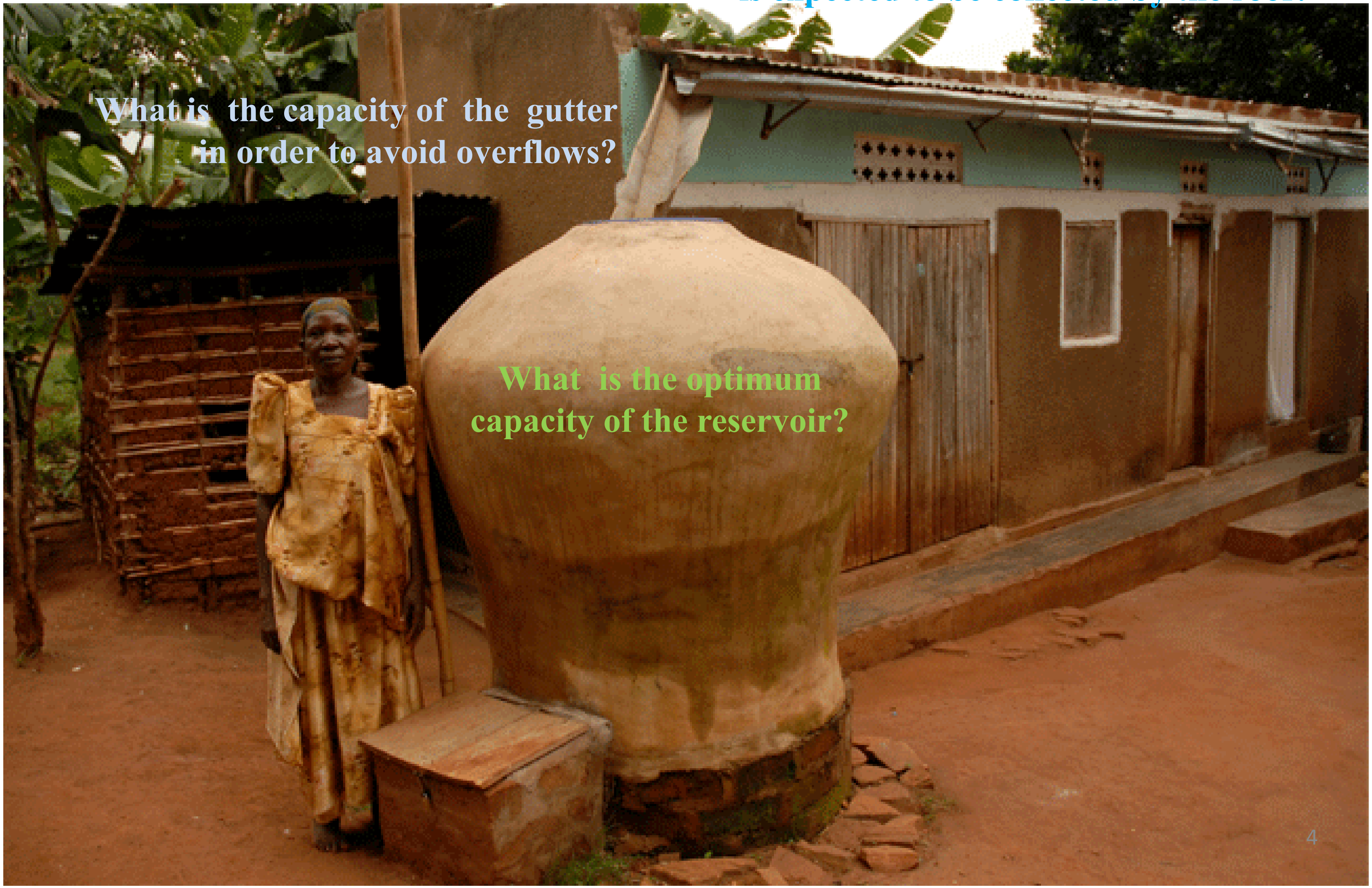
How to find water?

1. Ground water (wells, springs)
2. Surface water (rivers, torrents, lakes)
3. Rainwater (harvesting)
4. Sea water (desalination)
5. Atmospheric water (condensation)
6. Conveyance
7. Reuse

The primitive hydraulic works design

Three ancient engineering problems

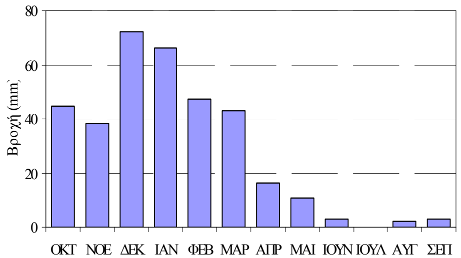
What is the annual water quantity that is expected to be collected by the roof?



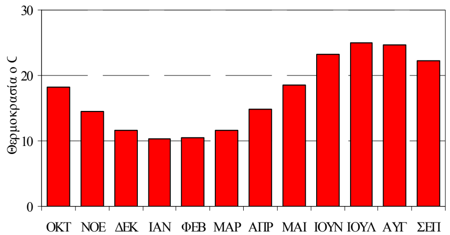
How to find water?

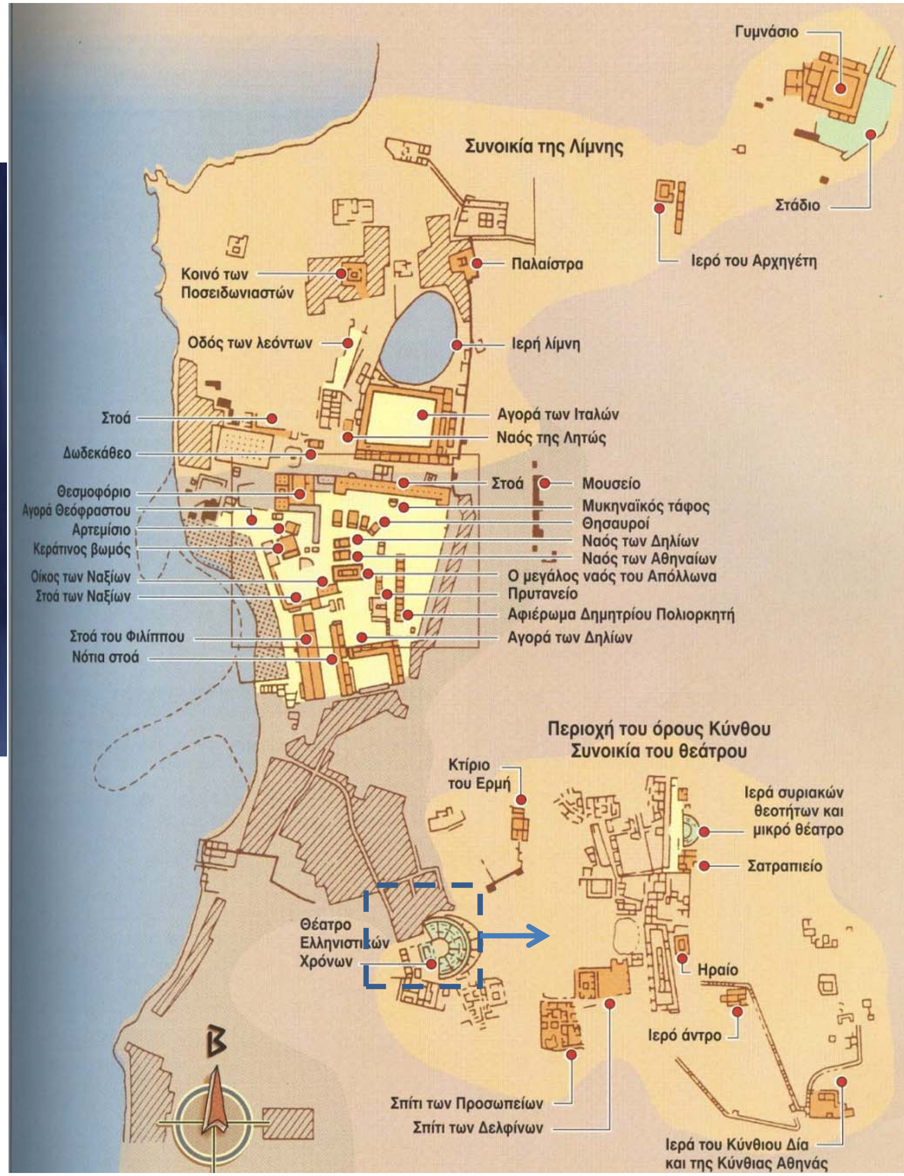
Delos island

Mean annual precipitation: 347 mm



Mean annual temperature 17.1 °C





Delos island located in the center of Aegean sea and has an area of 3.4 km^2. It was the sacred island of the Greeks and during Hellenistic and Roman period (4-1th century BC) it was very crowed (archeologists estimate about 30000 residents). In antiquity there were wells and many cisterns to collect rain water.

How to find water?

Cistern of theater at Delos island

Dimensions: 22.5×6×3 m

It constructed in 3th century BC with the theater. It was covered with a wooden roof and collected the rain water of the koilon and orchestra (total area about 5000 m^2).

To do what ?

- Domestic
- Agricultural
- Industrial
- Livestock

Consumptive water uses

- Energy
- Recreational
- River navigation
- Environmental flow

Non consumptive water uses

Mean world consumption: 559 (m^3/cap/year)
Agricultural: 390 (70%)
Domestic: 66 (12%)
Industrial: 103 (18%)

To do what ?

Consumptive water use. The water is permanently withdrawn from its source or otherwise is removed from the immediate water environment (because it has been evaporated, been transpired by plants, incorporated into crops or products, consumed by people or livestock).

Three main uses are mentioned in the literature (Irrigation, Industrial, Domestic)

Irrigation water is artificially applied to the land, mainly to assist in the growing of crops but also for protecting plants against frost or for removing the salts from the crop root zone.

Industrial water is used in industries for purposes such as processing, cleaning, dilution and cooling.

Domestic water is used in the home for normal household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering gardens.

Also there are more specific consumptive uses that are included to the above main uses

Commercial water for hotels, office buildings and other commercial facilities

Livestock water for stock animals, dairies, fish farms and other nonfarm needs.

Mining water for the extraction of minerals (coal and ores), crude petroleum; and natural gas.

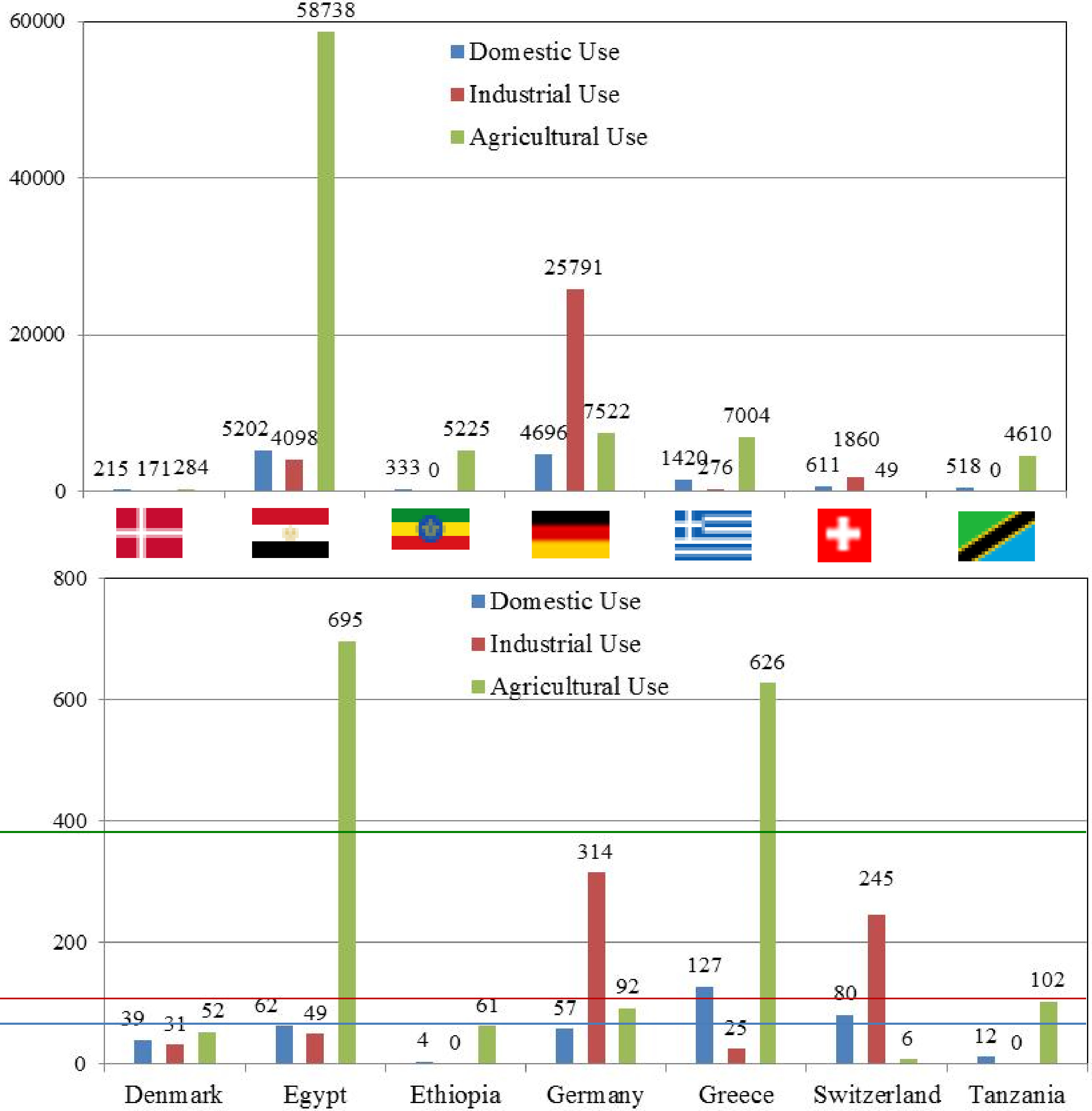
Public Supply water withdrawn by public and private water suppliers, such as county and municipal water works, and delivered to users for domestic, commercial, and industrial purposes

Thermoelectric Power water is used in the production of electric power that is generated by turning a turbine using steam power.

To do what ?

Water consumption on seven countries

hm³/year



Mean World Value: 390

m³/cap/year

Mean World Value: 103

Mean World Value: 66

To do what ?

Non-consumptive water use. The water is not removed from the water environment

Water for hydroelectric energy. The amount of produced electricity depends on (a) the height that water falls and (b) the quantity of water falling.

Recreational water. Fishing, sailing, swimming and other recreational activities that depend on water.

Navigation. River s are used as waterways for transport of people and products.

Environmental water. Water releases from reservoirs in order to help fish spawn, to restore natural river flow regime, for the watering of wetlands and the construction of artificial lakes intended to create wildlife habitat.

Why through history?

The study of ancient hydrosystems and scientific views can

- unveil various perspectives on water management that were adopted by ancient societies, under various circumstances

- follow the course from the primitive (simple) of the past to the sophisticated (complex) that prevails today

- evaluate the technical characteristics of hydraulic structures and their performance after an operation of thousands years

- discover the way of thinking in order to explain nature with insufficient data

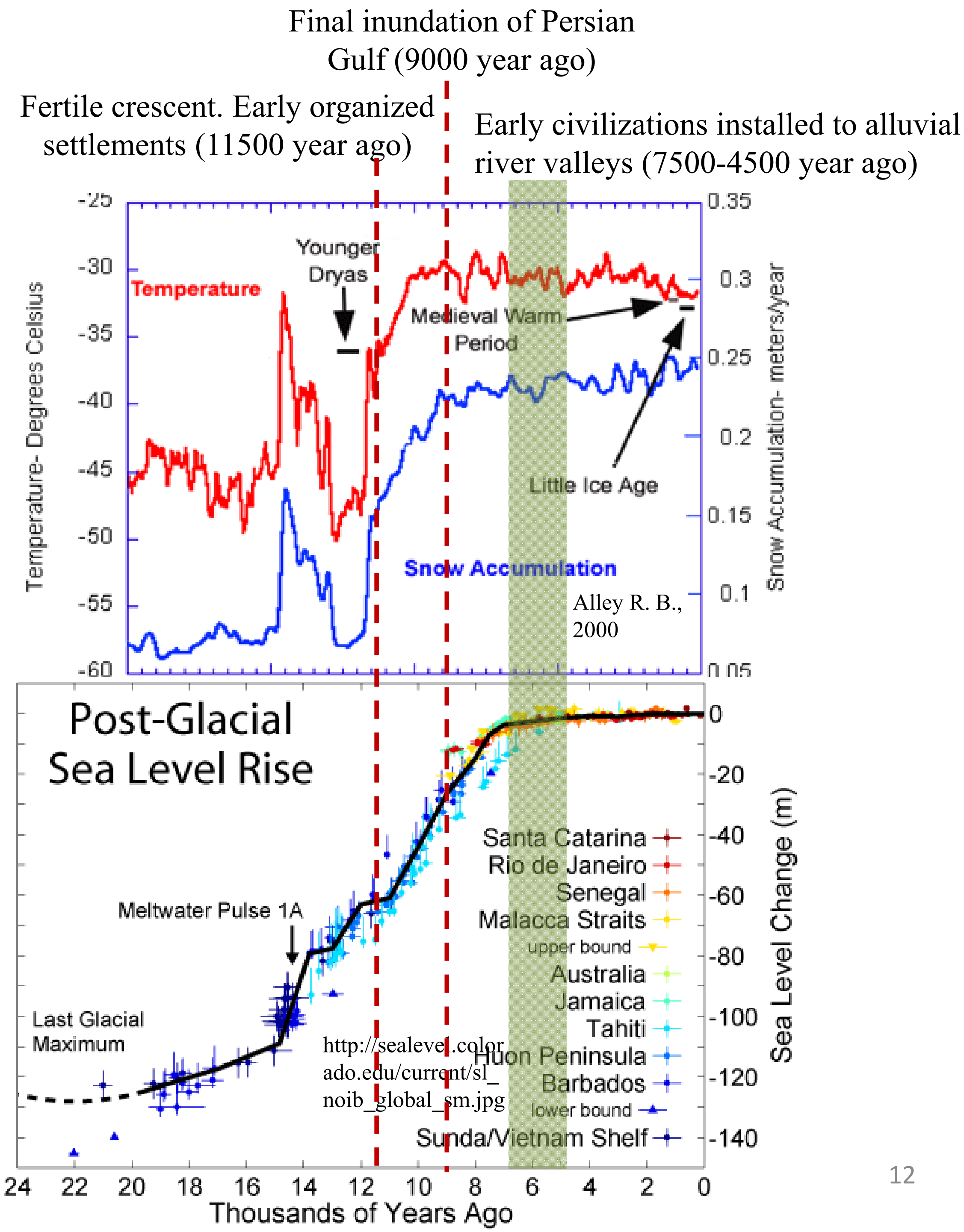
- study and evaluate the operation of hydrosystems through long time periods

This experience in many cases is useful for modern hydrosystems analysis, design and operation.

When early civilizations were developed?

Temporal evolution of temperature and snow accumulation

Temporal evolution of sea level



Where early civilizations were developed? (hydrology and climate)

Areas of first organized communities

Areas with American civilizations AD

7. Arizona

8. Mexico

9. Andes

1. Fertile crescent. Early agriculture areas, 9000 BC

Agriculture exported to alluvial river valleys from 6th to 3th millennium BC

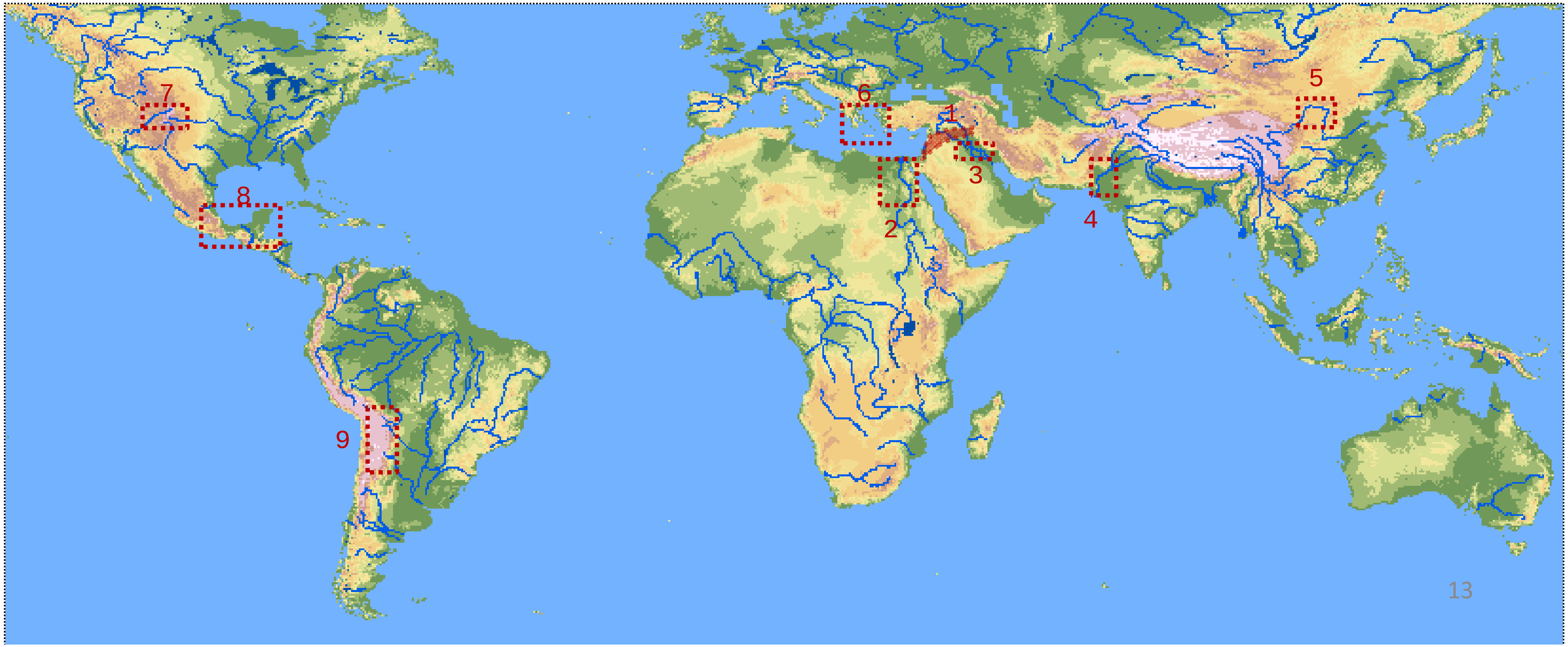
2. Nile valley

3. Mesopotamia (Tigris-Euphrates)

4. Indus valley

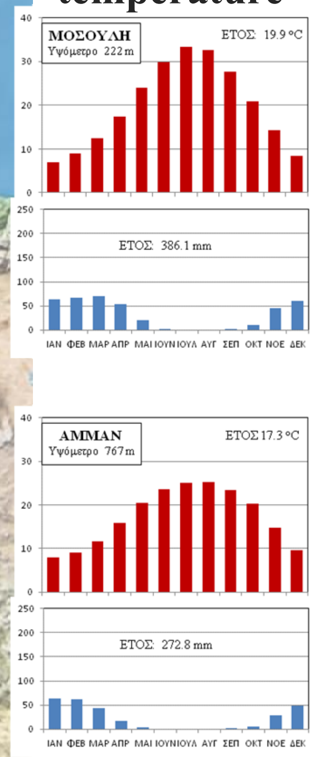
5. Yellow river valley

6. Greek civilizations from 3th millennium BC



Where early civilizations were developed? (hydrology and climate)

Mean monthly precipitation and temperature

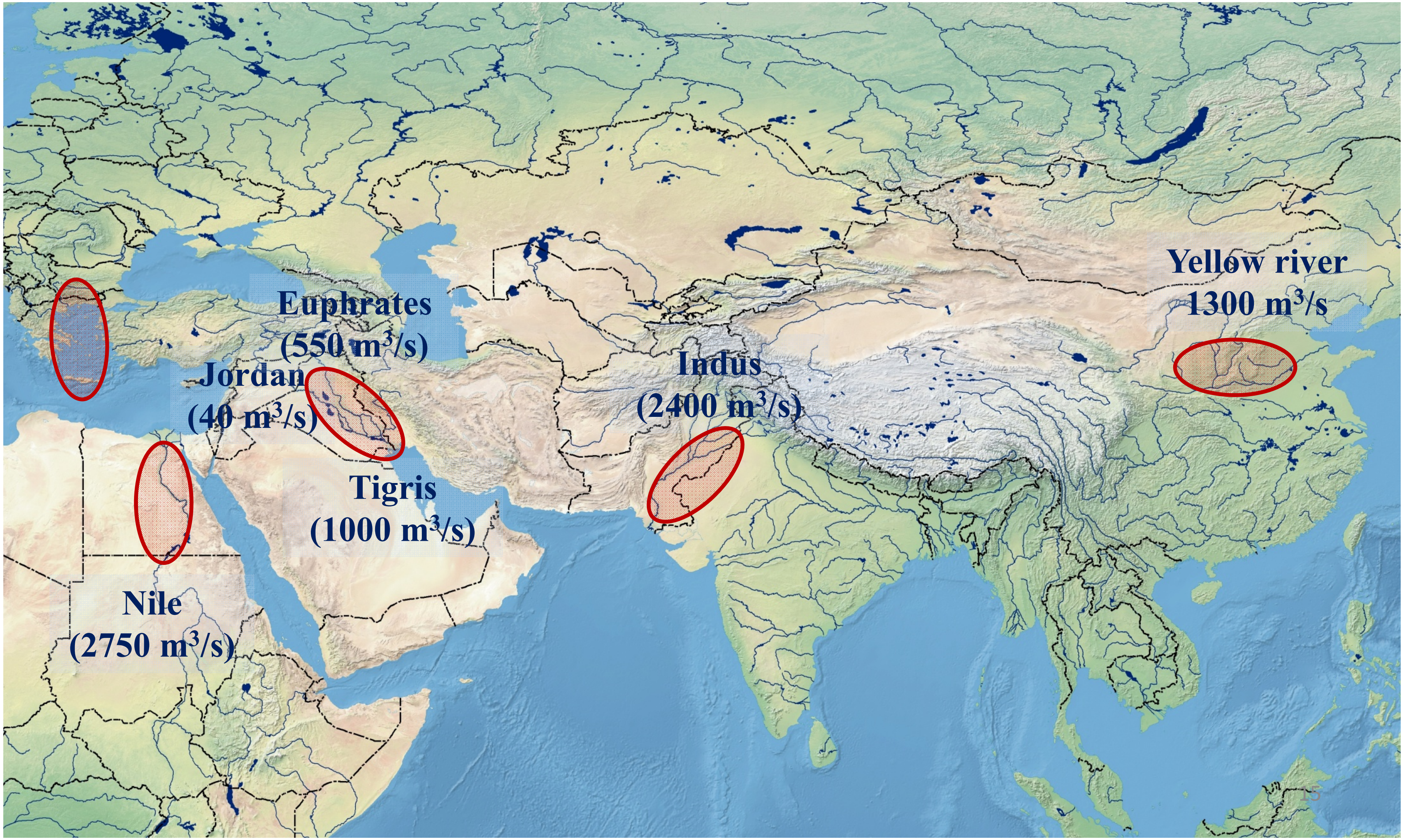


- During Neolithic period and after the last Ice Age, groups of people concentrated in a zone of hills extended from Syria-Palestine to the foot of Taurus and Zagros mountains, an area that is called **Fertile crescent**. In this area the winter rainfalls favored the natural grow of wild grains, such as barley and wheat.
- About 9000 BC, when the climate had almost been stabilized, these first residents came down from the hills to begin early cultivation of grains and cereals. These communities developed the first agricultural methods, animal domestication and constructed the first small hydraulic works.
- The population began to increase and was spread to nearby alluvial valleys of large rivers during a period of 7500 to 4500 BC so called as the Neolithic revolution

Where early civilizations were developed? Hydrology and climate

Ancient civilizations and hydrologic regime (mean annual discharge)

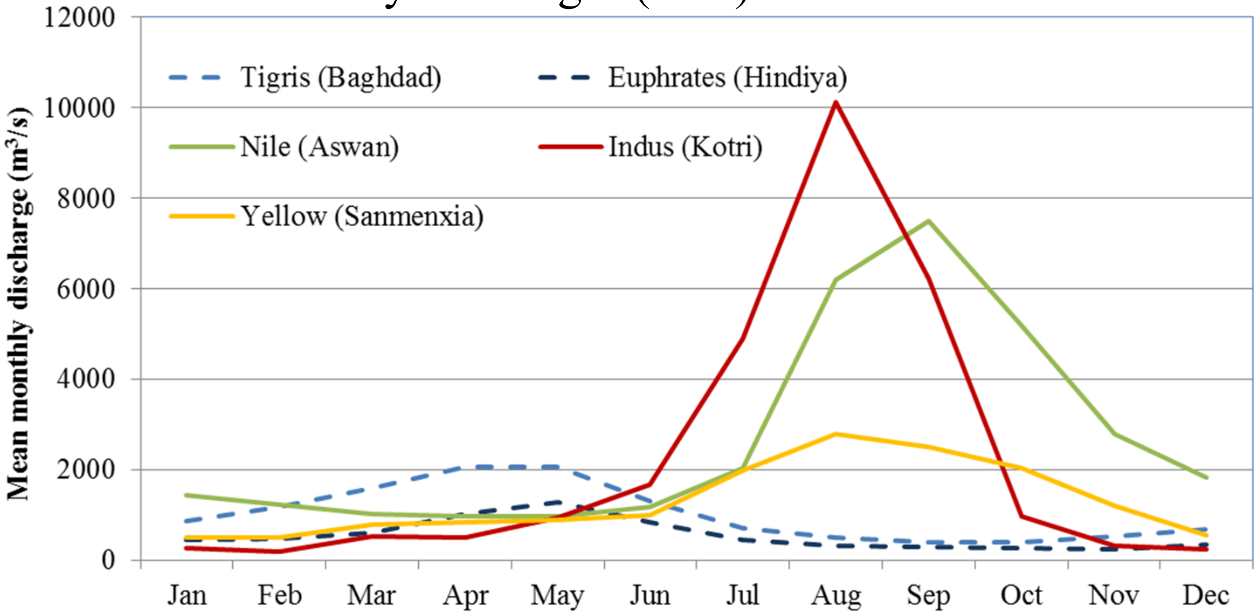
Minoan Civilization, Mycenaean Greece | Mesopotamia (Sumer, Acadian, Babylonian, Assyrian) | The Indus Valley Civilization (Harappa) | The Chinese Civilization

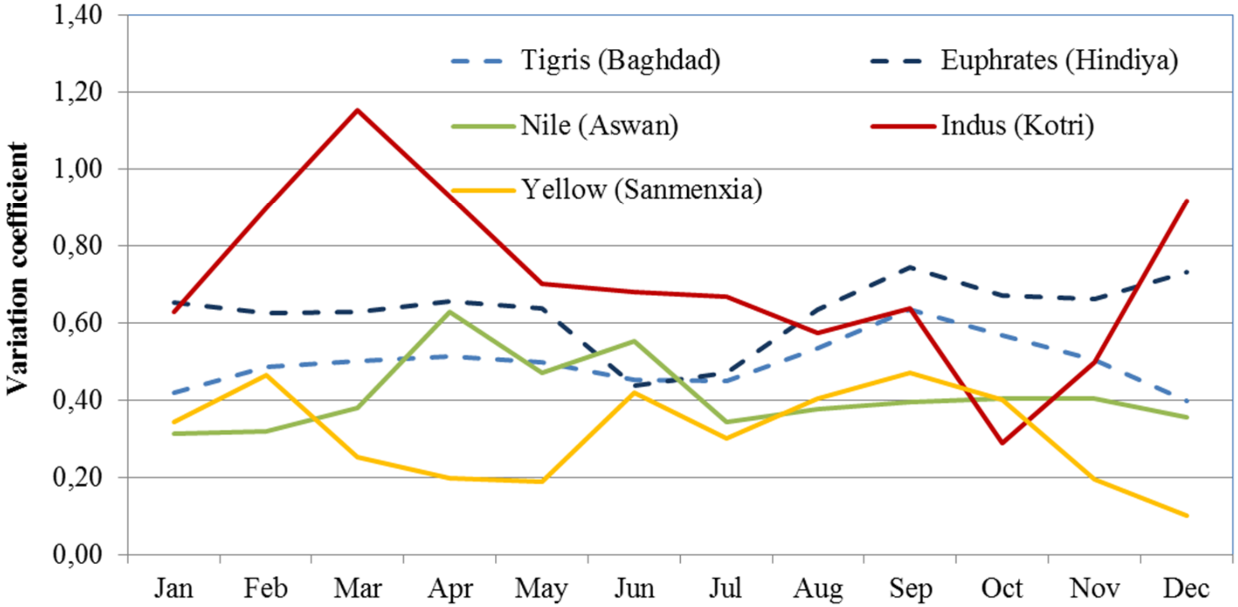


Where early civilizations were developed? Hydrology and climate

Hydrologic regime of rivers

Mean monthly discharges (m^3/s) and coefficients of variations





Mean annual discharges

	Tigris (Baghdad)	Euphrates (Hindiya)
m^3/s	1020	555
Gm^3	32	17
mm	240	64
CV	0,43	0,41

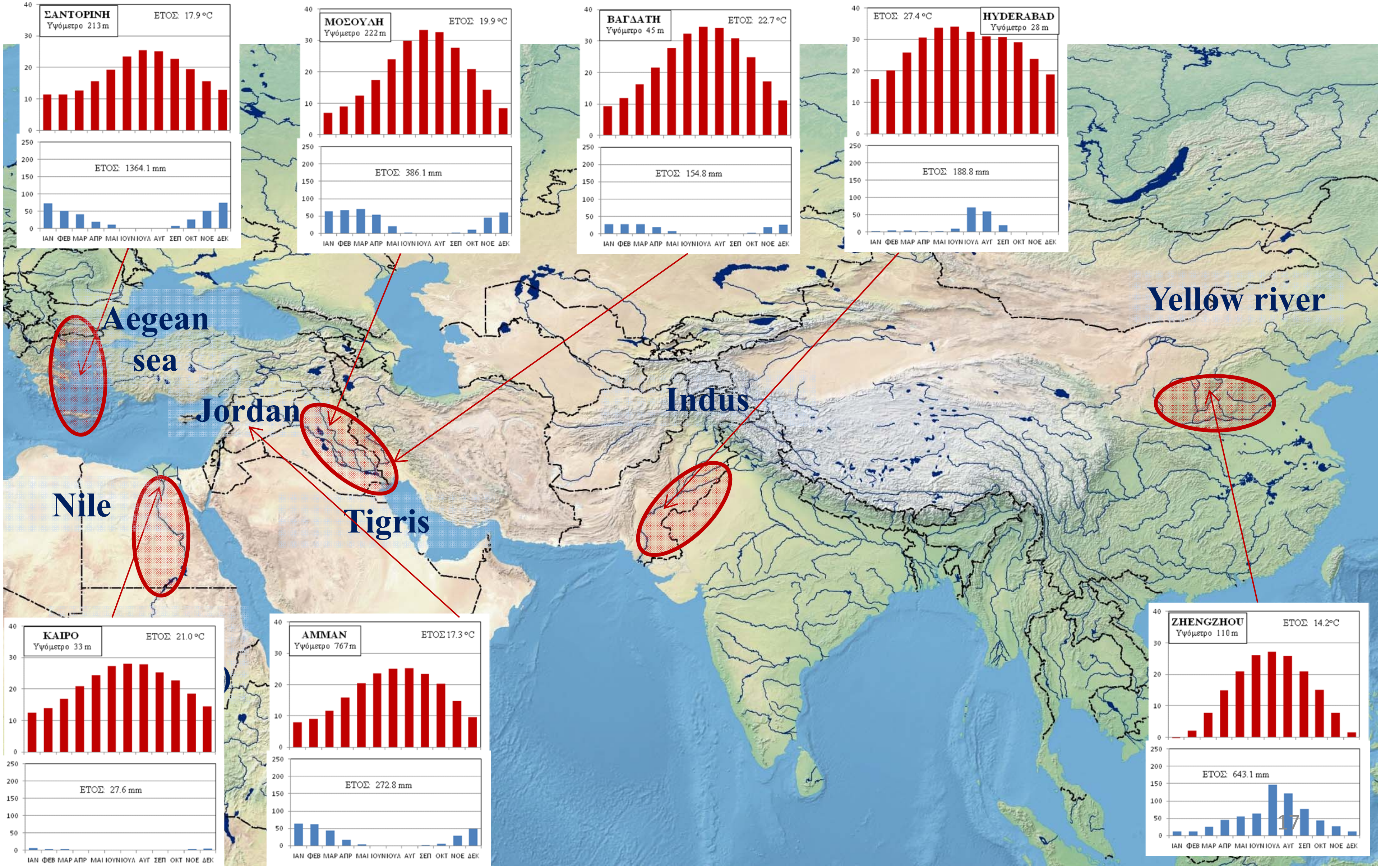
	Nile (Aswan)	Indus (Kotri)
m^3/s	2744	2396
Gm^3	87	76
mm	30	91
CV	0,24	0,33

	Yellow (Sanmenxia)
m^3/s	1304
Gm^3	41
mm	60
CV	0,21

Where early civilizations were developed? Hydrology and climate

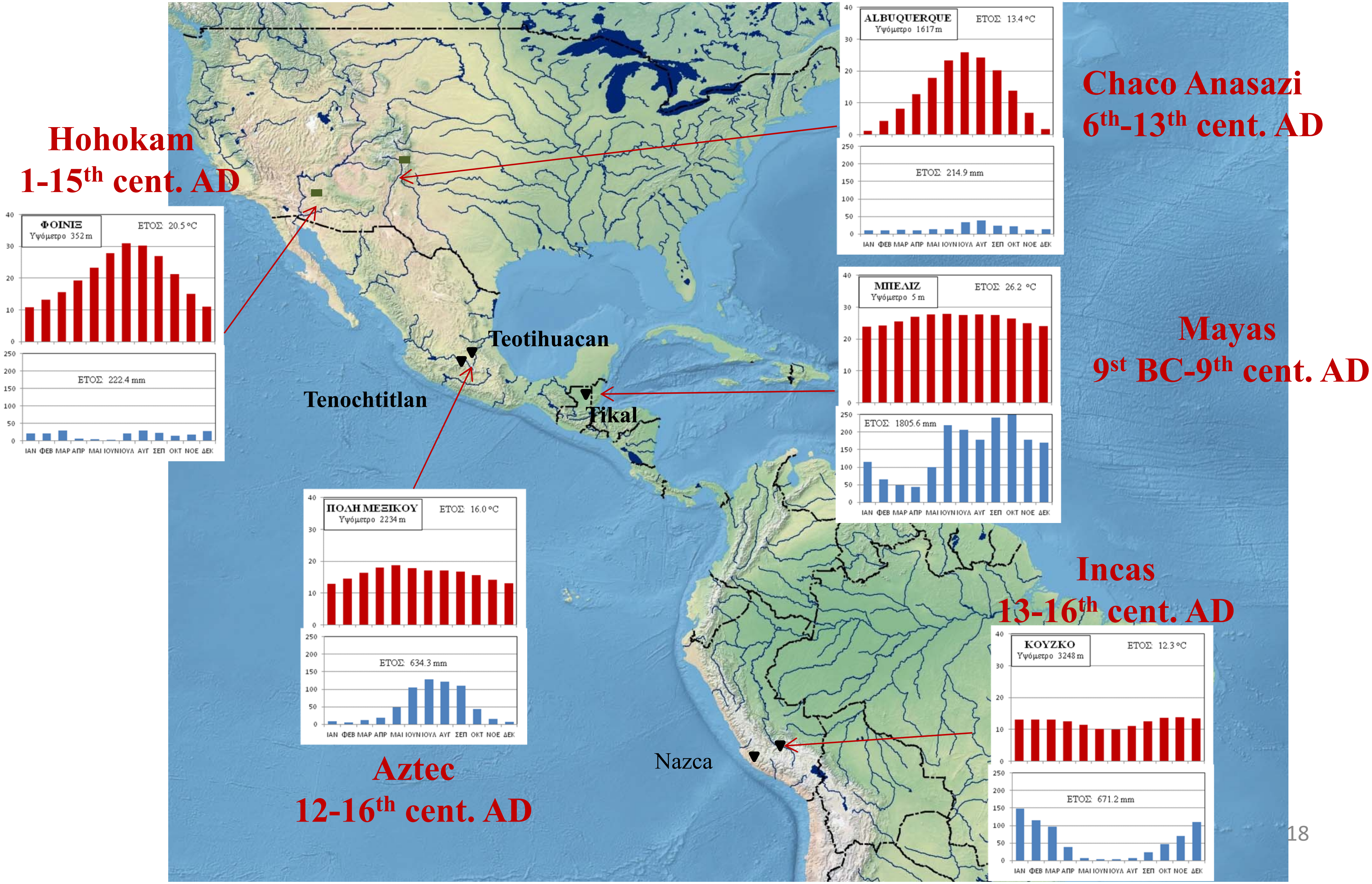
Ancient civilizations and climatologic regime

Mean monthly precipitation and temperature



Where early civilizations were developed? Hydrology and climate

A similar evolution? American ancient civilizations and climatologic regime



Water control in ancient world

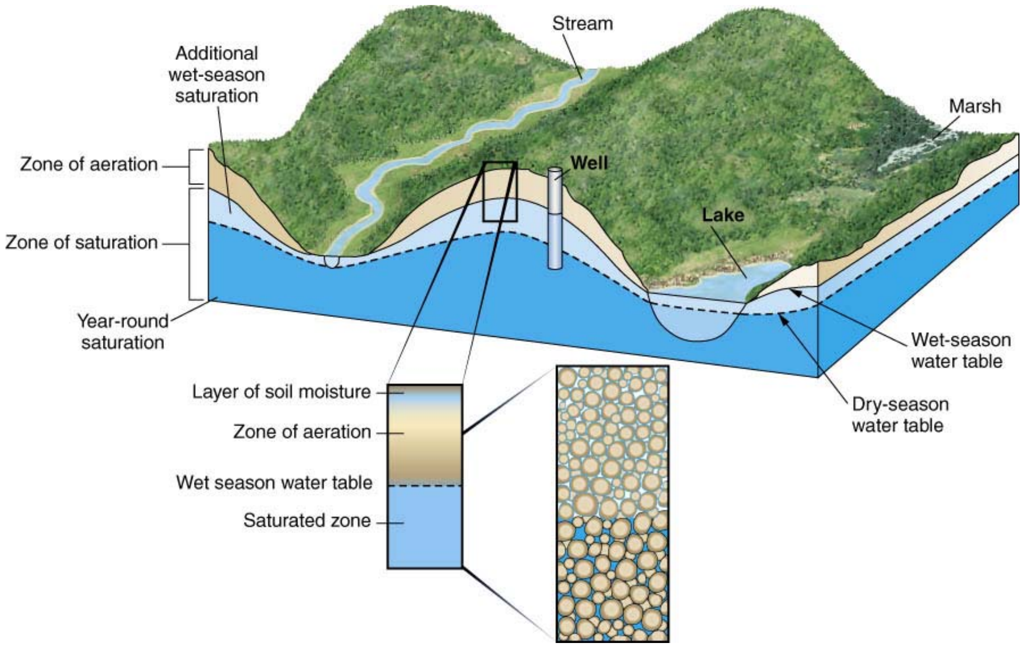
Main water control procedures and related hydraulic works

Initially the water was used at his source (river, spring, lake etc) or was transported in small quantities by hands. The necessity to control the water came with the development of the first civilizations. The main procedures for water control are given below with the related hydraulic works:

1. **Catchment** from the sources. Ground water exploitations works (wells, qanats), dams, water intakes from rivers and springs.
2. **Conveyance** of water to the site of demand (a procedure that in most cases includes **lifting** of water). Canals, pumping devices, distribution networks.
3. **Storage** of water for later use (next season or year). Cisterns, reservoirs.
4. **Protection** from water (floods). Levees, drainage networks, reservoirs.
5. **Waste water** management. Pits, networks.
6. Ensuring river **navigation.** Canals.
7. Exploitation of **water power.** Water mills.
8. **Cleaning** of potable water. Sand filters.
9. **Sediment** management. Dredging, dams.

Ground water exploitation

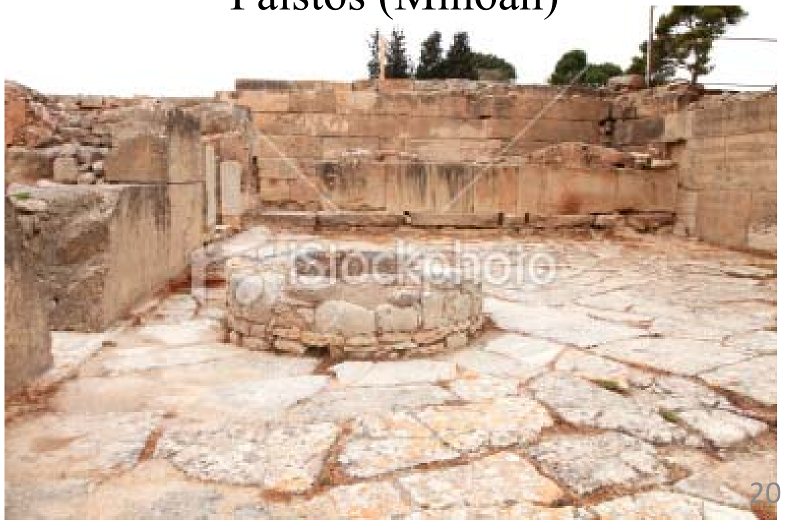
Wells in unconfined aquifers



Mohenjo Daro (Indus Valley)

Palekastro (Minoan)

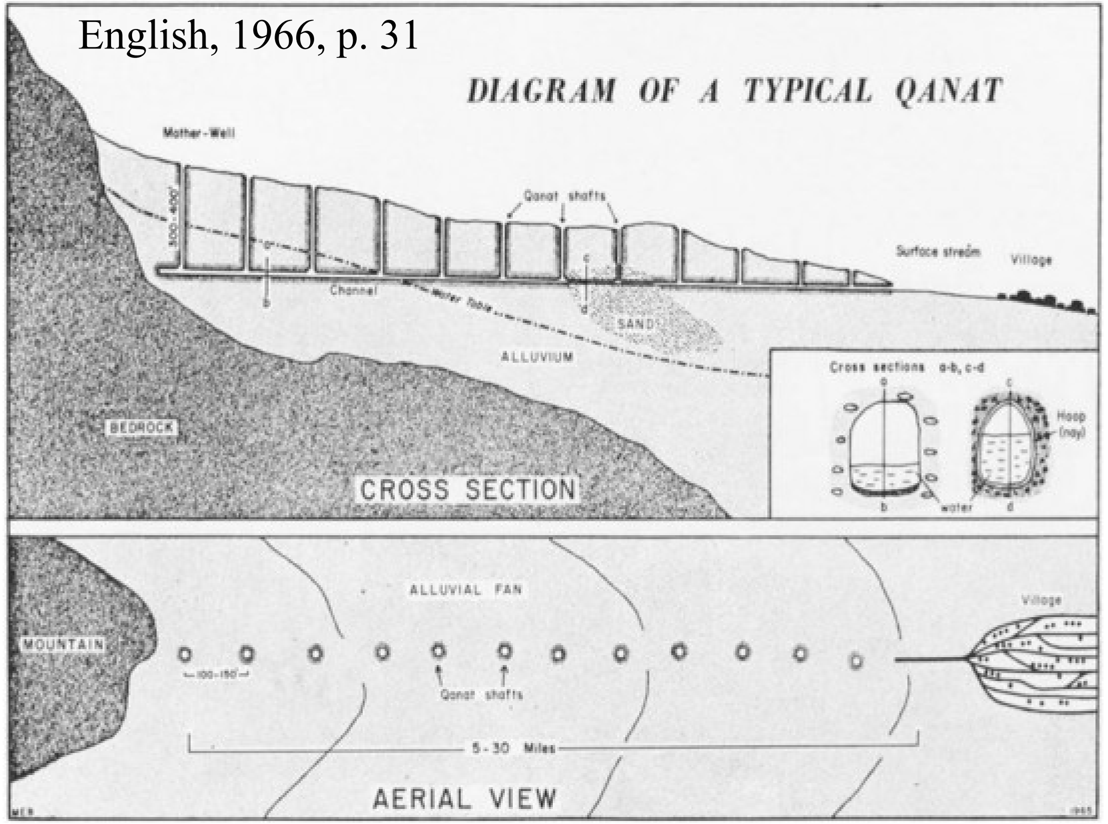
Faistos (Minoan)



Ground water exploitation

Qanat (kareez, foggara)

Qanat is a hydraulic work for horizontal water abstraction from ground water. The method includes the digging a series of wells and linking them underground with a channel that transfers groundwater by gravity.

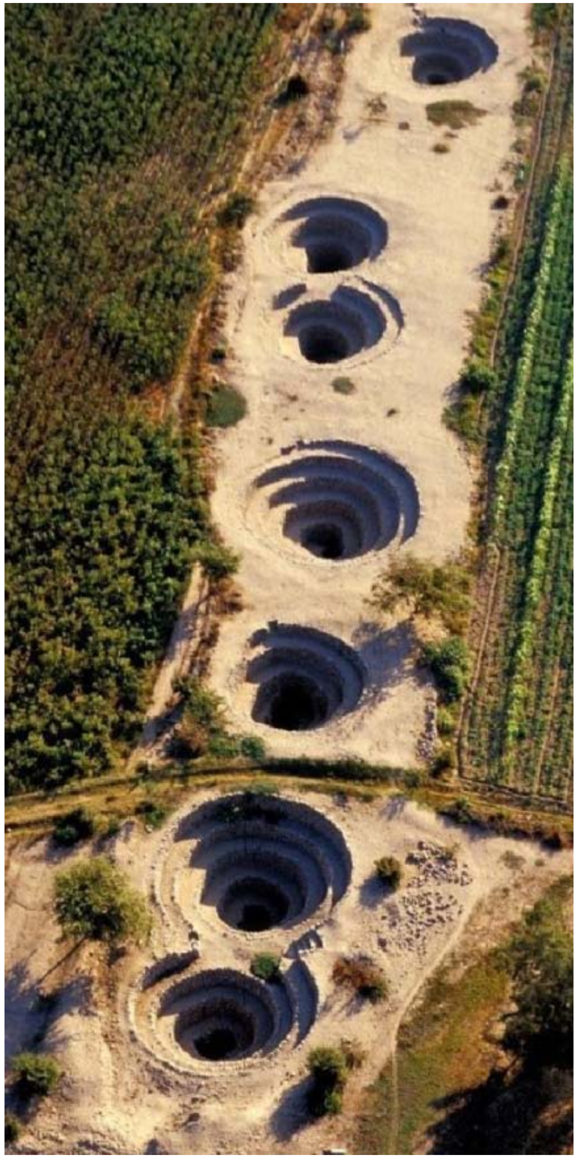


English, 1966, p. 31

The construction of **qanats** dates back to **1th millennium BC in Iran** territory. The oldest and largest known qanat is located in the Iranian city of Gonabad and it is still in use. The depth of its main well reaches down to more than 360 m while measuring 45 km in length. Over the centuries, the technology was transferred to all civilizations and became known with different names such as karez (Afghanistan and Pakistan), kanerjing (China), falaj (United Arab Emirates) and foggara/fughara (North Africa).

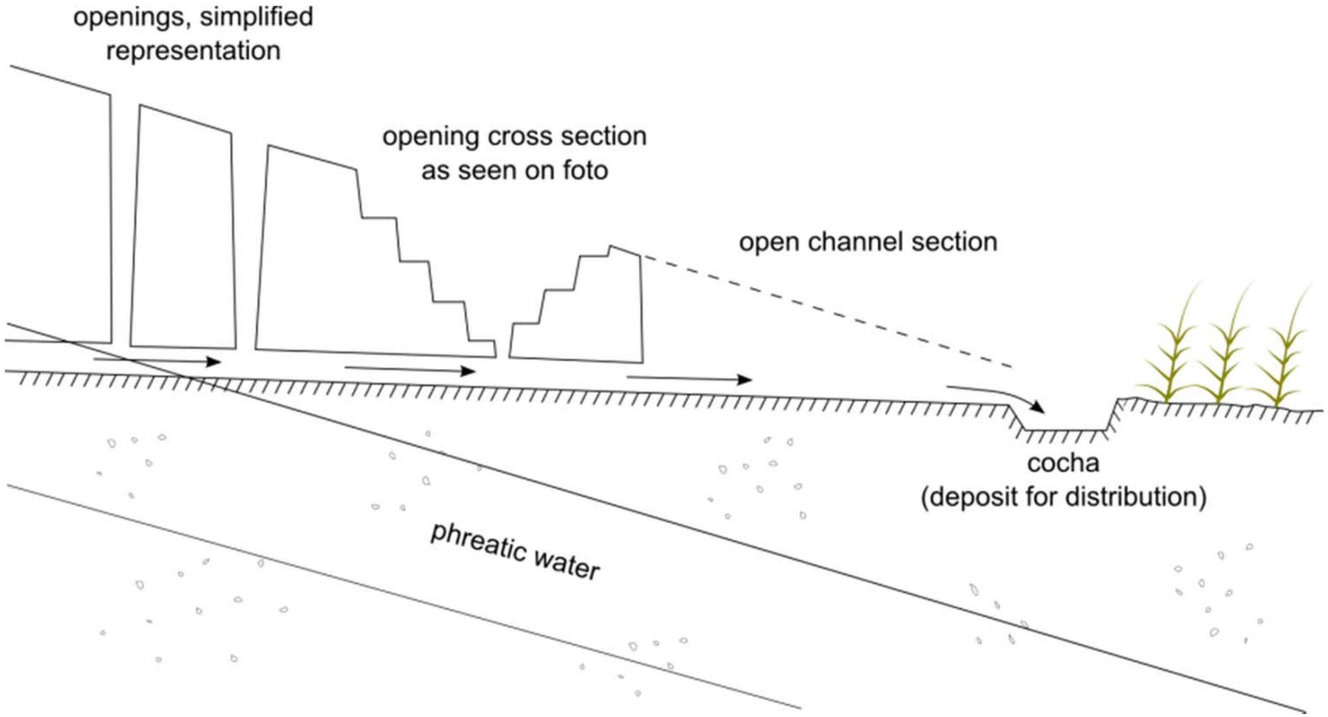
Ground water exploitation

A independent but similar approach



Openings along the Cantallo aqueduct

Underground aqueduct of Nazca



Sketch of the underground aqueduct

Source: *Alexander Reyes-Knoche, Sustainable water supply in Pre-Columbian Civilizations in Ancient Peru and South America*

Lifting of water

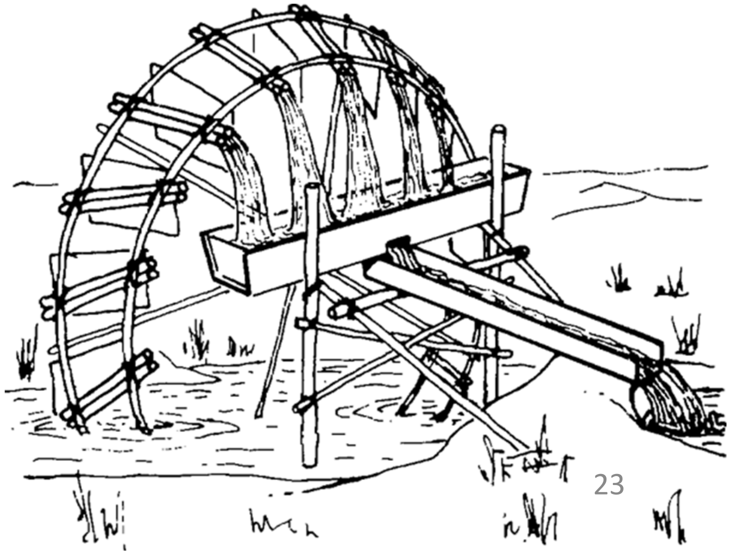
Shaduf

This device was invented in Mesopotamia and Egypt about **4th millennium BC** for lifting water from a well or a river. It consists of a long, nearly horizontal wooden pole, which it operates like a seesaw.

From the long end a vessel is hung on a rope and the system is balanced by counterweight from a stone that is hung on the short end. To raise water to higher levels, a series of Shadufs were fixed one above the other. An average water lifting rate is estimated of about ***2.5 m^3/d***. It is still used in many countries

Noria

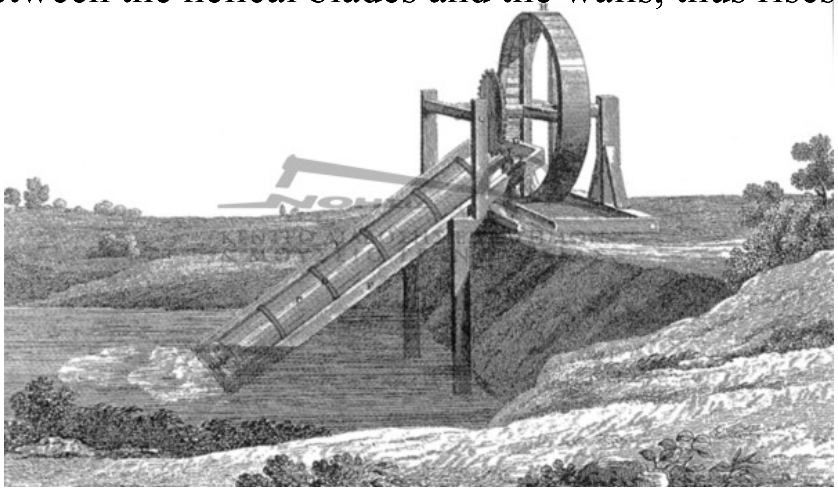
The Noria is the first horizontal axis water wheel and was invented by the Romans maybe during ***4th century BC.*** It consists of a wooden wheel, powered by water and fitted with buckets that lift water to another collector.

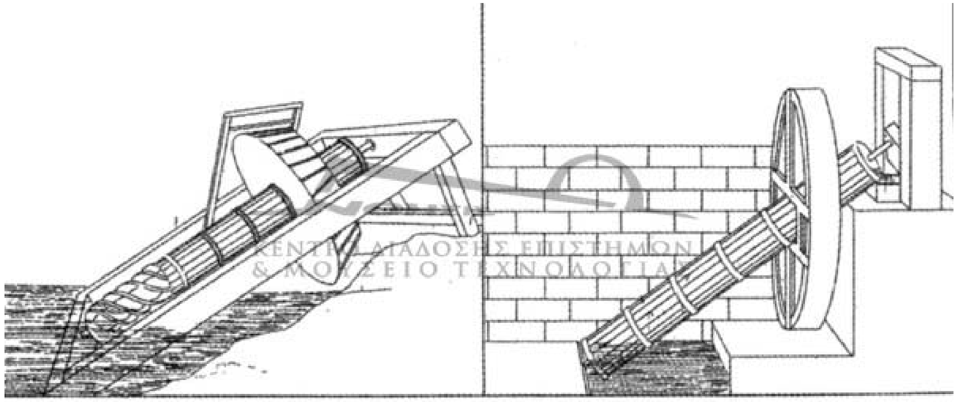


Sustainable inventions: Archimedes' screw

Water lift device, still in use

The first pump with the modern meaning is helix or water-screw of Archimedes (a Greek mathematician and engineer (287-212 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. The screw is worked within a wooden pipe. 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.





Holland

Greece

USA

Water use in ancient world

Agriculture in Mesopotamia

- During 7-4th millenniums the population expanded and cultivators settled in the large alluvial plain between the Tigris and Euphrates Rivers.
- The soil was fertile but needs irrigation, drainage and flooding protect.
- The water needs were lower than the minimum river discharge, so the first hydraulic works were simple irrigation canals that transferred the water from the rivers to cultivation areas
- The first evidence of irrigation (it dates from 9th millennium BC) there is at Choga Mami a site of Samaran civilizations, located in the middle Tigris valley at the foot of Zagros mountains. Two meters wide channels that convey the water from the river, following the elevation contours for several hounded meters and distribute it to the fields.
- During 6th millennium BC the first wells were opened and there are significant evidences for sewage network in specific residences
- Later, various hydraulic works were constructed continuously in order to drainage the lower areas and reclaim cultivations areas
- During 4th millennium the agricultural expansion followed by demographical and small cities were established. These were followed by large cities during next millennium. Many cities in the Tigris and Euphrates valleys (Uruk, Ur, Mari, and Babylon) connected to rivers with short canals.

Water use in ancient world

Agriculture in Egypt

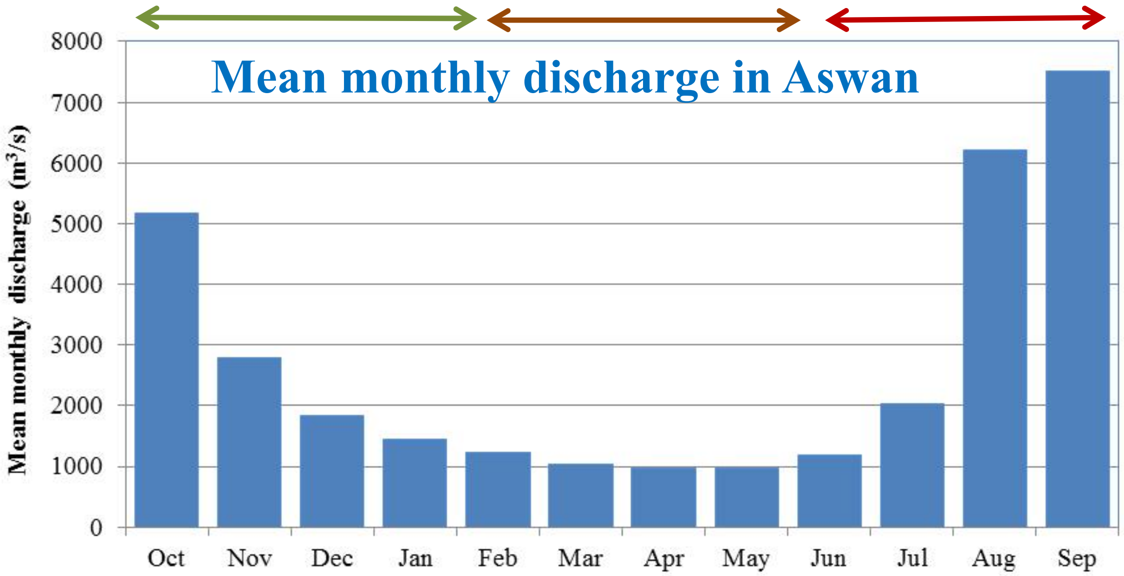
In ancient Egypt cereals, such as wheat and barley were cultivated. The amount of rainfall, is extremely small (less than 50 mm) and the irrigation of the crops was depended only on the water of river Nile

Agriculture in Egypt followed the hydrological cycle of river Nile

The **growing season** (October-February)
After the removal of floodwaters, farmers plowed the soil and planted the seeds. The fields were irrigated using ditches and canals.

The **harvest season** (March-May)
farmers harvest their crops and then separated the straw from the grain

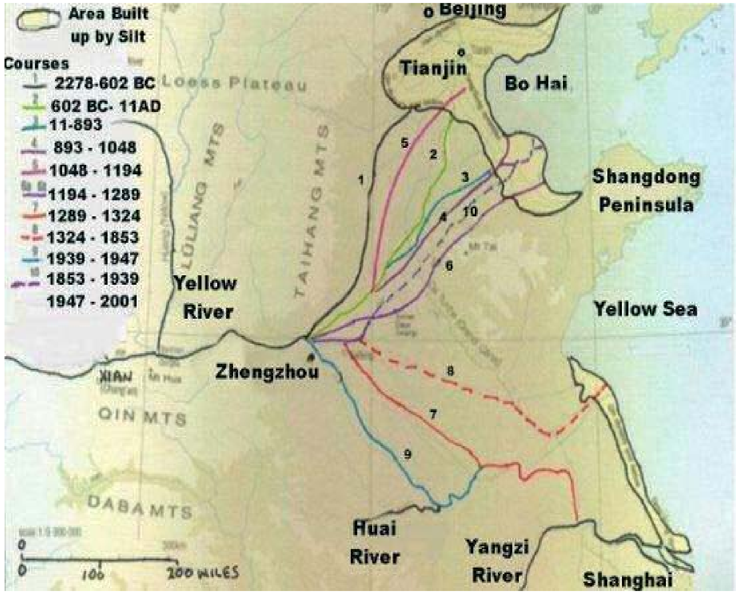
The **flooding season** (June-September)
A layer of mineral-rich silt (ideal for cultivating) deposited on banks of river Nile

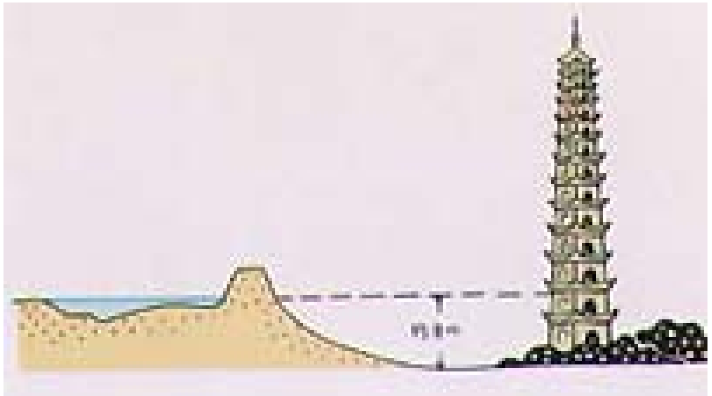


In gardens on higher ground vegetables (lettuce, leek, garlic, squash, pulse) and fruits (melons, grapes), were cultivated, and had to be irrigated by hand.

Water use in ancient world

Agriculture in China



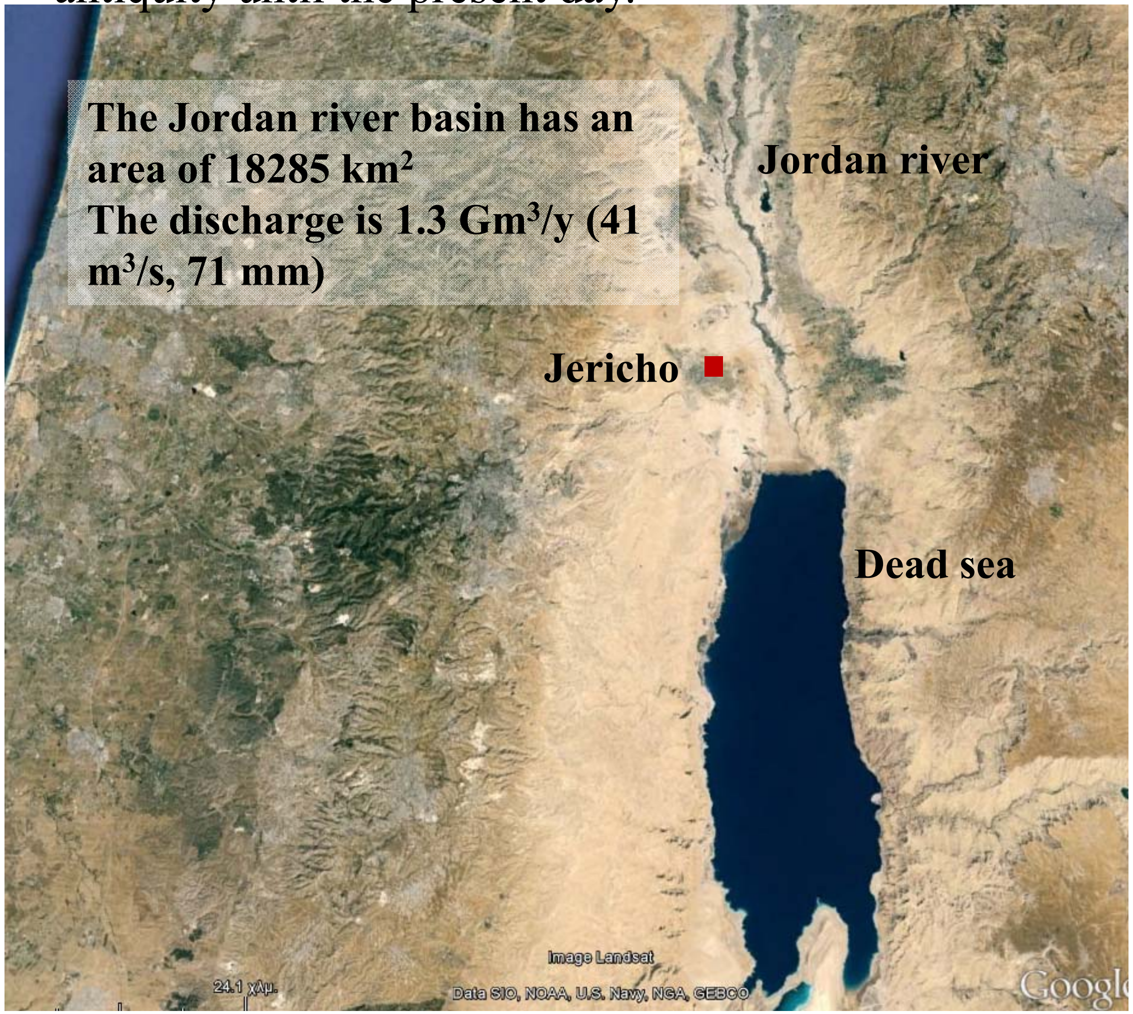


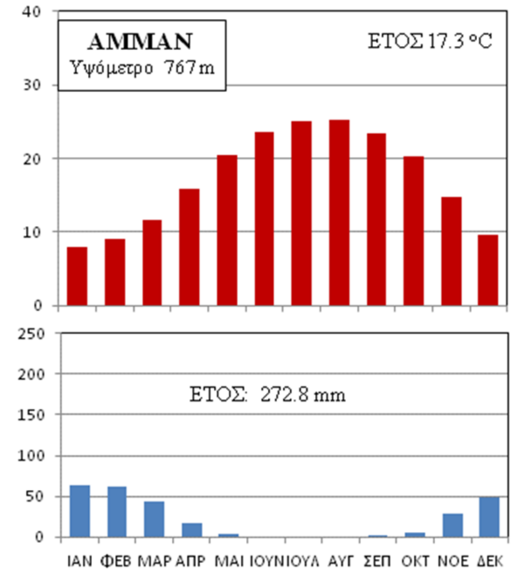
- Grain cultivation (millet) first appeared in 6th millennium BC along the middle basin of Yellow river.
- Initially, small scale farming and livestock developed, and later (at the end of 3th millennium BC) the cultivation of wheat and barley was added. Also during this period the first fortified villages were constructed.
- The Yellow river has one of the highest concentration of sediments in the world and bears this name because of the color of the sediments that it carries.
- In its middle of its course the river reaches the plain and the bed slope declines, the velocity decreases and the suspended sediments deposit on the bed.
- Gradually the sediments accumulated between dikes, and the rivers' bed raised (sometimes 10 m above the plain).
- From early years Chinese tradition emphasizes to dredging of the river bed during low flow periods and the construction and maintenance of dikes to protect villages and agricultural land. There are texts from about 2000 BC mentioned that ***Emperor Yu*** defined the unpredictable course of Yellow river through the construction of canals and deepening its bed, saving the empire from flood
- If the dredging failures the river overflows, the dikes ruptured and the river establishes a new course. In Chinese history are mentioned 2000 dike failure and 26 significant changes of the course of the river

Water use in ancient world

Jericho

The first permanent settlement developed on the site of Jericho near the Ein as-Sultan spring **during 9th millennium BC**. An initial population of about **2-3 thousand individuals** is estimated. Springs is currently, the main water supply source in the Jericho area with a capacity of **15600 m^3/day**. A system of canals and pipes supplied the whole oasis from antiquity until the present day.





Water use in ancient world

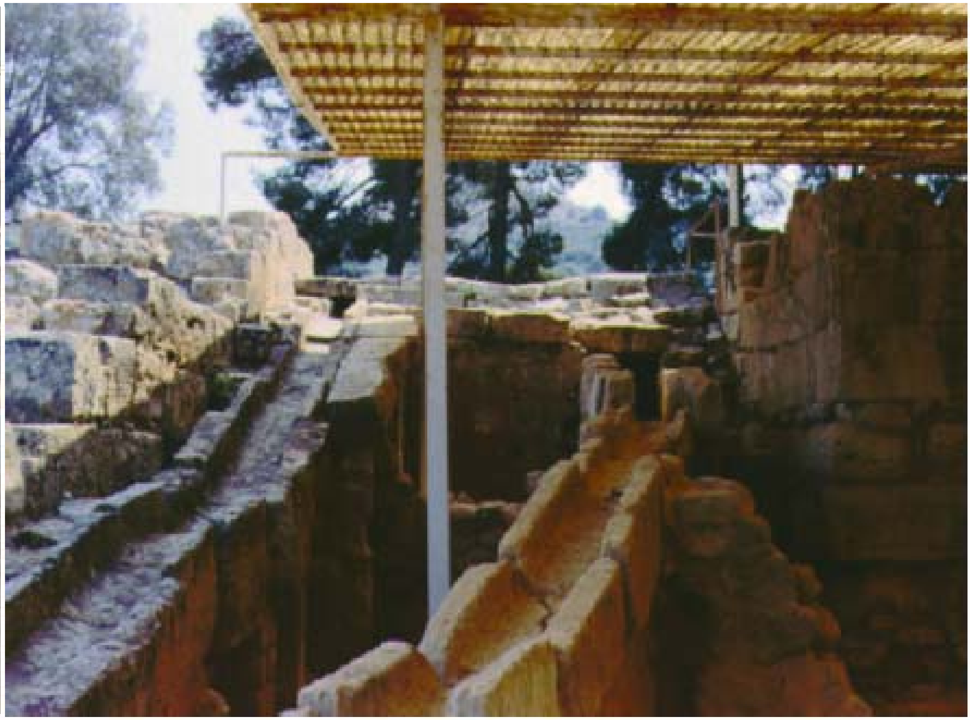
The first European civilization (Minoans)

The Minoan culture developed during the Bronze Age in Crete and a systematic evolution of water management began during the Early Minoan period (*ca.* 3200 – 2300 BC). A population of about **12 thousand individuals** is estimated. Wells, cisterns, aqueducts, fountains, and even recreational uses existed. Also the Minoan architecture played an important role in the water management as the rooftops and open courts acted as basins to collect rainwater from which it flowed to storage areas.

Water use in ancient world

Minoan sanitary and storm sewers

Part of restored stairway with parabolic runnels in Knossos Palace



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.

Water use in ancient world

Navigation in China

The Grand canal constructed between **6th-8th century AD**

The Hong Canal constructed in the **5th century BC**

It consisted from two branches with lengths 900 and 400 km.

Canals were navigable by boat and the water overflowed to smaller canals for irrigation

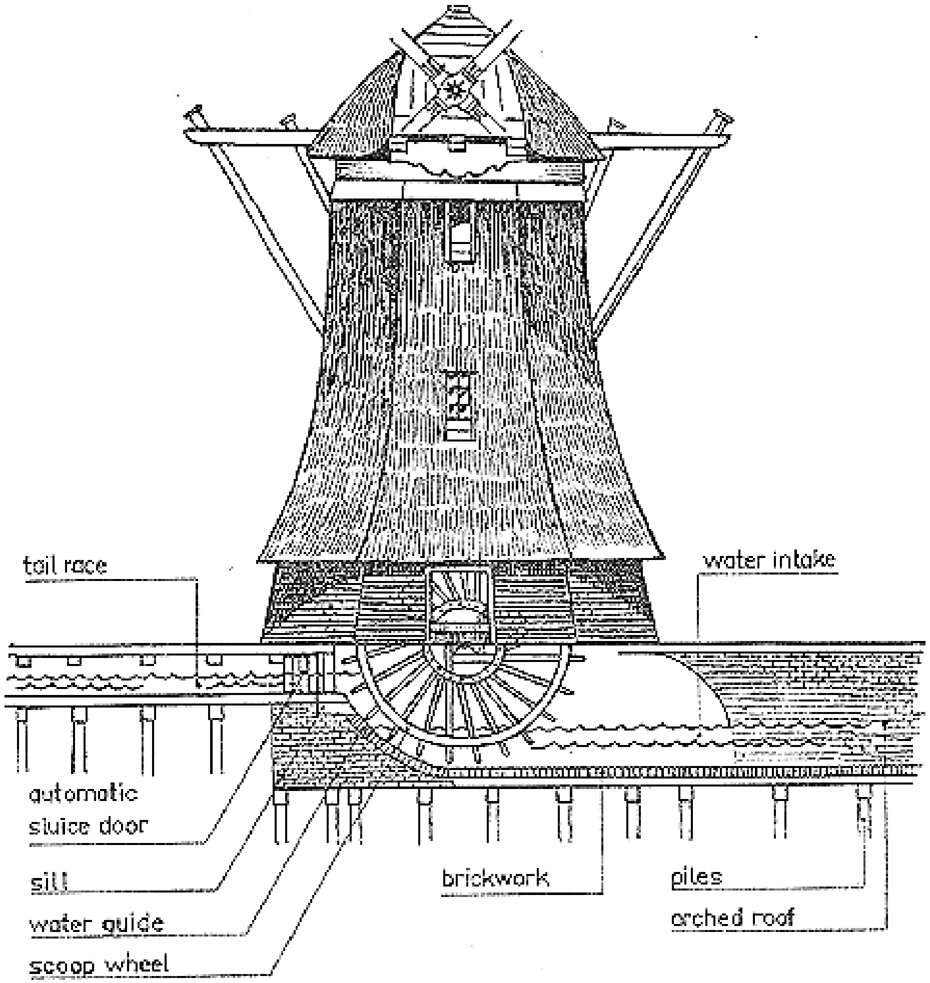
Water use in ancient world

Energy from water: Watermills

Grind grain into flour

Reconstruction of Vitruvius' undershot-wheeled watermill, Museu de la Ciència i de la Técnica de Catalunya

Drainage

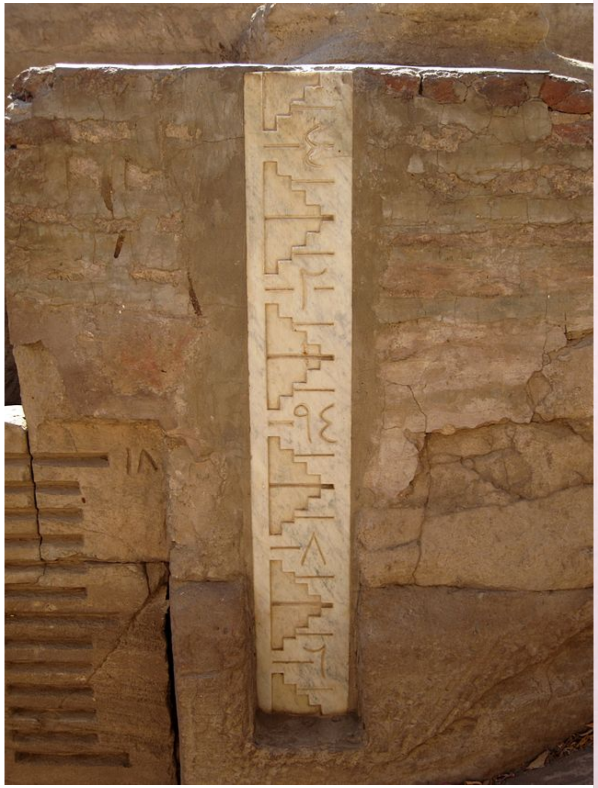


http://www.rug.nl/let/

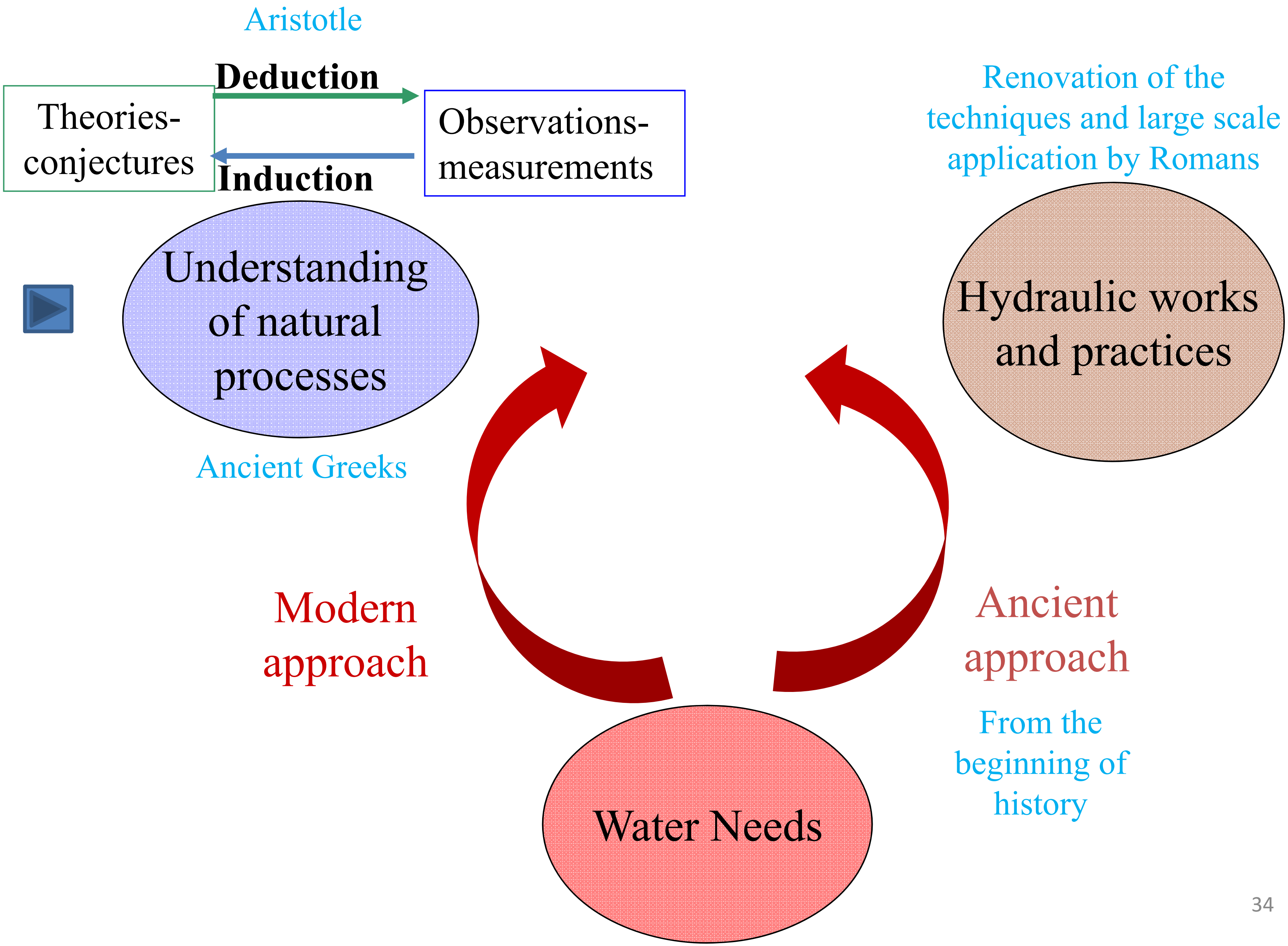
The first hydrological measurements

Egyptians measured river Nile levels, as taxes were extracted based on the flood levels. Earlier a moveable long reed stick on which different levels were carved, was placed vertically into the Nile to measure river levels. This device called **Nilometer** and later (during Ptolemaic period) in order to define taxes fairly, built temples along the Nile and installed Nilometers in them.

Assuan Elephantine Nilometer



Evolution of science and technology in ancient world



Evolution of science and technology in ancient world

- The natural recourses such as sun, wind and water were exploited by ancient civilizations with inventions, technological achievements and engineering works. With these achievements ancient communities managed the wind for sailing, exploited the water for drinking and irrigation and were taken advantages of the solar energy by appropriate orientation of buildings.
- Without doubt, such technological applications imply some understanding of nature. However, during the first historical periods the related explanations were hyperphysical, i.e. mythological.
- Later, communities became significantly depended on the natural resources and they needed to understand the processes and to describe them by laws, **in order to be more predictable**. The understanding of space-time regime of rainfall, river discharge, wind, solar radiation was essential for the management of important actions such as irrigation, navigation, hydraulic works construction etc
- The first scientific views of natural phenomena were formulated around 600 BC. Greek philosophers from Ionia (Thales, Anaximander, Xenophanes, Anaxagoras) rejected the hyperphysical approaches that were reflected in epic poems (mostly in Homer's Iliad and Odyssey), and tried to explain many physical phenomena in a scientific manner. **Ionians had the major contribution in the development of science**

Evolution of science and technology in ancient world

- During next centuries Greeks (Aristotle, Theophrastus, Epicurus) investigated the existing theories but mainly codified the existing knowledge and defined the scientific method. Aristotle (384-328 BC) codified the existing information for several natural sciences but also wrote the famous treatise 'Meteorologica'. Although many of his views were erroneous, he formulated correctly the hydrological cycle. But his main contribution was the consideration of **the way to understand the nature: Deduction-Induction, Today: Deterministic-Probabilistic**
- The Hellenistic period signifies the transformation of science to a more rigorous basis, closer to the modern sense. There was significant progress in mathematics (Euclid, Archimedes and Apollonius), physics (Archimedes), astronomy (Aristarchus of Samos and Eratosthenes) and technology (Heron); the scientific views were advanced and close to modern ones
- The Romans implemented the existing knowledge, renovated many techniques and constructed a huge number of large scale constructions. Most of them are admirable for the advanced techniques that they used and some of them are continuously working up today

The ancient Greek hydraulic culture

Some important issues

Sustainability of constructions. Many hydraulic works are still in use (Peisistratean, Hadrian aqueducts)

Technological achievements. Even today, several structures are admirable engineering solutions as the Tunnel of Eupalinos in Samos or the inverted siphon, a component of the Pergamon aqueduct

Development of science. Physical explanations of natural phenomena that had a relationship with the hydraulic works. Impressive. exegeses about hydrometeorological processes (e.g. evaporation, condensation, hail, snow, rain). Hydraulic devices and mechanisms that were invented (pump of Archimedes, a device that is still in use today)

Cooperation of different structures as a hydrosystem. In many important sites several hydraulic works operated as a hydrosystem. Legislation, institutions and public awareness about water strongly supported hydrosystem's operation. Such a case are the Minoan palace sites (Knossos, Zakros, Mallia) or the city of Athens from Archaic to Roman period

Relation of the implemented technology with socio-economical characteristics of the societies. During some periods, the political situation favored the construction of large public works (such as the Peisistratean aqueduct in Athens). On the other hand, during the democracy period in Athens, smaller constructions were preferred for collecting the storm water

The small facilities that improved the quality of life. Several small scale facilities (lavatories, bathtubs), related to water use can easily be compared with the modern ones (toilets of Knossos palace had seats, flushing equipment and were connected to sewers).

Evolution of science and technology in ancient world

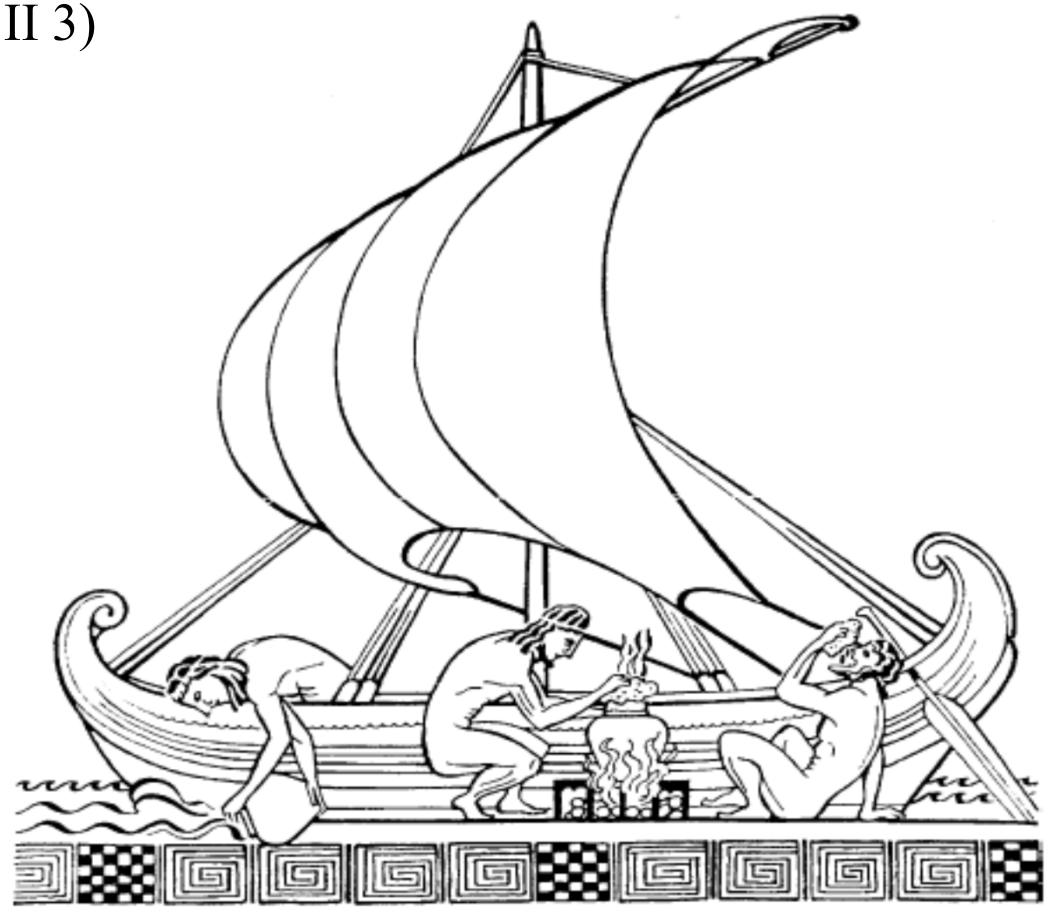
Desalination in ancient world?

The 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 vapor becomes sweet* [freshwater], *and the vapor does not form salt water when it condenses again; this I know by experiment*" (Meteorologica II 3)

We learn from the commentary on Aristotle's Meteorologica, written by Olympiodorus, who lived in the 5th century AD, that:

"*Sailors, when they labor under a scarcity of fresh water at sea, boil the seawater, 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)



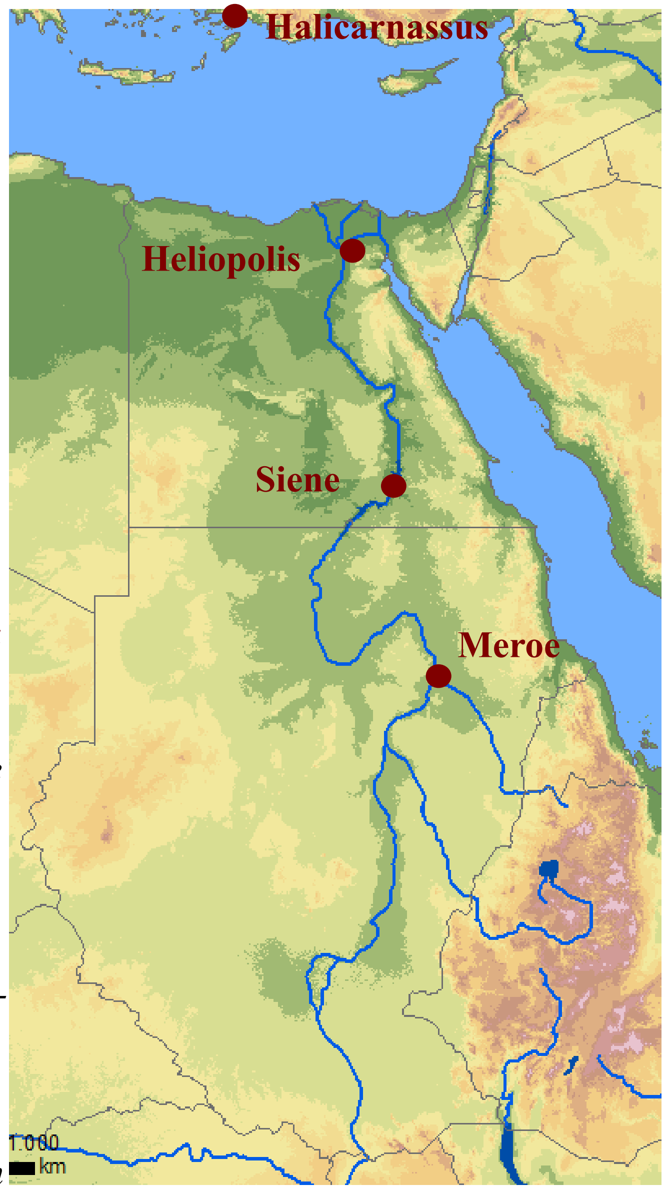
Kalogirou, S. (2005). Seawater desalination using renewable energy sources. *Progress in Energy and Combustion Science*, 242-281.

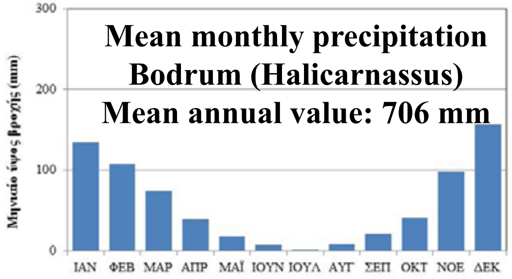
The struggle for understanding natural processes

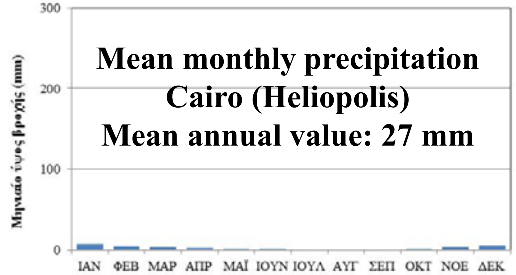
The "enigma" of Nile's floods

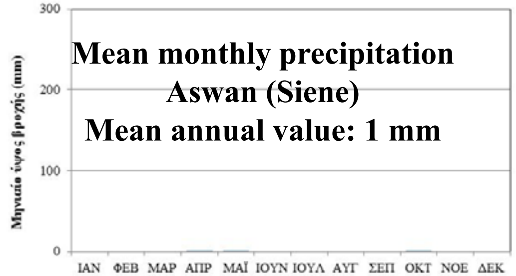
The "enigma" of Nile for the ancient Greeks was the different hydrological regime compared to the other Mediterranean rivers, with floods to occur in summer not during winter

Herodotus (5th century BC), mentions
Concerning the nature of the river, I was not able to gain any information either from the priests or from others. I was particularly anxious to learn from them ***why the Nile, at the commencement of the summer solstice, begins to rise, and continues to increase for a hundred days- and why, as soon as that number is past****, it forthwith retires and contracts its stream, continuing low during the whole of the winter until the summer solstice comes round again.* ***On none of these points could I obtain any explanation from the inhabitants****, though I made every inquiry, wishing to know what was commonly reported- they could neither tell me what special virtue the Nile has which makes it so opposite in its nature to all other streams, nor why, unlike every other river, it gives forth no breezes from its surface.*

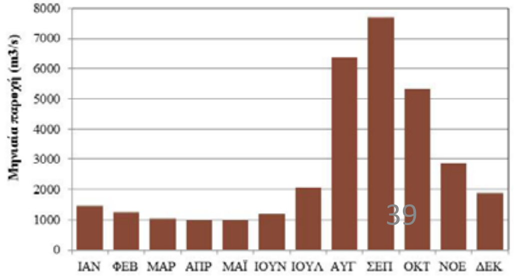








Mean monthly discharge in Aswan (Siene)
Mean annual value: 2780 m^3/s



The struggle for understanding natural processes

The "enigma" of Nile's floods

"*Some of the Greeks, however, wishing to get a reputation for cleverness, have offered explanations of the phenomena of the river, for which they have accounted* ***in three different ways****. Two of these I do not think it worth while to speak of, further than simply to mention what they are*"

1. One pretends that the Etesian winds cause the rise of the river by preventing the Nile-water from running off into the sea. But in the first place it has often happened, when the Etesian winds did not blow, that the Nile has risen according to its usual wont; and further, if the Etesian winds produced the effect, the other rivers which flow in a direction opposite to those winds ought to present the same phenomena as the Nile, and the more so as they are all smaller streams, and have a weaker current. But these rivers, of which there are many both in Syria and Libya, are entirely unlike the Nile in this respect.

2. The second opinion is even more unscientific than the one just mentioned, and also, if I may so say, more marvellous. **It is that the Nile acts so strangely, because it flows from the ocean, and that the ocean flows all round the earth.** …As for the writer who attributes the phenomenon to the ocean, his account is involved in such obscurity that it is impossible to disprove it by argument. For my part I know of no river called Ocean, and I think that Homer, or one of the earlier poets, invented the name, and introduced it into his poetry.

3. The third explanation, which is very much more plausible than either of the others, is positively the furthest from the truth; for there is really nothing in what it says, any more than in the other theories. **It is, that the inundation of the Nile is caused by the melting of snows.** Now, as the Nile flows out of Libya, through Ethiopia, into Egypt, how is it possible that it can be formed of melted snow, running, as it does, from the hottest regions of the world into cooler countries? Many are the proofs whereby any one capable of reasoning on the subject may be convinced that it is most unlikely this should be the case. **The first and strongest argument** is furnished by the winds, which always blow hot from these regions. **The second** is that rain and frost are unknown there. Now whenever snow falls, it must of necessity rain within five days, so that, if there were snow, there must be rain also in those parts. **Thirdly,** it is certain that the natives of the country are black with the heat, that the kites and the swallows remain there the whole year, and that the cranes, when they fly from the rigors of a Scythian winter, flock thither to pass the cold season. If then, in the country whence the Nile has its source, or in that through which it flows, there fell ever so little snow, it is absolutely impossible that any of these circumstances could take place.

Herodotus Book 2, chapters 19-35

The struggle for understanding natural processes

The "enigma" of Nile's floods

Herodotus explanation: "*Perhaps, after censuring all the opinions that have been put forward on this obscure subject, one ought to propose some theory of one's own. I will therefore proceed to explain what I think to be the reason of the Nile's swelling in the summer time.* ***During the winter, the sun is driven out of his usual course by the storms, and removes to the upper parts of Libya. This is the whole secret in the fewest possible words; for it stands to reason that the country to which the Sun-god approaches the nearest, and which he passes most directly over, will be scantest of water, and that there the streams which feed the rivers will shrink the most."***

Oinopides (5ος century BC). Based on water temperature observations on deep wells, he hypothesized (erroneously) that ground water was cooler in summer than in winter. ***According to his theory the winter rain water was evaporated when infiltrated though the ground, but in summer the evaporation was lower and the excess water flooded the river plain.***

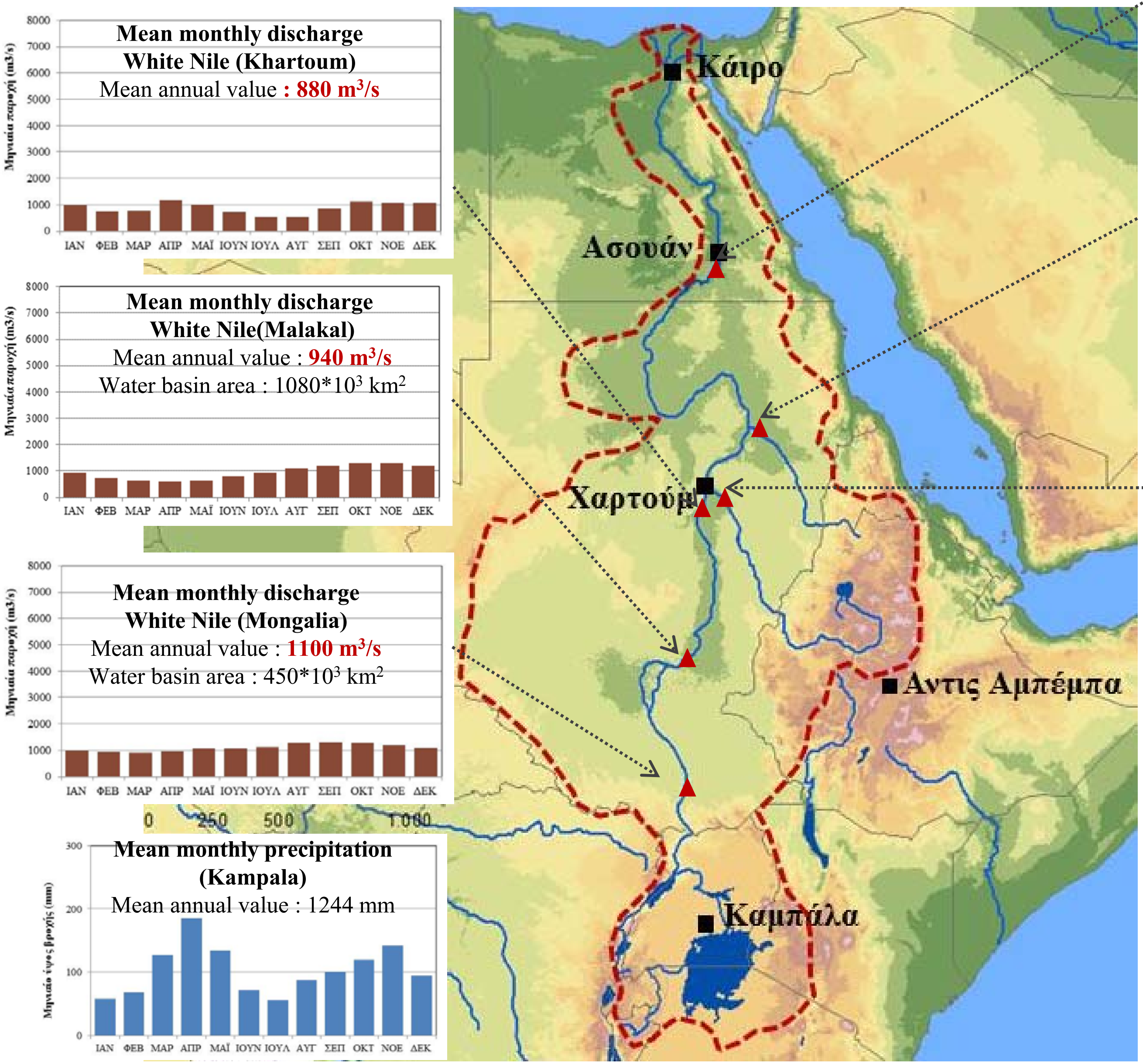
Kleomides (1ος century AD) that transfers opinions of **Posidonius (2ος century BC)**
In the equator the durations of day and night are equal and for this there is time for the ground to become cool and rainfall and wind are produced. Indeed, many say that there are summer rainfalls in Ethiopia near the solstice that provoke the summer floods of Nile

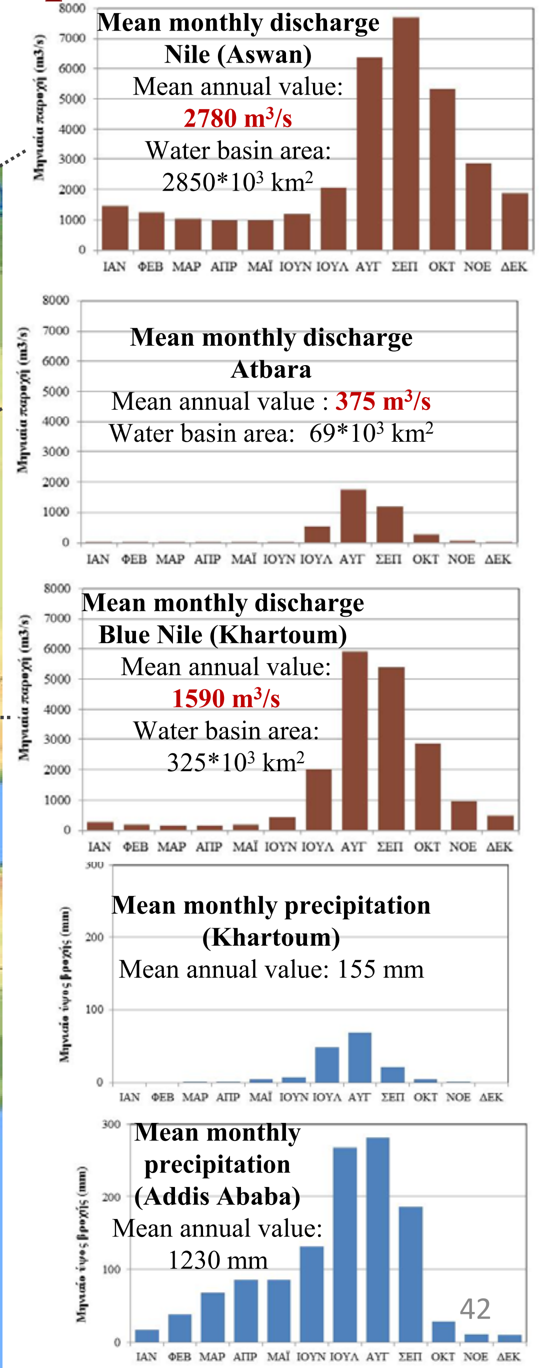
Strabo (1ος century BC) that transfers opinions of **Eratosthenes (3ος century BC)**: "…*Two rivers empty themselves into it, which issue out of some lakes towards the east, and encircle Meroë, a considerable island. One of these rivers is called Astaboras, flowing along the eastern side of the island. The other is the Astapus, or, as some call it, Astasobas.* ***But the Astapus is said to be another river, which issues out of some lakes on the south, and that this river forms nearly the body of the (stream of the) Nile, which flows in a straight line, and that it is filled by the summer rains;*** *that above the confluence of the Astaboras and the Nile, at the distance of 700 stadia, is Meroë…'"* ***Geographica 17.2***

The struggle for understanding natural processes

The “enigma” of Nile’s floods

The truth





Hydro politics

2500 BC Mesopotamia. The dispute over the “Guedena” (edge of paradise) region begins. Urlama, King of Lagash from 2450 to 2400 B.C., diverts water from this region to boundary canals, drying up boundary ditches to deprive Umma of water. His son Il cuts off the water supply to Girsu, a city in Umma.

1700 BC Mesopotamia. A grandson of Hammurabi, dams the Tigris to prevent the retreat of rebels led by Iluma-Ilum, who declared the independence of Babylon. This failed attempt marks the decline of the Sumerians who had reached their apex under Hammurabi.

539 BC Babylon. According to Herodotus, Cyrus invades Babylon by diverting the Euphrates above the city and marching troops along the dry riverbed. This popular account describes a midnight attack that coincided with a Babylonian feast.

430 BC Athens. During the second year of the Peloponnesian War when plague broke out in Athens, the Spartans were accused of poisoning the cisterns of the Piraeus, the source of most of Athens’ water.

Hydro politics

There is a plain in Asia shut in on all sides by mountains through which there are five passes. This plain was once the Chorasmians', being at the boundaries of the Chorasmians, the Hyrcanians, Parthians, Sarangians, and Thamanaei, but since the Persians have held power it has been the king's.
Now from the encircling mountains flows a great river whose name is the Aces. Its stream divides into five channels and formerly watered the lands of the above-mentioned peoples, going to each through a different pass, ***but since the beginning of the Persian rule the king has blocked the mountain passes, and closed each passage with a gate; with the water barred from outlet, the plain within the mountains becomes a lake, seeing that the river pours into it and finds no way out.***
Those therefore who before were accustomed to use the water endure great hardship in not being able to use it; for during the winter, god rains for them just as for the rest of mankind, but in the summer they are in need of the water for their sown millet and sesame. So whenever no water is given to them, they come into Persia with their women, and cry and howl before the door of the king's palace, until the king commands that the river-gate should be opened for those whose need is greatest; then, when this land has drunk its fill of water, that gate is shut, and the king has another opened for those of the rest who most require it. ***I know by hearsay that he gets a lot of money, over and above the tribute, for opening the gates.***

Herodotus, The Histories, Book 3, 117

Water laws

Hammurabi's Code

The Code of Hammurabi is a Babylonian law code of ancient Mesopotamia, dating back to about 1772 BC. It is one of the oldest deciphered writings of significant length in the world. The 6th Babylonian king, Hammurabi, created the code, and partial copies exist on various clay tablets. The Code consists of 282 laws, and includes scaled punishments.

Laws related to water management

48. If any one owe a debt for a loan, and a storm prostrates the grain, or the harvest fail, or the grain does not grow for lack of water; in that year he need not give his creditor any grain, he washes his debt-tablet in water and pays no rent for this year.

55. If any one open his ditches to water his crop, but is careless, and the water flood the field of his neighbor, then he shall pay his neighbor corn for his loss.

56. If a man let in the water, and the water overflow the plantation of his neighbor, he shall pay ten gur of corn for every ten gan of land.

259. If any one steal a water-wheel from the field, he shall pay five shekels in money to its owner.

260. If any one steal a shadduf (used to draw water from the river or canal) or a plow, he shall pay three shekels in money

Translated by L. W. King

Water management practices

Water legislation and management

Apart from the hydraulic works for 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,, who was elected archon in 594 BC 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 about ground water management rules:

"*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

Water management practices

Various legislation for water uses

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 "…*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)

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)

Water management practices

The first known flow regulation rule

It is saved in an epigraph of the 5th century BC in the ancient city of Gortyn in Crete. The city crossed by the river Lithaios (contemporary name Mitrpolianos) which dominates the valley of Messara

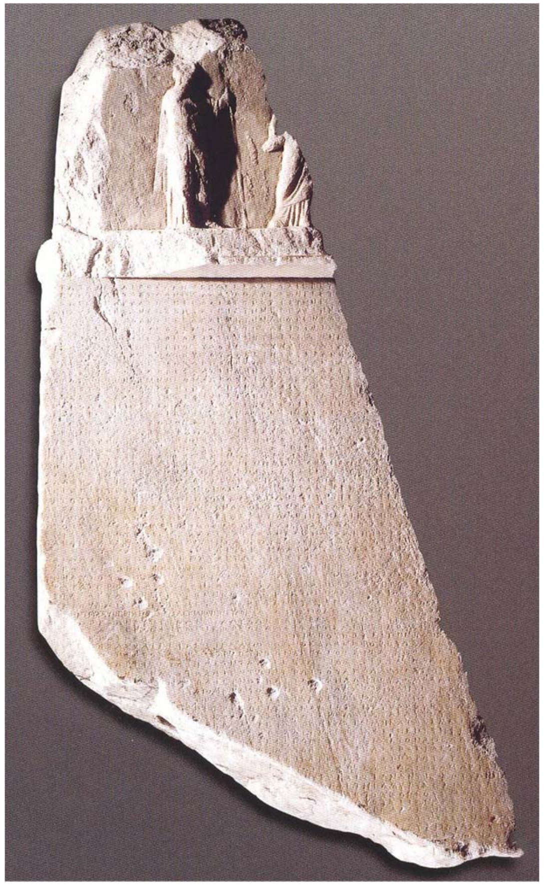
«Θιοί· τô ποταμô αἴ κα κατὰ τὸ μέττον
τὰν ῥοὰν θιθῆι ῥῆν κατὰ
το Fὸν αυτô, θιθεμένō̄ι ἄπατον ἤμην.
Τὰν δὲ ῥοὰν λείπεν ὅττον
κατέκει ἀ ἐπ᾽ ἀγορᾶι δέπυρα ἤ πλίον,
μεῖον δὲ μὴ.»

Gods. If anyone makes the flow run from the middle of the river towards his own property, it is without penalty for the person so doing. He has to leave the flow as wide as the bridge that the agora holds, or more but no less.

Efstratiadis, A., A. Tegos, A. Varveris, and D. Koutsoyiannis, Assessment of environmental flows under limited data availability – Case study of Acheloos River, Greece, Hydrological Sciences Journal, 59 (3-4), 731–750, doi:10.1080/02626667.2013.804625, 2014.

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



Tassios, T. P., Selected topics of water technology in Ancient Greece, Proceedings of the 1st IWA International Symposium on Water and Wastewater Technologies in Ancient Civilizations, Iraklio, Greece, 3-26, 2006

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

- 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

Source: Koutsoyiannis D., Water control in the Greek cities, 2012

Institutions for building public hydraulic works

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

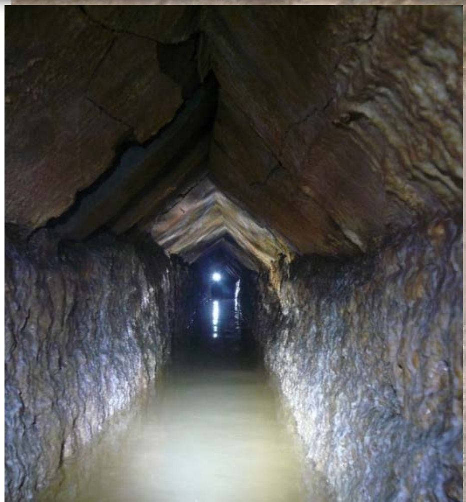
1. Between the city of the Eretrians representing the 31 municipalities of the Eretrian region and the contractor Chairephanes a contract is made concerning the draining of the Ptechae Lake
2. The draining works include the construction of drainage canals, sewers, and wells for the drainage of water 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

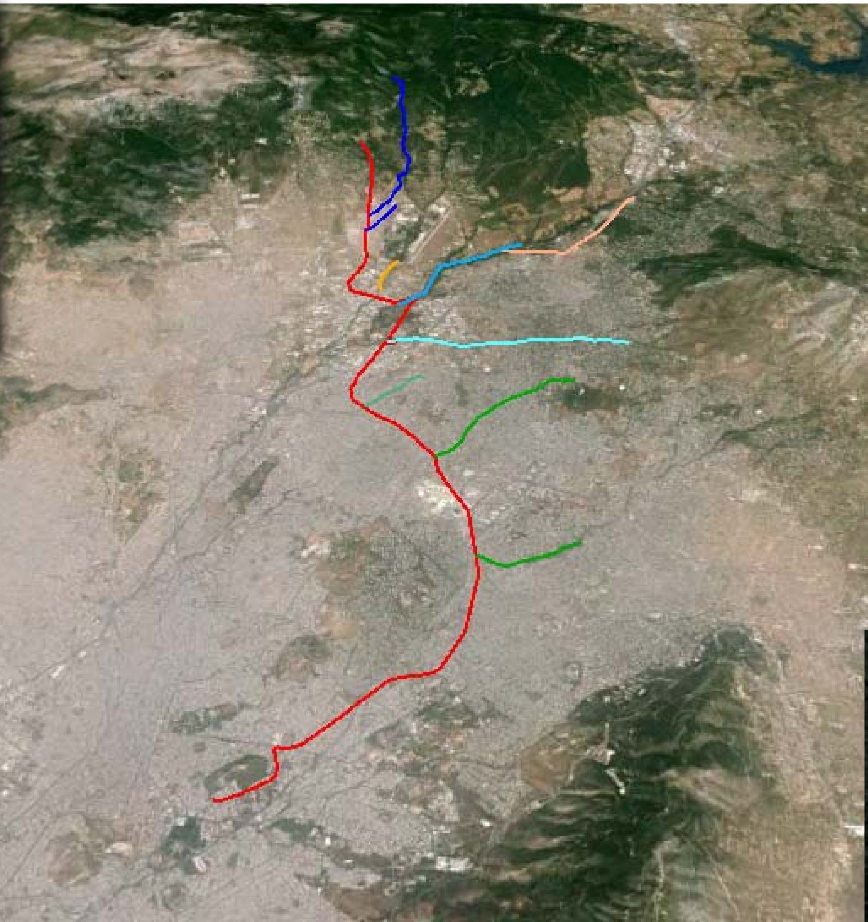
Source: Koutsoyiannis D., Water control in the Greek cities, 2012

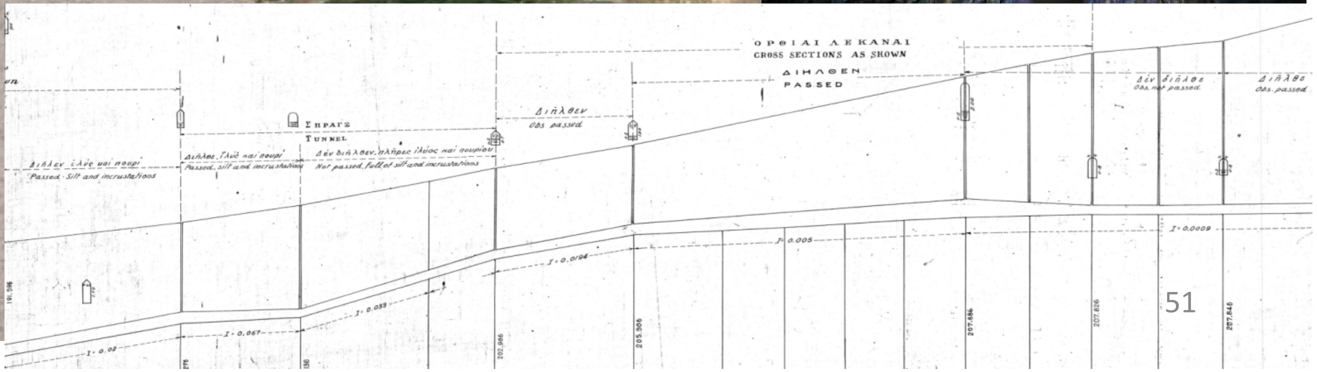
Sustainable works

Fotos: P. Deytereos

Hadrian' s aqueduct (Athens, partially in use)



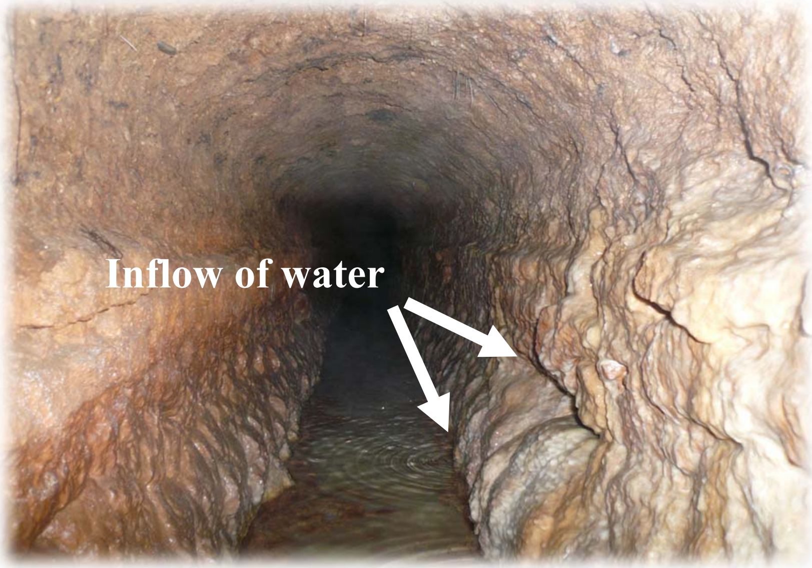




Sustainable works

Hadrian' s aqueduct (Athens, partially in use)

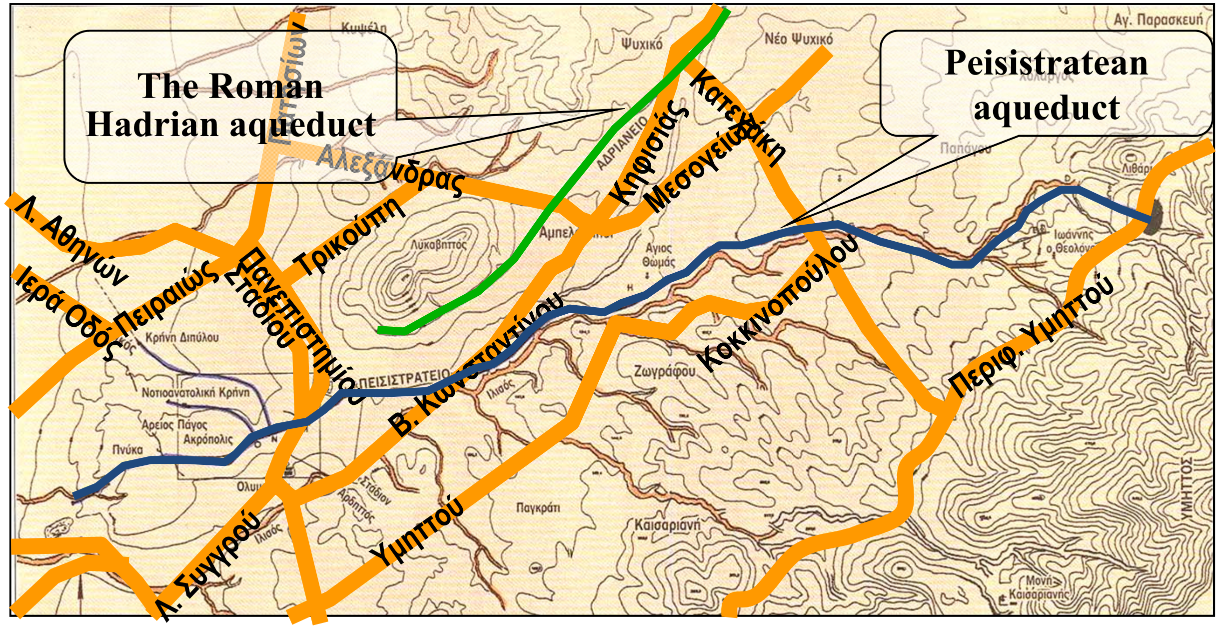
Tunnel that convey water but also drains water in his course



Lateral inflows with small works

Fotos: P. Deytereos

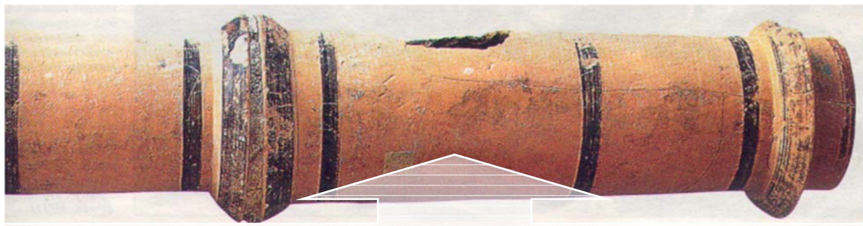
Sustainable works **The Peisistratean aqueduct (Athens, partially in use)**



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

Ceramic pipeline at the bottom.

Greek hydraulic constructions were mostly subterranean for security reasons (not no be exposed to aliens, e.g. in case of war)



Part of the Peisistratean aqueduct and detail of the pipe sections and their connection (photos reproduced from newspaper Kathimerini).

Sustainable works

Alyzia Dam (Western Greece)

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

The dam (most likely built during 5th century BC to protect the downstream plain from floods and sediments) is in perfect condition 2500 years after its construction

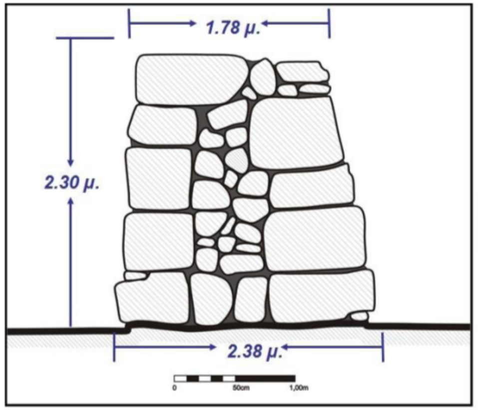
The spillway in operation

Technological achievements

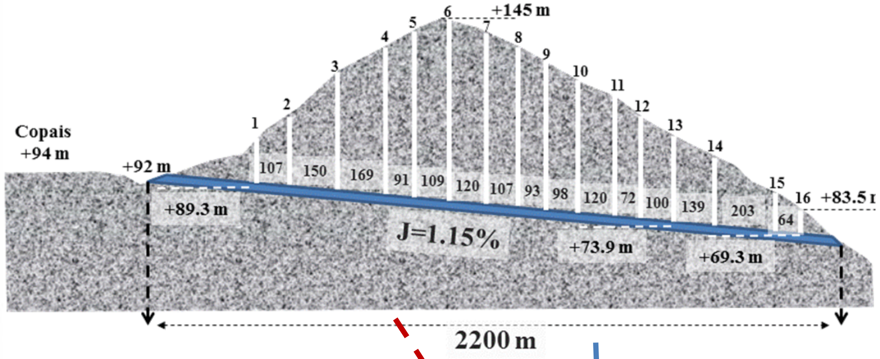
Ancient reclamation works at Lake Copais in Greece

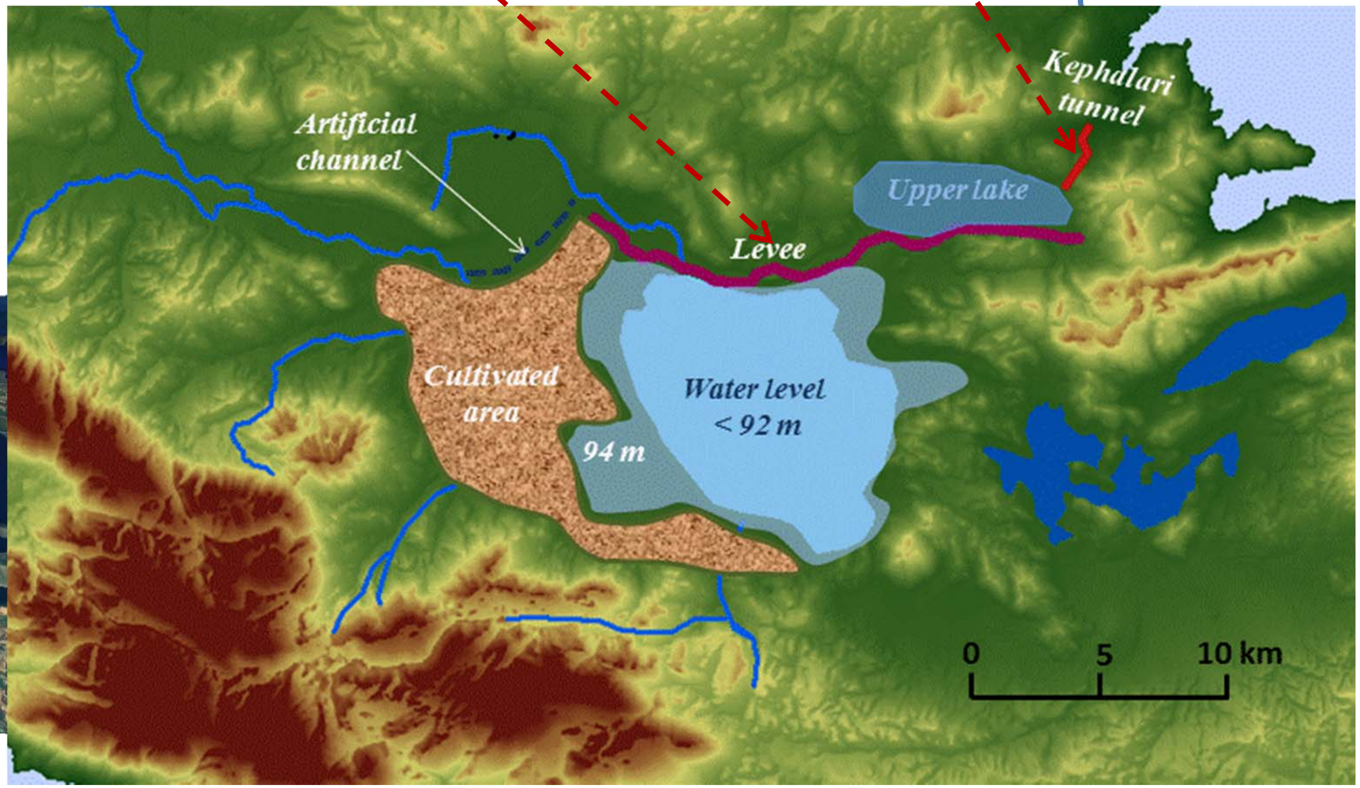
Diversion of two river using a canal and a levee to convey water to sinkholes
Minyans, 12th century BC

Levee



Diversion tunnel to sea (not be finished)

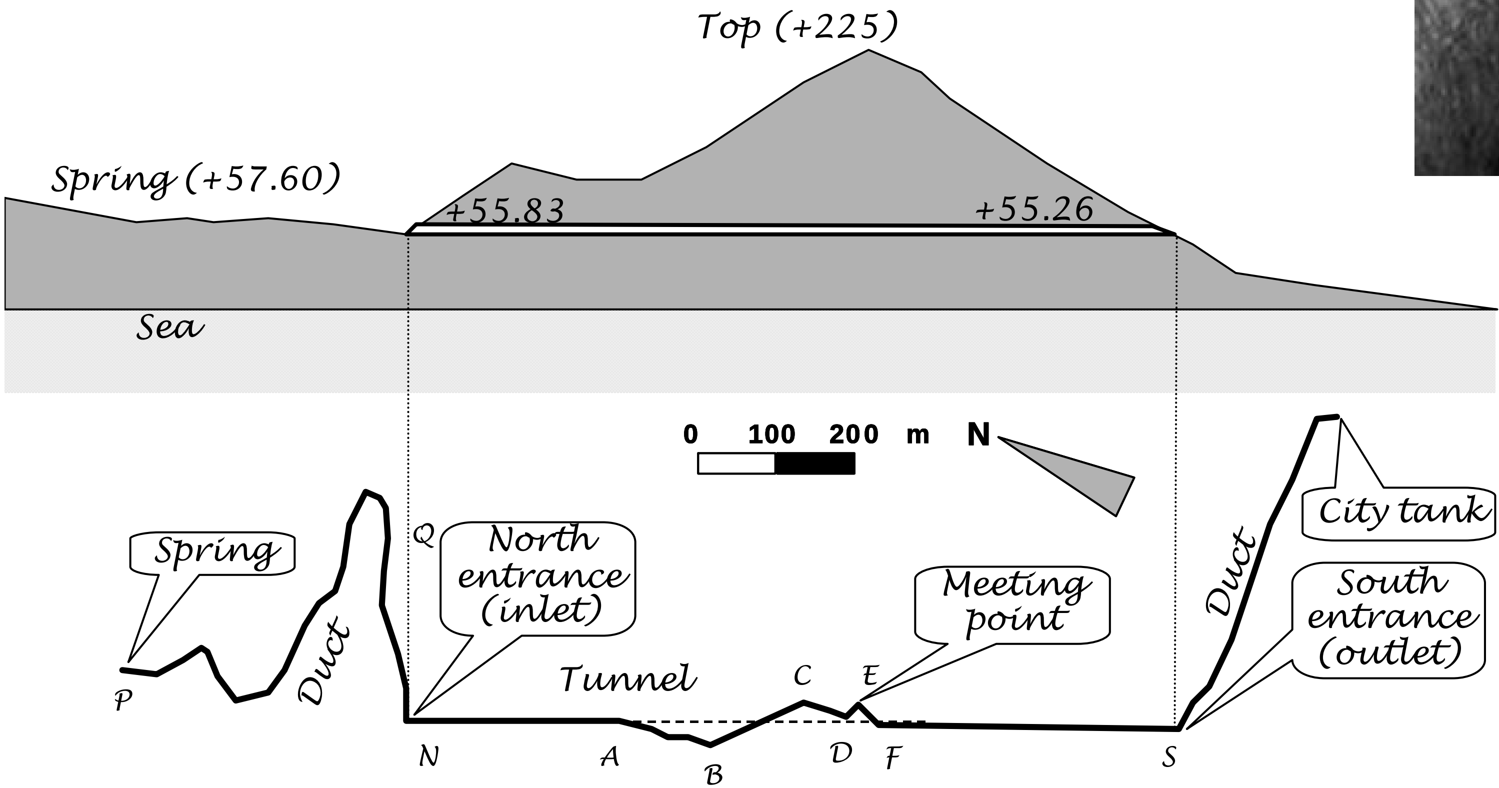




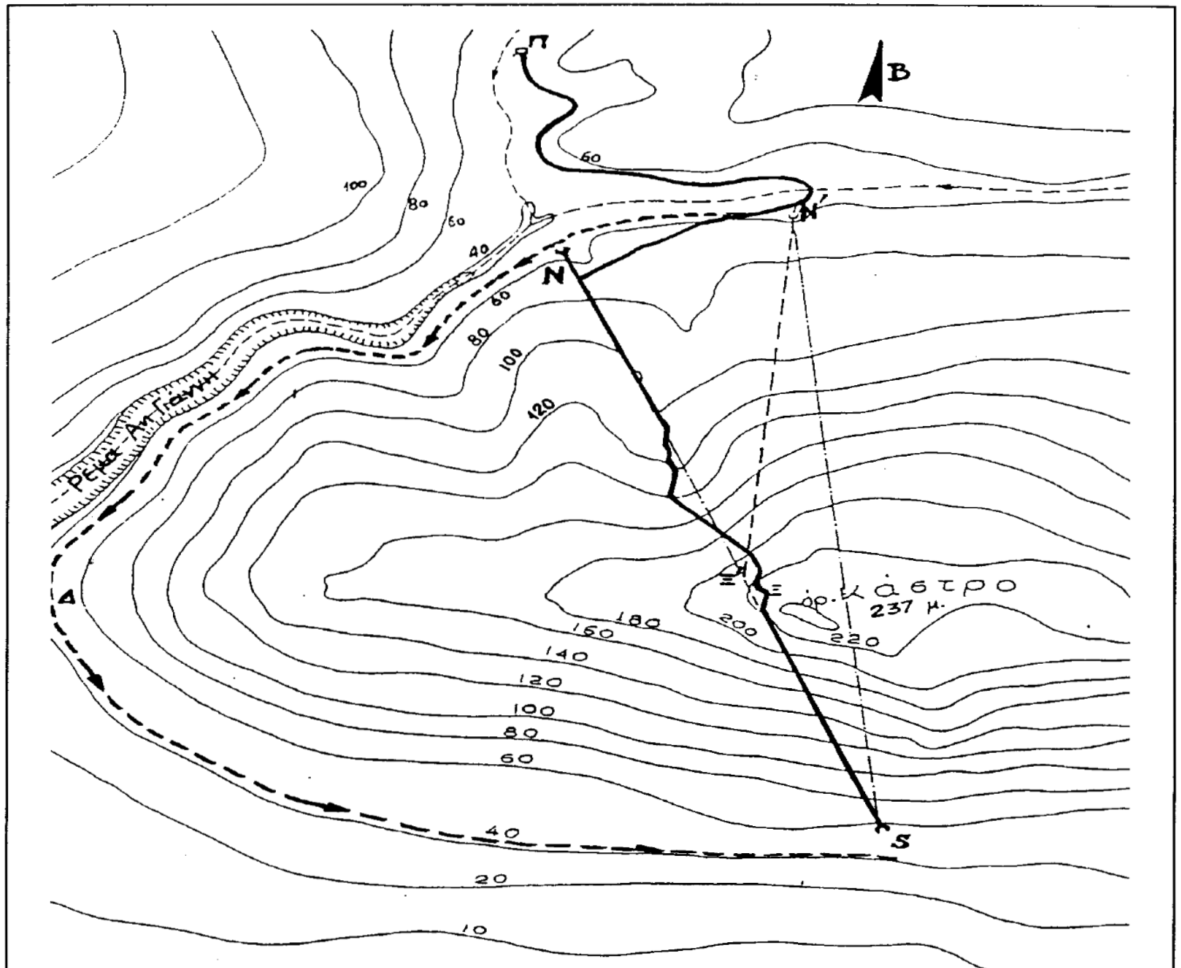
Technological achievements

Eypalinean aqueduct (Samos island)

The most famous hydraulic work of ancient Greece was the aqueduct of ancient Samos, which was admired both in antiquity and in modern times. The most amazing part of the aqueduct is the "Eupalinean digging", **a 1036 m long tunnel the first known deep tunnel in history**. Eupalinos an engineer from Megara dug the tunnel from two openings, a very modern practice. He also solved several technical problems as carving segments on straight lines, eliminating the impact of uncertainty in position, and ensuring the hydraulic gradient to sustain flow in the aqueduct. Its construction started in 530 BC, during the tyranny of Polycrates and **lasted for ten years**.



Why a vain aqueduct was constructed?



Πηγή : Ταμπουράκης Δ. Το όρυγμα του Ευπάλινου στην αρχαία Σάμο, 1997

…..καὶ τὸ πένητας ποιεῖν τοὺς ἀρχομένους τυραννικόν, ὅπως μήτε φυλακὴ τρέφηται καὶ πρὸς τῷ καθ᾽ ἡμέραν ὄντες ἄσχολοι ὦσιν ἐπιβουλεύειν. παράδειγμα δὲ τούτου αἵ τε πυραμίδες αἱ περὶ Αἴγυπτον καὶ τὰ ἀναθήματα τῶν Κυψελιδῶν καὶ τοῦ Ὀλυμπίου ἡ οἰκοδόμησις ὑπὸ τῶν Πεισιστρατιδῶν, καὶ τῶν περὶ Σάμον ἔργα Πολυκράτεια (πάντα γὰρ ταῦτα δύναται ταὐτόν, ἀσχολίαν καὶ πενίαν τῶν ἀρχομένων)

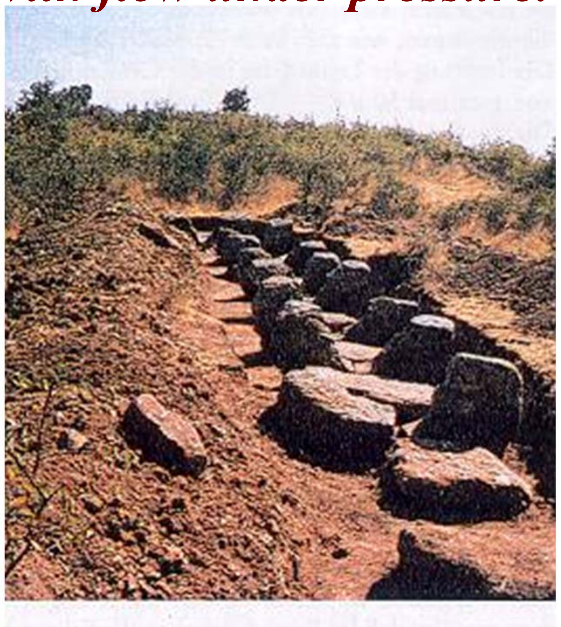
Αριστοτέλης Πολιτικά V 1313β

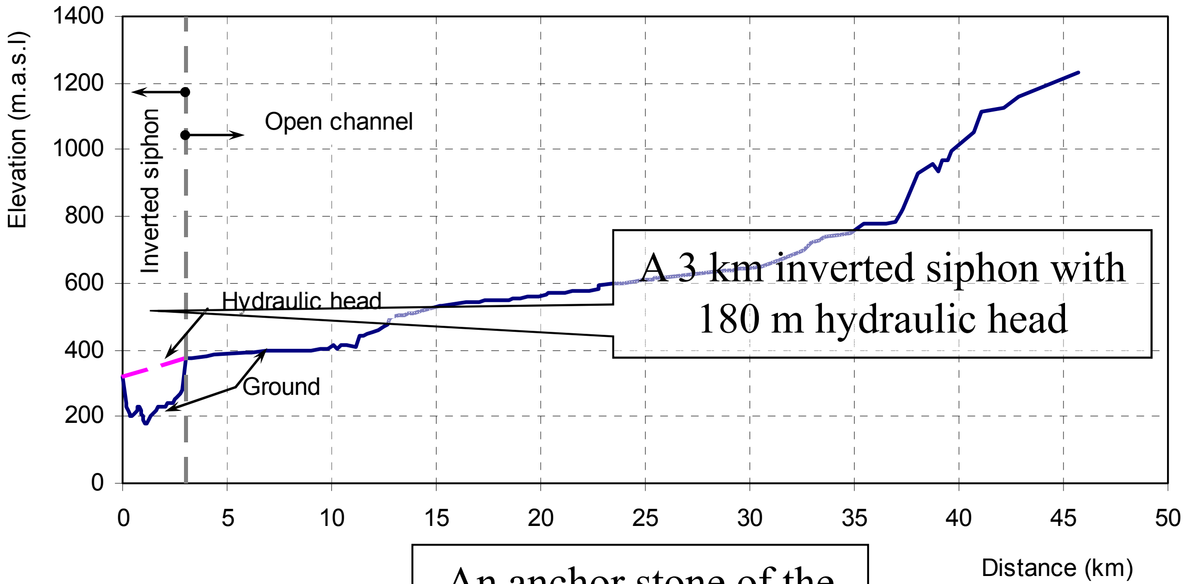
"And it is a device of tyranny to make the subjects poor, so that a guard may not be kept, and also that the people being busy with their daily affairs may not have leisure to plot against their ruler. Instances of this are the pyramids in Egypt and the votive offerings of the Cypselids, and the building of the temple of Olympian Zeus by the Pisistratidae and of the temples at Samos, works of Polycrates (for all these undertakings produce the same effect, constant occupation and poverty among the subject people)"

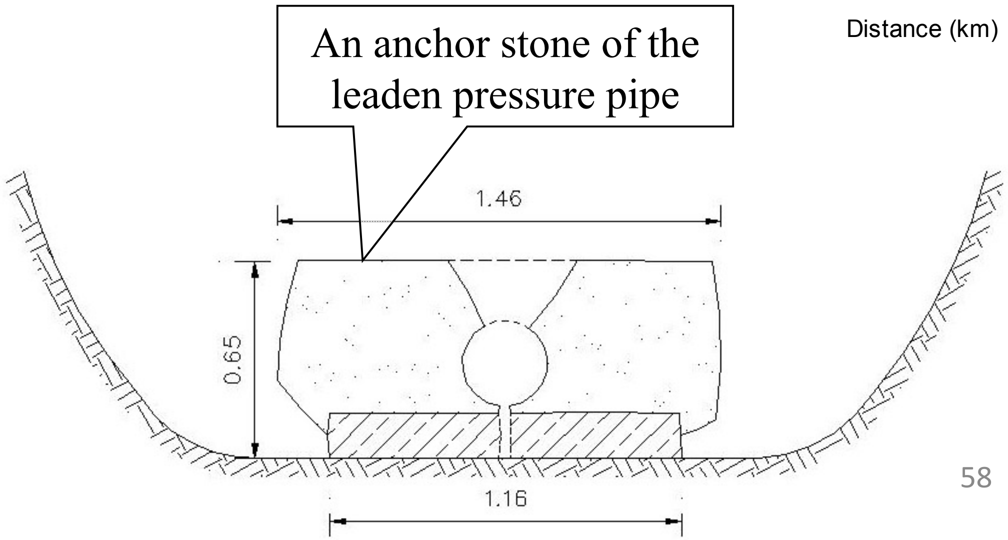
Technological achievements

The Pergamum aqueduct (Asia Minor)

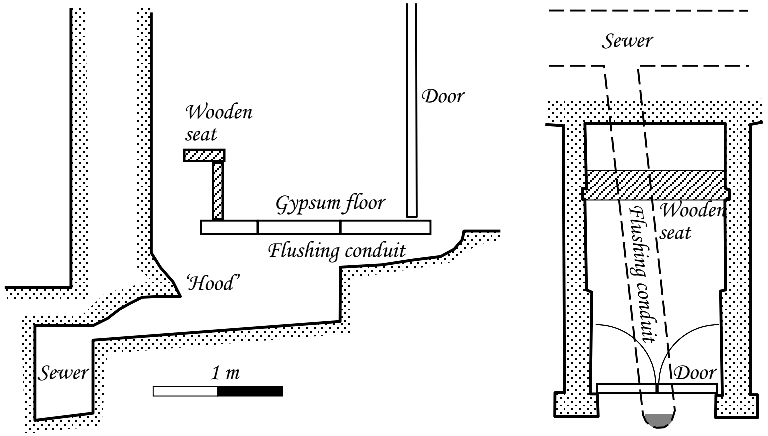
It was constructed around 200 BC. It includes an inverted siphon with length that exceeds 3000 m. ***It is the first large scale application where water was transported with flow under pressure.***



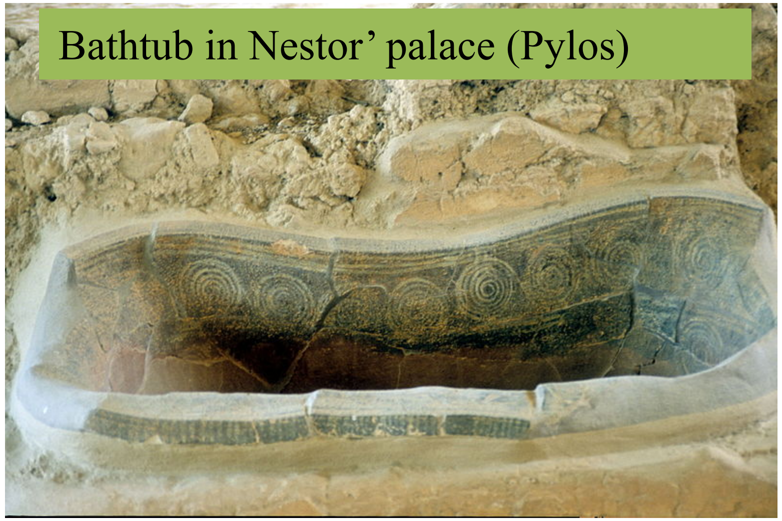




Quality of life

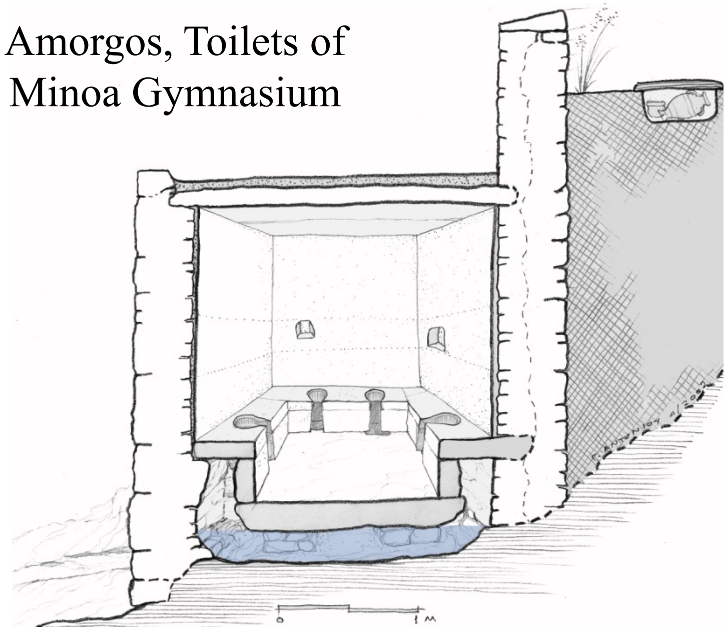


Section and plan of ground-floor toilet in the residential quarter of Palace of Minos (Graham, 1987).



Bathtub in Nestor' palace (Pylos)

Akrotiri (Thera)
(http://www.abovetopsecret.com/)



Amorgos, Toilets of Minoa Gymnasium

Source: Antoniou G.P., 2007. "Lavatories in Ancient Greece", Water Science and Technology: Water Supply, edit. A. Angelakis, D. Koutsoyiannis, IWA, London, p. 160

Present-day situation

Water Environment

Variables

Precipitation

Discharge

Evaporation

Interaction

Variation of hydrometeorological variables in space and time → Disturbances to hydrosystems

Water quality degradation ←

Human society

Main water uses

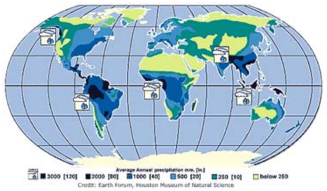
Domestic

Agricultural

Industrial

Water related problems

Unequal distribution of water availability and demand in space and time



Floods

Droughts

Quality

Problems handling

Hydraulic works-Hydrosystems

- ***Study*** (Evaluation of water availability and demand, Design)
- ***Construction*** (Dams, Drainage, Sewage etc)
- ***Management*** (Simulation, optimization)

Philosophy

- Environmental modeling
- Hydrosystem management
- Confrontation of hazards

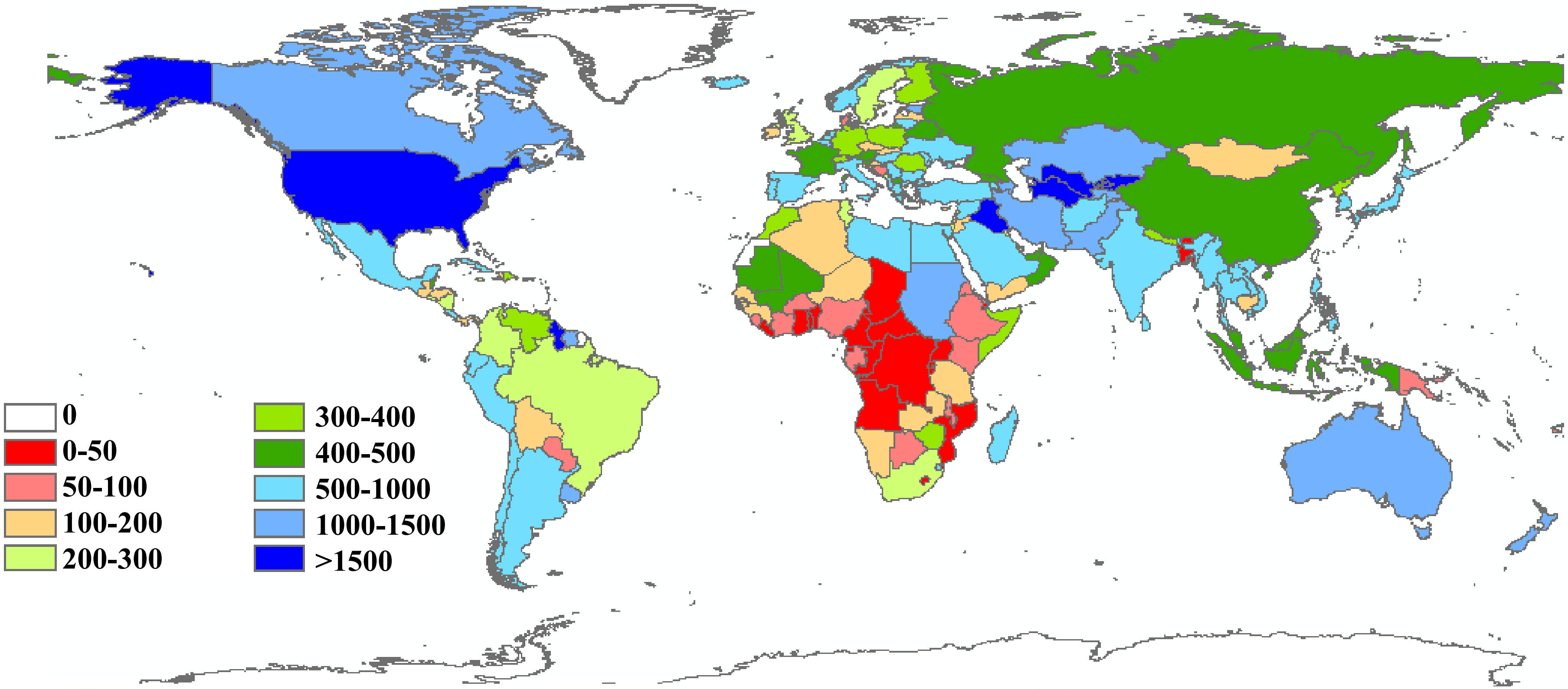
Actions

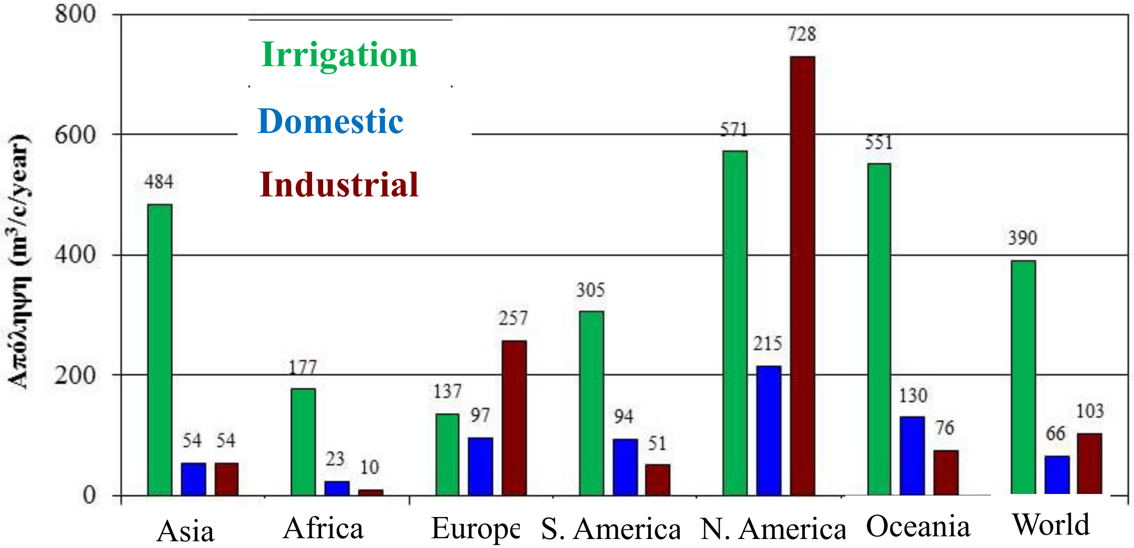
Institutional, Technological, Economical, Social, Environmental

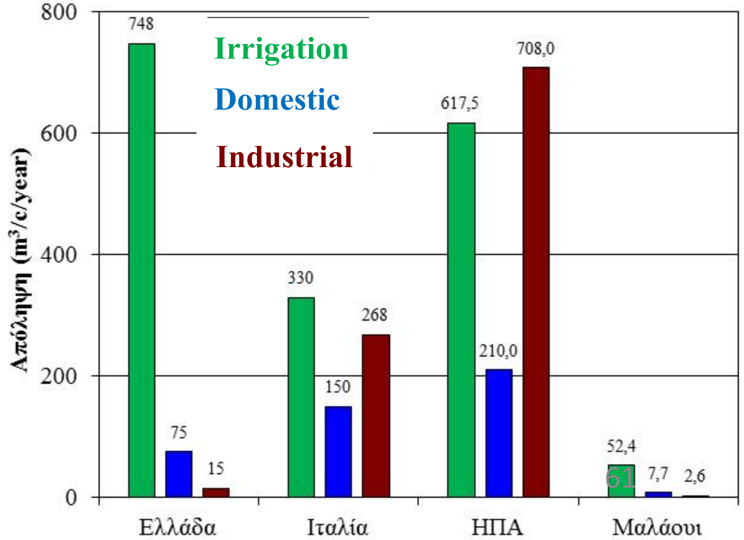
Directives, Water management plants, Flood Risk and hazard maps, Public awareness

Present-day situation

Total water withdrawal (m^3/cap/y)

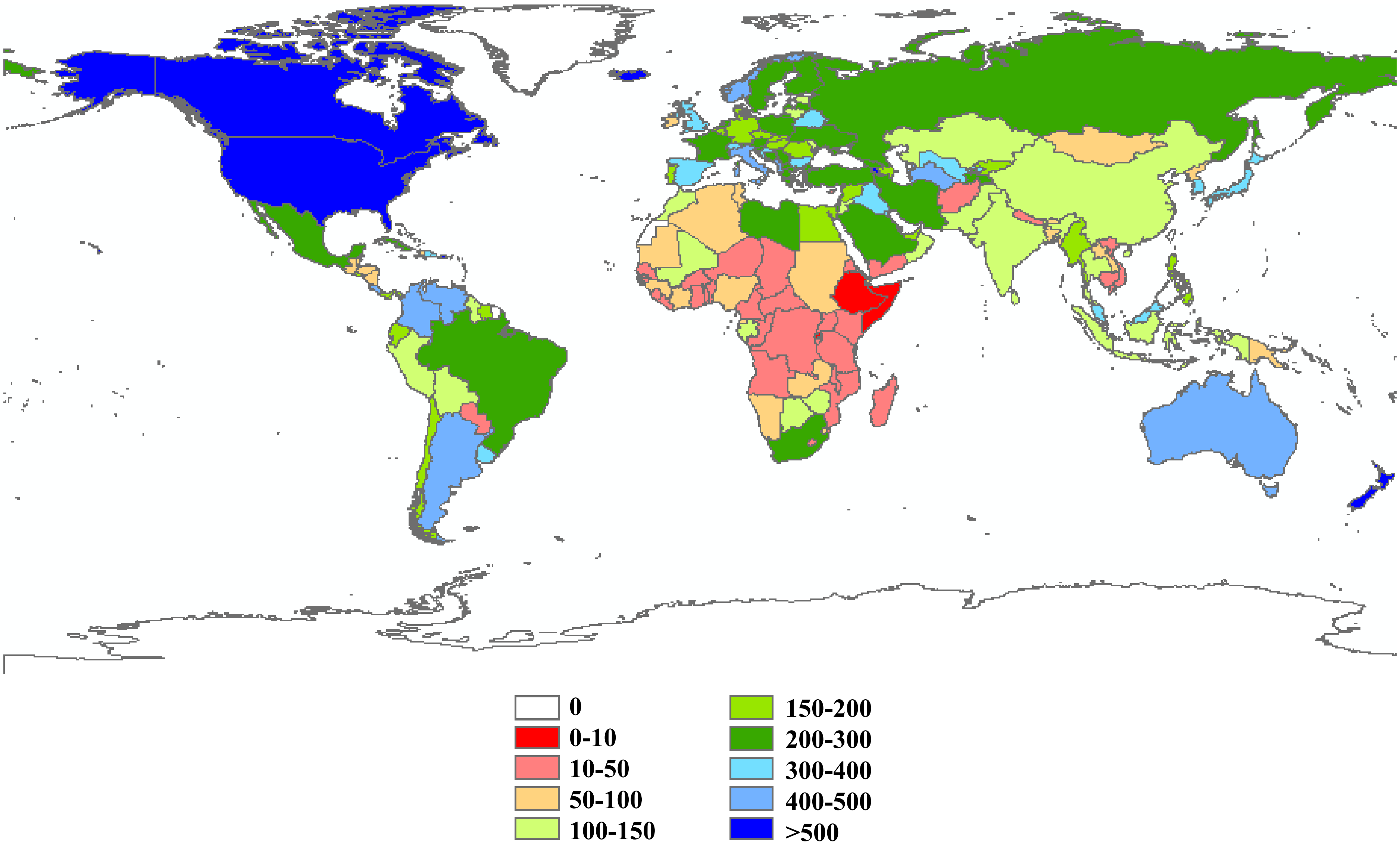






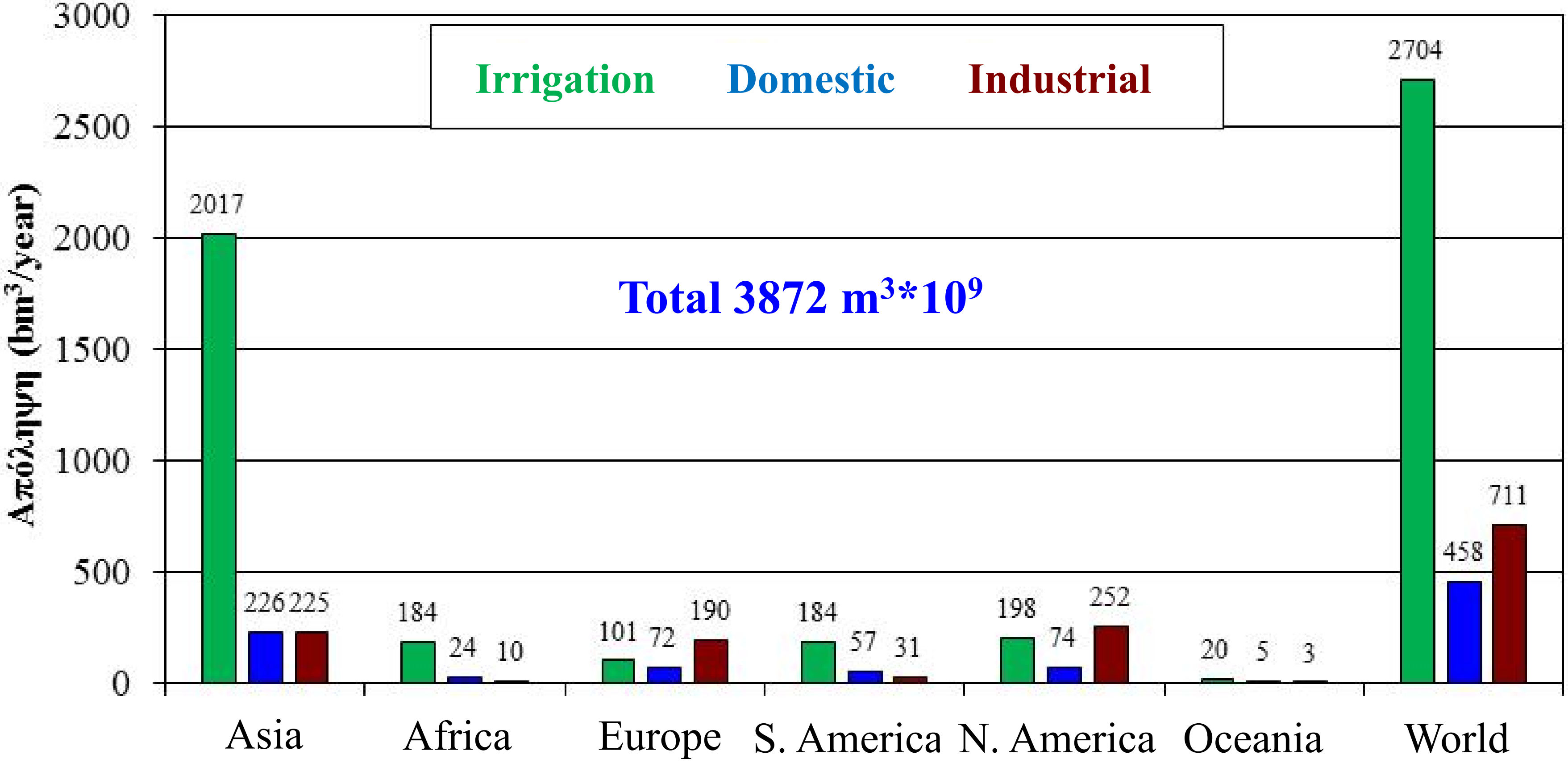
Present-day situation

Domestic use l/cap/d



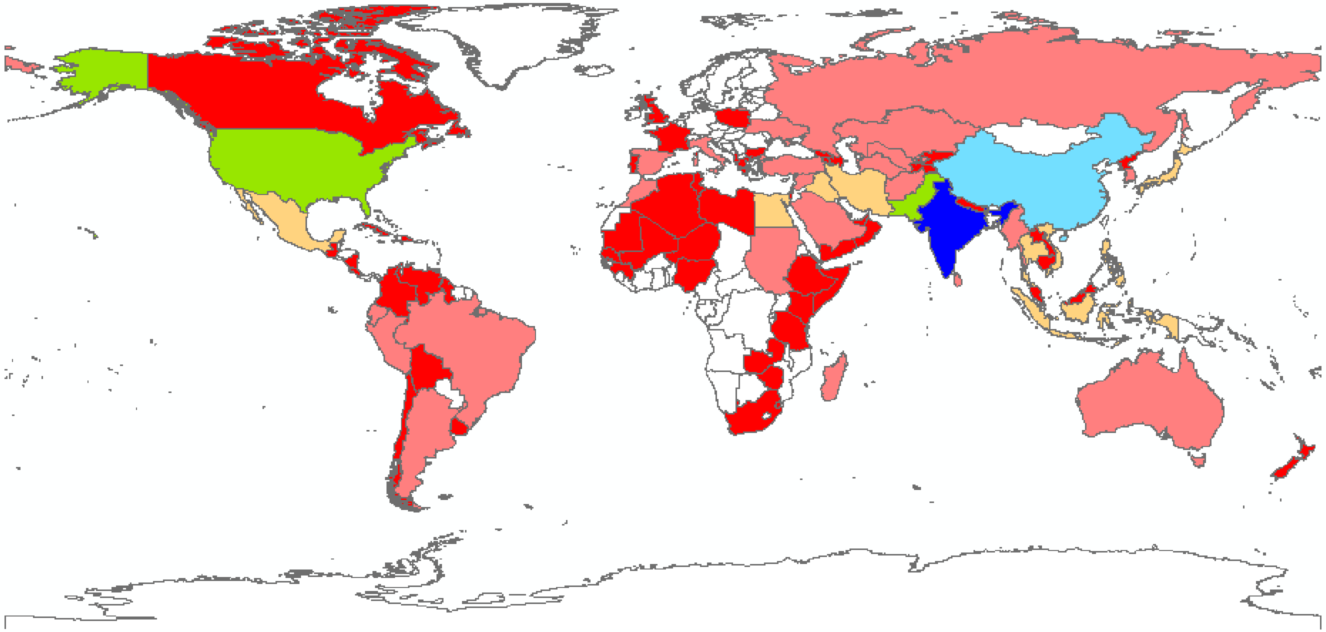
Present-day situation

Annual water withdrawal m^3*10^9



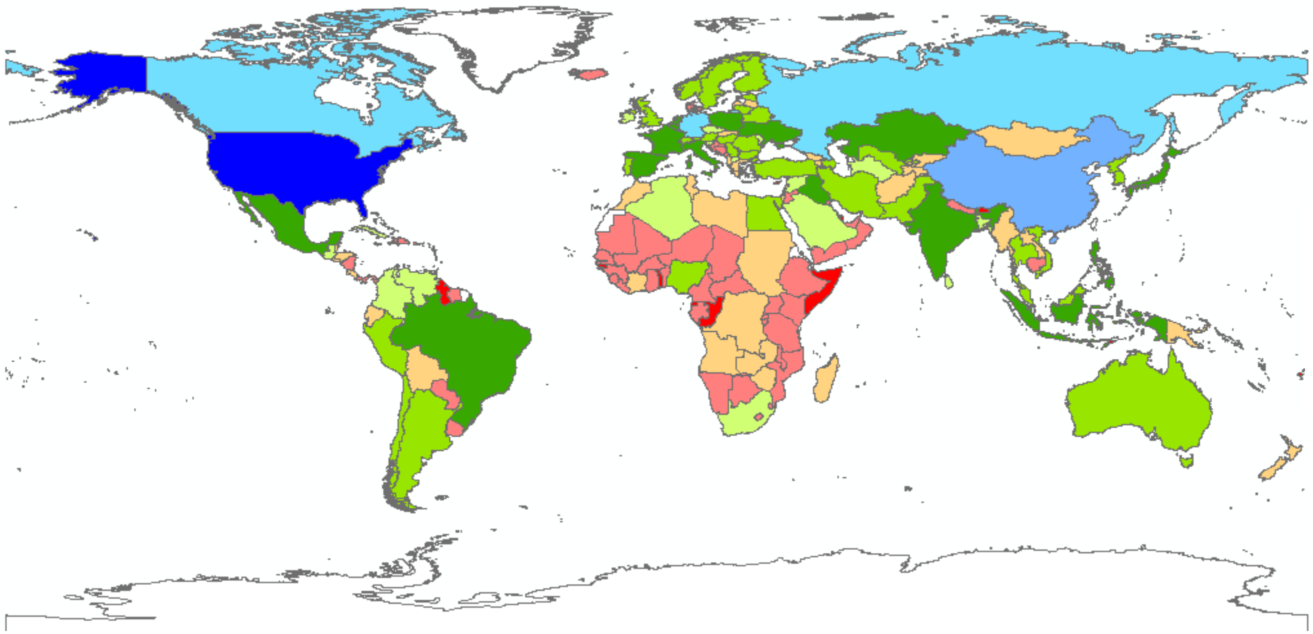
Area	Asia	Africa	Europe	S. America	N. America	Oceania	World
Number of countries	50	57	51	48	5	25	236
Population (10^9)	4.16	1.04	0.74	0.60	0.35	0.04	6.93
Area km^2*10^6	30.9	29.4	22.1	20.1	18.7	8.5	129.7

Present-day situation



Irrigation water (bm^3)

- <1
- 1-10
- 10-50
- 50-100
- 100-150
- 150-200
- 200-300
- 300-400
- 400-500
- >500

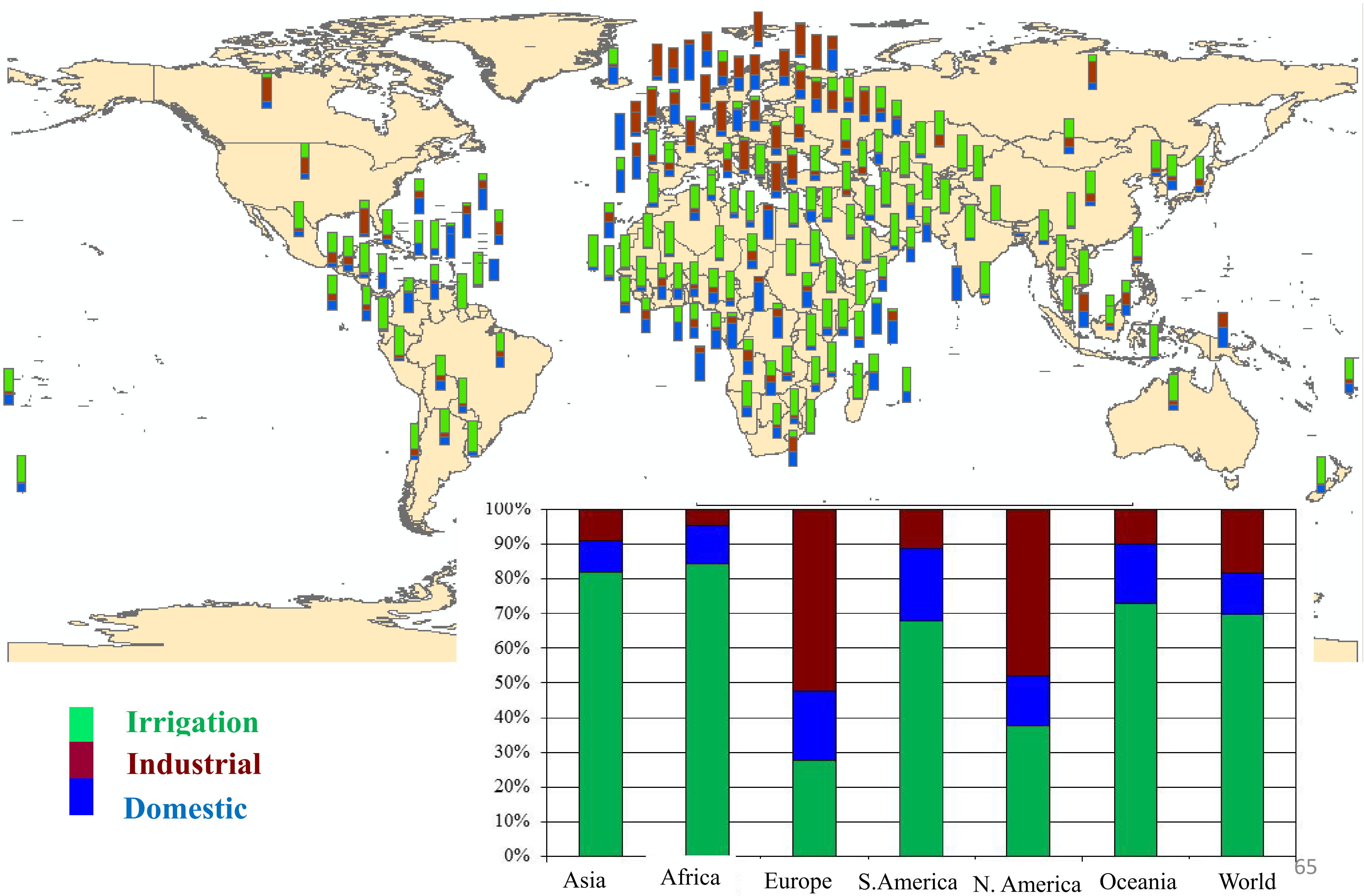


Industrial water (hm^3)

- 0
- 0-10
- 10-100
- 100-500
- 500-1000
- 1000-5000
- 5000-25000
- 25000-50000
- 50000-150000
- >150000

Present-day situation

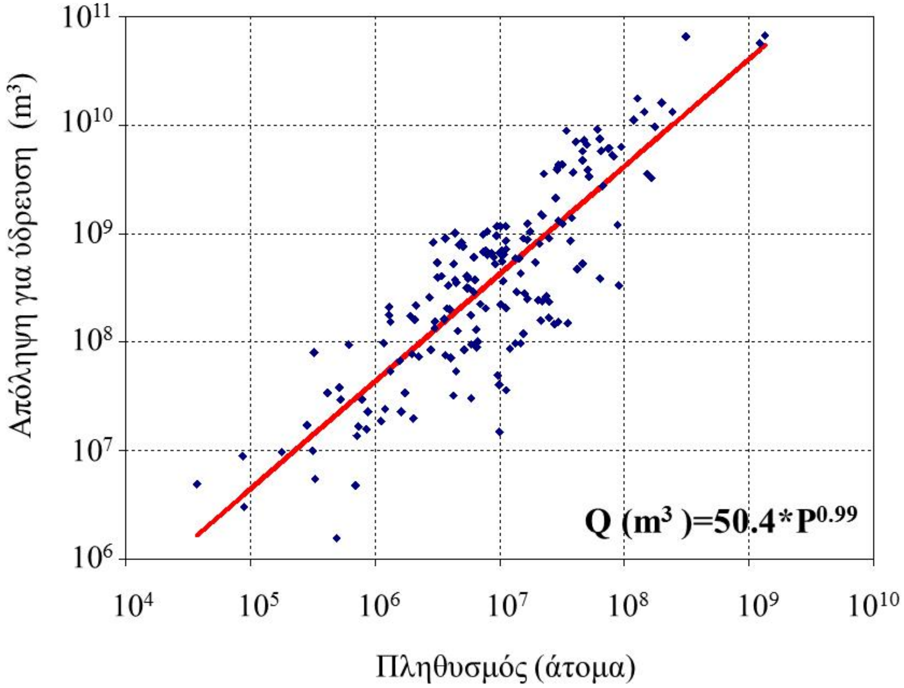
Percentage of water for irrigation, industrial and domestic use



Present-day situation

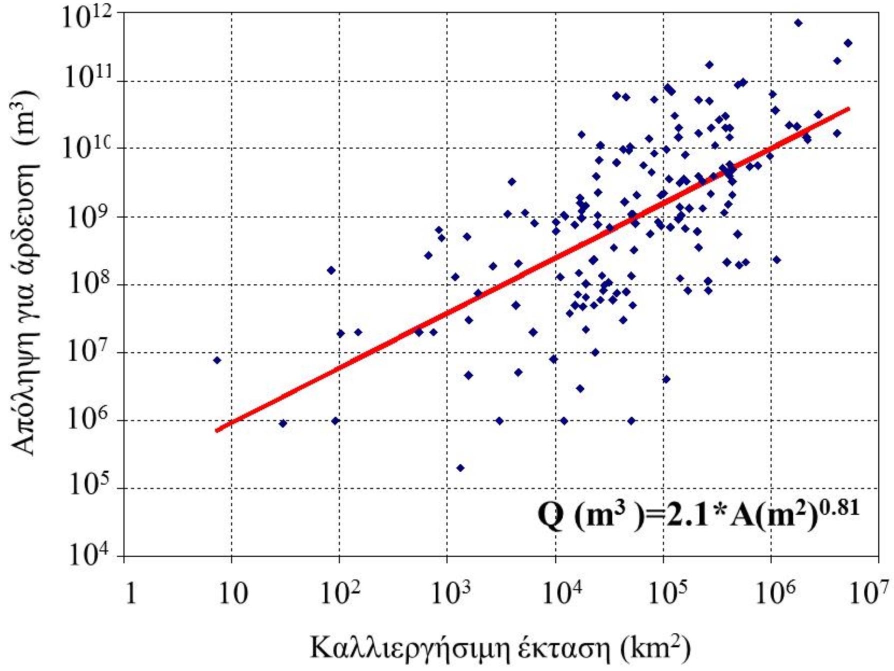
Correlation of water consumption

Domestic use versus population



174 countries

Irrigation use versus cultivated areas



166 countries

Present-day situation

Floods in Bangladesh…

Brahmaputra
Length: 2900 km
Basin: 651334 km^2
Average discharge: 19300 m^3/s

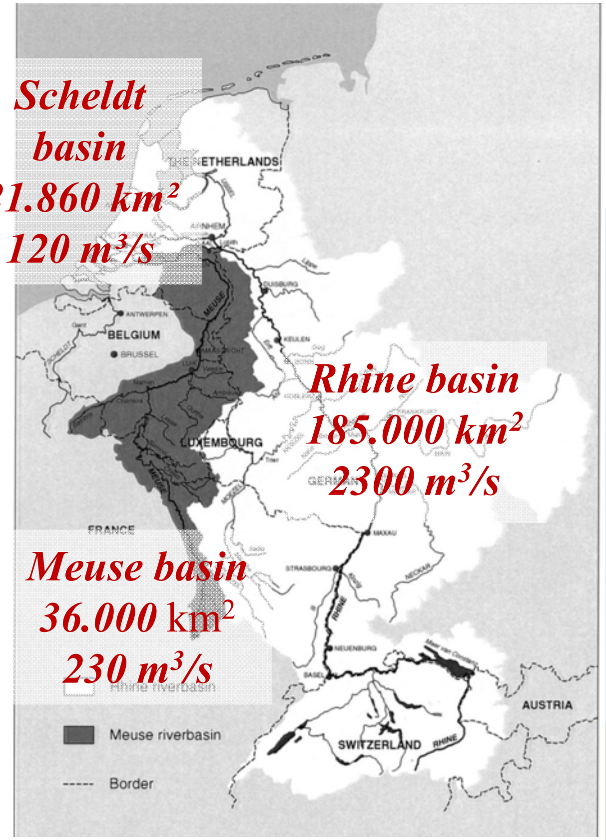
Ganges
Length: 2525 km
Basin: 1080000 km^2
Average discharge (Farakka Barrage): 16648 m^3/s

Main flood causes

- Three huge rivers converge in Bangladesh (Ganges, Brahmaputra, Meghna)
- Cyclones from the Bay of Bengal cause coastal flooding
- Monsoon rainfall, some parts of the Ganges basin receive 500 mm of daily rainfall
- Sediment deposition in Bangladesh, that blocks the river channels making them insufficient to convey flood waters

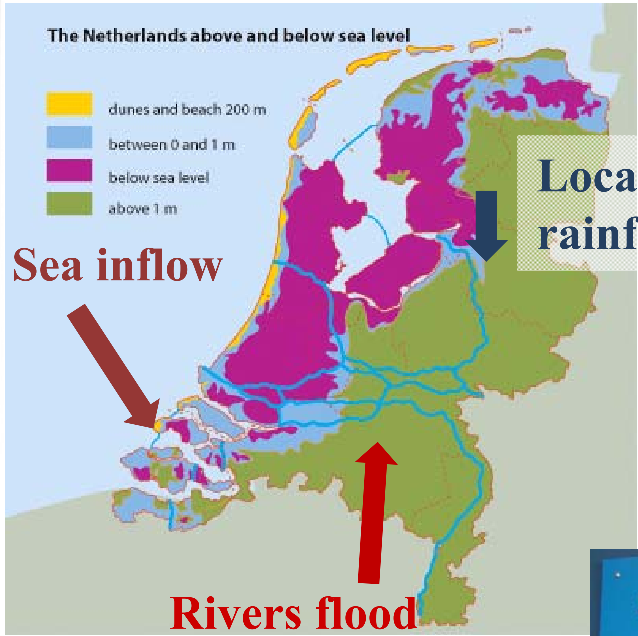
In years 1974, 1987 and 1988 about 29000, 2000 and 2500 deaths, have been reported.

More recently in 7/8/2007 the monsoon rains have caused human suffering in Bangladesh. More than half of the country's 64 districts (population 150 millions) are severely affected. Vast areas of land and crops are submerged, and millions of people have been left homeless. Parts of eastern Dhaka are also being inundated. Government figures show that a total of about 8 million people have been displaced and also 120 deaths have been reported.



Present-day situation

The rivers' delta has an area of 7500 km^2 with the main part altitude under the sea level (up to 6 m)



… and floods in Holland

Delta Works

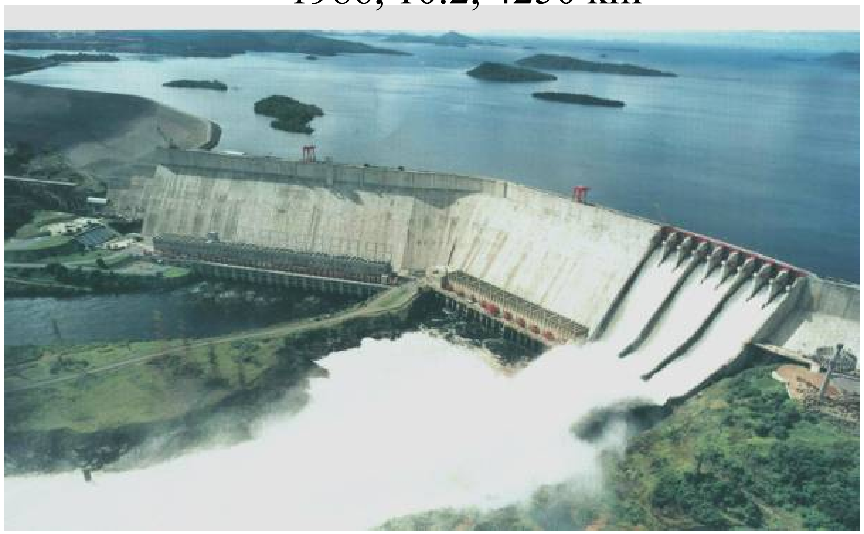
The flood of 1953 caused the death of more than 2000 people and the inundation of 1500 km^2. Soon the old idea of building dams in the rivers' mouths started to move. In 1959, the Delta Law was passed, in order to organize the construction of the dams. Although safety was the main priority, some seaways would have to stay open, because of the economic importance of the ports of Rotterdam and Antwerp. Also some auxiliary dams would first have to be built in the Zandkreek, the Krammer, the Grevelingen, and the Volkerak. The building of the Delta Works was an enormous project except the 14 large dams also incudes sluices, locks, dykes and levees.

Present-day situation

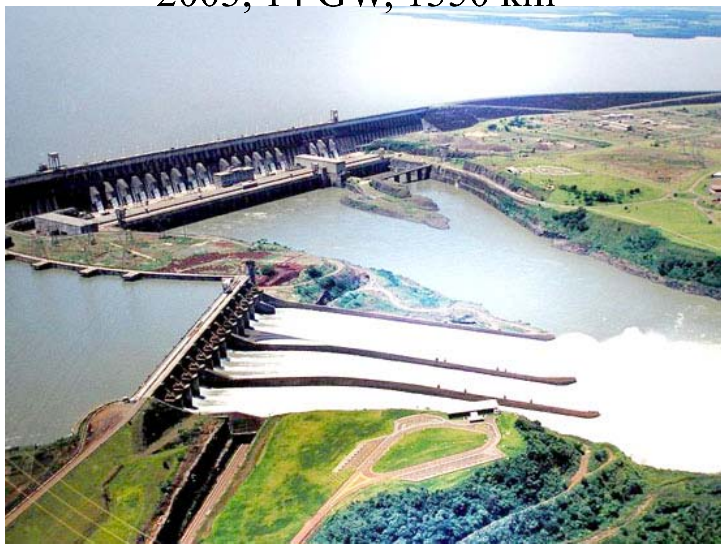
The four larger hydroelectric plants (name-country-year of construction, installed power, reservoir area)

Tucurui dam, Brasil,
1984, 8.37 GW, 3014 km^2

Guri (Simón Bolívar), Venezuela,
1986, 10.2, 4250 km^2



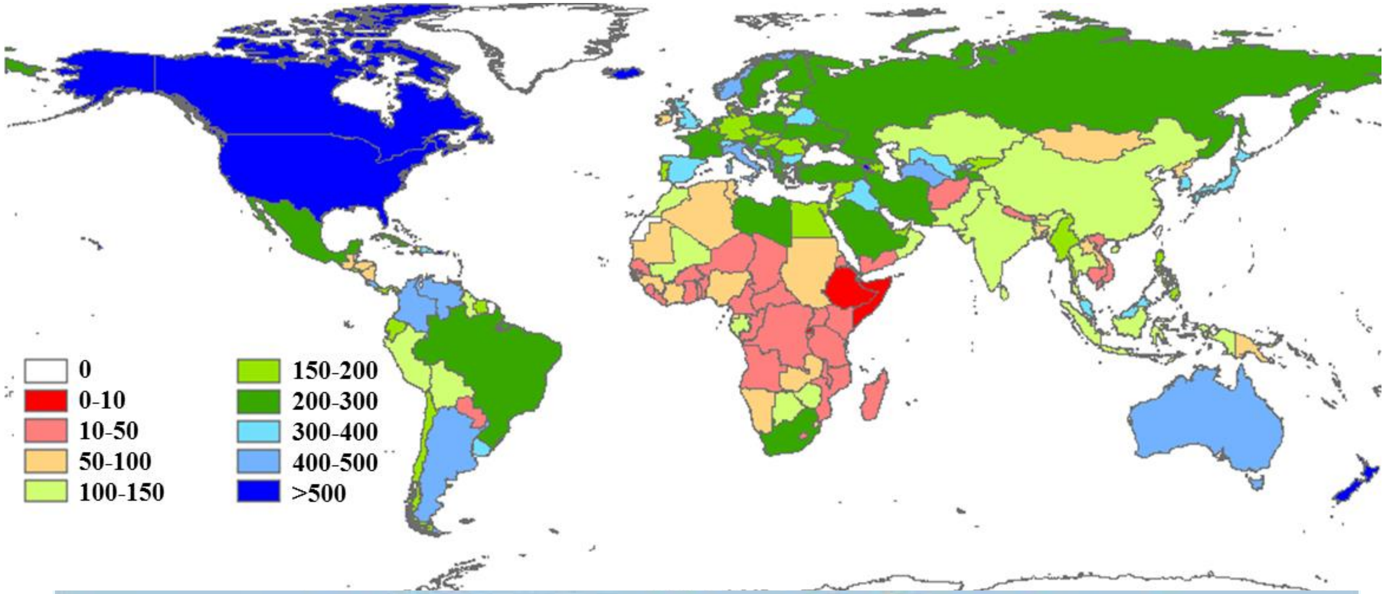
Itaipu, Brasil-Paraguay,
2003, 14 GW, 1350 km^2



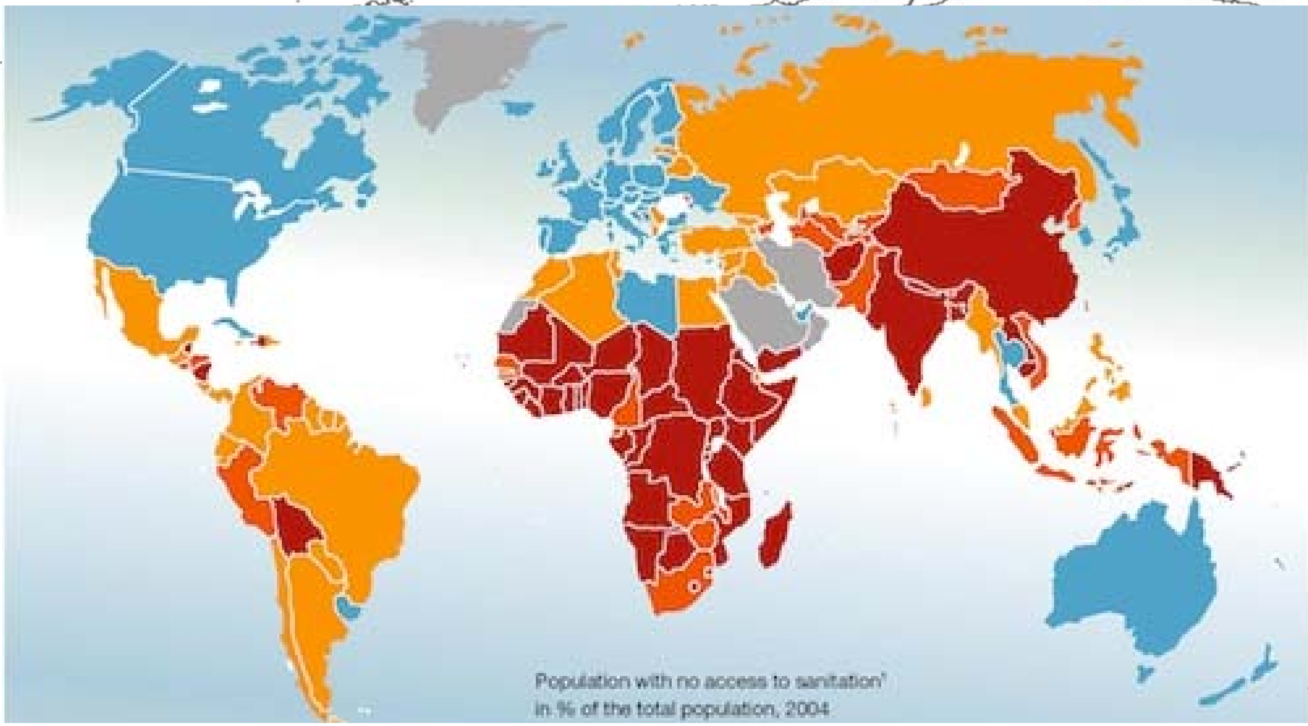
Three Gorges, China,
2011, 18.3-22.5 GW, 532 km^2

Ancient situations in present-day world;

Domestic use l/cap/d



Without access to sewage network (% of the population)



Ancient situations in present-day world;

Ethiopia

China

Uganda

768 million have no access to safe domestic water-11% (2011)
2.5 billion have no access to sewage network-36% (2011)
3.4 million people die each year **(more than 6 per min)** from water related diseases (99% of them to third world). ***United Nations report***

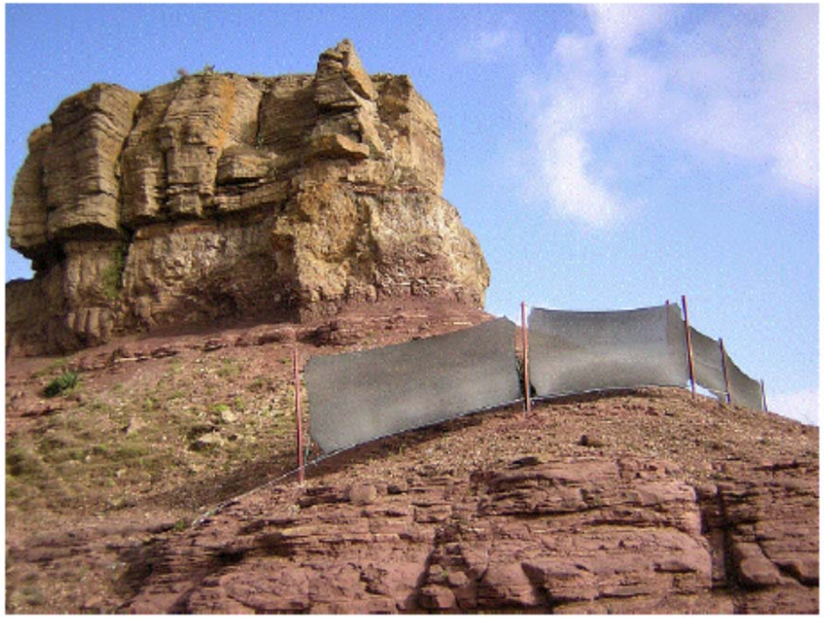
India

Haiti

Nigeria

Present-day situation

Desperate for water? Fog collectors



Fog collectors in Yemen

70 cm by 70 cm Tal Ya tray has the perfect size for pepper plants. Its cost is **$1 per plant**. When a change of 12 ^{o}C occurs, dew forms on the tray, which funnels the dew and condensation straight to the plant. The trays do not degrade in the sun or after the application of fertilizers. They have an estimated life time of **10 years**.

Fog collection potential

Several measurements in various locations in the world have shown annual average values from 1-5 l/m^2/day and seasonal average values from 3-70 l/m^2/day

Cost of water using fog collectors

Although is difficult to calculate the cost in a project in Chile was estimated about 1$ per m^3 for collection and another 1$ per m^3 for transportation to the end users

Water and Energy

How can I produce electricity?

Population: ≈ 100 people
Installed Power/capita: ≈ 1.5 kW
Installed electric power: ≈ 150 kW
Percentage of system operation: ≈ 50%
*Electric energy produced: ≈ 8760 hr*50%*150 kW =657000 kWh*

Fossil	Nuclear	Renewable
•Coal		•Hydraulic
•Gas		•Wind
•Oil		•Biomass
		•Solar
		•Geothermal
		•Marine (tides, waves, currents)

Water and Energy

Power and energy (basic calculations)

Air conditioner
Installed Power: 1 kW
Hours of operation (in maximum power): 24 hr
Energy consumed: 24 kWh

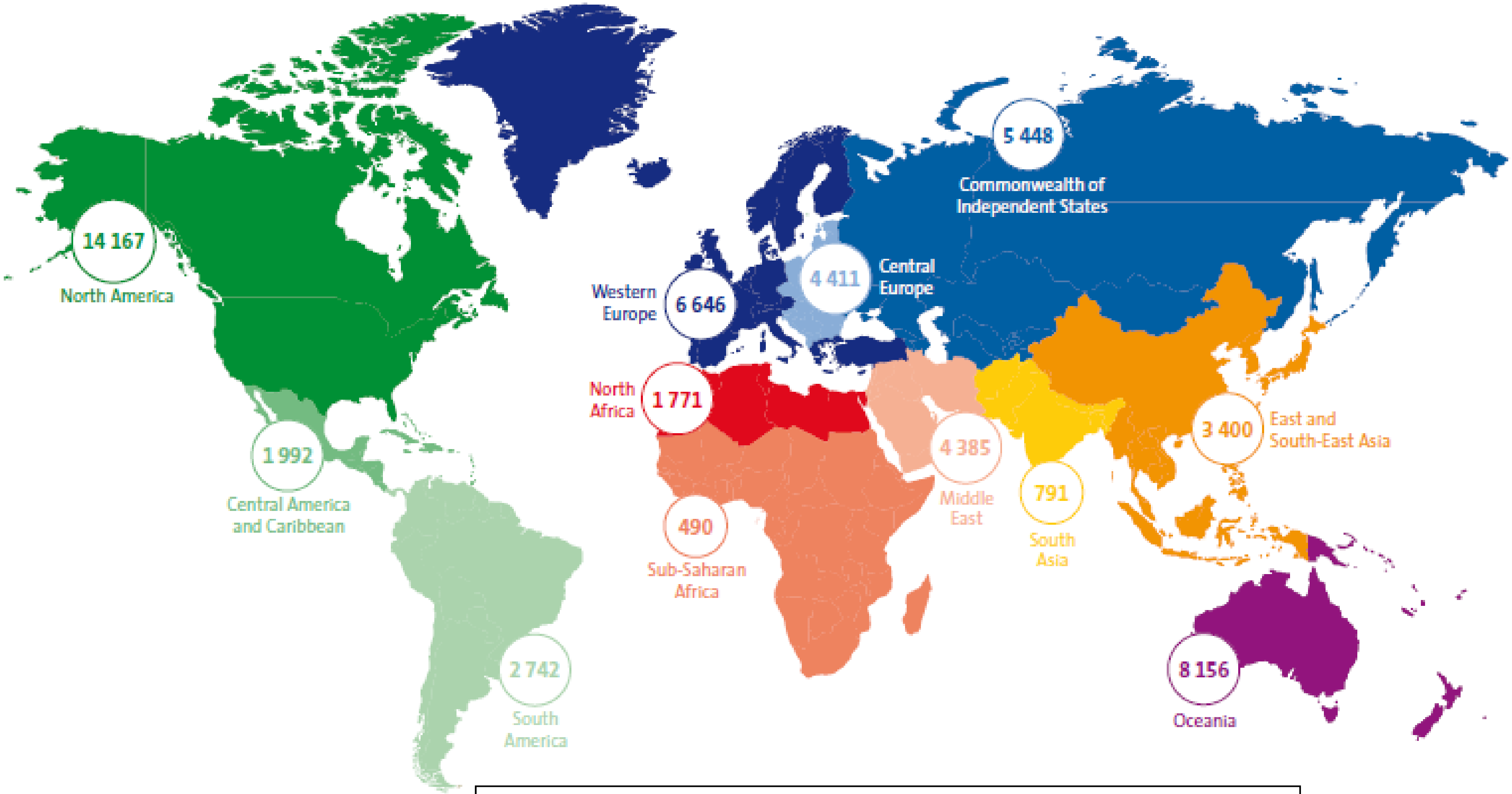
Wind turbine
Installed Power: 1 MW
Hours of operation hours (in maximum power): 3000 hr
Energy produced: 3000 MWh=3 GWh

Greek electric energy system
Population: ≈ $11*10^6$ people
Installed electric power: ≈ 15 GW
Electric energy produced: ≈ 58 TWh

Installed Power/capita: ≈ $15*10^6$ kW/$11*10^6$ ≈ *1.4 kW*
Energy consumed/capita: ≈ $58*10^9$ kWh/$11*10^6$ ≈ *5250 kWh*
Percentage of system operation: ≈ *58*10 GWh/(15 GW*8760 hr)* ≈ *44%*

Water and Energy

Electricity production (kWh/cap) in the various regions (2012)



$22616*10^9$ kWh/$6*10^9$ cap≈3500 kWh/cap

Source: *http://www.energies-renouvelables.org/observ-er/*

Water and Energy

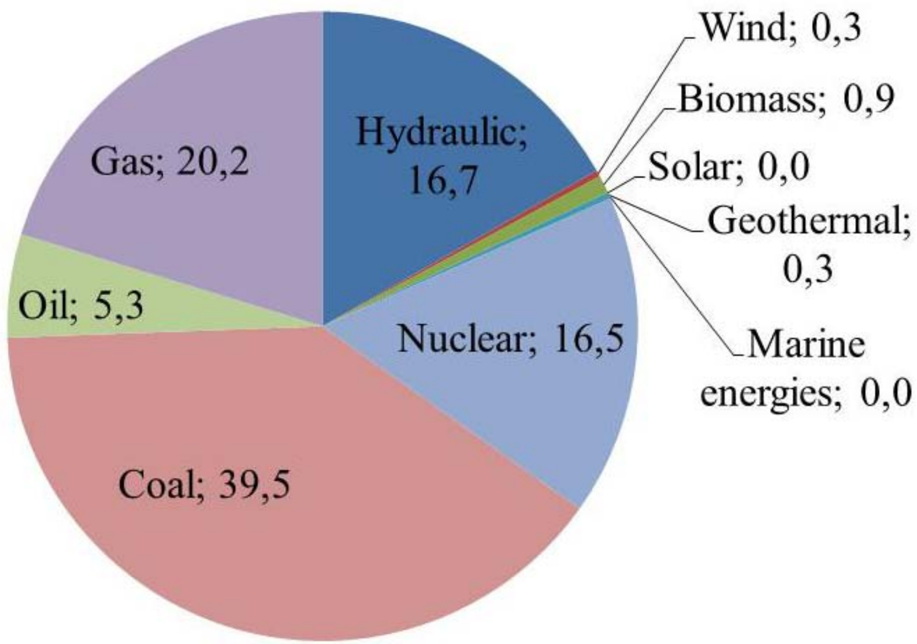
Electric energy systems

Country	Population (10^6)	Power (GW)	Energy (TWh)	*Power (kW/cap)*	*Energy (kWh/cap)*	*System operation (%)*
Denmark	**5.6**	**13.71**	**30.4**	*2.45*	*5429*	*25*
Egypt	**87**	**26.91**	**149**	*0.309*	*1713*	*63*
Ethiopia	**88**	**2.06**	**4.9**	*0.02*	*56*	*27*
Germany	**81**	**153.2**	**633.6**	*1.89*	*7822*	*47*
Greece	**11.1**	**15.12**	**58.3**	*1.36*	*5252*	*44*
Switzerland	**8.2**	**18.07**	**73.4**	*2.20*	*8951*	*46*
Tanzania	**44.9**	**0.84**	**4.3**	*0.02*	*96*	*58*

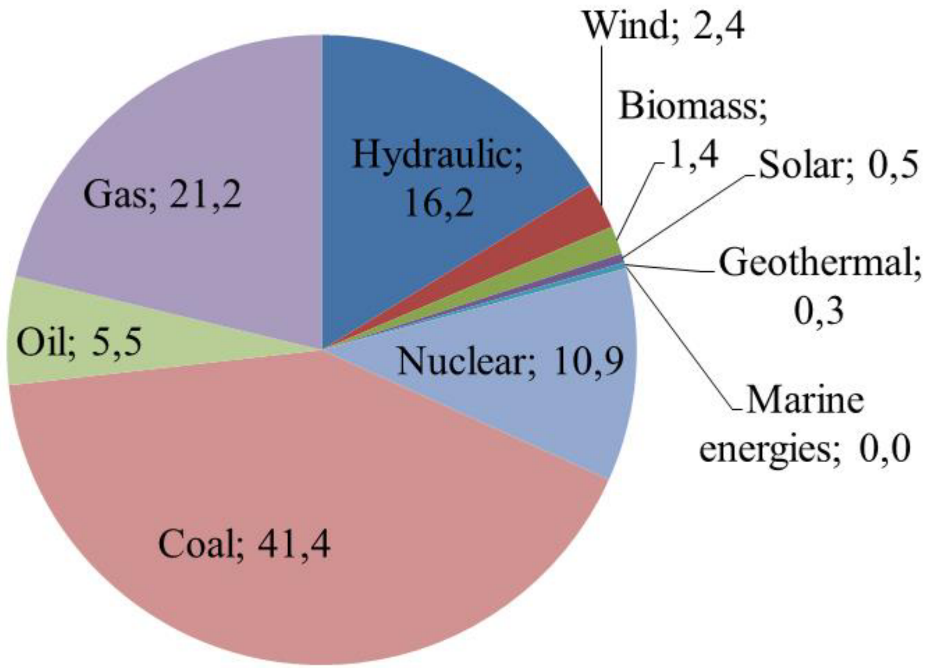
Water and Energy

Structure of world electricity production from various sources (energy mix) (%)

2002



2012

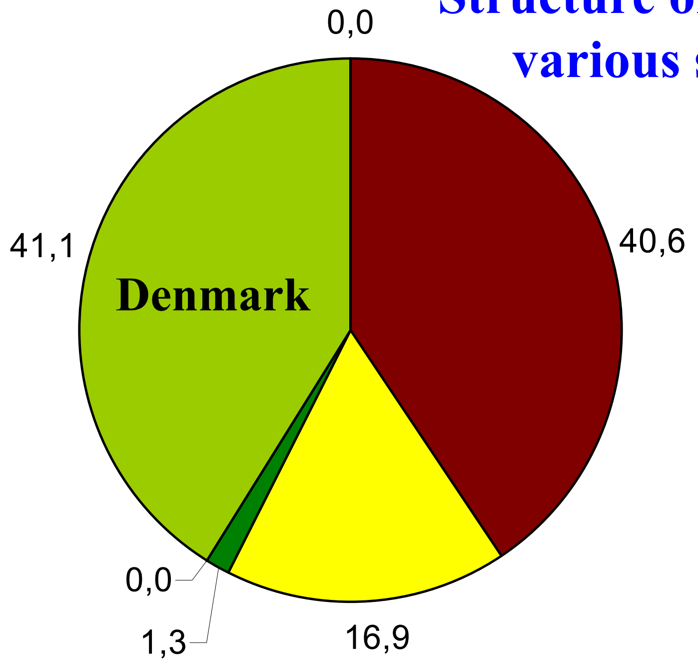


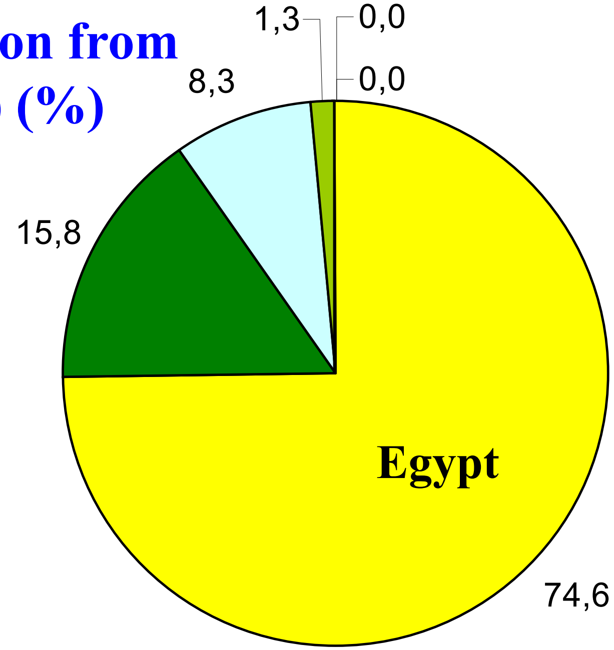
TOTAL: 16174 TWh
Renewable**:** 2959 TWh (18.3%)
Nuclear: 2661 TWh (16,5%)
Fossil: *10514* TWh *(65.2%)*

TOTAL: 22616 TWh
Renewable**:** 4699 TWh (20.8%)
Nuclear: 2463 TWh (10.9%)
Fossil: *15394* TWh *(68.3%)*

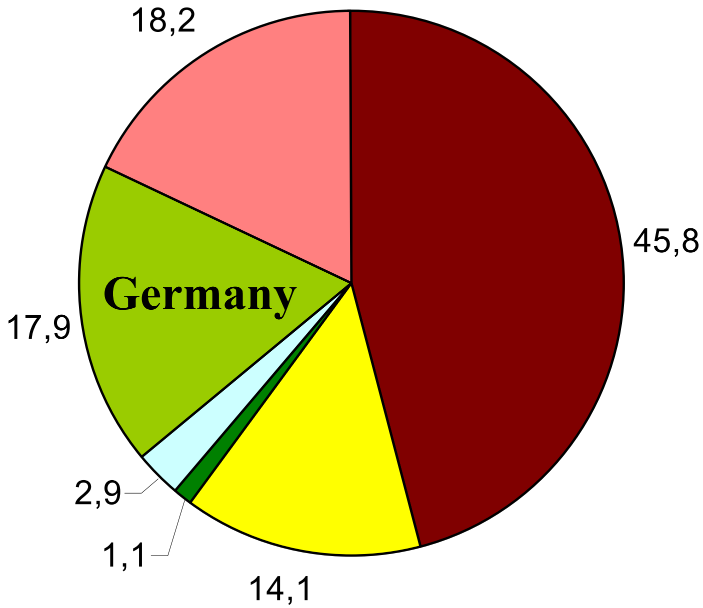
Water and Energy

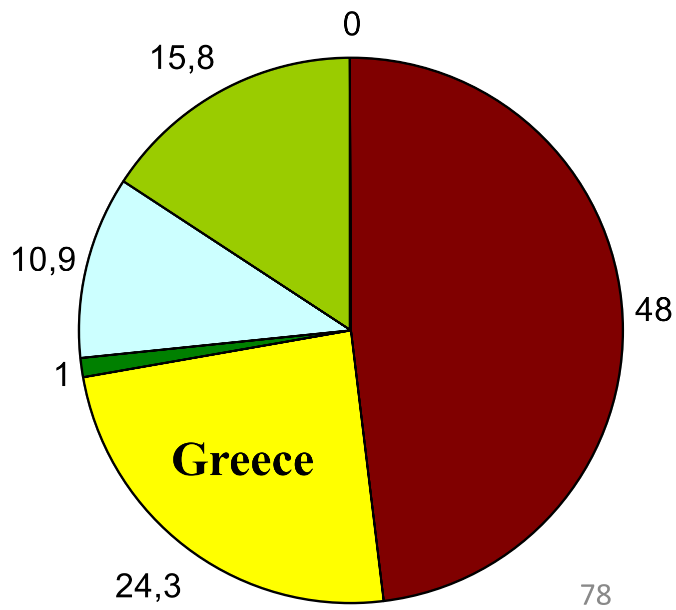
Structure of electricity production from various sources (energy mix) (%)





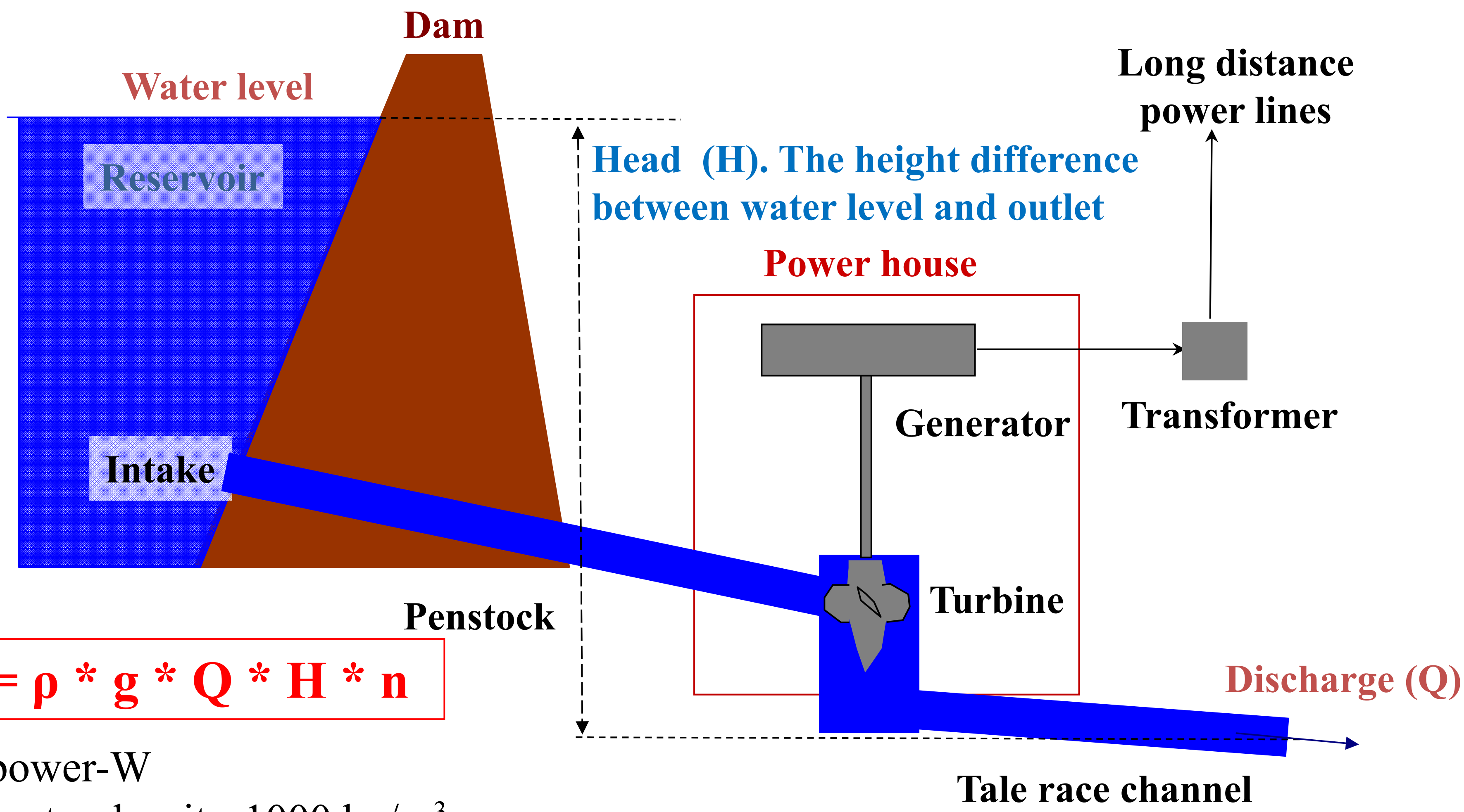
- Coal
- Natural gas
- Oil
- Hydropower
- Other renewable
- Nuclear power





Water and Energy

Main elements of a hydroelectric project

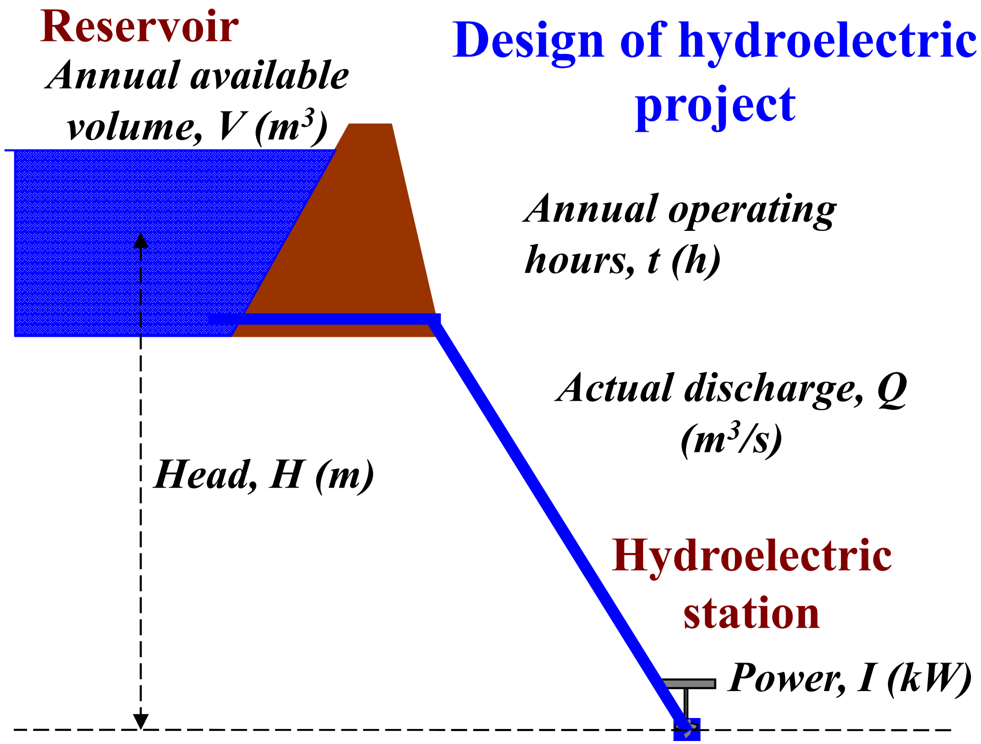


$$I = \rho * g * Q * H * n$$

I: power-W
ρ: water density-1000 kg/m^3
g: acceleration due to gravity-9.81 m/s^2
Q: discharge-m^3/s
H: head-m
n: efficiency-dimensionless

$$I\ (kW) = 9.81 * Q\ (m^3/s) * H\ (m) * n$$

Design of hydroelectric project



Mean annual actual discharge

$$Q\ (m^3/h) = V(m^3)/t(h)$$

$$Q\ (m^3/h) = Q(m^3/s)*3600$$

$$Q\ (m^3/s)*t(h) = V(m^3)/3600$$

Annual electric energy calculations

$$E\ (kWh) = g * n * H\ (m) * Q\ (m^3/s) * t(h)$$

$$E\ (kWh) = \frac{g * n * H\ (m) * V(m^3)}{3600}$$

$$E\ (kWh) \approx \frac{n * H\ (m) * V(m^3)}{367}$$

Power (I) and Energy (E)

$$I = \rho * g * n * H * Q$$

I: power (W)
ρ: water density 1000 kg/m^3
g: acceleration 9.81 m/s^2
n: efficiency dimensionless

$$\mathbf{I\ (kW) = g * n * H\ (m) * Q\ (m^3/s)}$$

$$\mathbf{E\ (kWh) = I\ (kW) * t\ (hr)}$$

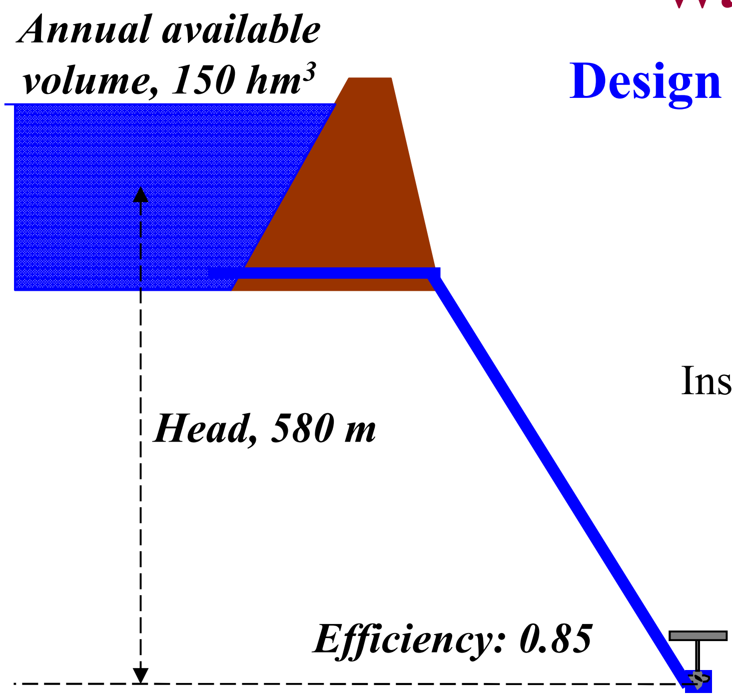
Example (using Plastiras' data)

Annual available volume: ***150 hm³***
Head: ***580 m***
Efficiency: ***0.85***
Potential annual electric energy: ***201.5 GWh***

Operating hours	Percentage of time that operates	Actual Discharge (m^3/s)	Installed power capacity (MW)
1500	0,17	27,8	134,3
3000	0,34	13,9	67,2
4500	0,51	9,3	44,8
8760	1,00	4,8	23,0

Water and Energy

Design of hydroelectric project



Case 1

Actual discharge: **4.8 m^3/s=17.280 m^3/hr**

Installed Power=9.81*4.8 m^3/s*580 m*0.85 ≈**23000 kW=23 MW**

Annual operating hours=
150.000.000 m^3/(17.280 m^3/hr)**≈8760 hr per year**

Annual produced electric energy=
23 MW*8760 hr =**201.500 MWh=201.5 GWh**

Case 2

Actual discharge: **27.8 m^3/s=100.080 m^3/hr**

Installed Power=9.81*27.8 m^3/s*580 m*0.85 ≈**134.300 kW=134.3 MW**

Annual operating hours=
150.000.000 m^3/(100.080 m^3/hr)**≈1500 hr per year**

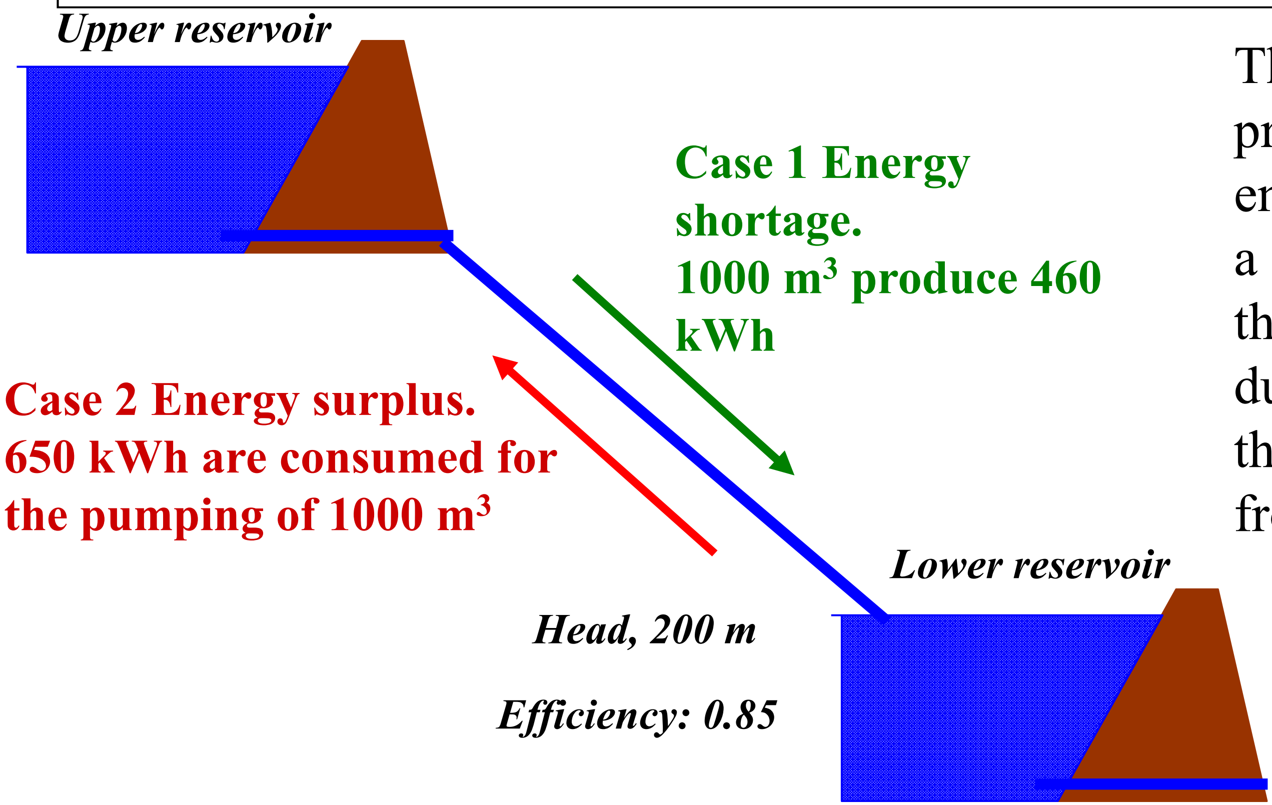
Annual produced electric energy=
134.3 MW*1500 hr =**201.500 MWh=201.5 GWh**

Water and Energy
Pump storage systems

Case 1 Energy shortage in the electric network. *There is need for energy production.*
1000 m^3 are transported from the upper to lower reservoir and produce about **460 kWh**

Case 2 Energy surplus in the electric network. *There is need for energy storage.*
1000 m^3 are pumped from lower to upper reservoir and about **650 kWh** are consumed

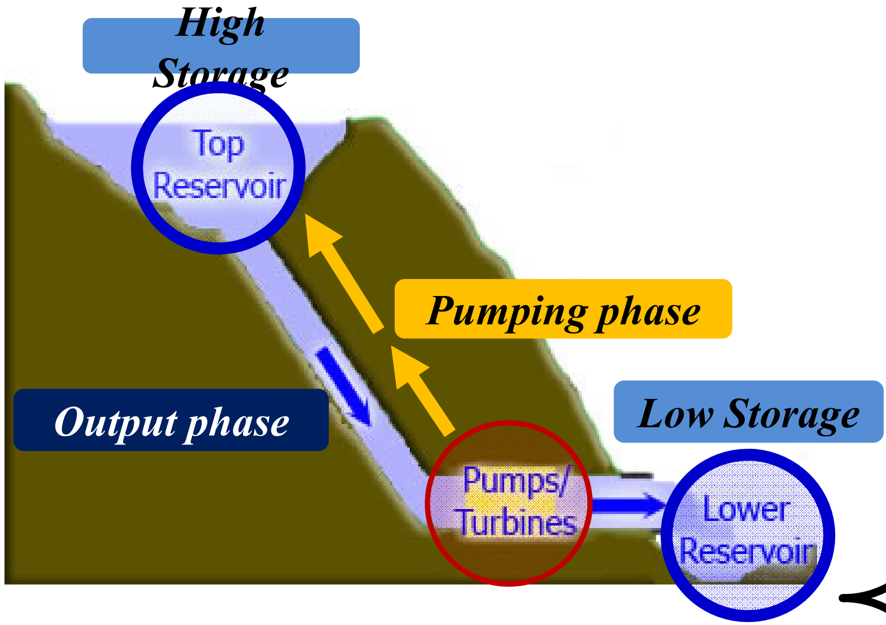
> In the electric networks the energy can not be stored and also the base units (coal, nuclear) can not interrupt their function immediately in case that there is not energy demand (for example during night hours).



The pump storage systems practically store the surplus energy of the network, loosing a 30%. Taking into account that the price of energy is half during surplus situations, there is a significant profit from this procedure

Water and Energy

Pumped-storage systems as natural energy capacitors



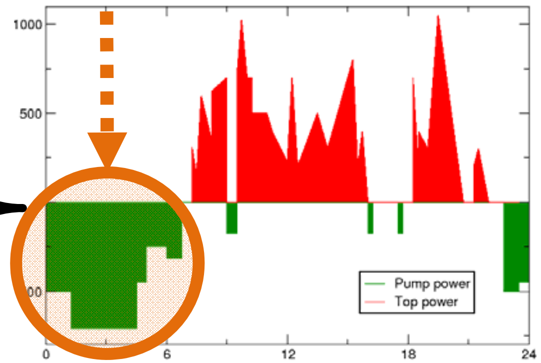
Pumped-storage comprises an energy system integrator in order to neutralize and utilize economically its inefficiencies. Main inefficiencies are:

(a) Output excesses of fossil fuel-fired plants (mostly coal-fired) due to minimum operation requirements

(b) Stochasticity of Renewable Energy Sources (RES)

…Other Renewables

Energy system inefficiencies comprise the energy source of water pumping



Source: *http://en.wikipedia.org*

The efficiency of pumped-storage cycles reaches 70-80%

Water and Energy

Key design features of pumped-storage deployment

Basic parameters of pumped-storage systems:

1. **Manometric altitude** (affects the per unit falling water energy productivity)
2. **Power of the pump** (affects pumping per unit time, storage speed and immediate water availability)
3. **Water type** (freshwater or saltwater, affects freshwater availability and turbine wearing)
4. **Size of the smallest reservoir** (affects maximum resource storage and the system's limiting factor)
5. **Isolation of the higher reservoir from the main stream** (affects operational costs, i.e. silt management)
6. **Grid connectivity** (affects economies of scale)
7. **Regulative operation measures** (affects maximum resource storage i.e. via minimum reservoir level)
8. **Property of each of the system's components** (affects revenue distribution and consumer surpluses)

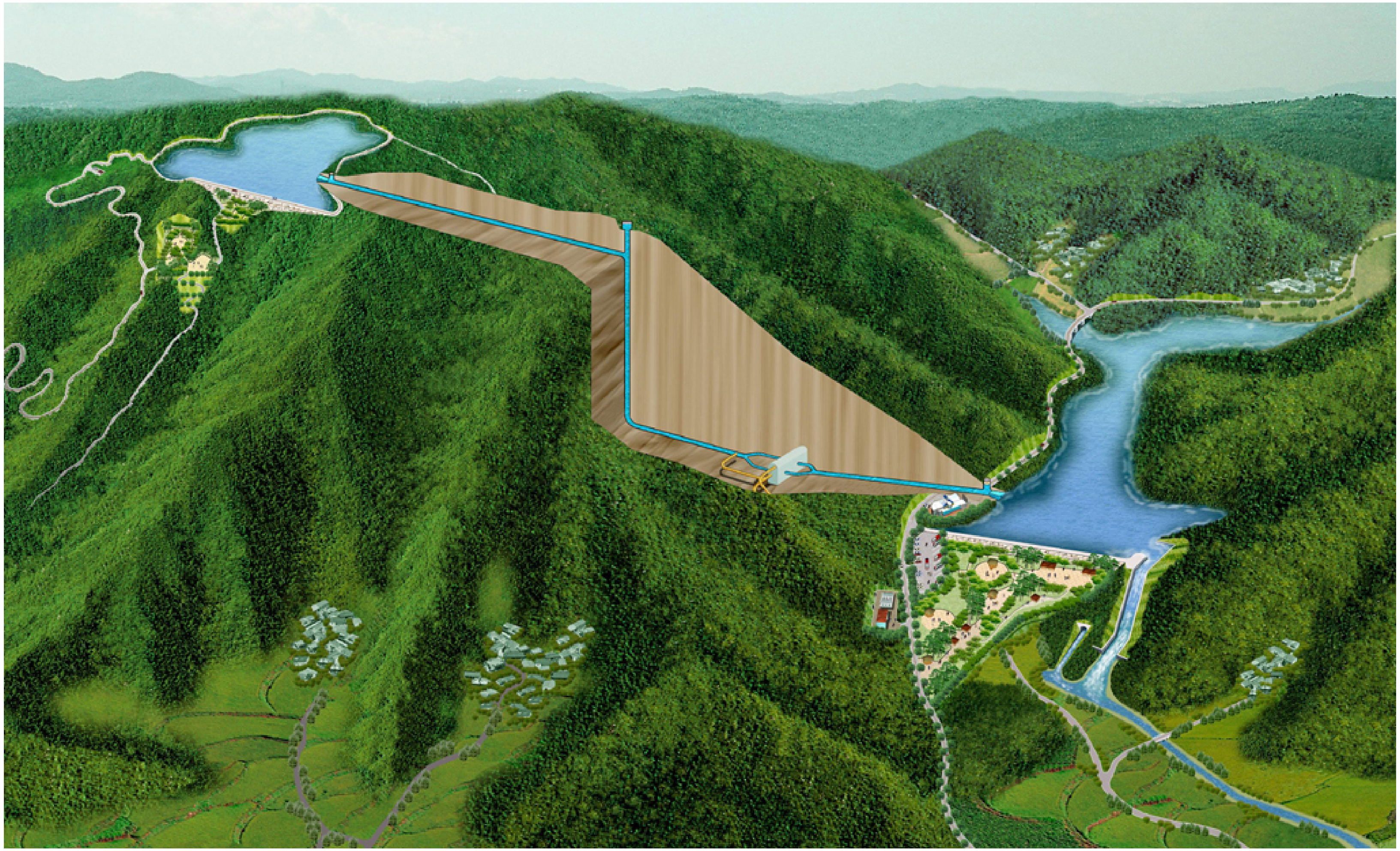
Water and Energy

Pump storage systems

Upper reservoir: Kamihikawa
Capacity 11.5 hm^3

Lower reservoir: Kazunogawa
Capacity 11.5 hm^3

Hydraulic head: 779 m
Pump-generators: 3 x 400 MW reversible Francis



Water and Energy

Pump storage systems

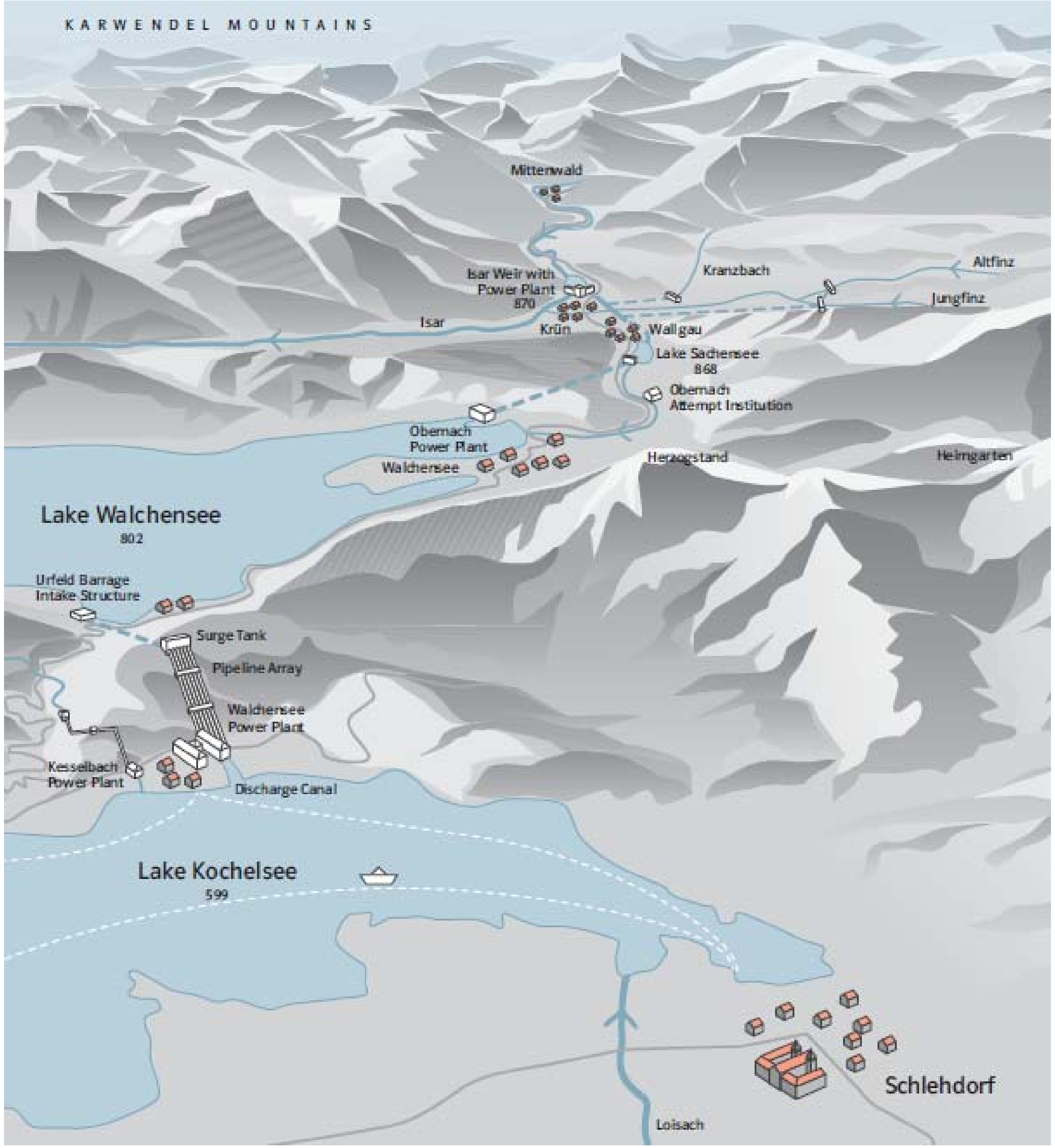
The first pump storage project that uses sea water, there is located in **Okinawa, Japan** and operates since 1999. Its installed power capacity is **30 MW**.

There is an upper artificial reservoir, about 600 m away from the seashore and **150 m** above the sea level with an effective storage capacity of **564.000 m^3**, and the sea operates as the lower reservoir

The effective head is **136 m** and the maximum discharge **26 m^3/s**

Water and Energy

Walchenseekraftwerk



With an installed capacity of **124 MW** it is one the largest of its kind in Germany. The storage power station uses the head of about **200 m** between the Walchensee (acting as the upper reservoir, at 802 m above sea level) and the Kochelsee (599 m a.s.l.) to generate electricity. Through **six 450 m pipes** connecting the two natural lakes, the water flows to the turbines of the hydroelectric plant **four Pelton** water turbines with single-phase generators and **four Francis** water turbines with three-phase generators and then into the Kochelsee. Because of the resulting variation in water level, neither lake freezes fully in the winter: the ice in each of the bays is thin and should not be walked upon. The natural outflow of the Walchensee at Niedernach—over the Jachen to the River Isar—is blocked by a weir, but the natural inflow to the lake is still insufficient to provide enough water for the operation of the storage power station, so the waters of the Ribach river are also used.

Water and Energy

Walchenseekraftwerk

Technical data (from leaflet)

Installed capacity: **124 MW**

Annual energy production: **300 GWh**

Drop (head): **200 m**

Discharge: **84 m^3/s**

Our calculations

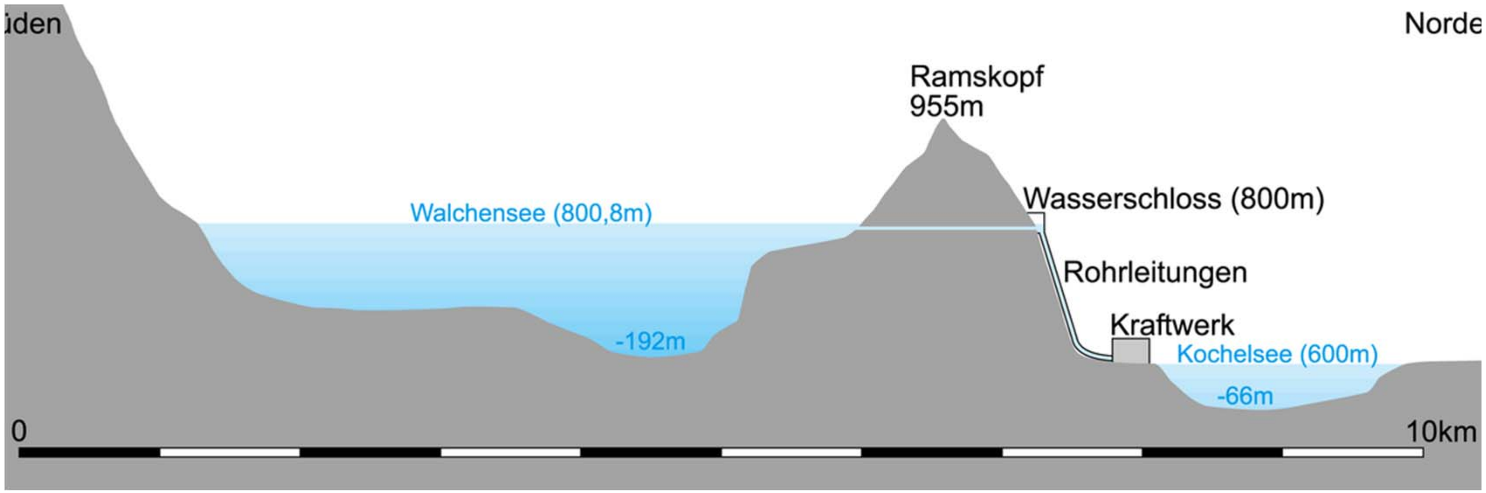
Operating hours per year=300.000 MWh/124 MW=

2420 hr per year

27.5% of the year

124.000 kWh=9.81*84 m^3/s*200 m**n**

=>***n* (efficiency)=0.75**



Influence of the philosophical perceptions to scientific method

What people expect from science?

- A method to organize and categorize existing knowledge
- Understand the causes that produce natural events. Explanations for past events
- Prediction of future events
- The chance to control the events

The control of the events is achieved by:

- intervention on the mechanism of evolution of natural process
- alteration of the influence of natural process to human systems

Influence of the philosophical perceptions to scientific method

Some common questions

Although observations validate the model, is the theory behind well structured?

How can I can predict the environmental variables in short and long time periods?

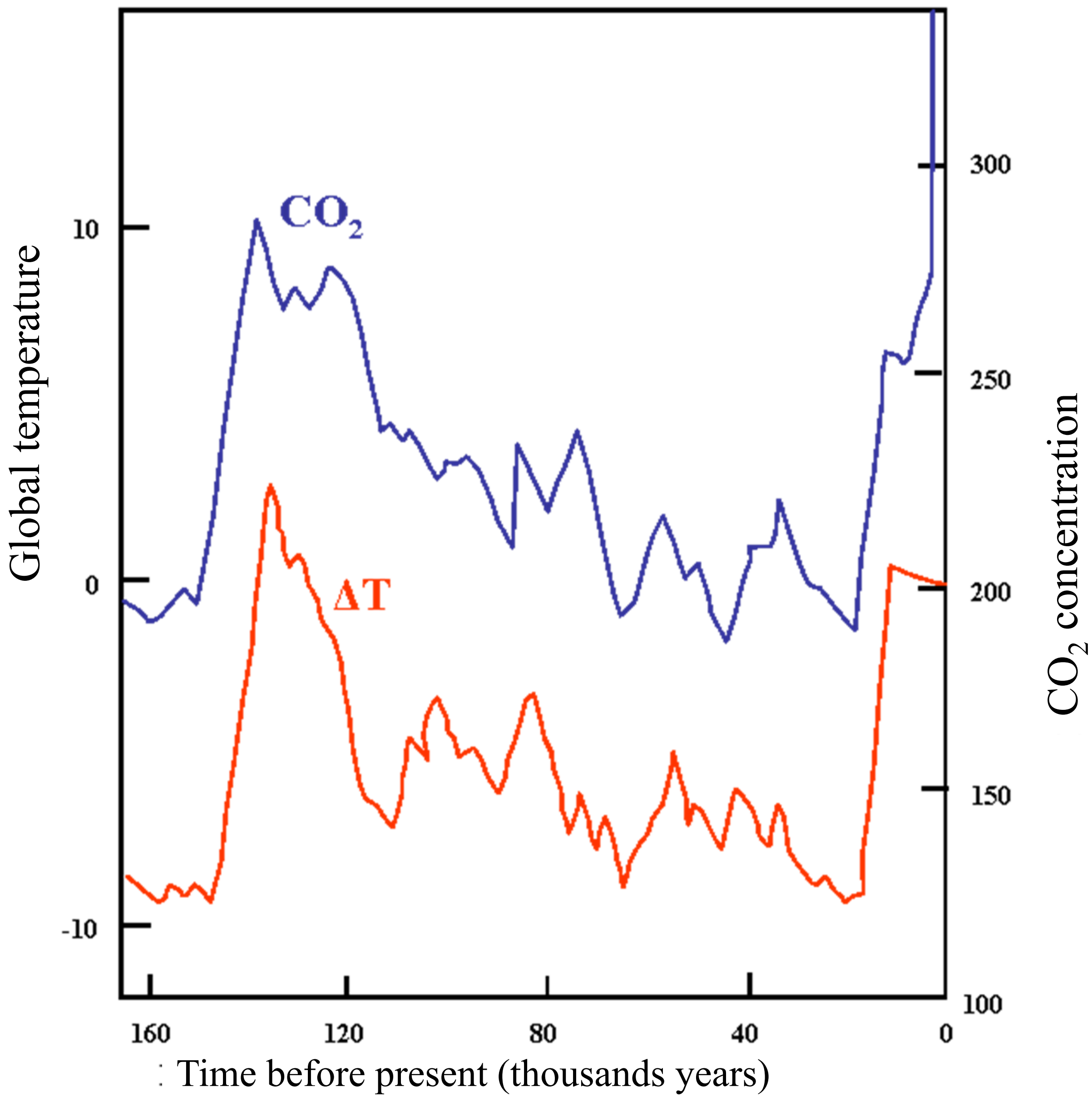
What is the best procedure for each problem?
Deterministic-probabilistic
Simple –sophisticated

How will confront natural extreme events? Adaptation or Mitigation

Influence of the philosophical perceptions to scientific method

Interpretation of observations with the wrong model

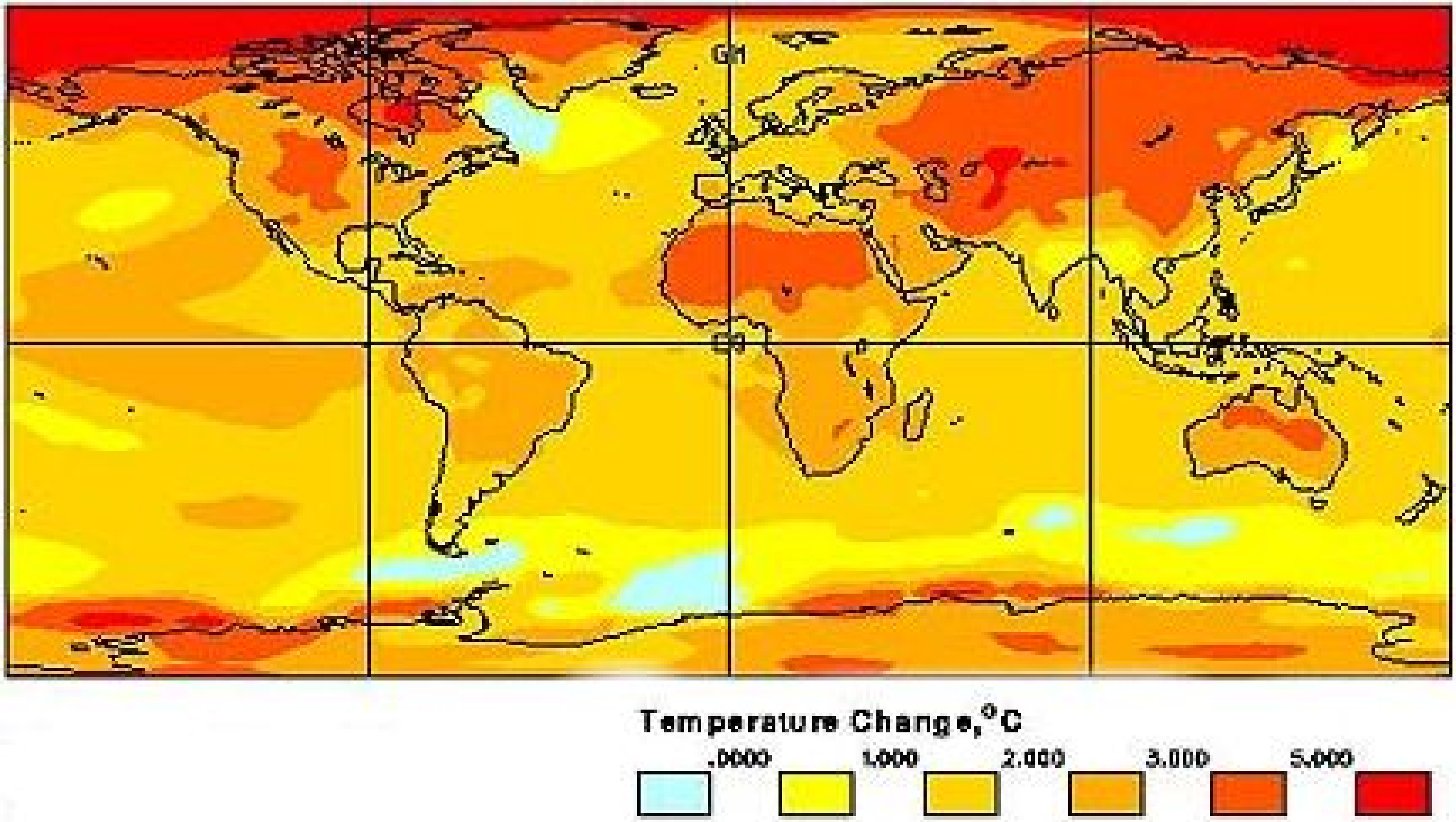
Time evolution of CO_2 concentration and global temperature



Influence of the philosophical perceptions to scientific method

Long term predictions

Predicted temperature anomaly (1970-1990 and 2040-2060)

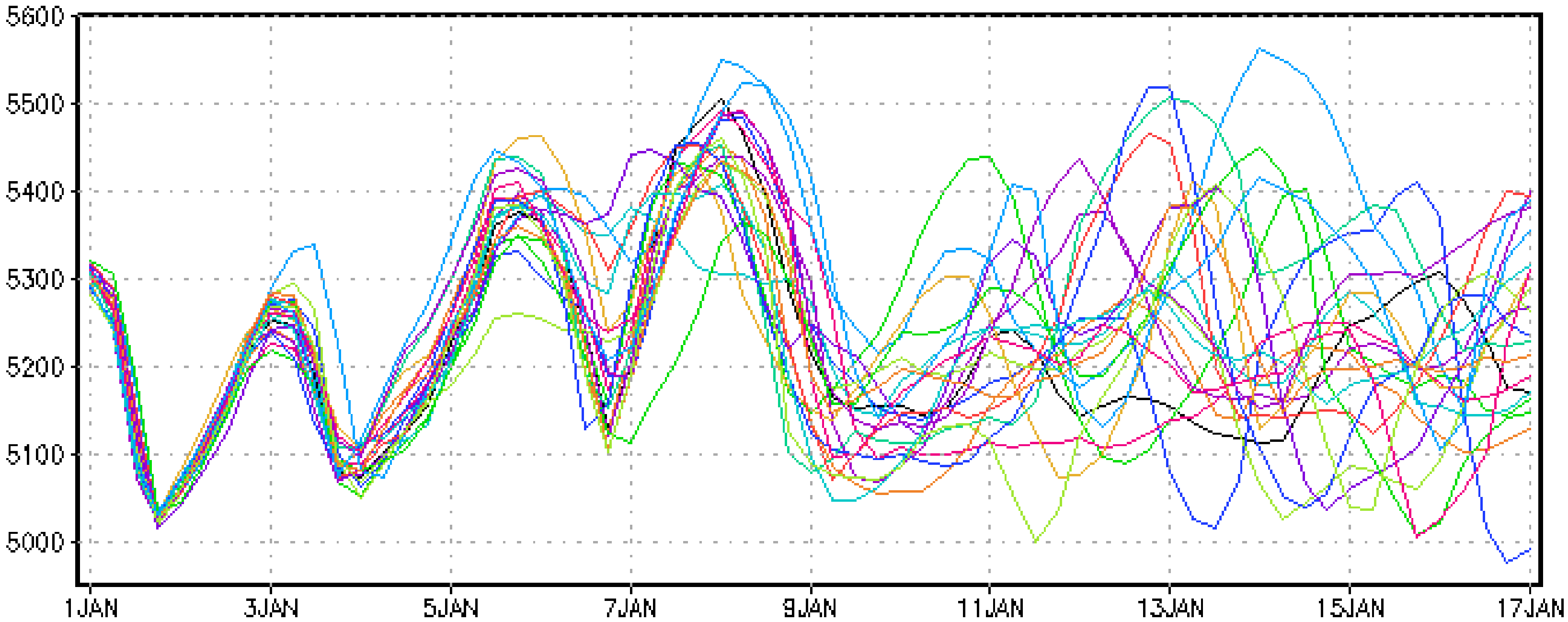


Πηγή: Canadian Centre for Climate Modeling and Analysis

Influence of the philosophical perceptions to scientific method

15 days weather prediction (Ensemble forecasting)

Lorenz (1963): «Even with perfect models and observations the chaotic nature of the atmosphere poses an upper temporal limit to weather prediction, that is **about two weeks**.



Ensemble forecasting technique: Several predictions changing the models or the initial conditions.

Influence of the philosophical perceptions to scientific method

Enlargement of disturbances in temporal evolution of a non linear phenomenon

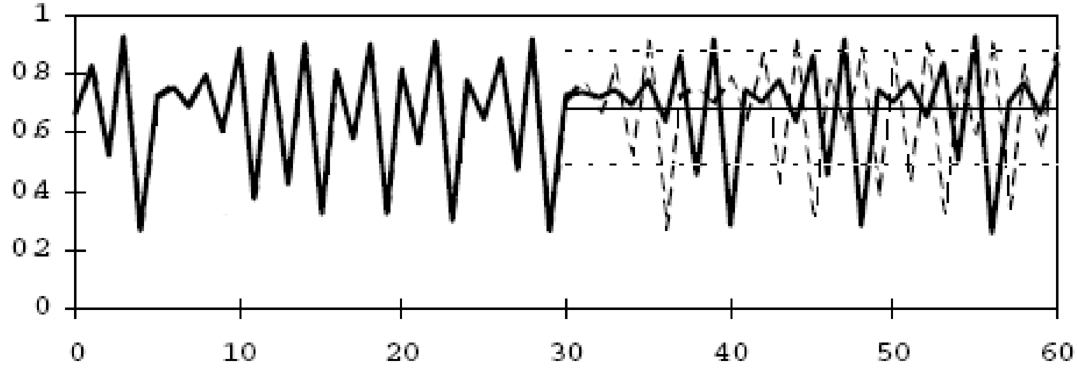
System that is described from the only variable X_t from the formula:

$X_t = k * x_{t-1} * (1 - x_{t-1})$

where t the time step

Time Evolution of $X1_t$, $X2_t$

With slightly different initial conditions

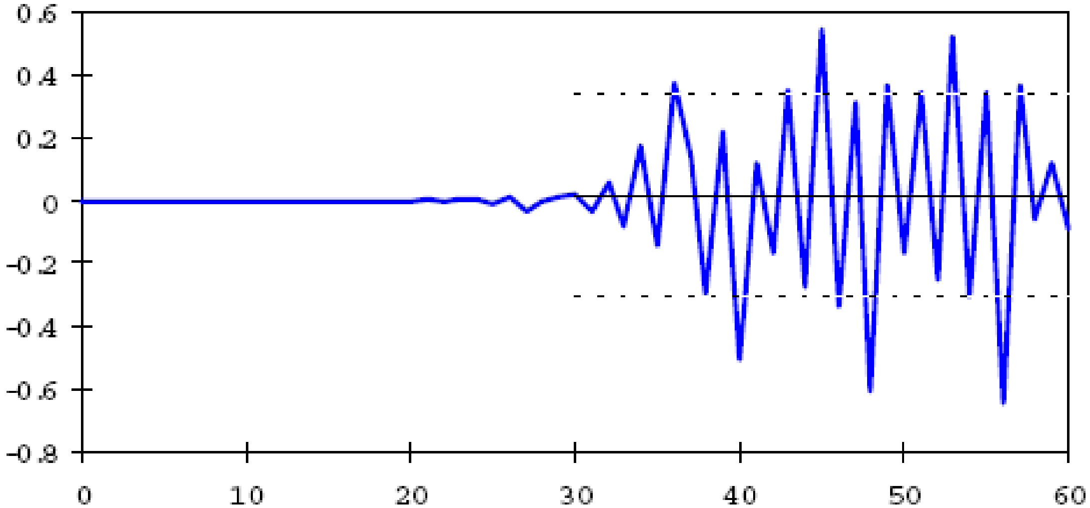


$X1_o = 0.660001$

$X2_o = 0.66$

Low uncertainty **High uncertainty**

Time Evolution $X1_t - X2_t$

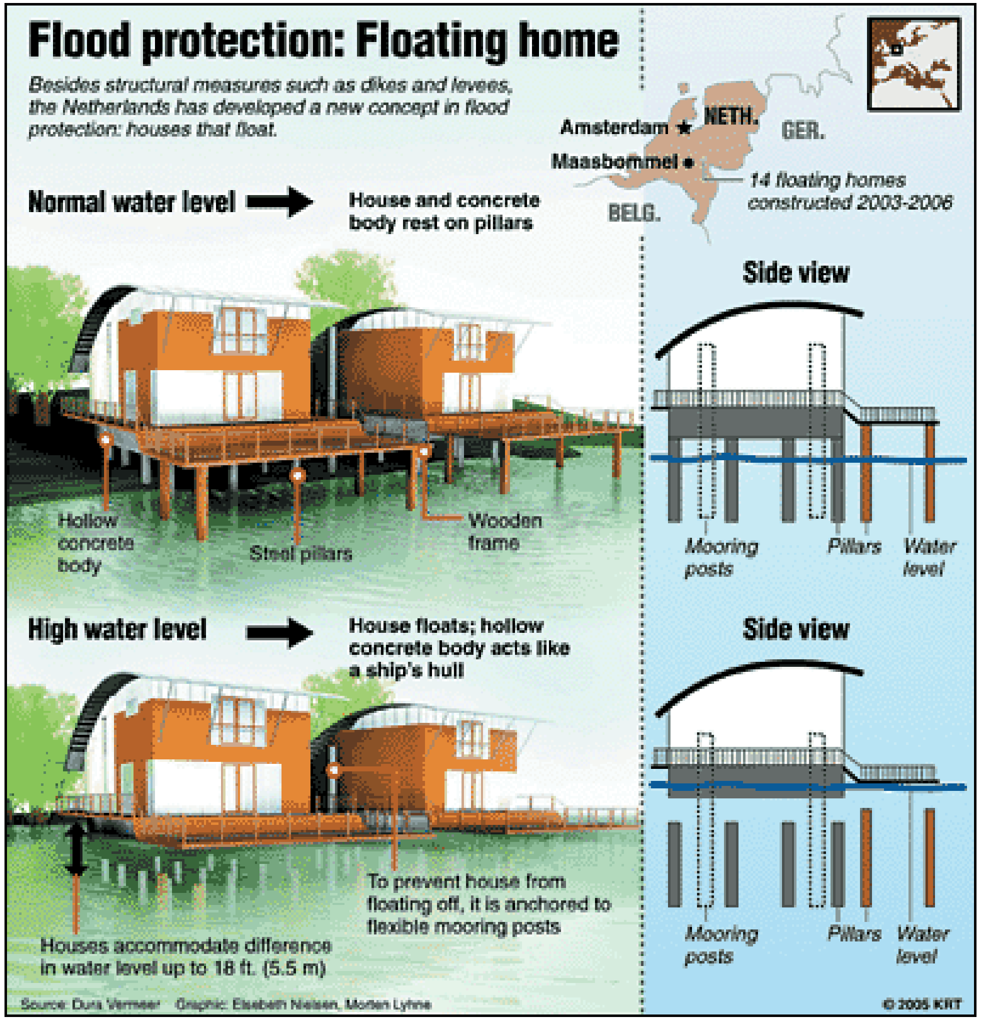


Source: Koutsoyiannis, D., and Th. Xanthopoulos, *Engineering Hydrology*, Edition 3, 418 pages, NTUA, Athens, 1999.

Influence of the philosophical perceptions to scientific method

Adaptation or Mitigation

Floating homes in Holland



Construction of levees

Influence of the philosophical perceptions to scientific method

Deduction –Induction

Aristotle taught that every belief comes through either deduction or induction (Prior analytics, 2, 23)

Given Theory-Model	Observations, measurements
The discharge of the rivers is originated from the rainfall to neighboring areas	*It has been observed that in many rivers discharge increases, when neighboring areas receive rainfall*
↓ ***Deduction***	***Induction*** ↓
Expected data	Inferred Model
Discharge increases, when neighboring areas receive rainfall	*The rivers discharge, usually is related to the rainfall*
A deductive argument is valid if the truth of its premises guarantees the truth of its conclusion, otherwise is invalid.	An inductive argument is strong if its premises support the truth of its conclusions to a considerable degree, and is weak otherwise

Deduction: inference by reasoning from generals to particular

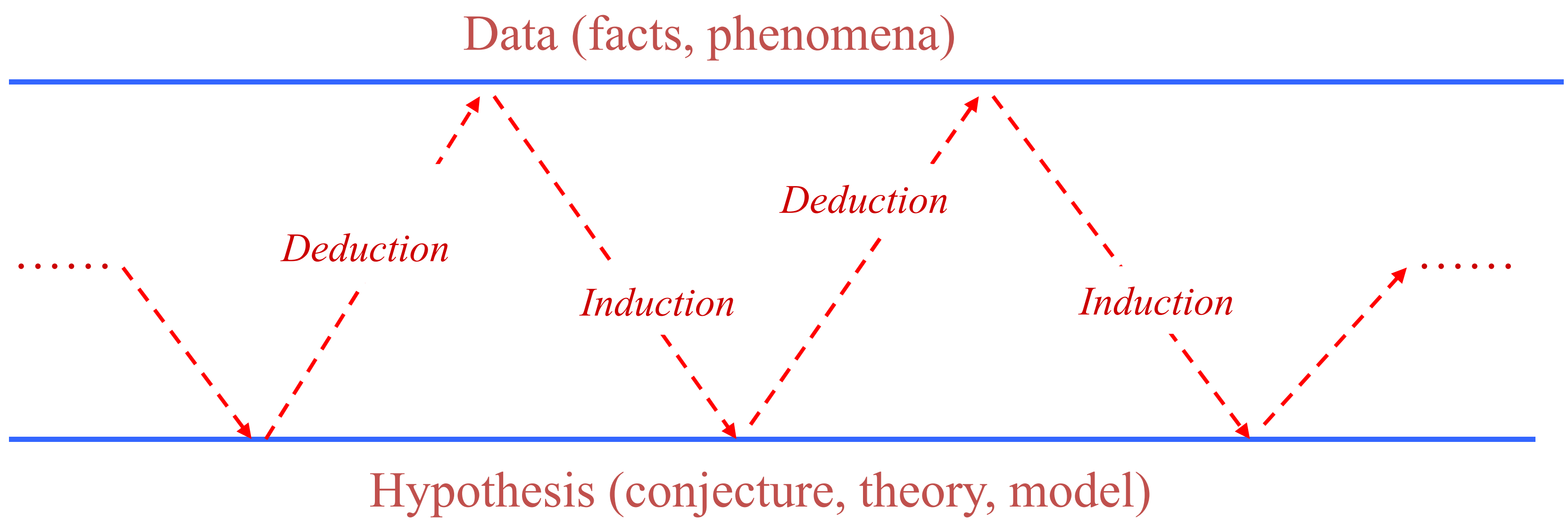
Induction: the process of inferring a general law or principle from the observation of particular instances

Oxford English dictionary

Influence of the philosophical perceptions to scientific method

Science's iterative learning process

Aristotle proposed an inductive-deductive model of scientific method that alternates from mental model to physical world and back again

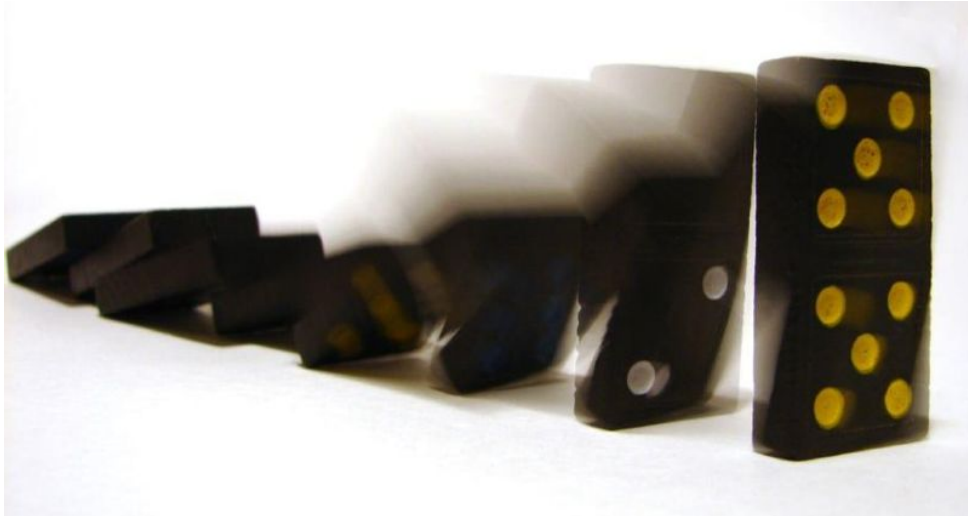


Source: H. Gauch, Scientific Method in Practice, 2003

Influence of the philosophical perceptions to scientific method

Deterministic versus probabilistic systems

In a **deterministic system** the occurrence of events is known with certainty. If at given time step the state of the system is known then the state to the next time steps can be predicted with accuracy



In a **probabilistic system** the occurrence of all events it is not known with certainty and every prediction is accompanied with a probability

Influence of the philosophical perceptions to scientific method

Environmental modeling

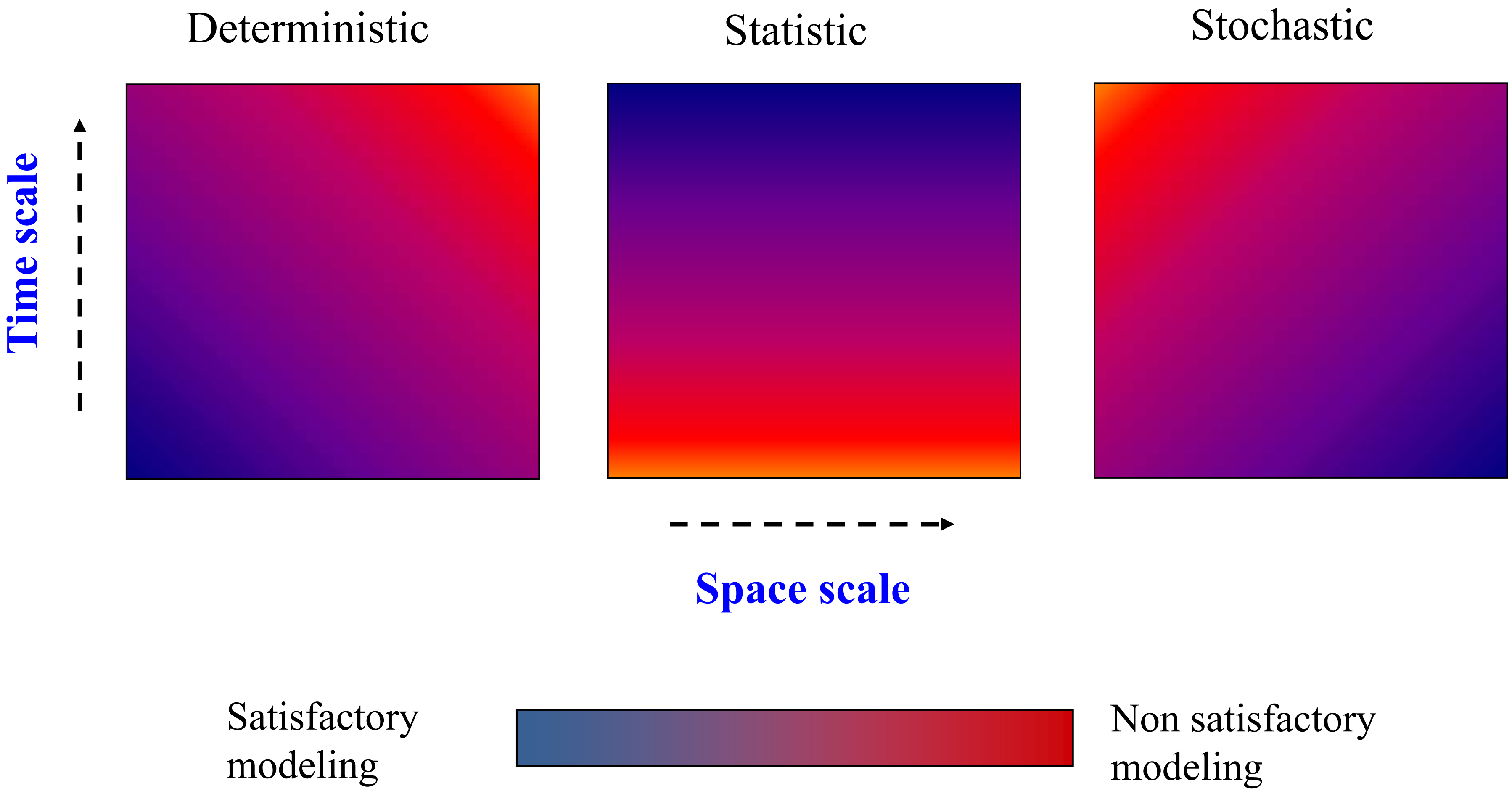
- A **deductive** model is a logical structure based on a theory
- An **inductive** model arises from empirical findings and generalization from them.

- A **deterministic** model is one in which every set of variable states is uniquely determined by parameters in the model and by sets of previous states of these variables. Events completely determined by cause-effect-chains (causality), therefore, deterministic models perform the same way for a given set of initial conditions.
- A **probabilistic** model includes randomness, and variable states are not described by unique values, but rather by probability distributions. Rules can be derived from a large number of similar events (based on experience). Events can be identified by the probability of occurrence

Influence of the philosophical perceptions to scientific method

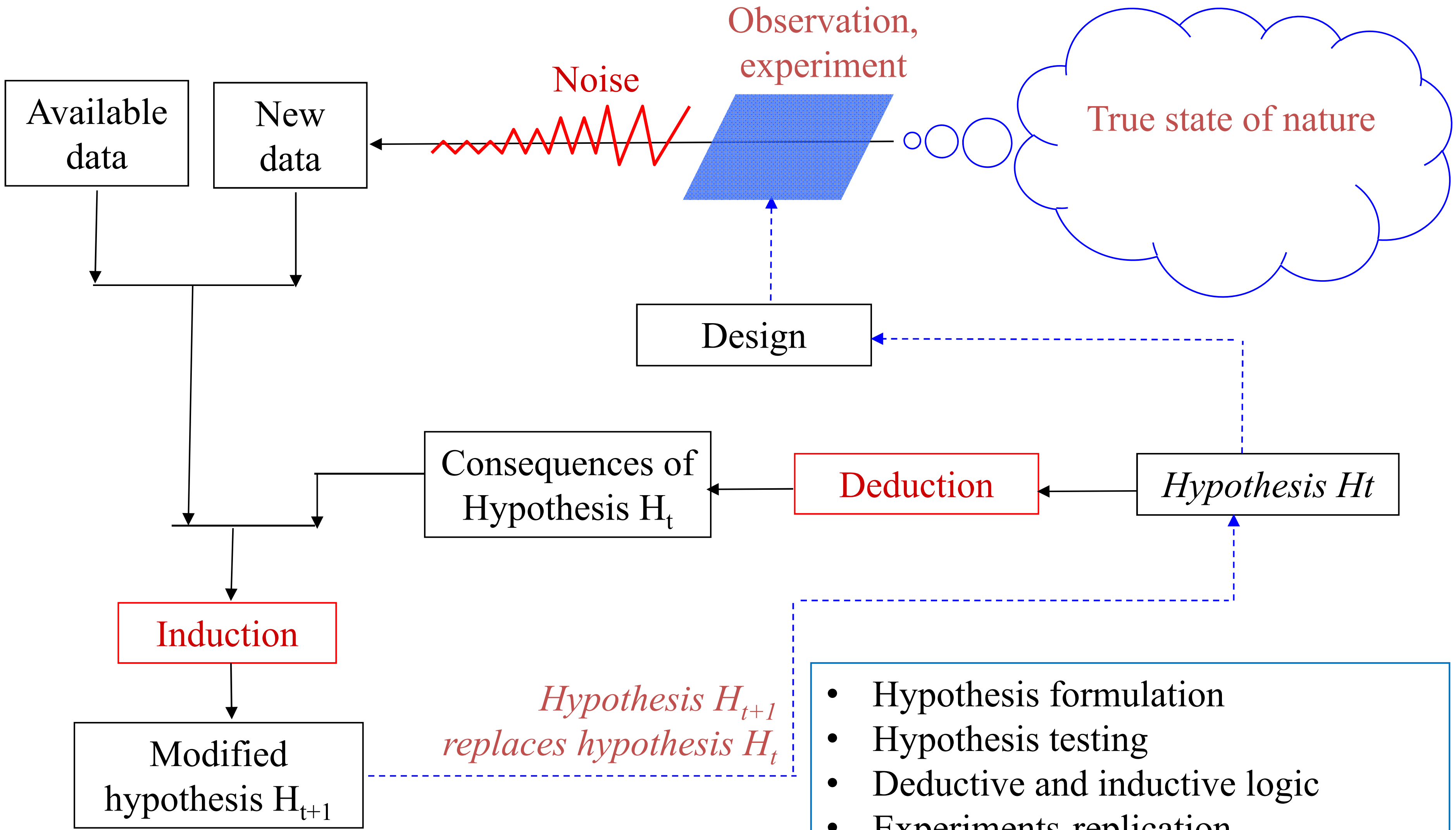
Deterministic-probabilistic

River discharge



Influence of the philosophical perceptions to scientific method

Overview of scientific method



- Hypothesis formulation
- Hypothesis testing
- Deductive and inductive logic
- Experiments-replication, repeatability, falsifiability
- Interactions between data and theory
- Limits to science's domain

Source: H. Gauch, Scientific Method in Practice, 2003

Influence of the philosophical perceptions to scientific method

Simple or sophisticated? Russian space pen

A common urban legend states that NASA spent a large amount of money to develop a pen that would write in space, while the Soviets just used pencils.

Like most urban legends, there is a grain of truth: NASA began to develop a space pen, but when development costs skyrocketed the project was abandoned and astronauts went back to using pencils, along with the Soviets. However, the claim that NASA spent millions on the Space Pen is incorrect, as the Fisher pen was developed using private capital, not government funding.

The meaning of this story is that in certain circumstances we use huge resources for a high tech solution when there are most simple ways to have the same result.

Influence of the philosophical perceptions to scientific method

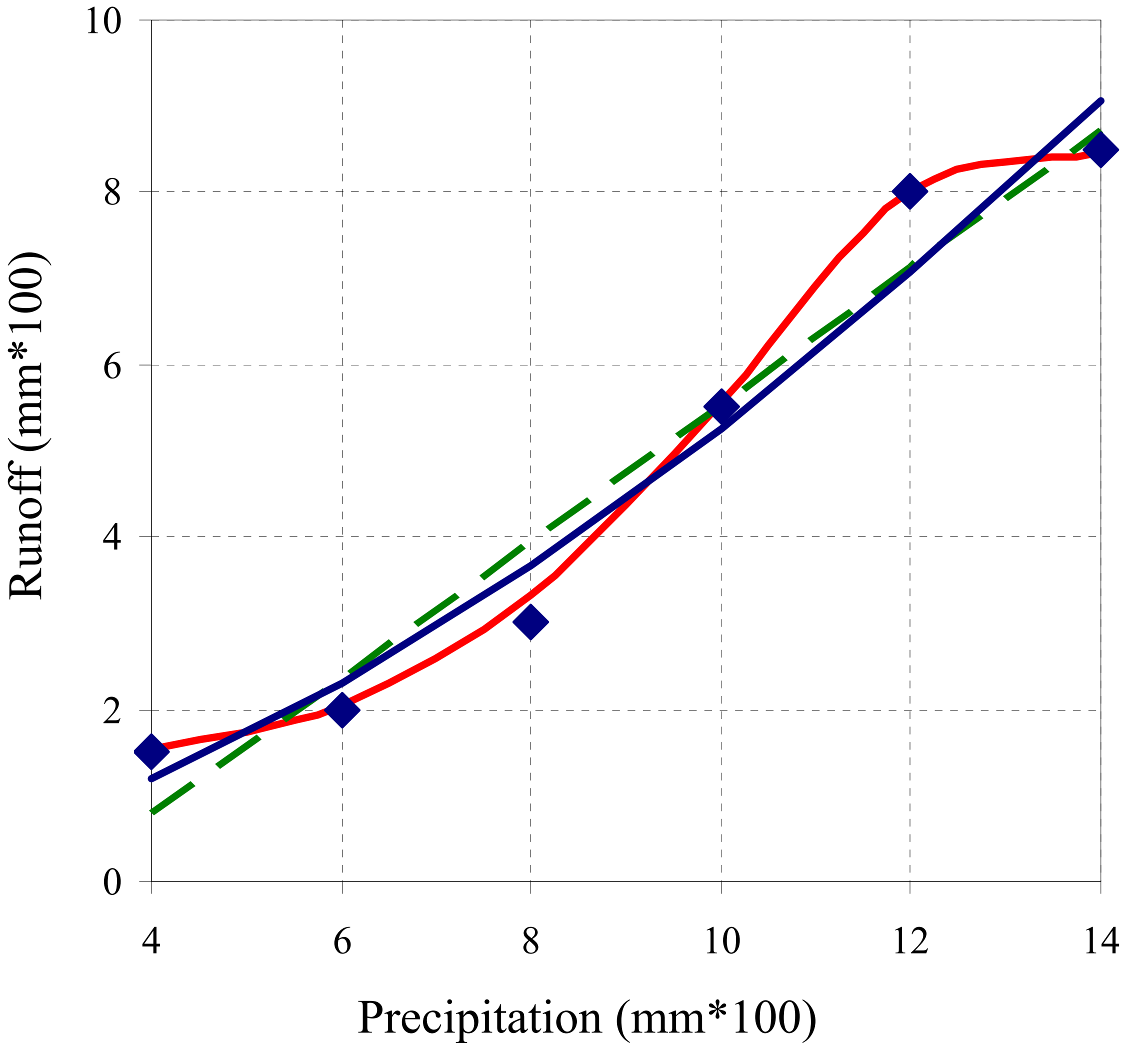
Parsimony and Efficiency

Rainfall-P (mm*100) Runoff-Q (mm*100) modeling

1. $Q=-0.001*P^5+0.0033*P^4-0.0166*P^3-0.001*P^2+0.2984*P+0.7$

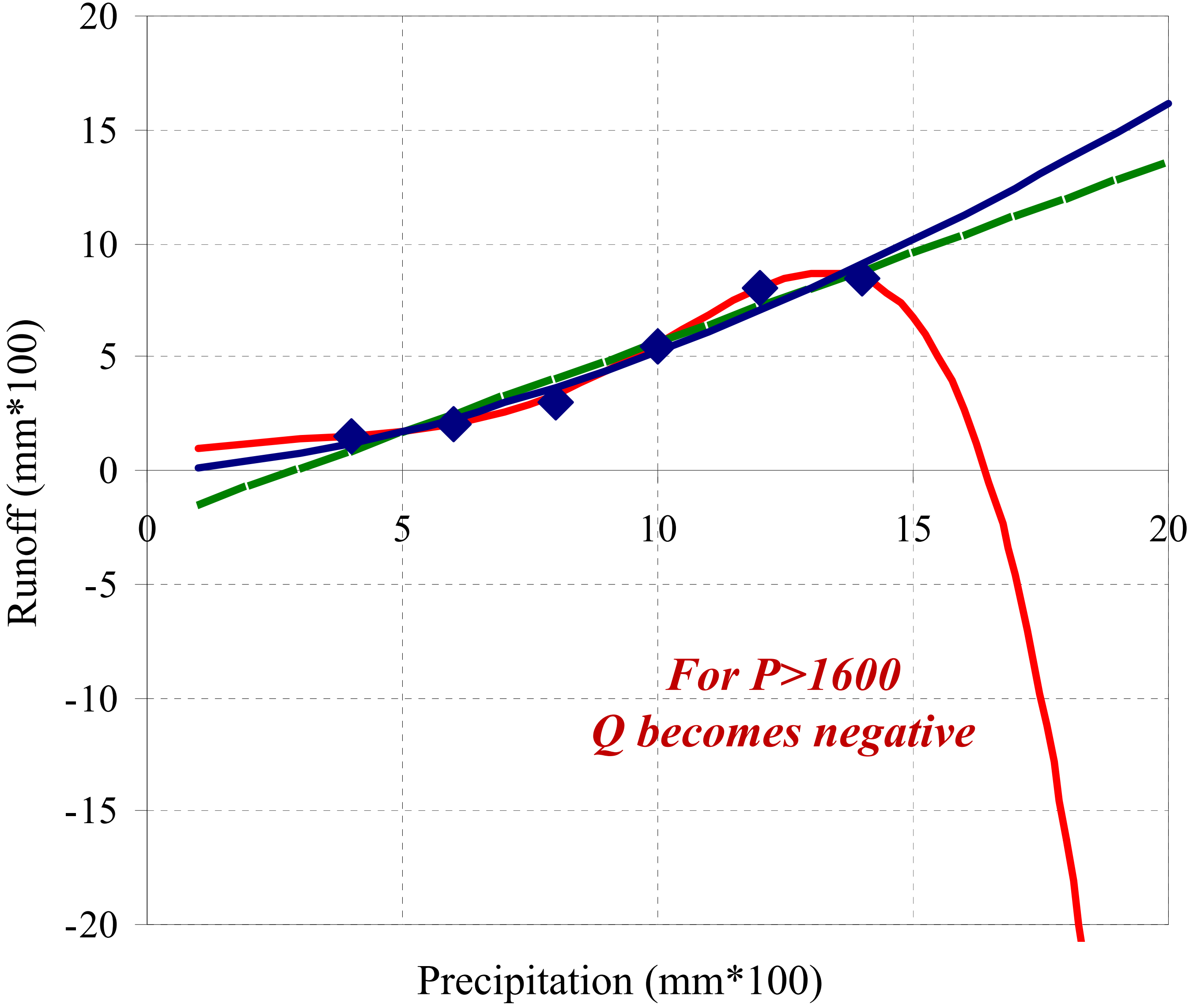
2. $Q=0.79*P-2.39$

3. $Q=0.125*P^{1.62}$



Influence of the philosophical perceptions to scientific method

Parsimony and Efficiency



We may assume the superiority of the demonstration which derives from fewer postulates or hypotheses

Aristotle
Posterior Analytics

Operation and optimization of complex hydrosystems

The Athens water supply system

Evinos
Annual inflow: 320 hm^3
Reservoir capacity: 104 hm^3

Evinos: High Spill

Mornos
Annual inflow: 320 hm^3
Reservoir capacity: 645 hm^3

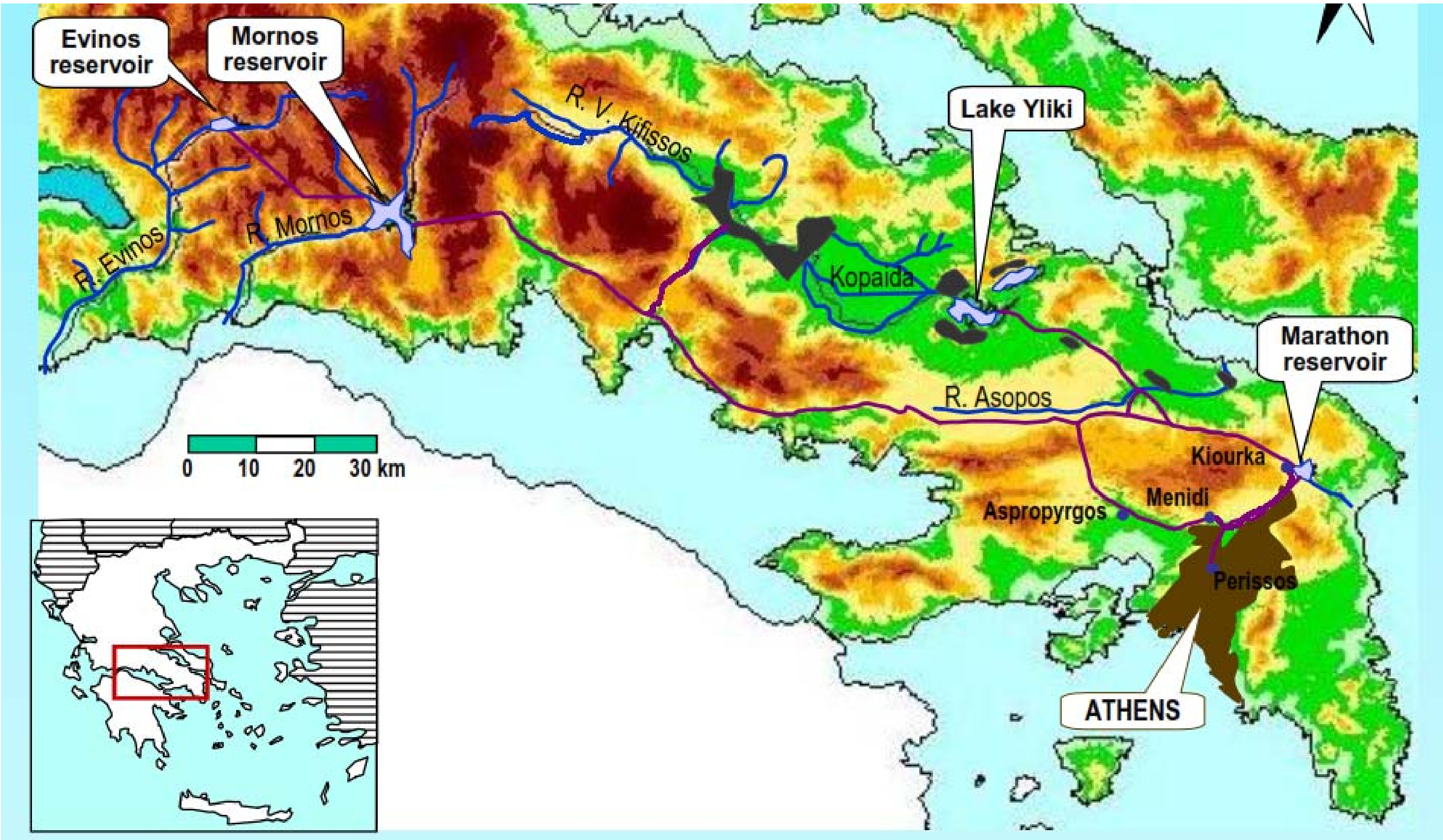
Annual demand:
430 hm^3

Yliki
Annual inflow: 350 hm^3
Reservoir capacity: 587 hm^3

Yliki: High Leakage

Yliki: Need for Pumping

Marathonas
Annual inflow: 20 hm^3
Reservoir capacity: 40 hm^3

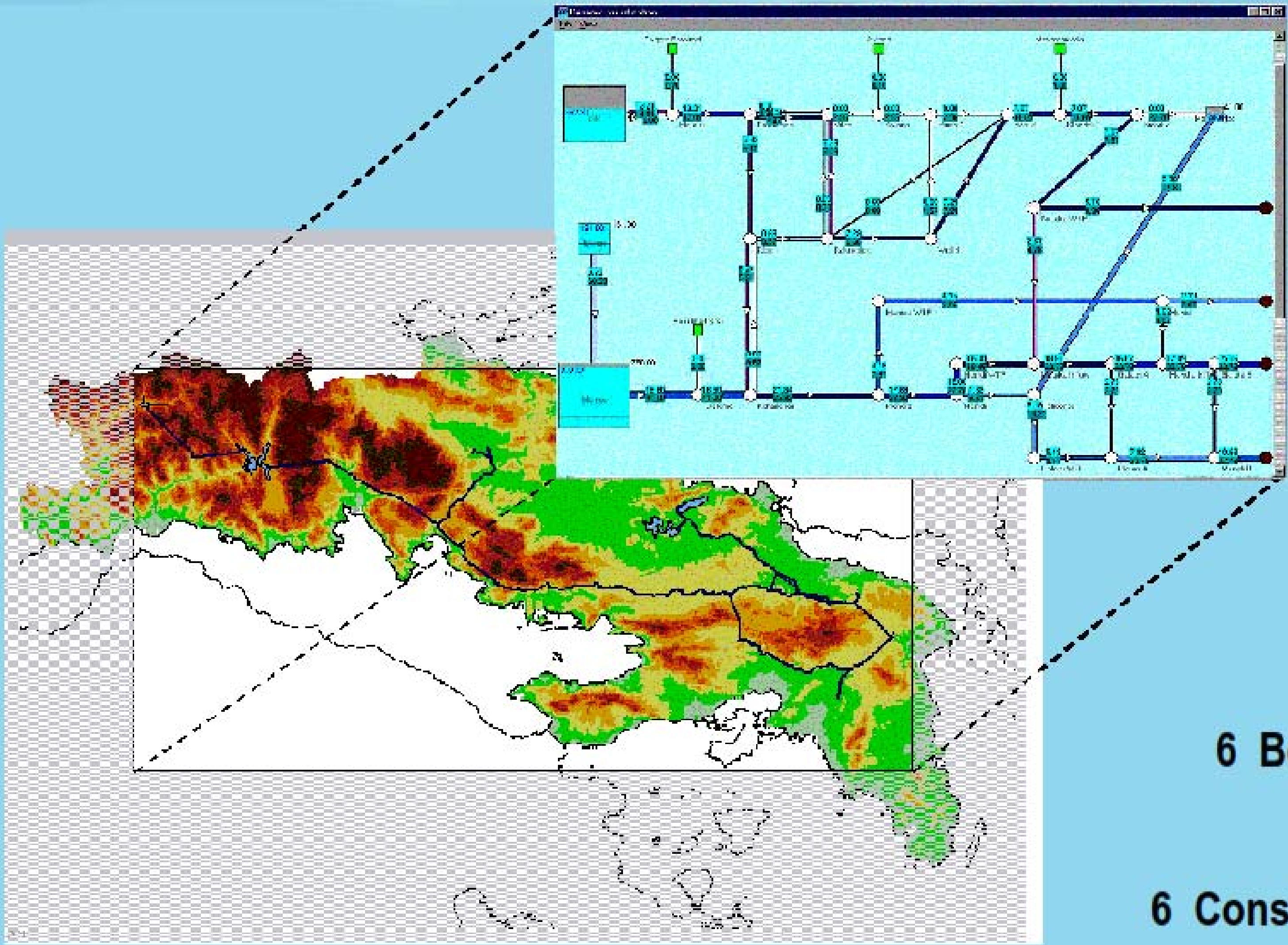


Operating rules

1. Convey water for Evinos to Mornos (to prevent spill)
2. Convey water from Mornos to Athens (there is no need for energy
3. Operate Yliki when the total storage of the system is low (in order to avoid leakage)
4. Matathonas is used as safety reservoir (cover the demand of 1 month)

Operation and optimization of complex hydrosystems

Schematization of the Athens Hydrosytem



36 Nodes

47 Pipes

4 Reservoirs

6 Borehole groups

4 WTP

6 Consumption nodes

Hydronomeas is used as the main decision support tool for WRM

Source: *Karavokiros, G., A. Efstratiadis, and D. Koutsoyiannis, Determining management scenarios for the water resource system of Athens, 2002*

Operation and optimization of complex hydrosystems

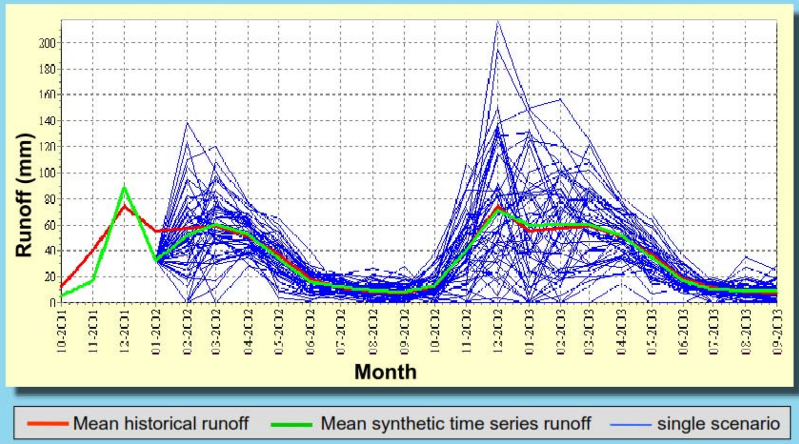
Hydrological Scenarios

- Hydrological scenarios include runoff, precipitation, and evaporation time series, derived from historical hydrometeorological data
- Corrections and transformations of the original data include:
  - Data validation (homogeneity test, screening, double mass analysis etc.)
  - Data compilation (aggregation/disaggregation, series transformation, spatial interpolation etc.)
  - Data filling-in (interpolation, regression analysis etc.)
- Selection of historical time periods (drought, normal, wet period)
  - Strongly dependent on the historic period
  - The results refer only to the selected conditions
- Generation of synthetic hydrological time series, based on the statistical properties of all available data
  - The hydrological scenario becomes independent of user decisions
  - Provides the ability to measure the uncertainty associated with hydrological conditions by means of probability

Source: *Karavokiros, G., A. Efstratiadis, and D. Koutsoyiannis, Determining management scenarios for the water resource system of Athens, 2002*

Operation and optimization of complex hydrosystems

Hydrological Scenarios for the Athens WRS



Runoff scenarios into the Mornos reservoir

Synthetic hydrological time series for the Athens WRS are generated by the stochastic simulator *Castalia*

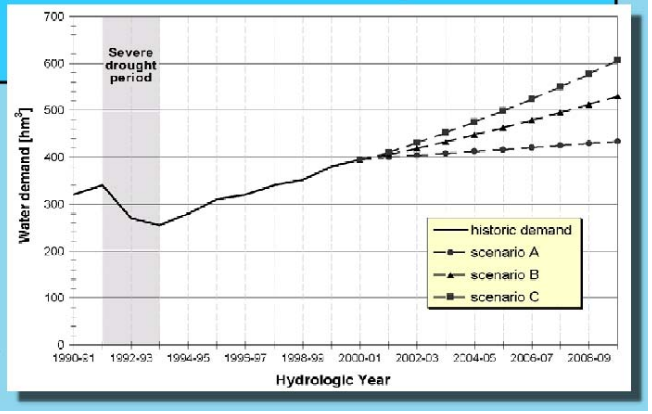
Water Demand Scenarios

Estimation of the water consumption in urban areas

- Population and industrial growth
- Living standard
- Land use in urban areas

Major influence factors

- Expansion of the water supply system
- Water charging policy
- Information campaign



Urban water demand scenarios for the metropolitan area of Athens

Targets, Constraints and Priorities

Water uses and operational requirements are modeled as **targets** and **constraints** from the following categories:

- water consumption (water supply, irrigation, etc.)
- discharge control (minimum, maximum or fixed flow in aqueducts)
- storage control (minimum or maximum water storage level in reservoirs)

Physical constraints imposed by the hydrosystem may prohibit the realisation of all predefined targets simultaneously. Typical reasons are:

- The exhaustion of water resources
- The exhaustion of the system discharge capacity

The targets are sorted in a **priority list**, in order to ensure that, in case of water shortage, water uses of high importance (e.g., water supply) are fulfilled first.

The Management Objectives

Management Objectives refer to the long-term operational goals of the WRS

In the Athens WRS the following three management objectives have been used in several scenarios:

- Maximisation of the total annual withdrawal of the Athens WRS, for a given reliability level
  - What is the operation policy for the theoretical potential of the WRS regardless of the limitations imposed by the discharge capacity of aqueduct?
  - What is the actual potential of the WRS?
- Minimisation of the water supply failure probability (risk) for a given set of targets
  - Which management policy ensures the supply of water to the metropolitan area of Athens with the highest reliability level, regardless of any operational cost?
  - Is it feasible to achieve the specified targets in an emergency situation?
- Minimisation of the total operational cost for a given set of operational goals and for a given acceptable (very low) water supply failure probability
  - Applied in scenarios which reflect a normal operation

Operation and optimization of complex hydrosystems

Hydronomeas
A DSS for the Athens Water Supply System

- *Hydronomeas* has been developed by the N. T. University of Athens within the framework of the project "Modernisation of the Supervision and Management of the Water Resource System of Athens", funded by the Athens Water Supply and Sewage Company (1999-2000).

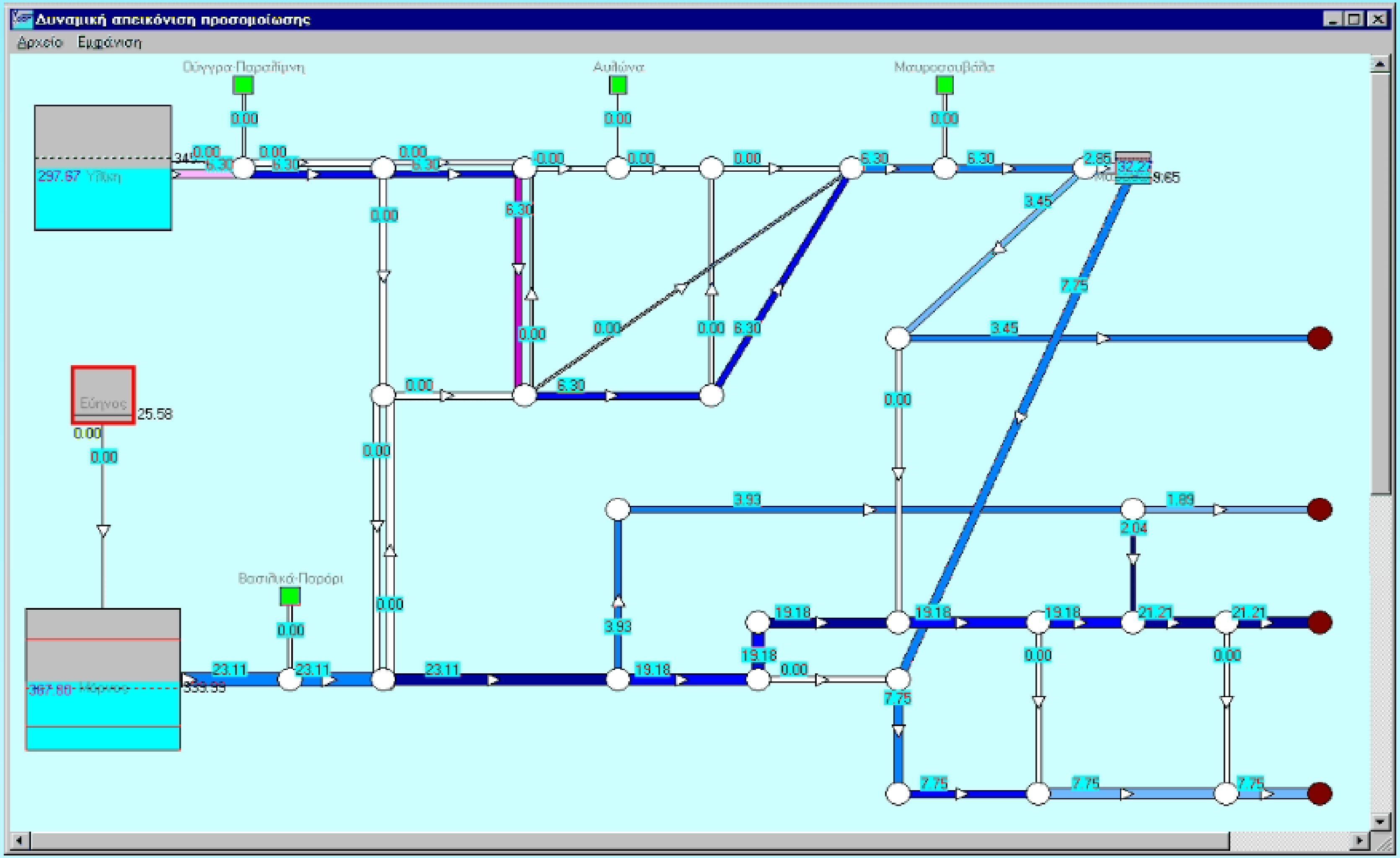
Critical questions to be answered

- What is the maximum total withdrawal from the hydrosystem, for a given hydrologic regime and a given reliability level?
- What is the minimum failure probability in achieving a given set of operational goals, for a given hydrologic regime?
- What is the minimum cost to achieve a given set of operational goals, for a given hydrologic regime and a given reliability level?
- What are the consequences of modifications in the hydrosystem (e.g., construction of new projects), and the impacts of different management policies or hydroclimatic scenarios?
- How could the system respond to special occasions such as channel damages or an intense increase of water demand for a specific period (e.g., during the 2004 Olympic Games)?

Source: *Karavokiros, G., A. Efstratiadis, and D. Koutsoyiannis, Determining management scenarios for the water resource system of Athens, 2002*

Operation and optimization of complex hydrosystems

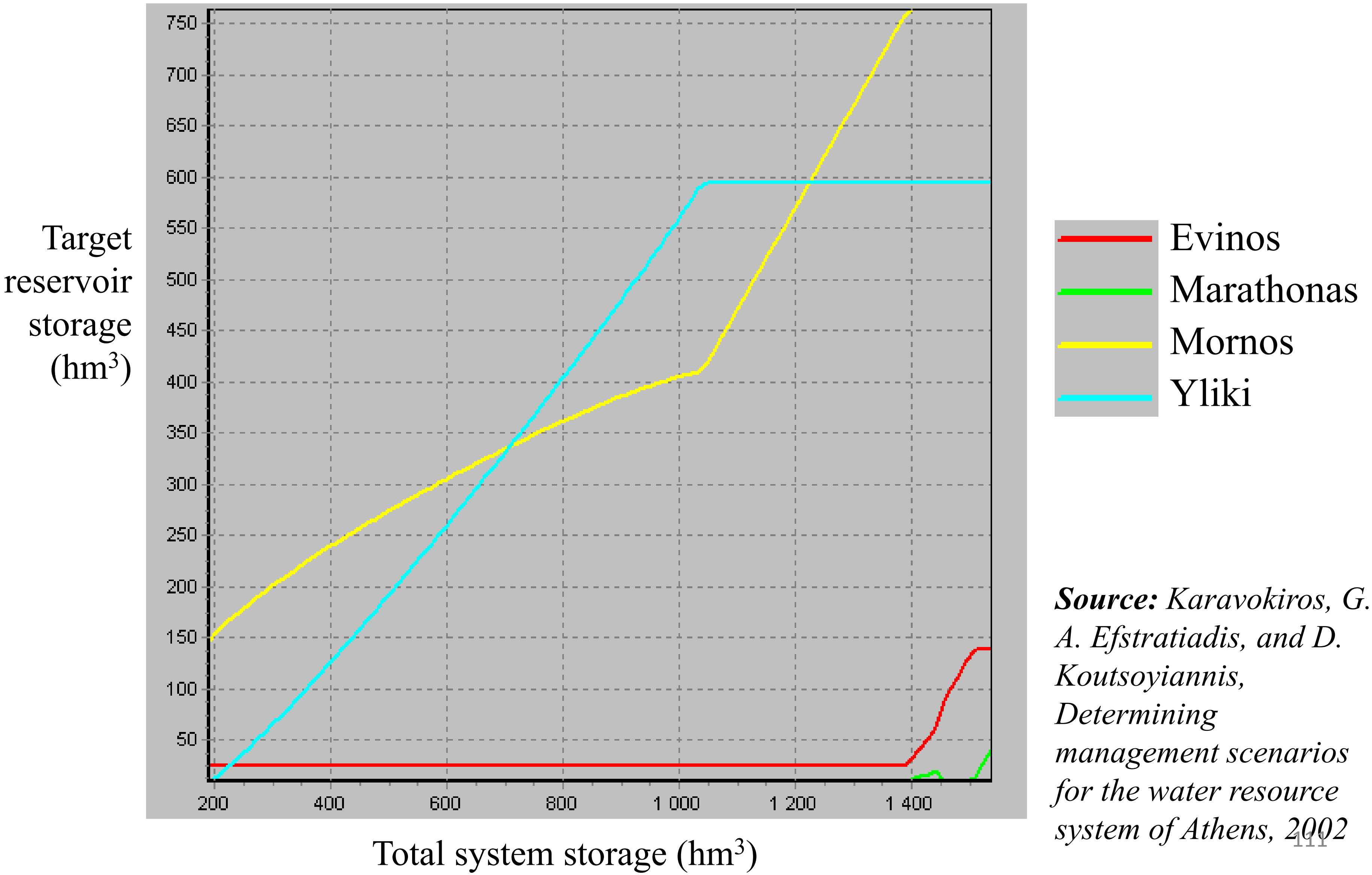
The visualisation of the simulation process



Source: *Karavokiros, G., A. Efstratiadis, and D. Koutsoyiannis, Determining management scenarios for the water resource system of Athens, 2002*

Operation and optimization of complex hydrosystems

Graphical representation of reservoir operating rules



Source: *Karavokiros, G., A. Efstratiadis, and D. Koutsoyiannis, Determining management scenarios for the water resource system of Athens, 2002*