Our Water Resources

Resources and Man

- The Malthusian trap
- The kinds of resources
  - renewable resources
  - Nonrenewable resources
  - Potentially renewable resources
- The nature of exhaustibility

Food is the most basic of all our needs

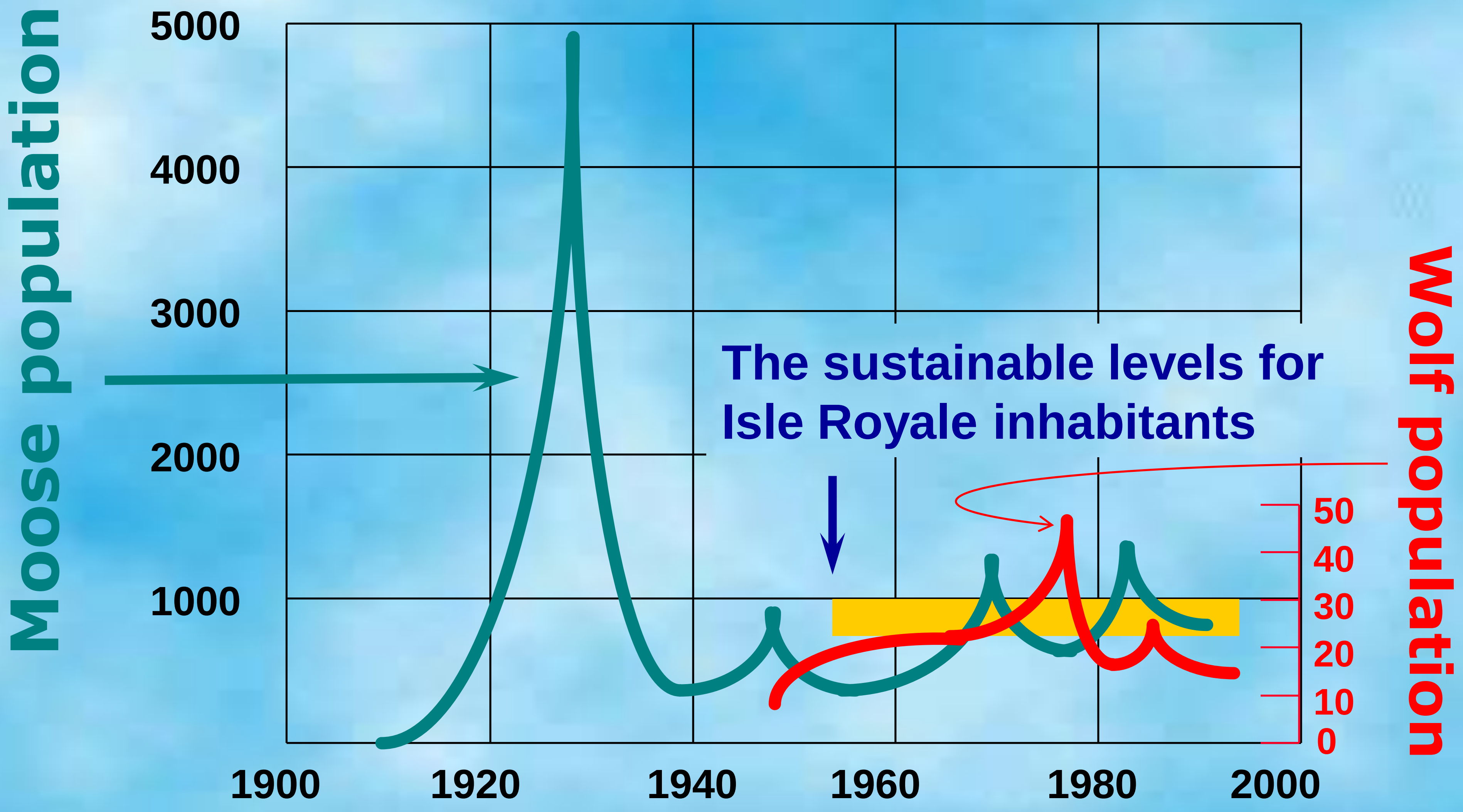
MASLOW'S HIERARCHY OF NEEDS

Thomas Malthus (1766-1834)

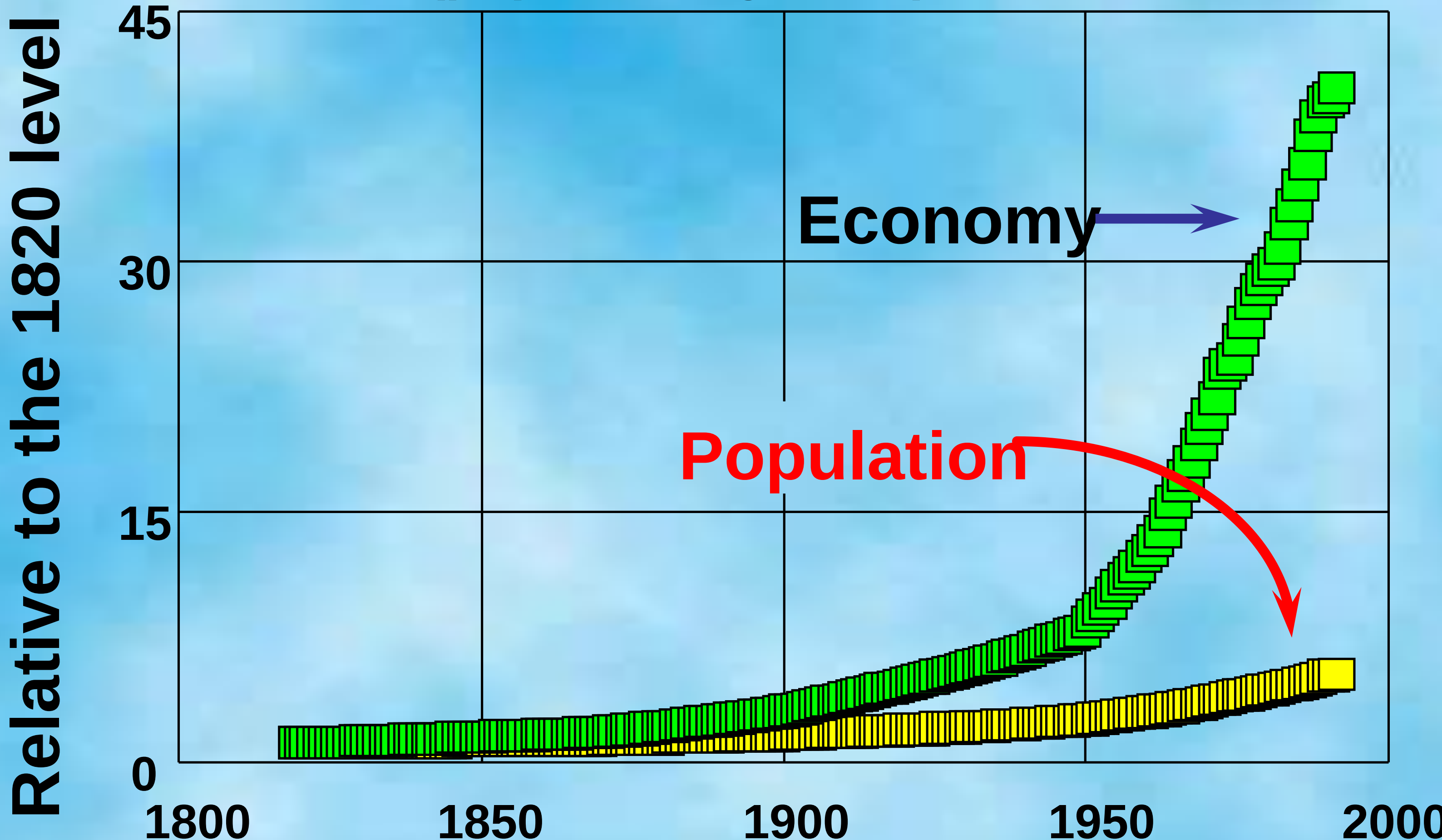
In *"An Essay on the Principles of Population"*, published in 1798, Thomas Malthus argued that while population

increases in geometric progression, the resources to sustain this growth do not. Thus, if population grows too much faster than food production, this growth is checked by famine, disease, and war.

This should ordinarily signal disaster. Take the case of wolves and moose at Isle Royale National Park, Lake Superior, for instance.

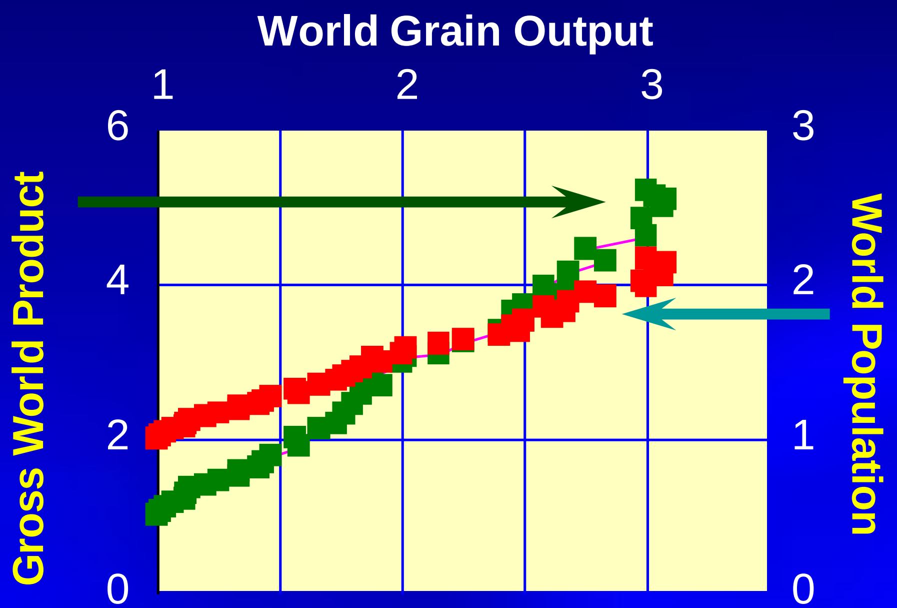


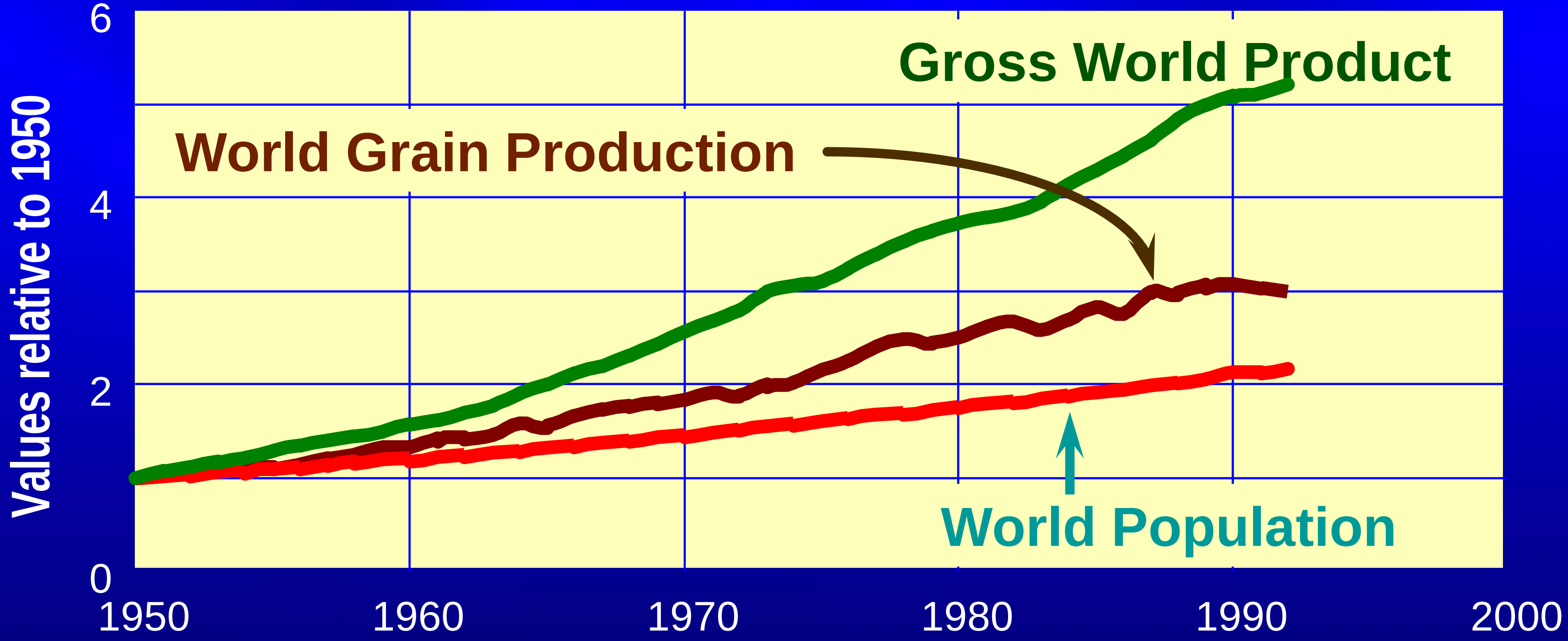
- World's population, a little over a billion at the time of Malthus, has multiplied about six-fold since then.
- Measured in inflation-adjusted dollars, world's total output, now about $40 trillion, was about $700 billion at the time of Malthus.
- Clearly, economic growth has been more strongly exponential than that of the demand (population growth) that created it.



Source: A. Maddison, *Monitoring the World Economy 1820-1992* (OECD, Paris, 1995).

The growth in world's grain output has been faster than population but world economy has growth even faster.



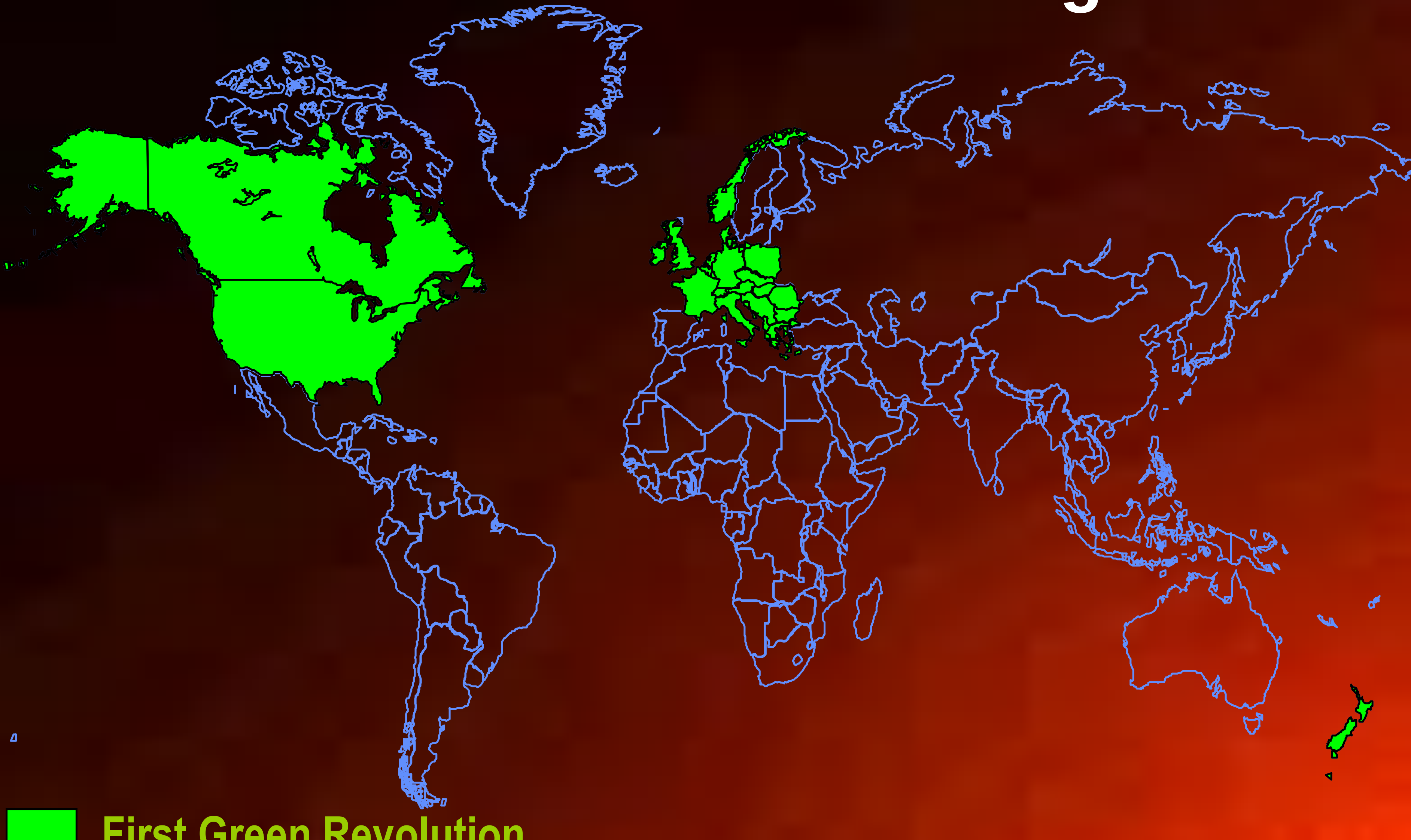


Adam Smith (1723-1790),

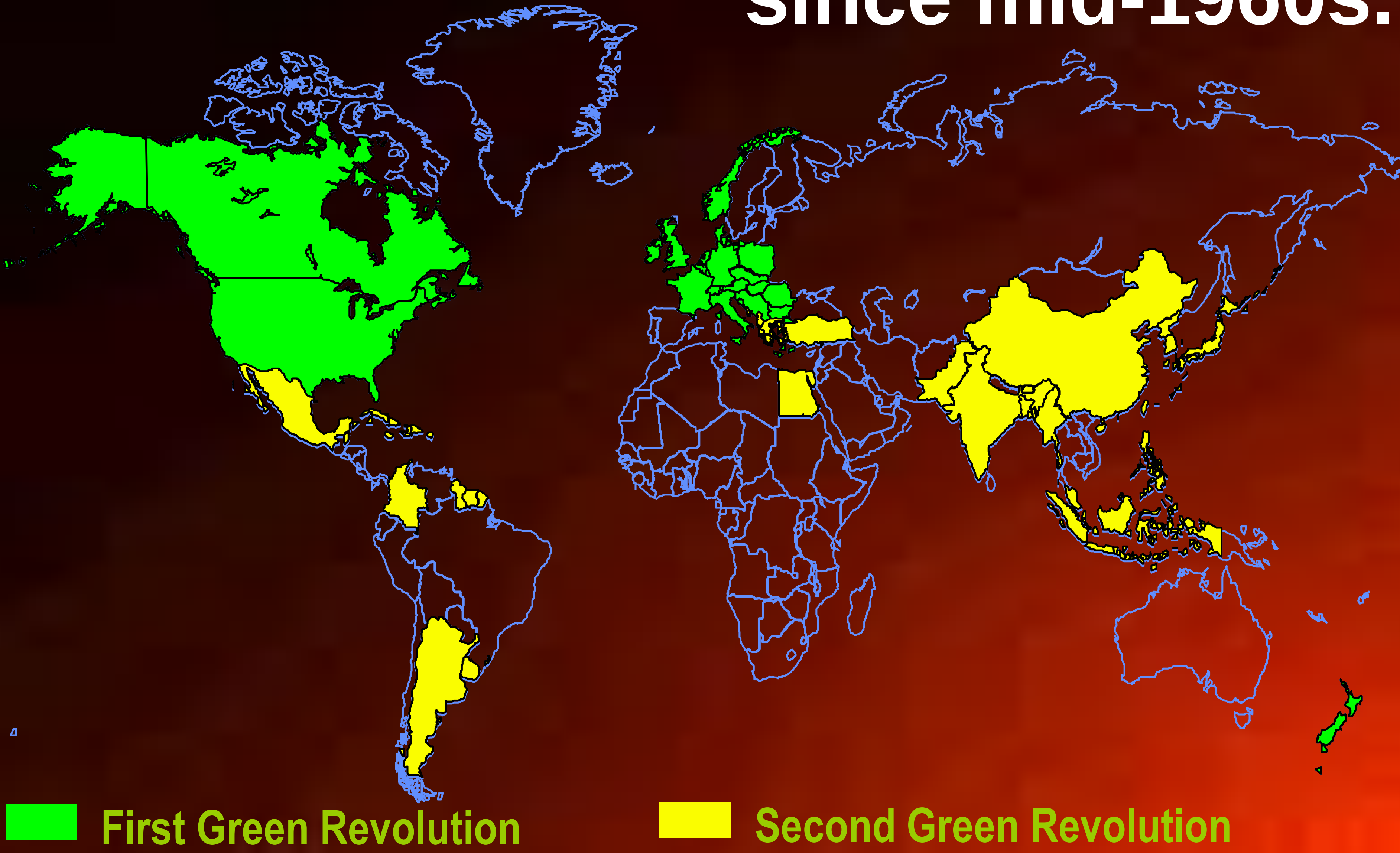
the British philosopher and economist, argued, in his celebrated treatise *An Inquiry into the Nature and Causes of the*

***Wealth of Nations* (1776), that every individual in pursuing his or her own good is led, as if by an invisible hand, to achieve the best good for all. Therefore any interference with free competition by the government is almost certain to be injurious.**

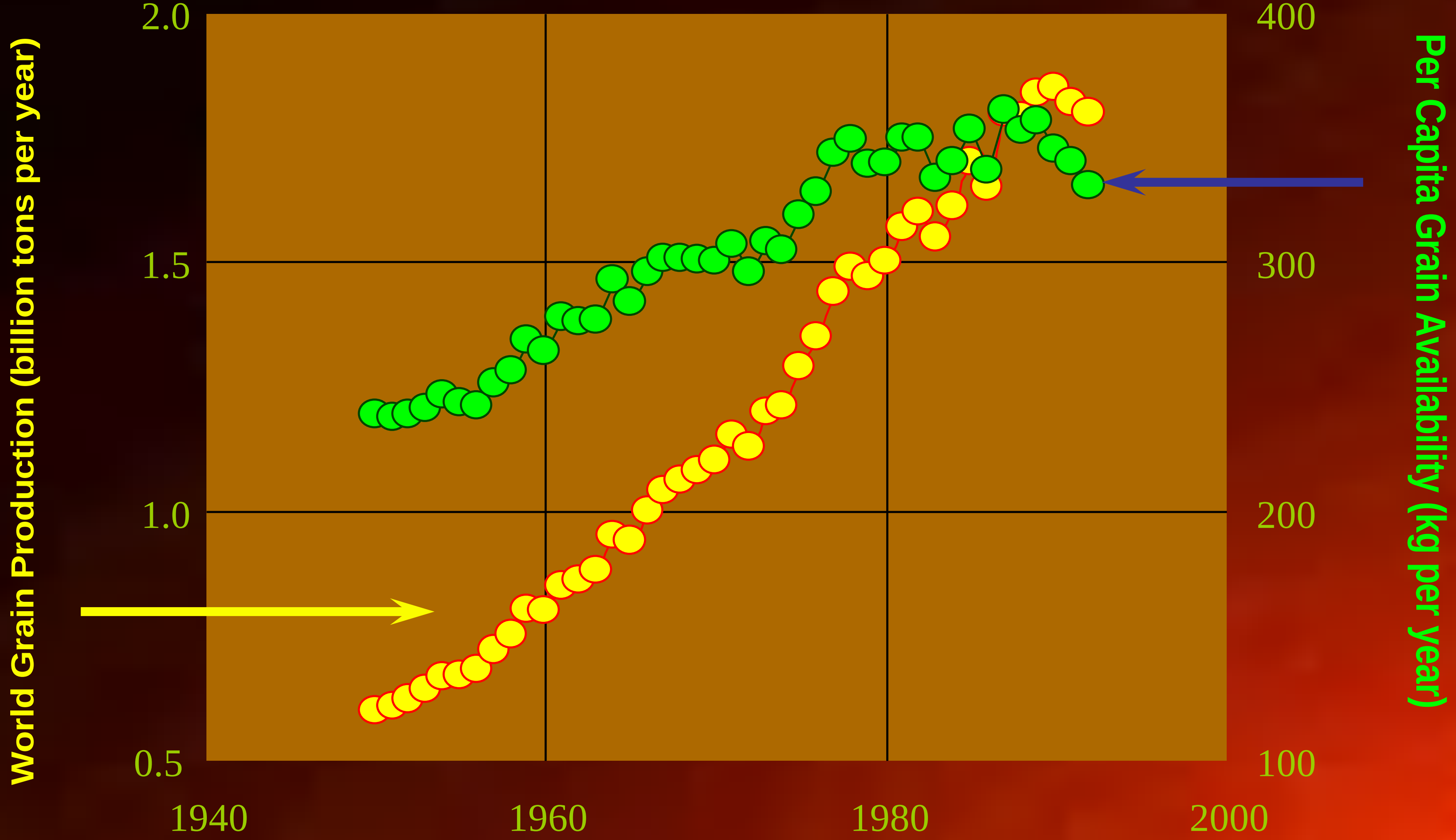
First Green Revolution in this century took place in developed countries during 1950-70.



Second Green Revolution has occurred in developing countries since mid-1960s.



Despite the tremendous strides in world grain production, per capita grain availability has remained unchanged since the mid-1970s*.



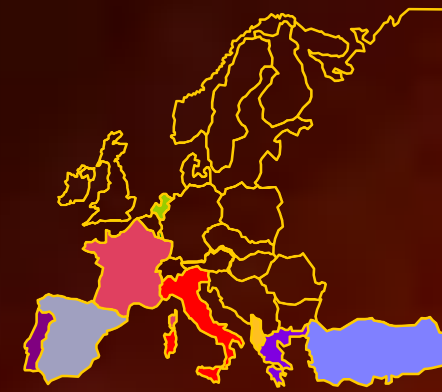
*Lester R. Brown: "Facing the Prospect of Food Scarcity" in STATE OF THE WORLD 1997 (Worldwatch Institute, 1997)

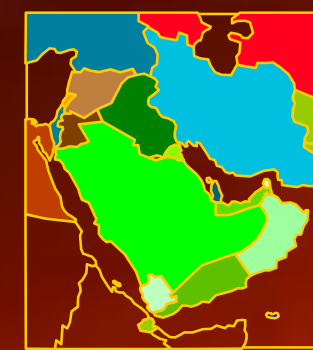
Currently,

the annual food production world-wide, including grains, poultry, seafood and meat,

- **is about 4 billion tons per year, or**
- **about 4½ lbs per person per day.**

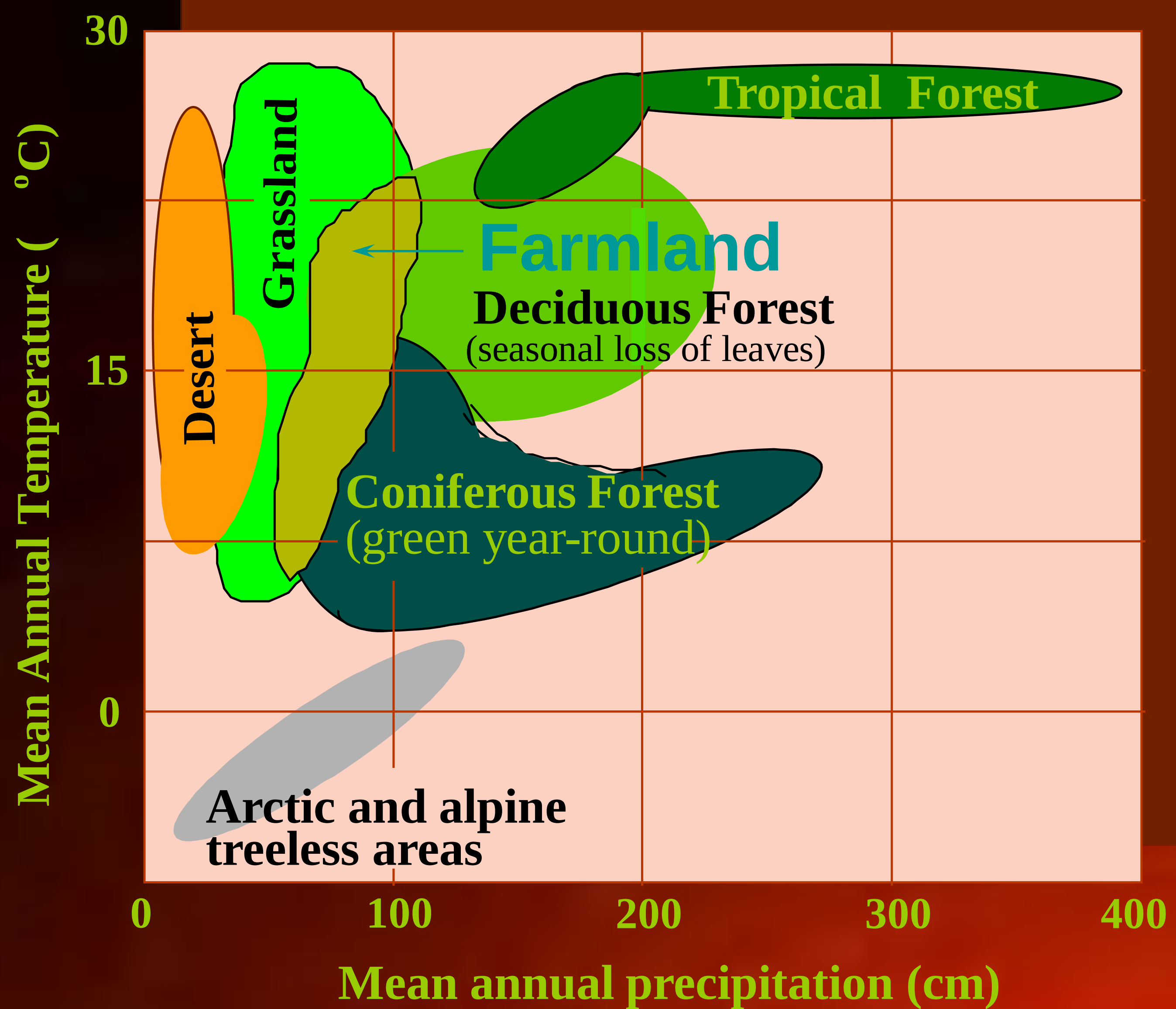
But per capita food consumption varies, worldwide,



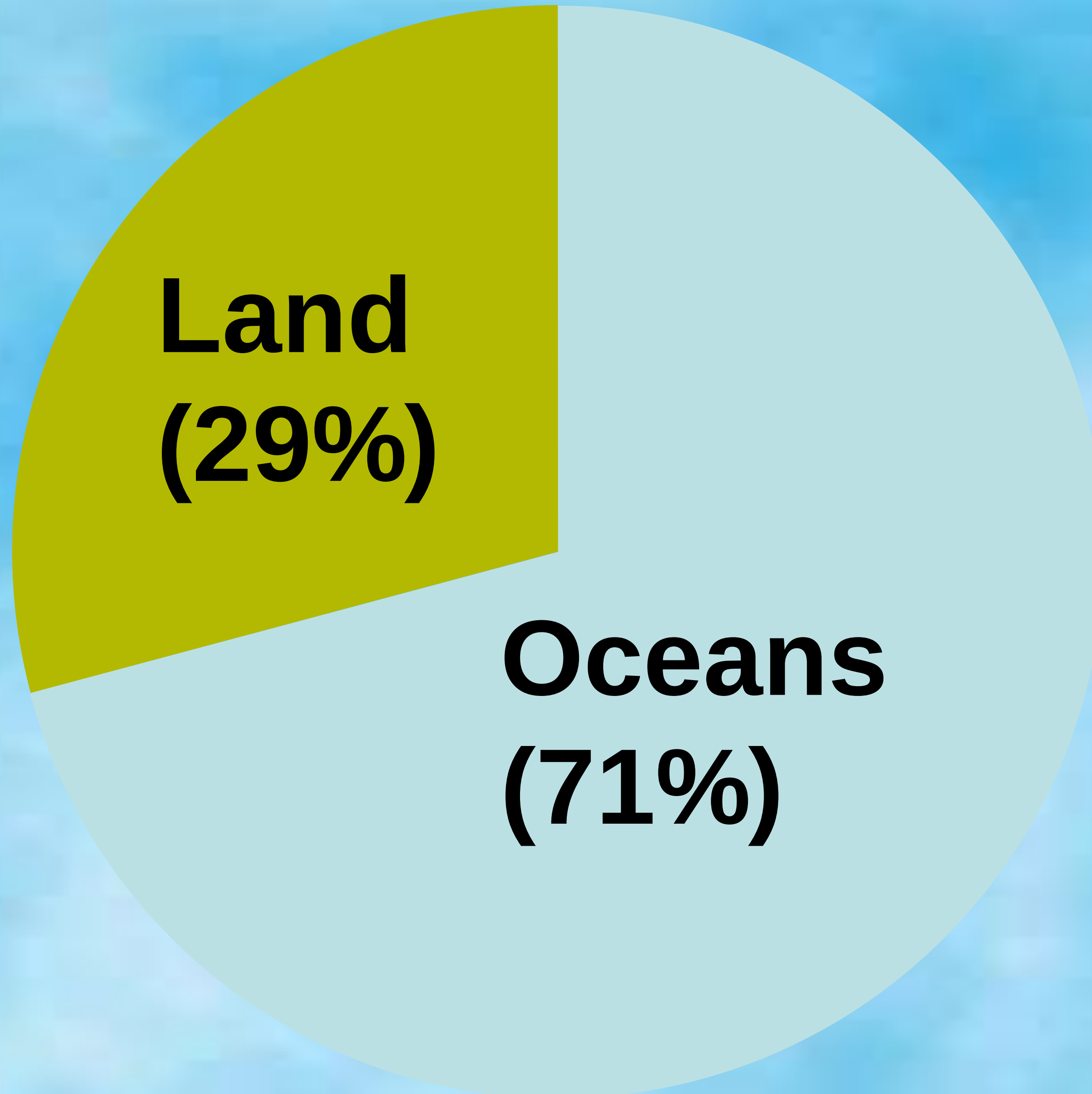


- from ~1500 lbs per year in America, to
- ~1000 lbs per year in Mediterranean/ Middle East region, and
- about 500 lbs per year in India and South Asia.

Being largely stenohumid as well as stenothermal, agricultural crops impose a rather restricted range of climatic conditions. Farmland therefore tends to be in short supply.

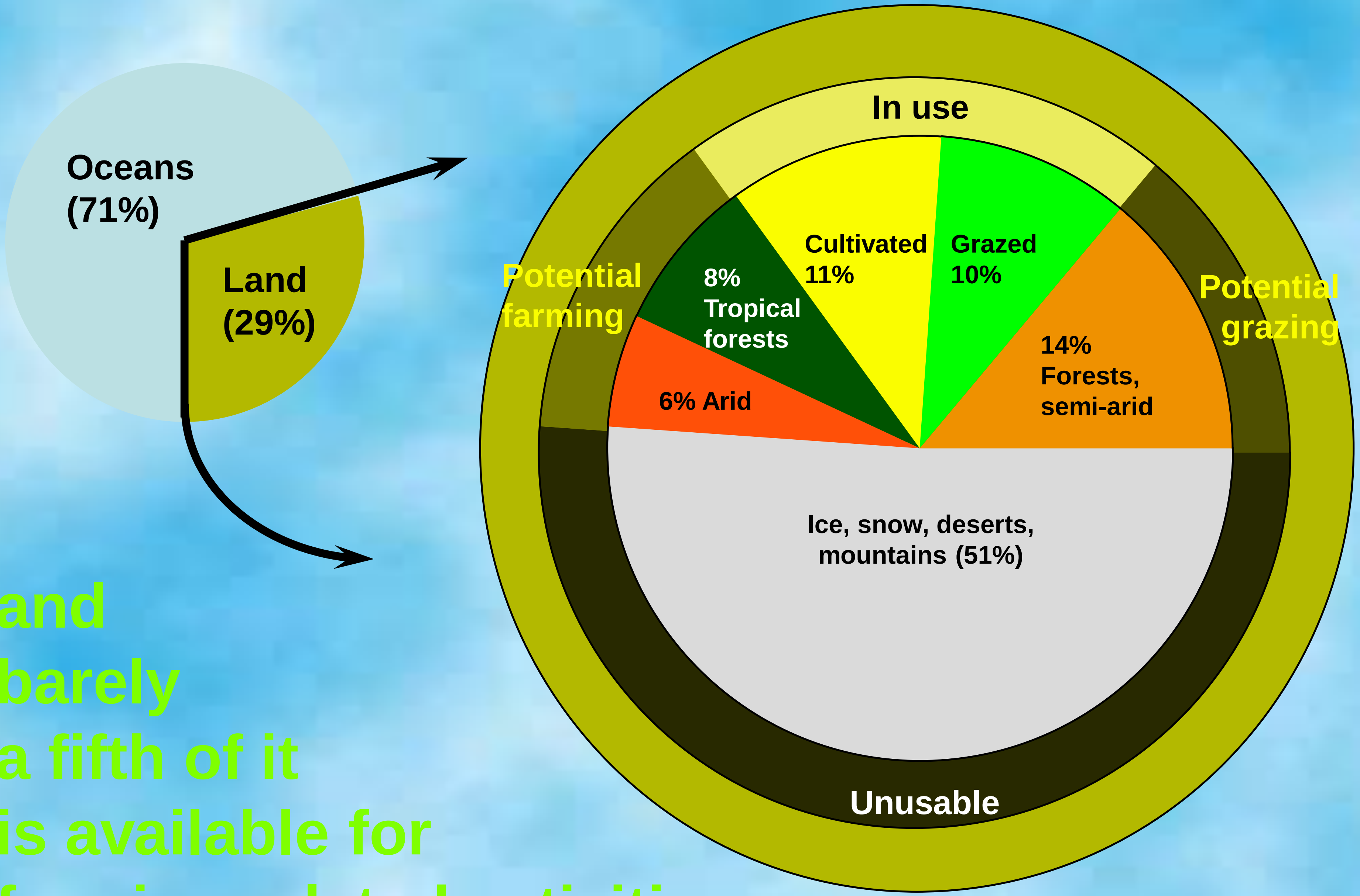


Most of the Earth is covered by water



"...water, water, every where nor any drop to drink!"

But the supply of land too is limited...

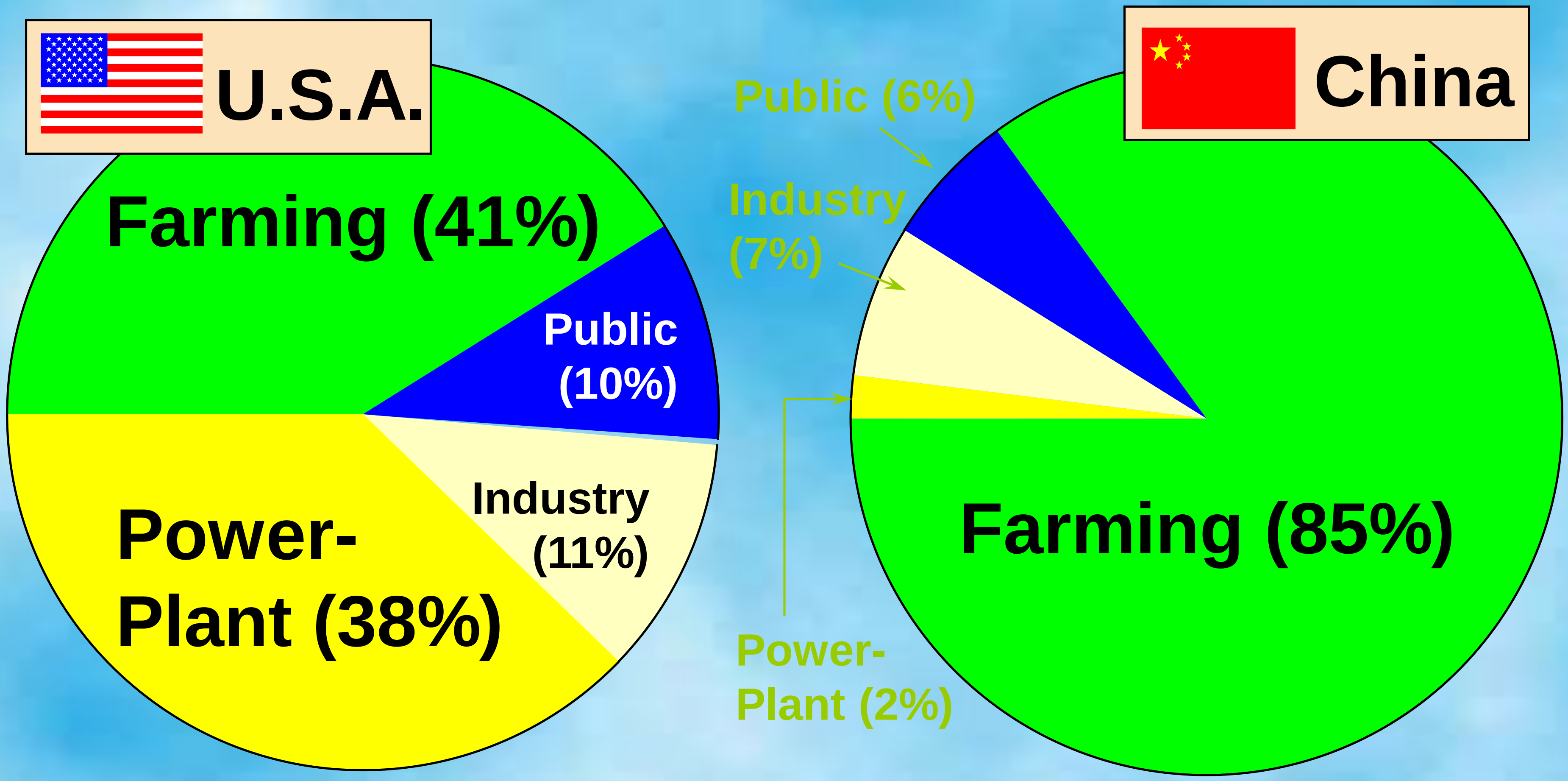


and
barely
a fifth of it
is available for
farming related activities.

Economic growth exacerbates the demand for water, e.g.,

- **with economic growth at 7-10% per year, poultry consumption is rising at the rate of 15% per year in India, Indonesia and China – the water demands of this nontraditional industry are only likely to grow;**
- **we need about 250,000 gallons of water to produce a ton of corn, 375,000 gallons to produce a ton of wheat, 1,000,000 gallons to produce a ton of rice, and 7,500,000 of water to produce a ton of beef.**

- to which we should also add industry's needs.



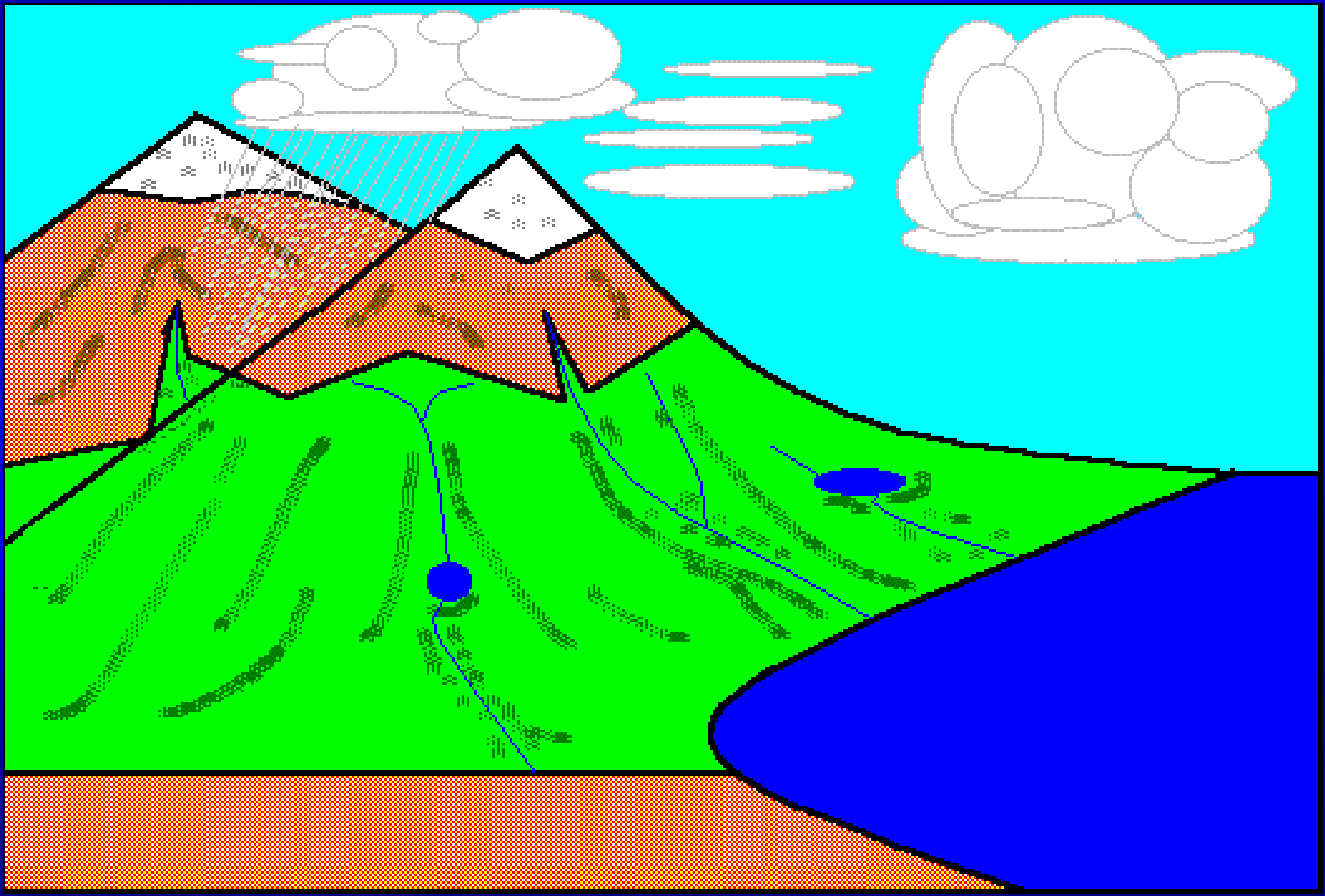
this comparison of U.S. and China shows how economic growth necessitates increased use of water for nonagricultural purposes.

Source: Worldwatch Institute

How much water do we have?

The hydrological cycle

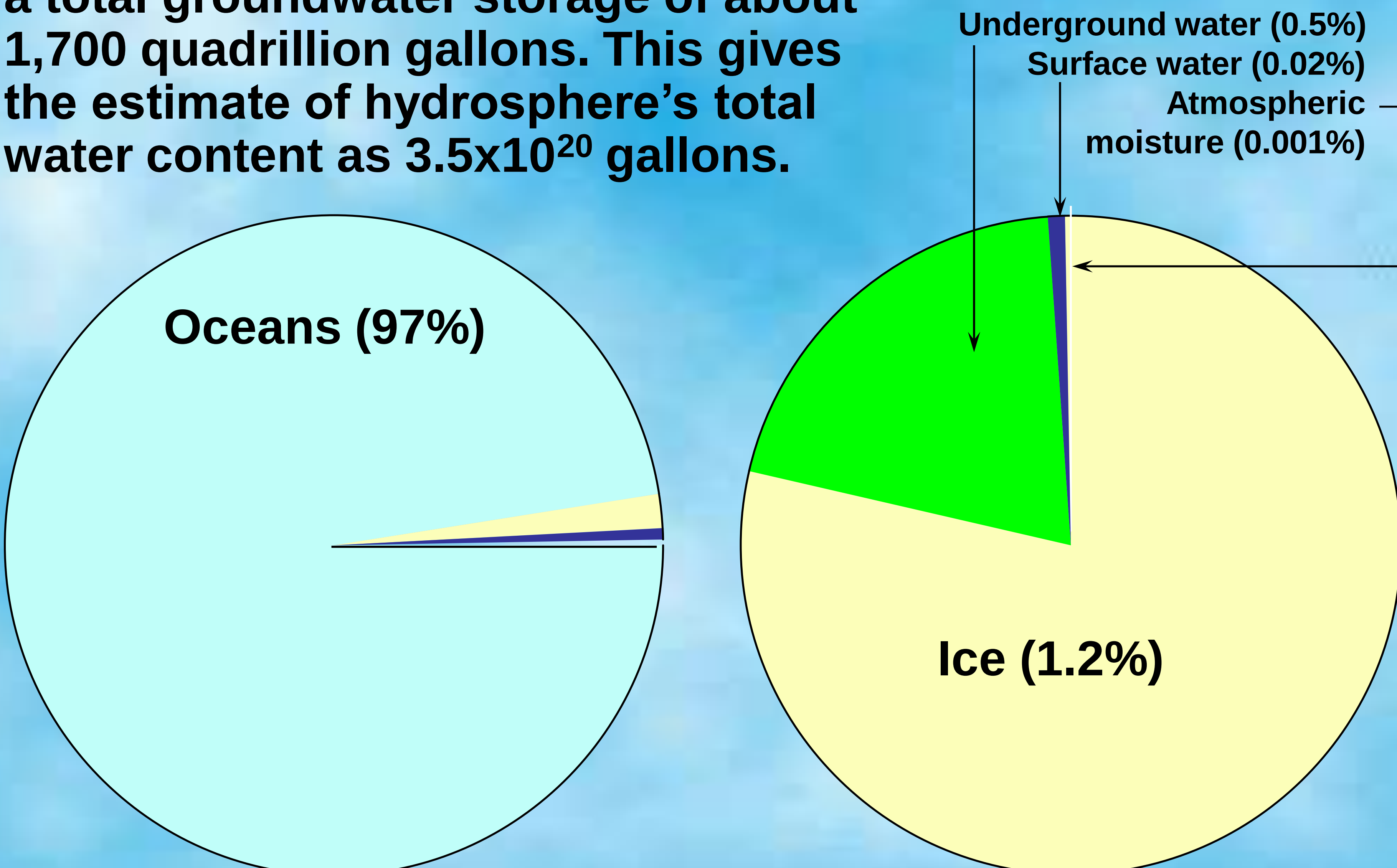
Ignoring such long-term effects as the changes in atmospheric storage conditions, run-off filling the ocean basins etc., hydro-logical cycle is merely the re-cycling of water between land and oceans.



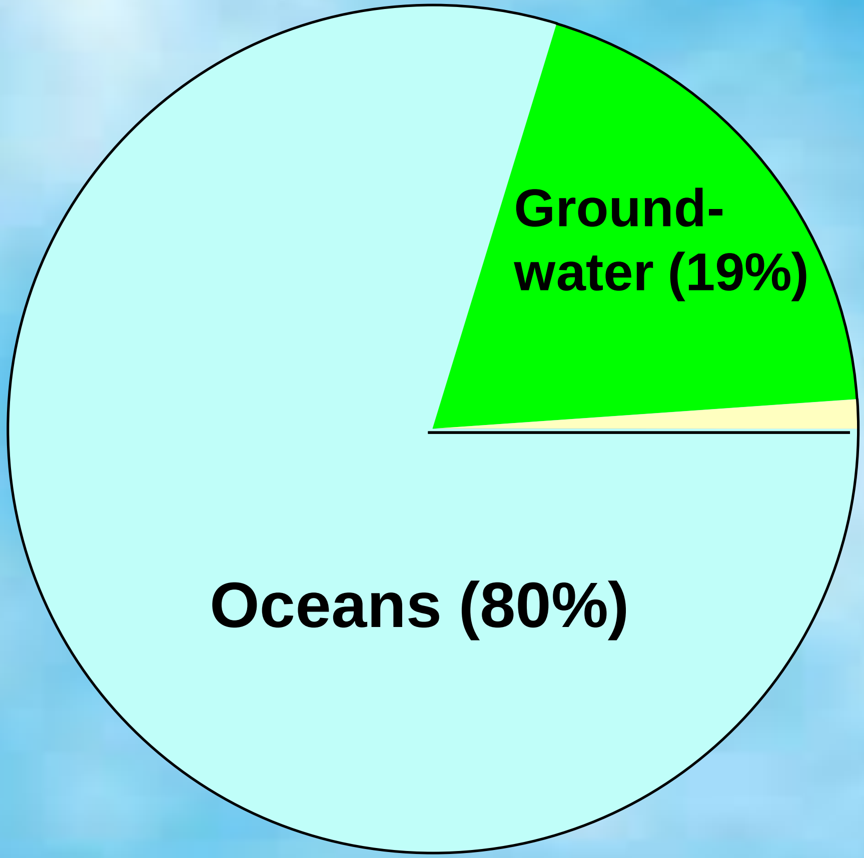
http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/hyd/smry.rxml

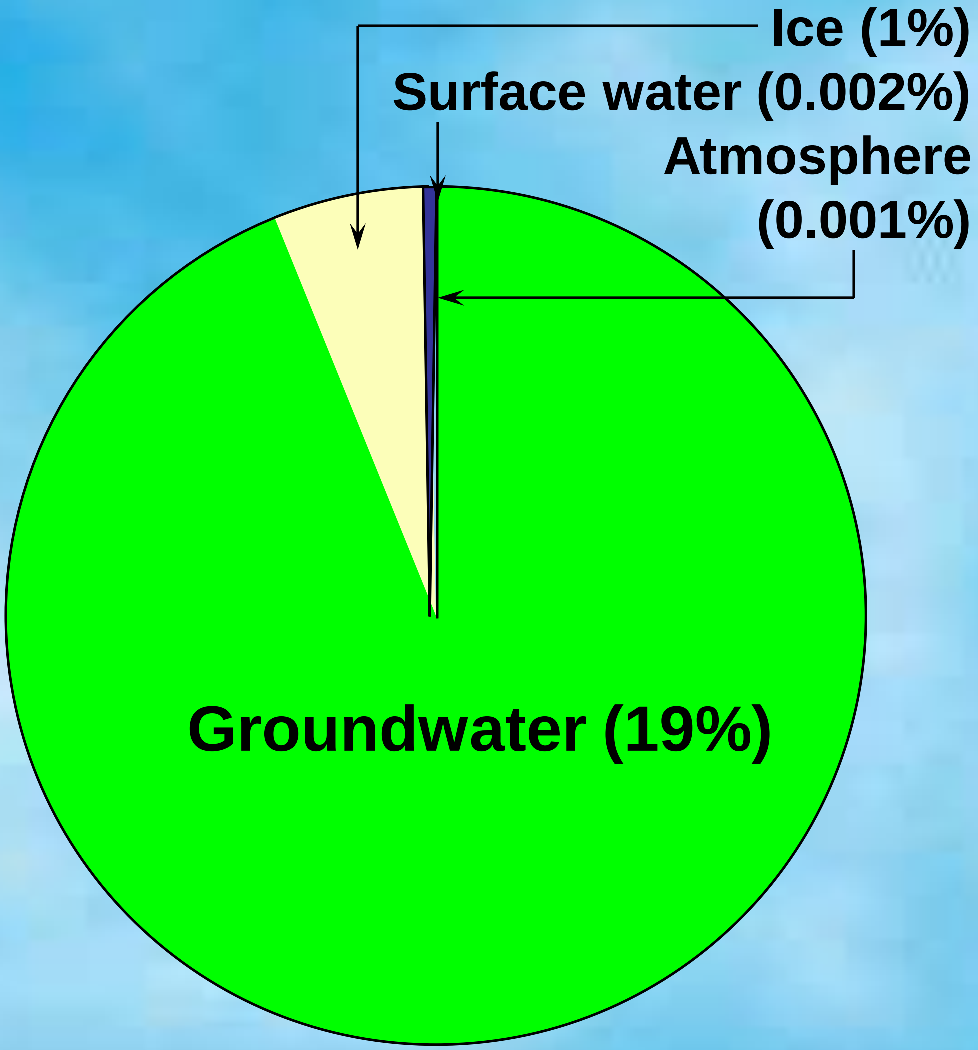
How much water in the hydrosphere?

Conventional estimate assumes a total groundwater storage of about 1,700 quadrillion gallons. This gives the estimate of hydrosphere's total water content as 3.5×10^{20} gallons.

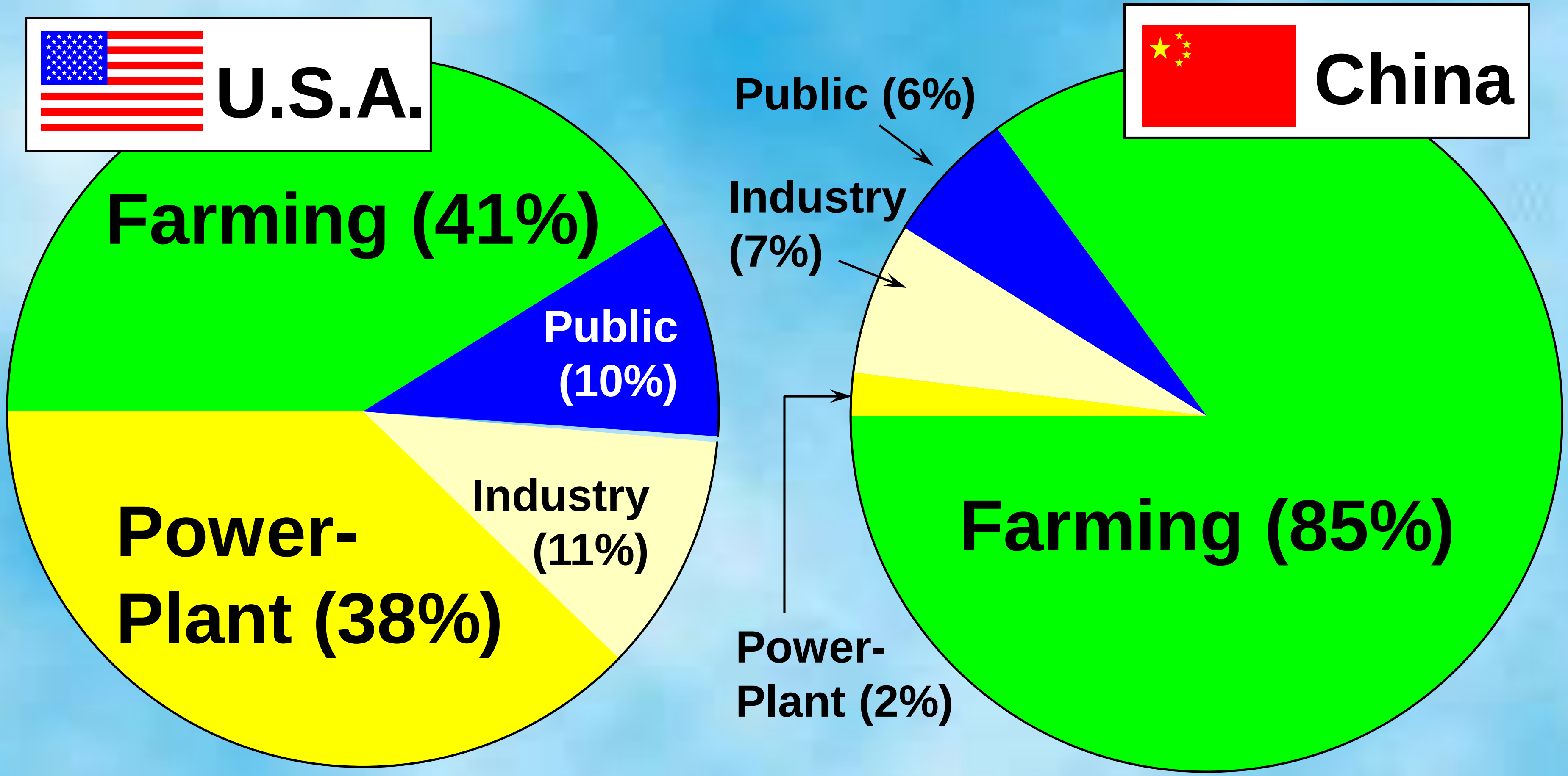


An alternate assumption is that pores in sediments contain about 80,000 quadrillion gallons of groundwater (almost 50 times the conventional estimate). This yields an estimate of about $4x10^{20}$ gallons of water in the entire hydroshere.



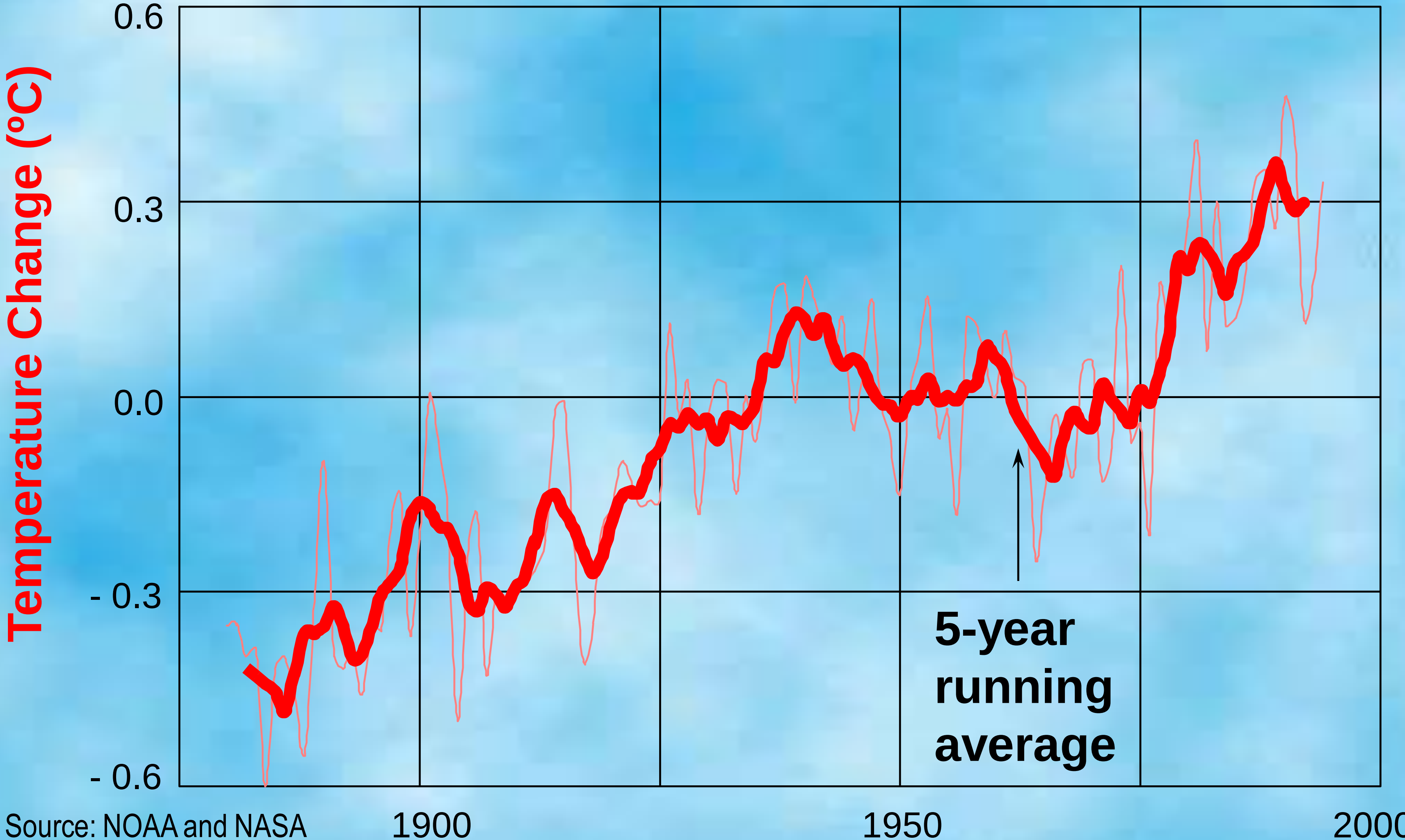


As is evident from the comparison of water use in the U.S. and China, economic growth necessitates increasing use of water for power generation.



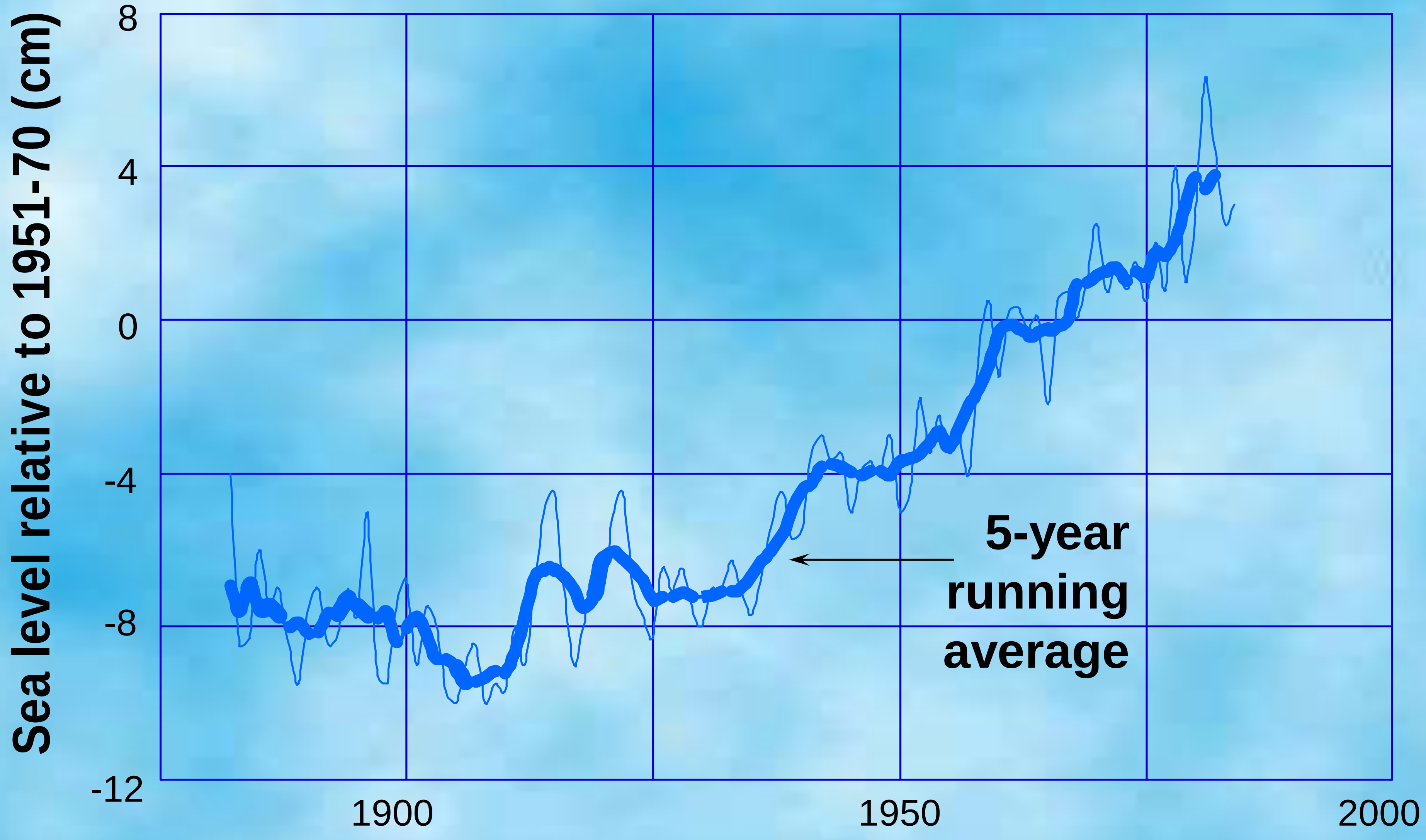
Source: Worldwatch Institute

Global mean temperature change through the past century



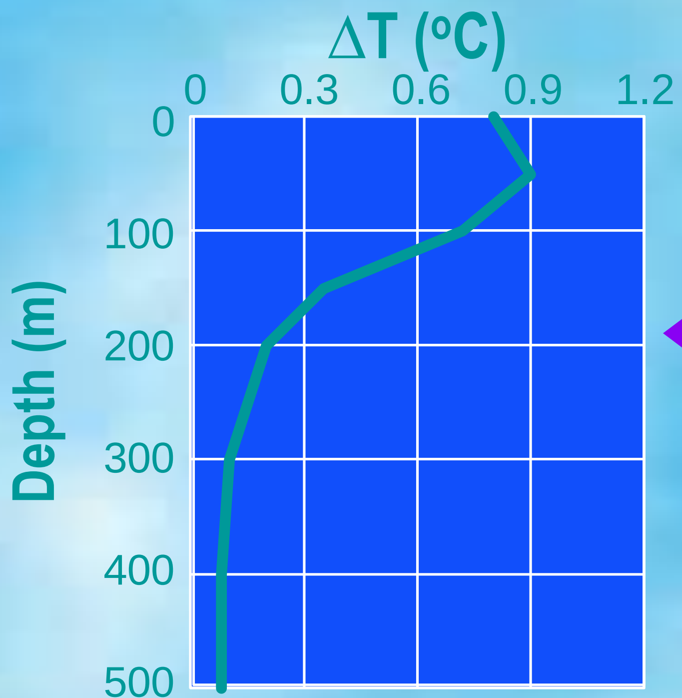
Source: NOAA and NASA

The global mean sea-level rise through last century



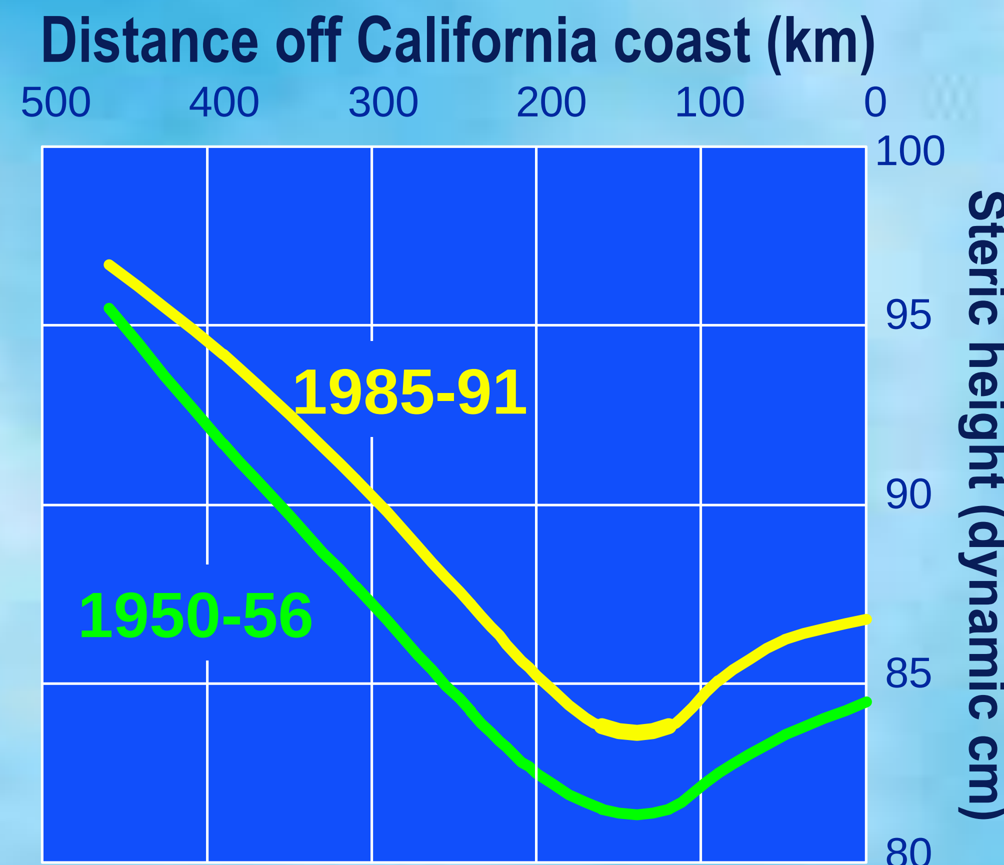
Source: T.P. Barnett, in CLIMATE CHANGE (IPCC Working Group Report: Cambridge University Press, 1990)

The 1950-91 hydrographic data off California coast show that



sea surface waters (0-100m) became ~0.8°C warmer in the 35-year period between 1950-56 and 1985-91; which

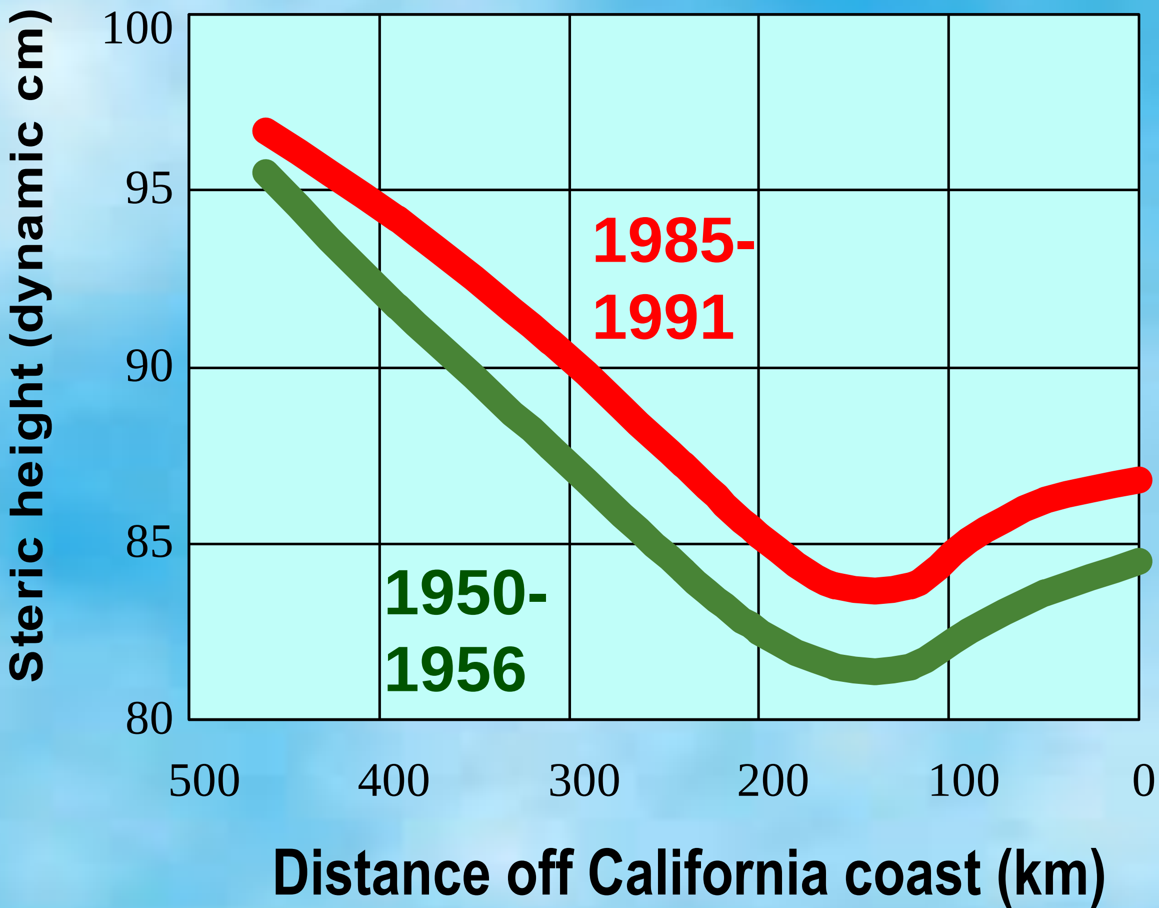
raised the sea level surface by 3.1±0.7 cm.

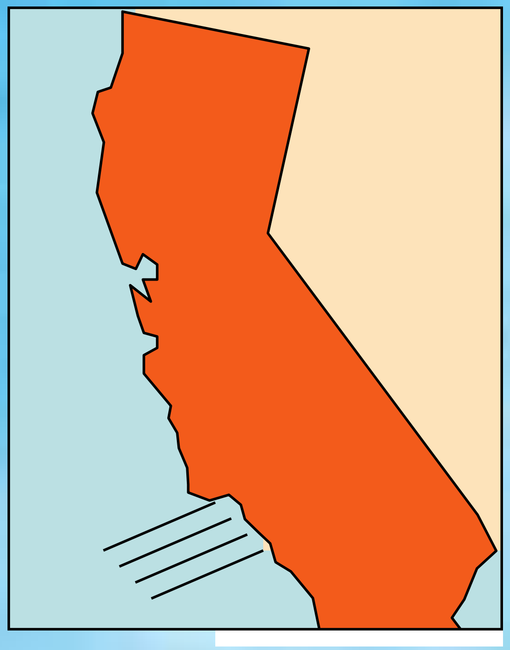


Note: Warming by 1°C the top 100 m of ocean with 15°C temperature and 3.4% salinity should raise the sea level by ~2.2 cm.

Source: D. Roemmich, SCIENCE: v. 257, p. 373-375 (July 17, 1992).

Sea surface off California has risen by about 2 cm, on average, between 1950 and 1991





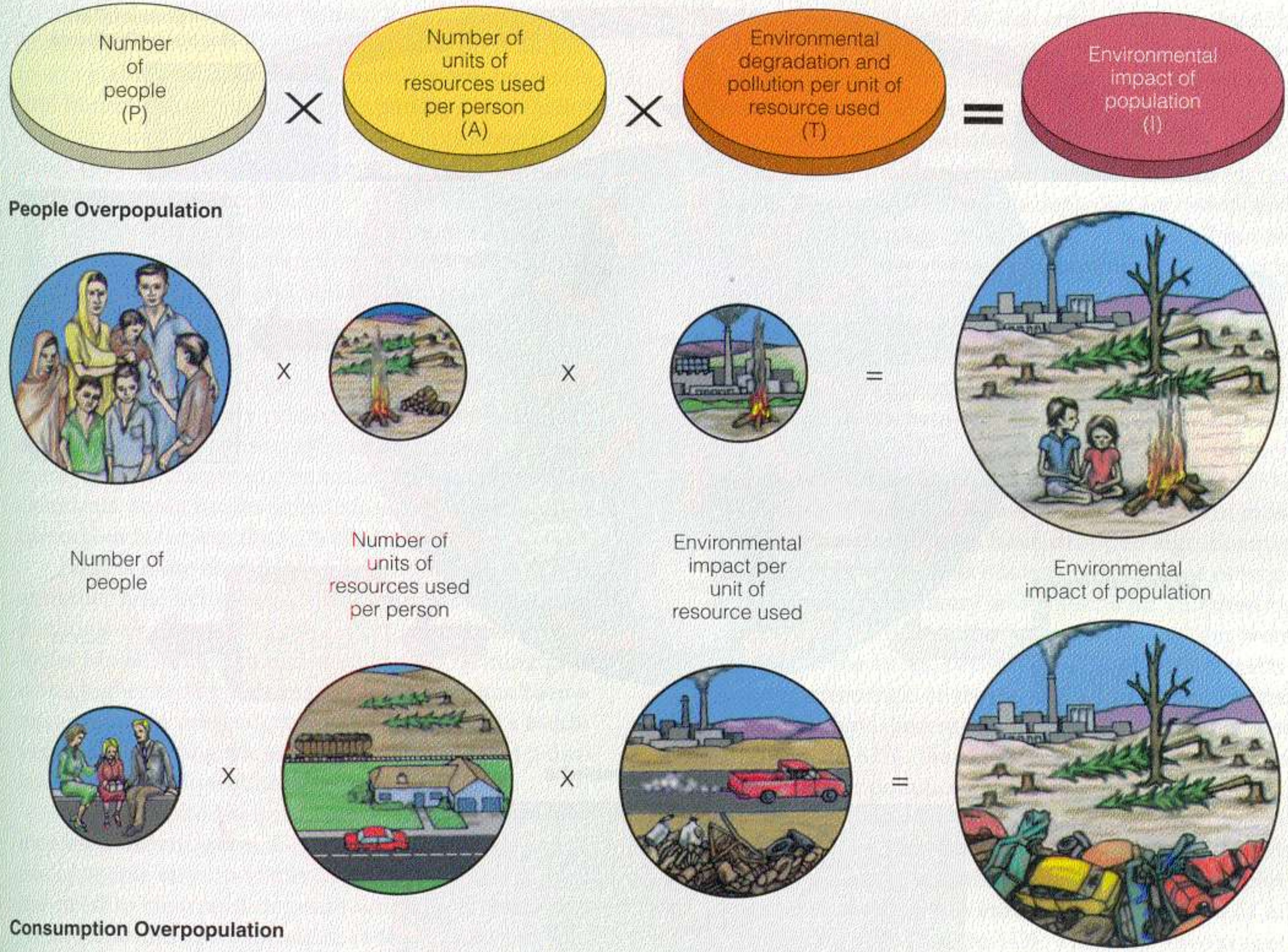
Dean Roemmich:
Ocean warming and sea level rise along the southwest U.S. coast [Science: 257 (373-375), 1992]

The availability of water too is a limiting factor. An average human needs about 300,000 gallons of water annually, including 250,000 gallons for growing food. Indeed, nations with under 150,000 gallons of annual per capita water supply face severe limits to their growth.

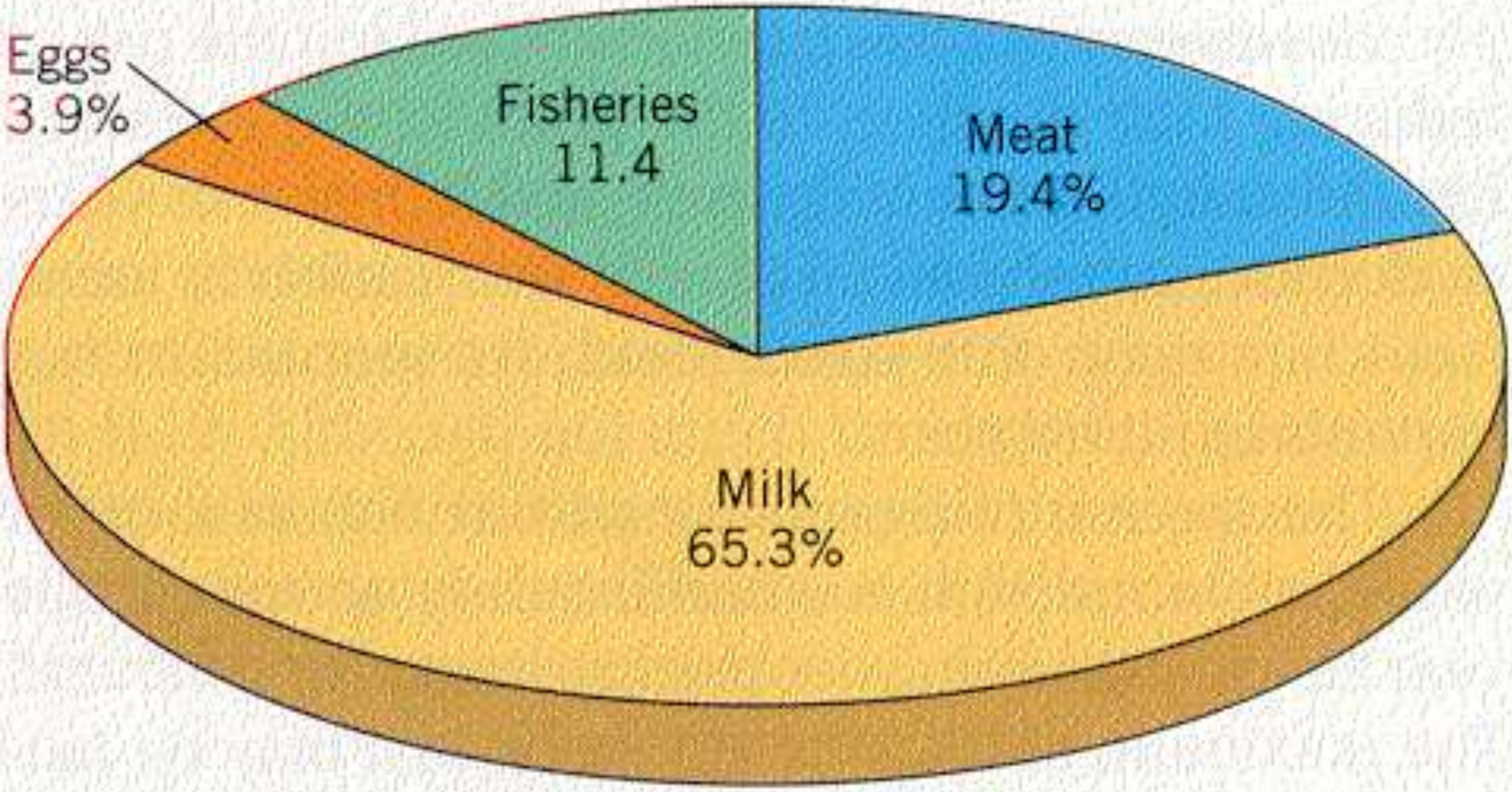
Mass of the present hydrosphere

	Considering all sediments*		Conventional estimates	
	Total mass (trillion tons)	Share of the hydrosphere	Total mass (trillion tons)	Share of the hydrosphere
Oceans	1,370,000	80%	1,370,000	97%
Pore water in the sediments	330,000	18.8%	7,000	0.5%
Ice-caps, glaciers	20,000	1.2%	20,000	1.4%
Rivers, lakes	300	0.02%	300	0.02%
Atmospheric moisture	13	0.0008%	13	0.0009%
Total hydrosphere	1,720,313	100%	1,397,313	100%

*Karl K. Turekian: GLOBAL ENVIRONMENTAL CHANGE (Prentice Hall, 1996)


Number of people (P)
×
Number of units of resources used per person (A)
×
Environmental degradation and pollution per unit of resource used (T)
=
Environmental impact of population (I)
People Overpopulation
Number of people
x
Number of units of resources used per person
x
Environmental impact per unit of resource used
=
Environmental impact of population
Consumption Overpopulation

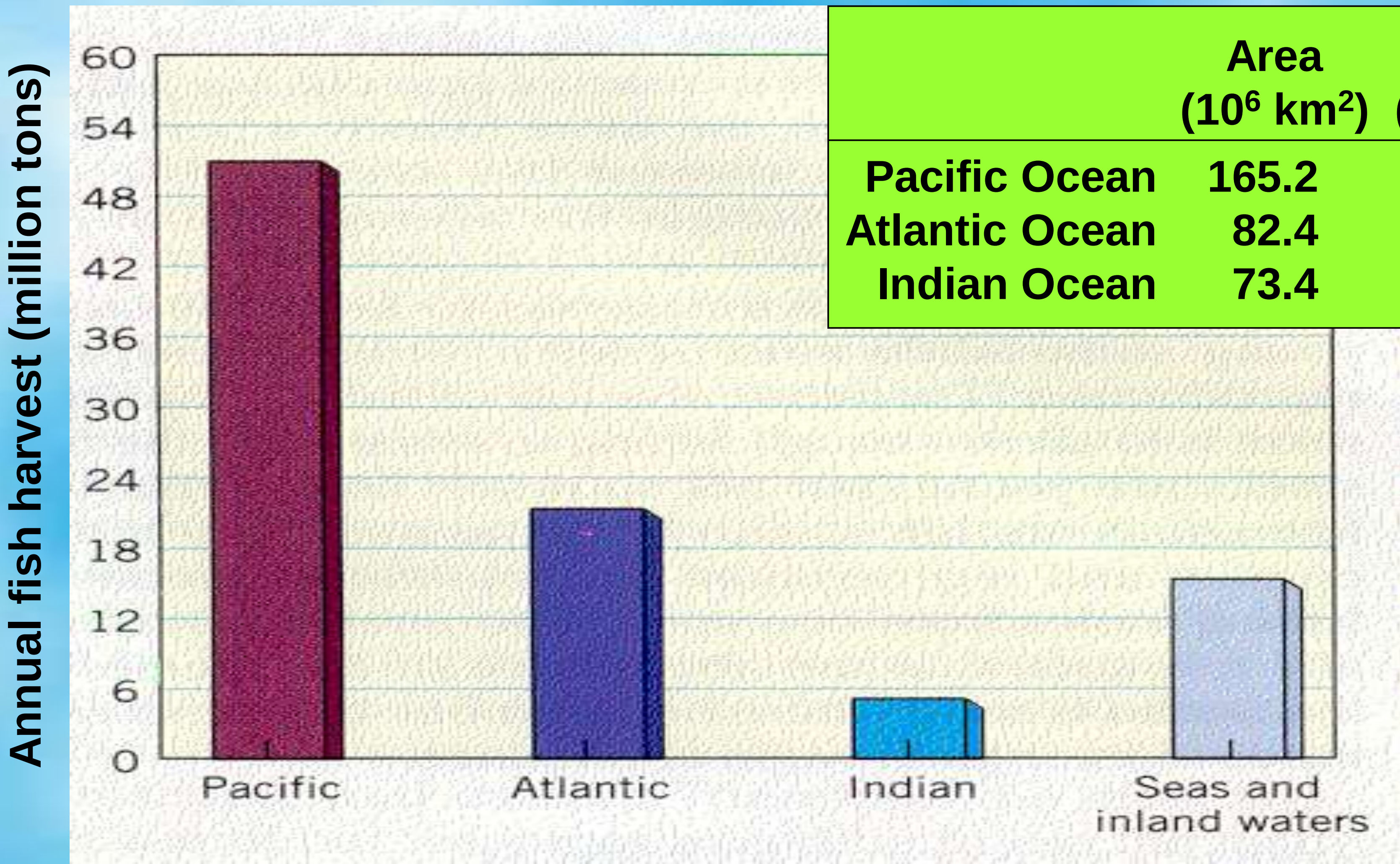
Seafood is an important source of animal protein worldwide, nonetheless.

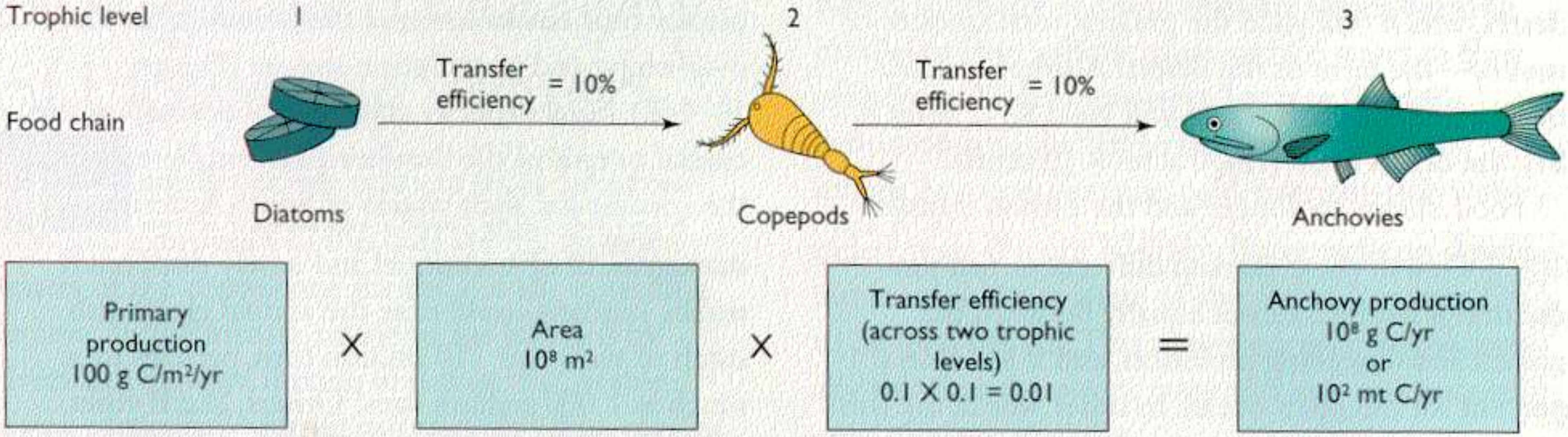


World fish harvest:

Note that Indian Ocean has the least yield.

	Area (10^6 km^2)	Volume (10^6 km^3)
Pacific Ocean	165.2	707.6
Atlantic Ocean	82.4	323.6
Indian Ocean	73.4	291.0

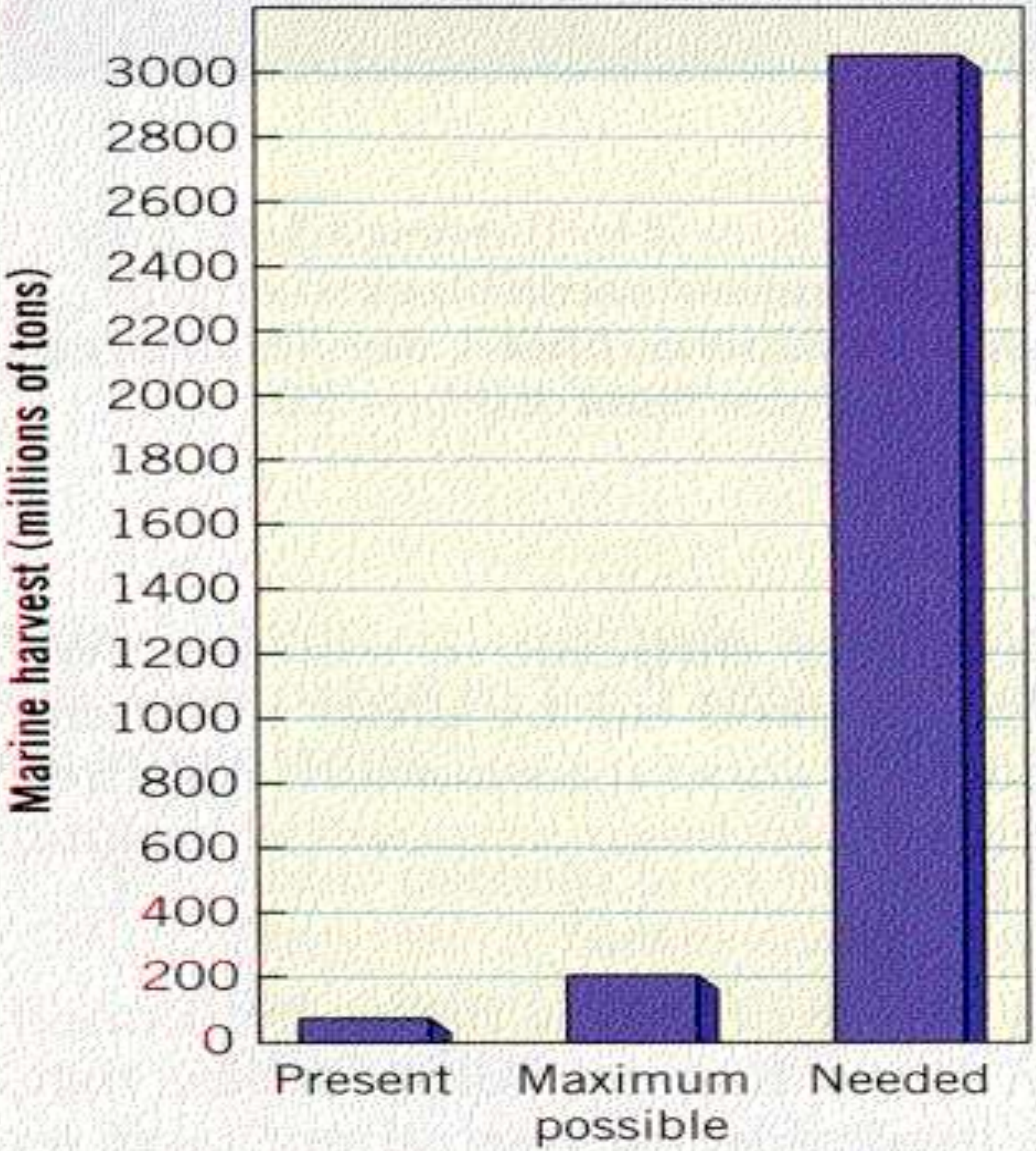




World fish production*

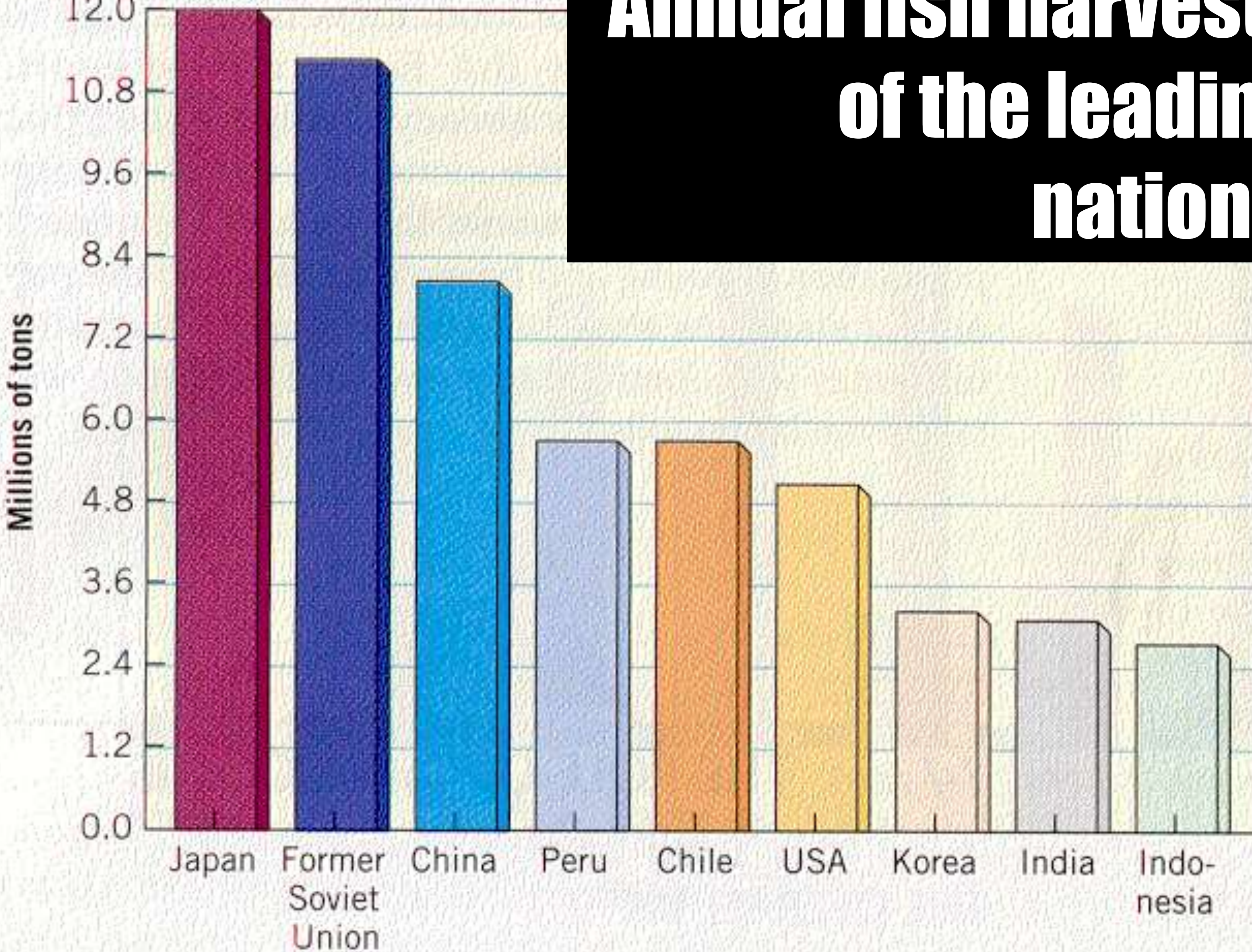
	Primary production ($gC/m^2/yr$)	Ocean area (km^2)	Average number of trophic steps	Net transfer efficiency ↓	Total fish production (tons/yr)
Oceanic	50	$325x10^6$ (90%)	5	0.0001	$1.63x10^6$ (<1%)
Coastal	100	$36x10^6$ (9.9%)	3	0.033	$120 x10^6$ (~50%)
Upwelling	300	$36x10^4$ (0.1%)	15	1.1	$120x10^6$ (~50%)

* J.H. Ryther: Science, 166 (1969): 72-76

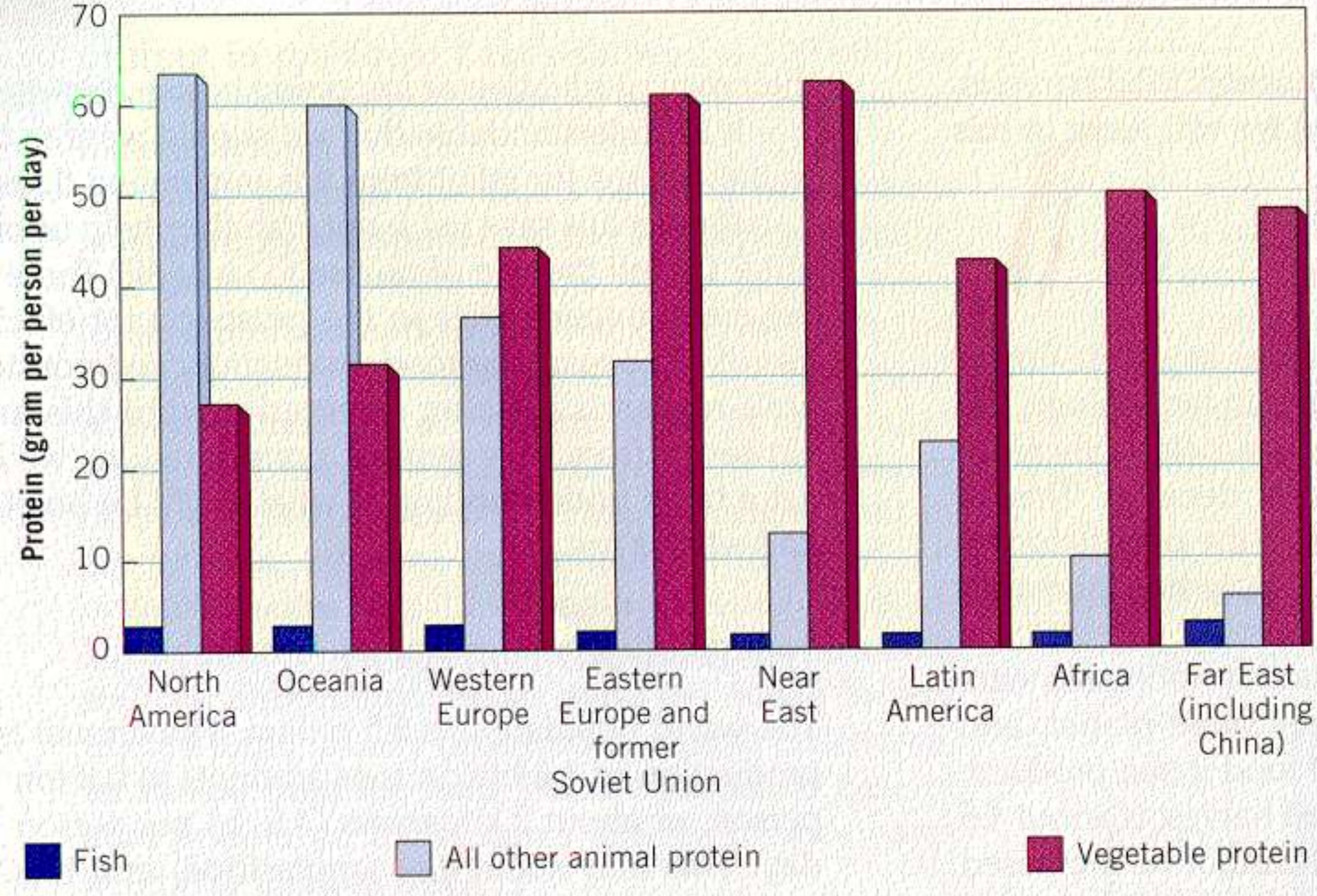


Even the maximum possible yield from world's oceans can hardly suffice.

Annual fish harvests of the leading nations.



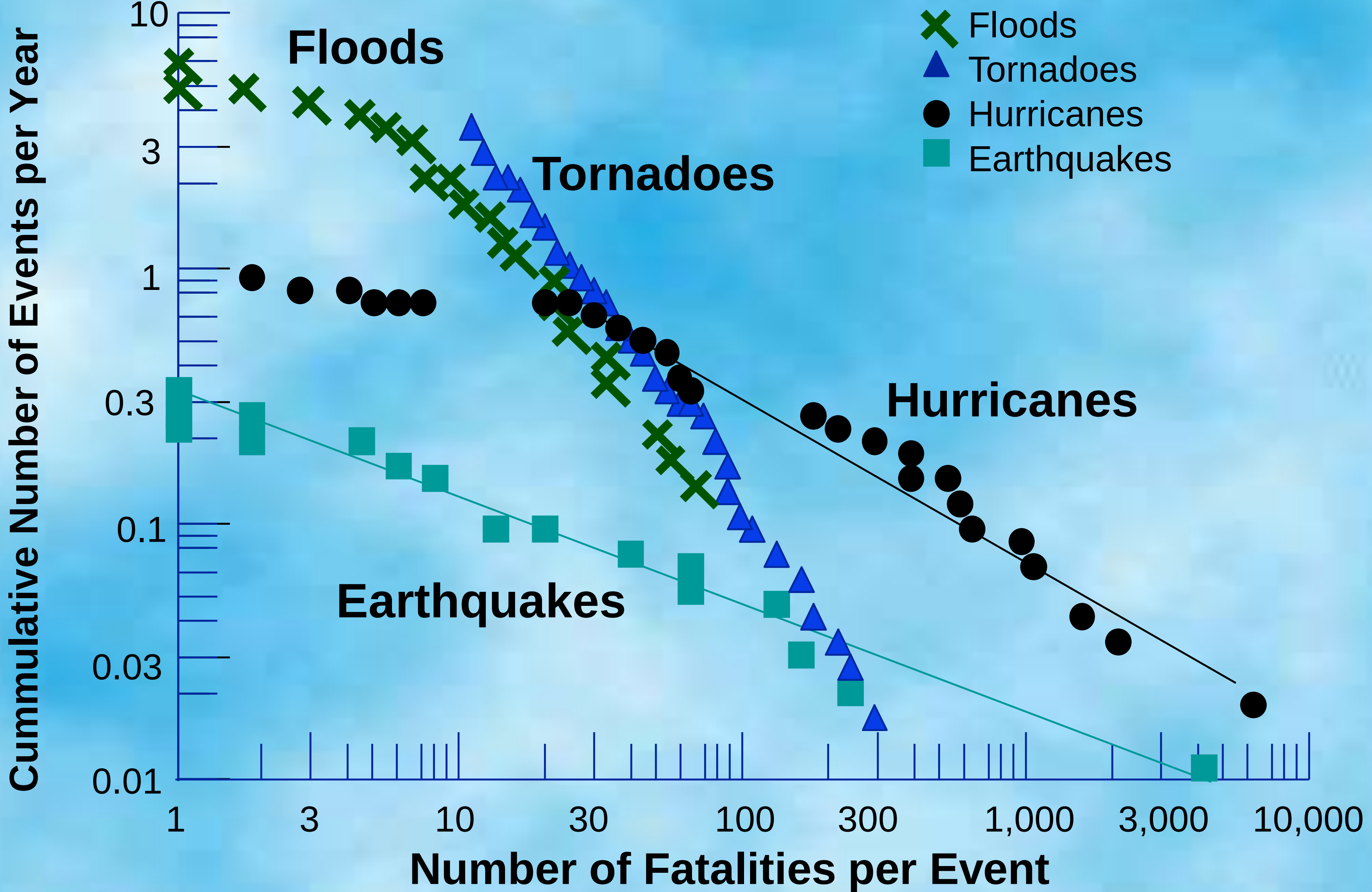
Seafood is already a major source of animal protein in the Asian diet.



That Climate Thing

- Global warming and its consequences
- The anthropogenic contributions

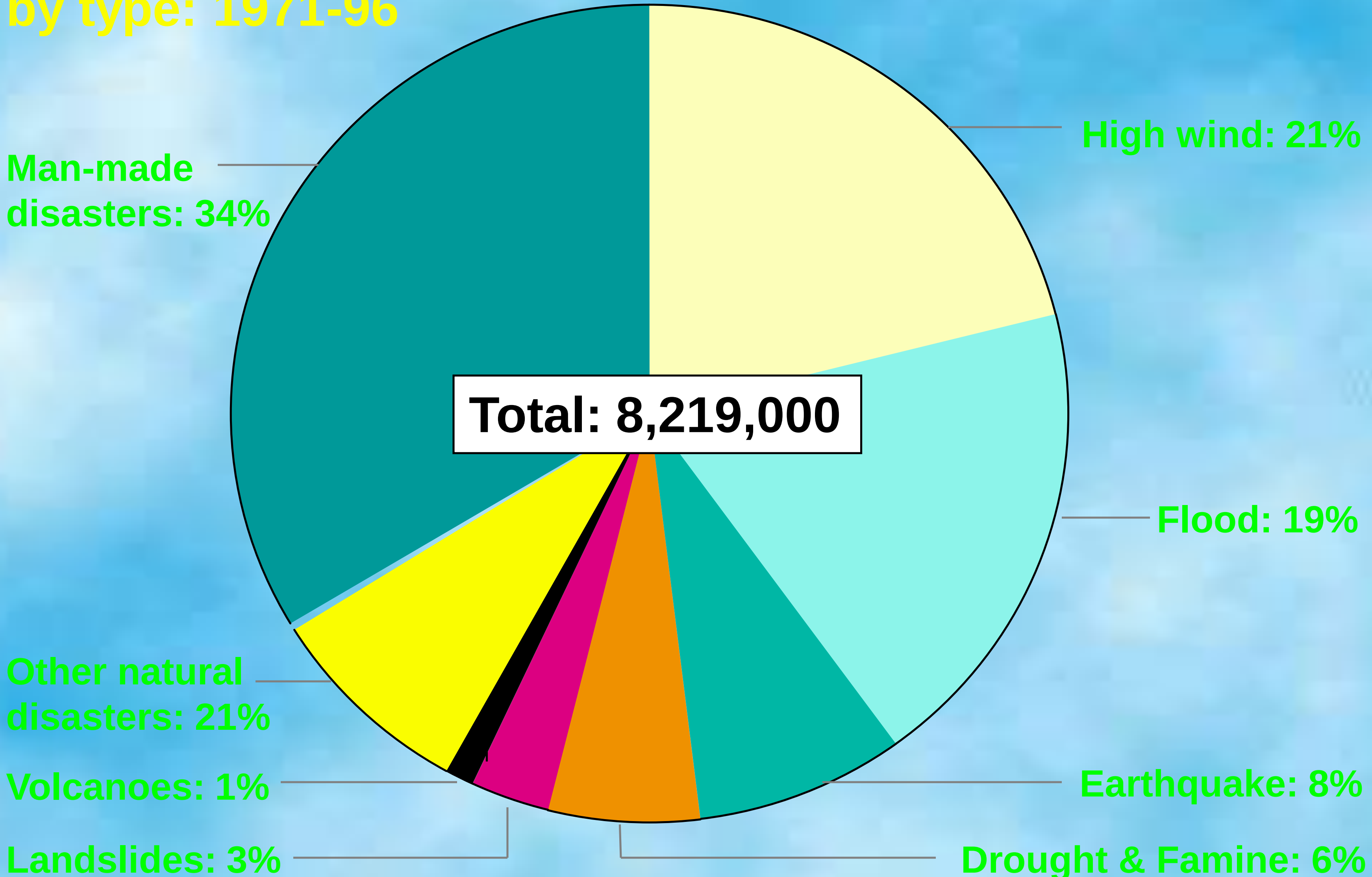
U.S. 20th Century Natural Disaster Fatality-Frequency Plots*



* S.P. Nishenko and C.C. Barton: "Scaling Laws for Natural Disaster Fatalities" in REDUCTION AND PREDICTABILITY OF NATURAL DISASTERS (Eds: Rundle, Turcotte and Klein) (Addison-Wesley, 1996)

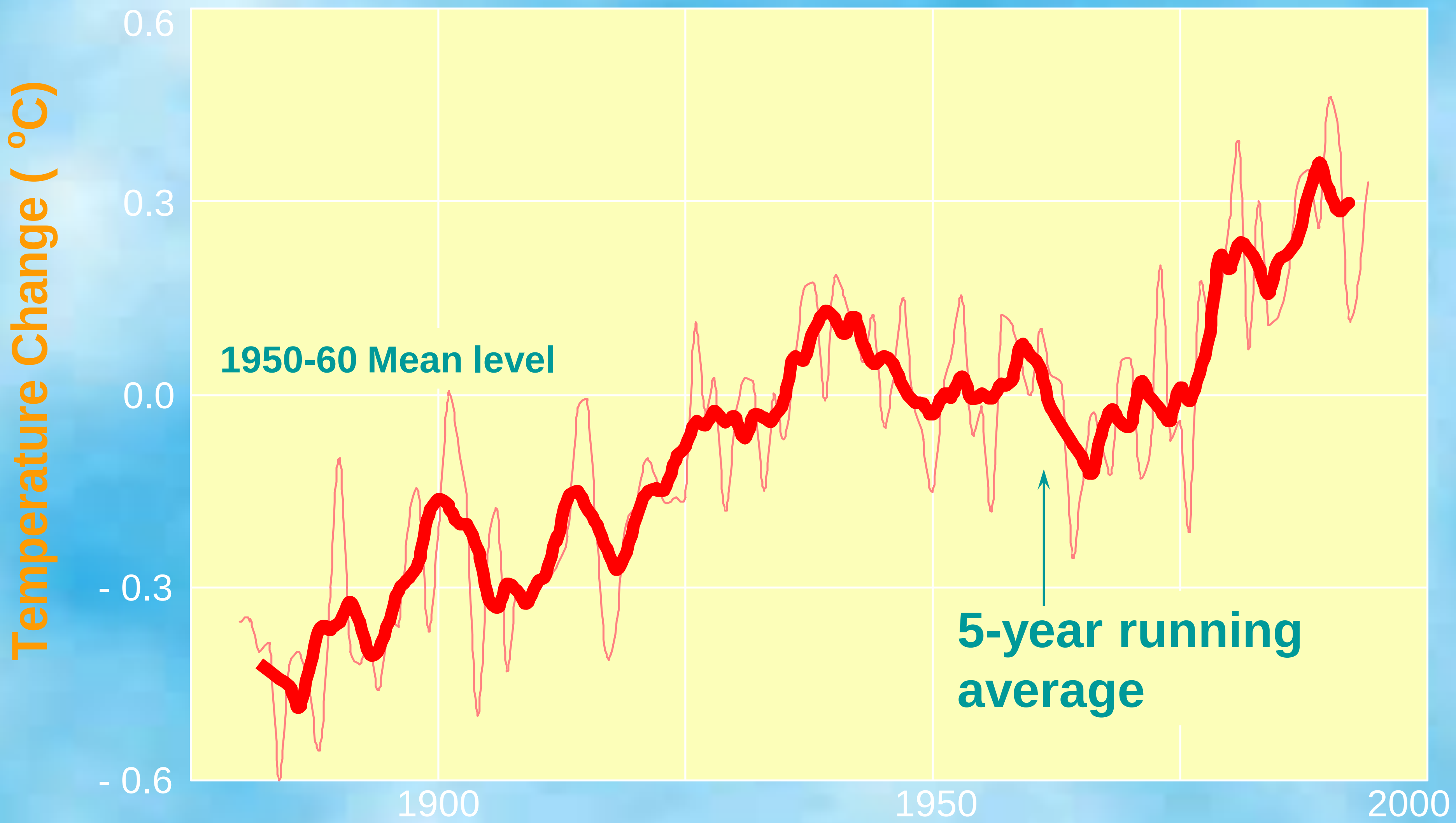
Disasters*

by type: 1971-96



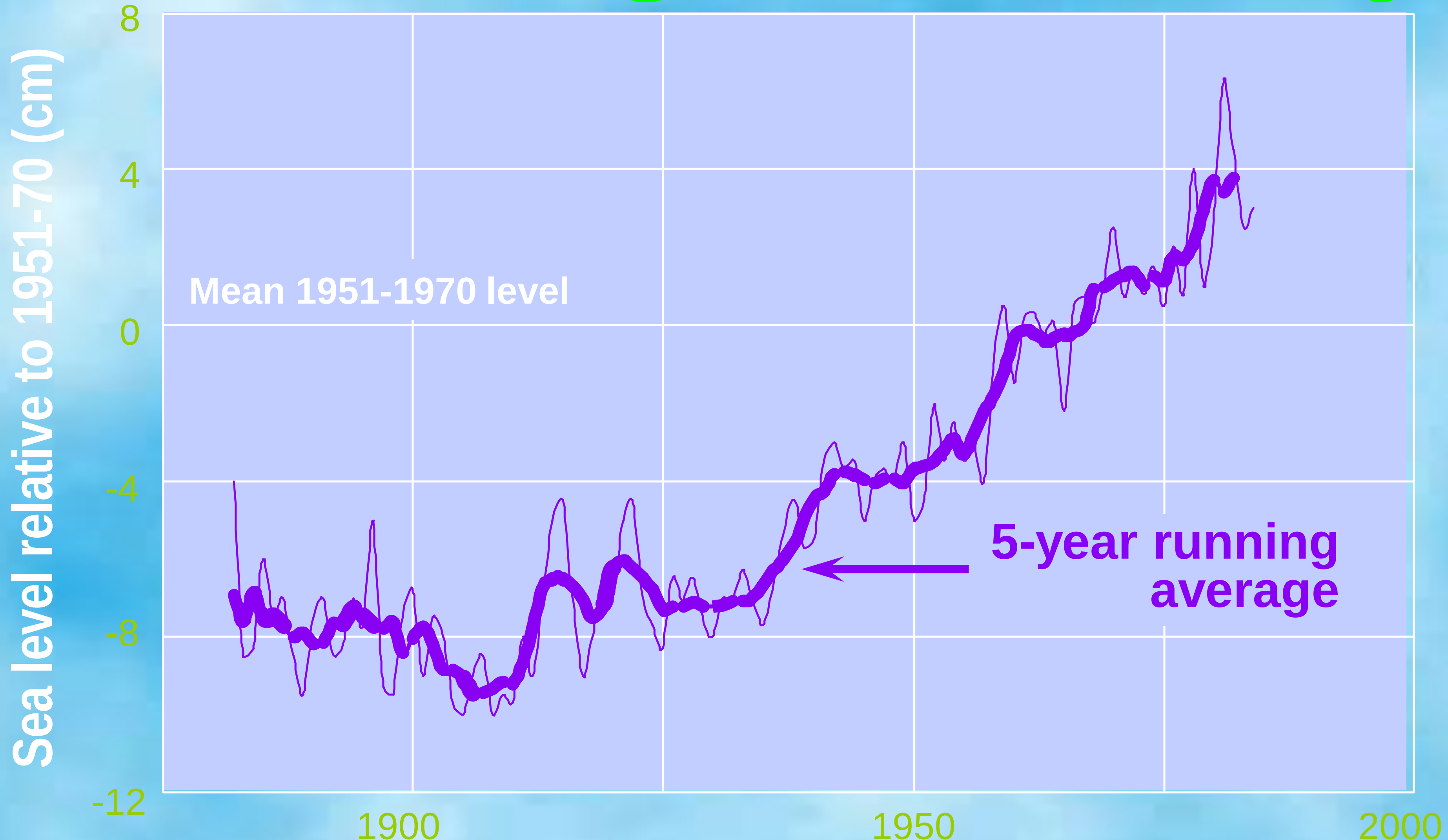
* International Federation of Red Cross and Red Crescent Societies (The Economist, Sept 6, 1997)

Global mean temperature change through last century



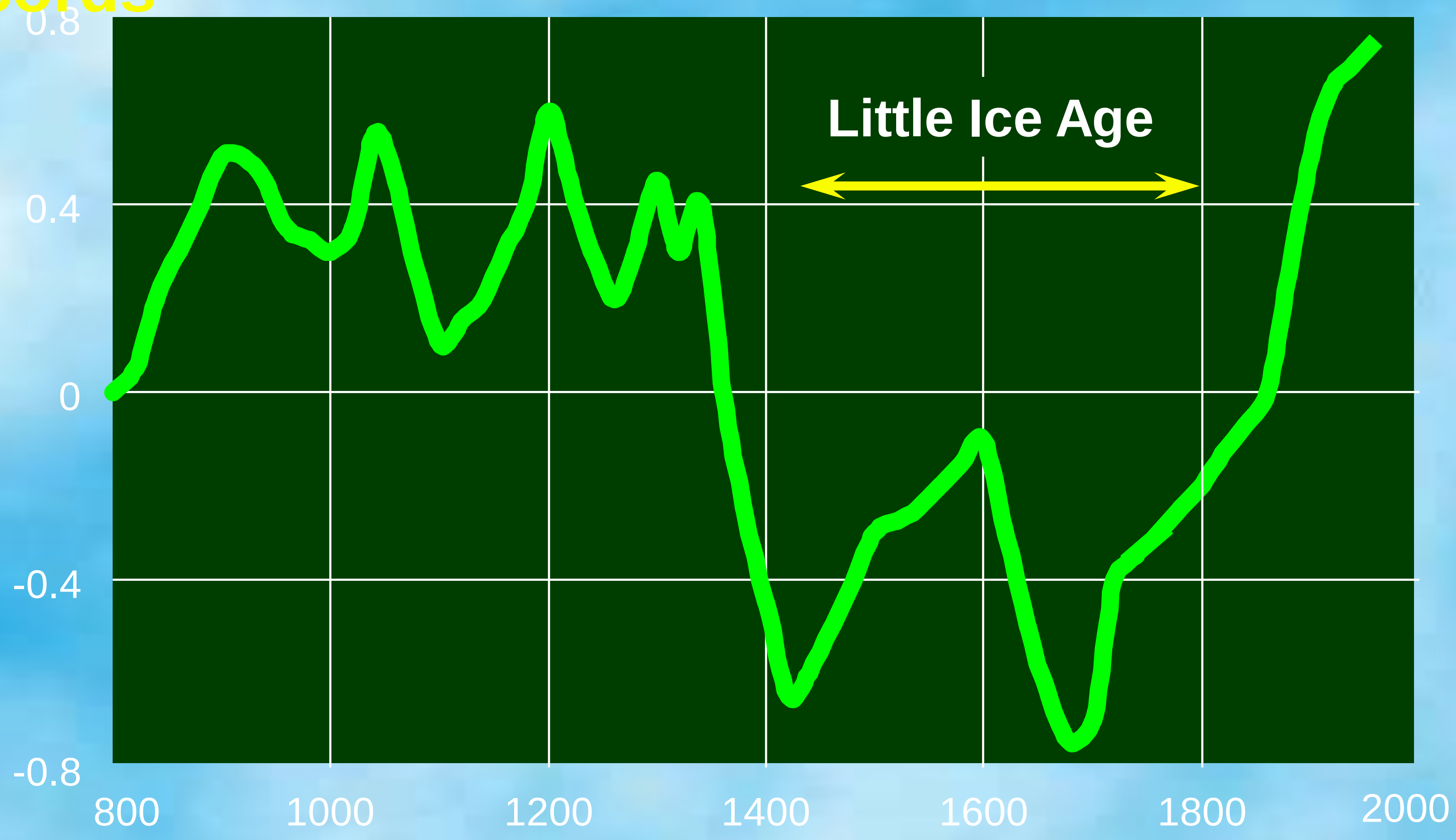
Source: Thomas Karl and C. Bruce Baker: GLOBAL WARMING UPDATE (NCDC-NOAA, 1994)

The global mean sea-level rise through last century

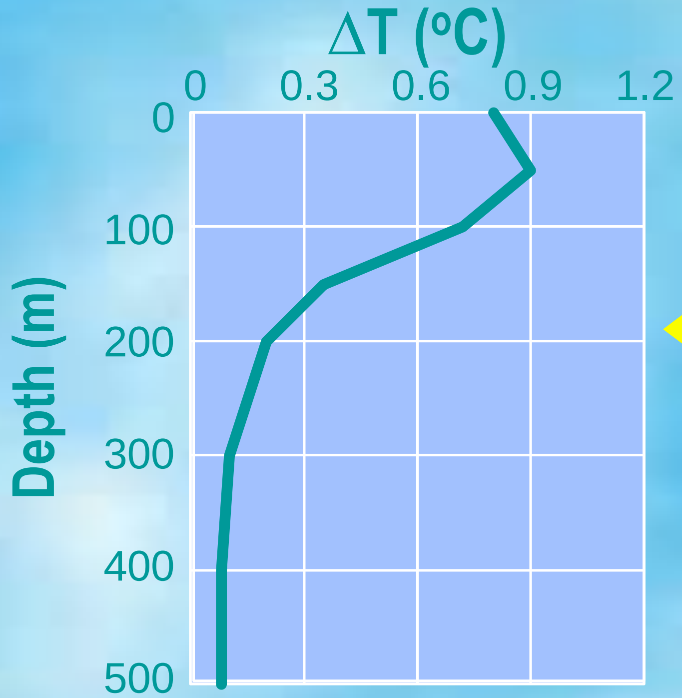


Source: T.P. Barnett, in CLIMATE CHANGE (IPCC Working Group Report: Cambridge University Press, 1990)

Winter conditions in Eastern Europe through the past millenium, based on manuscript records*



* J. Imbrie & K.P. Imbrie: ICE AGES (Enslow Publishers, 1979)



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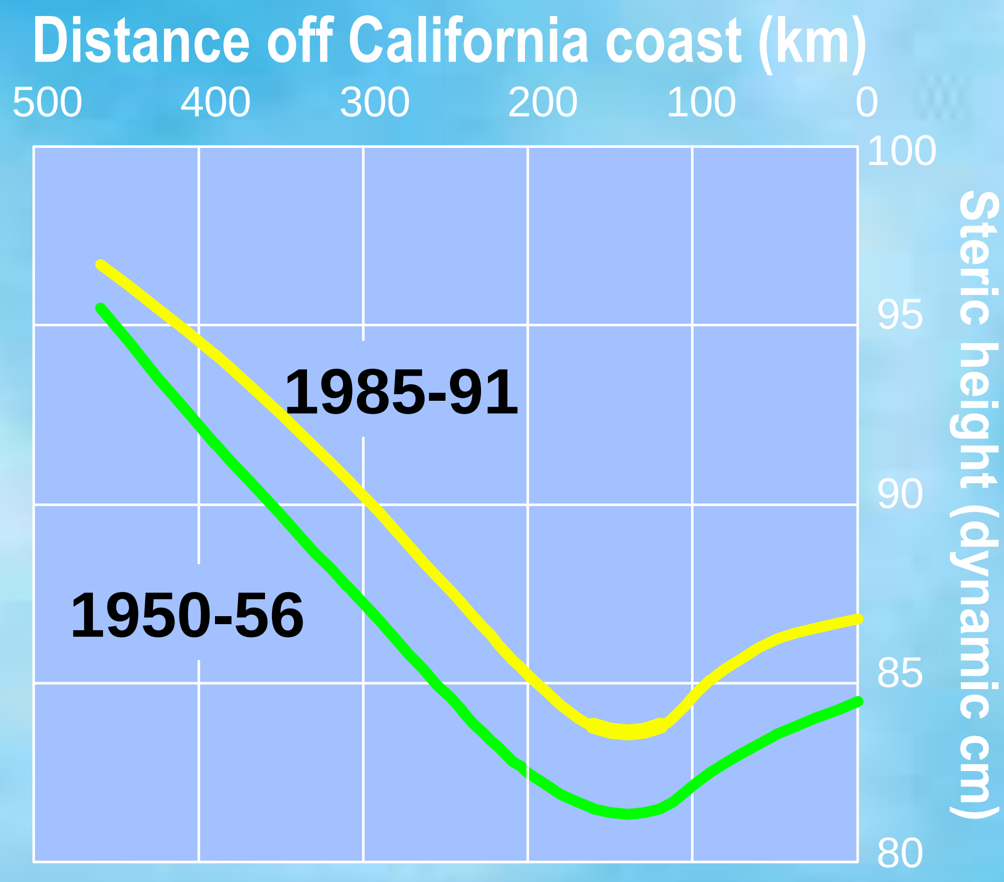
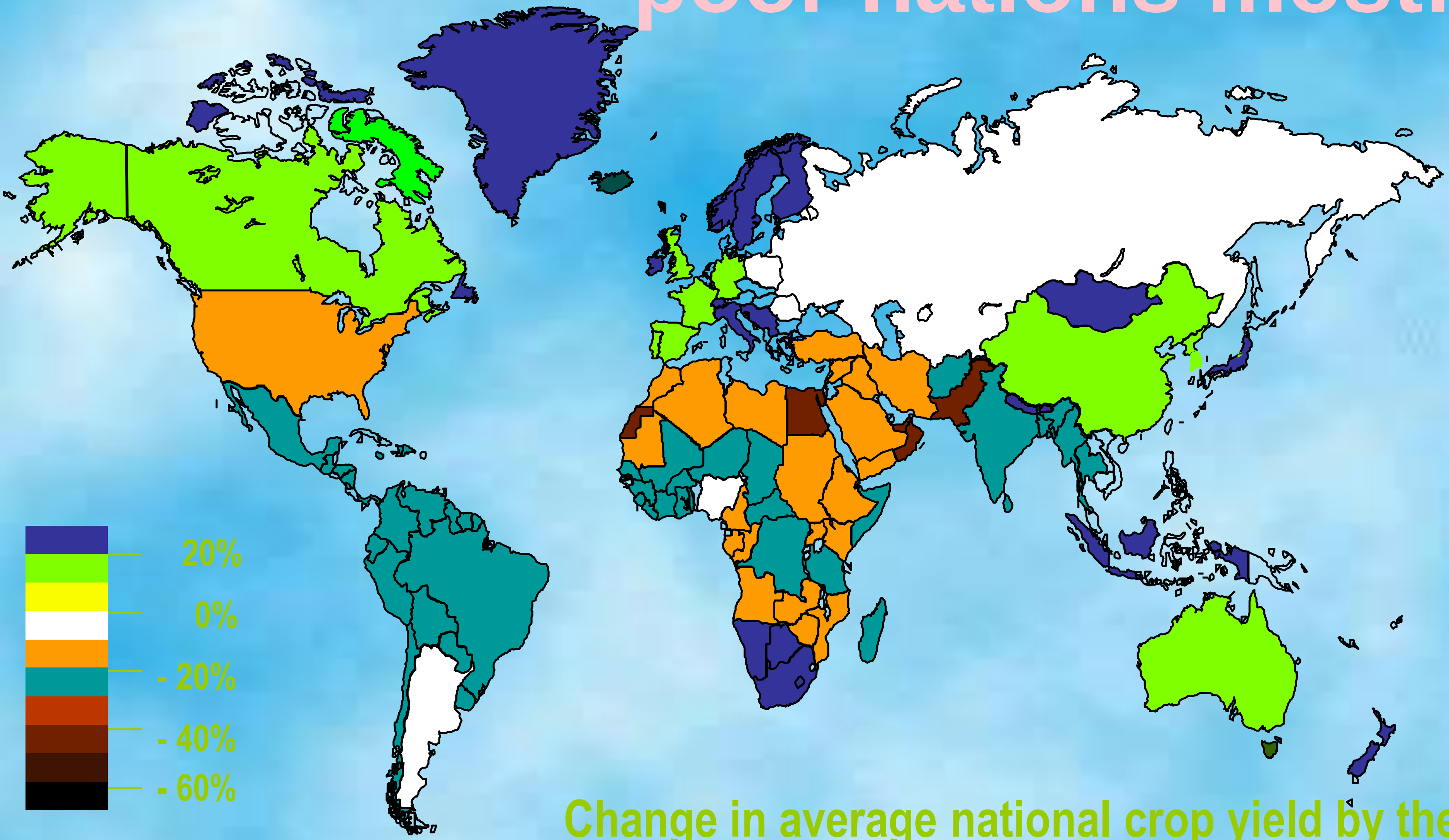


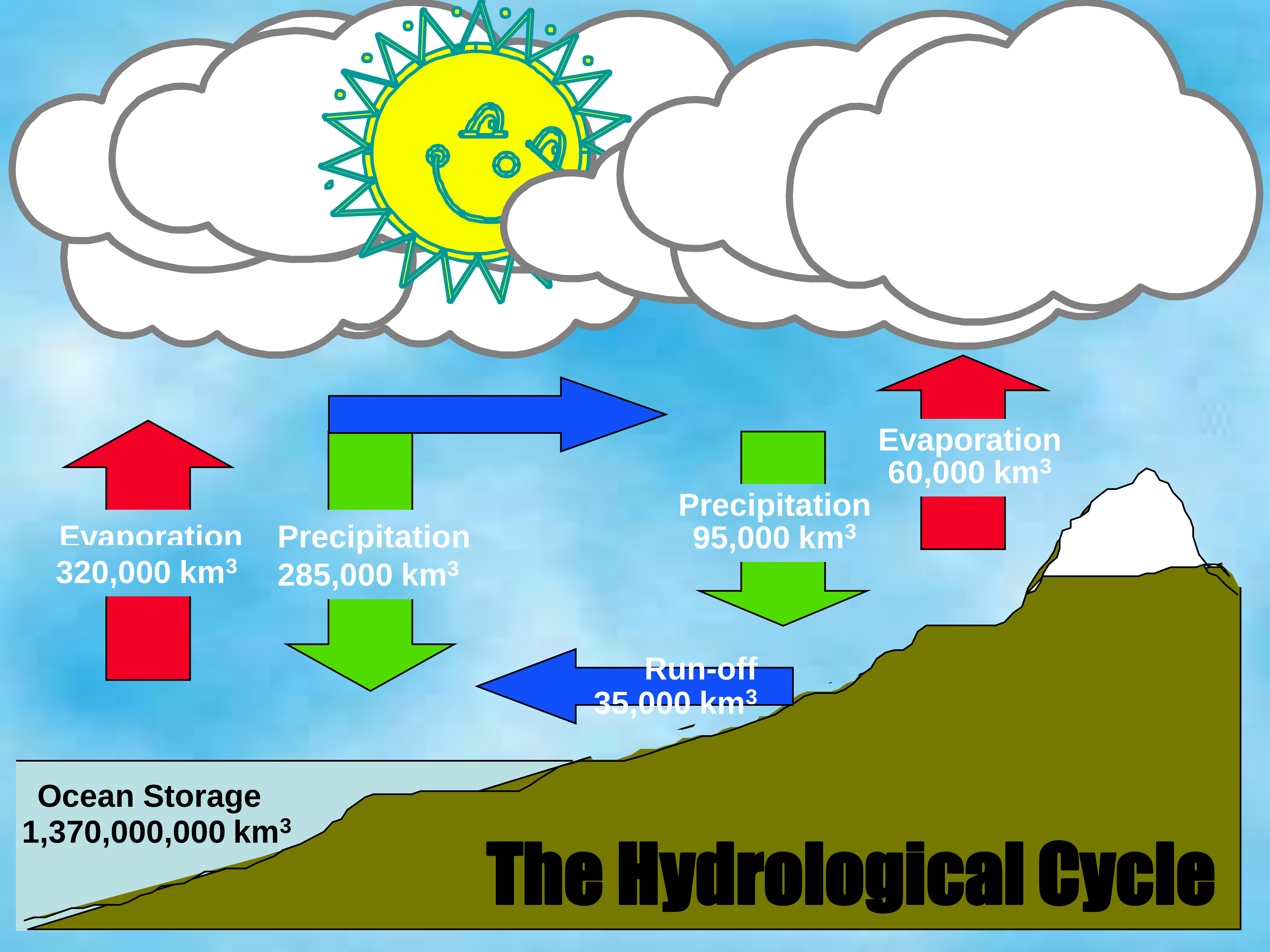
Note: Warming by 1ºC the top 100 m of ocean with 15ºC temperature and 3.4% salinity should raise the sea level by ~2.2 cm.

Source: D. Roemmich, SCIENCE: v. 257, p. 373-375 (July 17, 1992).

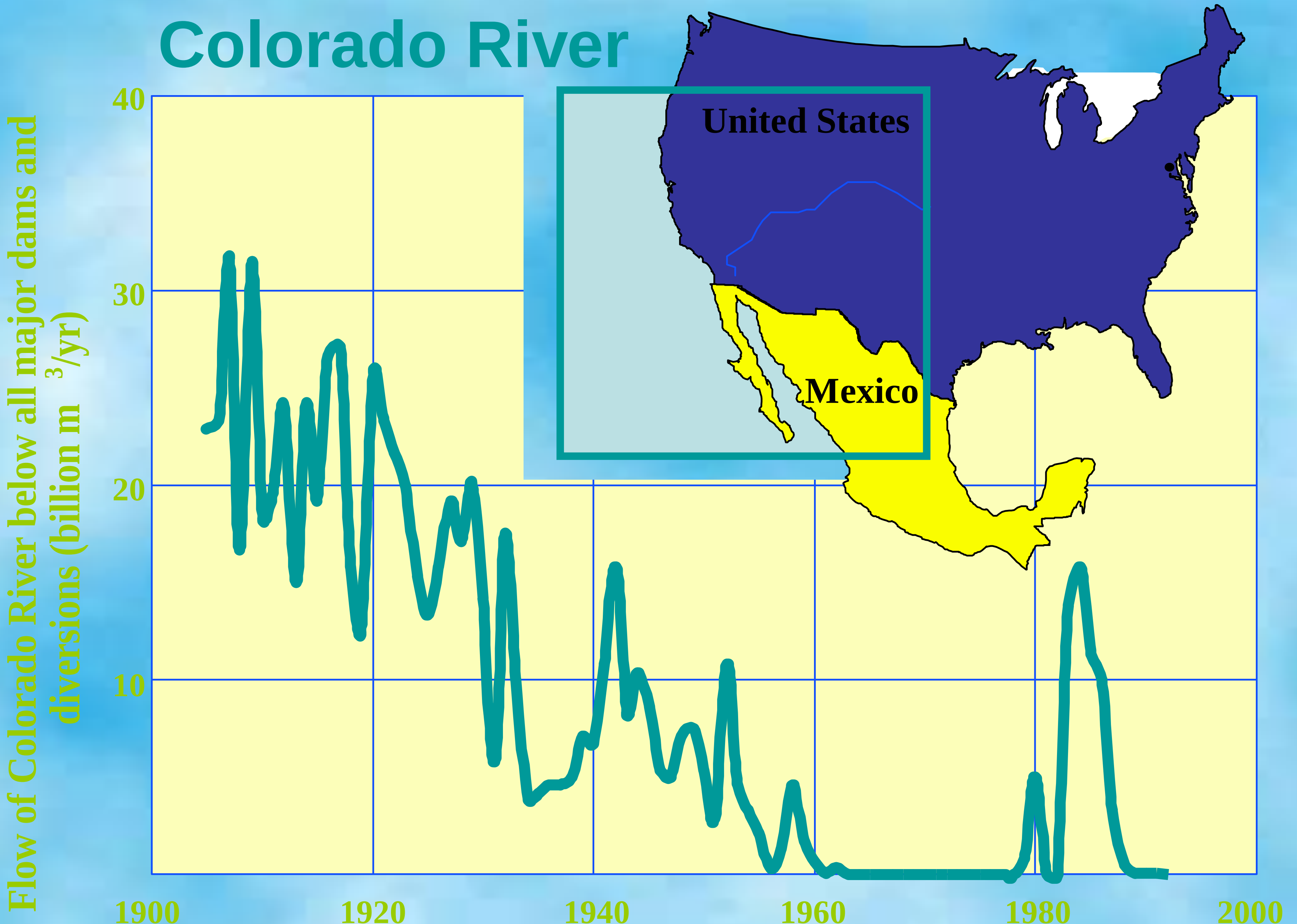
Global warming will hurt the poor nations most!



Change in average national crop yield by the year 2,060 compared to yield corresponding to no change in climate (based on the ocean-atmosphere coupling model) - SCIENCE NEWS, Aug 1992

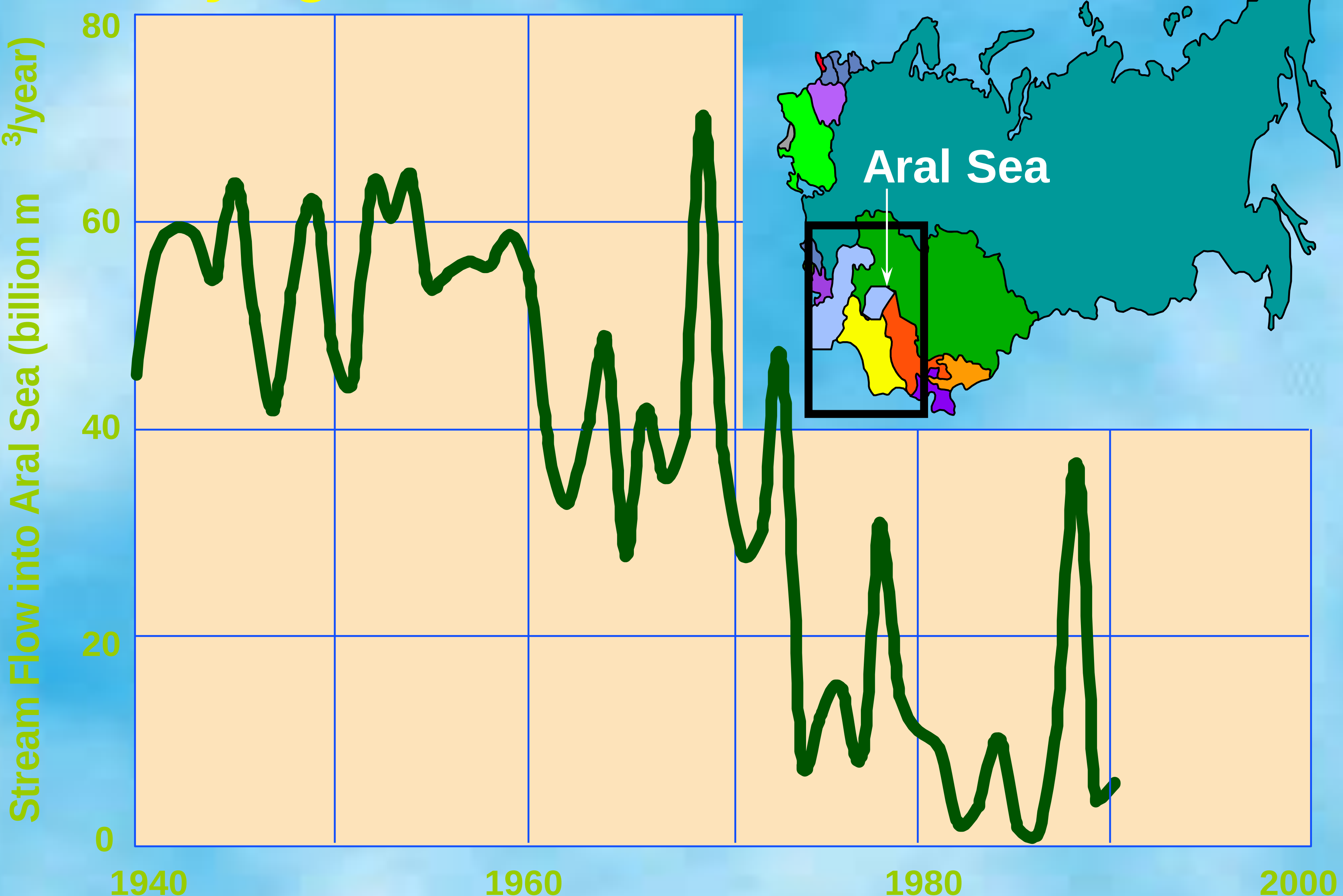

Evaporation
320,000 km³
Precipitation
285,000 km³
Precipitation
95,000 km³
Evaporation
60,000 km³
Run-off
35,000 km³
Ocean Storage
1,370,000,000 km³
The Hydrological Cycle

Colorado River



Sandra Postel: Forging a Sustainable Water Strategy (STATE OF THE WORLD 1996: Worldwatch Institute , 1996)

Drying of the Aral Sea



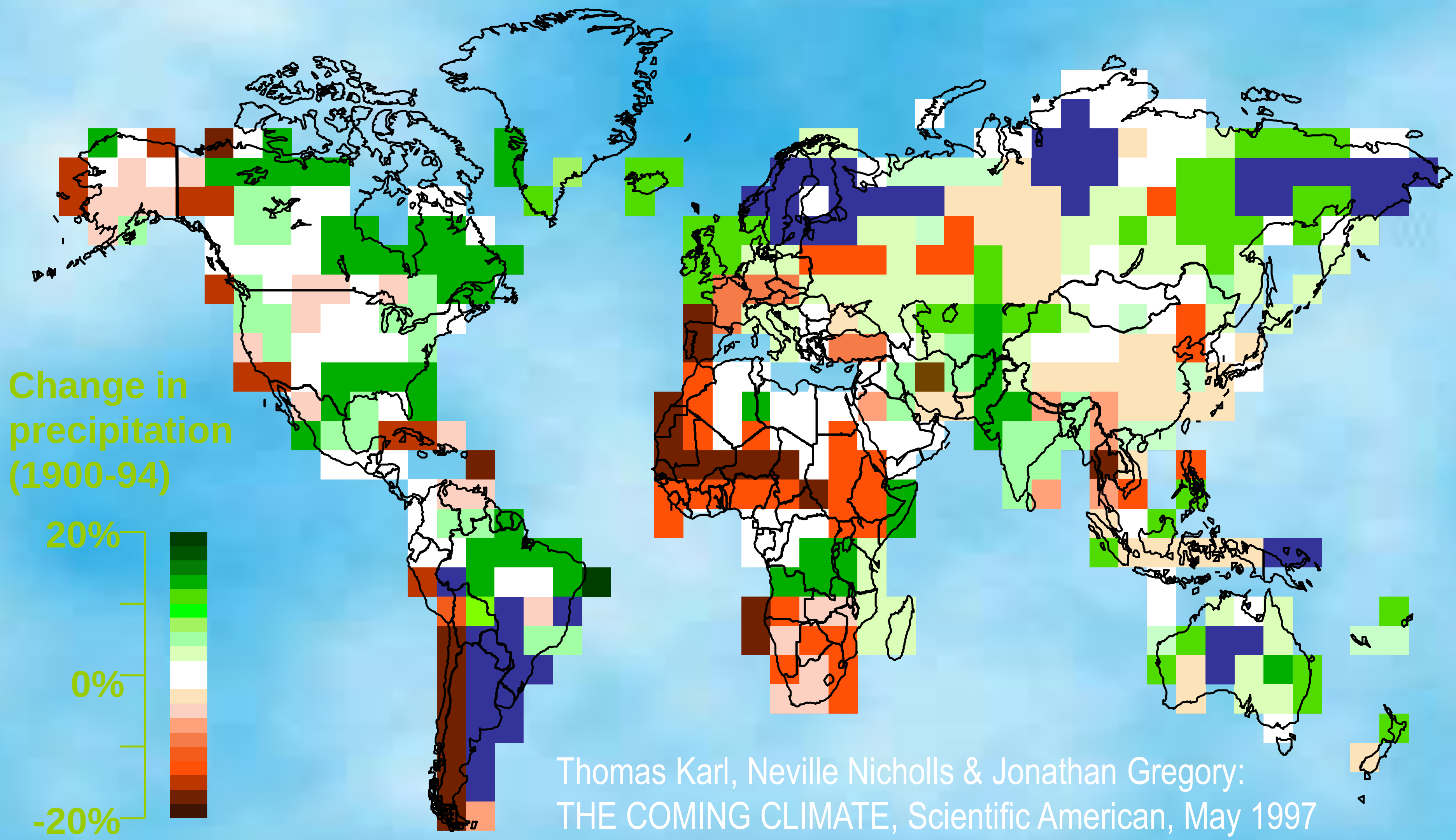
Sandra Postel: Forging a Sustainable Water Strategy (STATE OF THE WORLD 1996: Worldwatch Institute , 1996)

A century of human induced sea level rise*

	Removable volume (in 10^{12} m^3)	Extraction rate (in 10^{10} m^3/yr)	Sea-level rise rate (mm/yr)	Estimated sea-level change to date (mm)
North America				
High plains	4.0	1.20	0.03	1.10
Southwest	3.0	1.00	0.03	0.92
California	10.0	1.30	0.04	1.20
Africa and Asia				
Sahara	600.0	1.00	0.03	0.56
Sahel (soil water)	0.1	0.34	0.01	0.28
Arabia	500.0	1.60	0.04	0.89
Aral (Sea: 1960)	1.1	2.70	0.08	2.20
Aral (groundwater)	2.2	3.70	0.10	3.10
Caspian (Sea)	56.0	0.77	0.02	1.30
Caspian (groundwater)	220.0	0.47	0.01	0.78
Worldwide				
Deforestation	3.3	4.90	0.14	3.40
Wetland reduction	8.6	0.20	0.01	1.30
Dams	-1.9	-	-	-5.20
Total	1406.7	19.20	0.54	11.80

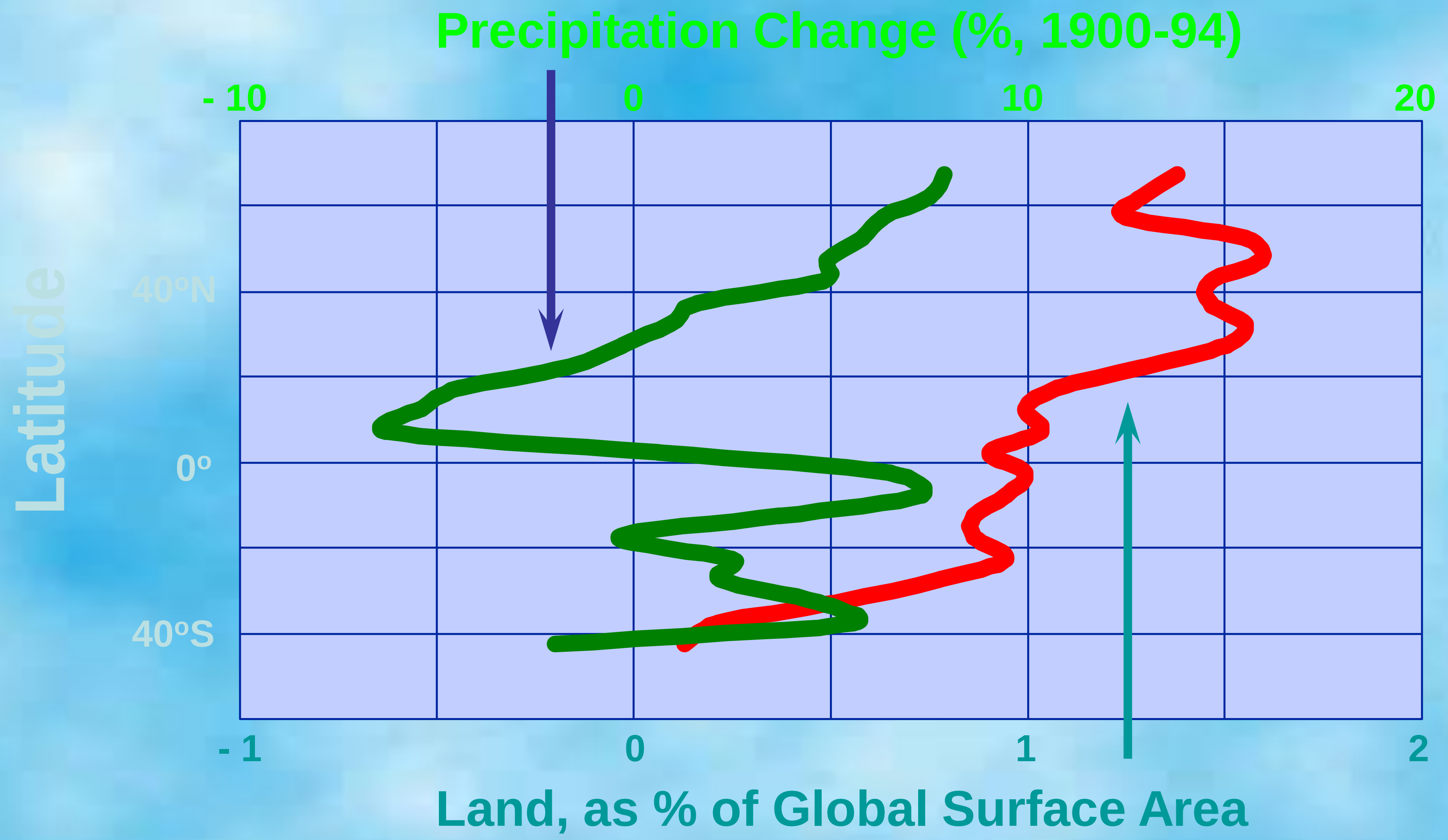
* Walter Newman and Rhodes Fairbridge: The Management of Sea-level Rise (NATURE, v. 320, p. 319-328, 1986). Dork Sahagian, Frank Schwartz and David Jacobs: Direct Anthropogenic Contributions to Sea-level Rise in the Twentieth Century (NATURE: v. 367, p. 54-57, 1994).

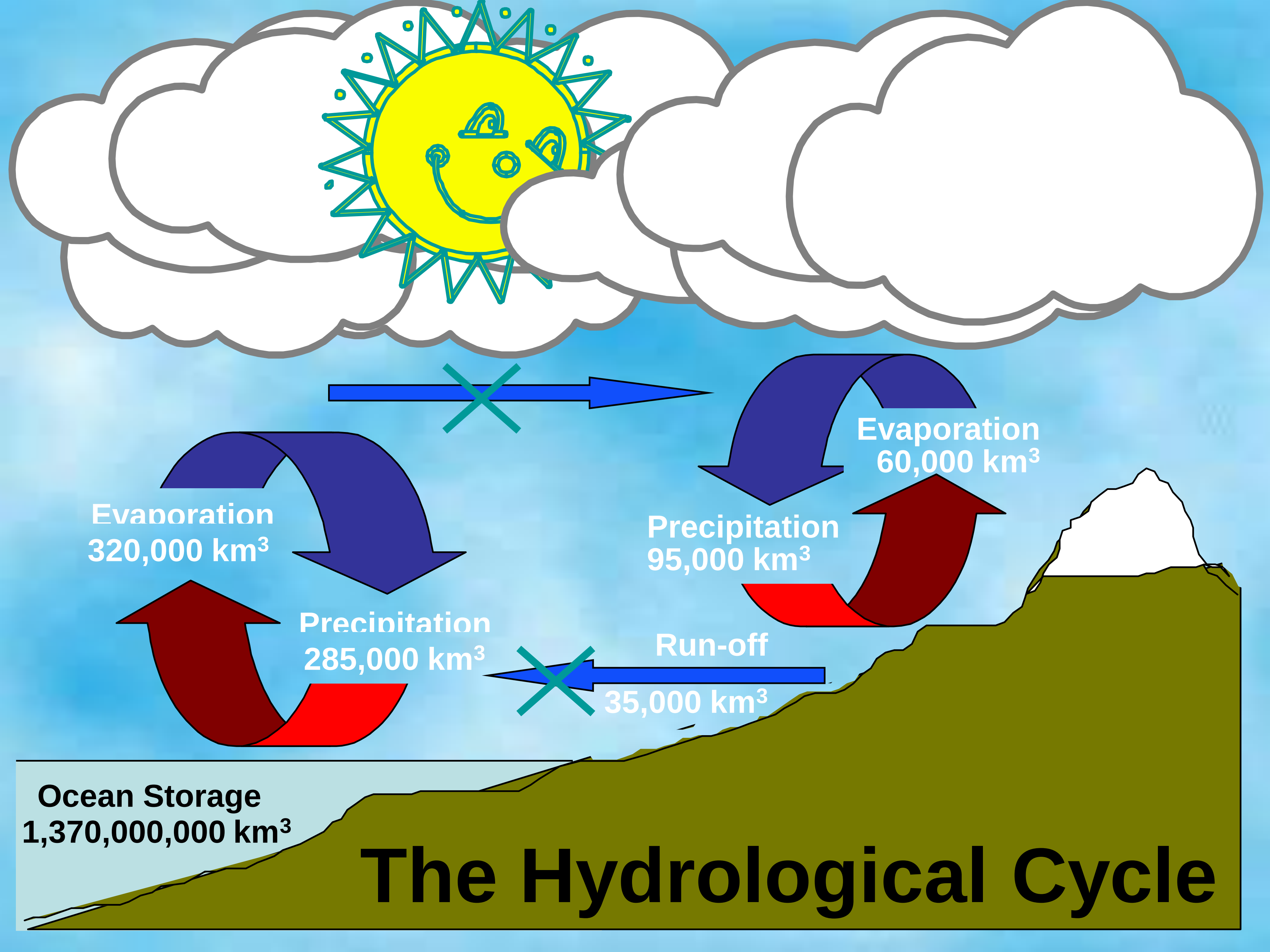
The 1900-94 trends reveal a general tendency towards greater precipitation (a) at higher latitudes and (b) on land



Thomas Karl, Neville Nicholls & Jonathan Gregory:
THE COMING CLIMATE, Scientific American, May 1997

Comparing the 1900-94 precipitation change with (a) latitude and (b) land area





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285,000 km3
Run-off
35,000 km3
Ocean Storage
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The Hydrological Cycle

In summary,

- **Human ingenuity has defied the "Malthusian Trap", that *the power of population exceeds that of the earth.***
- **This has resulted in modifying the most basic of nature's processes - the hydrological cycle.**
- **Perhaps technology defies the Gandhian dictum, that "nature has enough for our need, but not for our greed".**