The Nile Basin:
A Look at Ethiopia's Grand Dam Plan

Teaching Water: Global Perspectives on a Resource in Crisis.

Harvard University

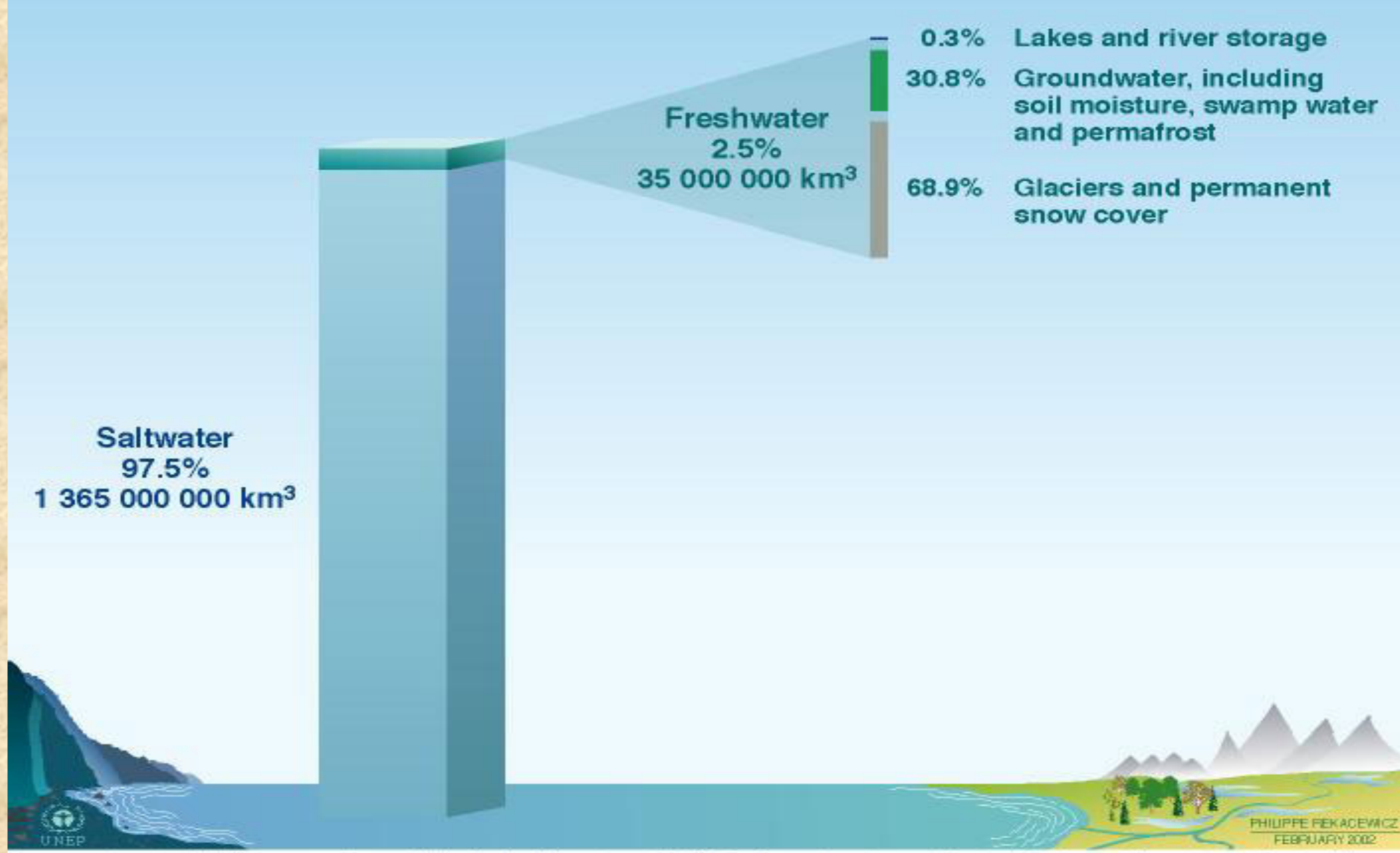
6 August 2013

Paul Block

University of Wisconsin

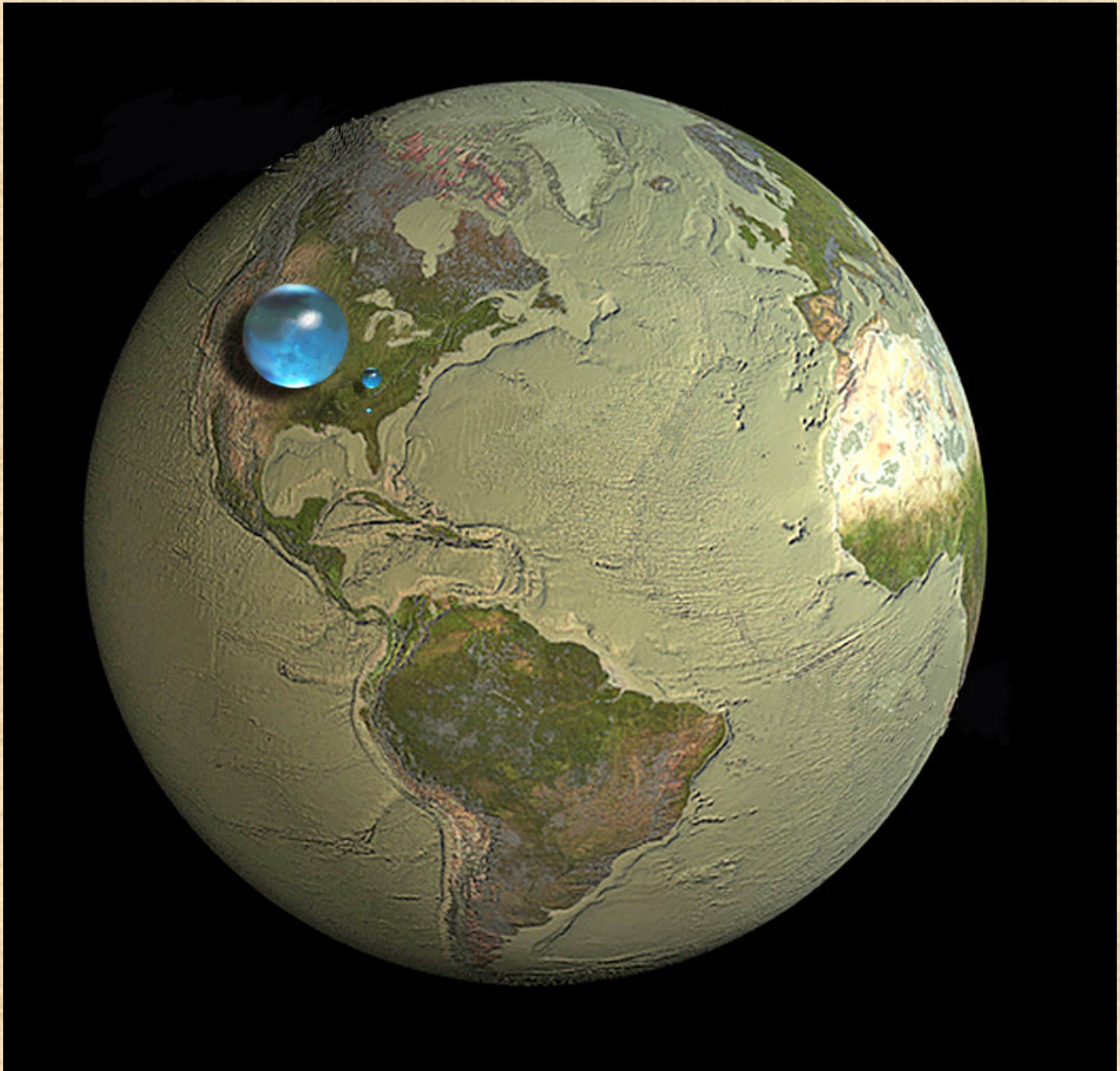
A World of Salt

Total Global Saltwater and Freshwater Estimates

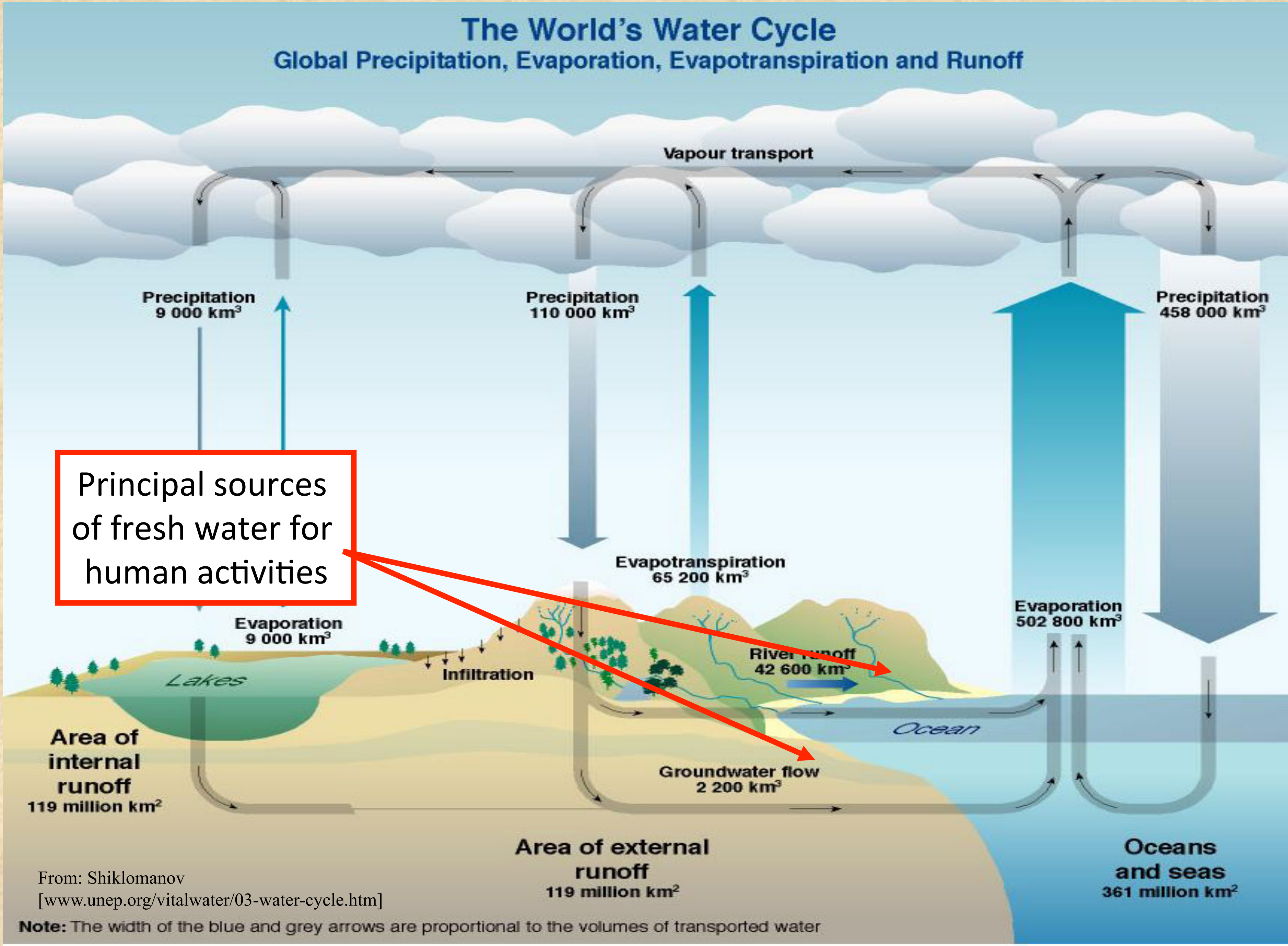


Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999.

World's Water

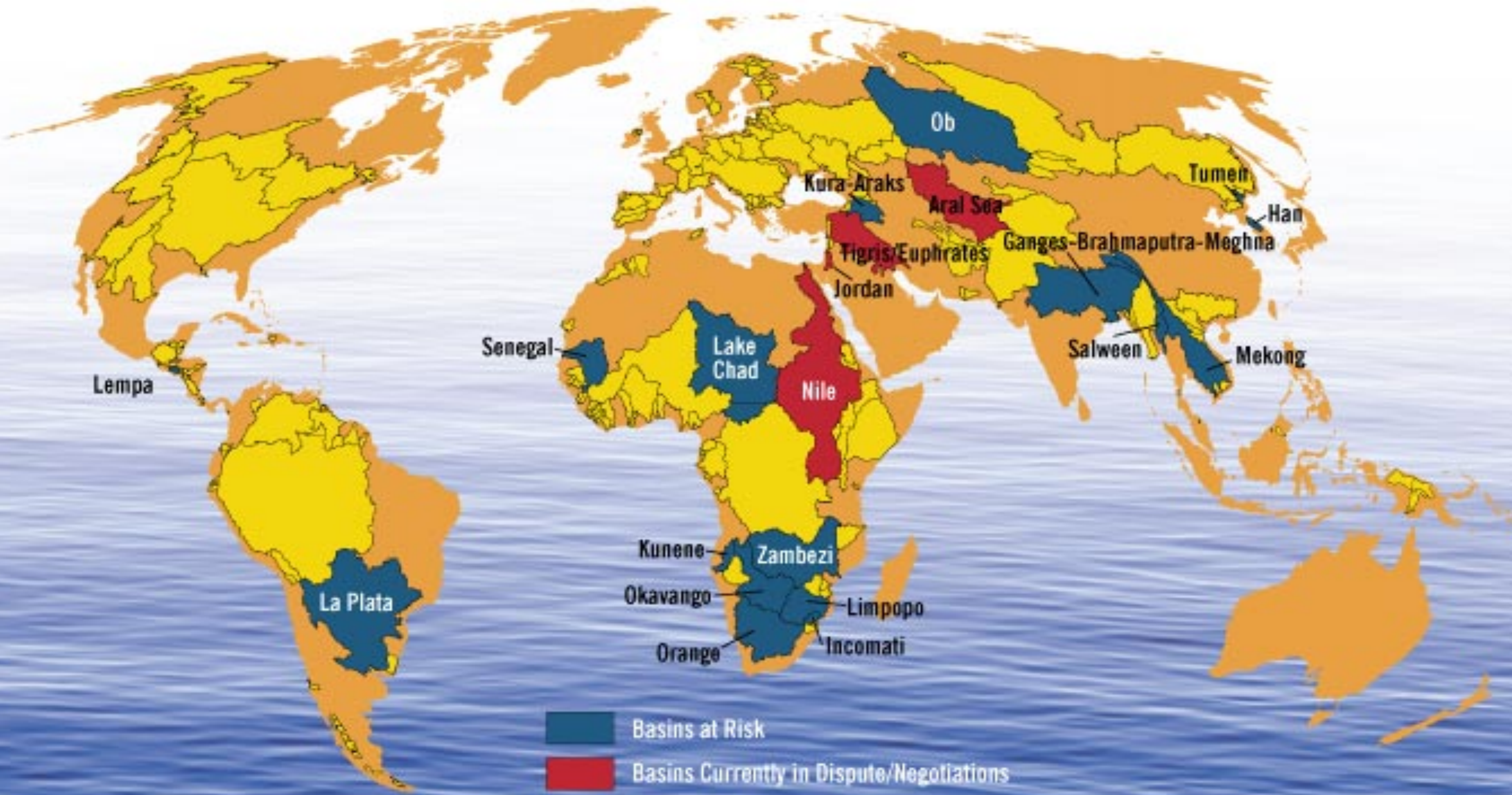


USGS



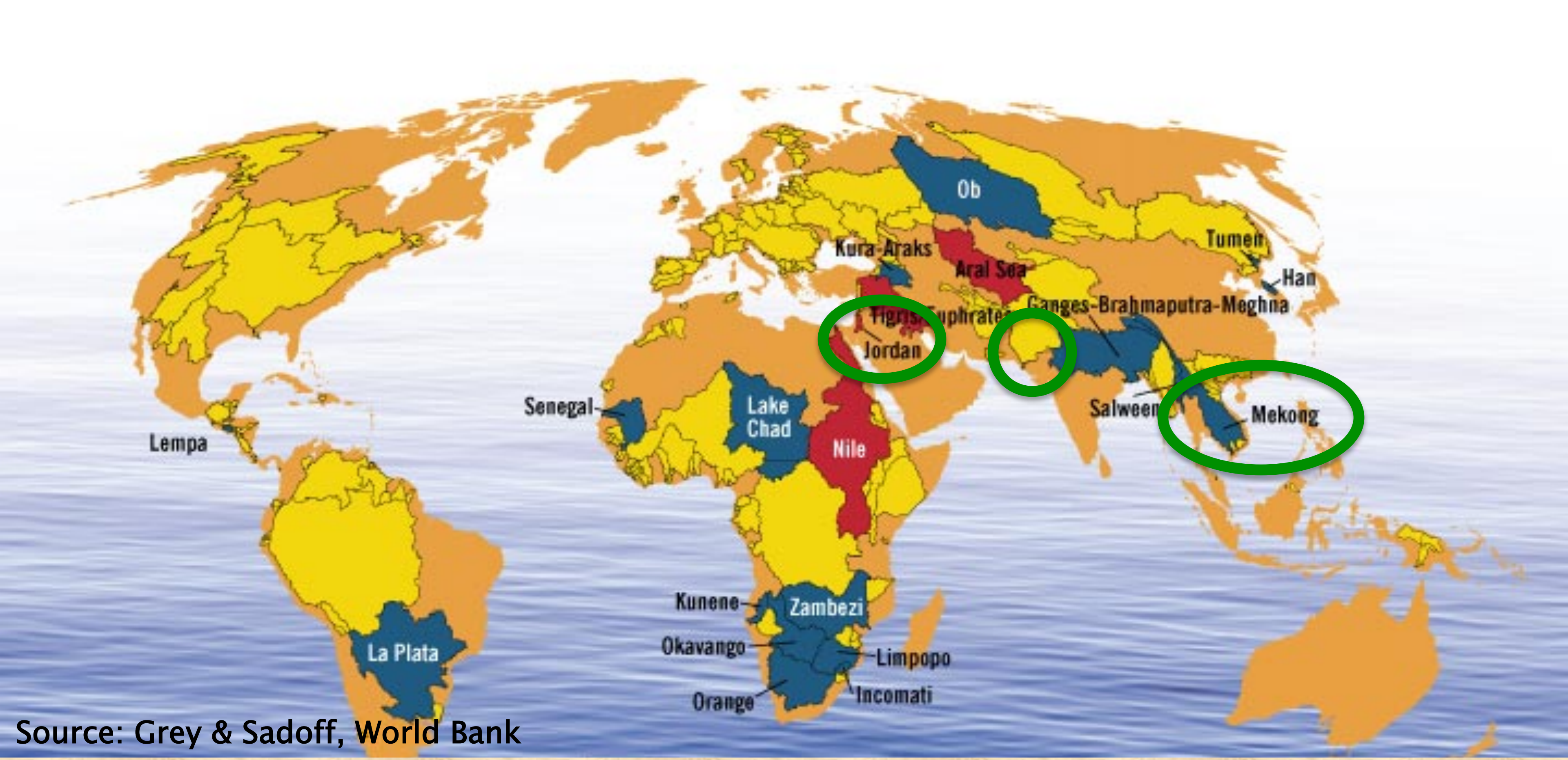
From: Shiklomanov [www.unep.org/vitalwater/03-water-cycle.htm]

“Fierce competition for fresh water may well become a source of conflict & wars in the future.”
Kofi Annan, March 2001



Source: Grey & Sadoff, World Bank

Some Exceptional Instances of Cooperation
Mekong Committee, Indus River Commission, Israel & Jordan secret talks

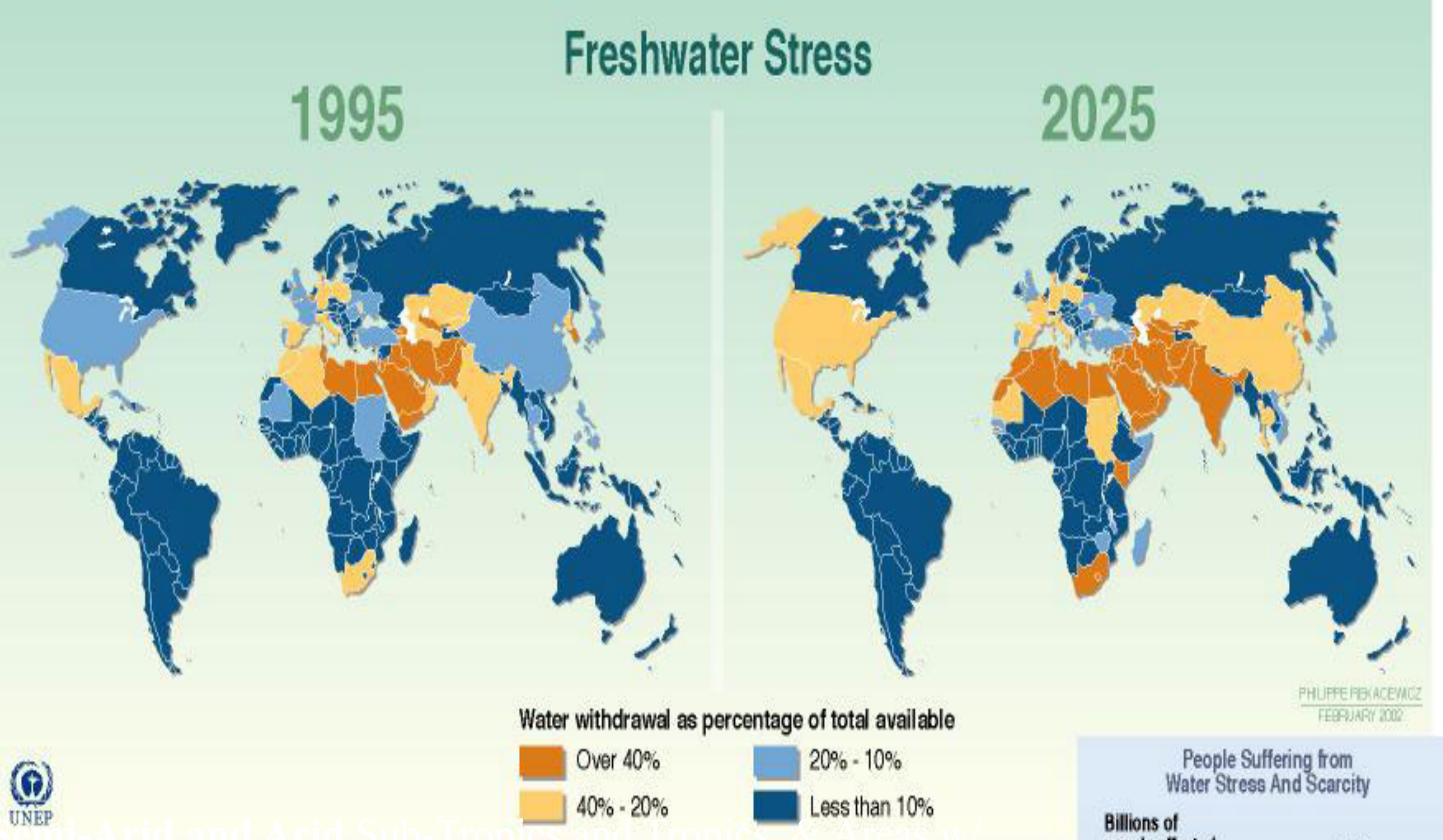


Source: Grey & Sadoff, World Bank

Major issues: water quantity and infrastructure

Potential for stress/conflict: rapid basin changes (institution, physical)

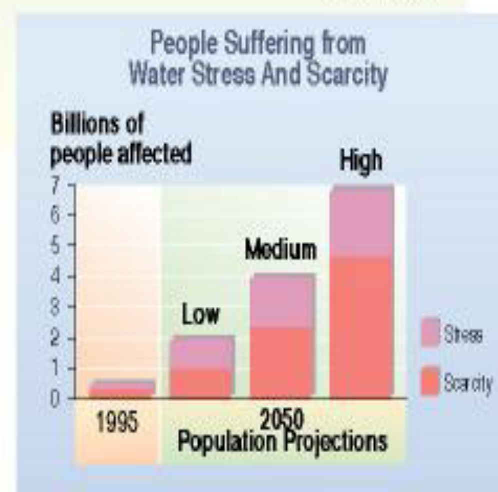
Wolf et al 2003



Source: World Meteorological Organisation (WMO), Geneva, 1996; Global Environment Outlook 2000 (GEO), UNEP, Earthscan, London, 1999.

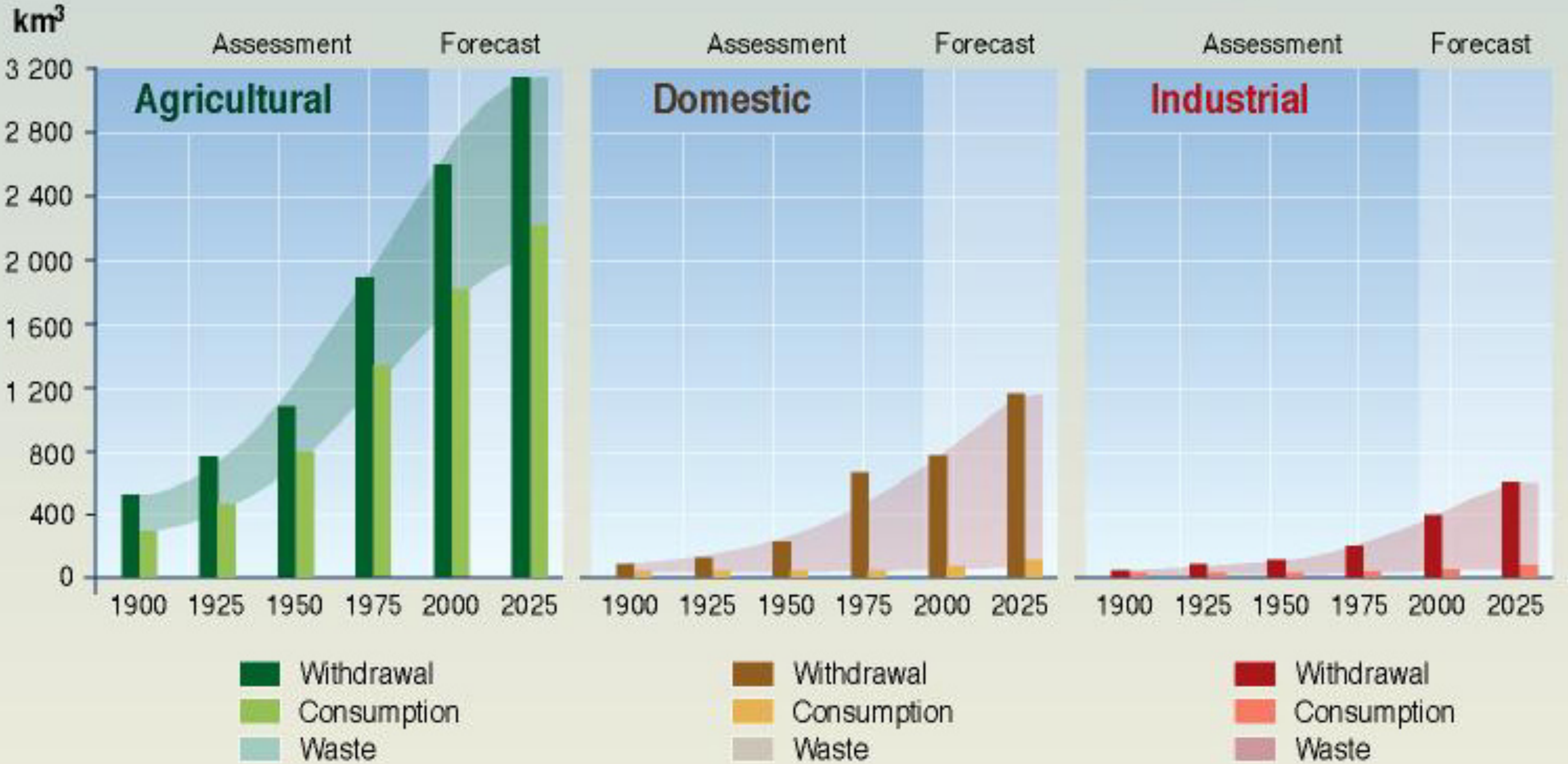
In the 20th century the world population tripled – while water use multiplied six-fold!

By 2025 two thirds of the people in the world are expected to live in areas of water shortage or stress.



Evolution of Global Water Use

Withdrawal and Consumption by Sector

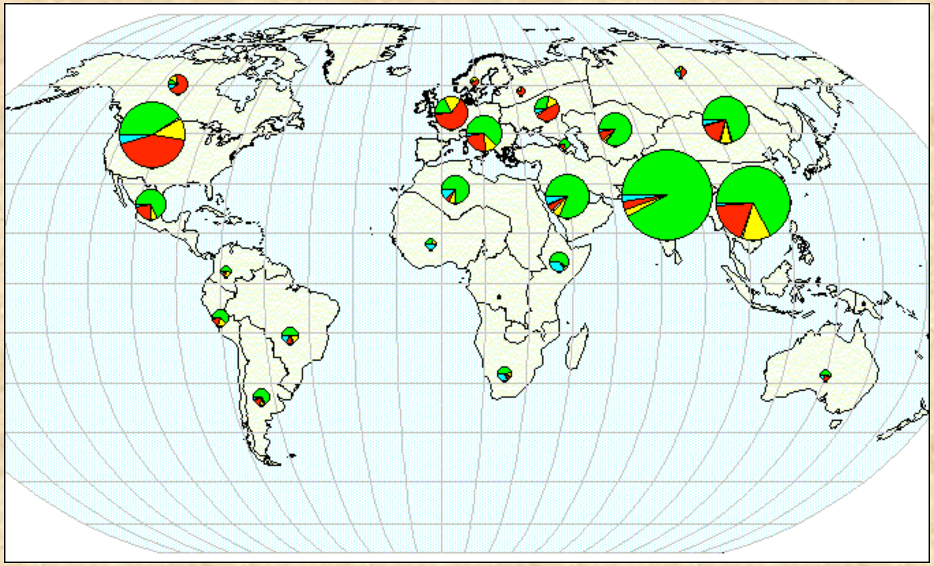


UNEP

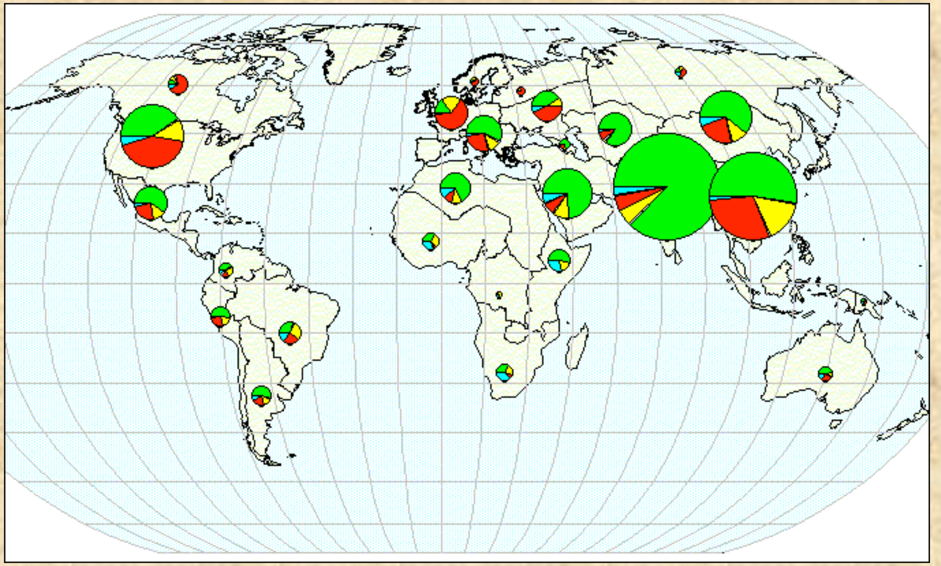
Note: Domestic water consumption in developed countries (500-800 litres per person per
is about six times greater than in developing countries (60-150 litres per person per

Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultur

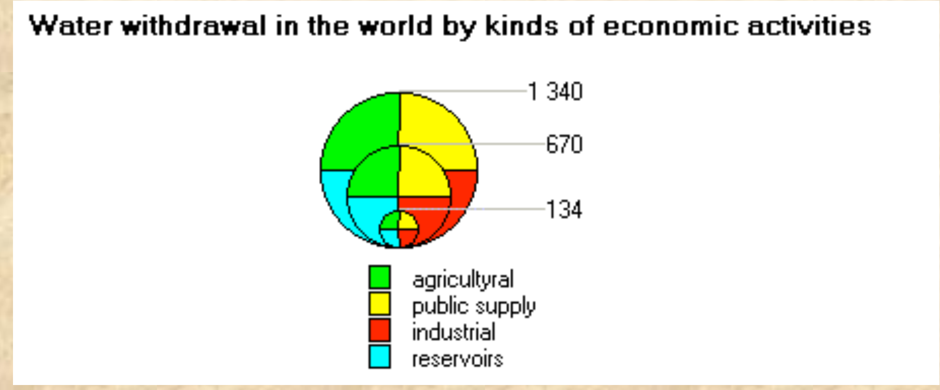
Water Withdrawal by Activity



1995

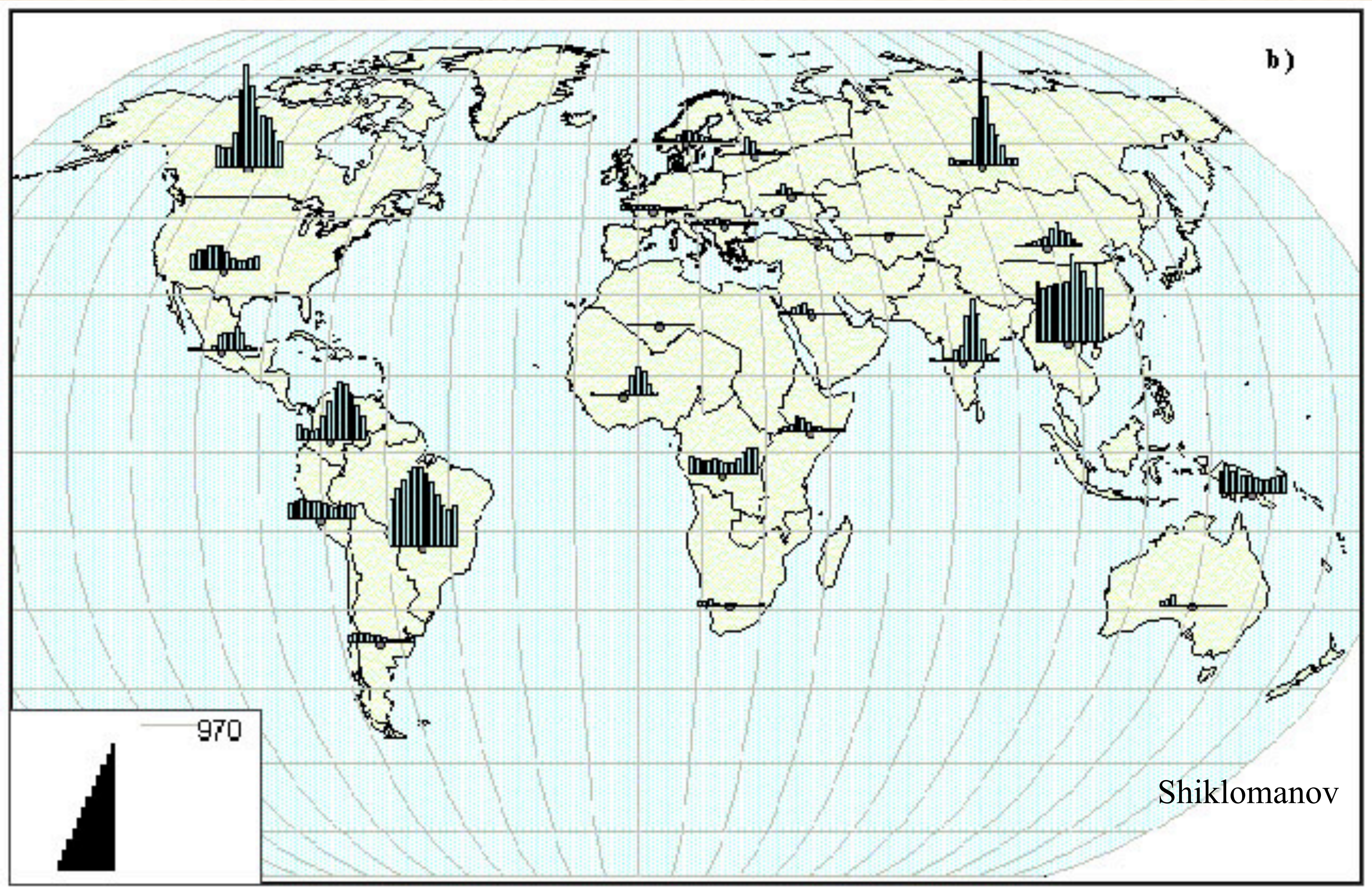


2025

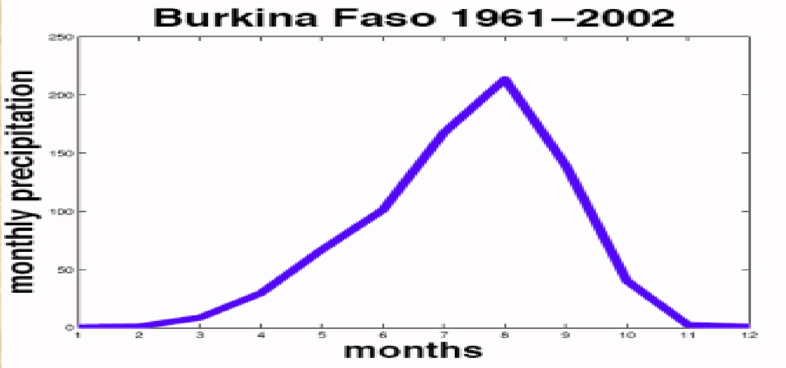


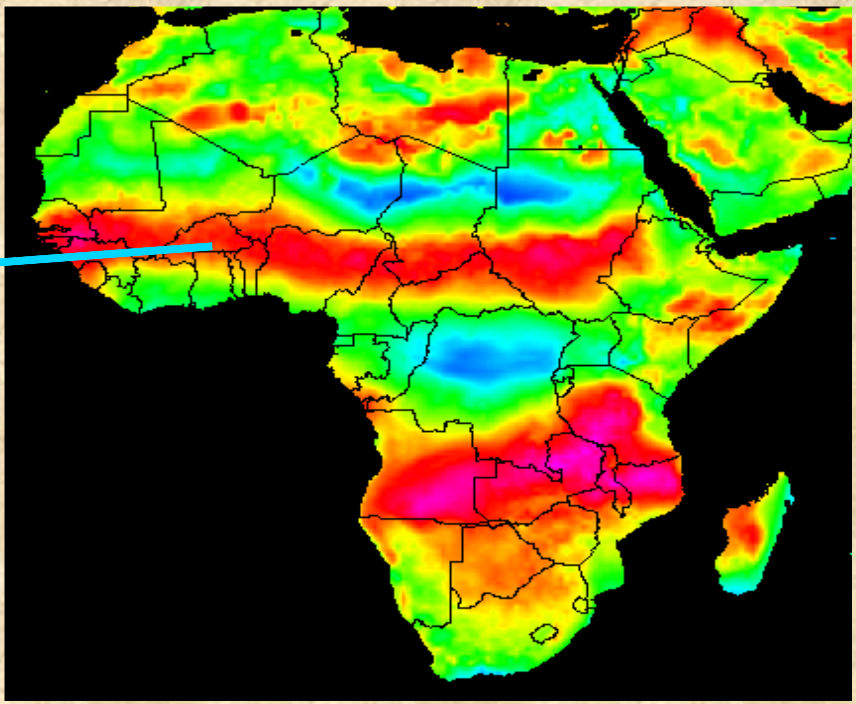
From: Shiklomanov
[webworld.unesco.org/water/ihp/db/shiklomanov]

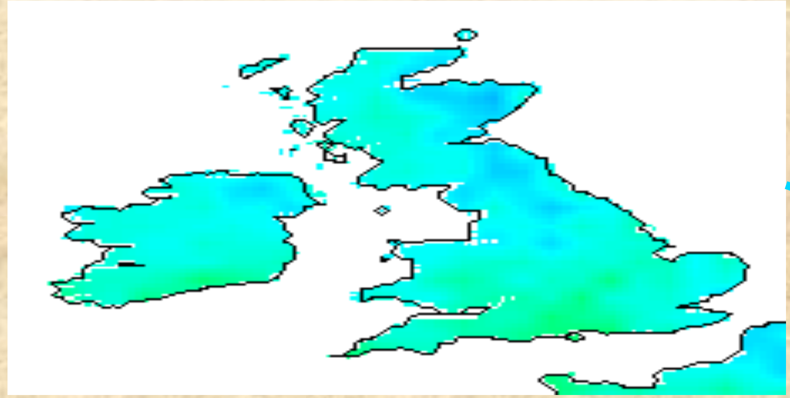
Monthly Distribution (km^3)

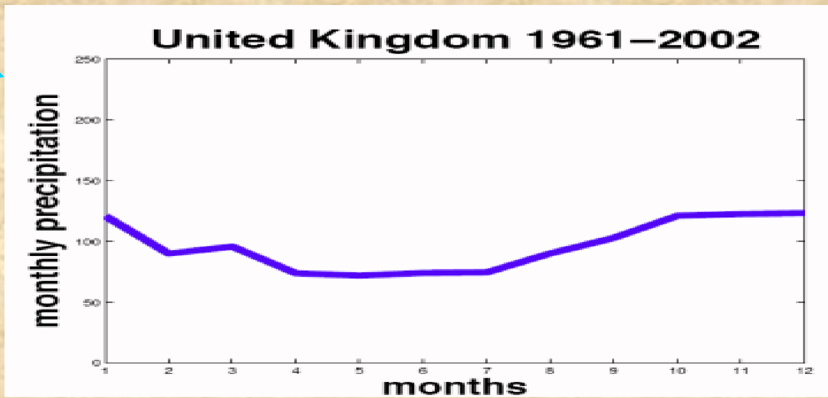


Monthly Distribution Precipitation



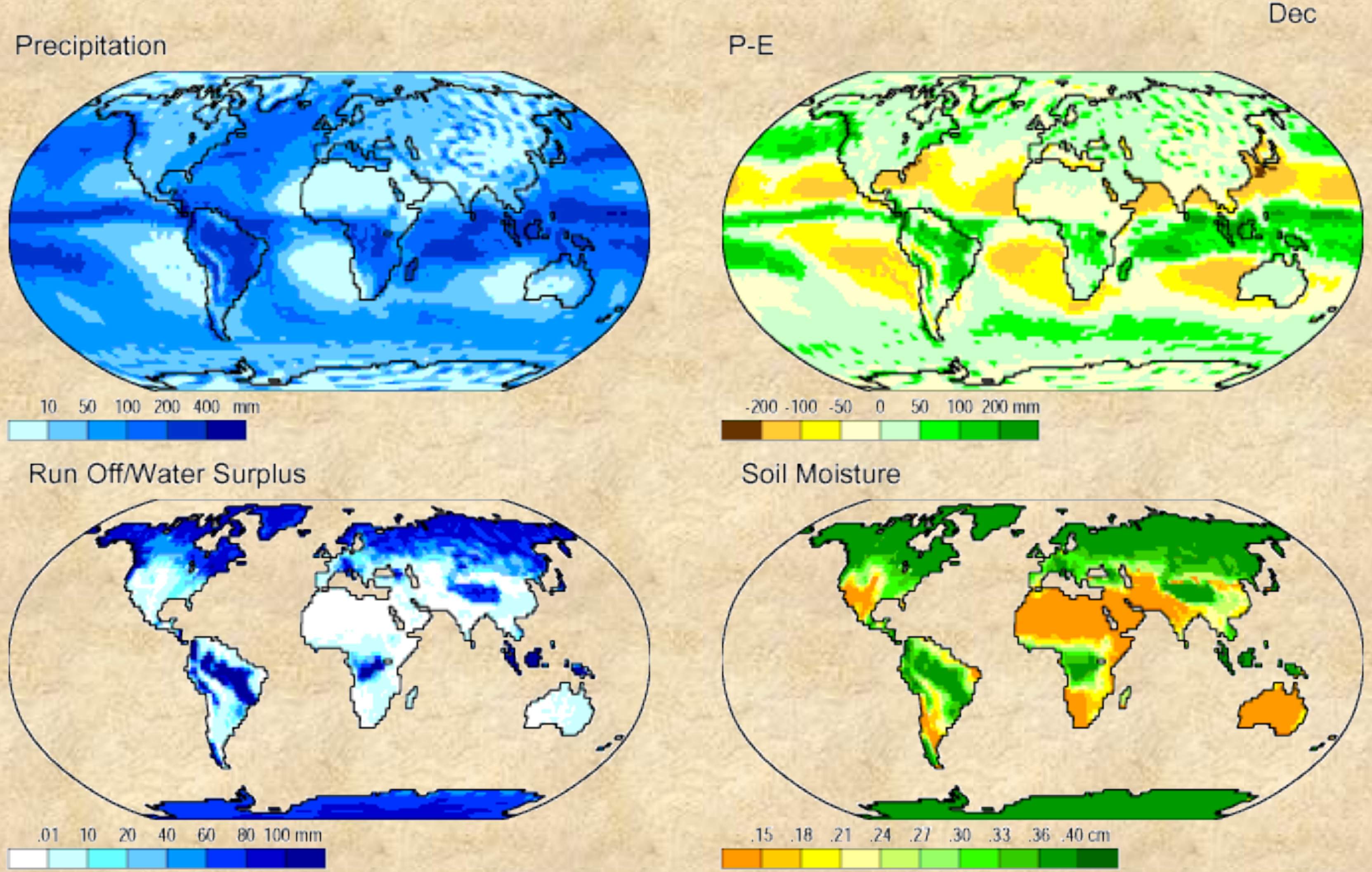






Annual Cycle

Important to understand intra-annual variability



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

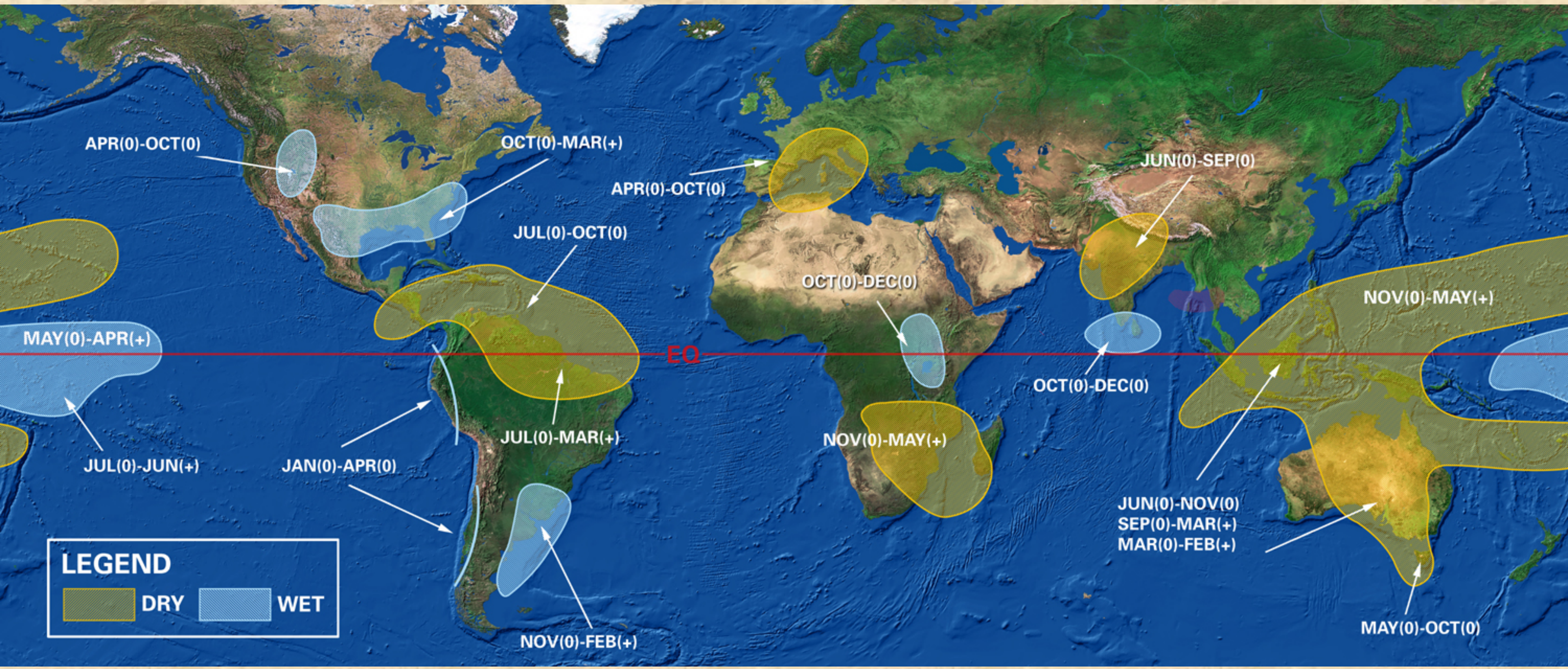
Precipitation

ITCZ

http://daphne.palomar.edu/pdeen/animations/23_weatherpat.swf

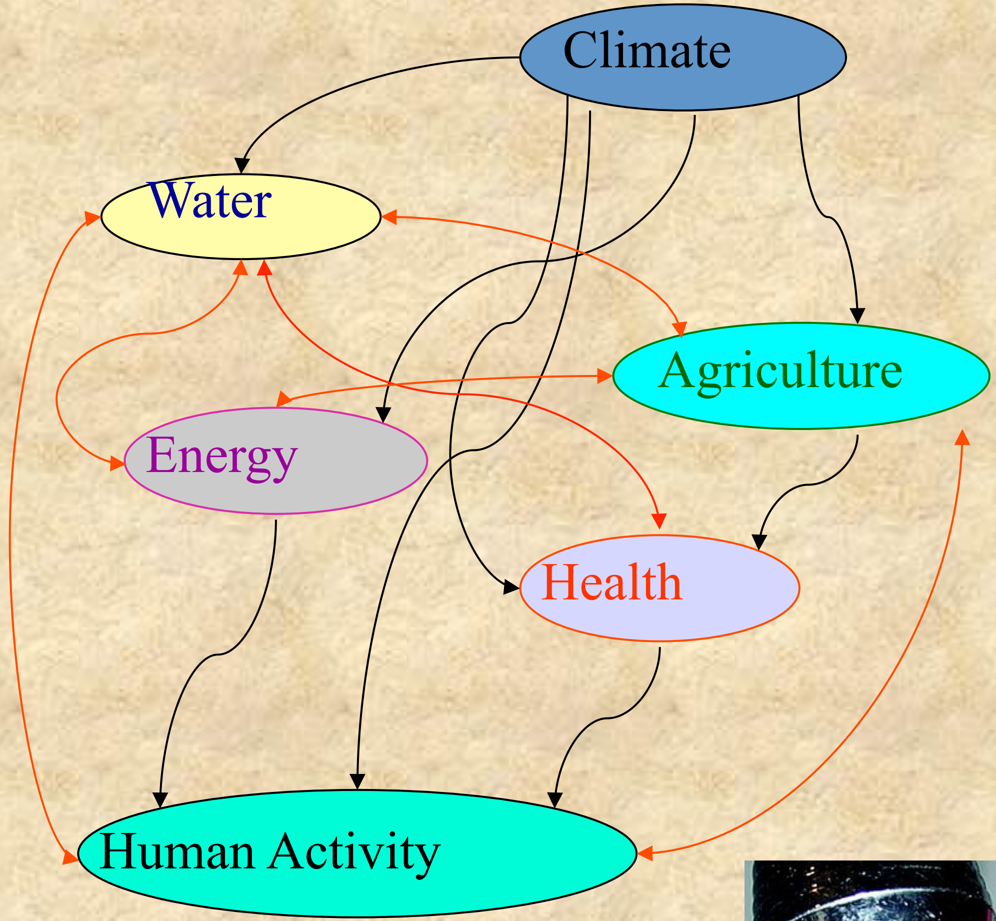
Modes of Climate Variability

ENSO – impact regions



NOAA CPC/NCEP

Water Management



Water System Management Goals

Allocation: Efficiency (physical and economic), Equity

Operation: Reliability (minimize risk), Resilience

Design: Highest Expected Benefit-Cost Ratio

Risk Reduction for Floods and Droughts

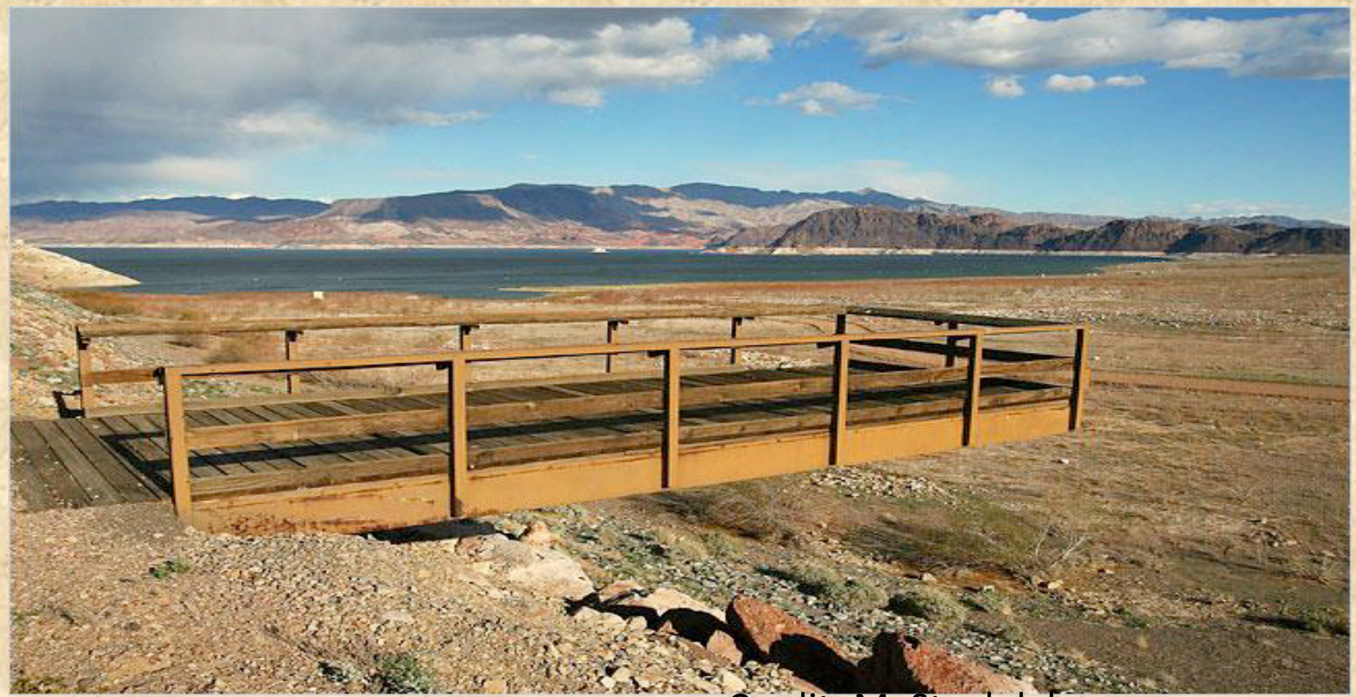
Traditional: Command & Control Management (Play God)

New Trend?: Open, Participatory, Informed, Negotiated, Regulated Process; Dynamic, flexible operations; Decision-making under uncertainty

The Current State

An imminent freshwater crisis

- Demand > Supply
- Access to safe drinking water is currently poor
- High variability in supply → Major investments needed for growth
- Potential for trans-boundary conflict
- Climate change poses significant uncertainty



Credit: M. Stockdale

The Challenge

How can we meet the challenges of providing water for the 21st Century?

- Changing (growing) population
- Competing (increasing) demands, preferences
- Variable supply, Extremes
- Climate change

Global or Local Issue?

Focus on Today (security) or the Future (sustainability and resilience)?

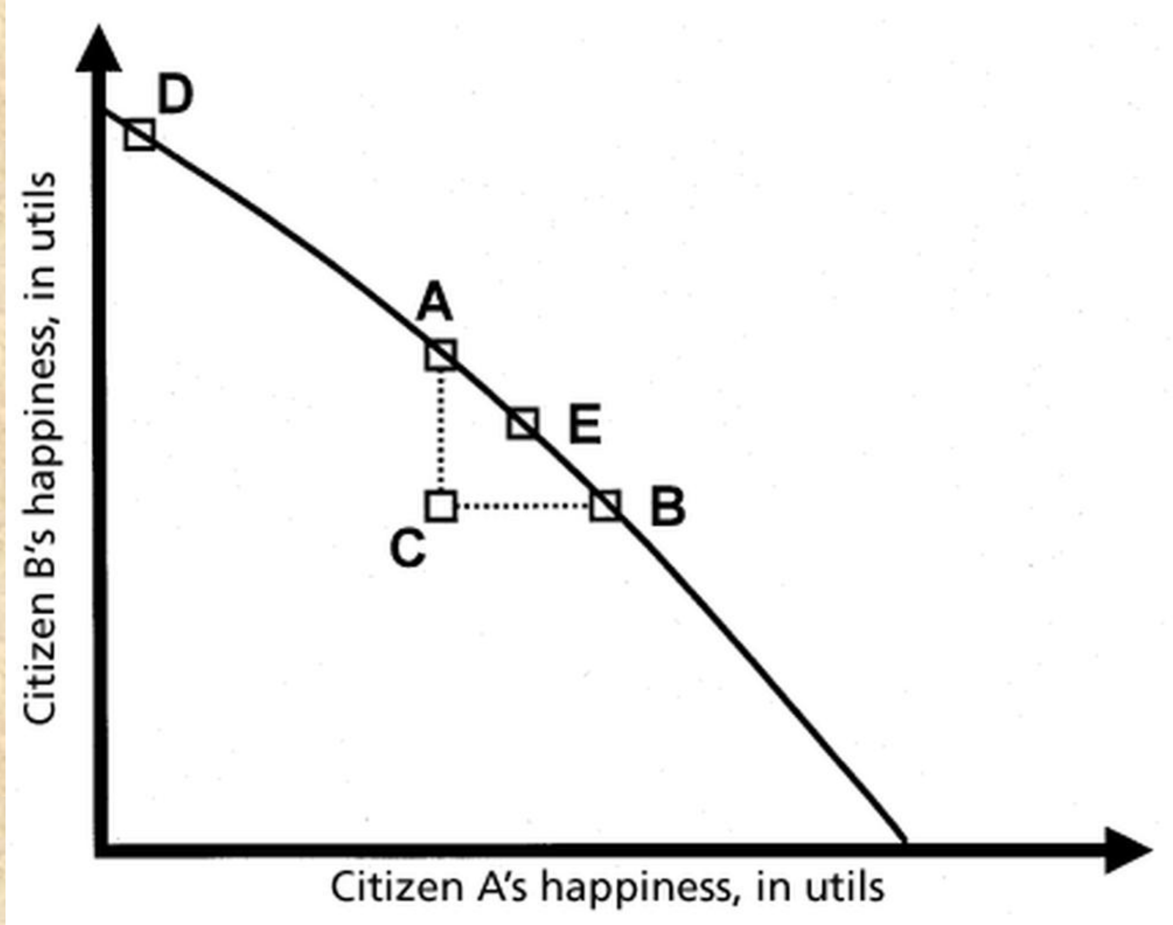
Tradeoffs

Hydropower vs Agriculture vs Domestic vs Environment vs Health vs Recreation vs Aesthetics

Upstream vs Downstream

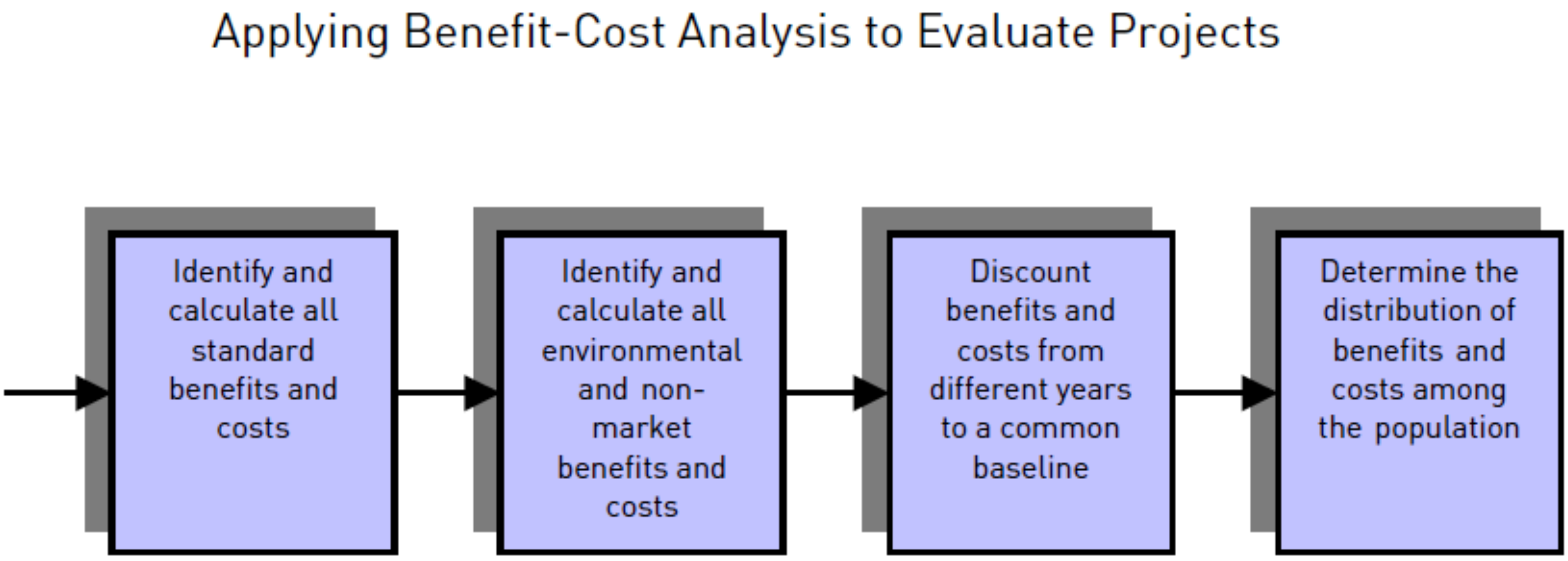
Timing

Stakeholders



Pareto Frontier

Benefit-Cost Analysis



(Environmental Defense, 2003)

The 1992 Dublin Principles
Principle 4

"Water has an economic value in all its competing uses and should be recognized as an economic good."

"Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price."

Gleick, 2002

Special Economics?

- "Common pool" resource
    - Rival, mostly non-excludable
- High exclusion costs
- Consumptive and nonconsumptive uses
- Economic and noneconomic uses
- Valuation

(Young, 2005)

Optimization

Mathematical

Max $B = \sum_{t=1}^{T} [BH^t(WH^t) + BE^t(WE^t)]$

s.t. $WH^t + WE^t \leq w^t$ *t=1, 2, … T*

B: total benefit

BH/BE: human/environment benefit

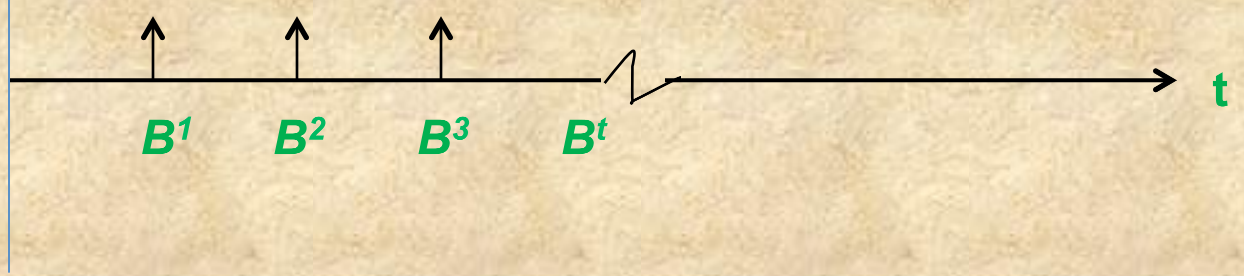
WH/WE: water for human/environment *w*: total water availability

Optimization

Actually more complicated…

Consider discount rate?

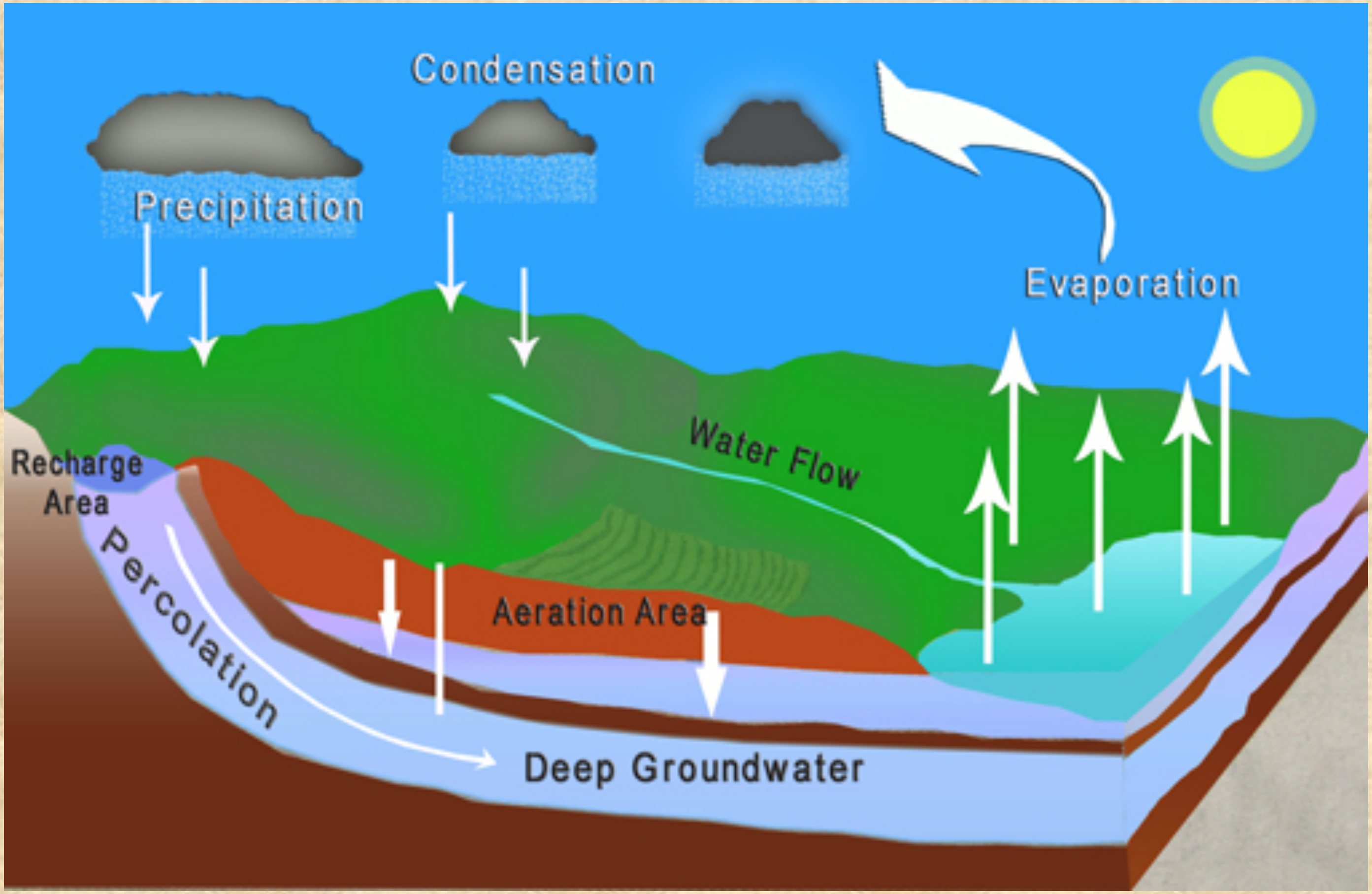
$$P = F/(1+r)^{t-1}$$



Optimization

Actually more complicated…

Renewable vs Non-renewable



Shared Vision or Consensus

Stakeholders congregate and discuss using tools and models

Concessions, tradeoffs, etc.

Nile Basin Hydrol

- Blue Nile
  - Headwaters: Lake Tana
  - Highlands
  - Steep gorge
- White Nile
  - Headwaters: Lake Victoria
  - Equitorial lakes & swamps
- Main Nile
  - Desert
  - 6700 km long
  - 10 countries in basin

Courtesy of World Bank

Nile River Allocation (Hydropolitics)

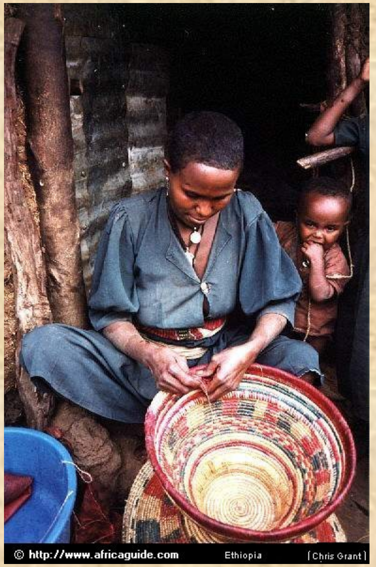
Agreement of 1959:
Egypt = 75%, Sudan = 25% of annual flow

Entebbe Agreement (2011): Upstream
Nile countries call 1959 Agreement invalid

Approximately 45 B m^3/yr
Contributes ~ 60% of full Nile at Aswan

http://assets.panda.org/img/nile_basin_map_235502.jpg

Ethiopia at a Glance



Courtesy of Chris Grant

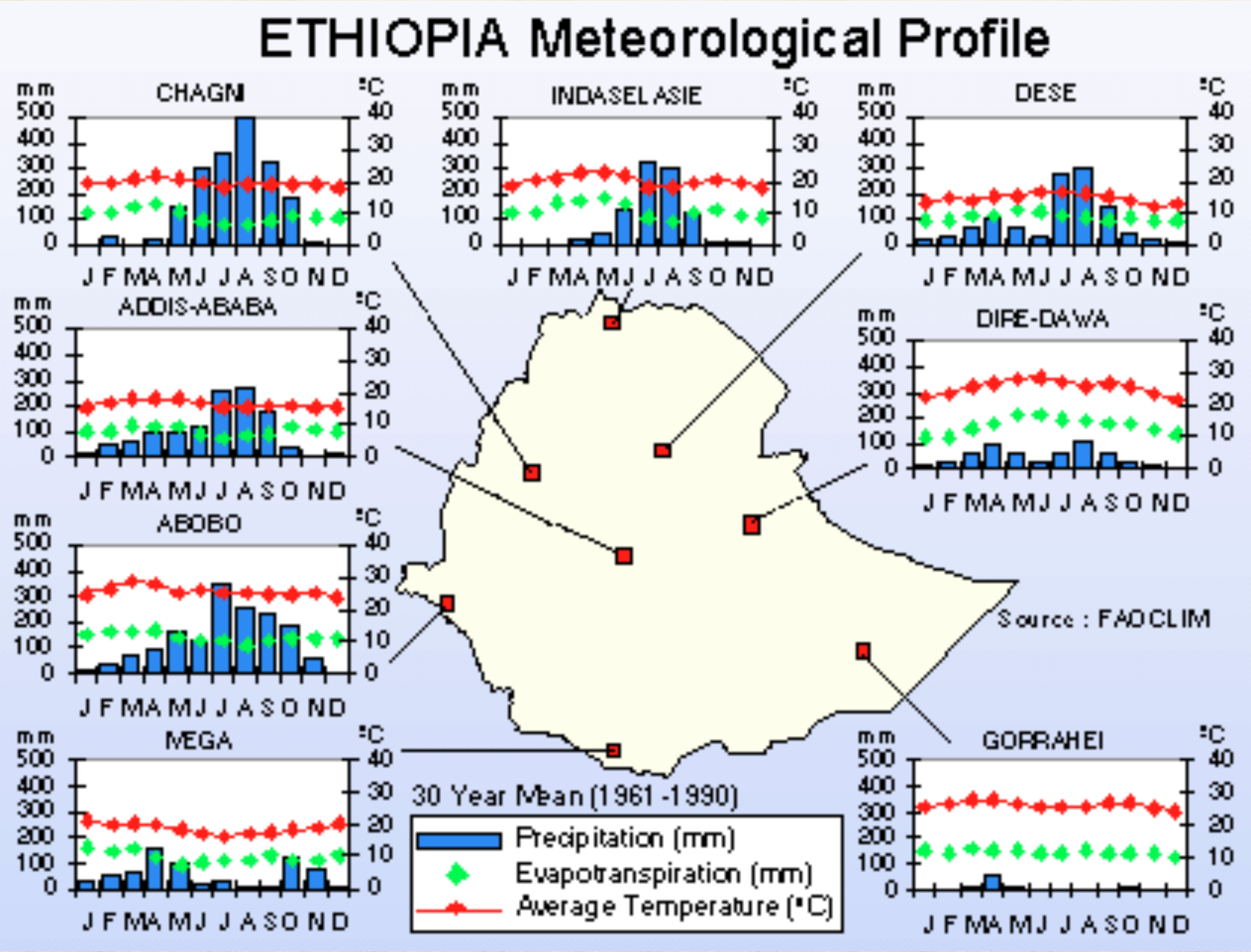
- Population = 90 million
- Growth rate = 2.3%

- Population living on less than $1 a day = 31%
- Population living below the national poverty line = 44%
- Population living below the minimum level of dietary energy consumption = 46%

- Infant mortality rate = 10%
- Life expectancy at birth = 42.5 years

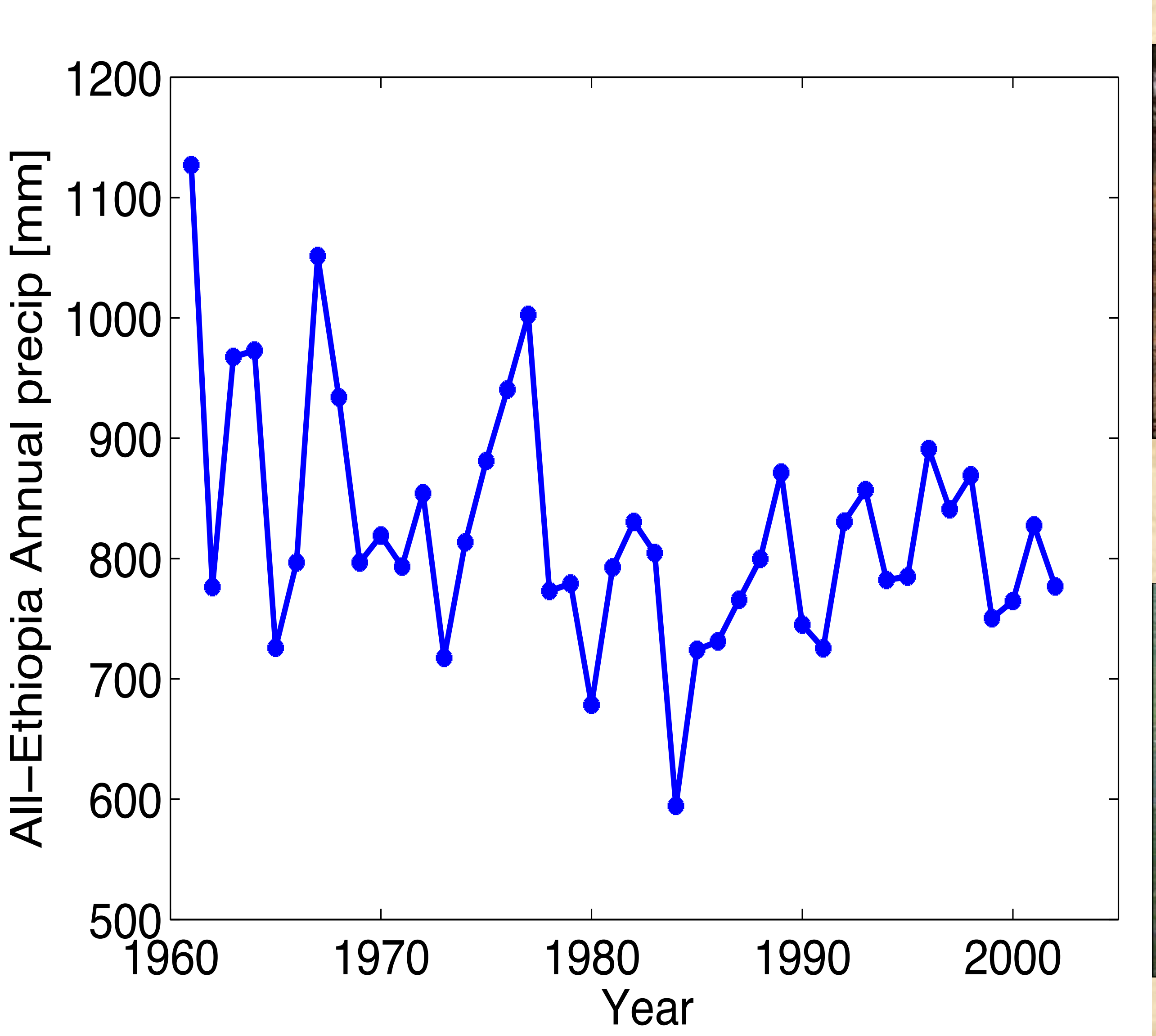
UN Millennium Development Goals & World Factbook

Variable Climate

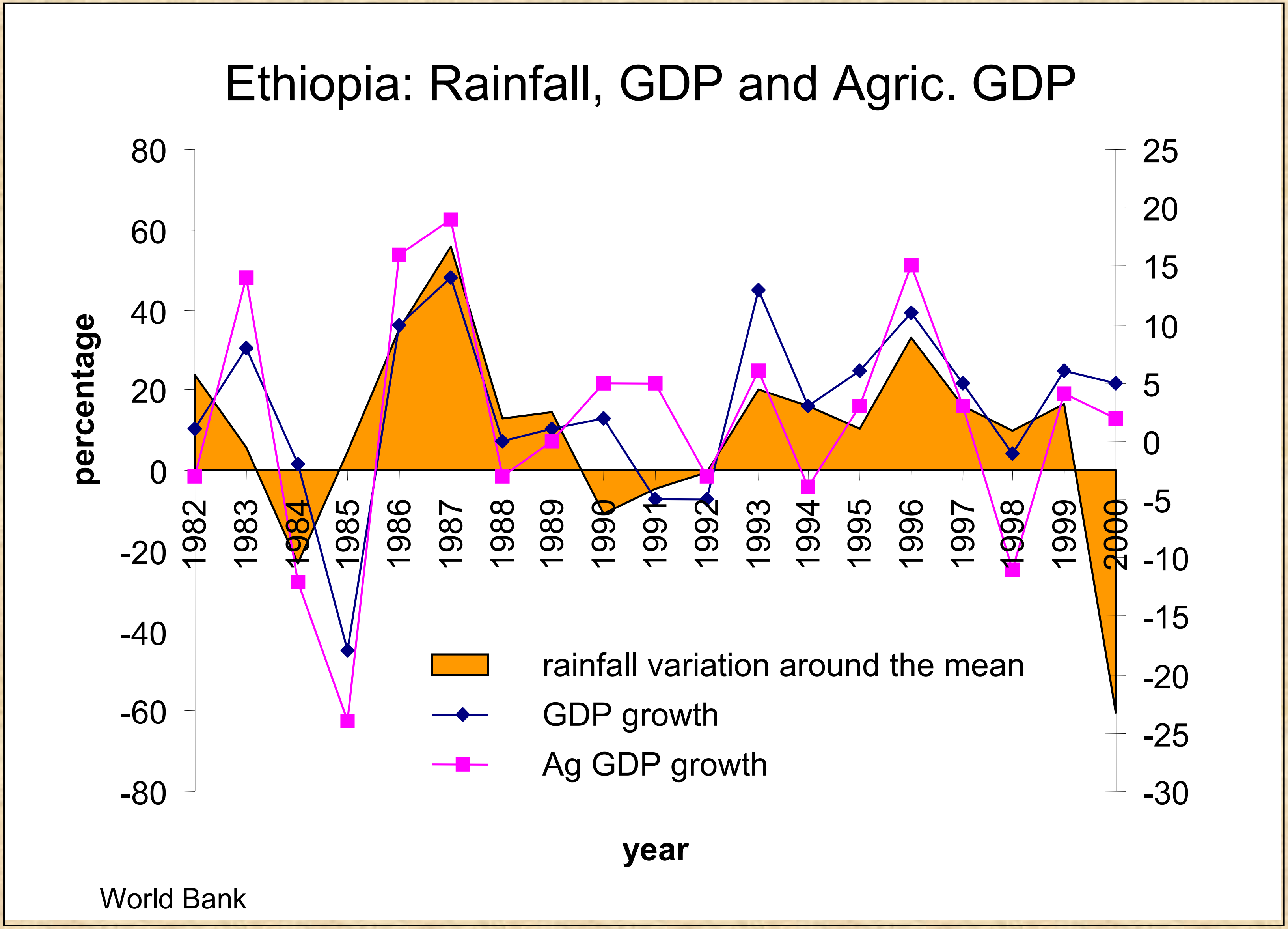


From FAO/GIEWS website

Variable Supply



Seasonal Climate Variability



Source: World Bank 2005

Pros and Cons of Large-Scale Storage

Advantages:

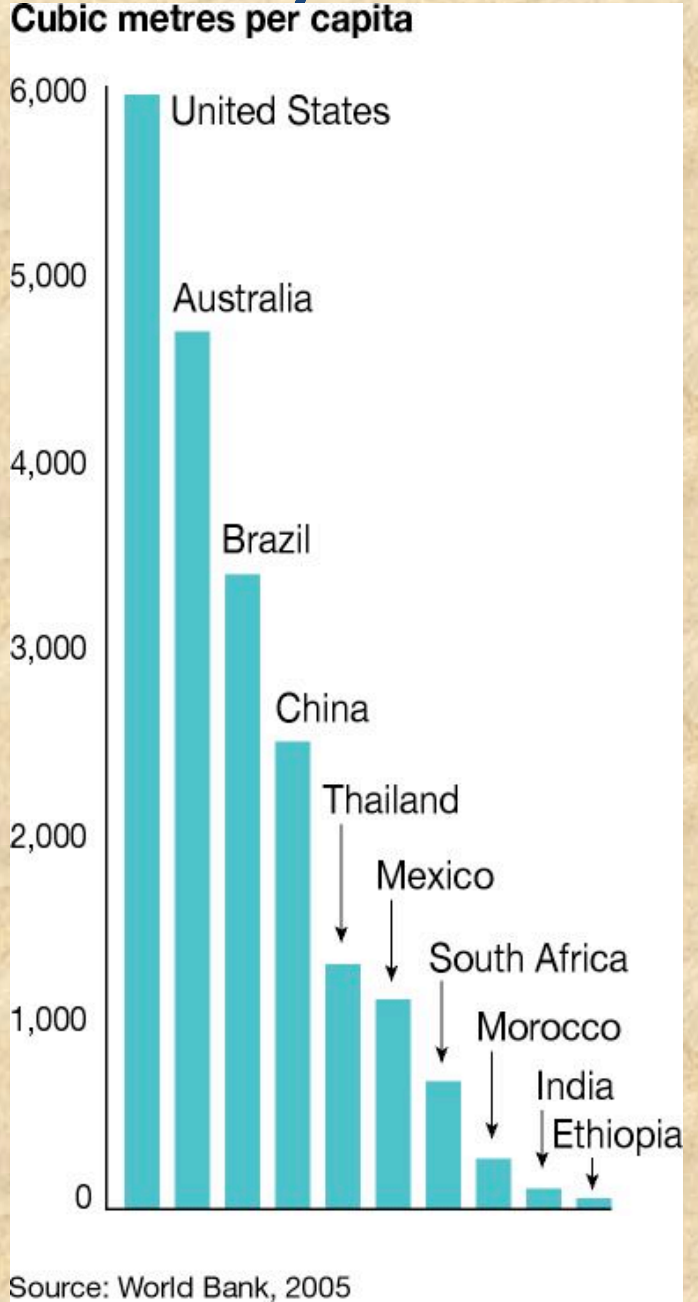
- flood protection
- electricity generation
- regularized flows
- municipal, agriculture, industrial supply
- recreation
- navigation

Disadvantages:

- inundation and relocation
- trapping sediment
- ecological (low) flows
- fish migration
- failure hazard

Existing Storage by Country

Buffers variability, but expensive and controversial



Ethiopia's Energy Challenge

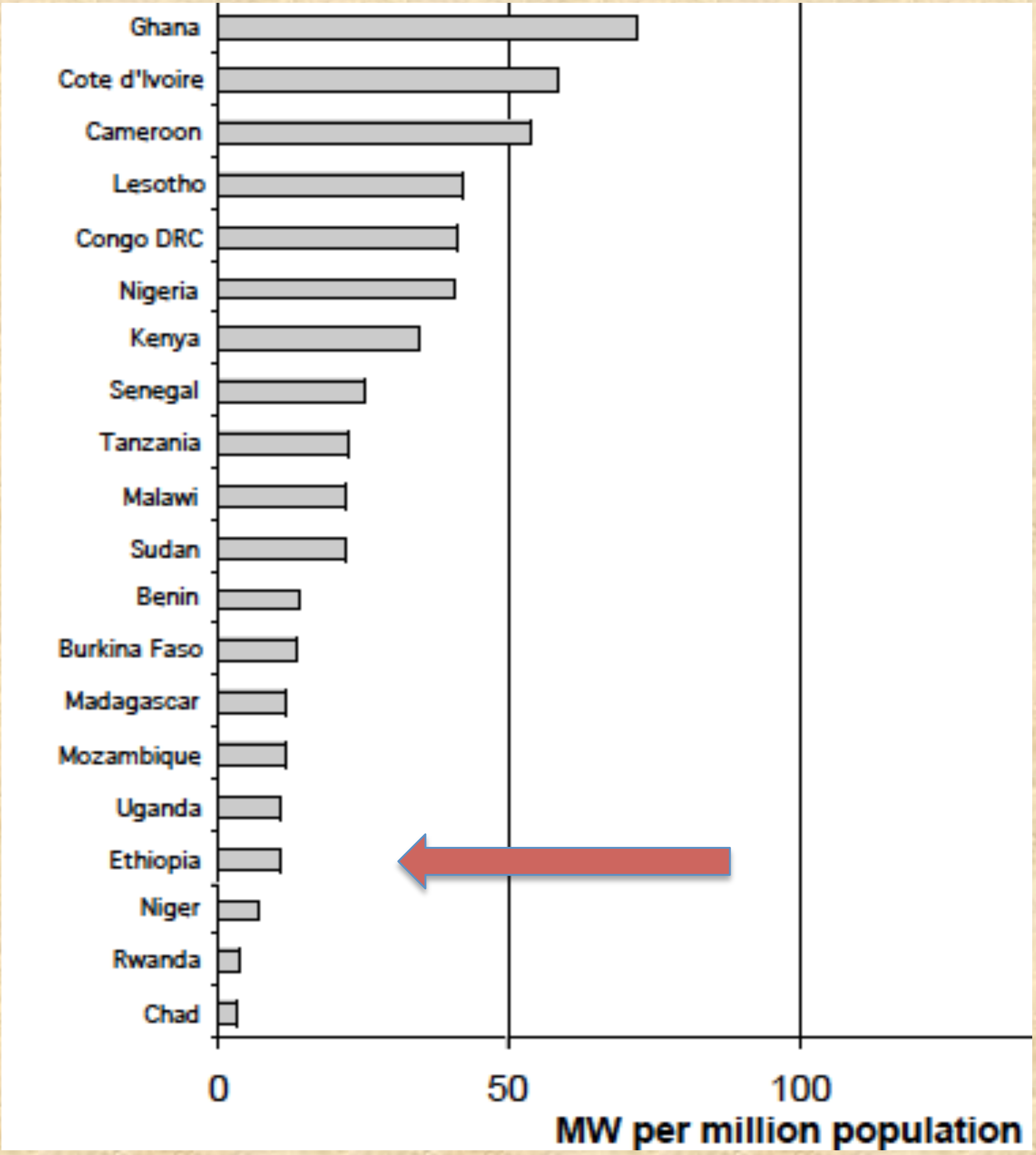
Wealth of hydropower potential

83% of Ethiopia's population lacking access to electricity

94% still relying on biomass for daily cooking and heating (Tegenu 2006)

Courtesy of Dorling Kindersley

SSA Energy Comparison

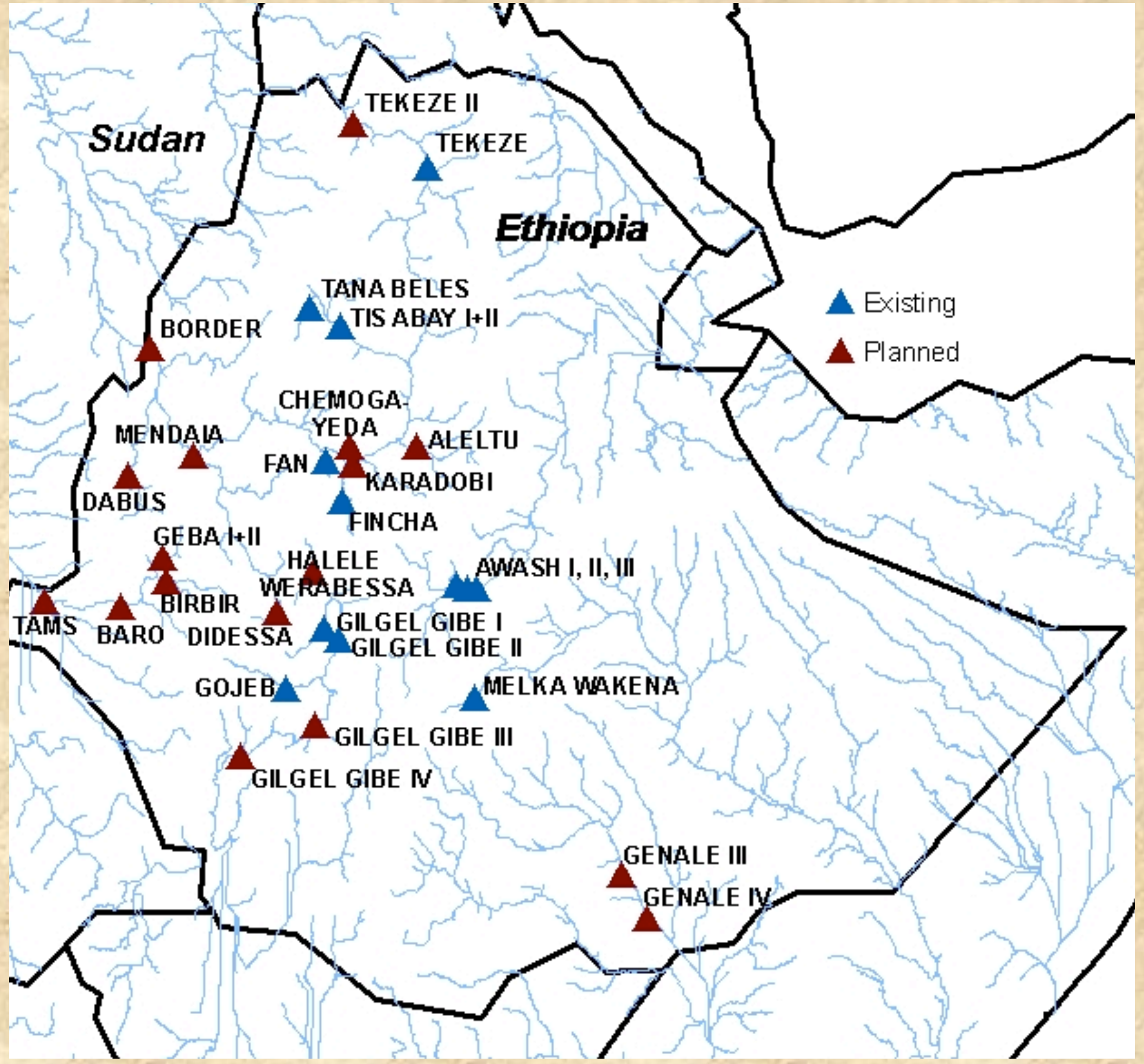


Source: Energy Information Agency, 2007

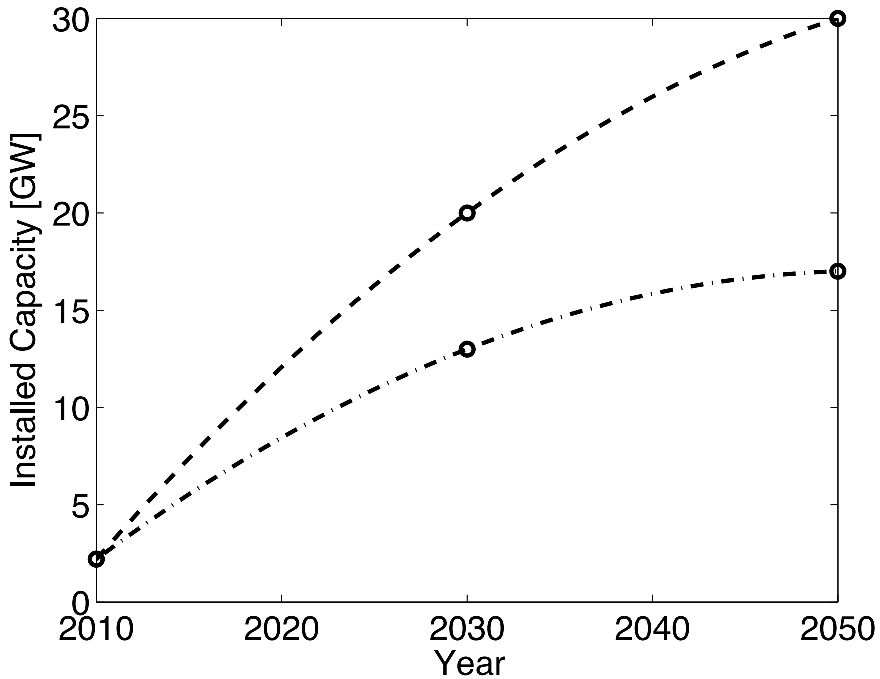
Ethiopia Development Plan

30,000 MW potential

< 10% developed

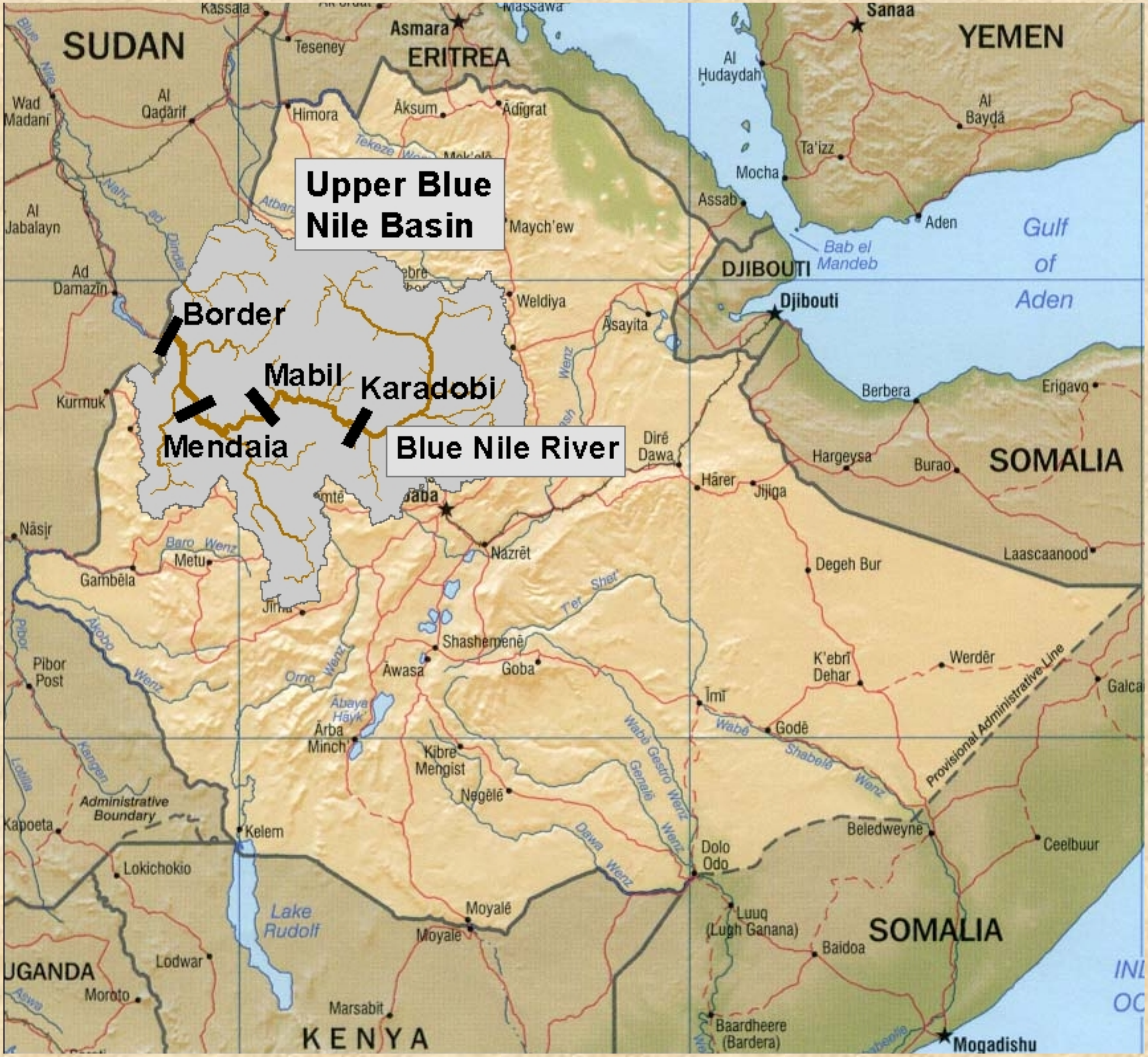


Ethiopia Development Plan



Energy Project *Existing*	Installed Capacity (MW)	Year of Commission	Cost ($M)
Awash I (Koka)	43	1960	
Awash II	32	1966	
Finchaa	134	1973	
Awash III	32	1974	
Melka Wakena	153	1988	
Tis Abay I & II	85	(1964) 2001	
Gilgel Gibe I	184	2004	
Gojeb (Independent)	150	2004	
Diesel & Geothermal	120		
Tekeze	300	2008	
Gilgel Gibe II	420	2008	
Tana Beles	460	2009	
Amerti-Neshi (FAN)	100	2010	
Fixed (committed)			
Wind - Ashegoba	120	2011	259
Gilgel Gibe III	1,870	2013	1730
Tendaho Geothermal	180	2013	305
Planned			
Gilgel Gibe IV	1,900	2014	2930
Halele Werabesa	450	2014	725
Chemoga-Yeda	278	2014	318
Geba I & II	366	2016	593
Genale III	258	2018	362
Genale IV	257	2018	456
Tekeze II	450	2020	694
Karadobi	1,600	2023	2411
Border	1,200	2026	1741
Mendaia	2,000	2030	2990
Baro	900	2034	914
Aleltu	405	2038	1444
Didessa	308	2038	523
Dabus	741	2042	1805
Birbir	467	2042	1199
Tams	1,060	2046	1805

Upper Blue Nile Basin



Base Map Courtesy of PLC Map Collection, UT

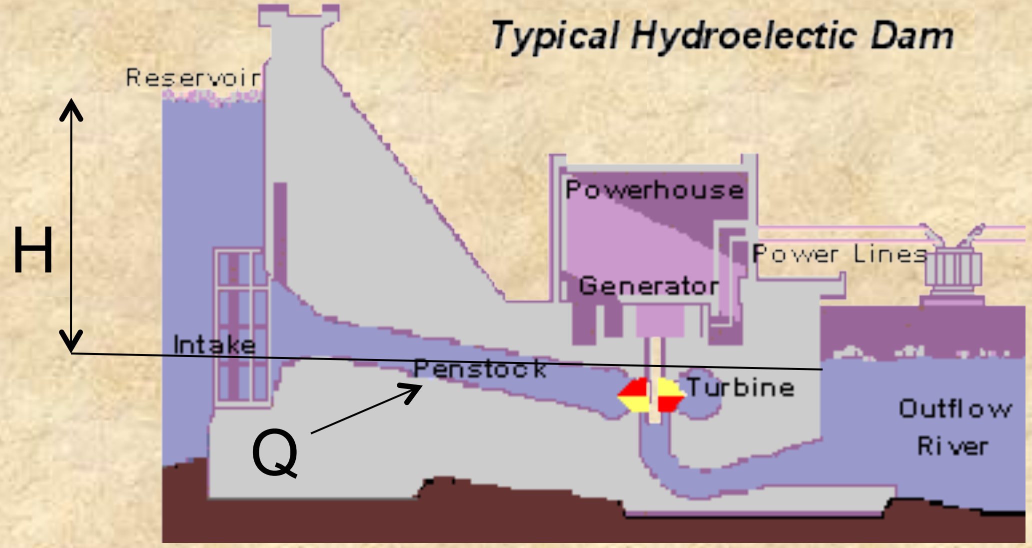
Hydropower Definitions

Working backwards…

Benefit = Hydroelectricity * $/kwh

Hydroelectricity = Power * time

Power = Head * Flow * e * constant



Credit: USGS

Head = *f*(storage)

Flow = *f*(precip, evaporation); evap =*f*(temp, winds, humidity)

Grand Ethiopian Renaissance Dam

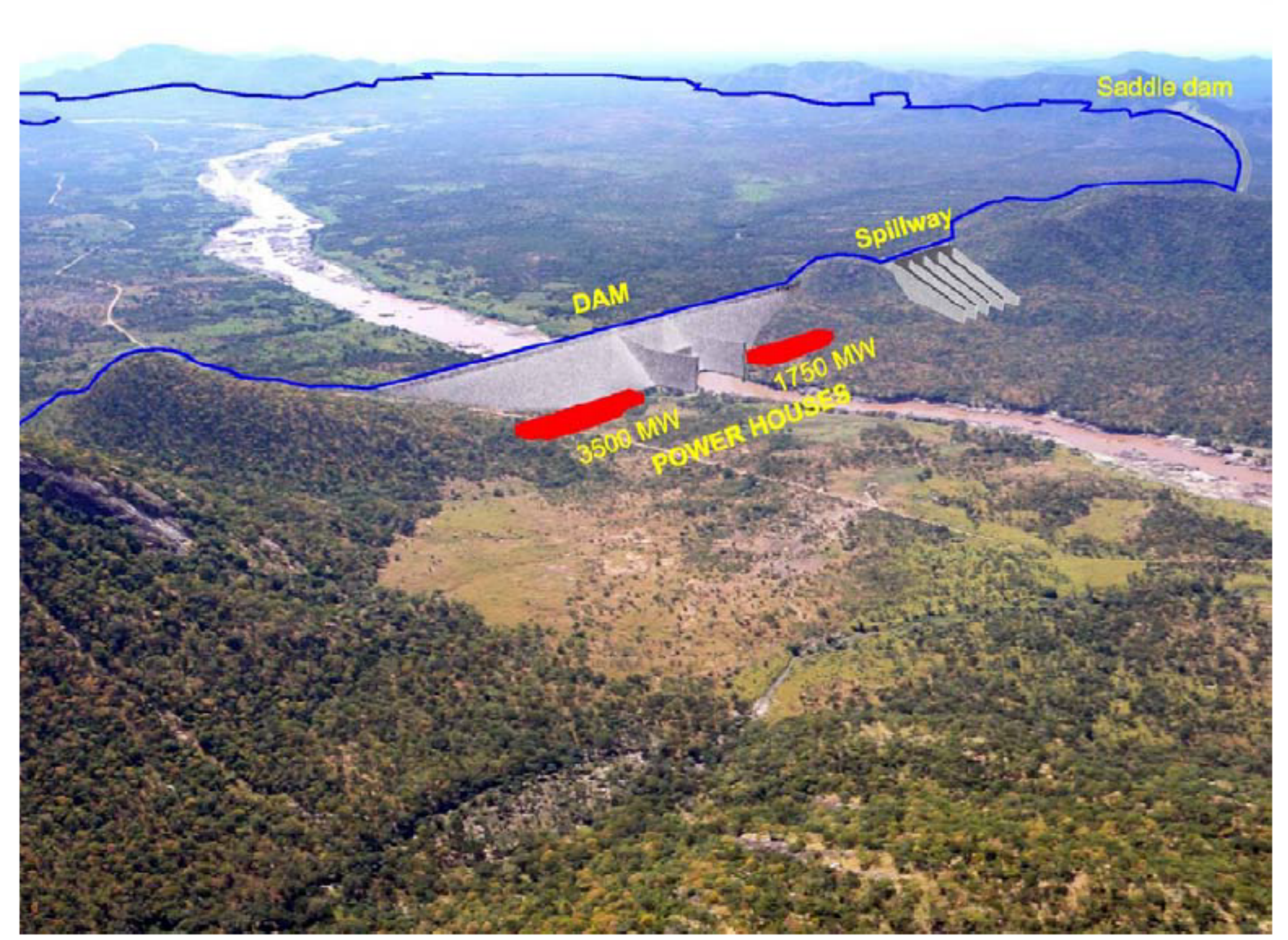
Will be largest dam in Africa

6000 MW

63 B m^3 Reservoir

$5 Billion

Res Filling Policy?
Climate Variability?
Climate Change?



http://seeker401.wordpress.com/2011/10/01/the-grand-ethiopian-renaissance-dam/

Grand Ethiopian Renaissance Dam

Grand Ethiopian Renaissance Dam

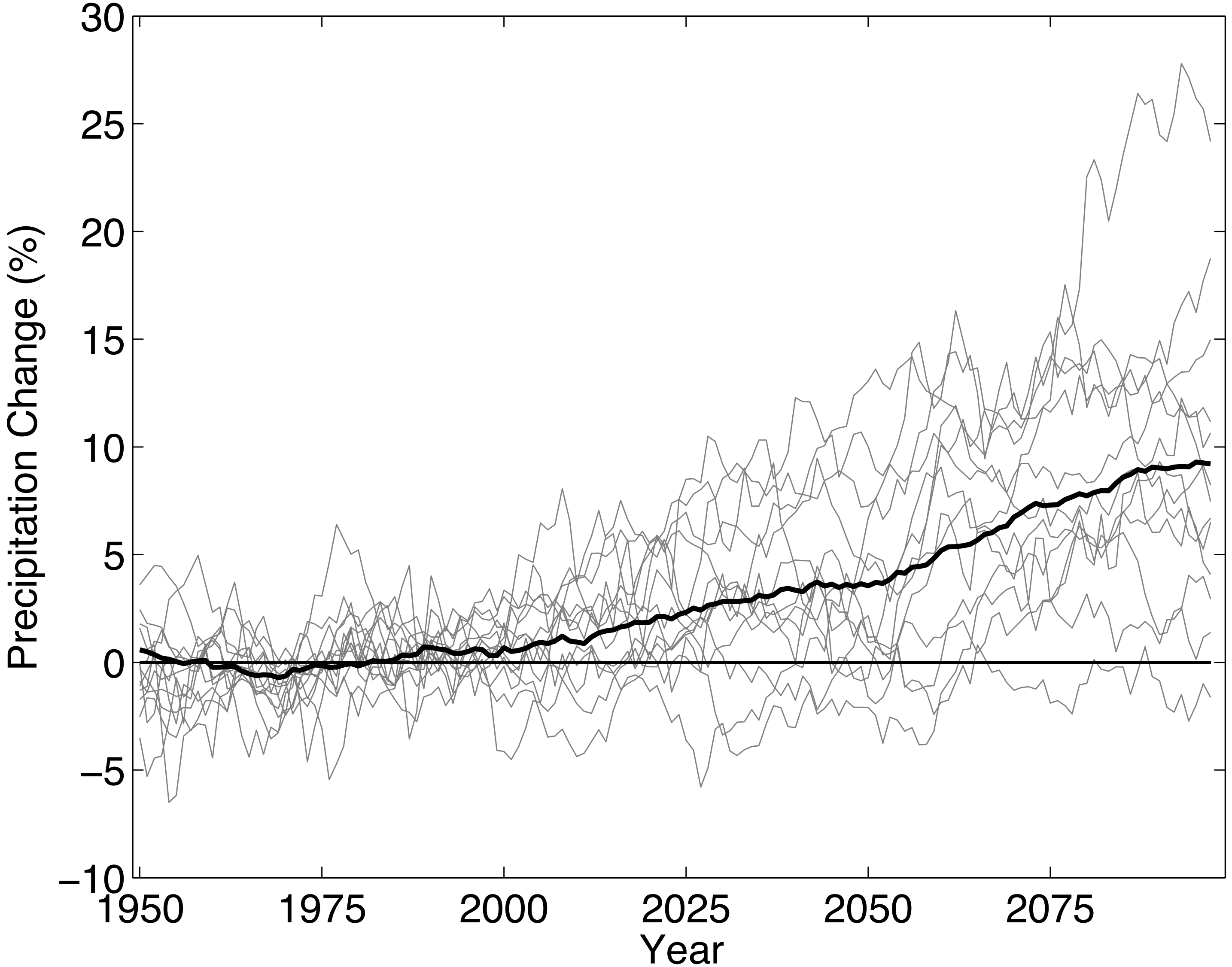
Reservoir Filling Policies

No established multi-national agreement on reservoir filling rate

- Percent Based
  - Impound a given percent of monthly streamflow
  - e.g., 5%, 10%, 25%
- Threshold Based
  - Impound streamflow exceeding a given threshold
  - e.g., >0.9*Historical Average Monthly SF

Climate Change: Precipitation

The ensemble of GCM runs



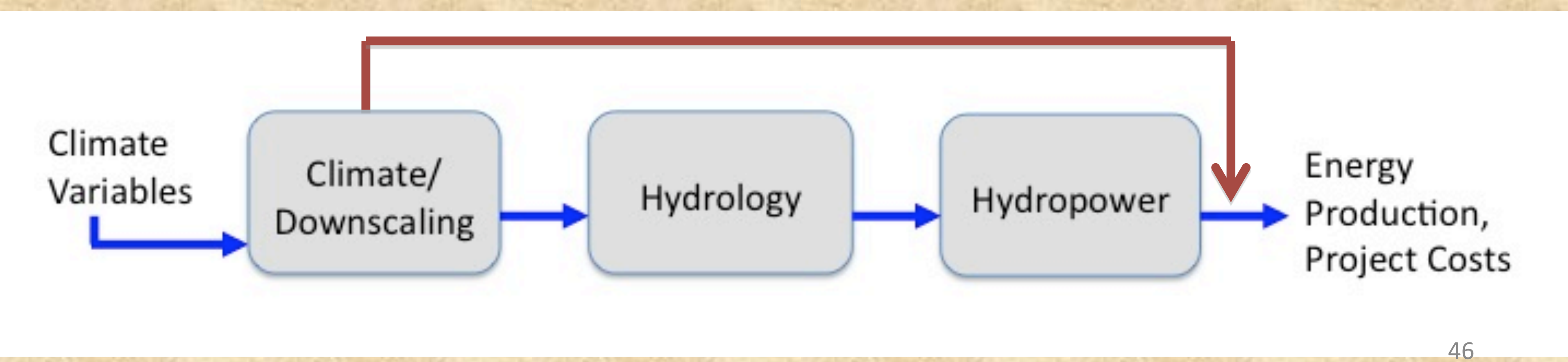
Modeling Framework

Sensitivity Analysis

Add linear trends (e.g. $\pm$ 5%, $\pm$ 10%, $\pm$ 20%) to Precipitation at 2060

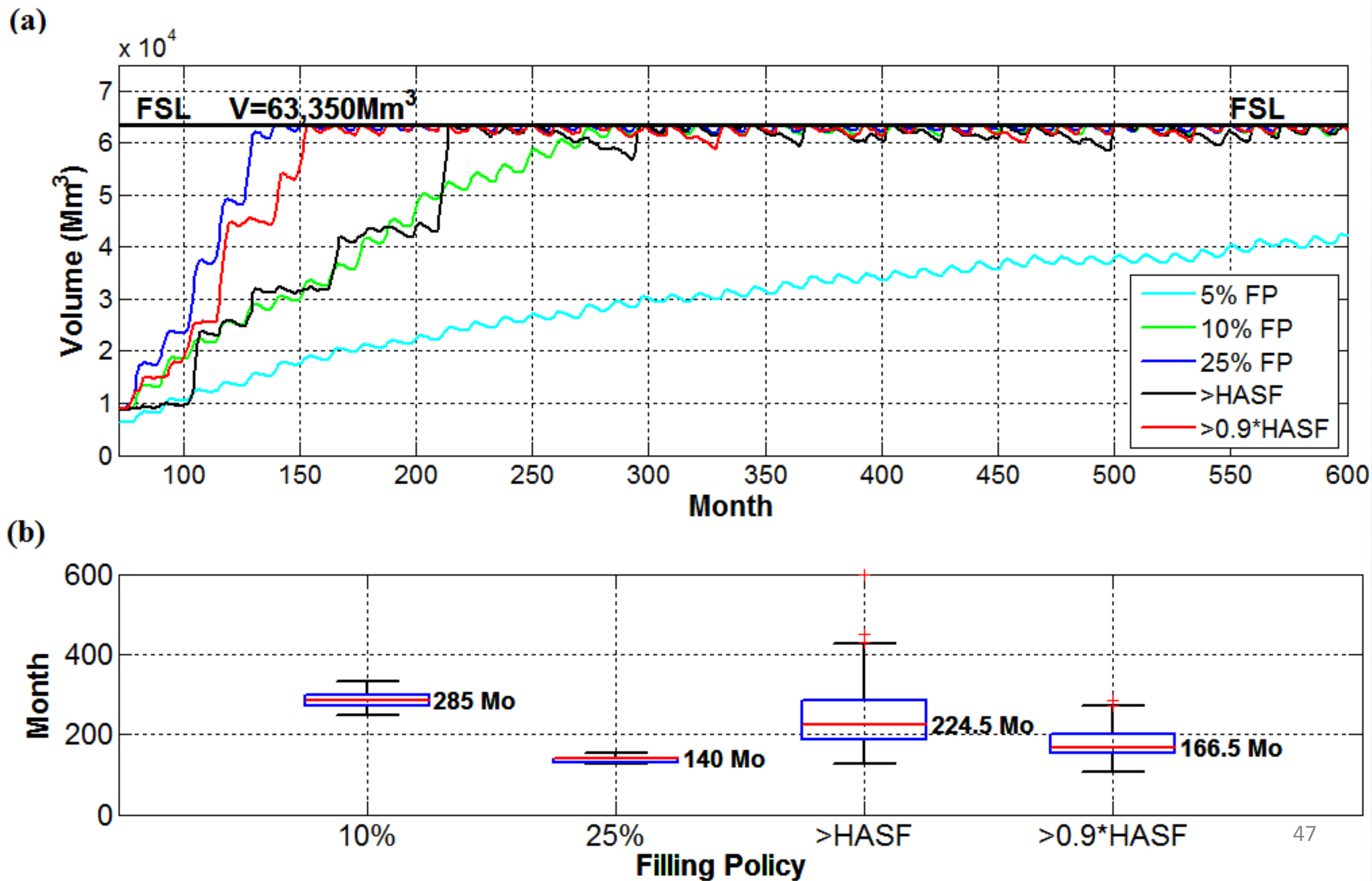
Temp assumed to increase by 2.5-degrees C

Various filling rates



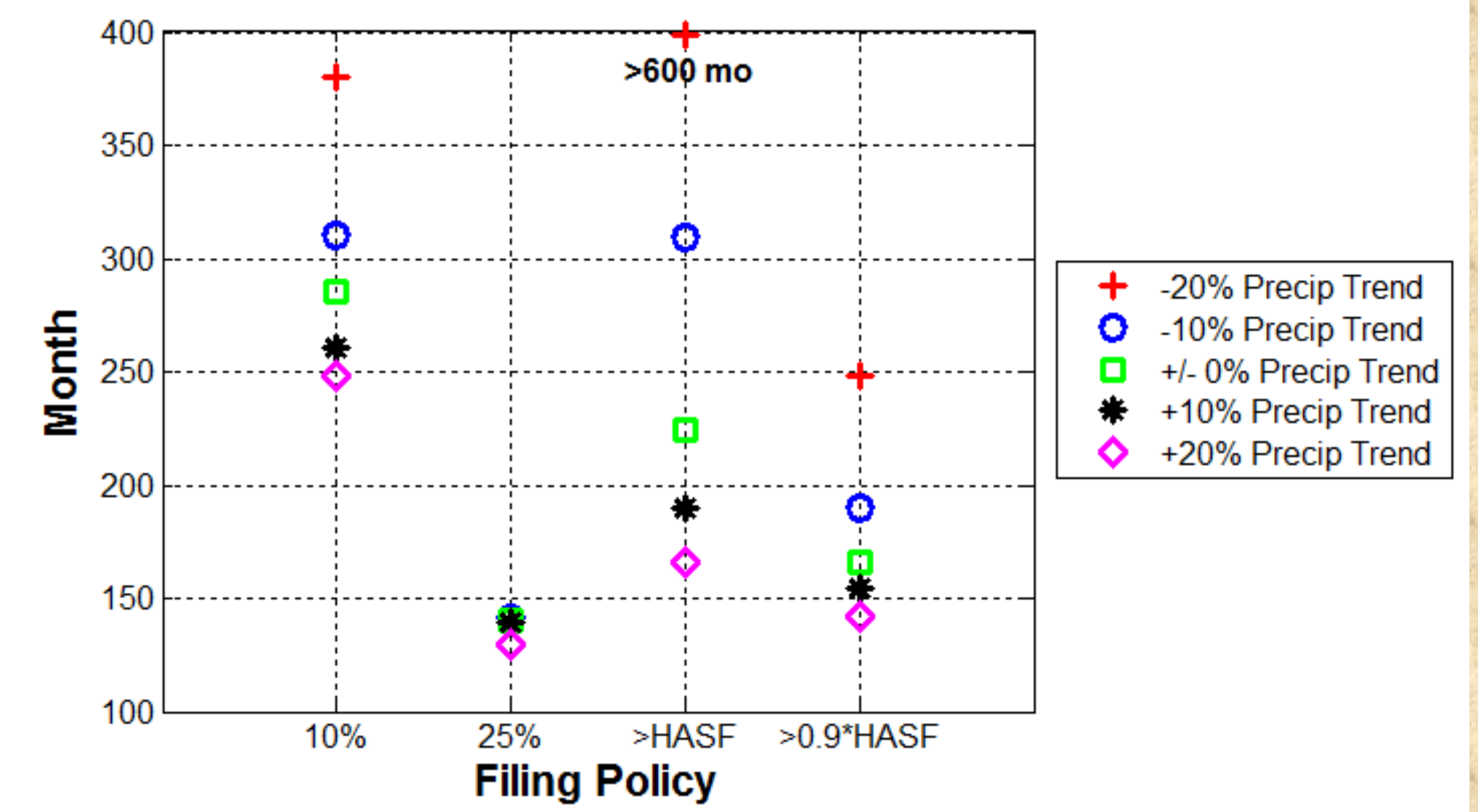
Time to Fill

No climate changes



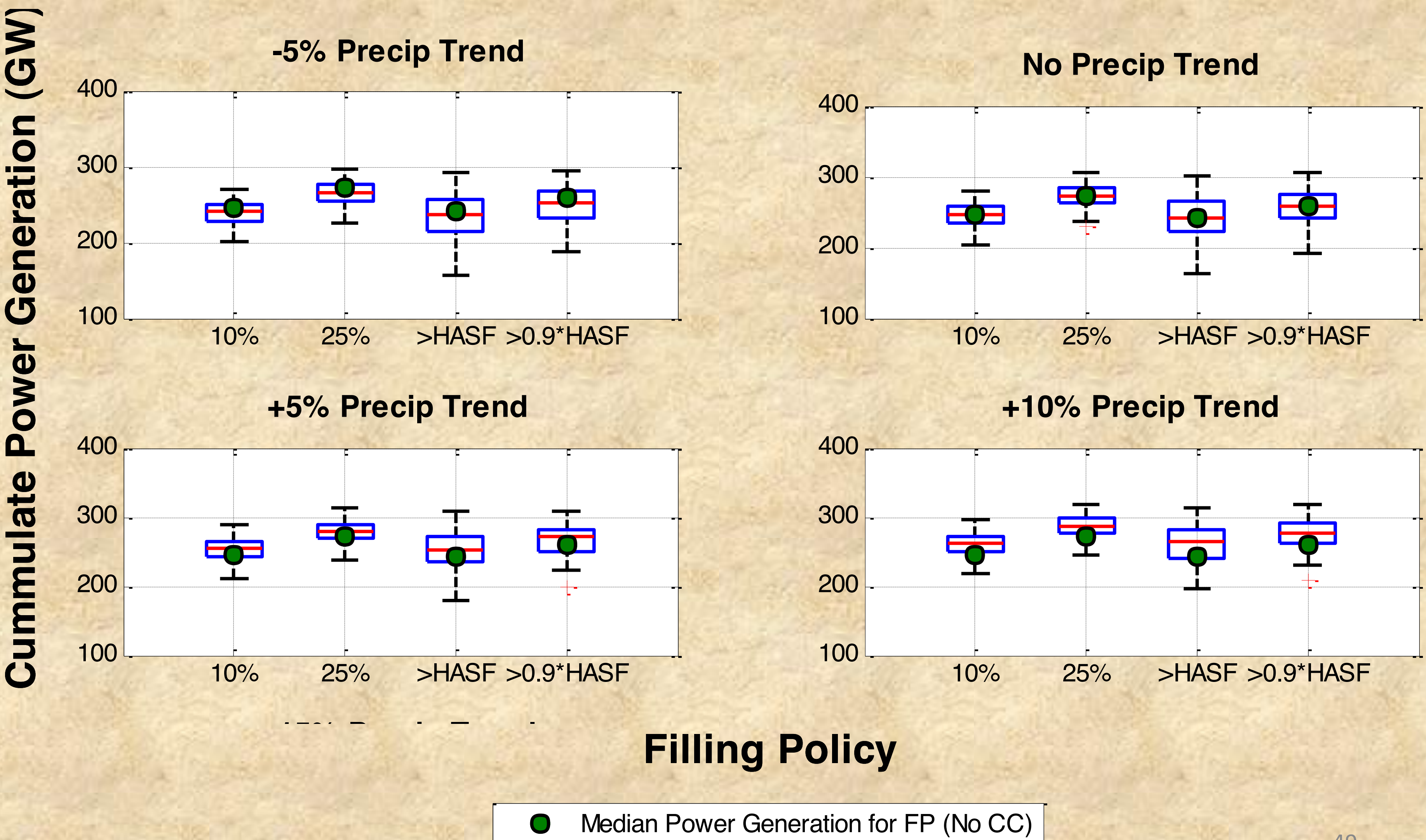
Time to Fill

With climate change



Hydropower Generation

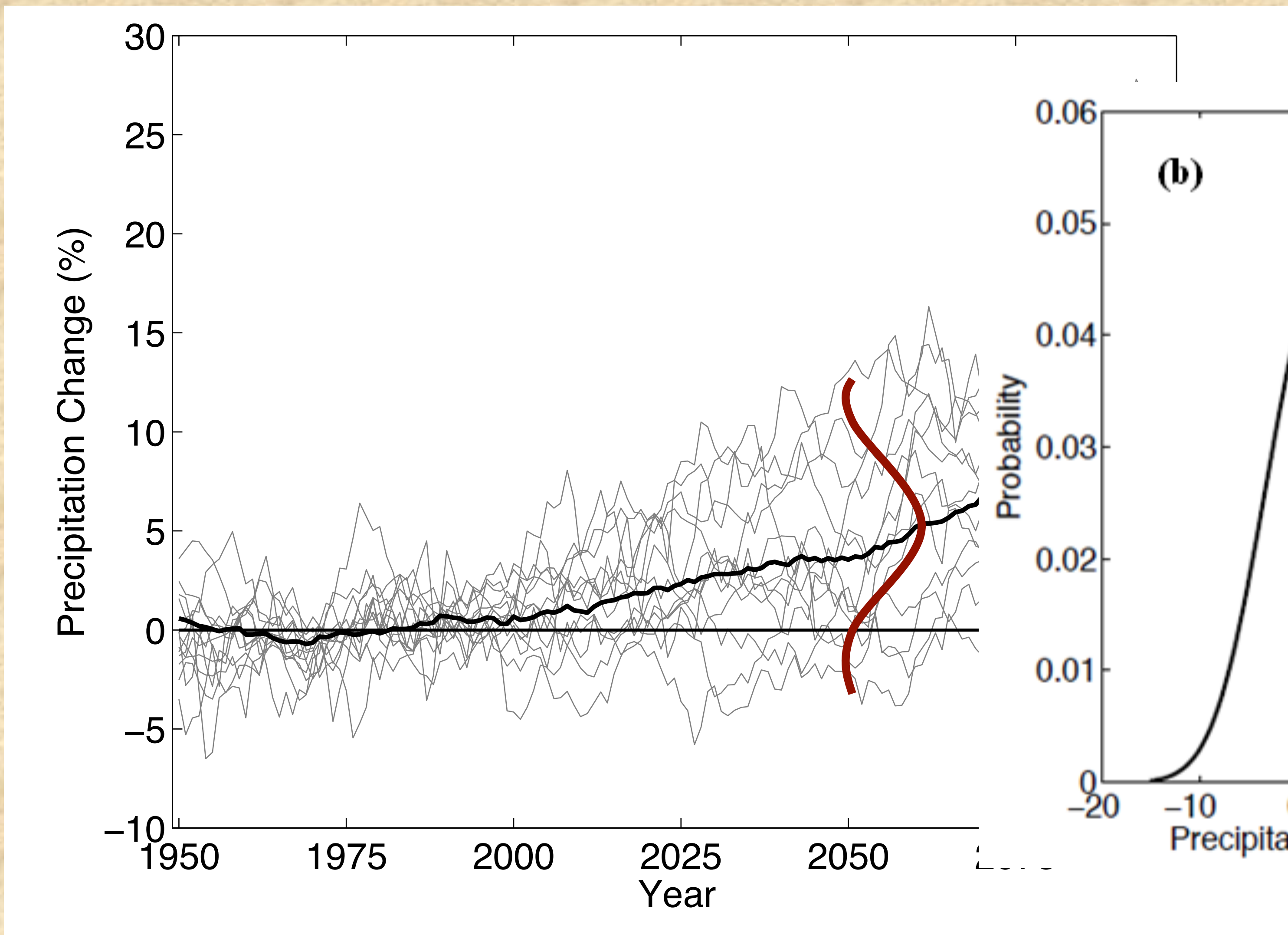
Climate changes & filling policies: 2014-2031

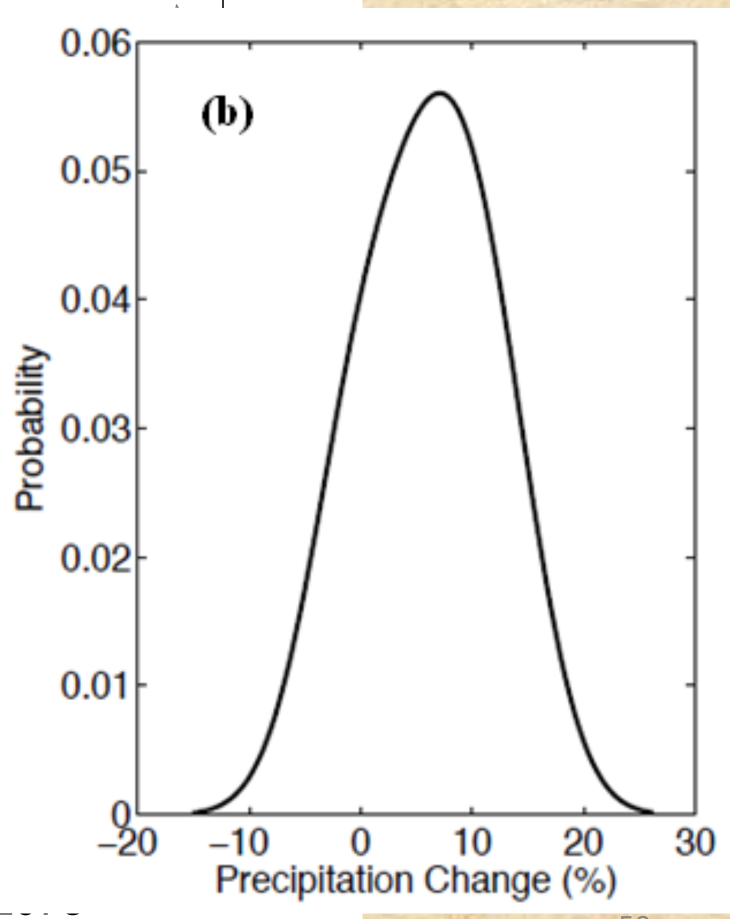


Climate Change: Precipitation

PDF for 2060

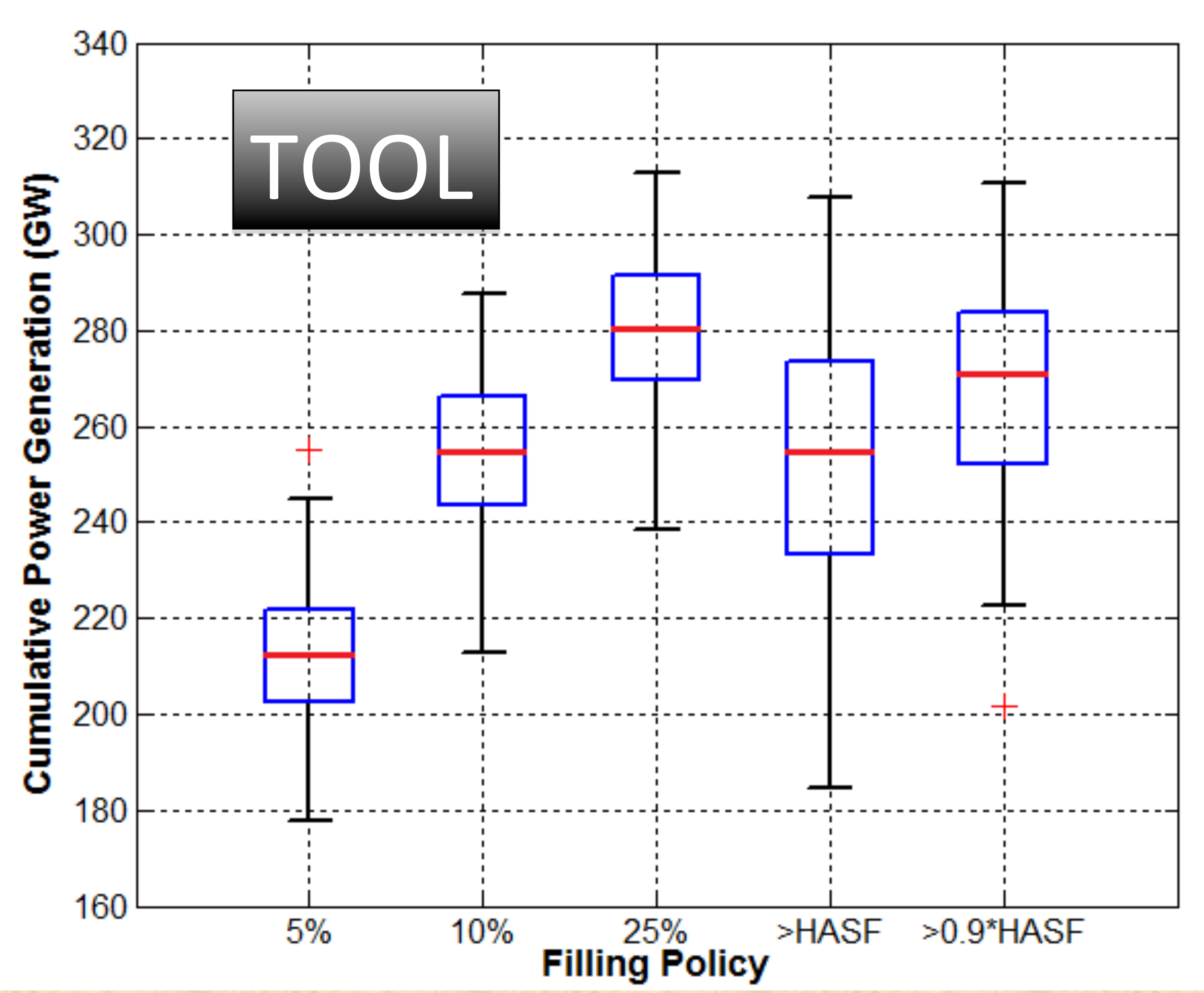
Represent the uncertainty in precipitation projections





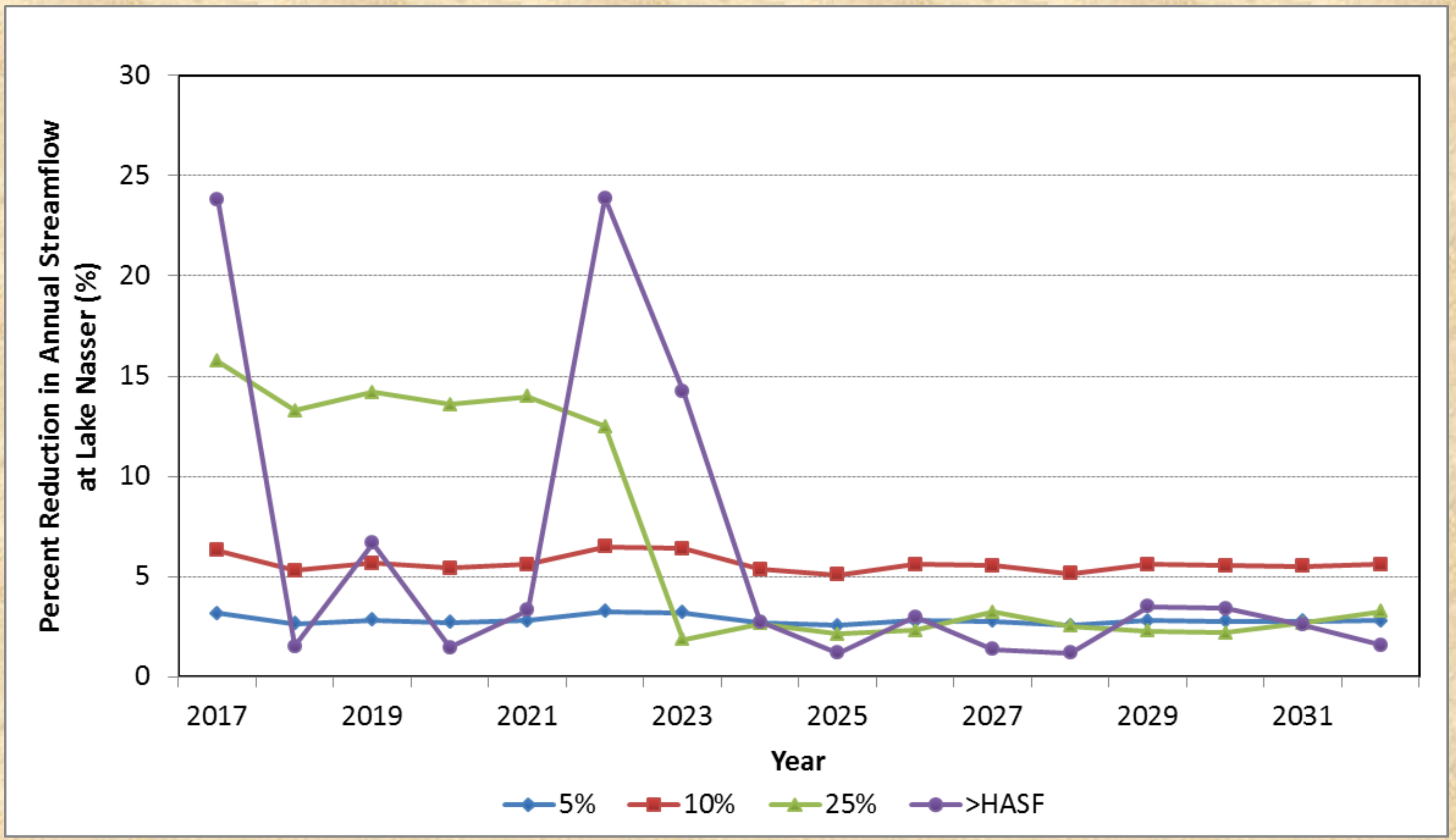
Filling Policy and Weighted CC

Estimated power generation, 2014-2031



Downstream Implications

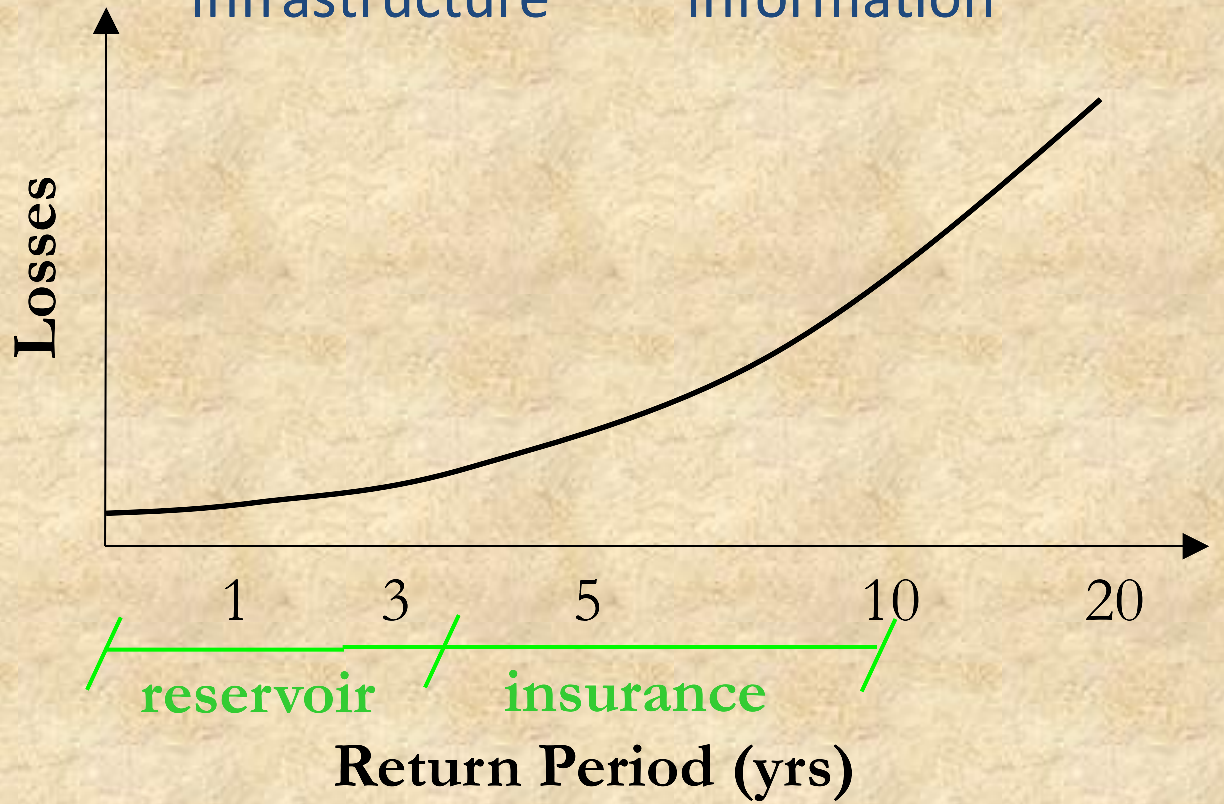
Downstream Implications



May need optimization framework

Layered Risk Management

Infrastructure + Virtual (soft) Infrastructure + HydroClimate Information + Capacity



- Relevant at all time scales: variability and change
- Allows for risk transfer
- All aspects require 'investment'

Final Thoughts

Proper decision making requires:

- All plausible outcomes taken into consideration
- Trade-offs evaluated (power, agriculture, streamflow reduction)
- Engineering design within a political context

Knowing is not enough;

we must apply.

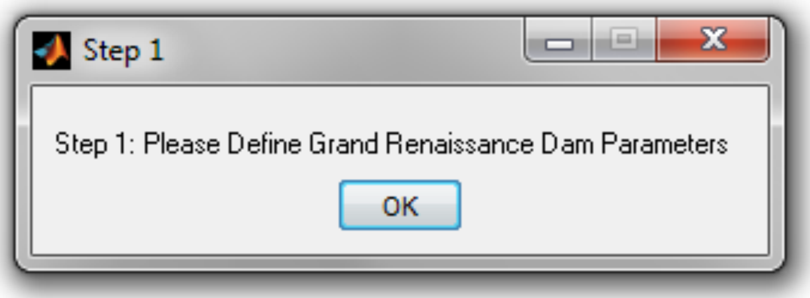
Willing is not enough;

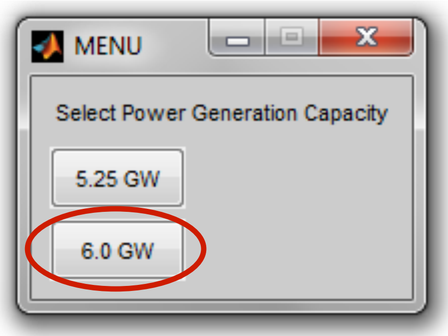
we must do.

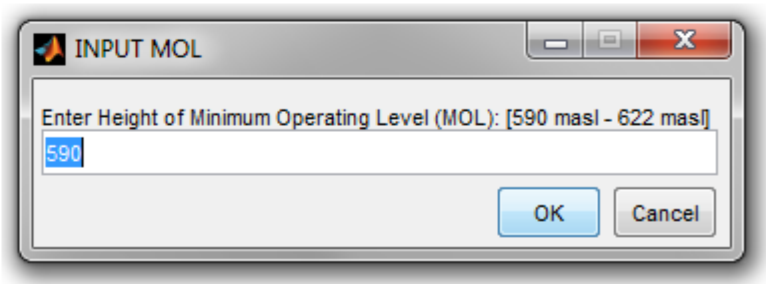
~Goethe

Credit: UN

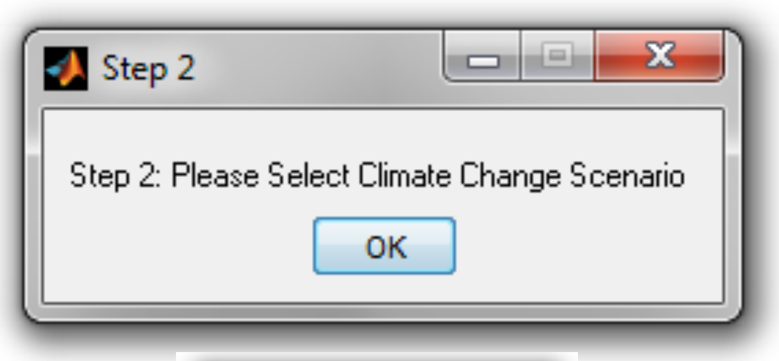
Reservoir Specifications

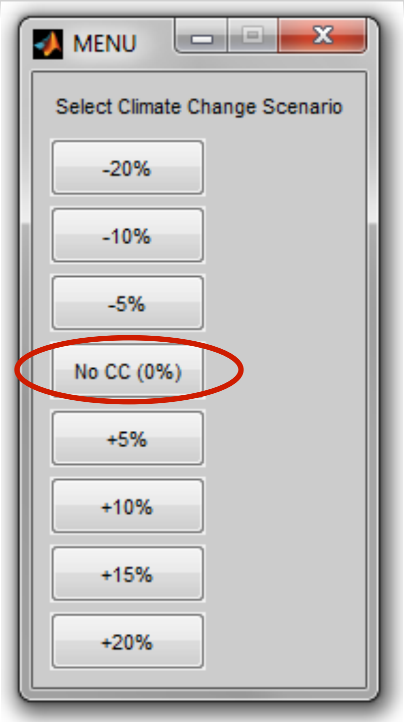


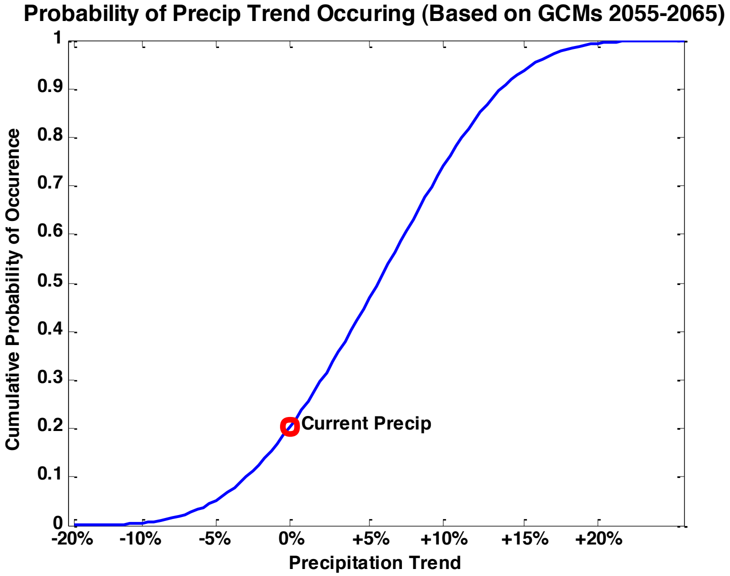


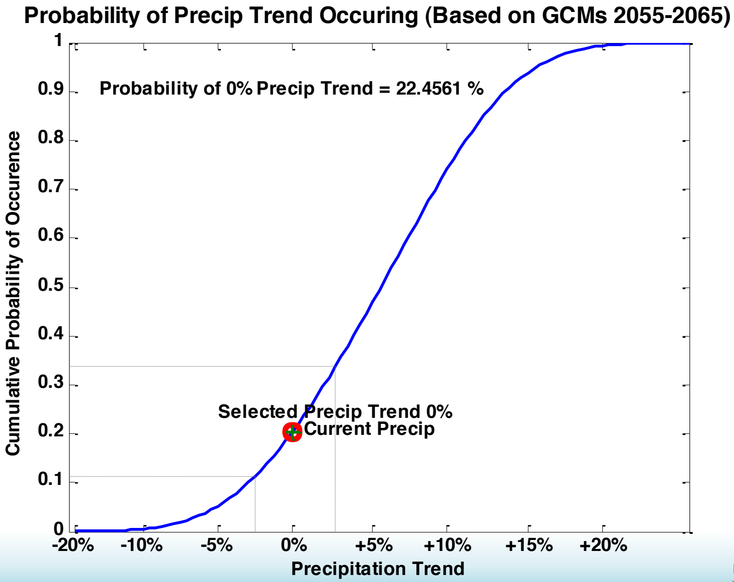


Precipitation Trend

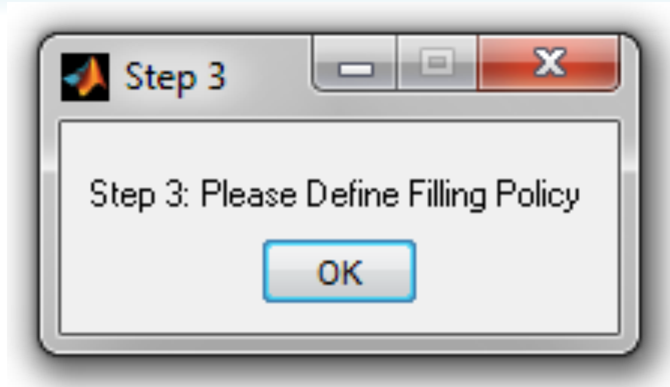






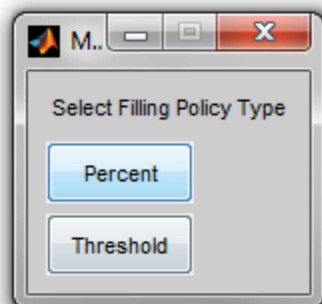


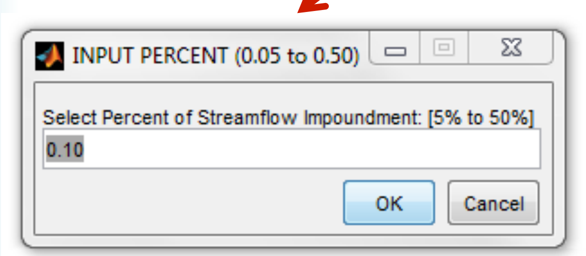
Filling Policy

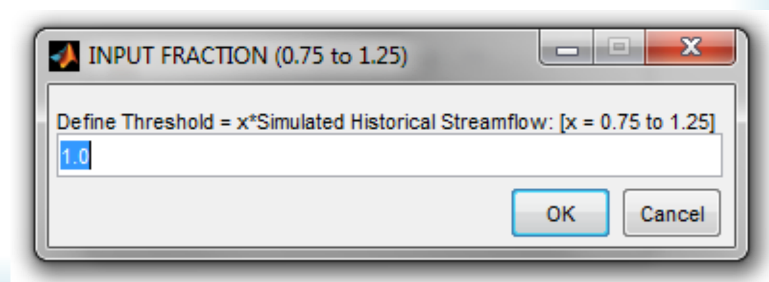


Percent based filling policies allow a selected fraction of the influent Blue Nile streamflow to be retained in the reservoir

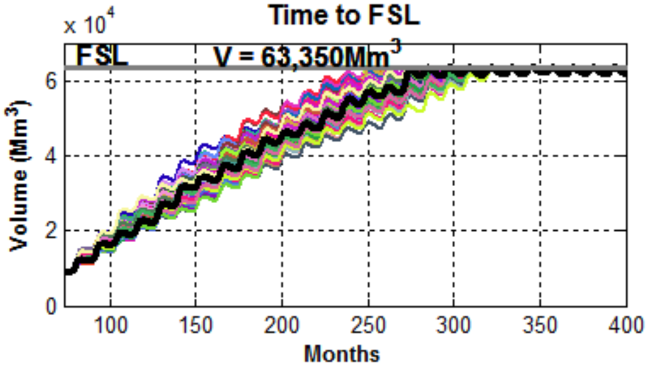
Threshold based filling policies require that the monthly influent streamflow surpass a selected factor times the simulated historical average streamflow

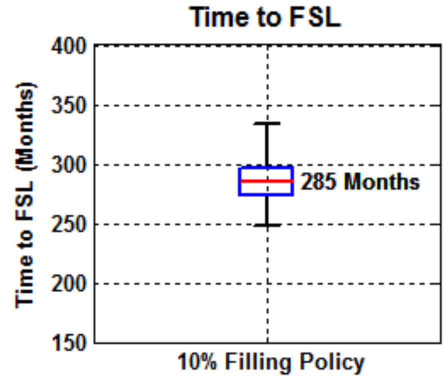


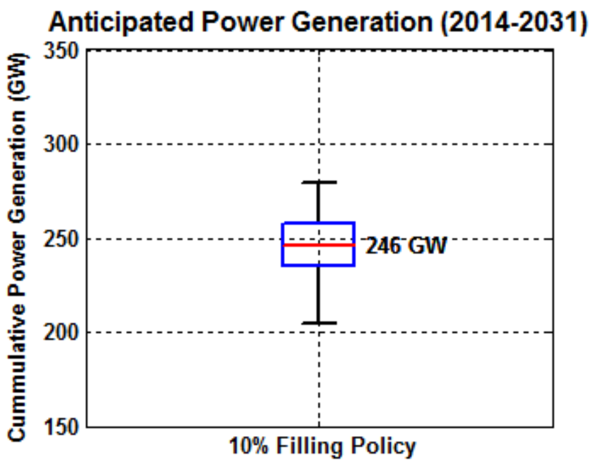


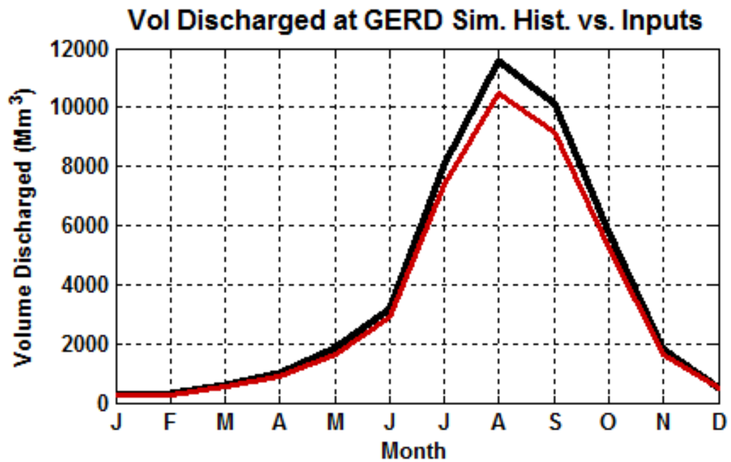


Resulting GERD Performance





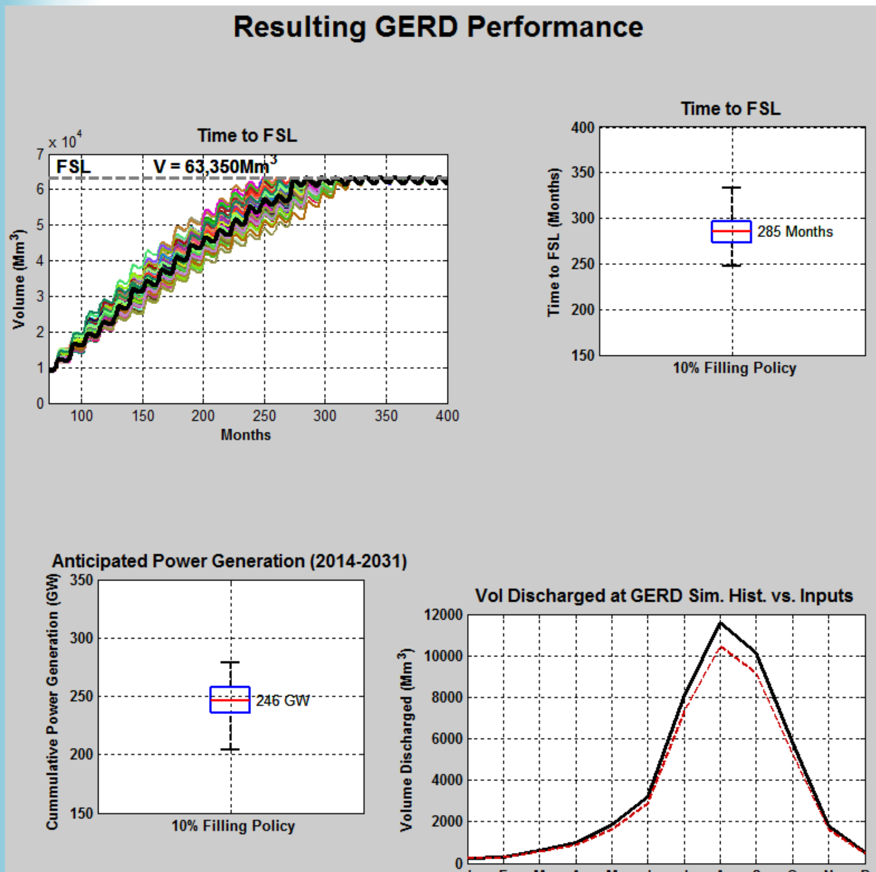




Results for Inputs of:

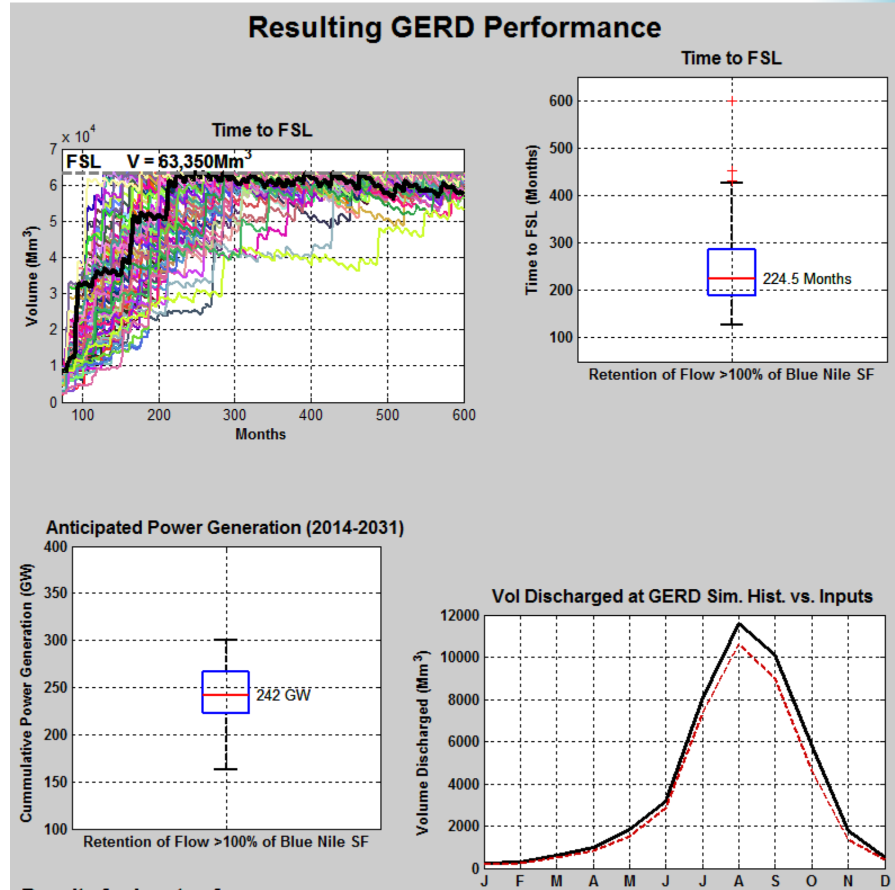
- Power Gen. Capacity = 6.0 GW
- Minimum Operating Level (MOL) = 590 masl
- No Climate Change Trend
- Filling Policy = Retain 10% of Blue Nile Inflow

Compare Results



Results for Inputs of:

Power Gen. Capacity = 6.0 GW
Minimum Operating Level (MOL) = 590 masl
No Climate Change Trend
Filling Policy = Retain 10% of Blue Nile Inflow

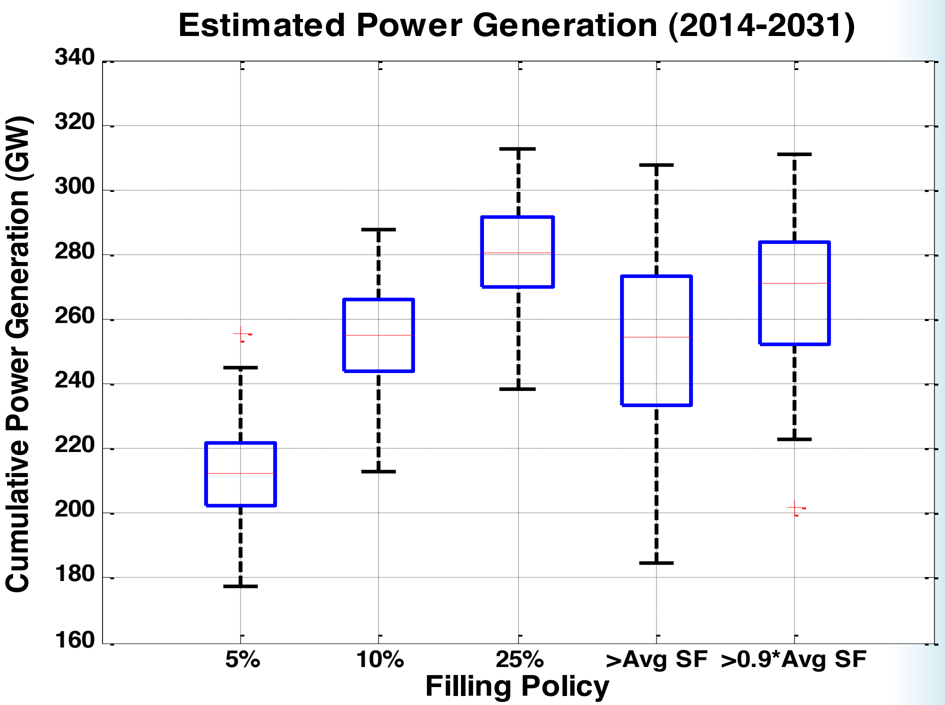


Results for Inputs of:

Power Gen. Capacity = 6.0 GW
Minimum Operating Level (MOL) = 590 masl
No Climate Change Trend
Filling Policy = Retention of Montlhy Flow >100% of Simulated Historical Blue Nile Stream Flow

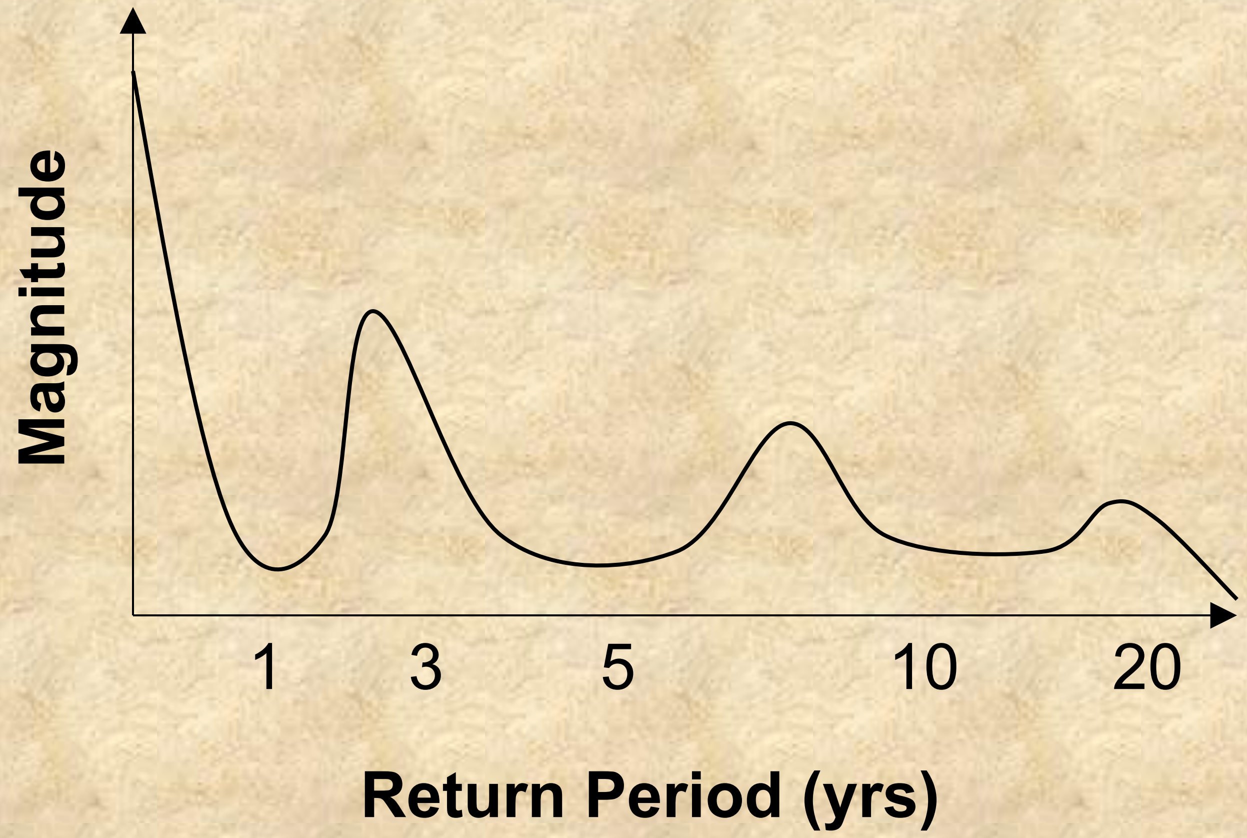
GCM Weighted Power Production

- Power generation outputs based on the likelihood of the precipitation trends

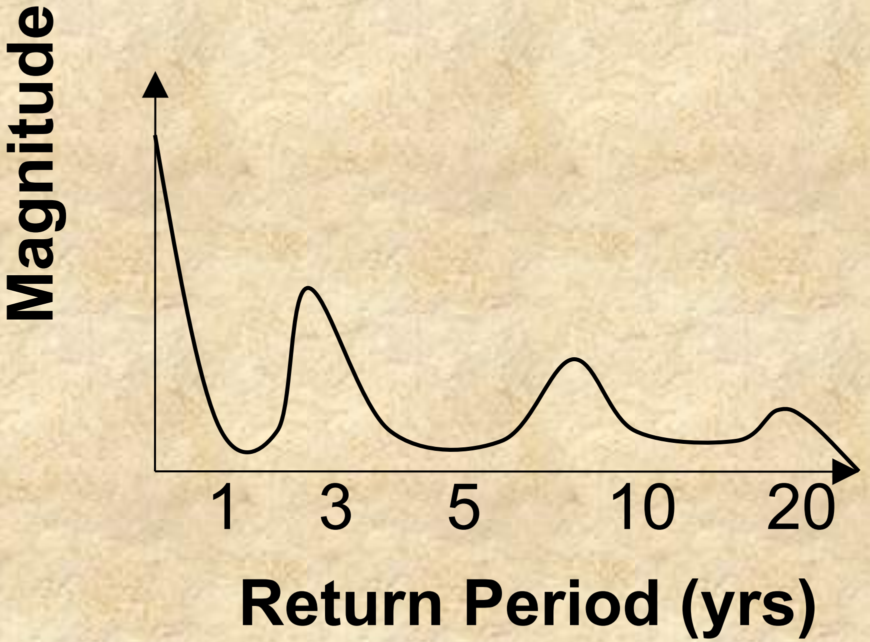


Climate Risk Management

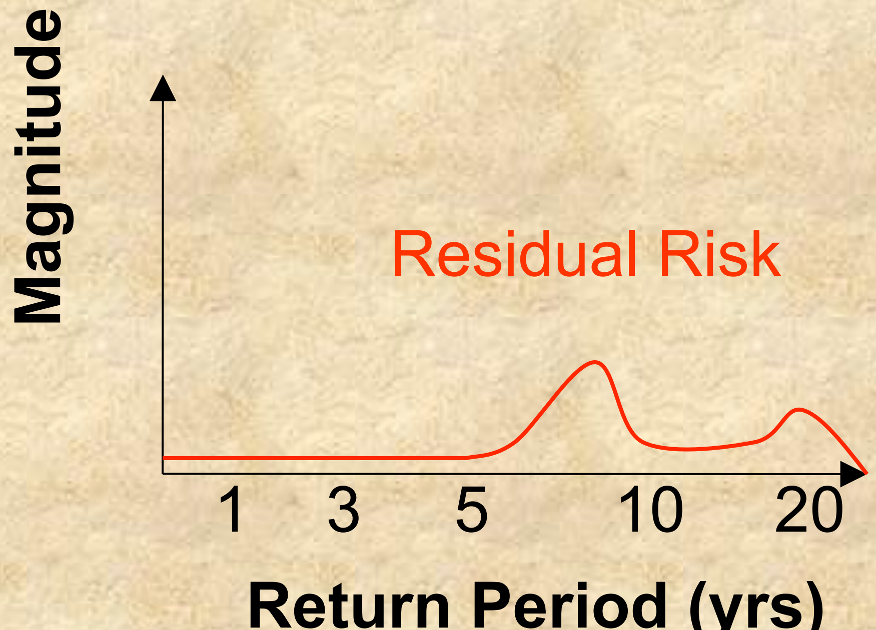
Illustration – Risk spectrum



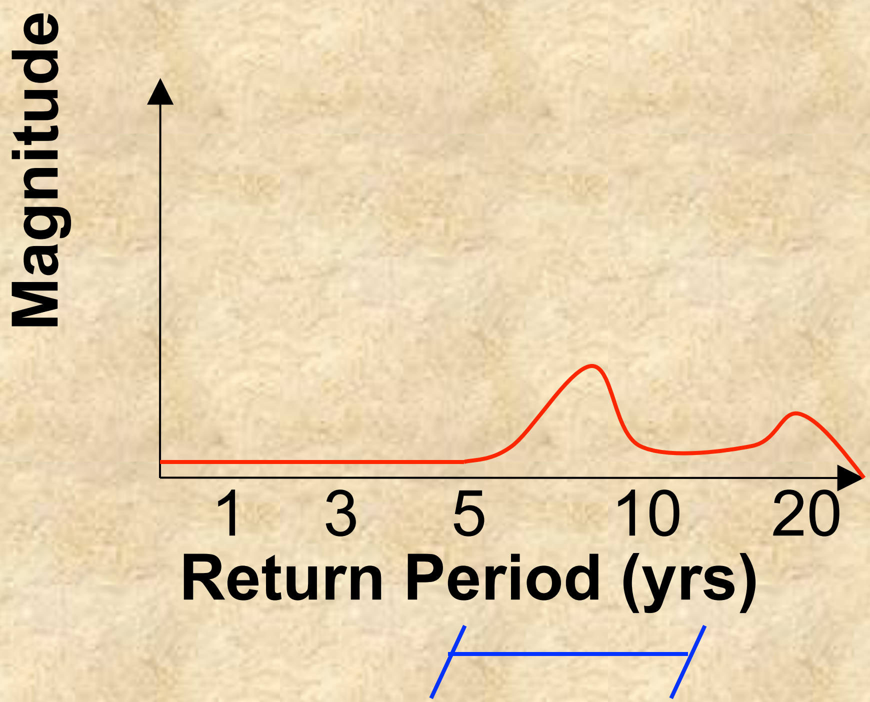
Climate Risk Management



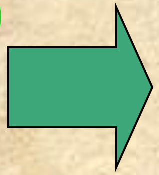
Add multiyear reservoir

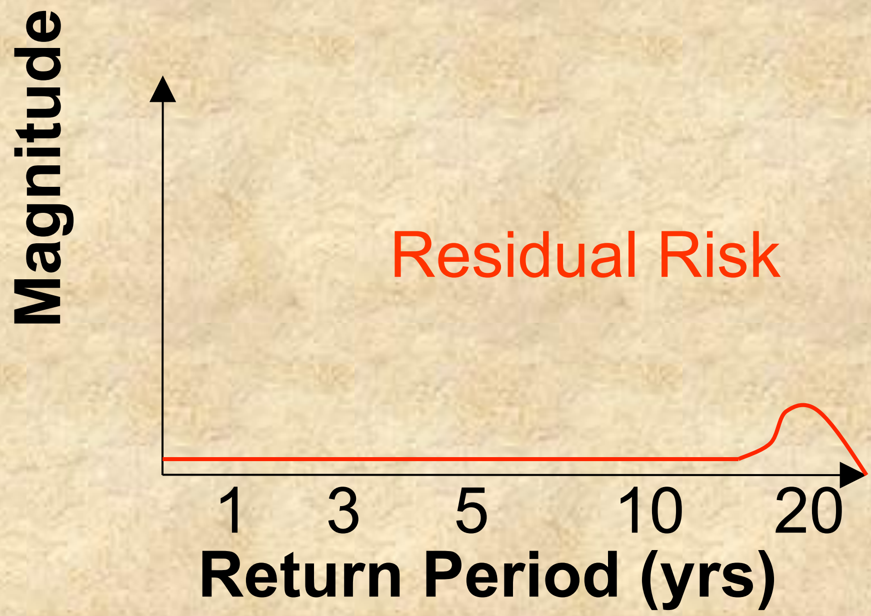


Climate Risk Management



Add option contracts (insurance)





Intra-basin transfer?

Weather vs Climate

In 2011, 14 events surpassed $1 billion in damages each

NWS (NOAA)