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The major challenges for ensuring a sustainable use of freshwater under change

ALMA MATER STUDIORUM
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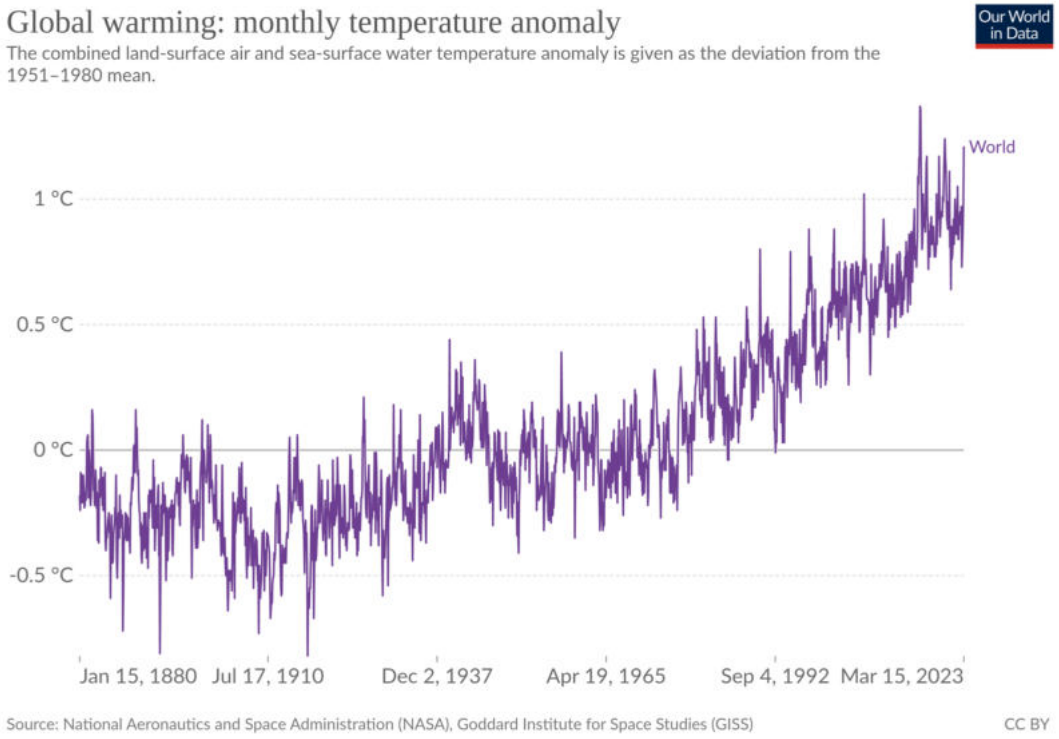
Water is essential for life but it is also a threat

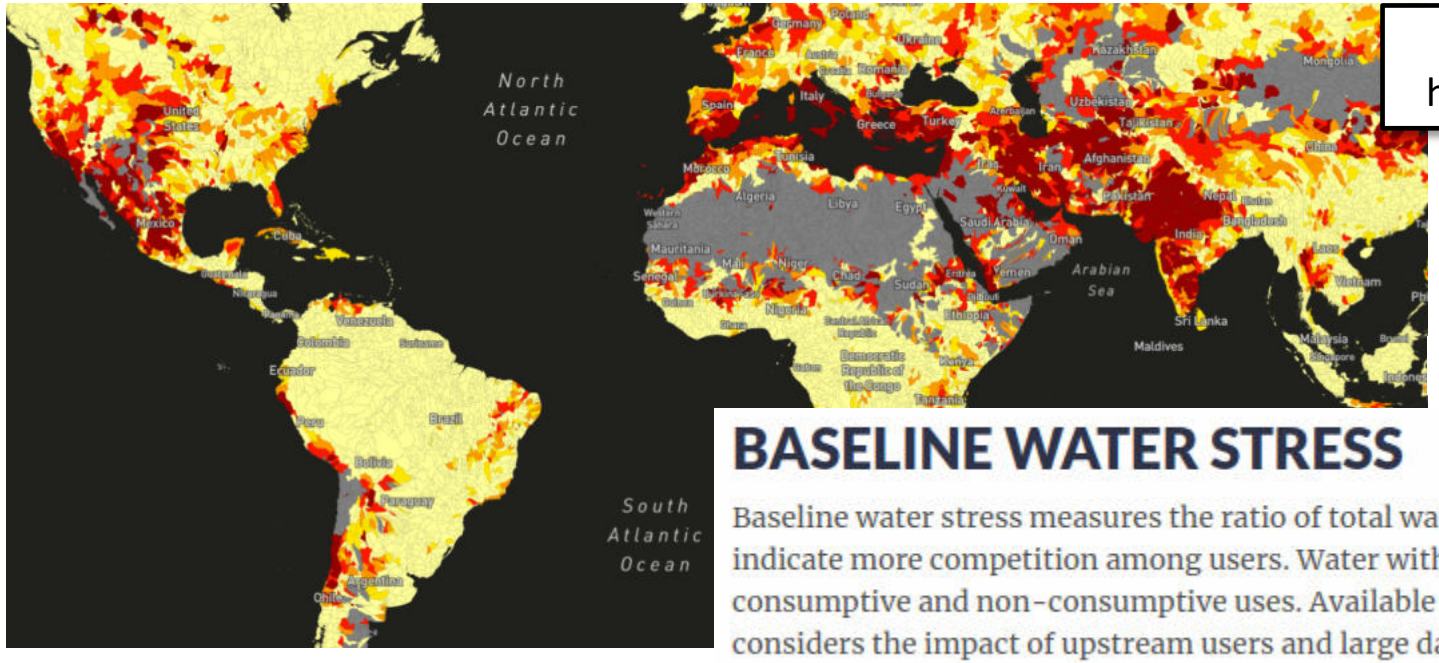
Flood in Florence (1966)

Lake Aral disaster

Water resources are under change

California(2009)





From Aqueduct and https://waterpeacesecurity.org/map

BASELINE WATER STRESS

Baseline water stress measures the ratio of total water withdrawals to available renewable water supplies. Higher values indicate more competition among users. Water withdrawals include domestic, industrial, irrigation, and livestock consumptive and non-consumptive uses. Available renewable water supplies include surface and groundwater supplies and considers the impact of upstream users and large dams on downstream water availability. Data is not updated temporally.

To assess sustainability of water uses we need to study the Hydrological cycle

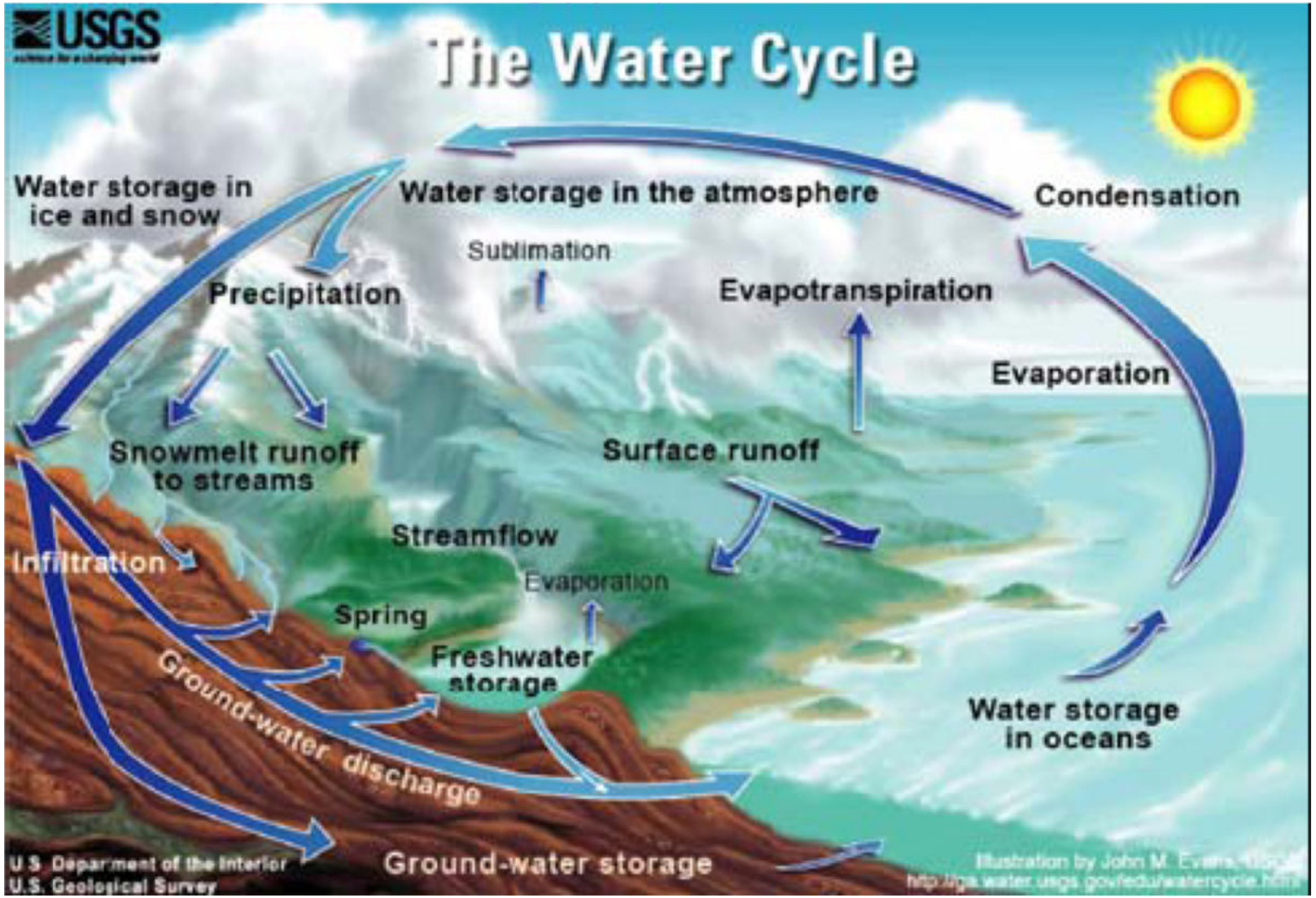


Image from: http://ga.water.usgs.gov/edu/watercycle.html

What is hydrology? It is the science of the water cycle

From Wikipedia
(https://en.wikipedia.org/wiki/Hydrology)

Hydrology is the scientific study of the movement, distribution, and management of water on Earth and other planets, including the water cycle, water resources, and drainage basin sustainability. Hydrologists are scientists studying earth or environmental science, civil or environmental engineering, and physical geography. Using various analytical methods and scientific techniques, they collect and analyze data to help solve water related problems such as environmental preservation, natural disasters, and water management.

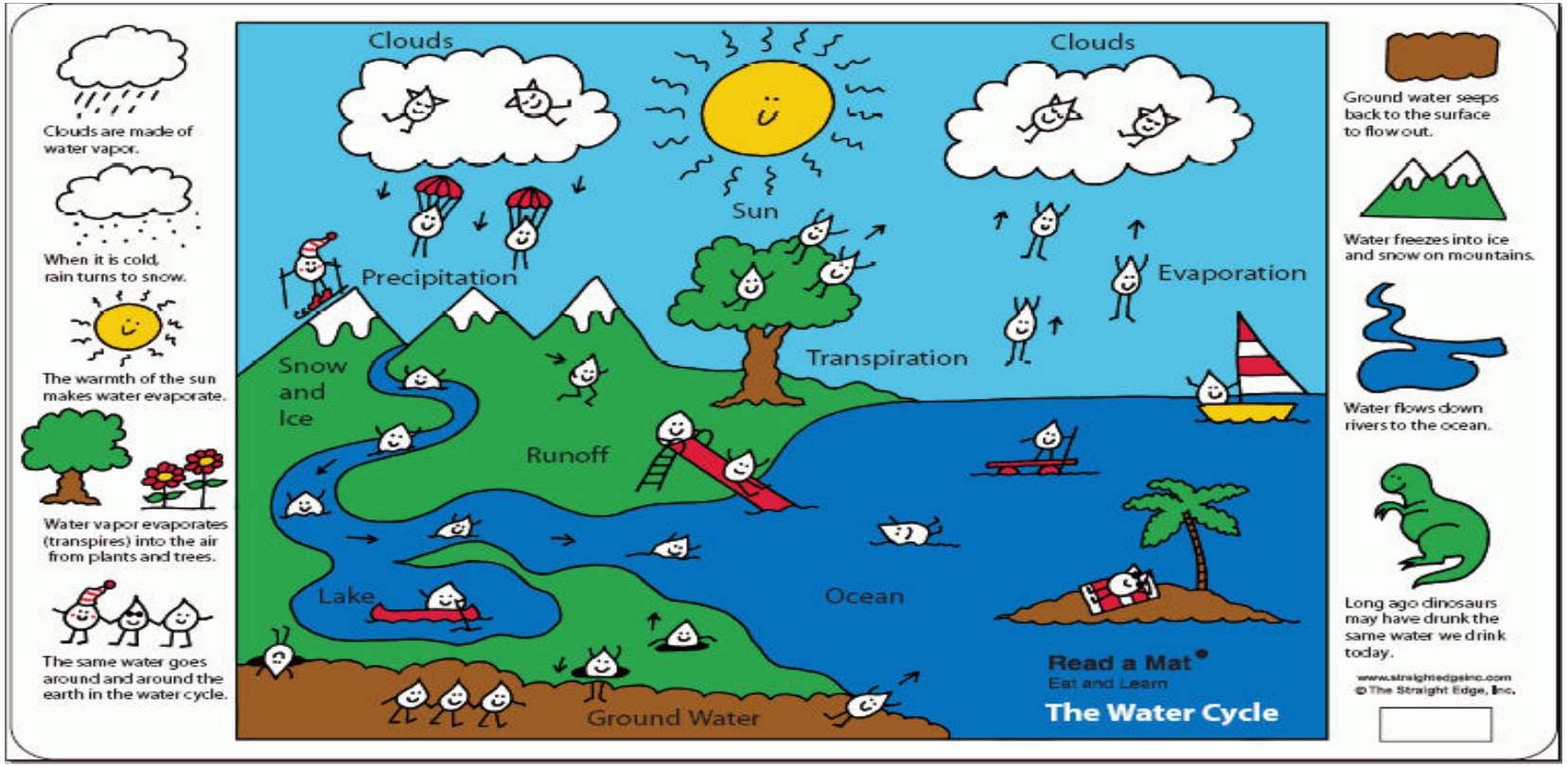
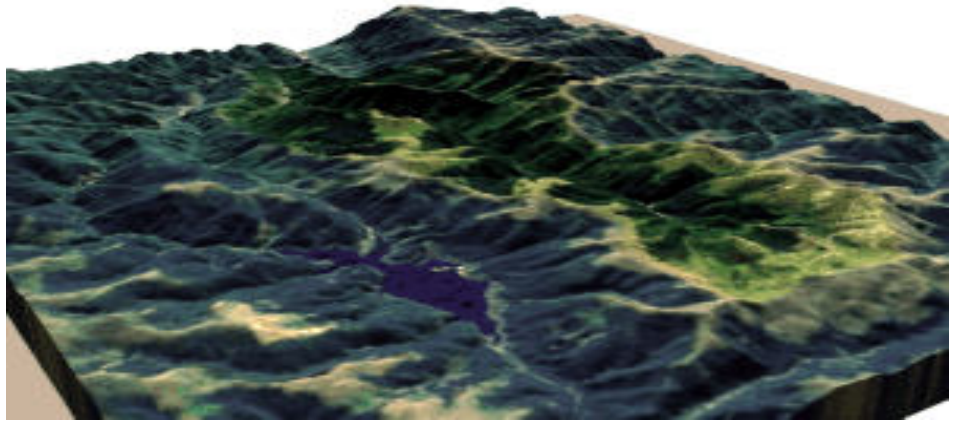


Image from: http://ga.water.usgs.gov/edu/watercycle.html

Hydrological cycle

There are many details of the water cycle that are not fully known.
For instance:

- How rainfall partitions into infiltration and overland flow?
- How does groundwater flow take place?
- What is the amount of direct fluxes of spring water into the oceans?



The watershed is still a partial mystery!
(Picture produced by NASA)

Humans only recently started to study water

Until the Middle Age (around 1600 AD) flow in rivers was assumed to mainly come from groundwater and only marginally from rainfall. This was an ancient theory that is attributed to Aristotelis.

Only some 400 years ago an Italian abbé, Benedetto Castelli, postulated that water balance on the Earth is mainly driven by rainfall input. He proved his theory by measuring rainfall with a glass and using the collected data to reconstruct the inflow to the Lake Trasimeno, located in Central Italy.

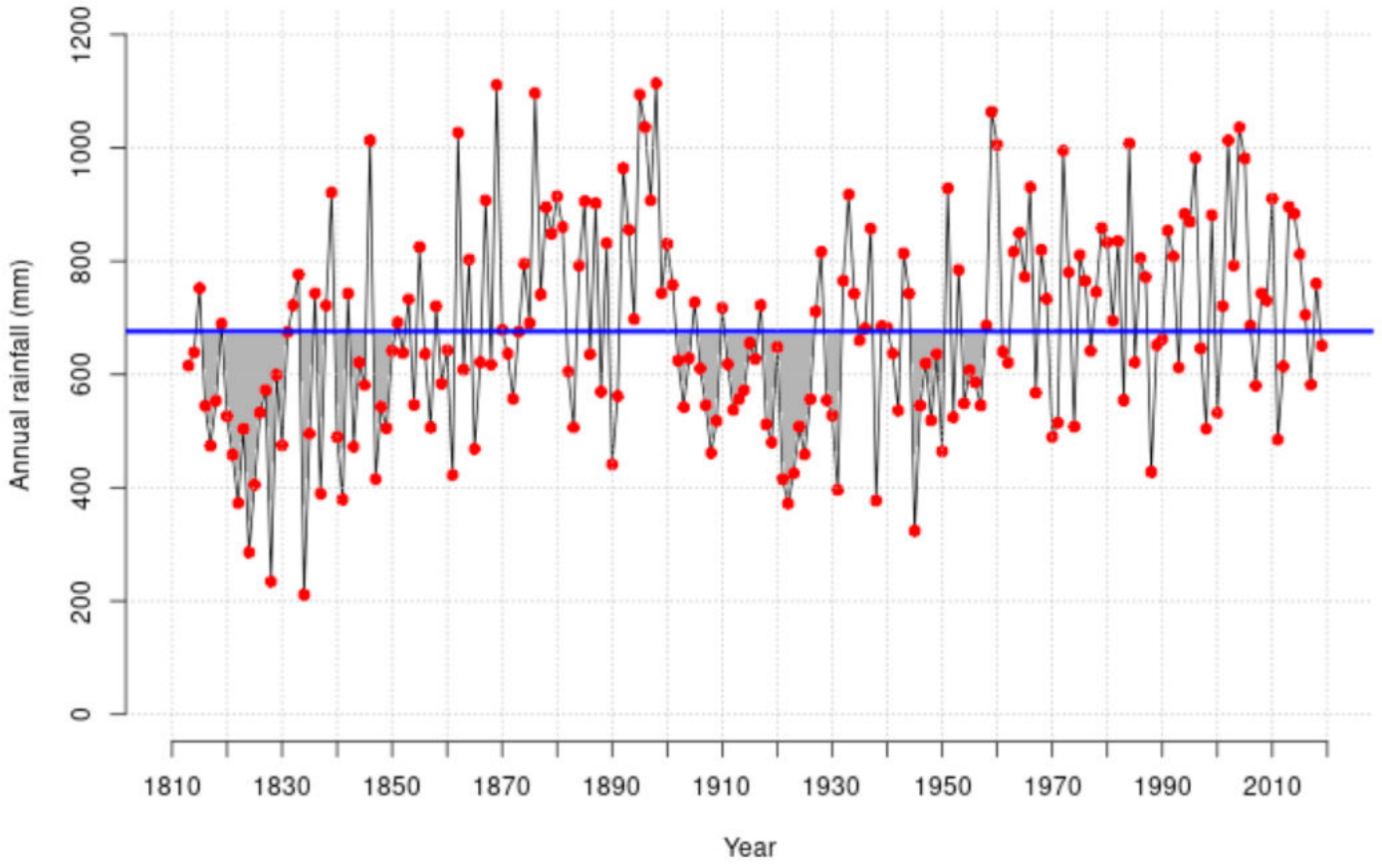
Curiously, no one had the idea of observing rainfall and river flows before. Humans started observing stars more than 5000 years ago, but waited until 400 years ago to observe water (with the exception of ancient civilizations, like Egyptians, that collected a few observations of water levels).

We wish we started before….

The results is that humans do not have long records of water observations (meteorology, water resources….).

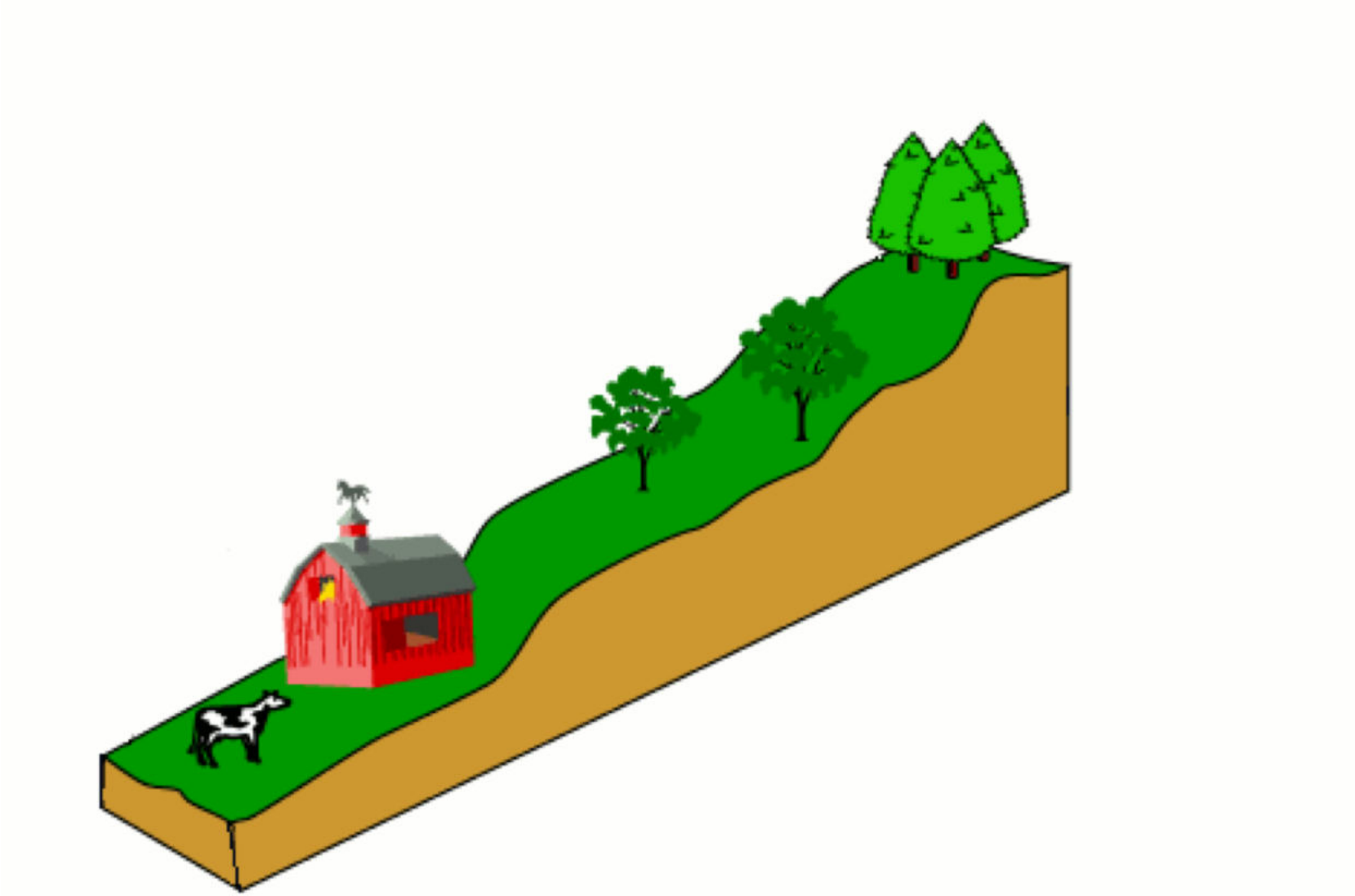
The longest rainfall series today available is the one collected in Padua (Italy), which was observed every day from 1725 (with only a few missing values up to today).

Had we longer observation records available, we would not spend much time discussing about climate change, water resources variability and so forth.



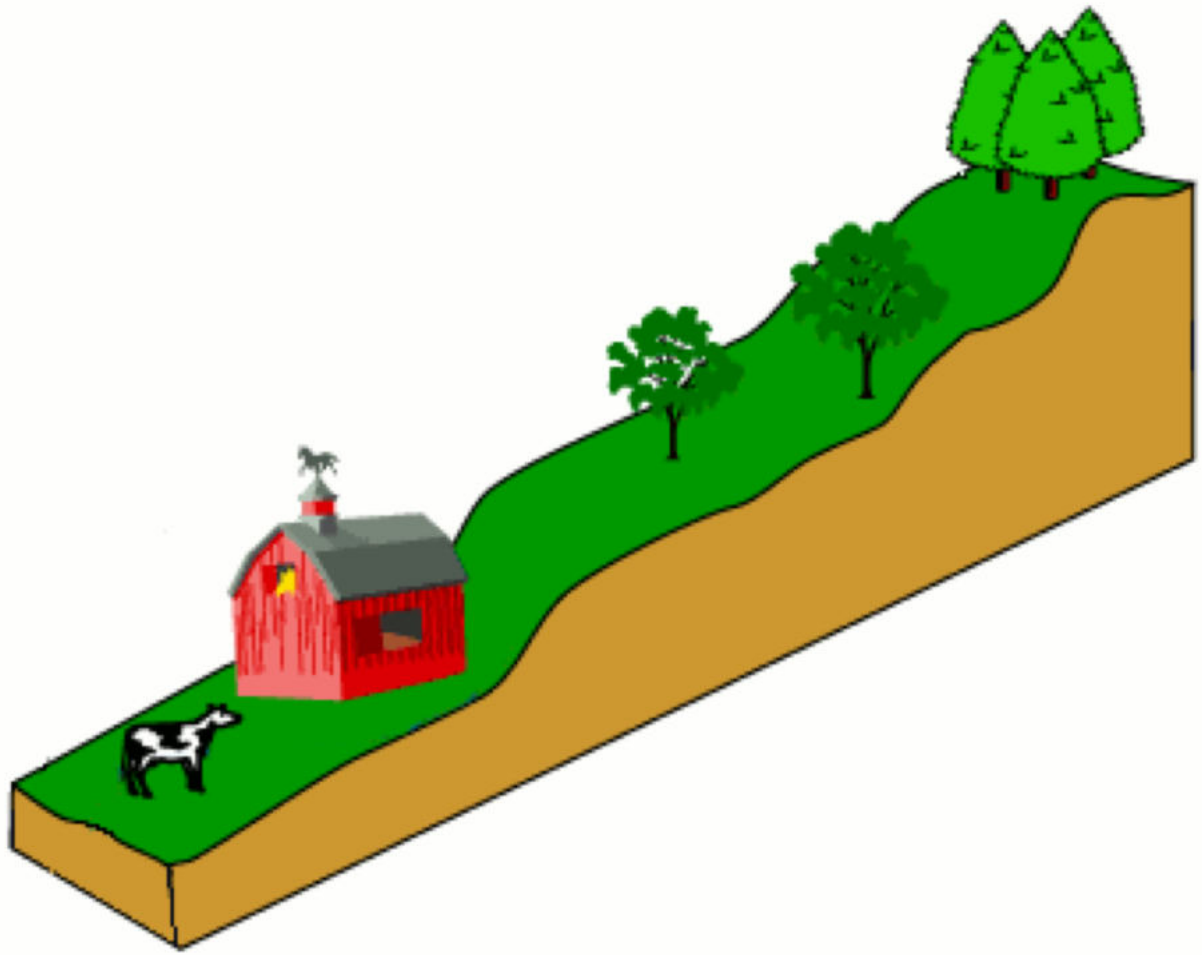
How rainfall partitions into infiltration and overland flow?

"Hortonian" mechanism of surface runoff formation
Infiltration excess



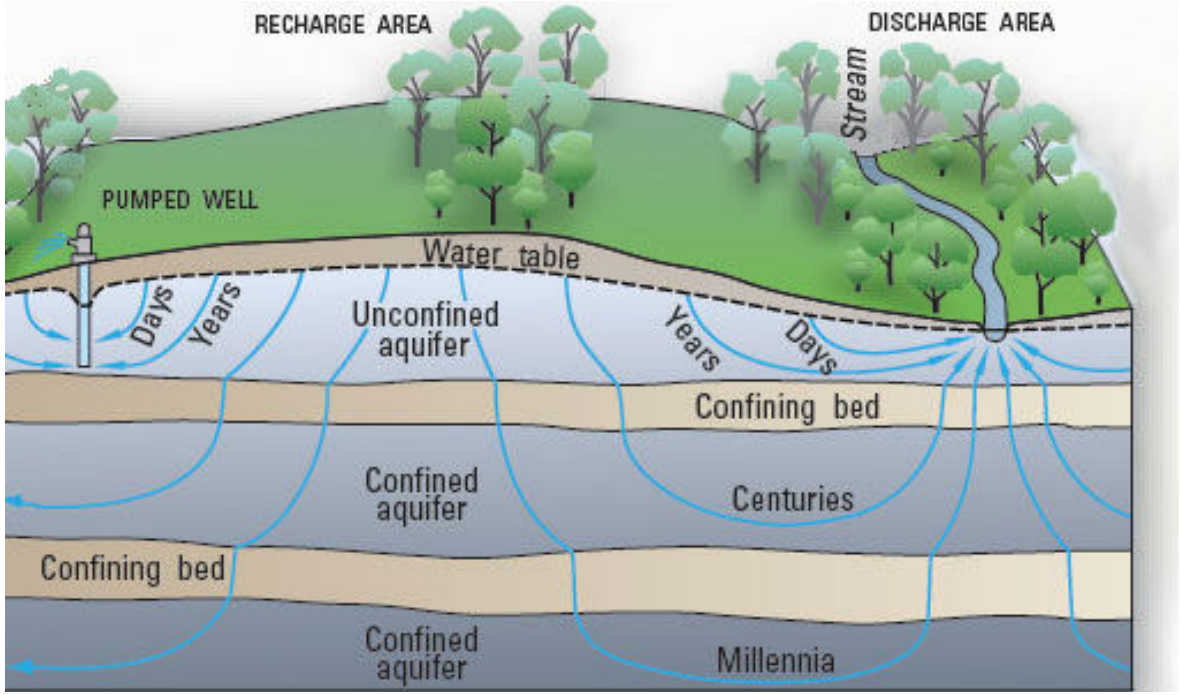
How rainfall partitions into infiltration and overland flow?

"Dunnian" mechanism of surface runoff formation
Saturation excess



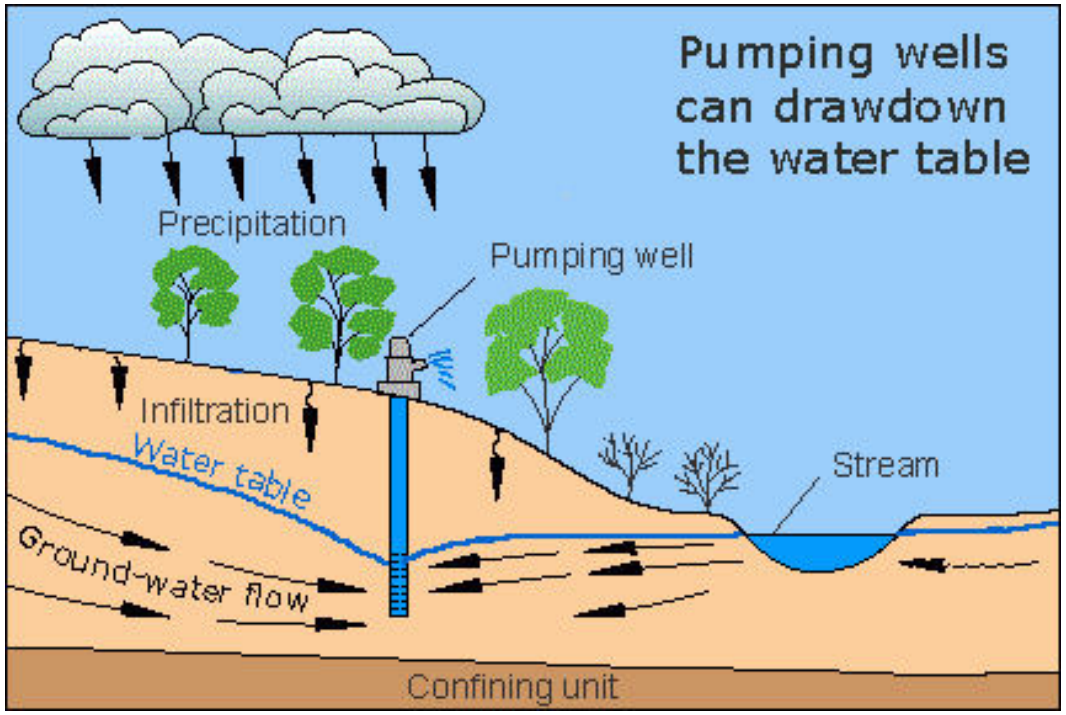
How groundwater flows?

Groundwater flow can take millennia to develop!



Humans have an impact!

Images from: http://ga.water.usgs.gov/



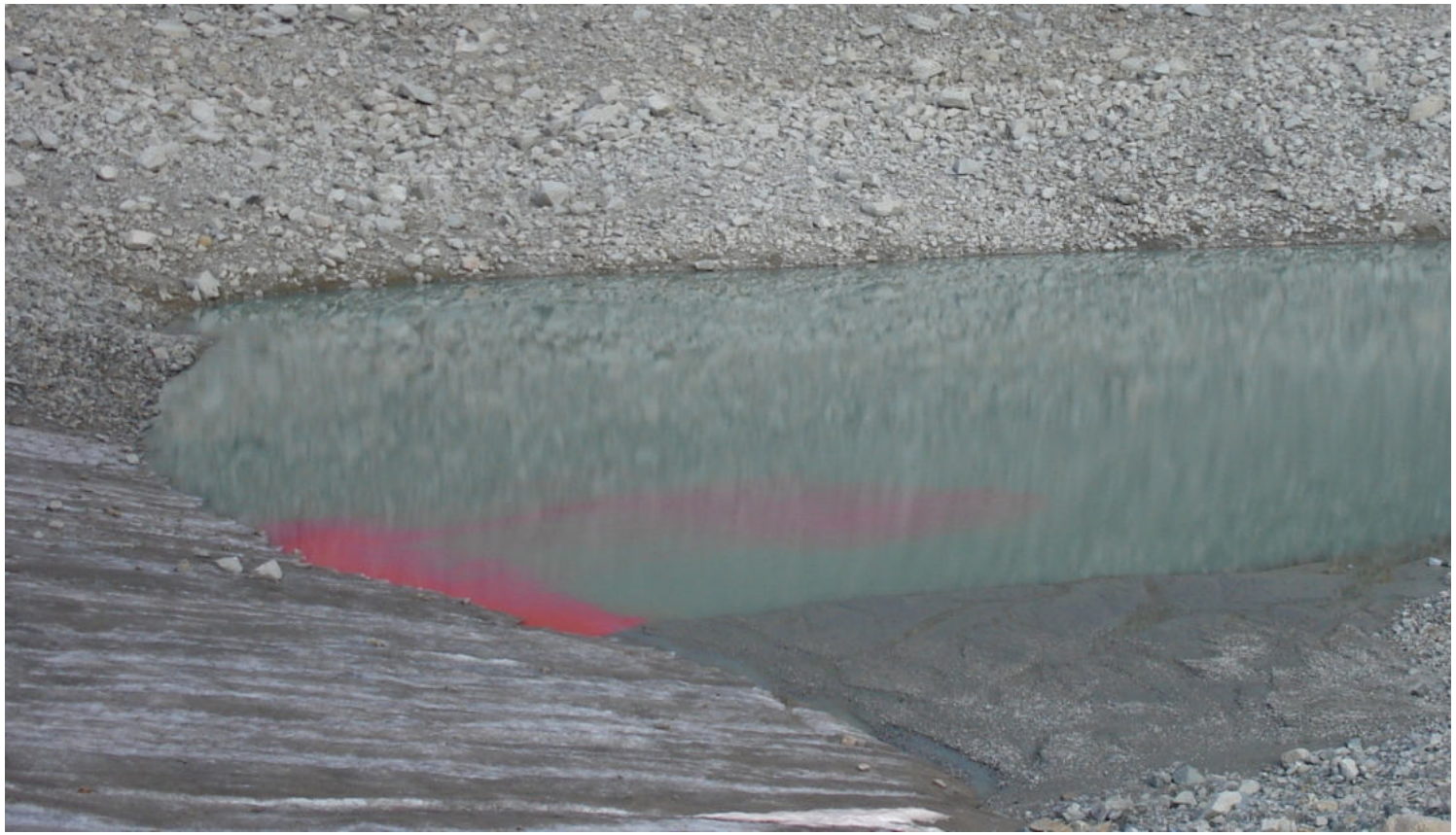
Some groundwater flows directly into the ocean…

- There is a considerable direct flux of groundwater into the oceans.
- Although hydrologists are trying to setting up global models, at the current state of the art we can get a very rough estimate only of such fluxes.
- Yet, mathematical model of ocean circulation show that these fluxes are impacting the major stream like the Gulf stream.
- Therefore these fluxes are impacting future climate.

Benjamin Franklin's map of the Gulf Stream. Source: Wikipedia

Topical research fields: looking for drop paths….

- Tracer studies



Source: http://serc.carleton.edu/microbelife/research_methods/environ_sampling/hydrotrace.html

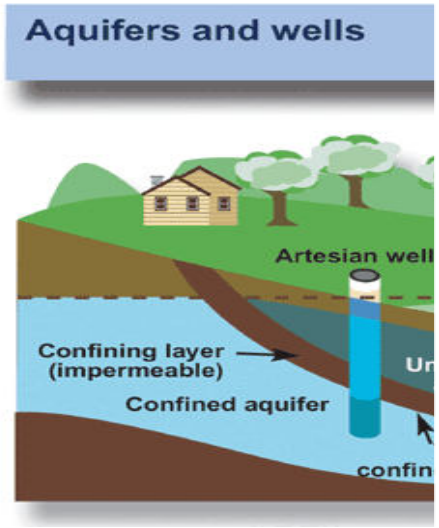
Topical research fields: looking for vegetation functioning

Topical research fields: analysis of human impact

- Sociohydrology

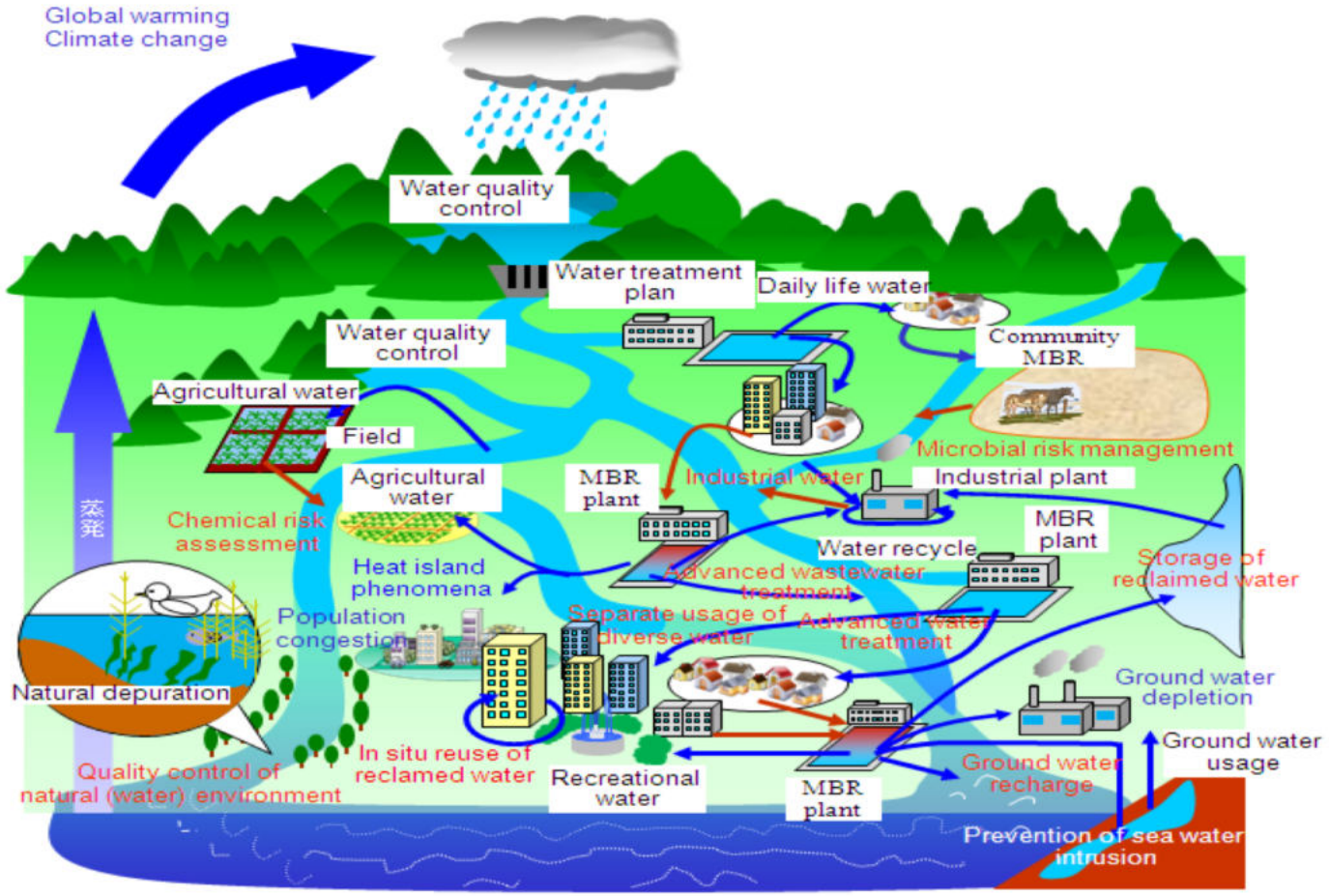
Source: courtesy by A. Sikorska - Warsaw University of Life Sciences

Socio-hydrology



Groun

Civil water use



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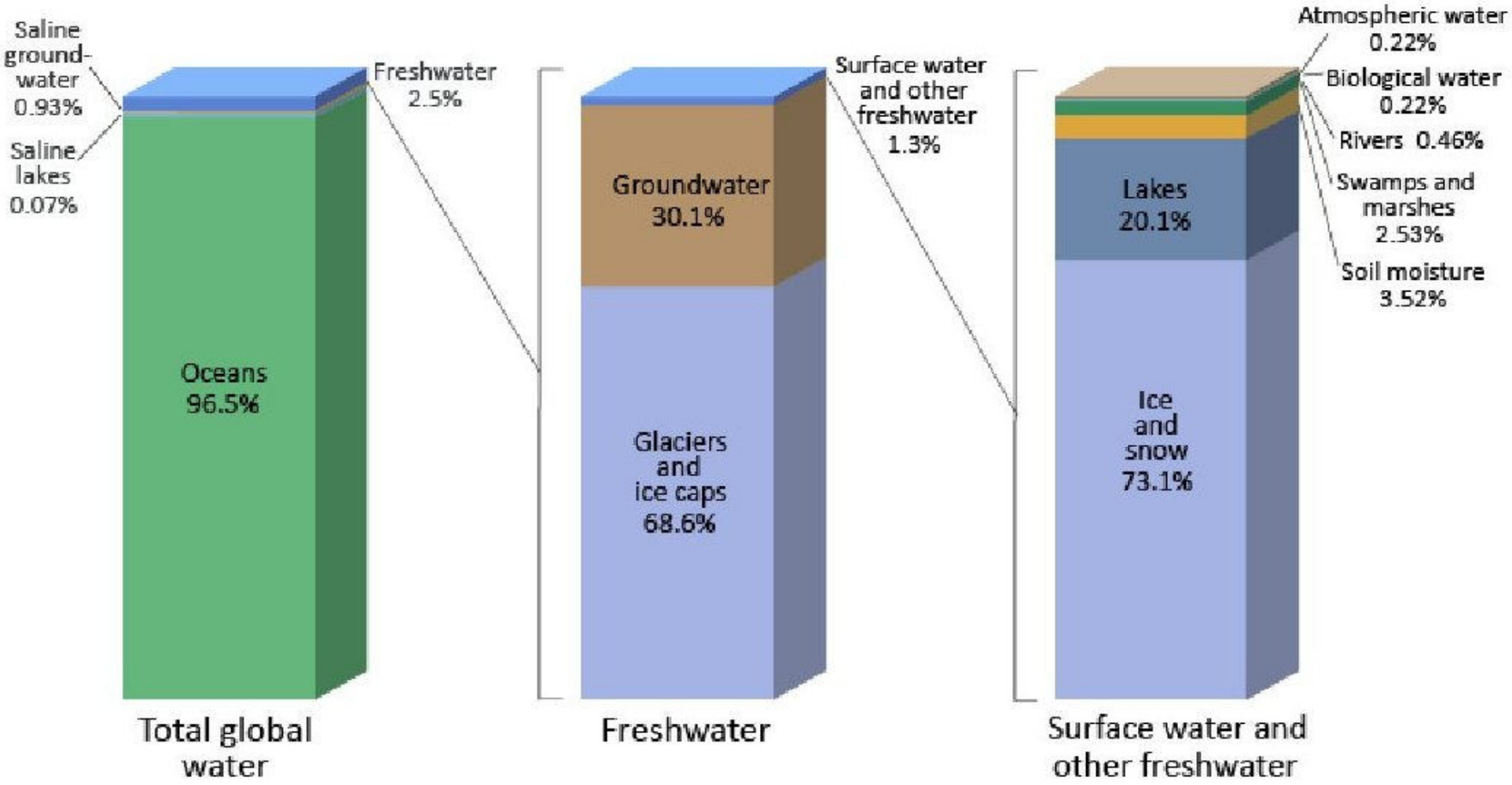
How much water do we have?

From http://ga.water.usgs.gov/edu/earthhowmuch.html

Water source	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	1,338,000,000	--	96.54
Ice caps, Glaciers, & Permanent Snow	24,064,000	68.6	1.74
Ground water	23,400,000	--	1.69
Fresh	10,530,000	30.1	0.76
Saline	12,870,000	--	0.93
Soil Moisture	16,500	0.05	0.001
Ground Ice & Permafrost	300,000	0.86	0.022
Lakes	176,400	--	0.013
Fresh	91,000	0.26	0.007
Saline	85,400	--	0.007
Atmosphere	12,900	0.04	0.001
Swamp Water	11,470	0.03	0.0008
Rivers	2,120	0.006	0.0002
Biological Water	1,120	0.003	0.0001

Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford University Press, New York).

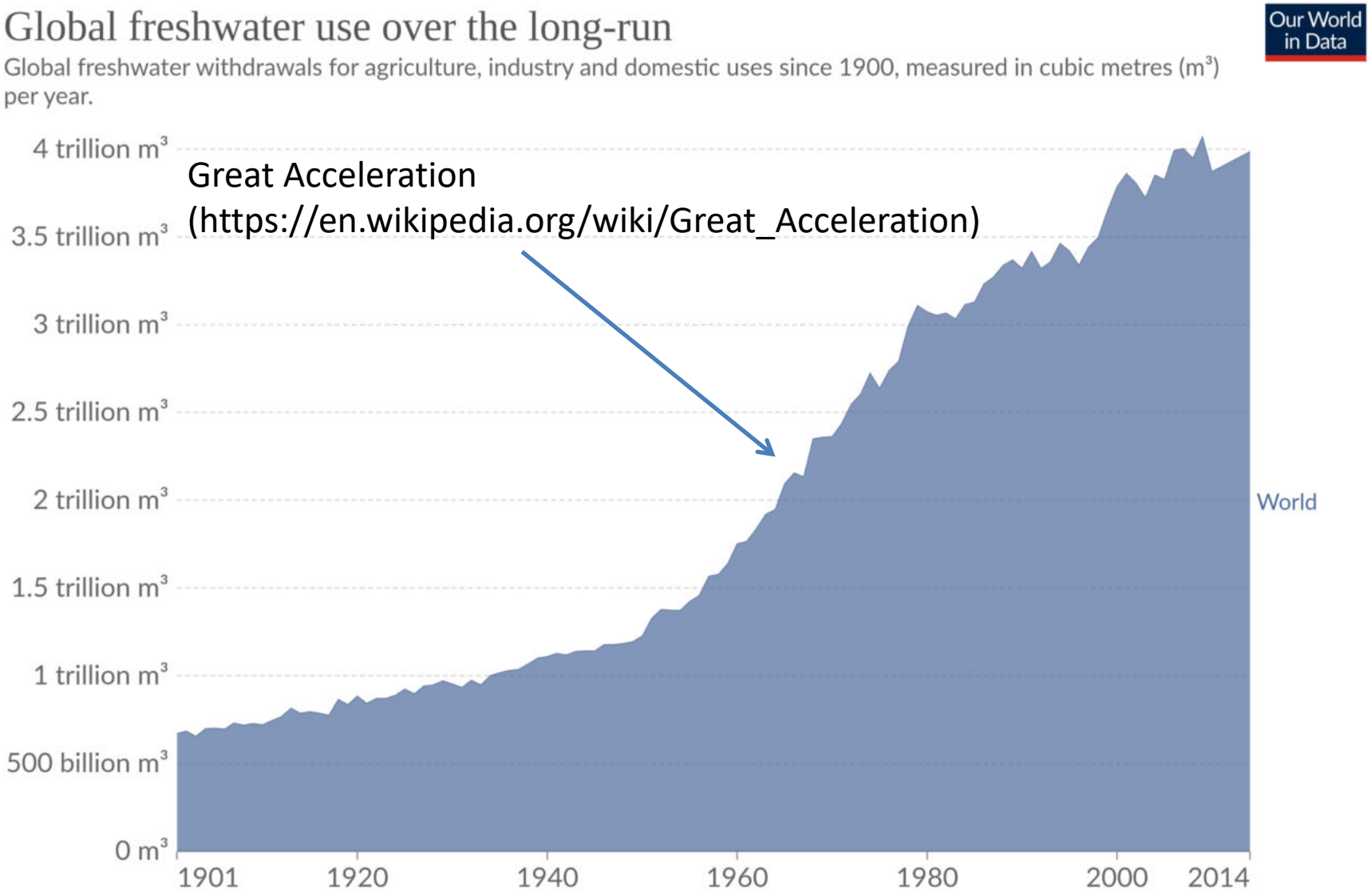
How much water do we have?



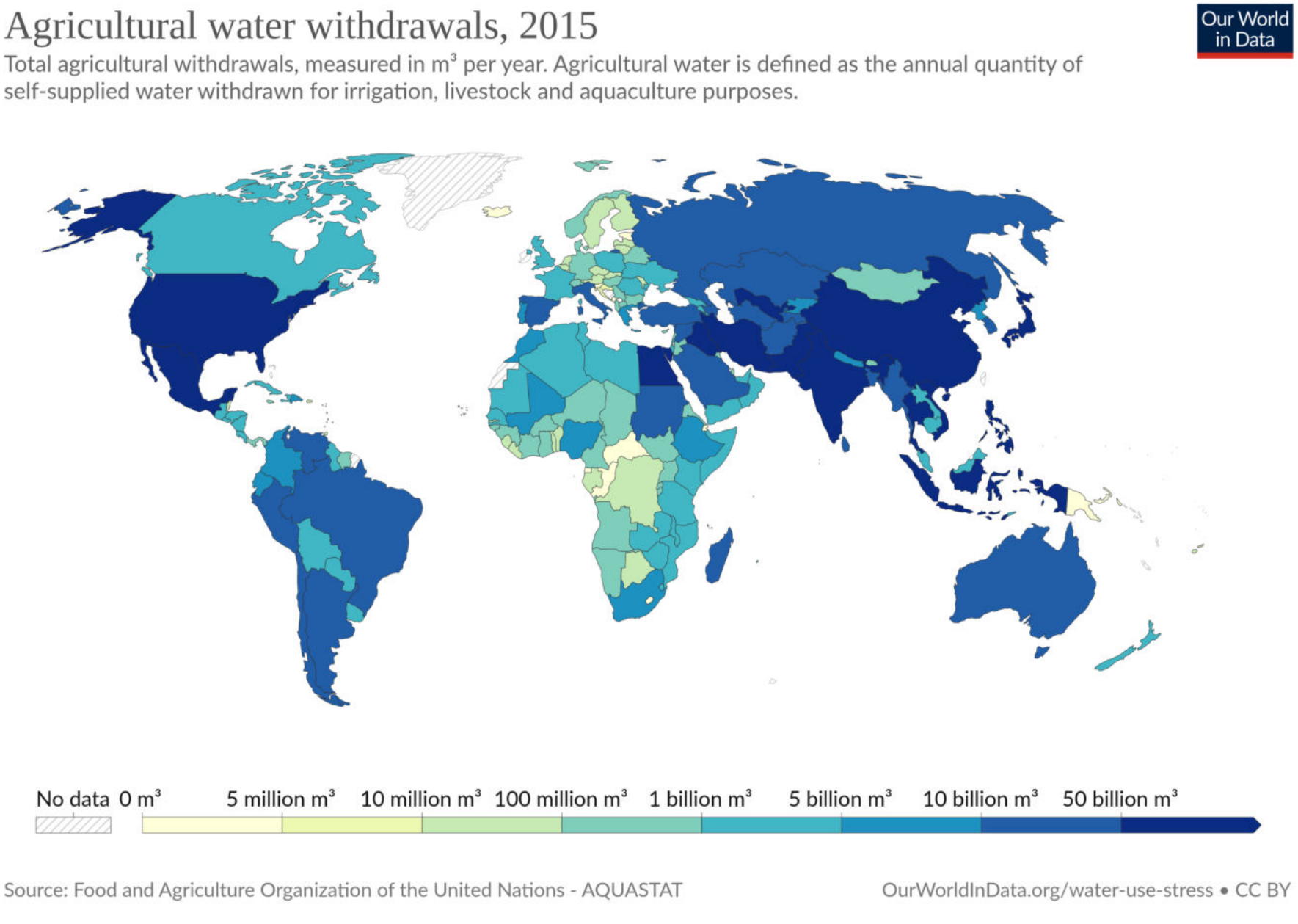
Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.

From http://ga.water.usgs.gov/edu/earthwherewater.html

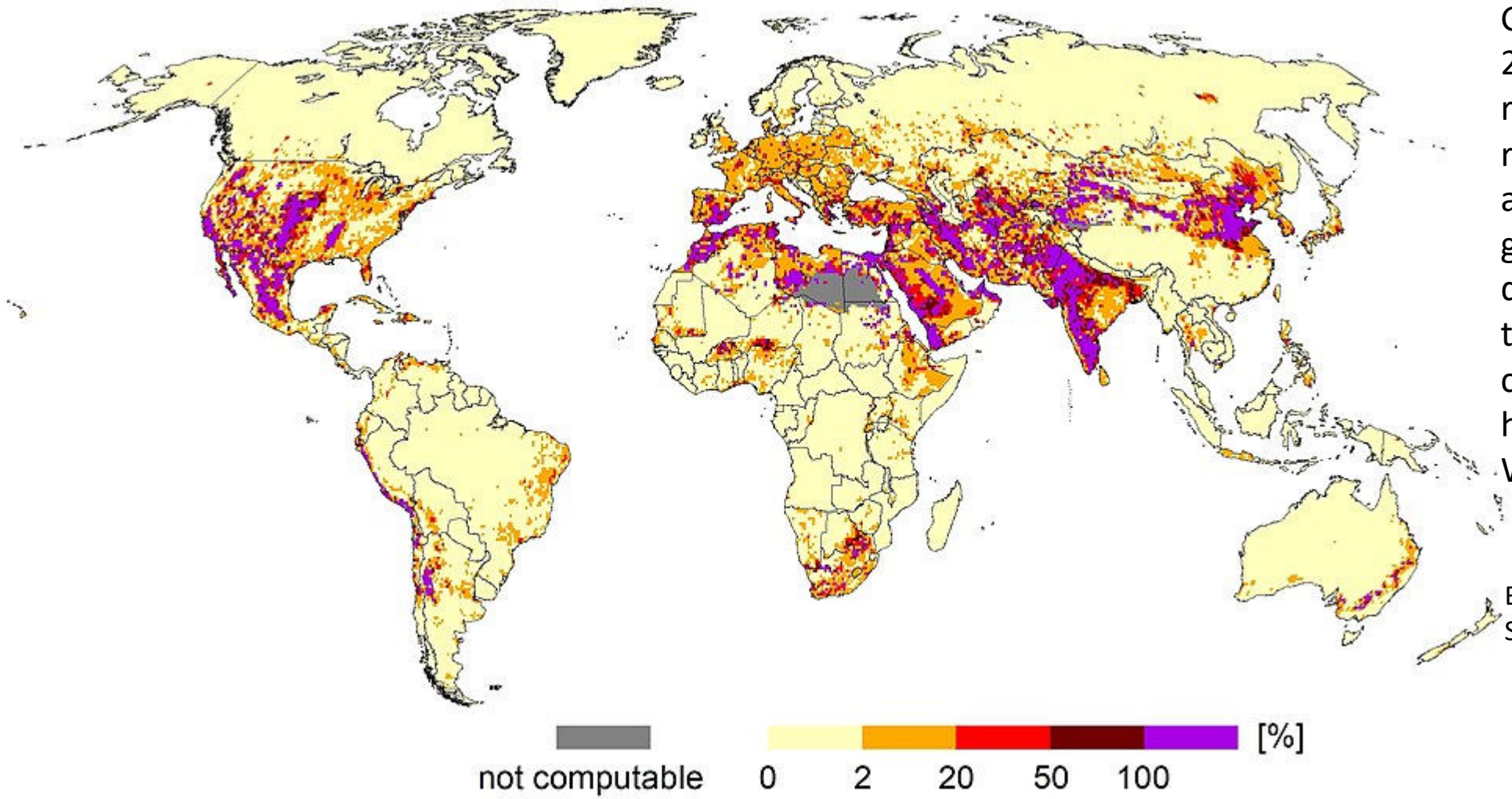
Global water uses



Global water uses

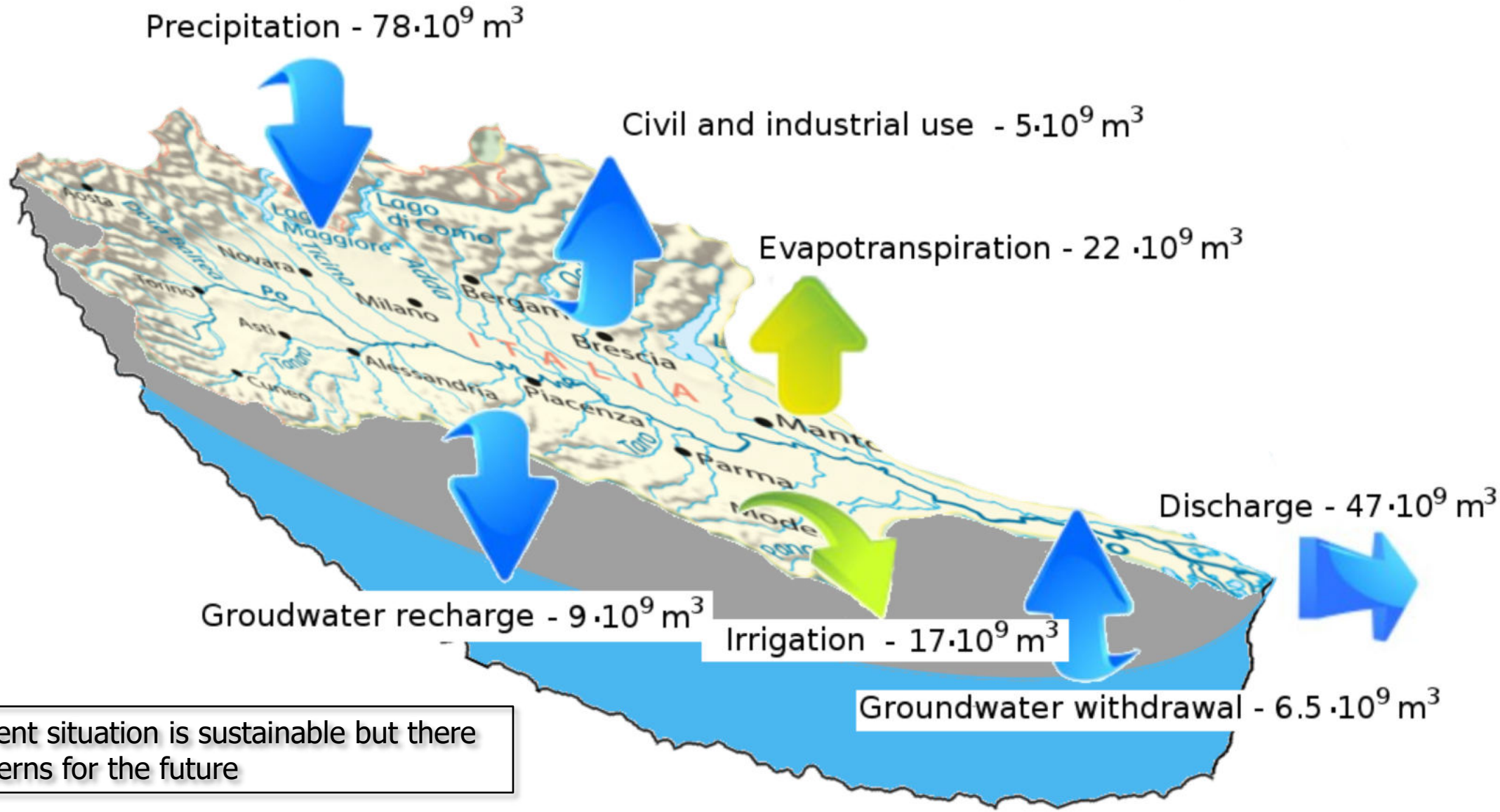


Groundwater stress



Groundwater withdrawals in 2010 in percent of renewable groundwater resources. Purple regions are likely to suffer from groundwater depletion, with declining groundwater tables. Values were computed by the global hydrological model WaterGAP.

Are these uses sustainable? The case of Po River (Italy)



The current situation is sustainable but there are concerns for the future

Are these uses sustainable?

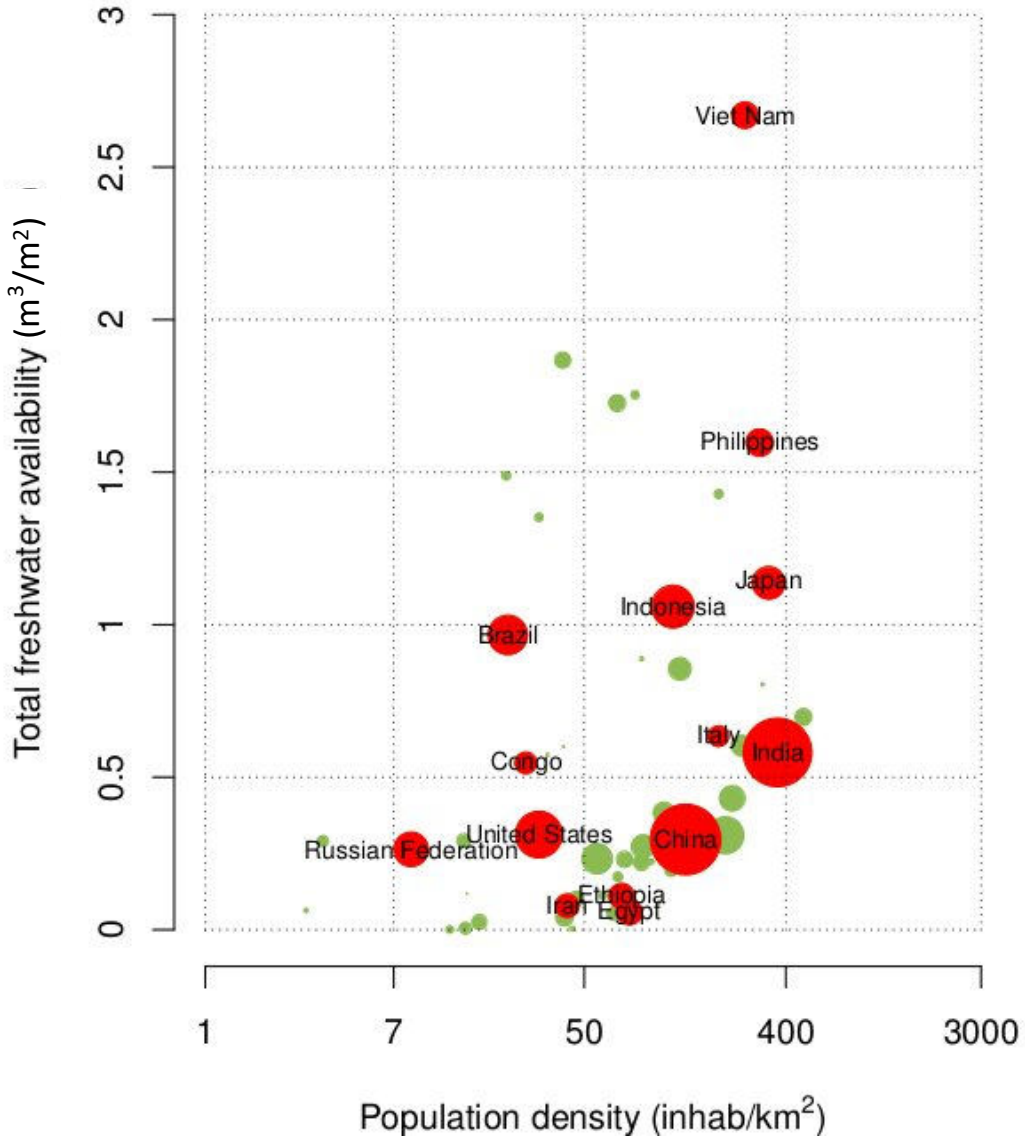
The size of the symbols is proportional to total population of the country.

Question: is freshwater availability enough to satisfy these countries?

The answer depends on A and B:

A: Percentage of freshwater availability that can be effectively withdrawn

B: Water needs for human use.

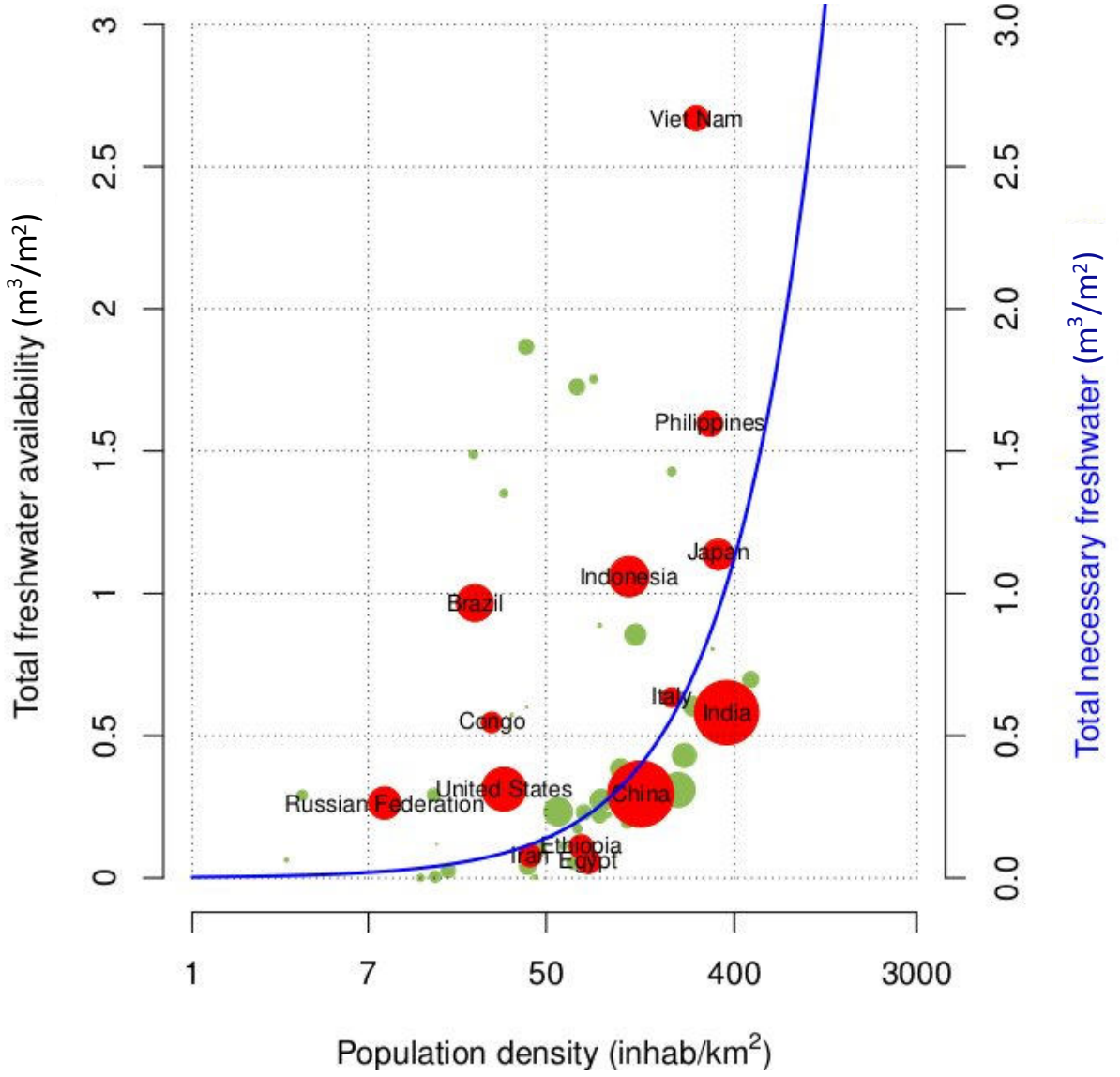


Are these uses sustainable?

The Italian picture:

Italy is efficient in exploiting water and has moderate water needs

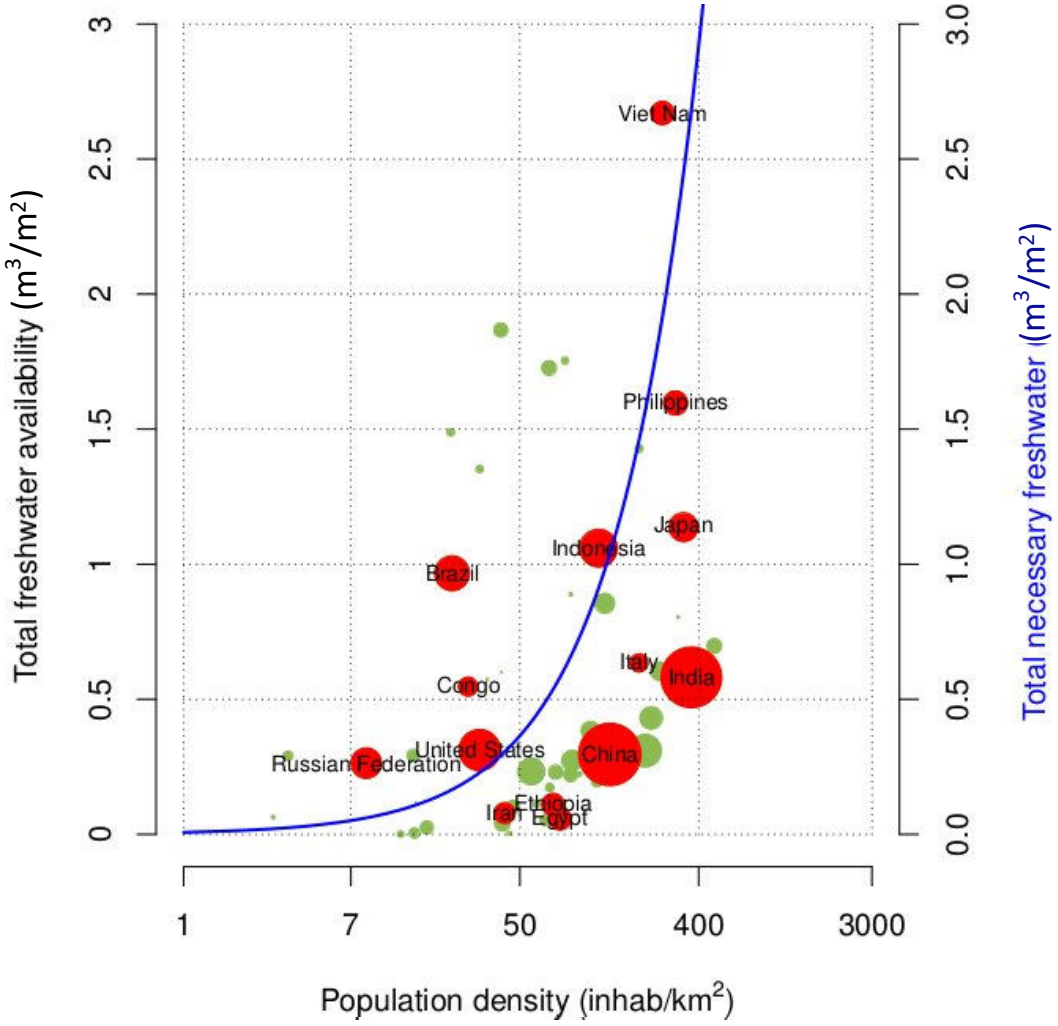
The situation of Italy is borderline and reflects limited resilience to ensure sustainability in the future



Are these uses sustainable?

What happens if the water use is less efficient?

Countries located below the blue line need to be very efficient in water use.



Multi-year droughts: an emerging threat to sustainability

The drought of Capetown (2015-2018)

- From 2014 to 2017 a multi-year drought hit Cape Town, after some years of precipitation abundance.
- The drought induced a critical situation in Cape Town.
- Restrictions were introduced to water use.
- The crisis had relevant societal implications.

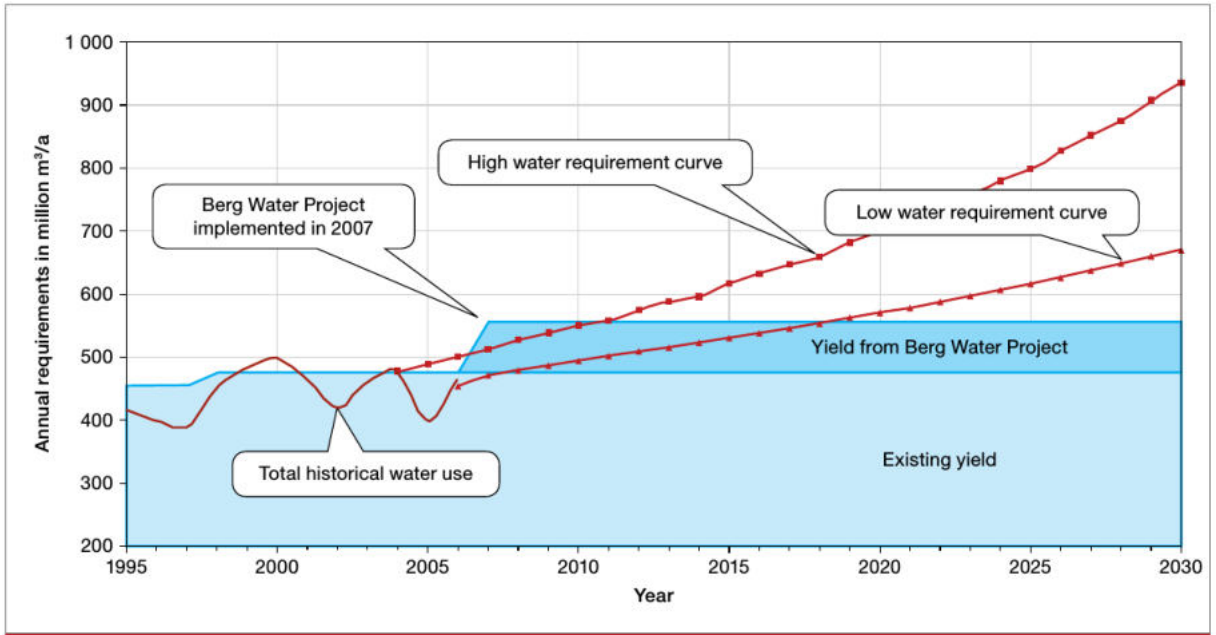


Figure 2: Comparison of historical water requirement, and a high and a low future water requirement scenario, with the available yields from the WCWSS (Figure E1, Summary Report 2007, page ii – redrawn for clarity)

Water balance for the water supply system of Cape Town as depicted by a master plan proposed in 2007

From: Muller, M. (2017). Understanding the origins of Cape Town's water crisis. Civil Engineering= Siviele Ingenieurswese, 2017(v25i5), 11-16.

Multi-year droughts

The drought of California (2011-2017)

- During 2011-2017 California was hit by a long drought that looks unprecedented in the available observation period.
- The impact of the drought was massive. About 102 millions of trees were lost.
- The drought was caused by an unusual circulation pattern in the atmosphere.
- In February 2017 a long period of rainfall closed the sequence of dry years.

By National Drought Mitigation Center - http://www.motherjones.com/blue-marble/2014/08?page=1, Public Domain, https://commons.wikimedia.org/w/index.php?curid=37336636

Multi-year droughts

The Millenium Drought in Australia (2001-2009)

- The “Millenium Drought” occurred in Australia from 2001 to 2009. It is considered the most devastating drought of the modern Australian society.
- During 1996 and 1997 rainfall was below average. From 2001 precipitation was very low until 2009, with 2006 being the driest year.
- Studies have estimated that the return period of the Millenium Drought may be higher than 1000 years. It is interesting to note that Australia already suffered from multi-year droughts in the past.
- In this case as well, it seems that the drought was induced by an anomalous atmospheric circulation pattern.
- During the drought the deficit in precipitation (-11%) has been amplified 4 times in the river discharge (-46%). The reasons for such amplification are not yet known.

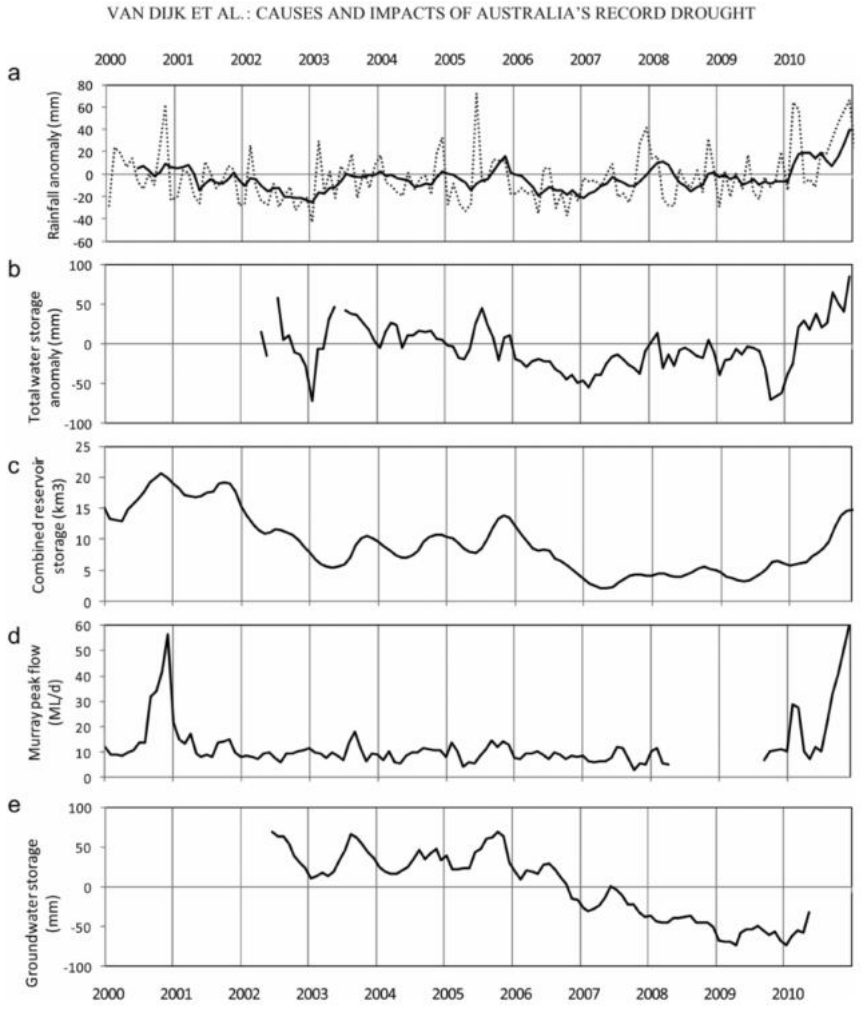
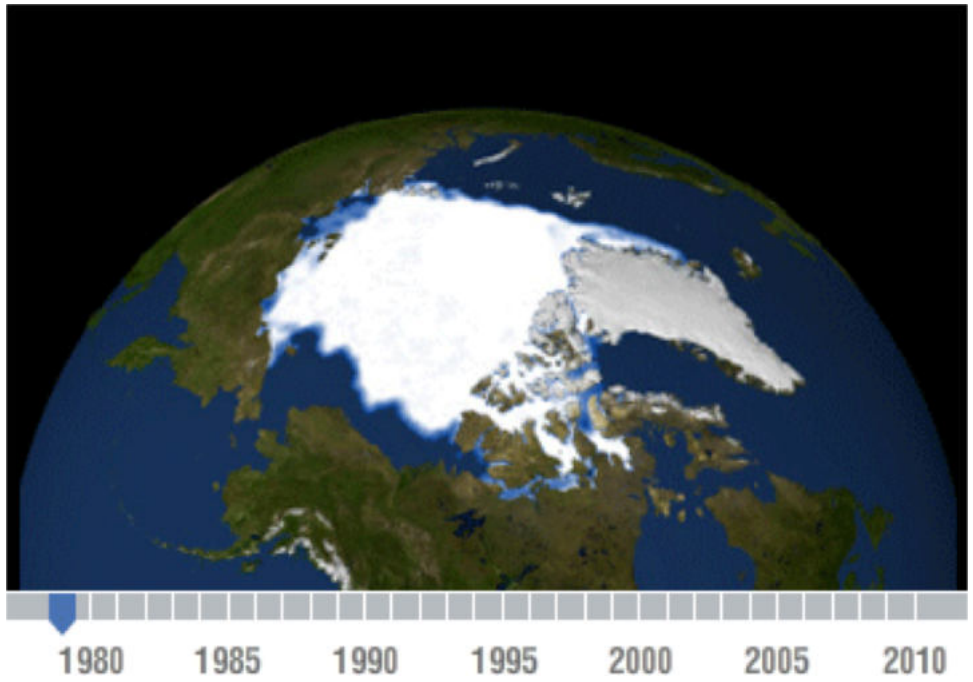
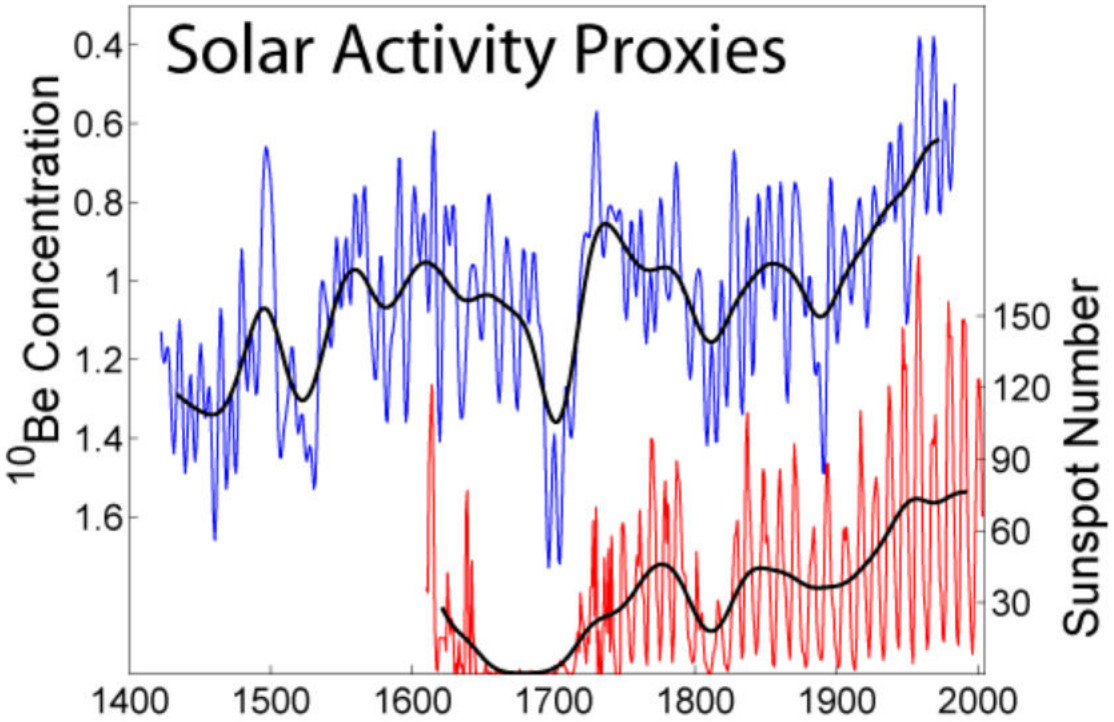


Figure 8. Propagation of the meteorological drought through the hydrological cycle in the MDB: (a) monthly rainfall anomalies (dotted) and 6 month running average (solid); (b) GRACE satellite-observed average monthly terrestrial water storage; (c) combined storage in public reservoirs; (d) daily peak flow by for each month in the Murray River at Wentworth; and (e) estimated MDB groundwater storage.

Are these uses sustainable in the face of climate change and increasing population?





Climate change is potentially much influential

Conclusions

- Hydrology is a young science; many of the processes taking place in the water cycle are still not known.
- To assess water resources sustainability we need a better understanding of hydrology and its linkages with relevant processes.
- Focused research is needed to address the world water problems. Water is a priority!
- Increasing water demands, climate change , long term droughts are concurrent factors threatening water security.
- Everyone of us needs to be better educated about water. Only with an increasing and public awareness of water dynamics we can improve our efficiency in planning water uses. Please help us to spread the awareness of water knowledge.


Thank you!

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