swarm

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Water Resources Modelling: Part2 - Reservoir operation

Introduction to water management

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Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders

Project number: 597888-EPP-1-2018-1-RS-EPPKA2-CBHE-JP

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The course goal

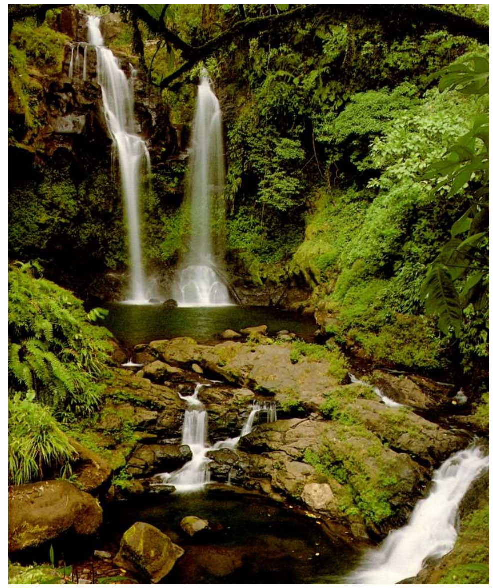
Loucks et al, 2005

- To discuss the ***challenge of water and watershed management*** and the existing approaches and tools to overcome them;
- Highlight the role of ***mathematical modelling***, both simulation and optimization;
- To discuss the ***technical, legal, economic and social aspects*** of water management problems and its solutions;
- As these are intricated (wicked) problems the main keywords are ***integrated management*** and ***adaptative and participative management***;

2

Water planning and management goals

- To achieve and protect a good chemical and ecological status of water bodies;
- To control and mitigate pressures on the environment;
- To guarantee water needs for different uses;
- Protect people and good from water related risks (floods and water related diseases).



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The challenges of water management

- Spatial and temporal variability of water availability;
- Problem complexity:
  - Need to involve many scientific areas;
  - Many interconnected issues;
  - Multiple possible solutions for each problem;
- Frequent conflicts of interests;
- Non-existence of ideal solutions (the interests of some or all stakeholders have to be partially sacrificed).
- Need to address different aspects:
  - Technical;
  - Economics;
  - Political;
  - Social;
- It is difficult to quantify some issues which hinders the comparison of different possible solutions.

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Path to success

- Water governance is key
  - Adequate legal and institutional framework
  - Stakeholders involvement with competent people with the right instruments
- In many parts of the world there is still a need for infrastructures:
  - There should be a business model to build, operate and maintain them.
  - In many cases, green infrastructures may be a solution.
- Promote water efficiency
  - Invest in infrastructure maintenance
  - Adopt a goof water pricing model to signal scarcity and promote efficient water use
  - Adopt flexible water allocation mechanisms
- Improve water quality
  - Wastewater collection and treatment
  - Non-point source is a major concern in most developed countries

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Course syllabus

WATER RESOURCES MODELING: PART 2: RESERVOIR OPERATION				
Monday Topic – Introduction to water management	**Tuesday** Topic – Simulation of reservoirs operation	**Wednesday** Topic – Optimization of reservoir operation	**Thursday** Topic – Optimization of reservoir operation	**Friday** Topic – Groundwater management
Lectures: • The importance of water for human development. • Fundamentals of water management and the challenges of integrated watershed and water resources management. • Water and civilization. • Consumptive and non-consumptive water uses. • Types of dams and reservoirs and its main structures. Students work (in groups)	Lectures: • Flow duration curves and empirical distribution curves • Reservoir sizing • Reservoir simulation • Performance indicators for reservoir operation • Reservoir operation rules. • Risk management and the concept of hedging. • Reservoir operation simulation models and integrated water management models. Students work (in groups)	Lectures: • Simulation vs optimization models. • Linear programming for water management. Students work (in groups)	Lectures: • Dynamic programming for water management. • Multi-objective optimization. Students work (in groups)	Lectures: • Basic concepts of groundwater resources. • Types of aquifers and aquitards. • Aquifer characterization. • Recharge estimation. • Surface water / groundwater interaction. • Groundwater models.

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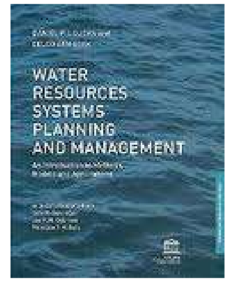
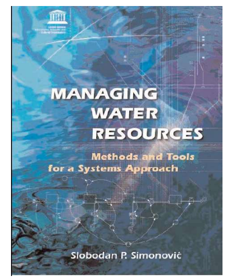
Supporting documentation

- Course site:
  - Slide courses
- Reference books:
  - Water Resources Systems Planning and Management - An Introduction to Methods, Models and Applications, Daniel P. Loucks and Eelco van Beek. http://ecommons.cornell.edu/handle/1813/2804;
  - Managing Water Resources: Methods and Tools for a Systems Approach, Slobodan Simonovic, 2009, UNESCO; http://www.slobodansimonovic.com/waterbook.pdf





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Water and civilization

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Water and civilization

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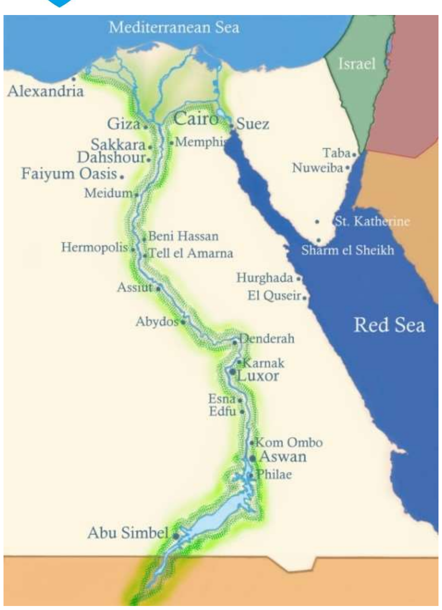
The Nile: Ancient Egipt (3000 – 1000 BC)



- Clockwork predictability in synchronization with the agricultural cycle;
- Good gradient helped to flush out soil salts;
- 2-way navigation;
- Dynastic rises and declines followed river cycles.

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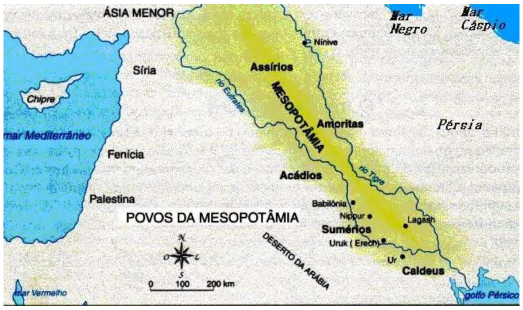
The Tigres and the Euphrates: Mesoptamia and the fertile crescent



- Birthplace of large scale (irrigated) agriculture and home of many great ancient civilizations: e.g. Sumerians (4000 BC), Babylons (1800 BC), Assyrians (700-600 BC), Babylons (500BC), Persians (500 BC).
- Irregular flows required flow regulation and extensive water works;
- These works allowed year-round multi-crop, farming;
- A change of course of the Euphrates helped the decline of the Sumerians;
- Poor drained soils and deforestation decreased soil fertility.

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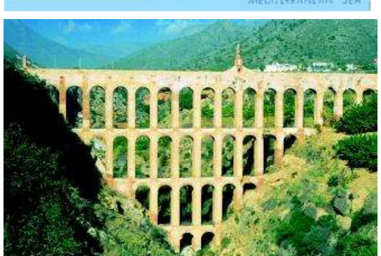
Sea trade and the birth of liberal market democracy



- Minoans of Crete, 2000 BC
- Phoenicians,1000-800 BC
- Etruscans,
- Classical greeks,
- Romans (260 BC – 410 AD).

- All these civilization built coastal towns with good water sources access.
- And put water at the center of its beliefs.
- Romans works for urban water supply and drainage are particularly impressive.

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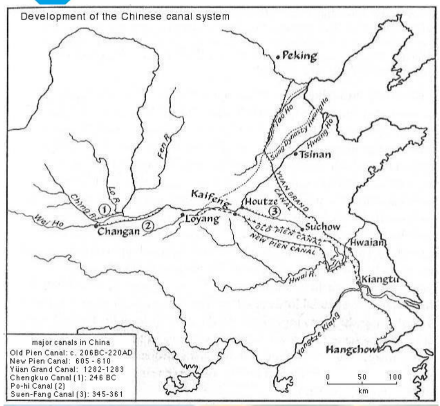
The Yellow and Yangtze rivers and the Grand Canal: The chinese civilization



- China main rivers:
  - Yellow river (Huang He) plateau: soft, easily farmed and rich soil with a harsh and drought prone climate;
  - Yangtze basin: hilly and humid;
- Several canals were built to connect these rivers:
  - Ling Chu canal (219 BC) – small countour canal:
  - Grand Canal (610 AD): 1100 miles linking Shanghai to Benjing;
  - New Grand Canal (1411).
- Easy movement(armies and tax inspectors) facilitated the centralization of government;
- Helped the rice-farming revolution in the south (8th-12th century)
- From 1411 onwards promoted china isolation.

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China: Recent or in construction canals

Source: NYT

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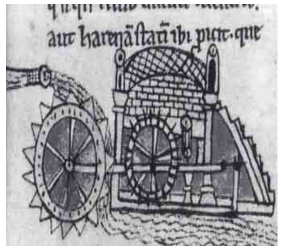
The rise of agriculture, irrigation and water mills

- Iron age (1000 BC);
- Technological breakthrough: moldboard plow (700 AD) – increased productivity and promoted the cultivation of larger field owned by a single lord.
- Water weels to elevate water and grind cereals (from 100 BC with continuous improvements)

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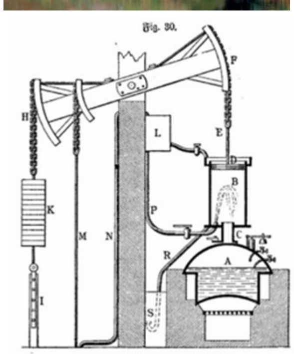
English industrialization



- Key factors:
  - Water weels: cotton textile factories;
  - Steampower (J.Watt, 1769);
  - Transportation canals to transport coal: 1759 (Duke of Bridgewater) ownwards;
- These technological advances allowed the transition from a rural society to an urban society.
- Towns sometimes located away from watercourses required large volumes of water delivered by steam pumps (London, 1778).
- Waterpower efficiency continued to increased, namely with the invention of the hydraulic turbine (1830s).

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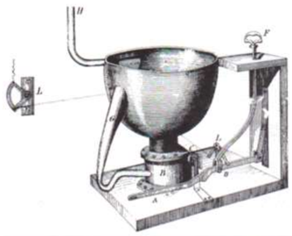
Sanitary revolution



- Industrialization and urbanization lead to pollution and health problems from water borne diseases: i.e. cholera and typhoid fever.
- Toilet invention (1596, 1775, 1860): a great idea that created many problems;
- London Great stink 1858;
- London Cholera outbreaks 1831-1832; 1848-1849; 1853-1854;
- Edwin Chadwick (1842): argued for the relation between health and unsanitary conditions – miasma theory: foul smells were the cause of cholera;
- John Snow (1854): advanced the idea that cholera was a waterborne decease;
- Joseph Bazalgette: designed the London's first modern urban water supply and sewage system (1869-1879).

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Bezalgette and the London embankments

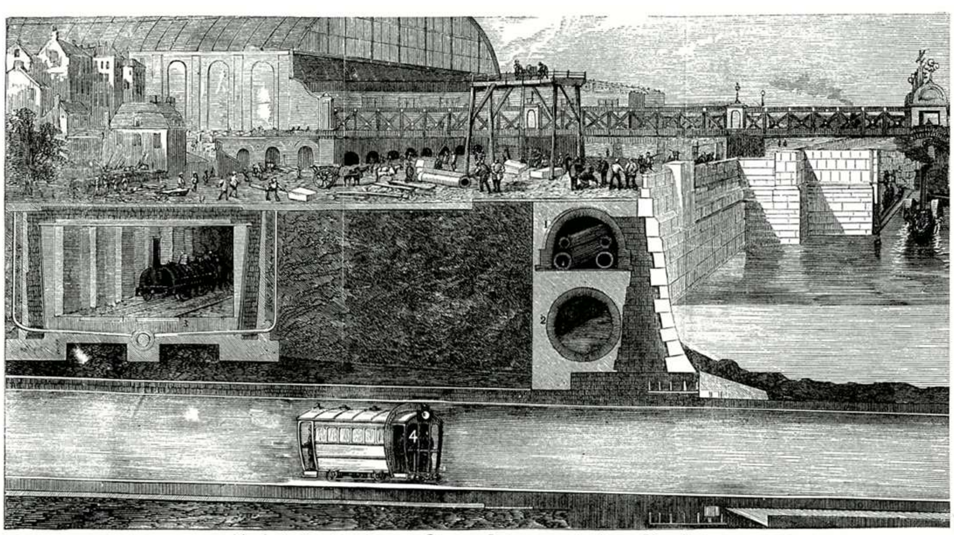

Fig. 6.—Section of the Pneumatic Passenger Railway under the Thames River, London.

(1.) Subway for Gas and Water Pipes. (2.) Sewer. (3.) Metropolitan Underground Steam Railway. (4.) Pneumatic Passenger Railway, now in course of construction. The Pneumatic Railway extends from Charing Cross, and passes under the Thames River to the Waterloo Road Station of the Southwestern Railway The engraving represents that portion under the Thames embankment which has been finished.

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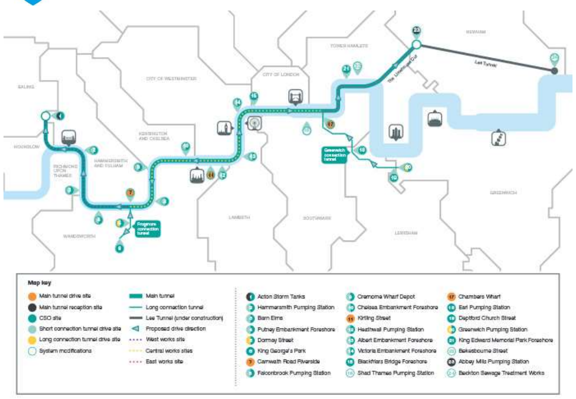
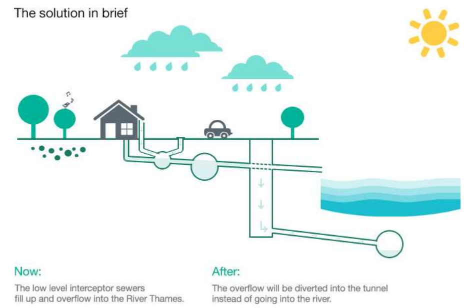
Thames Tideway Tunnel





- A tunnel with 25 km of length and 7 m of diameter, built 65 m below the Thames;
- It will receive 3,9 x10^9 m^3 of urban sewage to be delivered to the largest treatment plant in Europe;
- An investment of 4,2 x10^9 pounds.

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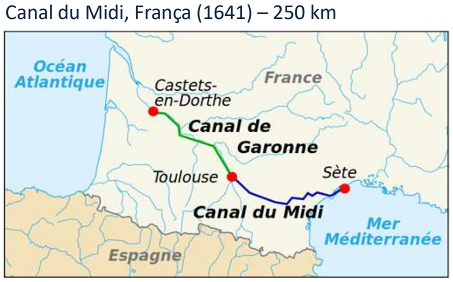
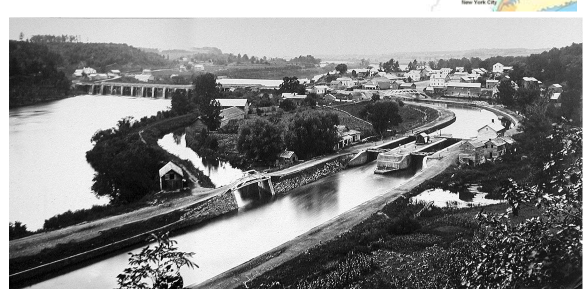
The great inland navigation cannals

Canal du Midi, França (1641) – 250 km



Rhine-Main–Danube canal (1992) - 106 miles

Erie canal, NY (1860)



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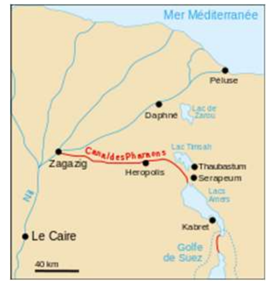
Great ocean canals

Suez canal (1869) – First dreamed and built in 600 BC by Pharaoh Neko II



Panama canal (1914)

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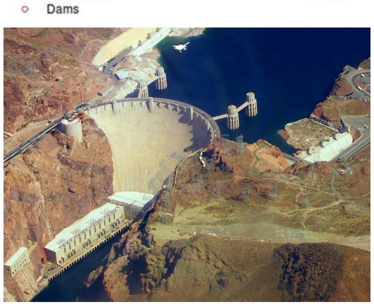
Dam construction boom



- In construction by 1935:
  - Hoover, Colorado river
  - Grand Coulee, Columbia river
  - Bonneville, Columbia river
  - Shasta, Sacramento river
  - Fort Peek, Upper Mississippi river
- Between 1933 and 1973, 36 huge dams were constructed.
- By 1980, Columbia river was providing 40% of America electricity needs.

Hoover dam, NV/NM, 1935

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The dust bowl: American and Canadian prairies, 1930's

Great Plains of the United States (1935):

- A humid period in the late 1920s led many to extensively cultivate the plains of Oklahoma, Texas and other states;
- There followed a drought that left the soil dry and exposed to winds;
- On April 14, 1935 million tons of soil were carried by the wind;
- Farms were abandoned and mass migrations of a poor population occurred;
- In 1939 Steinbeck wrote The Grapes of Wrath and in 1940 John Ford made a film.

Great Plains of the United States (1996):

- A new generation of farmers maintains practices of soil conservation, especially the maintenance of trees and soil cover with remnants of vegetation;
- A drought similar to that of 1930 did not cause so much damage.

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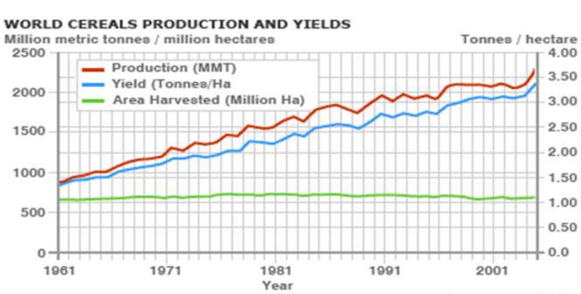
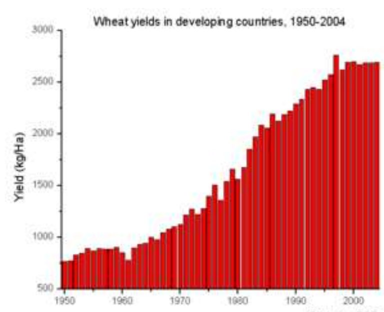
The green revolution

- Water availability offered by large reservoirs: Aswan dam in the Nile, Ataturk dam in Turkey, dams in the Volga, Dniepr, Don and Dniester(Russia), China, etc
- New crops varieties: e.g. hybrid American corn, hybrid dwarf wheat, hybrid dwarf rice.
- Fertilizers and pesticides;
- Mechanization.





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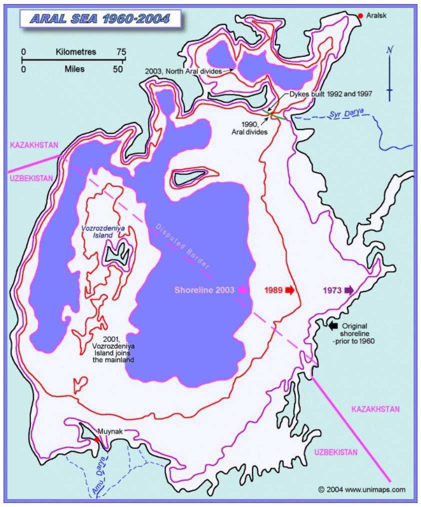
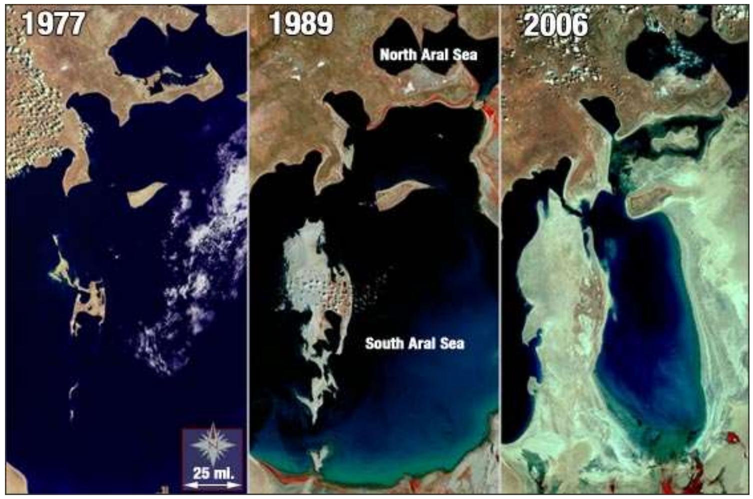
Aral sea





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Aral sea

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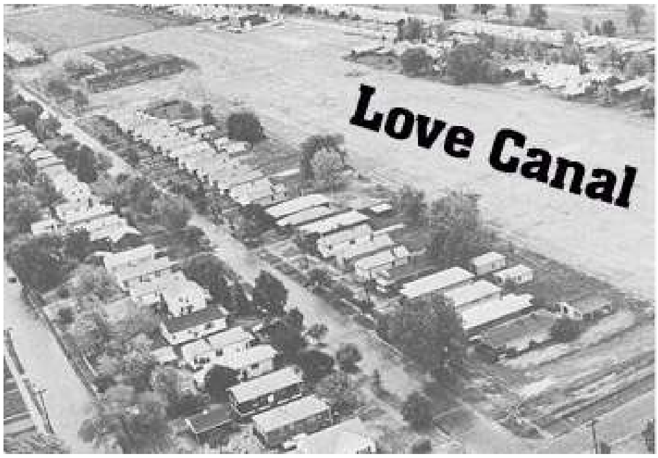
Contamination problems

Love Canal, NY, 1952



Cuyahoga River, OH, 1952

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Navigation: Germany and Scotland

Cannal-bridge over Elba river, near Magdeburgo and Berlin. It links west and east Germany, with a length of 918 m. It cost 500 millions euros and took 6 years to be built.

Scotland

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Water and civilization: main ideas

- Water is needed for many uses (urban supply, irrigation, navigation, energy production defense);
- Humans have always gathered around water sources and water bodies that enabled food production and transport;
- The access to water has always meant power and well being;
- Larger water uses and improved efficiencies has led to larger economic benefits;
- Water availability and its use has conditioned how human societies have been organized;
- Throughout history water technology has evolved and breakthroughs have overcome existing bottlenecks;
- Extreme water uses and some water works have led to significant pressures on water resources and ecosystems;
- Throughout history the management of water has always been a challenge with very specific characteristics.

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Water uses

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Water uses and other water management goals

- Water use: Any activity that uses water
- Off-stream consumptive uses:
  - Municipal uses (human consumption + other uses)
  - Industrial uses
  - Agricultural uses
- In-stream non-consumptive uses:
  - Energy production
  - Navigation
  - Fisheries
  - Recreation and leisure activities
- Other water management objectives:
  - Flood control
  - Water quality control
  - Ecosystem's support

Water bodies protection and improvement of its status

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Net and gross water requirements

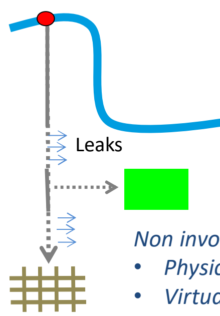
- Demand, need or requirement:
  - Water required for a given use;
- Gross demand or requirement:
  - Abstracted volume = Net requirements plus losses between abstraction point and consumption point.
- Net demand or requirement: Volume effectively needed for a given use;
- Consumption: Volume effectively used;
- Efficiency (various definitions):

$$Efficiency = \frac{Net\ requirements}{Gross\ requirements}$$

$$Efficiency = \frac{Net\ consumption}{Abstracted\ volume}$$

$$Efficiency = \frac{Invoiced\ volume}{Abstracted\ volume}$$

$$Inefficiencies\ (losses) = 1 - Efficiency$$



Non invoiced volumes include:
- *Physical losses (real leaks)*
- *Virtual leaks (non authorizes uses)*
- *Authorized non-invoiced uses*

According to ERSAR (2018), in Portugal:
- The volume abstracted from water sources for municipal uses which is not invoiced is:
  - Bulk distribution: 5% - 12% (68% are real losses)
  - Retail distribution: 11% - 38% (70% are real losses)
- A value of 15-20% is assumed as technically acceptable

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Measures to improve water use efficiency

- **Urban uses:**
  - Water supply networks: Loss control, pressure reduction, water reuse, water harvesting.
  - Buildings: Loss control, pressure reduction, water reuse, efficient equipment (flush toilets, washing machines)
- **Industrial uses:**
  - Improvements of industrial processes;
  - Water reuse;
  - Rainwater harvesting.
- **Agricultural uses:**
  - Improvement of the methods applied to estimate water needs from crops;
  - Losses reduction in water supply and distributions systems;
  - Upgrade of irrigation methods: Drip irrigation, sprinklers with wind curtains
  - Irrigation during the night.

To implement these measures: public awareness; command and control measures; tax and pricing schemes.

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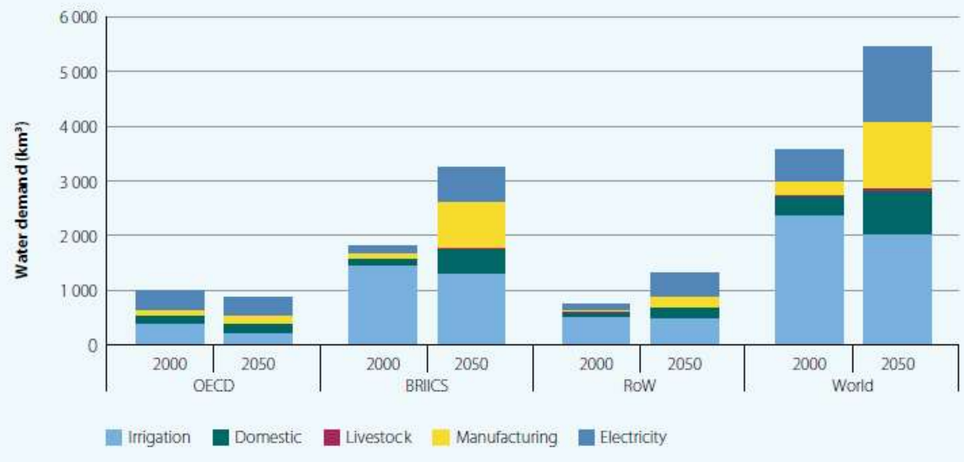
Global water demand (freshwater withdrawals)



Note: BRIICS (Brazil, Russia, India, Indonesia, China, South Africa); OECD (Organisation for Economic Co-operation and Development); RoW (rest of world). This figure only measures 'blue water' demand and does not consider rainfed agriculture.

Source: OECD (2012a, Fig. 5.4, p. 217).

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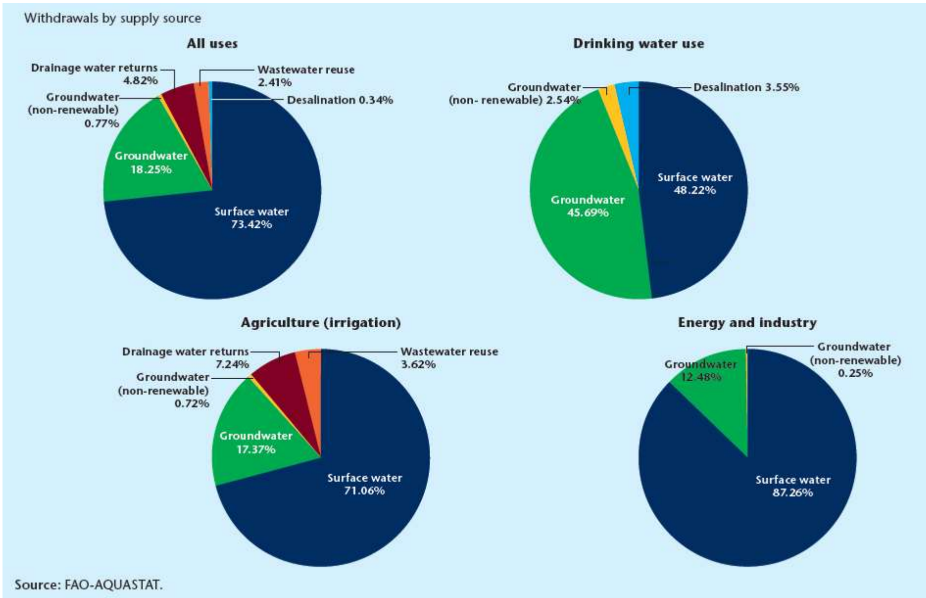
Withdrawals by water source (World)



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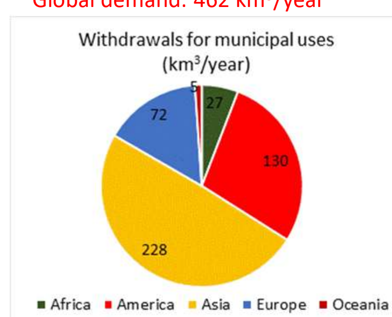
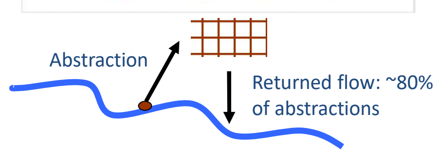
Municipal uses

- Municipal uses includes:
  - Domestic uses (or for human consumption) for cooking, bathing and washing;
  - Commercial uses and industrial uses supplied from the urban network;
  - Public uses (gardens, street cleaning);
- Water needs depends on:
  - Climate;
  - Home typology;
  - Environmental concerns / social habits;
  - Relevance of commercial and industrial uses.
- Approximate estimates:
  - Desirably 50 m^3/person/year, i.e. 120-130 l/person/day (much less in dry climates: ~50 l/person/day)
  - Return flow; ~80% abstraction
- Main characteristics:
  - Requires a high reliability of supply (~95%);

Global demand: 462 km^3/year





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Domestic water needs

- Typical values (Linsley - USA)
  - Domestic use: 225 l/hab/dia (150-300 l/hab/dia)
    - Lavatories / taps: 20 l/hab/dia (9%)
    - Cooking: 30 l/hab/dia (13%)
    - Bathing: 45 l/hab/dia (20%)
    - Clothes washing (machine): 35 l/hab/dia (16%)
    - Toilets: 95 l/hab/dia (42%) <<<< VERY HIGH FIGURE
  - Commercial and industrial use: 150 l/hab/dia (30-300 l/hab/dia)
  - Public use: 75 l/hab/dia (60-100 l/hab/dia)
- Distribution of domestic use (PNUEA - Portugal):
  - Taps: 41%
  - Shower: 39%
  - Toilet flush: 11%;
  - Laundry washer: 7% (35 a 220 litres/operation (5 kg load)).
  - Dish washer: 2%.

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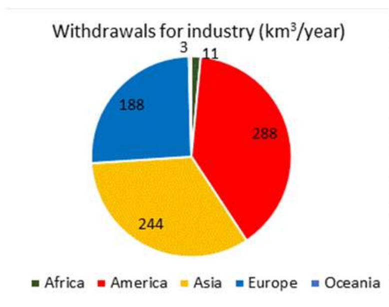
Industrial uses

Global demand: 800 km^3/year



- Main characteristics:
  - High reliability of supply (~95%);
  - Specific water quality.
- Water needs depend on:
  - Type of industry;
  - Industrial processes;
  - Existence of saving or reuse schemes;
- Industrial water requirements are quite difficult to estimate; Water requiremens depend on:
  - Type of industry;
  - Industrial processes;
  - Existence of saving or reuse schemes;
- There are no generic rules for wide application; The best approach is to perform industry surveys on water use.

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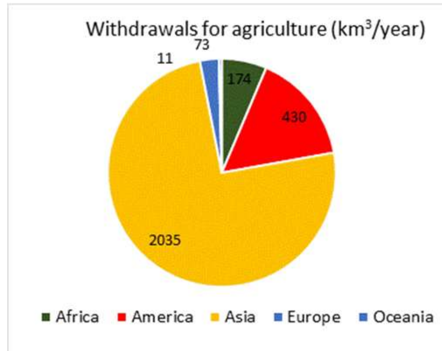
Agricultural uses

- Agricultural uses includes
  - Raising crops
  - Raising livestock
- Agriculture requires large volumes of water which means that reliability levels cannot be high;
- Two main types of agricultural practices.
  - Irrigated agriculture
  - Rain fed or dry land farming
- Global water needs (WWDR, 2015): 7500 km^3/year
  - Rainfed agriculture: 4800 km^3/year
  - Irrigated agriculture: 2700 km^3/year

Global demand: 2723 km^3/year



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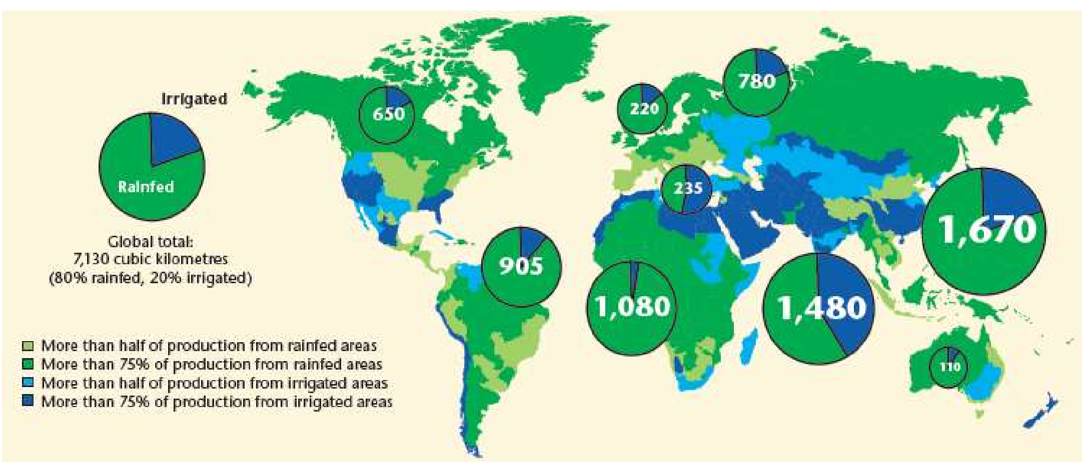
Irrigated versus rainfed agriculture



Source: Based on Comprehensive Assessment of Water Management in Agriculture 2007.

Direct precipitation supplies 80% of agricultural water needs, but only 60% of agricultural production. Irrigation is used in 20% of the land but support 40% of production.

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Irrigation methods

- Irrigation is an artificial application of water to the soil.
- Main irrigation methods:
  - Surface (efficiency: 0,40 a 0,55)
  - Sprinkler (efficiency: 0,50 a 0,50)
    - Central pivot
    - Linear advancing structure
    - Water canon
  - Drip irrigation (efficiency: 0,55 a 0,80)
- Factors that influence selection
  - Topography
  - Soil type
  - Wind
  - Water availability
  - Energy cost

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Water needs per crop

Crop water needs depend on:

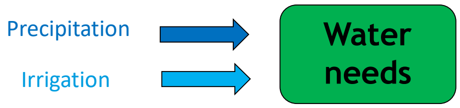
- Crop;
- Soil;
- Climate;
- Other factors (e.g. quantity of fertilizers applied)

Crop water needs (crop evapotranspiration) = $PET_c = K_c \times PET_o$

- K_c - Crop coeficiente: depends on crop and development stage

Crop net irrigation needs = $PET_c - P_{net}$

- P_{net} - Precipitation useful for plant growth: depends on soil, climate, precipitation pattern)



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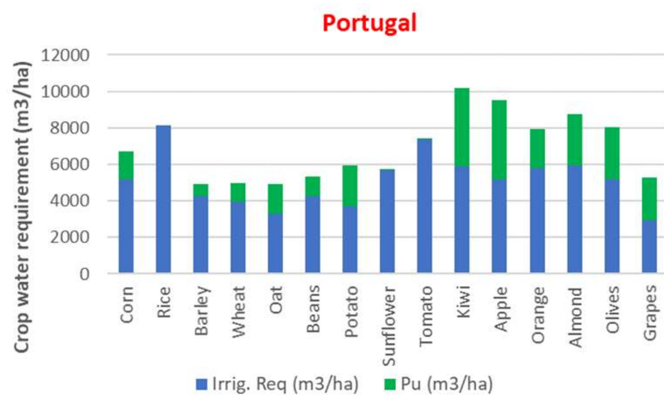
Crop water requirements

- Crop water requirement; crop irrigation needs: m^3/ha *1 m³/ha = 0.1 mm*
- Crop production yield: ton/ha
- Crop water productivity (water footprint): m^3/ton.



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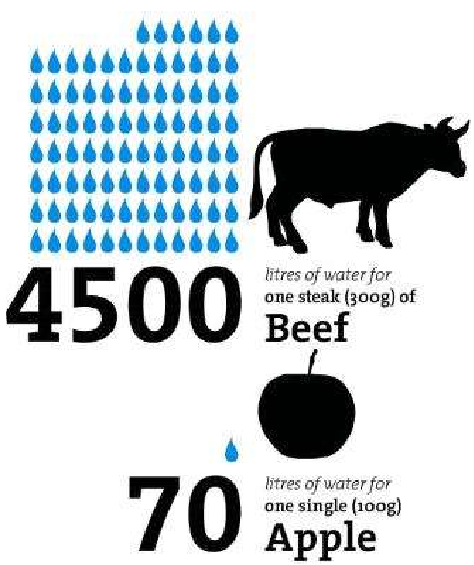
Virtual water



Product	Quantity	Virtual Water Content (liter)
Food and Drink		
Vegetarian diet	Daily (adult)	1,200
Meat-eating diet	Daily (adult)	16,000
Glass of milk	250 ml	250
Cup of coffee	125 ml	140
Cup of tea	125 ml	20
Slice of bread	30 g	40
Slice of bread with cheese	30 g + 10 g	90
Potato	100 g	25
Apple	100 g	70
Glass of wine	125 ml	120
Glass of beer	250 ml	75
Glass of apple juice	200 ml	190
Glass of orange juice	200 ml	170
Bag of potato crisps	200 g	185
Egg	40 g	135
Hamburger	150 g	2,400
Tomato	70 g	13
Orange	100 g	50

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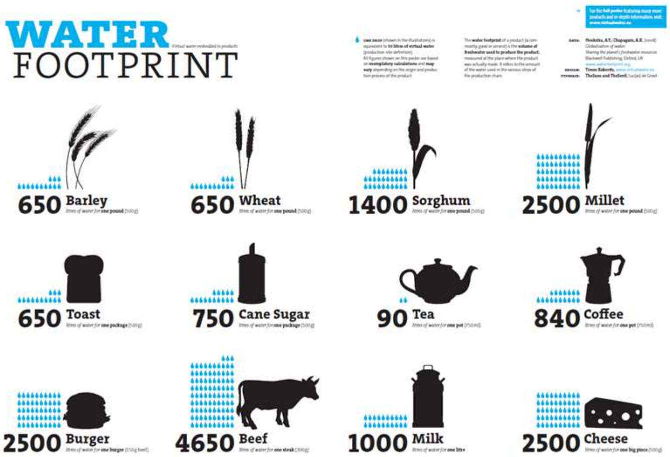
Water footprint



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Apple	100 g	70
Glass of wine	125 ml	120
Glass of beer	250 ml	75
Glass of apple juice	200 ml	190
Glass of orange juice	200 ml	170
Bag of potato crisps	200 g	185
Egg	40 g	135
Hamburger	150 g	2,400
Tomato	70 g	13
Orange	100 g	50

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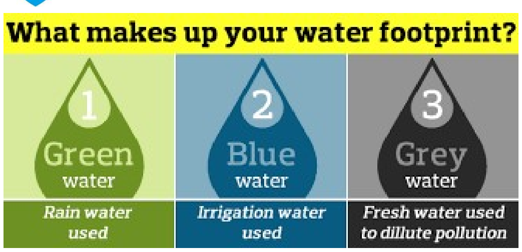
Water footprint & Virtual water
Water colors



Water colors (Falkenmark, 1995):

- **Blue water** – water in rivers and aquifers;
- **Green water** – Evapotranspired water
  - Productive – Plant evapotranspiration
  - Nonproductive – Evaporation from water and land surfaces
- **Grey water:** Water needed to assimilate discharges.

Virtual Water (Allan, 1997): Water included in a product.

Water footprint :

- Includes water consumption and pollution (throughout the full production cycle from the supply chain to the end-user): Direct and indirect water use;
- Can be applied to a process, product, company or sector.

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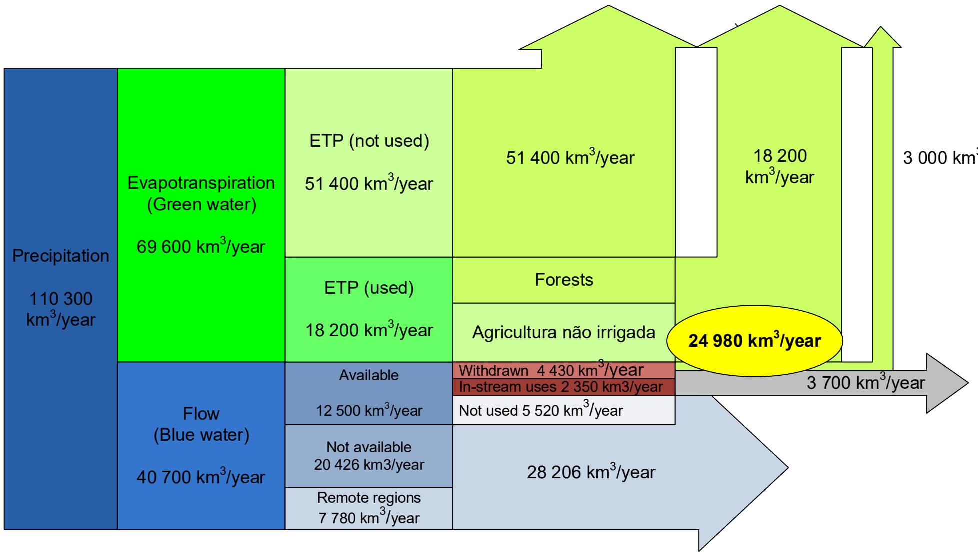
Available water resources



Fonte: baseado em Rogers, P., 2006, Water governance, water security and water sustainability. In: Rogers, Lamas e Martinez-Cortina, Water crisis: mith or reality?, Fundacion Marceino Botin, 2006

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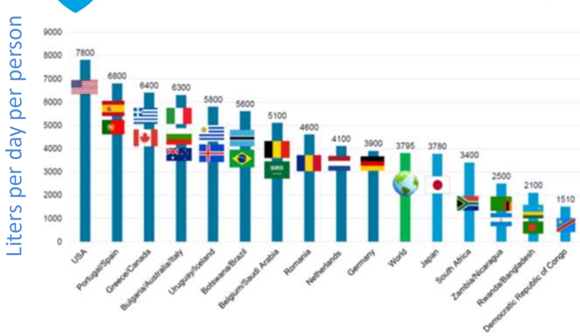
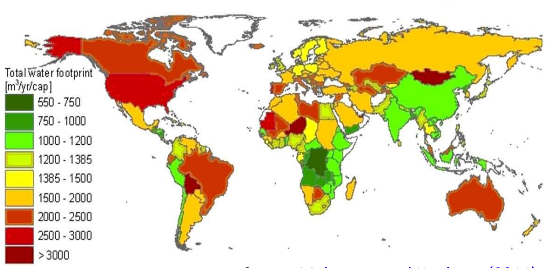
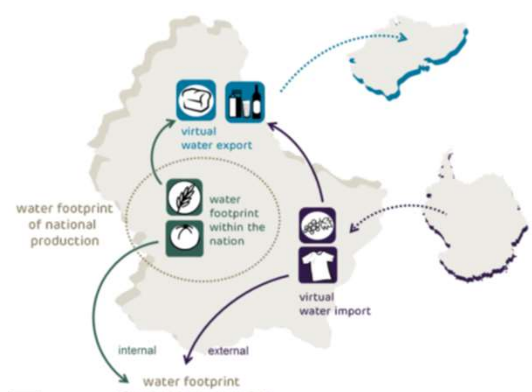
Water footprint of consumption





Source:Mekonnen and Hoekstra (2011).

Water footprint of national consumption: Amount of fresh water that is used to produce the goods and services consumed by the inhabitants of the nation; includes imports and excludes exports.



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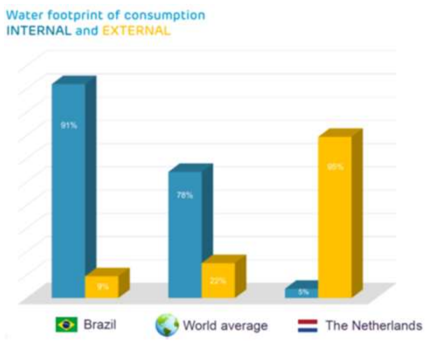
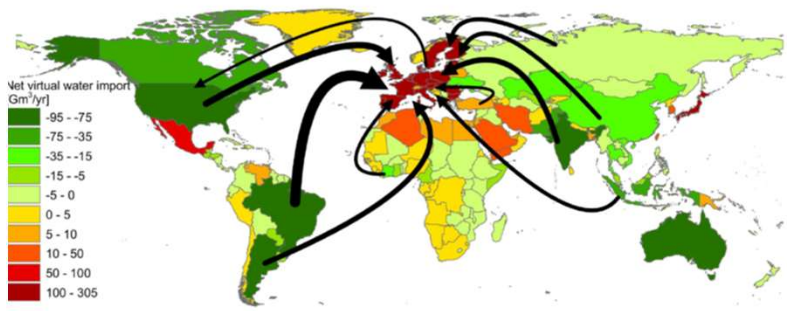
Internal and external water footprints of consumption



Internal water footprint of consumption + External water footprint of consumption = Water footprint of consumption

Net virtual water imports to Europe



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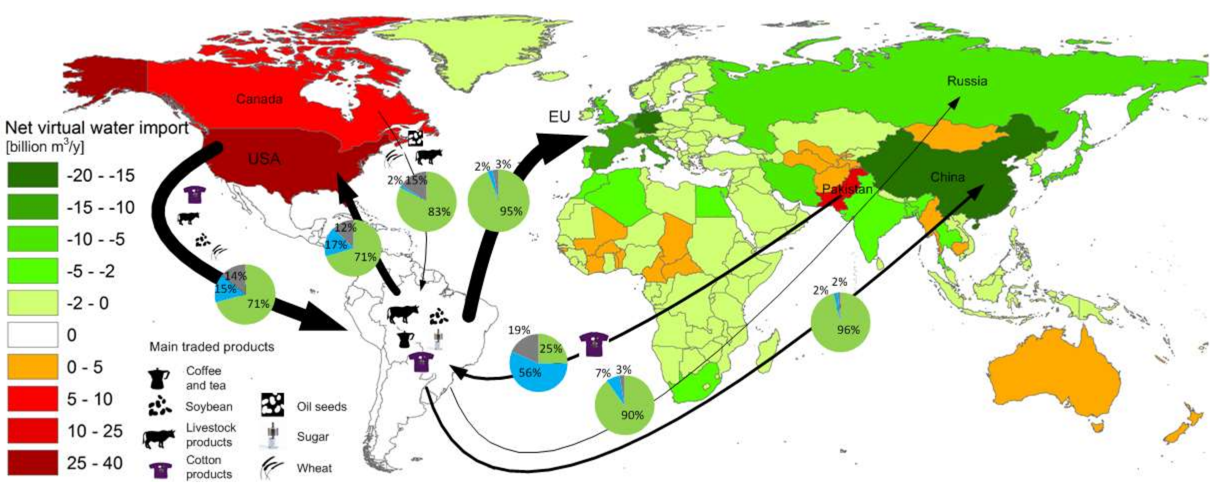
Virtual water trade (net imports) with Latin America



Countries with net virtual water import related to import of agricultural and industrial products from Latin America and the Caribbean (green) and countries with net virtual water export due to agricultural and industrial exports to Latin America and the Caribbean (red) over the period 1996-2005. Only the biggest gross virtual water flows (>10 billion m 3 /year) are shown.

Source: Mekonnen, M.M.; Hoekstra, A.Y. National Water Footprint Accounts: The Green, Blue and Grey Water Footprint of Production and Consumption; UNESCO-IHE: Delft, The Netherlands, 2011.

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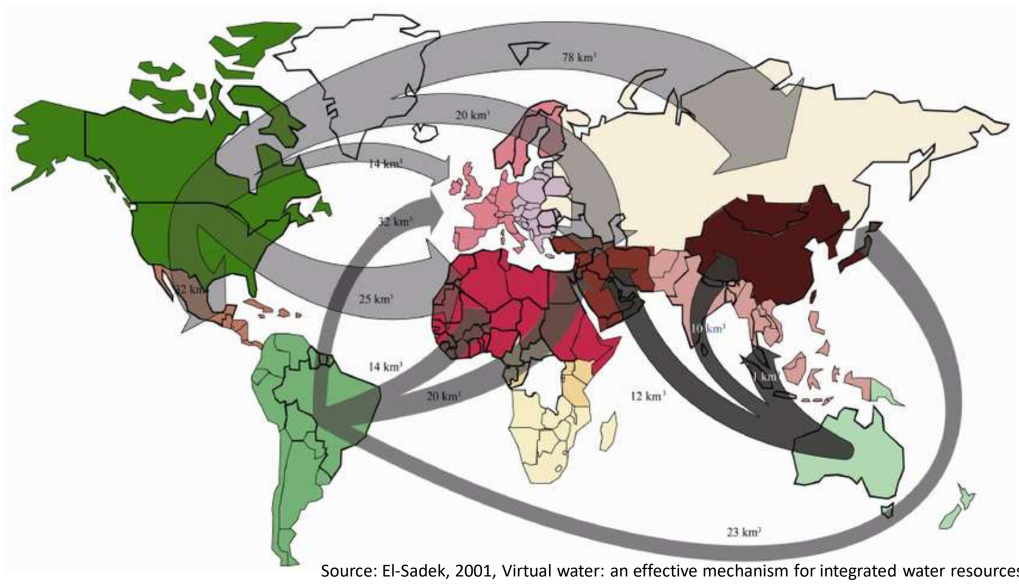
Virtual water trade (net imports)



Source: El-Sadek, 2001, Virtual water: an effective mechanism for integrated water resources management, Agricultural Sciences 2(03):248-261

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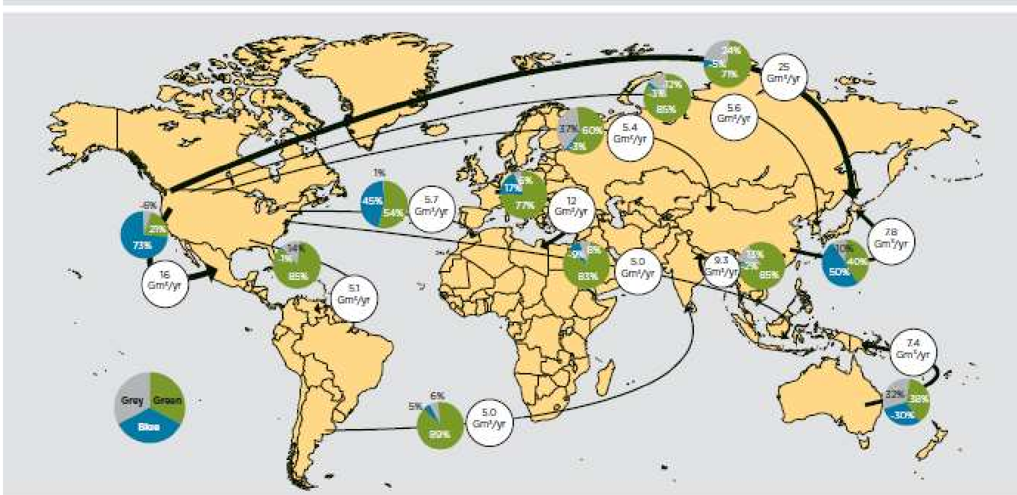
Global water saving from agricultural trade

Global water savings associated with international trade in agricultural products (1996–2005)



Note: Only the biggest water savings (> 5 Gm³ per year) are shown.
Source: Mekonnen and Hoekstra (2011, p. 24).

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Navigation

- **Navigation activities** requires a continuous water body (or linked water bodies) with a steady regime of adequate water depths and low water velocities;
- Locks and other hydraulic works are built to:
  - Maintain adequate water depths;
  - Ensure adequate rivers widths;
  - Maintain low river velocities;
  - Overcome natural or man-made barriers;
  - Docking for loading and unloading.

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Example: Missisipi river

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Recreation

- **Recreation activities** require water bodies in their almost pristine (natural) state, with specific water dynamics and healthy ecosystems.



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Aquaculture farming

- **Aquaculture farming** require water bodies with good/excellent status, low flow velocities and adequate water depths.



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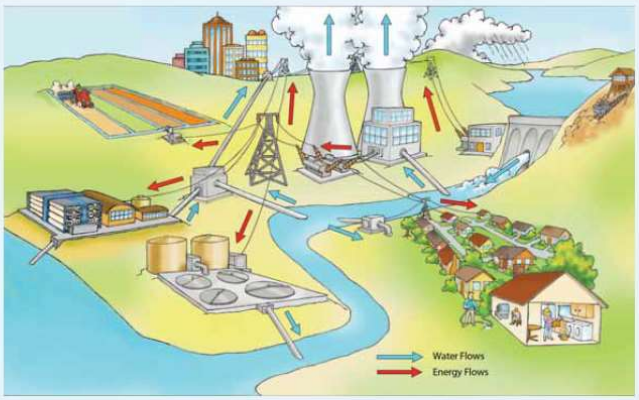
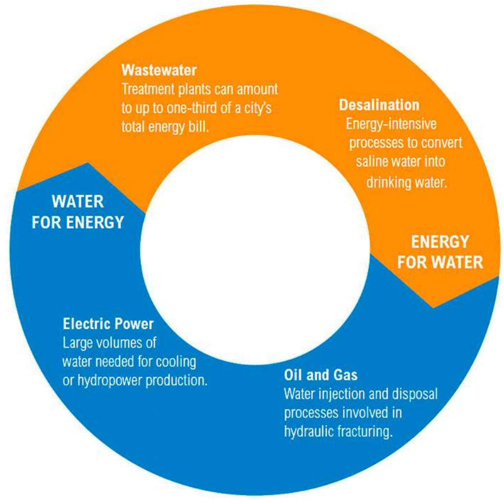
The water energy nexus

The energy-water nexus



Note: Energy flows are shown in red and water flows are shown in blue. As shown in the residential community, electricity and water are both used for different purposes.
Source: Courtesy of EPRI (prepared by EPRI for a US DOE Report to Congress in 2006).



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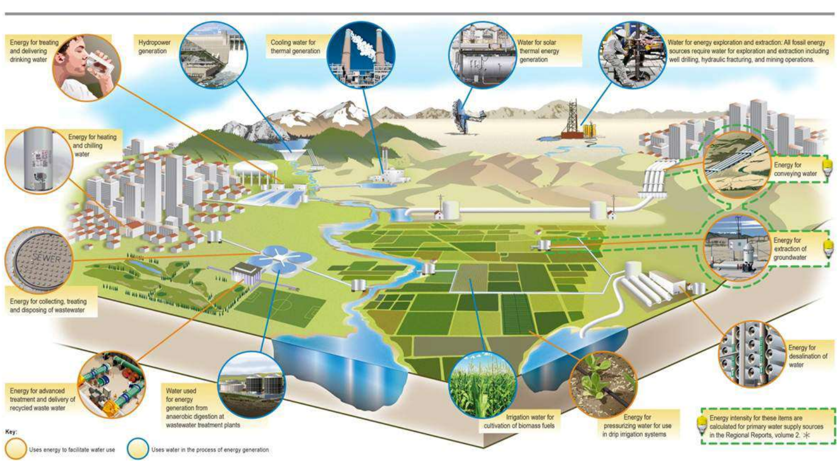
The water energy nexus



Águas de Portugal (Portugal's main water utility) represents 1,4% of the total electricity consumption in Portugal.

Water for energy

- Cooling of thermal plants;
- Hydroelectricity production;
- Electricity production through waves and tides;
- Electricity production from water treatment plants;
- Biofuel's production;
- Energy storage;
- Hydrogen production

Energy for water

- Water uptake;
- Water treatment;
- Water desalination.

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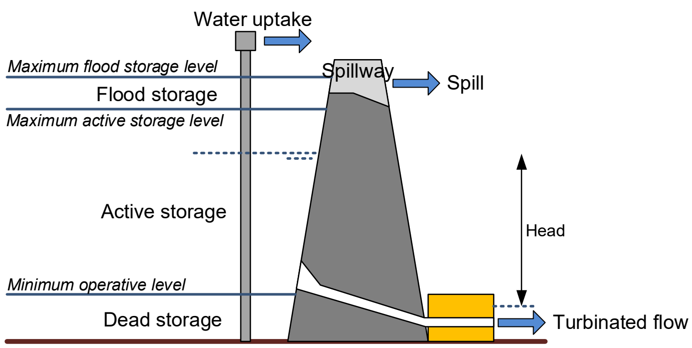
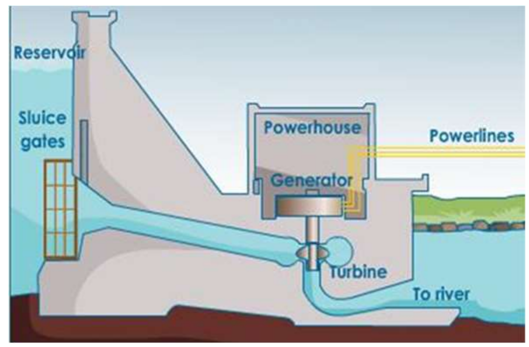
Power production

$$Power = \eta \cdot \gamma \cdot Q \cdot H$$

$$Energy = \eta \cdot \gamma \cdot V \cdot H$$

Q = discharge
V = Volume discharged over a period of time
γ= Water specific weight = 9800 N/m^3
η = efficiency (%)





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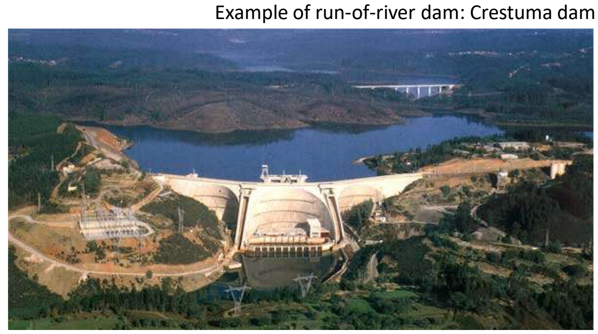
Types of hydropower plants

- Installed capacity
  - Micro (P<100 KW)
  - Mini (100 KW< 1 MW)
  - Small (1-25 MW)
  - Medium (25 -100 MW)
  - Large (P>100 MW)
- Head
  - Low head (H<30 m)
  - Medium head (30-300 m)
  - High head (H>300 m)
- Operative mode:
  - Run-of-river reservoirs
  - Storage reservoirs
  - Pump storage

$$Storage\ coef. = \frac{Net\ storage\ capacity}{Avg\ annual\ inflow}$$

Example of run-of-river dam: Crestuma dam



Example of a reservoir dam: Aguieira dam

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Largest power plants

Name	Year	Inst.capacity (Mw)	Energy prod. (GWh/year)	Country
INGA III	Proj.	40 000		Congo
SANXIA (Tres Garg.)	2010	22 500	84 900	China
ITAIPU	1991	14 000	90 000	Brazil / Paraguay
BAIHETAN (C)		14 000	51 500	China
XILUODU (C)		13 860	57 120	China
BELO MONTE	2011	11 234		Brazil
GURI	1986	10 000	52 000	Venezuela


Castelo de Bode (Portugal)


Three Gorges (Sanxia)


Itaipu (Brasil-Paraguai)

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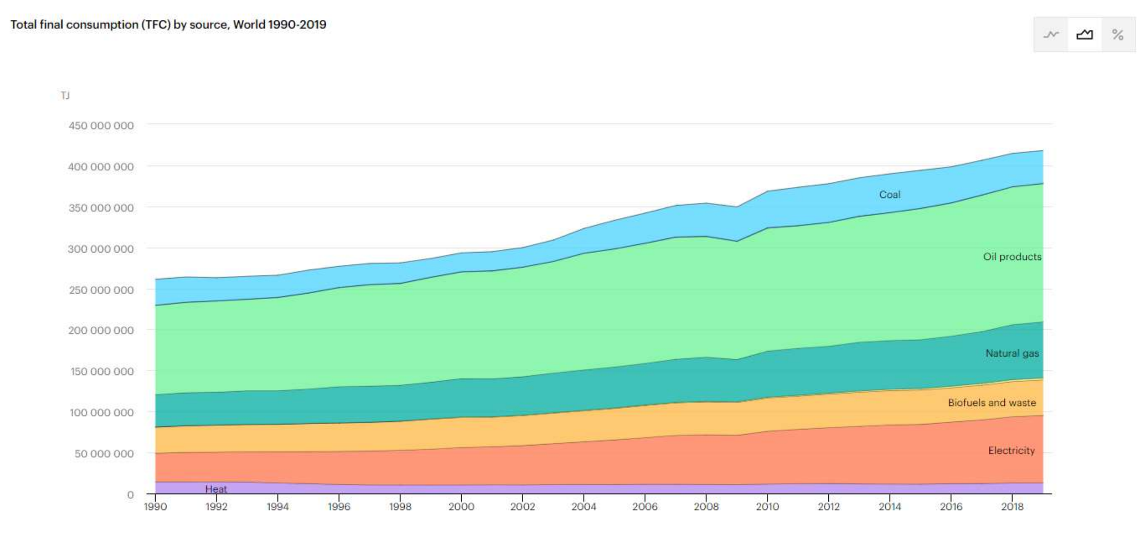
World total final consumption by source, 1990-2019



Source: www.iea.org/

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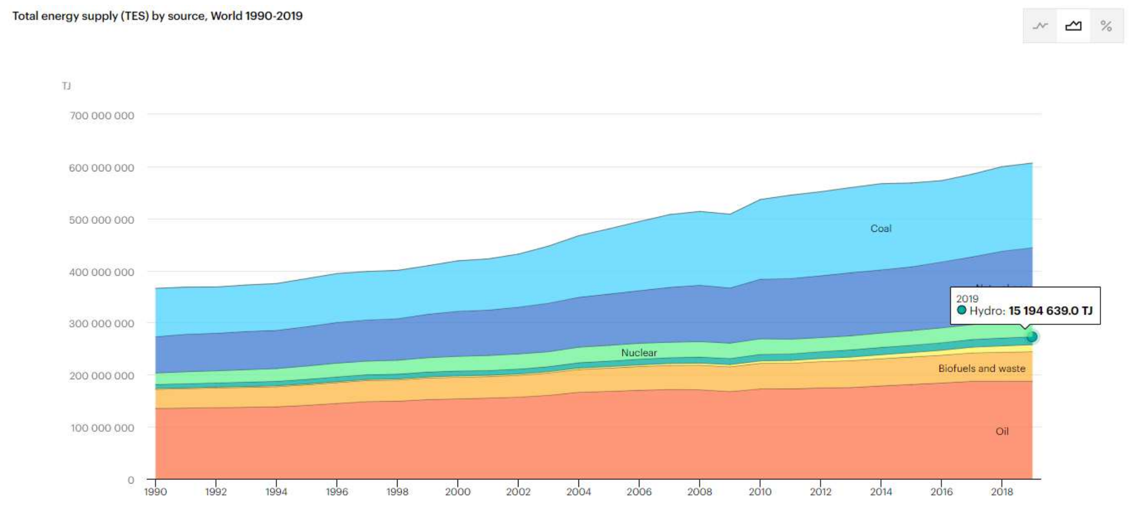
World total energy supply by source 1990-2019



Source: www.iea.org/

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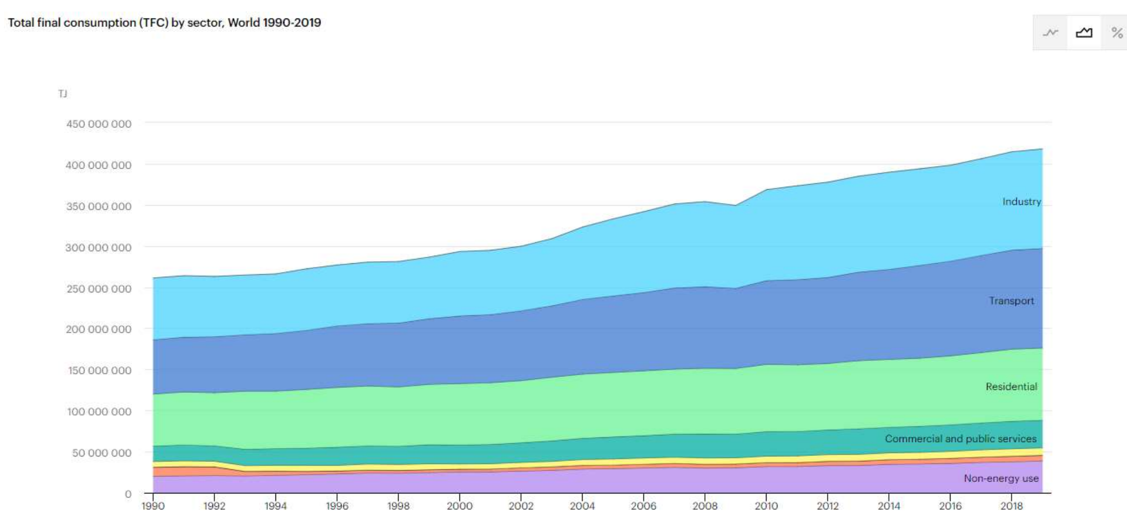
World total final consumption by sector, 1990-2019



Source: www.iea.org/

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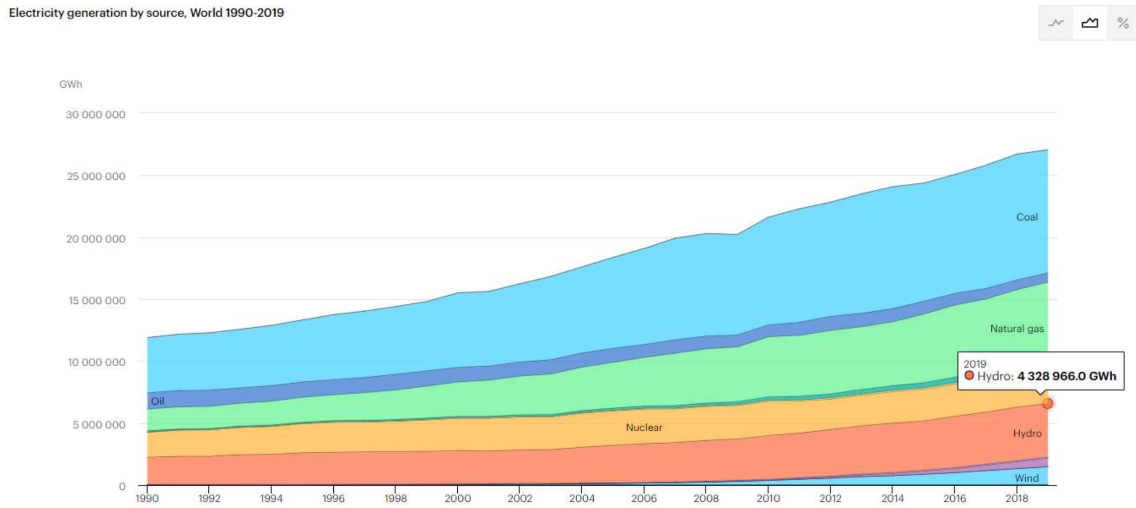
World electricity generation by source 1990-2019



Source: www.iea.org/

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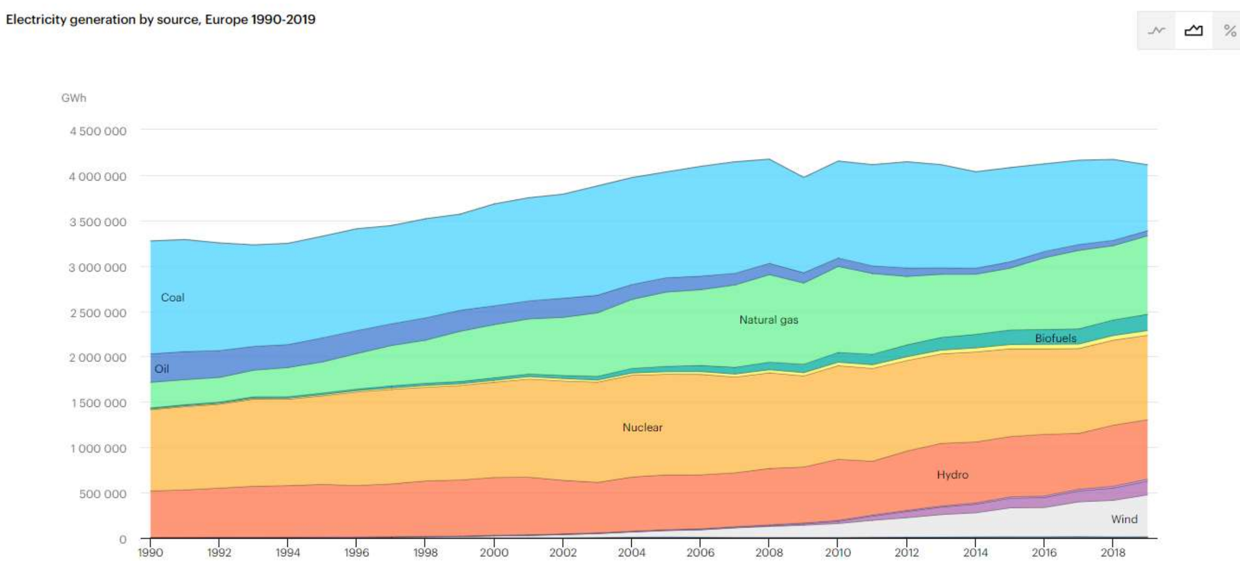
Europe electricity generation by source 1990-2019



Source: www.iea.org/

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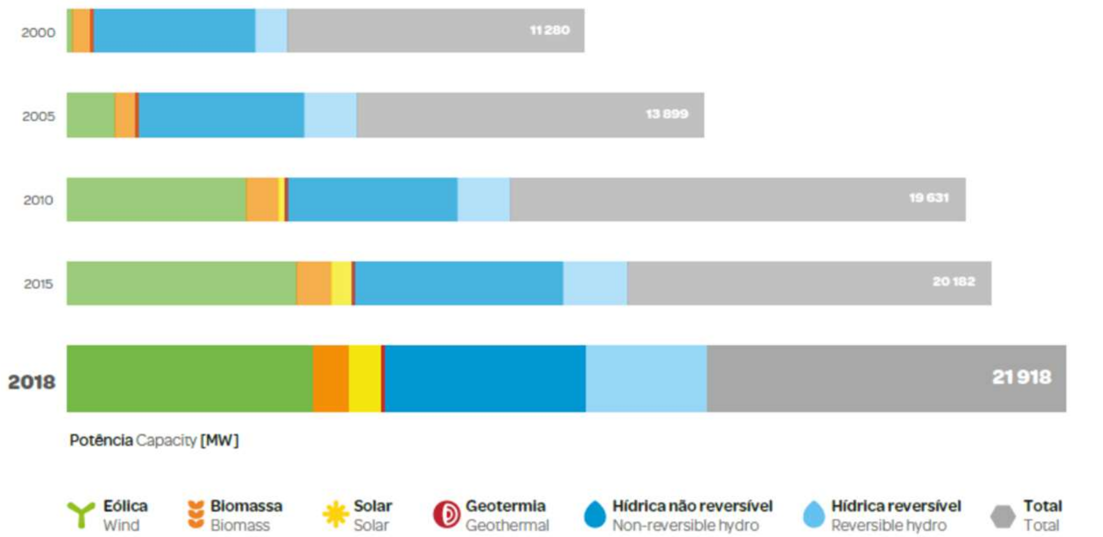
Installed electicity production capacity (Portugal)



Source: DGEG; Analysis: APREN

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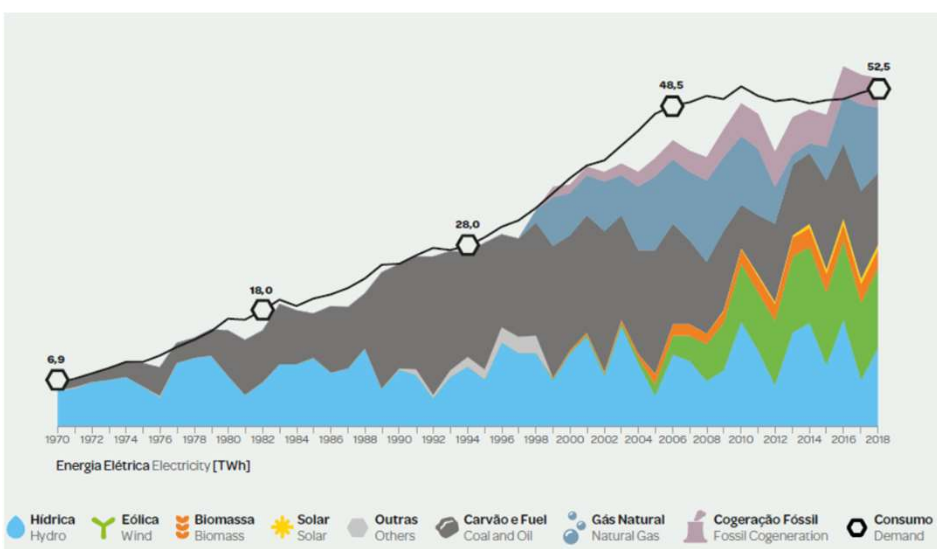
Electricity production by source (in Portugal)



Source: DGEG; Analysis: APREN

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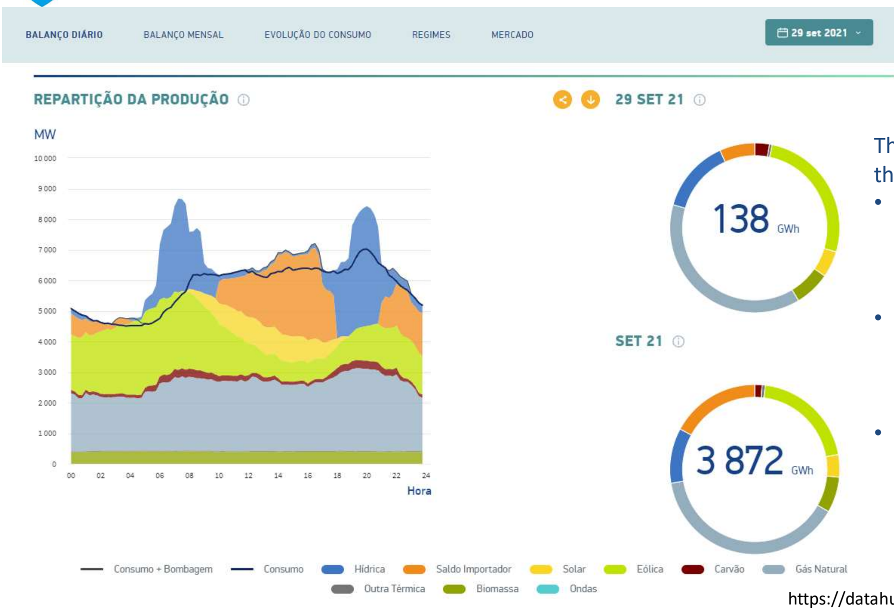
Electricity production distribution in Portugal



<<< 29Set2021

This graph does not distinguish the different types of hydro:

- **Small hydro** with very limited storage capacity and which often have special contracts to sell energy to the grid.
- **Run-of-river hydro**, which need to run many hours per day, as they have limited storage capacity.
- **Storage reservoirs hydro** which can hold water and not produce electricity for days or months.

https://datahub.ren.pt/pt/eletricidade/balanco-diario/

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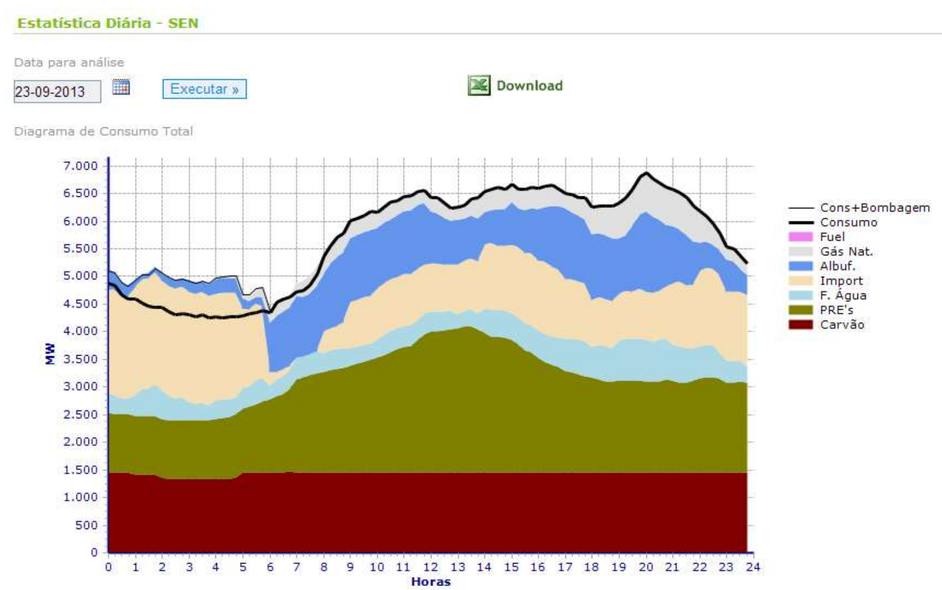
What happen in 23/9/2013?



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Energy production and its impacts on the water resources

- As energy consumption shifts to electricity from other sources, the production of electricity will increase.
- Electricity can be produced from water, but the various scenarios suggest the maintenance of the current net production of electricity from water resources;
- Hydroelectricity has and will have a role in storing energy produced by other renewable sources, such as wind and solar?
- Biofuels and hydrogen production require large amounts of water.
- What will be the impacts of these trends?

- Disruptive technologies:
  - Intelligent energy networks;
  - Local production and consumption, with surplus storage in "super" batteries;
  - Storage of energy by compressed air in geological masses.

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Social and environmental impacts of hydroelectric power

- Land flooding with impacts to population settlements, land habitats and historical heritage
- Disruption of human communities (population displacement)
- Fluvial barriers with impacts to aquatic habitats and navigation
- Alteration of the hydrological regime (including hydropeaking)
- Impacts on water quality (reservoir and downstream)
- Change of local climate
- Evaporation losses

Glen Canyon (Arizona, US)

Glen Canyon Dam (Arizona, US)

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Water infrastructures

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Types of dams according to its size (ref: ICOLD)

Large

- h > 15 m or
- 10 m < h < 15 m and one of the following situations:
  - Width > 500 meters
  - Reservoir capacity > 1 hm^3
  - Spillway capacity > 2000 m^3/s
  - Foundation problems
  - Non usual design

Small

- All other cases

Kariba dam (Zambia/Zimbabwe)

Rogun dam (Tajikistan)

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Largest dams and reservois (by height and reservoir volume)

Name	Height (m)	Purpose	Country
ROGUN (C)	335	HI	Tajikistan
BAKHTIYARI (C)	315	HC	Iran
JINPING 1 (C)	305	HC	China
NUREK	300	IH	Tajikistan
LIANGHEKOU (C)	295		China
XIAOWAN	294	HCIN	China
XILUODU (C)	286	HCN	China
GRANDE DIXENCE	285	H	Switzerland

Dam name	Volume (Mm^3)	Country
KARIBA	180 600	Zambia/Zimbabwe
BRATSK	169 000	Russia
HIGH ASWAN DAM	162 000	Egypt
AKOSOMBO	150 000	Ghana
DANIEL JOHNSON	141 851	Canada
GURI	135 000	Venezuela


Grand Dixence dam (Switzerland)


High Assuan dam (Egypt)

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Types of dams and reservoirs according to its purpose

- Storage
  - To transfer water from wet seasons to dry seasons and ensure the water needs satisfaction.
- Derivation
  - To create a small water body that enables the transfer of water to channels or pipes
  - Flood retention/attenuation:
  - To temporarily retain flood water or solid material
- Power production
- Multi-purpose


Alqueva dam


Alqueva irrigation channel

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Types of dams and reservoirs according to water usage

- Urban and industrial supply
- Irrigation
- Power production
- Flood control
- Navegation

- Associated uses:
  - Recreation
  - Aquaculture

Crestuma dam (runoff river dam)

Crestuma dam (runoff river dam)

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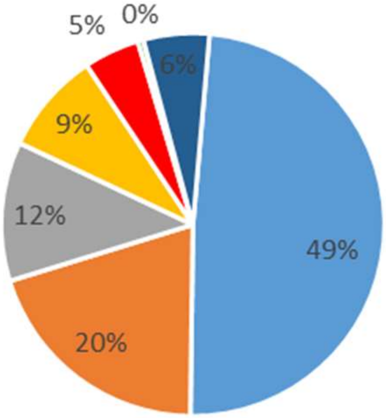
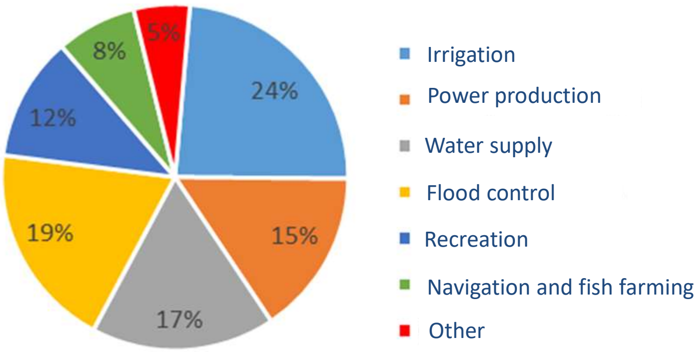
Distribution of large dams acording to water usage (source ICOLD)

Single purpose



Multiple purpose



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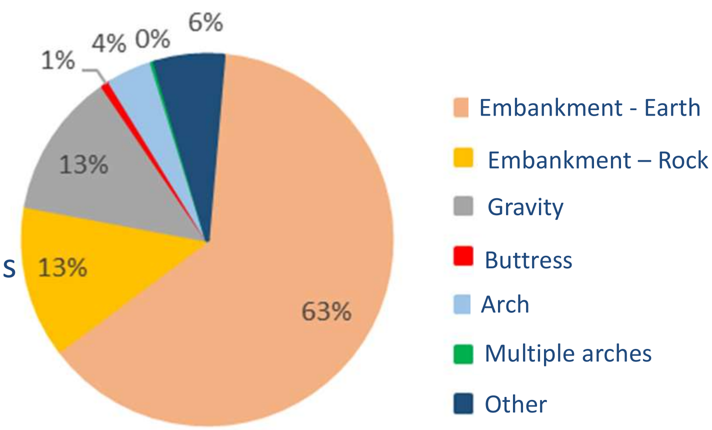
Types of dams according to its structure and material

- Concrete dams
  - Gravity dam
  - Arch dam
  - Multiple arches dam
  - Buttress dam
  - Moveable dam
- Concrete rol on dams
- Embankment dams
  - Earth fill dams
  - Rock fill dams



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Types of dams


Paradela dam (embankement)


Paradela dam


Pracana dam buttress dam)

Bemposta dam (gravity)


Chança dam (gravity)


Aguieira dam (múltiple arches)

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Dam infrastructures

- Spillways
- Bottom outlets
- Middle wall outlets
- Floodgates
- Water uptakes
- Derivation channels
- Fish ladders or lifts
- Navigation locks

Ontario, Canada

Spillway and water uptake tower at Castelo de Bode reservoir.

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Water upstake

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Fish ladders

Fish ladder at Bonnevile dam (USA)

Fish ladder at John Day dam (USA)

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Spillways

Barragem da Caniçada

Descarregador da barragem de Alqueva (Salto de ski)

Barragem de Castelo de Bode

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Spillways

Flood gates at Paradela dam

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Morning glory spillway

Barragem da Paradela

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Types of spillways

Discharge at Xiaolangdi dam (Yellow river, China), in July 2012

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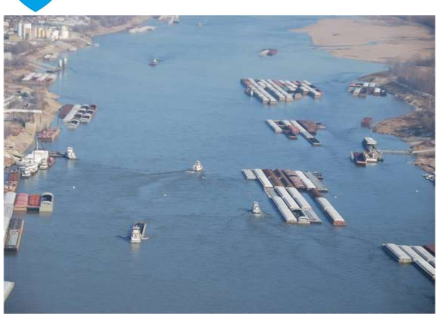
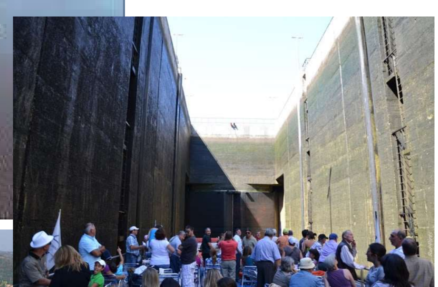
Locks for navigation

Mississipi river and Douro river





Navigation locks in Douro valley

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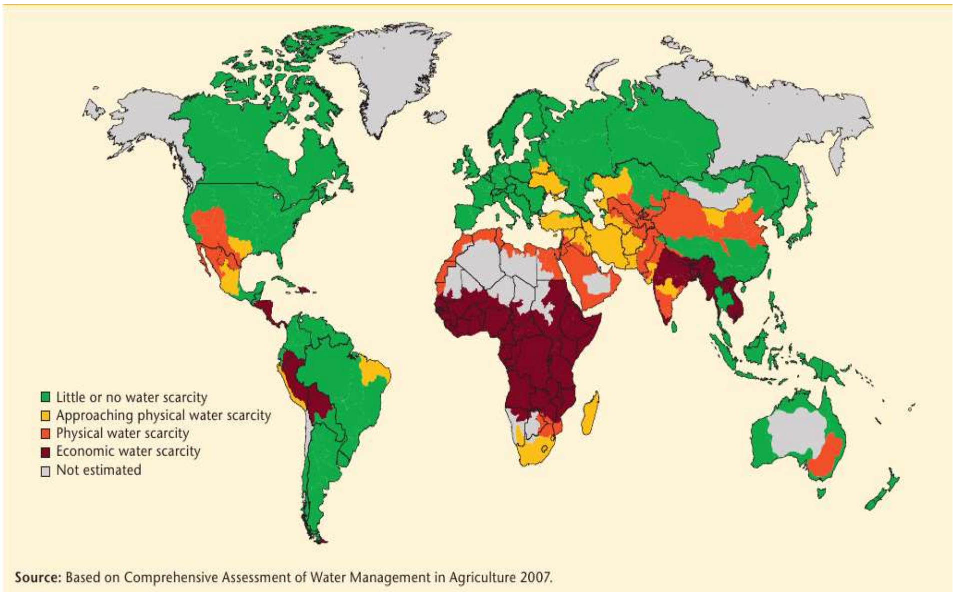
Physical and economic water scarcity



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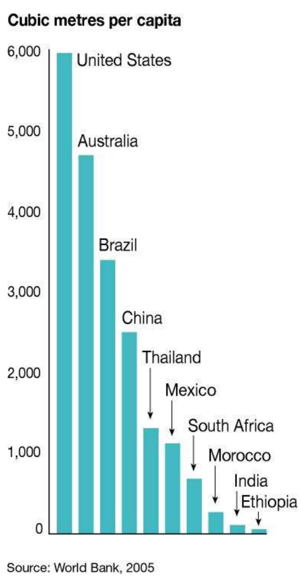
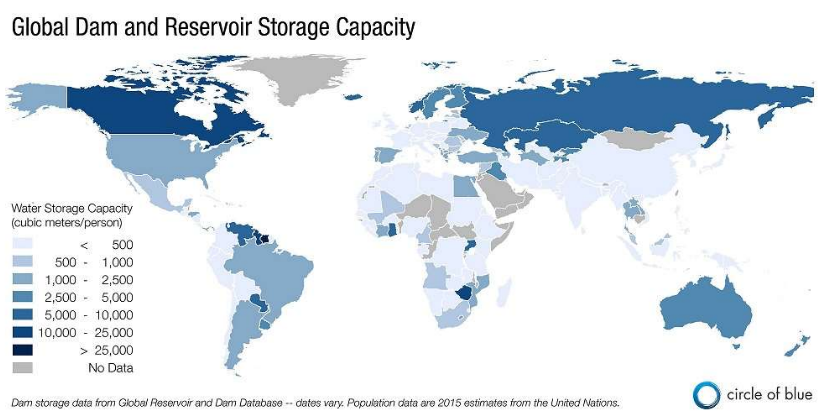
Storage capacity per capita in 2015





90