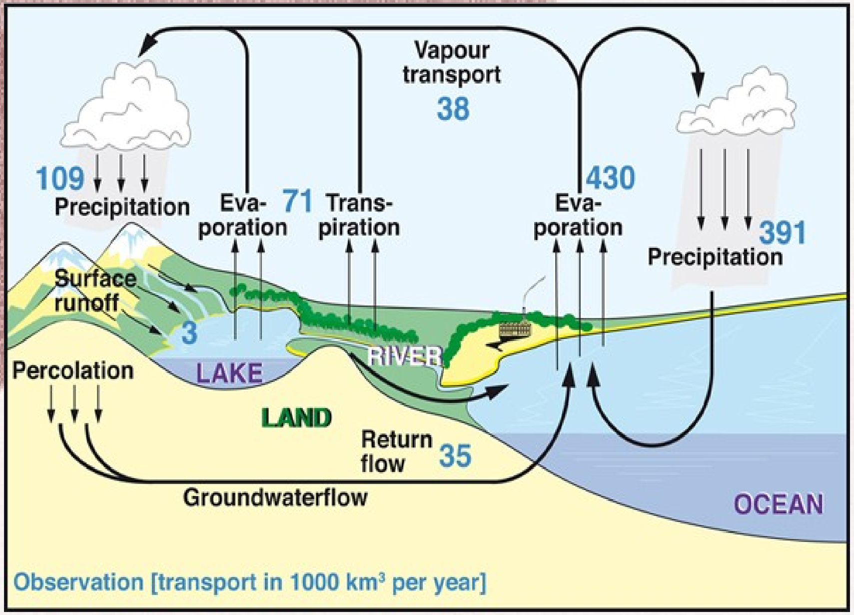
Sustainability in Civil Engineering

VI. Water

Water sustainability considerations

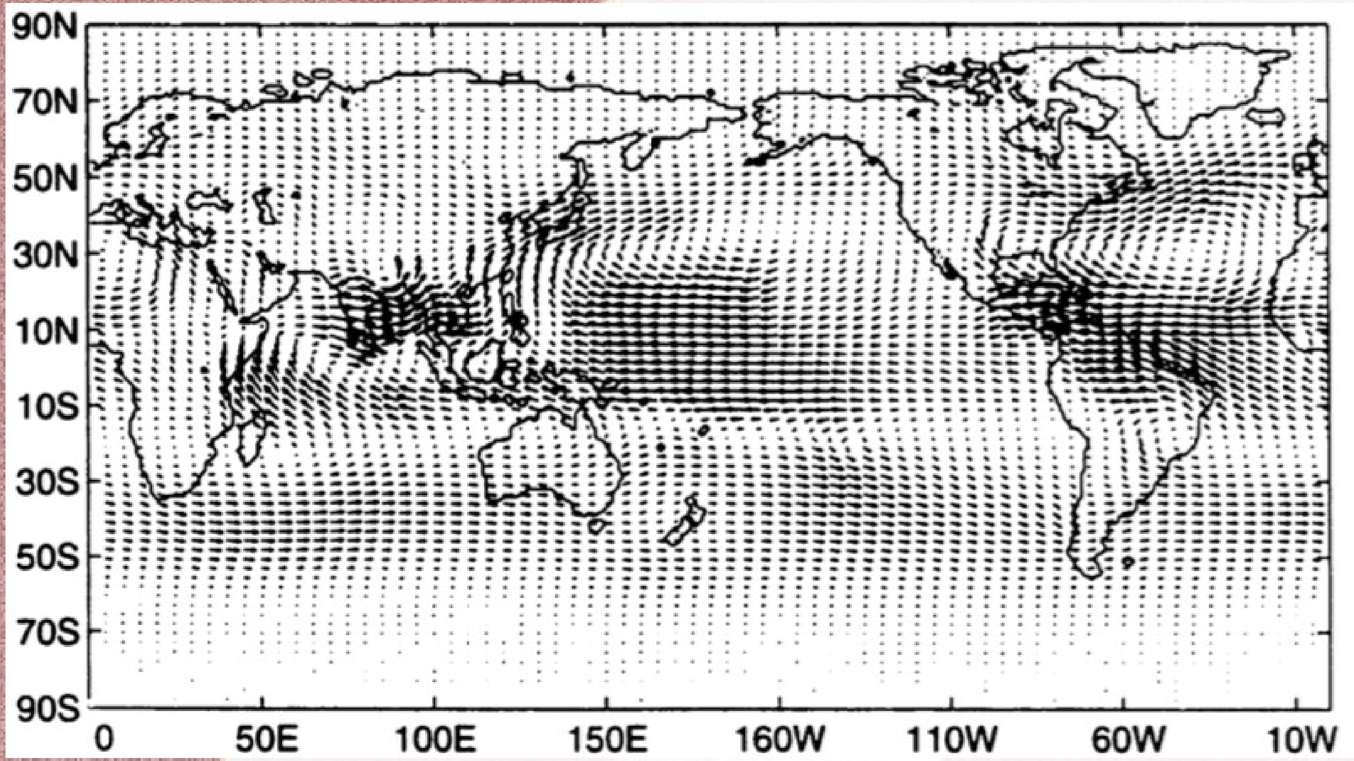
- Amount of water used relative to sustainable supply (esp. in dry areas)
- Management of flooding (in low-lying areas)
- Water pollution with drugs, nitrate, salt, etc.
- Aquatic ecosystems and fisheries (tend to be in trouble worldwide; hurt by traditional hydraulic engineering)

The water cycle



- Driven by solar exergy
- 1 m / y evaporates from the earth's surface, using 80 W m^{-2} (most of the sunlight that reaches surface), and then rains or snows back
- Keeps much of land moist even though it's elevated
- Water stocks: ocean (97%), glaciers (2%), groundwater (0.3%), lakes (0.15%), rivers (0.003%), soil (0.002%), atmosphere (0.002%)

Water transport

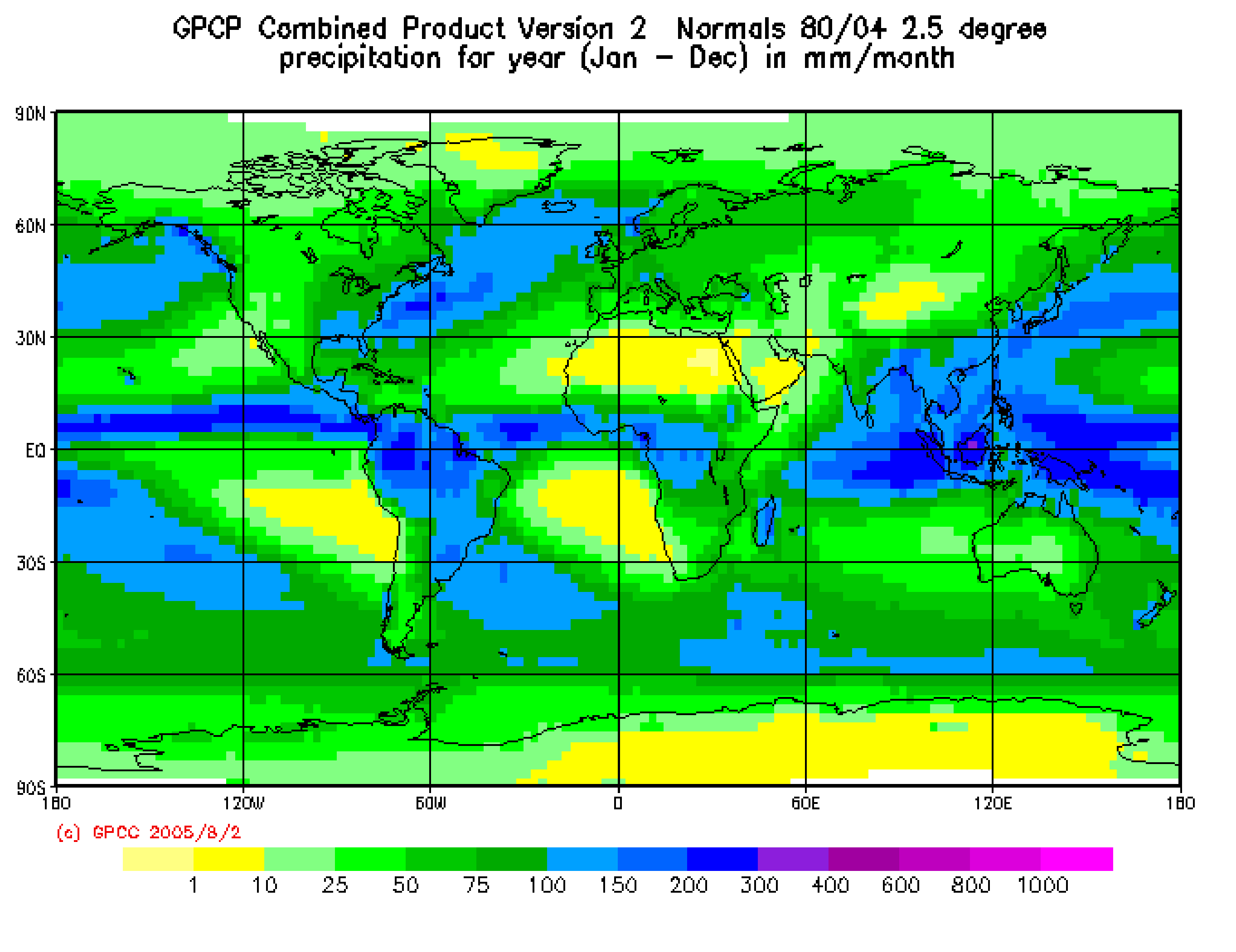


JJA water vapor flux

Karen S. Friedman, Global atmospheric water vapor flux climatology in the NCEP/NCAR reanalysis and the Oort data set, MIT PhD thesis, 1997

- In atmosphere: from equatorial to higher latitudes and from ocean to land
- In rivers: from mountains to valleys and to ocean

Deserts

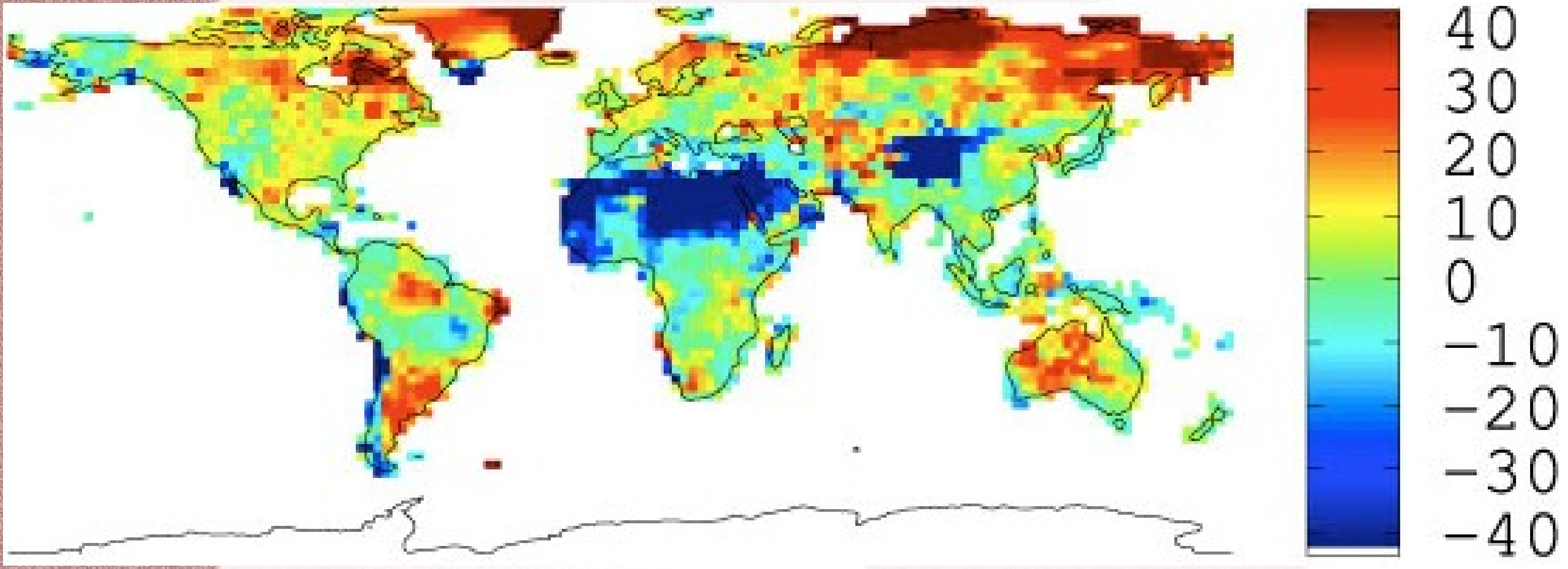


- Much of the land, close to cool ocean or far from ocean, gets little rain
- Deserts have historically been sparsely settled, but water and food imports have led to large population growth

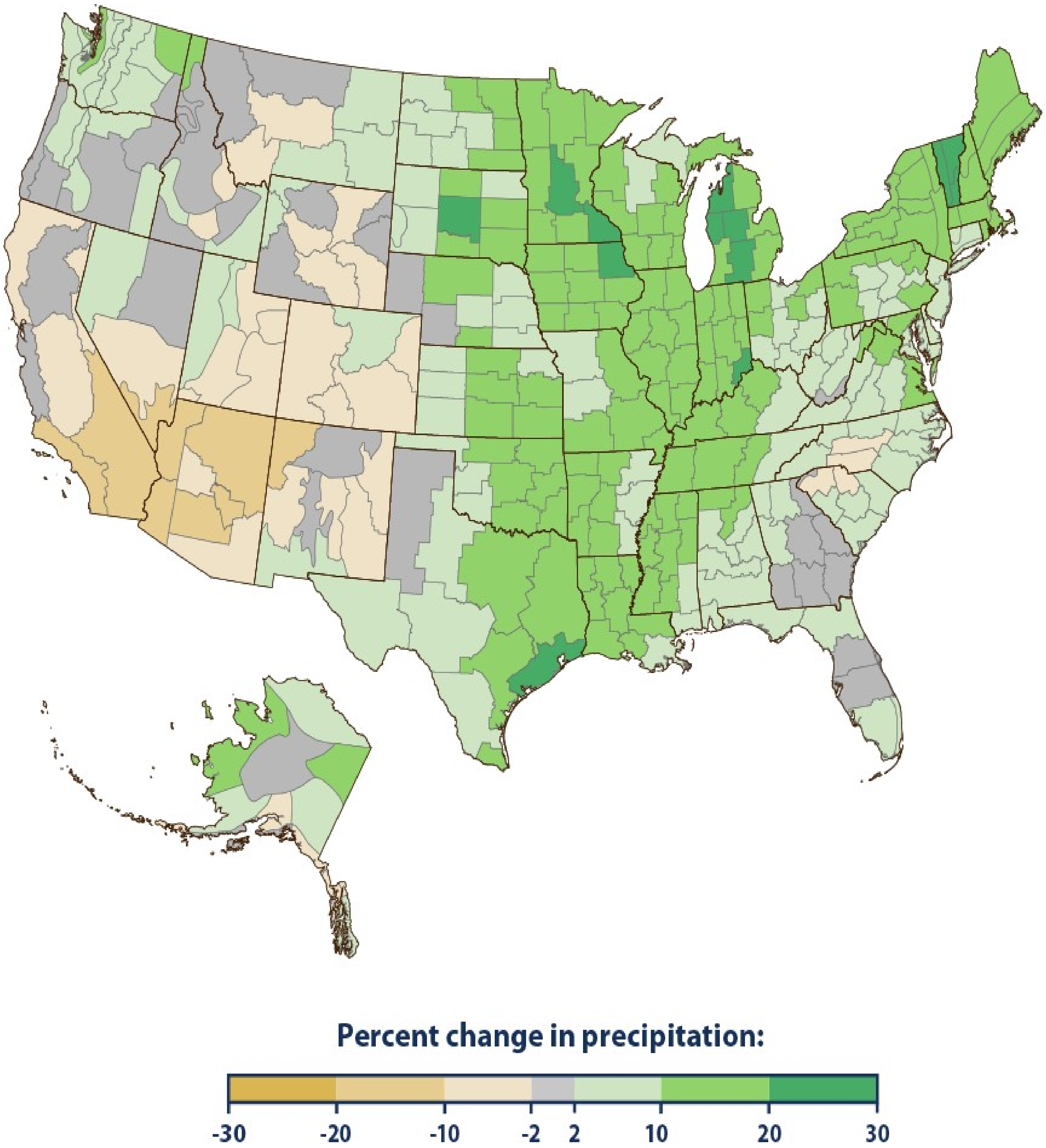
Water balance

- Δstorage = precipitation – evaporation – runoff
- Resource can be identified with runoff component
- In wet regions, more water falls that can evaporate, resulting in high runoff
- In dry regions, almost all available water is evaporated, so runoff is very low
- Aridity index: Precip. / Potential evaporation (map)

Precipitation trends



% change, 1901-2010



Regionally

1901-2021

Residential water use

- L per person per day:
  - Drinking: 2
  - Food prep / cooking: 4
  - Washing: 50 (7-min shower, low-flow head) + 10 (front-load washer, one load / week) + misc.
  - Flush toilets: 40 (low-flow, 6 L/ flush)
  - Other: gardens, lawns, swimming, car wash ...
- NYC water supply: 400 (US avg.:600; UK:150)
- Space Station: 12
- *Total* US freshwater withdrawal: 5000

Agriculture and water

- Growing plants transpire water at close to the potential rate – about 1 m / year in warm areas (1 ton per m^2)
- Plants grow up to 2 kg biomass per m^2 per year (rainforest, irrigated desert)
- Considering that not all crop biomass is edible and that not all applied water reaches plants, 1000 L (kg) water / 1 kg plant food is a reasonable rule of thumb; for grain-fed livestock, more like 10000 L water / 1 kg meat
- US water *withdrawal* for agriculture (irrigation): 1700 L / person*d

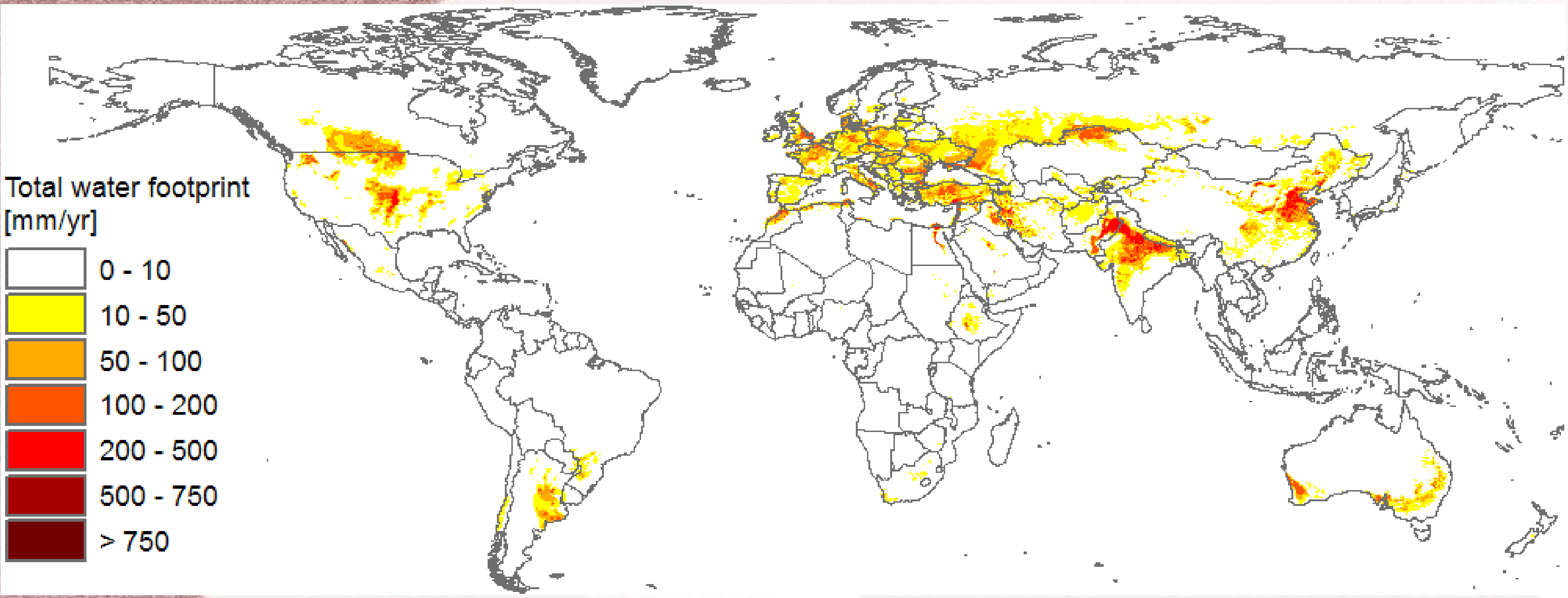
Water-energy nexus

- Serving as the heat sink in thermal power plants is the largest use of freshwater in the US, 1900 L / person*d (mostly heated, not evaporated; some saltwater also used)
  - New EPA, state regulations
- Hydroelectricity is 7% of total generation
- Pumping and purifying (and heating) water takes a lot of energy (of order 10% of commercial energy worldwide)

Water footprints

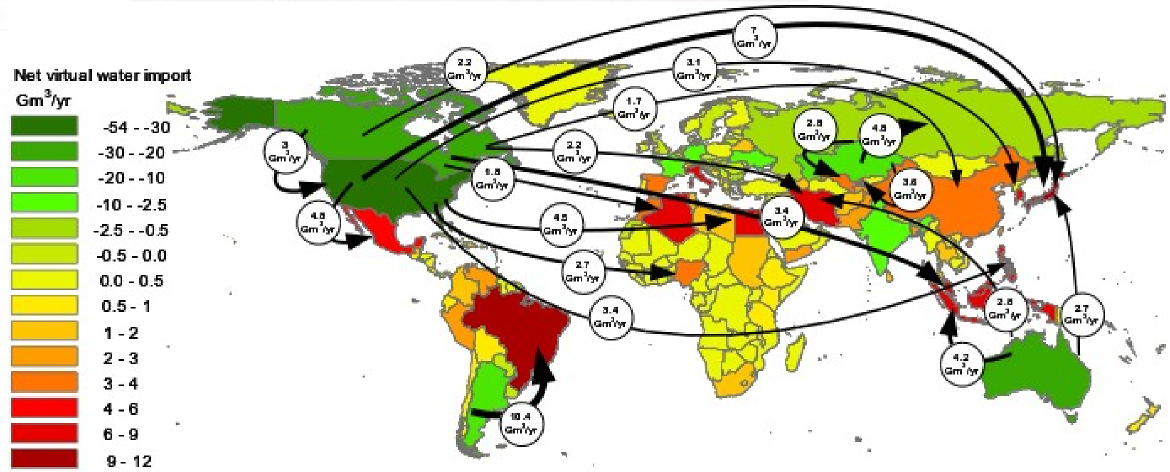
- About equally split between watering and heat-engine cooling requirements
- E.g. (Water Footprint Network Product Gallery, doesn't include cooling water):
  - 1300 L / kg wheat (40 L / bread slice)
  - 4000 L / kg grain-fed chicken (200 L / egg)
  - 2000 L / kg wood (10 L / paper sheet)
  - 10000 L / kg cotton (3000 L / T-shirt)
  - 80 L / $ industrial activity (global mean)
- Many urban or dry regions/countries are importing food that they don’t have the water to grow locally (virtual water trade)

Geographic variation and virtual water

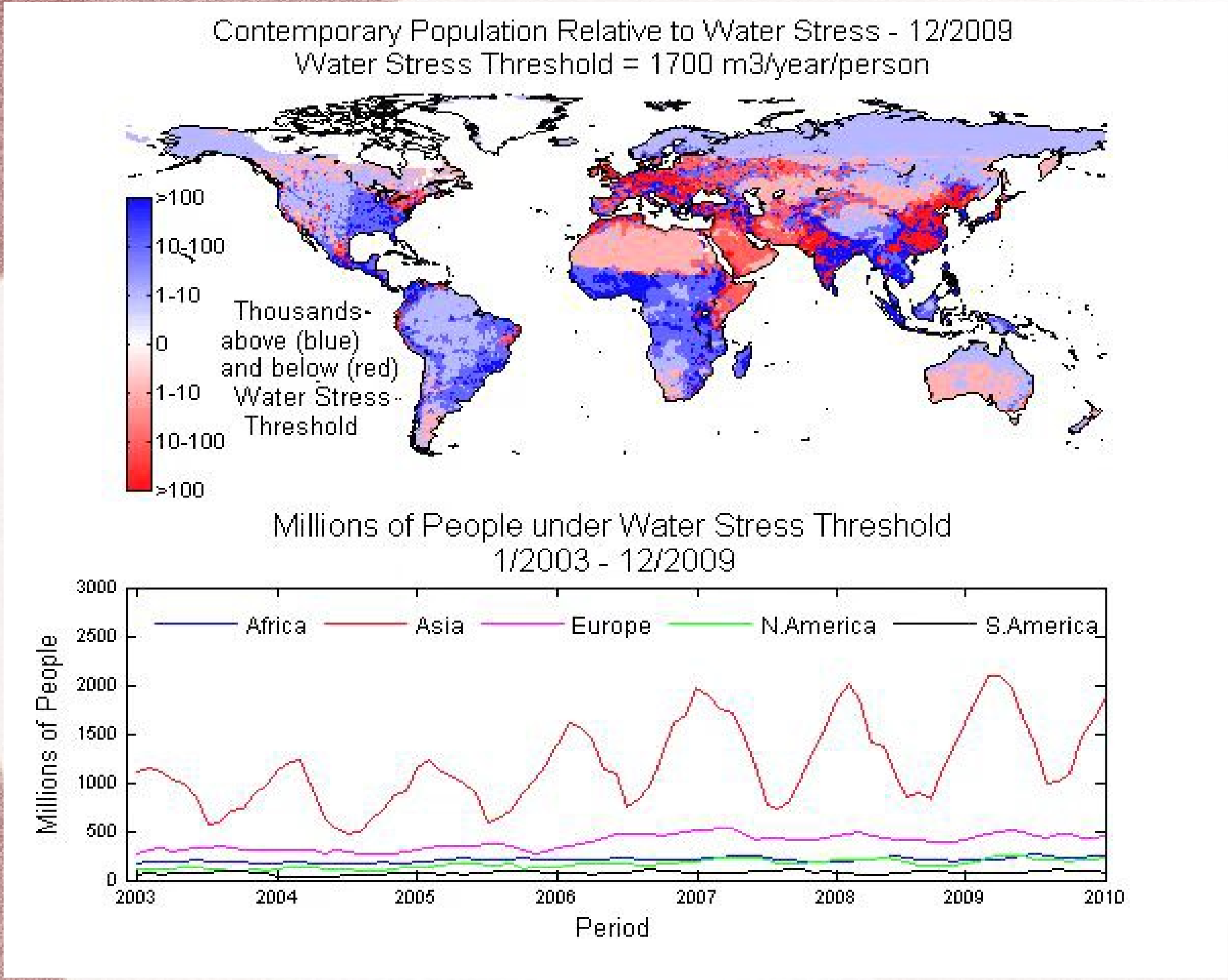


The global water footprint of wheat production. Source: Mekonnen and Hoekstra (2010).

National virtual water balances and net virtual water flows related to trade in wheat products in the period 1996-2005. Only the largest net flows (> 2 Gm³/yr) are shown. Source: Mekonnen and Hoekstra (2010)

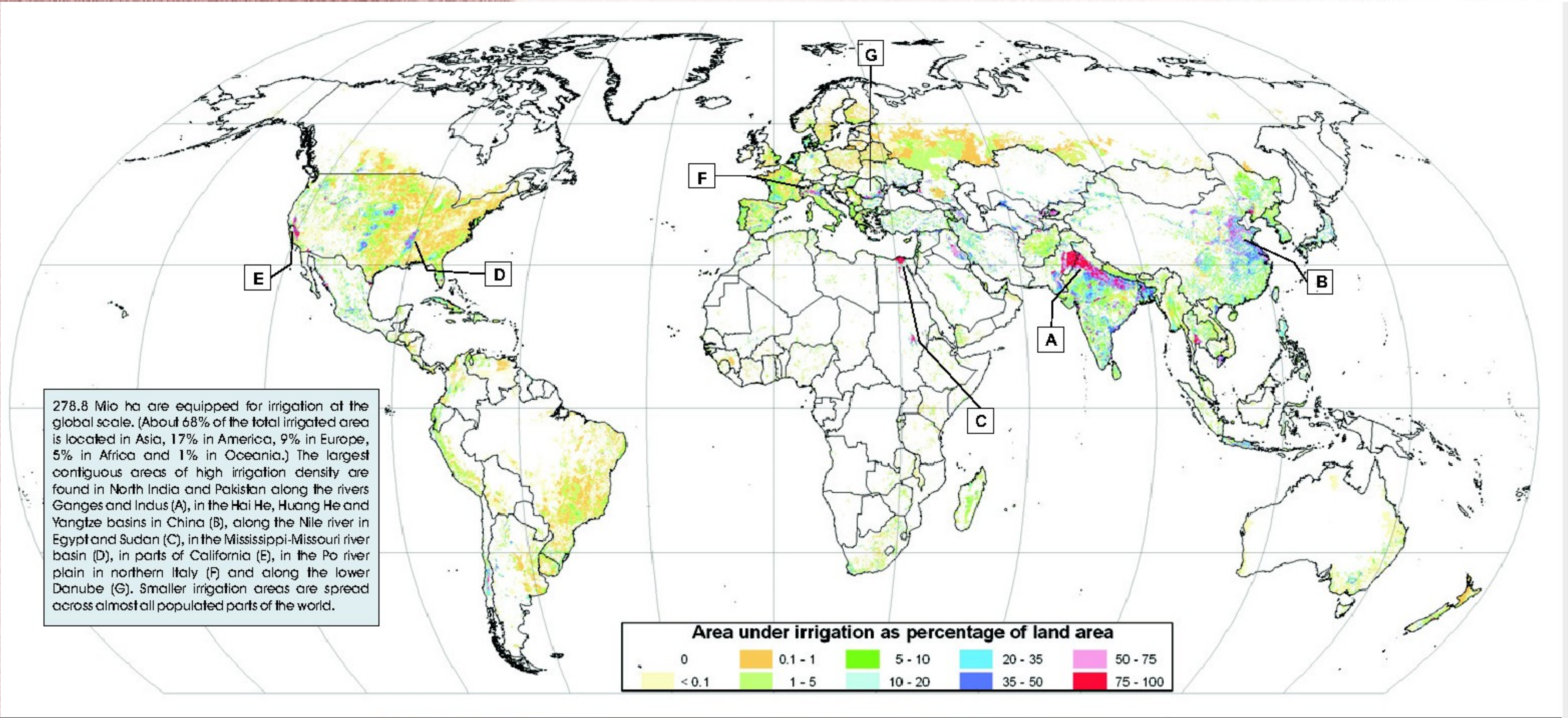


Drylands: where is water scarce?



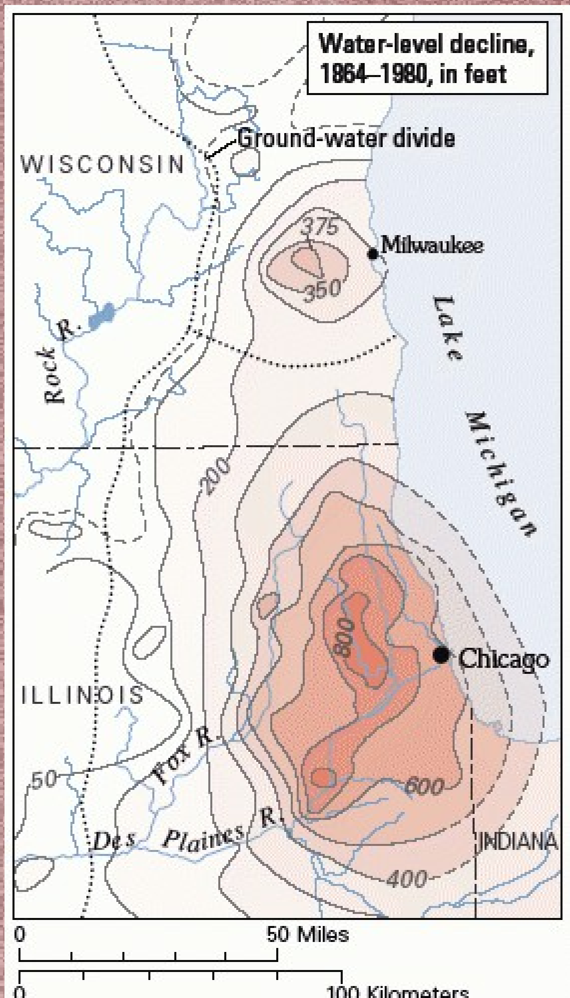
- Work by C. Vorosmarty's group: water demand taken to scale with population (4700 L / person*d)

Irrigated land

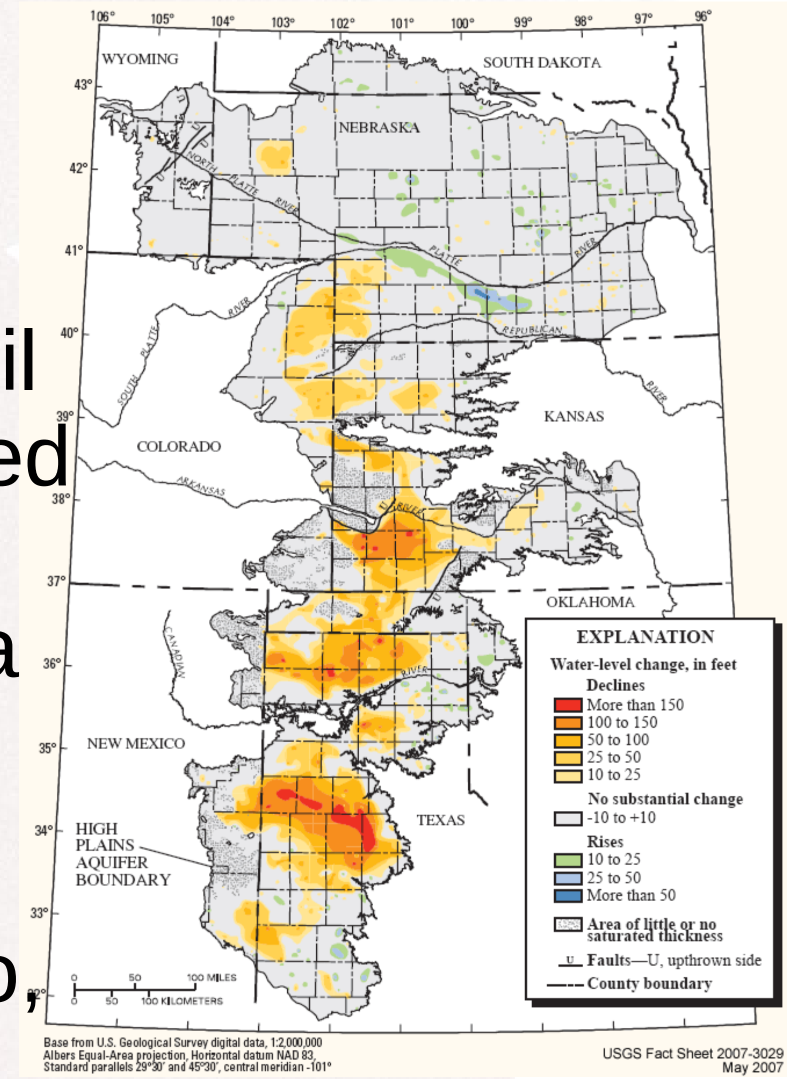


- High yields under warm climate, good soil
- ~1000 L / person*day in irrigation for the world!
- Unsustainable if demand exceeds renewable supply

Aquifer depletion

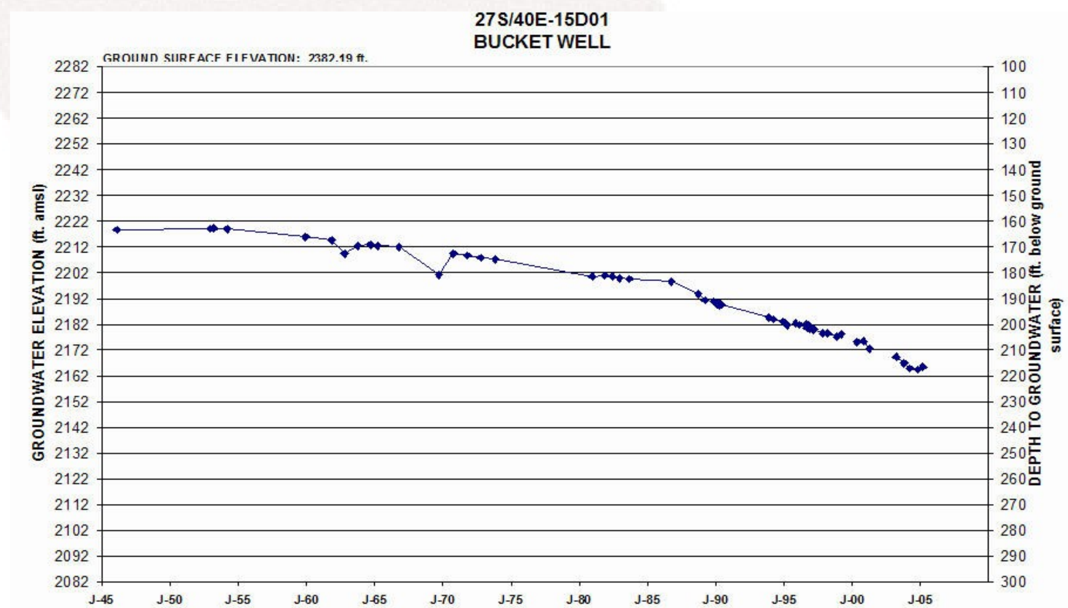


- Water flowing slowly at various depths can pumped up; fossil fuels have allowed deep aquifers to be exploited on a larger scale
- Cases in point: Arizona, Chicago, Arabia, China, India



An example of water unsustainability: Ridgecrest, CA

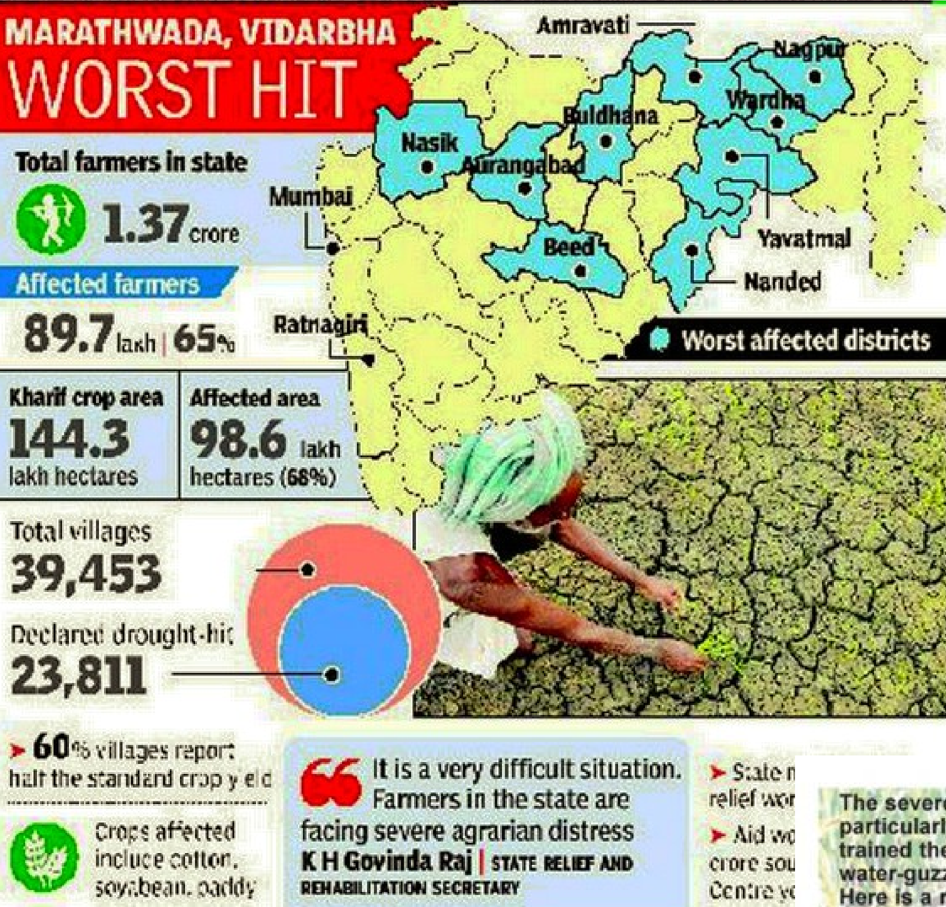
- 30,000 people (Navy base) in Mojave desert, annual rainfall <15cm
- Water supply is groundwater (3000 L/person*d), used at ~3x recharge (<1 cm/y); 50% for irrigation (alfalfa)
- Wells falling at 6-50 cm/year



Ridgecrest news

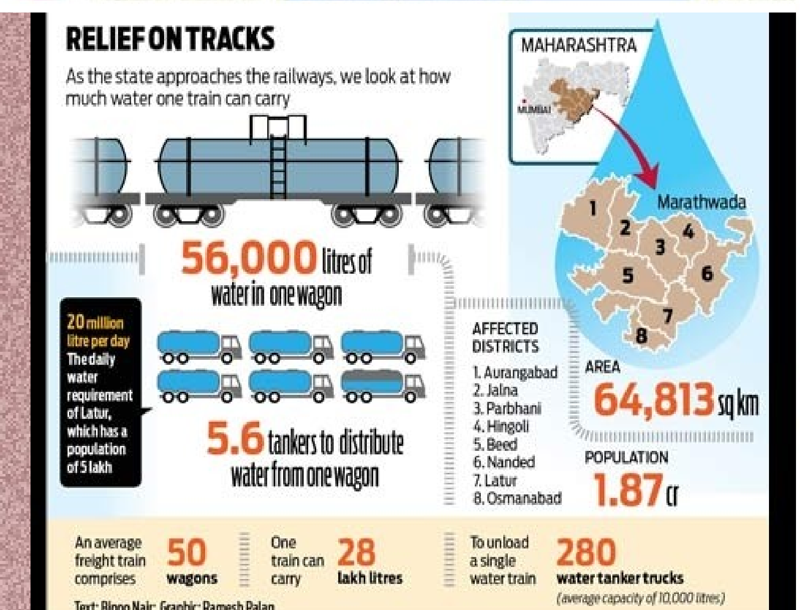
- Tiered rate structure (more expensive over 500 Lpd)
- Building expensive new treatment plant for groundwater As
- Constructing new water storage tanks
- Hired a Conservation Specialist, banned front-yard lawns, wasting water, summer midday watering, restricted lawn area to 50% of new developments, conducted education on desert-adapted plants
- City will buy out farms’ water usage
- Solar thermal?
- Imports, groundwater desalination also proposed

Maharashtra: does sugar make sense?

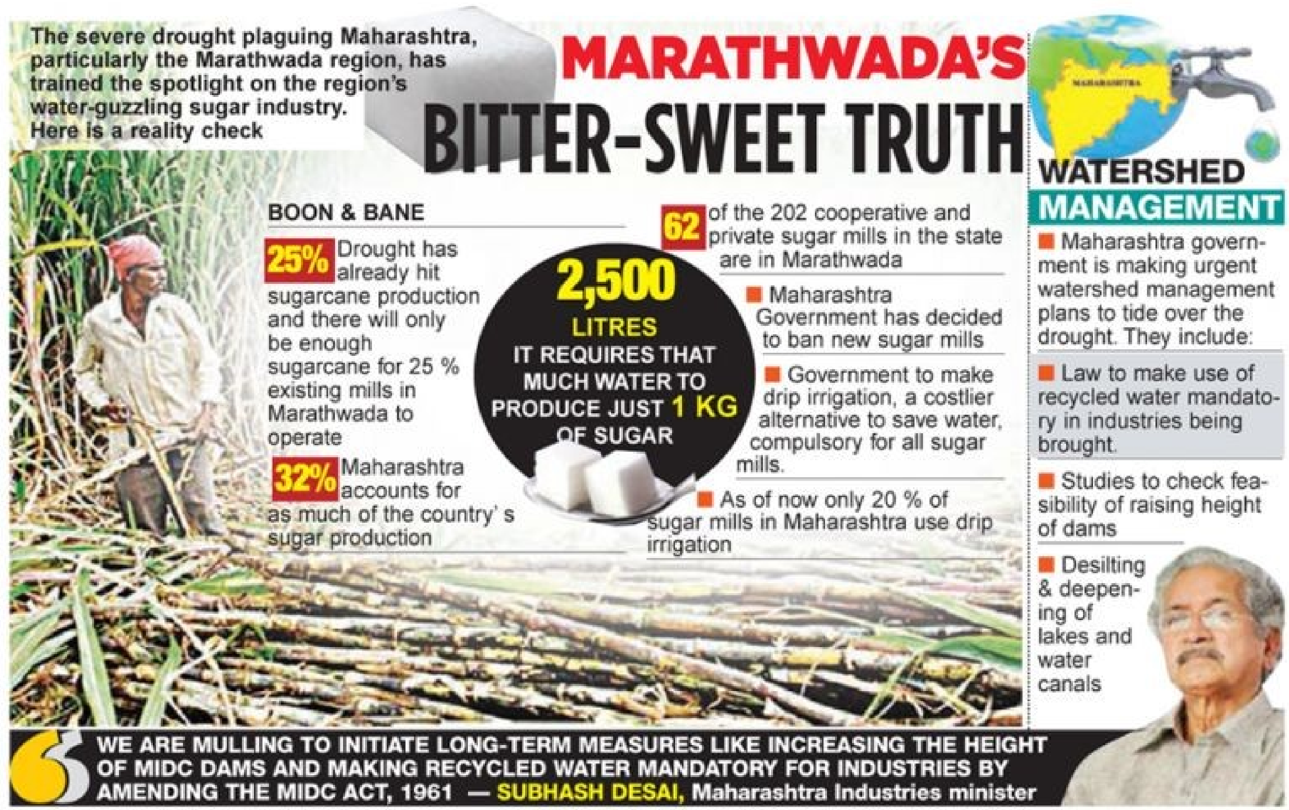


Rural India Online, 2015

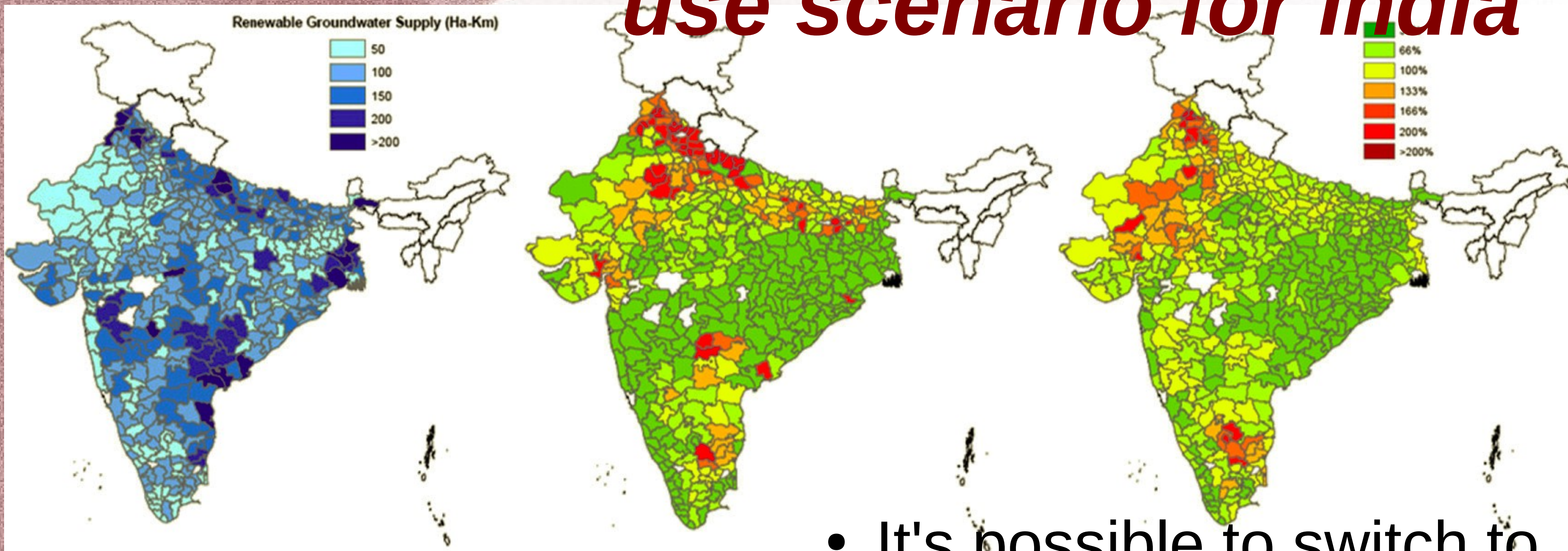
Deccan Chronicle, 2016



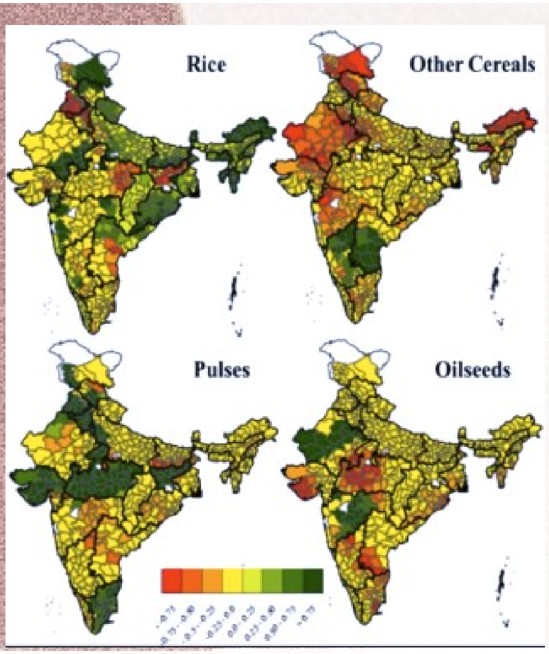
DNA India, 2016



A sustainable agricultural water use scenario for India



Groundwater supply and current exploitation (Fishman et al. 2015)



Proposed change in production (Devineni and Perveen, 2012)

- It's possible to switch to less water-demanding crops (pulse, oilseed) in area that are drier
- Nationally, the same amount of food can still be produced

Surface water exploitation: dams and reservoirs

- Dependable water for irrigation and other uses
- Flood control
- Hydroelectricity

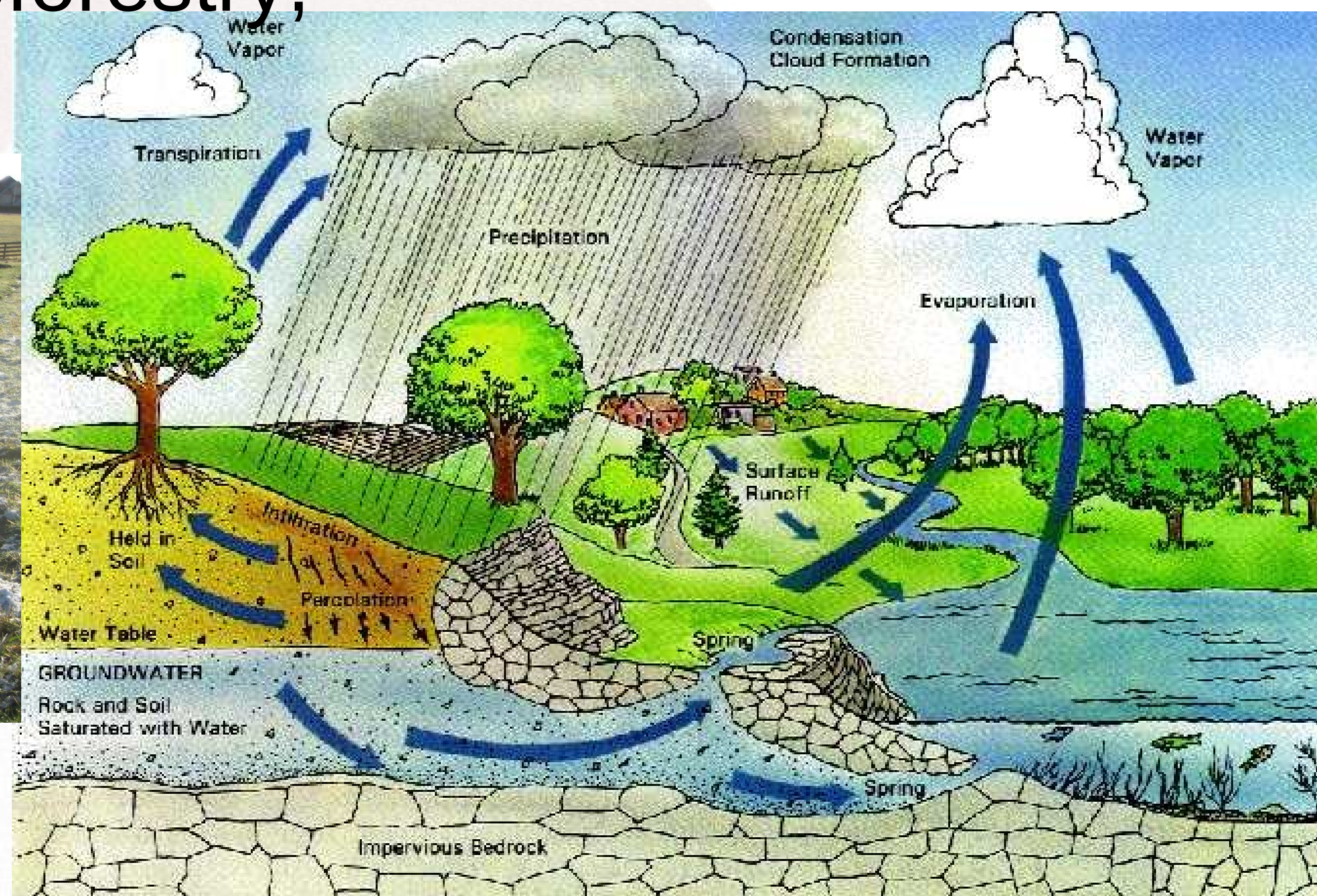
- Damage to river and wetland life and fisheries
- Flooding of farmland
- Reservoirs fill with sediment
- Loss of sediment in deltas (cf. Louisiana)
- Dam failure is catastrophic

Living in deserts

- Water storage in tanks/cisterns
- To grow food, need to concentrate what little water is available
- Many historic examples, e.g. in Mideast

Farm water management

- Water harvesting: microdams, subsurface tanks, farm ponds
- Promoting infiltration: Terracing, trenches
- Reducing evaporation: mulch, soil building, agroforestry, windbreaks



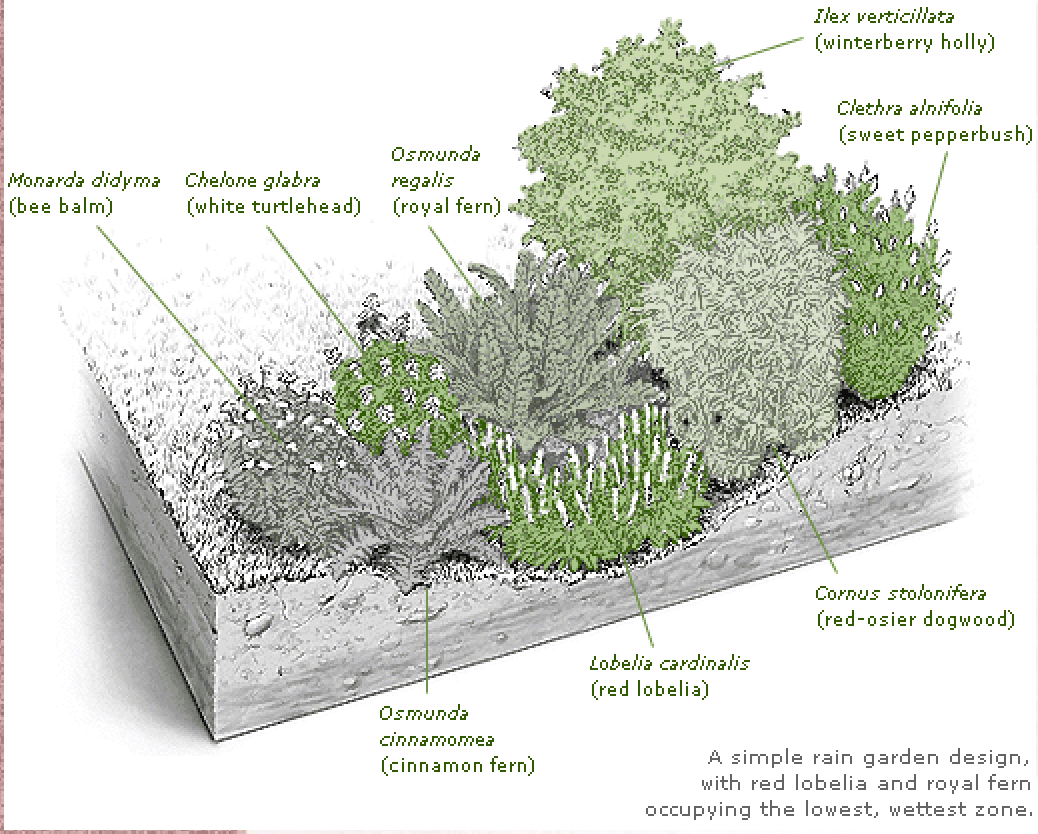
Municipal water supply

- Cities may import surface water (NYC, Boston, Los Angeles, San Francisco) or groundwater (Chicago, Miami)
- Treatment and distribution are complex and expensive
- Pricing typically covers operating, not capital costs

NYC water system

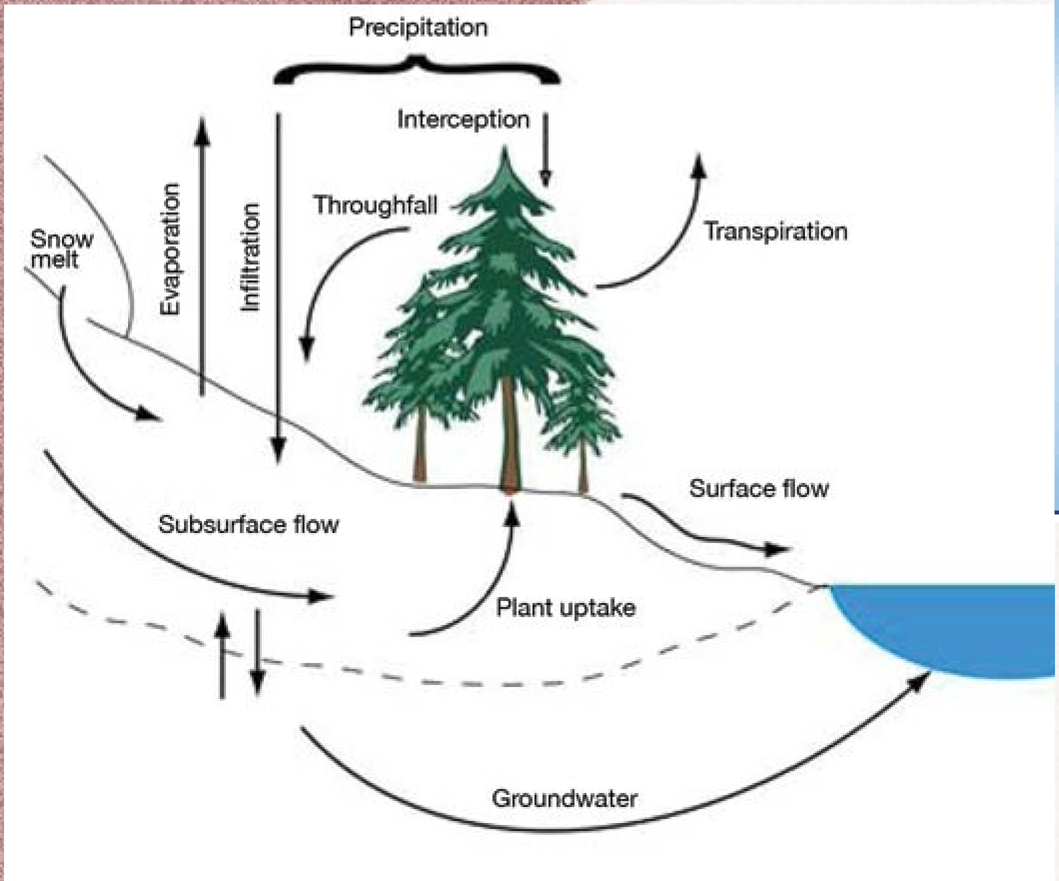
- Originally local supply
- Croton River: 1842 (Roman-inspired); 1905
- Catskill Aqueduct: 1924
- Delaware Aqueduct: 1945
- Mostly gravity flow
- Maintaining water quality remains a challenge (turbidity)

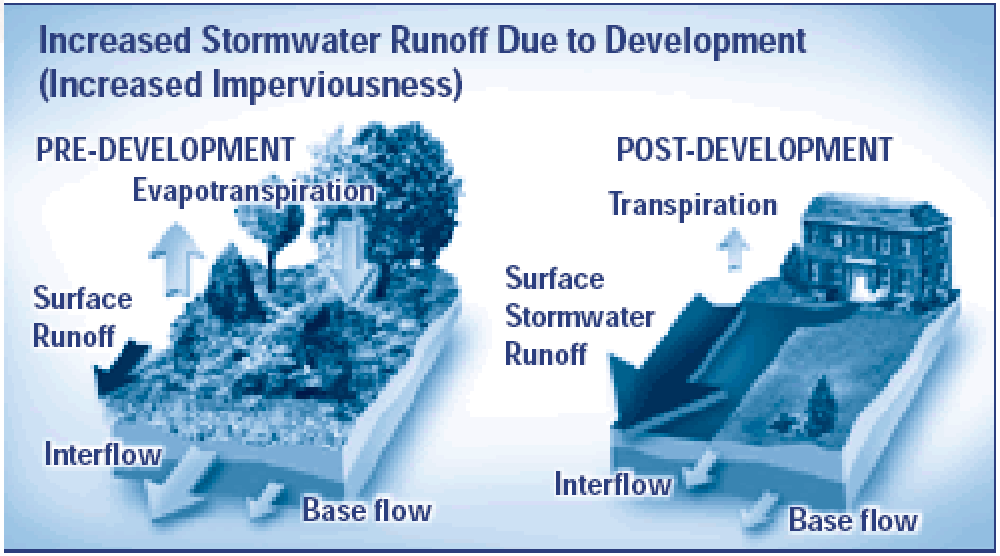
Urban rainwater management



- Problems: sewer overflow, flooding, water pollution
- Direct excess water to plants, which will evaporate it, or enhance percolation to groundwater – permeable pavement, rain gardens and wetlands, green roofs

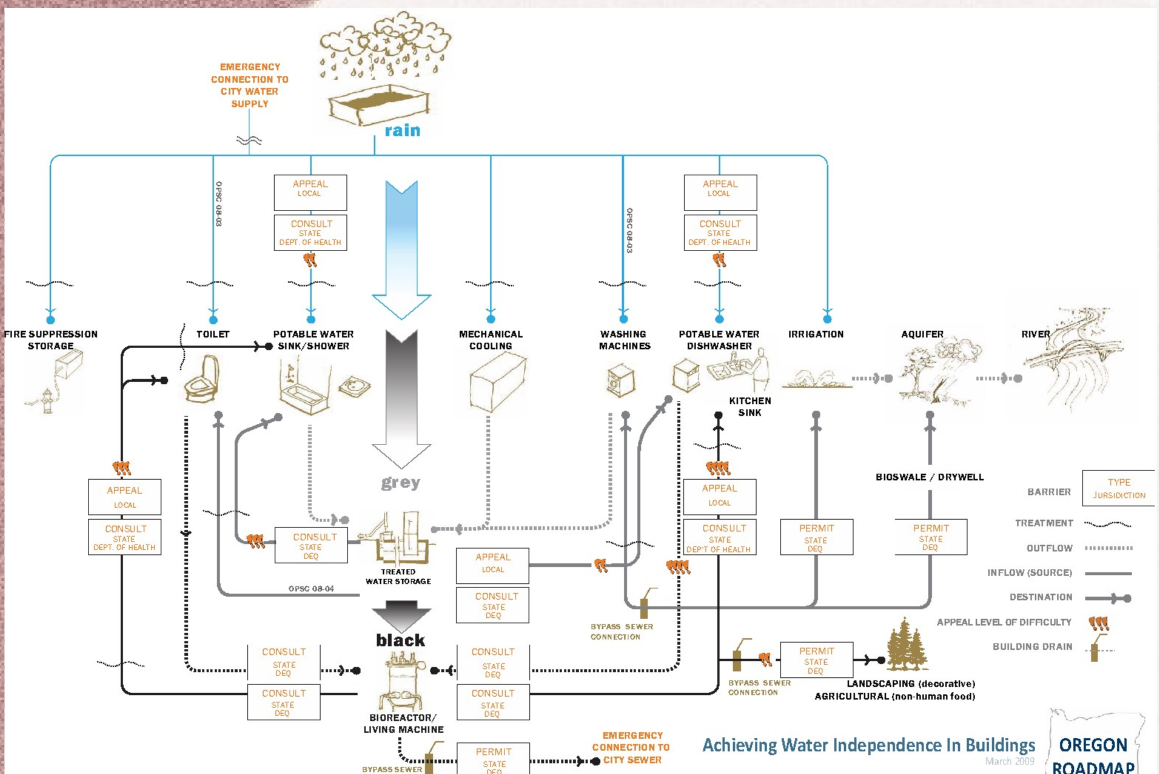
Alteration of natural hydrology





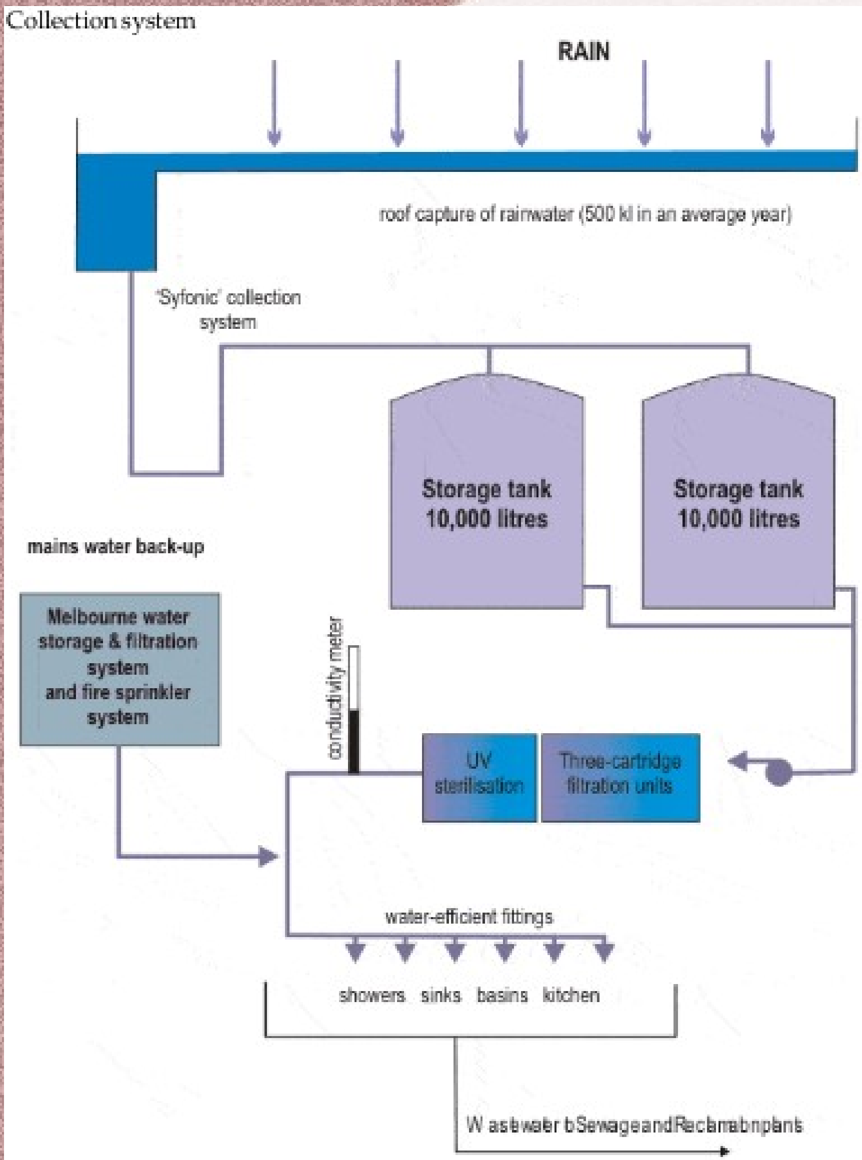
- In intact forests and perennial grassland, water is absorbed by vegetation and mulch, and there is relatively little surface runoff. This mitigates flooding and results in cleaner rivers and lakes.

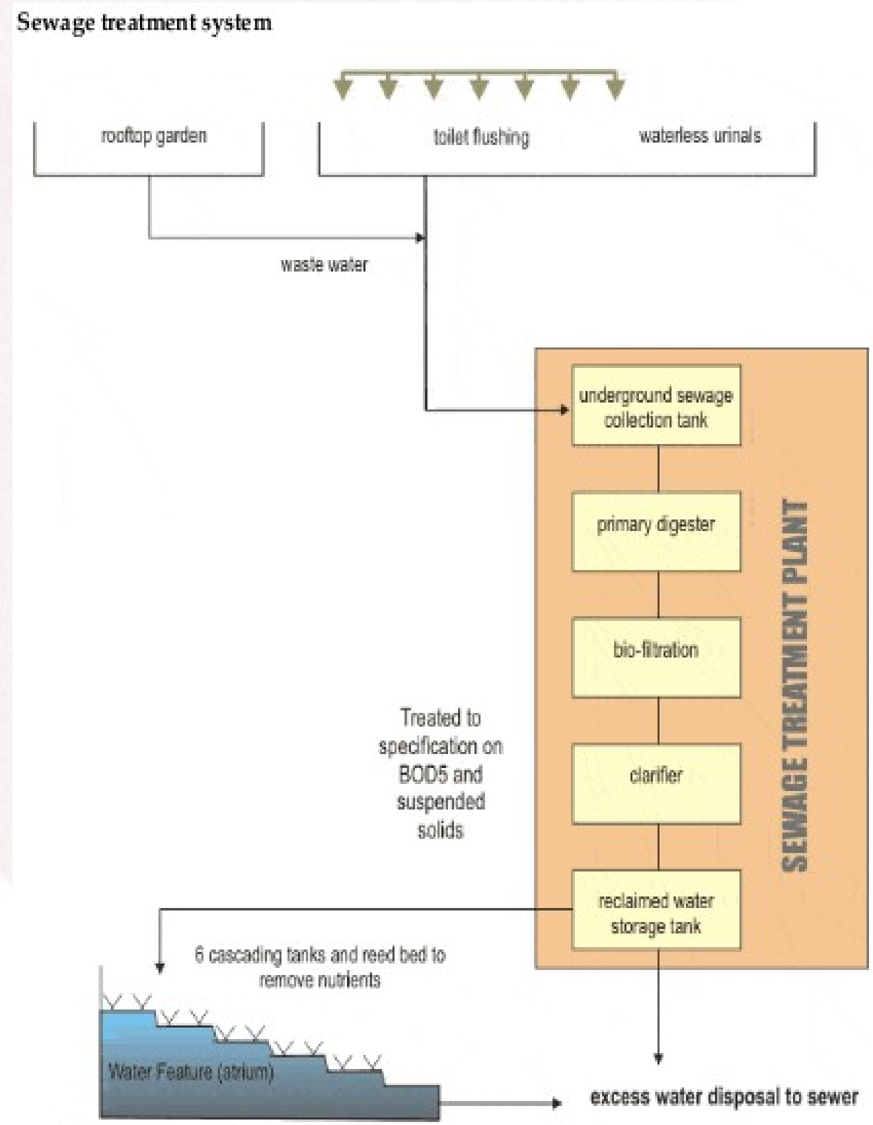
Architecture for rain as a resource



- Rainwater harvesting for flushing, watering plants is increasingly encouraged, though legal obstacles persist
- Generally requires treatment for drinking

A water-quality-friendly building example





60L Green Building (2002), Australian Conservation Foundation, Melbourne

Example (continued)