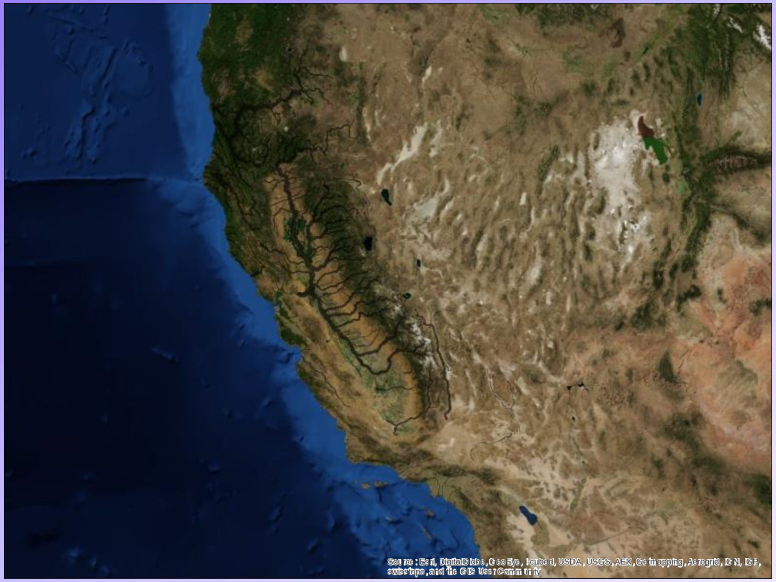
UCCHM

University of California
Center for Hydrologic Modeling

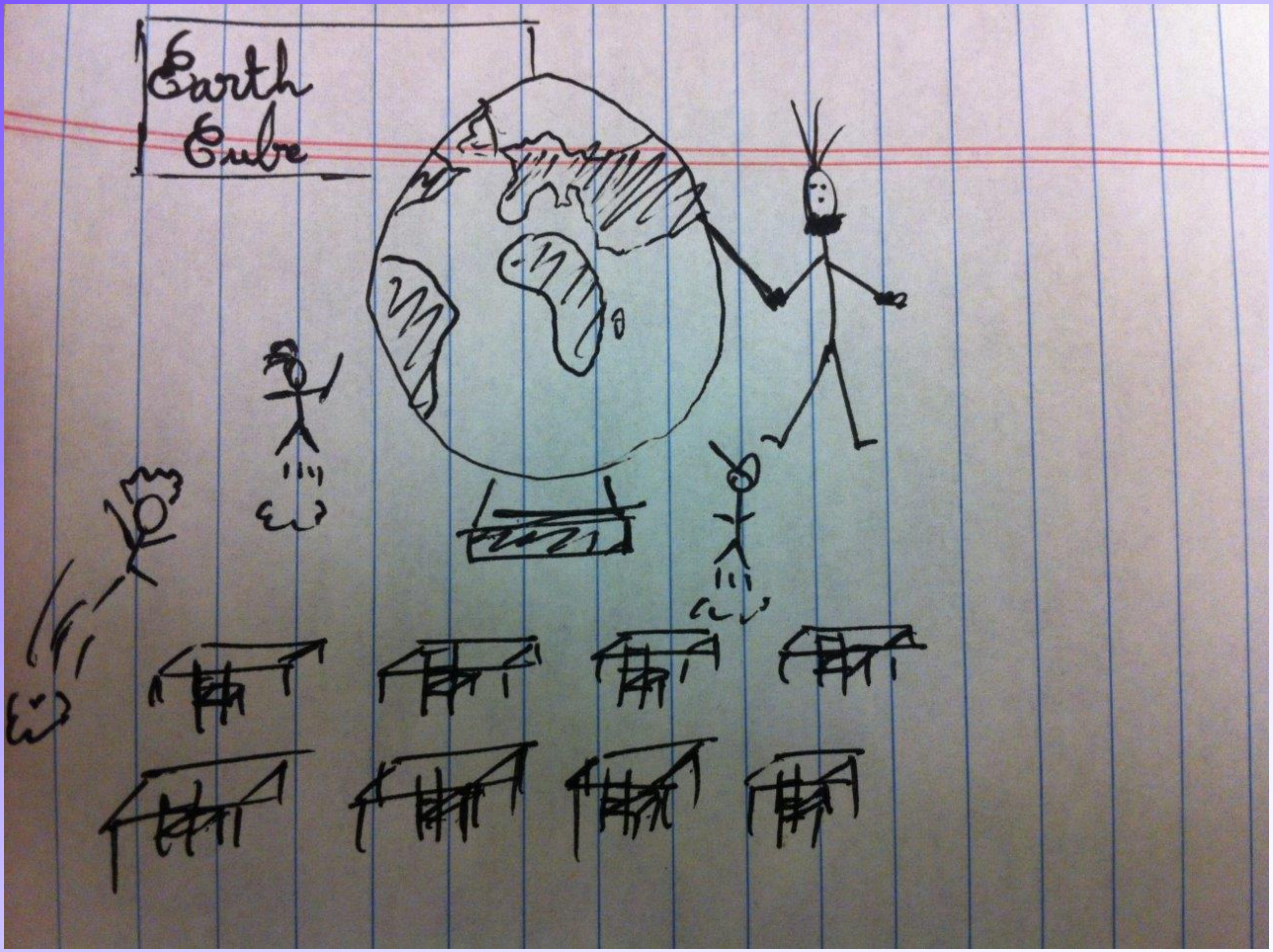
On the Use of Technology to Enable the Flow of Digital Rivers at the Continental-Scale



Cédric H. David
University of California Center for Hydrologic Modeling

NSF EarthCube Modeling for the Geosciences
Boulder, CO
23 April 2013

An EarthCube vision…

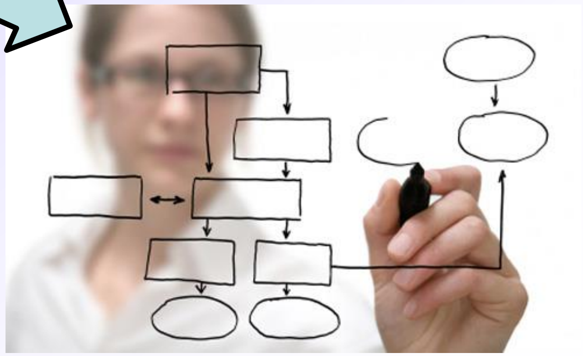


Making **all** geosciences accessible to **everybody**,
in an **exciting** way!!!

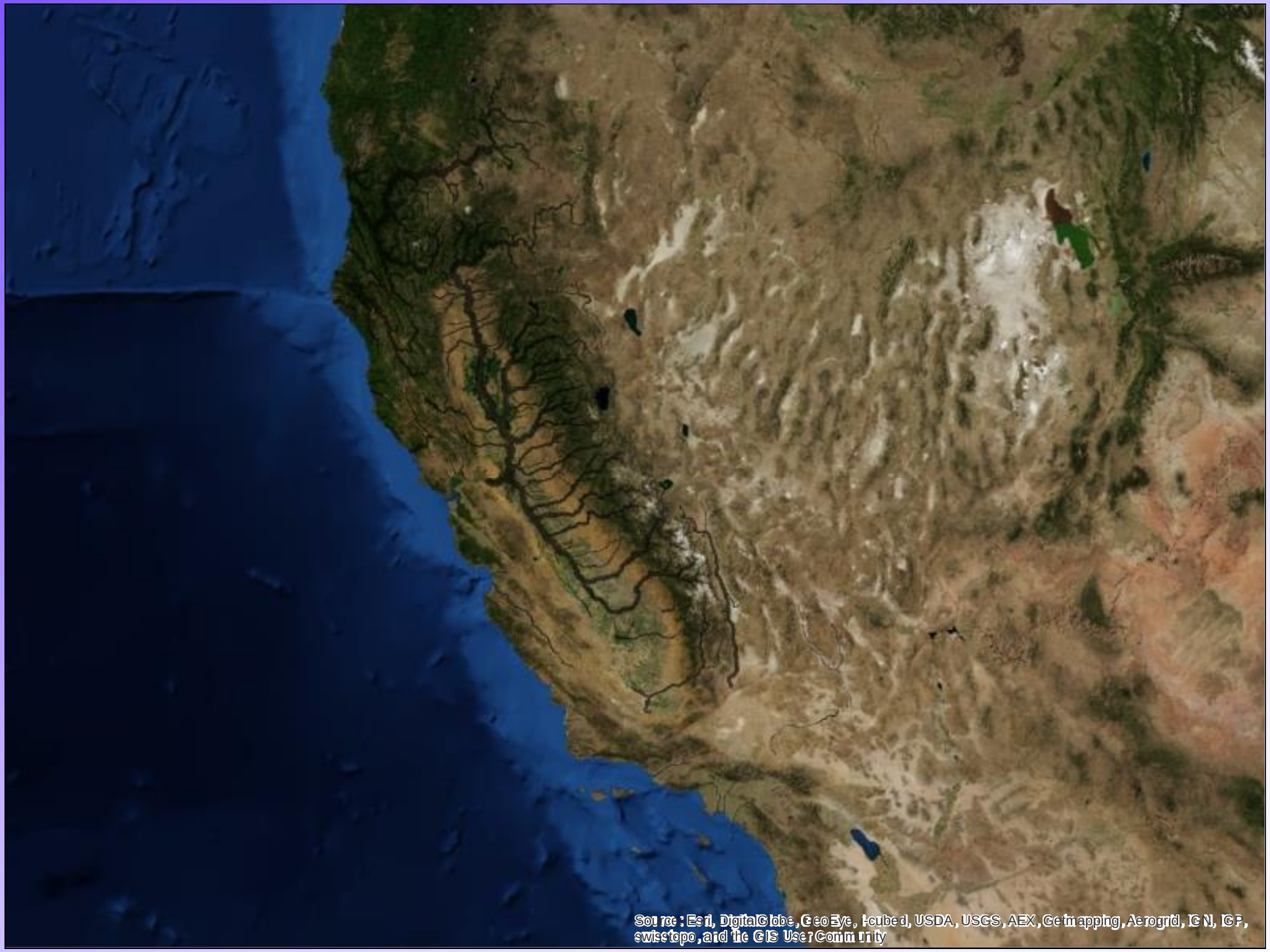
…not science fiction!

Holland Family Student Center – Univ. Texas at Austin

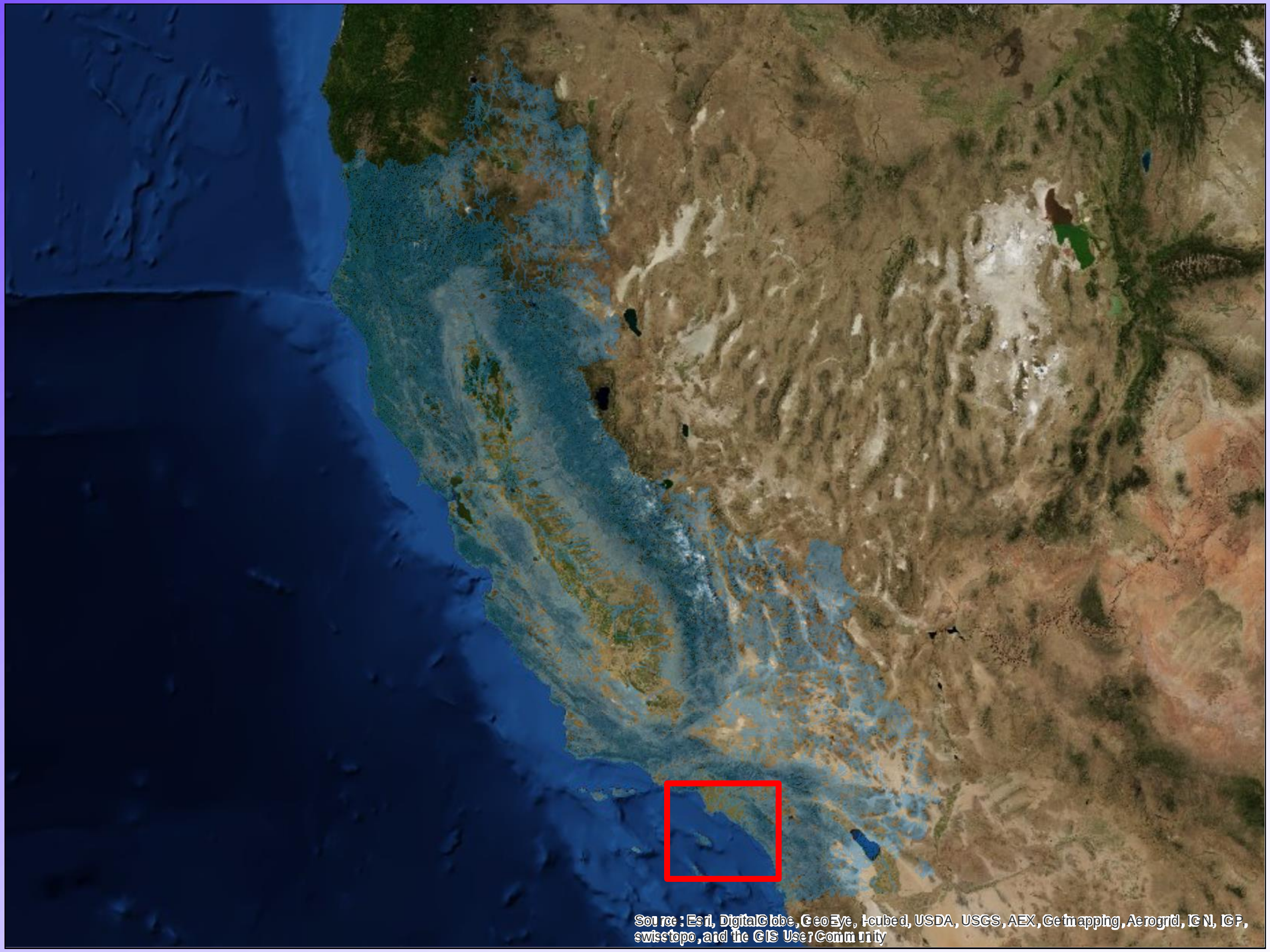
Help managers



Major rivers of California

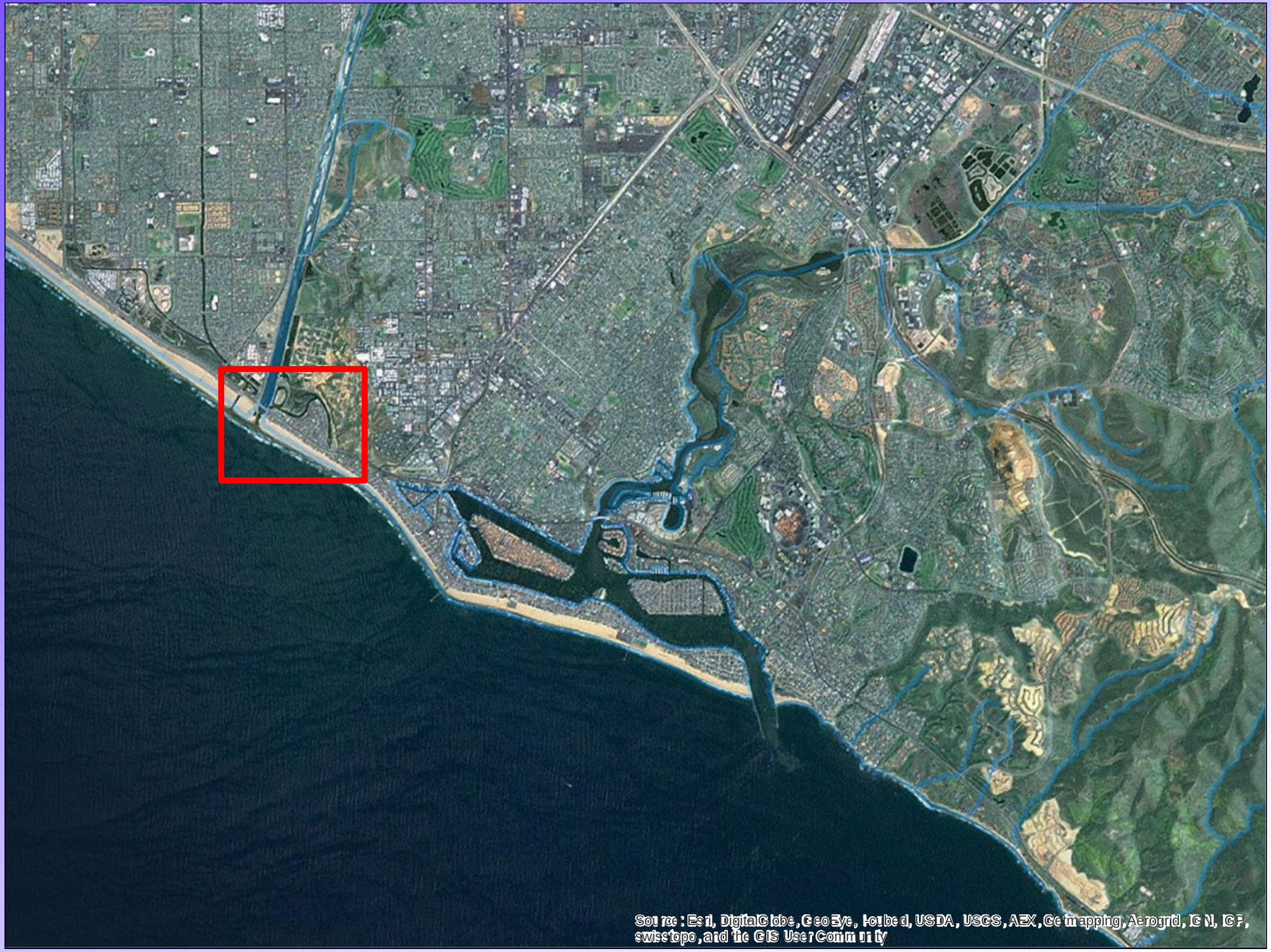


Mapped rivers of California



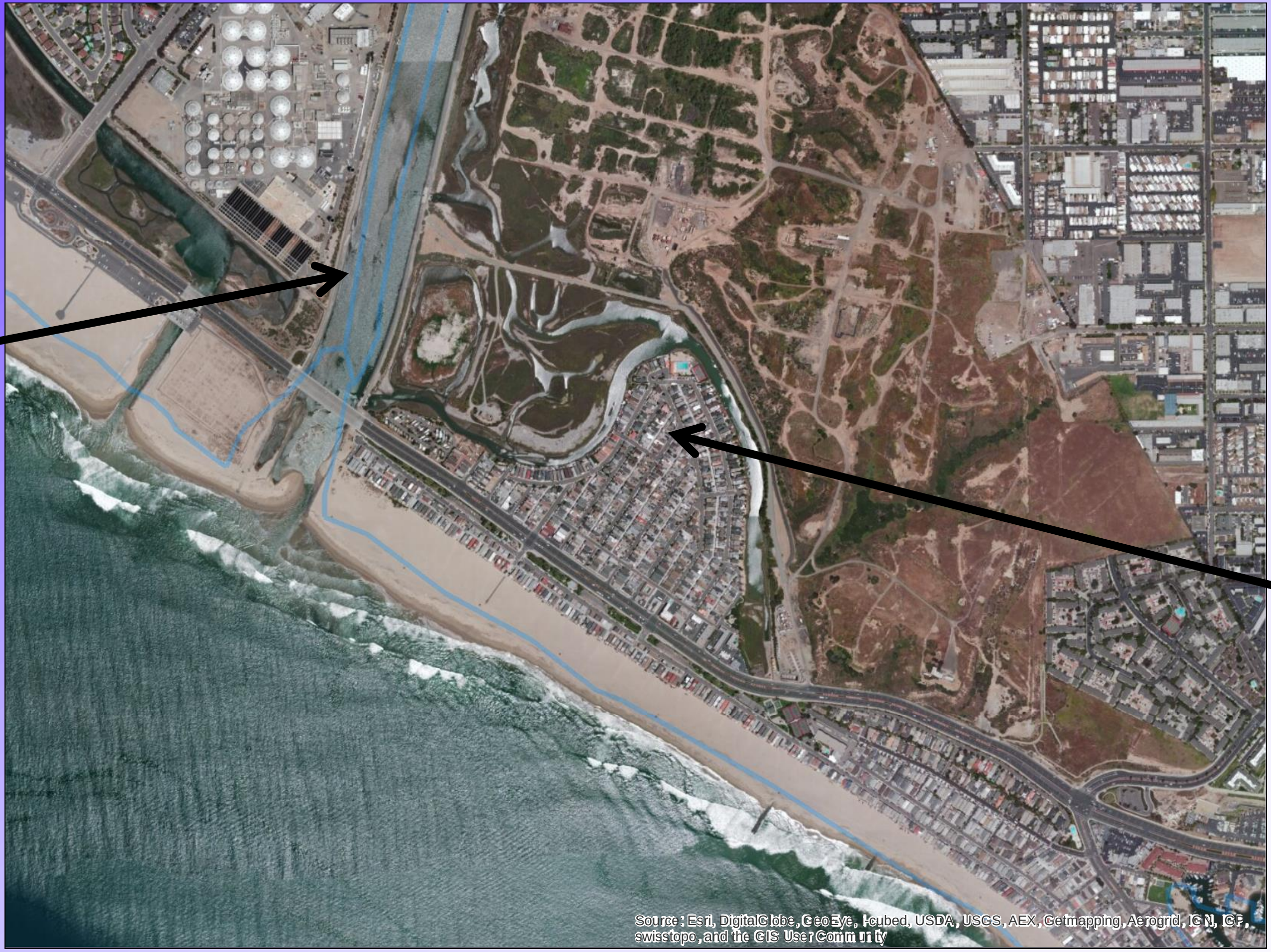
Mapped rivers of Orange County

Mapped rivers of Newport Beach



Santa Ana River

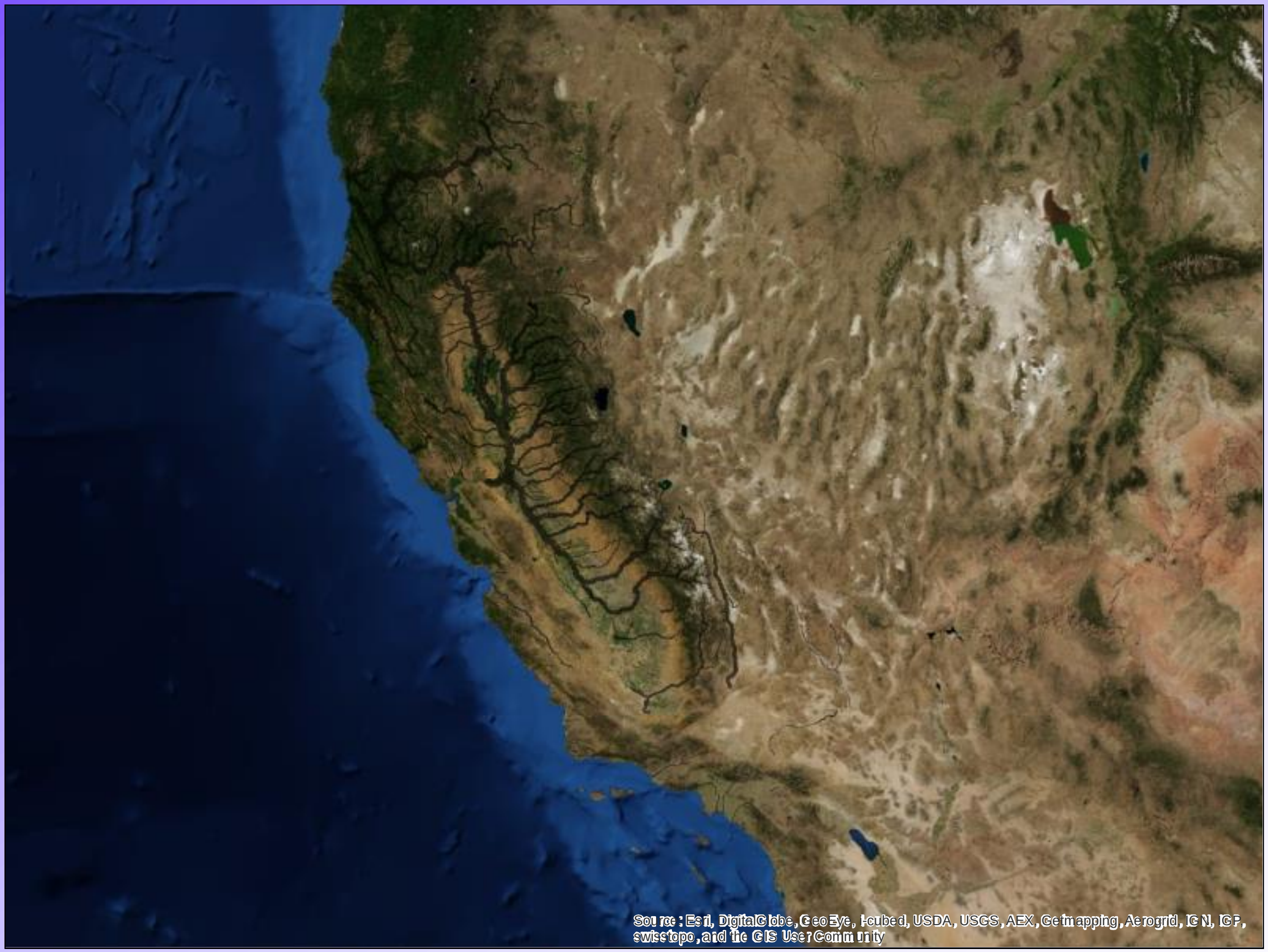
No gage available here



Where I live

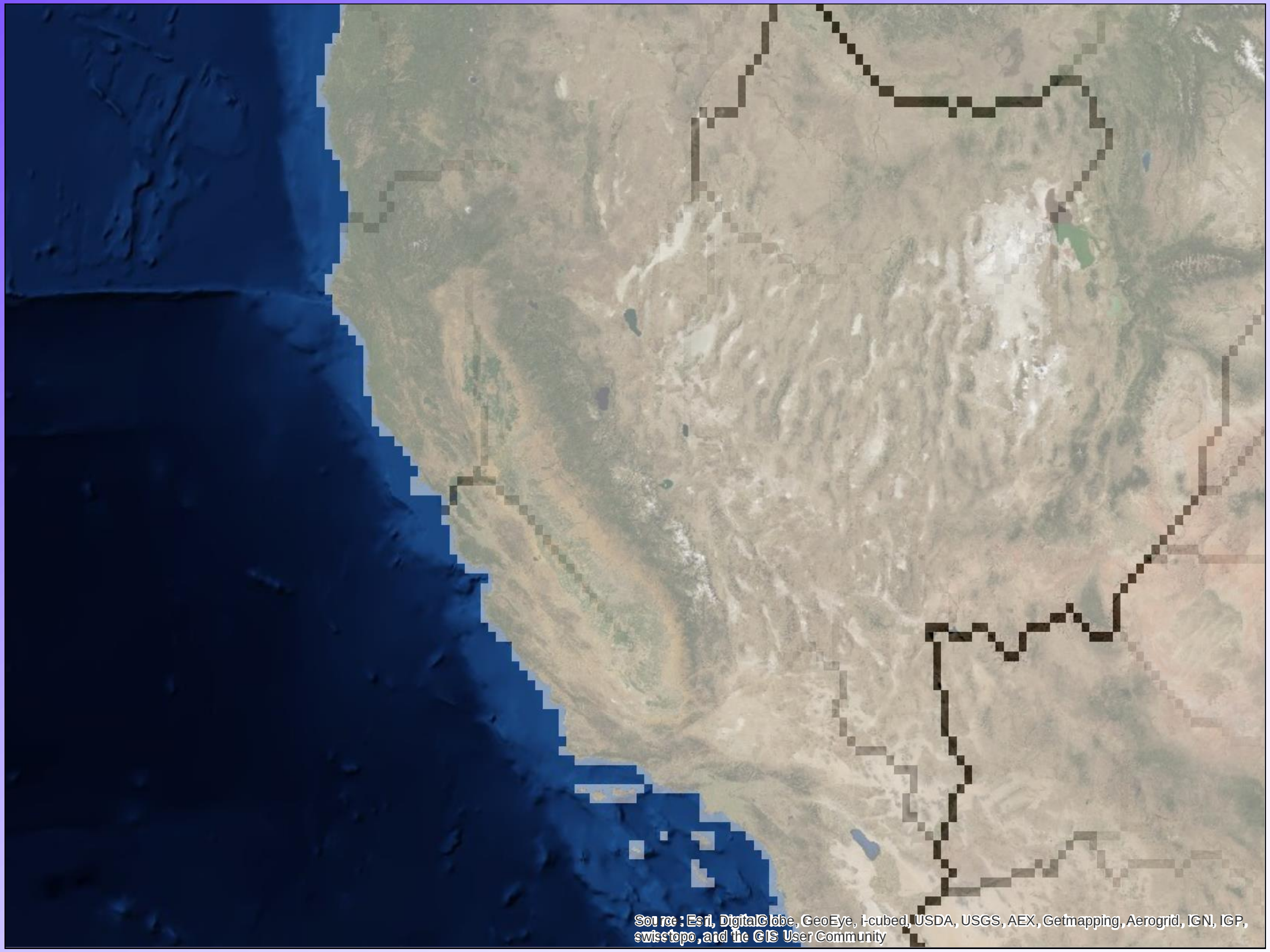
What if **anyone**, **anywhere** could have access to the flow in the **river next to their home**?

Need access to continental-scale model results



Unified management for a nation
General understanding by its citizens

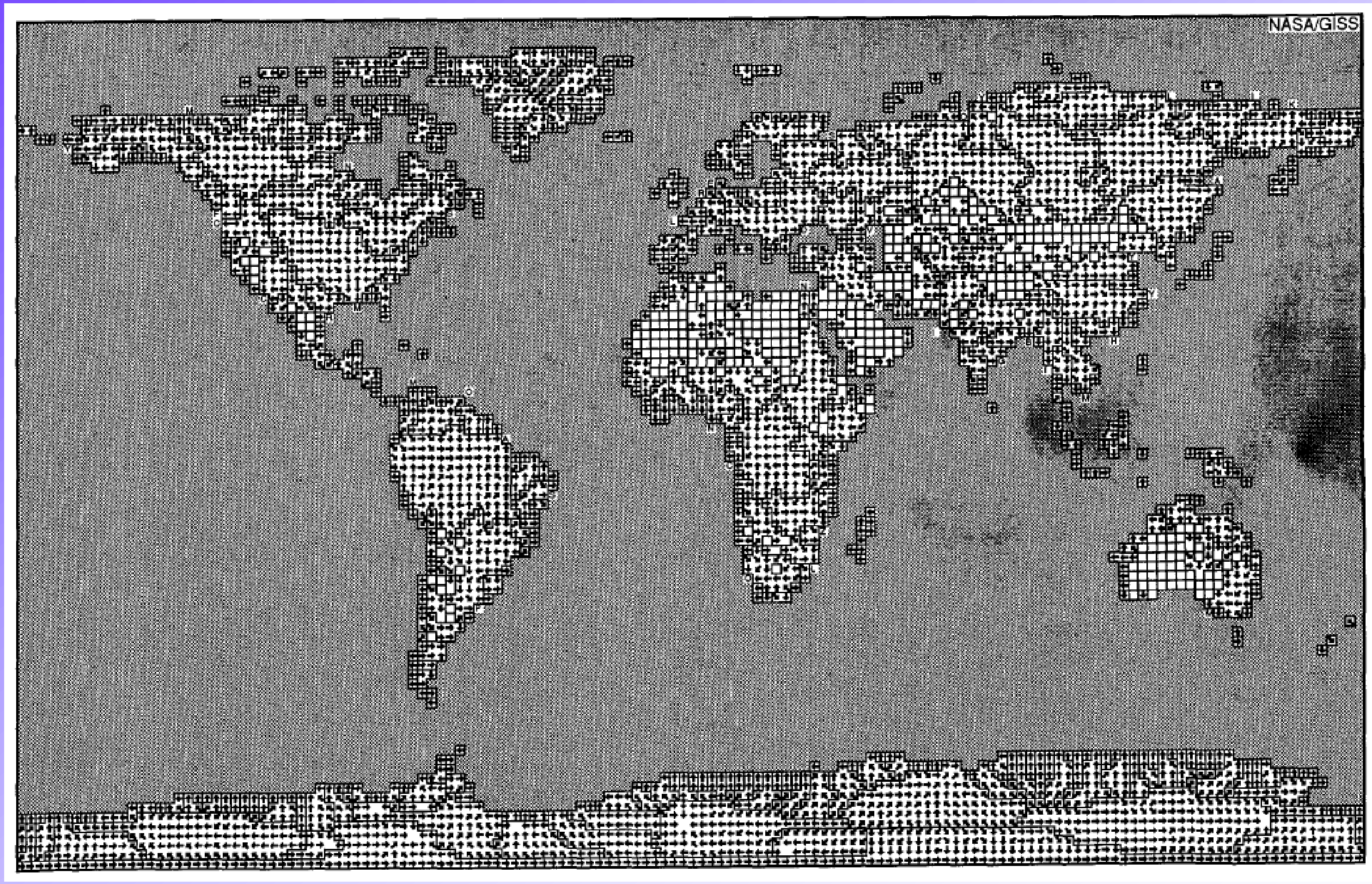
State-of-the-art continental-scale river modeling



Why so coarse?

River network of Lohmann et al (1996), Mitchell et al. (2004), and Xia et al. (2012)

Scientific legacy - We've come a long way!

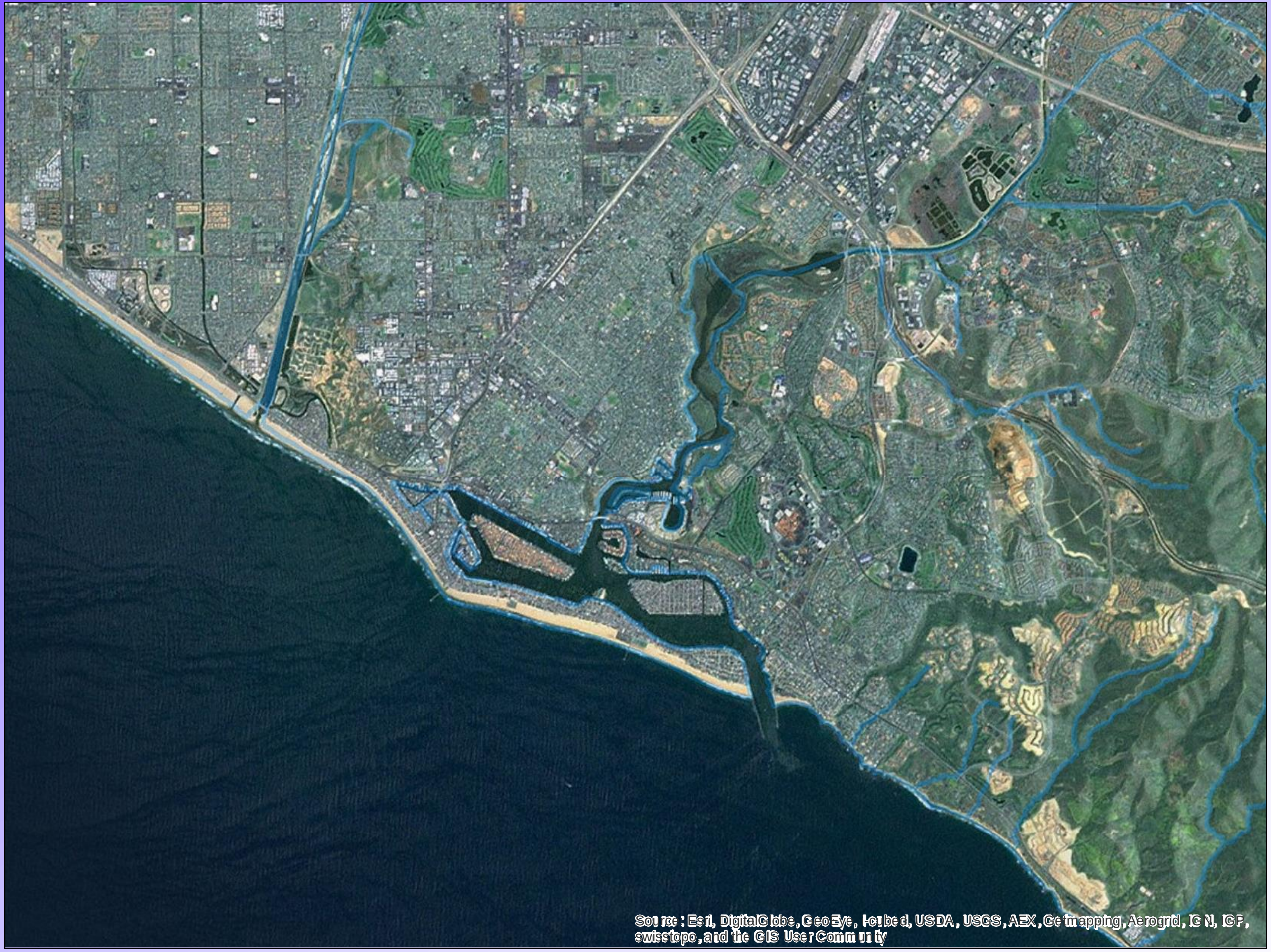


Miller et al. (1994) J. Clim.

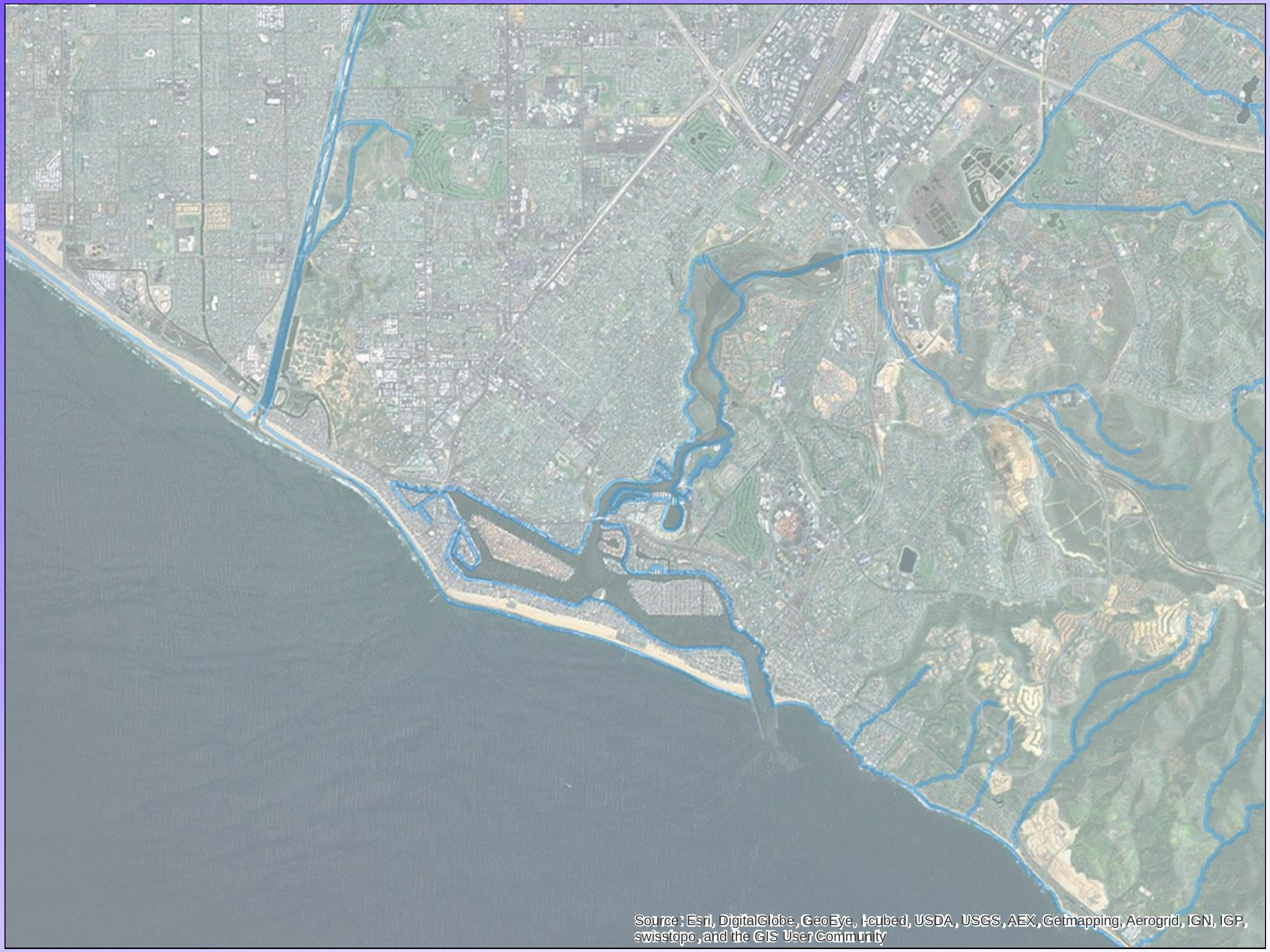
Mapped rivers of Orange County

State-of-the-art river continental-scale modeling

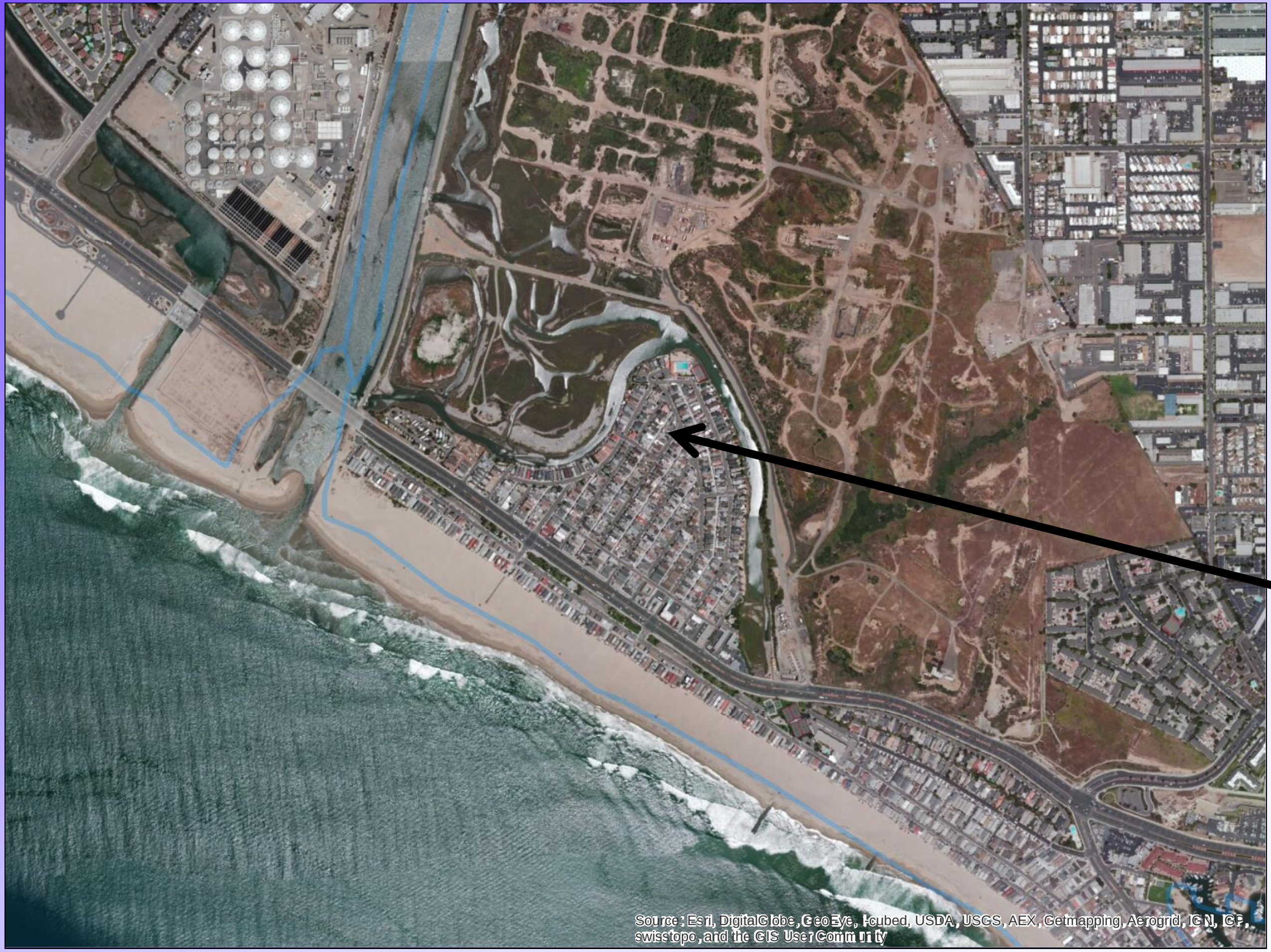
Mapped rivers of Newport Beach



State-of-the-art river continental-scale modeling



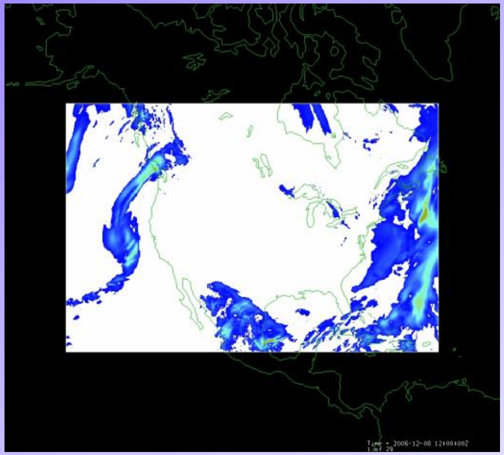
Santa Ana River

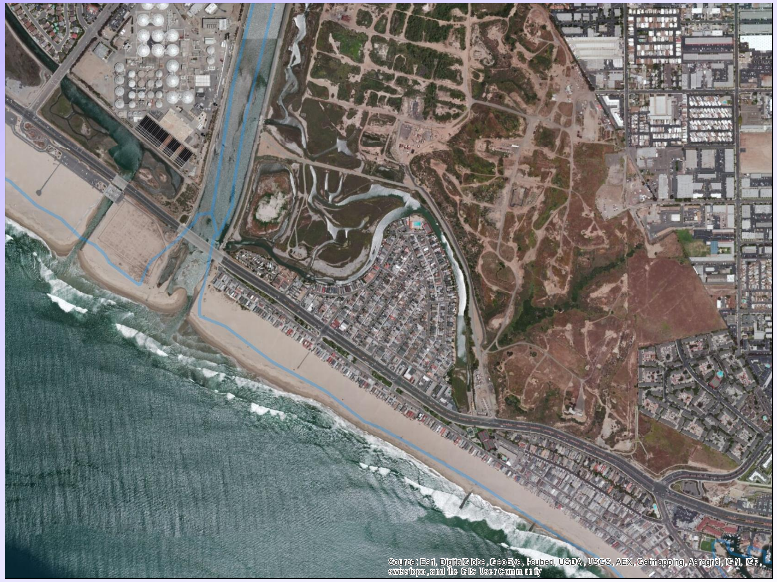


Where I live

State-of-the-art river continental-scale modeling

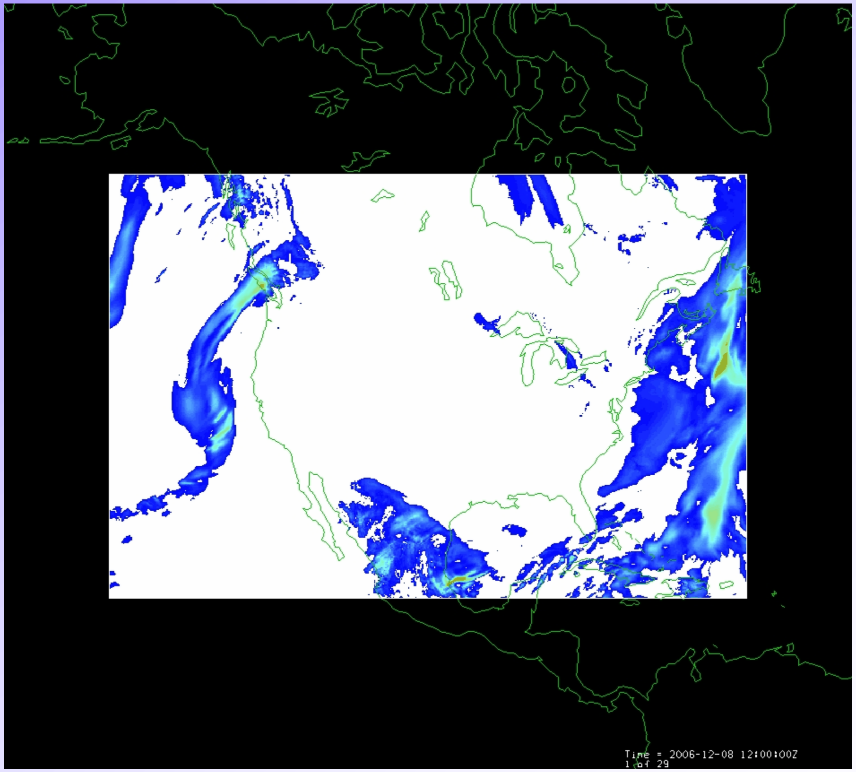
What technology can we use to enable the flow of digital rivers at the continental scale?





Atmospheric modeling

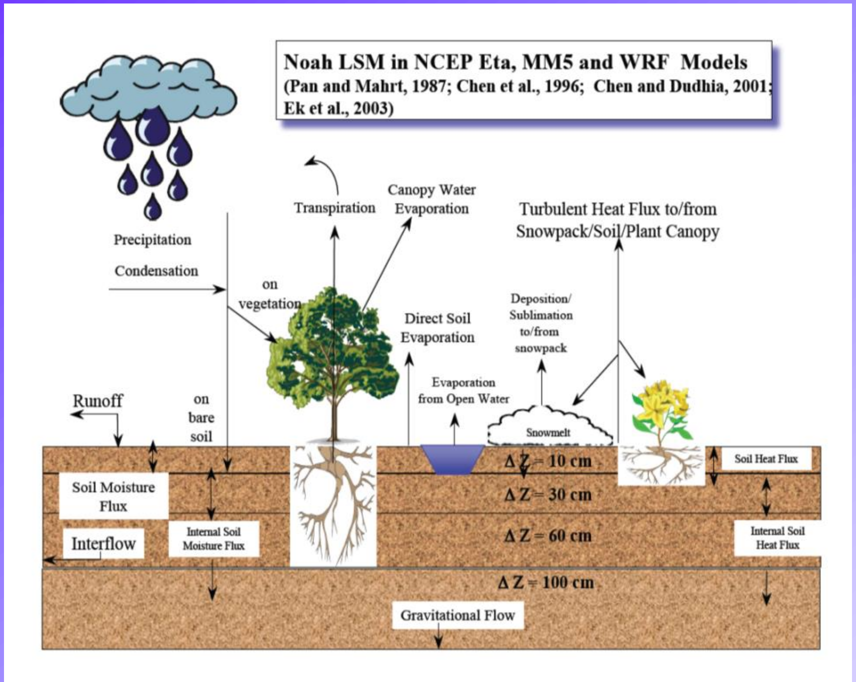
- Equations of fluid mechanics and thermodynamics of the atmosphere commonly solved everyday by computer models
- Temperature, pressure, winds, precipitation, etc. are available
- For past, present and future
- Dynamic maps



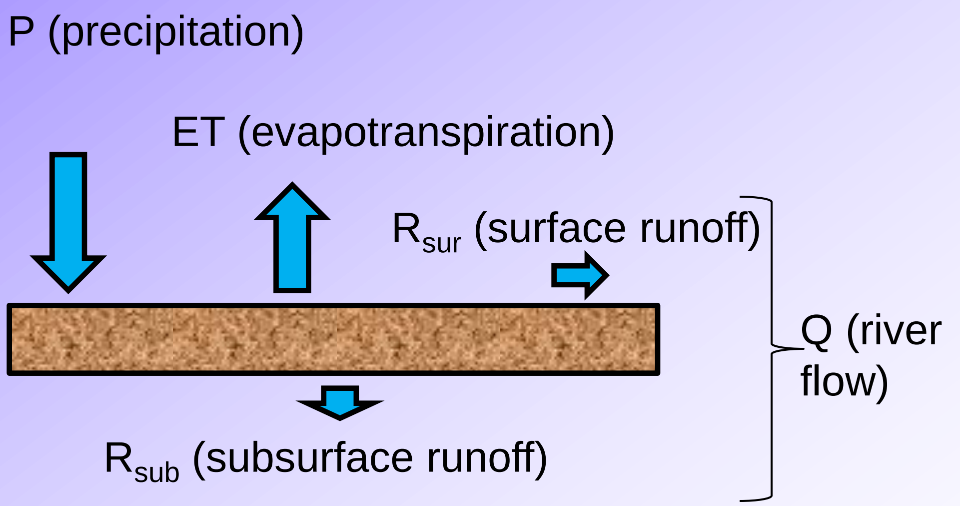
Animation of precipitation over the U.S.

Models and datasets available cover the entire U.S.

Land surface modeling



Noah land surface model (first version in 1999), serves as the land model for operational weather prediction in North America



Bottom boundary conditions for atmospheric models
Models and datasets also cover the entire U.S.

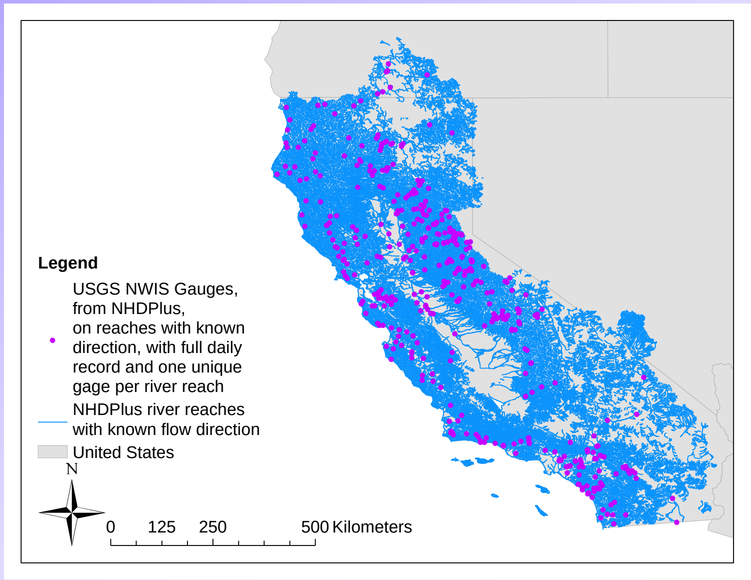
NHDPlus – River and Catchment Network for the Nation

Entire dataset

3 million river reaches

Connectivity information

Region 18 = California



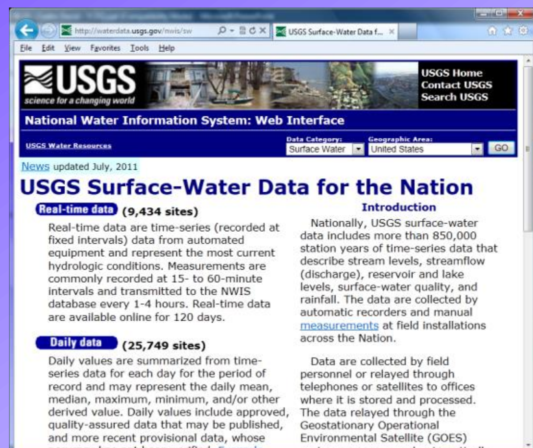
137,401 river reaches
420,000 km^2

Integration of the National Hydrography Dataset, National Elevation Dataset and National Land Cover Dataset completed by EPA in 2006

"Blue line" rivers available for the entire U.S.

USGS National Water Information System

20,000+ gauges available for the United States


http://waterdata.usgs.gov/nwis/sw
USGS Surface-Water Data f...
File Edit View Favorites Tools Help
USGS Home
Contact USGS
Search USGS
National Water Information System: Web Interface
USGS Water Resources
Data Category: Surface Water
Geographic Area: United States
GO
News updated July, 2011

USGS Surface-Water Data for the Nation

Real-time data (9,434 sites)

Real-time data are time-series (recorded at fixed intervals) data from automated equipment and represent the most current hydrologic conditions. Measurements are commonly recorded at 15- to 60-minute intervals and transmitted to the NWIS database every 1-4 hours. Real-time data are available online for 120 days.

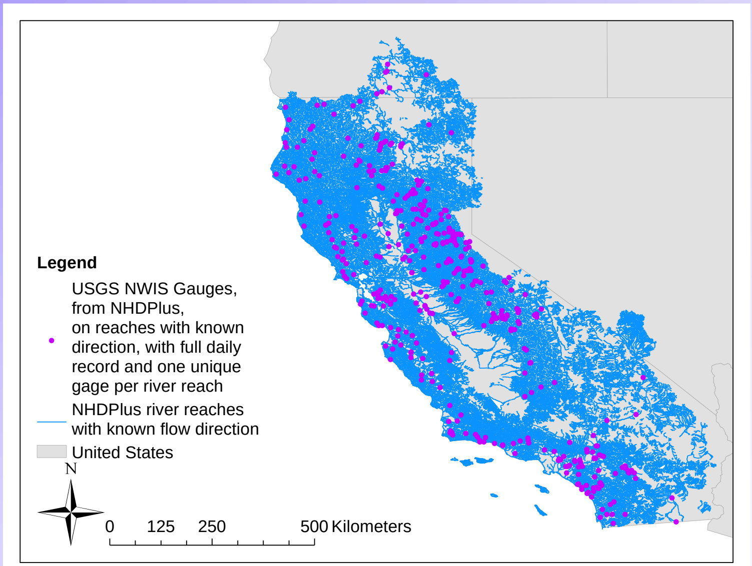
Daily data (25,749 sites)

Daily values are summarized from time-series data for each day for the period of record and may represent the daily mean, median, maximum, minimum, and/or other derived value. Daily values include approved, quality-assured data that may be published, and more recent provisional data, whose

Introduction

Nationally, USGS surface-water data includes more than 850,000 station years of time-series data that describe stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. The data are collected by automatic recorders and manual measurements at field installations across the Nation.

Data are collected by field personnel or relayed through telephones or satellites to offices where it is stored and processed. The data relayed through the Geostationary Operational Environmental Satellite (GOES)

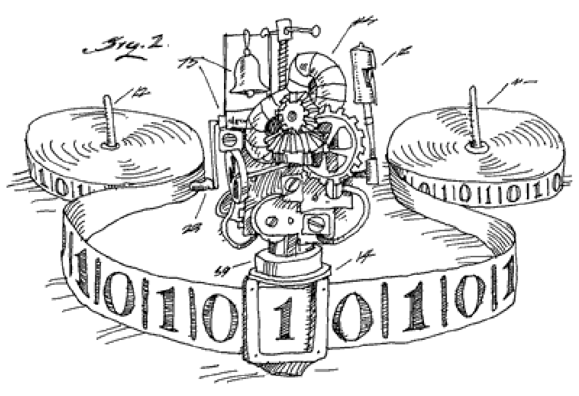


2311 gages total in Region 18. 433 with full daily data for 2000/01/01 – 2007/12/31 and on reaches with known direction

Computers and computing tools have evolved

Williamina Fleming stands in the centre of the Harvard computers as Edward Pickering looks on.

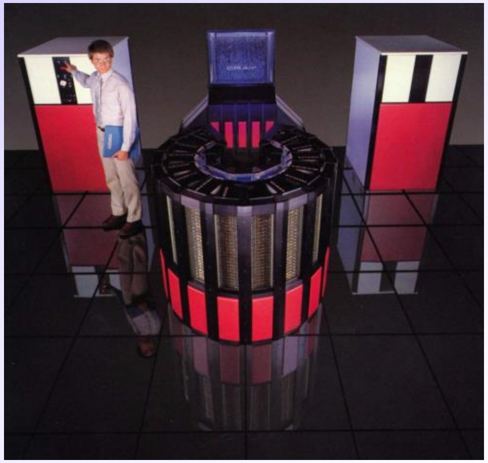
People in 1880s (Nature, 2008)



Turing machine (1936)

IBM Portable PC 5155 (1984)

Sun Supercomputer (Ranger) World's fastest computer for open science when released (2008)



Cray 2 Supercomputer World's fastest computer when released (1985)

TACC

Computing Centers

PETSc

Scientific computing libraries

River modeling and Computing

What's being used:
Desktop computers

What could be used:
Parallel computers

Lonestar
5,840 processors

Ranger
62,976 processors

- Today's computers are as powerful as supercomputers ten years ago
- Most computers come with multiple cores
- Parallel computing is becoming increasingly accessible

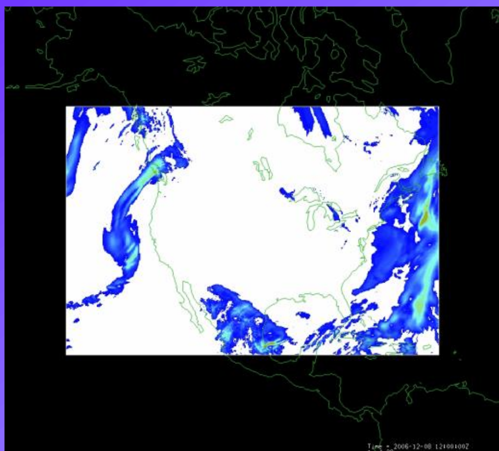
- Need to know parallel computing
  - A learning curve

Existing Large-scale River Routing Models

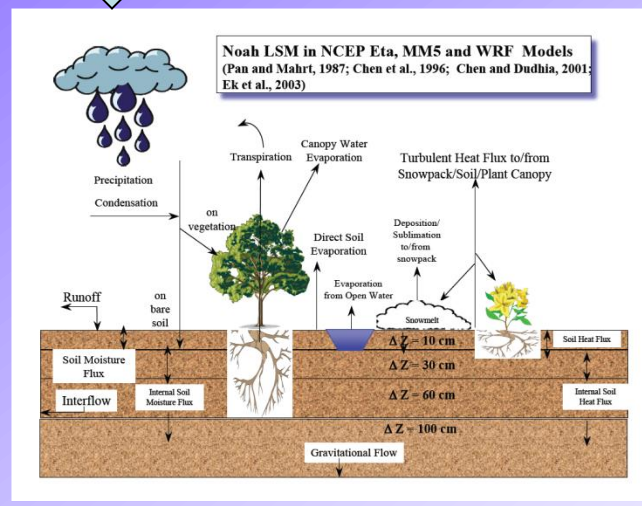
- *Miller et al. (1994)*
- *Lohmann et al. (1996)*
- *Olivera et al. (2000)*
- *Oki et al. (2001)*
- *Goteti et al. (2008)*

Almost no vector-based (GIS) hydrography,
Almost no parallel computing

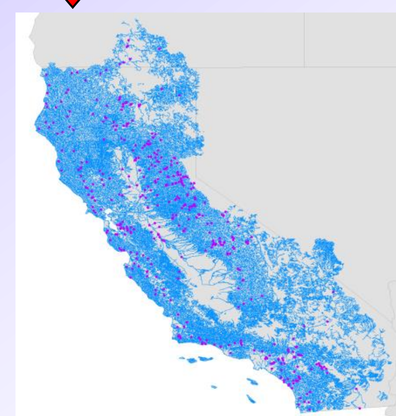
Integrated River Modeling



Atmospheric Model or Dataset



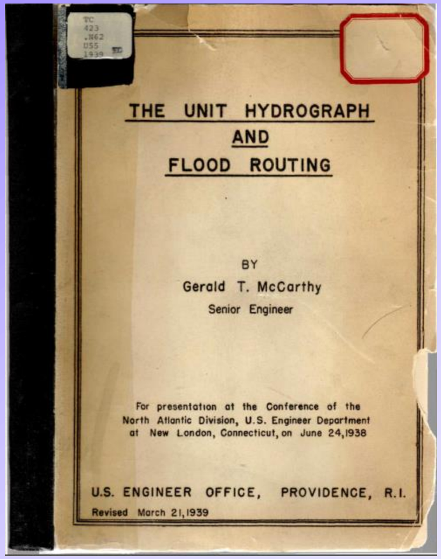
Land Surface Model



"Blue Line" River Network - High-Performance Computing River Network Model

First presented at AGU FM 2006…

From available technology to applications



THE UNIT HYDROGRAPH
AND
FLOOD ROUTING

BY
Gerald T. McCarthy
Senior Engineer

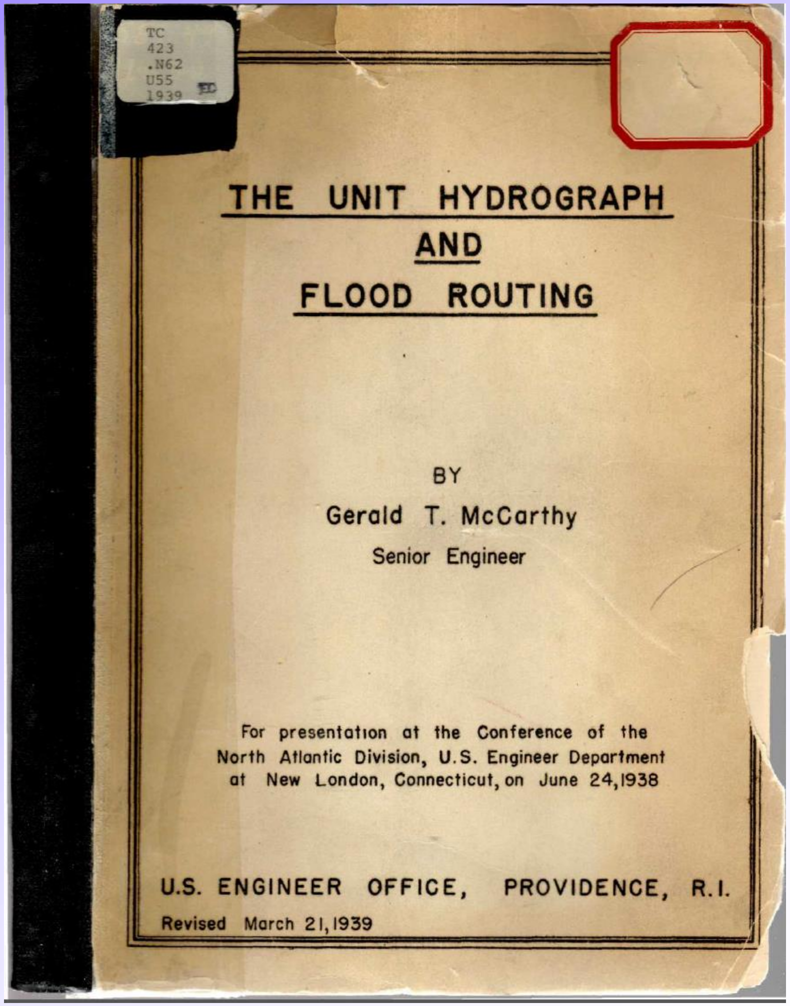
For presentation at the Conference of the North Atlantic Division, U.S. Engineer Department at New London, Connecticut, on June 24, 1938

U.S. ENGINEER OFFICE, PROVIDENCE, R.I.
Revised March 21, 1939

The Muskingum method

$$Q_j\left(t+\Delta t\right)=C_{1_j}\cdot Q_j^{up}\left(t+\Delta t\right)$$
$$+C_{2_j}\cdot Q_j^{up}\left(t\right)$$
$$+C_{3_j}\cdot Q_j\left(t\right)$$

IBM Portable PC 5155 (1984)
Price : $4,225 (256 - 640K RAM)

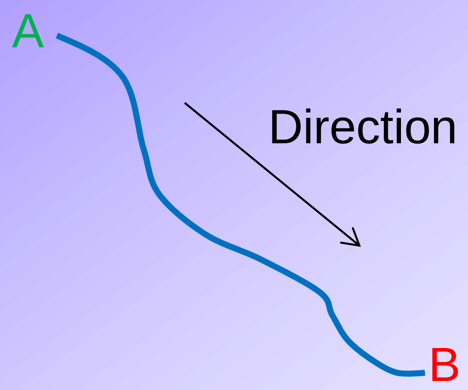


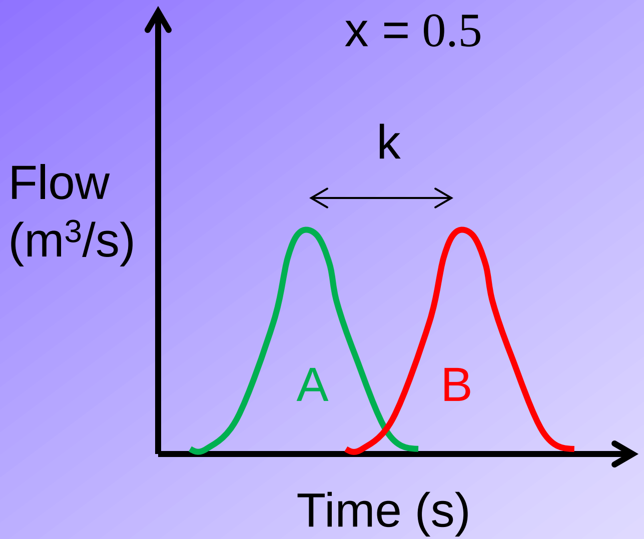
McCarthy (1938)

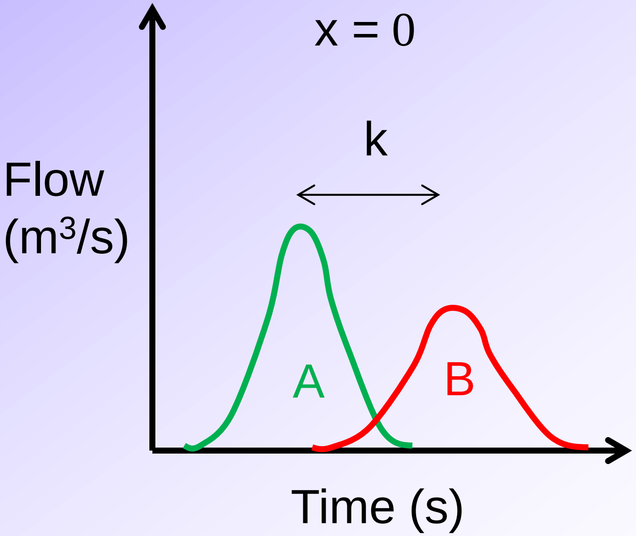
Meaning of the Muskingum parameters

k is a time ($k \geq 0$) related to the celerity of the flow wave

x is a non-dimensional parameter ($0 \leq x \leq 0.5$) related to diffusion of the flow wave







A vector-matrix version of the Muskingum method

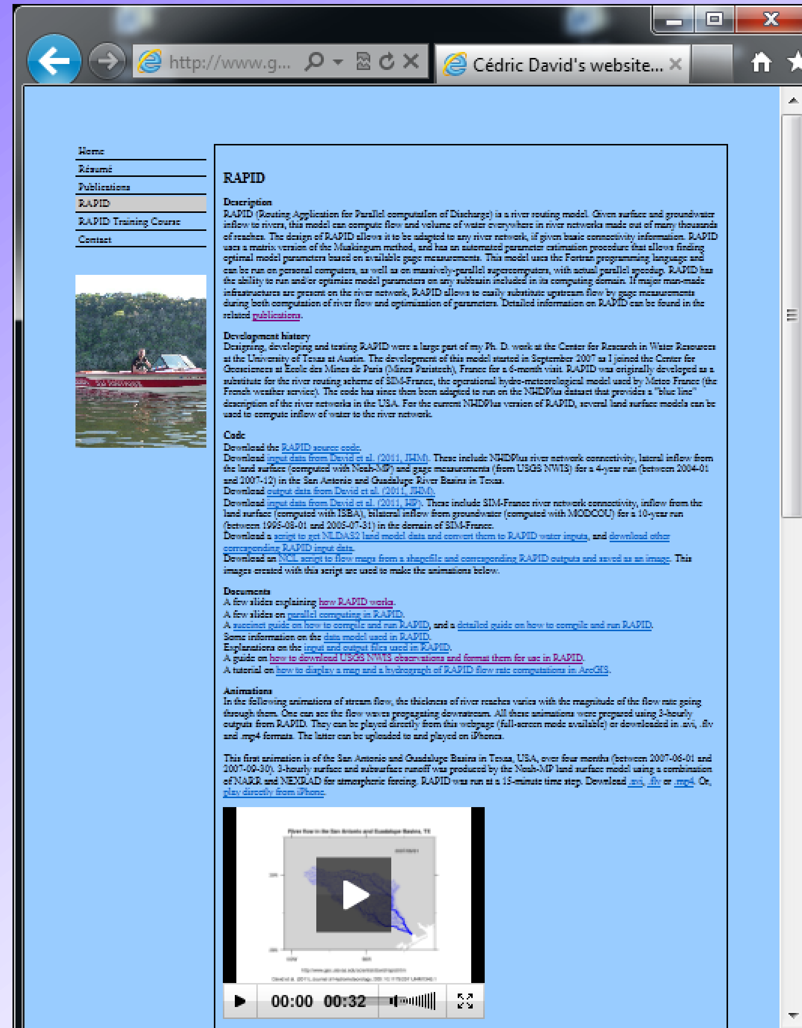
$$(\mathbf{I} - \mathbf{C_1} \cdot \mathbf{N}) \cdot \mathbf{Q}(t+\Delta t) = \mathbf{C_1} \cdot \mathbf{Q^e}(t) + \mathbf{C_2} \cdot \left[\mathbf{N} \cdot \mathbf{Q}(t) + \mathbf{Q^e}(t)\right] + \mathbf{C_3} \cdot \mathbf{Q}(t)$$

$\mathbf{I}$	Identity matrix
$\mathbf{N}$	Network matrix, computed based on network connectivity information
$\mathbf{Q^e}$	Vector of flow rates from outside the network into upstream of each river reach
$\mathbf{C_1}, \mathbf{C_2}, \mathbf{C_3}$	Parameter matrices, computed based on the values of k and x
$\mathbf{Q}$	Vector of flow rates at the outlet of each river reach (output of RAPID)

(First formulated in 2007)

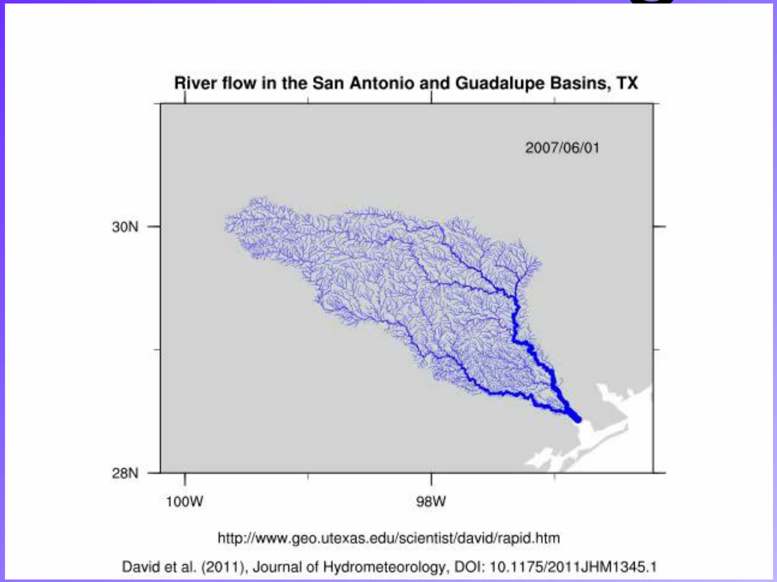
River model

- **RAPID** (Routing Application for Parallel computatIon of Discharge)
- Computes flow and optimizes model parameters
- Model code, input data and animations are available online
- Can run on supercomputers

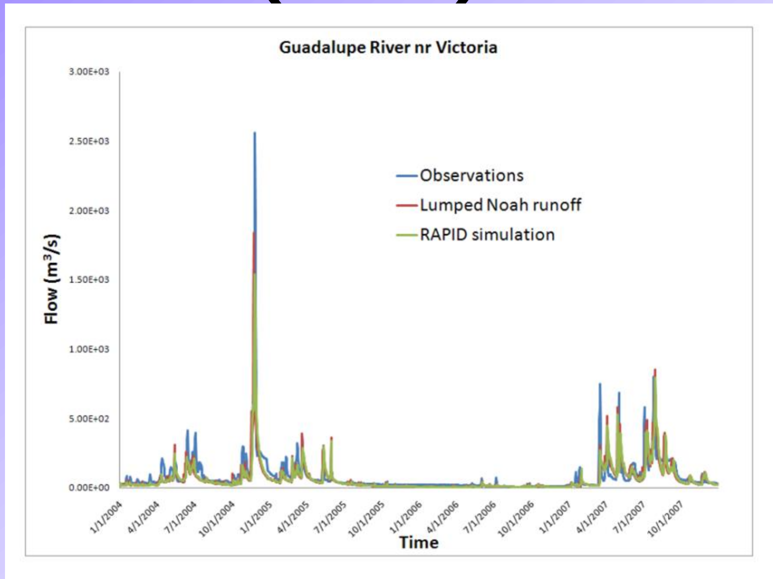


http://www.ucchm.org/david/rapid.htm

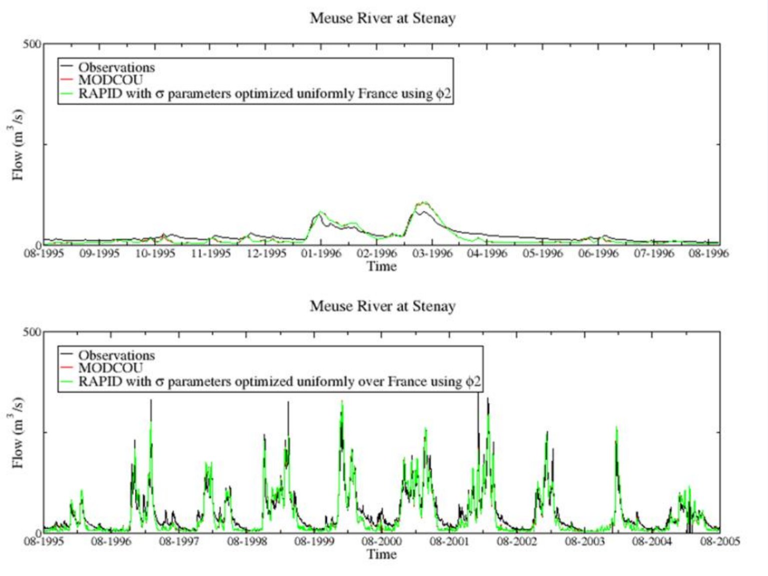
Existing Applications (1/3)



David et al. 2011a *J. Hydromet.*

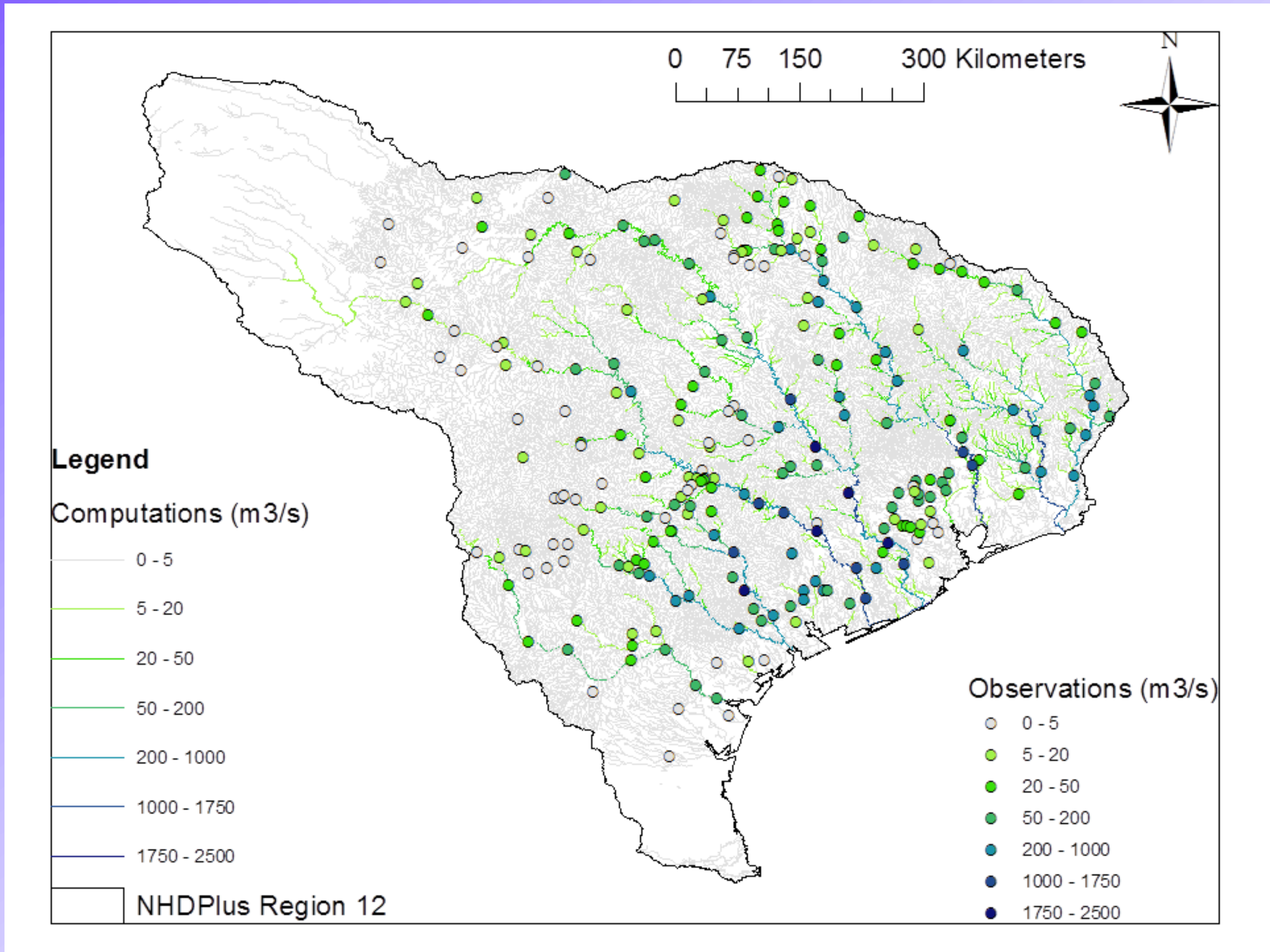


David et al. 2011b *Hydrol. Proc.*



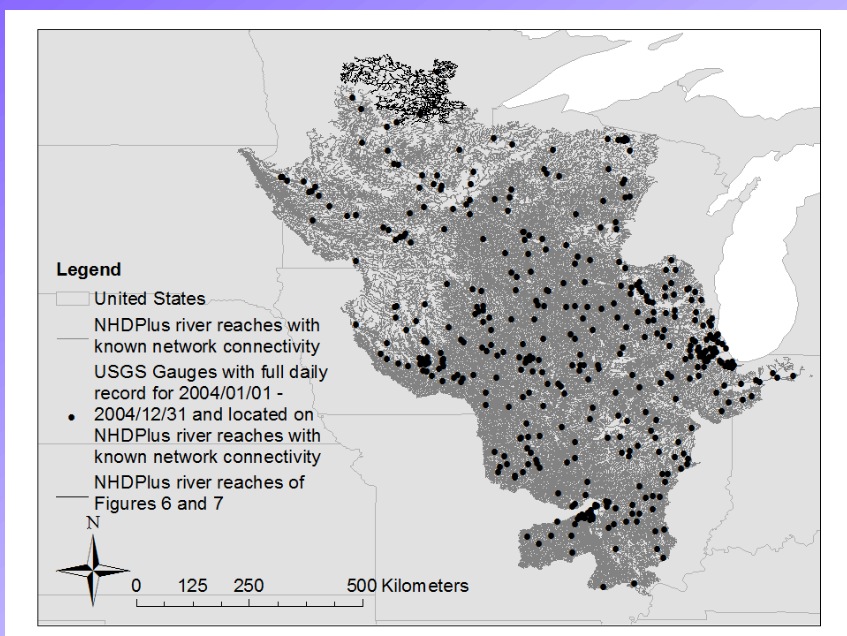
Existing Applications (2/3)

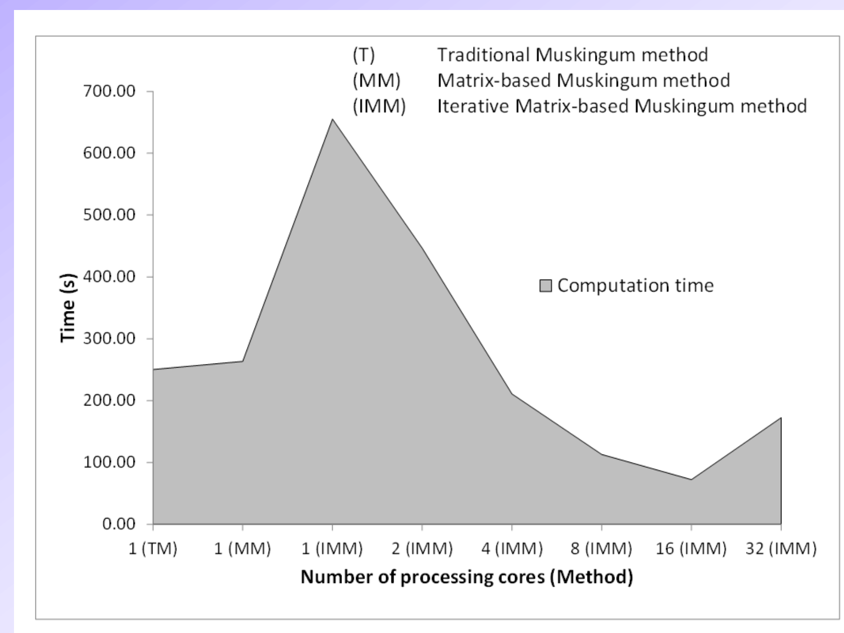
David et al.
2013a
Env. Mod. & Soft.



Existing Applications (3/3)

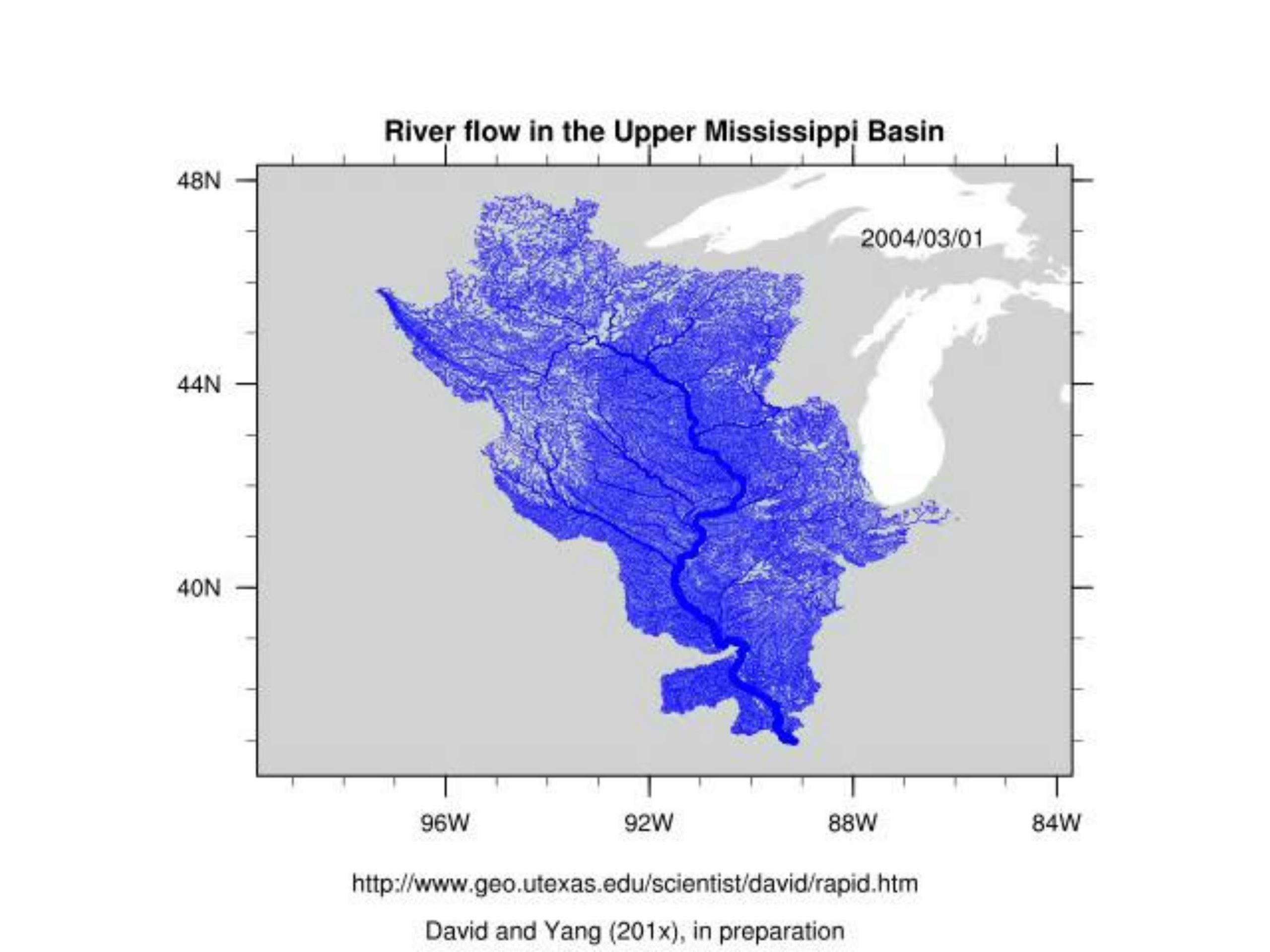
David et al.
2013b
Water. Resour. Res.





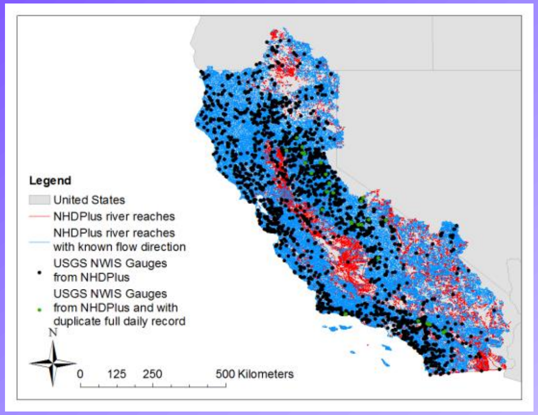
So fast theory had to be revised!!!

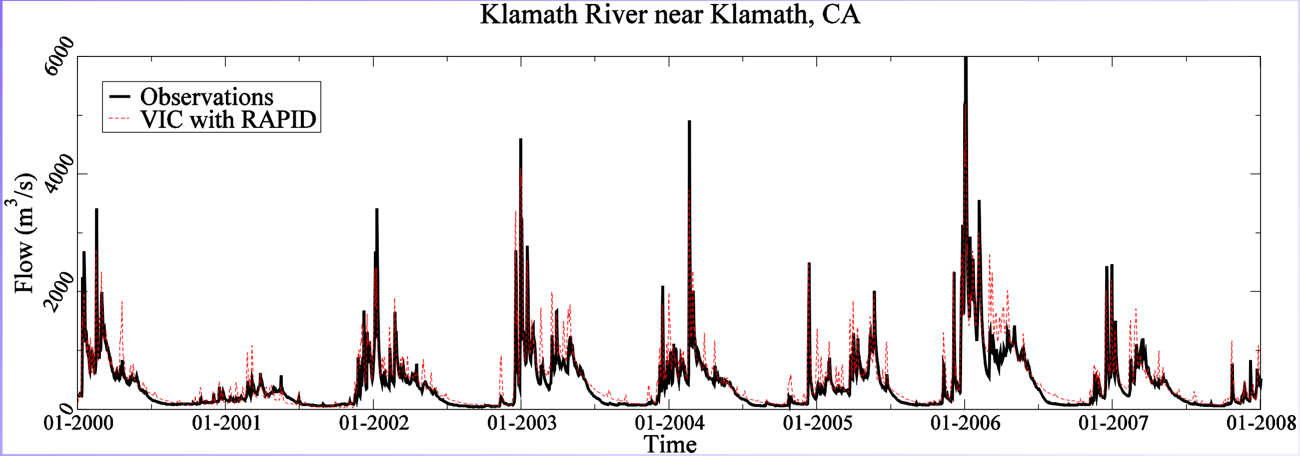
Animation of Upper Mississippi Basin

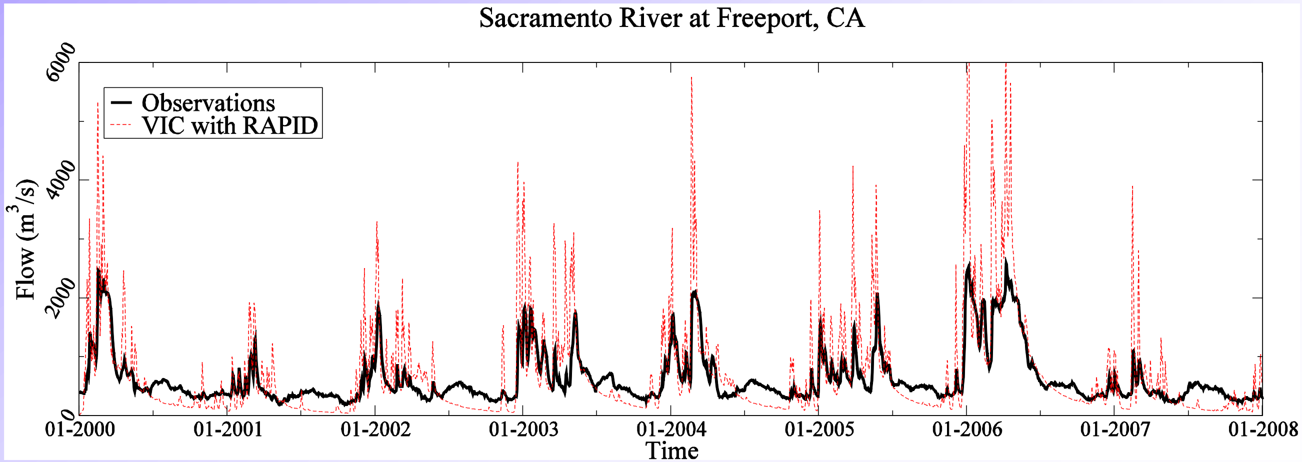


Challenges remain!!!

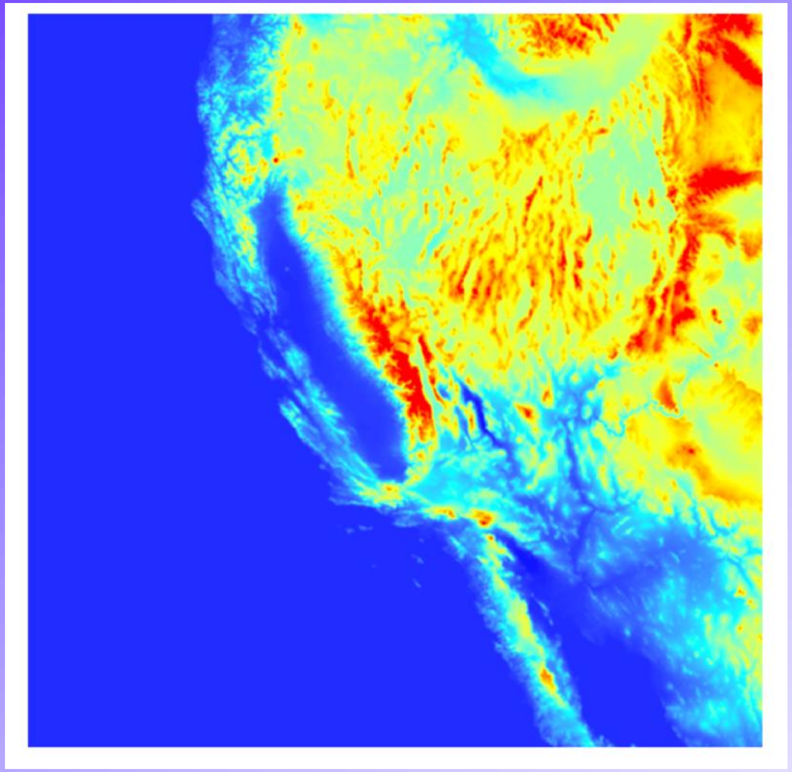
Human influence on surface water



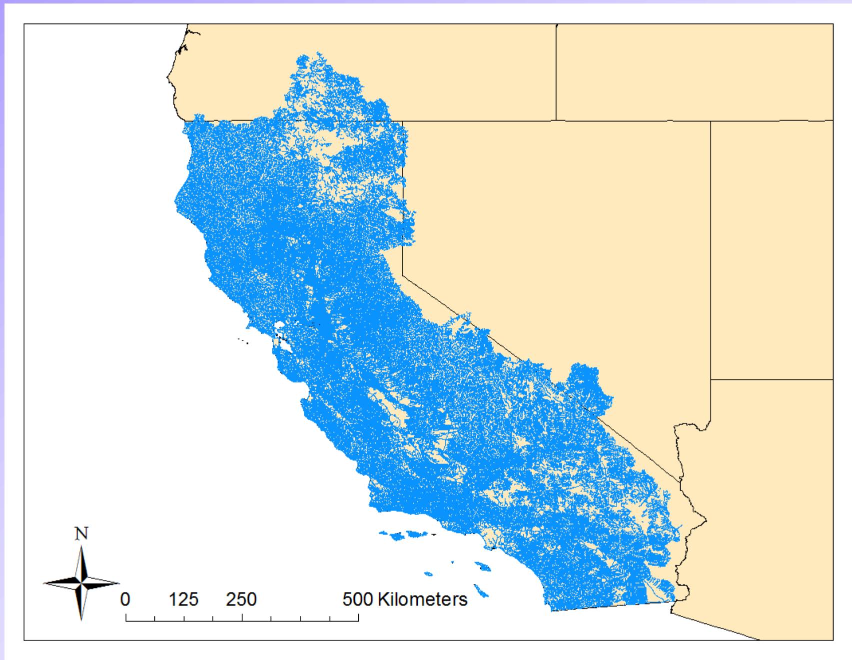




New domain = New data processing

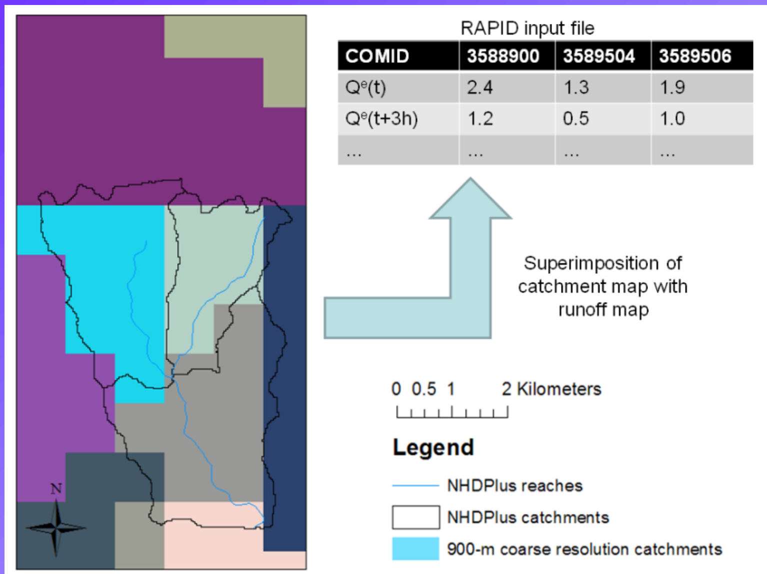


Existing WRF-Hydro domain over California

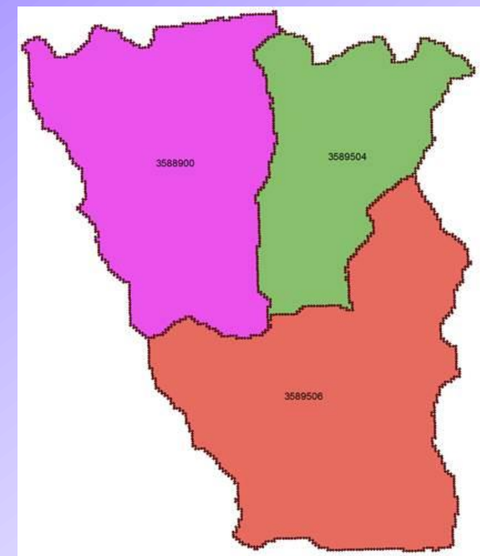


River networks of California

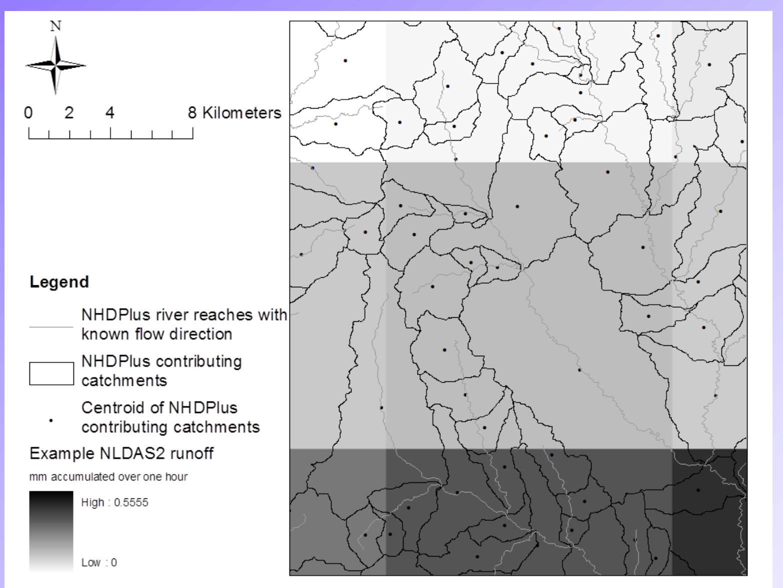
Land/river connection



David et al. (2011a)



Parallel re-gridders

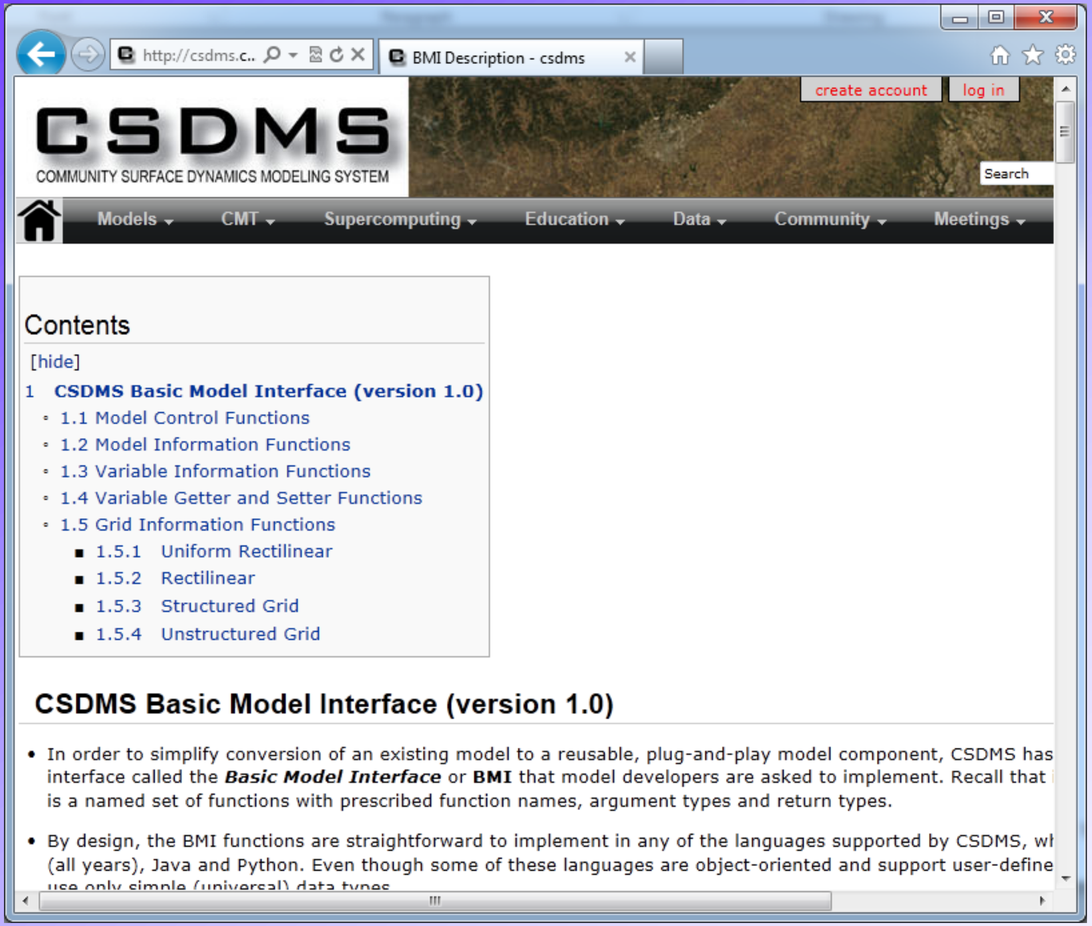


David et al. (2013a)

ESMF

Workflow opportunities

Inclusion in existing coupling frameworks

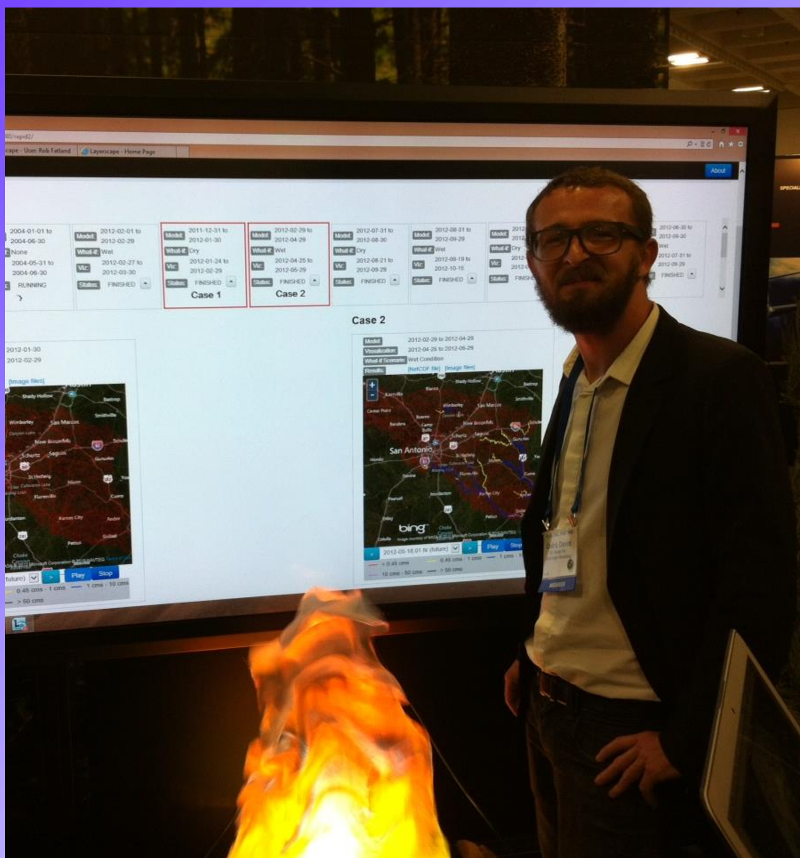


CSDMS-enabled RAPID

Re-think the organization of the model code

Teaches you model servitude!

Near real-time modeling???



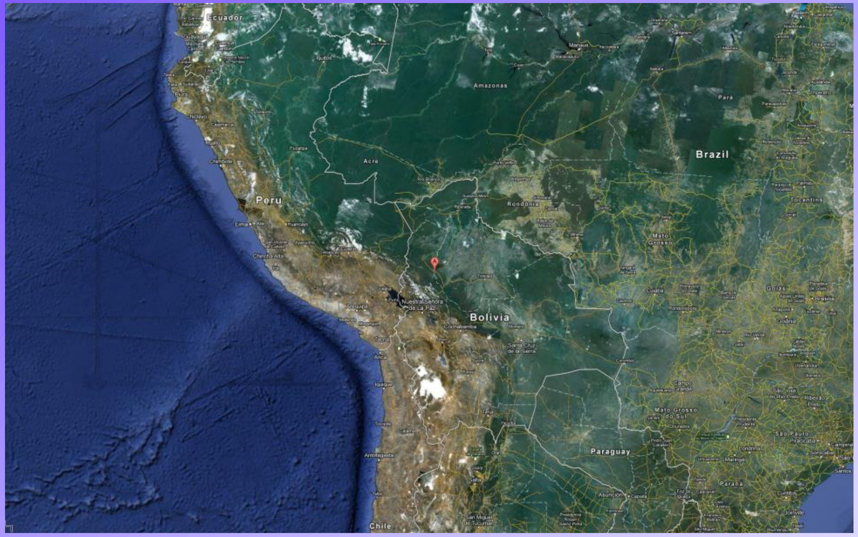
Microsoft Booth at AGU Fall Meeting 2012

Near real-time model input available

Can we automate all modeling steps?

- Pre-processing of data
- Model run
- Post-processing of data

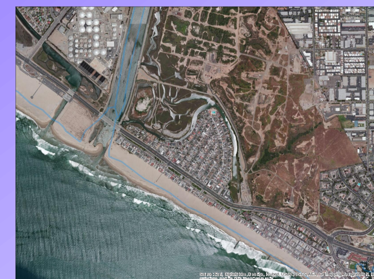
What if we did the whole world?



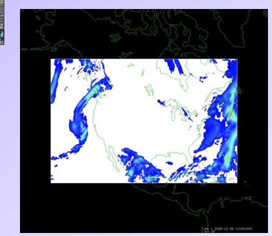
Rio Beni, Bolivia

Summary

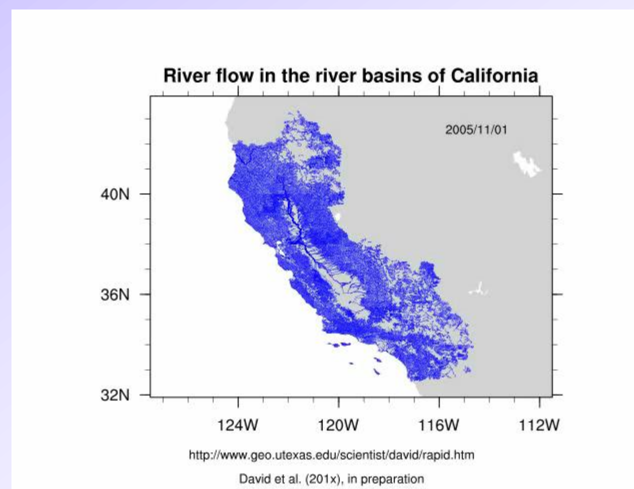
Vision



Technology

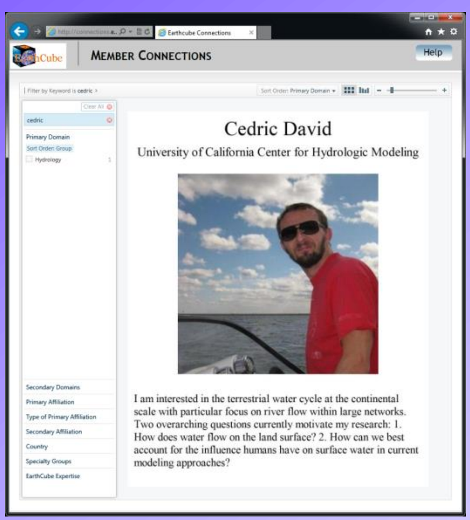


Society



Science

Want to collaborate???



Thank you!

Questions?

More information on RAPID at:
http://www.ucchm.org/david/rapid.htm
chdavid@uci.edu