The Science of Global Hydrology: *Lessons from the U.S. Northeast Corridor*

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UNIVERSITY of NEW HAMPSHIRE

Fall Water Institute Seminar Series
University of Florida 6 November 2007

Goals for This Discussion

- Describe chief forces shaping the contemporary and future water system --*the globe, the U.S., the region*
- Highlight contributions from Earth system science & technology to strategic water assessment and forecasting
- Announce a NE corridor community-based hydro-synthesis effort

For the Global Climate Challenge

A Scientific Data Set That Has Mobilized the Politics of a Planet

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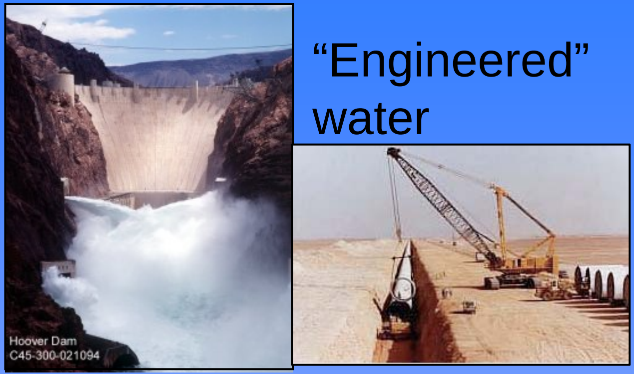
Global Water Resource Challenges

Sanitation and access to clean water

"Engineered" water



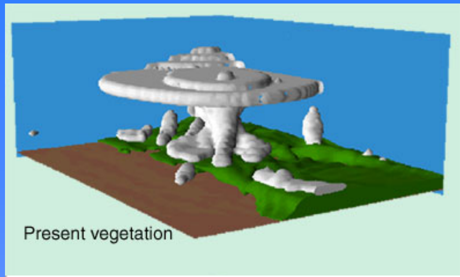
Water for development

Food security

Weather extremes

Maintaining aquatic ecosystem services

Pollution

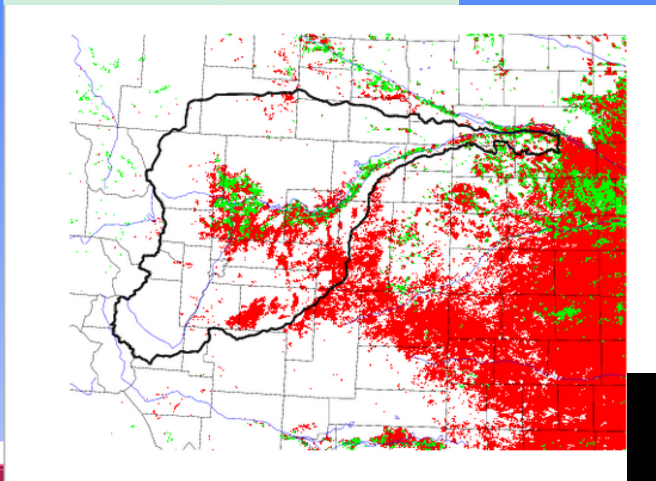


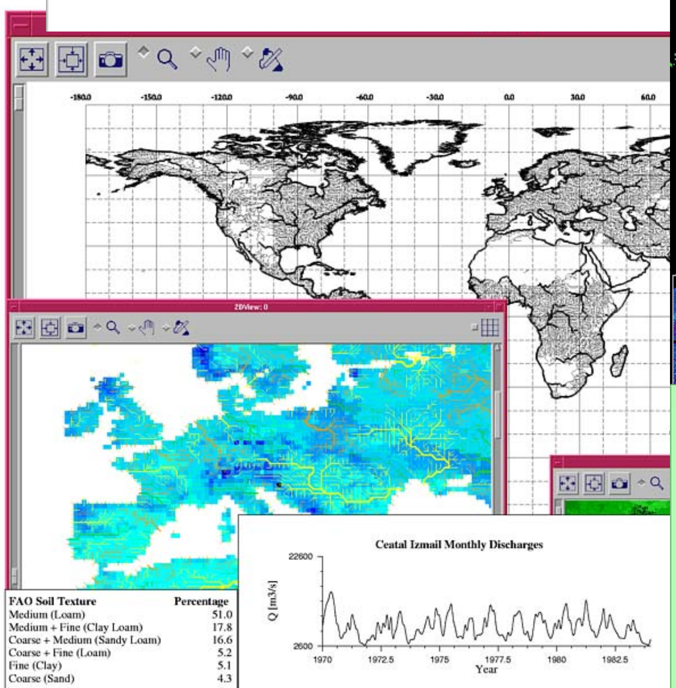
Contributions from Earth System Science

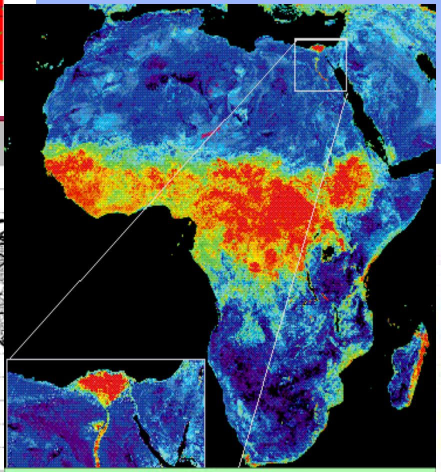
- *In situ* networks
- Operational satellite-based monitoring of the hydrosphere
- Simulation models and data analysis tools (NWP-4DDA, GCMs, RCMs, ESMs)
- Geo-referenced social science data

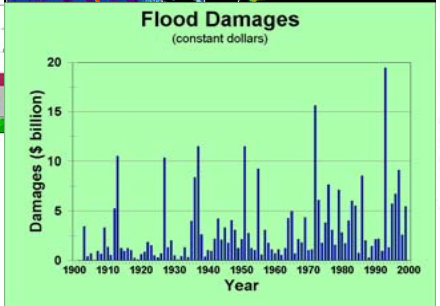
…are creating new ways to view the "global water crisis"

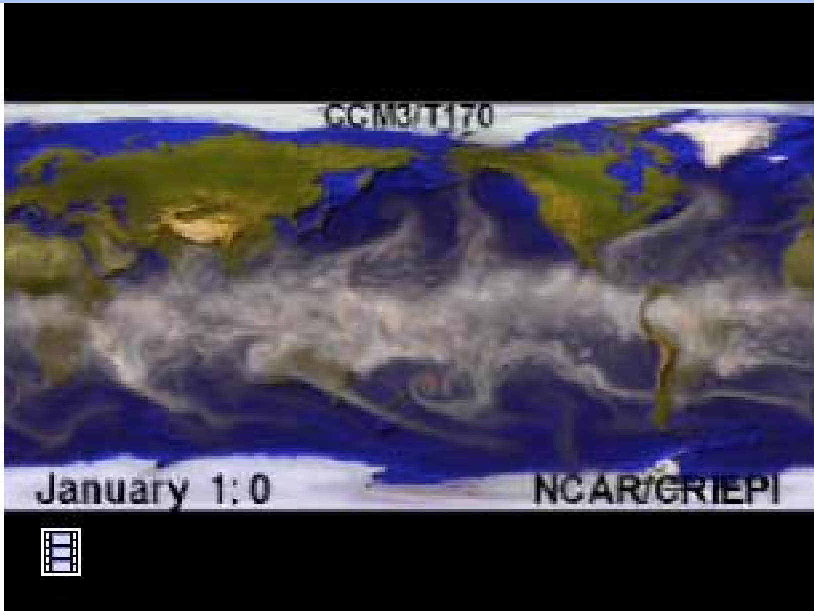
…to inform policy and improve management





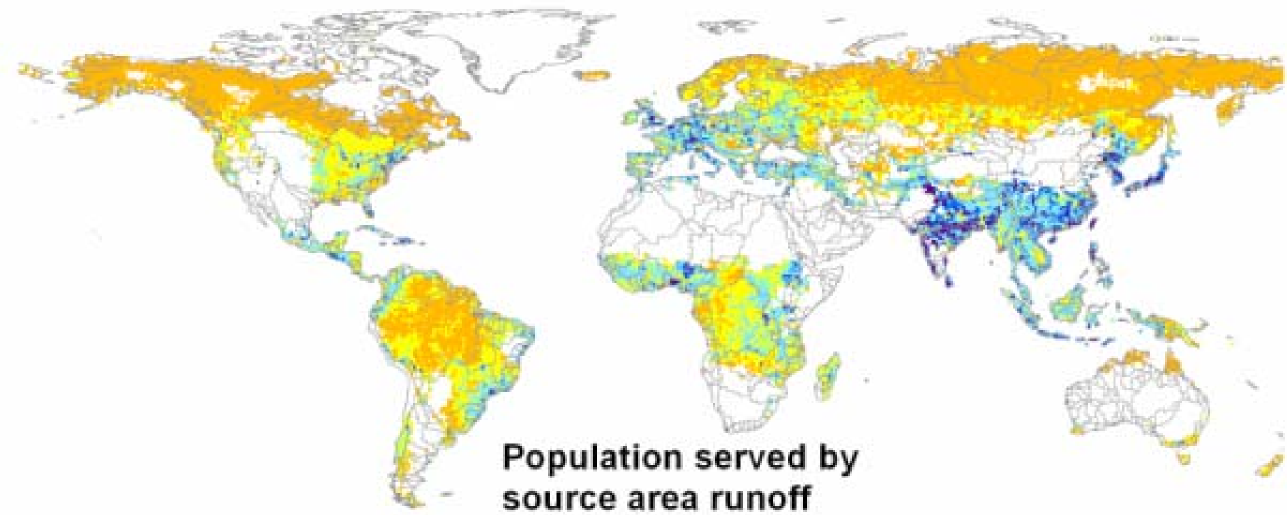






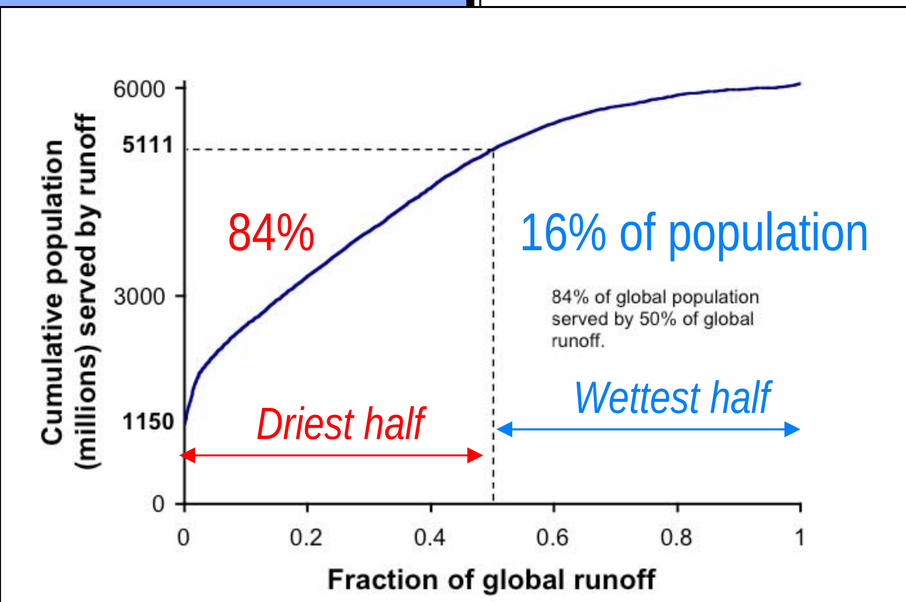
Humans Interacting w/ the Global Water Cycle--

The Picture Today



Population served by source area runoff (thousands per grid cell)

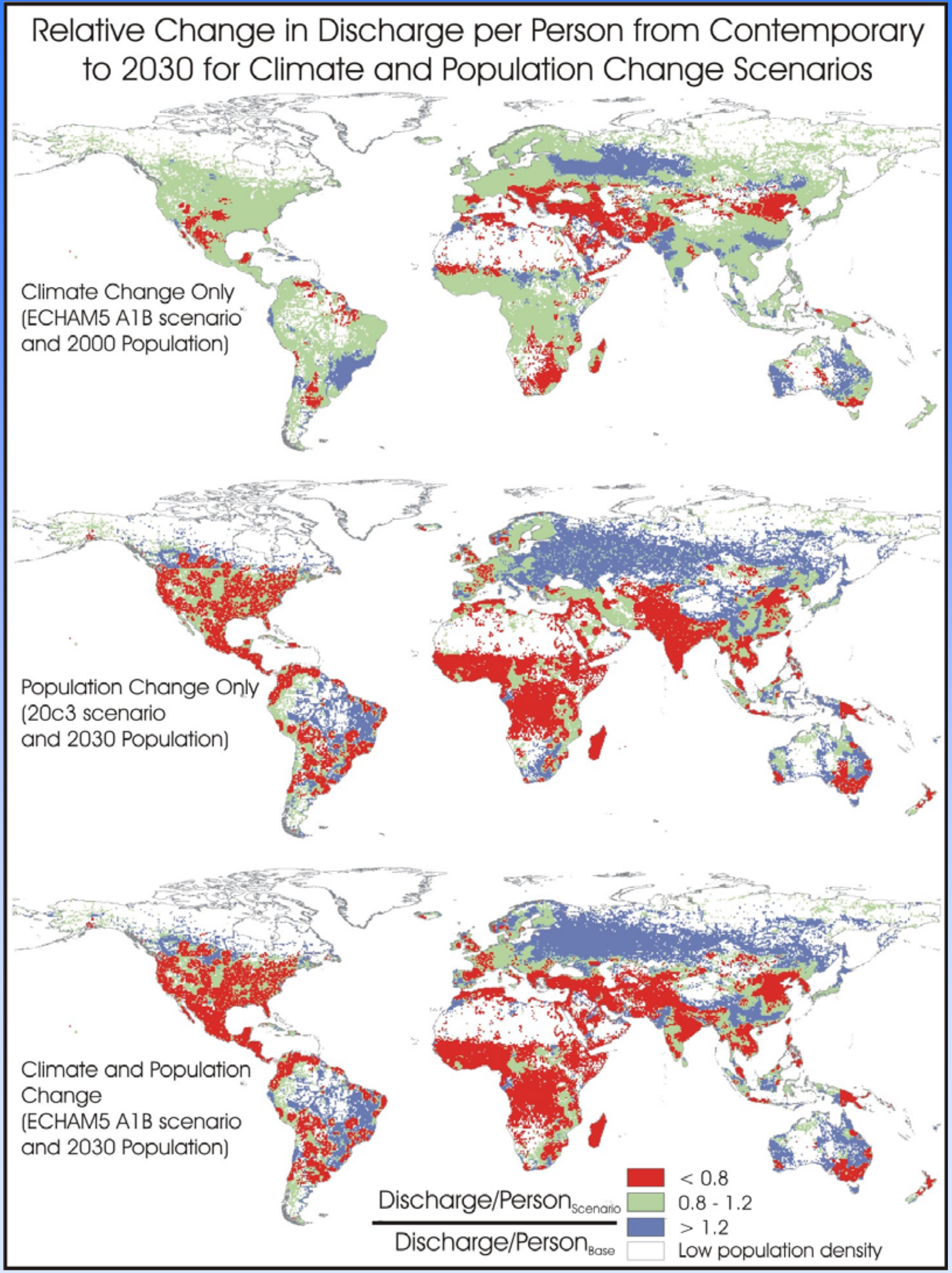
High resolution mapping shows ca. 20% population w/ no access to renewable water supply



Vörösmarty et al. (2005), Millennium Assessment, Conditions & TrendsWorking Group

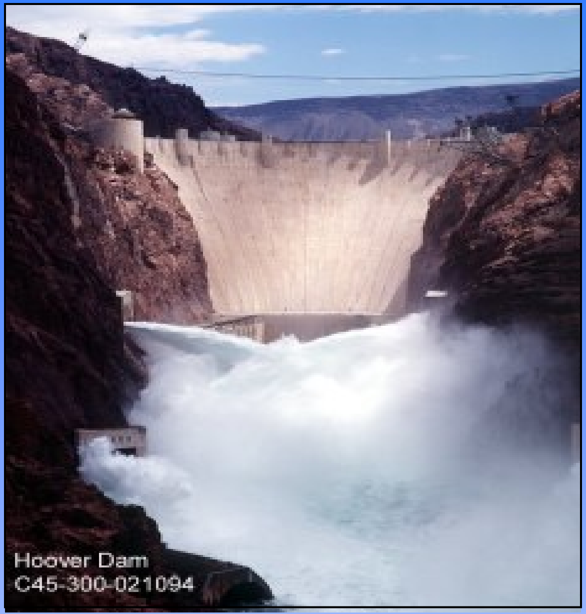
- Importance of upstream source areas: note Amazon/S. Asian contrast
- Dry half to experience increasing pressure on water resource base

- Climate Change only part of our water resource worries
- Population growth and economic development another critical issue



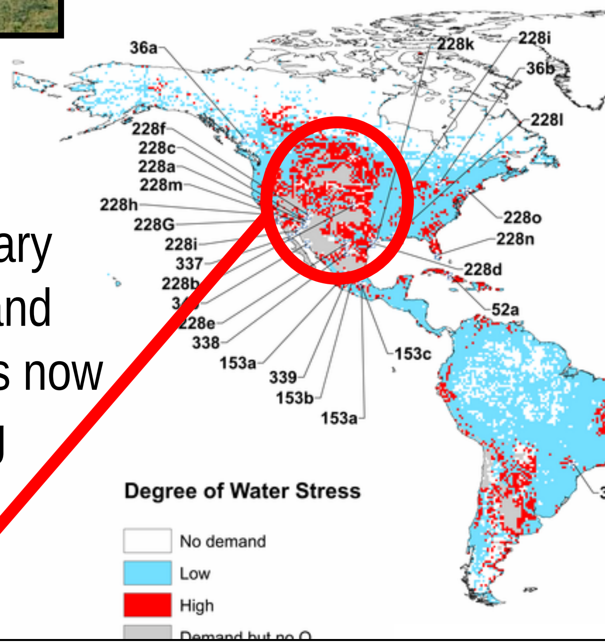
More People, More Development, Means More Water Engineering

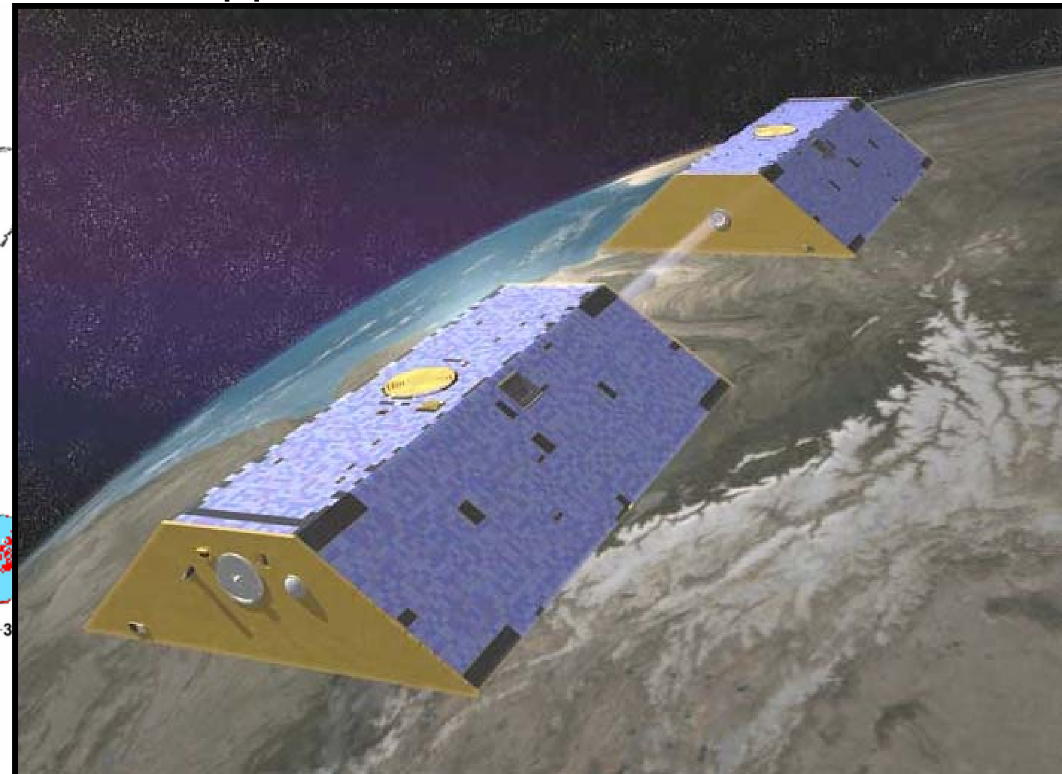
- Widespread Hydrological Alterations Arising from
  - *Irrigation*
  - *Dams and Reservoirs*
  - *Interbasin Transfer/Flow Diversion*
- Benefits & Concerns
- Often These are Costly Supply-side Solutions



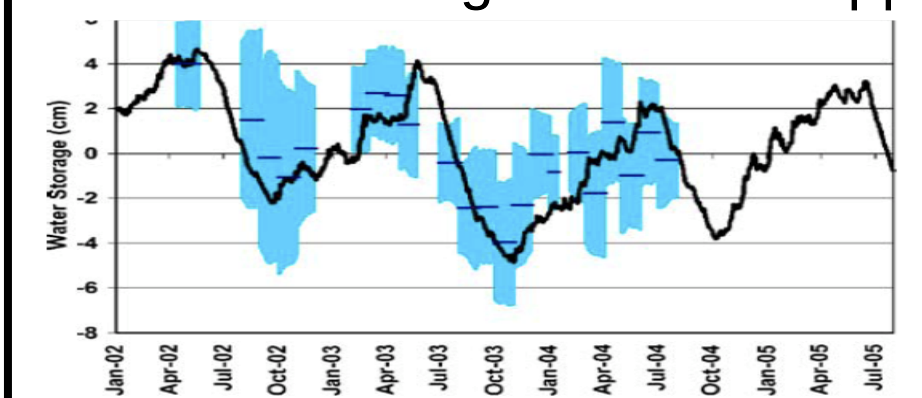
Irrigation & Urban Water Use in Excess of Sustainable Supplies

Documentary evidence and simulations now converging





GRACE Δstorage for Mississippi

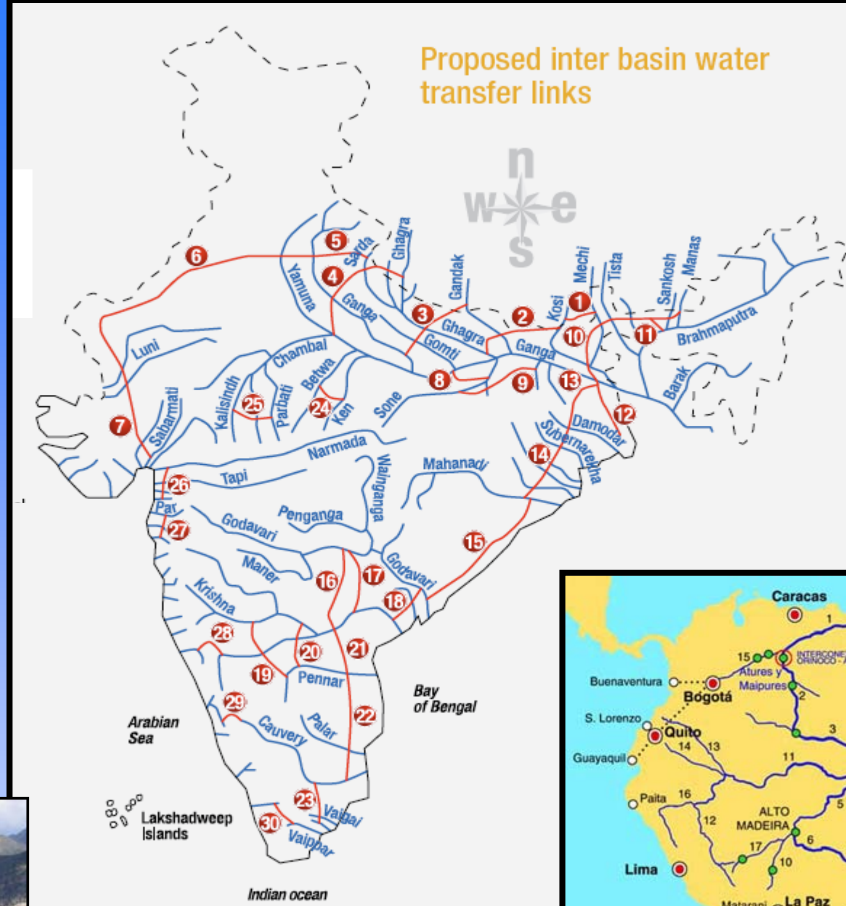


Western US Basin Transfers

Great Man-Made River Project, Libya

Physical Tele-Connections: Inter-Basin Transfers & Flow Diversions

- Costly 'hard path'
- Engrain patterns of overuse
- Creates a biodiversity teleconnection on both nature & economies

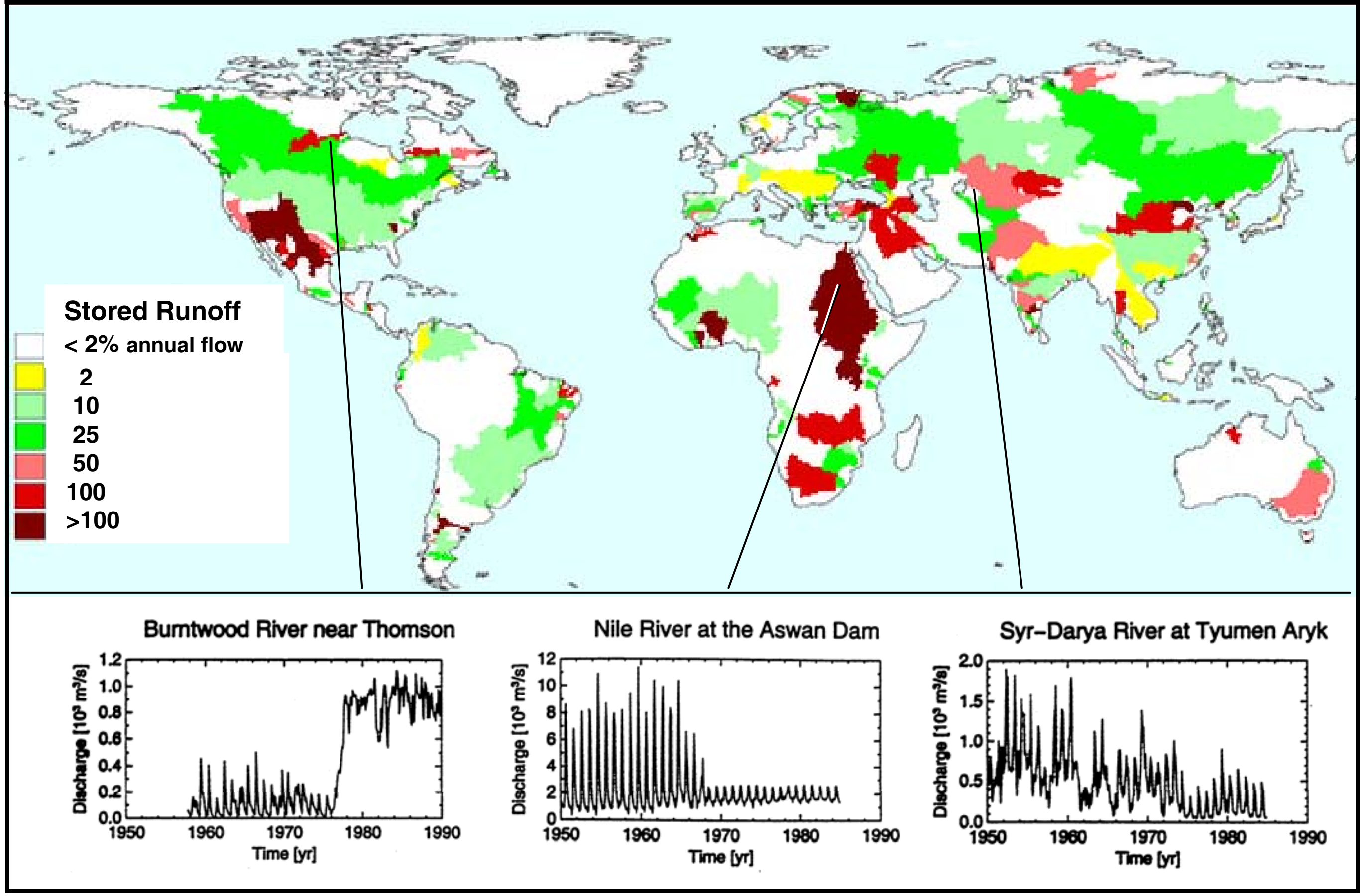


Forced by food security issues

35,000 km of hydrovias…. direct links to globalization & food trade

PANDEMIC ENGINEERING OF SURFACE WATERS

Distortion of Natural Hydrographs

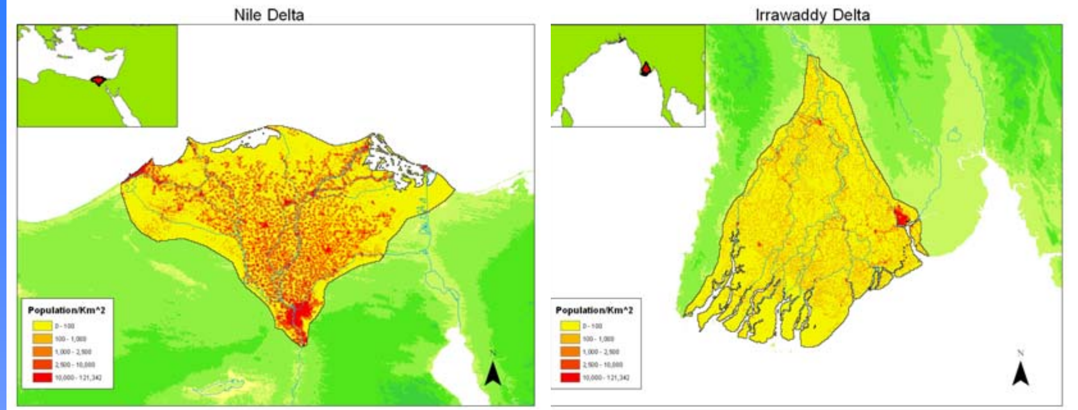


- 700% increase in water held by river systems
- Several years of residence time change in many basins
- Tripling of river runoff travel times globally (from 20 up to 60 days)
- Substantial impact on aquatic biodiversity
- Interception of 30% of continental TSS flux

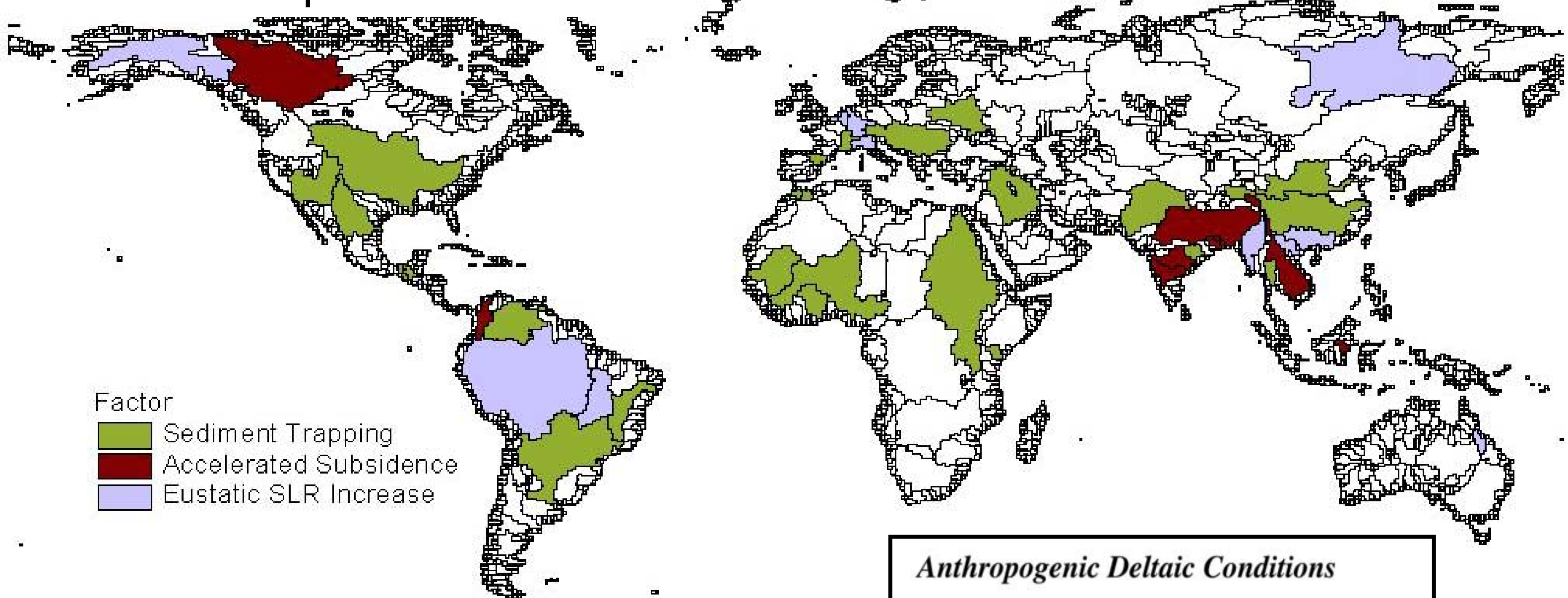
Framing Committee/GWSP 2004, Eos AGU Transactions

Deltas Under Threat

Major Sources of Chronic RSLR:
Eustatic Sea Level Rise Only
Part of the Story



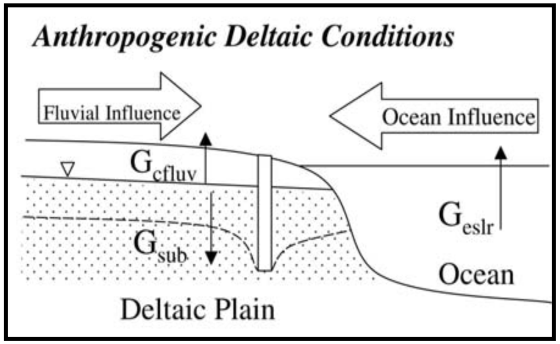
Global Sample of 40 Basins



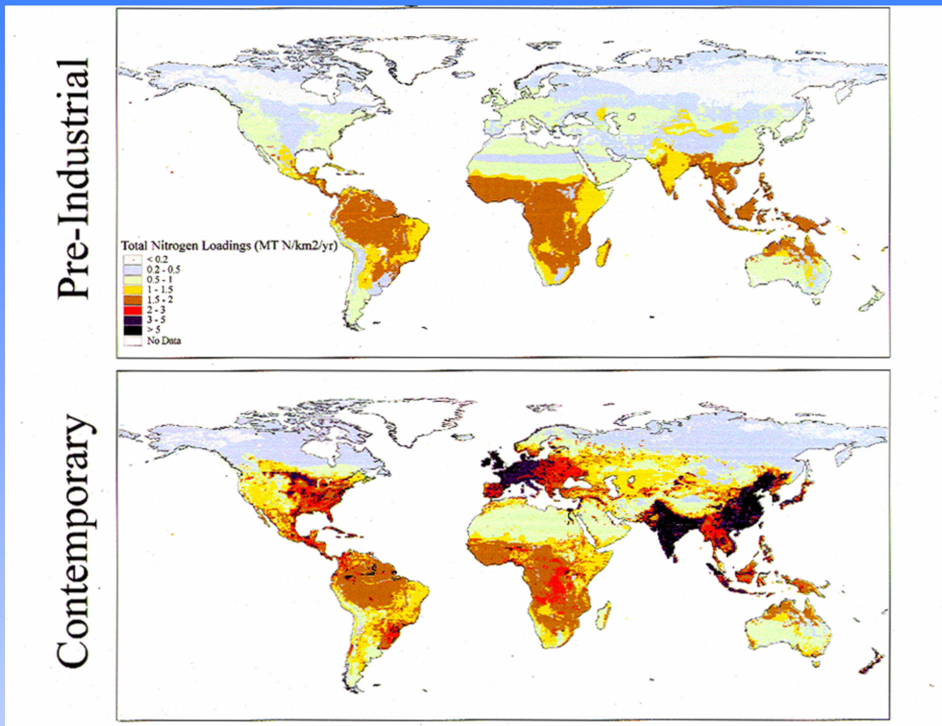
Sources of Change:

- -- 5 Eustatic Sea Level Rise
- -- 8 Groundwater/petroleum extraction
- -- 27 Upstream sediment trapping & diversion

Ericson et al., 2006, *Global and Planetary Change*



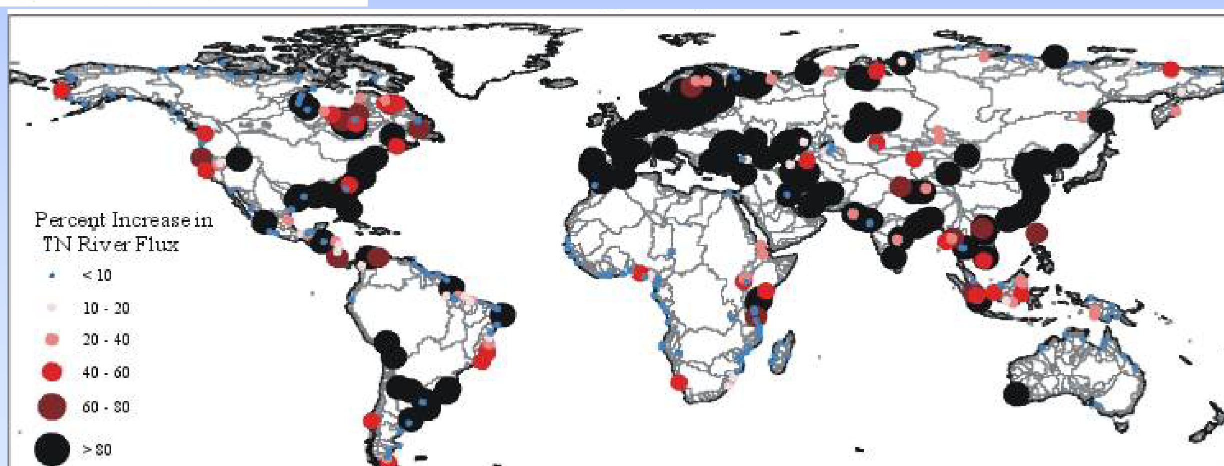
Water Supply-- Doubling of Global Nitrogen Pollution



Obvious consequences on: water resources, aquatic biodiversity, human health

Terrestrial Loading

% Change in River Fluxes



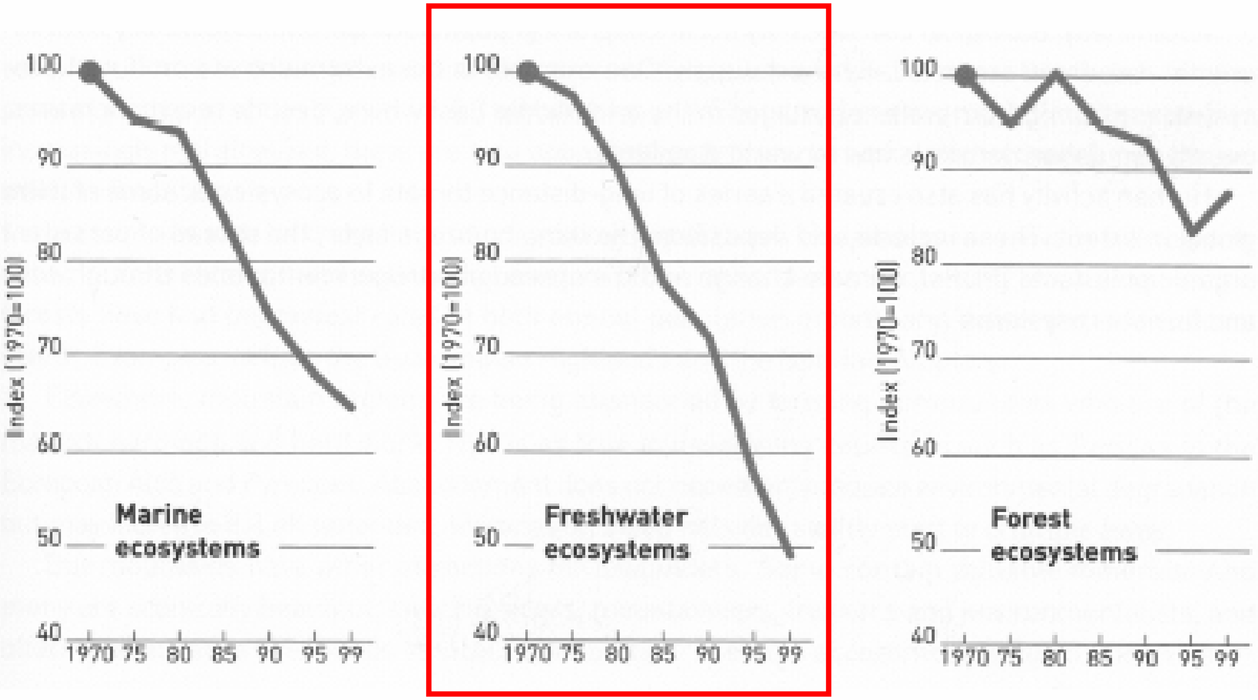
Green et al. 2004; Biogeochemisty

(GWSP Theme 3) RESILIENCY STUDIES

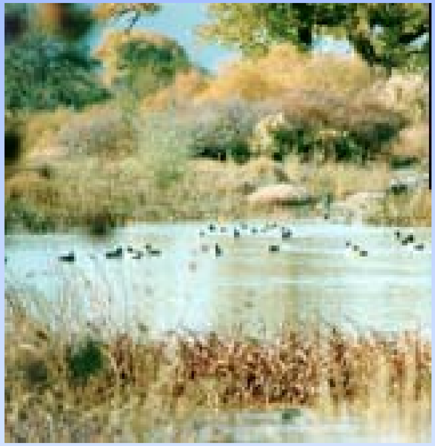
Status of aquatic biodiversity ?

Links to hydrology and environmental flows? Pollution? Poor governance?

The Living Planet Index, 1970-99



The Living Planet Index, developed by the World Conservation Monitoring Centre (UNEP-wCMC) and WWF, provides an indicator of the health of the three major ecosystems types of the planet. It is based on the population trends of marine, freshwater and forest species.



Earth System Science Partnership

GWSP Global Water System Project

Provision of Clean Water and Sanitation:
A Millennium Development Imperative & Destabilizing Force

<u>1.1 billion</u> people lack clean drinking water

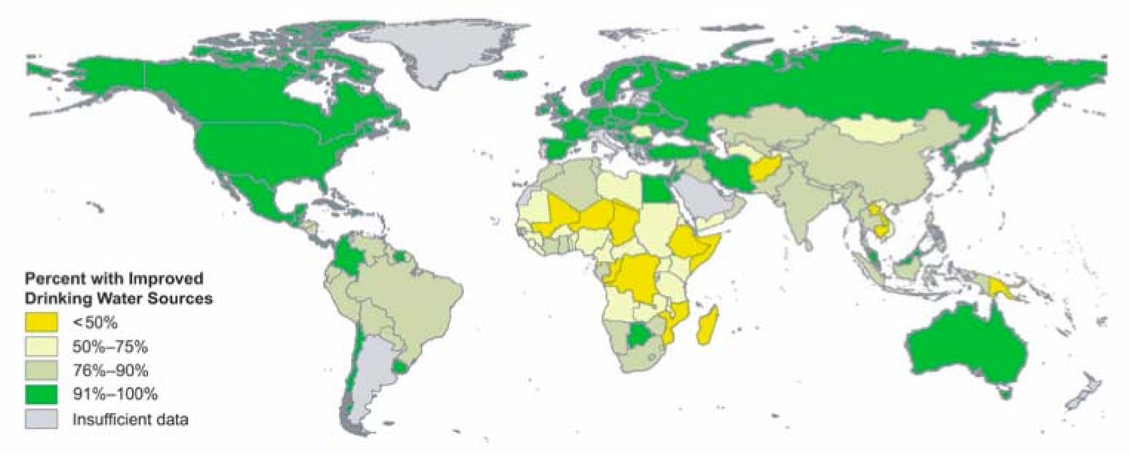


Figure 7.13. Proportion of Population with Improved Drinking Water Supply, 2002 (WHO/UNICEF 2004)

<u>2.6 billion</u> people lack basic sanitation

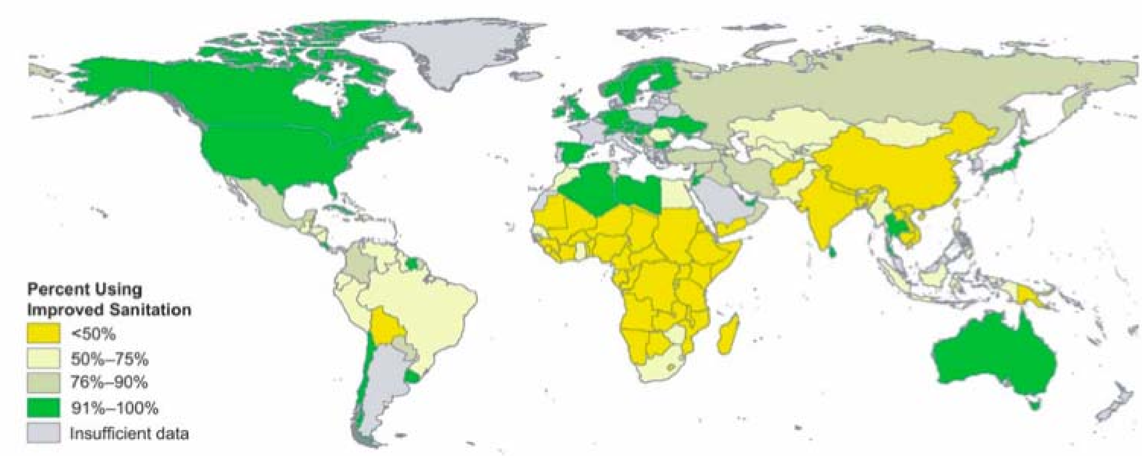


Figure 7.14. Proportion of Population with Improved Sanitation Coverage, 2002 (WHO/UNICEF 2004)

- 1.7M deaths from water-related diarrheal disease
- Annual losses of $85 billion globally from health costs and decreased labor productivity

WHO/UNICEF 2004

NSF-CUAHSI Pilot Synthesis Center Activities (2007-2010)

"Humans Transforming the Water Cycle: Community-Based Activities in

Hydrologic Synthesis"

<u>Central Goal</u>:

To quantify widespread alteration of hydrologic systems over local-to-regional domains focusing on the North East corridor of the United States over a 500-yr period (1600 to 2100)

……..."The 500-year Challenge"

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CUAHSI

Strategic Transformations of Environmental Systems in the NE

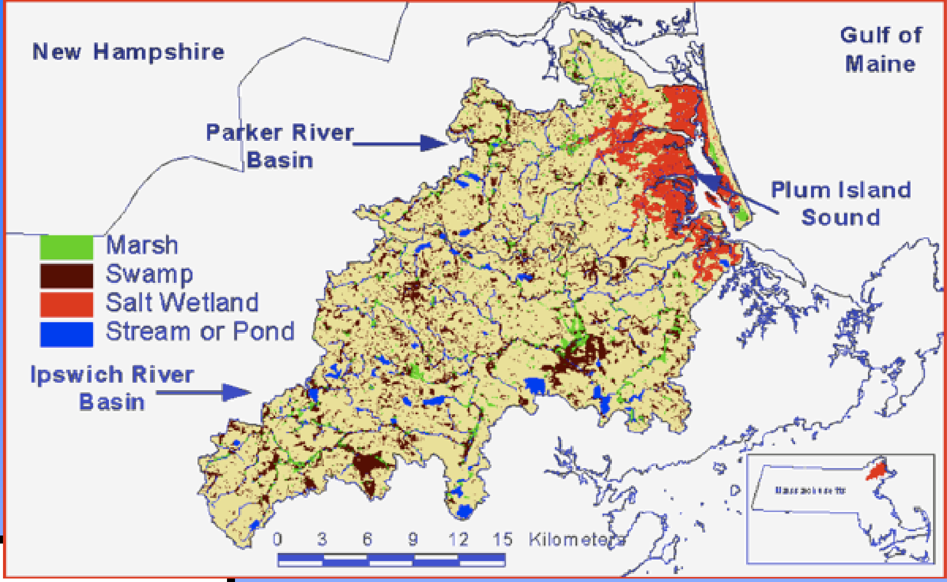
Historical trends of land use and land cover for the Chesapeake region (modified from Brush 1994)

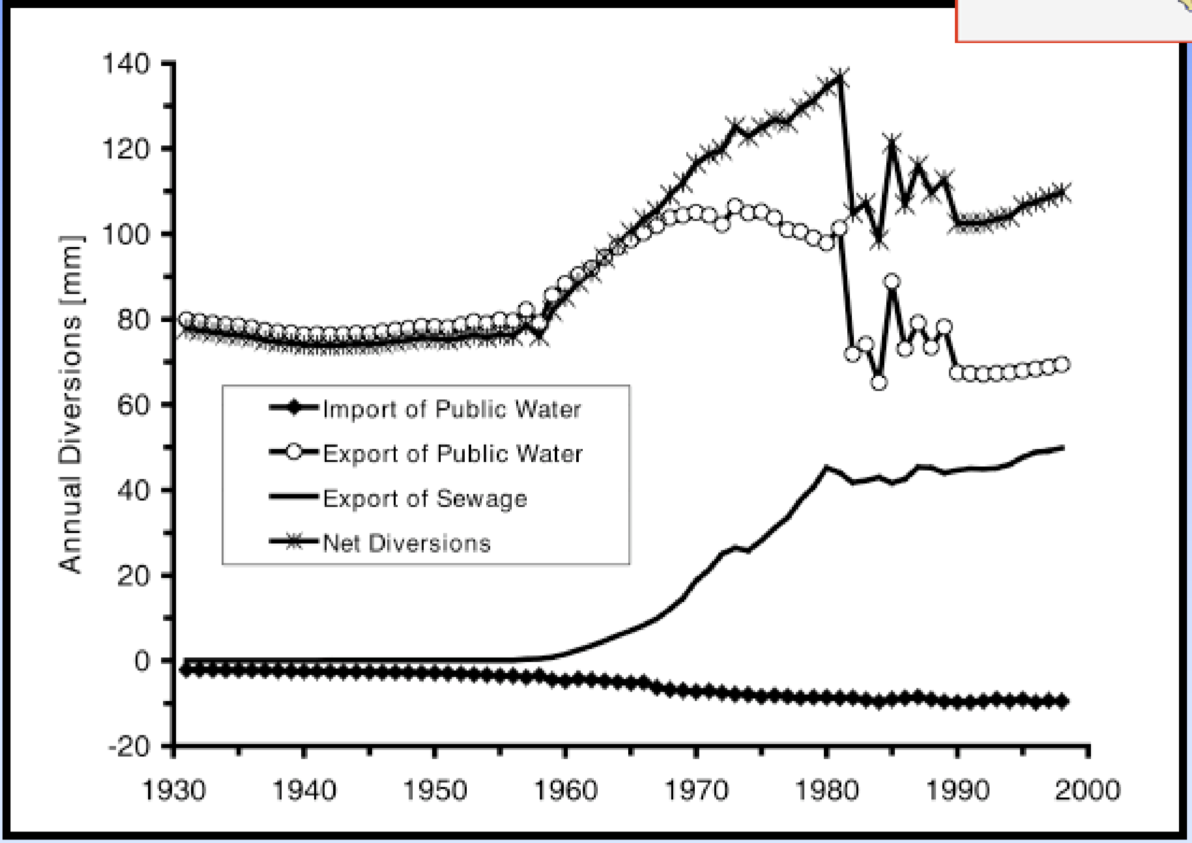
Time Frame	Period	Land-use/landcover characterization
10,000 - 5,000 B.C	Pre-human	Boreal type forest succeeded by hemlock into enclosed canopy mixed conifers-deciduous forest
5,000 B.C.- A.D. 1600	Pre-European	Oak-hickory, closed canopy forest
1600-1800	Early settlement colonial towns	20-40% land cleared for tobacco, grain, small farms, iron furnaces, and construction
1800-1900	Agrarian to industrial	60-80% land cleared for large farms, transition introduction of deep plough and guano-based fertilizers, metropolitan expansion
1900-25	Industrial urbanization	Chemical-based fertilizers, "inter-urban" rail feeding industrial suburbs
1925-50	Automotive urbanization	Increased fertilizers, large farm operations, wetlands drainage, suburban expansion
1950-75	Highway urbanization	Modern highway connections, drive-in commerce, mega-suburbs encroaching upon farmlands, wetlands, forest
1975-90	Modern urban sprawl	Decrease in cultivated land and forest, urban expansion forms, megalopolis
The future	Post-industrial	Regional ecosystem management, climate change, US energy policy carbon mitigation/sequestration, pollution management

Ipswich River (MA)

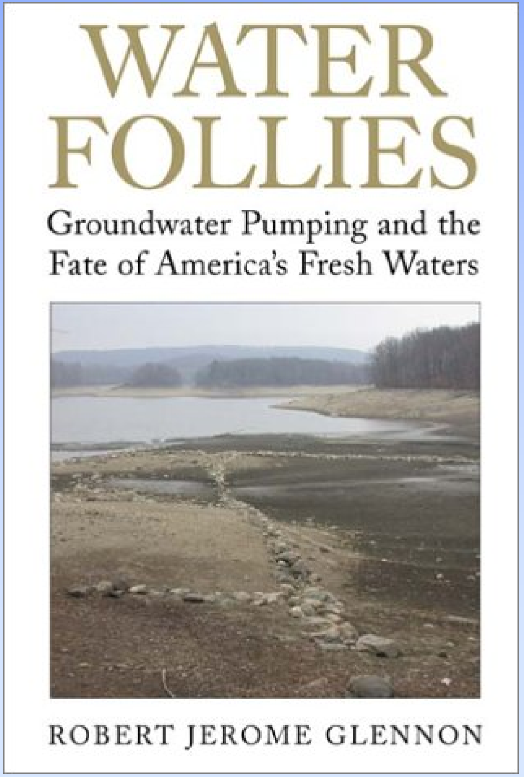
Transboundary Water Engineering

- *Net 20-25% streamflow exported*
- *Complex time series*
- *Induced seasonal water shortages*

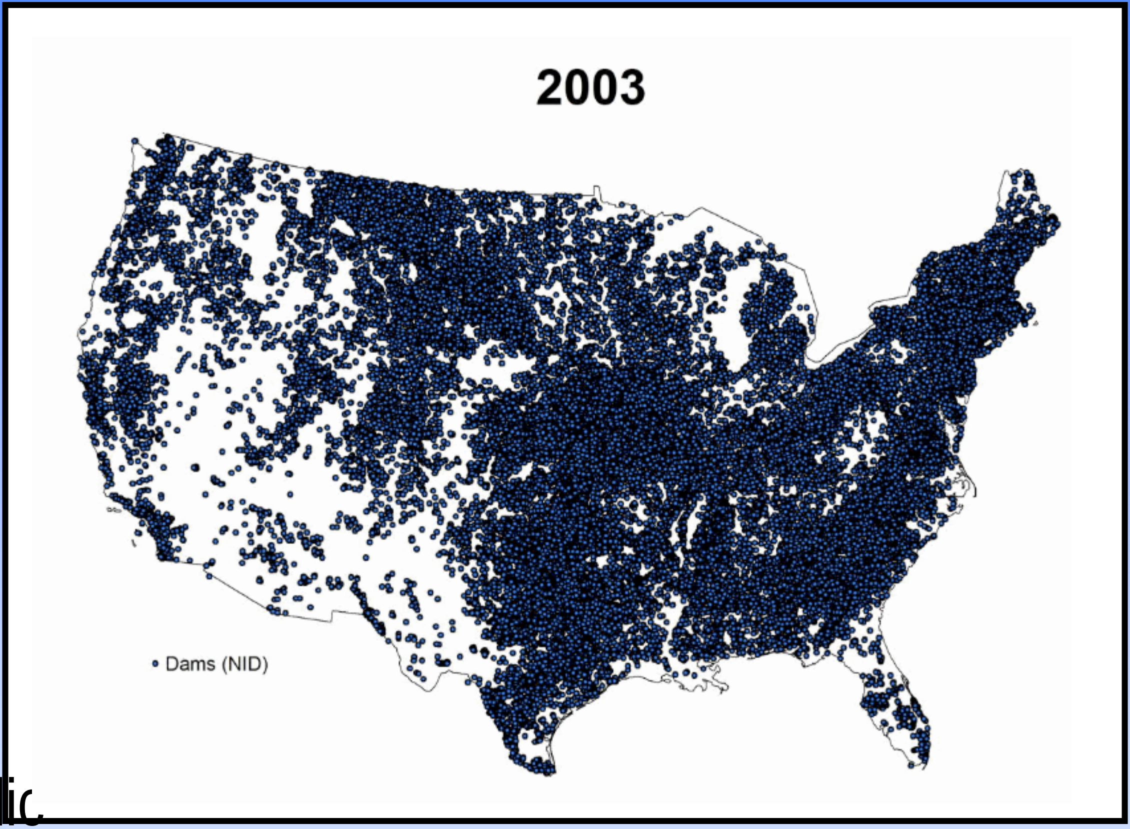




Claessens et al. 2005



History of US Dam and Reservoir Construction

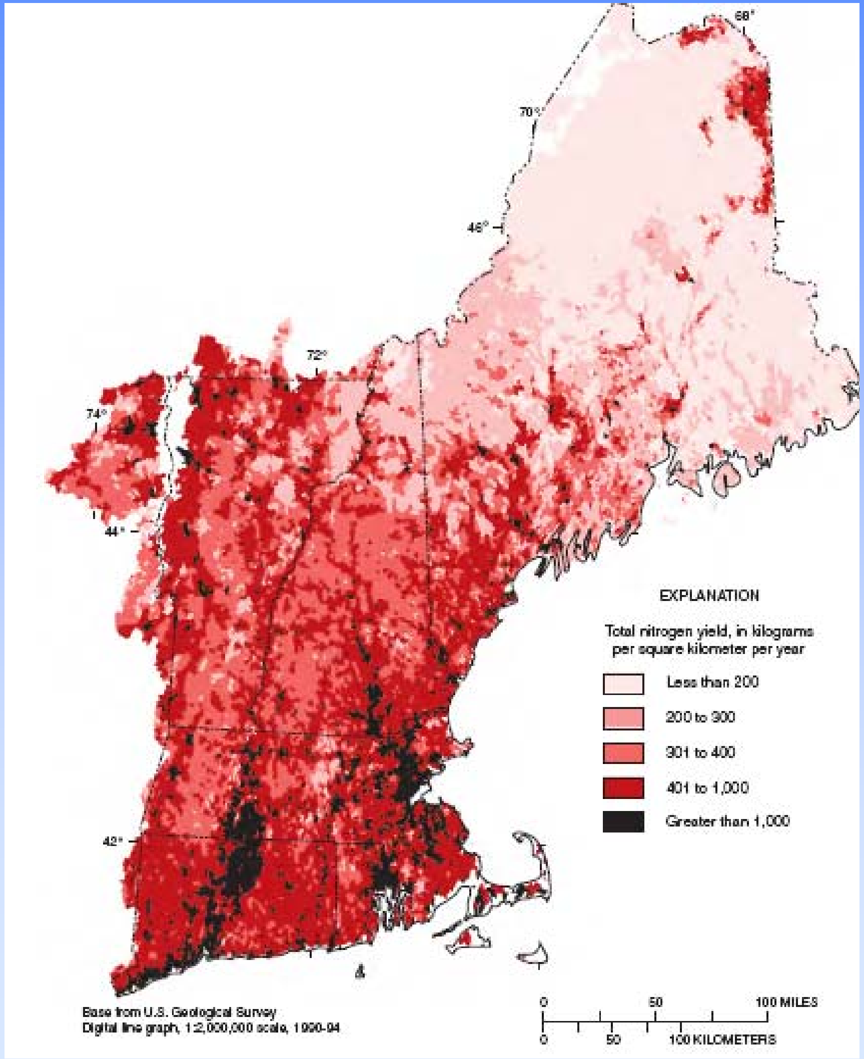


How and why did hydraulic engineering evolve in the NE corridor? And what is its likely trajectory into the future?

…emblematic of water development globally

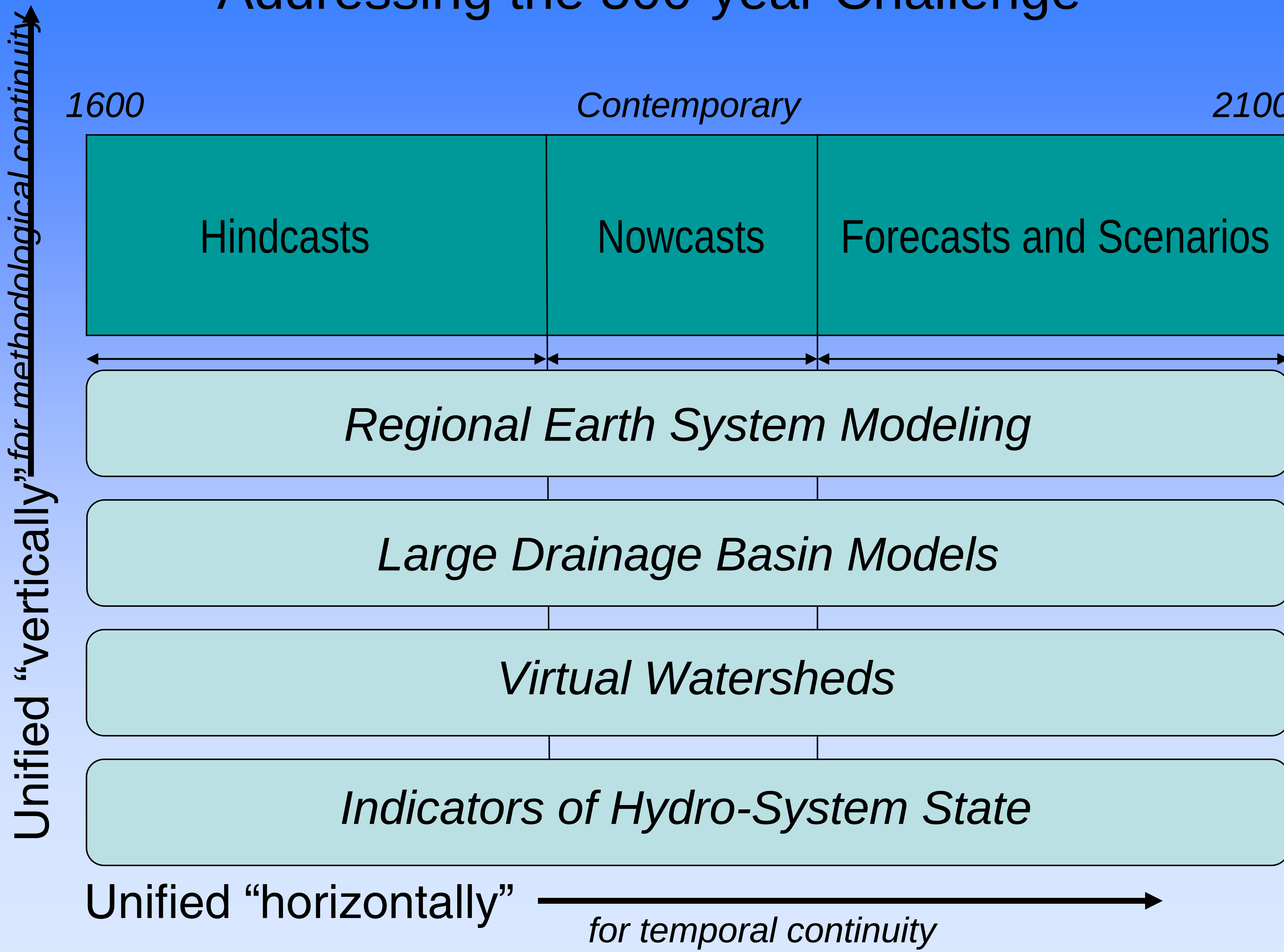
Source : National Inventory of Dams

Atmospheric Sources Join Point and Non-Point Sources to Generate Regional Aquatic Chemical Loads and Potential Limits on Available Water Resources

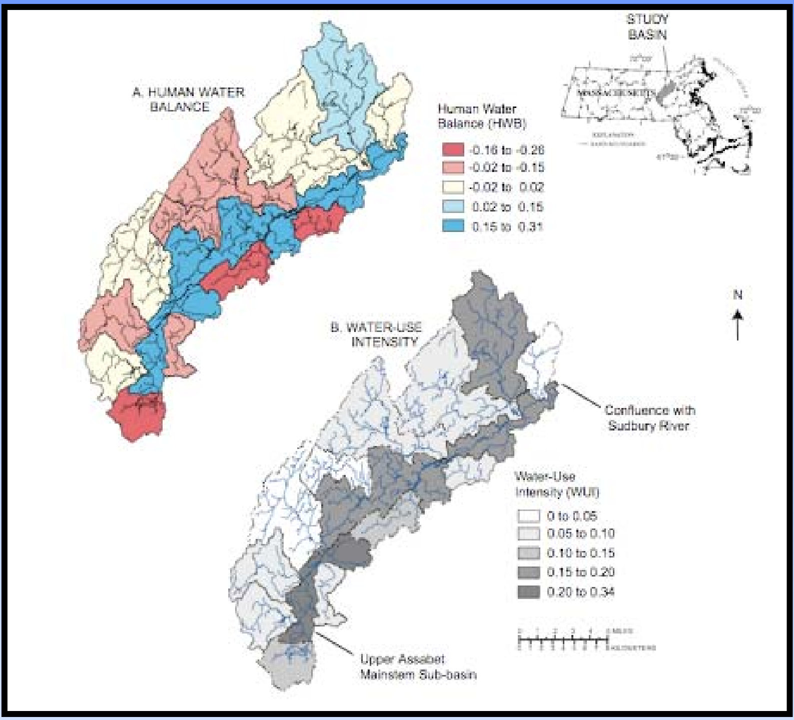


Total Nitrogen Yield
New England Sparrow Model (USGS)

Addressing the 500-year Challenge



TYPOLOGIES OF HUMAN-WATER INTERACTIONS



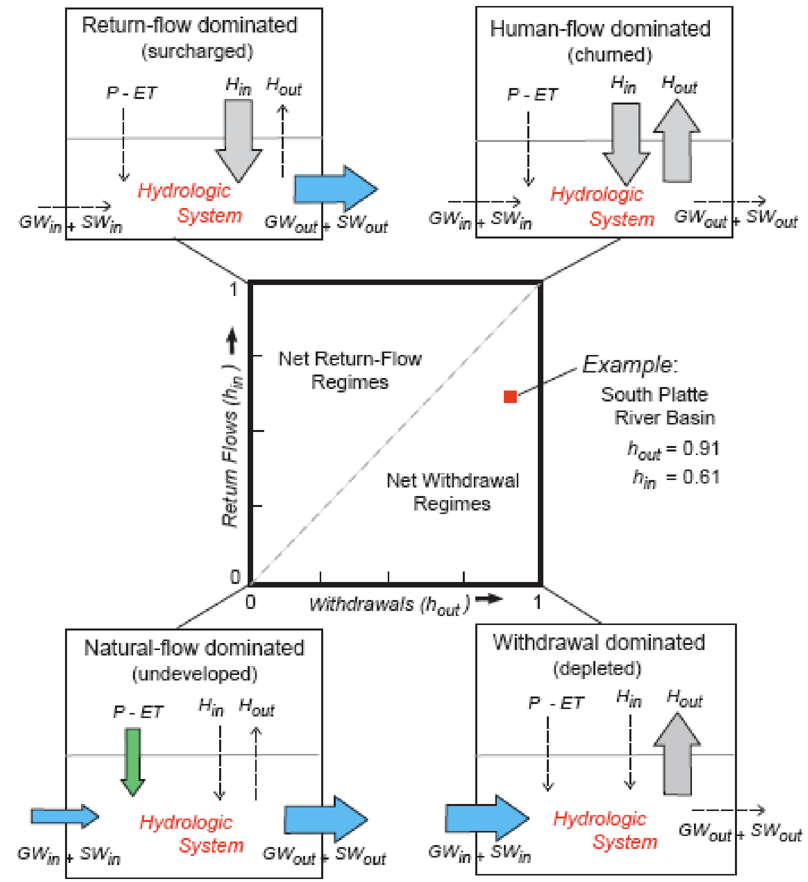
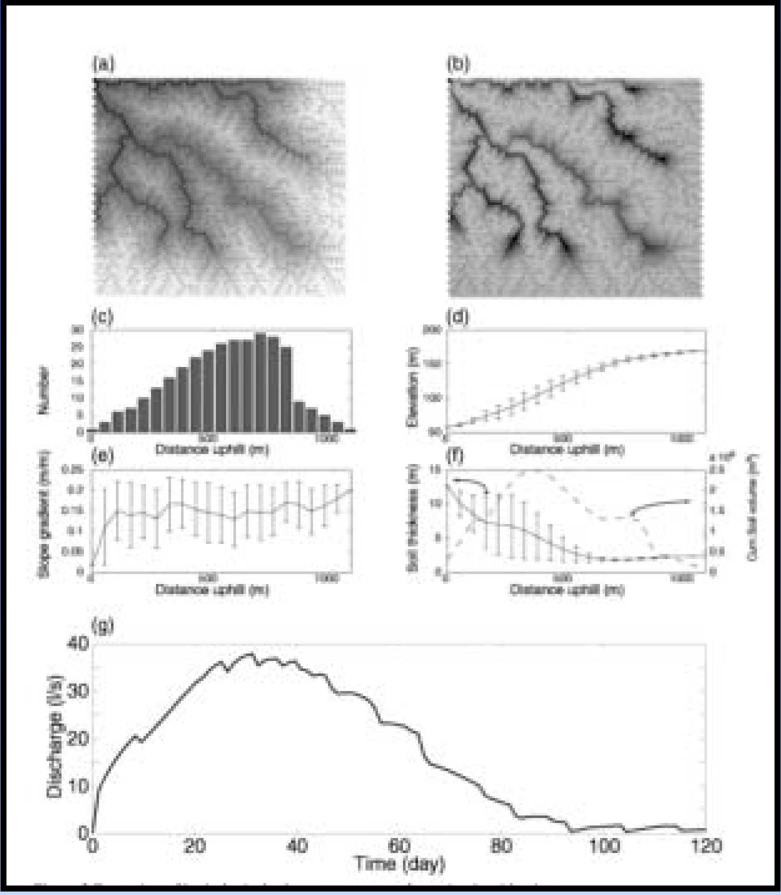


Figure 2. Human water-use regimes. The relative magnitudes of normalized human withdrawals (h_{out}) versus return flows (h_{in}) are plotted on the central plot. Example regime is given for South Platte River Basin, U.S., based on *Dennehy et al.* [1993]. The panels show the four end-member regimes that bound the domain of possible water-use regimes for a hydrologic system. Dashed arrows indicate fluxes that are either zero or very small relative to the other fluxes on each panel. For convenience, the natural-flow-dominated panel asumes humid climatic conditions ($P > ET$). See text equations (3), (6), and (7) for definitions of all terms. Fluxes into and out of storage are not shown.

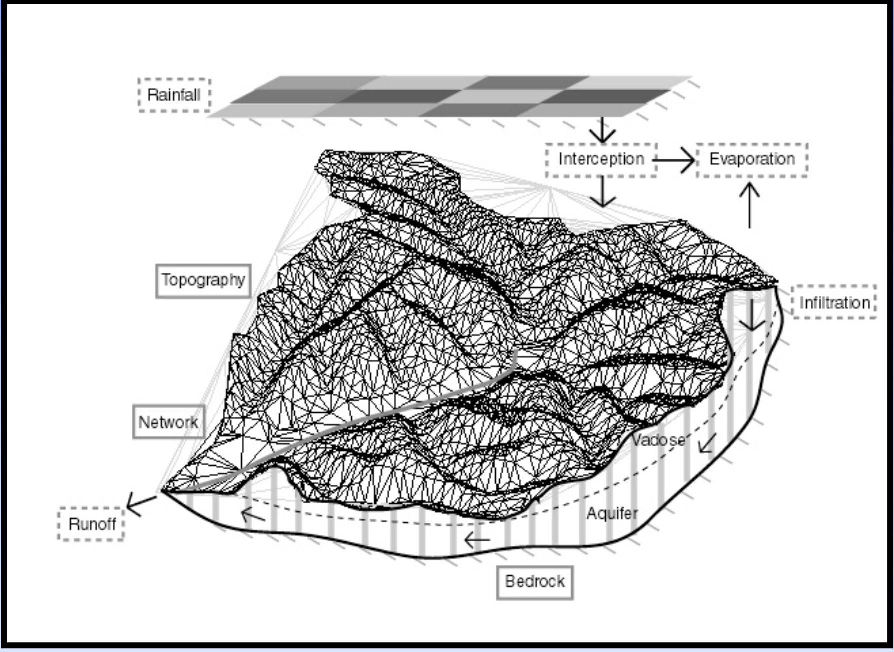
From: Weiskel et al. 2007, WRR

Some Candidate
Virtual Watershed Models

hsB(Troch et al.)



tRIBS (Bras et al.)



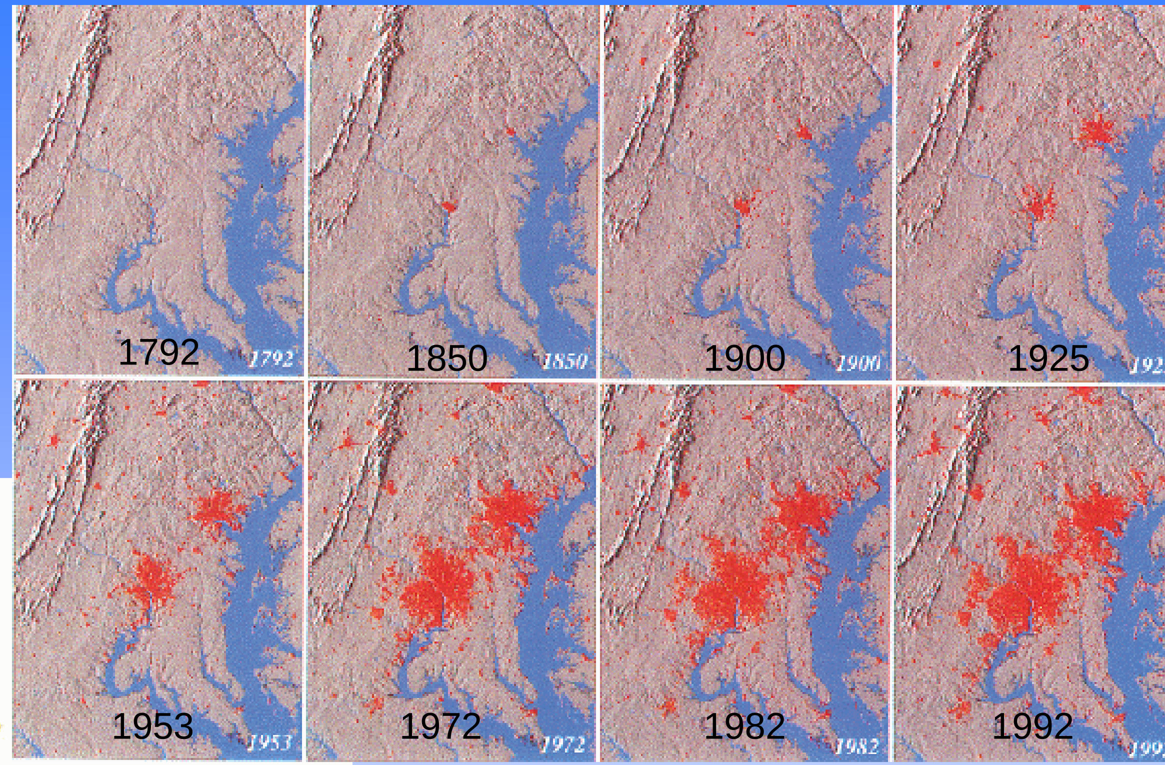
<u>Potential Testbed Basins</u>:

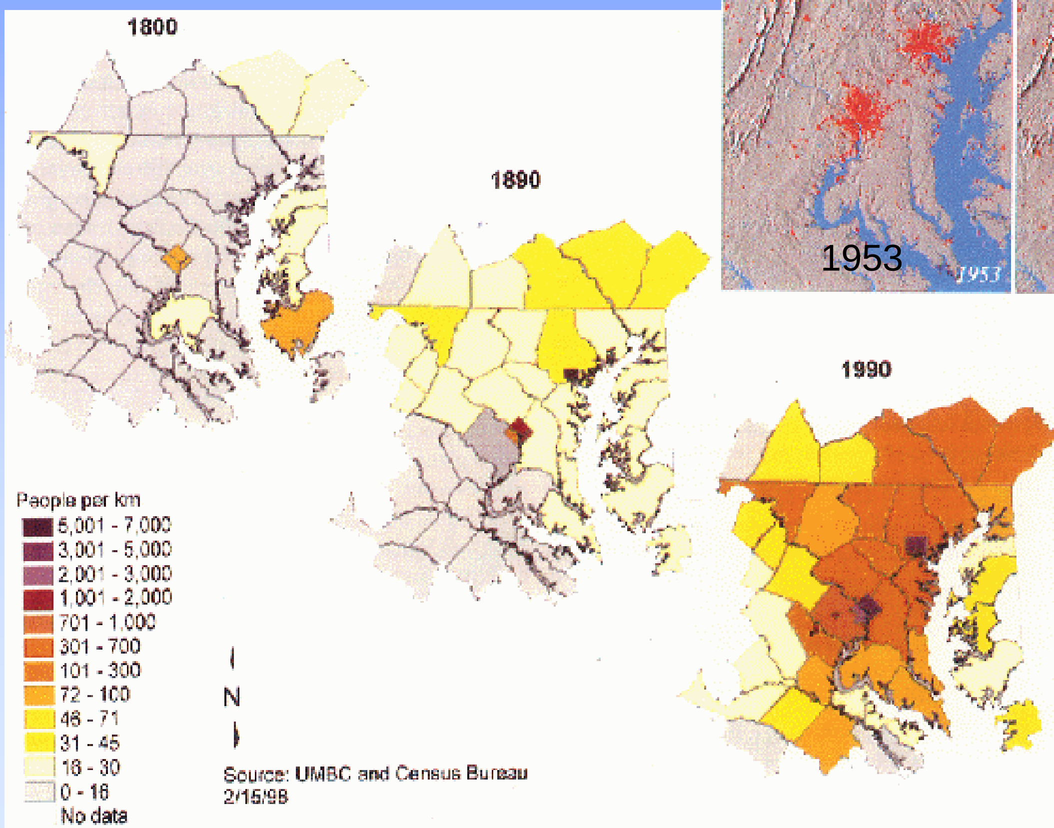
Neuse, Baltimore, Boston Metro, Connecticut River, NYC

The Baltimore-Washington Regional Collaboratory Land-Use History Research Program

Timothy W. Foresman, *U. Maryland-Baltimore County,* *foresman@umbc.edu*

Urban density in Baltimore-Washington region 1792-1992



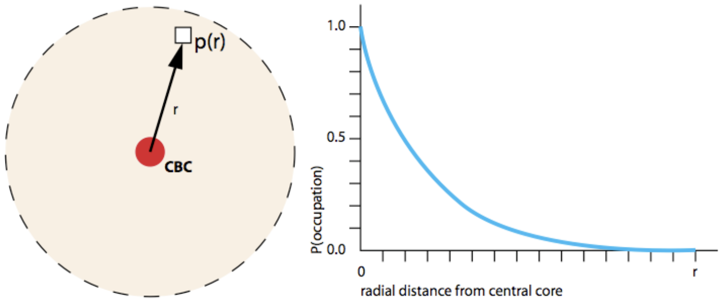


Population density by county 1800, 1890, 1990

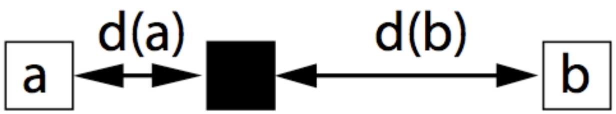
Human Development and Water Infrastructure Modeling

1. Population density p(r) follows the relation:

$$p(r) = p_0 e^{-\lambda r}$$

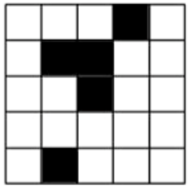


2. There exist a correlation between occupied locations in the city and the probability of developing empty locations



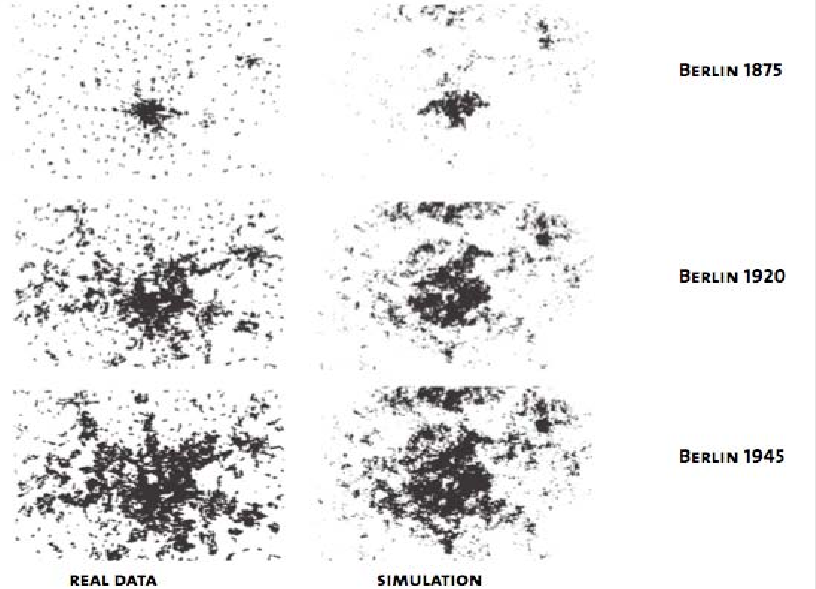
d(a)< d(b)

p_occupied(a)> p_occupied(b)

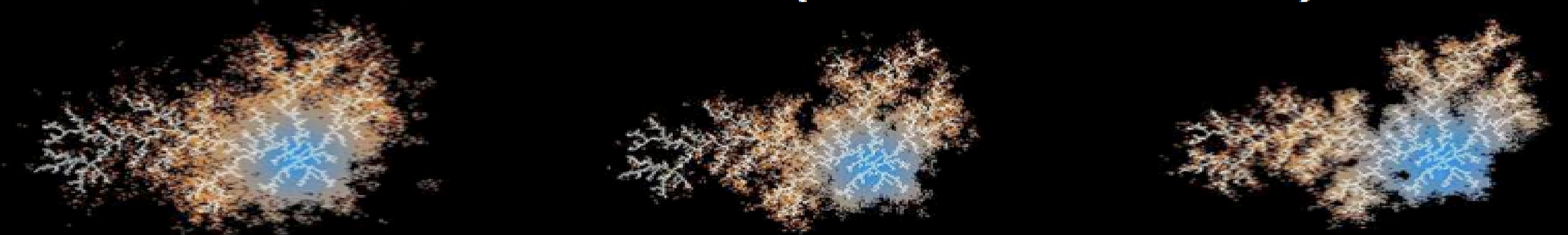


site percolation

Correlated Percolation Model (CPM)



-Redistribution based on fractal structure (compare to infrastructure!)

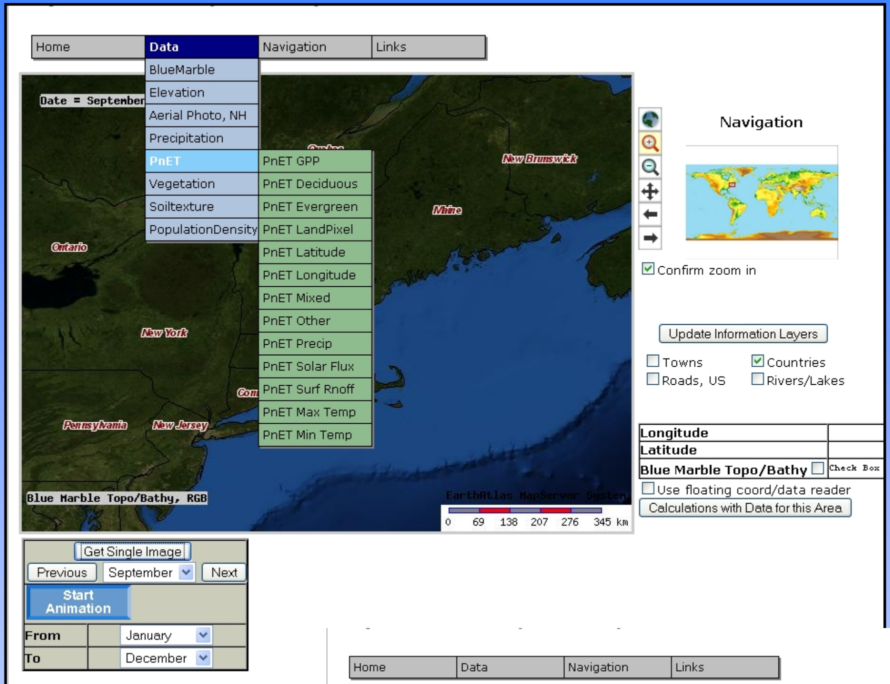


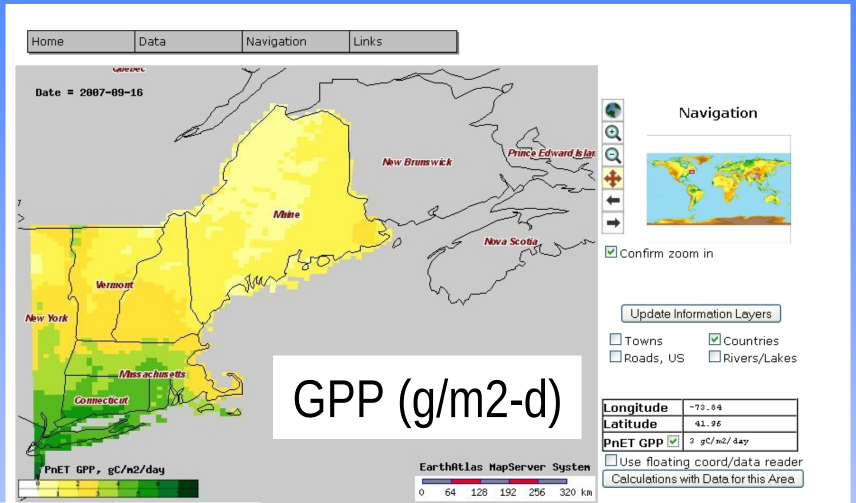
D.P. Ward et. al, 'An Optimized Cellular Automata Approach for Sustainable urban Development in Rapidly Urbanizing Regions (1999)

Courtesy: C. Zevenbergen, UNESCO-IHE Delft

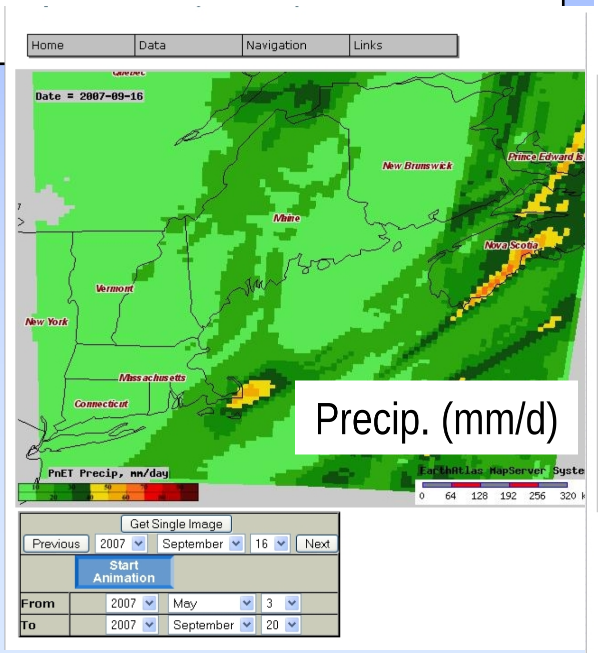
Operational Ecosystem Surveillance

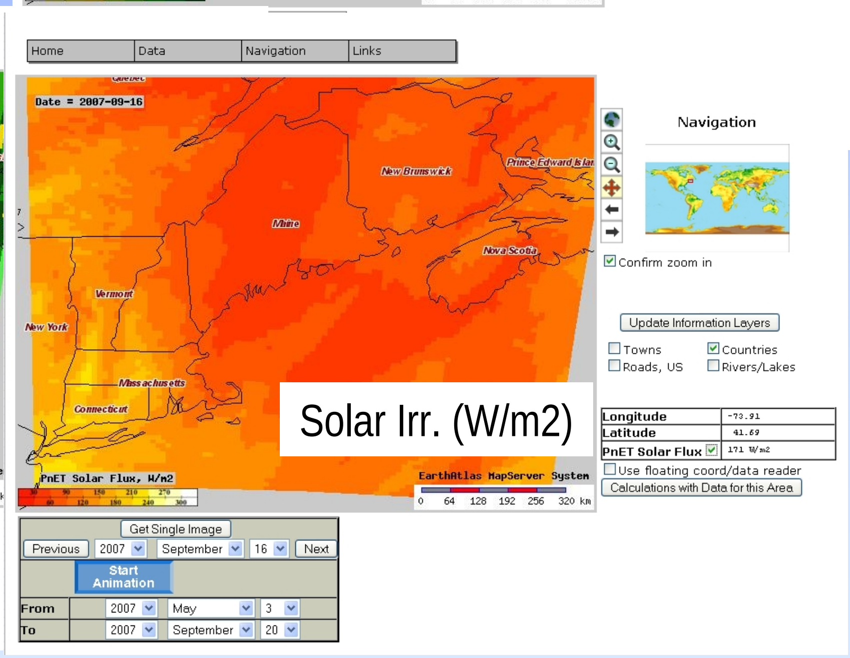
e.g. Terrestrial C Flux



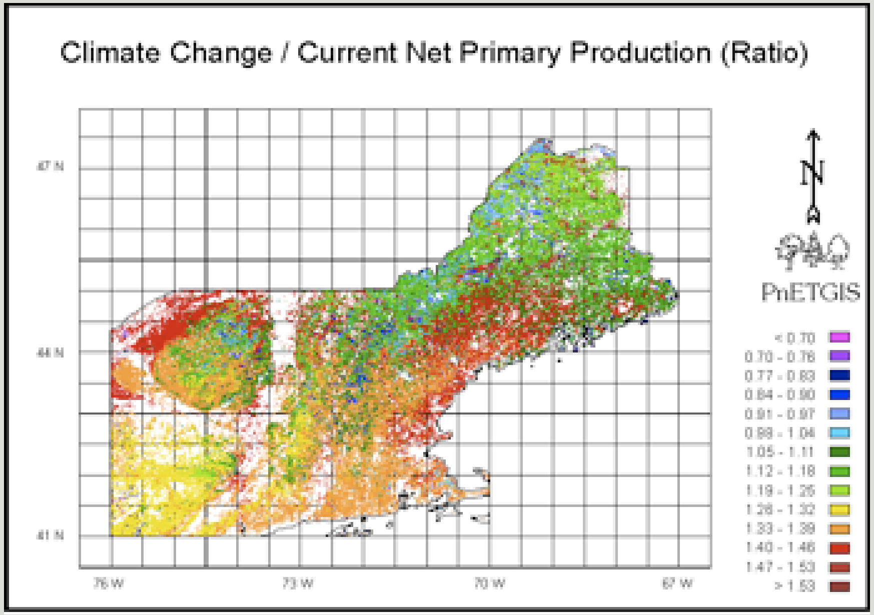


16 Sept. 2007

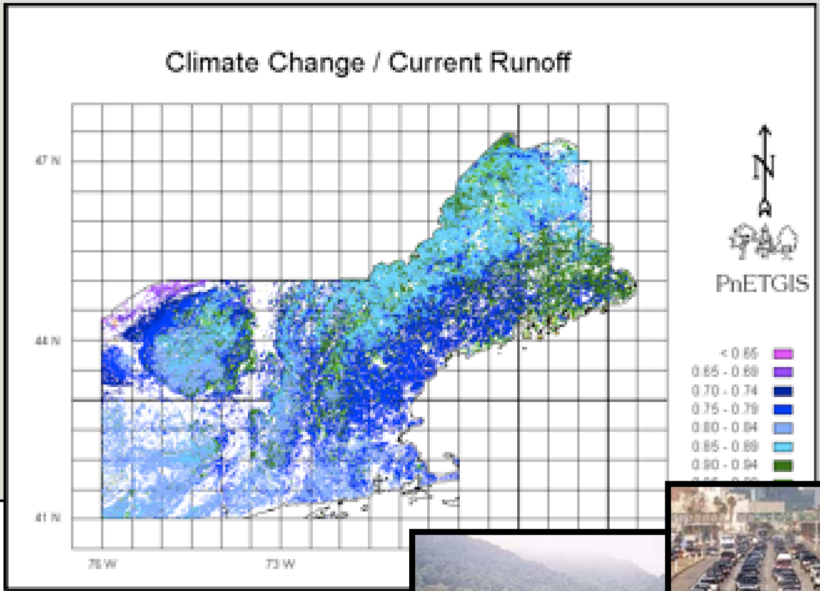




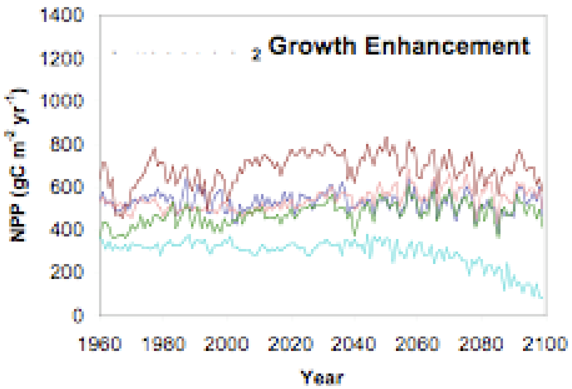
The Day Has Arrived Where We Need to Think of Regional Carbon Inventories and Regional Ecosystem Management

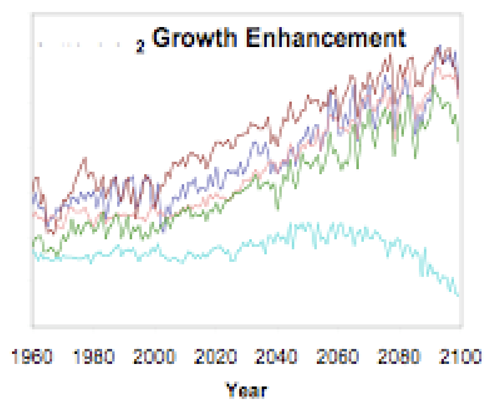


Inverse relationship between changes in productivity and runoff



Uncertainty surrounding effects of rising CO_2 on forests:





Ollinger et al. 1998, 2007

Conclusions

- Humans increasingly defining the mechanics of the hydrologic cycle
- Recent S&T developments enable a new interdisciplinary science of water, but require social science perspectives
- Regional-scale gives "ground-truth" to global patterns

  ……global patterns give context to regional change
- N.E. emblematic of patterns globally: rich set of synthesis topics & opportunities for environmental surveillance

- Join the regional CUAHSI and NOAA hydro-system partnership (*www.wsag.unh.edu*)
- Summer Synthesis Institutes:
  - 6-8 Weeks in residence Boston Metro Area
  - Team-oriented work driven by graduate students & several mentors
  - Topic for 2007

    Water in the Northeast: The 16th and 17th Centuries