Impact of Climate Change and Variability on the Nation's Water Quality and Ecosystem State

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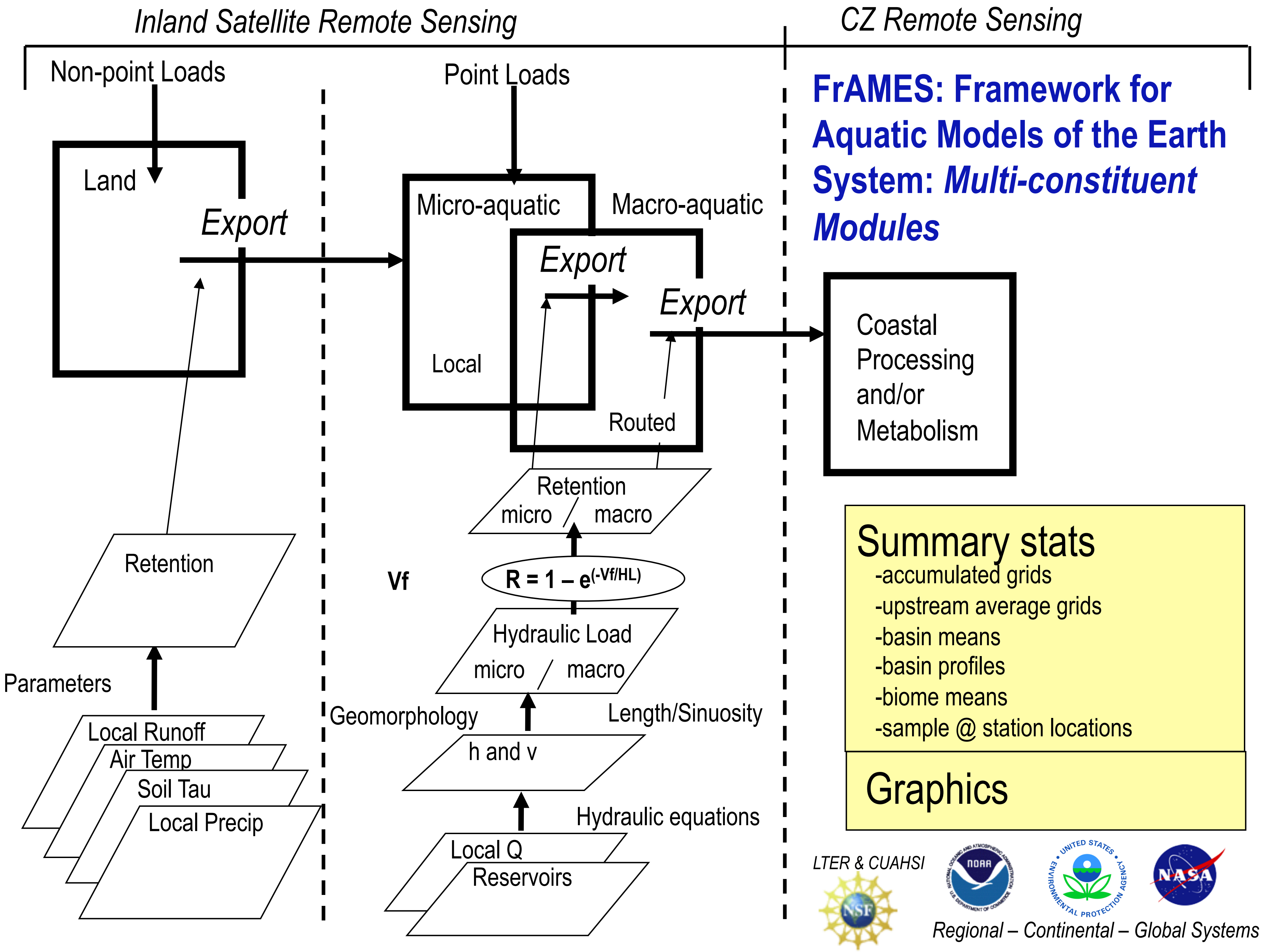
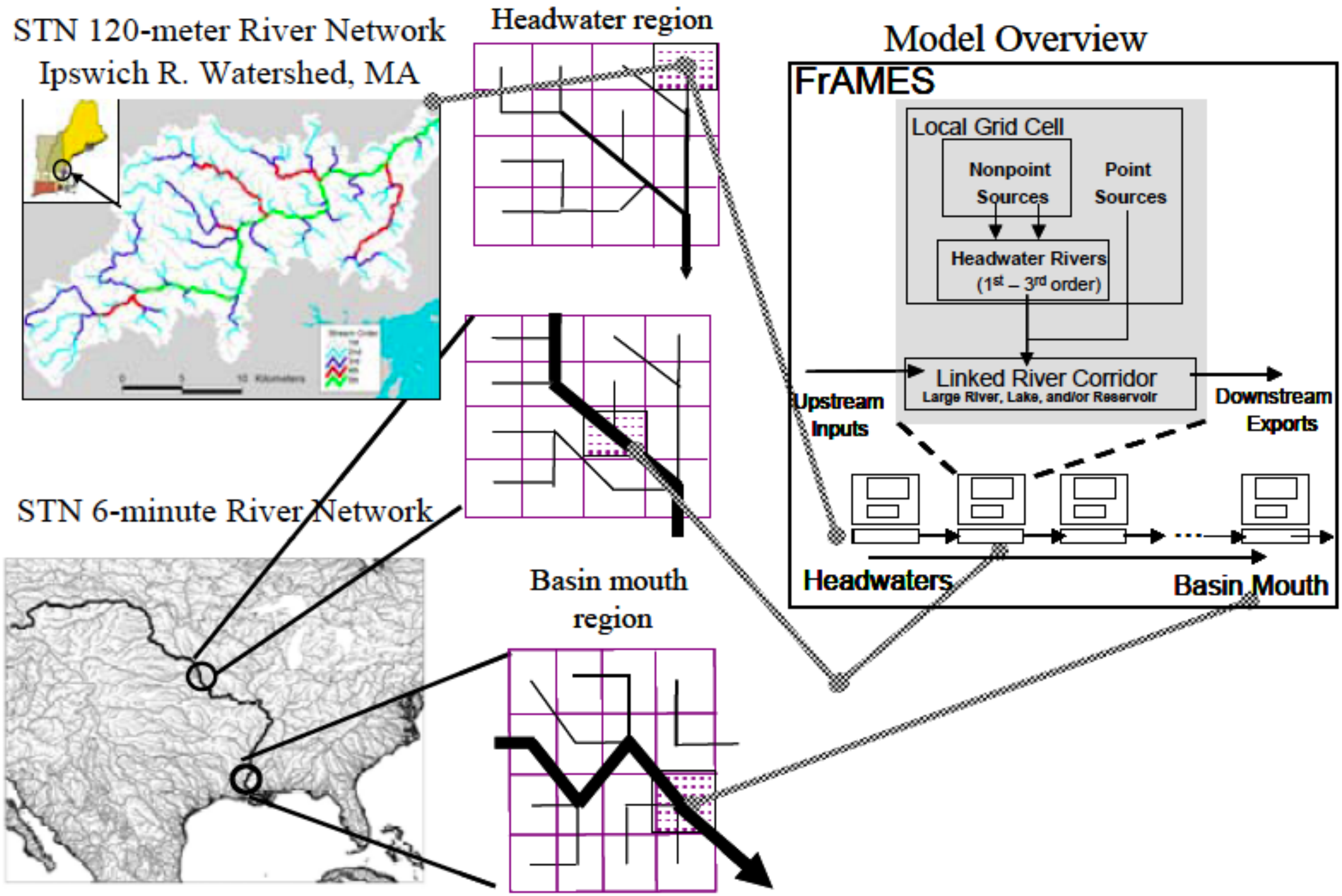
EPA Program Review: Consequences of Global Climate Change: Water Quality Impacts, Ecological Impacts & Nonlinear Responses
Washington DC *22 September 2011*

Overall Goal

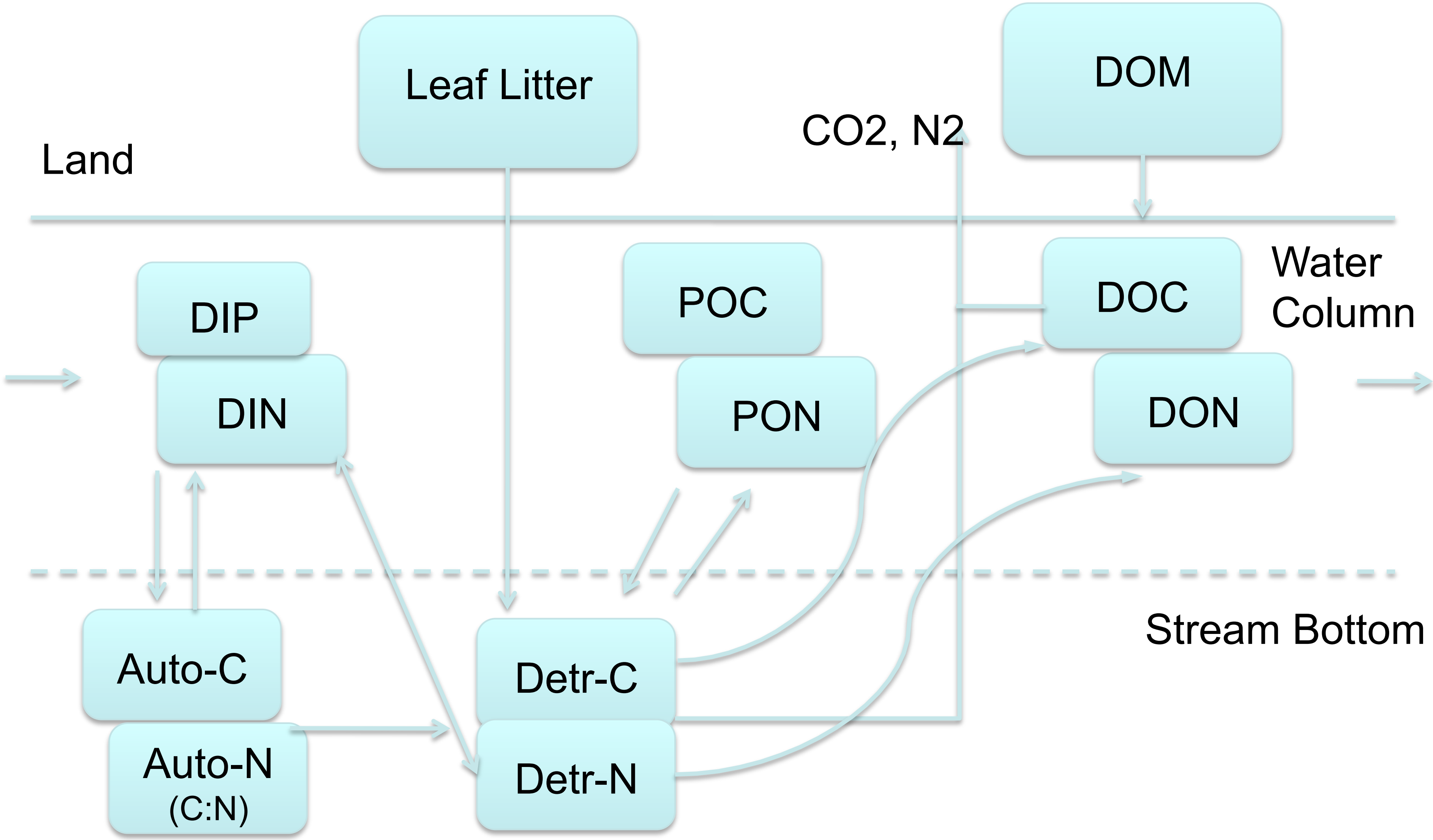
- To expand an existing modeling framework to analyze water system sensitivity to climate change and other stress factors
- Four component efforts:
  - FrAMES
  - Pollution applications: Thermal and N
  - Water Management: Reservoirs and Water Transfers
  - Links to habitat and biodiversity



Inland Satellite Remote Sensing
CZ Remote Sensing
FrAMES: Framework for Aquatic Models of the Earth System: Multi-constituent Modules
Non-point Loads
Point Loads
Land
Export
Micro-aquatic
Macro-aquatic
Export
Export
Local
Routed
Coastal Processing and/or Metabolism
Retention
micro / macro
Vf
R = 1 – e(-Vf/HL)
Hydraulic Load
micro / macro
Geomorphology
Length/Sinuosity
h and v
Hydraulic equations
Local Q
Reservoirs
Retention
Parameters
Local Runoff
Air Temp
Soil Tau
Local Precip
Summary stats
-accumulated grids
-upstream average grids
-basin means
-basin profiles
-biome means
-sample @ station locations
Graphics
LTER & CUAHSI
Regional – Continental – Global Systems

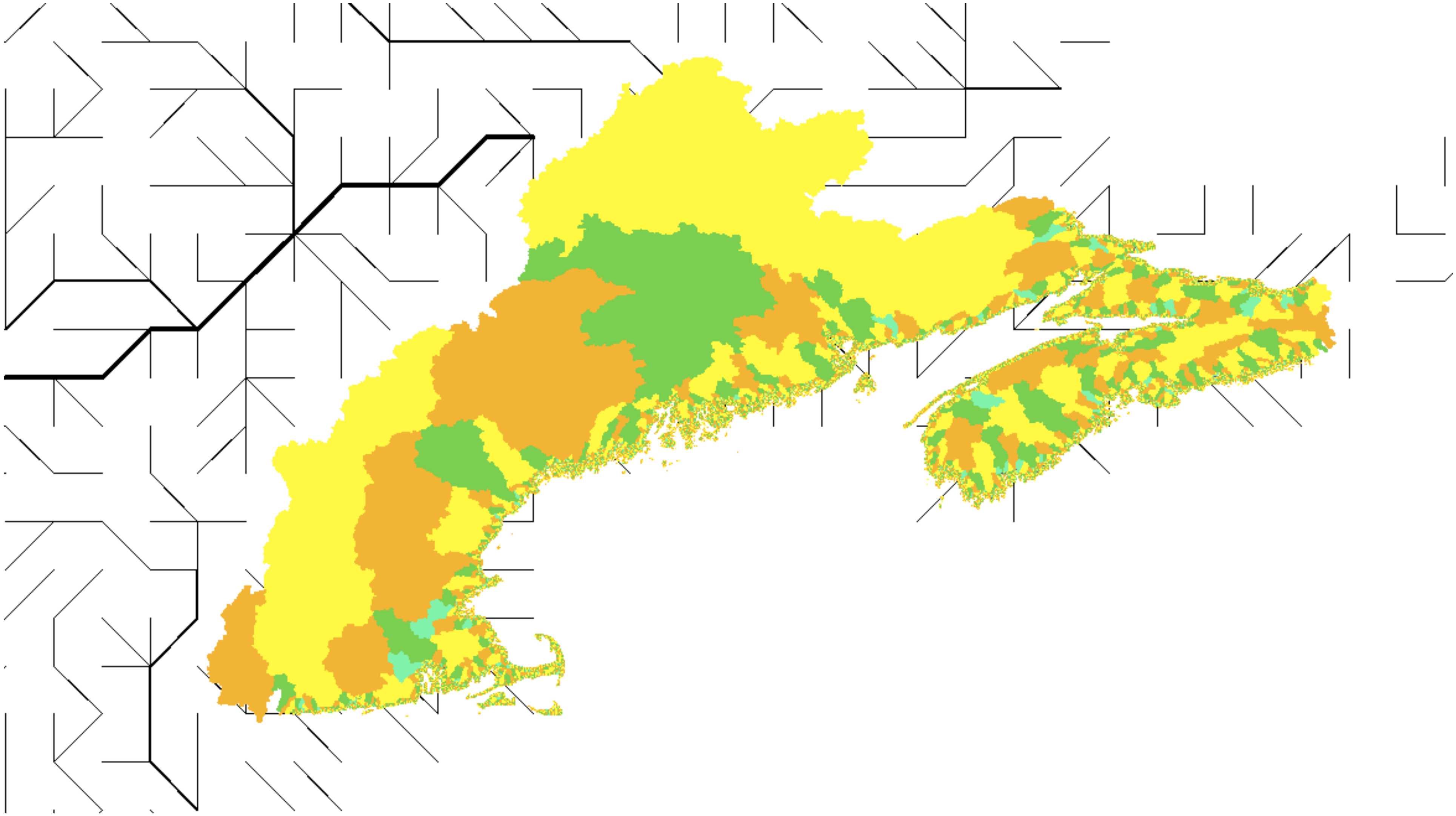

STN 120-meter River Network
Ipswich R. Watershed, MA
Headwater region
Model Overview
FrAMES
Local Grid Cell
Nonpoint Sources
Point Sources
Headwater Rivers
(1st – 3rd order)
Linked River Corridor
Large River, Lake, and/or Reservoir
Upstream Inputs
Downstream Exports
Headwaters
Basin Mouth
STN 6-minute River Network
Basin mouth region

Conceptual Model - AEM
(Aquatic Ecosystem Model)

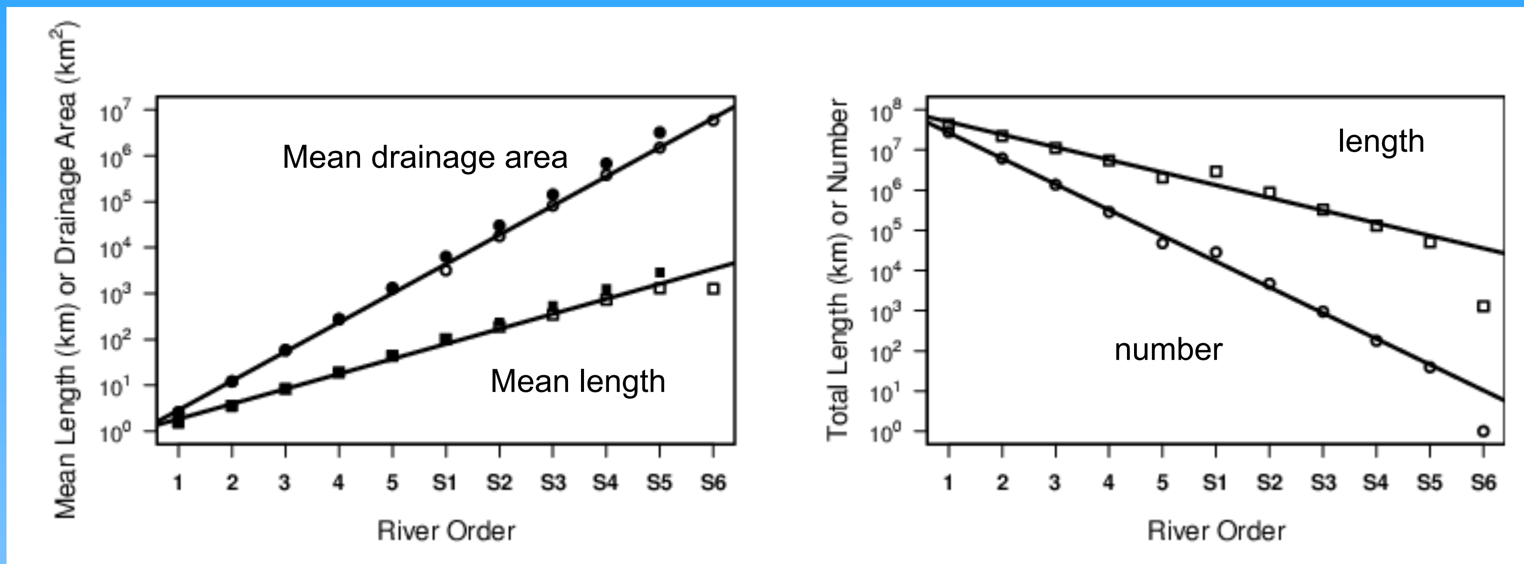


Courtesy: W. Wollheim

Merging Macro-Microscale Rivers in Continental Models



River Network Characteristics



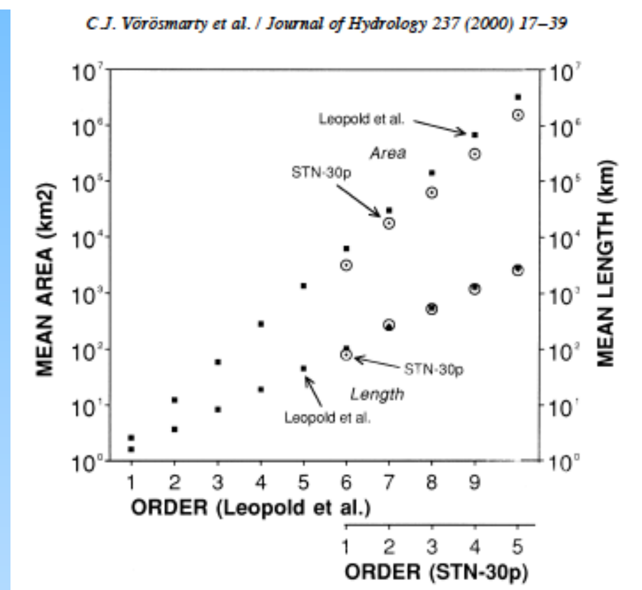
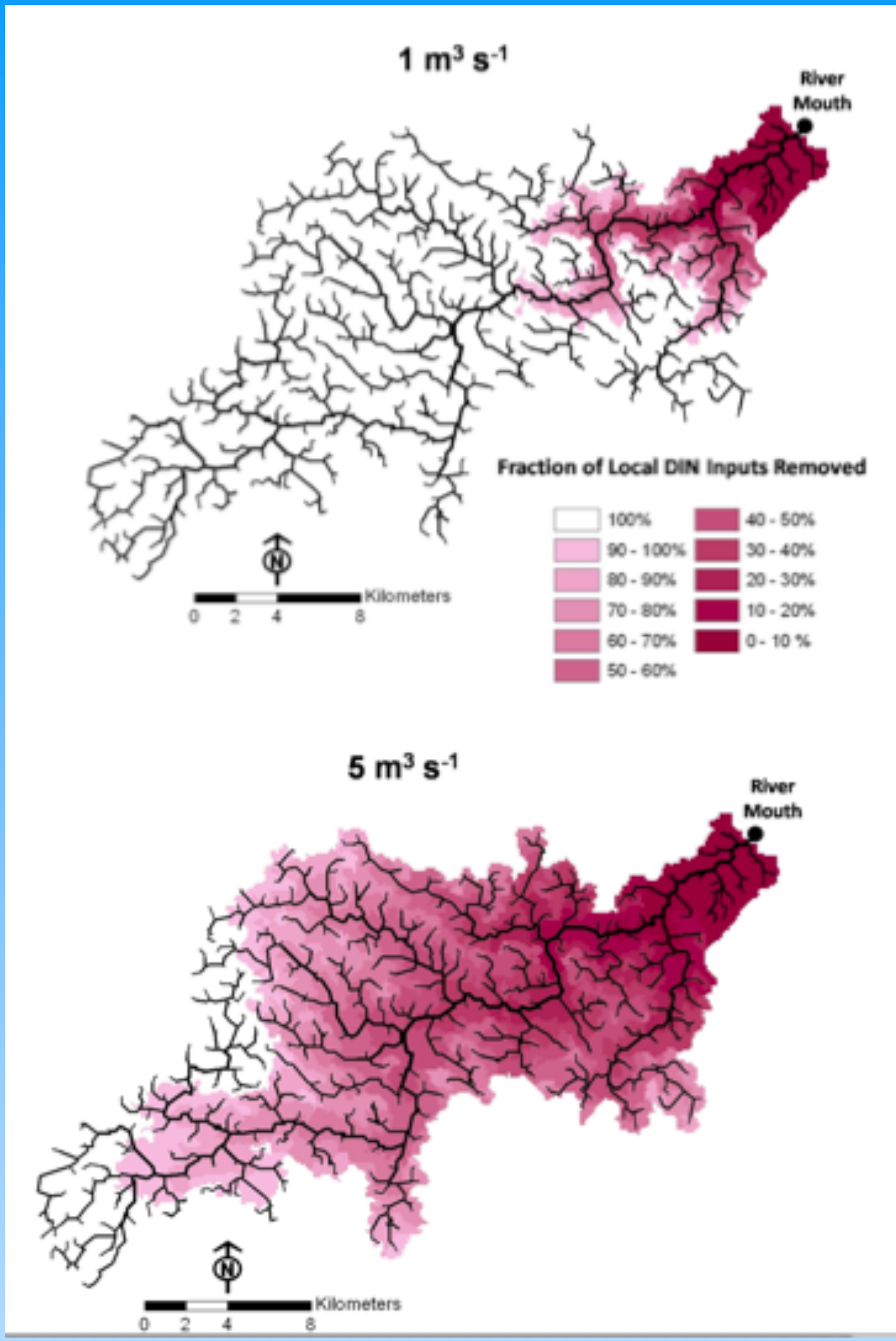


Figure 1. Network statistics in FrAMES assuming geomorphic and hydraulic characteristics in Table 1. A) mean drainage area and

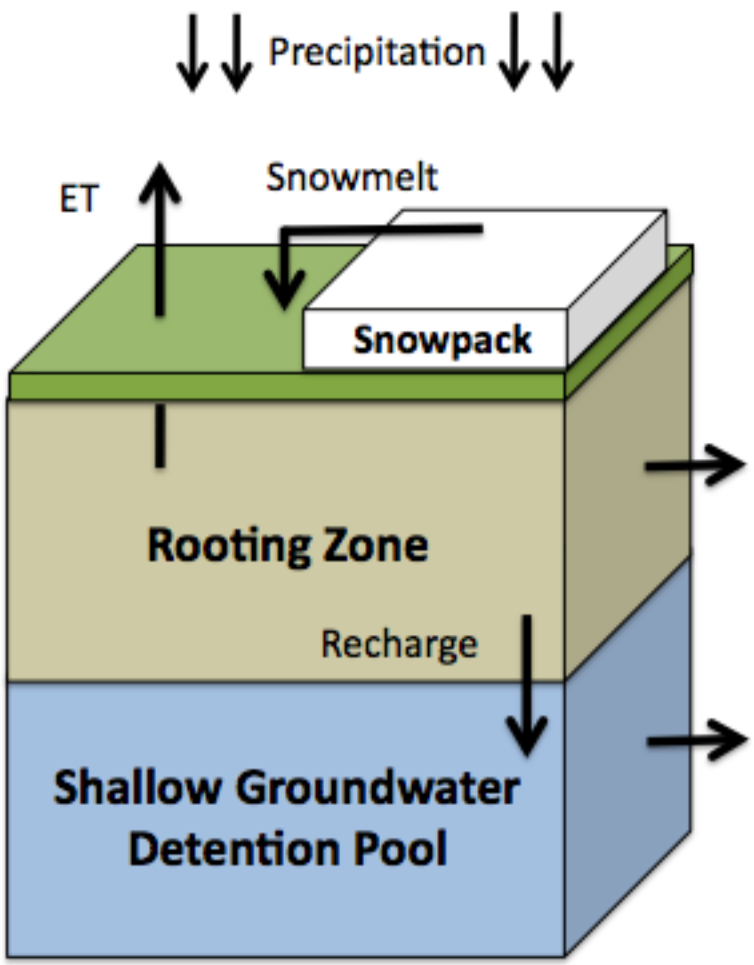


Dynamic Watershed Zone of Influence on Land-to-Coastal Fluxes

--Dependent on hydraulics, biogeochemical processing & temperature

Linking WBM and Thermal Loading

WBM Grid Cell



Thermal Loading

Precipitation = Mean Daily Air Temperature

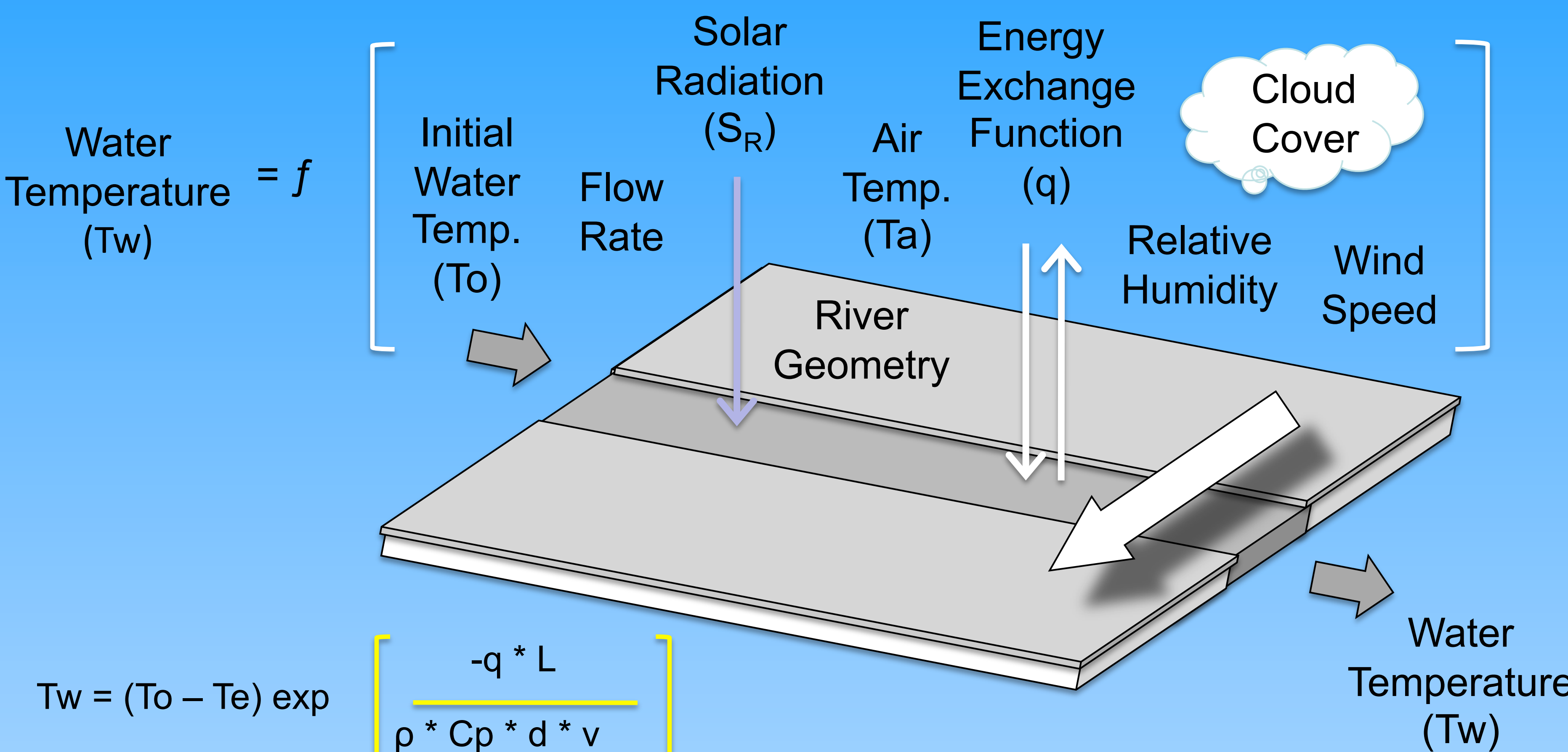
Snowmelt = 0 °C

Ro_{surf} = Volume weighted mixture of **precipitation** and **snowmelt** temperatures

Ro_{gw} = Volume weighted mixture of **recharge** temperatures over time

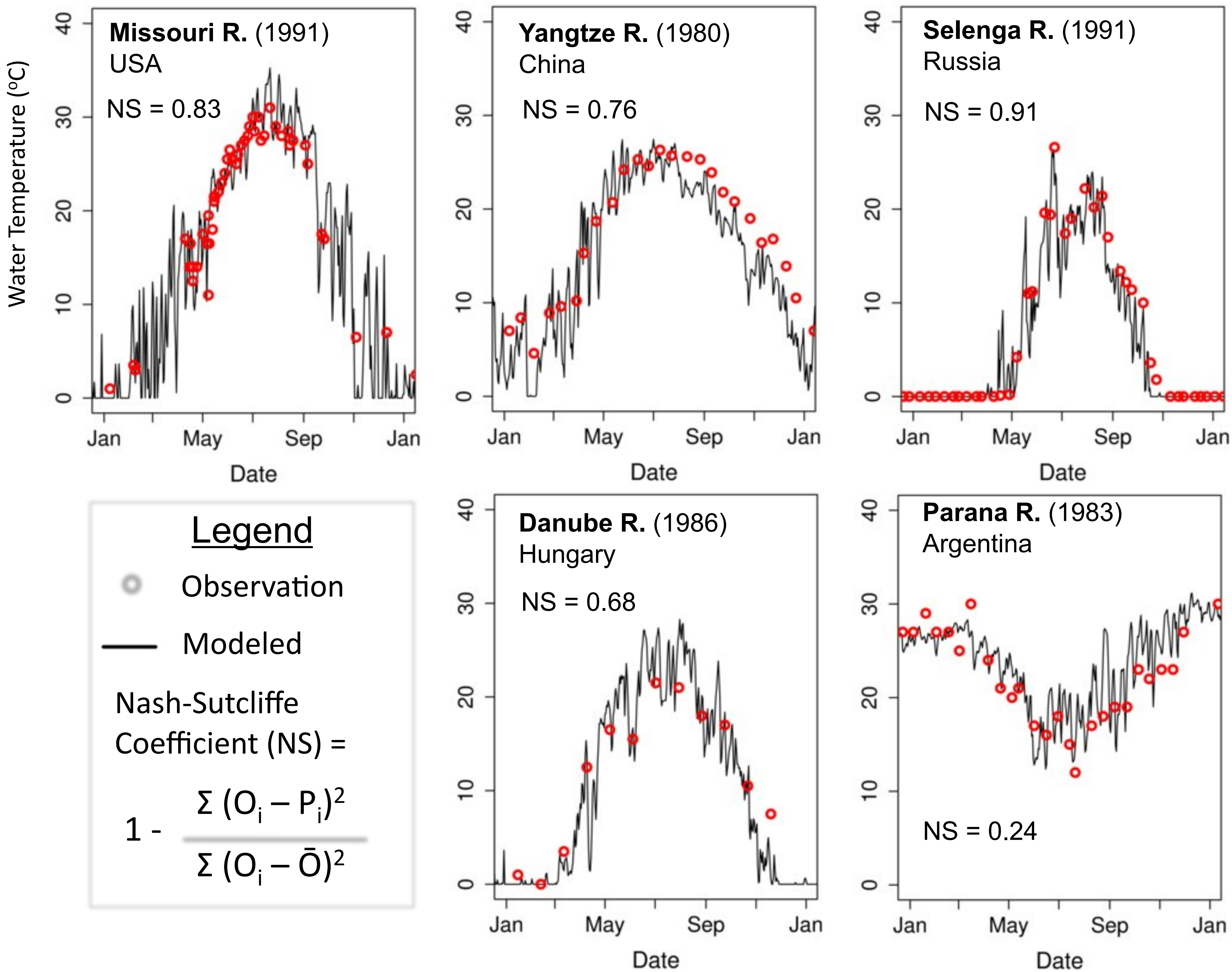
In-Stream Temperature Equilibrium Model

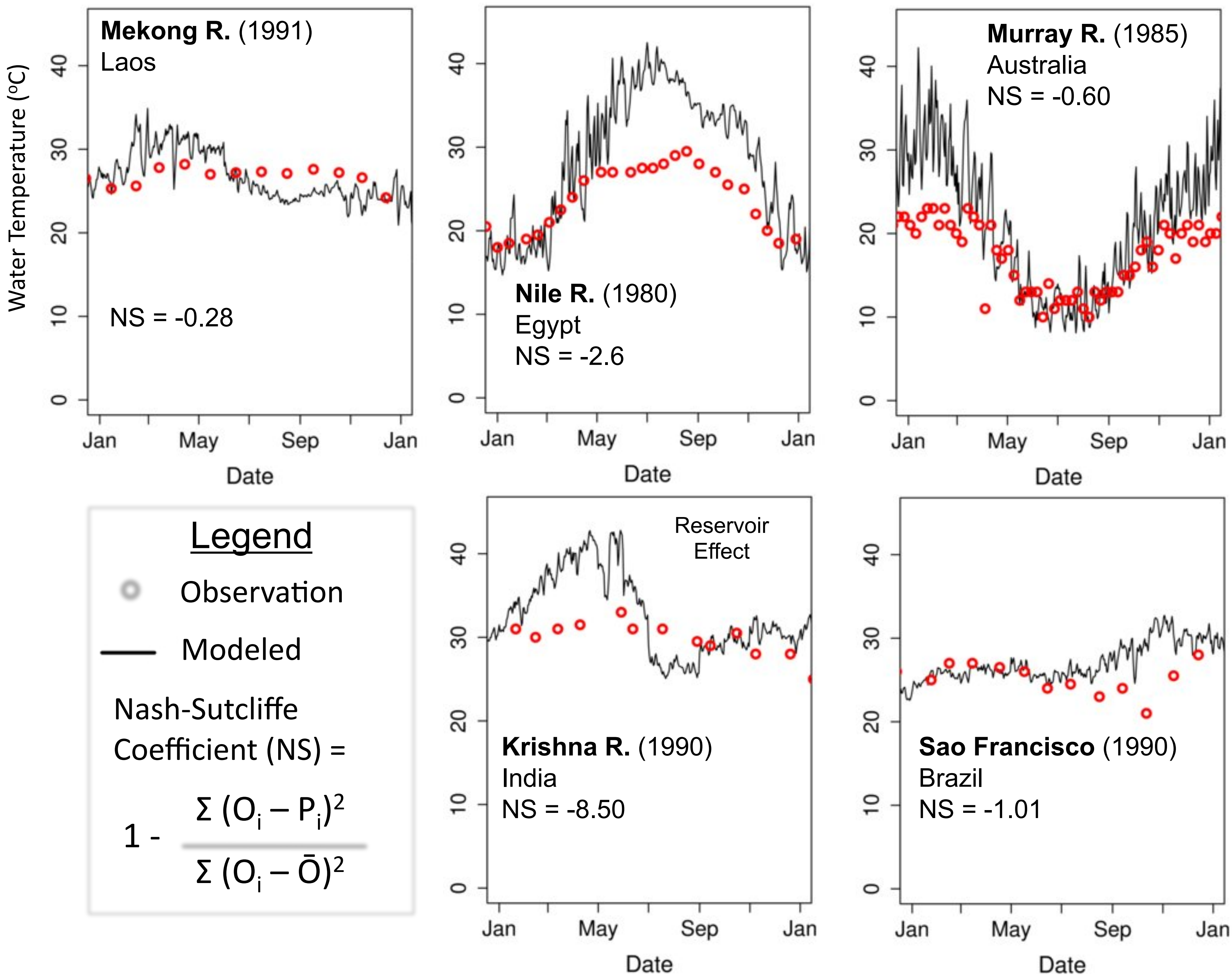
(Dingman, 1972)



$$Tw = (To - Te) \exp \left[\frac{-q * L}{\rho * Cp * d * v} \right]$$

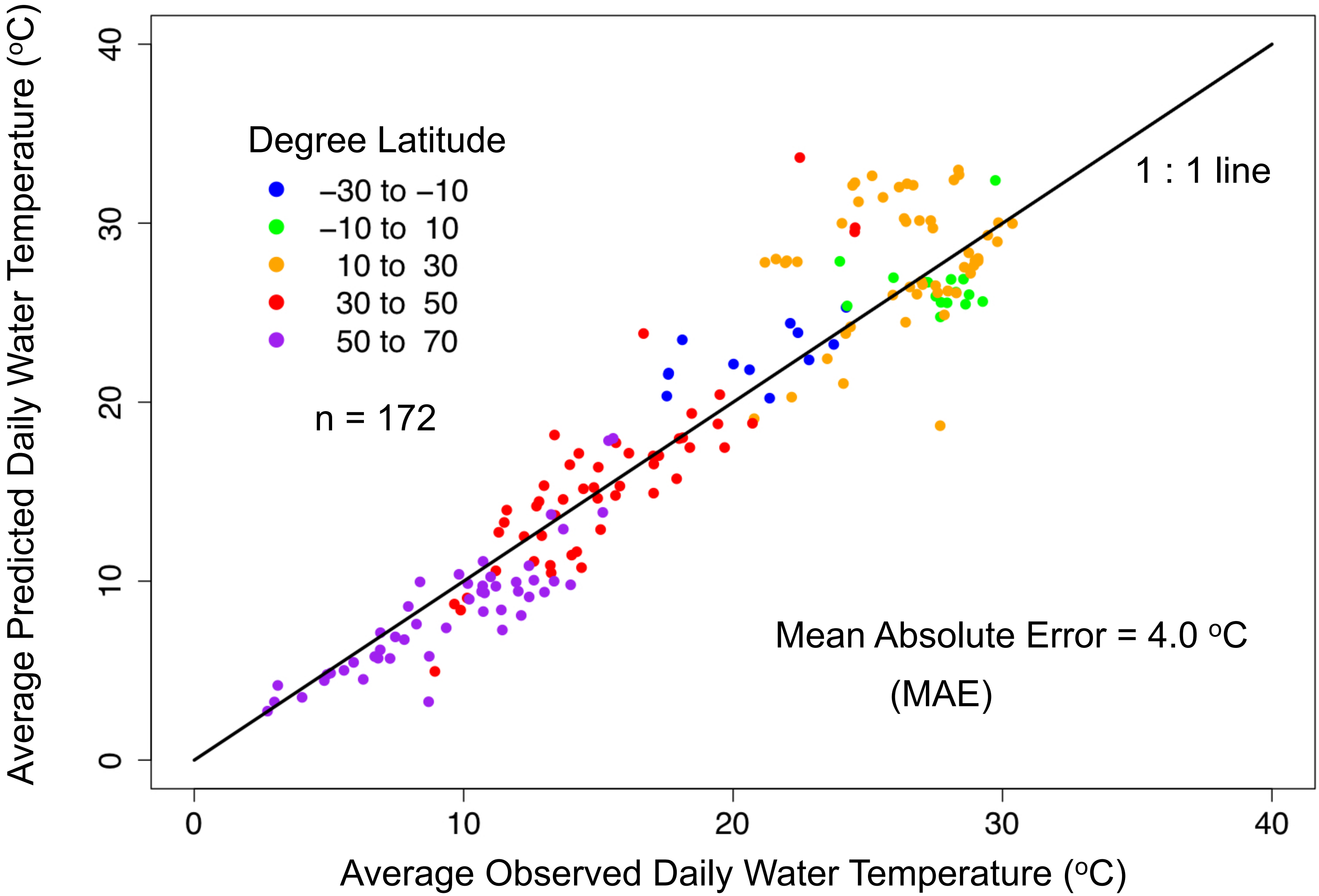
$$Te = Ta + [(S_R - Q_O) / q]$$


Missouri R. (1991)
USA
NS = 0.83
Yangtze R. (1980)
China
NS = 0.76
Selenga R. (1991)
Russia
NS = 0.91
Danube R. (1986)
Hungary
NS = 0.68
Parana R. (1983)
Argentina
NS = 0.24
Water Temperature (ºC)
Date
Jan
May
Sep
Jan
0
10
20
30
40
Legend
Observation
Modeled
Nash-Sutcliffe Coefficient (NS) =
$1 - \frac{\Sigma (O_i - P_i)^2}{\Sigma (O_i - \bar{O})^2}$

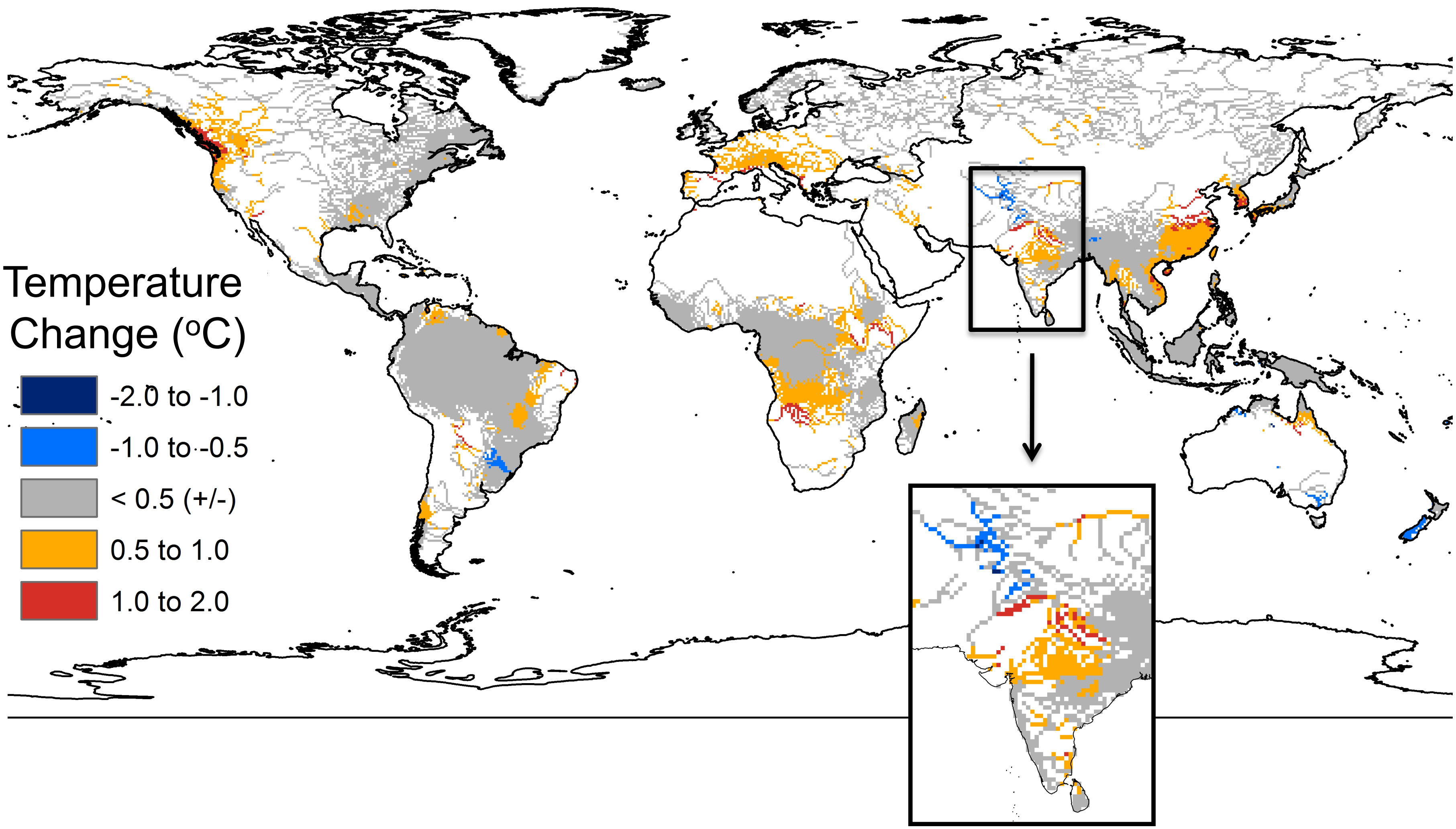


Mekong R. (1991)
Laos
NS = -0.28
Nile R. (1980)
Egypt
NS = -2.6
Murray R. (1985)
Australia
NS = -0.60
Krishna R. (1990)
India
NS = -8.50
Reservoir Effect
Sao Francisco (1990)
Brazil
NS = -1.01
Water Temperature (°C)
Date
Jan
May
Sep
Jan
0
10
20
30
40
Legend
Observation
Modeled
Nash-Sutcliffe Coefficient (NS) =
$1 - \frac{\Sigma (O_i - P_i)^2}{\Sigma (O_i - \bar{O})^2}$

Comparison of Average Daily
Observed and Predicted Temperatures



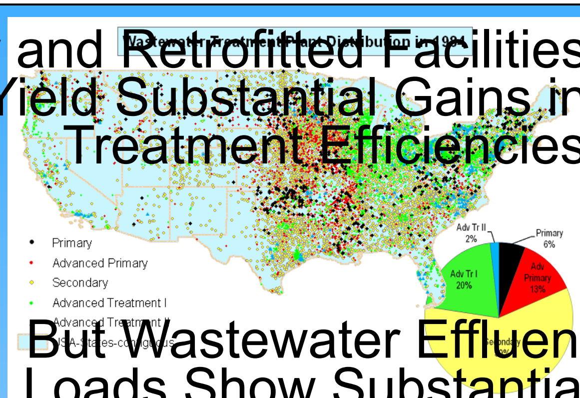
Change in Mean Decadal Water Temperatures in Large Rivers
[1970-1979] to [1990-1999]
($Q > 30\ m^3\ s^{-1}$)



IMPACT OF $80-100B* IN INVESTMENTS IN SEWAGE TREATMENT PLANT UPGRADES (1984-2004)….*a job half-done?*

~Half-Trillon $ needed through 2030

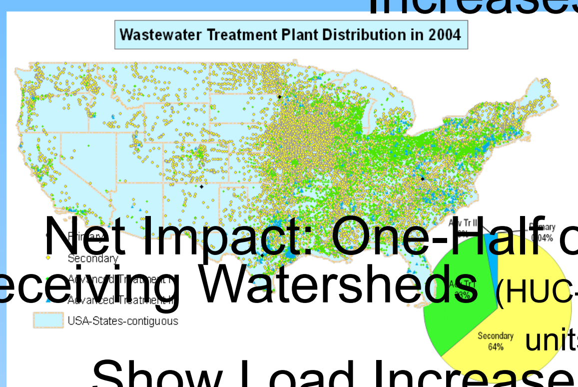
** provisional est.*



New and Retrofitted Facilities Yield Substantial Gains in Treatment Efficiencies →

But Wastewater Effluent Loads Show Substantial Increases →

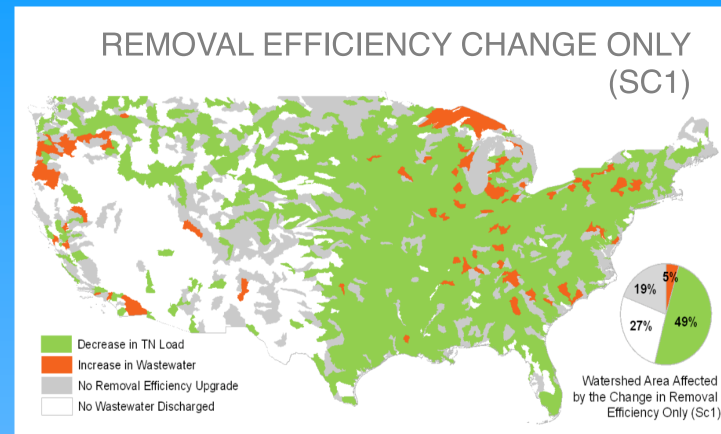
n =11,996

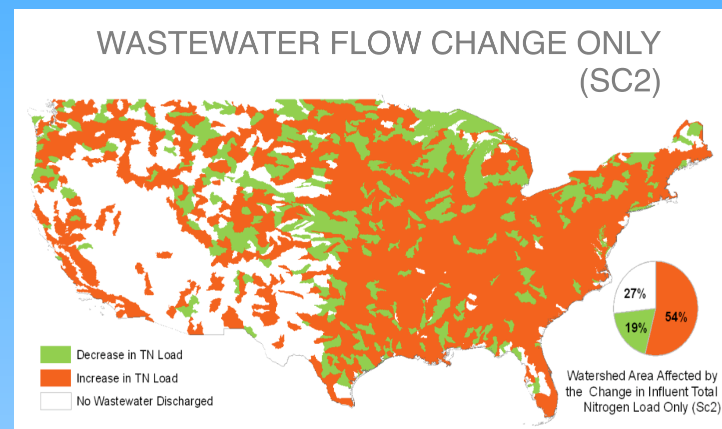


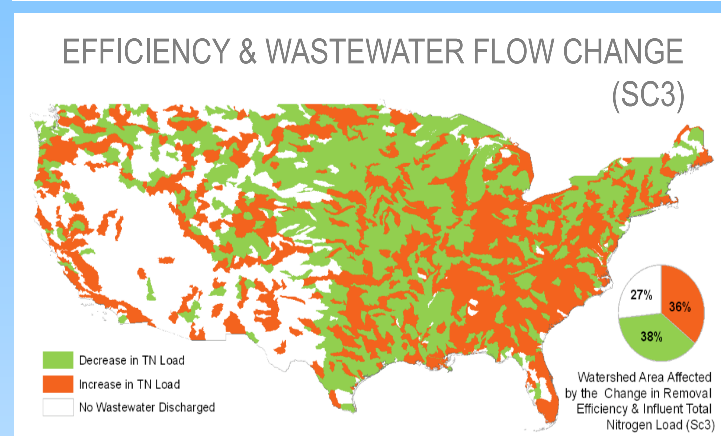
Net Impact: One-Half of Receiving Watersheds (HUC-8 units) Show Load Increases →

n =13,307

RELATIVE CHANGE IN TOTAL N LOAD





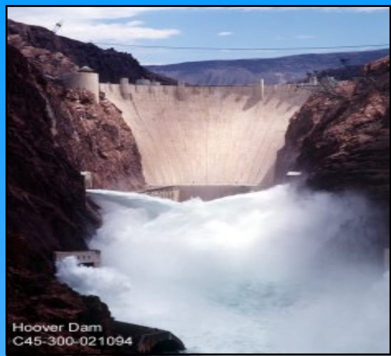


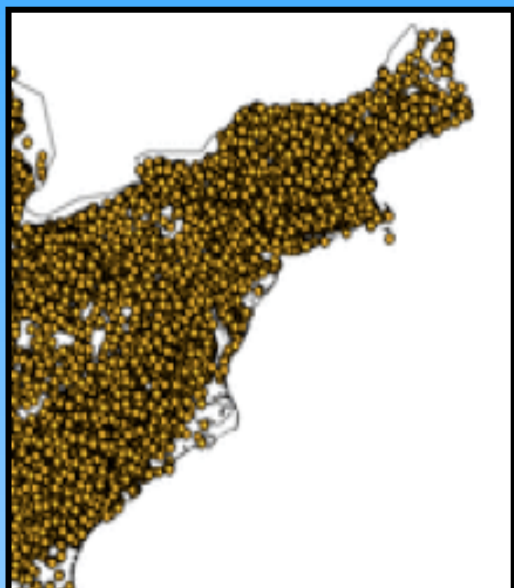
First National Geospatial Synthesis

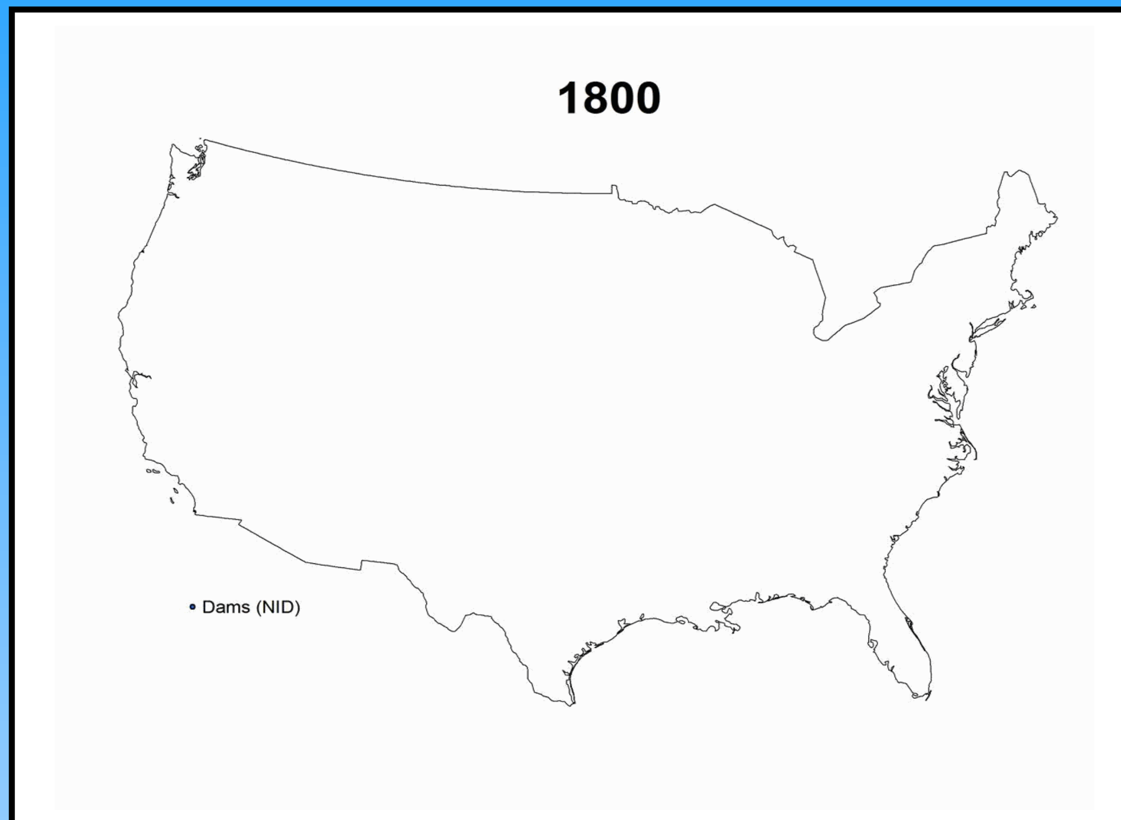
(based on EPA Clean Watershed Needs Assessment)

M. Rychtecka, C.J. Vörösmarty / City University of New York

History of US Dam and Reservoir Construction





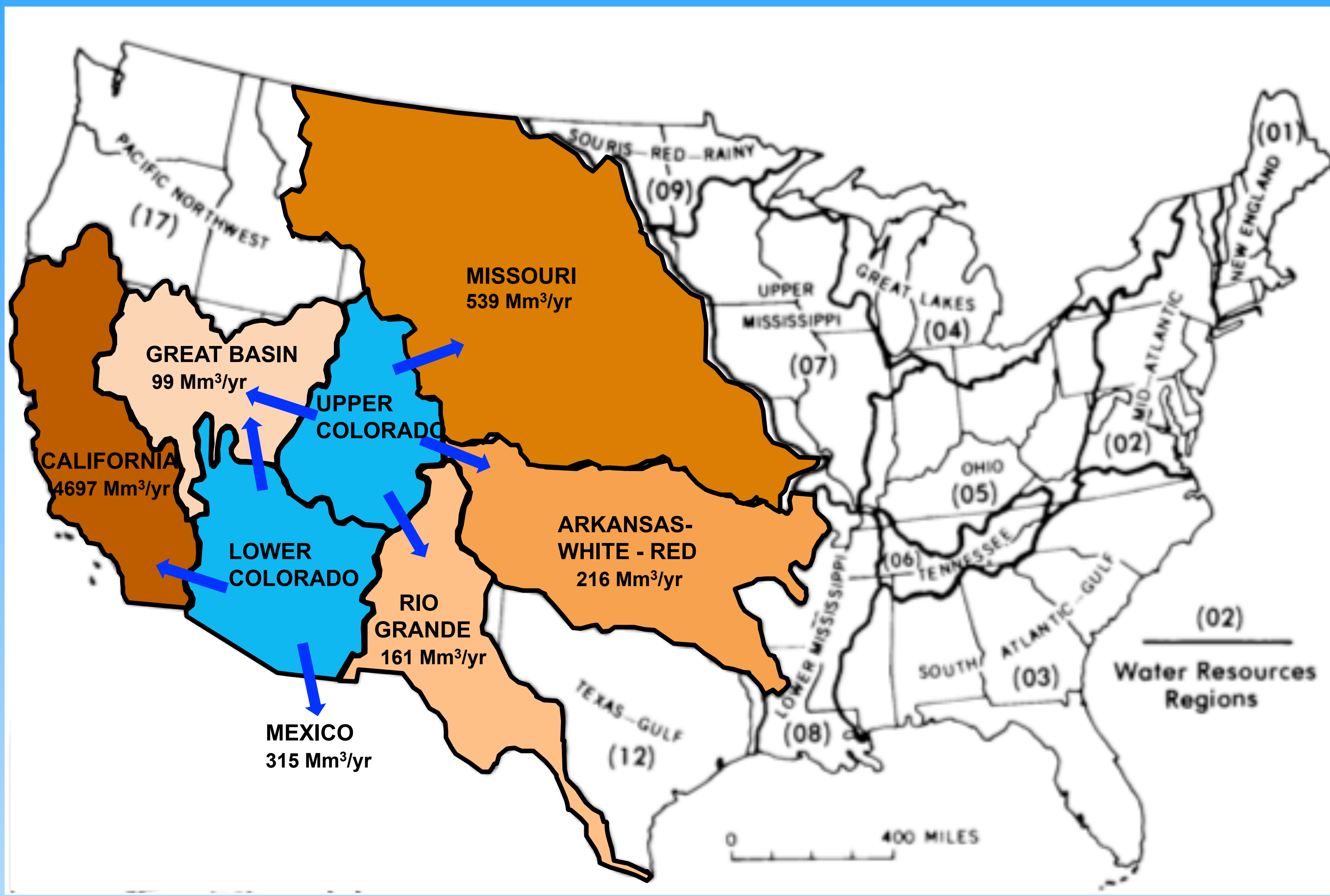


How and why did hydraulic engineering evolve? And what is its likely trajectory in the future?

…emblematic of water development globally

Source : National Inventory of Dams

Inter-Basin Water Transfers from Colorado

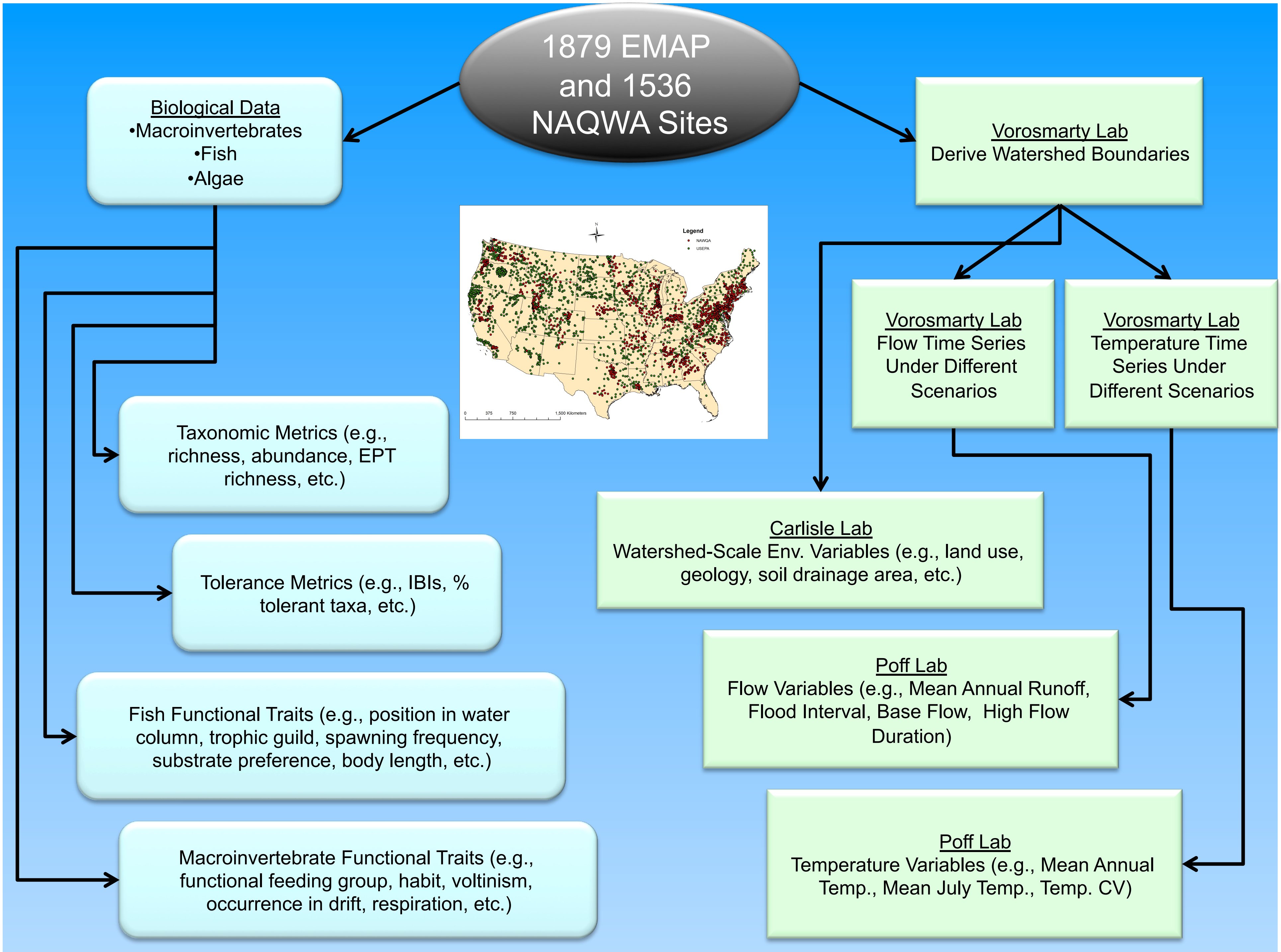


4) Within Upper Colorado:

# Database	IBWT within UPPER COLORADO Subregions	m^3/year
65	Sarvis Ditch	146,784
66	Stillwater Ditch	5,254,633
67	Dome Creek Ditch	822,732
60	Divide Creek Highline feeder ditch	1,307,491
61	Main Canal 1	82,088,216
62	Main Canal 2	79,263,543
63	Summit Reservoir outlet canal	9,732,172

5) Within Lower Colorado :

# Database	IBWT within LOWER COLORADO Subregions	m^3/year
86	Pipeline from pumping plant on Black River	6,882,829
87	Eastern Canal (at head)	92,363,120
88	East Branch Consolidated Canal	109,656,535
89	Roosevelt Water conservation District main canal	47,612,399
80	Pipeline from blue Ridge Reservoir	11,520,720
81	Cila Graviti Main Canal	632,381,468


1879 EMAP and 1536 NAQWA Sites
Biological Data
•Macroinvertebrates
•Fish
•Algae
Vorosmarty Lab
Derive Watershed Boundaries
Vorosmarty Lab
Flow Time Series Under Different Scenarios
Vorosmarty Lab
Temperature Time Series Under Different Scenarios
Taxonomic Metrics (e.g., richness, abundance, EPT richness, etc.)
Tolerance Metrics (e.g., IBIs, % tolerant taxa, etc.)
Fish Functional Traits (e.g., position in water column, trophic guild, spawning frequency, substrate preference, body length, etc.)
Macroinvertebrate Functional Traits (e.g., functional feeding group, habit, voltinism, occurrence in drift, respiration, etc.)
Carlisle Lab
Watershed-Scale Env. Variables (e.g., land use, geology, soil drainage area, etc.)
Poff Lab
Flow Variables (e.g., Mean Annual Runoff, Flood Interval, Base Flow, High Flow Duration)
Poff Lab
Temperature Variables (e.g., Mean Annual Temp., Mean July Temp., Temp. CV)

In Conclusion

- FrAMES (Framework for Aquatic Models of the Earth System) provides computational backbone to multi-stressor analysis
- Major advance: In-basin, time-varying fluxes
- Core data sets include: thermal loading and impact, nutrients, water engineering works
- *Next steps:* integration of component models, downscaled climate forcings; links to habitat, taxonomic groups, impact assessment