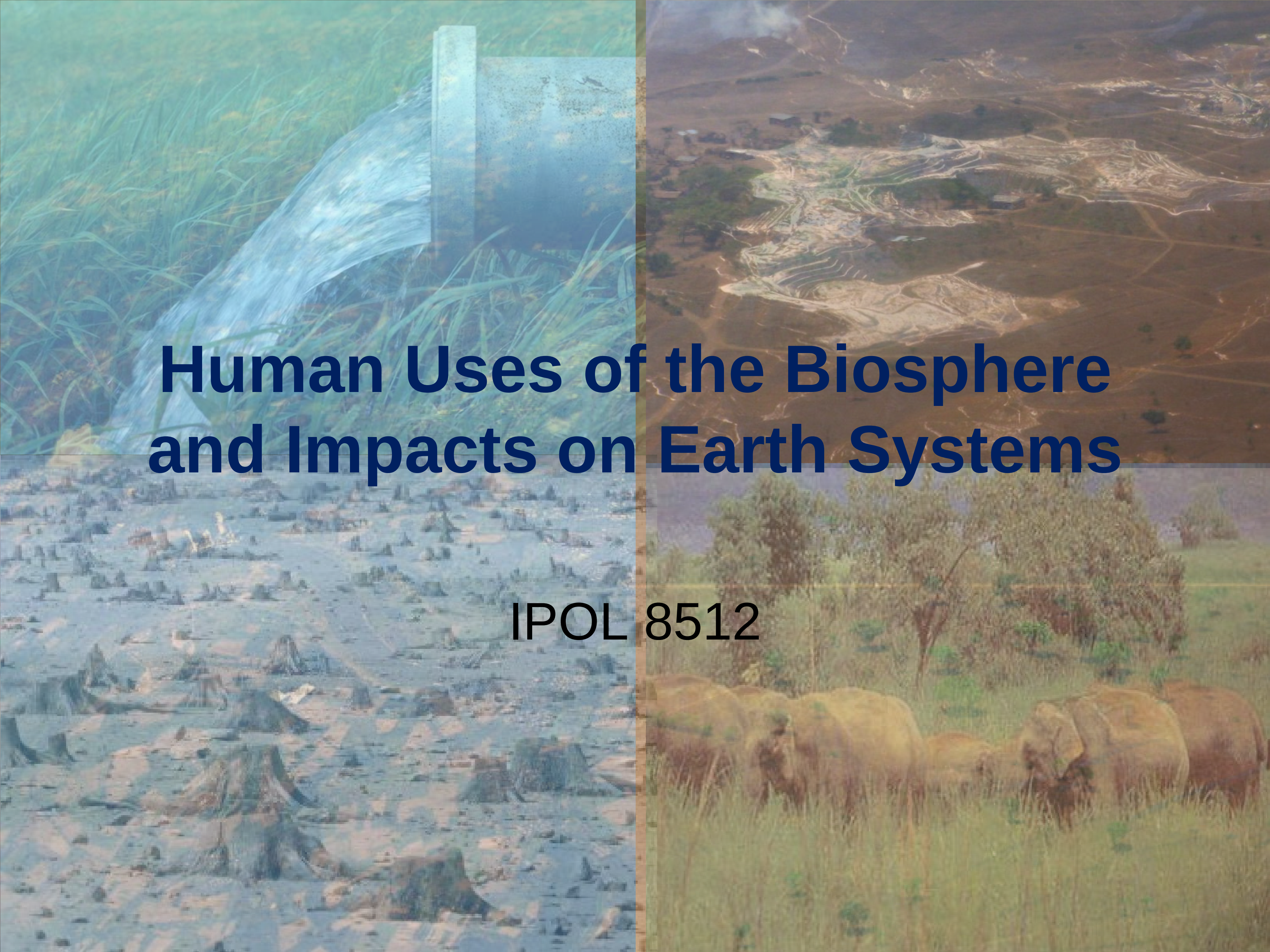
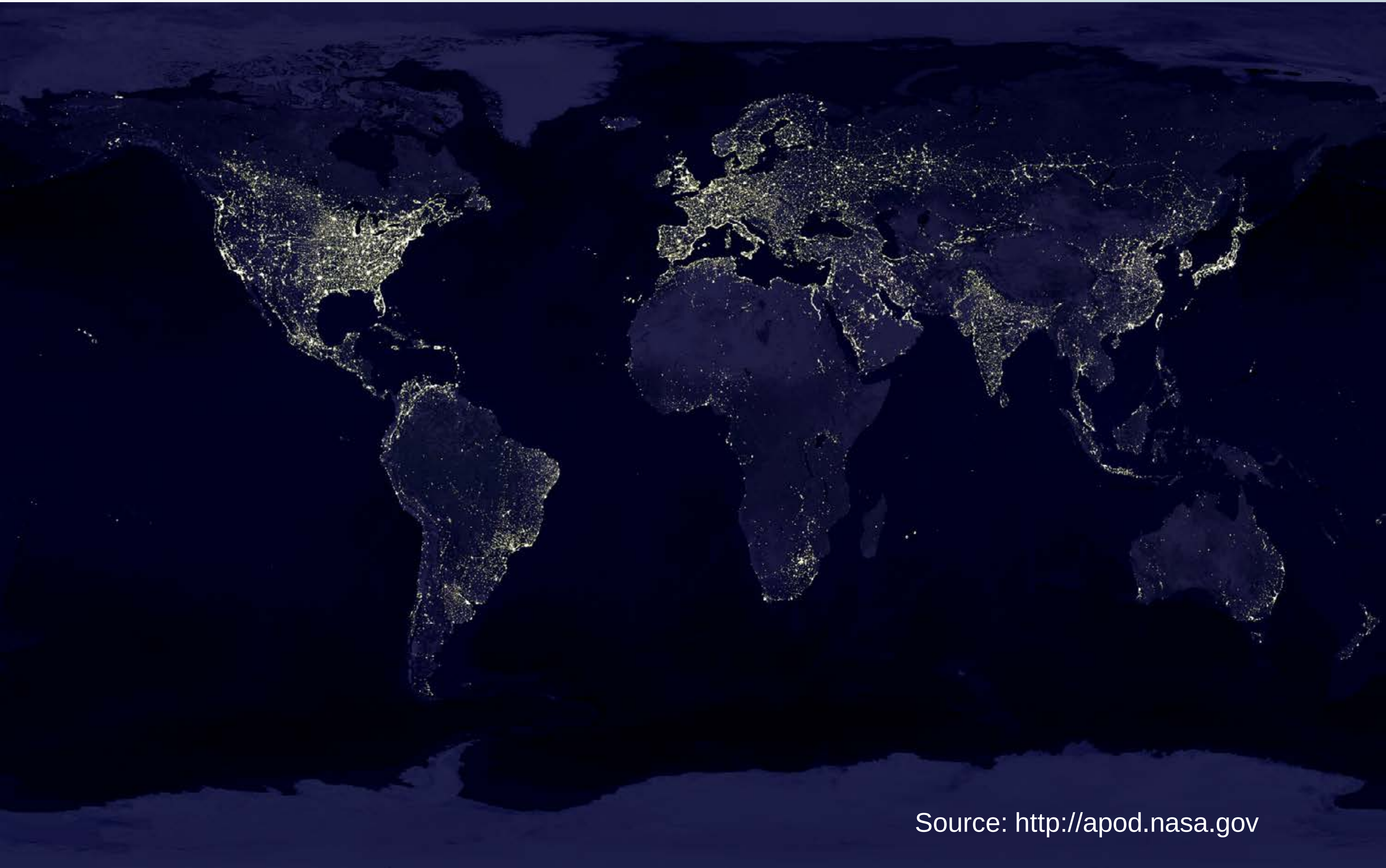


Human Uses of the Biosphere and Impacts on Earth Systems

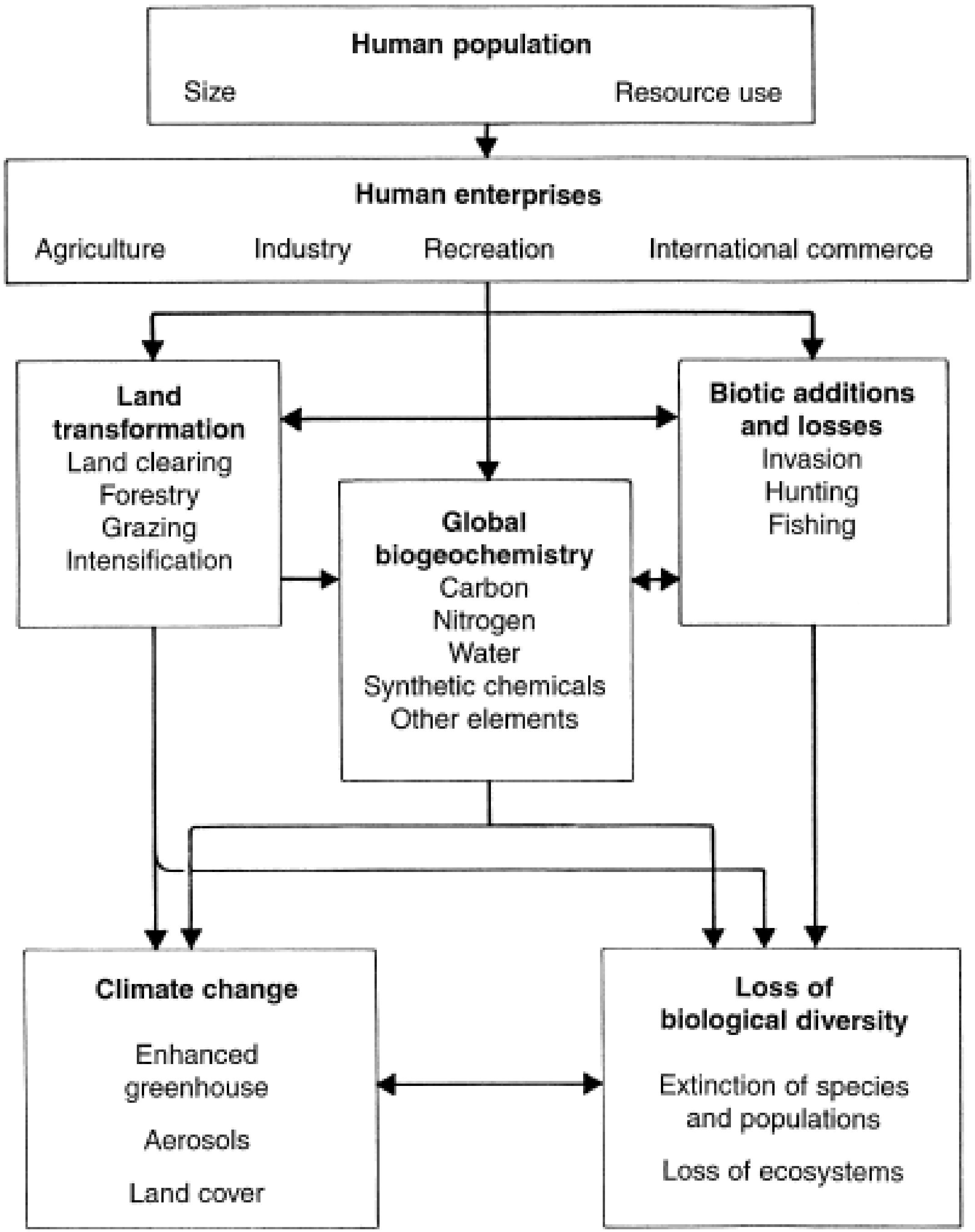
IPOL 8512

Human impacts revealed: Earth at night



Source: http://apod.nasa.gov

Causes and Effects of Human Impacts on the Natural Environment



Source:
Vitousek, P.M., et al. (1997). "Human domination of Earth's Ecosystems." *Science* 277: 494.

Human Uses of the Biosphere and Impacts on Earth Systems

Topics

- Water
- Energy
- Biomass & net primary production
- Land, ecosystems, soils
- Biodiversity
- Population

See course glossary for definitions

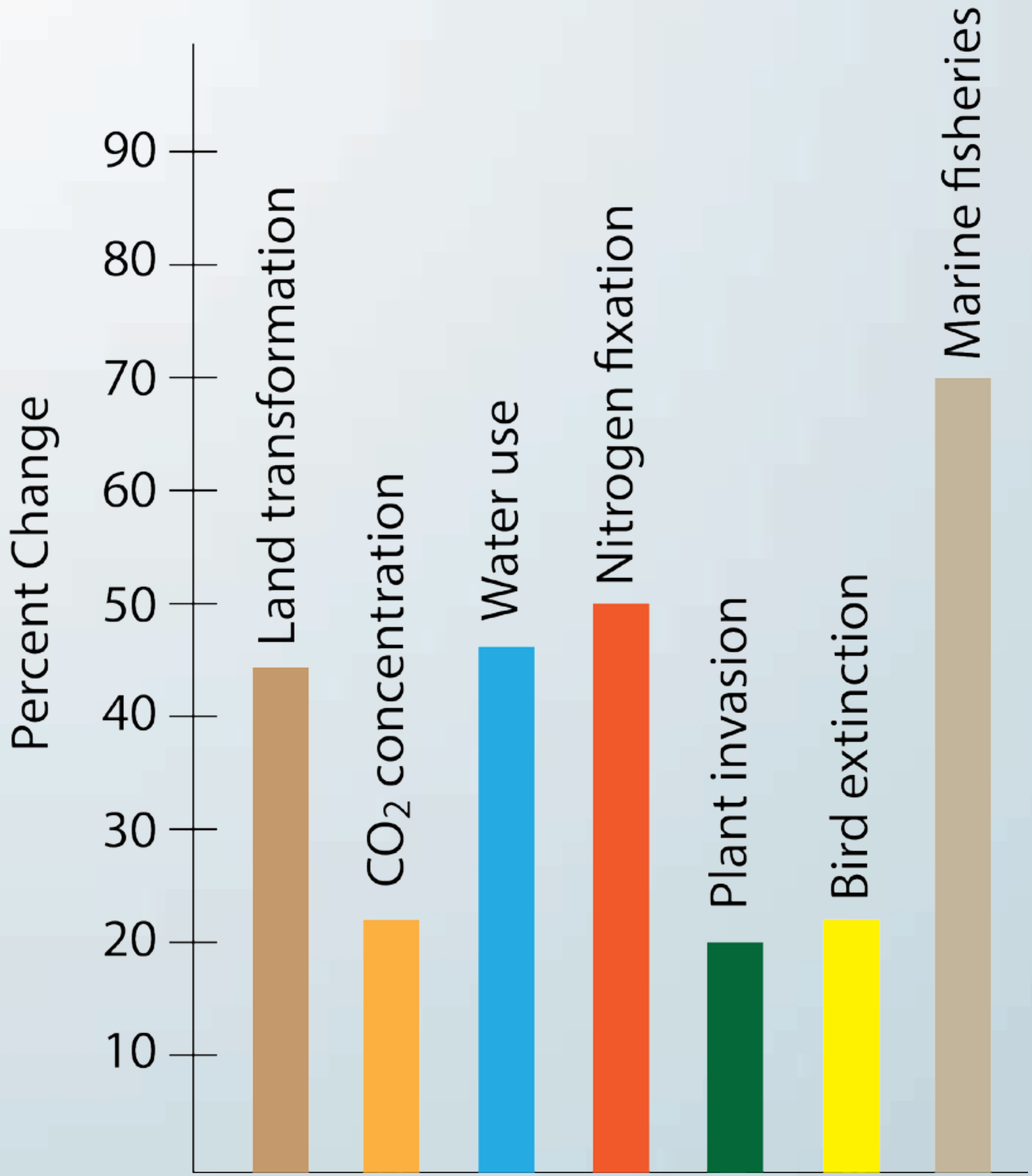
http://institutebishop.org/Glossary_IPOL_8512.pdf

Sneak Preview

Question: Are human impacts on earth systems significant in comparison to natural cycles, stocks, and flows?

Answer: Yes.

Some Measures of Human Impact



Vitousek et al, Human Domination of Earth's Ecosystems, Science Vol 277, 1997

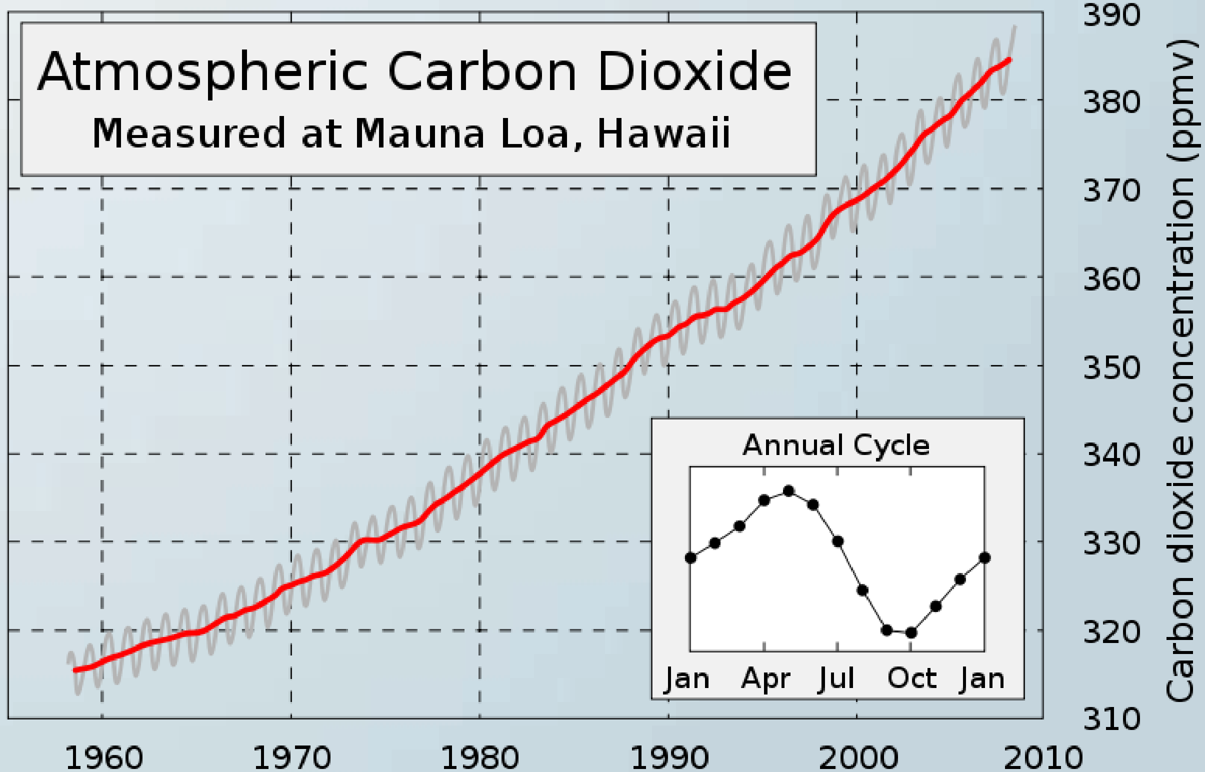
Human Dominated Ecosystems

Information from
Vitousek et al, Human Domination of Earth's Ecosystems,
Science Vol 277, 1997

- Land Transformation – 39-50% of vegetated surface
  - 10-15% of Earth's land surface agriculture or urban-industrial
  - 6-8% pastureland
  - Harvested forests
  - Primary driving force behind loss of biodiversity
- Oceans
  - 1995 – about 22% of recognized marine fisheries overexploited or already depleted
  - Human causes of destructive algae blooms

Human Dominated Ecosystems

- Biogeochemical Cycles
  - Carbon – CO_2 concentration increased from 315 ppm in 1957 to 392 ppm in 2011 – 30% increase from pre-industrial era



Human Dominated Ecosystems

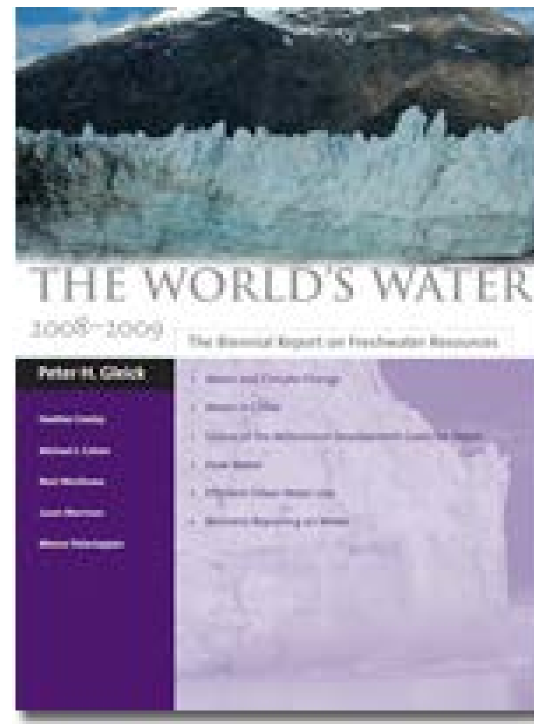
- Biogeochemical Cycles
  - Water
    - U.S. only 2% of rivers run unimpeded
    - As much as 6% of Earth's runoff is evaporated due to human manipulations
    - About ¾ of Saudi Arabia's water from fossil water
  - Nitrogen fixation
    - Human activities (e.g. production of ammonia for fertilizers, conversion of nitrogen to nitrogen oxides in fossil fuel combustion, and others) add at least as much fixed nitrogen to terrestrial ecosystems as do all natural sources.

Human Dominated Ecosystems

- Biotic Changes
  - Rates of species extinctions 100-1000 times greater than before human dominance of the Earth.
  - As many as ¼ of bird species driven to extinction by human activities
  - 11% of remaining birds,18% of mammals, 5% of fish, 8% of plant species are threatened with extinction.
  - Rearrangement of Earth’s biotic systems, mixing flora and faunas.

Water

Resource for Water Studies



http://www.pacinst.org/

Water Issues

- Over 1 billion people lack access to clean water.
- Thousands die daily for lack of it.
- Millions die every year due to preventable water-related diseases.
- Many of our most important aquifers are over-pumped.
- Half of the world's wetlands have been lost to development.
- Causes political tension…almost every major river system is shared among two or more nations, making water a source of international conflict and a matter of national security.

Water Issues (cont.)

- Conflicts between urban, agricultural, and environmental water interests
- Growing number of endangered and threatened water-based species – 3500 species threatened, ¼ fish and amphibians
- By 2025, some scenarios show water withdrawals increasing 50% in developing countries and 18% in developed countries

Threats to Freshwater Resources

- Growth of human populations – 2-3% annual increase in developing countries – leads to increases in
  - Water diversion
  - Acid rain
  - Cultivated land
  - Climate change
- Infrastructure development (dams, dikes, levees, river diversions)
  - Loss of ecosystem integrity due to changes in timing and quantity of water, temperature, nutrient, and sediment transport
  - Blocks fish migration

http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Threats to Freshwater Resources

- Land conversion
  - Eliminates aquatic environment
  - Decreased biodiversity
  - Alters runoff patterns
  - Inhibits natural recharge
  - Increases salt content of water
- Overexploitation
  - Falling groundwater levels (0.5-5 meters per year in some places)
  - Along coast, can lead to saltwater intrusion

http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Threats to Freshwater Resources

- Overharvesting
  - Depletes living resources
  - Disrupts ecosystem
  - Diminishes biodiversity
- Introduction of exotic species
  - Eliminates native species
  - Alters production of nutrient cycles
  - Loss of biodiversity
- Deforestation
  - Increases peak flows and reduces low flows, leading to both flooding and water shortages

http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

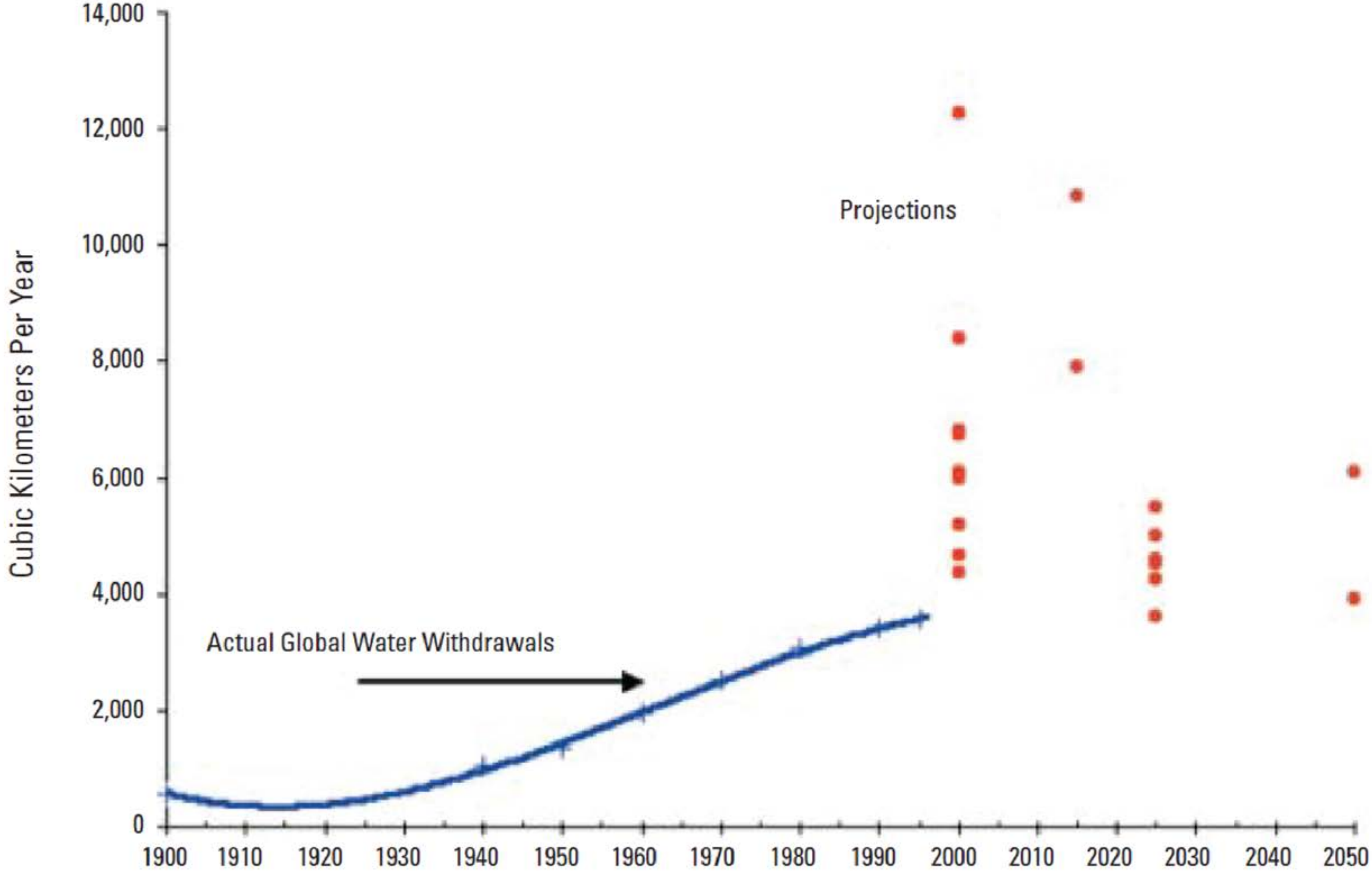
Threats to Freshwater Resources

- Chemical and biological pollution
  - From municipal, industrial, and agricultural sources
  - Phosphorus and nitrogen (mostly in the form of phosphates, PO_4^{3-}, and nitrates, NO_3^-) from agricultural fertilizers and municipal wastes (with phosphates from detergents) – can cause eutrophication of lakes
  - Alters ecology
- Greenhouse gases and climate change
  - Potential dramatic changes in runoff patterns due to temperature changes and changes in the rates of evaporation and precipitation
- Acidification
  - From sulfur oxides, SO_x, and nitrogen oxides, NO_x, which form acids when combined with water in the atmosphere
  - Decreases biological density and diversity

http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Projected and Actual Global Water Withdrawals

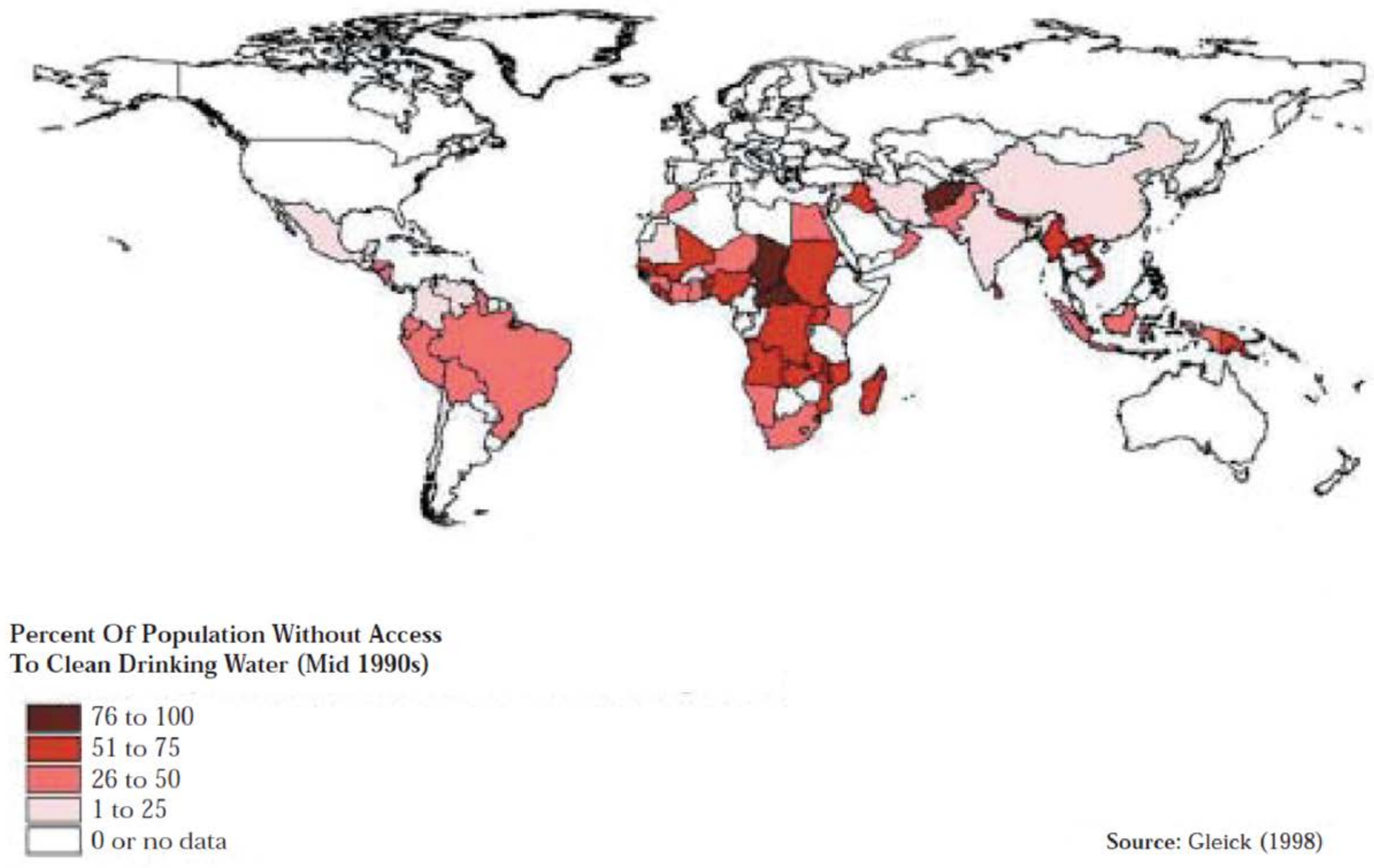
Very wide range of projected future water needs



http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Access to Clean Drinking Water

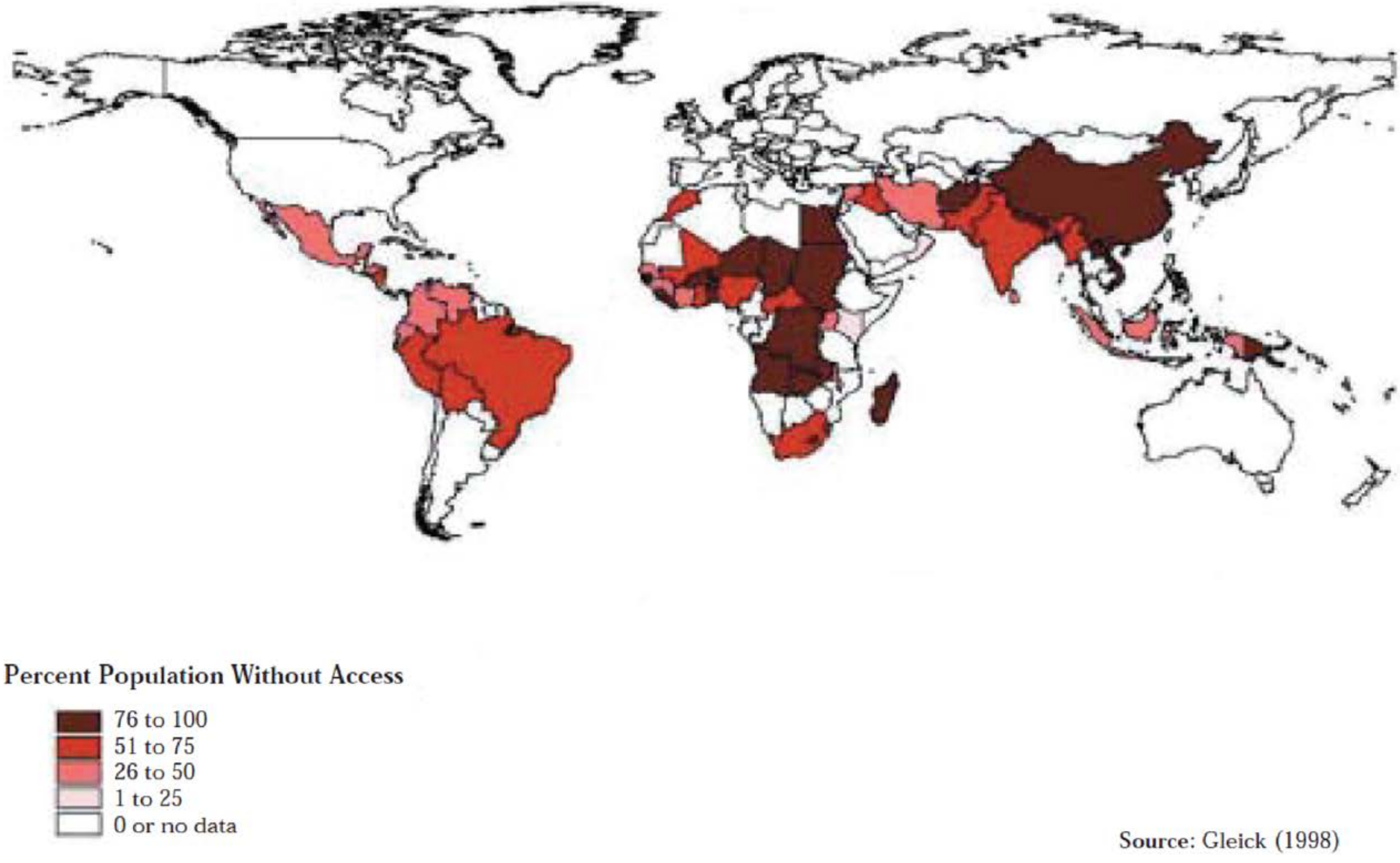
World Health Organization (WHO) – 1.3 billion without clean drinking water



http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Access to Adequate Sanitation Services

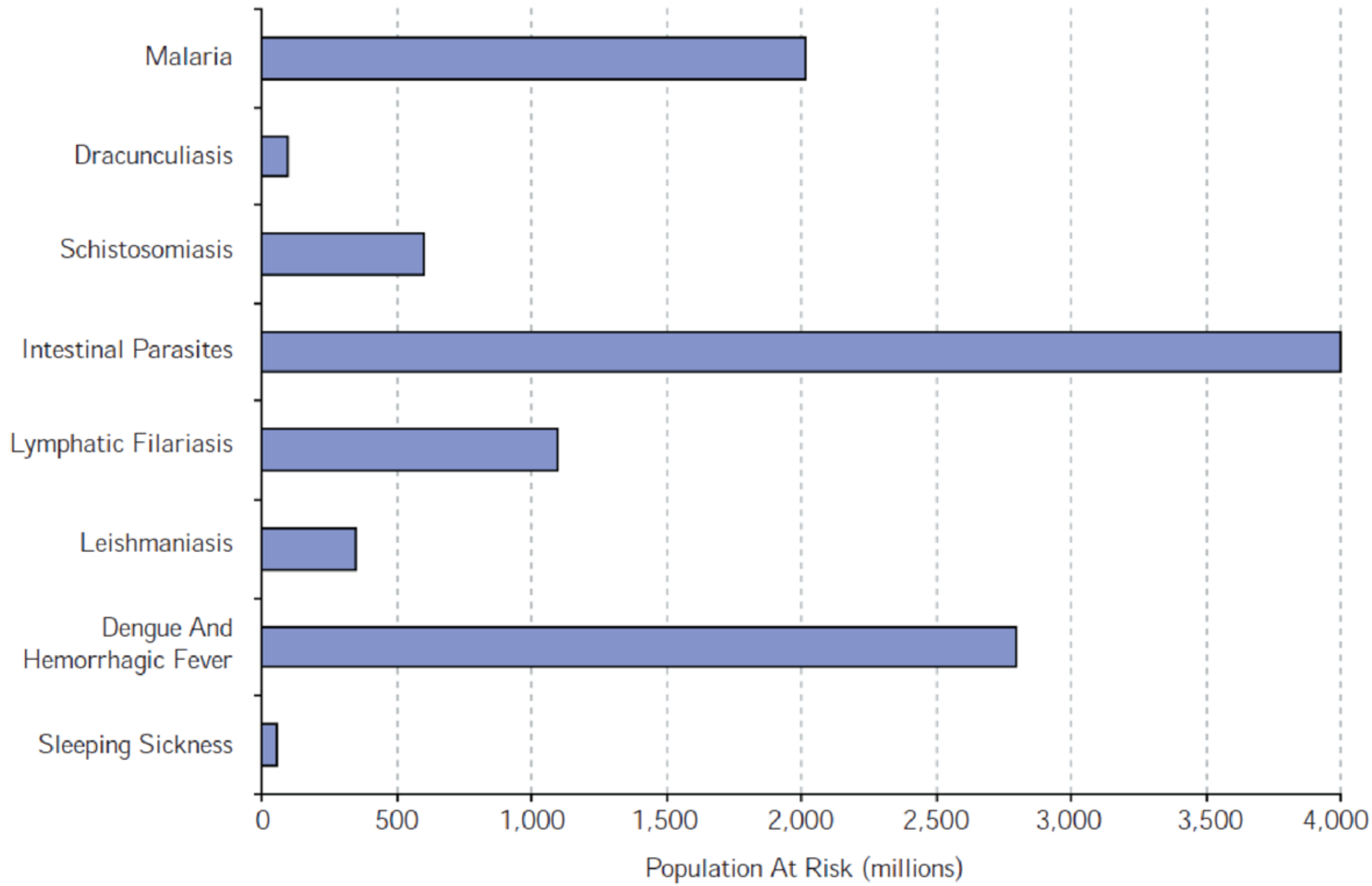
World Health Organization (WHO) – 2.4 billion without proper sanitation



http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Risk of Water-Related Diseases

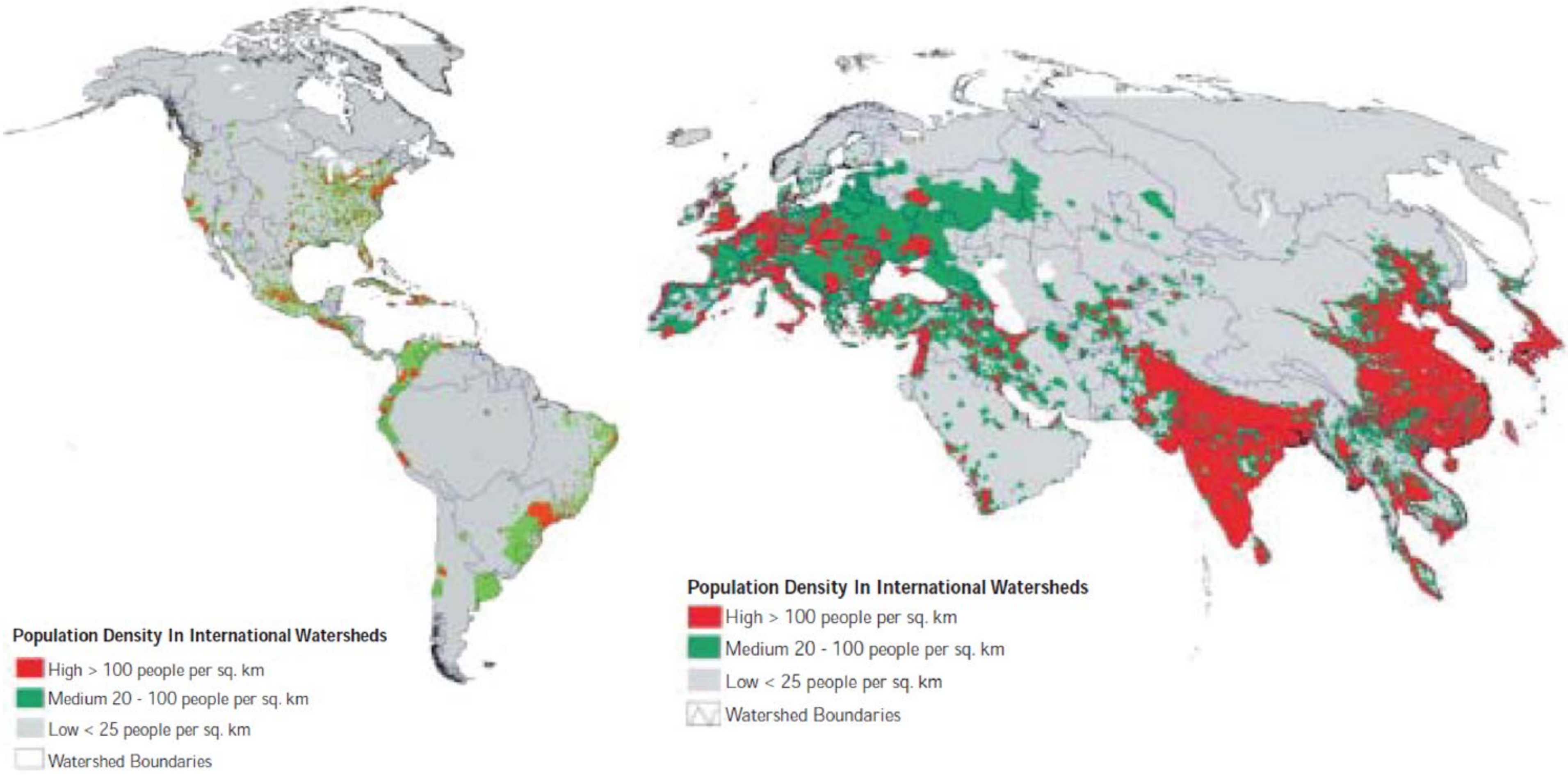
250 million cases of water-related diseases per year with 5-10 million deaths



Source: Gopalan, H.N.B. and S. Saksena (1999)

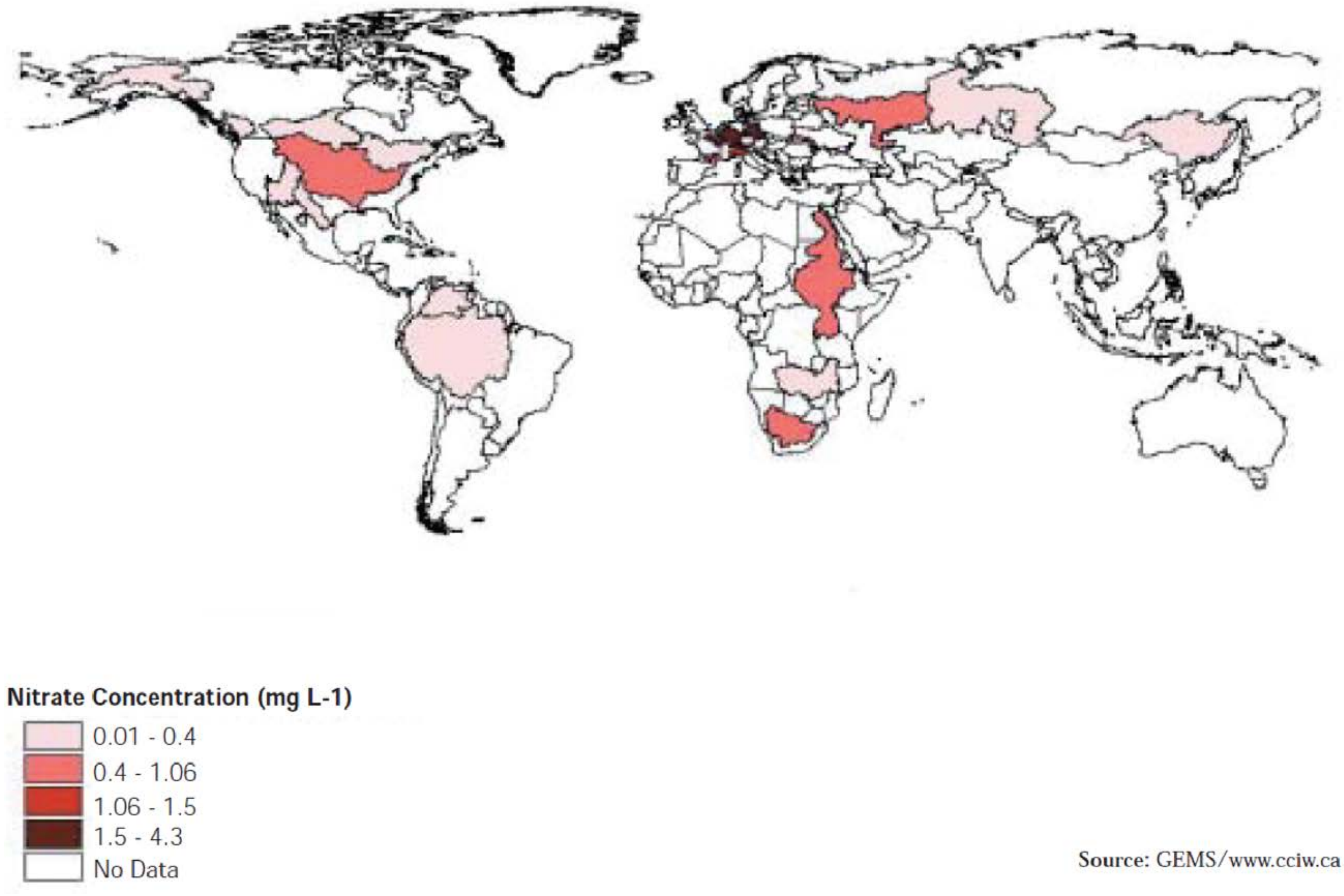
http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Threats Greater in Some Areas



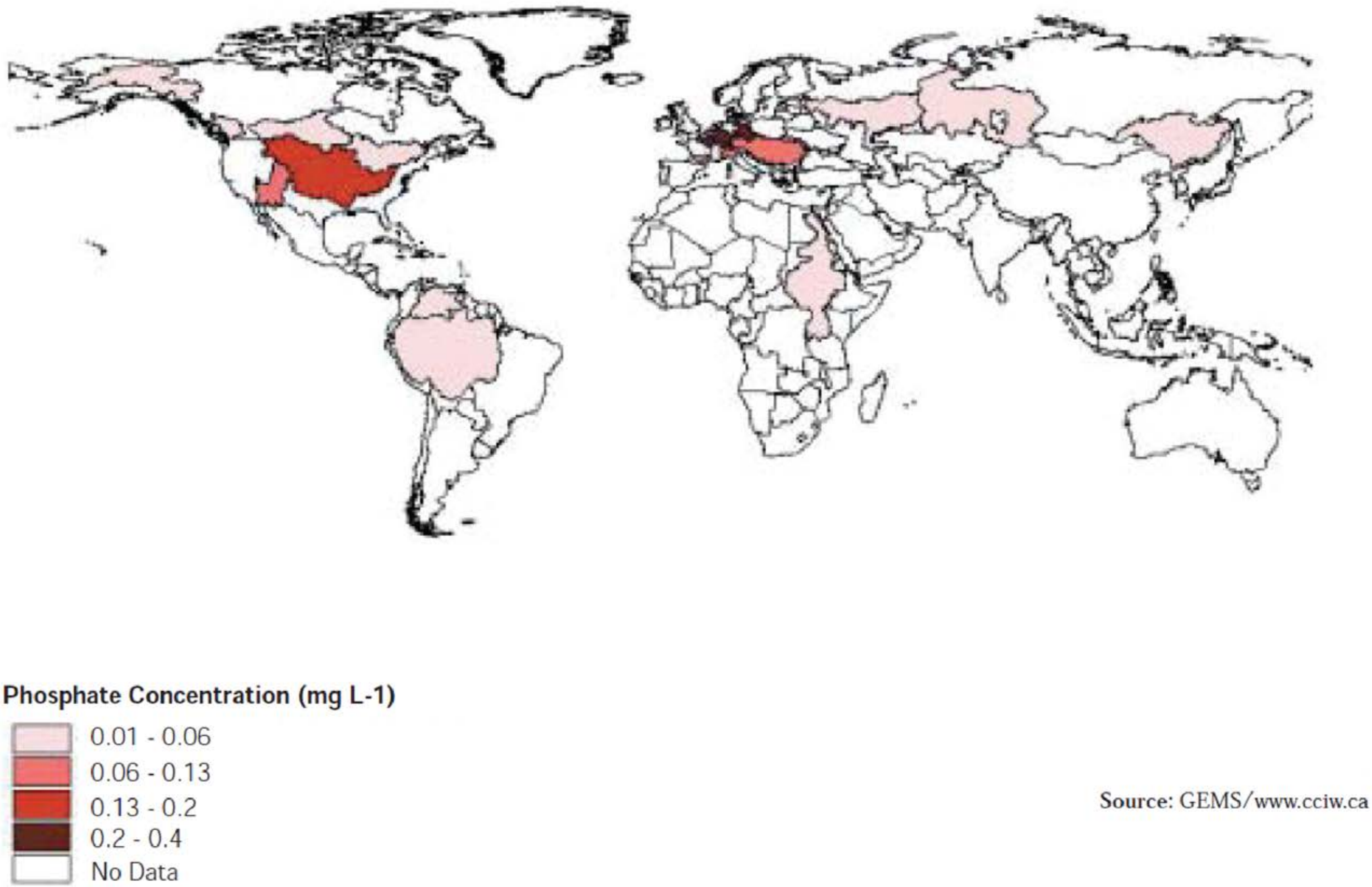
http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Nitrate Concentrations



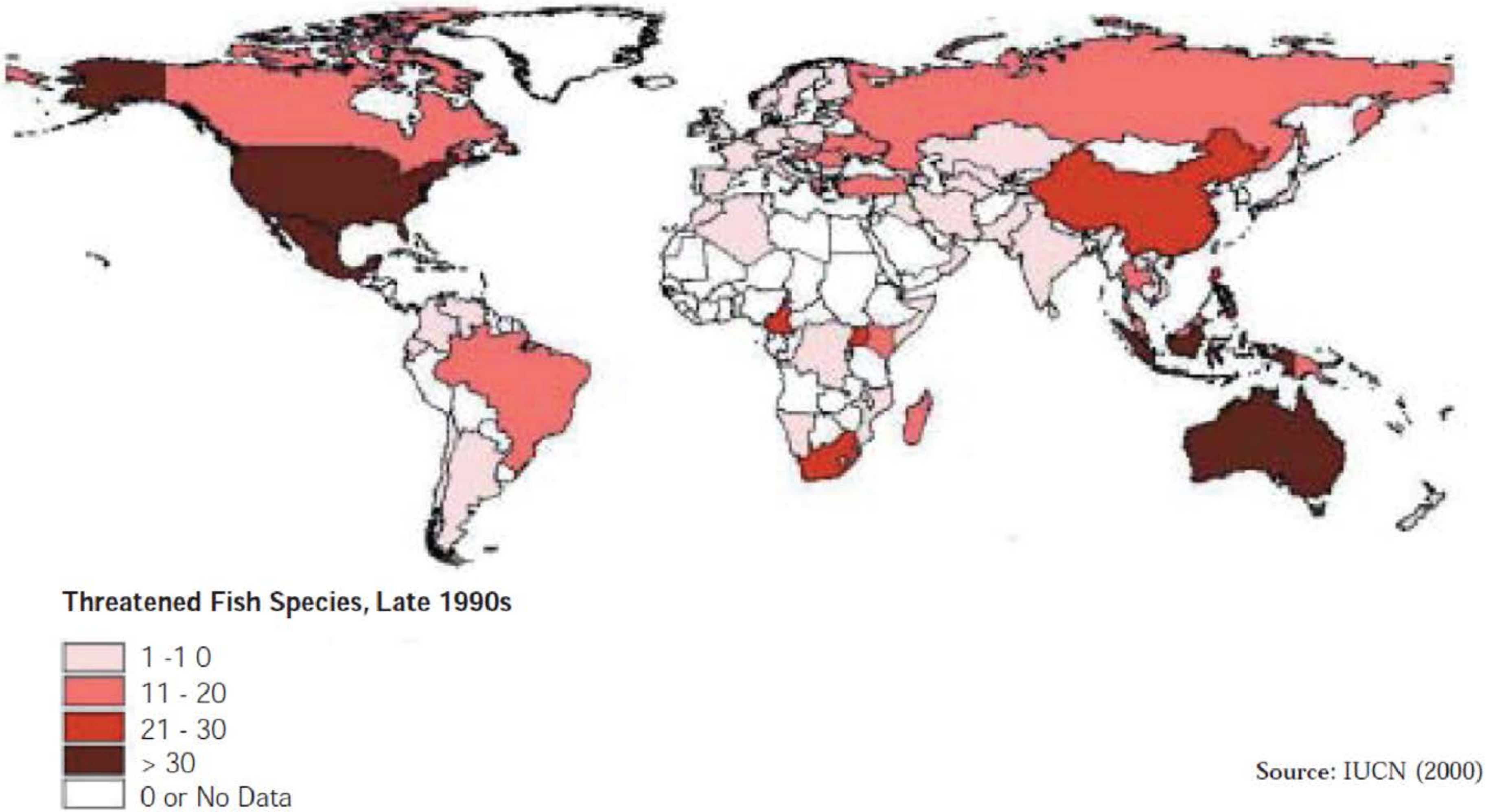
http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Phosphate Concentrations



http://www.pacinst.org/reports/freshwater_threats/threats_to_the_worlds_freshwater.pdf

Threatened Fish Species



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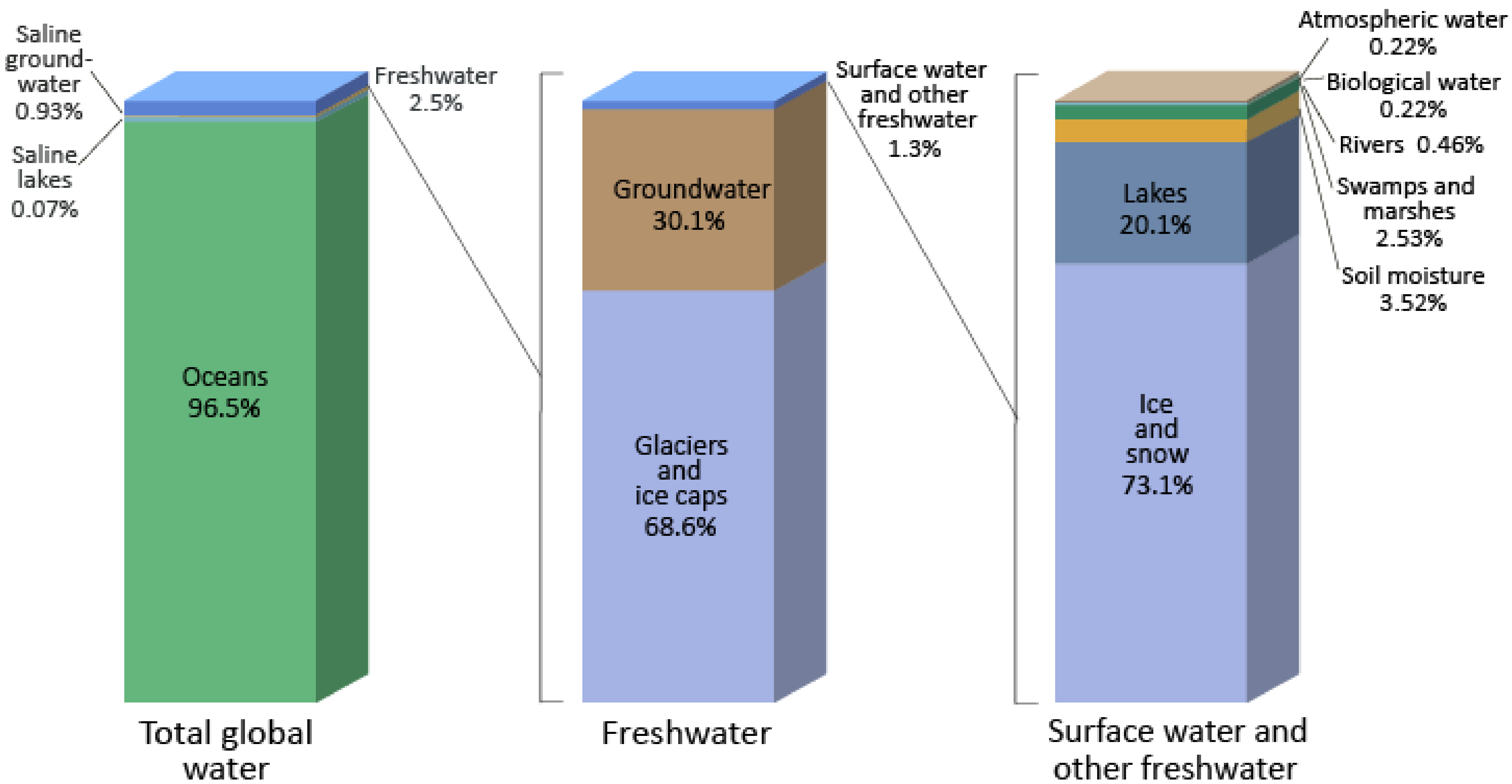
Distribution of Earth's Water



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.

The vast majority of Earth's water is inaccessible to terrestrial organisms.

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

Global Hydrologic Cycle: Stocks

ATMOSPHERE

0.013×10^6 km^3

LAND 38×10^6 km^3

$V_{L\text{-ice}} \approx 30 \times 10^6$ km^3

$V_{L\text{-ground}} \approx 10 \times 10^6$ km^3

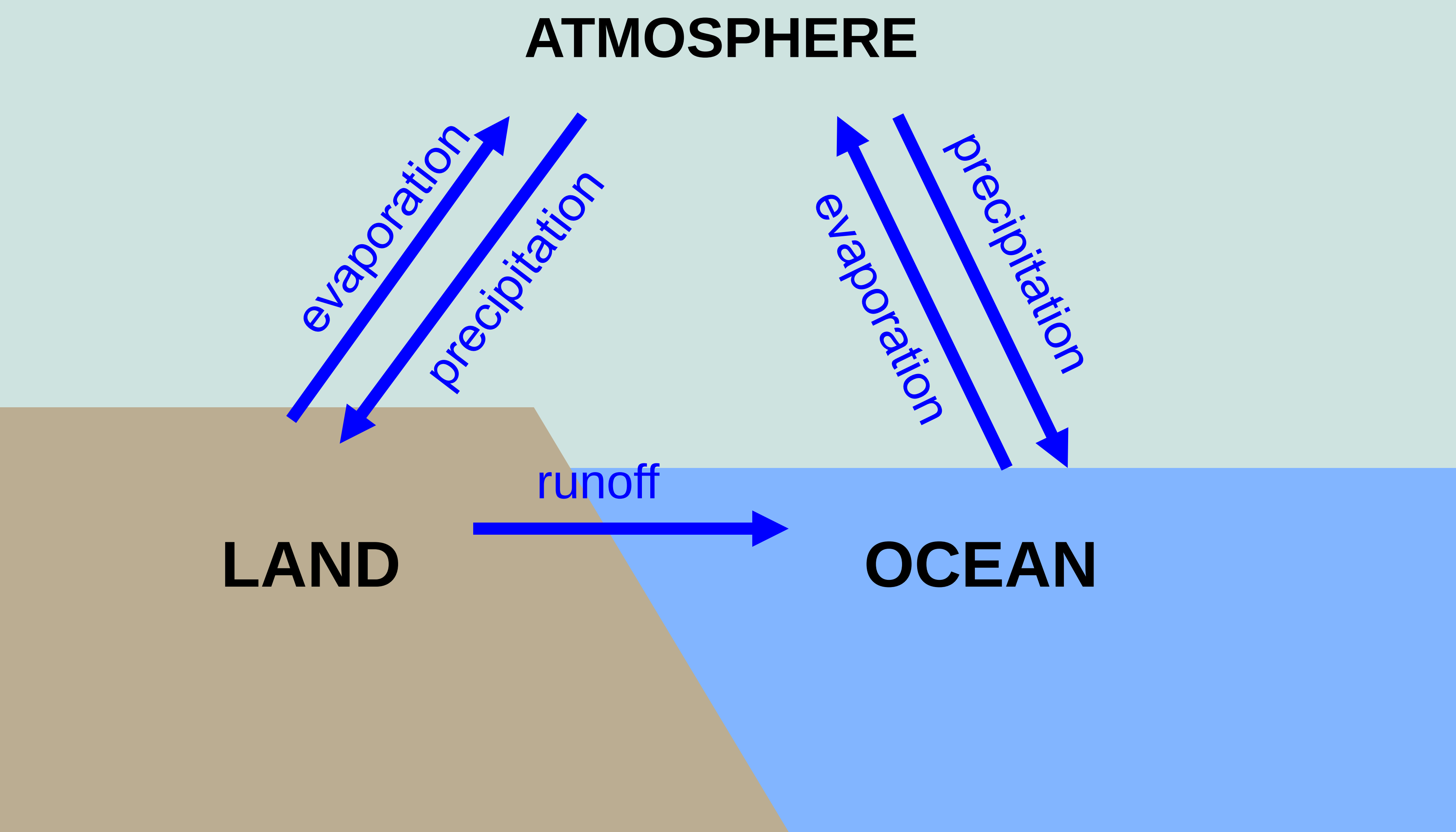
$V_{L\text{-lakes}} \approx 0.1 \times 10^6$ km^3

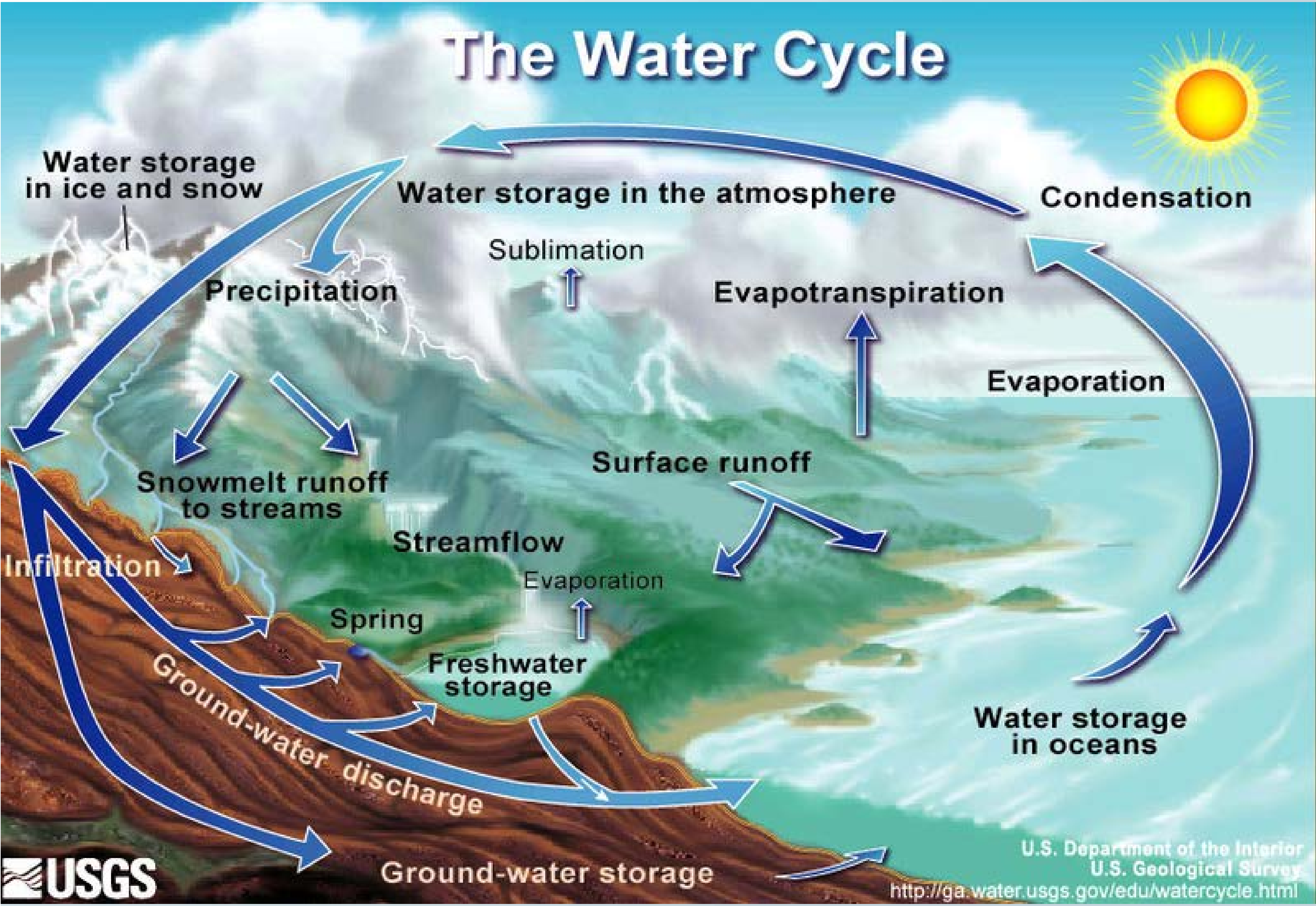
$V_{L\text{-rivers}} \approx 0.001 \times 10^6$ km^3

OCEAN

$1{,}350 \times 10^6$ km^3

Global Hydrologic Cycle: Flows





The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Snowmelt runoff to streams
Surface runoff
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
USGS
Ground-water storage
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html

Precipitation

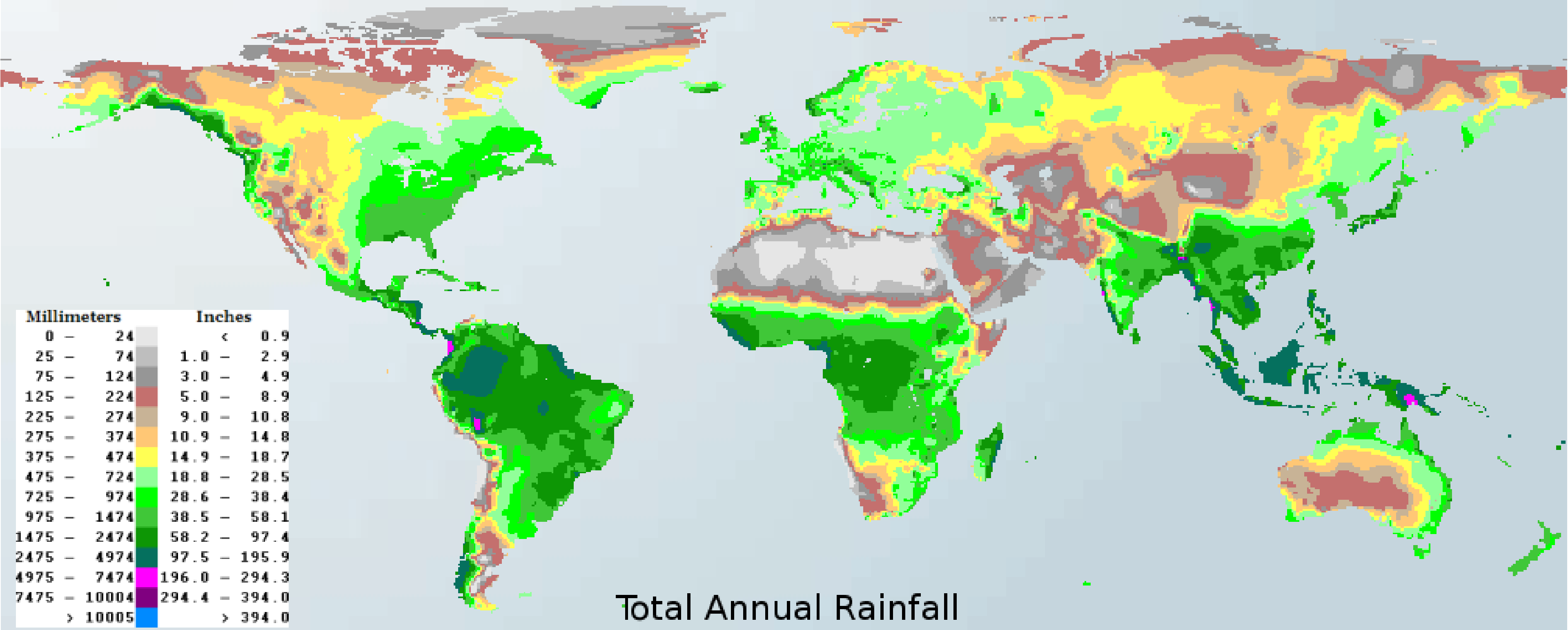
- Global average precipitation – 1 m/yr
- Global annual total precipitation = V = A•h

$$\frac{?\ \text{km}^3}{\text{yr}} = 5.0 \times 10^8\ \text{km}^2 \bullet \left(\frac{1\ \cancel{\text{m}}}{1\ \text{yr}}\right)\left(\frac{1\ \text{km}}{10^3\ \cancel{\text{m}}}\right)$$

$$= \mathbf{5.0 \times 10^5\ km^3/yr}$$

- Annual precipitation on land = 110,000 km^3
- Annual precipitation on oceans = 500,000 – 110,000 = 390,000 km^3

Flows in the Hydrologic Cycle



Water Equilibrium on Land

- Equilibrium: outflow = inflow
  = 110,000 km^3

- Outflows
  - ≈60% Evapotranspiration or about 70,000 km^3
    - **Evapotranspiration (ET)** = the sum of evaporation and plant transpiration from the Earth's land surface to the atmosphere.
    - **Transpiration** = the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.
  - ≈40% Runoff or about 40,000 km^3

Steady-State Calculations

$$\text{Flow in} = F_{in} = \frac{\text{amount into system}}{\text{time}}$$

$$\text{Flow out} = F_{out} = \frac{\text{amount out of system}}{\text{time}}$$

$$\text{Stock} = M$$

$$\text{Residence time} = T$$

$$F_{in} = F_{out} = \frac{M}{T}$$

Two Ways to Do Steady-State Calculations

What is the residence time of H_2O in Earth's atmosphere? Report your answer in days.

- Equation-based
- Unit Analysis

From COW appendix,

- the precipitation rate is 5.18×10^{14} m^3/yr.
- the amount of water in the atmosphere is 1.3×10^{13} m^3.

Steady-State Calculations

That is the residence time of H_2O in Earth's atmosphere?

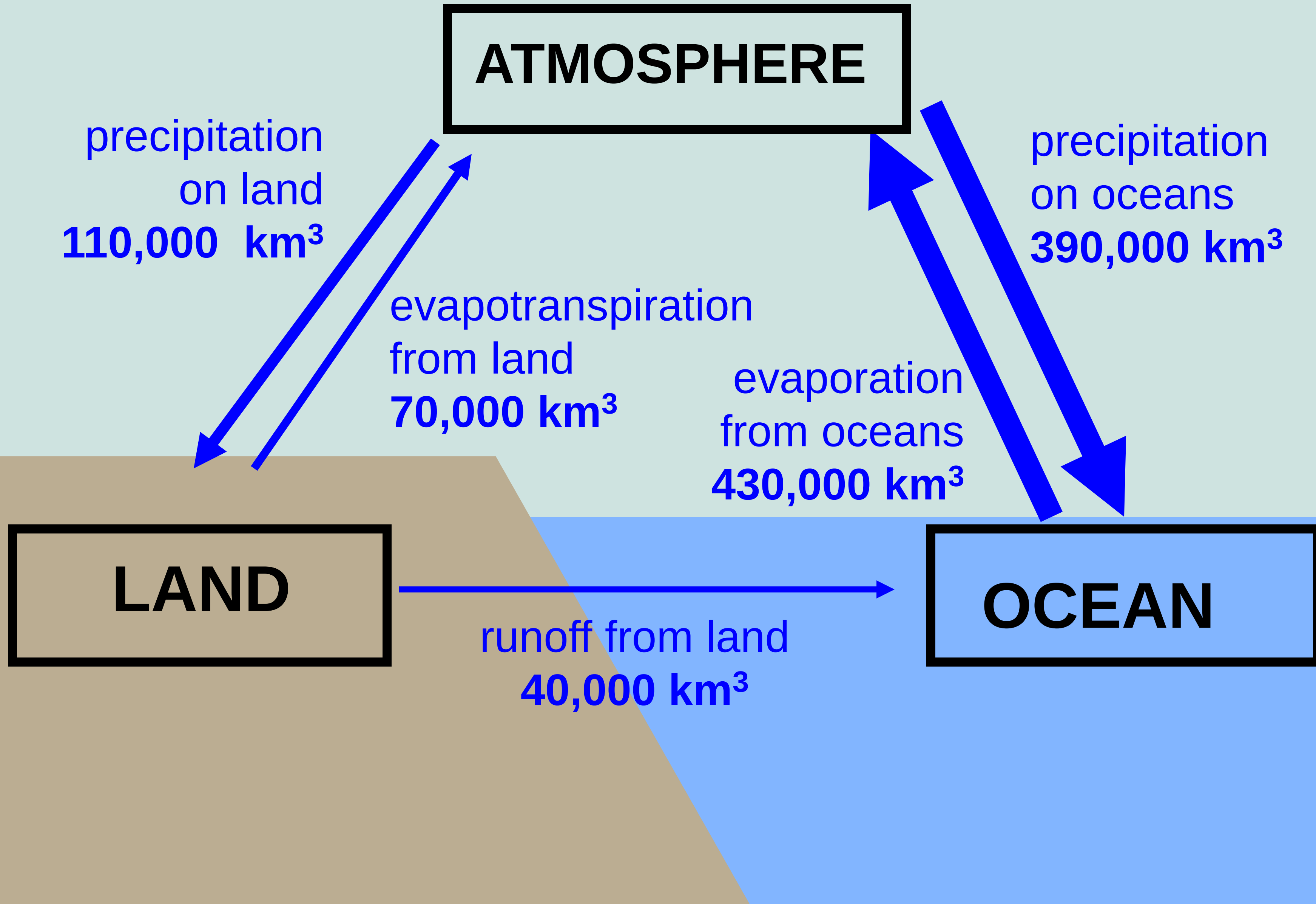
$$F_w = \frac{M_w}{T_w}$$

$$T_w = \frac{M_w}{F_w} = \frac{1.3 \times 10^{13}\ \text{m}^3}{5.18 \times 10^{14}\ \text{m}^3/\text{yr}} = \mathbf{0.025\ yr} \left(\frac{365\ \text{day}}{1\ \text{yr}} \right) = \mathbf{9.1\ days}$$

or

$$?\ \text{day} = 1.3 \times 10^{13}\ \cancel{\text{m}^3} \left(\frac{1\ \cancel{\text{yr}}}{5.18 \times 10^{14}\ \cancel{\text{m}^3}} \right) \left(\frac{365\ \text{day}}{1\ \cancel{\text{yr}}} \right) = \mathbf{9.1\ days}$$

Hydrologic Cycle Box Model: Flows



Residence Times of Water

Residence time: The average amount of time that a particle will spend in a given part of a system.

Reservoir	Average residence time
Atmosphere	9 days
Soil moisture	1 to 2 months
Rivers	2 to 6 months
Seasonal snow cover	2 to 6 months
Glaciers	20 to 100 years
Lakes	50 to 100 years
Groundwater: shallow	100 to 200 years
Groundwater: deep	10,000 years

Source: Pidwirny, M. (2006). "The Hydrologic Cycle." *Fundamentals of Physical Geography, 2nd Edition*. Retrieved 23 Sep 2009 from http://www.physicalgeography.net/fundamentals/8b.html.

How do humans use fresh water?

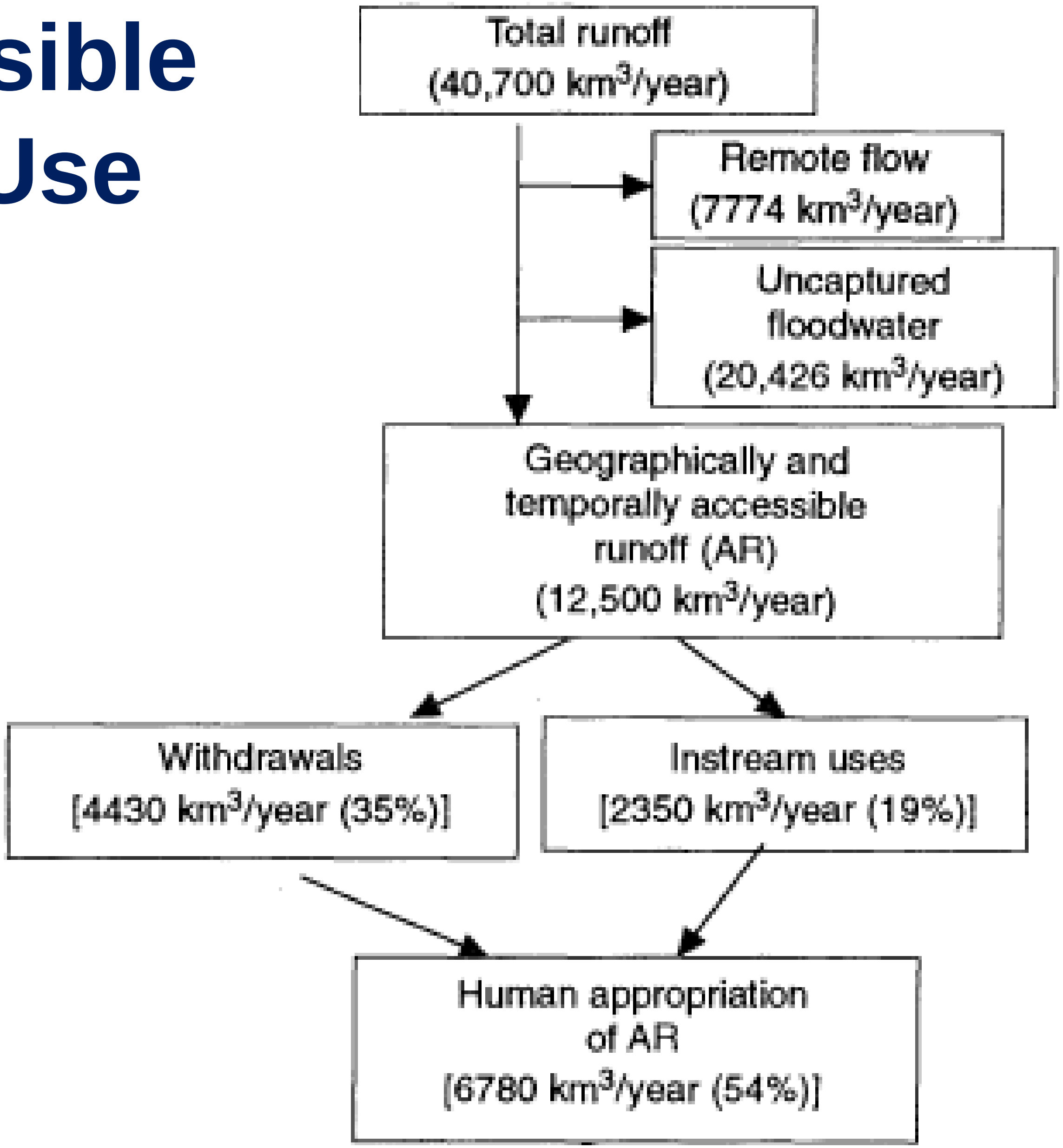
- **Withdrawal** = Water removed from the natural surface or ground water system.
- **Consumption** = Withdrawn water that cannot be reused, such as evaporation from agricultural fields.
- **Instream use** = Water not removed from the natural system but used in some way (e.g. for navigation, run-of-river hydropower, fishing).

California Aqueduct

Mosel River, Germany

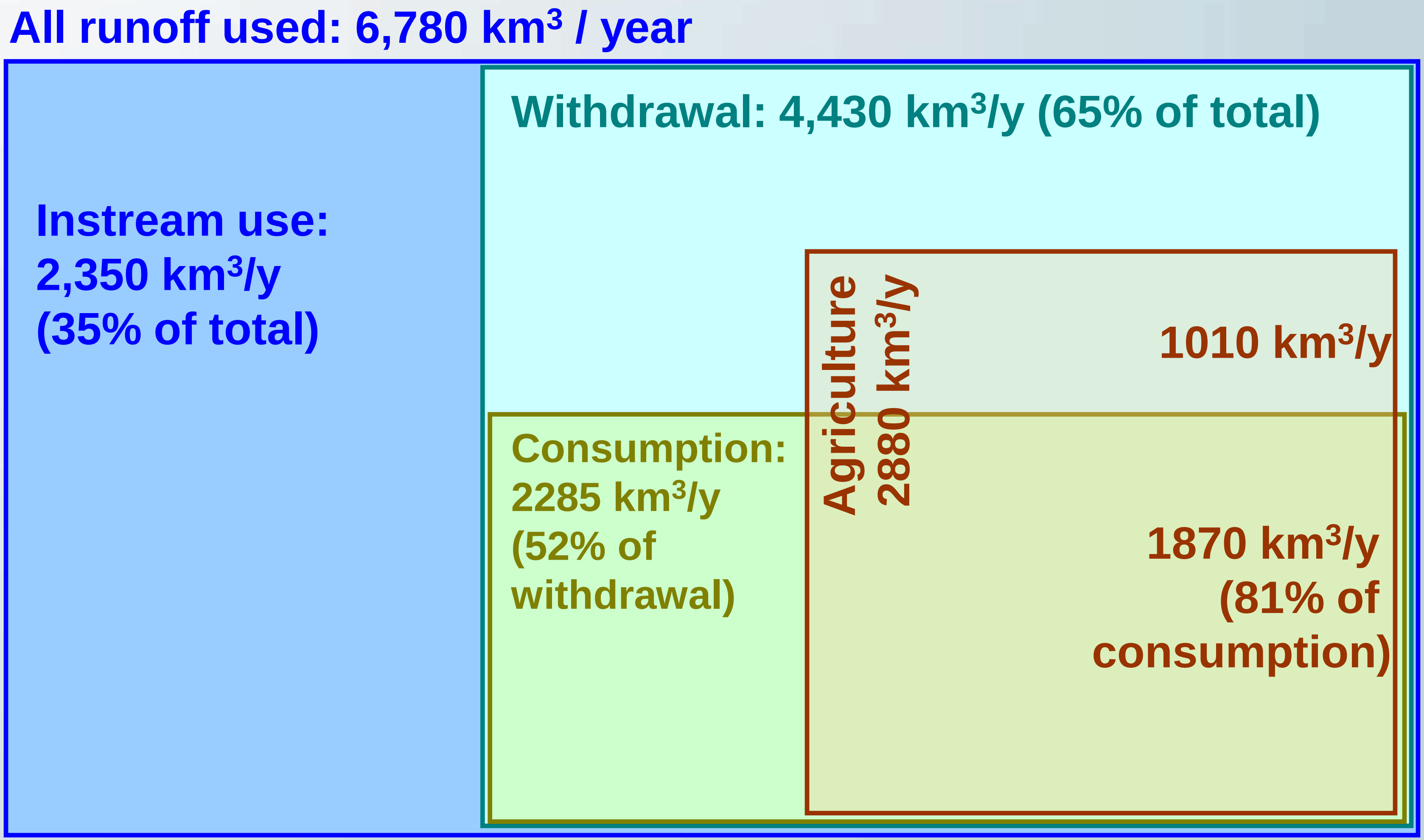
Water Accessible for Human Use

- A large fraction of runoff is too remote (20%) or too large a flux (50%) for humans to intercept.
- Runoff mismatched with population. Examples, Amazon basin: 15% runoff/0.4% pop. and Asia: 35% runoff/60% pop.
- The remainder (30%) is "**accessible runoff**" (AR). **We use ~54%** of this.



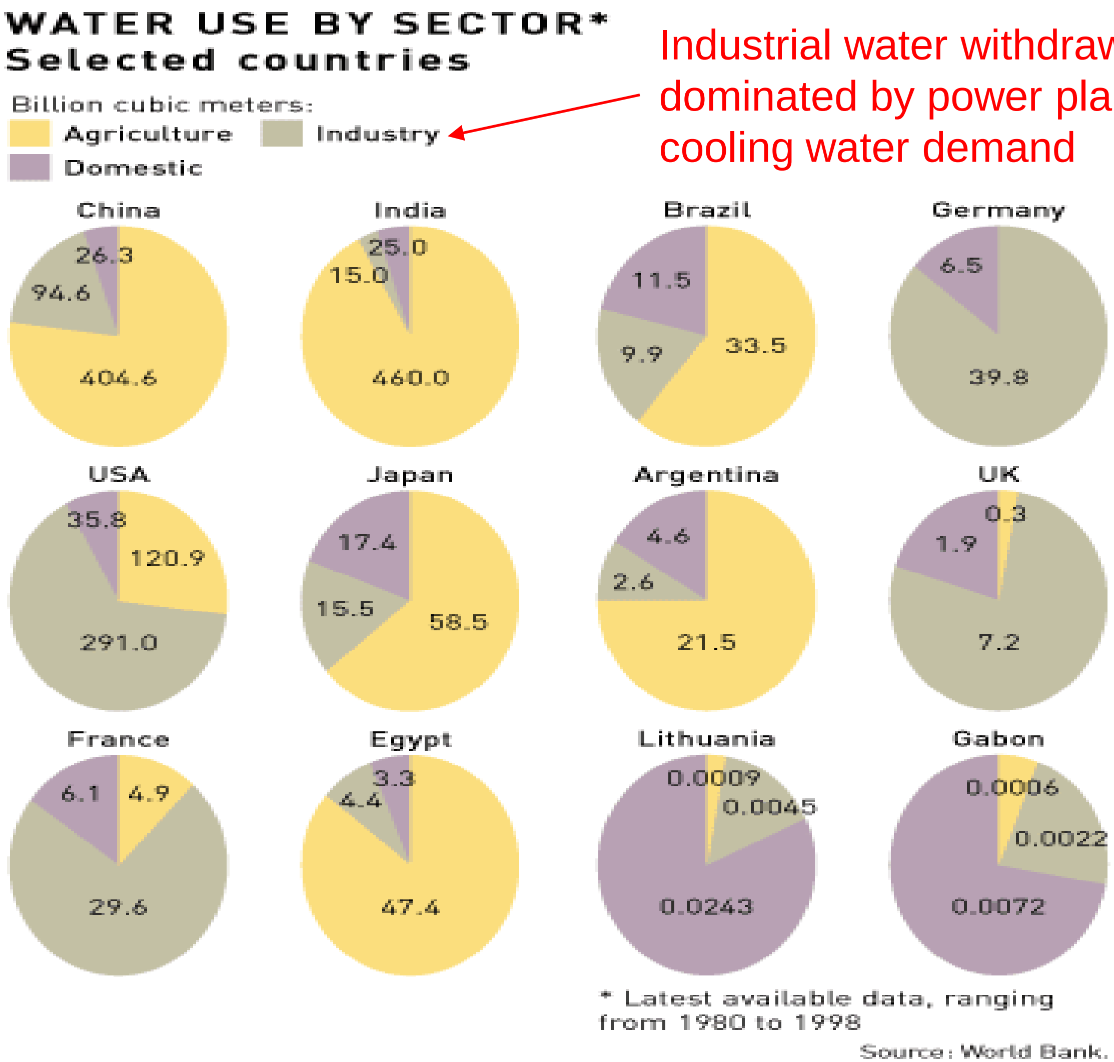
Source: Postel, Sandra; Gretchen Daily; and Paul Ehrlich (1996). "Human appropriation of renewable fresh water." *Science* 271(5250): 721-725.

Statistics on Human Water Use



Source: Postel, Sandra; Gretchen Daily; and Paul Ehrlich (1996). "Human appropriation of renewable fresh water." *Science* 271(5250): 721-725.

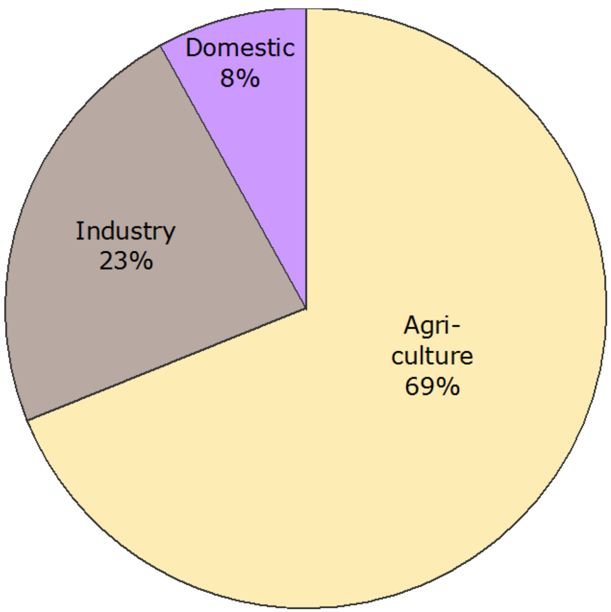
What Drives Water Demand?



Industrial water withdrawals dominated by power plant cooling water demand

AGRICULTURE

accounts for nearly 70% of global water withdrawals. However, this varies greatly by country.

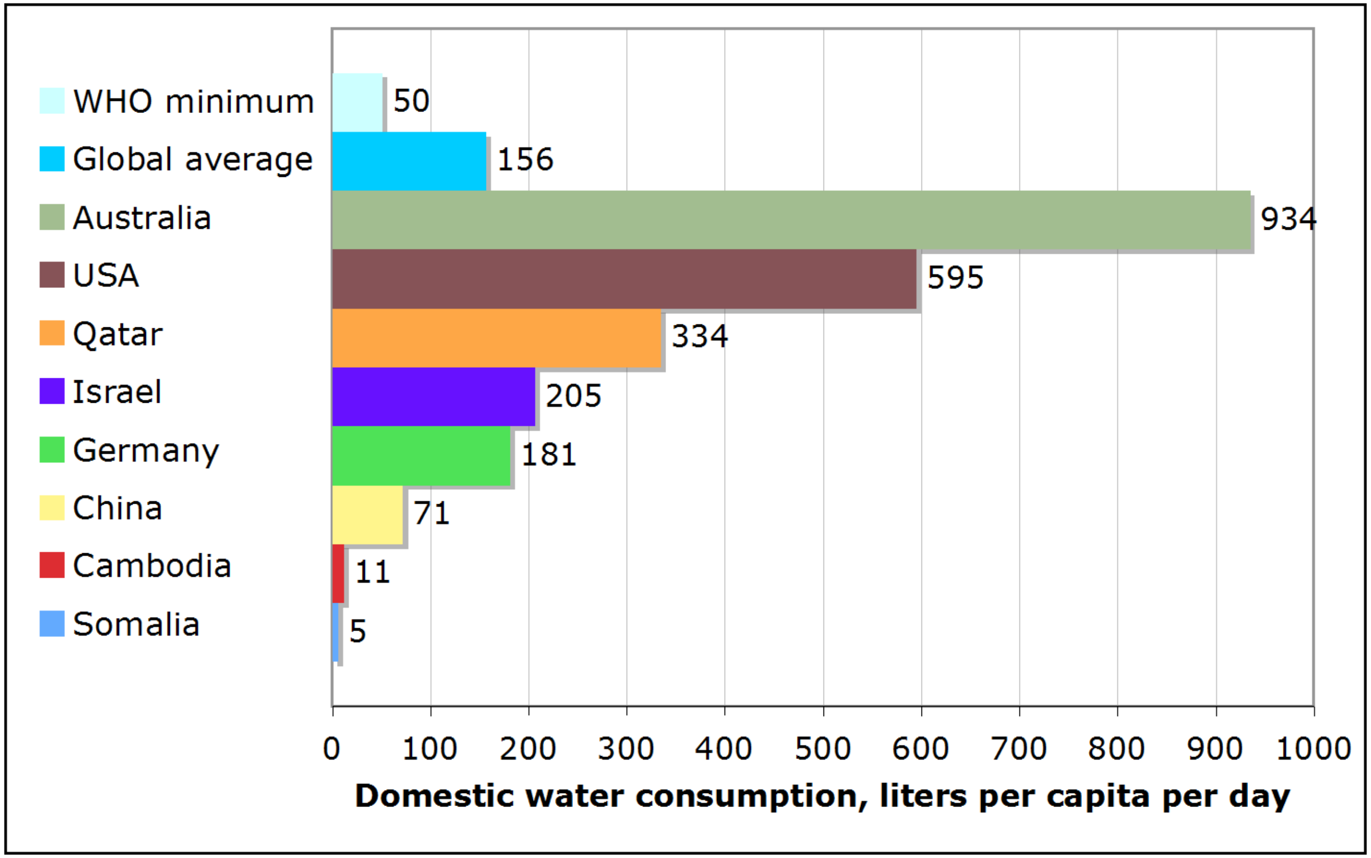


Global average

Sources: atlas.aaas.org; www.ozh2o.com/h2use.html

Domestic water use: a drop in the bucket

In most countries, only a tiny fraction of water is consumed *directly* by humans (drinking, cooking, washing, sanitation). We use much more *indirectly* through consumption of food and industrial products.



Source: Hoekstra, A.Y. and Chapagain, A.K. (2008) Globalization of water: Sharing the planet's freshwater resources, Blackwell Publishing, Oxford, UK. From www.waterfootprint.org.

Global Precipitation Patterns

Which regions have high population density but low precipitation?

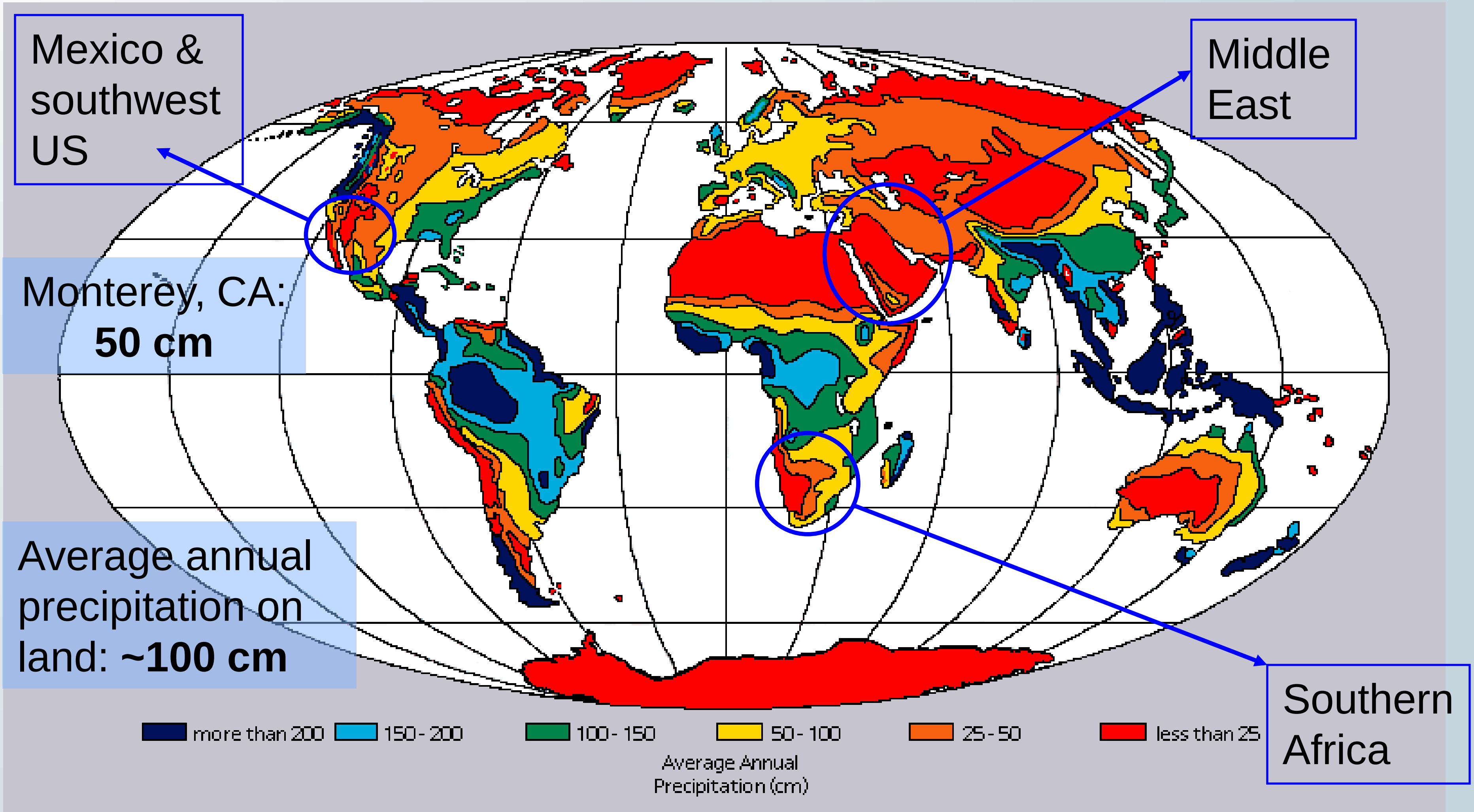
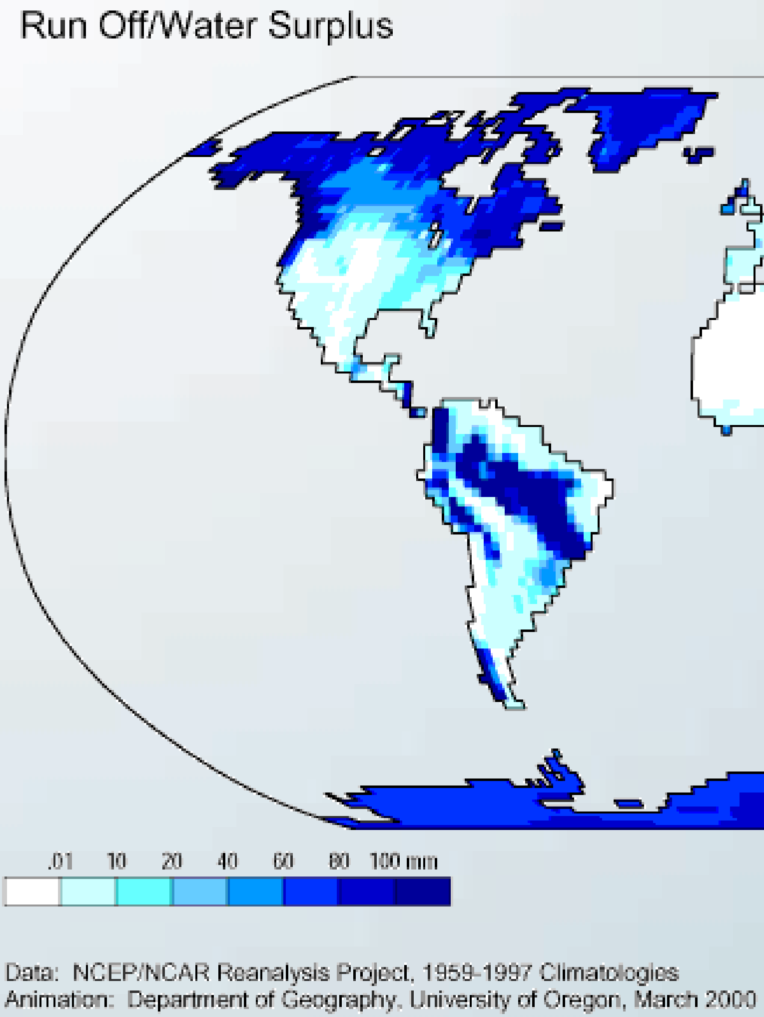


Figure 5. Global average annual precipition. (From H. L. Penman, "The Water Cycle."

Which regions have extra water?



Precipitation alone does not determine water availability. Evaporation depends on air temperature, wind, surface albedo, and other factors.

http://geography.uoregon.edu/envchange/clim_animations/index.html

Impacts of Water Use on Human Populations

- DIA/Q > 0.4 $\rightarrow$ severe water stress

  DIA = domestic, industrial, agricultural consumption

  Q = accessible runoff
- 0.5-2.0 billion people in severe water stress in year 2000
- 2025 forecast: total usage 54% $\rightarrow$ 70%
- Water reuse index = $\sum$DIA/Q for whole length of river

  $\sum$DIA/Q = 4 for Yellow River, dry > 1/2 year for 600 km

Groundwater Use

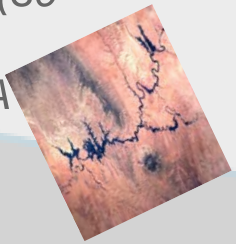
- **Withdrawals of groundwater are increasing** as urbanization and agriculture increase in arid regions.
- Groundwater is usually **replenished slowly**. If withdrawal >> recharge, use is **unsustainable** (mining “fossil water”). Rapid withdrawal can cause land subsidence.
- Current groundwater withdrawals are **600-700 km^3/y**, ~ 20% of the amount of surface withdrawals.

Land subsidence due to groundwater withdrawal, Mendota, CA, 1977

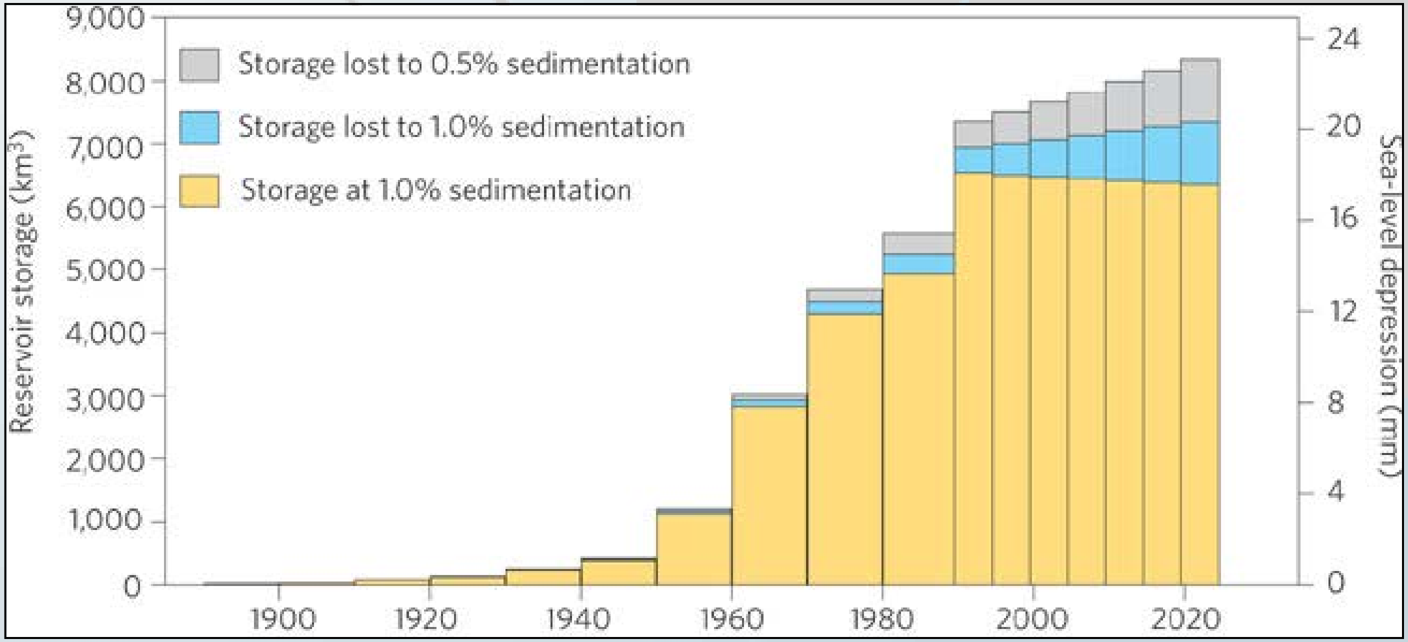
Photo source: http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/
Data source: http://www.unep.org/dewa/assessments/ecosystems/water/vitalwater/02.htm

Dams and Reservoirs

Lake Powell (30 km^3), Utah/ Arizona, USA



- Dams & reservoirs contain ~**7000 km^3** of water, equal to
  - **6% of that in natural freshwater lakes**
  - **15% of annual river runoff**
- This impoundment has **reduced sea level by 2 cm.**
- **>50% of major rivers** are significantly affected by dams.



Sources: (1) Lettenmaier, D., and P. C. D. Milly (2009). "Land waters and sea level." *Nature Geoscience* 2, 452-454. (2) Nilsson, C., et al. (2005). "Fragmentation and Flow Regulation of the World's Large River Systems." *Science* 308(5720): 452-4.

Environmental Effects of Large Dams

There are currently ~45,000 large (>15m high) dams. Large dams can profoundly affect both riverine and terrestrial ecosystems due to:

- **Submergence** of land area
- **Sediment** and nutrient trapping
- Changes in **downstream hydrology**:
  - Reduced water flows
  - Flows out of sync with ecosystem need
  - Changes in water temperature
- **Fragmentation** of ecosystems

Three Gorges Dam, China

Most suitable sites for large dams are now used, so construction has slowed.

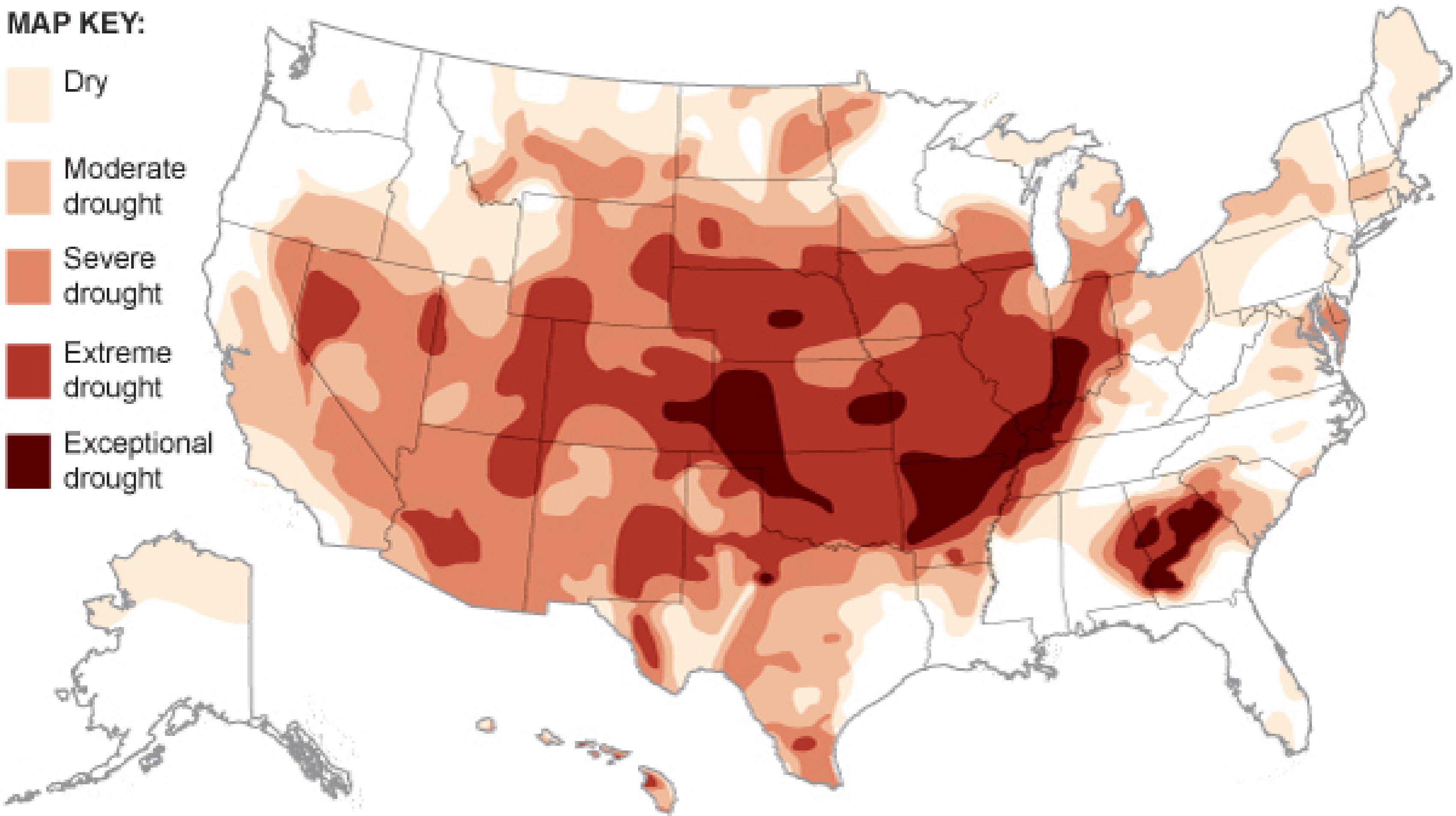
Summary: Human Freshwater Use

- Less than **3%** of Earth's water is **fresh**, and less than **1%** of that is **surface** water.
- The water cycle has three main pools - **oceans**, **land**, and **atmosphere** - and three types of fluxes: **precipitation**, **evaporation**, and **runoff**.
- Humans use about **54% of available runoff**. Of that, **65% is withdrawal** (of which half is consumed) and **35% is instream use**.
- **Groundwater** use is **~20%** of surface withdrawal.
- **Agriculture** accounts for **70%** of global water use.
- Human water use has profound effects on freshwater ecosystems.

Drought in the U.S. August 2012

The Current Disaster

National drought conditions as of last week. About 52 percent of the United States was in moderate drought, or worse; 20 percent was in extreme or exceptional drought.



Drought in the U.S.

- 2012 – severe drought in U.S.
- *Future precipitation trends, based on climate model projections for the coming fifth assessment from the Intergovernmental Panel on Climate Change, indicate that droughts of this length and severity will be commonplace through the end of the century unless human-induced carbon emissions are significantly reduced. Indeed, assuming business as usual, each of the next 80 years in the American West is expected to see less rainfall than the average of the five years of the drought that hit the region from 2000 to 2004.*

Christopher R. Schwalm, Christopher A. Williams and Kevin Schaefer

http://www.nytimes.com/2012/08/12/opinion/sunday/extreme-weather-and-drought-are-here-to-stay.html?ref=opinion

http://www.ipcc.ch/

Intergovernmental Panel on Climate Change (IPCC)

- *"…international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts."*
- *"The IPCC is a scientific body. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct any research nor does it monitor climate related data or parameters."*

http://www.ipcc.ch/

http://www.ipcc.ch/publications_and_data/publications_and_data.shtml#.UFHrR1FyDag

http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html

Drought in the U.S.

- Christopher R. Schwalm is a research assistant professor of earth sciences at Northern Arizona University.
- Christopher A. Williams is an assistant professor of geography at Clark University.
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http://www.nytimes.com/2012/08/12/opinion/sunday/extreme-weather-and-drought-are-here-to-stay.html?ref=opinion

http://www.nature.com/ngeo/archive/subject_ngeo_s3_2012.html

(need to be a subscriber to access articles)

Drought in the U.S.

- The link below takes you to a chart that shows the proportion of what is now the contiguous U.S. in various stages of drought over 118 years of record-keeping.

http://www.nytimes.com/interactive/2012/08/11/sunday-review/drought-history.html?ref=sunday

Drought in the U.S.

- *A megadrought would present a major risk to water resources in the American West, which are distributed through a complex series of local, state and regional water-sharing agreements and laws. Virtually every drop of water flowing in the American West is legally claimed, sometimes by several users, and the demand is expected to increase as the population grows.*
- *Many Western cities will have to fundamentally change how they acquire and use water. The sort of temporary emergency steps that we grudgingly adopt during periods of low rainfall — fewer showers, lawn-watering bans — will become permanent. Some regions will become impossible to farm because of lack of irrigation water. Thermoelectric energy production will compete for limited water resources.*

Christopher R. Schwalm, Christopher A. Williams and Kevin Schaefer

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