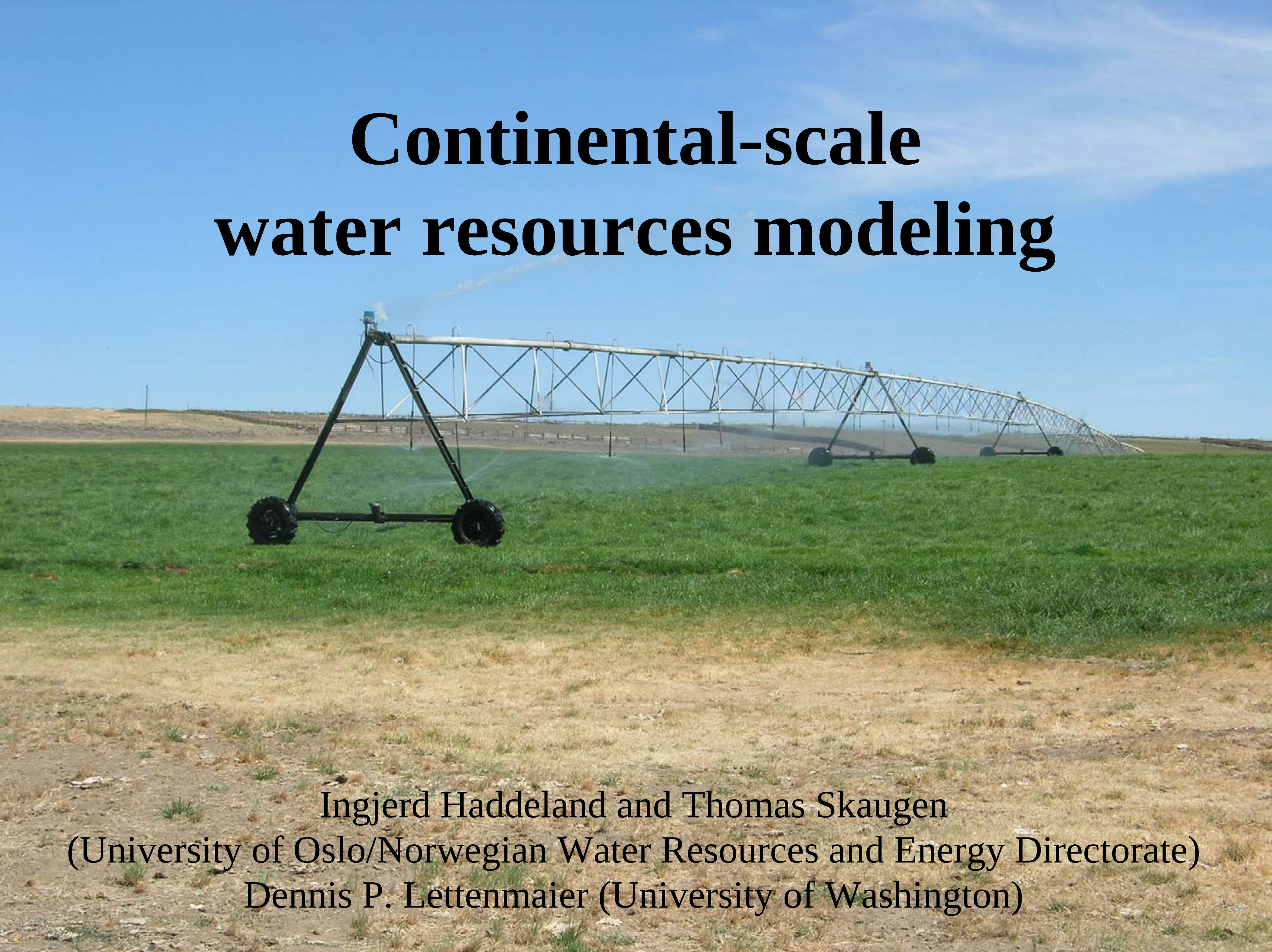

Continental-scale water resources modeling

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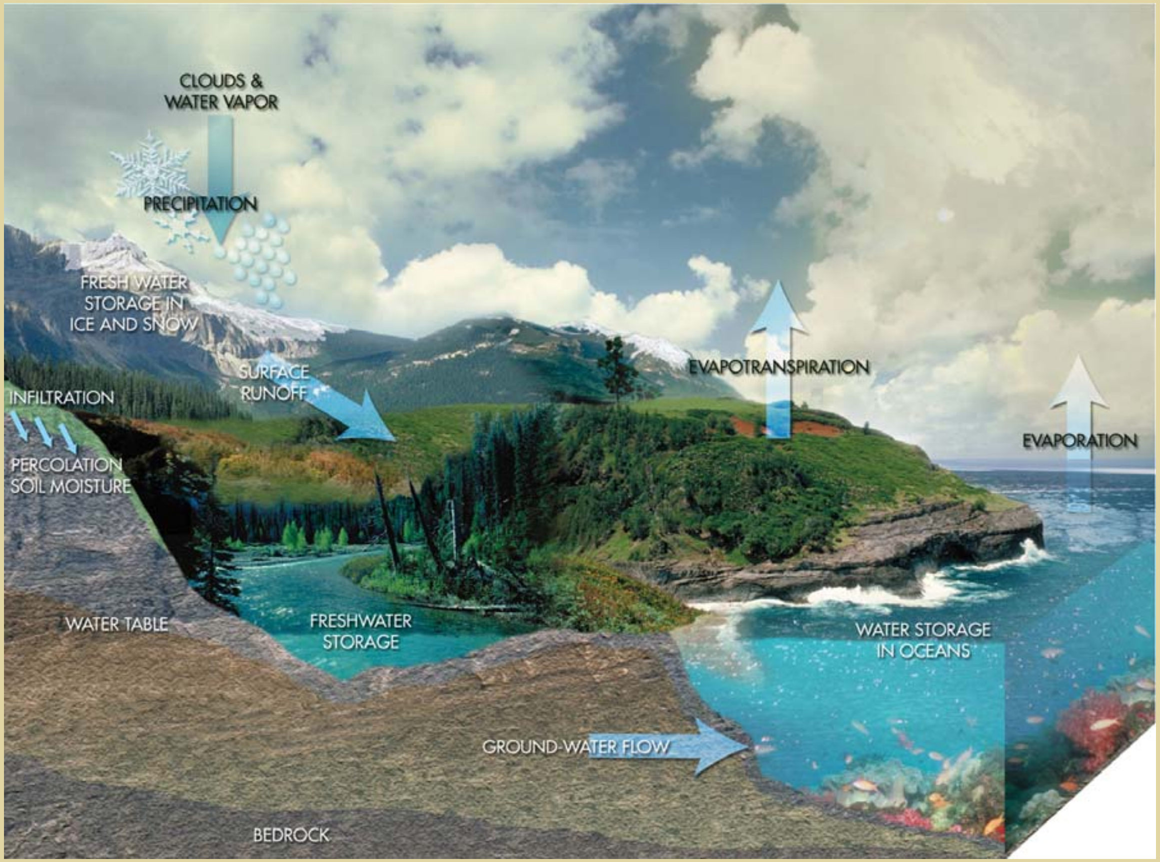
(University of Oslo/Norwegian Water Resources and Energy Directorate)
Dennis P. Lettenmaier (University of Washington)

Outline

- Background
  - What, why
- Approach
  - Model, data
- Results
- Conclusions



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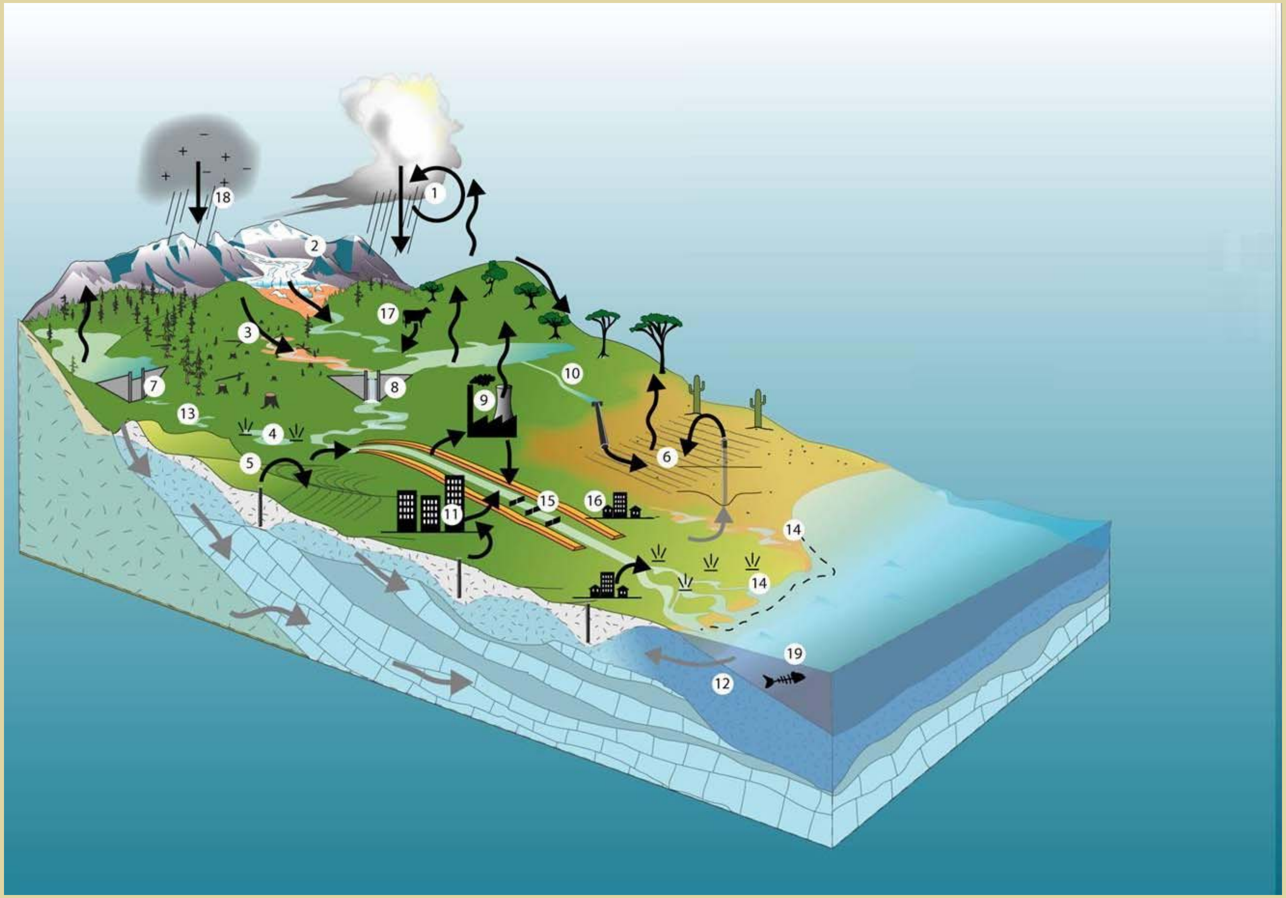


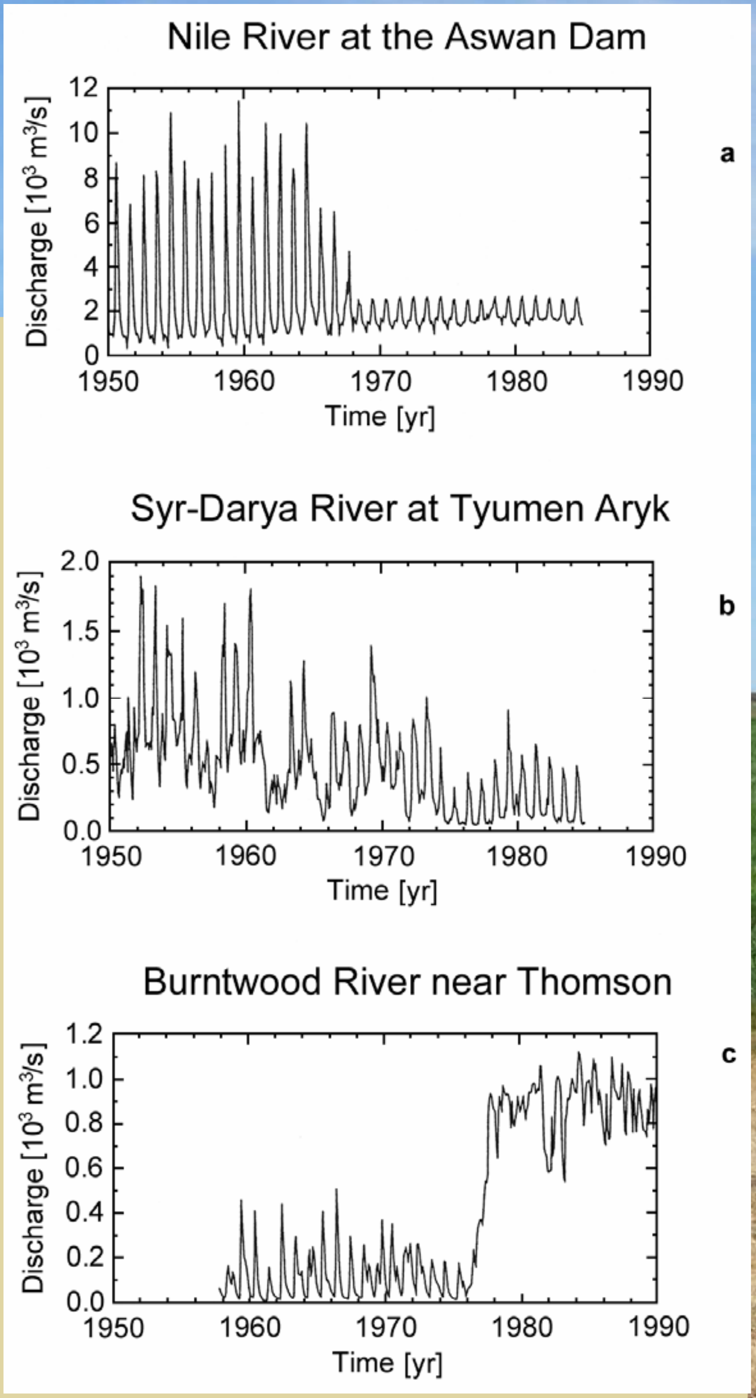
Introduction

- Irrigation
  - 60-70 % of global water withdrawals *(Shiklomanov, 1997)*

- >30,000 large dams
  - 20% of global mean annual runoff can be retained in reservoirs (Vörösmarty et al., 1997)

  - 35 % built for irrigation purposes alone (*ICOLD, 2003*)

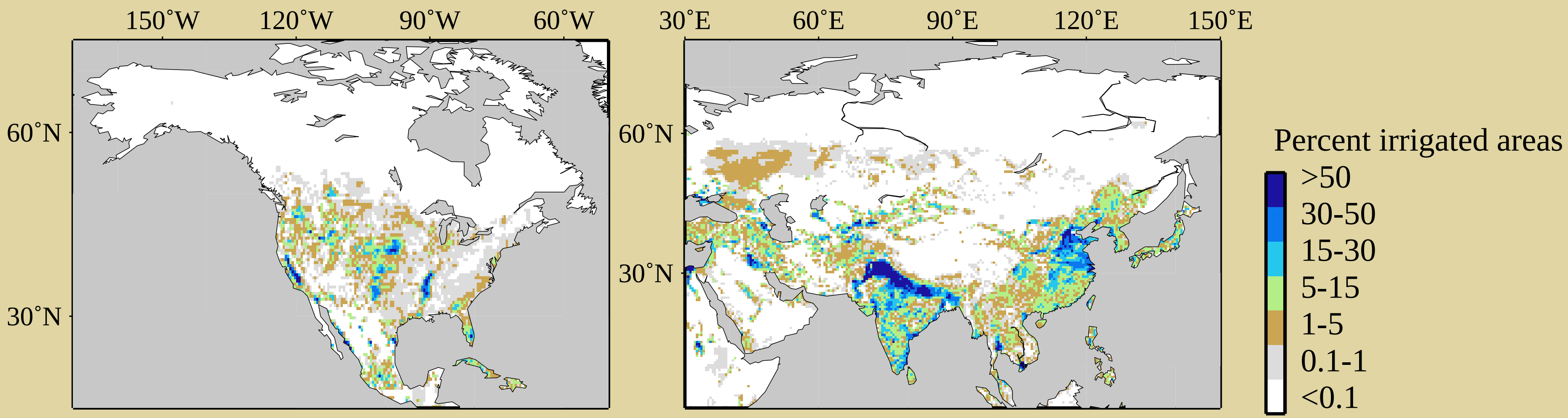
- Freshwater scarcity: one of the most important environmental issues of the 21st century *(UNEP, 1999)*



Vörösmarty and Sahagian, *Bioscience*, 2000.

Irrigation

Irrigated areas



Stefan Siebert, Petra Döll, Sebastian Feick and Jippe Hoogeveen (2005), Global map of irrigated areas version 3, Institute of Physical Geography, University of Frankfurt, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy

- Irrigated areas, globally:
  - $2.8*10^6$ km^2
  - ~2 % of global land area

- Location of irrigated areas:
  - Asia: 68%
  - America: 16%
  - China, India, USA: 47%

Irrigation: Definitions

- Irrigation water requirements:
  - Water required in addition to water from precipitation (soil moisture) for optimal plant growth during the growing season

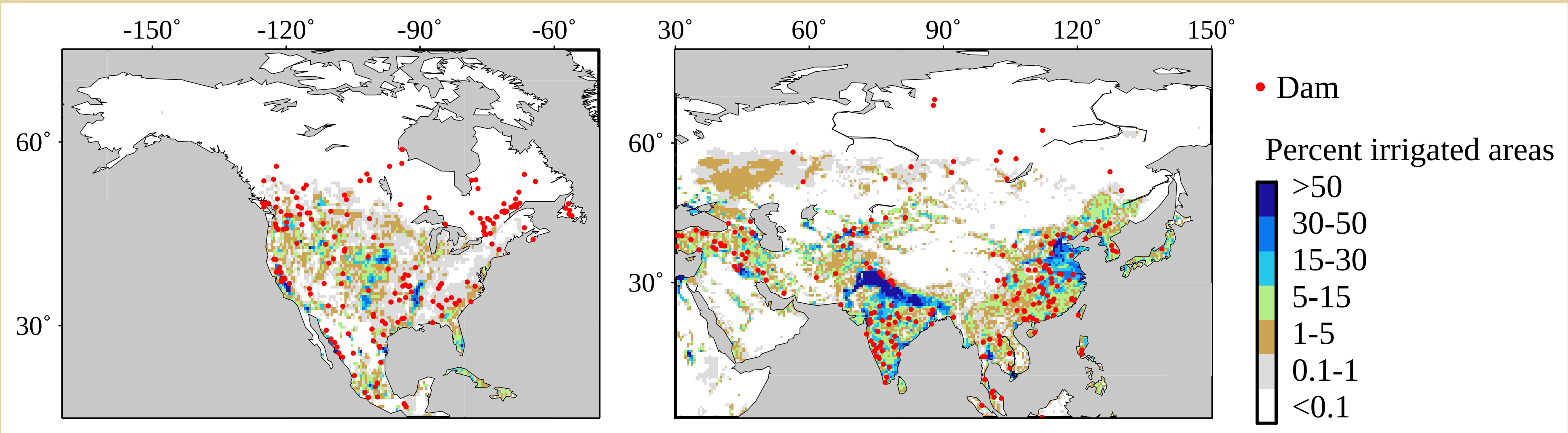
- (Consumptive) irrigation water use:
  - Water, in addition to water from precipitation, actually used by plants. Is equal to, or less, than irrigation water requirements.

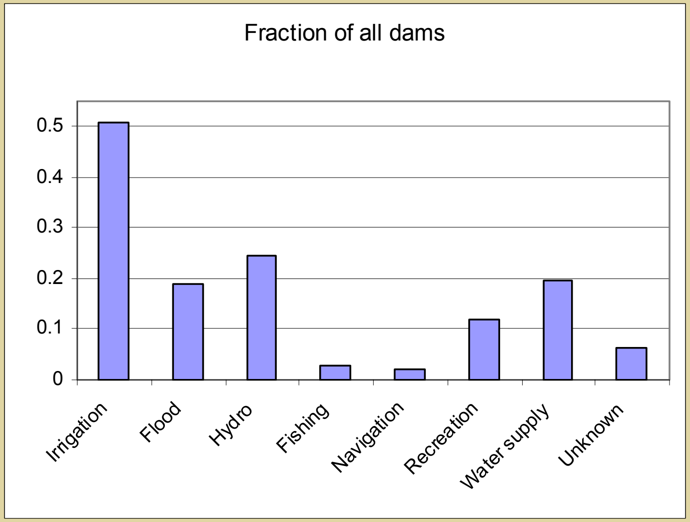
- Irrigation water deficits:

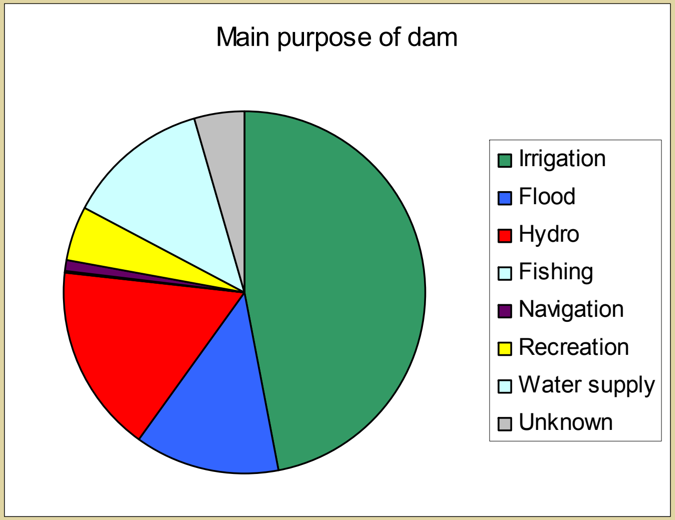
  Irrigation water requirements – Irrigation water use

Reservoirs

Reservoirs



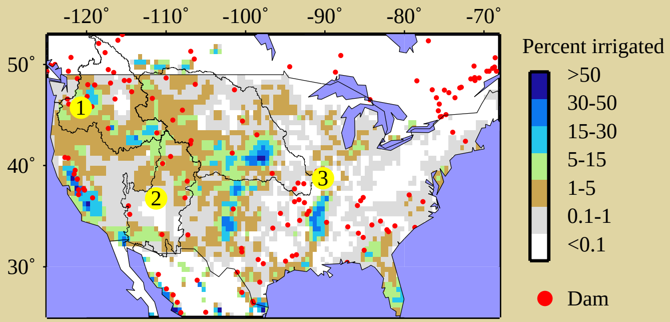




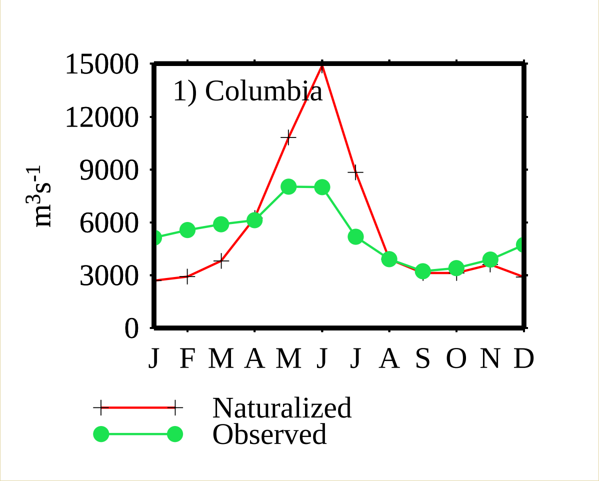
ICOLD, 2003. World Register of Dams 2003, International Commission on Large Dams (ICOLD), Paris, France.

Objectives of this study

- Model the effects of irrigation and large reservoirs on the water balance, with the objective of obtaining plausible reproductions of observed flows at the outlets of large river basins, with a special emphasis on river basins affected by irrigation.

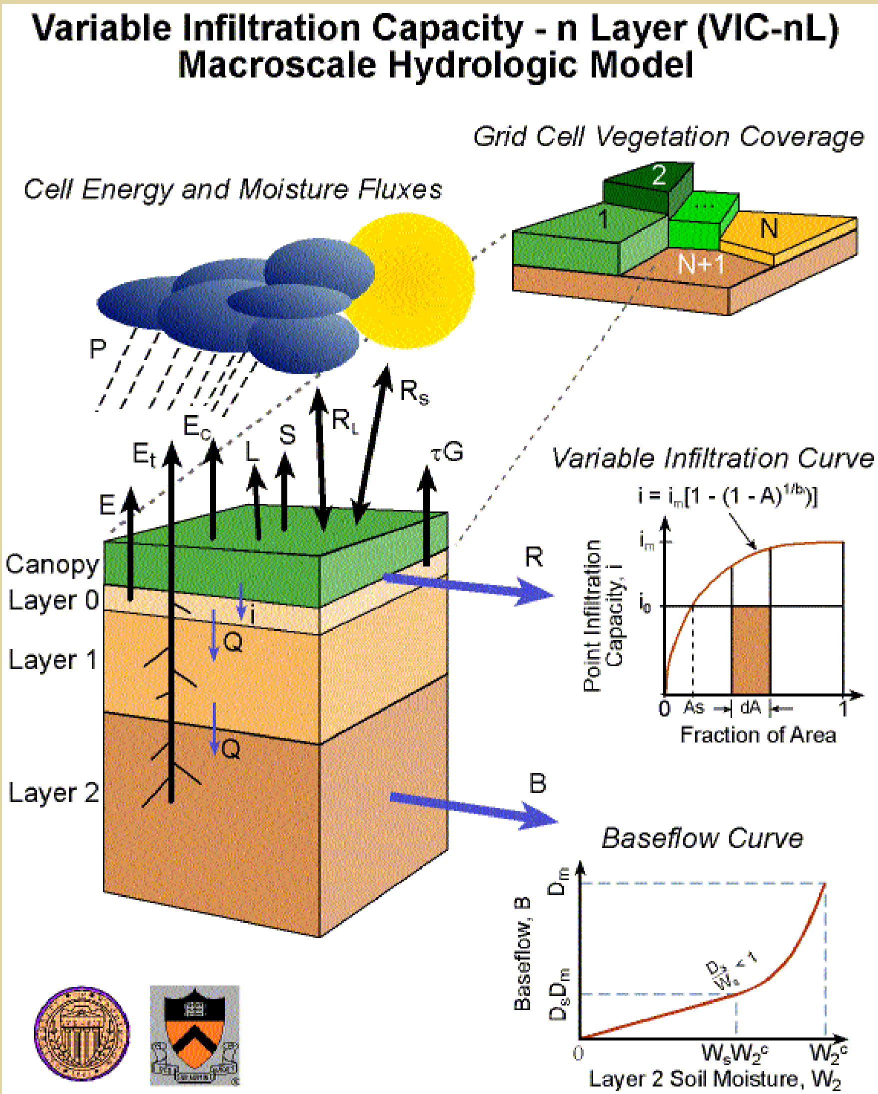


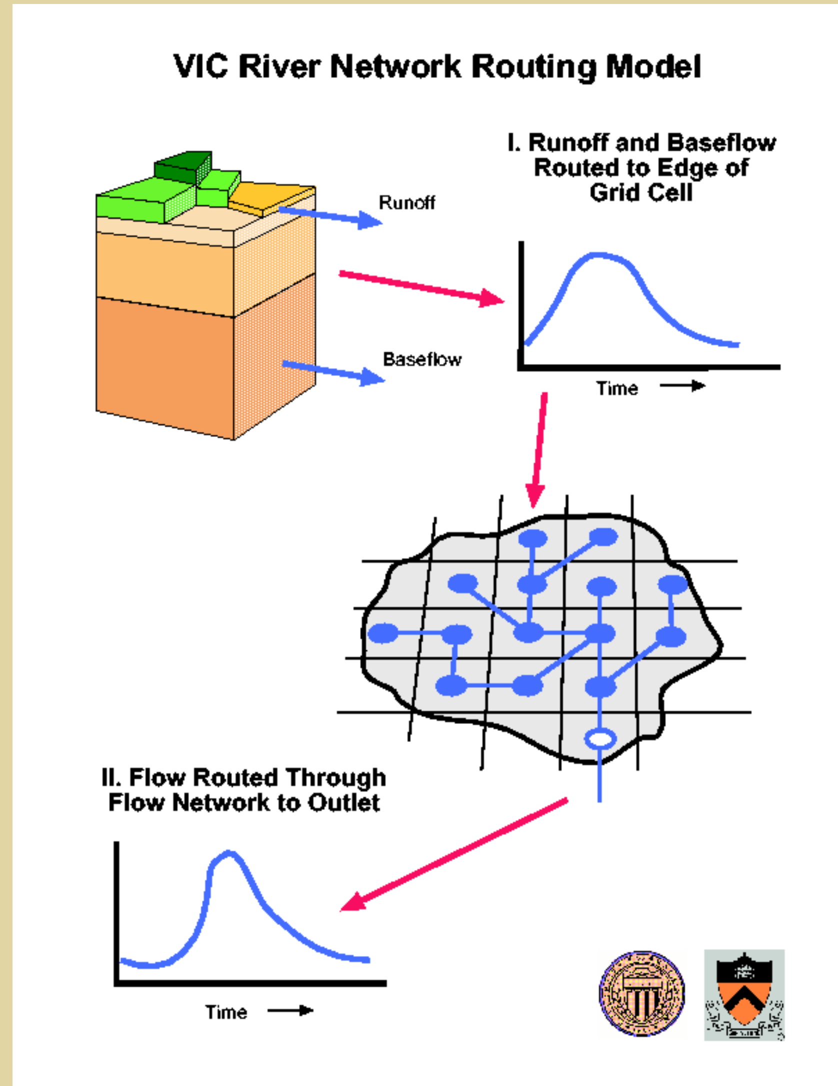
- ”Traditional” land surface schemes:
  - Simulates naturalized runoff



- Model development:
  - Generic reservoir model
  - Irrigation scheme

Variable Infiltration Capacity model

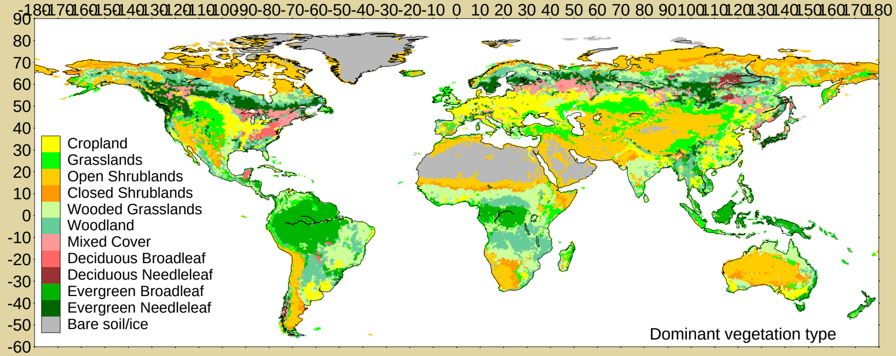


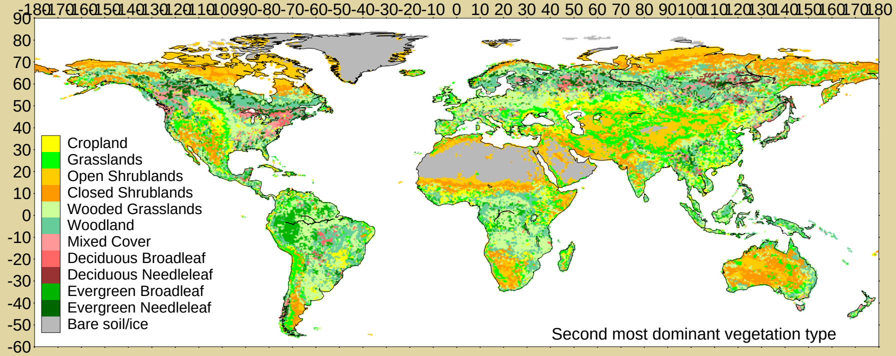


Approach

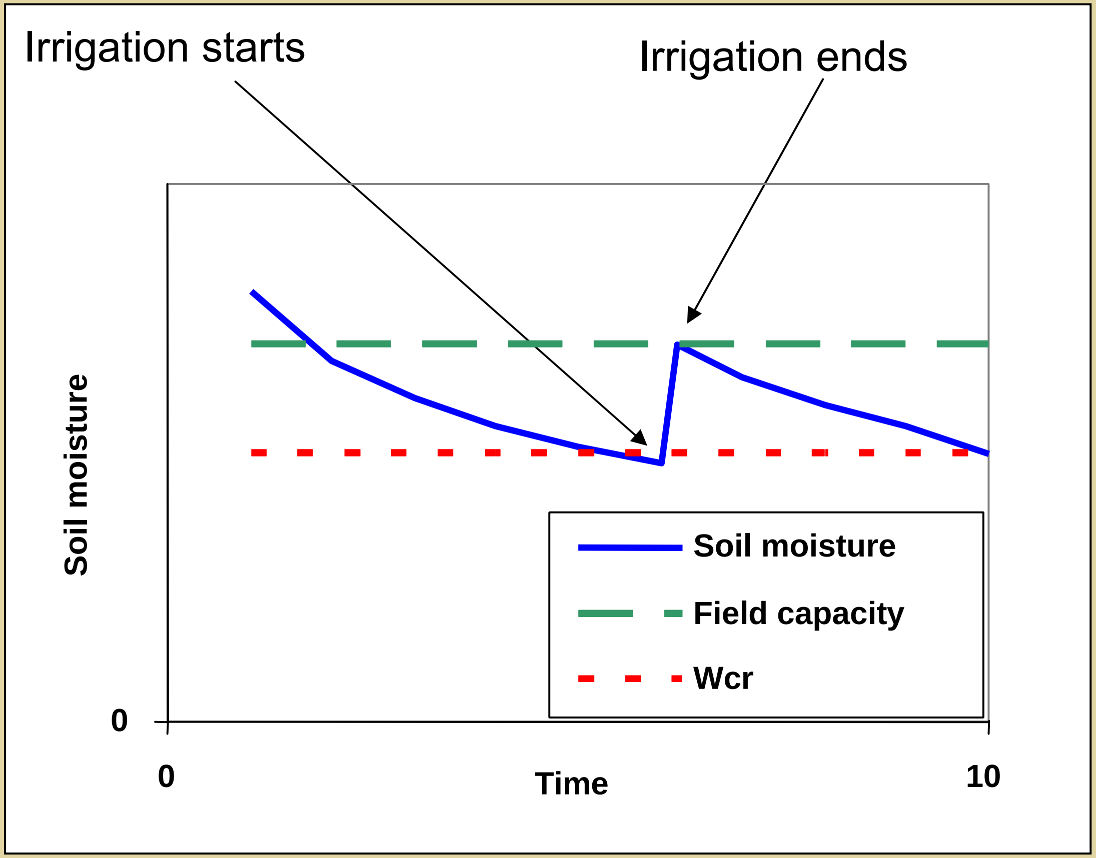
- Macroscale hydrologic model: VIC
- Resolution
  - Spatial: 0.5 degrees
  - Temporal: Daily
- Input data
  - Precipitation, max/min temperature, wind
  - Land cover data (vegetation, soil properties, topography)
- Time period: 1980 – 1999

- Irrigation scheme
  - VIC. Surface water withdrawals only
- Reservoir module
  - Routing model

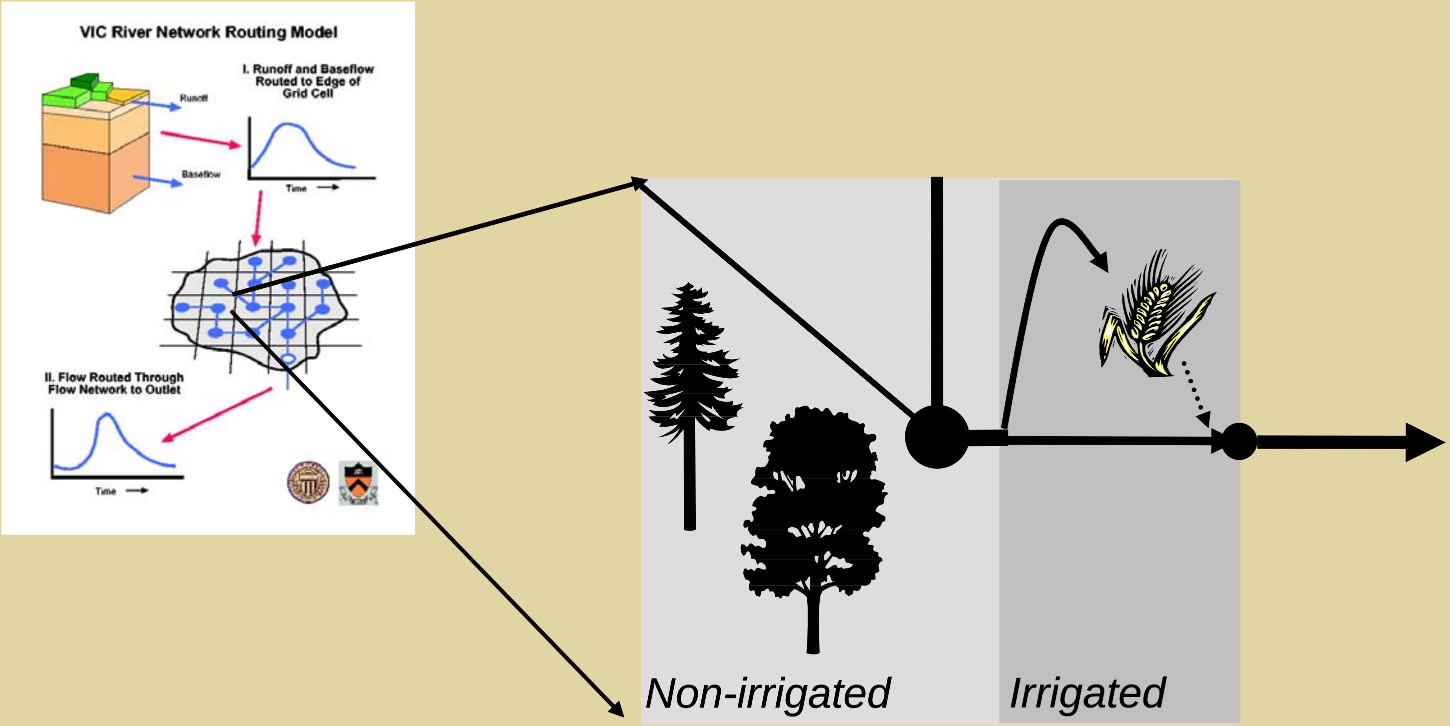




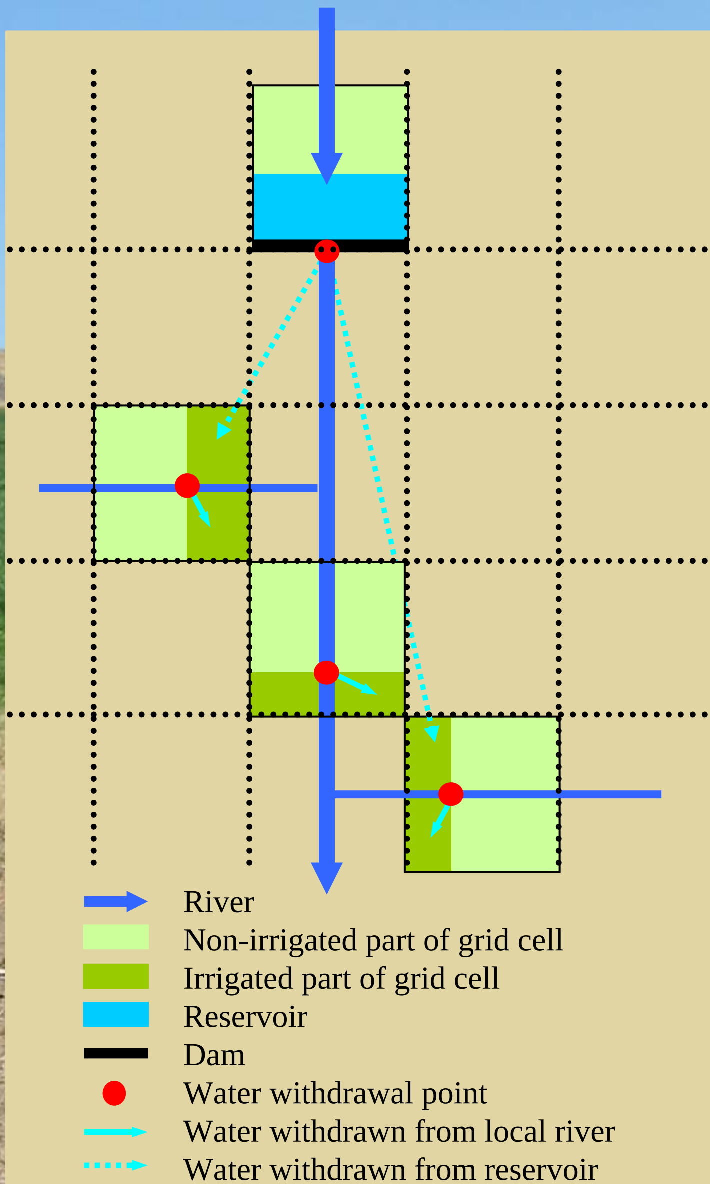
Irrigation scheme



Irrigation scheme



Reservoir model



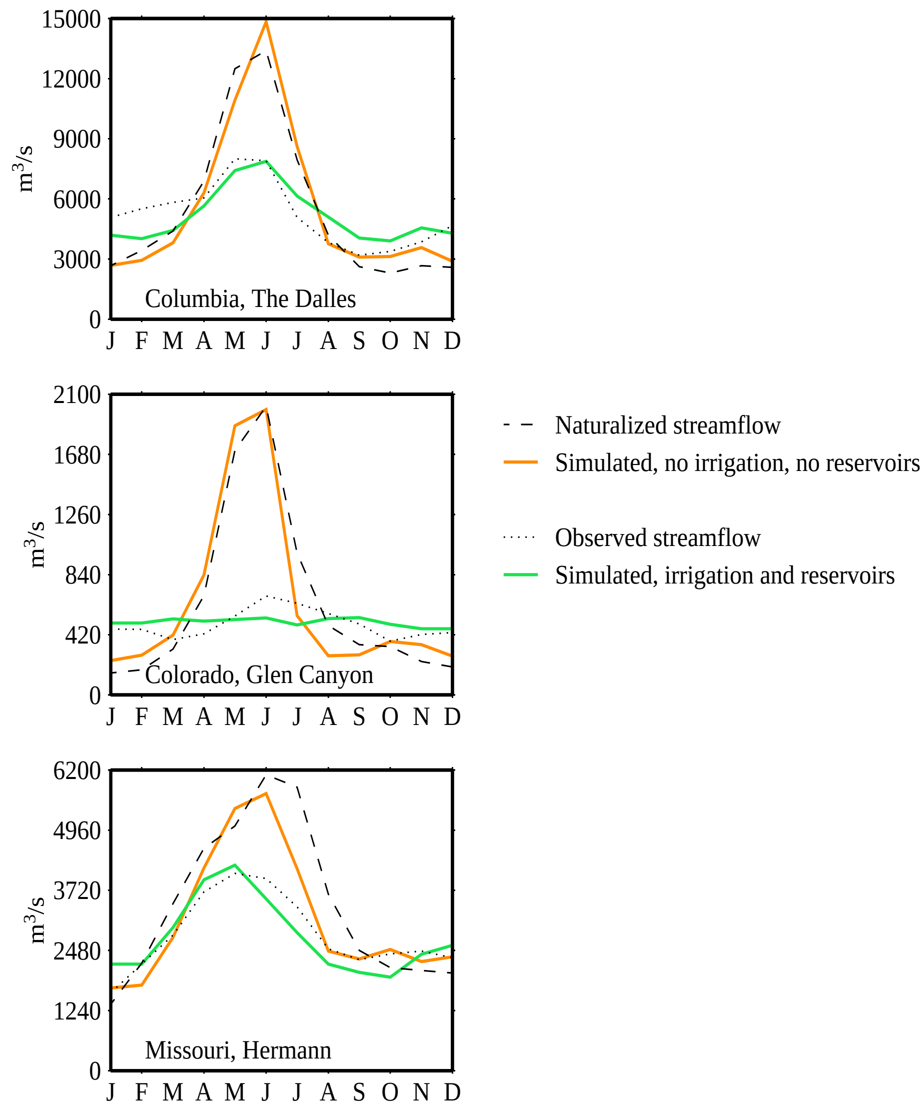
1st priority: Irrigation water demand
2nd priority: Flood control
3rd priority: Hydropower production

If no flood, no hydropower:
Make streamflow as constant as possible

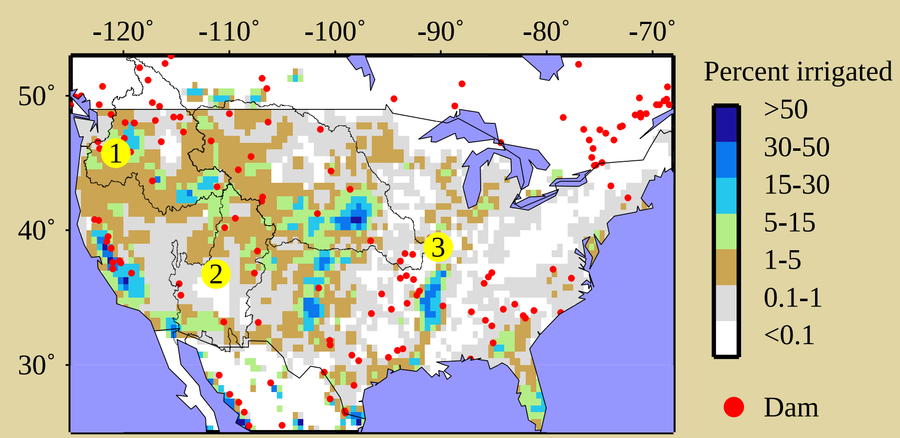
$$Q_{\min_i} = 7Q10$$

$$Q_{\max_i} = \min\left[\begin{array}{l}\left(S_{i-1} + Q_{in_i}\right), \\ \left(S_{i-1} - S_{end} + \sum_{day=i}^{365} Q_{in\,day} - \sum_{day=i+1}^{365} Q_{\min} - \sum_{day=i}^{365} E_{res\,day}\right)\end{array}\right]$$

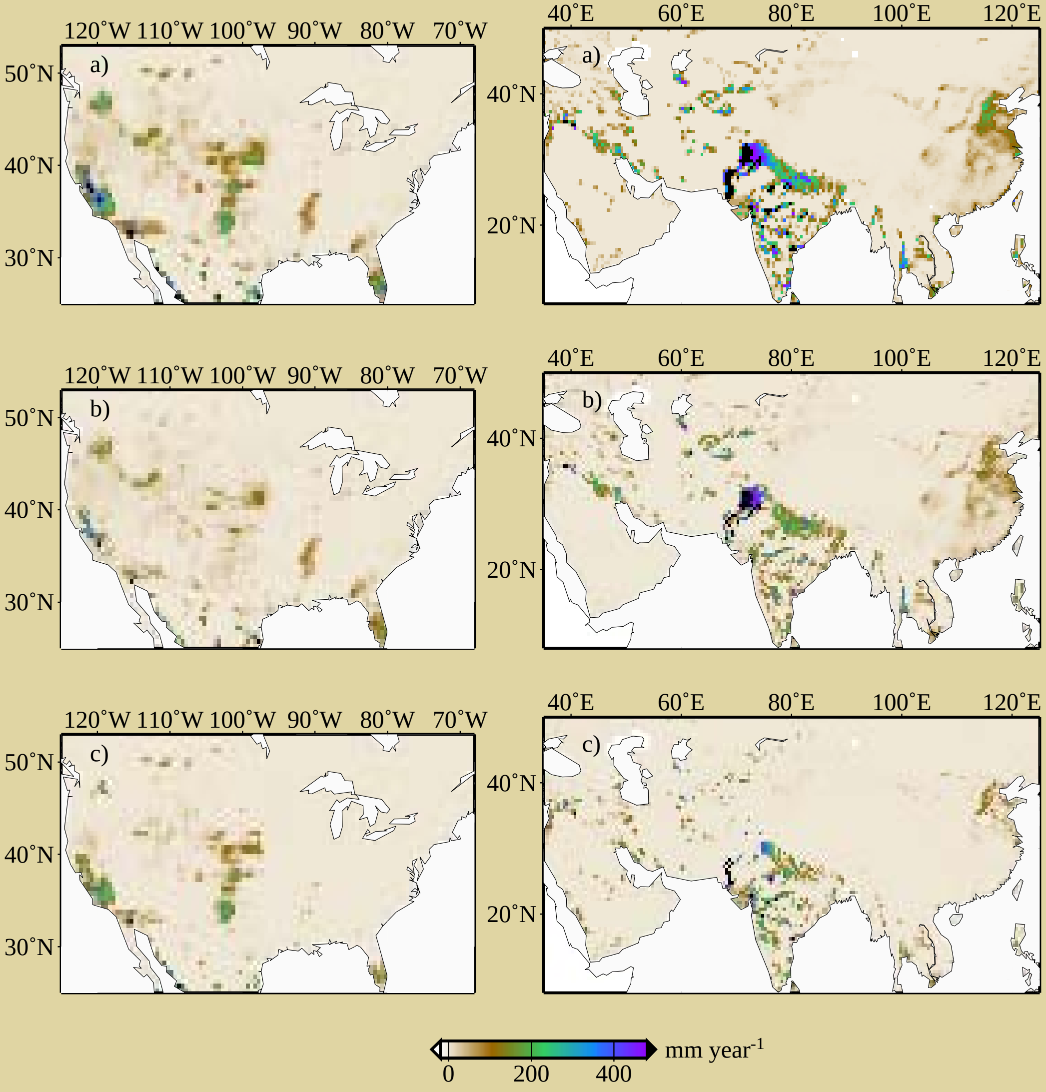
Validation



Model evaluation:
1) Columbia, 2) Colorado, and 3) Missouri River basins



Results: Irrigation water



a) Irrigation water requirements
b) Irrigation water uses
c) Irrigation water deficits

Irrigation water requirements

USA+: 18 mm year^{-1}

Asia: 16 mm year^{-1}

Irrigation water uses

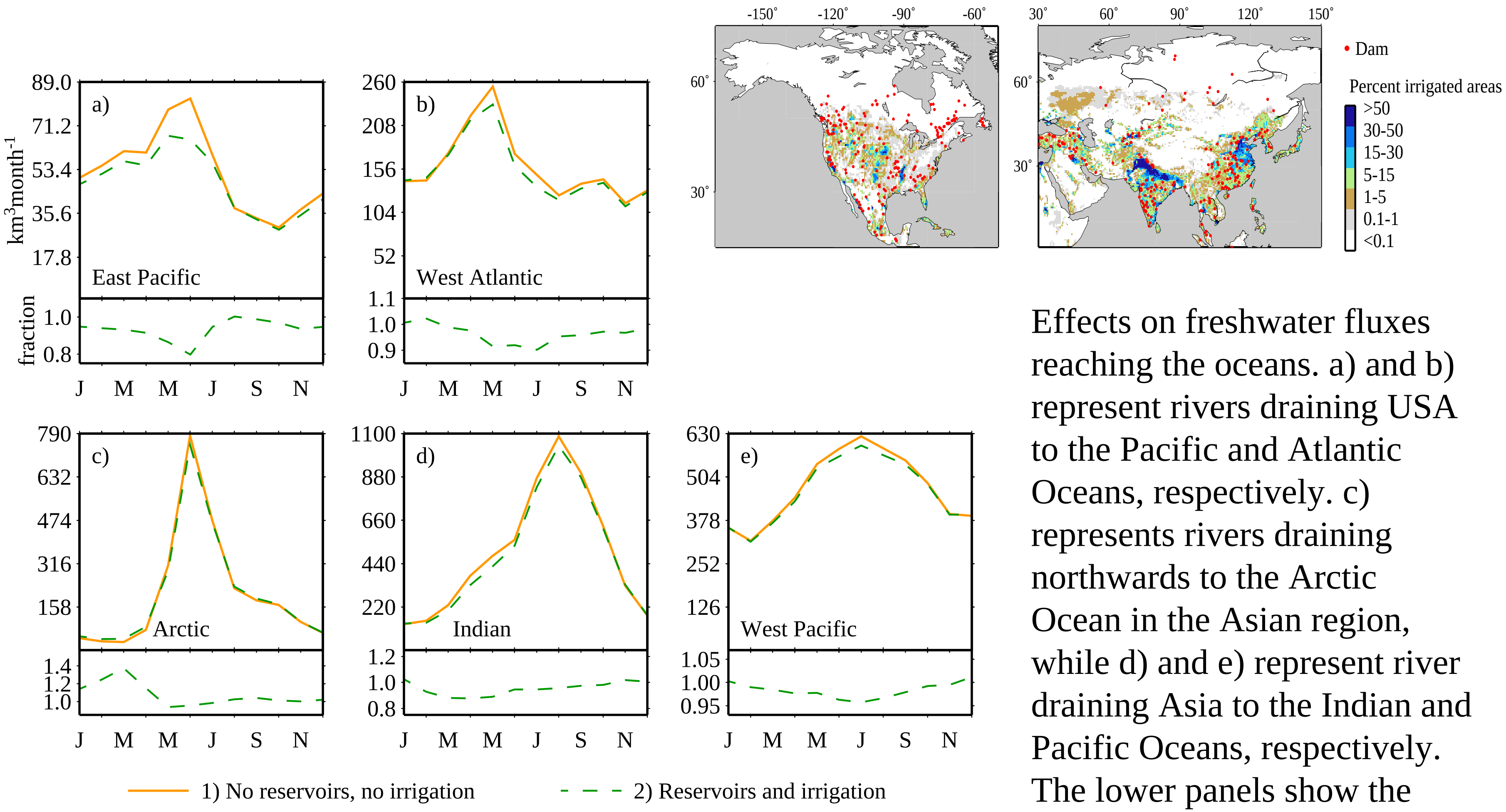
USA+: 10 mm year^{-1}

Asia: 10 mm year^{-1}

Global terrestrial

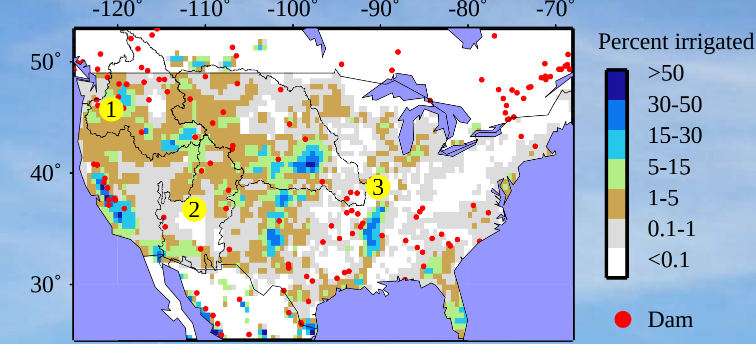
- precipitation: 800 mm year^{-1}
- evapotr.: 400 mm year^{-1}

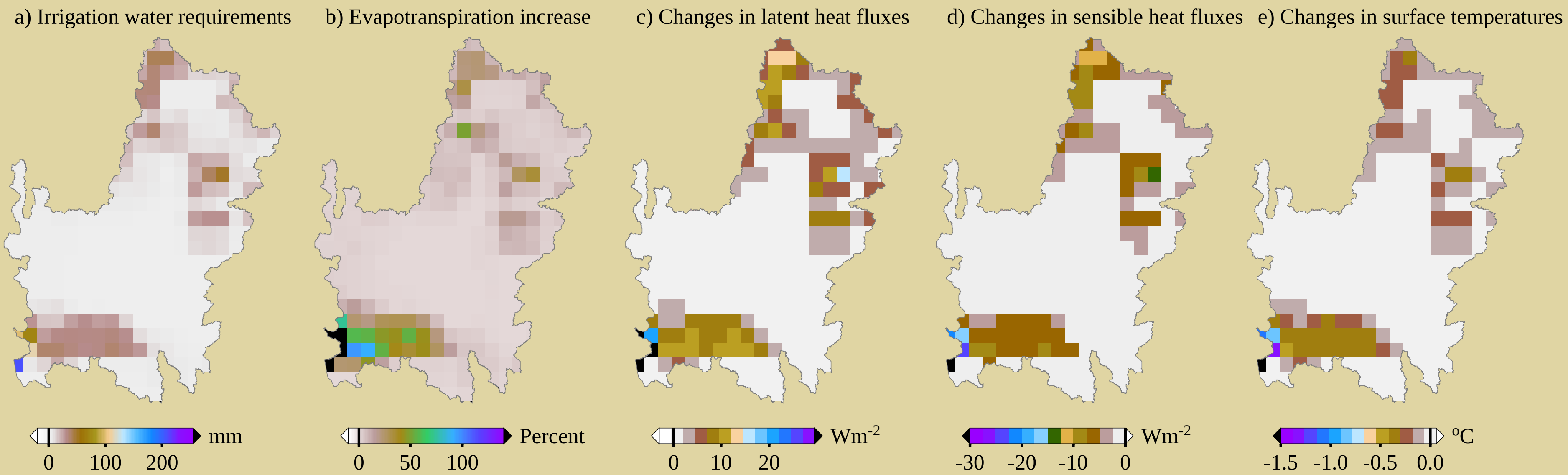
Results: Streamflow



Effects on freshwater fluxes reaching the oceans. a) and b) represent rivers draining USA to the Pacific and Atlantic Oceans, respectively. c) represents rivers draining northwards to the Arctic Ocean in the Asian region, while d) and e) represent river draining Asia to the Indian and Pacific Oceans, respectively. The lower panels show the results of simulations 2 divided by simulation 1.

Colorado River basin





- Naturalized:
  - Q: 42.3 mm year^{-1}
  - ET: 335 mm year^{-1}
- Irrigation included:
  - Q: 26.5 mm year^{-1}
  - ET: 350 mm year^{-1}

Conclusions

- The model does a reasonable job of reproducing the effects of management on selected large rivers.
- Reservoirs and crop irrigation water use has the potential of altering the natural hydrologic water balance of river basins.
- The effects of land use changes can be significant locally. Averaged over larger regions, the effects are most noticable in the area draining to the Eastern Pacific Ocean.

Questions?

References

Haddeland, I., D.P. Lettenmaier, and T. Skaugen, 2006, Effects of irrigation on the water and energy balances of the Colorado and Mekong River basins, *Journal of Hydrology*, 324(1-4), 210-223

Haddeland, I., T. Skaugen, and D.P. Lettenmaier, 2006, Anthropogenic impacts on continental surface water fluxes, *Geophysical Research Letters*, 33, L08406, doi:10.1029/2006GL026047