Groundwater and Hydro Power: Resources vulnerable to climate change

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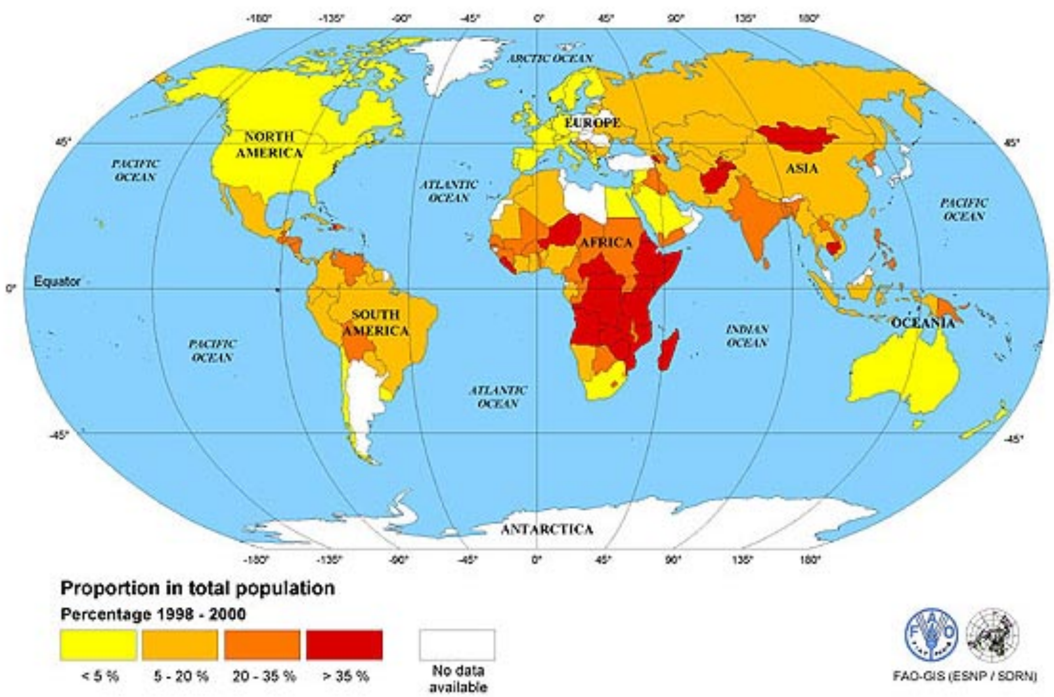


LA-UR 12-20951

Abstract

Sustainable development and utilization of water resources is critical for the well-being of mankind and the planet. It is a resource under threat and this talk will examine the challenges of past and future development globally. Currently, the steps being taken to ensure adequate supply of water for power, industrial, residential, agriculture and esthetic needs are falling short of the growing needs, and pollution is impacting terrestrial and marine life and the environment at an unprecedented scale and rate. I will also examine emerging issues impacting world's water resources with growth in population and prosperity, and impacts of climate change.

If you think we are doing a bad job of addressing climate change or environmental impacts of energy production & use

Just take a look at world's water resources, much of which we can see, touch, hear and feel

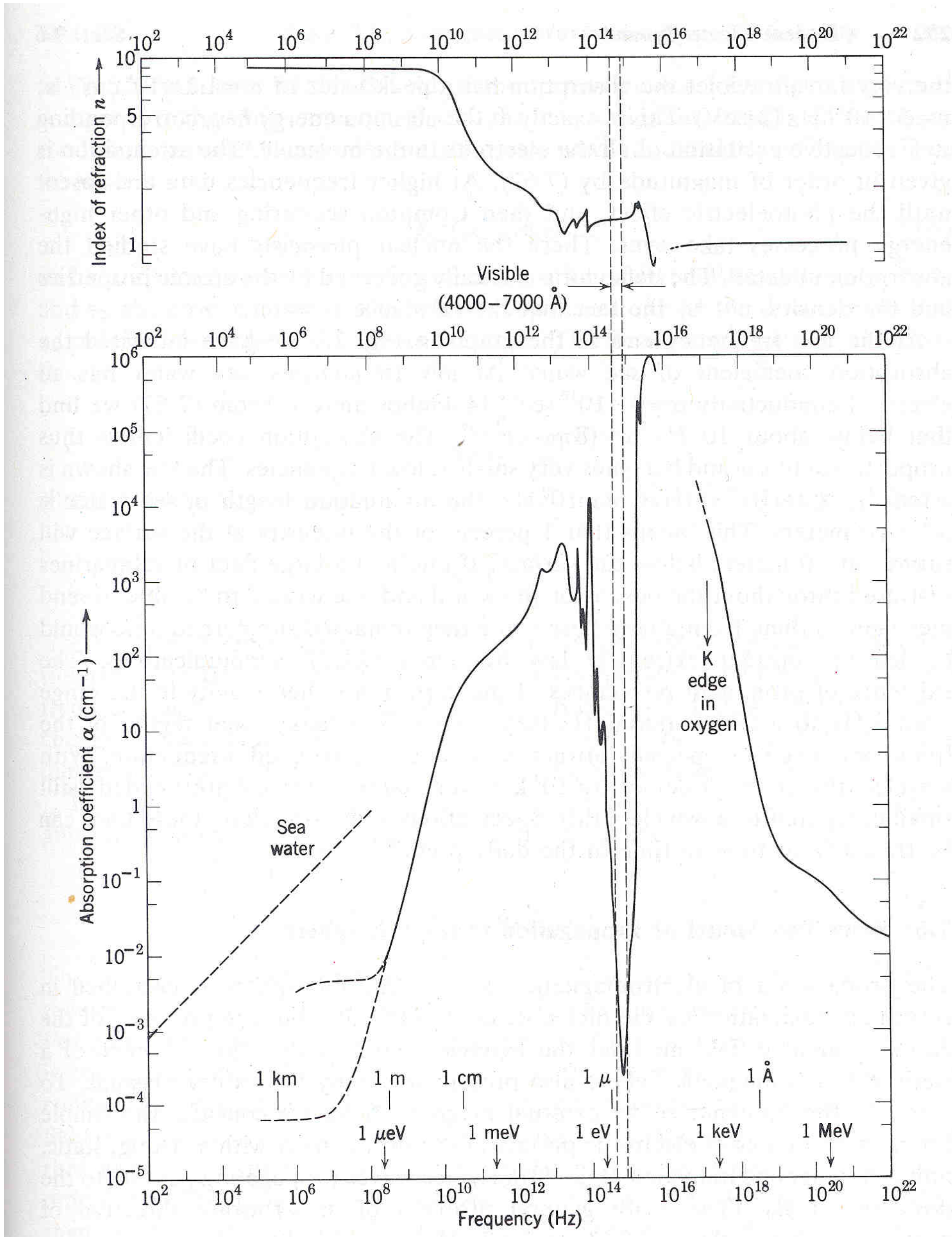
Energy & Water
Two inter-related key resources

Energy is needed for water management and treatment

Water is needed for the generation of power

MIRACLE PROPERTIES OF WATER

- Transparency to visible light: The absorption of electromagnetic radiation decreases by ~10^7 (10 million) times in the visible part of spectrum
- Density profile versus temperature: Water is densest at 4^o C
- Chemically neutral: Neither acidic nor alkaline
- A very good solvent: Medium in which all biochemical reactions take place
- High specific heat: Moderates weather



Water is transparent only to visible light

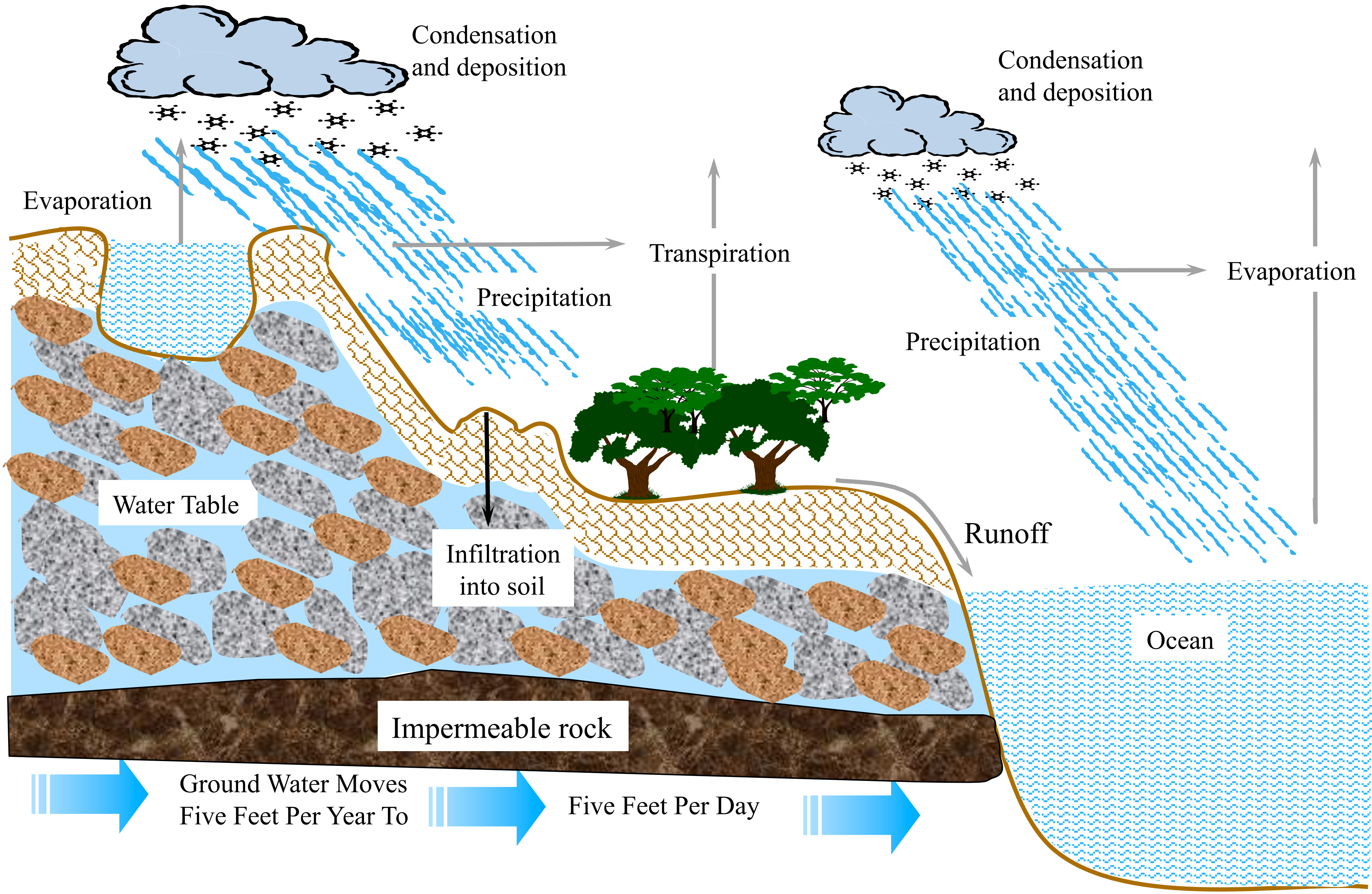
This property played a key role in the evolution of eyes in primordial (marine) life

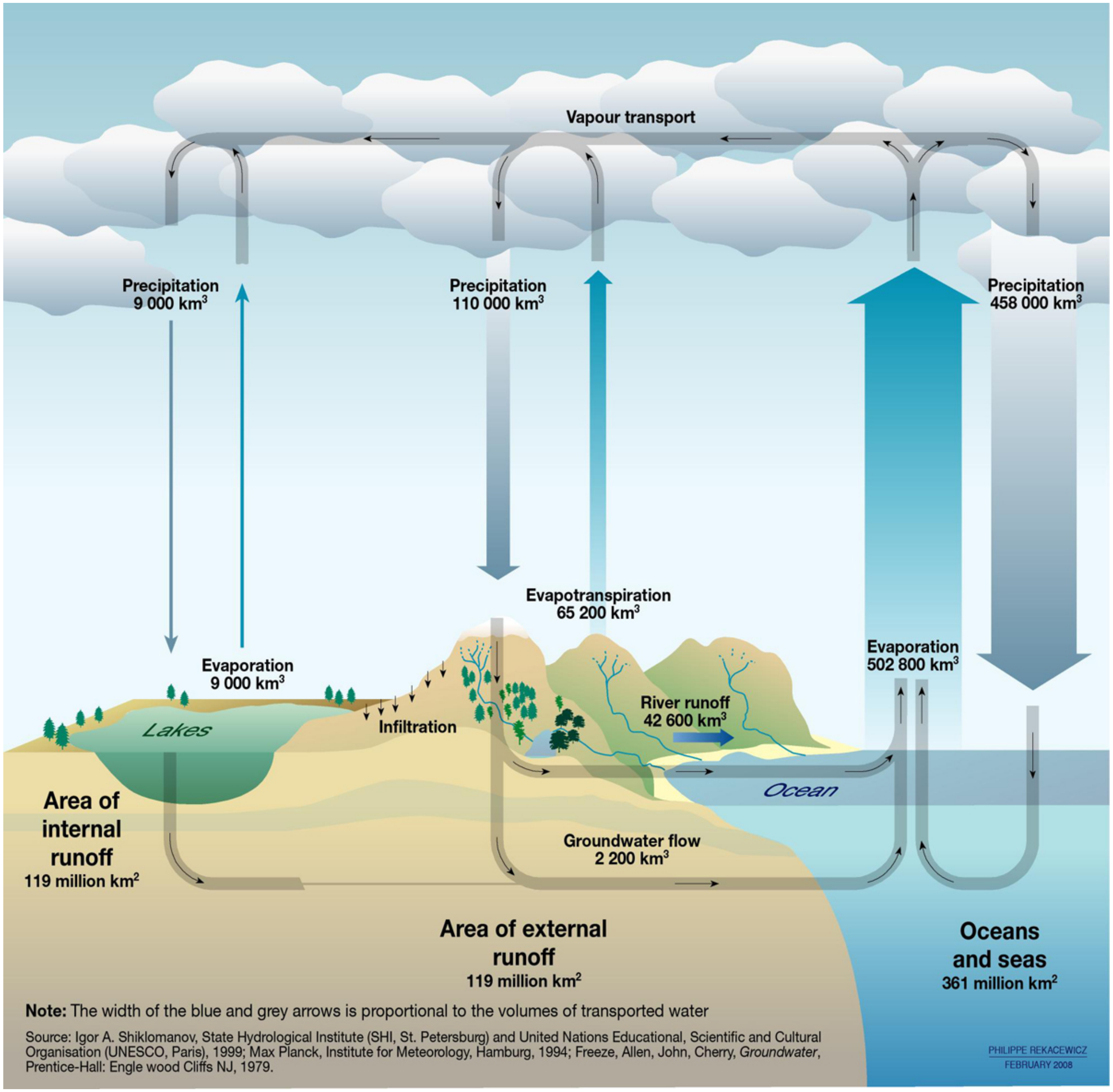
Source: J.D. Jackson, *Electrodynamics*, Wiley

Water is the basis of life

- Water is not fungible
- Water is neither created nor destroyed – water cycles
- The water cycle is driven by the heat of the sun. The heat provides energy for circulation between the oceans, atmosphere, and the land
- We can increasingly quantify how much water is available in each basin and how much is required by each eco system within it for health
- The annual availability varies – so developing sustainable models is essential
- Climate change can be a significant effect on top of natural variation

THE WATER CYCLE





Source: http://www.unep.org/dewa/vitalwater/rubrique2.html

Water is a non-fungible resource

- Rain/Snow (surface water)
- Groundwater
- Seawater (desalination)

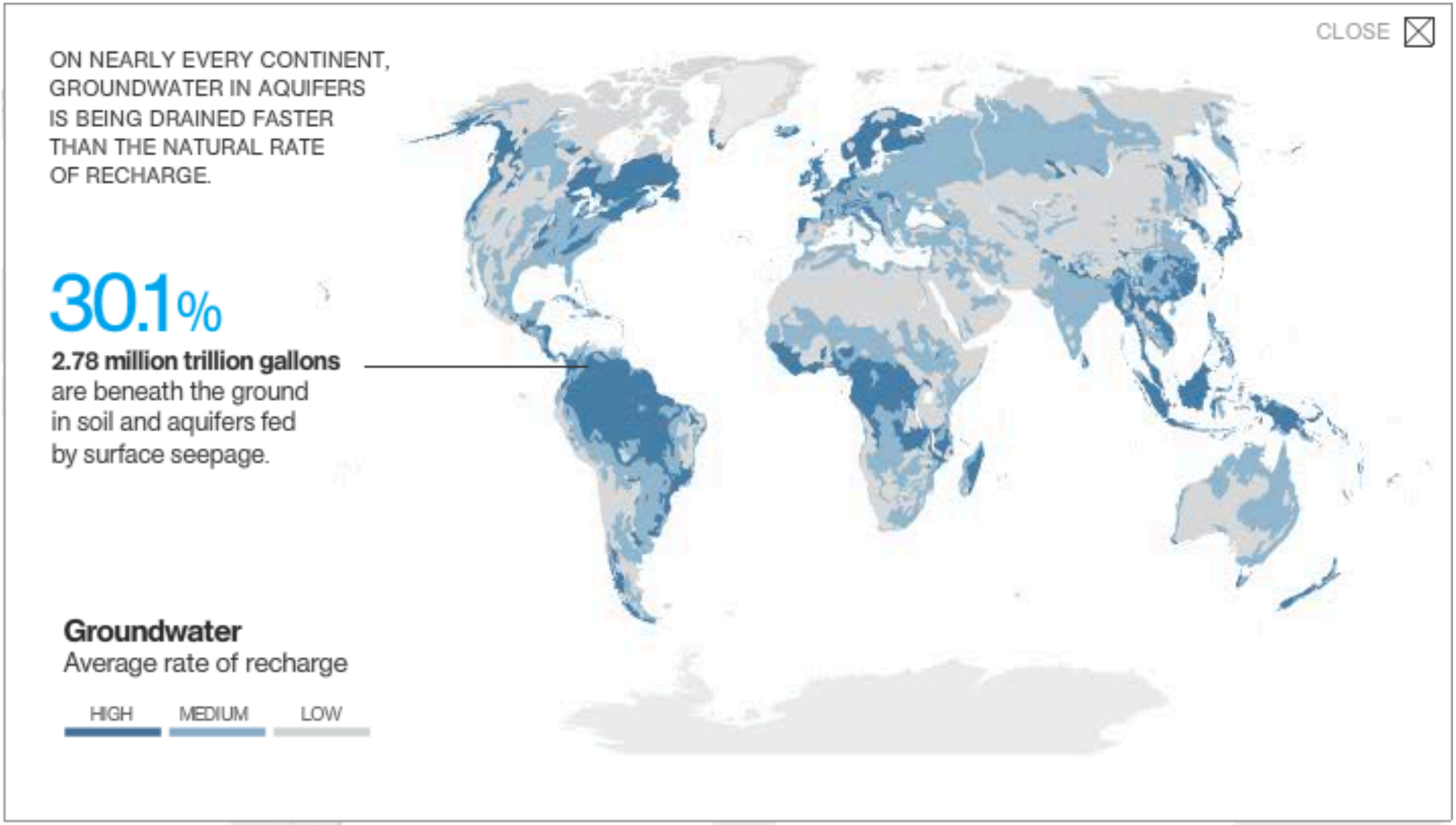
- Essential for
  - photosynthesis
  - all food production
- Thermal power plants
- Industrial processes
- City water
- Healthy Ecosystems
- Transport, recreation, fish

A resource highly vulnerable to climate change

GROUNDWATER

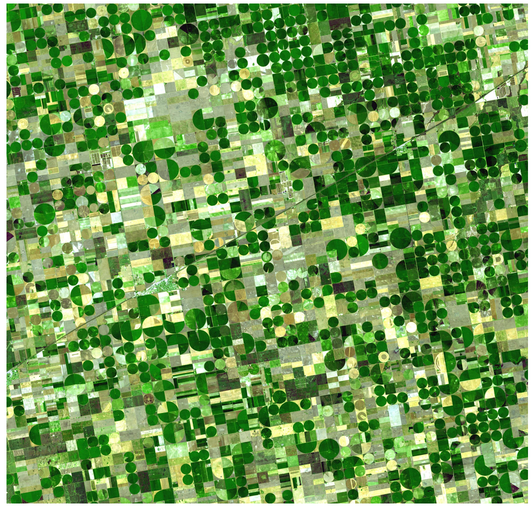
- The ground acts like a sponge to hold water
- There is more than 20 times the amount of surface water in the first half mile below the surface
- Natural reservoir under almost all land
  - No storage cost
  - No transportation cost
- Groundwater provides good quality drinking water that is increasingly being polluted
- Replenished by seepage of rain water through the soil – soil acts as a filter
- Gravity causes slow flow to the oceans
- *Withdrawal rates have exceeded natural recharge*
- *Pollution (amount and toxicity) is increasing*

Groundwater

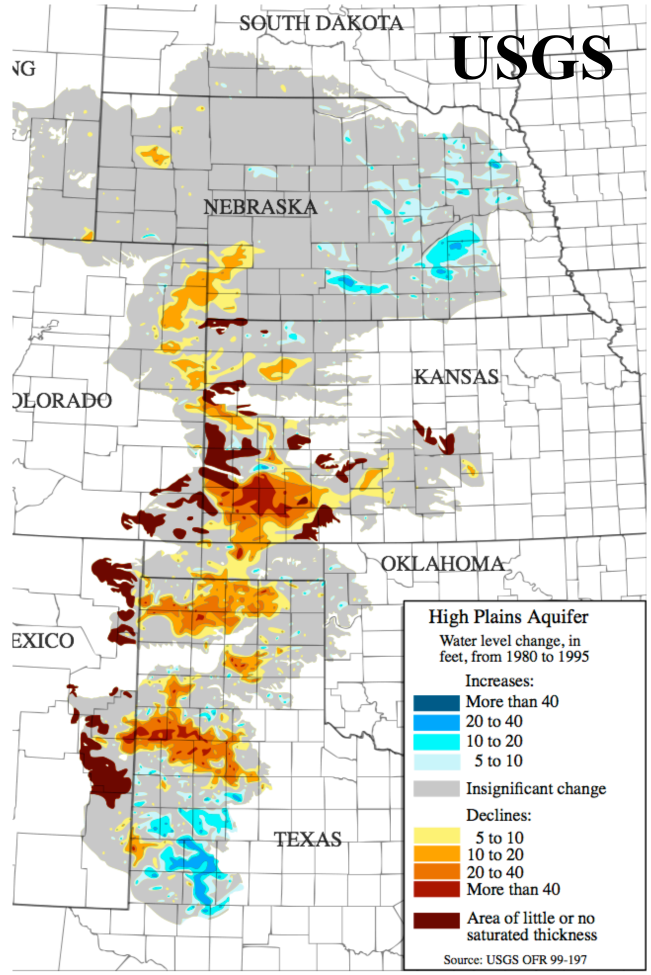


Source: http://ngm.nationalgeographic.com/2010/04/water/water-animation

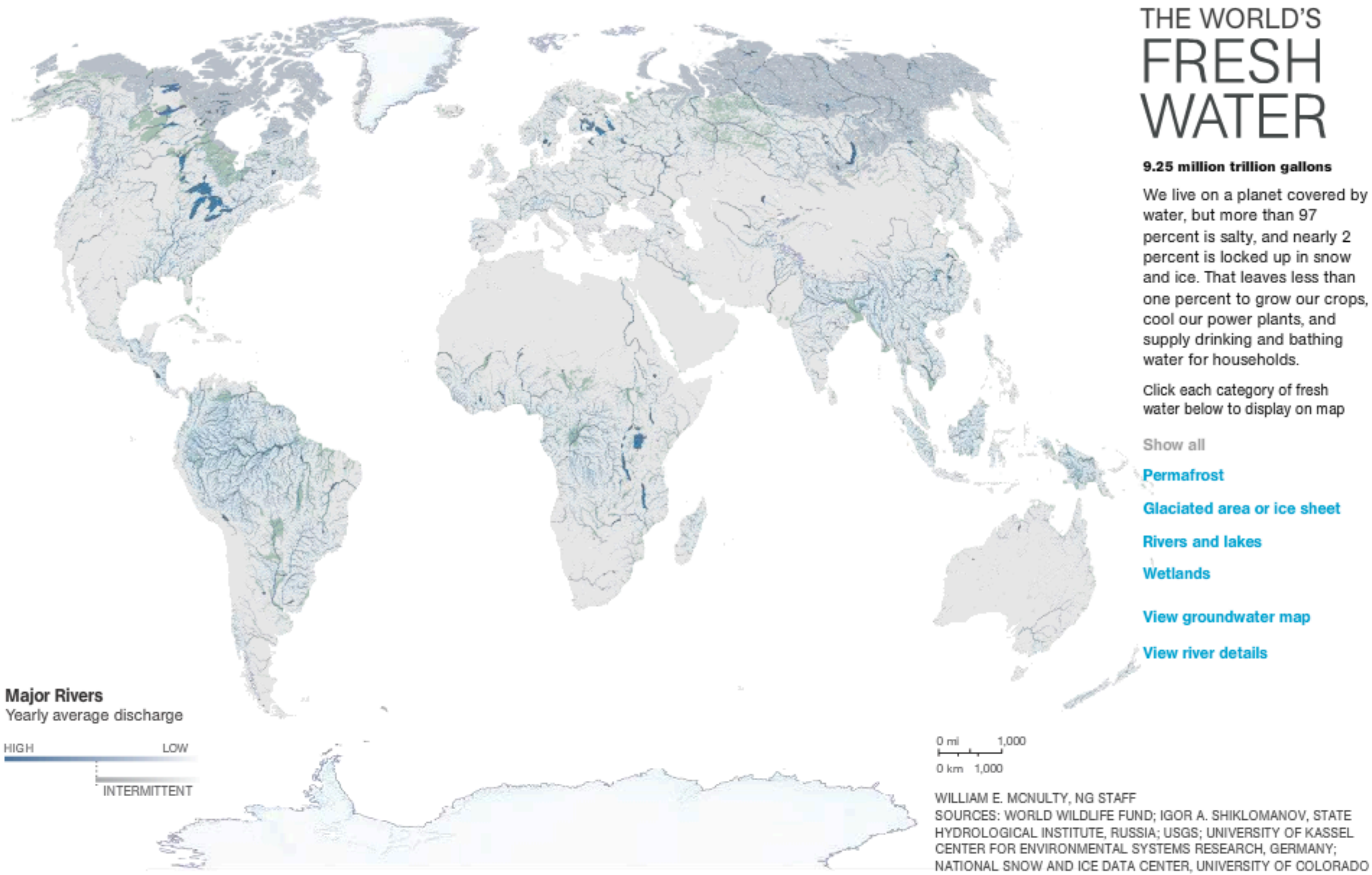
Pumping the Ogallala Aquifer



Center pivot irrigation on 557 m2 in Kansas. NASA ASTER



174,000 square miles in the Great Plains region, particularly in the High Plains of Texas, New Mexico, Oklahoma, Kansas, Colorado, and Nebraska. *http://en.wikipedia.org/wiki/Ogallala_Aquifer*



Source: http://ngm.nationalgeographic.com/2010/04/water/water-animation

Major River Basins

North America
1 Yukon
2 Mackenzie
3 Nelson
4 Mississippi
5 St. Lawrence

South America
6 Amazon
7 Paraná

Europe
25 Danube

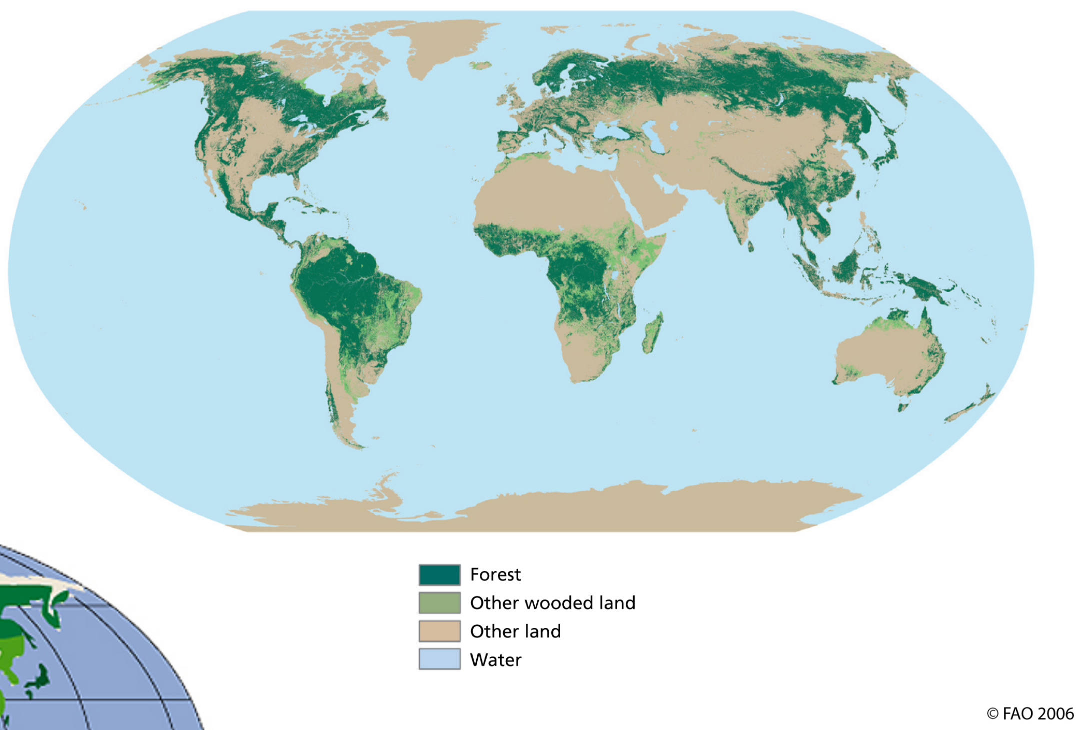
Africa and West Asia
8 Niger
9 Lake Chad Basin
10 Congo
11 Nile
12 Zambezi
26 Orange
24 Euphrates and Tigris

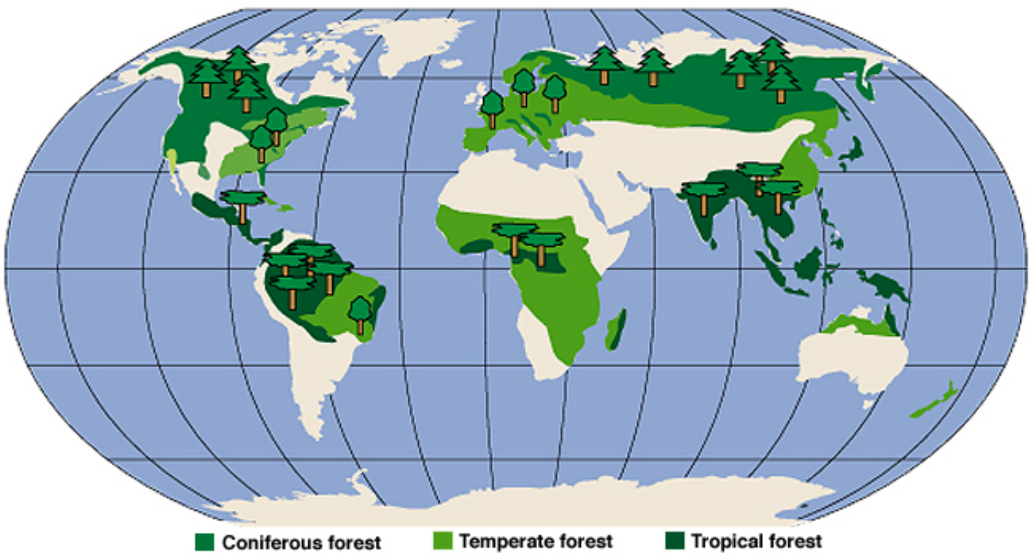
Asia and Australia
13 Volga
14 Ob
15 Yenisey
16 Lena
17 Kolyma
18 Amur
19 Ganges and Brahmaputra
20 Yangtze
21 Murray Darling
22 Huang He
23 Indus

Source: United Nations Environment Programme (UNEP); World Conservation Monitoring Centre (WCMC); World Resources Institute (WRI); American Association for the Advancement of Science (AAAS); *Atlas of Population and Environment*, 2001.

PHILIPPE REKACEWICZ
MAY 2002

World Forests





The highest biodiversity occurs in the tropical forests

Source: http://earth.rice.edu/mtpe/bio/biosphere/topics/biomes/forest.html

Forests are correlated with river basins and groundwater recharge

Groundwater Management

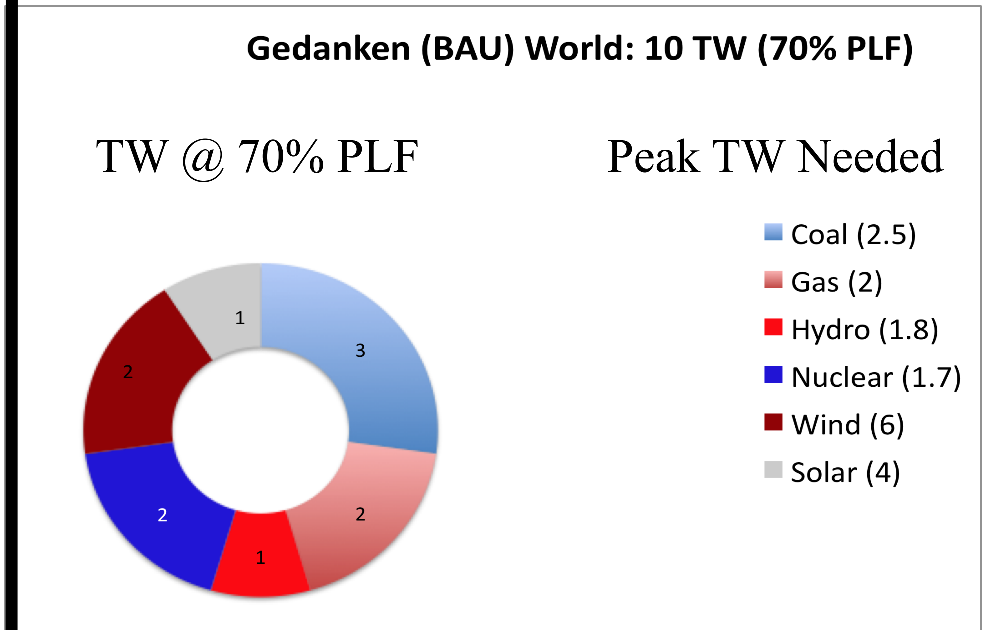
- Need integrated planning and analysis on the multiple benefits from river systems, instead of focusing on individual sectors such as hydropower, irrigation, industry, recreation, esthetics, city water, …

- Need to develop a “water value” based on an integrated analysis and then price water accordingly

Hydropower

Constructing Solution Wedges for electric power

- Need **10 TW** Electric Power:
  - **1 TW ←→ 6000 TWh**



- Need **85 mbo/day** Liquid Fuel:
  - **10** million barrels oil/day

HYDRO:
Installed capacity ~1TW
Generation ~3500 TWh
Will achieve target by 2050

Countries that get >50% of their electric power from hydro

- Canada
- Venezuela
- Brazil
- Paraguay, Uruguay
- Norway
- Switzerland
- Austria
- Albania
- Montenegro
- Latvia
- Africa between tropics
- Tajikistan
- Kyrgyzstan
- Georgia
- Nepal
- Bhutan
- Burma
- Laos

10 largest hydropower producing countries

Country	Annual hydroelectric production (TWh)	Installed capacity (GW)	Capacity factor	% of total capacity
China	652.05	196.79	0.37	22.25
Canada	369.5	88.974	0.59	61.12
Brazil	363.8	69.080	0.56	85.56
USA	250.6	79.511	0.42	5.74
Russia	167.0	45.000	0.42	17.64
Norway	140.5	27.528	0.49	98.25
India	115.6	33.600	0.43	15.80
Venezuela	85.96	14.622	0.67	69.20
Japan	69.2	27.229	0.37	7.21
Sweden	65.5	16.209	0.46	44.34

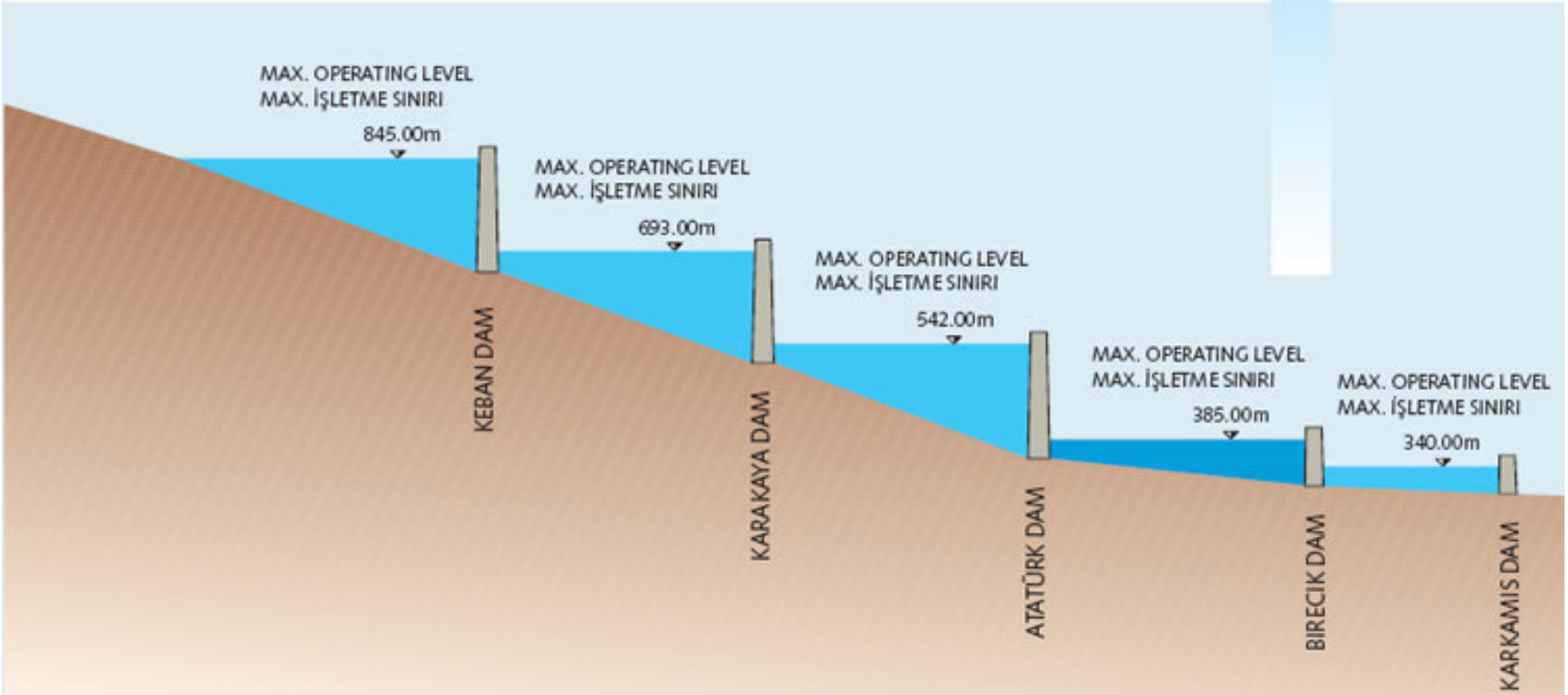
Source: http://en.wikipedia.org/wiki/Hydroelectricity

Hydroelectric Potential of a river

- Total energy in a river segment is = mgh
  - Mass m = volume × flow rate
  - Height h = difference in elevation
  - Gravity g = universal constant
- Useful energy
  - Mass: subtract water extracted/released for all other purposes plus evaporation losses
  - Height: subtract segments where it is not cost effective to build a hydroelectric system
  - Efficiency of conversion

DEVELOPMENT OF EUPHRATES RIVER
FIRAT NEHRİ ÜZERİNDEKİ BARAJLAR

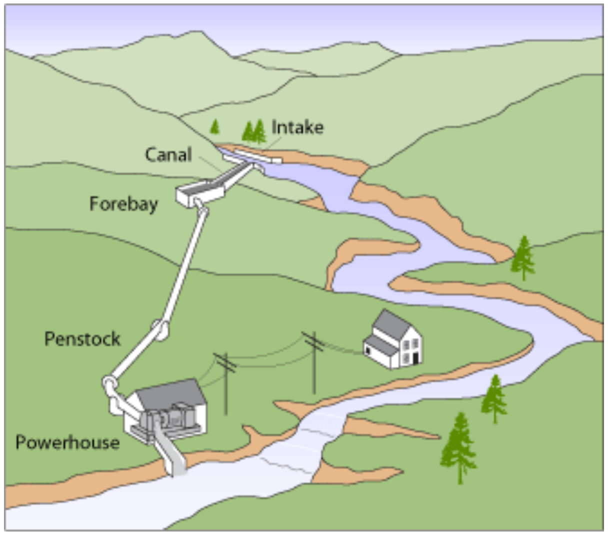
TOTAL STORAGE	TOPLAM HACİM	Mio. m^3	30700	9580	48700	1220	157
LIVE STORAGE	AKTİF HACİM	Mio. m^3	16300	5580	19300	620	0
MAX. FLOW	MAX. DEBİ	m^3/sec	1080	1182	1746	1900	1900
OUTPUT	ÇIKIŞ	MW	1240	1800	2400	672	180
YEARLY PRODUCTION	YILLIK ÜRETİM	GWh	5800	7500	8900	2500	650
NUMBER OF UNITS	ÜNİTE SAYISI		8	6	8	6	6
DISTANCE	UZAKLIK	km		166	180	100	32
YEAR OF COMMISSIONING	HİZMETE GİRİŞ YILI		KEBAN 1: 1973 KEBAN 2: 1983	1987	1992	2001	2000



Source: http://www.verbundplanbirecik.com.tr/content/english/euphra.htm#

Types of Projects

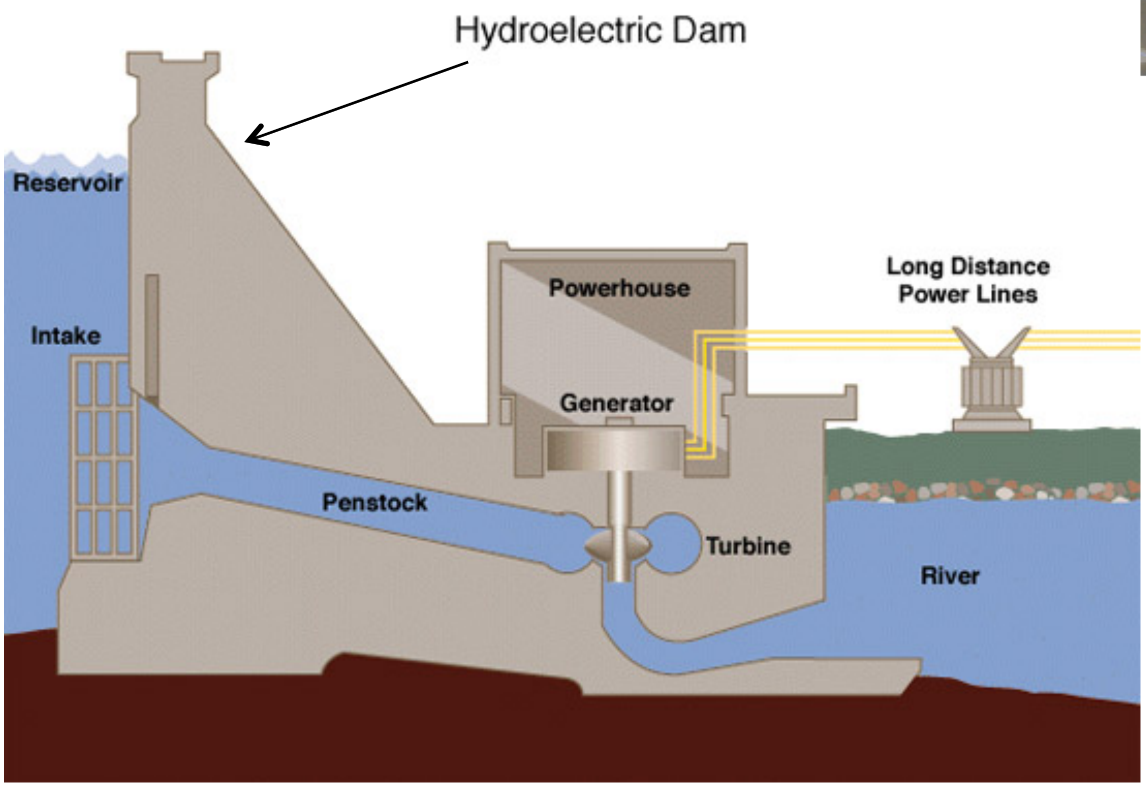
- Reservoir based
  - Annual regulation
- Run-of-the-river
  - Low dam with little storage
  - Seasonal regulation
- Mini & Micro
- Pumped storage
  - Day regulation
- Tidal Power



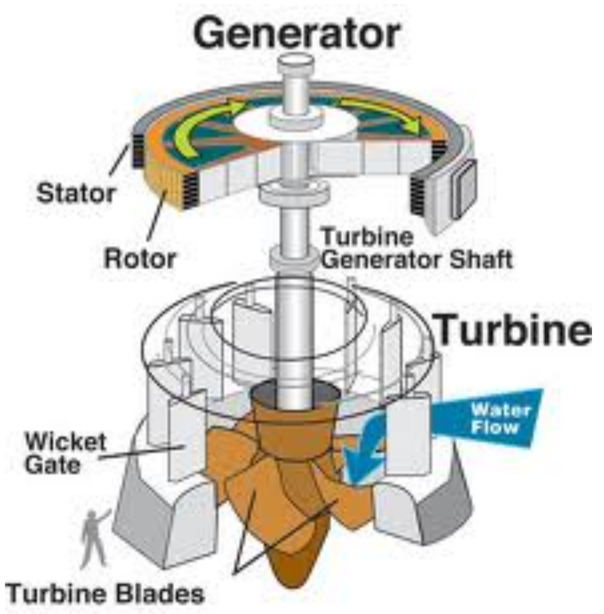
Low flow, large height

High flow, low height

A typical hydroelectric system



Pelton—impulse turbine



Pumped Storage Power Plants

Water cycles between upper and lower reservoirs:
Generation mode during peak demand
Pumping mode during low demand

Pump-turbine

Future Development of Hydropower

- China
- South Asia (India, Nepal, Bhutan, Pakistan)
- South-East Asia (Burma, Laos)

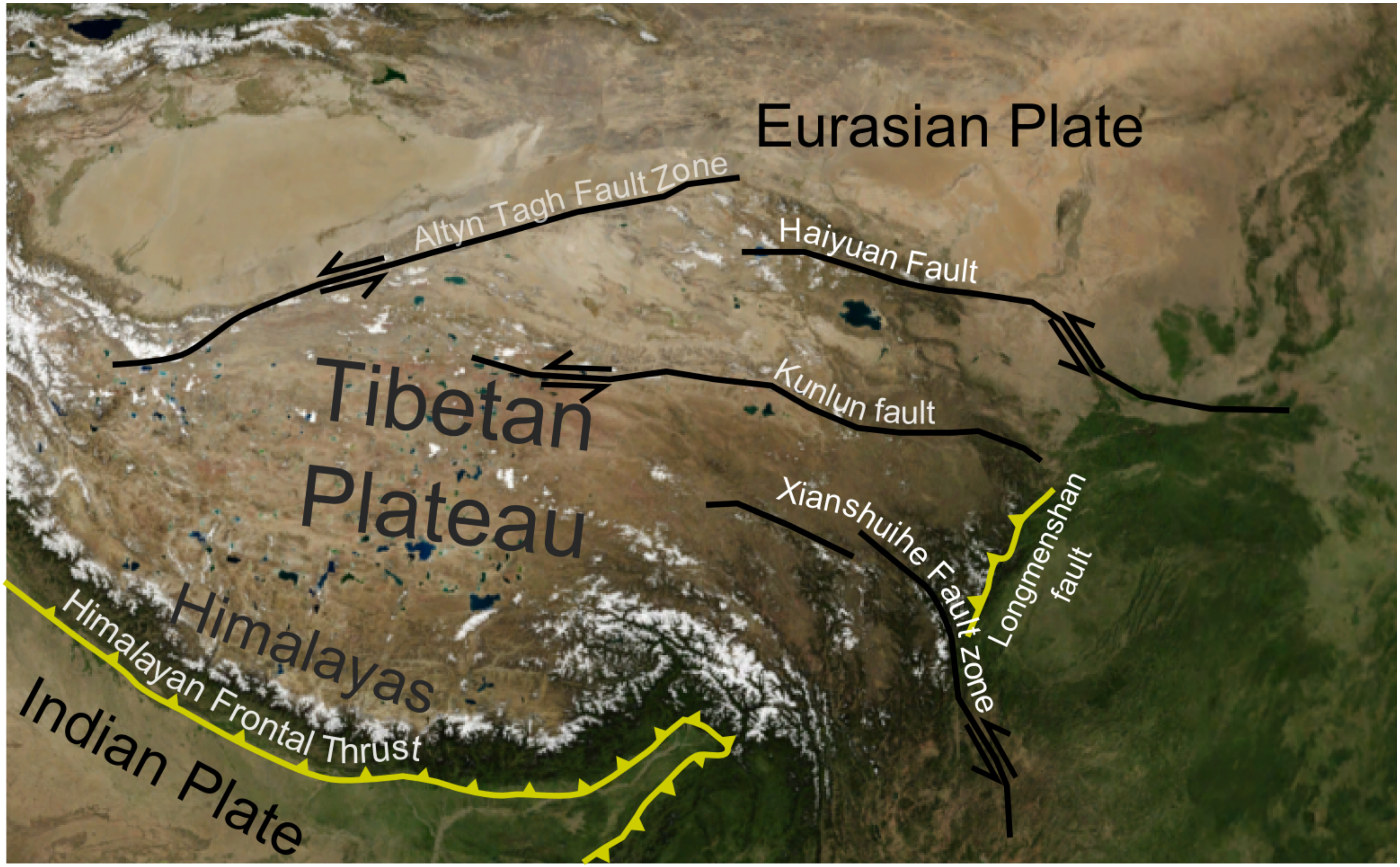
- Africa between the tropics

Pumped storage hydro is a large and efficient energy storage system to moderate peak loads and integrate solar and wind.
Unfortunately, the global resource is small compared to need

China/India: Development of Hydroelectric Projects

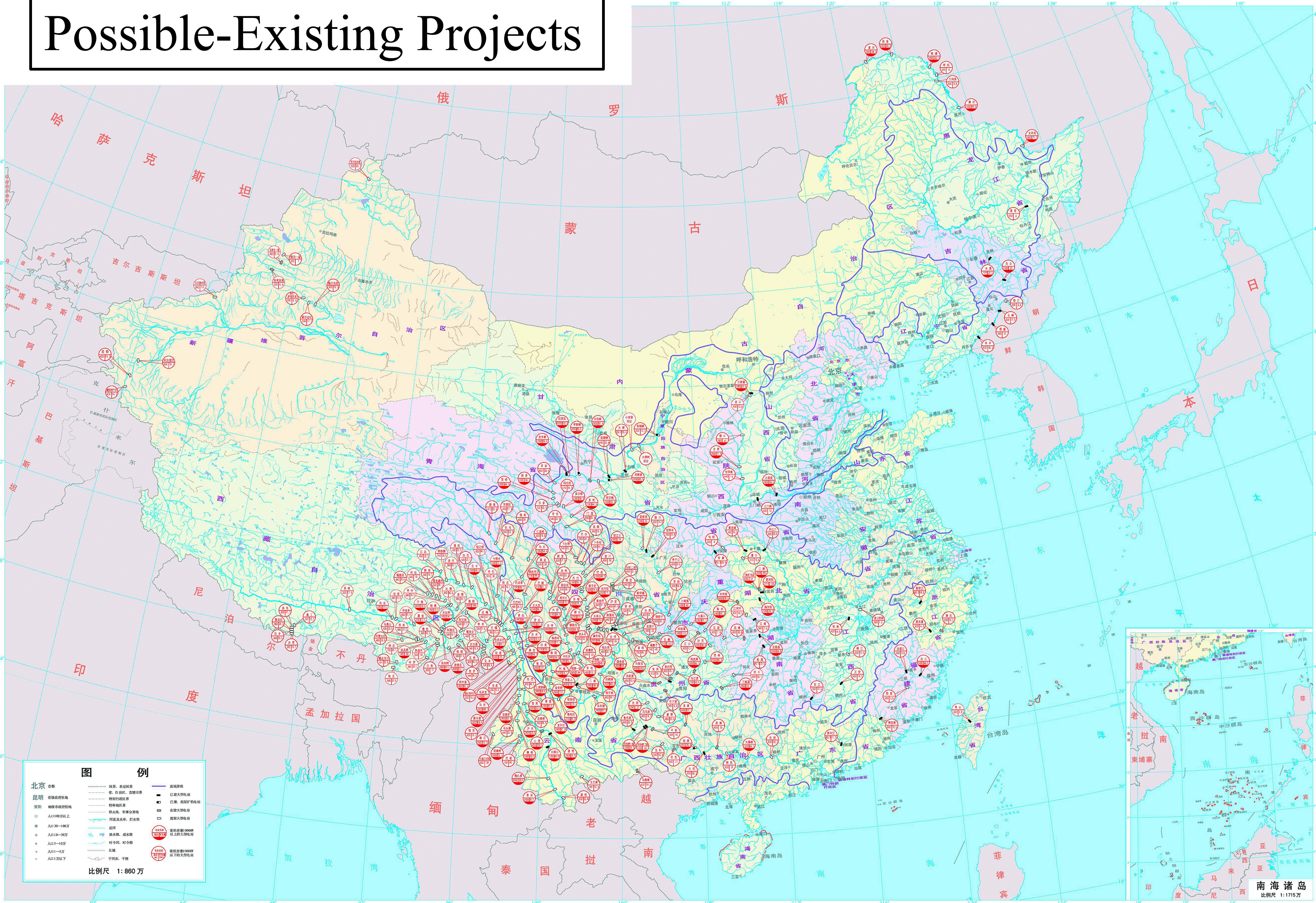
- China and India are aggressively developing hydro potential
- Tsangpo-Brahmaputra river system in Tibet (China) and Arunachal Pradesh (India) is the last major virgin system
- ***First large-scale development of hydro in high mountains***
  - Fragile earthquake prone zones: magnitude 8+ earthquakes
  - Steep canyons and frequent landslides
- Himalayan rivers carry a large amounts of silt (young mountains)
- Downstream Impacts (sharing water between riparian states)
  - Water resource and flow
  - Displaced Populations & impacts on River based Livelihood
  - Health of Ecosystems

An active Seismic Zone



Map Source: Terry Wallace

Possible-Existing Projects



Drichu (Yangtze), Zachu (Mekong) and Gyalmo Ngulchu (Salween) Hydropower Projects

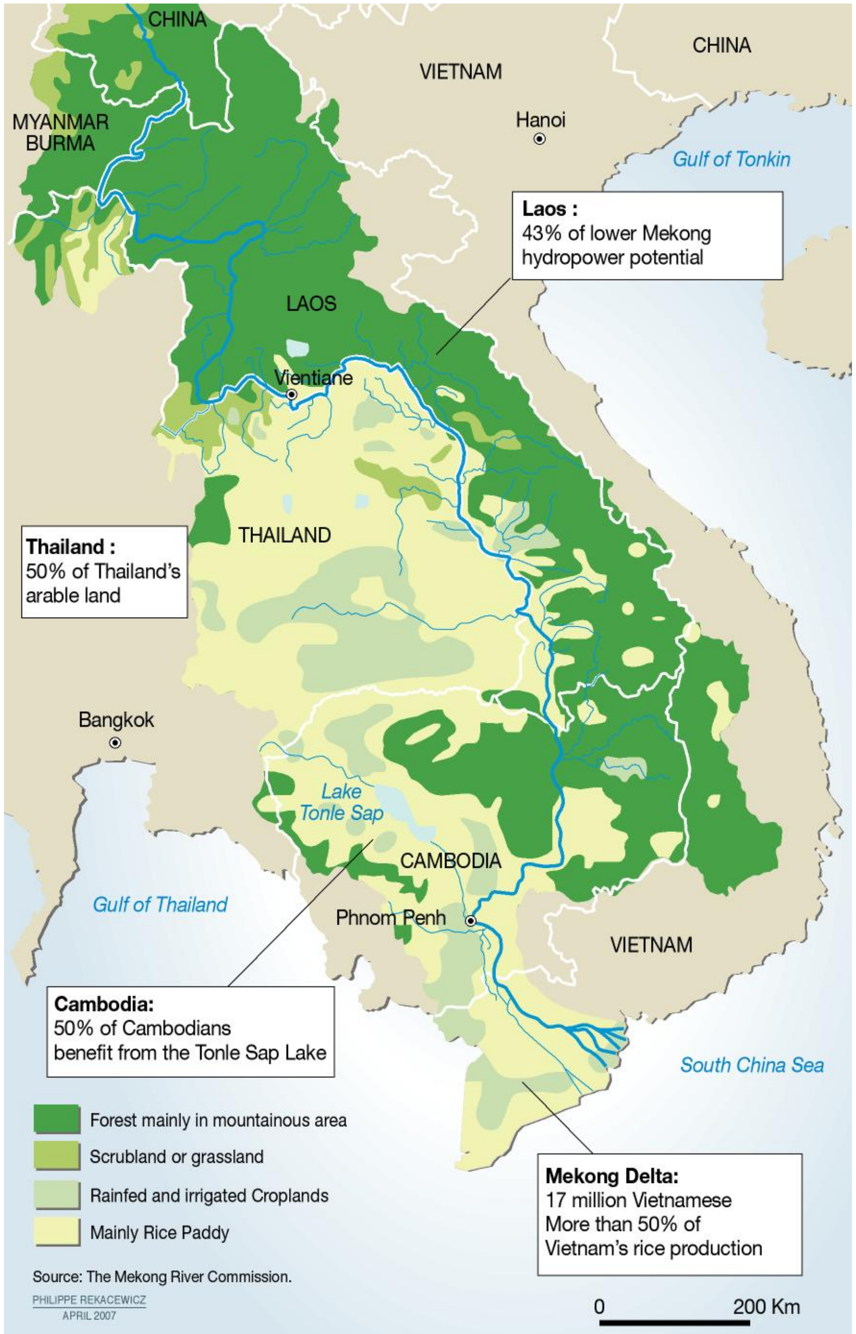
Name	Size(MW)
Biru	n/a
Chalong	10.8
Jinhe	60
Lagong	6
Longqingxia	2.52
Nieqiahe	n/a
Ahai	2160
Boluo	960
Chalongtong	10.5
Gangtuo	1100
Guoduo	150
Huangdeng	1600
Jinganqiao	465
Lawa	1680
Lidi	300
Liyuan	2400
Longkaikou*	1800
Ludila*	2280
Angsai	n/a
Baiyu	1500
Batang	740
Cefanggou	158
Changbo	1060
Charikou	36
Dequkou	276.5
Dongba	510
Dongjiula	400
Dongzhong	108
E'nan	900
Genzhou	612.5
Gushui	2200
Guxue	2800
Hutiaoxia*	4200
Jiabi	1200
Jiayu	420
Jiangquhekou	3200
Kademu	1320
Leyi	112.8
Liangjiaren	4000
Lichang	72
Longpan	2000
Lumari	72
Maji*	4200
Mariji	10.4
Nabacun	n/a
Nujiangqiao	800
Reqin	200
Rimian	3720
Rumei	3000
Ruyi	114
Sewu	560
Shabucun	n/a
Suwalong	1160
Tuoba	900
Tuoding	2500
Wangdalong	2800
Wunonglong	1340
Xiangda	66
Yabiluo*	1800
Yage	63.6
Yanbi	300
Yebatan	1980
Babacun	480
Balonggu	1240
Bijiang*	1500
Bingzhongluo*	1600
Dahuaqiao	n/a
Fugong*	400
Gerongban	510
Jiangda	450
Longpan	4000
Lumadeng*	2000
Luohe	360
Luola	1050
Seyinongba	1140
Songgu	330
Songta*	4200
Tongla	420
Wangka	1500
Zhuangga	400

Province
Country
City
River/Lake

Built/Operational
Under Construction
Under Active Consideration
Proposed
'*' On Hold

Tongjia: Western Route of the South-North Water Diversion

http://tibetanplateau.blogspot.com/ Version 1.00 17/02/10



Mekong River Basin

- China
- Burma-China
- Burma-Laos
- Laos-Thailand
- Laos-Cambodia
- Cambodia
- Vietnam

Irrespective of whether China, India, Burma, Laos, ... collaborate or compete

The impacts of increasing resource exploitation by them are very large, global & transformational

Manufacturers of Hydro Systems

Major Technology Innovators & Manufacturers

- Voith-Siemens

China: Major Manufacturer and EPC Contractor

- Chinese companies are bidding for projects worldwide
- Providing financing and on-schedule construction

Regional Manufacturers

- Canada: Canadian GE, Dominion, Allis Chalmers
- USA: Westinghouse, GE
- Europe: Alstom, Asea Brown Boveri (ABB), Ansaldo
- India: BHEL
- Japan: Hitachi, Mitsubishi, Toshiba
- Russia: Power Machines (LMZ, Ural, Kharkov, ...)

Challenges to Water Quantity and Quality

Quantity

- Population Growth
  - Humans
  - Livestock, poultry
  - Aqua-agriculture
- Higher water intake foods
- Diversion and Damming of rivers
- Climate Change

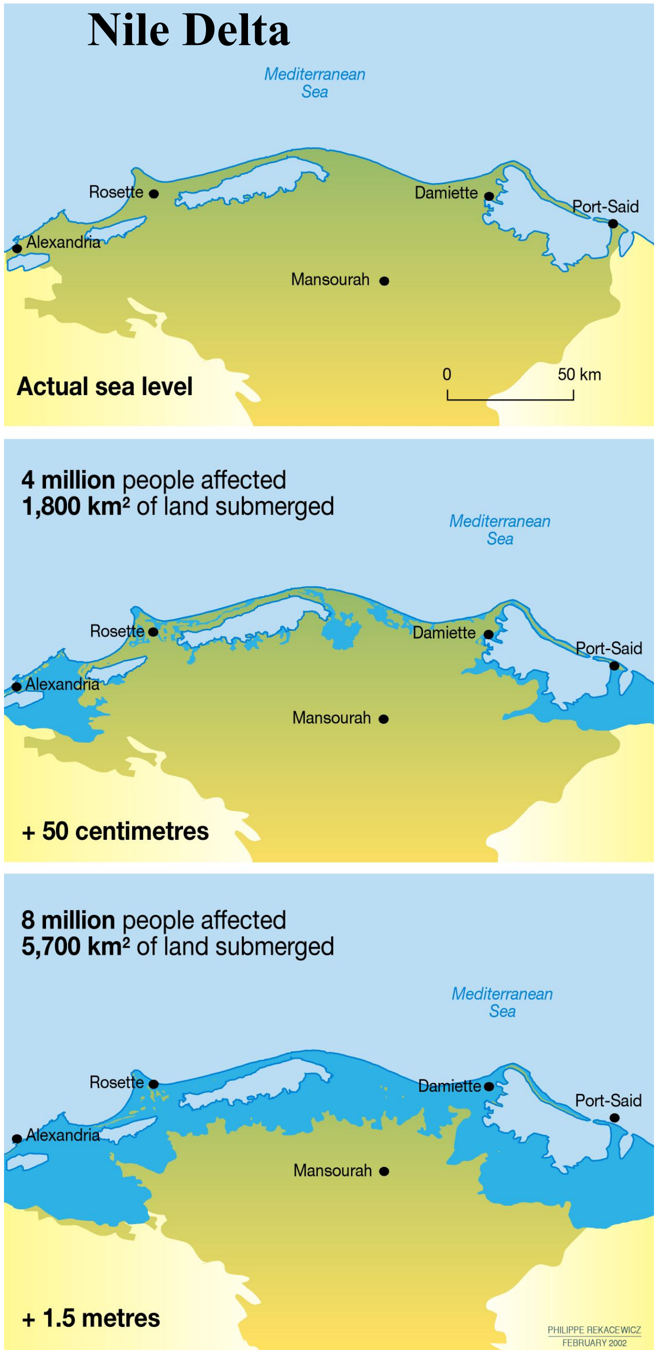
Quality

- Human Activity
  - Bio, chemical, metal waste
- Industrial Waste
  - Chemicals
  - Metals
- Agriculture run-off
  - Bio
  - Chemicals (fertilizers, pesticides, herbicides)
- Mining and Processing

Climate Change

Changes in

- Precipitation: frequency and intensity
- Evaporation and transpiration
- Demand
- Icecaps and glaciers



Sources: The Sea elevation model has been calculated by Otto Simonett (UNEP/GRID, Arendal and Nairobi) at the beginning of the 1990s.
See also http://blog.mondediplo.net/2008-01-22-Le-delta-du-Nil-menace-par-les-eaux

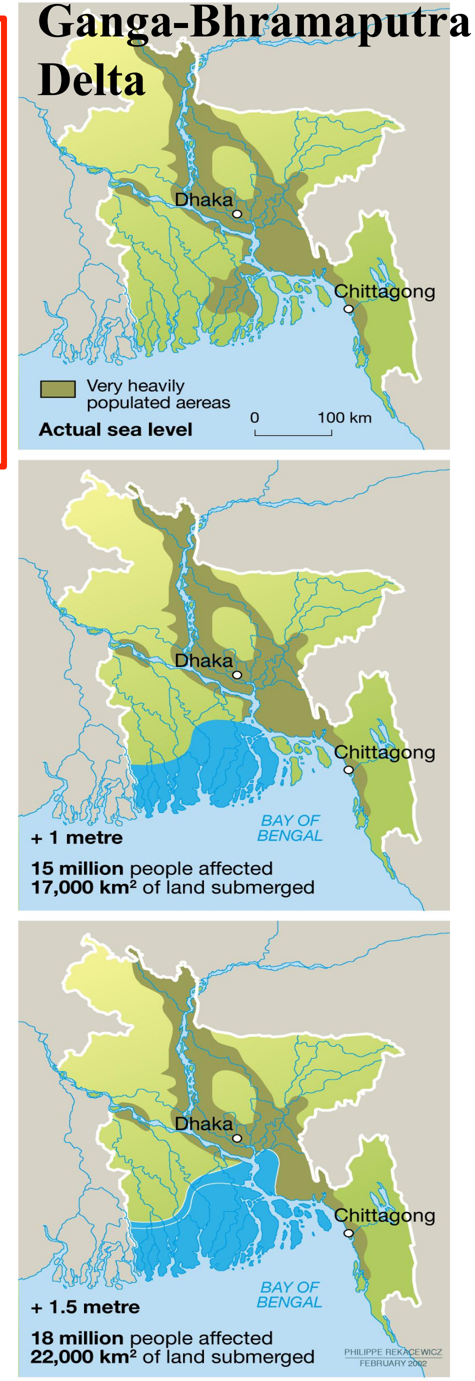
Impact of sea-level rise can be determined

Debate is about

- Rise height (1.5m?)
- When?
- At what CO_2 level?

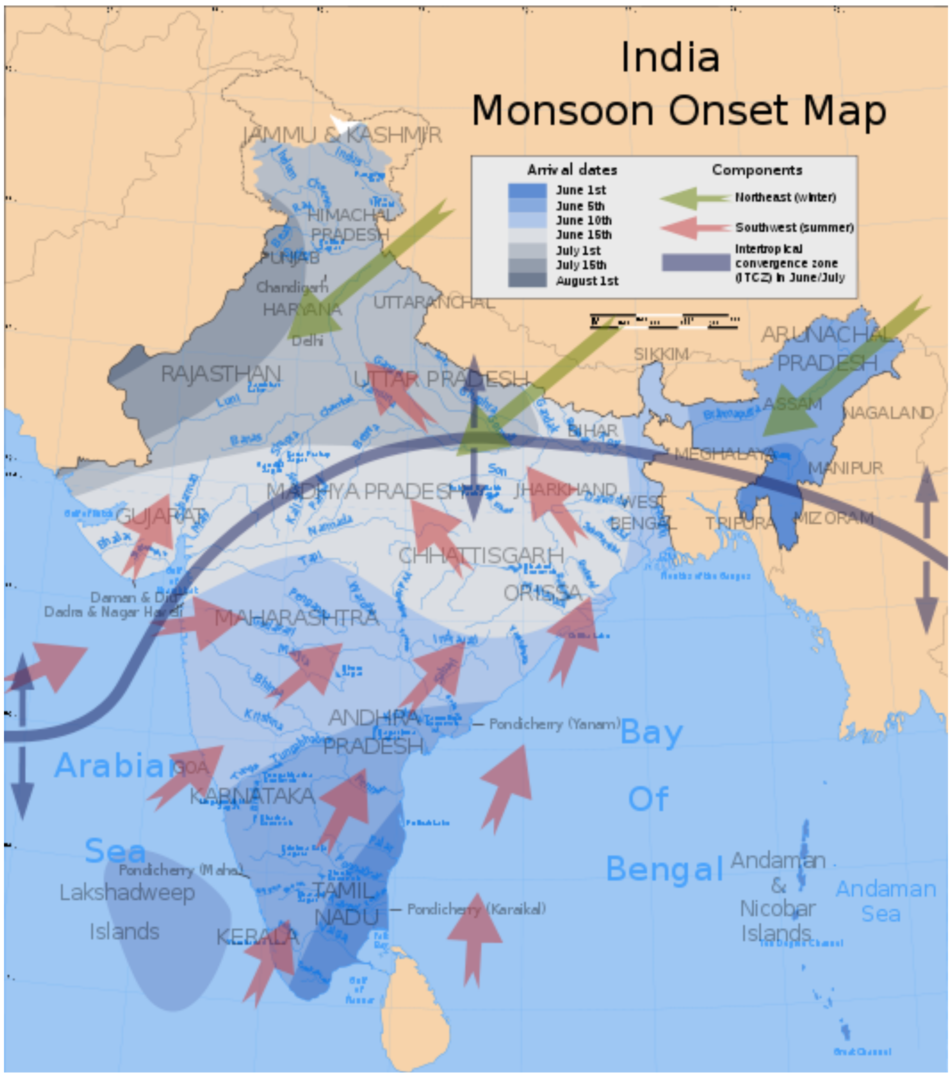
  > At what T rise?

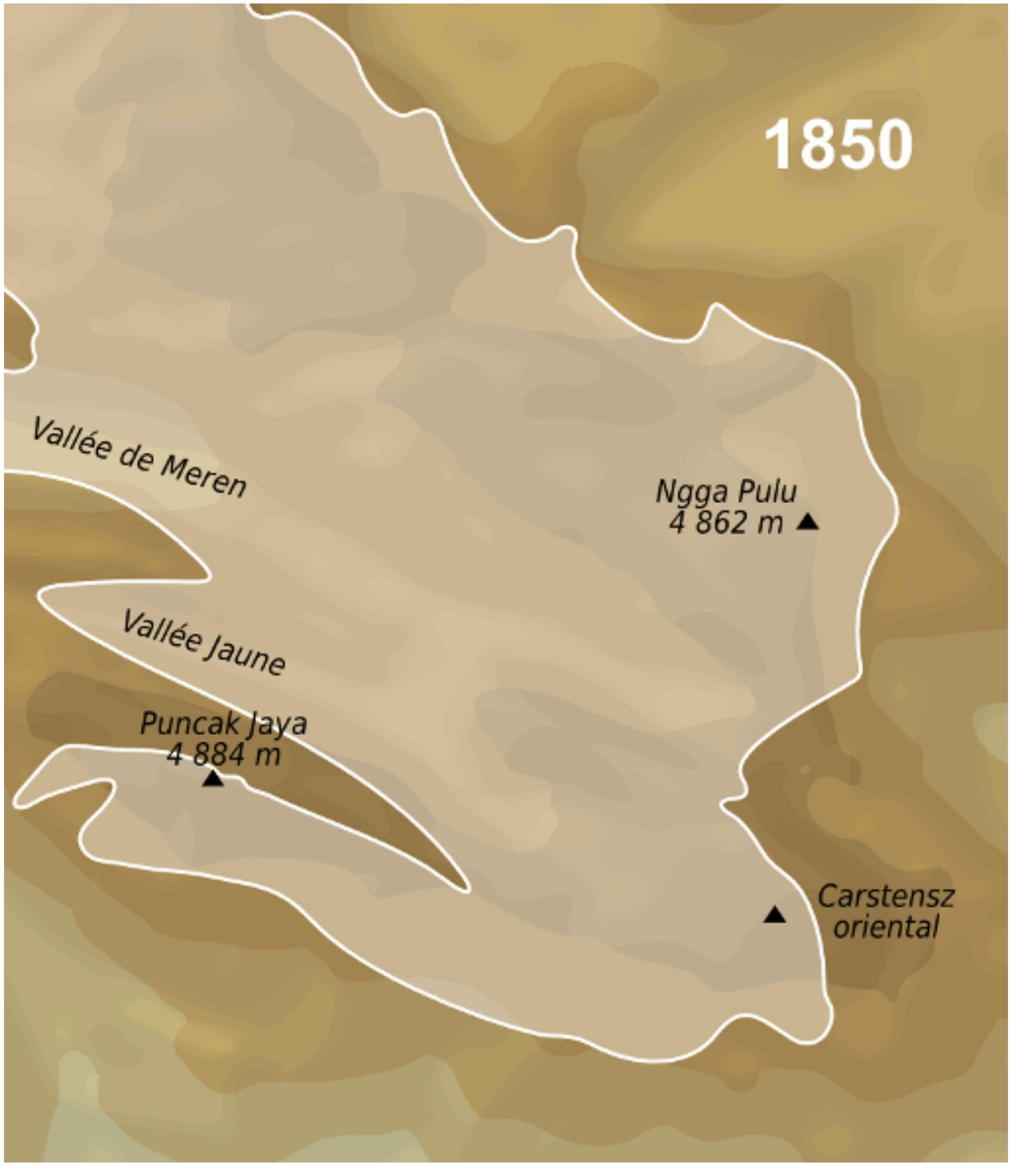
http://www.unep.org/dewa/vitalwater/article155.html



Sources: Dacca University; Intergovernemntal Pannel on Climate Change (IPCC).

India is highly dependent on the Monsoon for Rain and Himalayan Snow cover



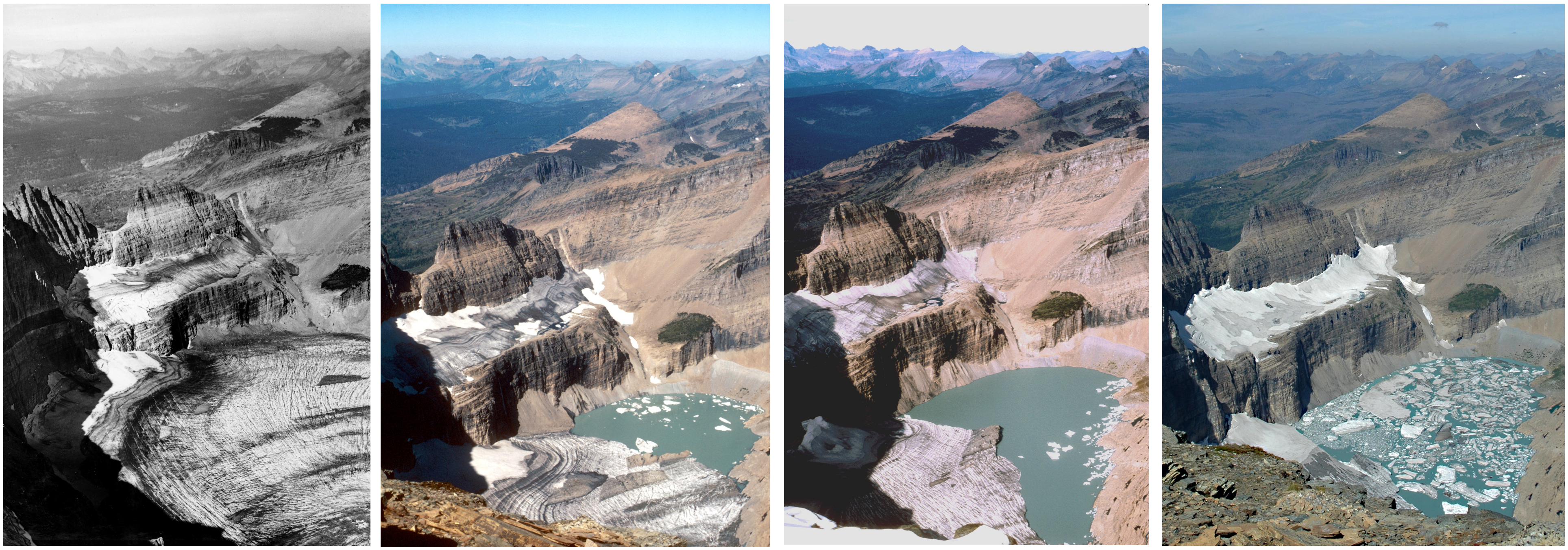


Receding glaciers

Puncak Jaya glacier on New Guinea's highest mountain, Mount Carstensz (4,884m /16,024 ft) is estimated to have had an area of 20 km^2 (7.7 sq mi) in 1850

Source (very good reading): http://en.wikipedia.org/wiki/Retreat_of_glaciers_since_1850

Grinnell Glacier in Glacier National Park, USA



T.J. Hileman
1938: (GNP)

Carl Key
1981: (USGS)

Dan Fagre
1998: (USGS)

Lindsey Bengtson
2009: (USGS)

Source: http://en.wikipedia.org/wiki/Retreat_of_glaciers_since_1850

McCall Glacier, North Alaska

Source: http://www.bbc.co.uk/news/science-environment-17843648

Irrigation increased food production

→ Population growth

- Most of this population sustains itself by doing marginal agricultural work. Replaceable by technology
- Soil salination
- Loss of ecosystems

Need to accelerate transition to modern methods:
drip + on demand irrigation can vastly increase acreage under irrigation & reduce impacts.

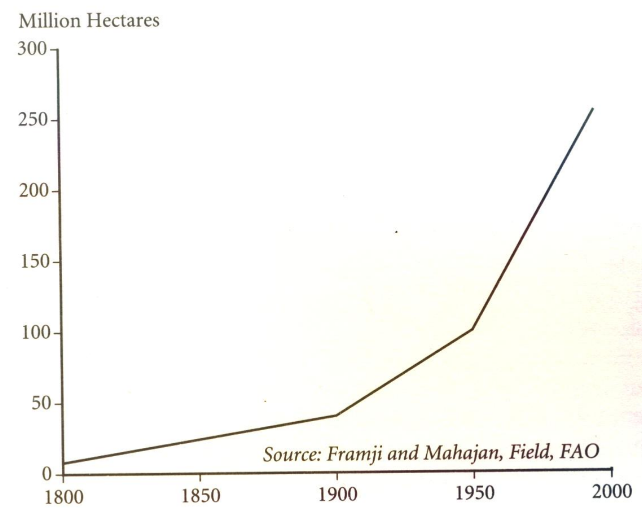


Figure 3–1. Growth of World Irrigated Area, 1800–1995

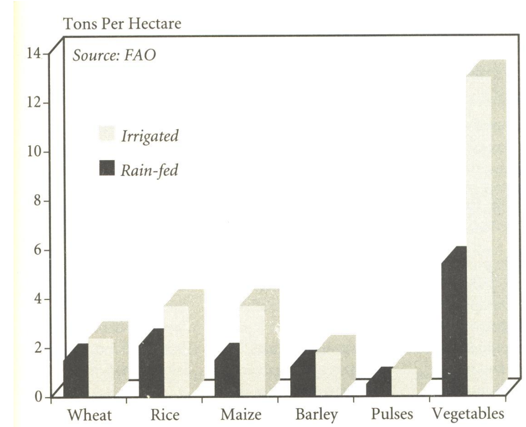
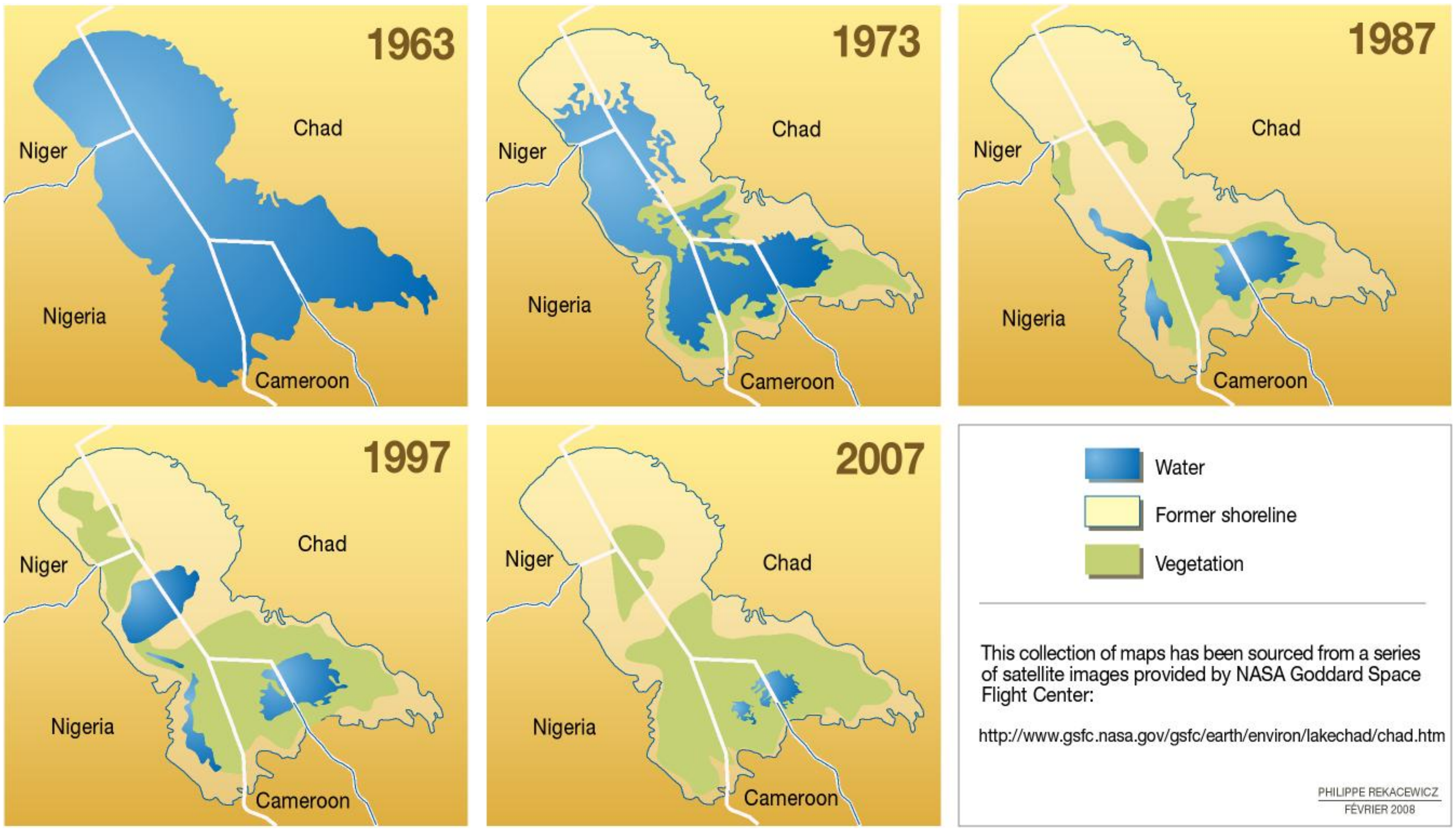


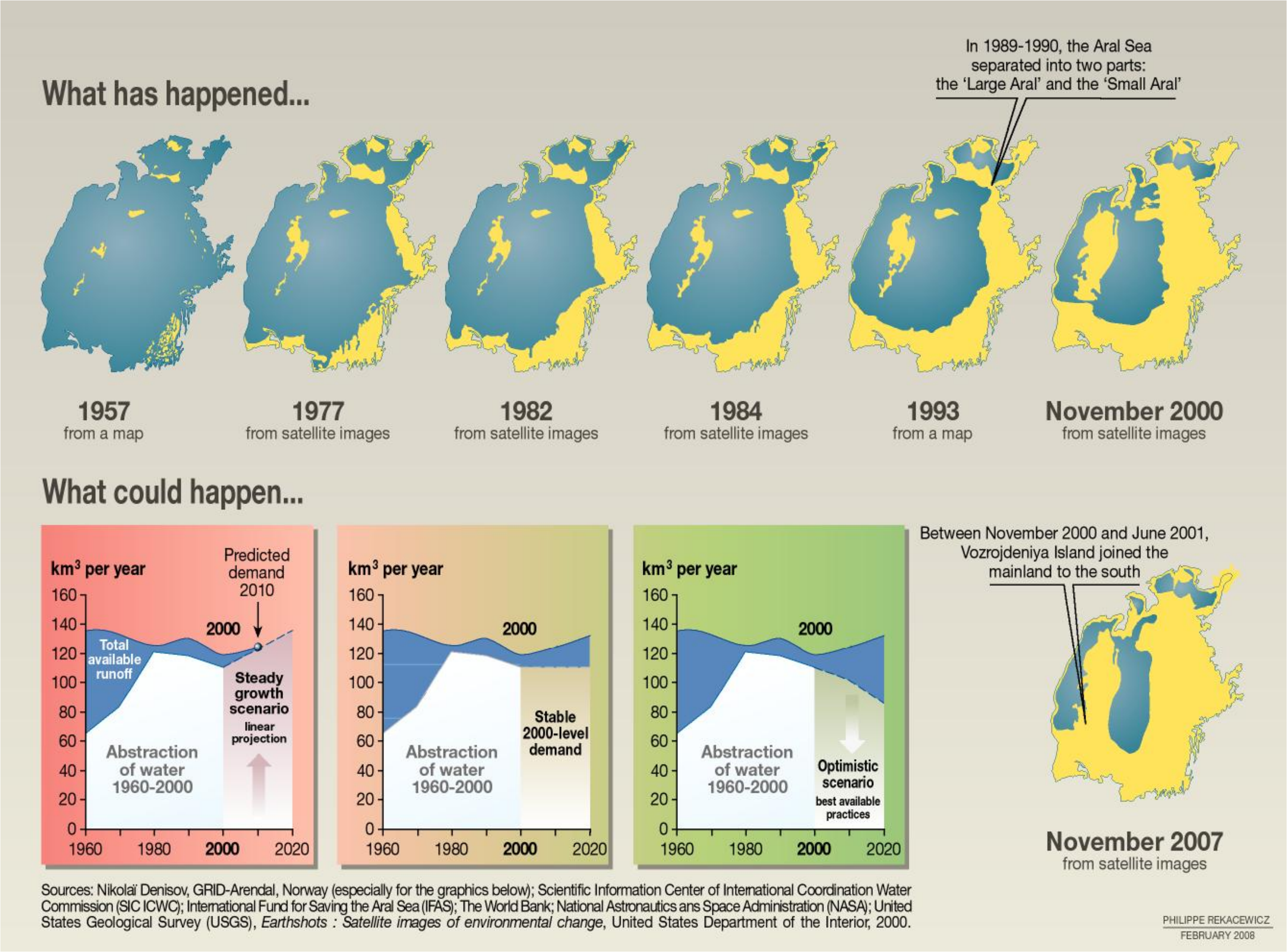
Figure 9–1. Average Yields on Rain-fed and Irrigated Land, Developing Countries

Lake Chad: Reduced to less than 1/20 of original 22,772 km^2 due to persistent droughts (climate change) and high demands for agriculture



Source: http://www.unep.org/dewa/vitalwater/article116.html

Aral Sea: Salt and sand blowing from dry bed is impacting an area of 300km radius



Areas of freshwater vulnerability: IPCC

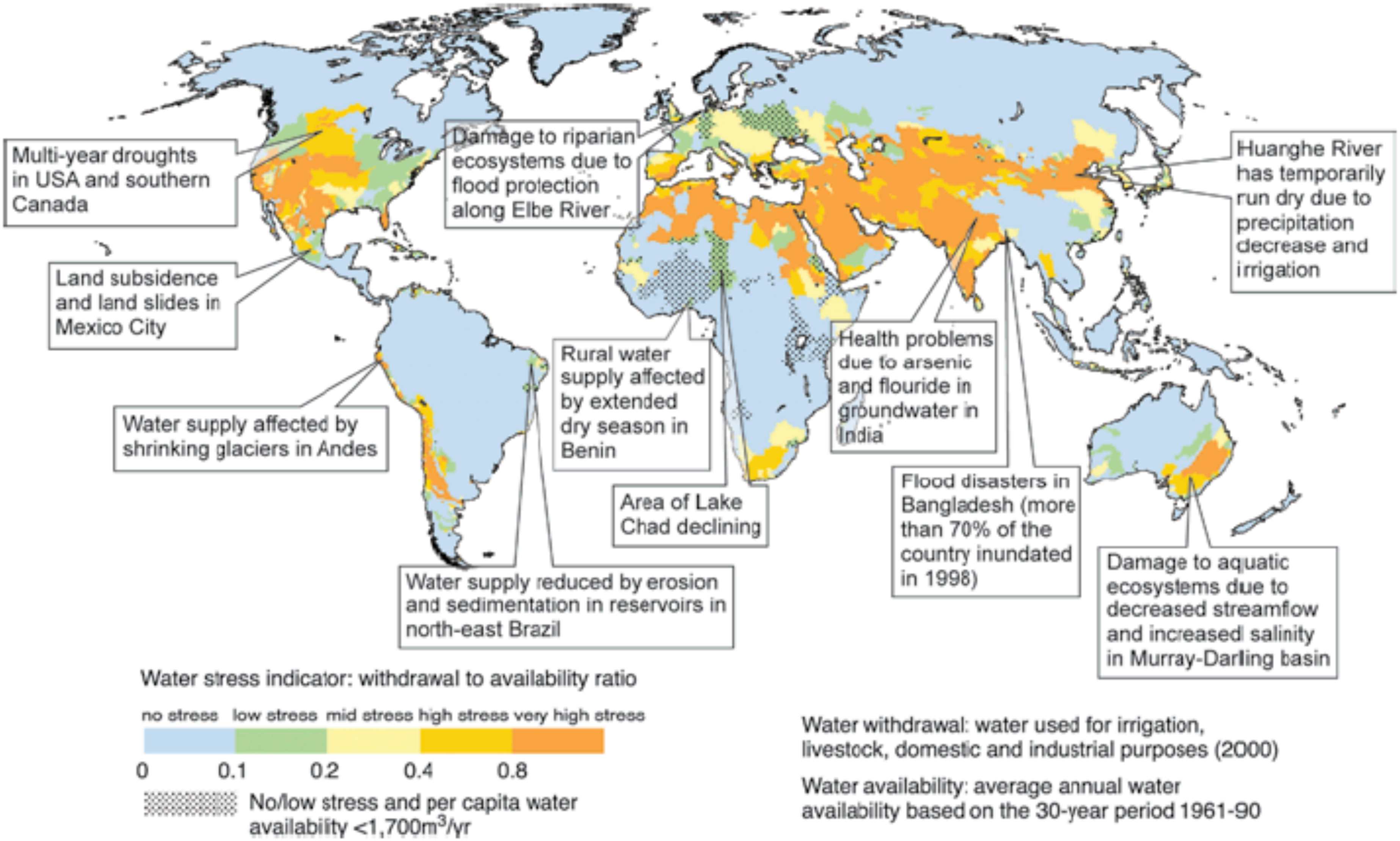
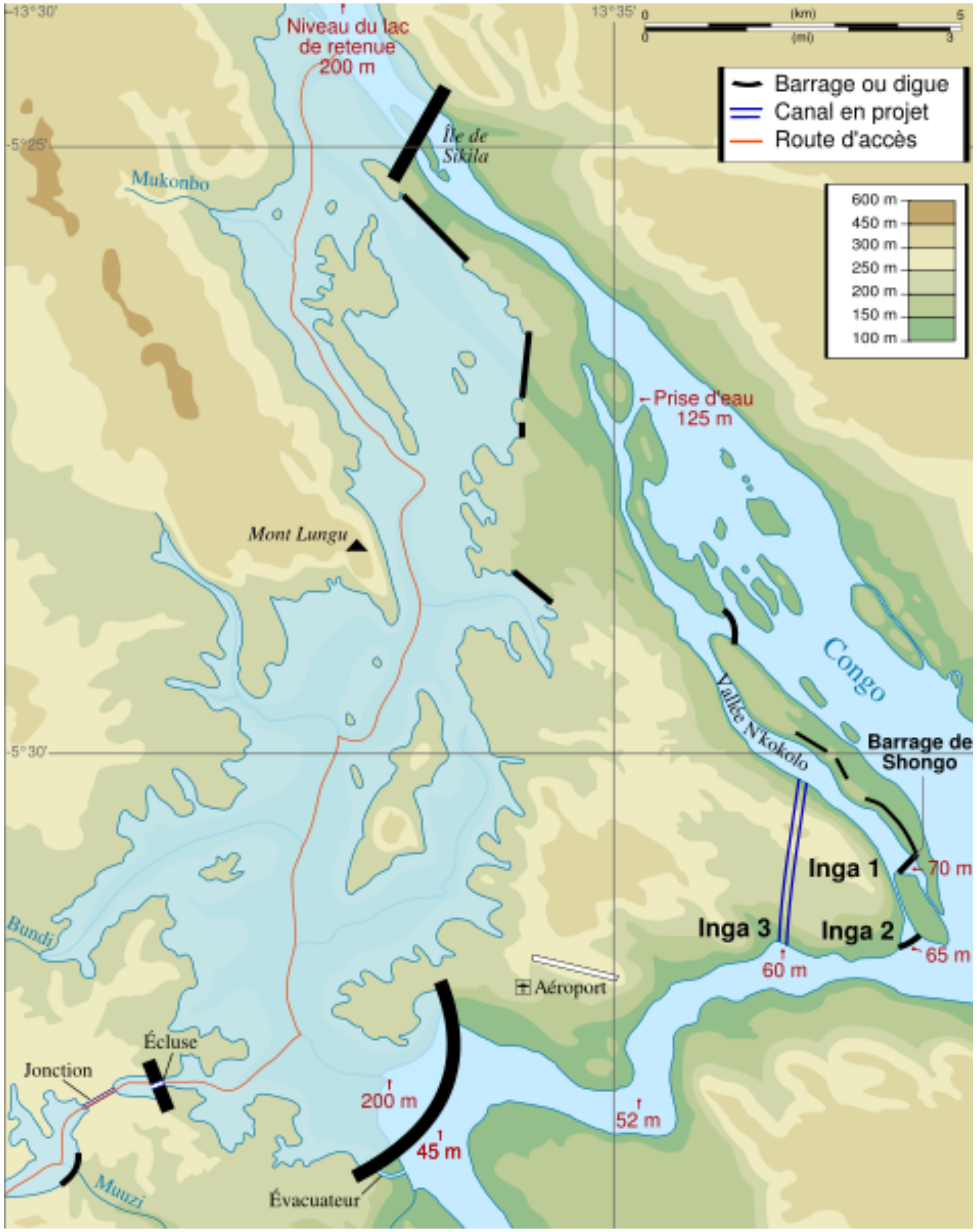


Figure 1.1: Examples of current vulnerabilities of freshwater resources and their management; in the background, a water stress map based on WaterGAP (Alcamo et al., 2003a). See text for relation to climate change. [WGII Figure 3.2]

Human ingenuity has transformed societies: *Mega-projects*

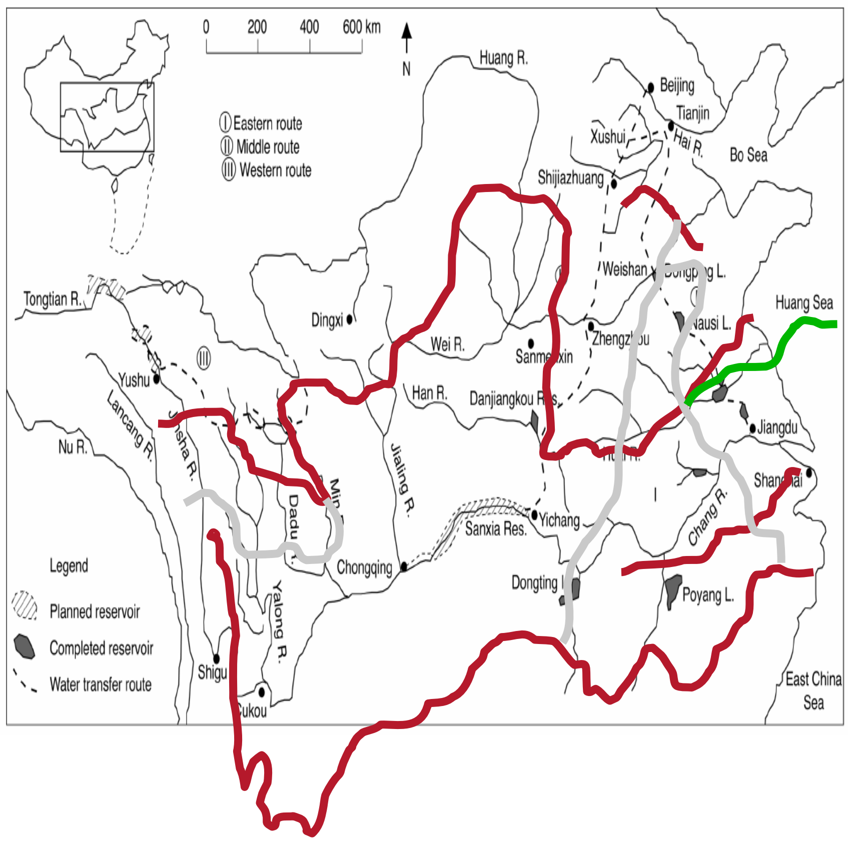
Living in an increasingly resource constrained but technological world, it is imperative we anticipate and limit impacts rather than post facto live with them (politely called adaptation)

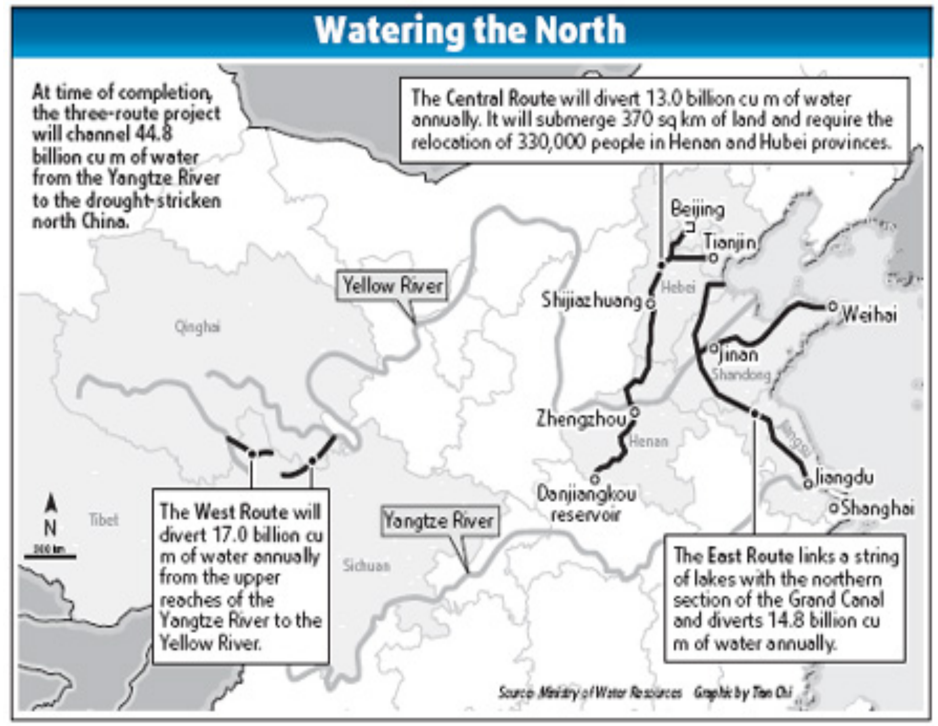
Inga Dams: Congo



Project	Year	Rated MW	Cost
Inga I	1972	351	$550 million (rehab.)
Inga II	1982	1,424	
Inga III	2012	3,500	$5 billion
Grand Inga	??	39,000	$80 Billion

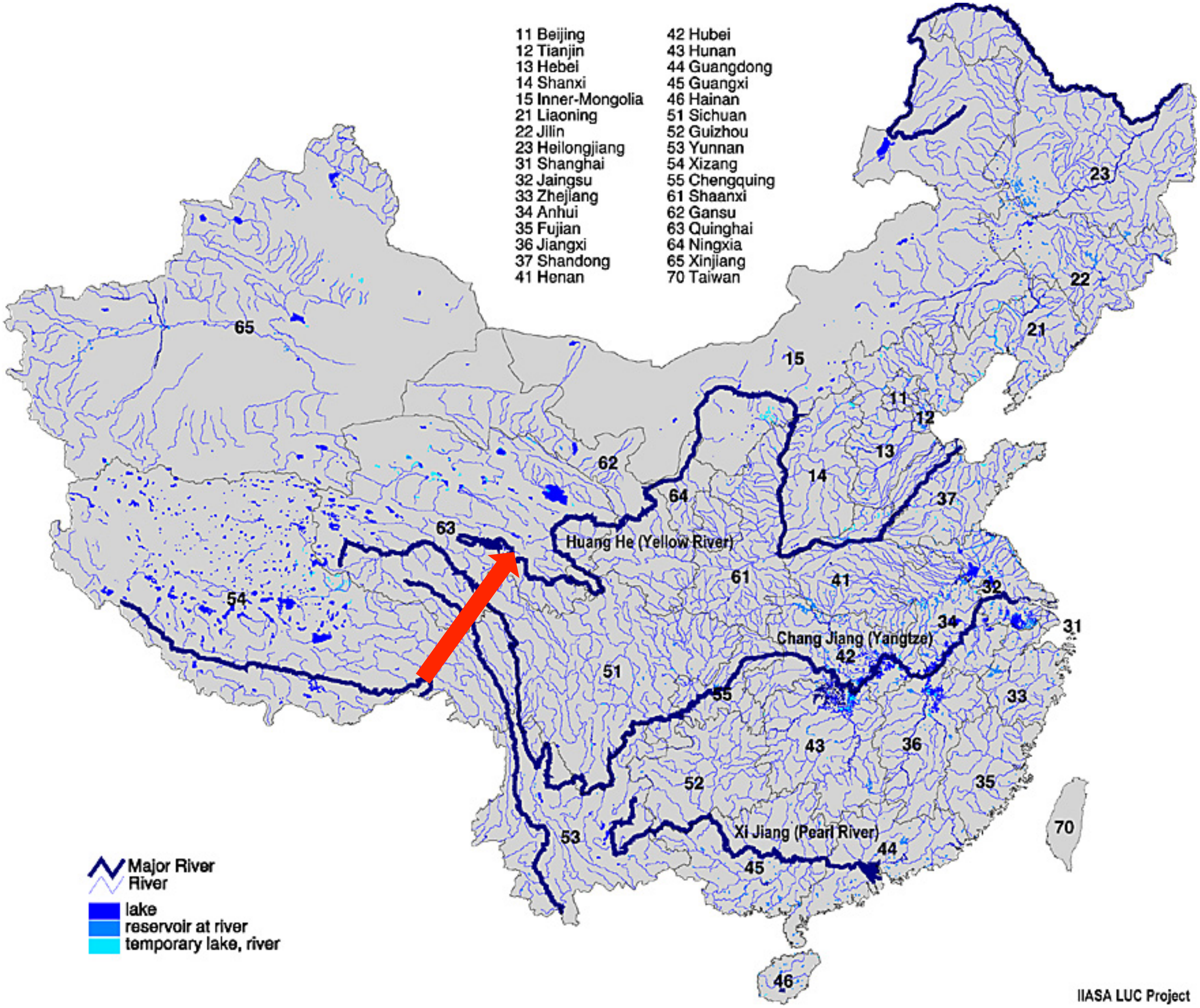
China: Grand Water Management Schemes





Liu, C & Zheng, H (2002), 'South-to-north Water Transfer Schemes for China', *Water Resources Development*

Diversion of Yarlung Tsangpo-Brahmaputra Waters



Impacts of mega-projects

Positive impacts of dams and canals

- provided irrigation
- Irrigation transformed food production over much larger areas than flood plains
- Prevented floods

Negative

- Soil in flood plains no longer replenished
- Soil salination, a cumulative effect
- Runoff carries fertilizers, pesticides

International Disputes

Riparian States

- Many watersheds span international borders
  - Indus basin: India & Pakistan
  - Ganges: Nepal, India, Bangladesh
  - Tsangpo/Brahmaputra: Tibet, India, Bangladesh
  - Irrawaddy: China, Burma
  - Salween: China, Burma
  - Mekong: China, Laos, Thailand, Vietnam

  - Nile: Ethiopia, Sudan, Egypt, Kenya, Rwanda, Uganda
  - Senegal river: Mauritania, Senegal
  - Cubanga, Cuito, Cuando, Congo, Zambezi: Central Africa

  - Jordan River: Syria, Jordan, Israel, PPR
  - Tigris&Euphratis: Turkey, Syria, Iraq
  - Amu & Syr Darya (Aral): Kazakhstan, Turkmenistan, Uzbekistan

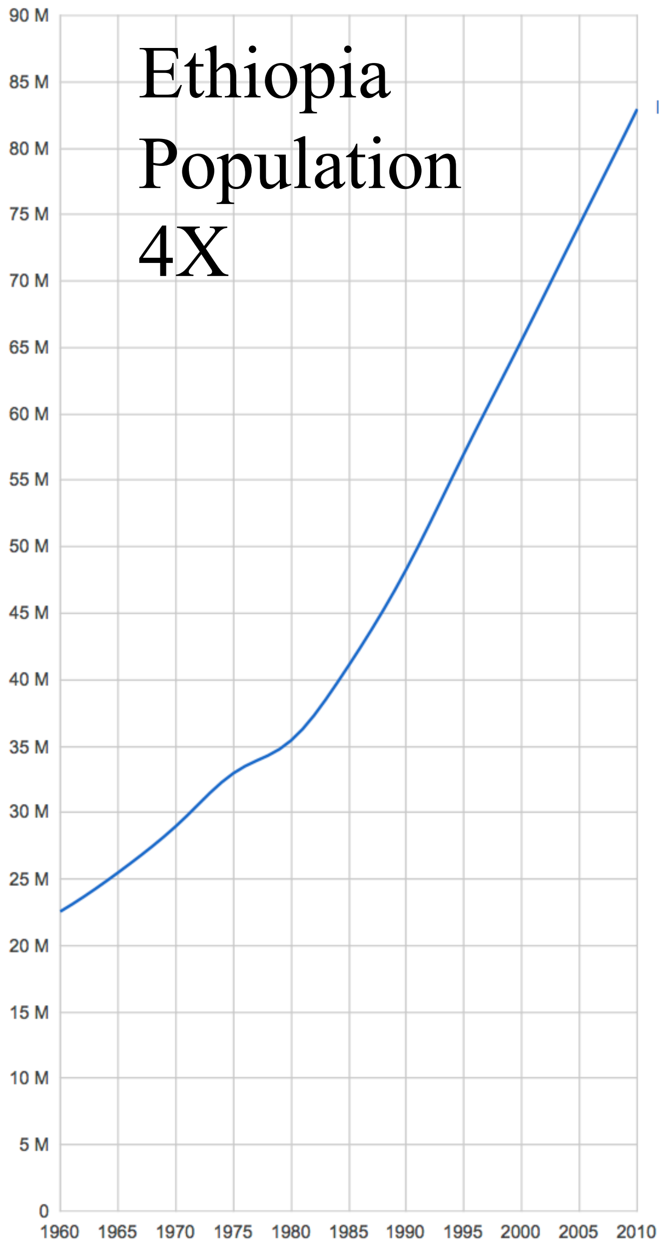
  - Colorado: USA & Mexico

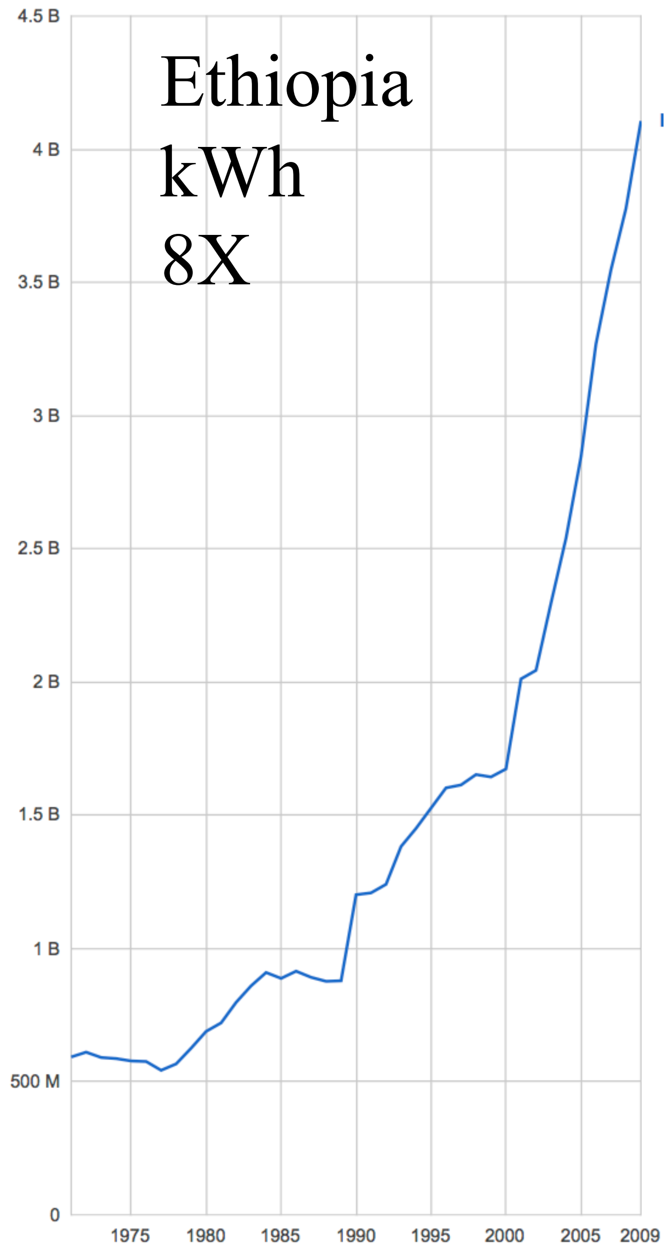
Water Wars

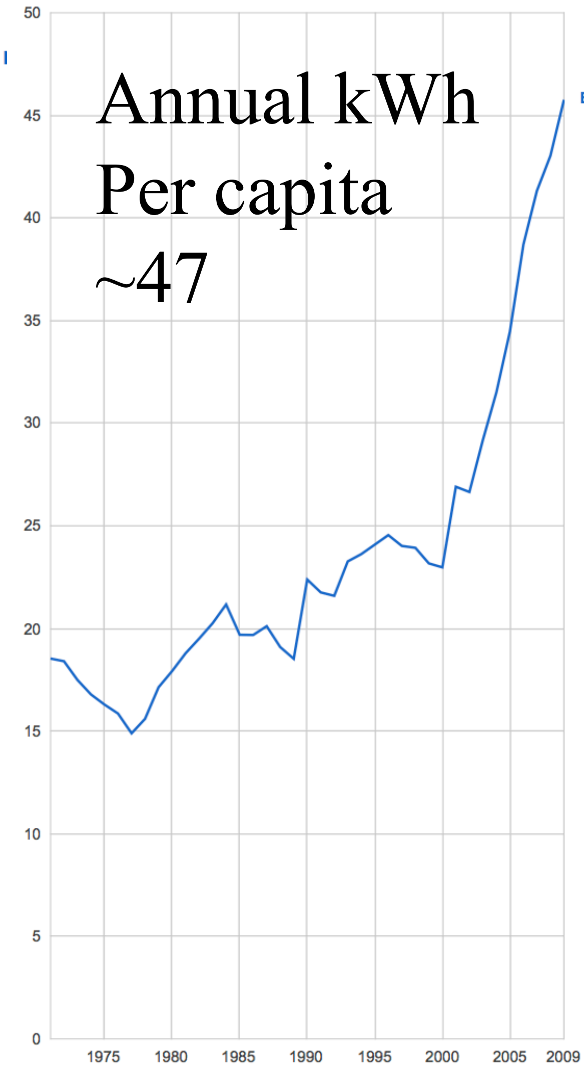
- When watersheds span international borders – who owns the water?
  - Build water management and use systems
    - Dams
    - Canals
    - Hydroelectric Power Plants
  - How much water can a country withdraw for its "needs"
  - Evaporation losses
- Water rights reflect history not equity
  - Militarily strongest nations dictate rights and "historic rights are hard to change

The Nile

- Ethiopia and Uganda are hydropower dependent
- Ethiopia's growing population needs water
- Evaporation at Aswan dam (lake Nasser) is ~30%

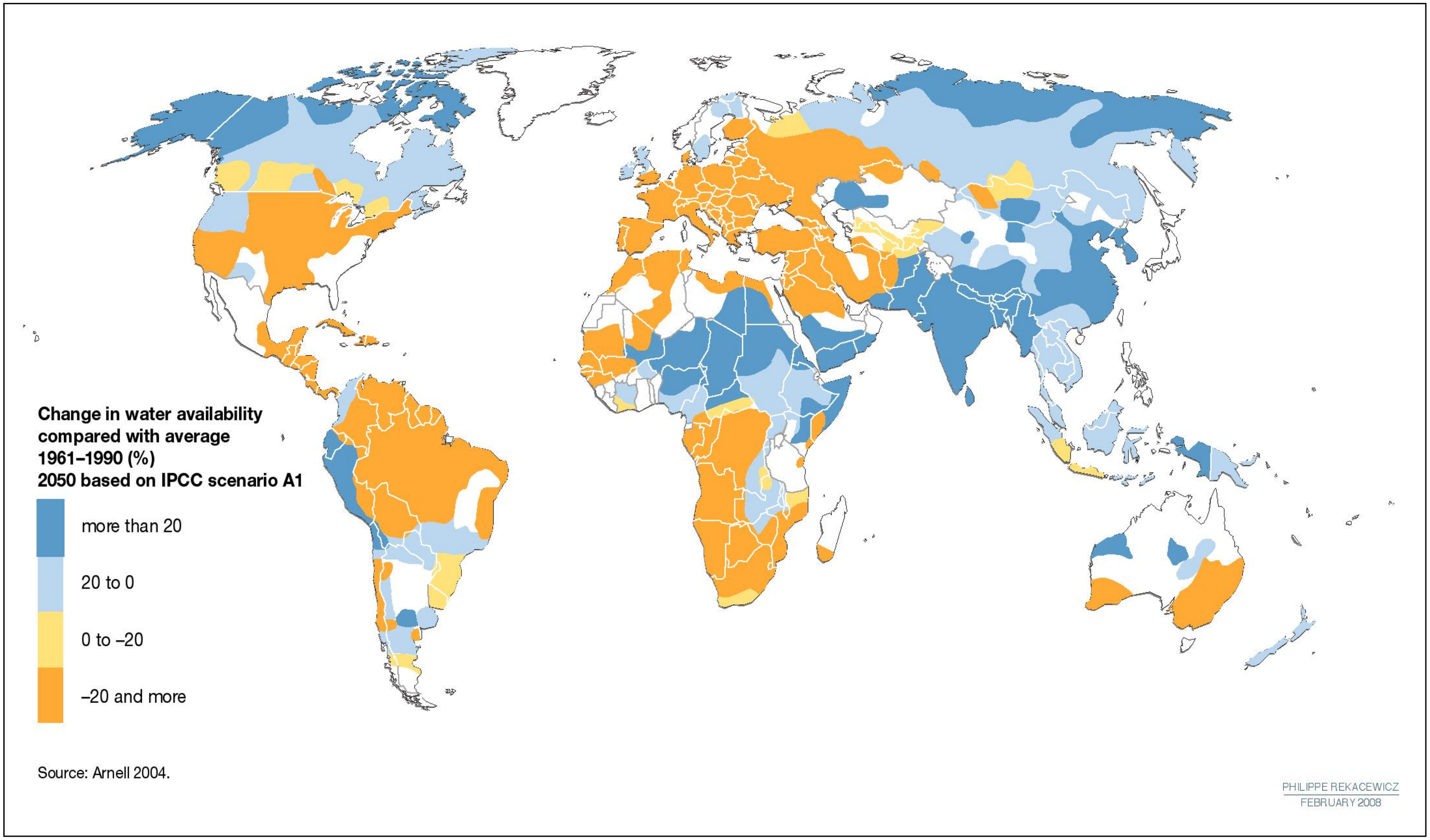






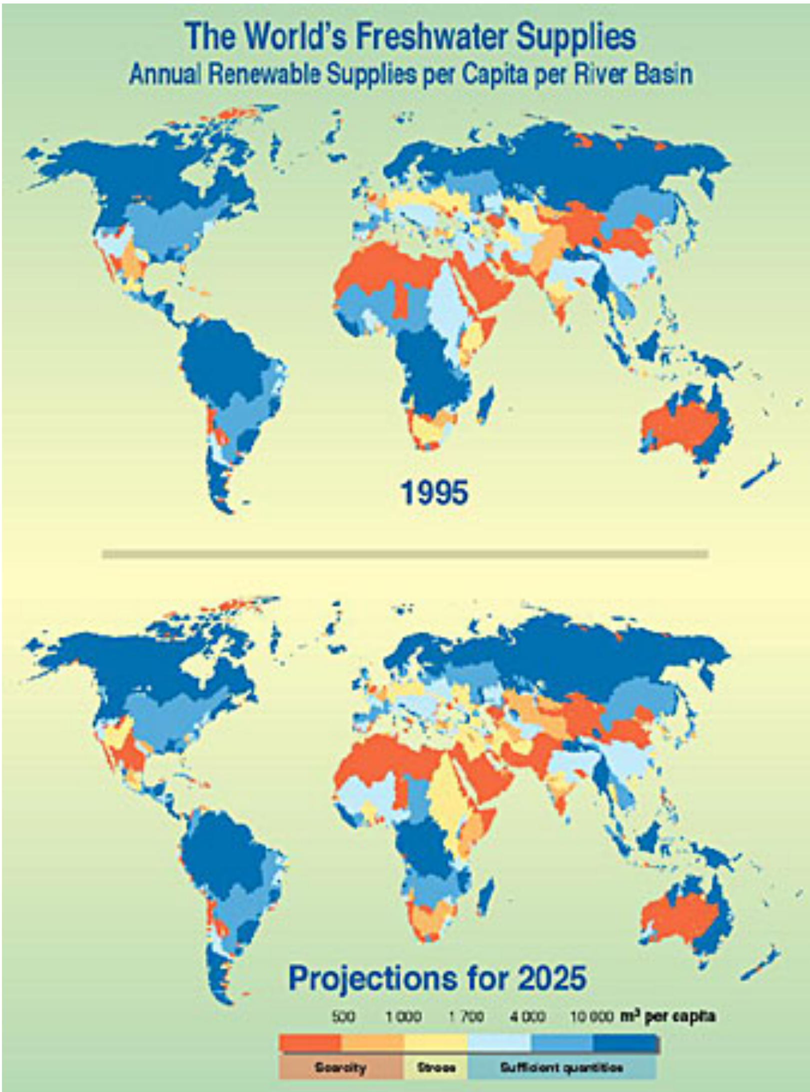
Source: http://www.google.com/publicdata/directory (World Bank data)

There will be winners and losers as resources are stressed & impacts of climate change increase



Challenges

- Climate change
- Agriculture using irrigation → Soil salination
- Fertilizers in run-off → Eutrophication
- Large reservoirs → Evaporation losses
- Large water transfers → Impacts
- Pollution
- The big hydro projects from (1930-50) will reach the end of their design life ~2050
- To prevent seawater incursion, rivers and groundwater need to consistently flow to the sea
- Growing contention for water between riparian states



	m³ per capita per year		m³ per capita per year		m³ per capita per year
North America		**Europe**		**Asia and Australia**	
1 Yukon	1 249 832	25 Danube	2 519	13 Volga	4 260
2 Mackenzie	408 243			14 Ob	14 937
3 Nelson	15 157	**Africa and West Asia**		15 Yenisey	79 083
4 Mississippi	8 973	8 Niger	4 076	16 Lena	161 359
5 St Lawrence	9 095	9 Lake Chad Basin	7 922	17 Kolyma	722 456
		10 Congo	22 752	18 Amur	4 917
South America		11 Nile	2 207	19 Ganges and Brahmaputra	-
6 Amazon	273 767	12 Zambezi	-	20 Yangtze	2 265
7 Paraná	8 025	26 Orange	1 050	21 Murray Darling	-
		24 Euphrates and Tigris	2 139	22 Huang He	361
				23 Indus	830

Source: Revenga et al. 2000, from Pilot Analysis of Global Ecosystems: Freshwater Systems.

Will water shortages and pollution lead to

- Food insecurity?
- Disease and increased morbidity?
- Mass migrations?
- Civil wars / conflict?
- Wars between nations?

In the case of water resources the evidence is clear & in plain view

Need for individual short-term prosperity has been winning the what-to-do debate

Are there enough resources for 7 → 10 billion people to avail 21st century opportunities?

- Energy
  - 1 kW / person (power)
  - 0.4 kW / person (transport)
- Water
  - 1500 cubic meters/year/person

Healthy Sustainable Environment
Food & Shelter
Healthcare
Security

Education
Job Skills
Jobs

Summary

- Water availability (= associated health of the biosphere) will determine the prosperity level and numbers of people the Earth can sustain with access to modern opportunities

- This challenge will have to be addressed in the 21st century – by our children

Finding a sustainable balance

- Facilitating Development Requires
  - Energy for Electricity and Transportation
  - Modern forms that are cheap and "clean"
- Energy and Water Security
  - Adequate supply to prevent resource wars & losers
- Addressing Environment & Climate Change
  - Sustainable management of water resources
  - Efficient and decreasing use of fossil fuels
  - Integration of solar & wind into the grid
  - New/disruptive technologies

The Energy-Development-Environment-Climate Challenge