Fundamentals on Environment and Sustainability

WATER

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February 12th, 2025

The origin of water

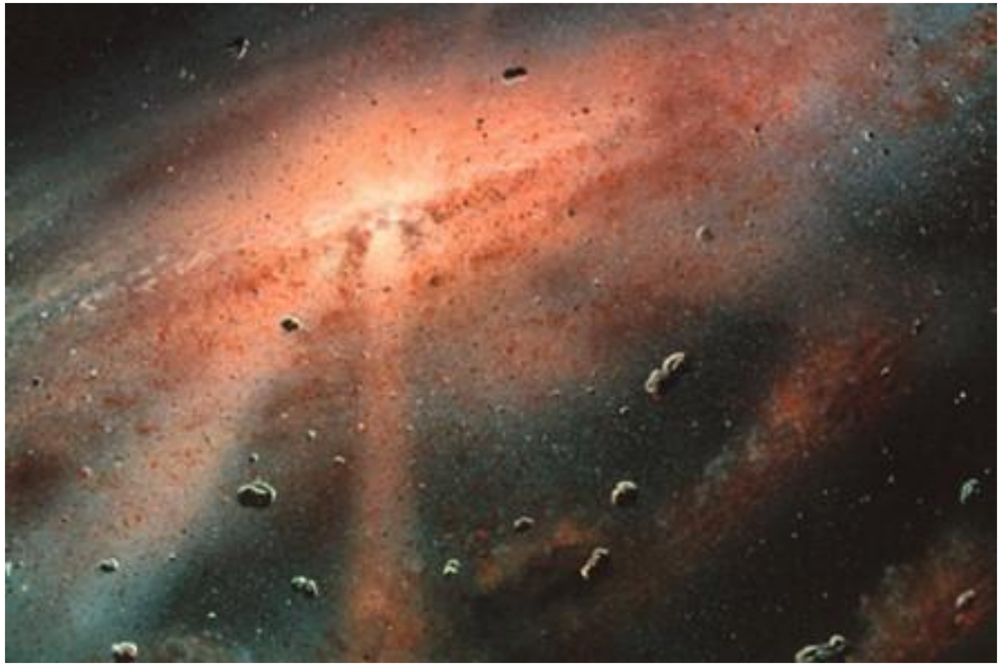
There are three main theories about the origin of water on Earth

(Gleick. P, 2023, The Three Ages of Water):

1. **Solar Nebula Theory. Water has been here the whole time:**

Our solar system was formed around 4500 million years ago from a huge cloud of interstellar gas and dust that slowly condensed and combined into the sun and planets.

The abundance of hydrogen and oxygen in that primordial cloud guaranteed that water would be present throughout the solar system, including in the swirling gas and dust that became Earth.



(https://astrobiology.nasa.gov/news/a-nebular-origin-of-earths-water/)

The origin of water

There are three main theories about the origin of water on Earth

(Gleick. P, 2023, The Three Ages of Water):

2. Dry Earth/Wet Asteroid Theory

Water was brought to Earth by collisions with water-rich bodies formed in the colder outer reaches of the solar system

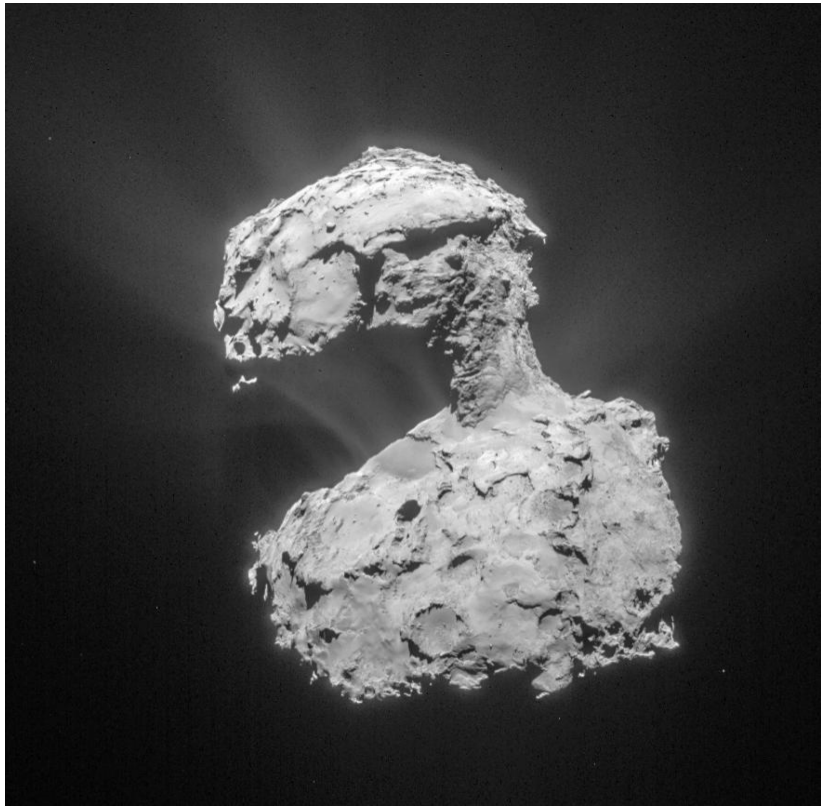
https://www.sciencenews.org/article/how-did-earth-get-its-water

The origin of water

There are three main theories about the origin of water on Earth

(Gleick. P, 2023, The Three Ages of Water):

3. Wet Comet Theory



A third hypothesis is that Earth has been systematically bombarded since creation by water-carrying comets, bit by bit bringing the water we see here today

https://www.sciencealert.com/earth-s-water-didn-t-just-come-from-comets-says-new-study

https://science.nasa.gov/solar-system/comets/nasa-led-team-links-comet-water-to-earths-oceans/

The importance of water

Life as we know it requires **WATER** (although we only have one sample...).

In some organisms, up to 90% of their body weight comes from water [(1)].

Up to 60% of the human adult body is water [(1)].

The human brain and heart are composed of 73% water, and the lungs are about 83% water. [(2)]

The skin contains 64% water, muscles and kidneys 79%, and even the bones are watery: 31%. [(2)]

(1) https://www.usgs.gov/special-topics/water-science-school/

(2) Mitchell, H.H., Hamilton, T.S., Steggerda, F.R., and Bean, H.W., 1945, The chemical composition of the adult human body and its bearing on the biochemistry of growth: Journal of Biological Chemistry, v. 158, issue 3, p. 625-637.

The importance of water

WE NEED WATER FOR:

Maintenance of ecosystems

Water supply

Food production

Industrial processes

Energy production






The importance of water

WE NEED WATER FOR:

Ecosystem maintenance:

Ecosystems supply, purify and protect freshwater resources

Freshwater ecosystems mitigate the effects of floods and drought

Biodiversity in freshwater ecosystems is in danger

Human impact on ecosystems is affecting water quantity and quality

Surface water area is changing fast

(Source: https://www.unwater.org/water-facts/water-and-ecosystems)

The importance of water

WE NEED WATER FOR:

Ecosystem maintenance:

Freshwater ecosystems must be protected and losses reversed.

Nature-based solutions to climate change are essential.

‘Ecosystem services’ can contribute to wastewater treatment.

Wastewater can help rejuvenate ecosystems.

Data is key.

Coordination across sectors and borders is vital.

(Source: https://www.unwater.org/water-facts/water-and-ecosystems)

The importance of water

WE NEED WATER FOR:

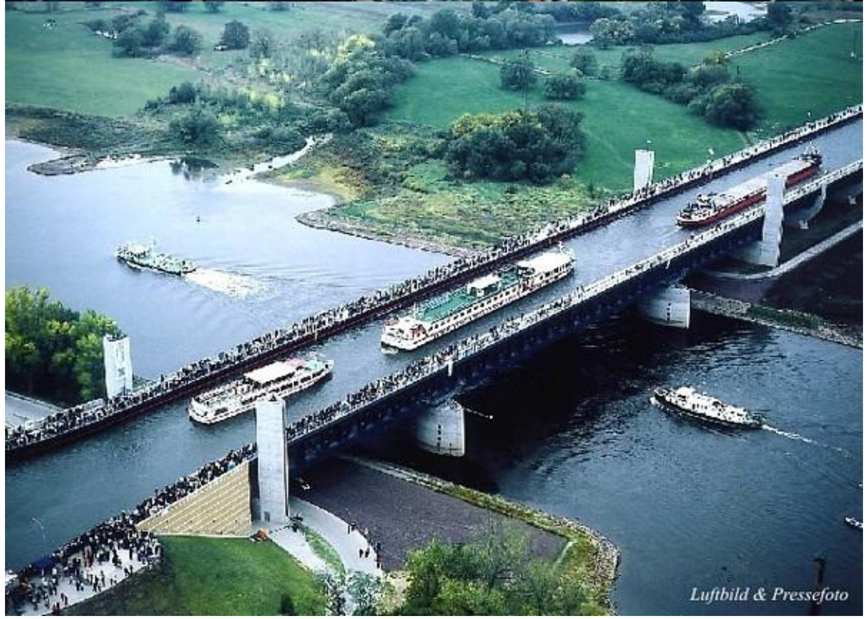
Agriculture is responsible for ~70% of freshwater use

Urban supply ~ 20%

Industry ~10%

Energy production

Transport (sea but also canals)

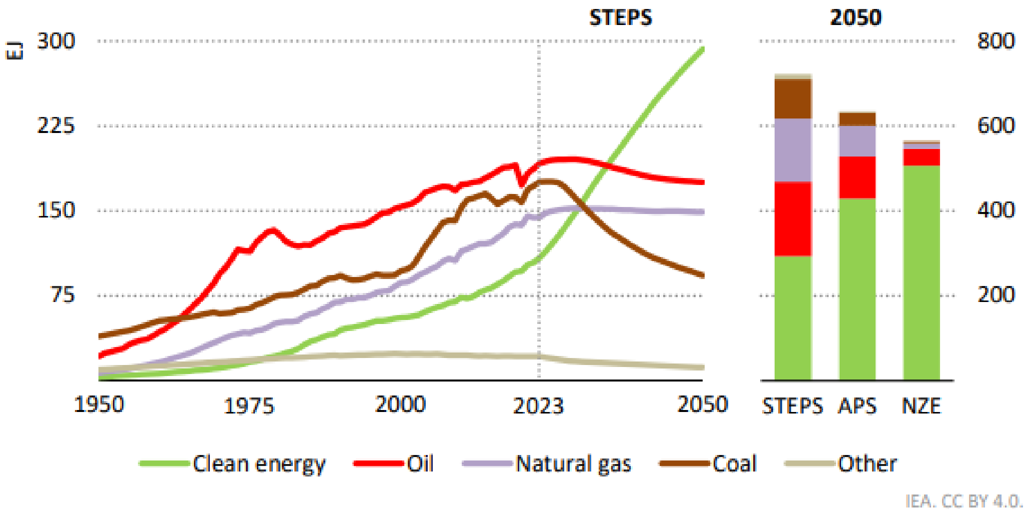


The importance of water

WE NEED WATER FOR:

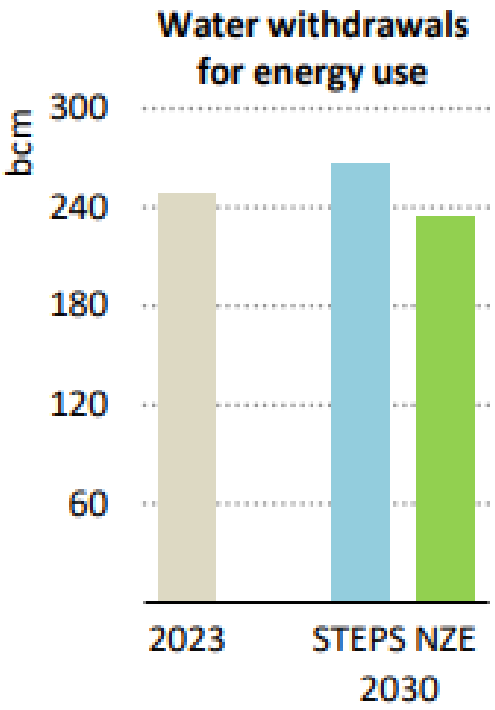
ENERGY PRODUCTION

Figure 1.1 ⊳ Global energy mix by scenario to 2050



STEPS, a scenario based on current policy settings, sees clean energy poised for huge growth, while coal, oil and natural gas each reach a peak by 2030 and then start to decline

Notes: EJ = exajoules; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; NZE = Net Zero Emissions by 2050 Scenario. Oil, coal and natural gas refer to unabated uses as well as non-energy use. Clean energy includes renewables, modern bioenergy, nuclear, abated fossil fuels, low-emissions hydrogen and hydrogen-based fuels. Other includes traditional use of biomass and non-renewable waste.



(World Energy Outlook 2024 – International Energy Agency)

The importance of water

WE NEED WATER FOR:

Energy production:

The WATER-ENERGY interdependence is highly significant and is expected to intensify rapidly due to the water needs of the energy sector and the energy needs of the water sector.

Water is essential at all stages of energy production, not only in power plants but also for the production of fossil fuels and biofuels. The energy sector is responsible for 10% of global water withdrawal.

In 2014, about 4% of the energy produced globally was used to extract, distribute, and treat water or wastewater.

(World Energy Outlook 2016 – International Energy Agency)

The importance of water

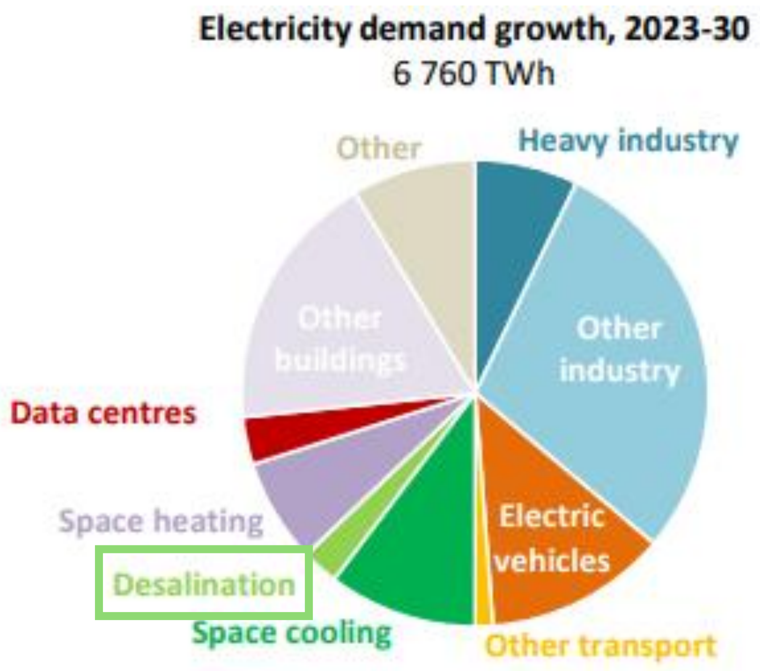
WE NEED WATER FOR:

Energy production

By 2040, the amount of energy used in the water sector could double: the increase in desalination (Middle East and Africa) as well as the growing need for water and wastewater treatment will be key determining factors.

By 2040, in the Middle East, 16% of energy will be allocated to water distribution.

(World Energy Outlook 2016 – International Energy Agency)



(World Energy Outlook 2024 – International Energy Agency)

WATER

BUT WATER IS ALSO RELATED TO SEVERE PROBLEMS

Too much water...

Too less water...

Pollution

WATER

BUT WATER IS ALSO RELATED TO SEVERE PROBLEMS

Every child of the Western religions of Judaism, Christianity, and Islam hears the story of the **Great Flood sent by God.**

Too much water...

What most of us didn't learn as children is that the origins of this story predate the Bible by as much as 2 000 years, appearing in some of the oldest writings recovered from the ruins of more ancient Mesopotamian empires.

(Gleick. P, 2023, The Three Ages of Water)

WATER

But WATER is also related to severe problems

Too less water...

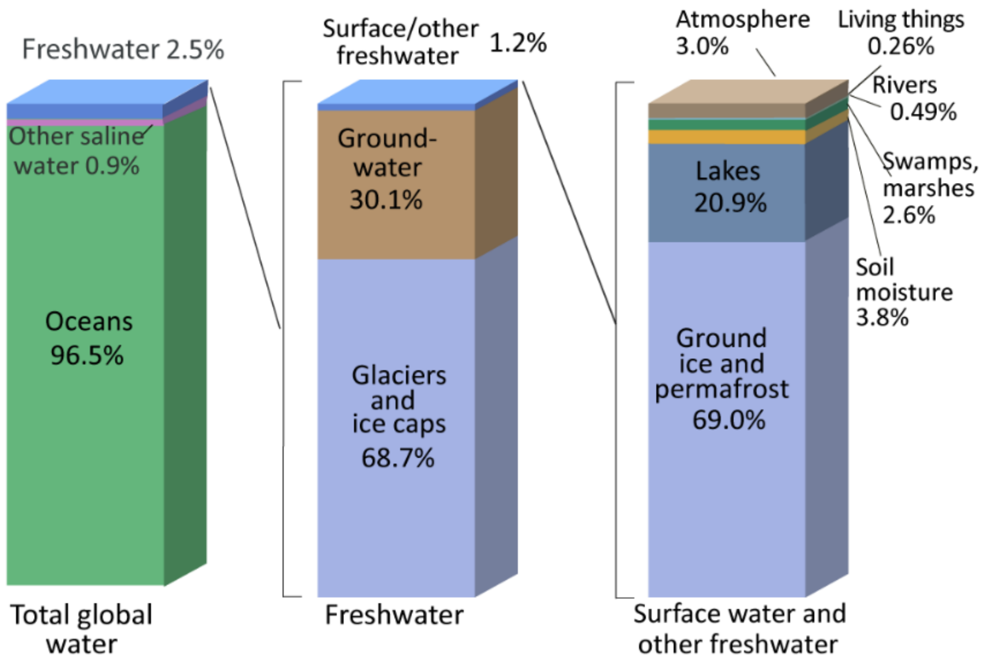
WATER

But WATER is also related to severe problems

Pollution

WATER

WHERE IS THE EARTH'S WATER?



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. (Numbers are rounded).

One estimate of global water distribution
(Percents are rounded, so will not add to 100)

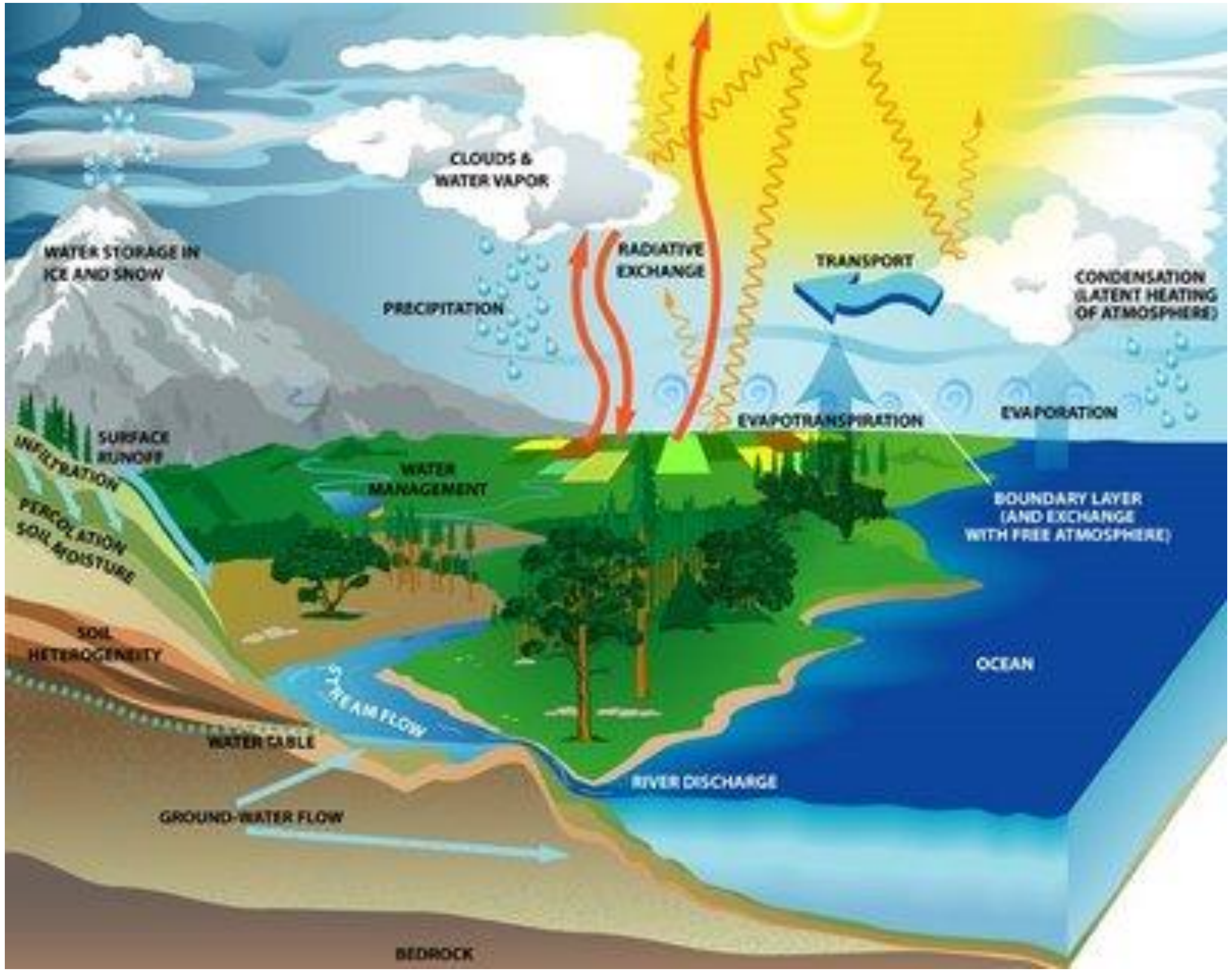
Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	321,000,000	1,338,000,000	--	96.54
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74
Groundwater	5,614,000	23,400,000	--	1.69
Fresh	*2,526,000*	*10,530,000*	*30.1*	*0.76*
Saline	*3,088,000*	*12,870,000*	*--*	*0.93*
Soil Moisture	3,959	16,500	0.05	0.001
Ground Ice & Permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	--	0.013
Fresh	*21,830*	*91,000*	*0.26*	*0.007*
Saline	*20,490*	*85,400*	*--*	*0.006*
Atmosphere	3,095	12,900	0.04	0.001
Swamp Water	2,752	11,470	0.03	0.0008
Rivers	509	2,120	0.006	0.0002
Biological Water	269	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).

https://www.usgs.gov/special-topics/water-science-school/science/where-earths-water

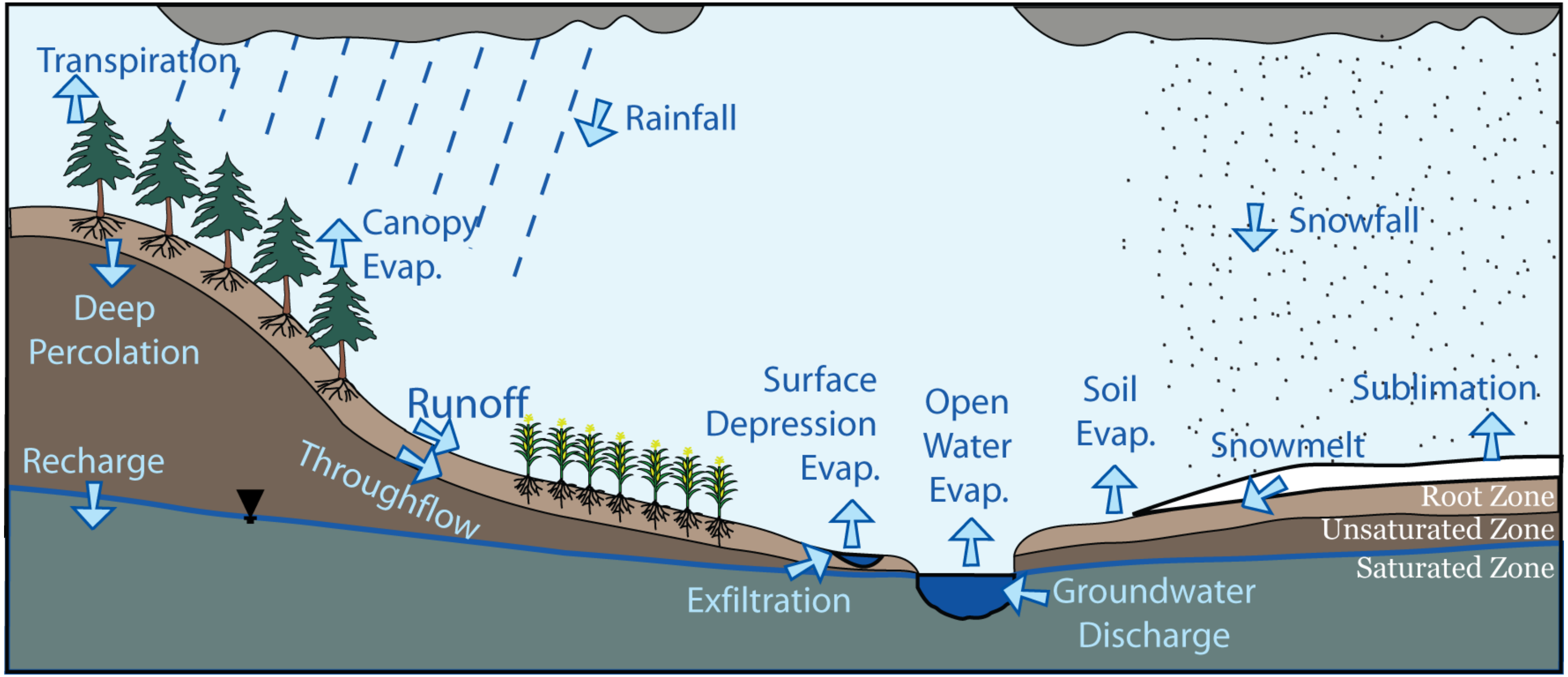
WATER

GLOBAL HYDROLOGICAL CYCLE



WATER

GLOBAL HYDROLOGICAL CYCLE (SCHEMATIC)



WATER

Dry < 20%
Average 20 – 80%
Wet > 80 %

GLOBAL HYDROLOGICAL CYCLE

Precipitation

Varies in time, quantity and intensity.

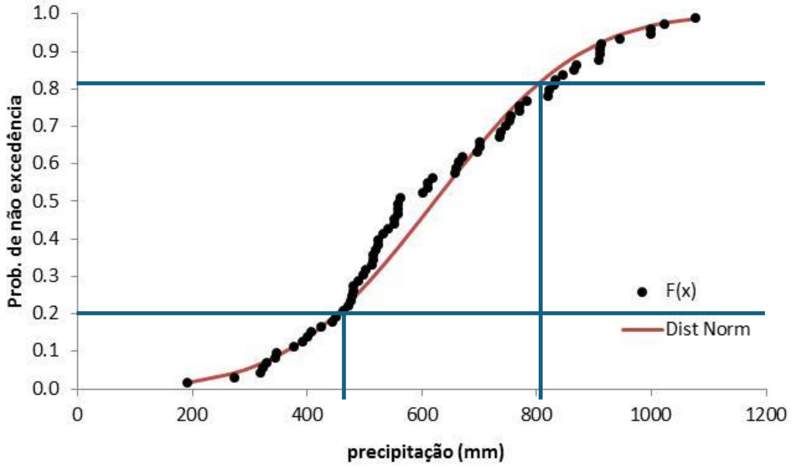
Statistics using measured annual values

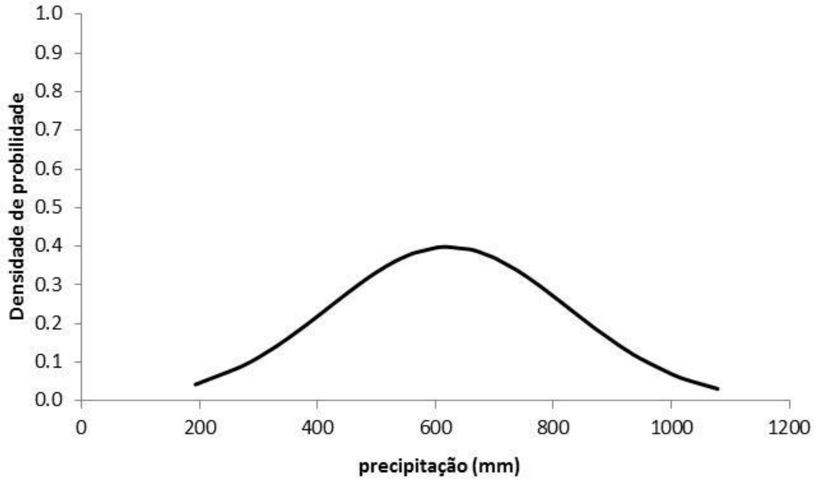
are used to classify (dry/wet/average) hydrological years.

We need long term data do identify trends (min 30 years)

Multiple time scales of analysis:

For water resources management: annual, monthly, daily,
For flood management: hours, minutes

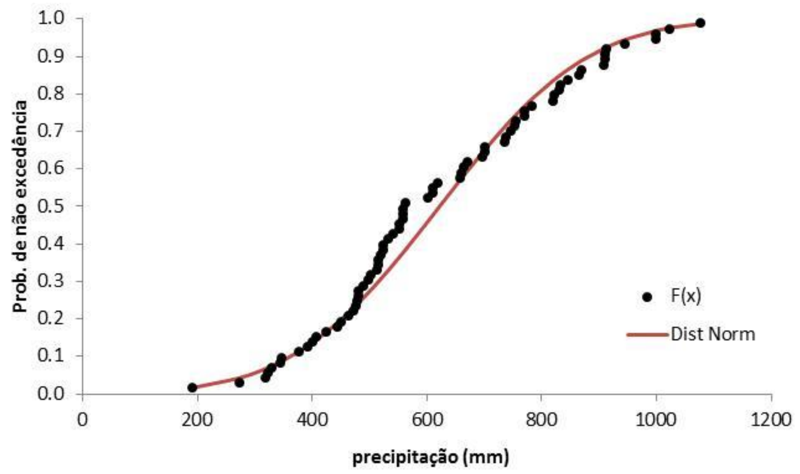




WATER

GLOBAL HYDROLOGICAL CYCLE

Precipitation



Return Period:

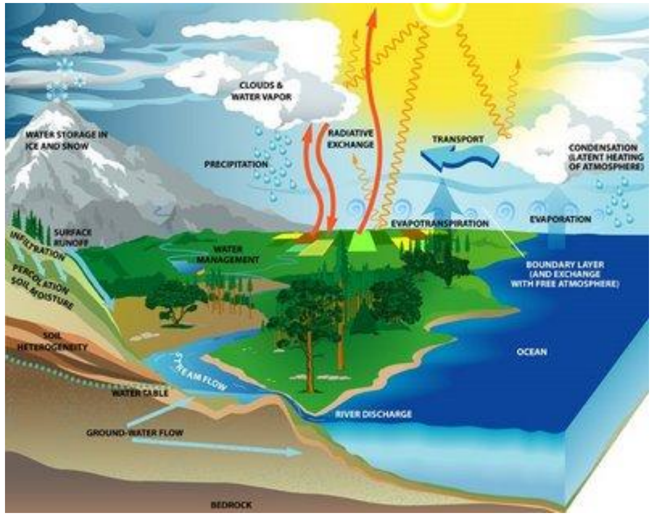
The average number of years required for a given occurrence to repeat is equal to the inverse of the probability of that event occurring in a given year.

$T = \frac{1}{p}$, where p = probability of occurence, and so $T = \frac{1}{1-F(x)}$

The concept of T is generally applied to droughts, floods, intense precipitation and in general, hydrological events

WATER

GLOBAL HYDROLOGICAL CYCLE



Evaporation

Like precipitation it is measured in mm.

Although natural, it is relevant for lake and manmade reservoir management.

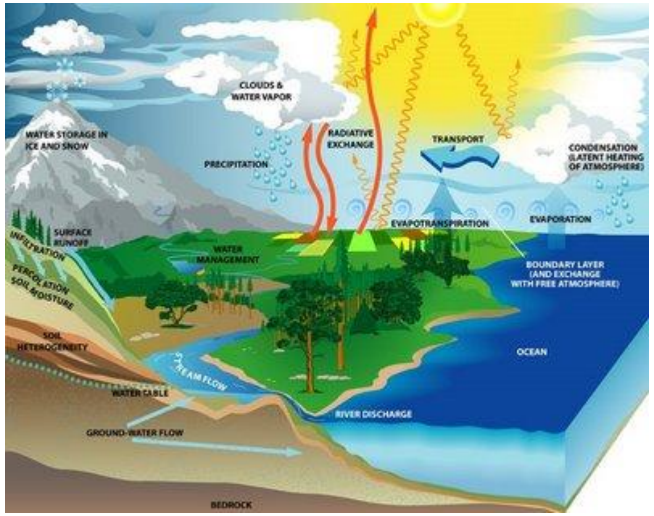
e.g. annual evaporation ~ 1300 mm

from the Alqueva reservoir the evaporation can be 325 × 10^6 m^3,

or 10 % of the total usage volume.

Must be taken into account for reservoir design and management

WATER



GLOBAL HYDROLOGICAL CYCLE

Evapotranspiration

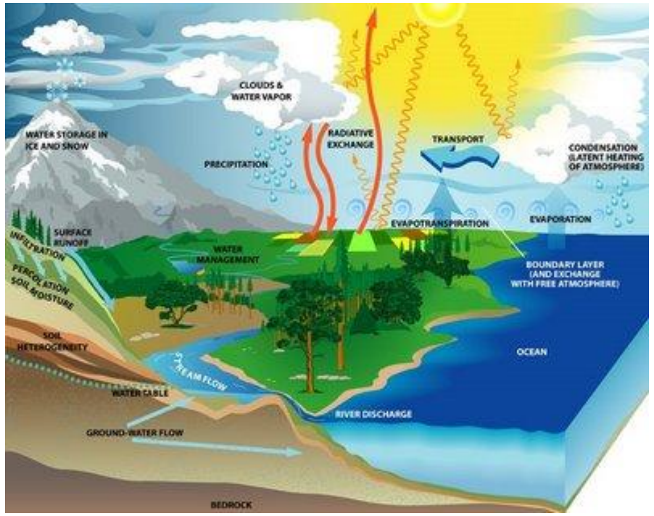
The concept includes evaporation from soil as well as transpiration from vegetation

Is an important part of the hydrographic basin water balance

Its concepts are also used to determine crop irrigation needs

Crop	Water Consumption (m^3/ha/year)
Avocado trees	5600 - 6600
Carob trees	4150
Almond trees	7500 - 7900
Citrus	6400 - 7600
Persimmon trees	6800 - 7200
Fig trees	5500 - 5800
Walnut trees	8600 - 9000
Olive groves	5500 - 6800
Pomegranate trees	6300 - 6500
Table grapes	5600

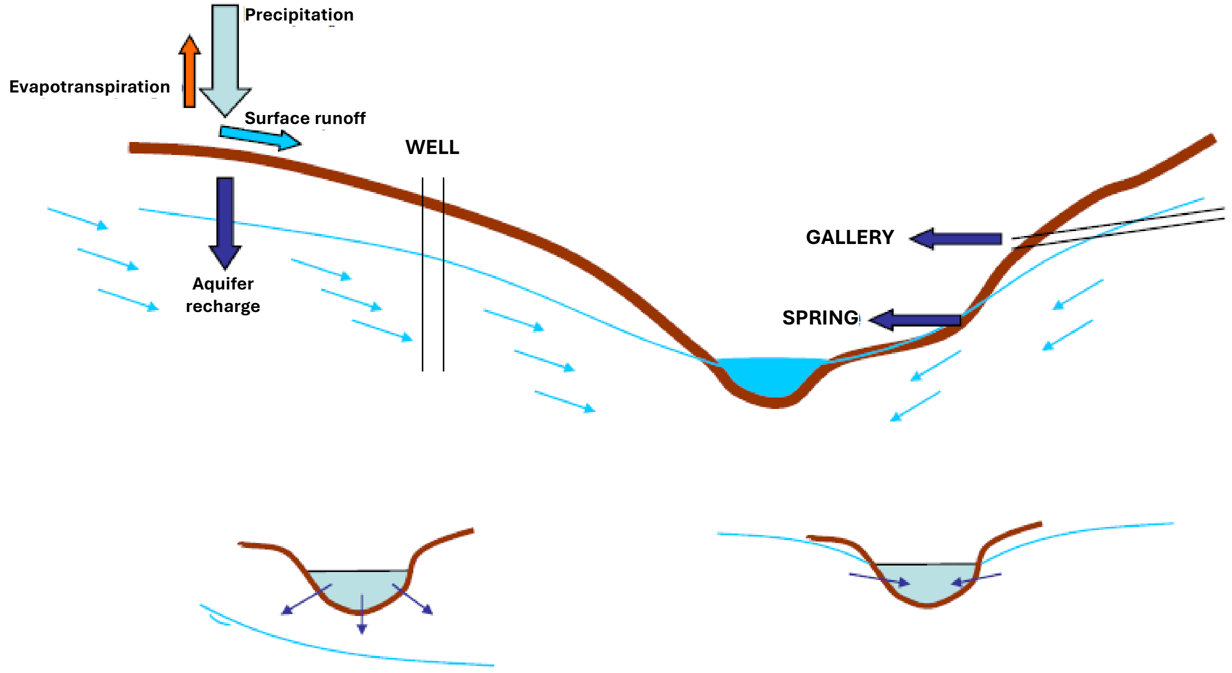
WATER



GLOBAL HYDROLOGICAL CYCLE

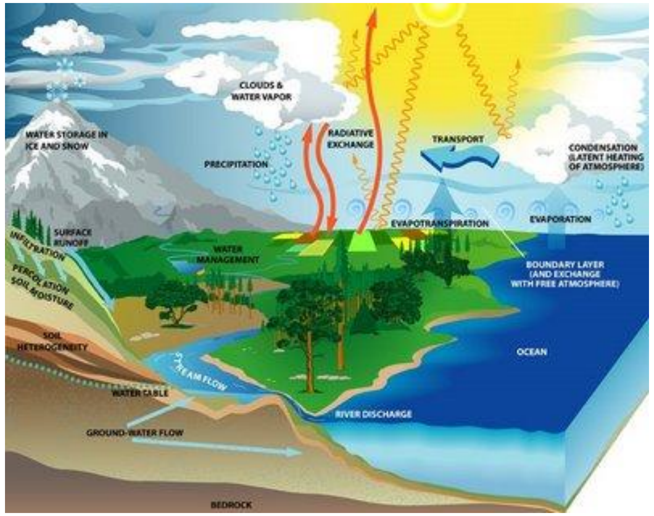
Ground Water flows

Recharge is dependent on precipitation and infiltration



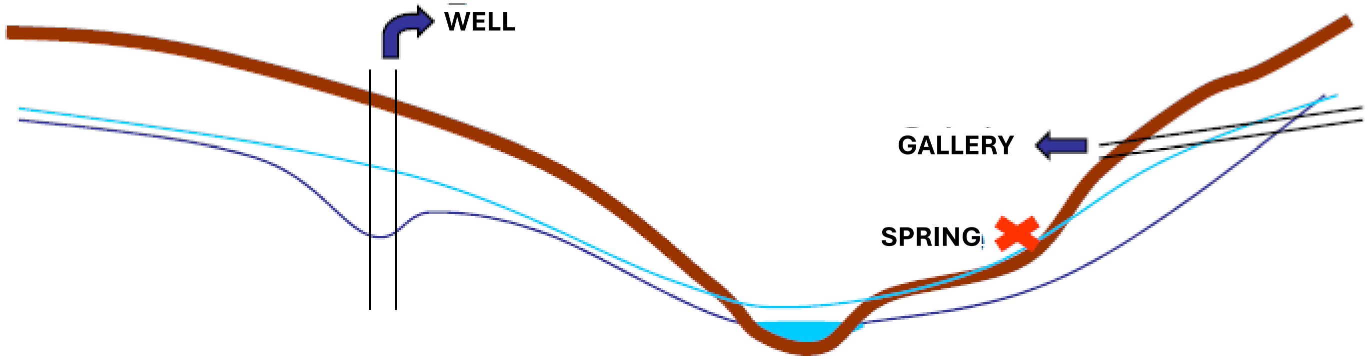
Although represent close to 30% of freshwater, its sustainable use is difficult to achieve as aquifers recharge tends to be very slow, very often lower than withdrawals (unsustainable withdrawals)

WATER



GLOBAL HYDROLOGICAL CYCLE

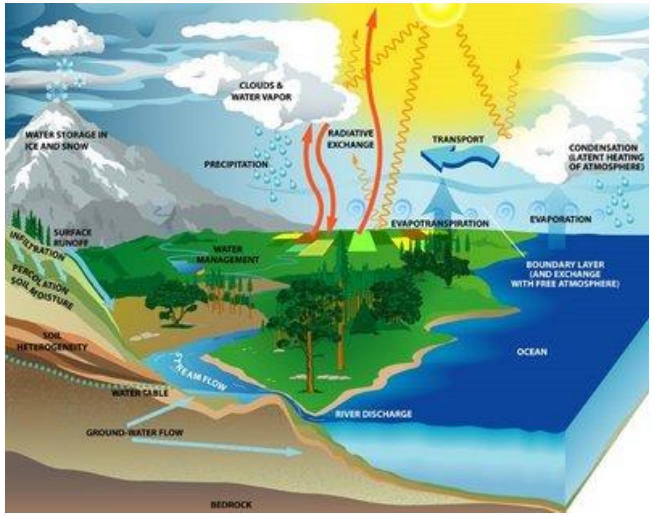
Ground Water flows



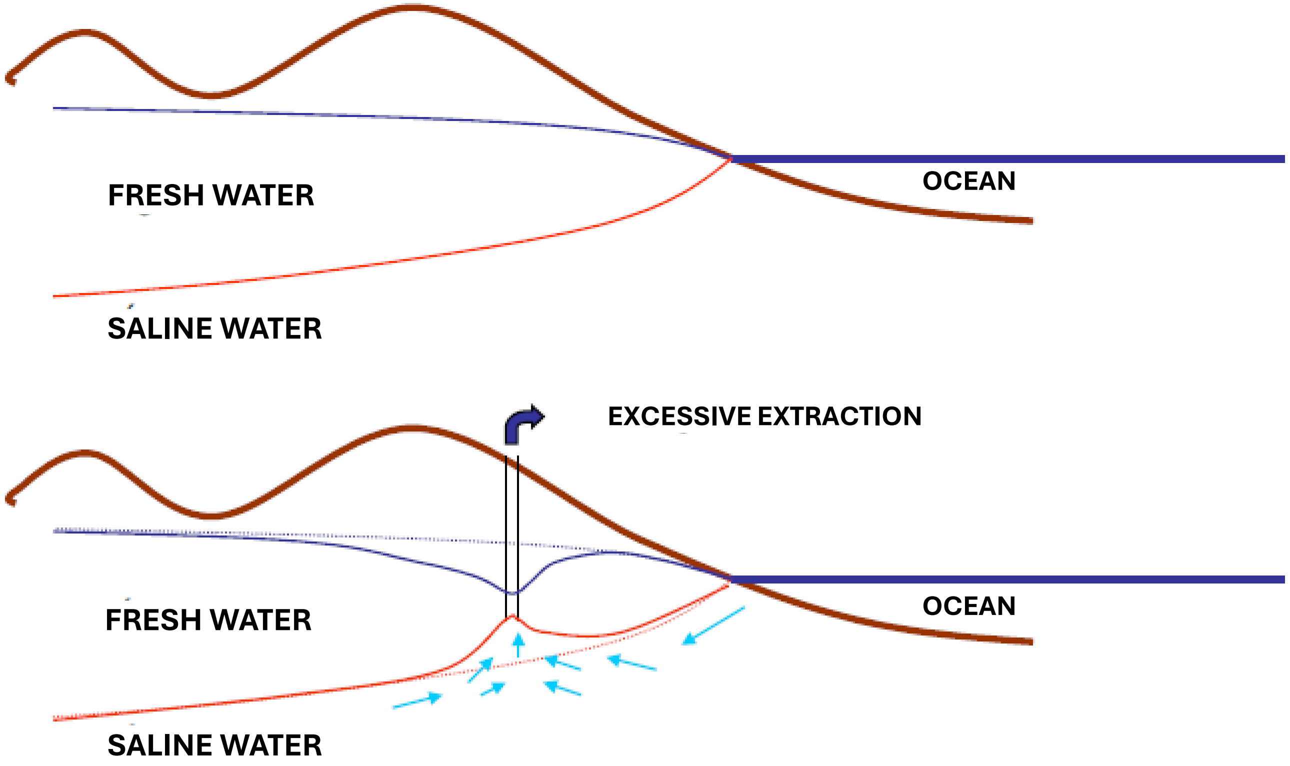
The water level in aquifers is not static and varies with:
the precipitation that occurred, the extraction of groundwater, tidal effects on coastal aquifers, the sudden variation in atmospheric pressure, especially in winter, changes in the flow regime of influent rivers (which recharge aquifers), evapotranspiration, etc.

WATER

GLOBAL HYDROLOGICAL CYCLE



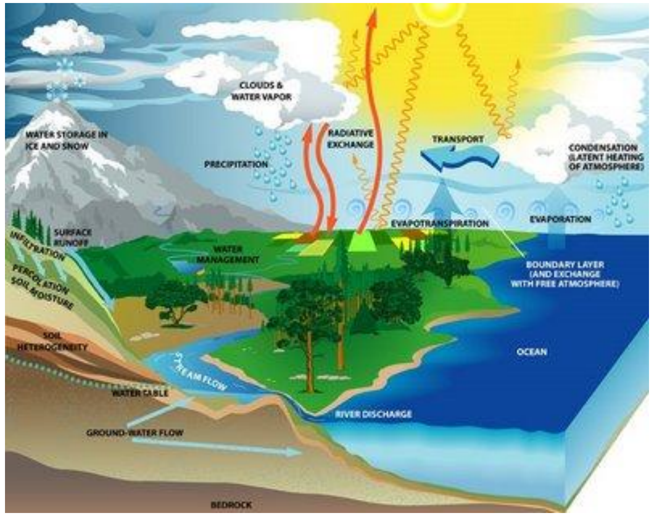
Ground Water flows



The problem of saline intrusion in coastal areas

WATER

GLOBAL HYDROLOGICAL CYCLE

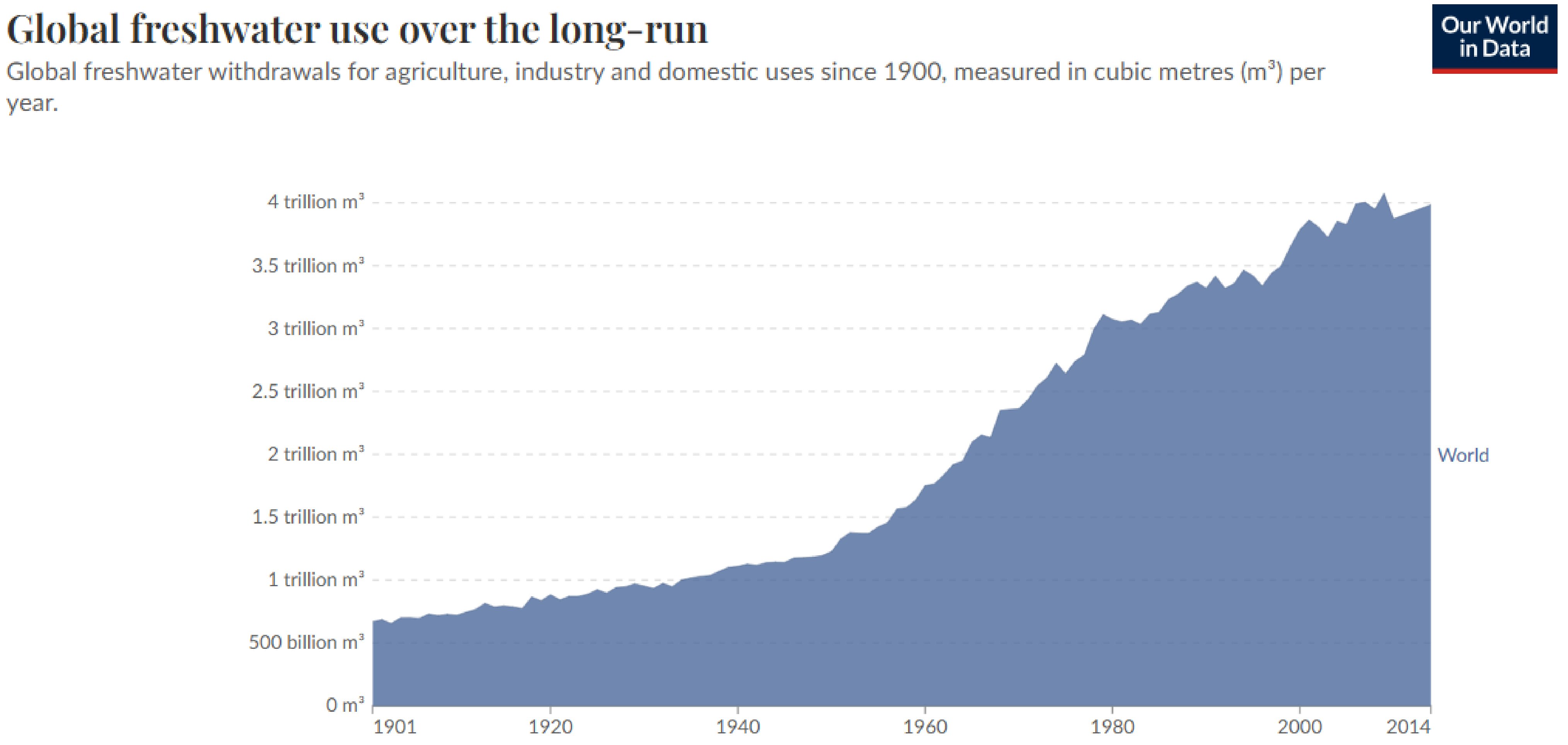


Surface runoff

Rivers, lakes and reservoirs (all can be used as water sources)

All water on the land surface

WATER



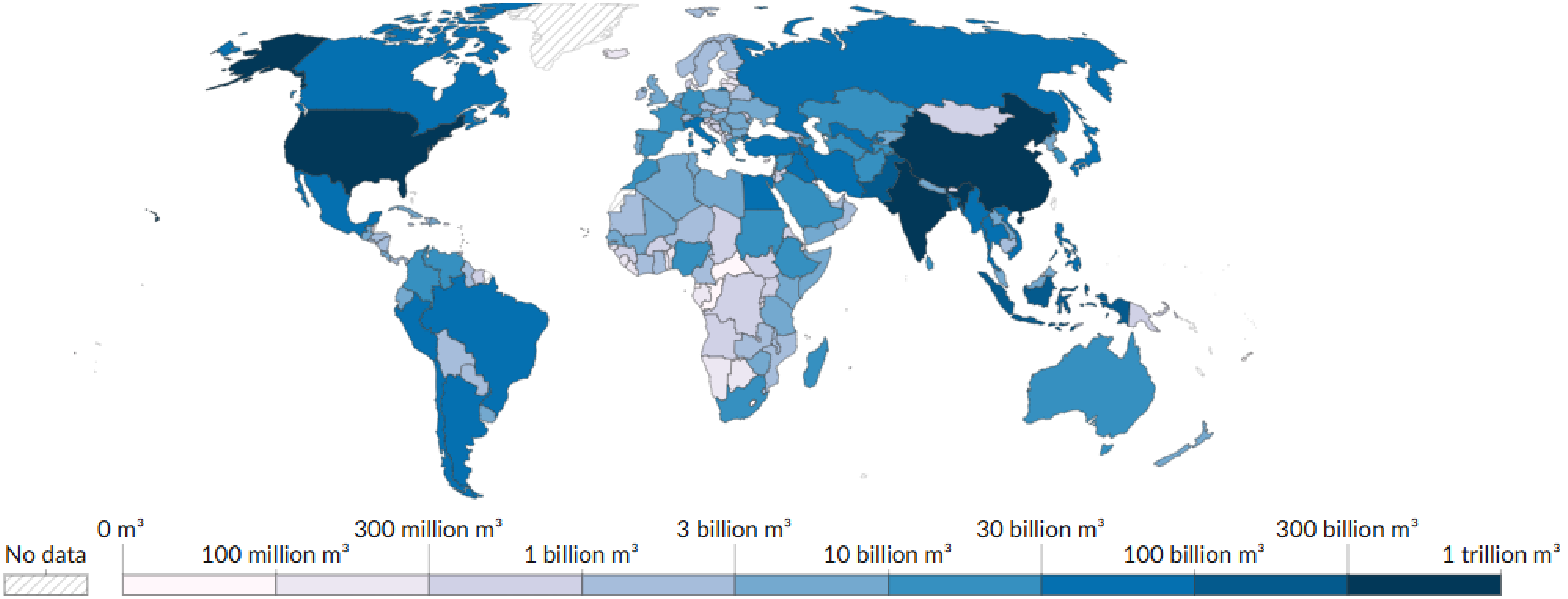
Global freshwater use over the long-run
Global freshwater withdrawals for agriculture, industry and domestic uses since 1900, measured in cubic metres (m³) per year.
Our World in Data
4 trillion m³
3.5 trillion m³
3 trillion m³
2.5 trillion m³
2 trillion m³
1.5 trillion m³
1 trillion m³
500 billion m³
0 m³
1901
1920
1940
1960
1980
2000
2014
World

WATER

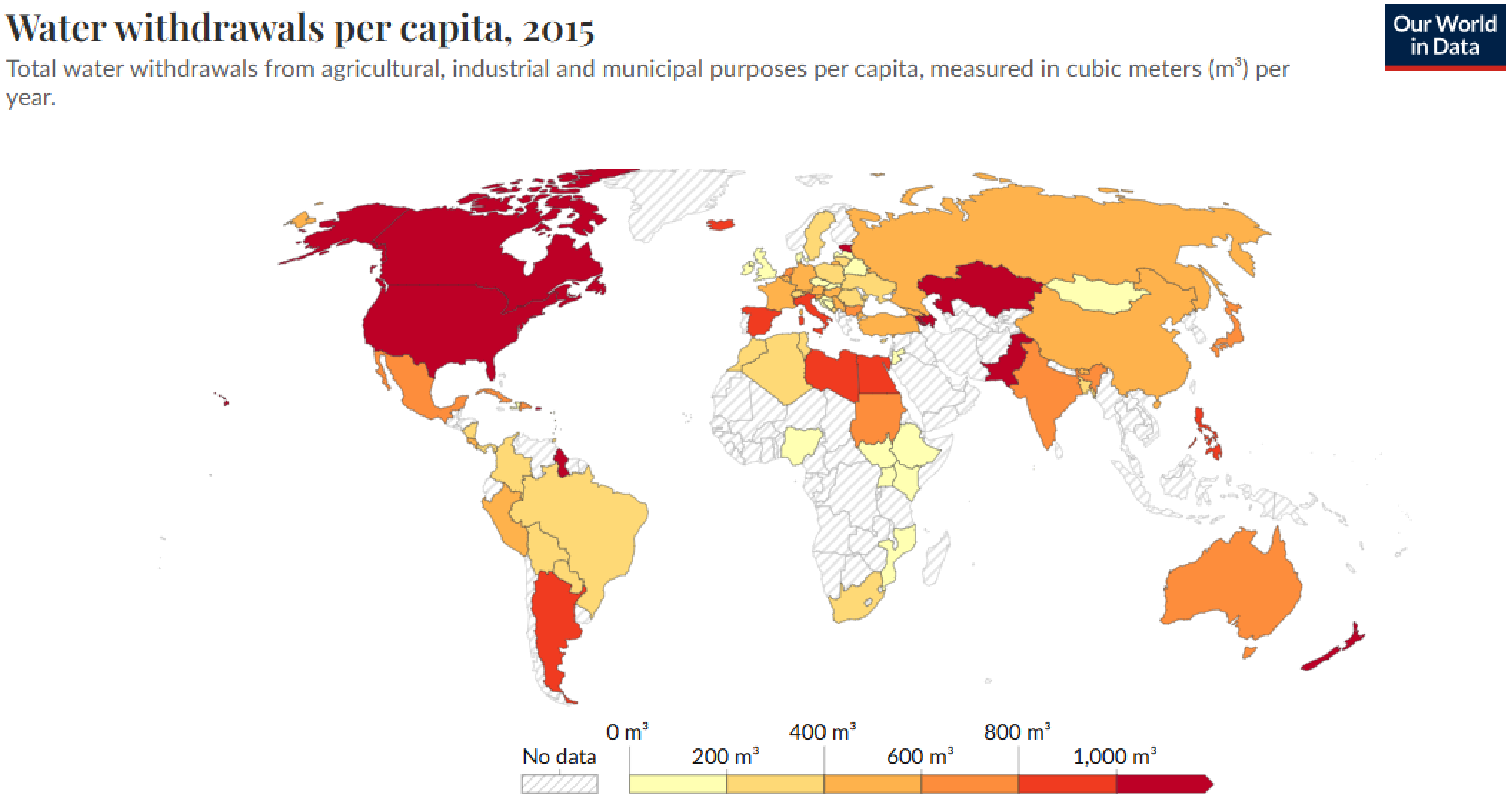
Annual freshwater withdrawals, 2021

Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins, measured in cubic metres (m^3) per year. Total water withdrawals are the sum of withdrawals for agriculture, industry and municipal (domestic uses). Withdrawals also include water from desalination plants in countries where they are a significant source.

Our World in Data



WATER


Water withdrawals per capita, 2015
Total water withdrawals from agricultural, industrial and municipal purposes per capita, measured in cubic meters (m³) per year.
Our World in Data
No data
0 m³
200 m³
400 m³
600 m³
800 m³
1,000 m³

WATER

Ground water overuse: the problem of subsidence
Overexploitation of aquifers can cause the earth to sink

California

Mexico City

WATER

Ground water overuse: the problem of subsidence
Overexploitation of aquifers can cause the earth to sink

Source: Observer , 2019

As Jakarta sinks, Indonesia wants to move capital to Borneo

With 40 percent of Jakarta below sea level, President Widodo says the solution is to move the capital 1,000 kilometers to the island of Borneo. If parliament approves, construction could begin as early as 2020.

It was the disorderly construction on swamps, together with the illegal drainage of aquifers, that brought the Indonesian capital to the situation it finds itself in today: 40% of Jakarta's territory is already below sea level and in the worst neighborhoods the land subsides at a rate of 10 or 20 centimeters per year, which could lead to the total submersion of a third of the city by 2050.

WATER

Ground water overuse: the problem of subsidence
Overexploitation of aquifers can cause the earth to sink

As Jakarta sinks, Indonesia wants to move capital to Borneo

Written by Maria-Cristina Florian

Published February 23, 2024

The Indonesian parliament has approved a bill to relocate the capital from the city of Jakarta to a completely new city to be built on the island of Borneo, 1,300 kilometers from the current capital. The decision, first announced in 2019, comes as a reaction to the myriad of challenges faced by Jakarta, including pollution, traffic congestion, and, perhaps the most threatening, rising sea waters. As a consequence of excessive groundwater extraction, rapid urbanization, and rising sea levels, 40% of the city is currently below sea level, making it increasingly difficult for the infrastructure to protect the residents. President Joko Widodo proposes an alternative: relocating the administrative center of the country to a new green metropolis, to be named Nunsantara, meaning 'archipelago' in ancient Javanese.

WATER

WATER SHORTAGE

Whether there is insufficient water to meet human needs is driven by population, but also depends on ‘needs’ vs. ‘wants’, what water sources are accessible, and whether needs can be met in other ways. Human water needs include water supply security, food security, minimum water levels, minimum water quality and maintaining ecosystem services.

WATER STRESS

As water use increases, it becomes more difficult to access the resource sustainably. Water users need to handle conflict or cooperation, as well as avoiding breaching ‘planetary boundaries’, and eating into “environmental flow requirements”.

LEVEL OF WATER STRESS

Freshwater withdrawal as a proportion of available freshwater resources.

WATER

WATER SCARCITY:

situation where the demand for water exceeds the available supply in a specific region or period. It occurs due to a combination of factors such as population growth, climate change, inefficient water use, and over-extraction of freshwater resources.

Physical Water Scarcity

When natural water resources are insufficient to meet demand, often occurring in arid or drought-prone regions.

Economic Water Scarcity

When water is available, but inadequate infrastructure, governance, or financial constraints prevent access to clean and safe water.

Water scarcity has severe implications for agriculture, industry, ecosystems, and human health, making sustainable water management essential for long-term environmental and societal well-being.

WATER

WATER SCARCITY

Already affects every continent. Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity, and 500 million people are approaching this situation. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage (where countries lack the necessary infrastructure to take water from rivers and aquifers).

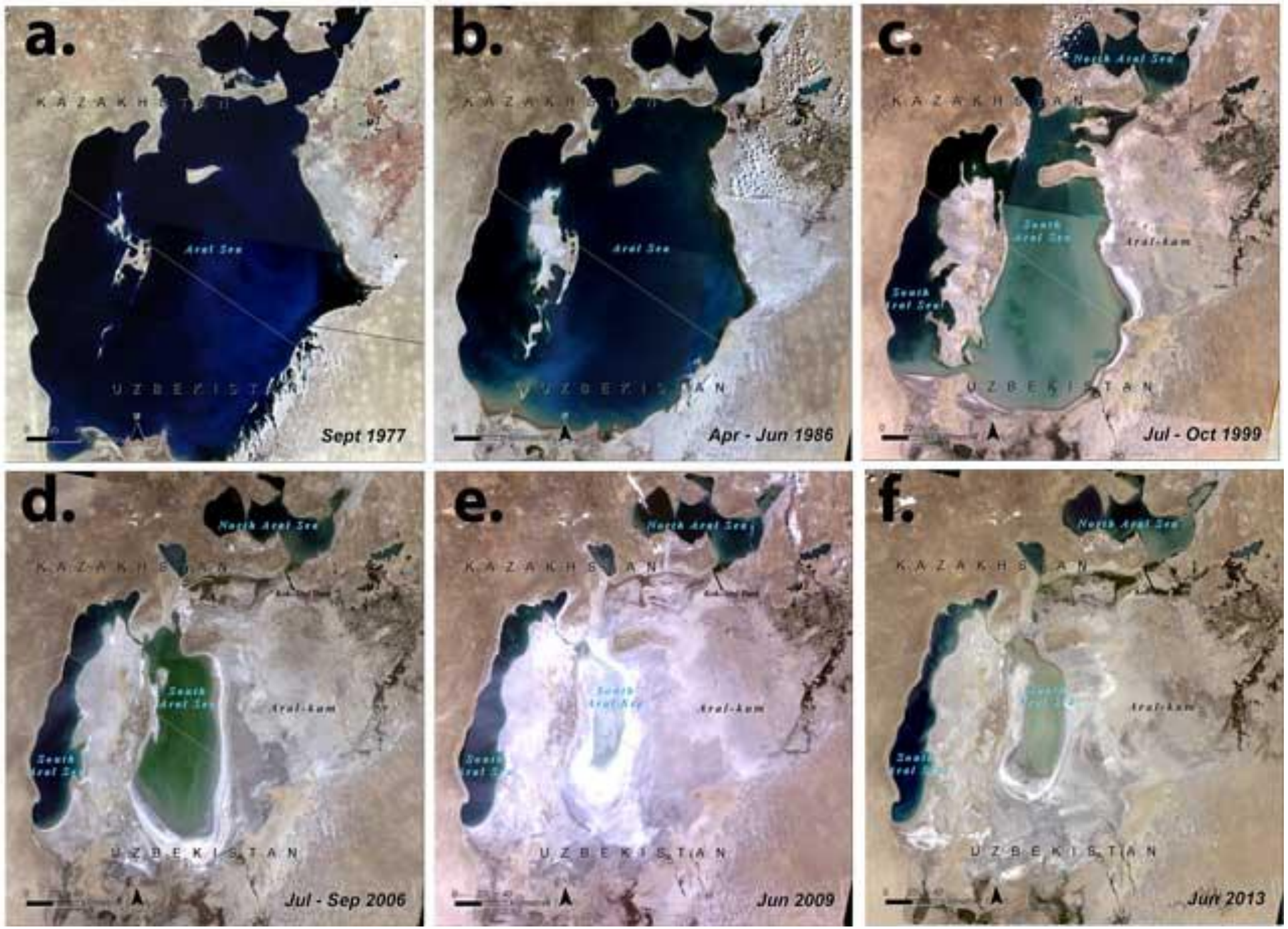
Is among the main problems to be faced by many societies and the World in the XXIst century. Water use has been growing at more than twice the rate of population increase in the last century, and, although there is no global water scarcity as such, an increasing number of regions are chronically short of water.

Is both a natural and a human-made phenomenon. There is enough freshwater on the planet for seven billion people but it is distributed unevenly and too much of it is wasted, polluted and unsustainably managed.

WATER

THE TRAGEDY OF THE ARAL SEA.

Starting from the 1960's, the former Soviet states of Kazakhstan, Turkmenistan and Uzbekistan began to divert massive amounts of water from the rivers feeding the Aral Sea to irrigate cotton and rice crops. Estimates of peak water withdrawal in the 1980's are about 120 cubic km per year. That's the equivalent of enough swimming pools to cover the entire country of Singapore. A hundred times over.



Source: https://www.iwanderwhy.net/blog/paradise-lost-the-great-tragedy-of-the-aral-sea

WATER

WATER SHORTAGE/SCARCITY

	1995		2025	
	Countries	Pop.	Countries	Pop.
Water Stress	24	460 M	48	2,850 M
Water Shortage	18	167 M	29	804 M

Source: https://earth.org/causes-and-effects-of-water-shortage/

WATER

CAUSES OF WATER SHORTAGE/SCARCITY

Decrease in supply	Water intakes, Diversions (ex: Aral Sea, Cazaquistan) Water quality deterioration (ex: Love Canal, 1970s, USA) Climate change
Increased demand	Population growth (ex: Mexico City) More than 50% of the world population lives, since 2007, in urban areas, many of them are located in coastal zones (in 2010 there were 26 cities with a population higher than 10 million inhabitants)Today, the world's population is just short of eight billion people, which translates to a growing demand for water amid water stress from climate change. Urbanisation and an exponential increase in freshwater demand for households are both driving factors behind water shortages, especially in regions with a precarious water supply.
Limitations on management	Water supply systems, insufficient data, insufficient infrastructure.

Source: https://earth.org/causes-and-effects-of-water-shortage/

WATER

CAUSES OF WATER SHORTAGE/SCARCITY

Droughts

One of the biggest drivers of water scarcity is drought. Drought is a natural phenomenon in which dry conditions and lack of precipitation – whether it is rain, snow or sleet – occur over certain areas for a period of time.

Climate Change

In the 2018 Intergovernmental Panel on Climate Change (IPCC) report, climate scientists say that groundwater stored in aquifers, which provides 36% of the world's domestic water supply for over 2 billion people, is highly sensitive to future climate change. They also concluded that wet regions are expected to get wetter while dry regions will get drier.

Poor Water Management and Growing Demand

Today, the world's population is just short of eight billion people, which translates to a growing demand for water amid water stress from climate change. Urbanisation and an exponential increase in freshwater demand for households are both driving factors behind water shortages, especially in regions with a precarious water supply.

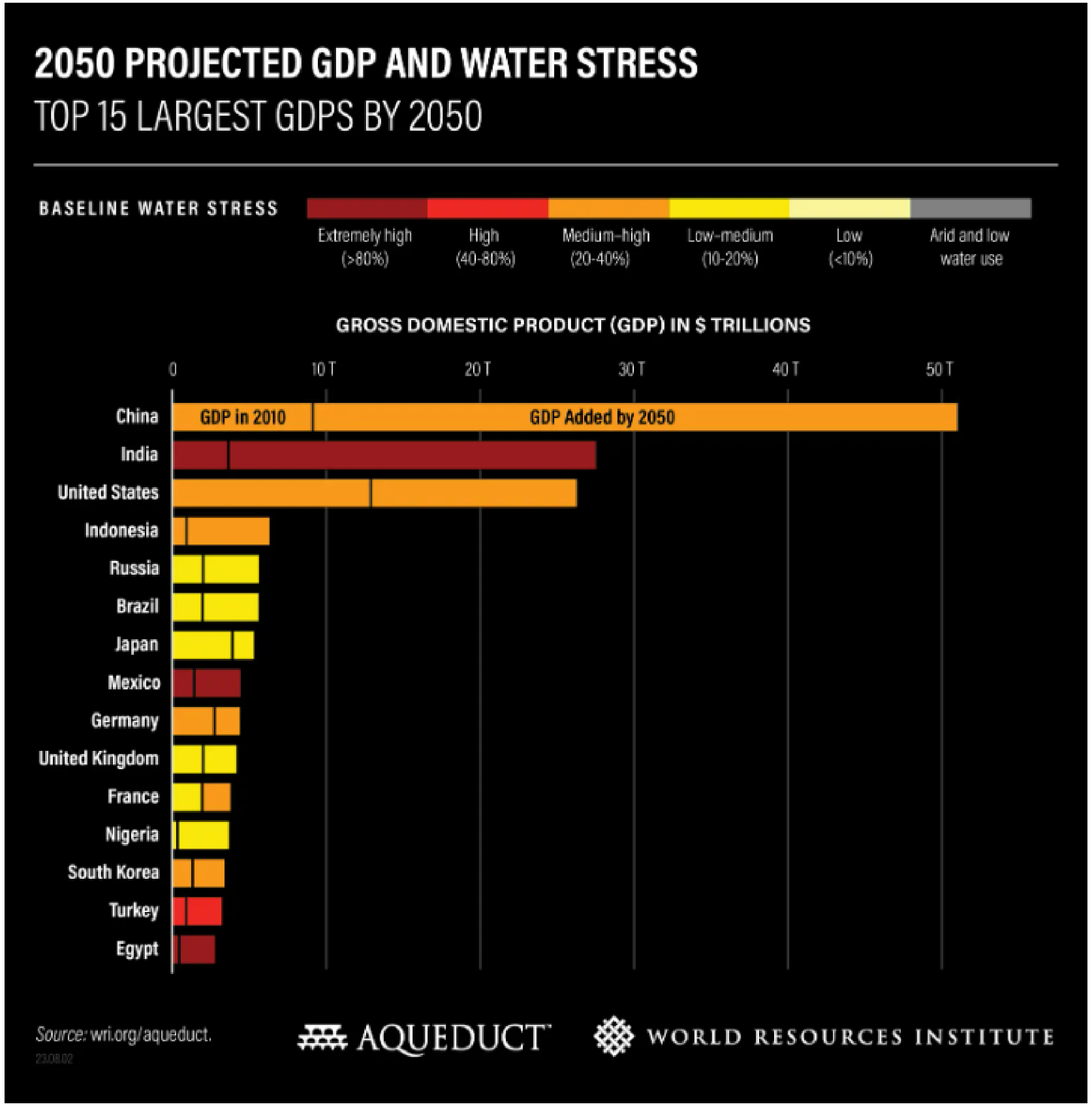
Water Pollution

Water pollution already kills more people each year than war and all other forms of violence combined. As we only have less than 1% of the Earth's freshwater accessible to us, human activity is actively threatening our own water resources

Source: https://earth.org/causes-and-effects-of-water-shortage/

WATER

Water Stress and GDP



WATER

WATER STRESS

NATIONAL WATER STRESS RANKINGS

Search for a country...

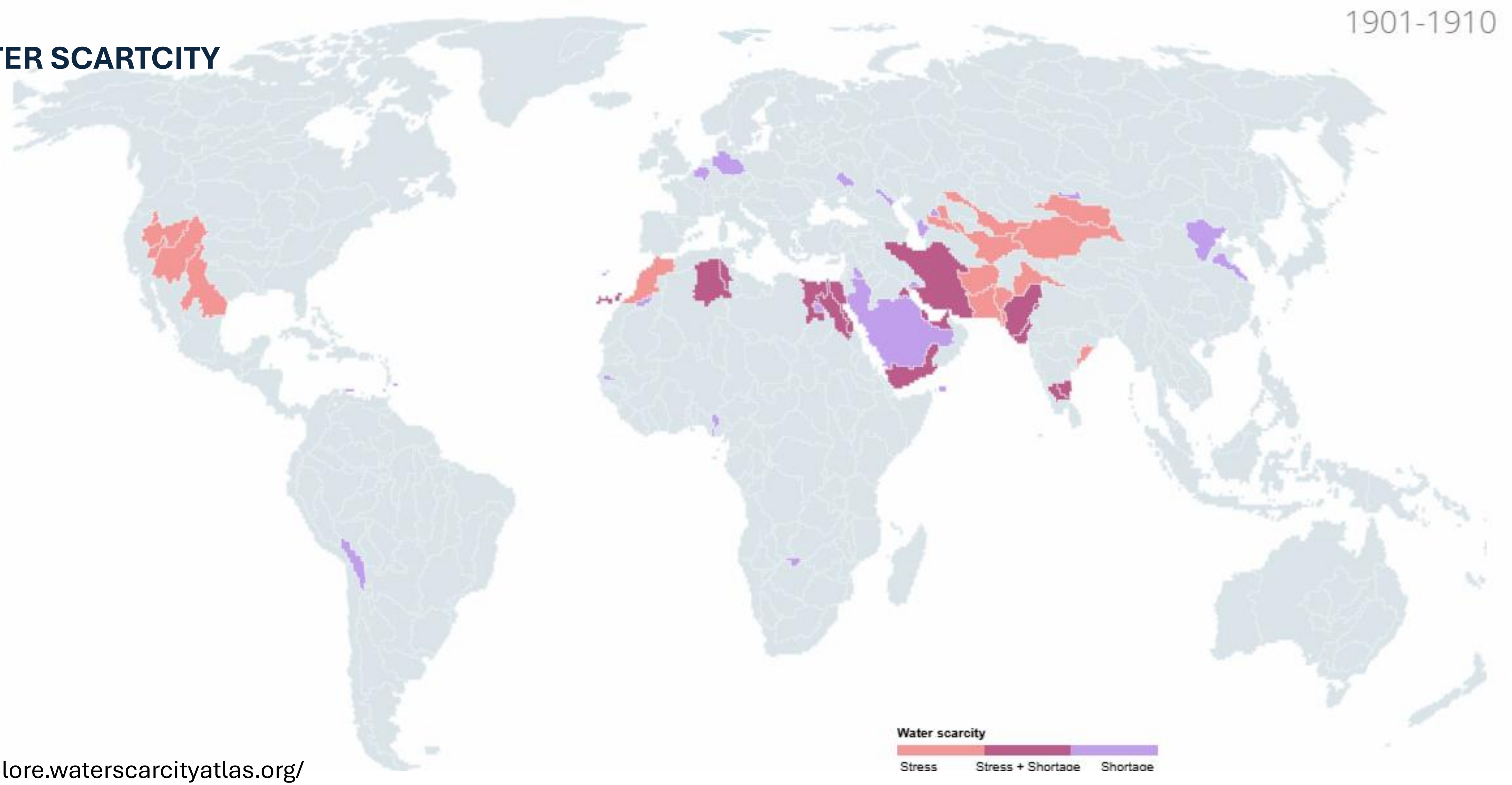
BASELINE WATER STRESS	COUNTRY RANKING, 2019
Extremely High (>80%)	1. Bahrain, 2. Cyprus, 3. Kuwait, 4. Lebanon, 5. Oman, 6. Qatar, 7. United Arab Emirates, 8. Saudi Arabia, 9. Israel, 10. Egypt, 11. Libya, 12. Yemen, 13. Botswana, 14. Iran, 15. Jordan, 16. Chile, 17. San Marino, 18. Belgium, 19. Greece, 20. Tunisia, 21. Namibia, 22. South Africa, 23. Iraq, 24. India, 25. Syria
High (40-80%)	26. Mexico, 27. Morocco, 28. Eritrea, 29. Spain, 30. Algeria, 31. Pakistan, 32. Peru, 33. Turkmenistan, 34. Uzbekistan, 35. Thailand, 36. Andorra, 37. Albania, 38. Niger, 39. Turkey, 40. Afghanistan, 41. Italy, 42. Kyrgyzstan, 43. Portugal, 44. Nepal, 45. Djibouti, 46. Mongolia, 47. Macedonia
Medium - High (20-40%)	48. Armenia, 49. Lesotho, 50. Luxembourg, 51. Australia, 52. China, 53. Mauritania, 54. Guyana, 55. Indonesia, 56. Bangladesh, 57. United States, 58. Kazakhstan, 59. Azerbaijan, 60. South Korea, 61. Sri Lanka, 62. Tajikistan, 63. North Korea, 64. Senegal, 65. Zimbabwe, 66. Lithuania, 67. Myanmar, 68. Vietnam, 69. Germany, 70. Philippines
Low - Medium (10-20%)	71. Japan, 72. El Salvador, 73. France, 74. Tanzania, 75. Cambodia, 76. Czech Republic, 77. Argentina, 78. Uruguay, 79. Venezuela, 80. Timor-Leste, 81. Somalia, 82. Suriname, 83. Poland, 84. Cuba, 85. Burkina Faso, 86. Slovakia, 87. Dominican Republic, 88. Haiti, 89. Netherlands, 90. Sudan, 91. Bulgaria, 92. South Sudan, 93. Ukraine, 94. United Kingdom, 95. Moldova, 96. Serbia, 97. Canada, 98. Estonia, 99. Romania, 100. Belarus, 101. Russia, 102. Angola, 103. Brazil, 104. Malaysia, 105. Guatemala
Low (<10%)	106. Ethiopia, 107. Denmark, 108. Georgia, 109. Madagascar, 110. Chad, 111. Zambia, 112. Liechtenstein, 113. Finland, 114. Nigeria, 115. Kenya, 116. Sweden, 117. Malawi, 118. Panama, 119. Laos, 120. Montenegro, 121. Mali, 122. Ecuador, 123. Costa Rica, 124. Latvia, 125. Slovenia, 126. Colombia, 127. Hungary, 128. Switzerland, 129. Bosnia and Herzegovina, 130. Mozambique, 131. Bhutan, 132. Ireland, 133. Guinea, 134. Swaziland, 135. Guinea-Bissau, 136. Austria, 137. Nicaragua, 138. Uganda, 139. Norway, 140. Croatia, 141. Bolivia, 142. Honduras, 143. Ghana, 144. Belize, 145. New Zealand, 146. Gambia, 147. Republic of Congo, 148. Democratic Republic of the Congo, 149. Central African Republic, 150. Cameroon, 151. Benin, 152. Togo, 153. Paraguay, 154. Burundi, 155. Brunei, 156. Côte d'Ivoire, 157. Gabon, 158. Equatorial Guinea, 159. Iceland, 160. Jamaica, 161. Liberia, 162. Papua New Guinea, 163. Rwanda, 164. Sierra Leone

Source: wri.org/aqueduct

AQUEDUCT WORLD RESOURCES INSTITUTE

WATER

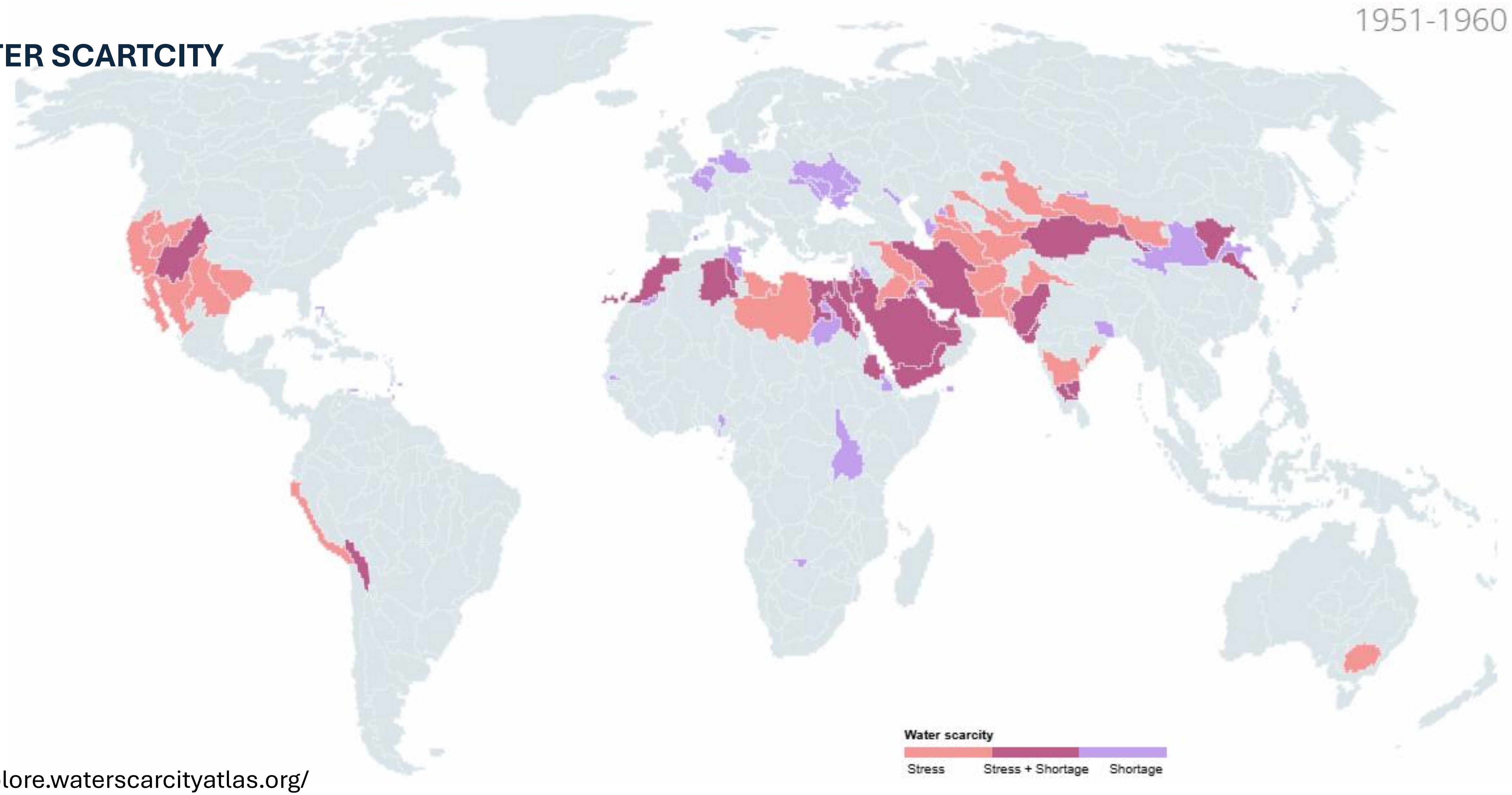
WATER SCARTCITY



https://explore.waterscarcityatlas.org/

WATER

WATER SCARTCITY



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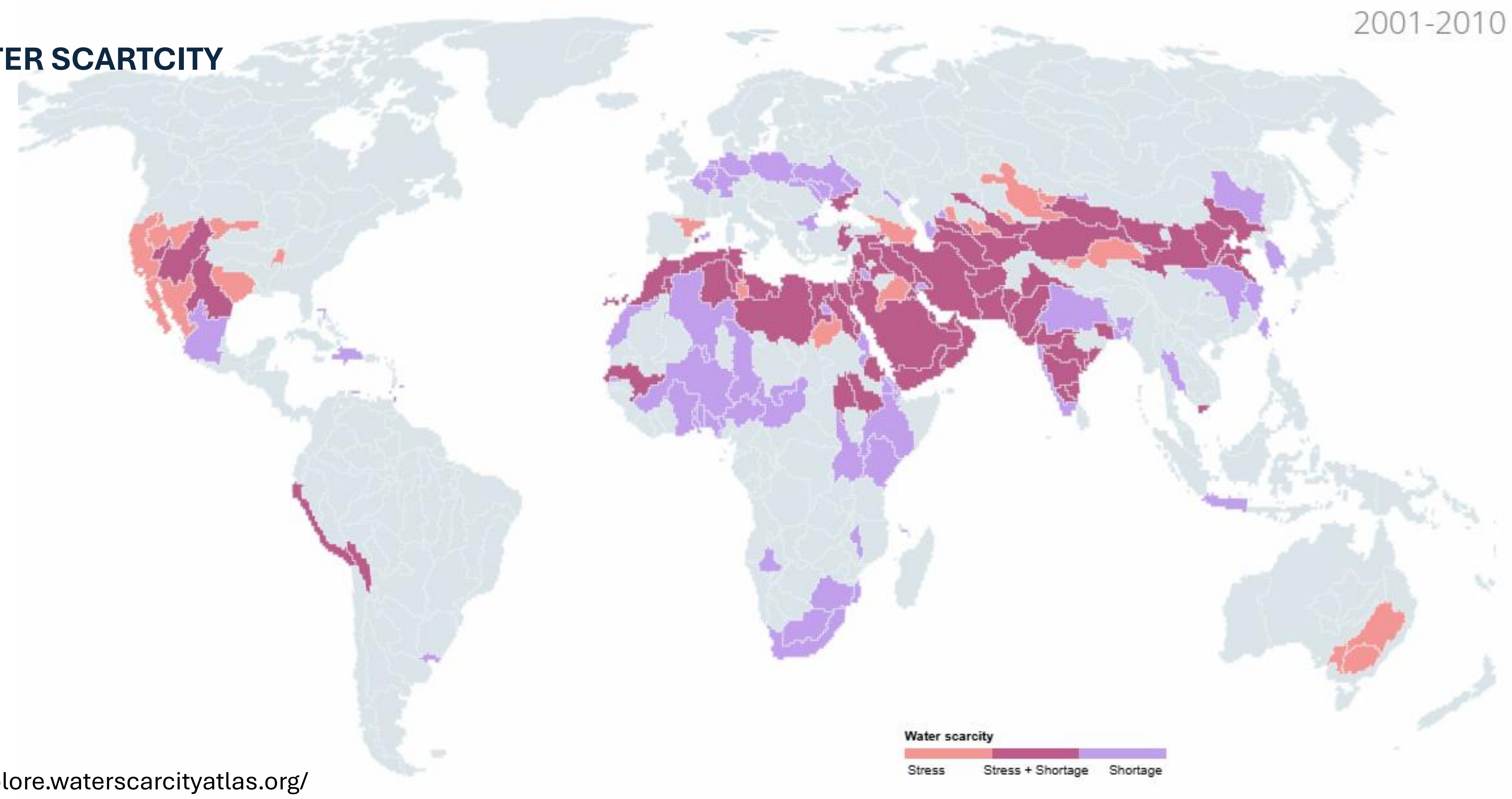

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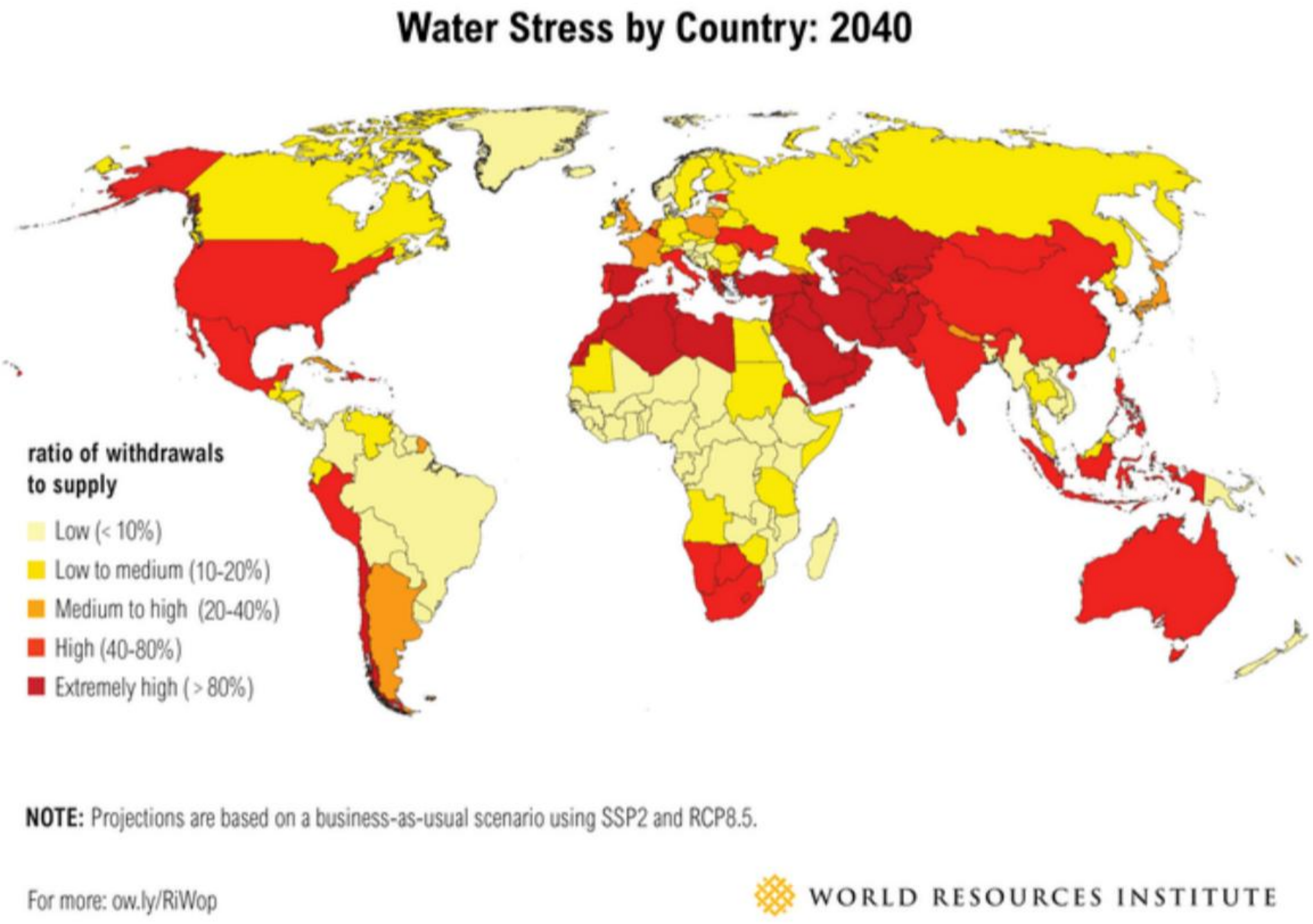
WATER

WATER STRESS



WATER

SUSTAINABLE DEVELOPMENT GOAL 6

Billions of people are still living without safely managed water and sanitation.

Sustainable Development Goal (SDG) 6 is to ensure the availability and sustainable management of water and sanitation for all by 2030.

Achieving SDG 6 is integral to the success of the 2030 Agenda for Sustainable Development, which aims to end extreme poverty and protect the planet.

Source: https://www.unwater.org/

WATER

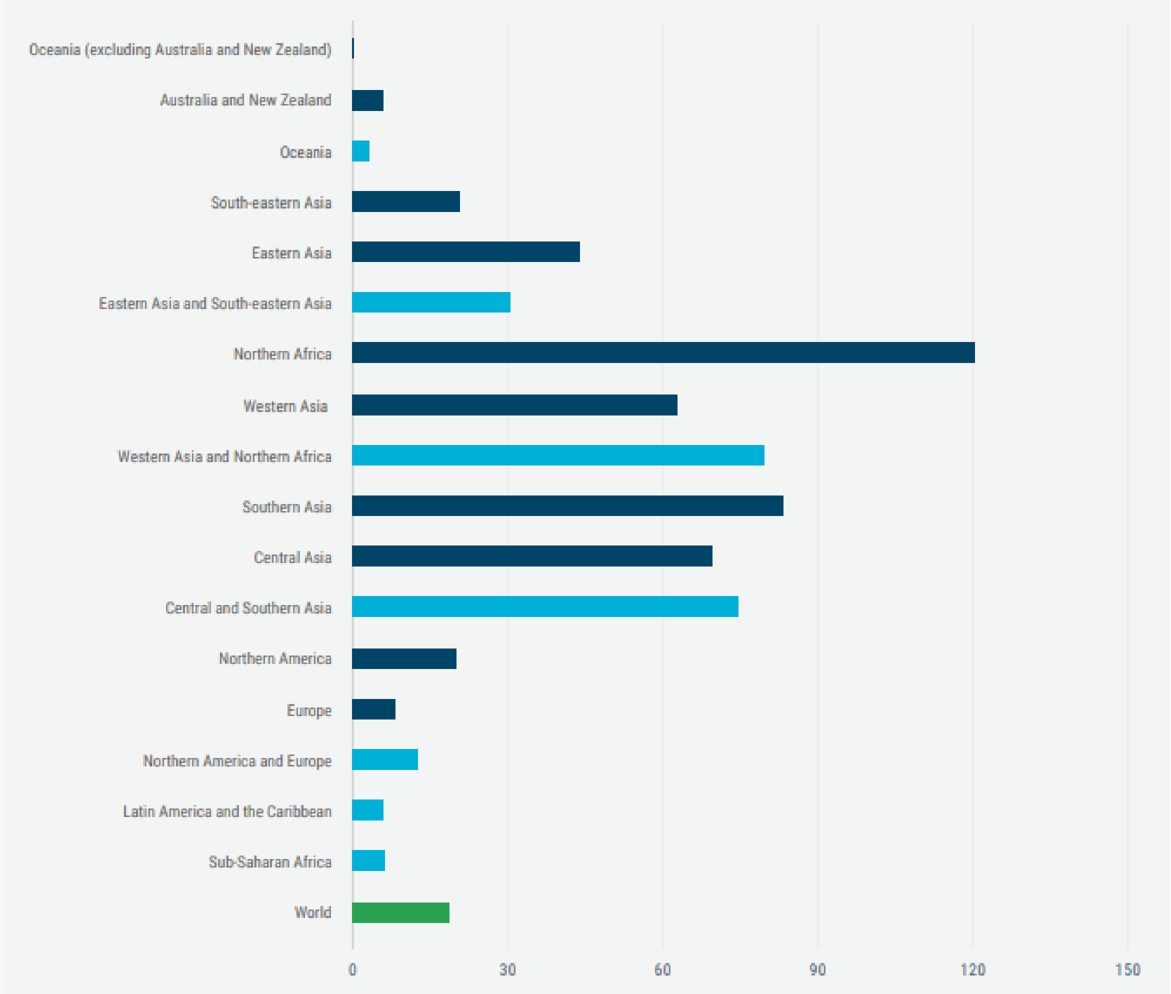
SUSTAINABLE DEVELOPMENT GOAL 6

Key messages:

Water stress is particularly acute in the Northern Africa Region and Western Asia as will as Southern and Central Asia.

Globally, agriculture emerges as the main user of water resources, accounting for 72 percent of total freshwater water withdrawals in 2021. Following agriculture, the industrial sector used 15 percent, while the service sector accounted for 13 percent of the total withdrawals.

Figure 5. Water stress levels at SDG region (light blue) and subregional level (dark blue) in 2021



UN Water - Progress on the level of water stress, 2024

WATER

United Nations | UN WATER

Water Facts

- 2.2 billion people (1 in 4) still live without **safely managed drinking water**, including 115 million people who drink surface water. (WHO/UNICEF, 2023).
- 3.5 billion people (4 in 10) still live without **safely managed sanitation**, including 419 million who practise open defecation. (WHO/UNICEF, 2023).
- 2 billion people still lack **basic hygiene services**, including 653 million with no facility at all. (WHO/UNICEF, 2023).
- Around 1,000 daily **deaths of children under five** are due to unsafe water, sanitation and hygiene. (WHO, 2023)
- Children under the age of 15 living in countries affected by **protracted conflict** are, on average, almost three times more likely to die from diarrhoeal diseases caused by a lack of safe water, sanitation and hygiene than by direct violence. (UNICEF, 2019)
- More than 2 billion people live in countries under **water stress** and 3.6 billion face **inadequate access to water** at least one month per year. (WMO, 2021)
- Water-related **disasters** account for 70% of all disaster related deaths. (World Bank Group, 2022)
- Since 2000, **flood-related disasters** have increased by 134%. (WMO, 2021)
- In 2023, **glaciers** lost more than 600 gigatons of water, the largest mass loss registered in the last five decades. (WMO, 2024)
- Only 0.5% of water on Earth is **useable and available freshwater**. (WMO, 2021)
- To meet SDG 6, **progress needs to increase**, on average, by 6x for safely managed drinking water, 5x for safely managed sanitation and 3x for basic hygiene. (WHO/UNICEF, 2023)
- 72% of all **freshwater withdrawals** are used by agriculture, 16% by industries, and 12% by municipalities. (FAO, 2023)
- Global **water demand** is projected to increase by 20 to 30% by 2050. (UN, 2018)
- To produce a person's **daily food**, it takes 2,000-5,000 litres of water. A 50% increase in food demand is expected by 2050. (FAO, 2020)
- **Water-use efficiency** has increased by 19.3% globally from 2015 to 2021, but around 58% of countries still exhibit low **water-use efficiency**. (FAO, 2024)
- The world will not achieve **sustainable water management** until 2049. (UNEP, 2024)
- Only 27% of **industrial wastewater** is safely treated. (UN-Habitat, WHO, 2024)
- 42% of **household wastewater** is not safely treated. (UN-Habitat, WHO, 2024)
- Only 56% of monitored water bodies in 120 reporting countries are in "good ambient **water quality**". (UNEP, 2024)
- Just 43 out of 153 countries sharing **transboundary waters** have operational arrangements covering 90% or more of their shared water bodies. (UNECE, UNESCO, 2024)
- Every US$ 1 invested in water and sanitation **yields a return** of US$ 4.3. (UN-Water GLAAS, 2014)
- **Aid for water and sanitation** decreased by 5% between 2015 and 2022. (UN-Water GLAAS, 2022).
- Estimates indicate that **to achieve SDG 6**, over US$1 trillion will be needed per year. (World Resources Institute, 2020).

January 2025

Source: https://www.unwater.org/

WATER

SITUATION IN PORTUGAL

- Portugal is not a poor country in terms of water resources
  - Portugal: 150 inhab/hm^3/year – Spain: 400 inhab/hm^3/year – UK: 450 inhab/hm^3/year

- Spatial variability
  - Mean annual precipitation: ~900 mm
  - North of the country (Gerês): ~4000 mm
  - Alentejo and inner Douro: ~550 mm

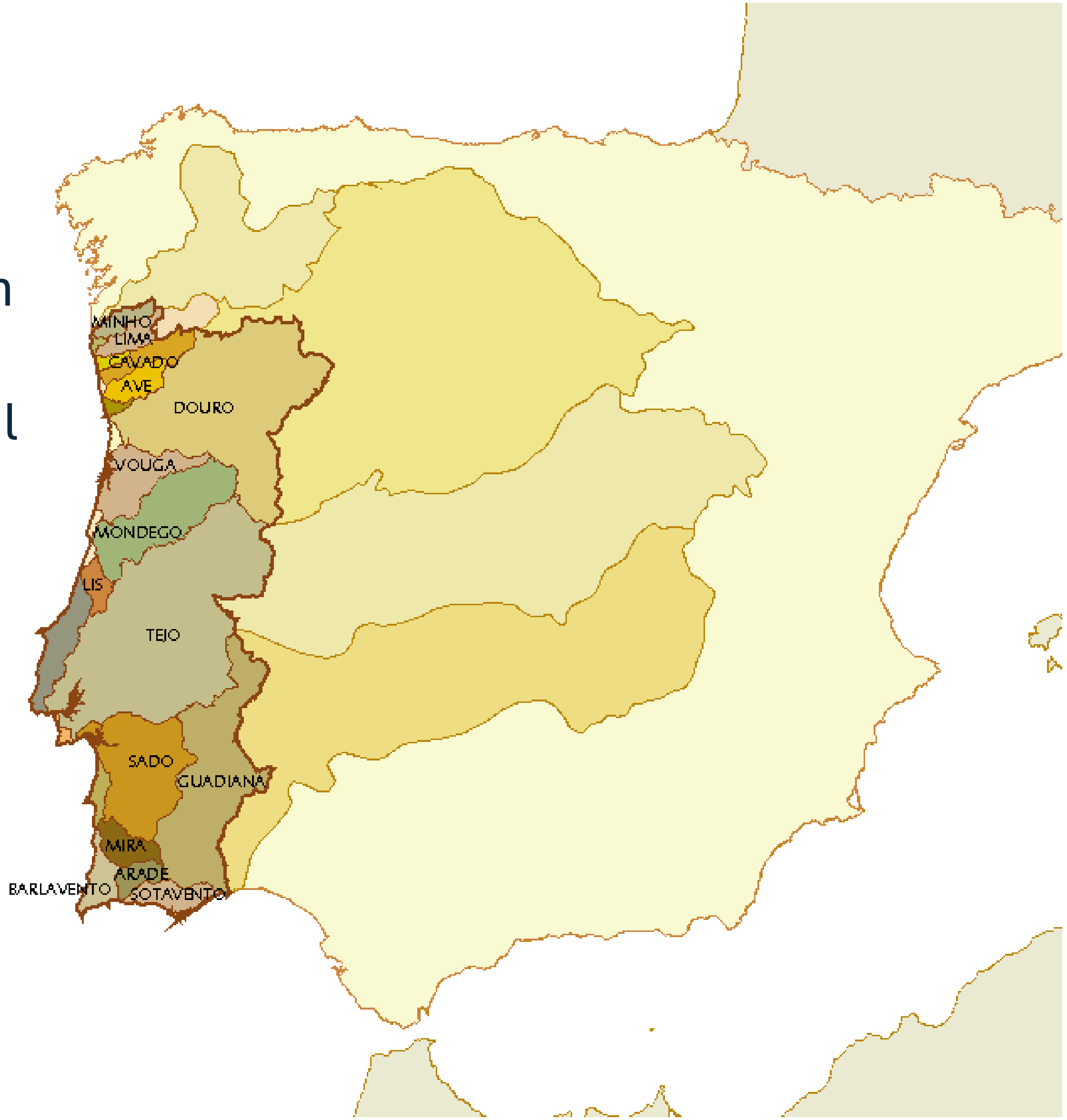
- Seasonal variability
  - wetter semester (Oct.-Mar.): ~700 mm
  - dryer semester (Apr.-Sep.): ~200 mm

- Interannual variability
  - Annual precipitation: 560 mm – 1400 mm
  - 25% of the years below 800 mm or above 1100 mm.

WATER

SITUATION IN PORTUGAL

- 60% of the water resources originate from Spain
- 64% of the territory corresponds to international river basins
- Tagus, Douro, and Guadiana are the main international rivers
- The location of Castelo do Bode illustrates the importance of the transboundary water issue



WATER

TRANSBOUNDARY RESOURCES MANAGEMENT

Transboundary issues are addressed by means of joint international Agreements

Albufeira Convention - Commission for the Implementation and Development of the Convention on Cooperation for the Protection and Sustainable Use of the Portuguese-Spanish River Basin Waters. (https://www.cadc-albufeira.eu/pt.html)

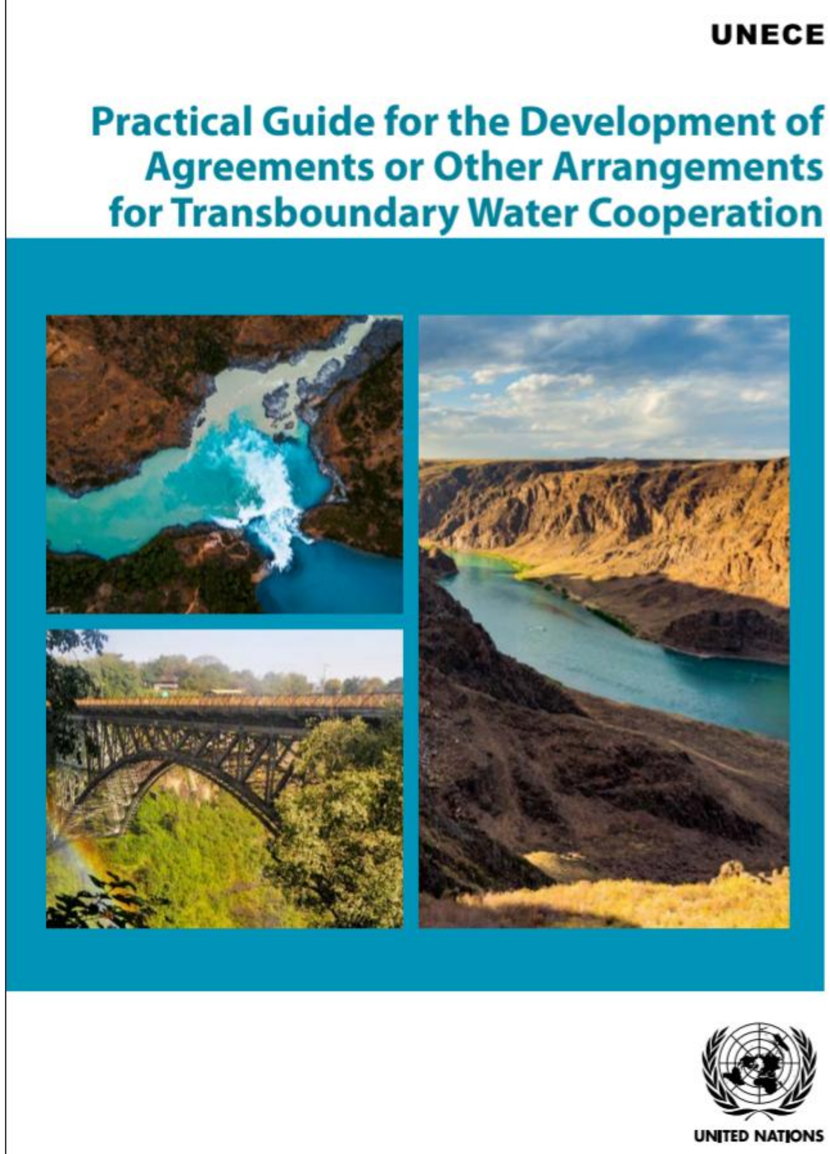
The Danube River Protection Convention forms the overall legal instrument for co-operation on transboundary water management in the Danube River Basin. (https://www.icpdr.org/about-icpdr/framework/convention)

The Zambezi Watercourse Commission (ZAMCOM) is a major river basin organisation in Africa: Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe. ZAMCOM promotes and coordinates the cooperative management and development of the Zambezi Watercourse in an equitable, efficient and sustainable manner. The Commission is headquartered in Harare, Zimbabwe.
(https://www.zambezicommission.org/zsp/zambezi-watercourse-commission-zamcom)

The Amazon Cooperation Treaty (ACT), signed on July 1978 by Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela, is a legal instrument that recognizes the transboundary nature of the Amazon
(https://otca.org/en/project/amazon-cooperation-treaty/).

WATER

TRANSBOUNDARY RESOURCES MANAGEMENT



WATER

VIRTUAL WATER

The concept of virtual water was introduced by Professor John Anthony Allan in the early 1990s. He developed this idea to explain how water-scarce countries, particularly in the Middle East and North Africa (MENA) region, manage their water resources by importing food rather than producing it domestically. Since agriculture is one of the most water-intensive sectors, importing food effectively means importing the water used to grow those crops—hence the term "virtual water.“

The concept has more recently also been used two address the so called “embedded water” or “indirect water”, that is the water “hidden” in the products, services and processes people buy and use every day.

WATER

VIRTUAL WATER

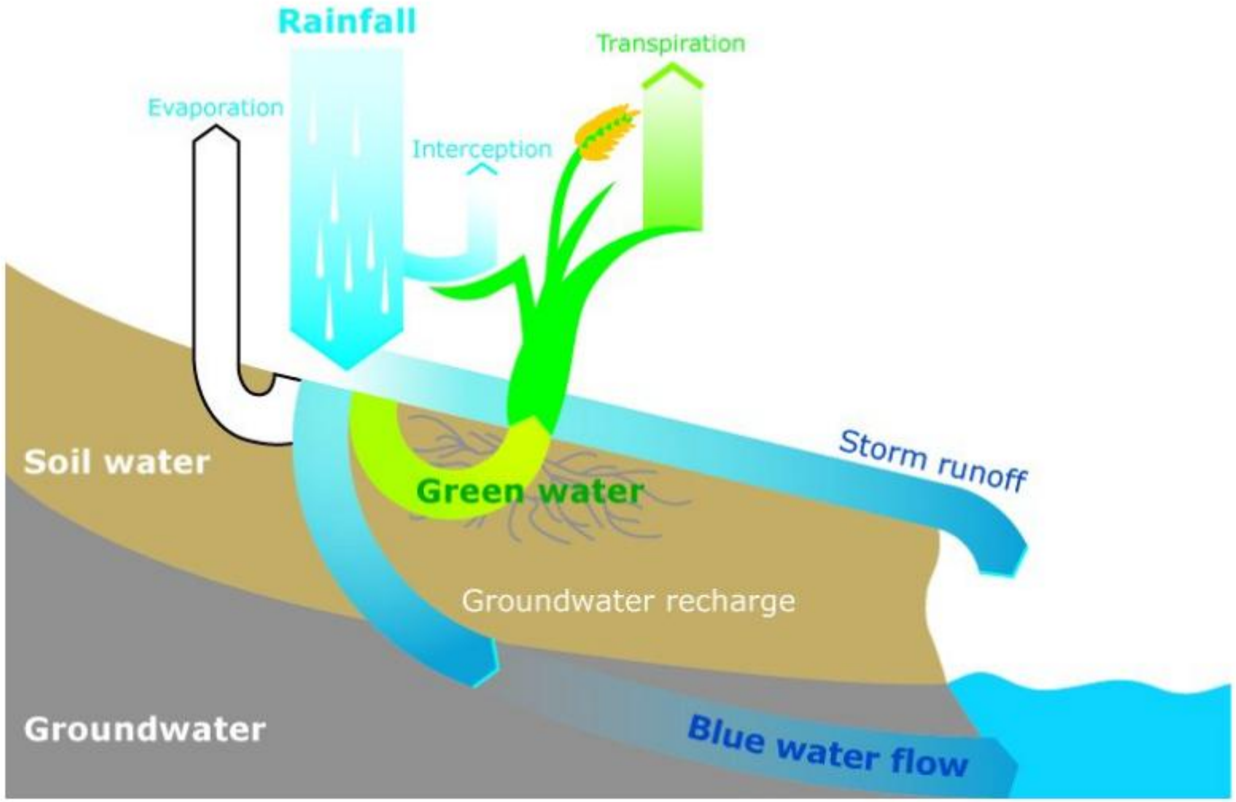
The water that is used in the production process of an agricultural or industrial product is called the 'virtual water' contained in the product. A water-scarce country might wish to import products that require a lot of water in their production (water-intensive products) and export products or services that require less water (water extensive products).

This implies net import of 'virtual water' (as opposed to import of real water, which is generally too expensive) and will relieve the pressure on the nation's own water resources. Until date little is known on the actual volumes of virtual water trade flows between countries.

WATER

WATER FOOTPRINT

The water footprint is a measure of humanity's appropriation of fresh water in volumes of water consumed and/or polluted.



WATER

WATER FOOTPRINT GREEN | BLUE | GREY WATER

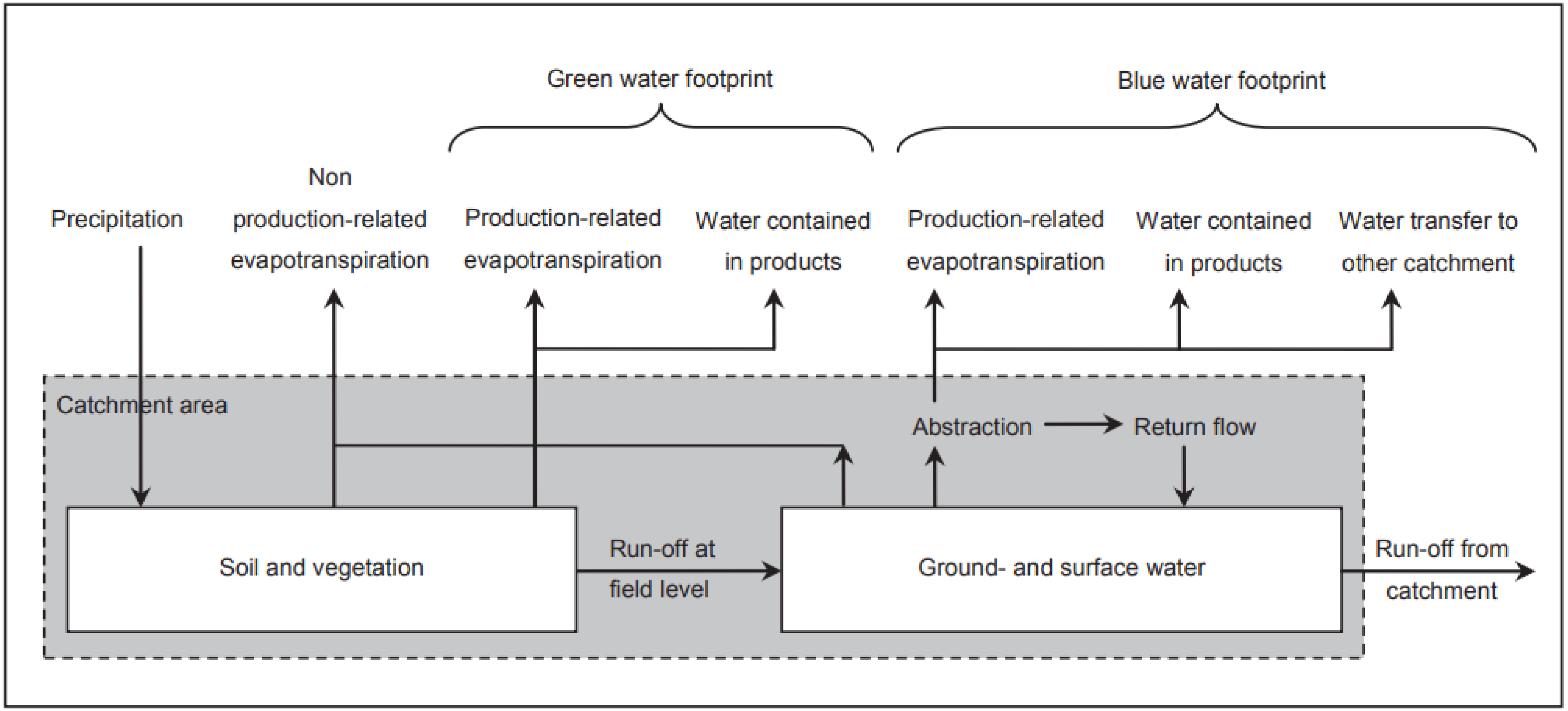


Figure 3.1 The green and blue water footprint in relation to the water balance of a catchment area

WATER

WATER FOOTPRINT GREEN | BLUE | GREY WATER

The **grey water footprint** of a process step is an indicator of the degree of freshwater pollution that can be associated with the process step.

It is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards.

The water footprint is a measure of humanity's appropriation of fresh water in volumes of water consumed and/or polluted.

WATER

VIRTUAL WATER

Milk

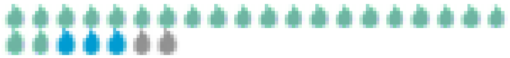
The global average water footprint of milk is 1020 litre/kg. Assuming a protein content in milk of 33 gram/kg, this means that the water footprint of milk is 31 litre of water per gram of protein, which is more than in the case of for example pulses (with an average water footprint of 19 litre per gram of protein). The precise water footprint of milk in each specific case will depend on the place where and the production system in which the cow is raised, and on the composition and origin of the feed.

The global water footprint of dairy cattle in the period 1996-2005 was about 470 billion m3/yr, which was 19% of the total water footprint of animal production in the world (all farm animals) (Mekonnen and Hoekstra, 2010, 2012).

Global average water footprint

255 litre for a glass of 250 ml

85% green, 8% blue, 7% grey



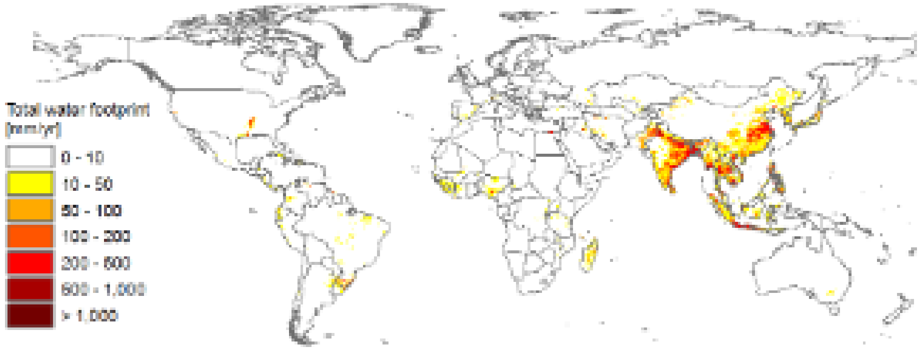
WATER

VIRTUAL WATER

Rice

Paddy rice (the rice as harvested from the field) requires 1670 litres of water per kg (Mekonnen and Hoekstra, 2010, 2011). One kg of paddy rice produces 0.67 kg of milled rice on average. In the shop we buy milled rice in the form of white rice or broken rice. The water footprint of rice in this form is 2500 litres of water per kg.

In the period 1996-2005, global rice production contributed 13% to the total and 22% to the blue water footprint of crop production in the world (Mekonnen and Hoekstra, 2010, 2011).

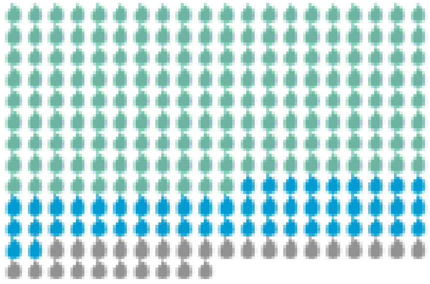


The global water footprint of rice production. Source: [Mekonnen and Hoekstra (2010)](#).

Global average water footprint

2497 litre/kg

68% green, 20% blue, 11% grey



WATER

VIRTUAL WATER

Banana

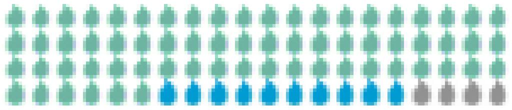
On average, one large banana (200 gram) costs 160 litres of water.

In India, the largest banana producing country in the world, the average water footprint of bananas is 500 litre/kg. The global average is 790 litre/kg.

Global average water footprint

790 litre/kg

84% green, 12% blue, 4% grey



Publications

2011	Mekonnen, M.M. and Hoekstra, A.Y. (2011) The green, blue and grey water footprint of crops and derived crop products, *Hydrology and Earth System Sciences*, 15(5): 1577-1600.	Download 1.2 MB
	Mekonnen, M.M. and	

WATER

VIRTUAL WATER

Wine

The global average water footprint of grapes is 610 litre/kg. One kilogram of grapes gives 0.7 litre of wine, so that the water footprint of a wine is 870 litre of water per litre of wine. This means that one glass of wine (125 ml) costs 110 litre.

In France, Italy and Spain, the largest wine producing countries in the world, the average water footprint of wine is 90, 90 and 195 litre per glass of wine, respectively.

Publications

2011	Mekonnen, M.M. and Hoekstra, A.Y. (2011) The green, blue and grey water footprint of crops and derived crop products, *Hydrology and Earth System*	Download 1.2 MB

Global average water footprint

109 litre for a 125ml glass of wine

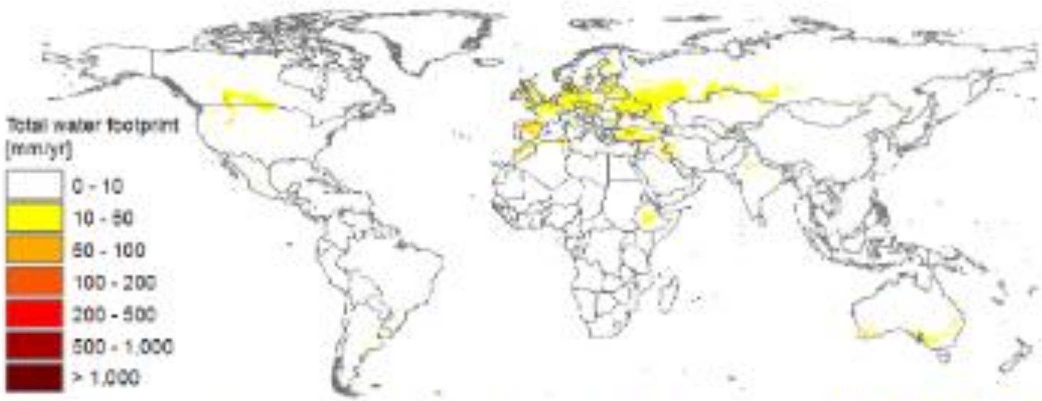
70% green, 16% blue, 14% grey

WATER

VIRTUAL WATER

Beer (from barley)

The global average water footprint of barley is 1420 litre/kg. When we consider the amount of malted barley to produce beer, the water footprint of beer is 298 litre of water per litre of beer. This means that one glass of beer (250 ml) costs 74 litre. This excludes the water footprint of other (smaller) ingredients used in the beer production process.



The global water footprint of barley production. Source: Mekonnen and Hoekstra (2010).

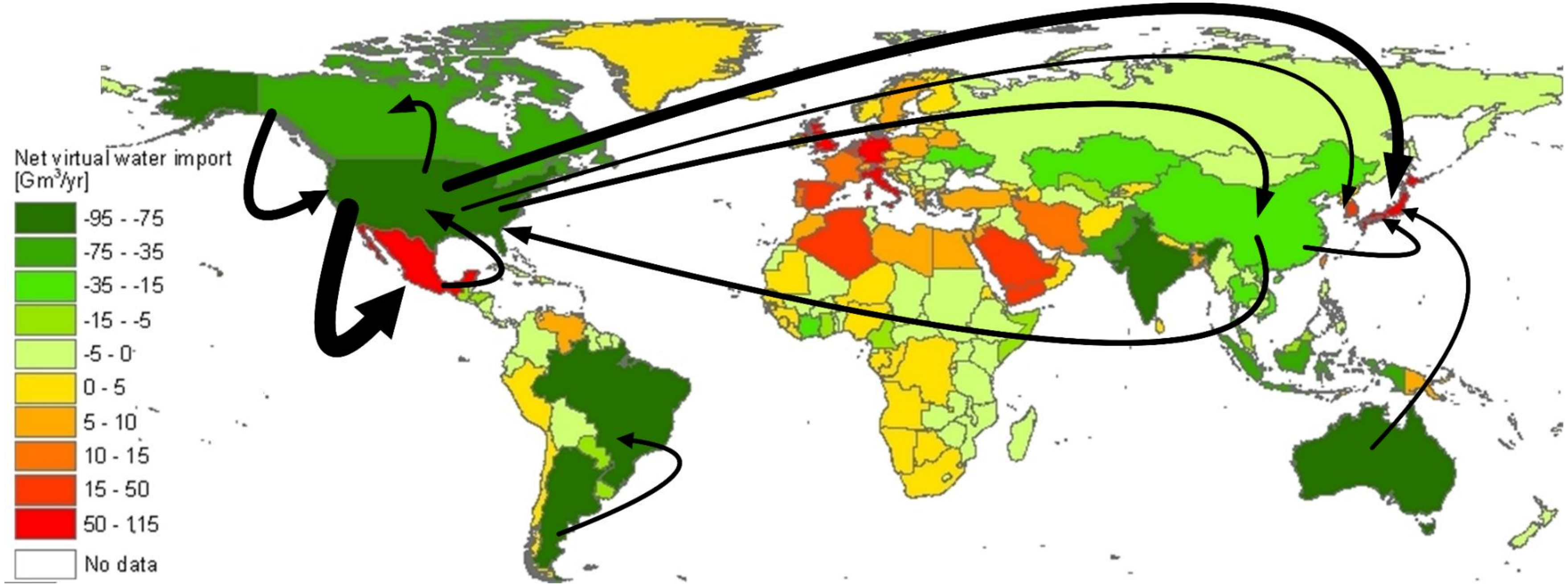
Global average water footprint

74 litre for a glass of 250 ml

85% green, 6% blue, 9% grey

WATER

VIRTUAL WATER:



Virtual water balance per country and direction of gross virtual water flows related to trade in agricultural and industrial products over the period 1996-2005. Only the biggest gross flows (> 15 Gm^3/yr) are shown; the fatter the arrow, the bigger the virtual water flow.

Source: http://www.waterfootprint.org/Reports/Report50-NationalWaterFootprints-Vol1.pdf

WATER

WATER FOOTPRINT

National water footprint accounts: the green, blue and grey water footprint of production and consumption (m³ ano⁻¹ *per capita*)

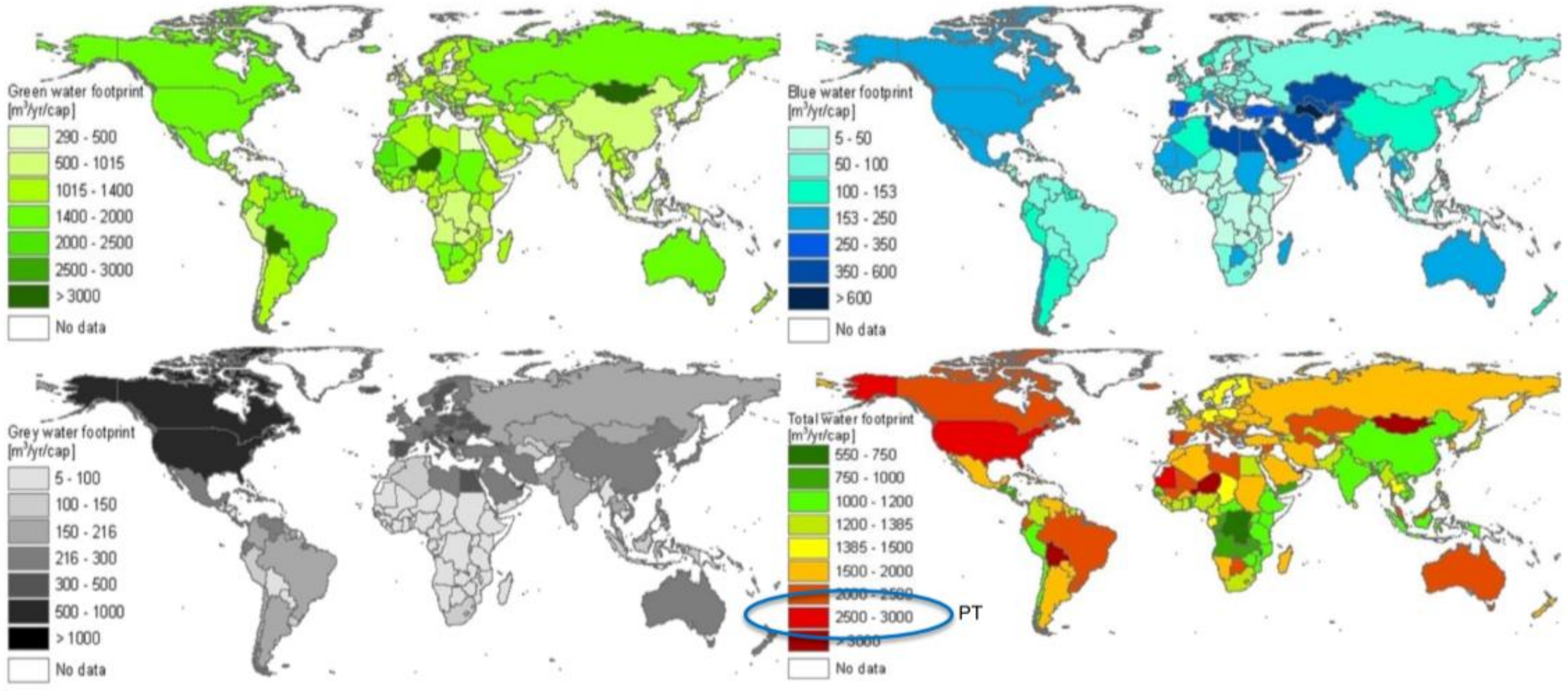


Figure 10. The green, blue, grey and total water footprint of consumption per country in the period 1996-2005 (m³/yr per capita). In the map showing the total water footprint of consumption per country (bottom-right), countries shown in green have a water footprint that is smaller than the global average; countries shown in yellow-red have a water footprint larger than the global average.

Mekonnen, M.M. and Hoekstra, A.Y. (2011) National water footprint accounts: the green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No. 50, UNESCO-IHE, Delft, the Netherlands.

WATER

Virtual Water

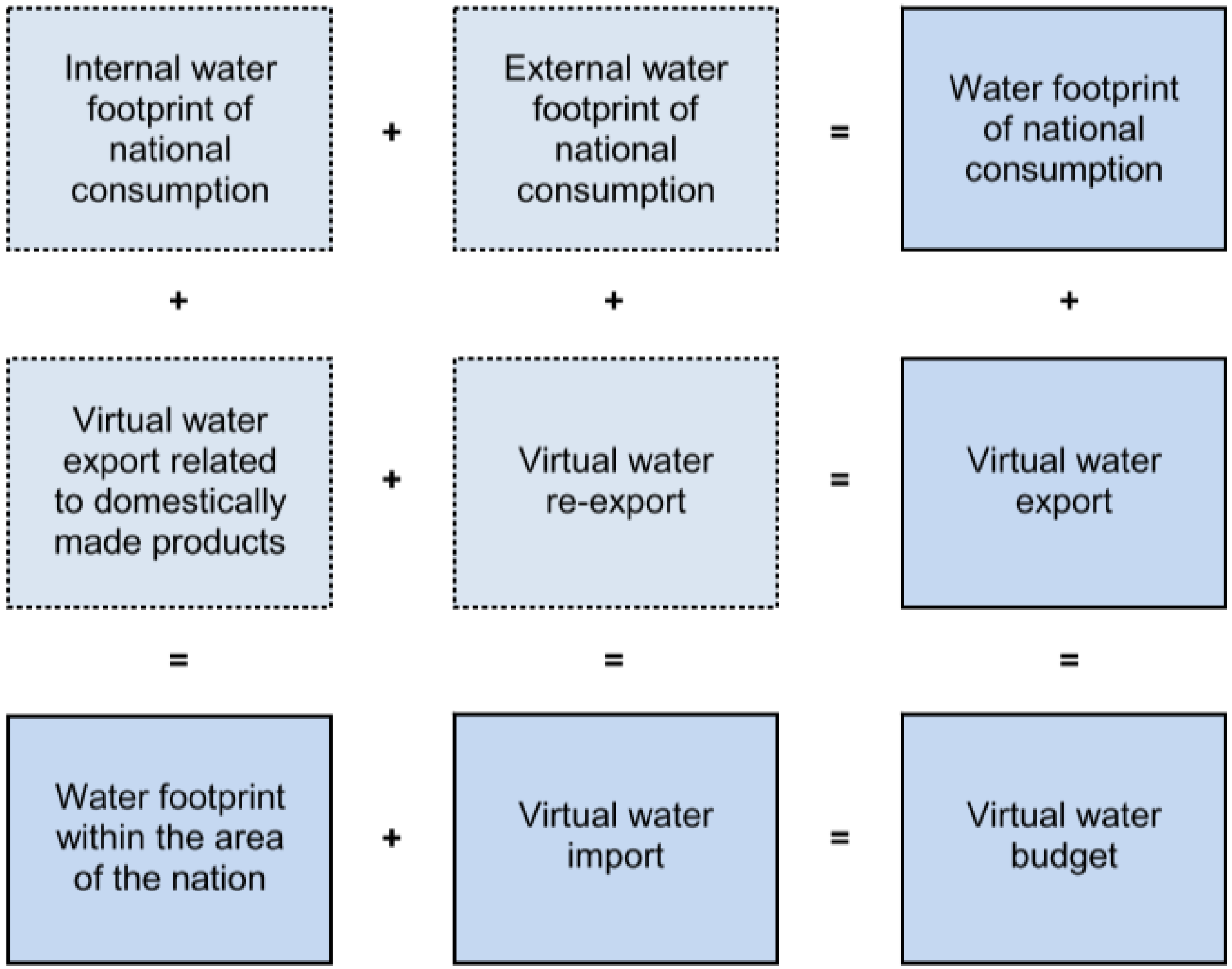


Figure 1. The national water footprint accounting scheme. Source: Hoekstra et al. (2011).

WATER

SOME DEMOGRAPHIC DATA

In 1800, only **3%** of the world population lived in cities

At the end of the XXth century, it went up to **47%**

In 2007, it overpassed **50%**

The world population reached **7 thousand million** people in 2011

In 1950, there were **83** cities with a population larger than 1 million people

In 2007, it reached **468**

Today (2016) there are **21 cities** with a population higher than **20 million people**

The urban population is today (2016) about **3.5 thousand million people**

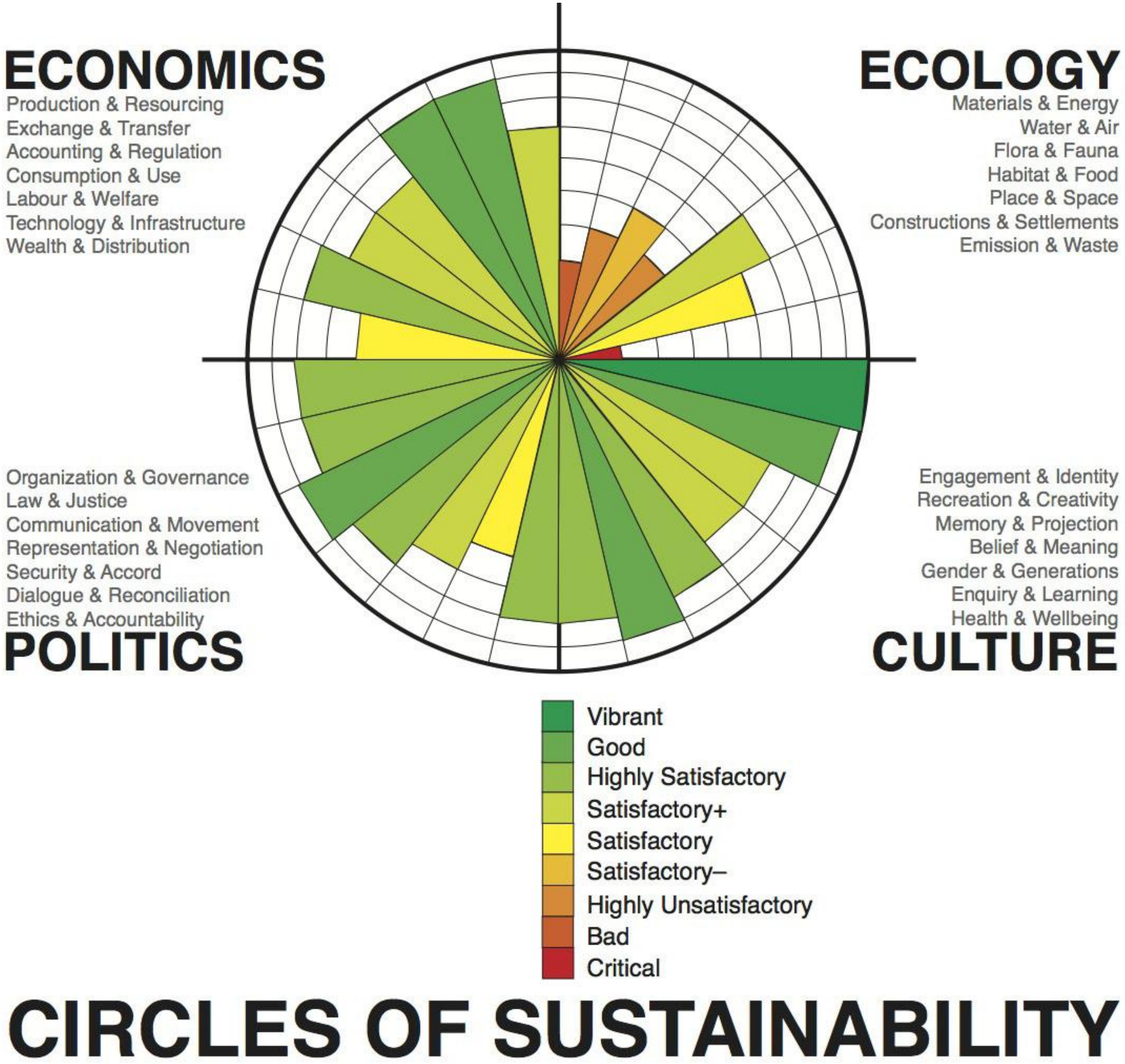
The United Nations estimate that in **2030** it will **be 5.0 thousand million** (3 out of 5 people will live in cities)

WATER

Framing of sustainable development progress according to the Circles of Sustainability, used by the United Nations.

Are we getting it right

!?



WATER

WATER GOVERNANCE

Along with Virtual Water the concept of WATER GOVERNANCE was introduced in the the early 1990s. Traditional water management focused on engineering solutions (dams, irrigation systems, and infrastructure).

Water governance introduced a broader approach including institutions, policies, social equity, and stakeholder engagement. Today, water governance is a key aspect of climate resilience, environmental sustainability, and socio-economic development worldwide.

Water governance refers to the political, social, economic, and administrative systems that influence how water resources are managed, allocated, and regulated. It encompasses the institutions, policies, and processes that determine who gets water, when, how, and at what cost.

WATER

WATER GOVERNANCE

Institutions and Stakeholders: governments, water utilities, local communities, private sector actors, and international organizations involved in water management.

Policies and Laws: Regulatory frameworks, water rights, environmental laws, and international agreements that guide water distribution and conservation.

Water Management Practices: Strategies for water allocation, pollution control, conservation, infrastructure development, and disaster preparedness.

Public Participation and Transparency: Ensuring that decisions are inclusive, accountable, and involve local communities in water resource planning.

WATER

INTEGRATED WATER RESOURCES MANAGEMENT

Cross-sectoral Coordination

Integrating policies across agriculture, energy, urban planning, and industry.

Watershed and River Basin Management

Managing water at a basin level rather than by administrative borders.

Stakeholder Engagement

Ensuring the involvement of local communities, governments, and private sectors.

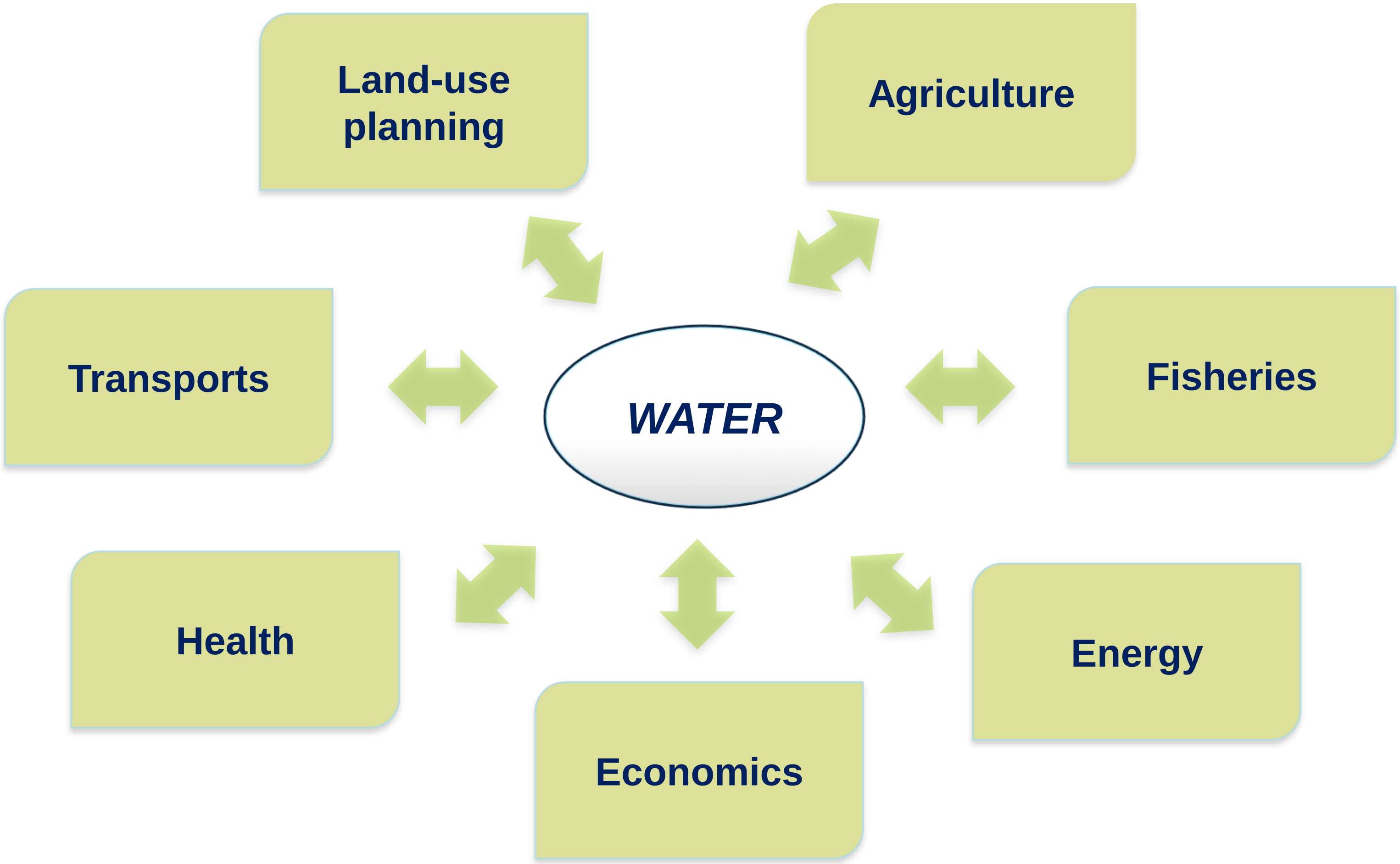
Sustainability and Resilience

Addressing climate change, pollution, and over-extraction of water resources.

WATER

INTEGRATED WATER RESOURCES MANAGEMENT

Integration of policies



WATER

INTEGRATED WATER RESOURCES MANAGEMENT

Strategy

IWRM is a process that aims to meet social, economic and environmental objectives, from a sustainability perspective, based on the principle that water resources are limited, and their uses are interdependent.

Traditional water management models, based on sectoral criteria, have been superseded by the actual integrated management that considers three strategic objectives:

- **efficiency in use;**
- **equity in allocation;**
- **environmental sustainability.**

The Water Framework Directive encompasses the concepts related to IWRM and targets insuring Europe's water resources sustainability.

WATER

INTEGRATED WATER RESOURCES MANAGEMENT

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WATER

INTEGRATED WATER RESOURCES MANAGEMENT

Key Objectives of the WFD:

Achieve "Good Status" for All EU Water Bodies: Ensures that all surface and groundwater bodies reach good ecological and chemical status by 2027 (extended from the original 2015 target).

Protect and Restore Aquatic Ecosystems: Focuses on biodiversity conservation, reducing pollution, and maintaining natural hydrological conditions.

Promote Sustainable Water Use: Balances environmental protection with economic activities, ensuring efficient water use across industries, agriculture, and households.

WATER

INTEGRATED WATER RESOURCES MANAGEMENT

Key Objectives of the WFD:

Prevent and Reduce Water Pollution: Controls pollution from agriculture (nitrates, pesticides), industry (chemicals, heavy metals), and urban wastewater.

Encourage Public Participation: Engages stakeholders, local communities, and NGOs in decision-making and water management planning.

Integrate Water Policies Across Sectors: Aligns with policies on climate change, energy, agriculture, and urban planning to promote holistic water governance.

WATER

INTEGRATED WATER RESOURCES MANAGEMENT

How Is the WFD Implemented?

River Basin Management Plans (RBMPs):

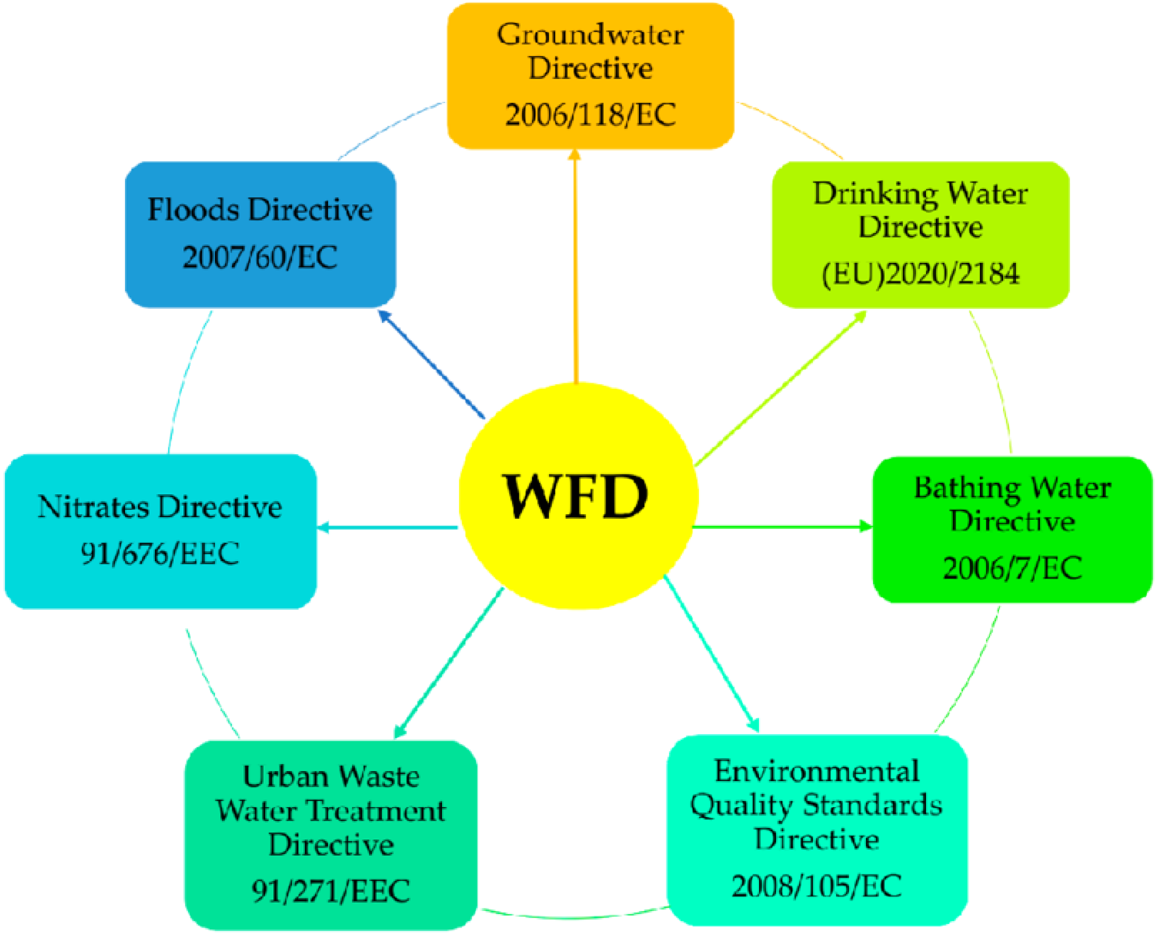
Each EU country must develop management plans for its river basins, updated every six years.

Monitoring and Reporting: Member states must monitor water quality and report progress to the European Commission.

Cross-Border Cooperation: Ensures transboundary water resources (e.g., Portugal and Spain's shared river basins) are jointly managed.

WATER

INTEGRATED WATER RESOURCES MANAGEMENT



WATER

CLIMATE CHANGE IMPACTS ON WATER RESOURCES

Insufficient supply to meet needs – scarcity

Degradation of water quality (increases unavailability)

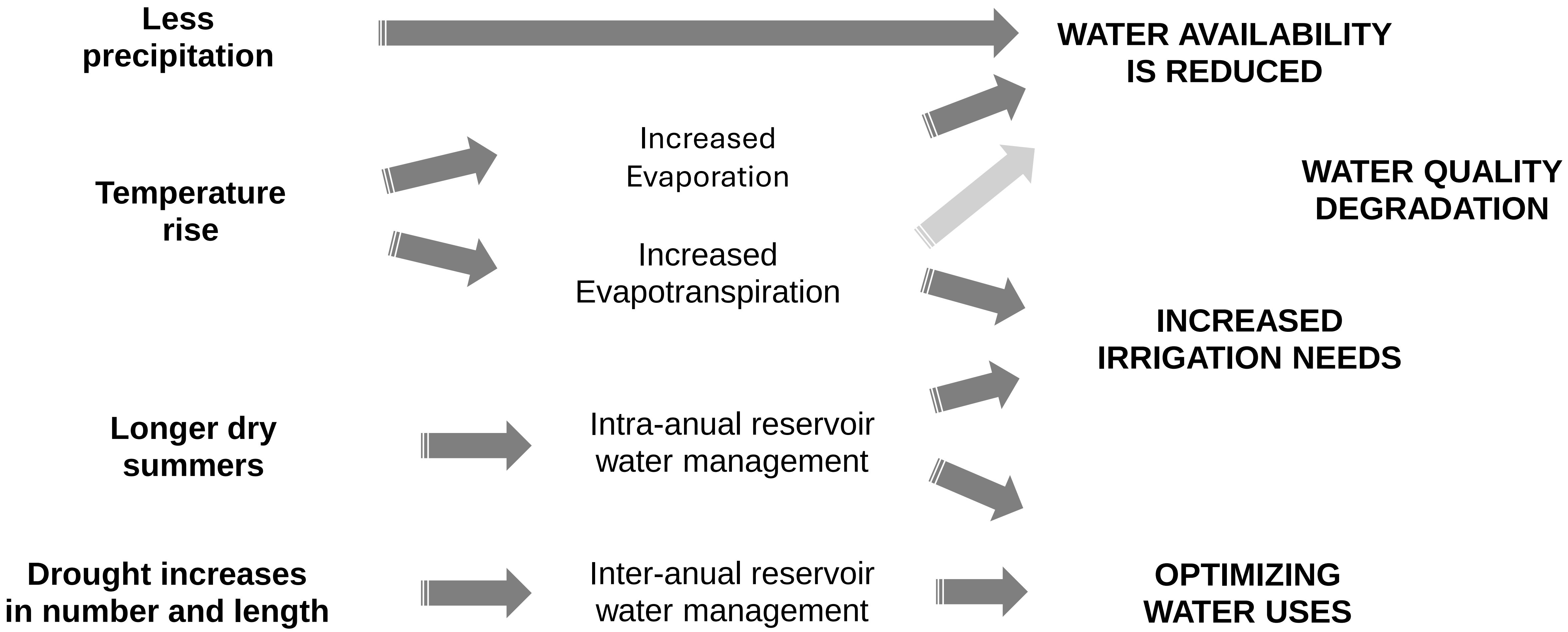
Competition for water use

Increased costs (risks, water transportation)Higher risk of scarcity

Reduced hydropower production

WATER

CLIMATE CHANGE IMPACTS ON WATER RESOURCES



WATER

CLIMATE CHANGE IMPACTS ON WATER RESOURCES

AGRICULTURE

- **Availability insufficient to satisfy needs – irrigation and livestock - SCARCITY**
- **Insecurity in the production**
- **Increased costs**
- **Increased risks economic**

WATER

CLIMATE CHANGE IMPACTS ON WATER RESOURCES

URBAN SUPPLY

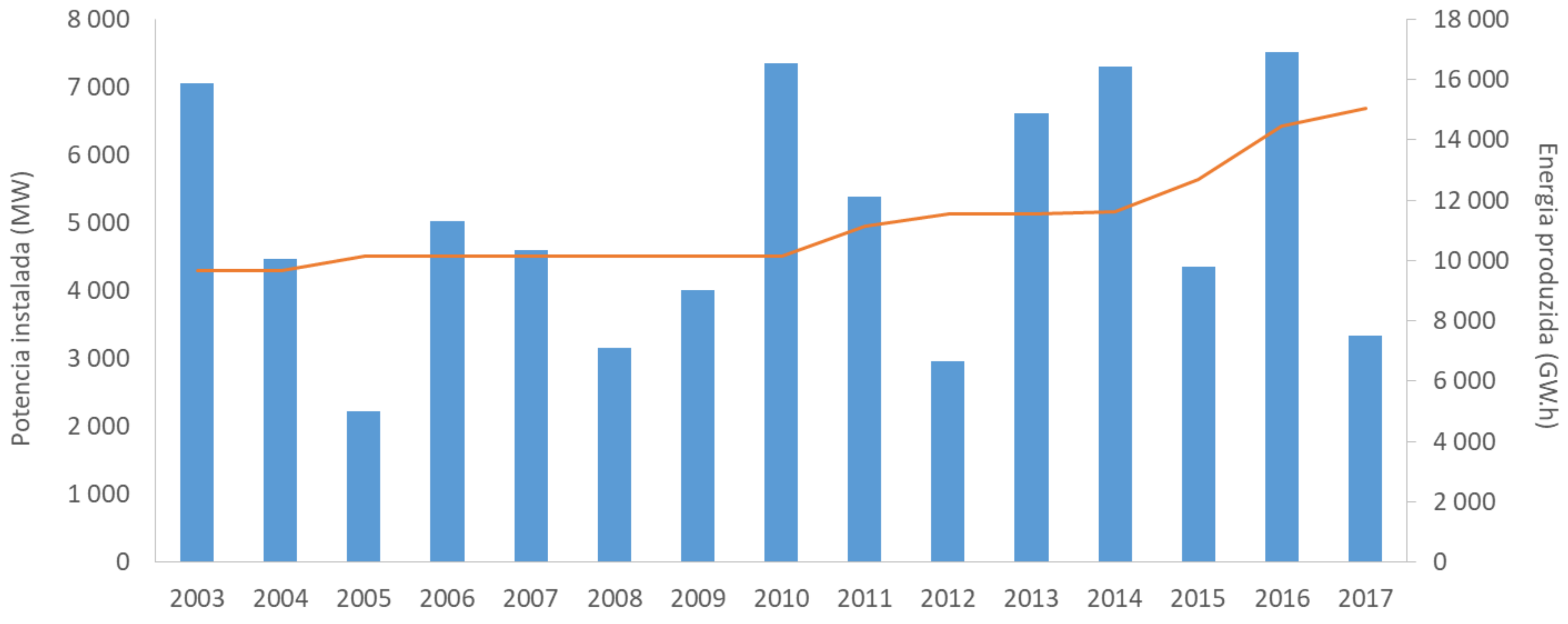
- **Risks to satisfy needs – SCARCITY**
- **Worse water quality increases treatment costs**
- **Water transportation costs**

WATER

CLIMATE CHANGE IMPACTS ON WATER RESOURCES

HYDROPOWER

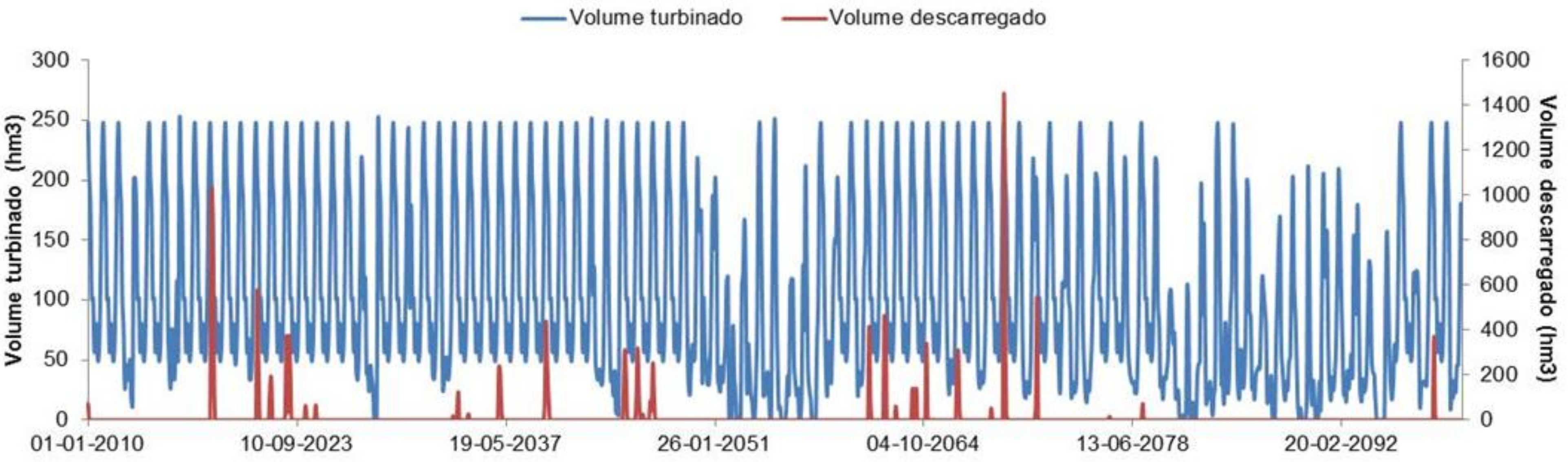
- **Less Water means less energy production**



WATER

WATER USE COMPETITION

- **Less water determine the need to improve water supply reserves, affecting other water uses**
- **Increased Flood risks require existing reservoirs water levels to be lowered**



WATER QUALITY ISSUES

Water quality problems

lower water levels and, in principle, worse water quality

Erosion contributes to an increase in inflow loads to water bodies:

sediments, nutrients, and other toxic pollutants are carried away in precipitation events

Soils are drier due to extended dry periods

Increased air temperature can intensify thermal stratification processes

Longer periods without flow reduce hydrodynamics in water bodies

WATER

FLOOD RISKS

Increased frequency of river floods

increased risks in agricultural systems

Increased frequency of urban floods

risks to people and property

WATER

FLOOD RISKS

Flooding in urban areas is becoming <u>more frequent</u> and <u>more intense</u>

USA

Brazil

Germany

Australia

WATER

FLOOD RISKS

Spain - Valência

Source: Expresso

Source: Público

Source: Expresso

Source: Globo

WATER

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Water availability

- **Increase reserve capacity** – effective but expensive and with high environmental impact; there may not be available area
- **Make the use of systems more flexible** - connections between reservoirs, transfers (e.g. Alqueva – Monte Novo – Vigia – Alvito – Roxo) - systems may still reach their limit and involve transport costs

=> ENVIRONMENTAL IMPACTS

- **Reduce urban consumption** – little flexibility in consumption makes this alternative ineffective
- Choose **agricultural systems that are less demanding** in terms of water
- **Efficiency** in industrial use
    - **Diversify sources?** **WATER REUSE! DESALINATION!**

WATER

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Water availability

- The issue of water availability is largely an **energy problem**
  - transporting water over long distances requires energy
  - in turn, energy requires water…
  - Salinization also requires energy…
- It is necessary to look for **proximity solutions** – sometimes it may be preferable to treat wastewater rather than transport water over long distances

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Increase in air temperature

- It can have implications on energy consumption and therefore also on water needs.
  - for cooling power plants
  - for the transportation of raw materials associated with energy production
  - Increased consumption in irrigation

- building construction systems and green space planning can contribute to lower energy needs

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Water quality

- Management of stored volumes and implementation of aeration/hydrodynamic measures in water bodies

- Qualitative control of inflows:
  - barriers to nutrient retention
  - Soil erosion control
  - Reduction of pollution sources in river basins

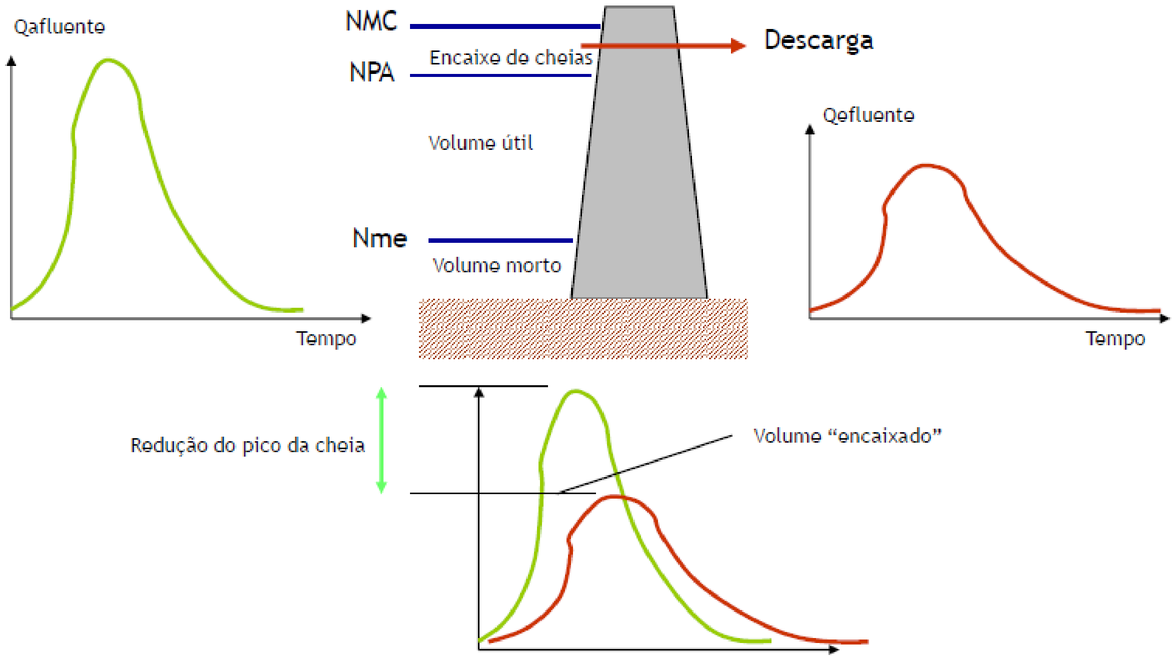
DIFFUSE POLLUTION!!!

WATER

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Runoff control – Floods

Management adequate use of **dams** and reservoirs: operating curve that allows for anticipatory management (it is necessary to ensure that the flood volume is adequate).



Once the control systems are in place, it is necessary to ensure their operability

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Runoff control – Floods

Flood warning systems

- Identification of flood marks and risk areas
- Characterization of flow paths
- Hydrometric monitoring
- Telemanagement
- Warning and alert

Flood Warning and Alert System (SVAC) – SNIRH – regional system

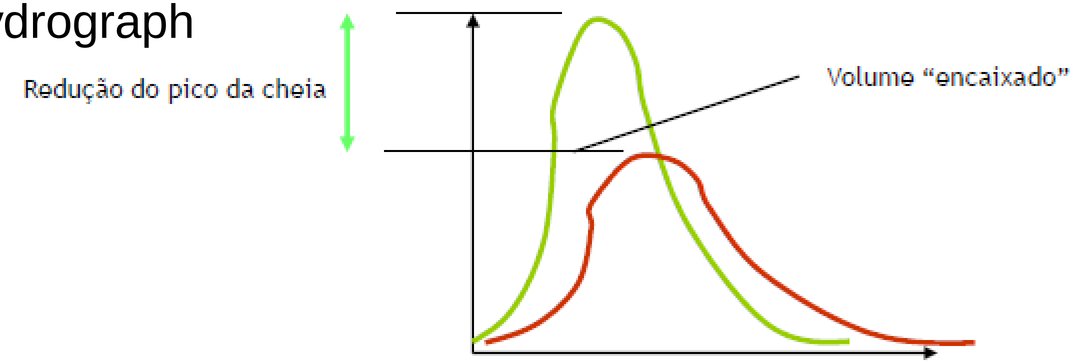
Local/municipal SVACs can also be created

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Runoff control – Floods

Intervention in water lines

- **Unblocking water lines**
- **Hydraulic reprofiling**
- Release and creation of **floodplains** (Flood beds!)
- Measures to **reduce** river **flow speed**
- Creation of **containment systems** that allow reducing the peak of the flood hydrograph



CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Urban Floods

SUDS

Sustainable Urban Drainage systems - Sustainable drainage

The concept is not new and consists of creating drainage conditions that are less favorable to flooding and that allow flood situations to be controlled.

There are many systems that can be introduced into urban spaces with benefits also from the point of view of bioclimatic comfort.

The concept includes retention systems and reduction of flow velocities in public spaces but also in private spaces.

Sustainable Drainage can also include water quality control systems

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Sustainable Drainage – passage and water containment ditches

Rainwater bed
of water passage

Rainwater bed
for water absorption

WATER

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Sustainable Drainage – ditch lined with vegetation

WATER

CLIMATE CHANGE ADAPTATION – SOME THOUGHTS

Urban river restoration

WATER

Individual assignment (0-5)

1. Water is getting more “*expensive*”. How to ensure it as a social good ?

2. Water Resources Equity is a goal according to IWRM. How to overcome the growing regional differences and ensure water scarce countries adequate availability

3. Climate change is inducing growing agricultural water needs. But producers are demanding support to insure increased water reserves and availability for agricultural purposes. **Is this sustainable? Or availability creates demand?**

Write a short essay (maximum 1 page) addressing the suggested topics.

Don’t forget to write your name and student number.

THANK YOU FOR ALL YOUR ATTENTION !

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February 12th, 2025