

Representing the physical processes:
How well-equipped are we to model water availability?
How can we improve?

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Snowmass, CO 29 July 2015

To simulate the hydrological system at all places and all times

Agriculture

Evapotranspiration

Direct human consumption (Domestic and Industrial)

Dams/Reservoirs

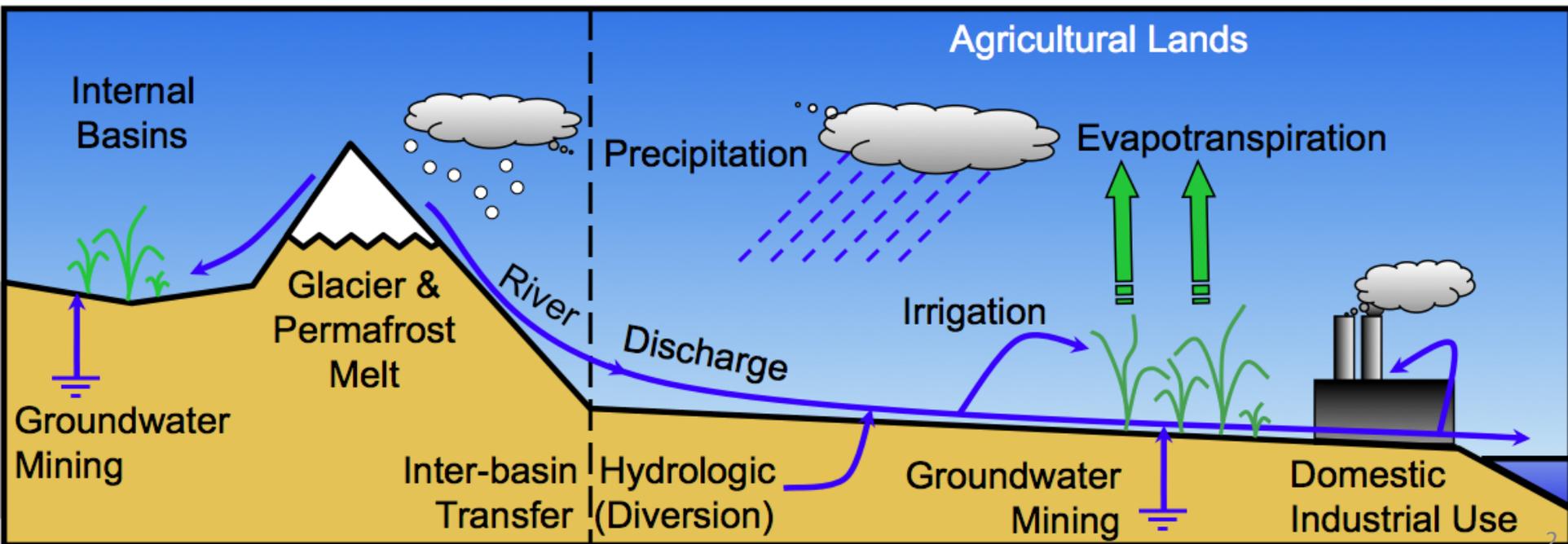
River Diversions

Wells/Groundwater mining

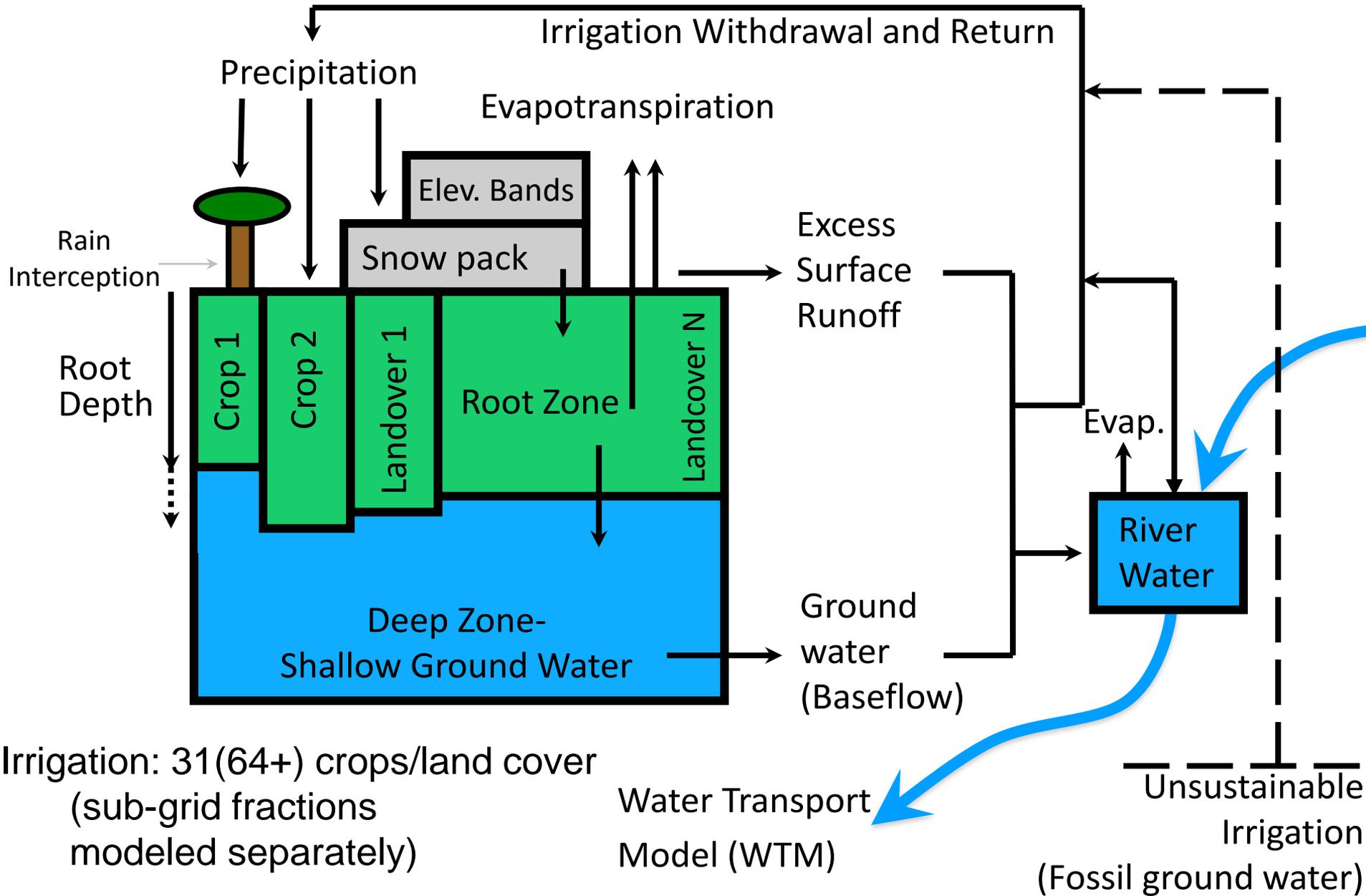
Land cover/Land use changes

Hydrological changes with land use changes (linked through PET function)

etc...

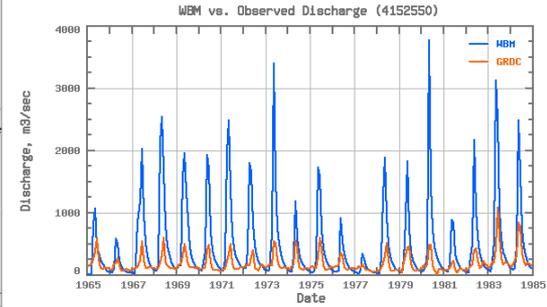
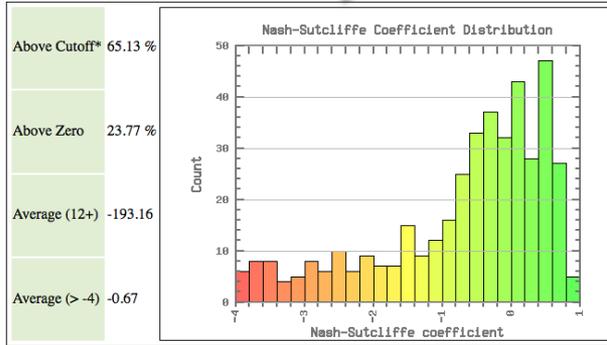
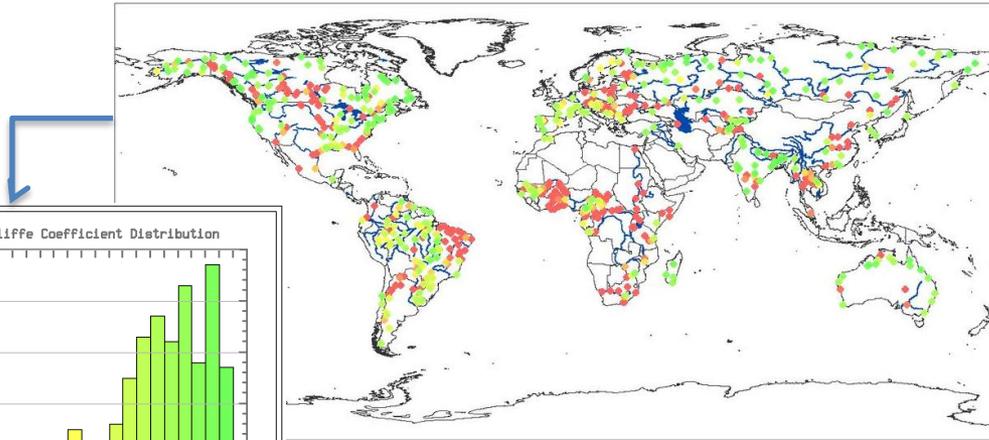


WBM/WTM Model Structure - Single Grid Cell, Daily Time Step



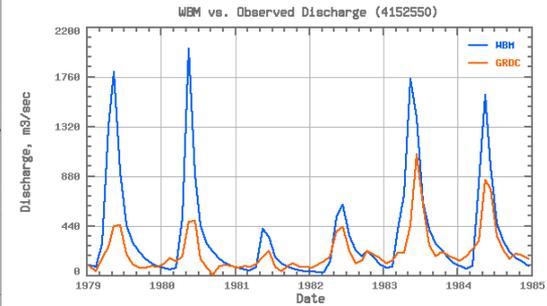
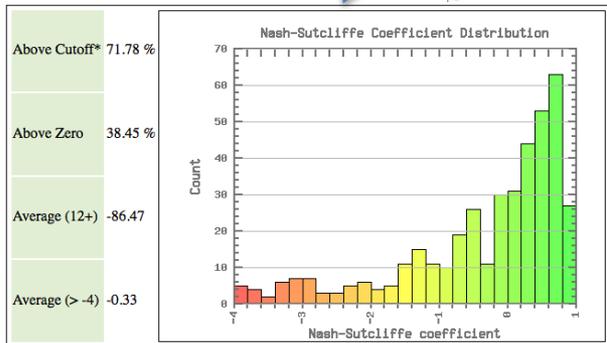
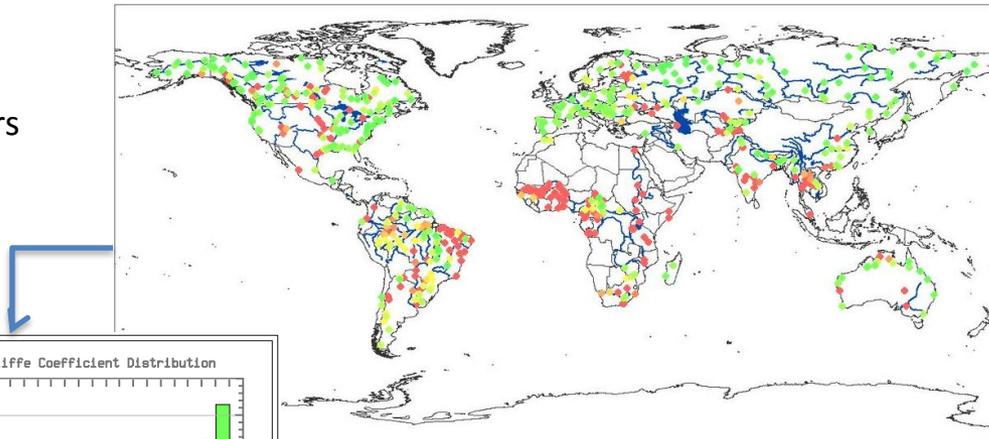
Expanded validation of model results to observed river flow Using Nash-Sutcliffe Coefficient

NCEP Climate drivers
(n = 631 stations)



Green River (Tributary of the
Colorado R.) 116,000 km²

MERRA Climate drivers
(n = 567 stations)



WBM Tracking Water Components in Runoff, River Discharge, and Groundwater

Several component assemblages can be tracked in WBM-TrANS

Assemblage by

Age

Runoff origin-

- Glacial melt
- Snow melt
- Rain storm water
- Baseflow water

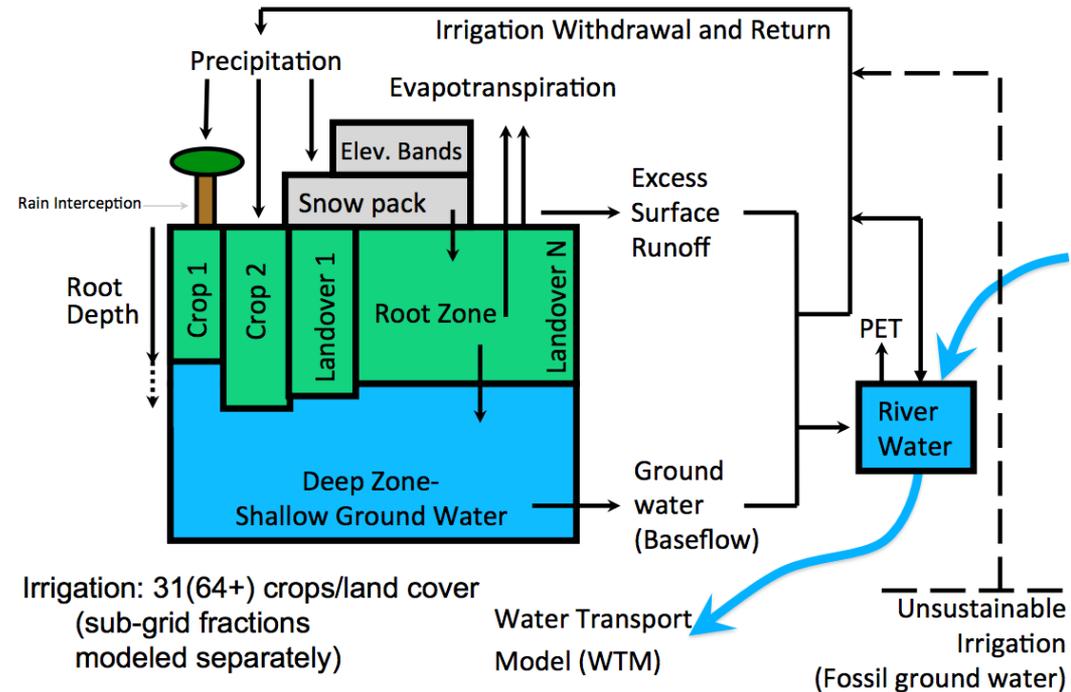
Primary origin-

- Glacial melt
- Snow melt
- Rain
- Unsustainable water

Water use (irrigation)-

- Pristine water
- Irrigation return water

WBM-TrANS Model Structure - Single Grid Cell



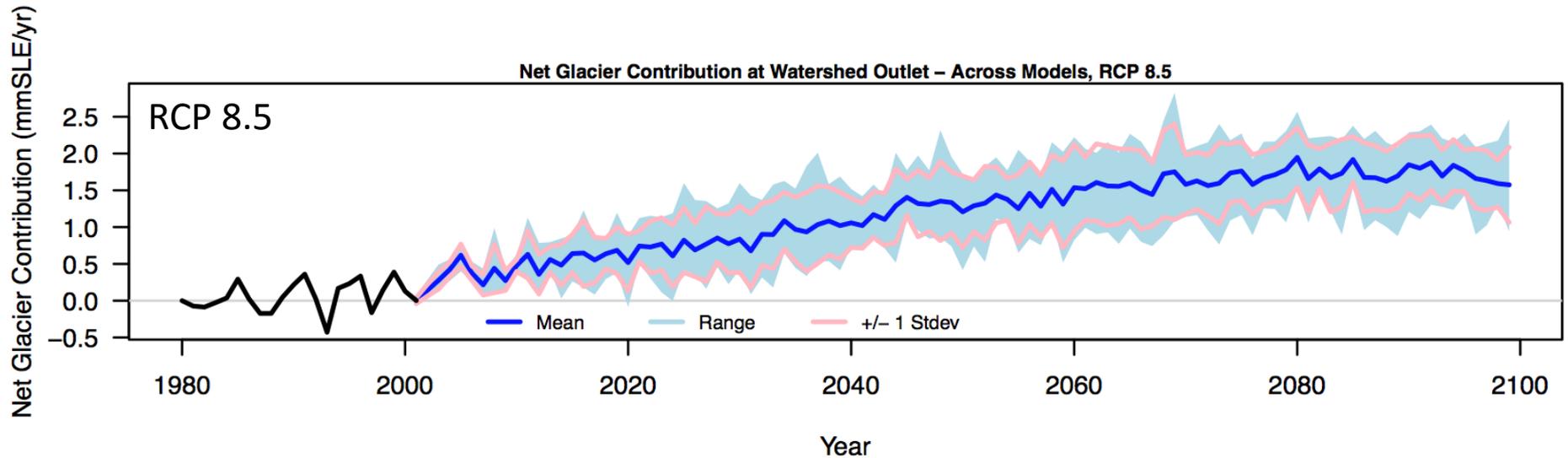
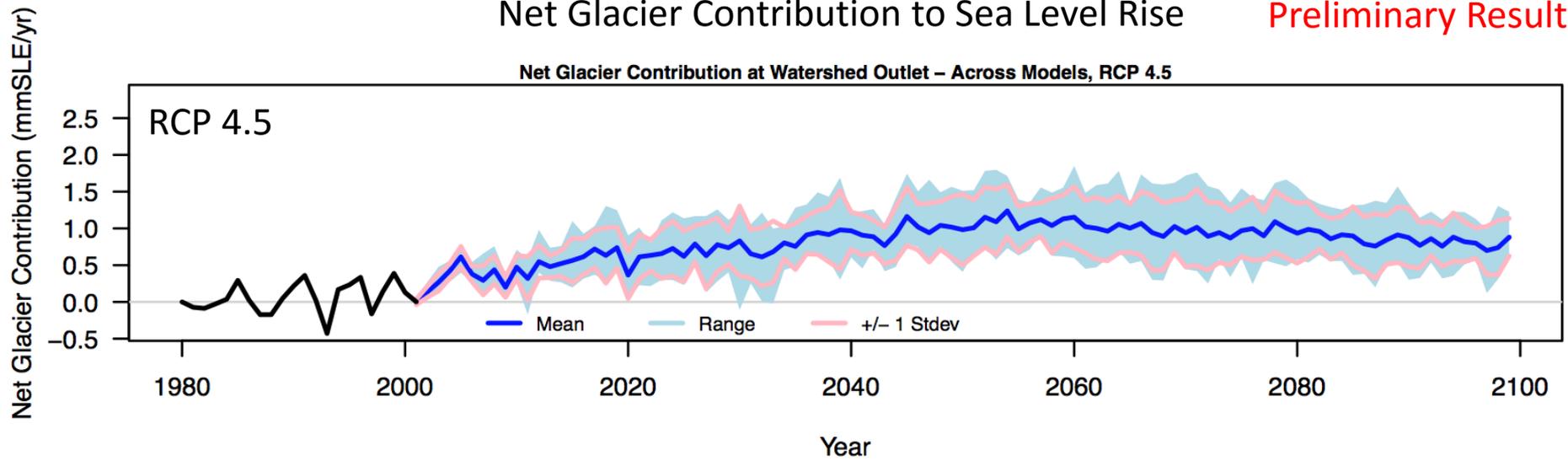
Component concentrations change as water is routed downstream due to local runoff tributary inflow and additional water use.

Why is this important?

Allows for an understanding of the downstream impacts due to upstream changes (natural or human sources)

Net Glacier Contribution to Sea Level Rise

Preliminary Results



- Global runs 6 models per scenario
- Internal (endorheic) basins removed
- Glaciers from Randolph Glacier Inventory v. 4.0
- Does not include ice sheets (Greenland, Antarctica)

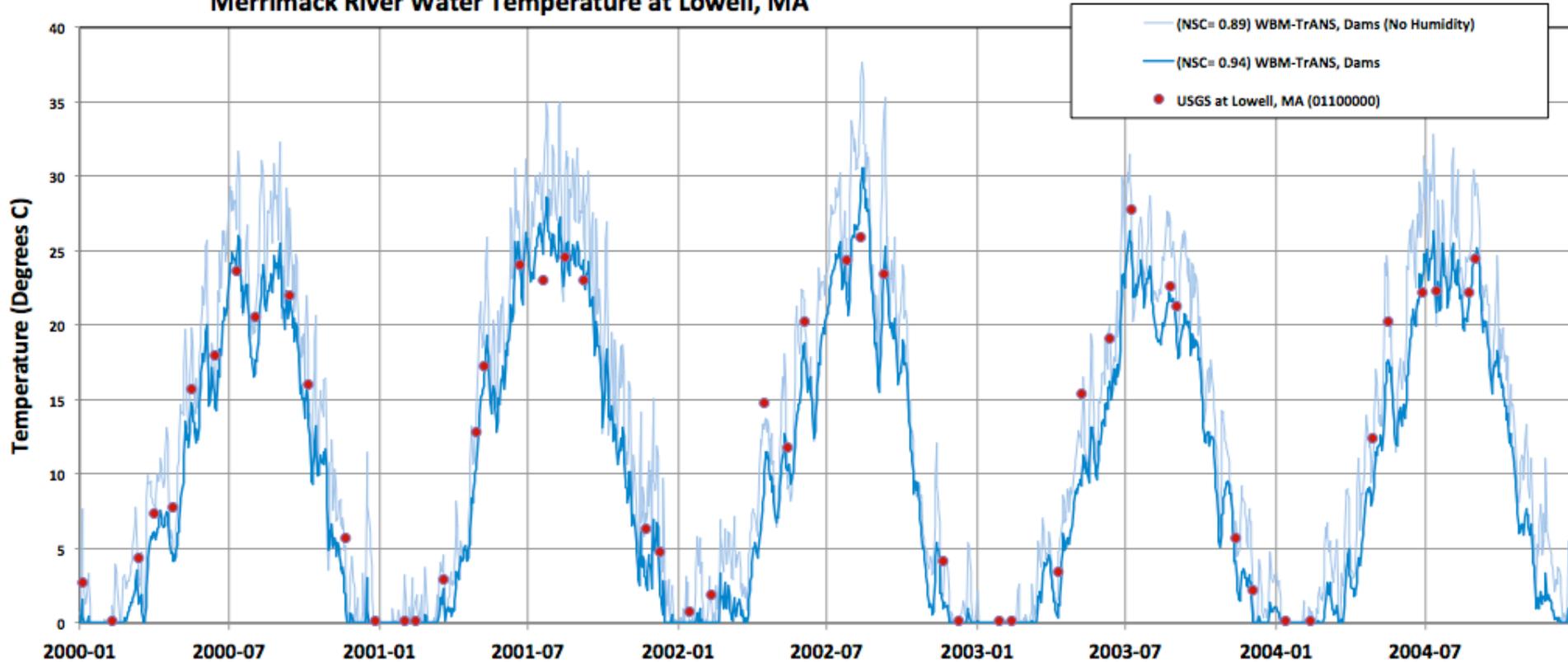
With Regine Hock, U. Alaska Fairbanks
Matthias Huss, University Fribourg, Switzerland

Water Quality – This version of the model has started to incorporate
(parallel version of the model has this as main focus)

Water Temperature implemented now. Important for:

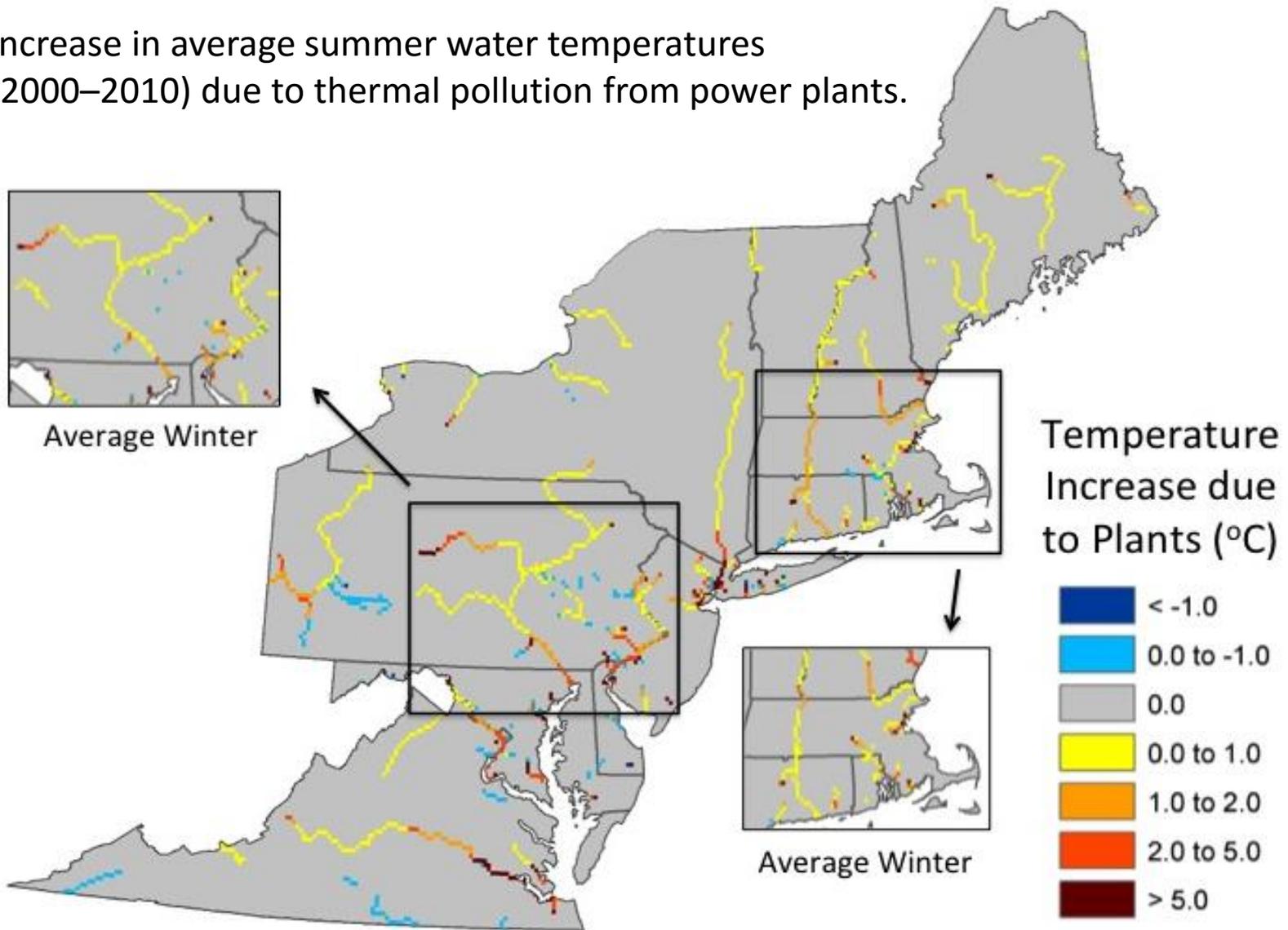
- In-stream processes
- Fish habitat
- Power plant regulation and operation

Merrimack River Water Temperature at Lowell, MA



WBM run with very fine spatial resolution

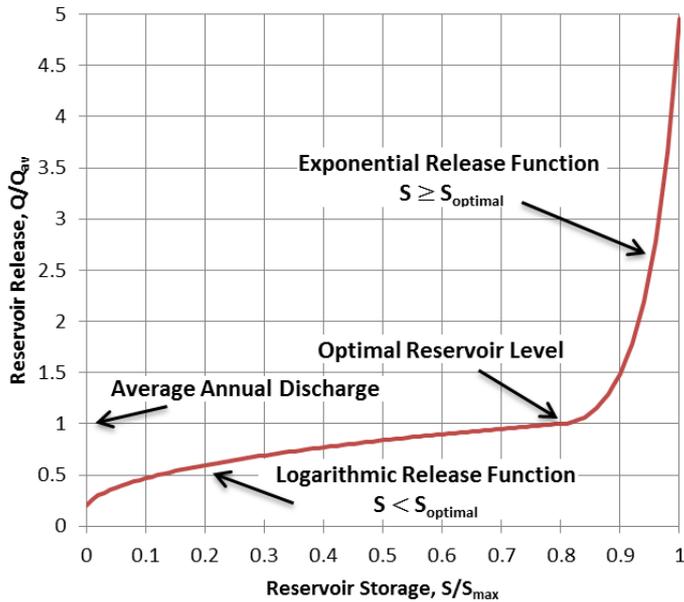
Increase in average summer water temperatures (2000–2010) due to thermal pollution from power plants.



Callout boxes show results for average winter conditions. Plants which use recirculating cooling tower technology often reduce downstream water temperatures while "once-through" cooling technologies return water to the stream at much high temperatures.

Dam/reservoir operating rules

Generic Reservoir Operating Rule



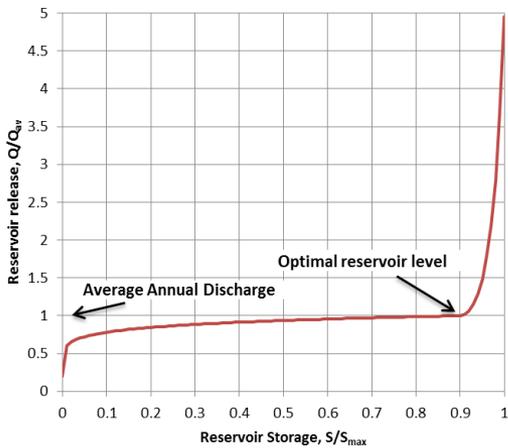
- For large dams that are operated
- Water release is a function of reservoir storage level
- Multiple water release “rules” depending on major function of dam (when known)

Primary Function:

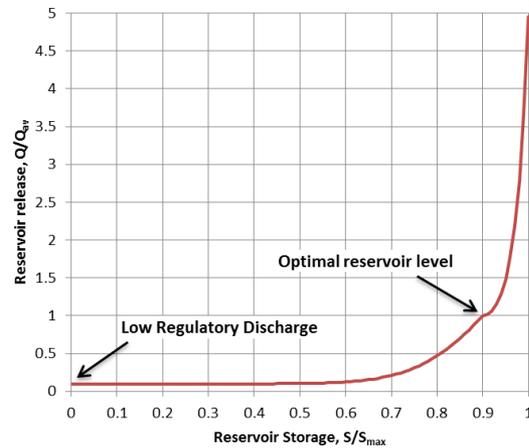
- Hydropower** - Maximize high potential energy with steady flow
- Irrigation** - Save water for later (local access)
- Flood Control** - Maintain buffer
- Generic** - When function is not known, average response

But: Most dam operation involves more complex regulation/operation and human decision making

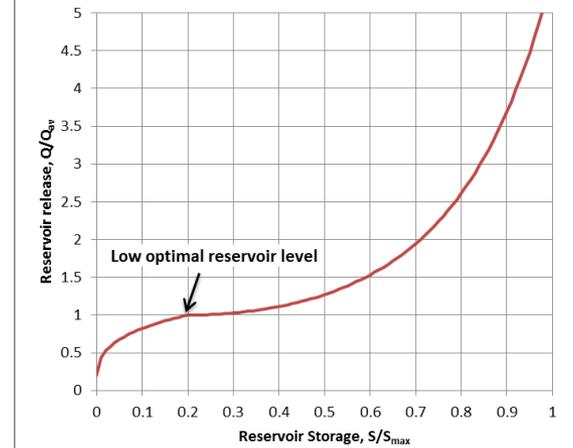
Hydropower



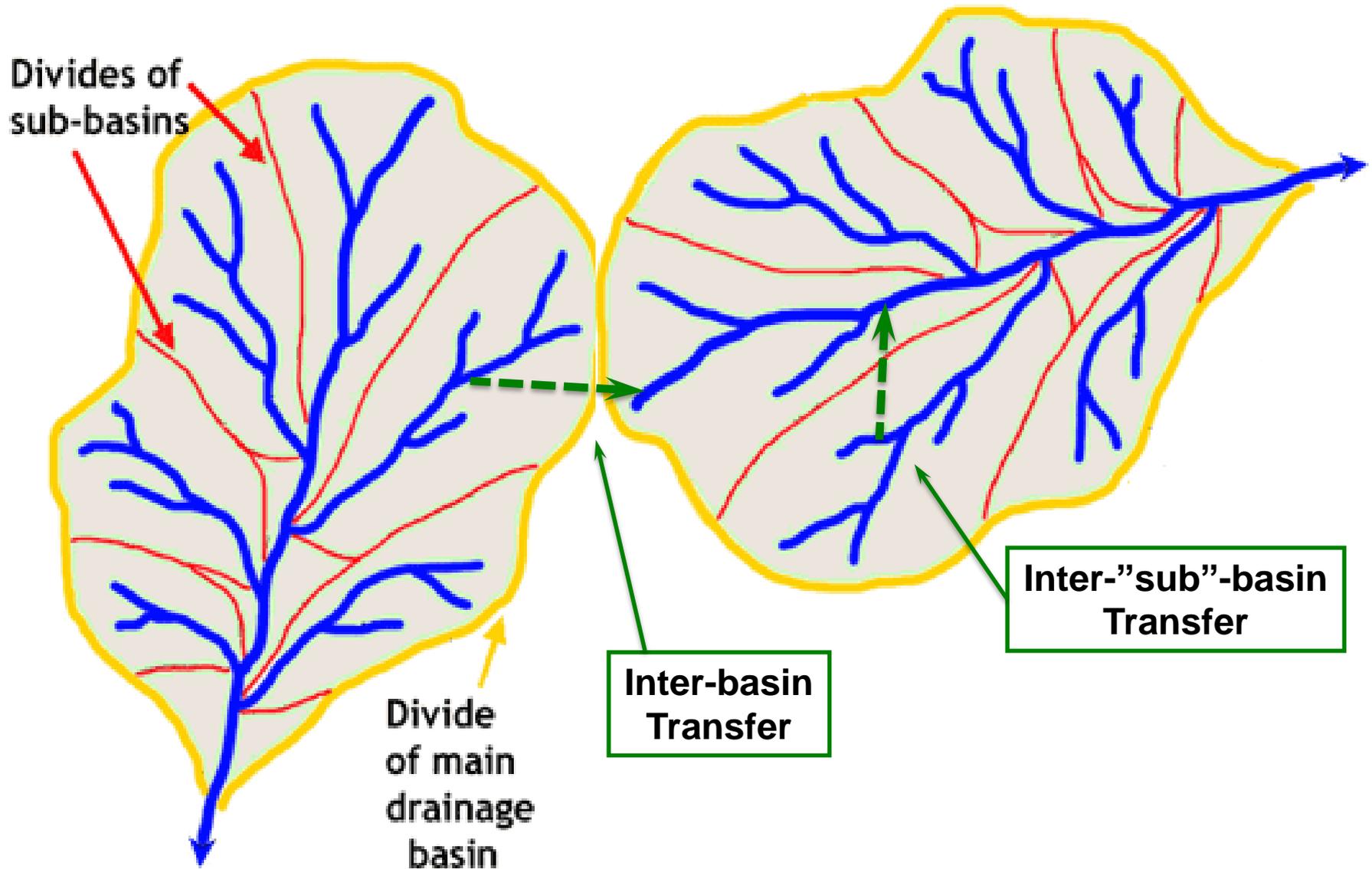
Irrigation, Water Supply

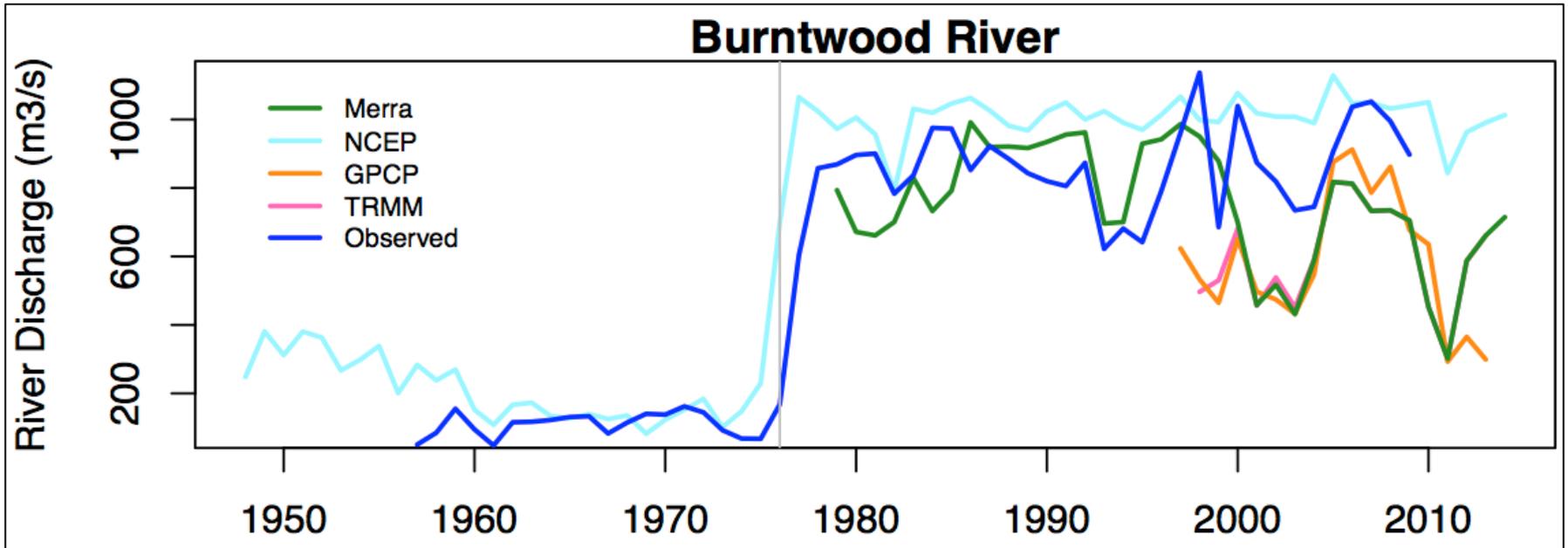


Flood Control

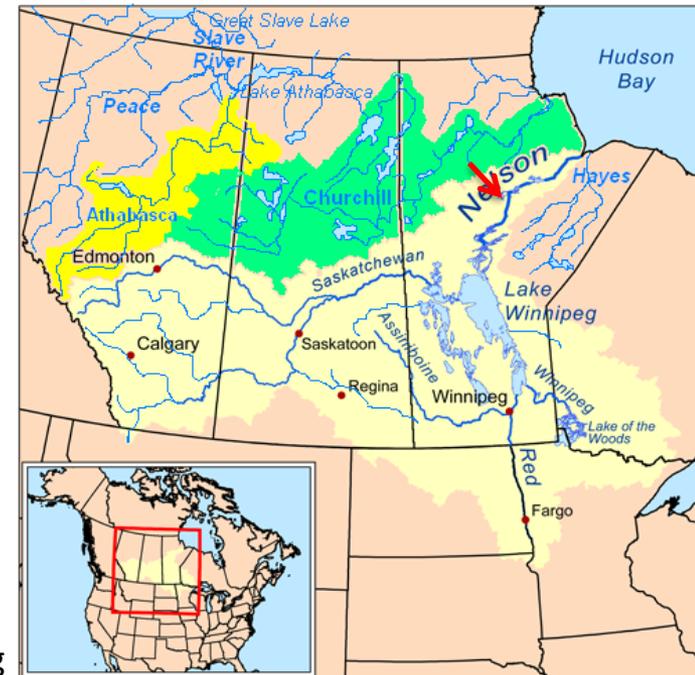
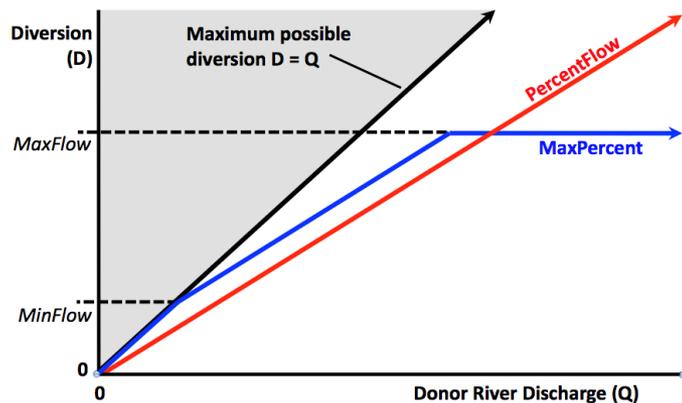


What are Inter-basin Hydrological Transfers? (also known as Diversions)



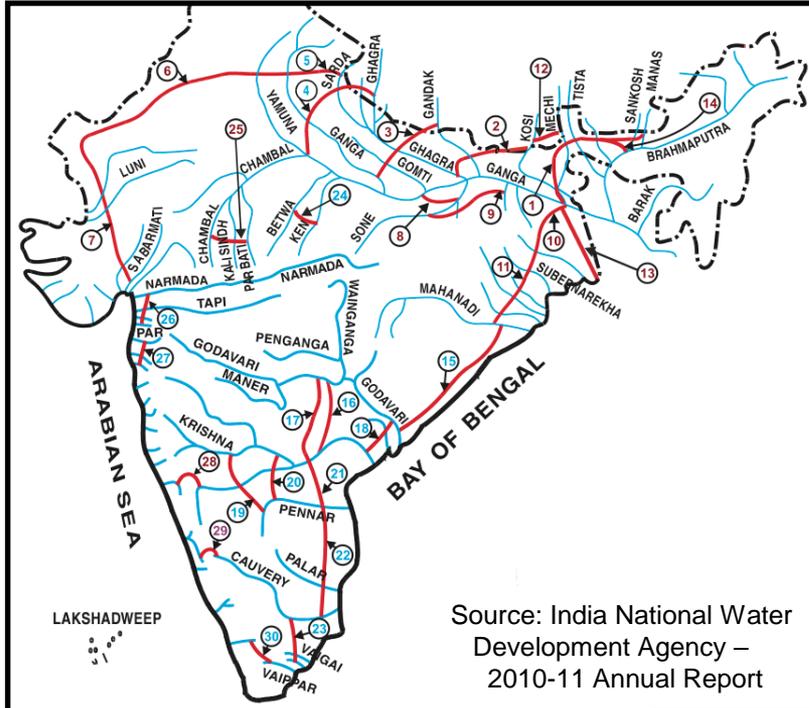


- Diversion from the Churchill R. to the Nelson R. via the Burntwood R. (Nelson R. tributary)
- For hydropower generation on the Nelson R.



Future inter-basin hydrological transfer impacts?

India's Proposed National Water Linking Project



Source: India National Water Development Agency – 2010-11 Annual Report

- International Boundary — — — — —
- Rivers —————
- Inter-Basin Transfers —————

Himalayan & Peninsular components, including Nepal sources

Planned water transfer ~ 175 km³ yr⁻¹

China's Proposed South-to-North Water Transfer Schemes



Source: modified from futuretimeline.net

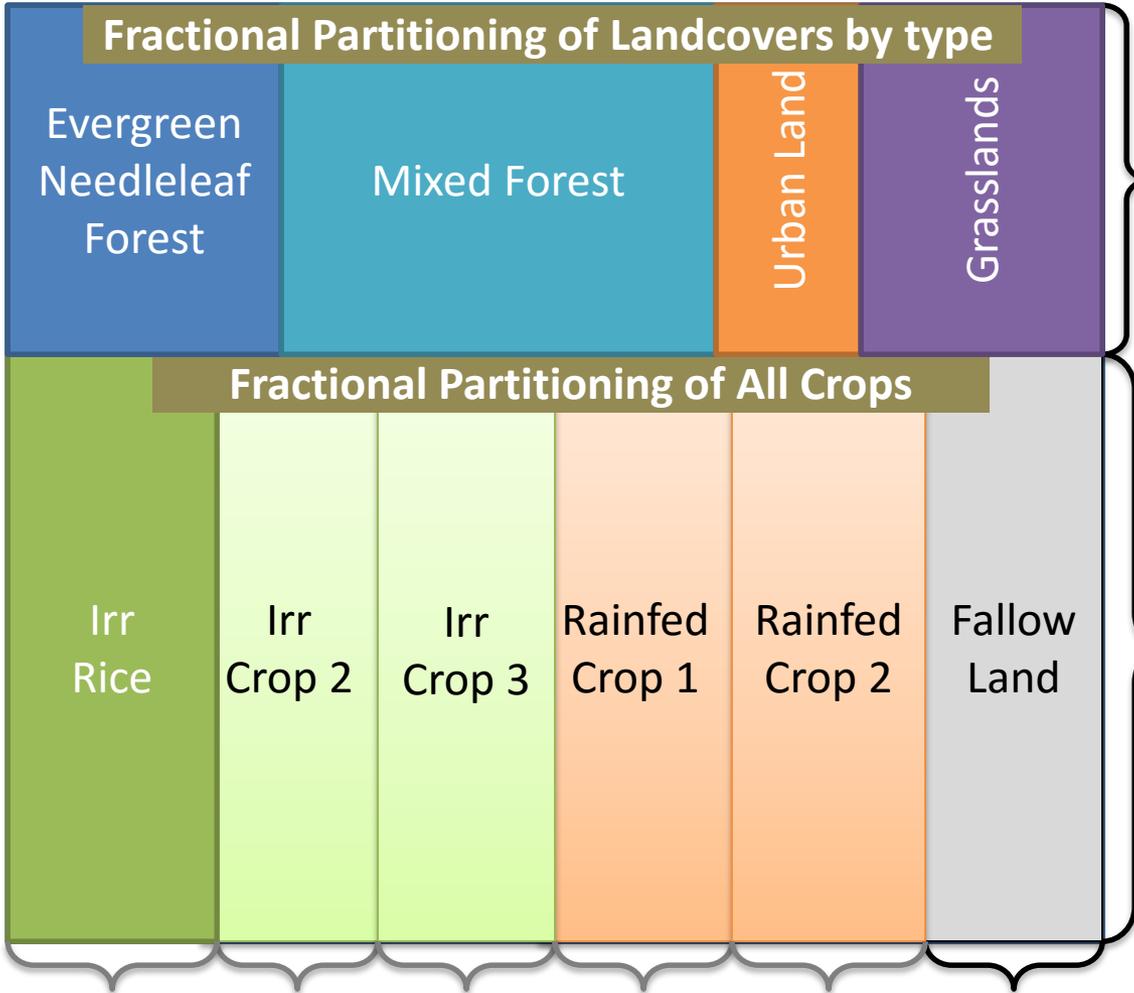
Under Construction & Planned: 
(Western, Central and Eastern Routes)

Planned water transfer ~ 50 km³ yr⁻¹

California State Water Project ~ 5 km³ yr⁻¹
Central Arizona Project ~ 1.85 km³ yr⁻¹

Land Partitioning Model in a Grid Cell: Include Land Covers

Example of a Grid Cell



Natural and Anthropogenic (non-crop) Land cover

Can be a time series dataset. Presently we use 14 MODIS LC types. Each type has its own set of WBM parameters (e.g. root depth) that results in LC dependent runoff. Area is the remainder after assigning the Total Crop Area.

Total Crop Area -

Can be a time series dataset. Presently we use 52 MIRCA crop types (26 irrigated and 26 rainfed). Each crop has its own within cell water balance.

Irrigated and Rainfed Crop Fractions

Daily time series for each crop. (26 irrigated and 26 rainfed)

Fallow Land -

Daily time series. Equals the fraction of total crop area that is not taken up by assigned crops.

Effects of improving irrigation efficiency (Preliminary results)

Two WBM runs:

1. "WBM-FAO": With FAO country-level irrigation efficiencies 34% - 70%
2. "WBM-70%": All countries set to maximum global irrigation efficiency 70%

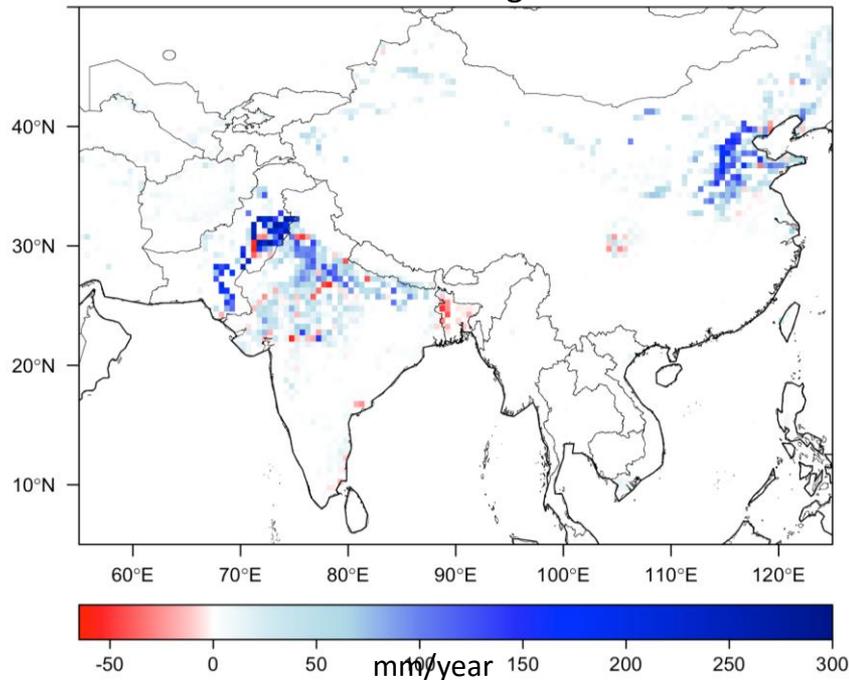
- Irrigation water demand is completely fulfilled by first using shallow (sustainable) groundwater, then river/reservoir water, then lastly unsustainable groundwater pool.

- Maps are WBM-FAO minus WBM-70%

Preliminary Results

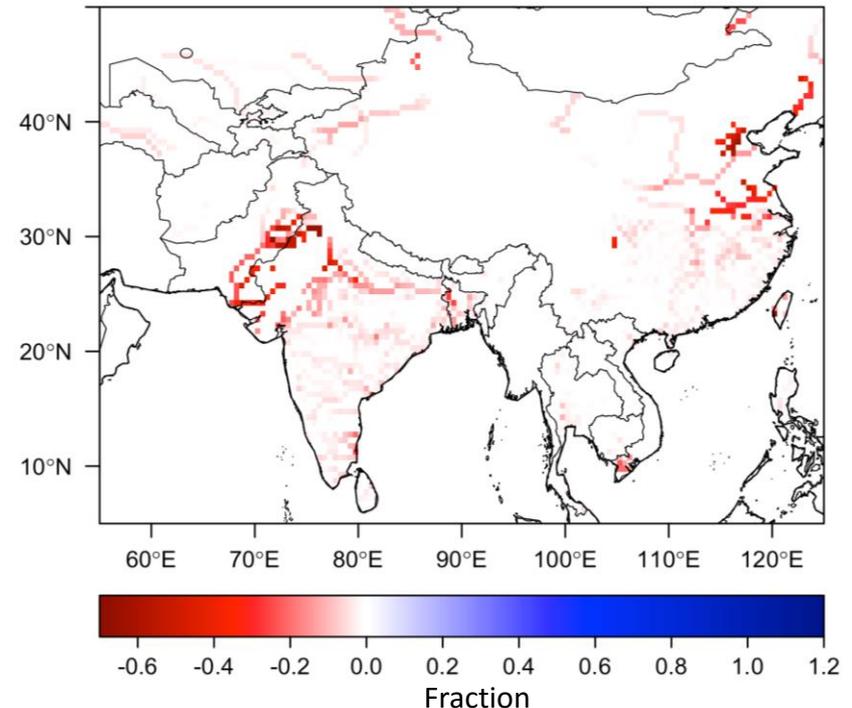
Unsustainable Groundwater Demand

BLUE = Decrease in unsustainable groundwater demand
RED = Increase in unsustainable groundwater demand



River Discharge Change in average daily flow

RED = Decrease in flow from increased irrigation efficiency



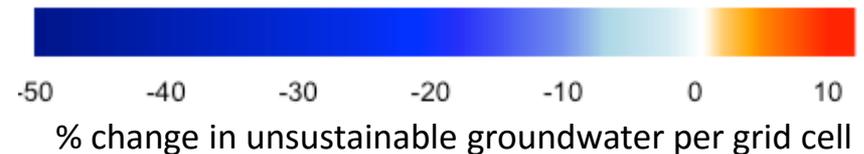
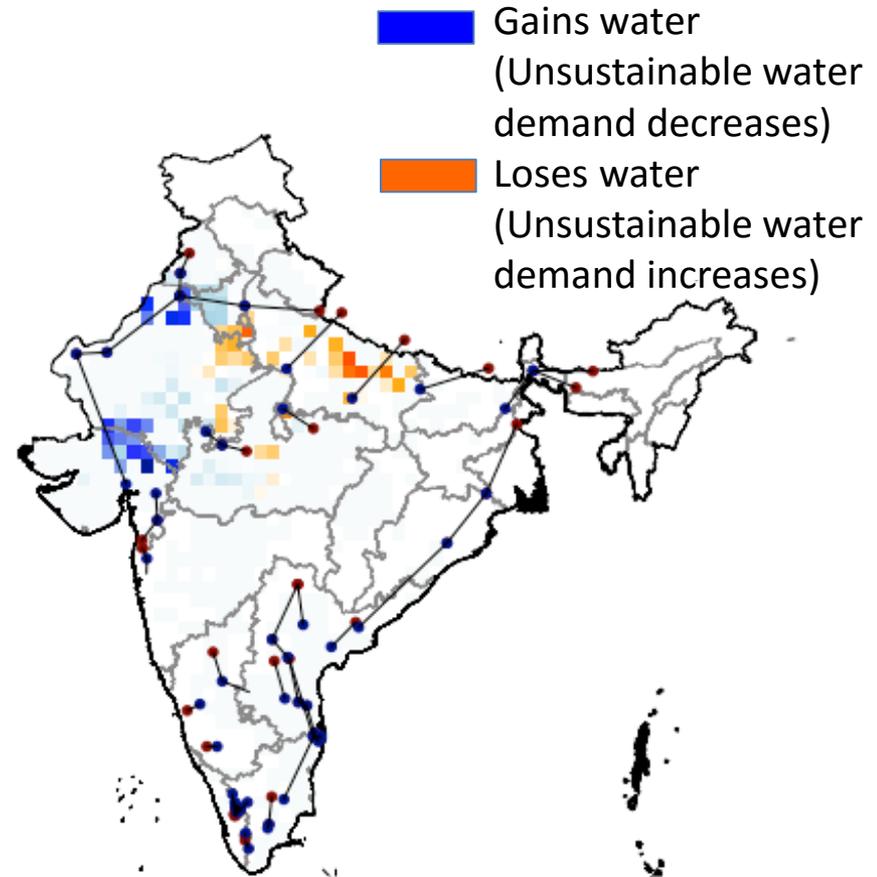
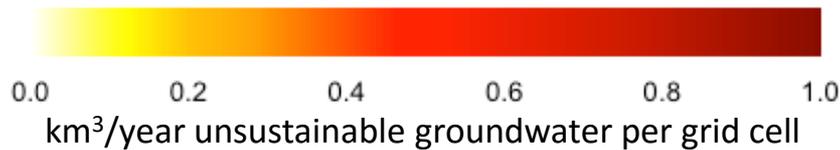
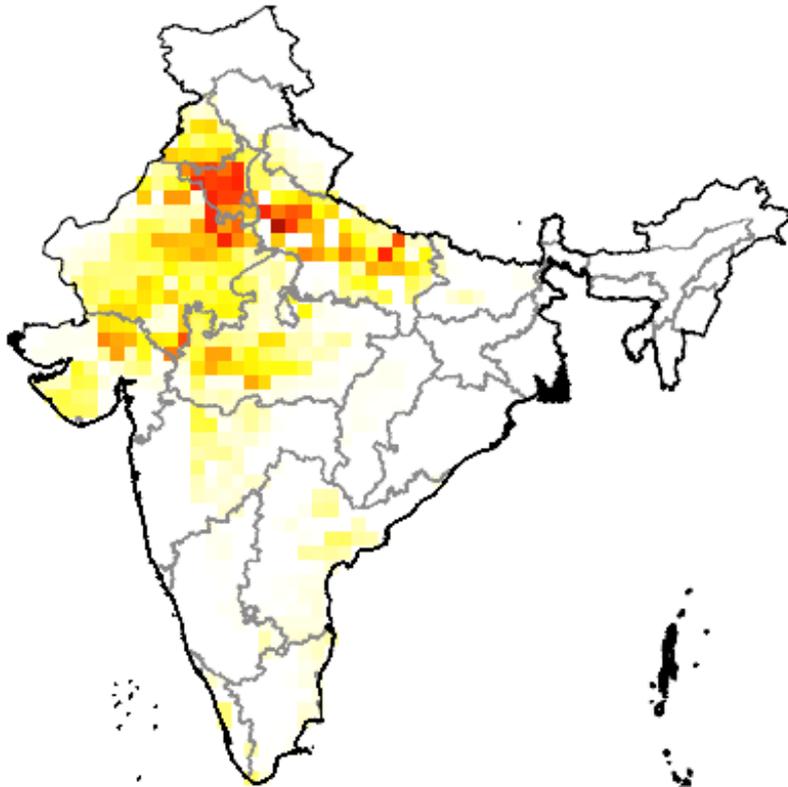
India's National River Linking Project

Preliminary Results

Analysis under current climate and agriculture (c. 2000)

Unsustainable groundwater demand
(Average km³/year)
National total = 42 km³/year

% change unsustainable water demand with NRLP
(Average % change)
National total = -2.2 %



- Gains water
(Unsustainable water demand decreases)
- Loses water
(Unsustainable water demand increases)

Problem: As physical scientists, we develop simple rules, often based on physical characteristics, that are parameterized and implemented with existing maps and data sets.

To bring this to the level of integrated assessment, i.e., to determine the consequences of change in climate/management on water resources, we need a better understanding of the social, economic and health dimensions, what drives change in water use, management, and infrastructure.

Process	Short time frame (this is about water volume)	Long time frame (this is about infrastructure)
Dams and Interbasin Transfers	How much water to release/move and when	When to build or decommission dam/canal/pipeline
Irrigation	How much to irrigate, which crops to plant	When to add additional fields to be irrigated; improvements in agricultural technology (giving improved water use efficiency)
Domestic Use	Household water demand, climate response	Changing attitudes, laws, planning codes and messaging
Industrial Use	Limitations due to regulation, supply/demand of industry	Structural shifts in economy

WBM can do some of this

WBM does not do this

Run-time Coupling of SWIM/ABM Model with WBM/WTM

Agent-Based Model (SWIM)

- **Strength:** Anthropogenic processes within the water cycle
- **Weakness:** Water cycle through atmospheric, land and riverine systems

Physical Hydrology Model (WBM)

- **Strength:** Water cycle through atmospheric, land and riverine systems
- **Weakness:** Anthropogenic processes within the water cycle

Run-time Coupling

ZeroMQ communication module allows the two models to talk to each other and exchange data/information across Internet.

How much water is available at these locations? —————> $X \text{ m}^3$ is available and crop/soil irrigation demand is $Y \text{ m}^3$

Take $Z_1 \text{ m}^3$ for human use, release return $Z_2 \text{ m}^3$ there, and irrigate/move $Z_3 \text{ m}^3$ to these fields <-----

—————> Update soil moisture, runoff and river flow at affected cells

Next Day

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Etc...

Next Day

Etc...

Coupled Physical Hydrology and Social Behavior Model (WBM/SWIM)

- **Strength:** Water cycle through atmospheric, land and riverine systems
- **Strength:** Anthropogenic processes within the water cycle

Summary:

- We (physical scientists) are very fortunate
 - Physical constants are just that – universal and constant
 - Conservation of mass & energy is a safe bet
- **Simple book-keeping can go a long way**, providing useful insights into water supply constraints and impacts (intended, unintended) of system changes, e.g., climate, infrastructure, behavior.
- We will always complain about **data quality**, and it will continue to hinder improving spatial resolution; our most fundamental variable – precipitation – is most critical and can have significant variability.

Summary:

- *Physical models do not represent:*
 - **Human behavior**, which responds to many things to influence water use on short to medium time scales (e.g., farmer irrigation response of monsoon precipitation, water conservation appliances, ...)
 - **Socio-politico-economic systems** that determine long-term infrastructure development pathways (e.g., construction of reservoirs, canals, water conservation policies/pricing, ...)
 - **Feedbacks** between physical water system and policy/behavior (e.g., drought response in California)

