Computer Models and Water Resources Management: Examples, Perspectives, and a Few Opinions

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Water Resource Problems

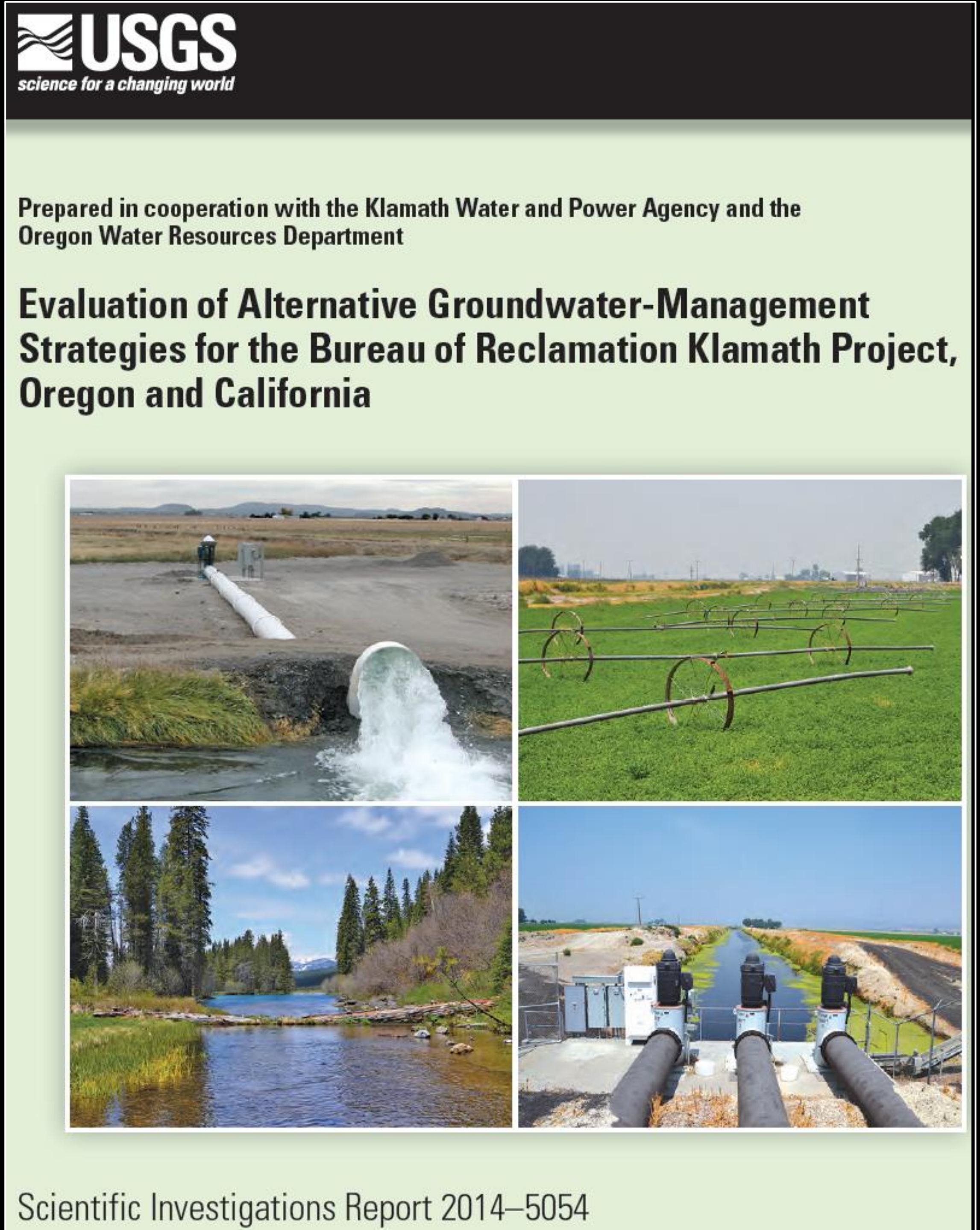
- Water supply
- Land subsidence
- Transboundary disputes
- Nuclear waste disposal
- Affects of climate change
- Contaminant remediation

Drought and floods

➤Model execution times can be seconds to days.

Examples, Perspectives, and a Few Opinions

- Examples
    - Klamath Basin, Oregon – a chronic situation
    - Deepwater Horizon Blowout – an acute situation


USGS
science for a changing world

Prepared in cooperation with the Klamath Water and Power Agency and the Oregon Water Resources Department

Evaluation of Alternative Groundwater-Management Strategies for the Bureau of Reclamation Klamath Project, Oregon and California

Scientific Investigations Report 2014–5054

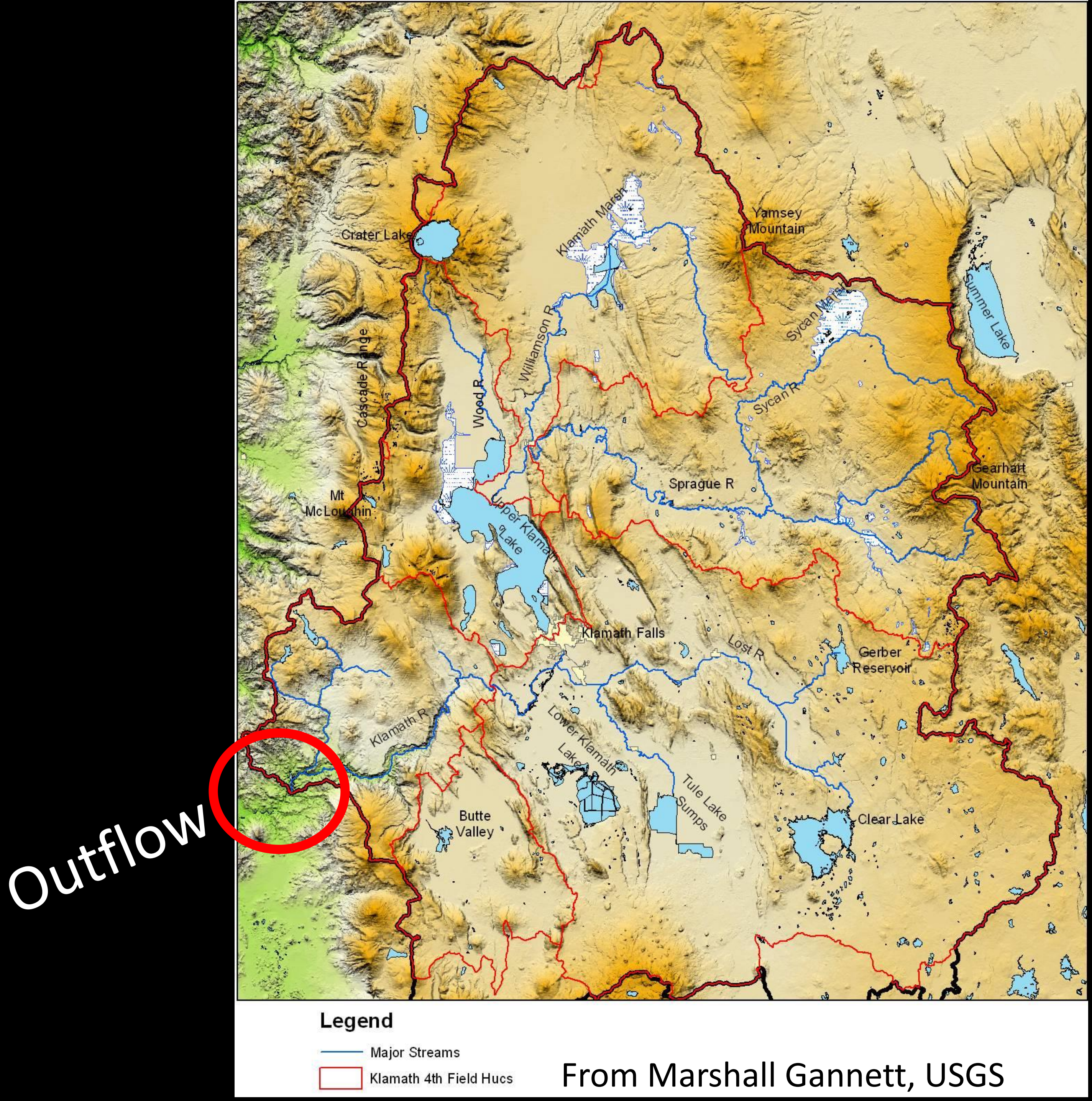
Klamath Basin, Oregon, USA

Brian Wagner and Marshall Gannett

U.S. Geological Survey

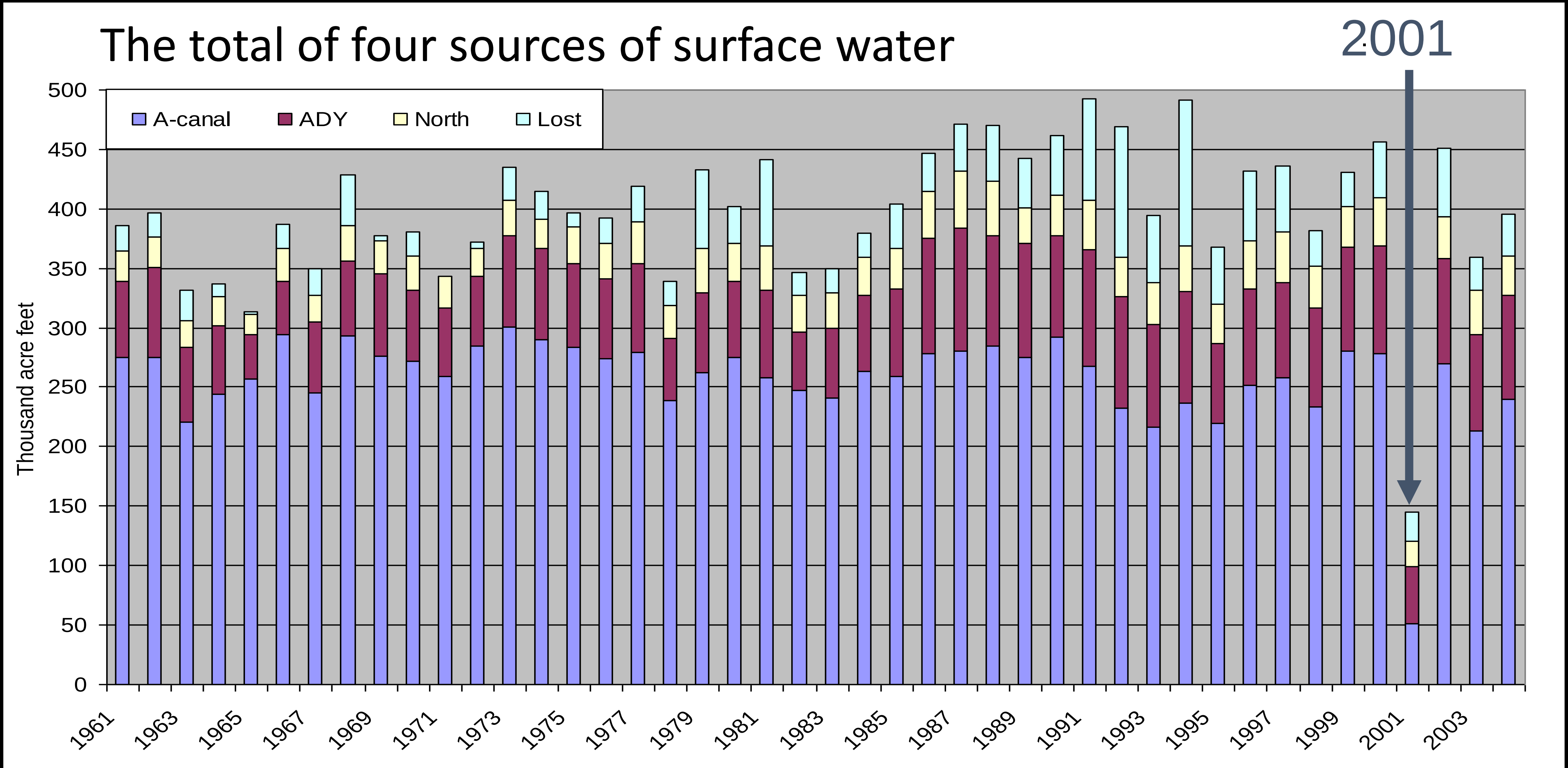
Klamath Basin

- Not enough flow is leaving the Klamath to support salmon in the lower reaches.
- The salmon is critical to native American tribes
- The water is critical to farmers.
- Entities involved: Indian tribes, states of Oregon and Washington, US Bureau of Land Management, all people of the Klamath valley



From Marshall Gannett, USGS

Why 2001?



The total of four sources of surface water
2001
A-canal
ADY
North
Lost
Thousand acre feet
500
450
400
350
300
250
200
150
100
50
0
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003

Conflict in the western USA

Plenty of local links action ... Sports, B1 and B2

www.heraldandnews.com

FRIDAY-SATURDAY

Herald and News

April 6, 2001— No. 19,739

Klamath Falls, Oregon

Weather
Mostly cloudy, chance of snow showers. Highs near 40 Saturday.
Details, page B8.

50 Cents

No water for most farmers

Thousands of acres will go dry for benefit of fish

By JOHN BRAGG
H&N Staff Writer

Federal ...

... spokesman for Walden, said there was little to do now but try to minimize the damage.

The announcement included word from the Department of Agriculture that most crops in the affected area are eligible for crop insurance or other assistance, including "prevented planting" payments for farmers who purchased crop insurance before the drought was declared. Farmers should contact their crop insurance agents for details, Reclamation officials said.

Sen. Gordon Smith will be in Klamath Falls Saturday morning for a town hall meeting at 10:30 a.m. at the Shilo Inn. Afterwards he ... have lunch ... the Kla...

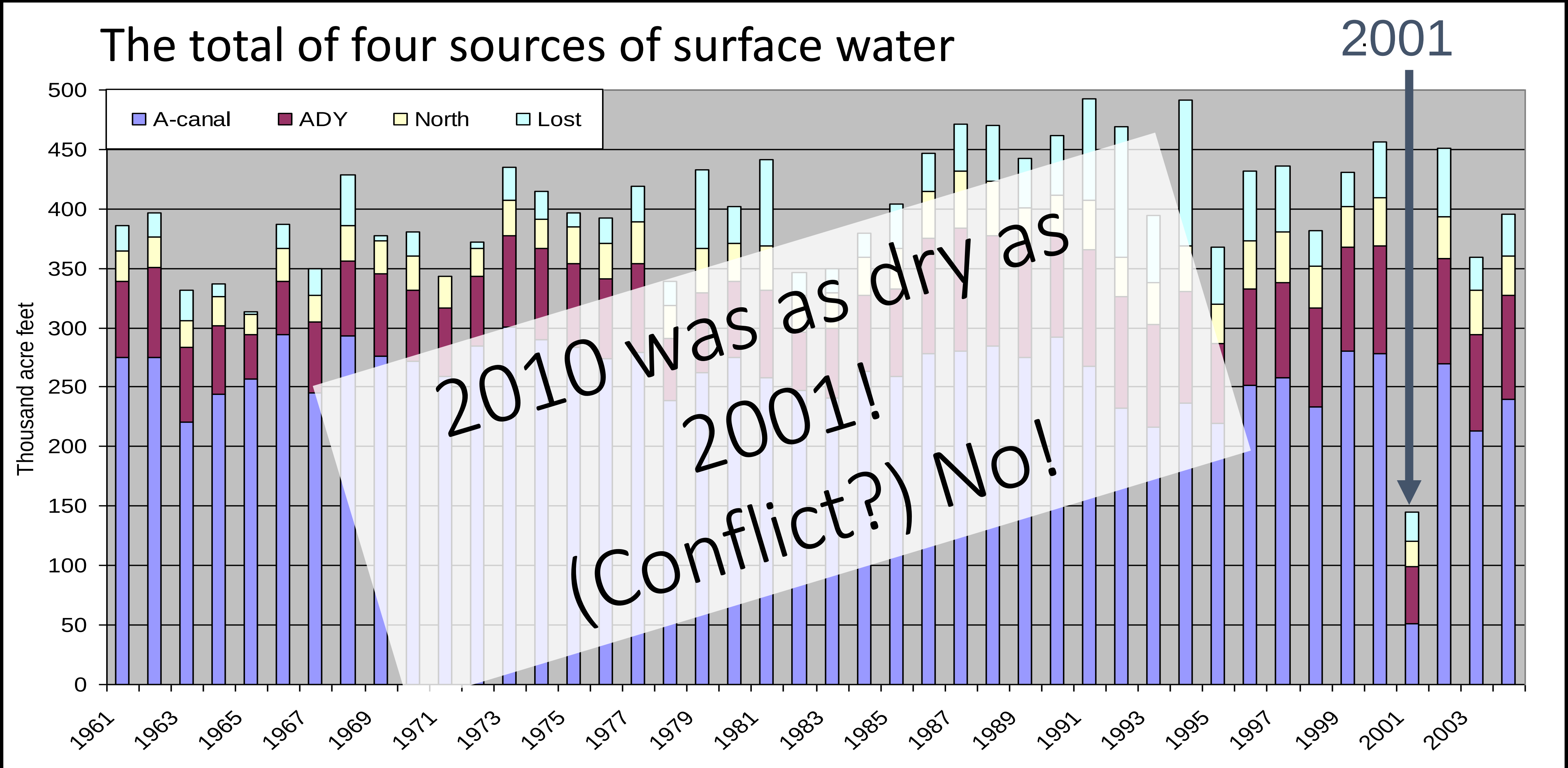
... marshes flooded this summer ... will be diverted for agricu...

H&N photo by Gary Th...

Priorities shift to protect aquatic habitat

- In 2001, water-management priorities in the basin shifted to protect aquatic habitat.
- This realignment of water supply and demand has reduced surface water agriculture and increased demand for groundwater, particularly in drought years.

Why 2001?



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500
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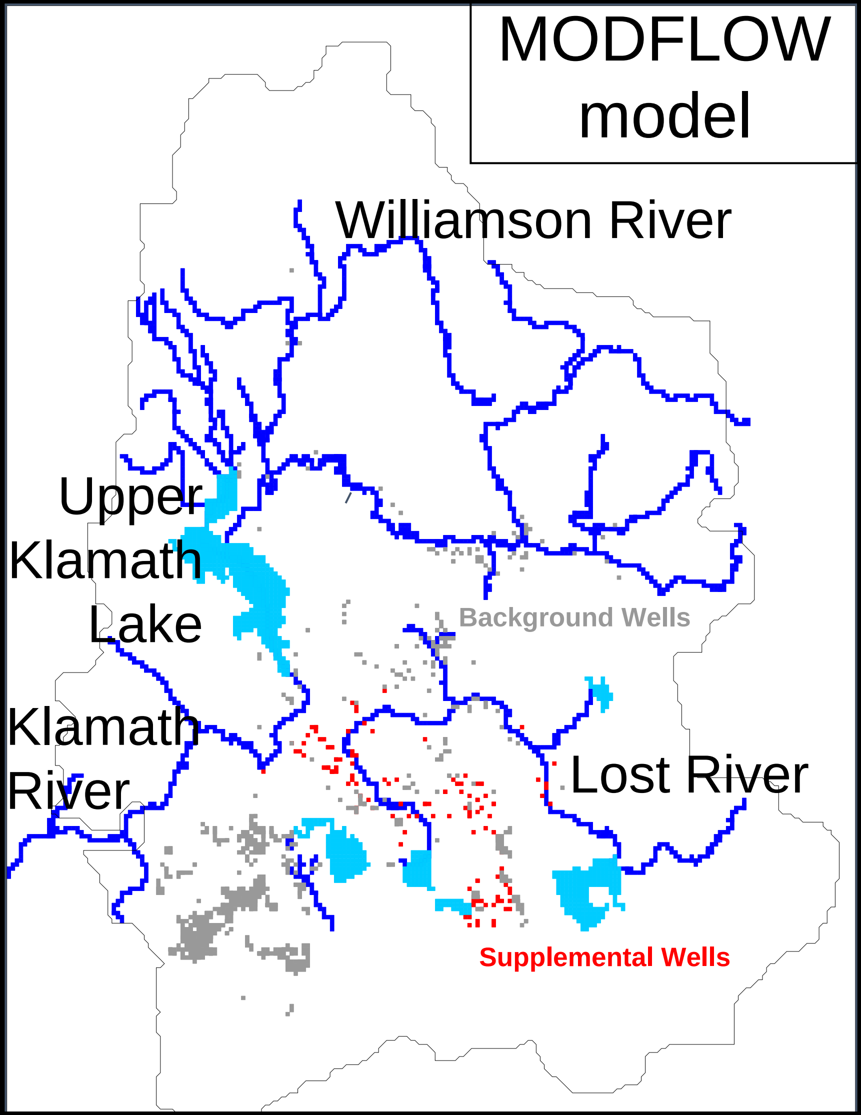
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2010 was as dry as 2001!
(Conflict?) No!

Resolution

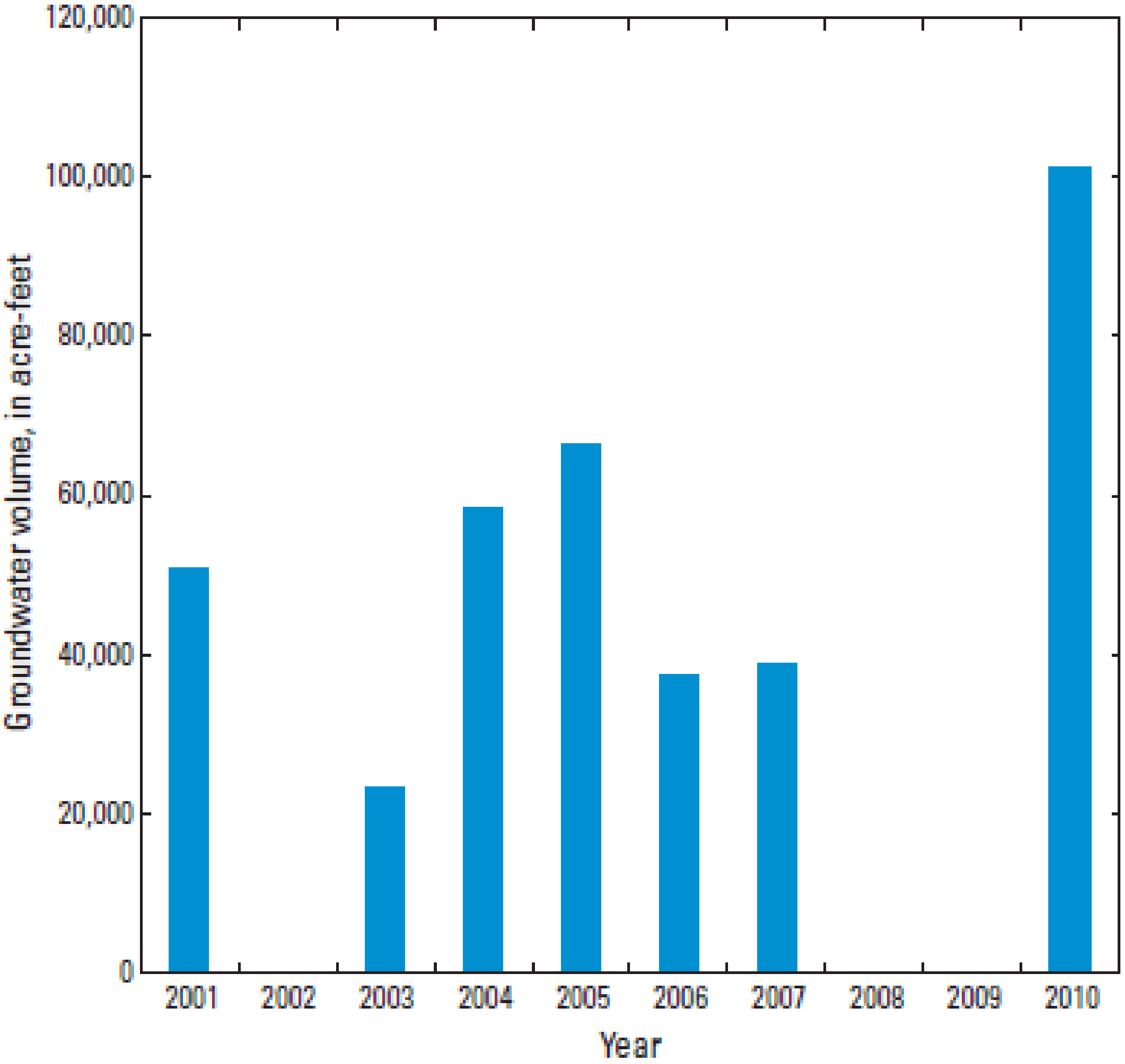
- Technical Goals
  - Protect environmental flows
  - Meet water demand
  - Evaluate effects of climate change
- Societal goals
  - Find constructive solutions
    - Involve stakeholders
    - Establish trust
- How?
  - Determine water demand as the larger
    - simulated value
    - value obtained directly from data
  - Federal agency BLM buys water from users in dry years



Brian Wagner & Marshall Gannett, USGS. Klamath Basin Science Conference. 2010

Solution

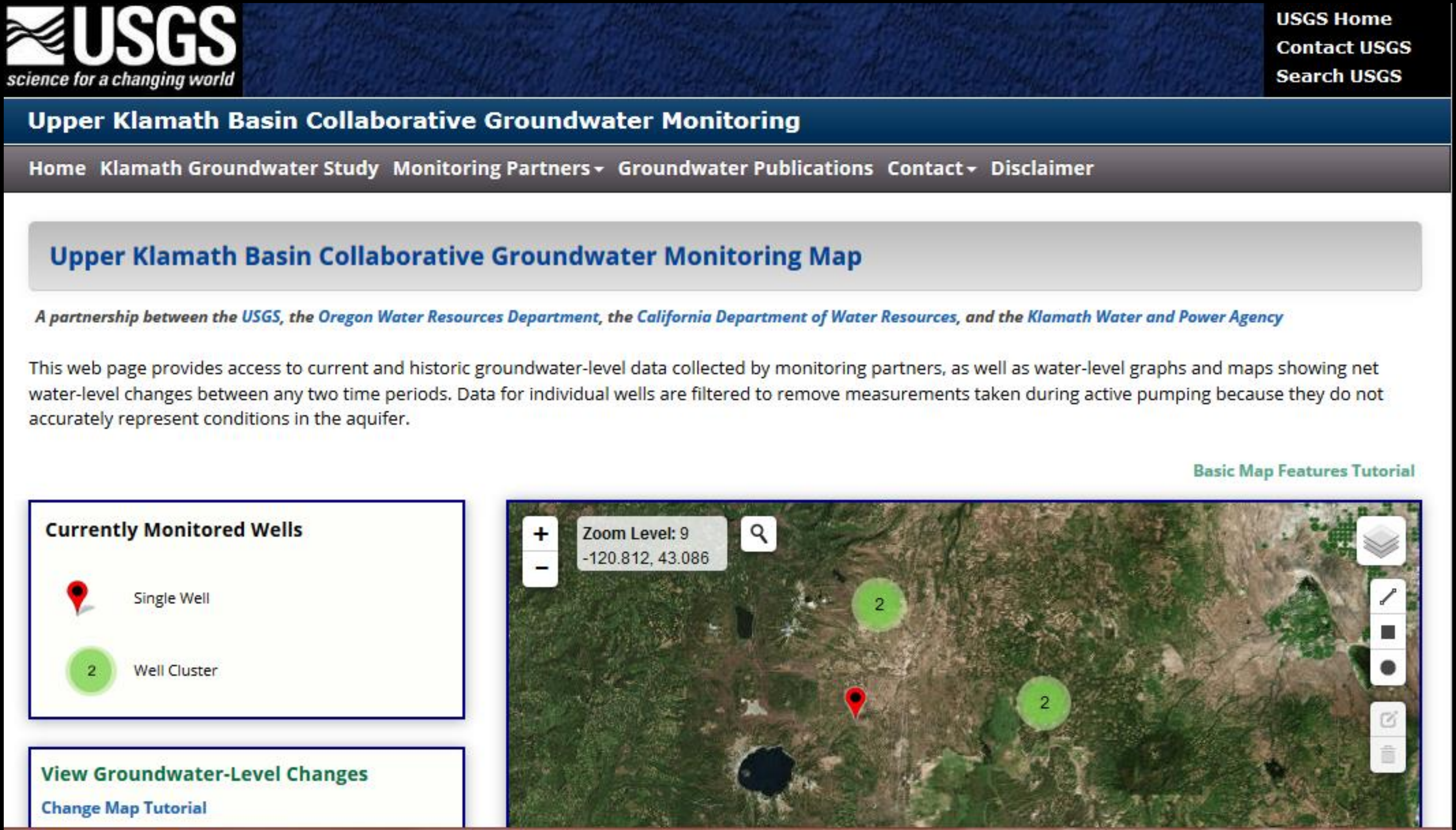
- Supplemental groundwater volume purchased for the Bureau of Reclamation Klamath Irrigation Project, upper Klamath Basin, Oregon and California, 2001–10.
- Groundwater was not purchased in 2002, 2008, and 2009.



Now

- Bureau of Reclamation provides yearly projections
- 2015 is a year of drought
- October 2014 through April 1, 2015, 96% of average precip, but snowpack is only 7% of average.
- Allocations to many water users are reduced.

USGS collects data and makes it available at
http://or.water.usgs.gov/projs_dir/klamath_cooperative_monitoring/index.html



Role of Modeling in this work

- Provided a focal point for data collection, analysis, and interpretation
- Helped people involved to understand the problem and adapt to being proactive and constructive
- Provides a continuing tool for deciding how much groundwater to pump each year

Examples, Perspectives, and a Few Opinions

- Examples
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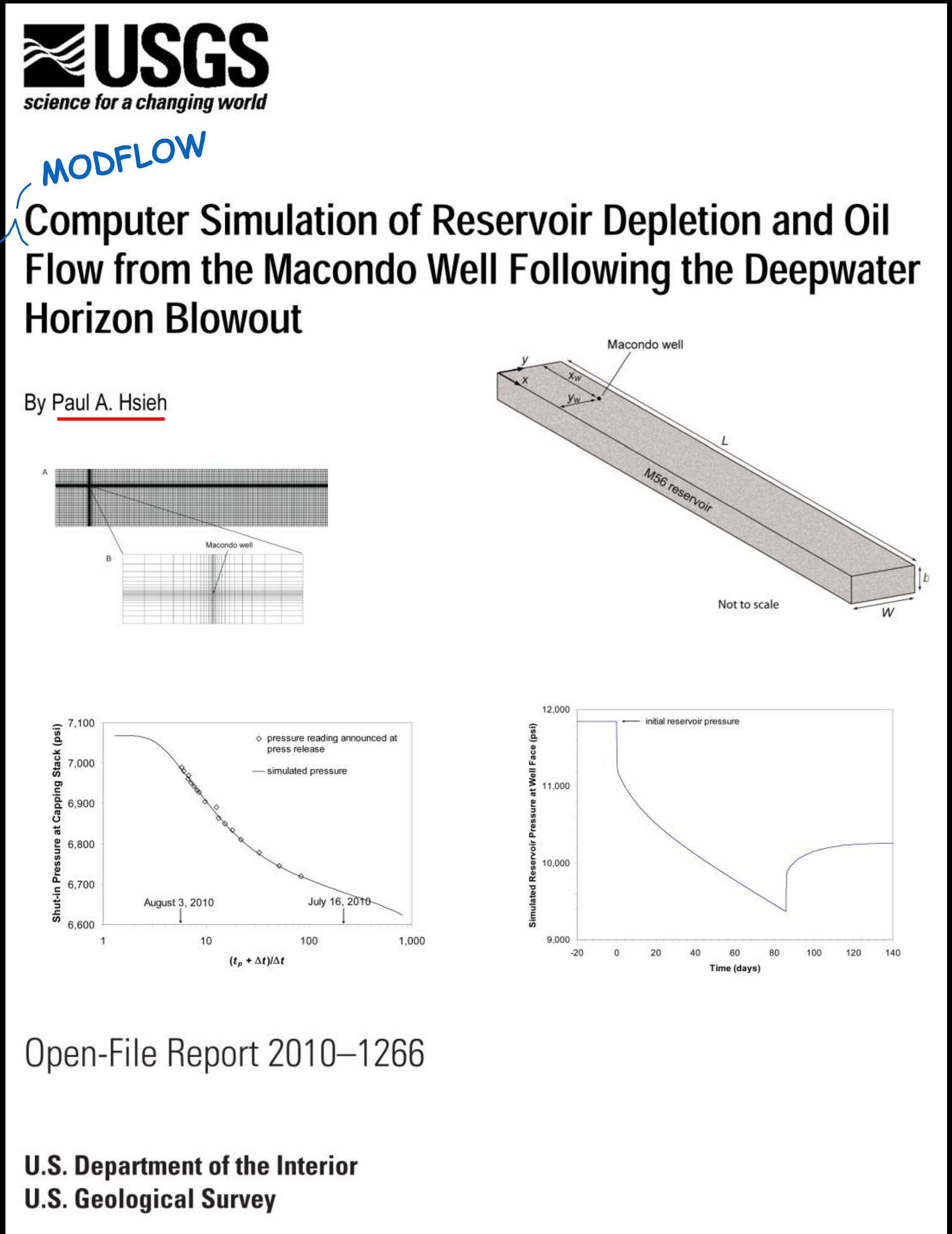
  - Deepwater Horizon Blowout – an acute situation

Simulation of Flow of the Deepwater Horizon Blowout

From Report by Hsieh 2010

Presented by Mary C Hill

Groundwater Modeling in a Time of Crisis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MODFLOW

Computer Simulation of Reservoir Depletion and Oil Flow from the Macondo Well Following the Deepwater Horizon Blowout

By Paul A. Hsieh

Open-File Report 2010–1266

U.S. Department of the Interior
U.S. Geological Survey

Groundwater Modeling in a Time of Crisis

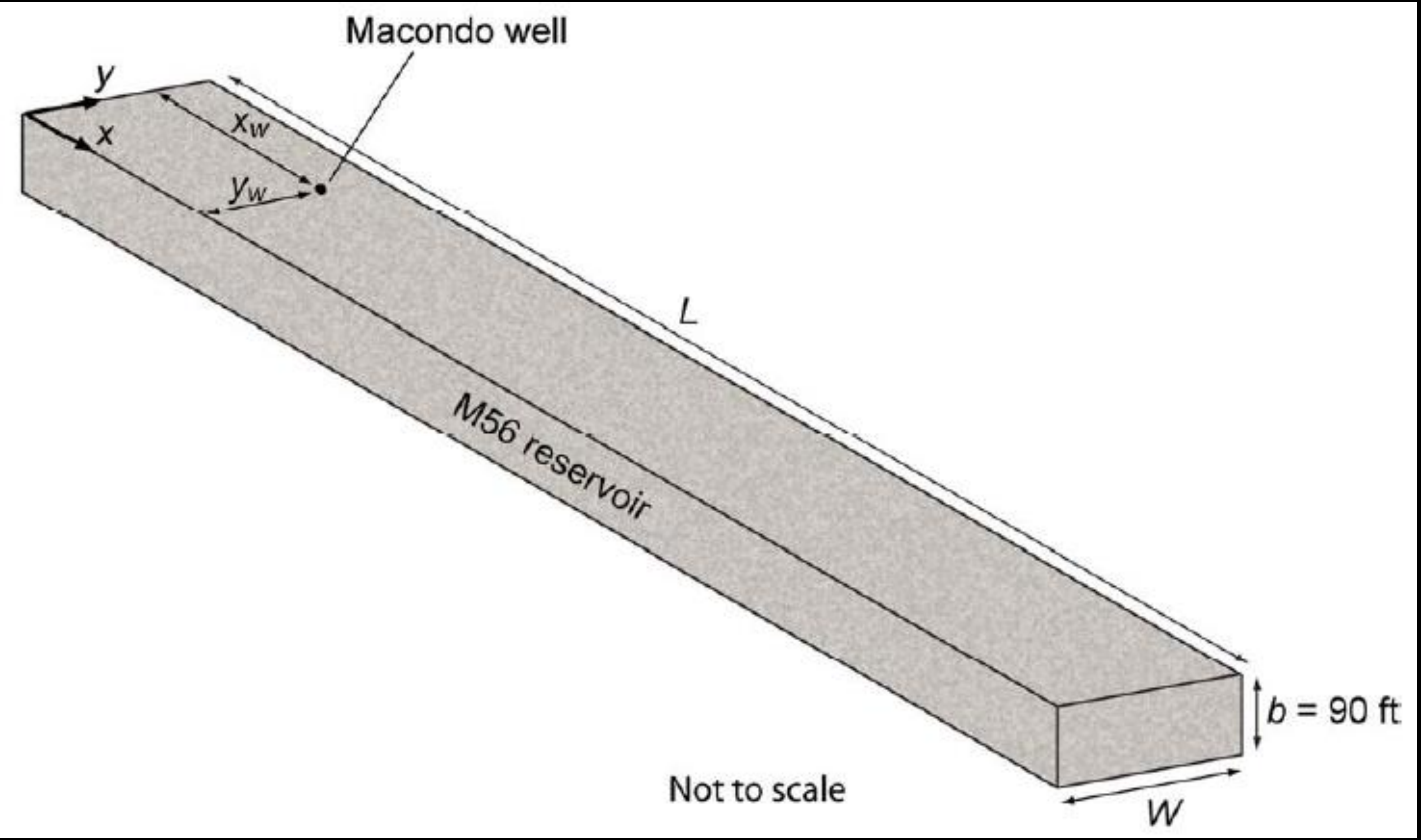
Deepwater Horizon Blowout, April 20, 2010

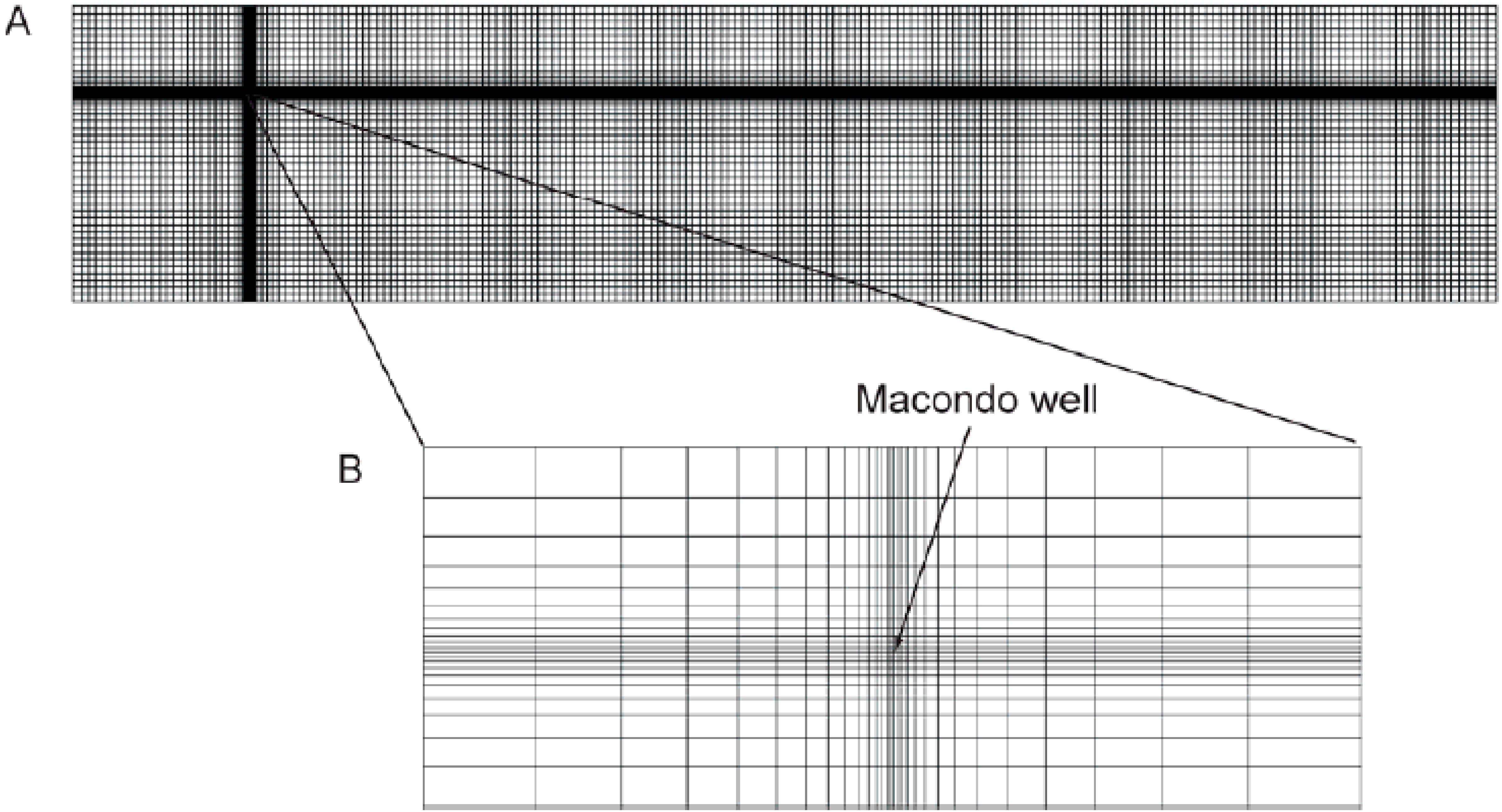
- July 15, 2010 (86 days): the Macondo well was shut in to begin the Well Integrity Test.
- A computer simulation was carried out to analyze the shut-in pressure data obtained during this test in order to:
  - assess reservoir depletion resulting from oil flow during the 86 days from blowout to shut in
  - estimate oil flow rate from the well
  - estimate of total volume of oil discharged
- These results have been critical to deciding what compensation is owed by the oil producer, BP

Why was MODFLOW Used?

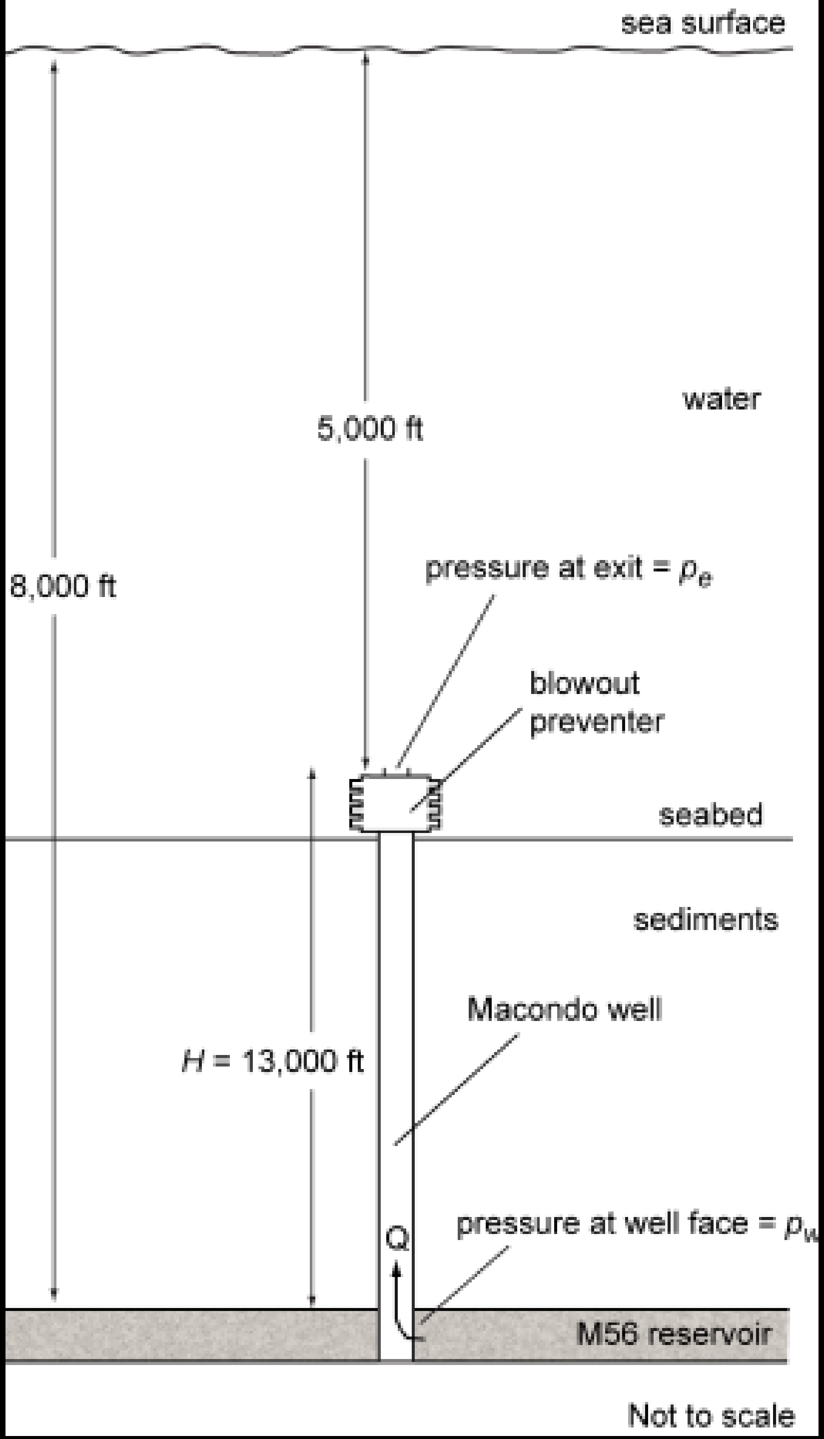
- MODFLOW was originally designed to simulate the flow of groundwater in aquifers.
- It can be readily adapted for simulating flow of oil in reservoirs under single-phase and isothermal conditions
  - Changed interpretation of the model input and output.
  - The model and data input structure stay the same

Simulated dimensions of the oil reservoir

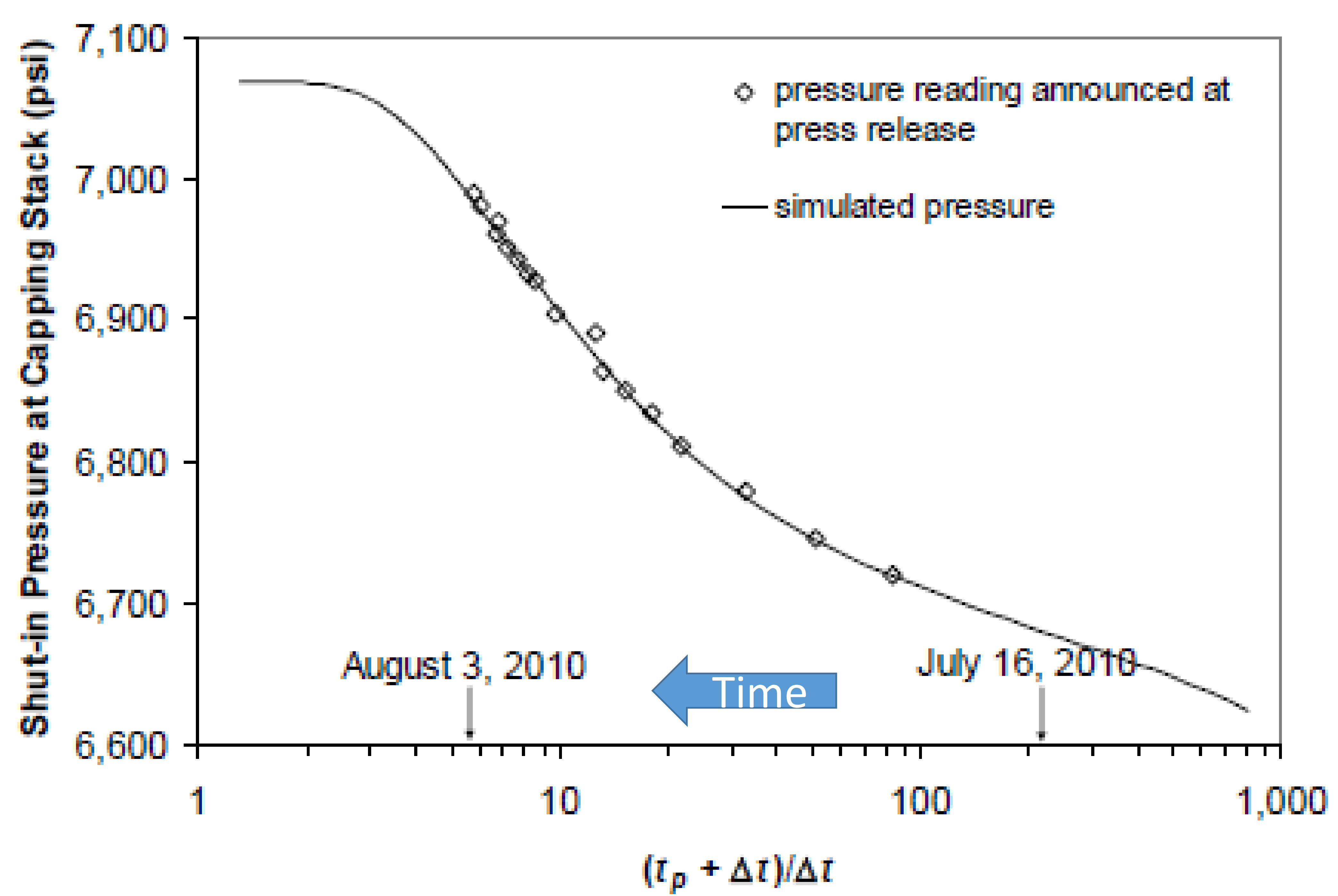



A
B
Macondo well

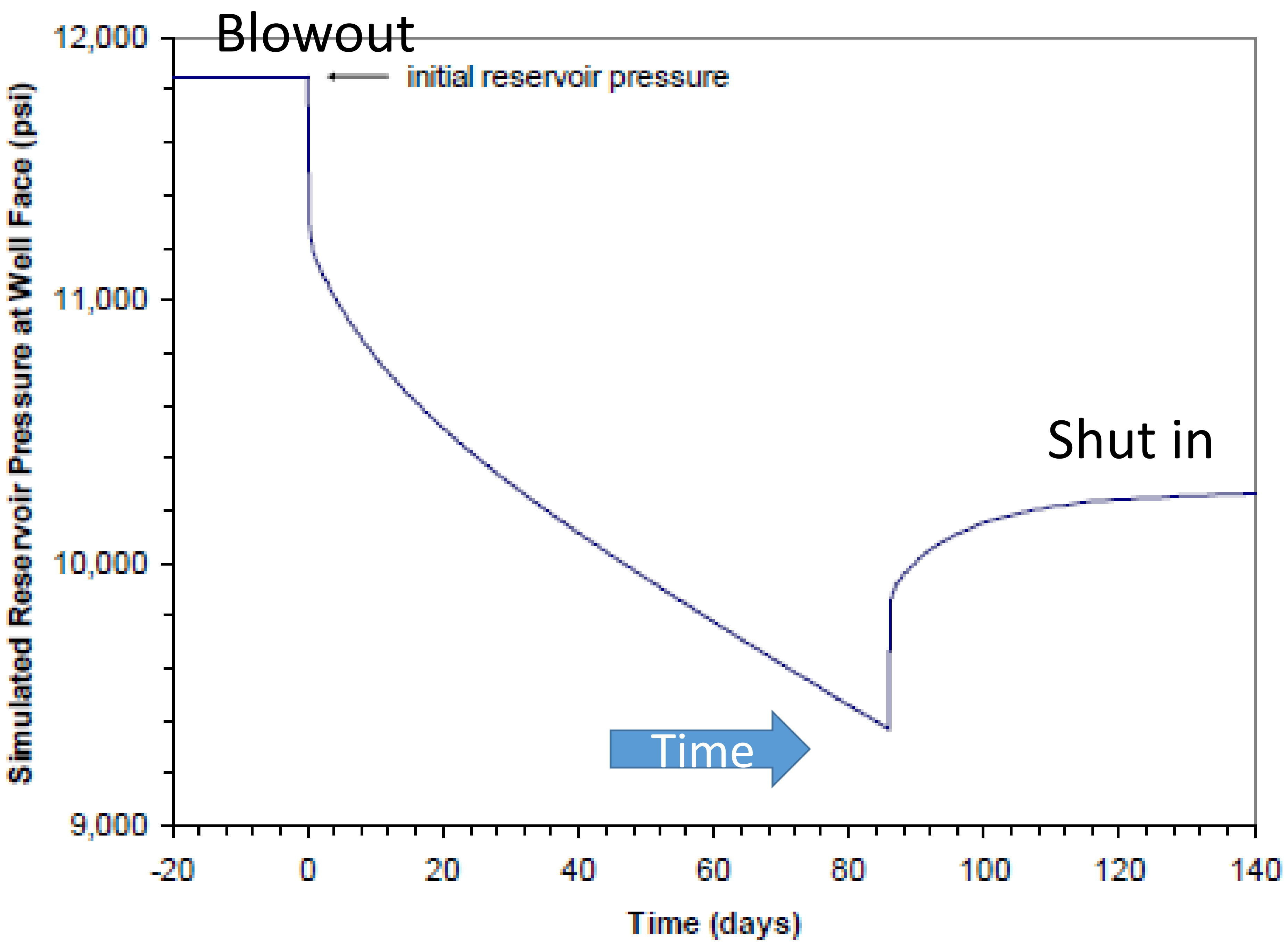
Cross-section of the Macondo Well



Oil Reservoir



Shut-in Pressure at Capping Stack (psi)
7,100
7,000
6,900
6,800
6,700
6,600
pressure reading announced at press release
simulated pressure
August 3, 2010
Time
July 16, 2010
1
10
100
1,000
$(t_p + \Delta t)/\Delta t$


Blowout
initial reservoir pressure
Shut in
Time
12,000
11,000
10,000
9,000
Simulated Reservoir Pressure at Well Face (psi)
-20
0
20
40
60
80
100
120
140
Time (days)

Final Results

- Oil flow from damaged well ~ 50,000 barrels per day
- Total spill ~ 4.1 million barrels
- These results could only be obtained through modeling

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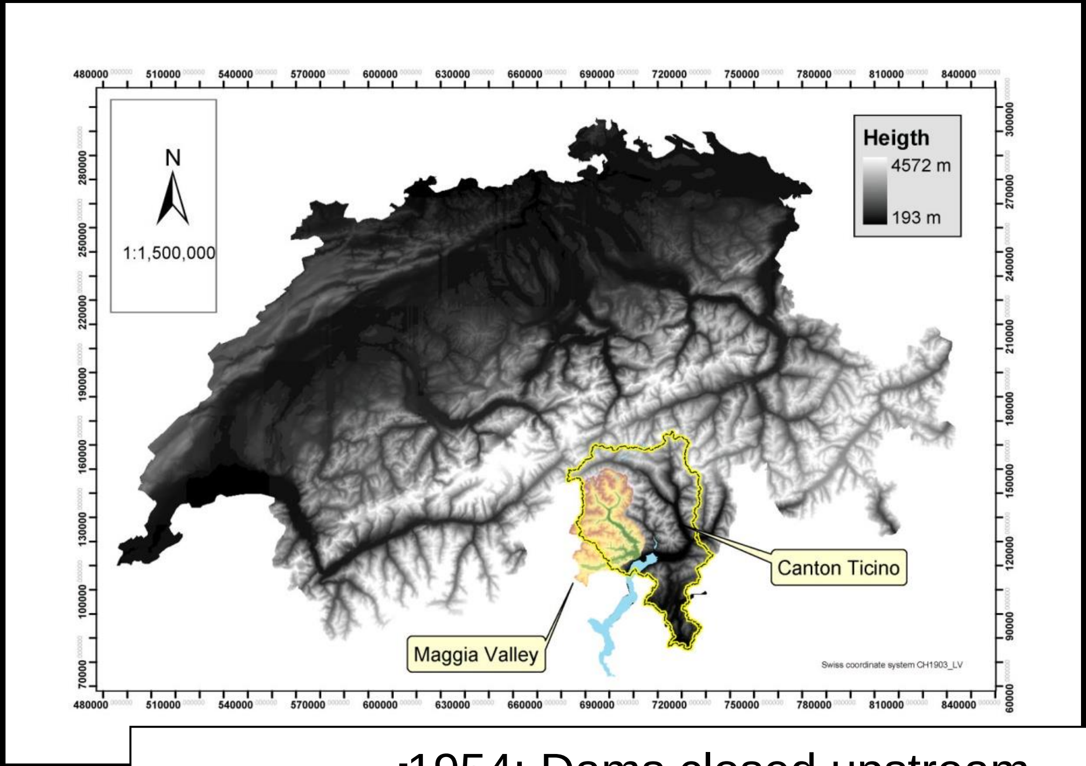
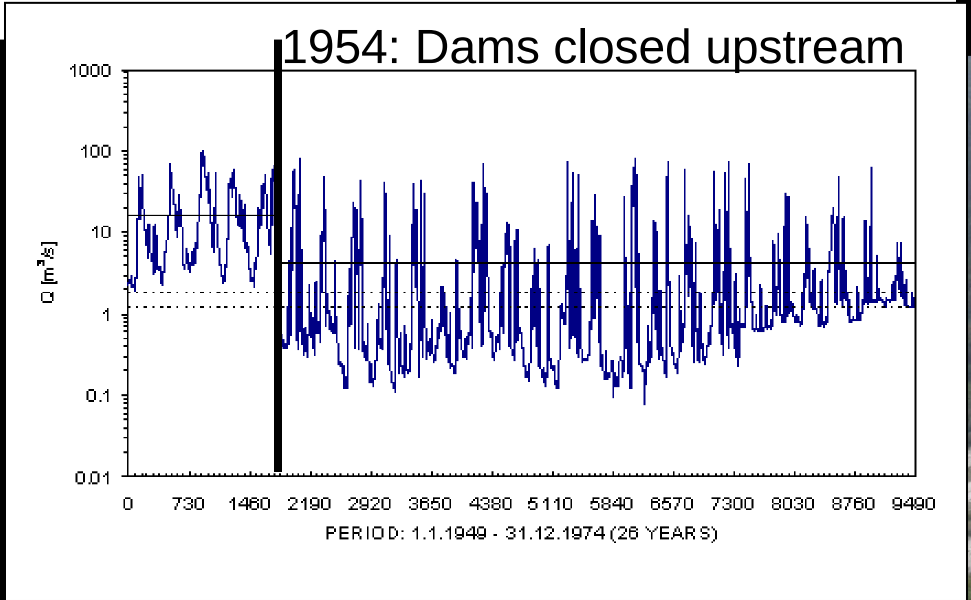
- Perspectives. More can be obtained from models than matching observations and making predictions
  - What about the model is important and unimportant?
  - Of the data used in model development, what was important?
  - How sure is the prediction?
  - What new data would be most important?

Example: Maggia Valley, southern Switzerland





- Goal: Integrated hydrologic model to help manage the ecology of this altered hydrologic system.

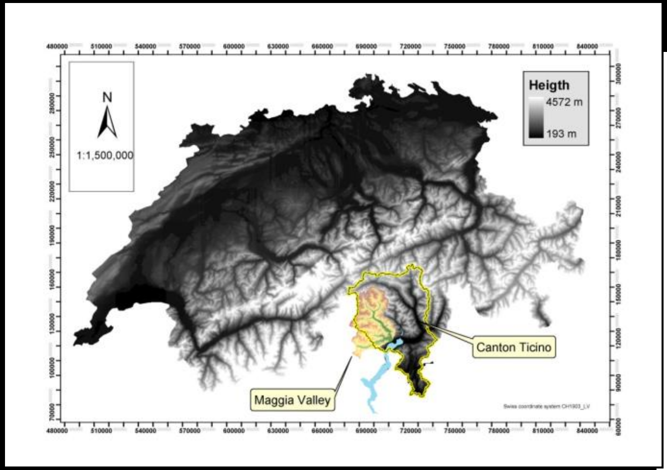
Foglia 2007, 2009, 2013

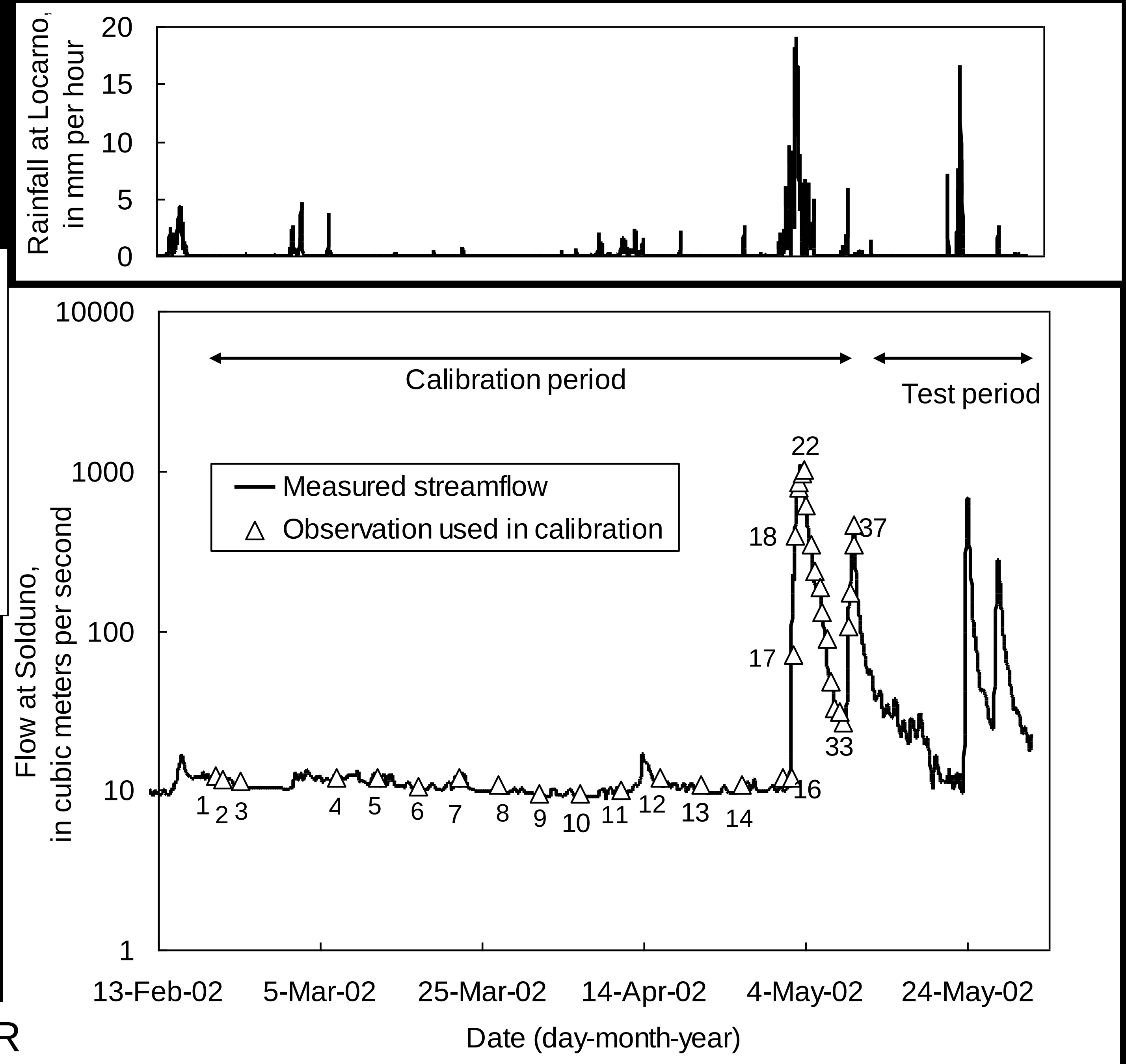
Maggia Valley, southern Switzerland

Series of studies to identify and test a useful, computationally frugal protocol with which to develop the eventual integrated hydrologic model, which will be computationally demanding. Use the component surface and groundwater models for the tests.

1. Test frugal sensitivity analysis (SA) using cross-validation
   - Foglia + 2007 Ground Water
2. Demonstrate frugal optimal calibration method
   - Rainfall-Runoff model (Foglia + 2009 WRR)
3. Test of how well AIC, AICc, BIC, KIC identify models with good predictive ability using cross validation
   - Use SA and calibration methods (Foglia + 2013 WRR)

Maggia Valley, Switzerland



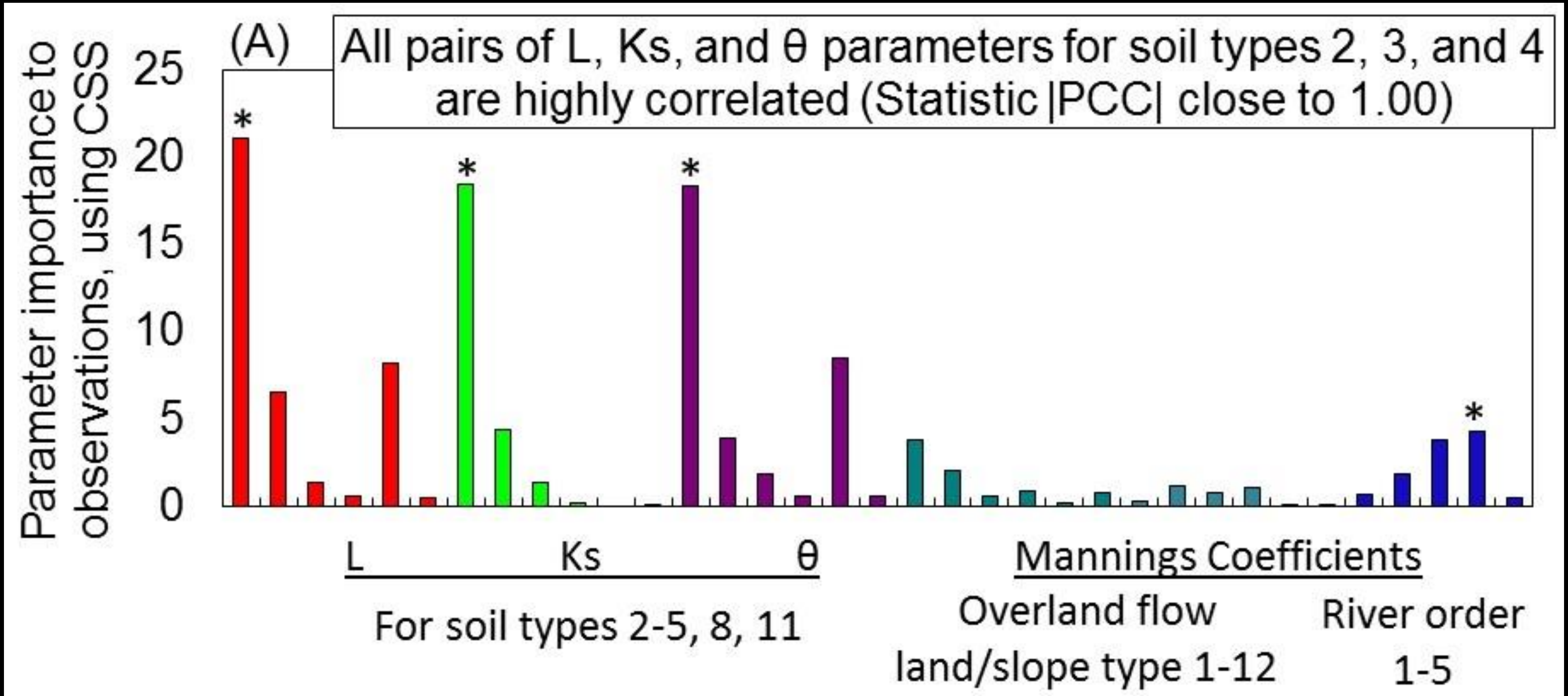


Foglia + 2009 WRR

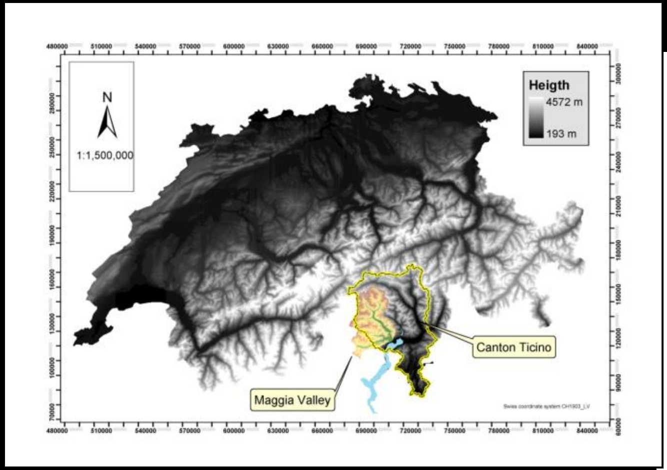
Which parameters are important and unimportant?

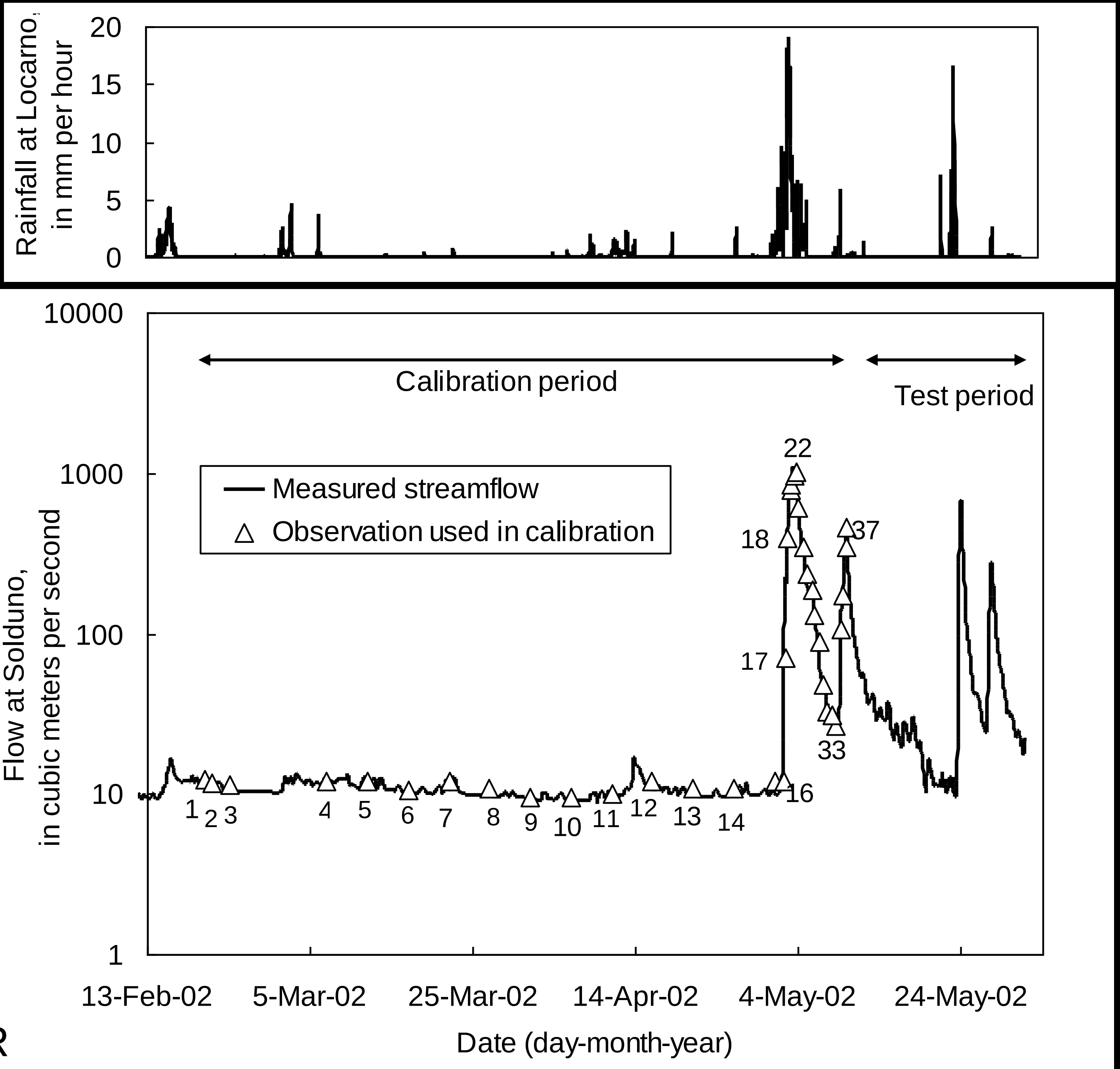
High bars indicate important parameters

Learned something! Only a few parameters are important and they cannot all be estimated because of parameter interdependence.



Maggia Valley, Switzerland



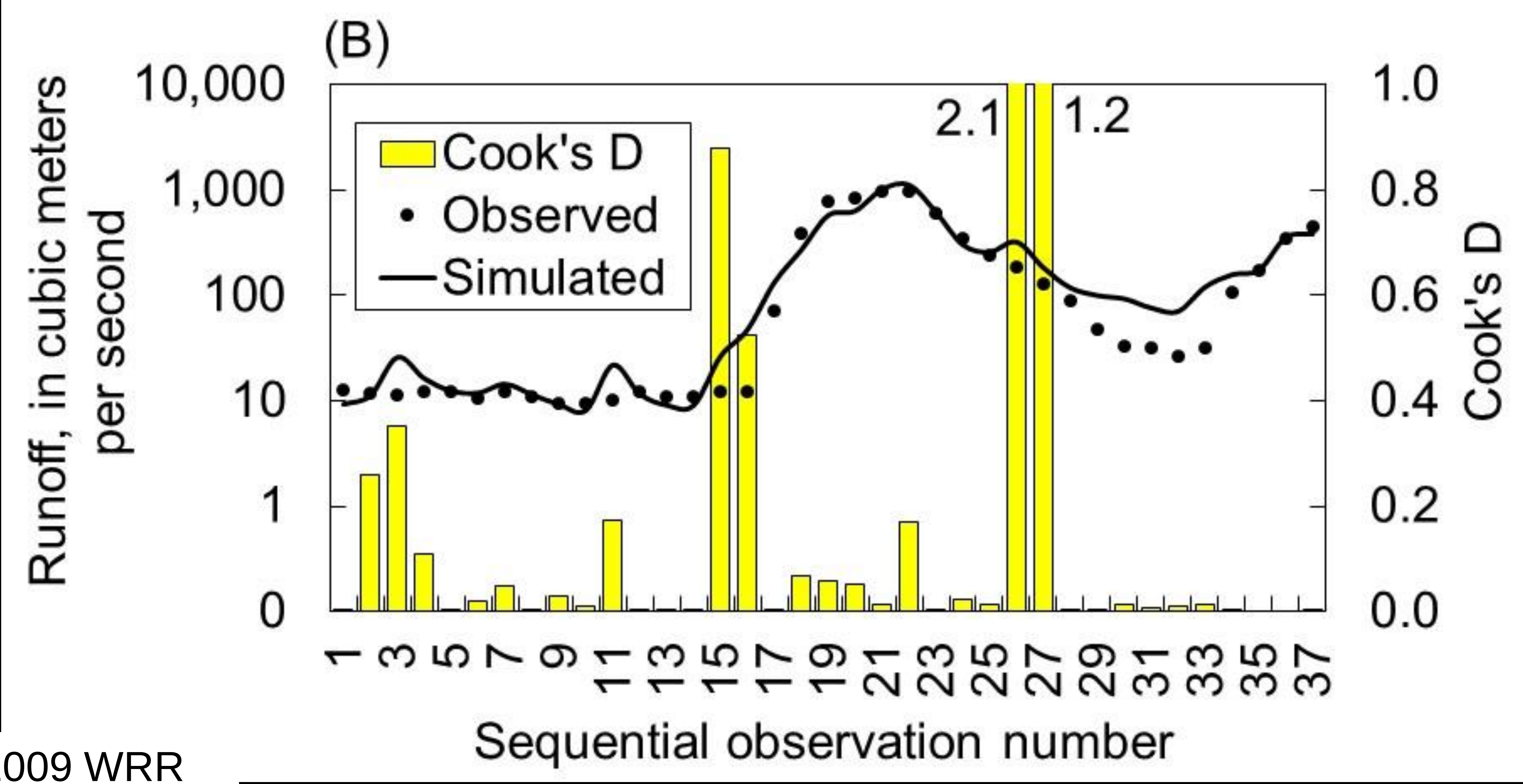


Foglia + 2009 WRR

Which observations are important and unimportant?

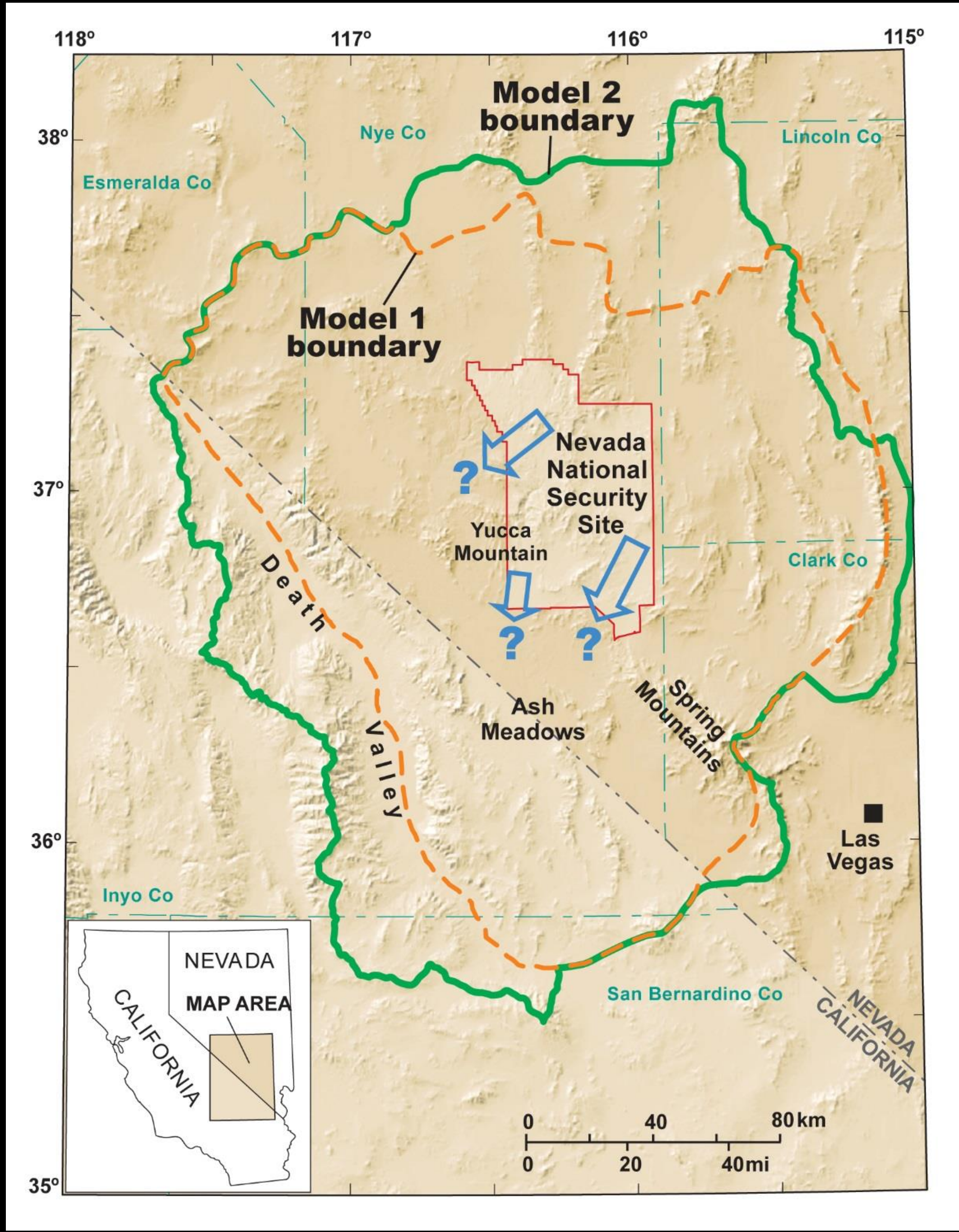
High bars indicate important parameters

Learned something!
Assumed dominance of flows during peak are incorrect. Resample low flows.



Foglia + 2009 WRR

Death Valley regional flow system



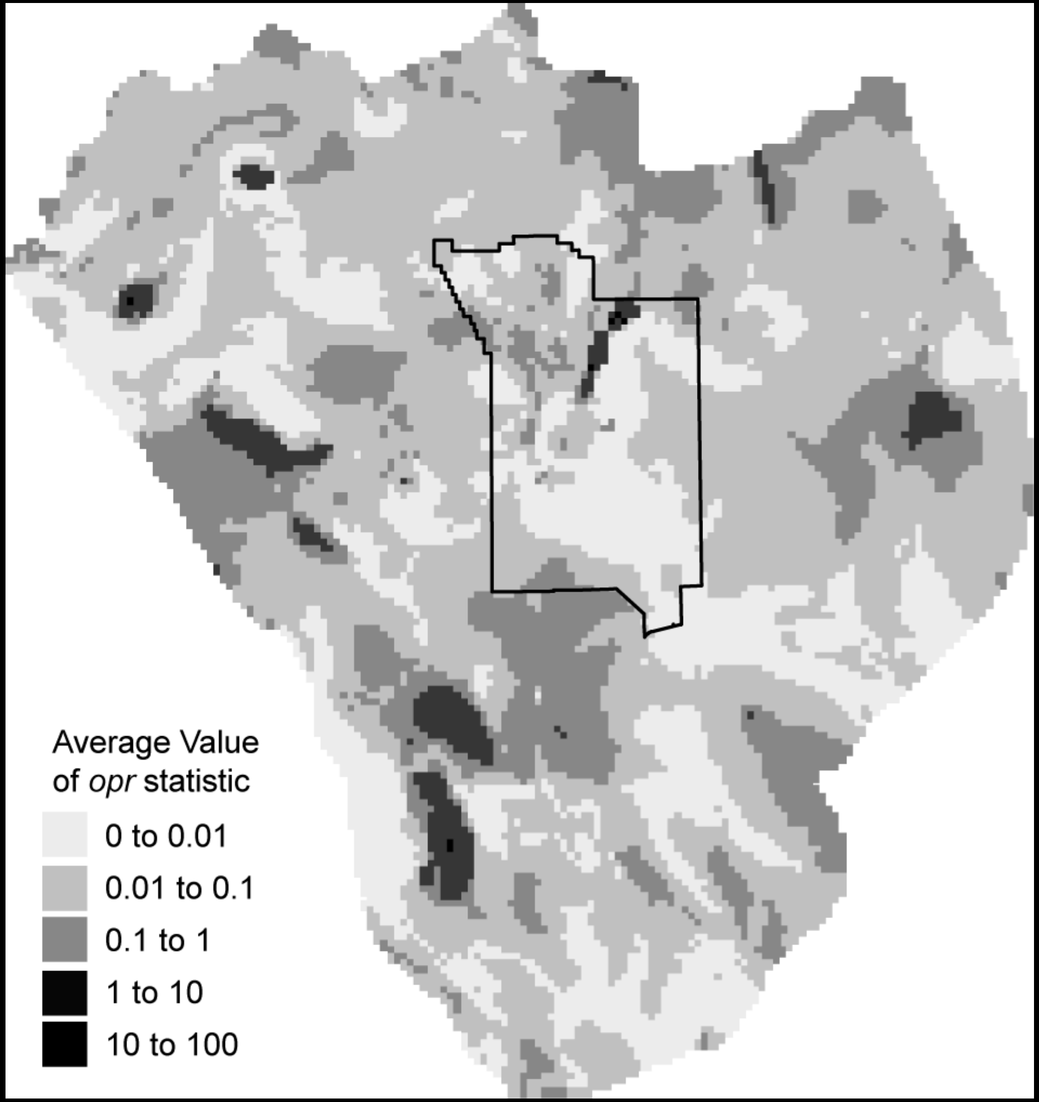
What new observations would be important (or not) to predictions?

Consider one potential new head observation in each cell of model layer 1.

Determine weights for the potential observations.

Here, same weighting strategy used as for weighting existing observations – weights smaller for heads in high-gradient areas.

Calculate **$opr_{(+1)}$** for each cell in the layer, even those with an existing observation, so that **$opr_{(+1)}$** is continuous over the whole map.



Hill and Tiedeman, 2007, fig. 15.10. p. 369

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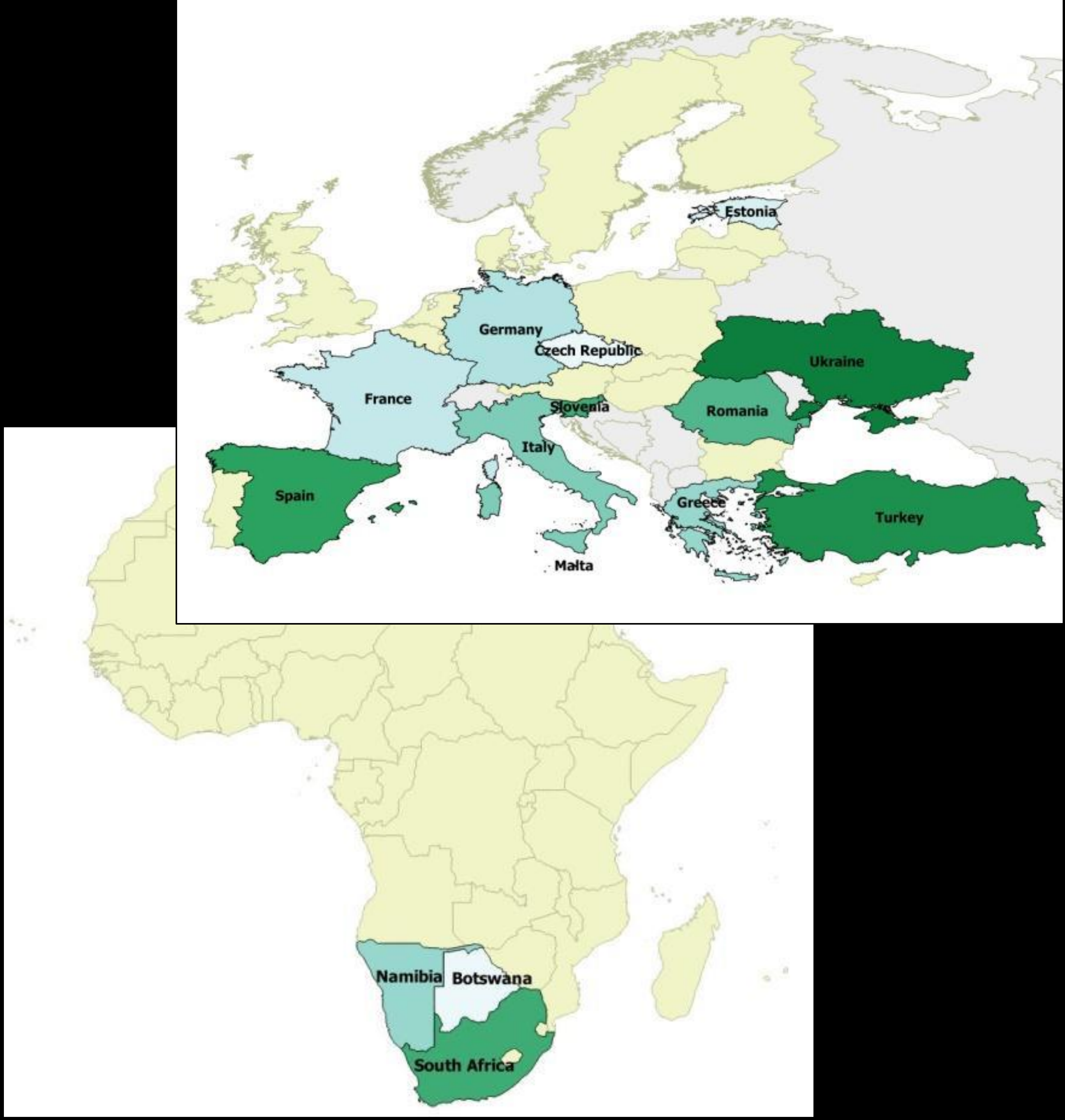
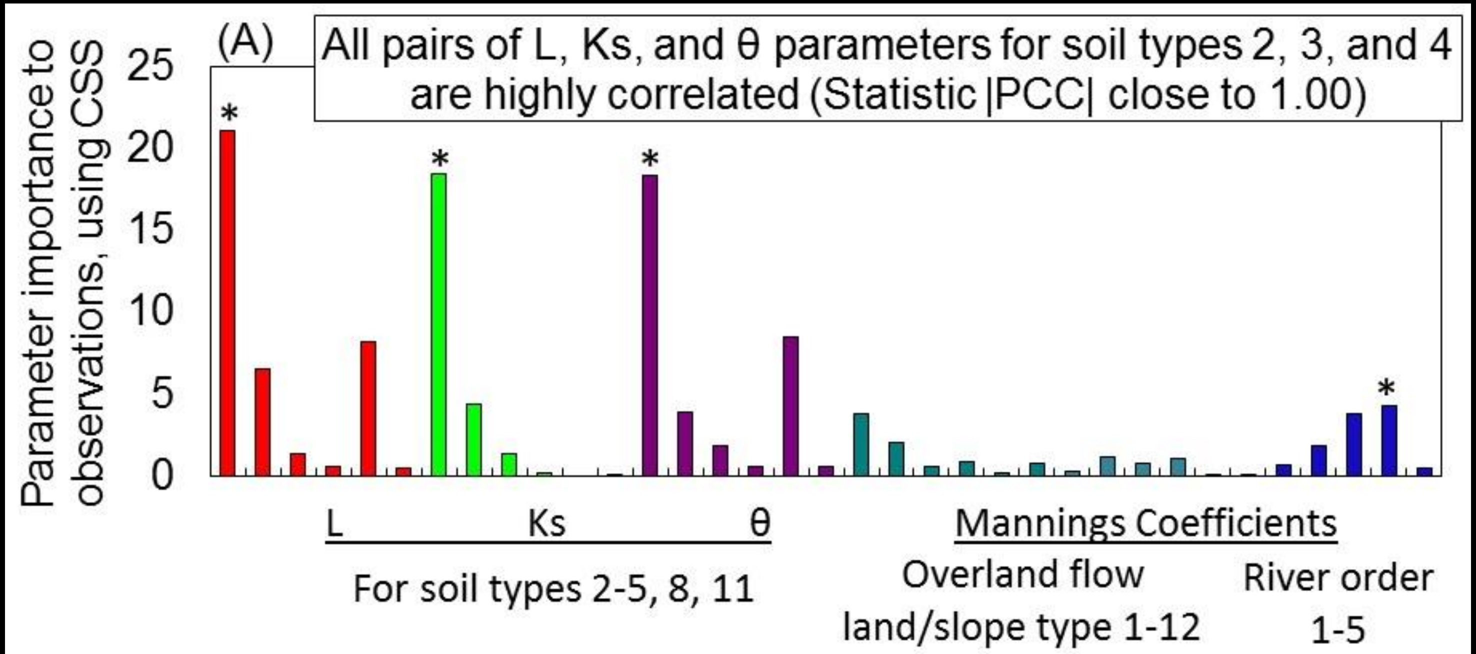
- Opinions
  - Learn more from models by using convenient sensitivity analysis and uncertainty quantification methods
  - Hill et al 2015 Ground Water

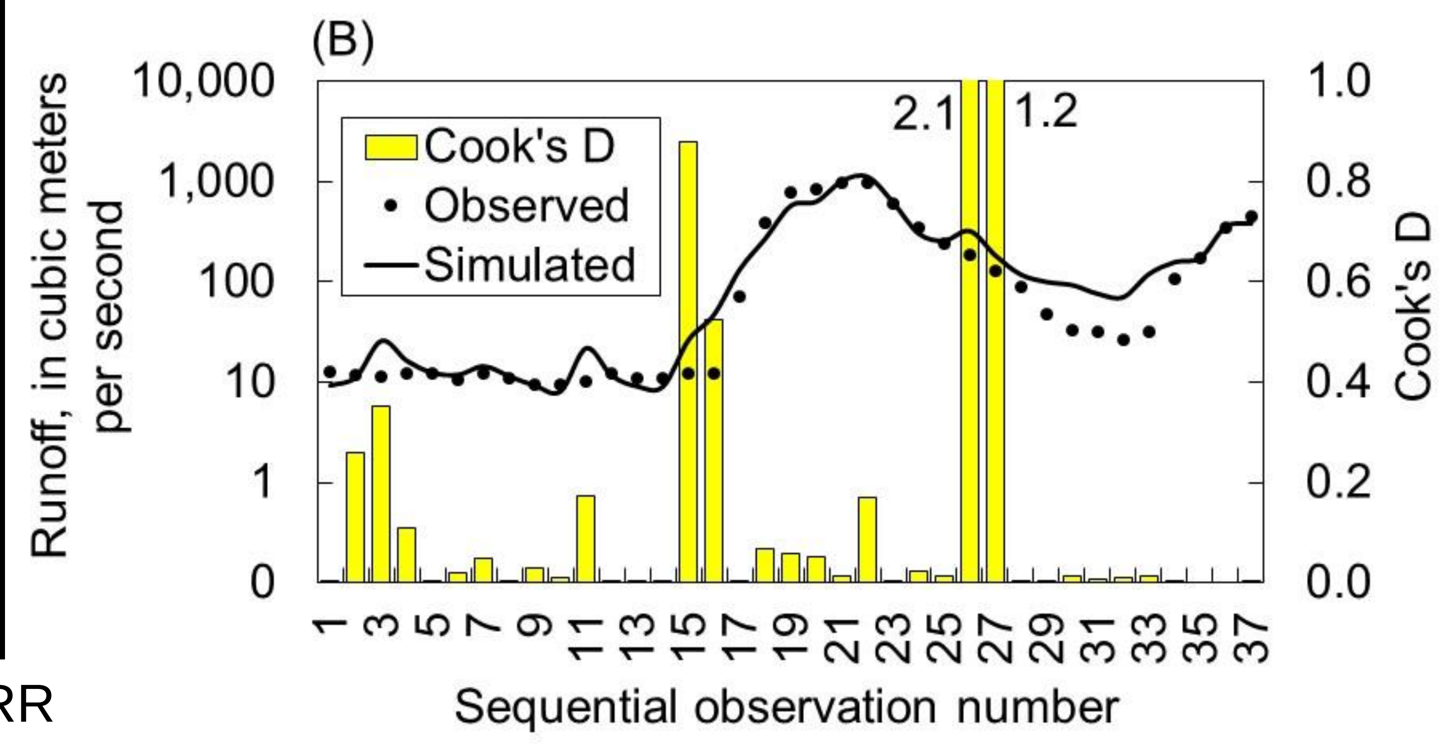
FREEWAT

- An exciting new EU program that will allow more to be learned from a set of existing constructed models and provide approaches and tools for the future.



71 highly parallelizable model runs





Foglia + 2009 WRR

Test Case

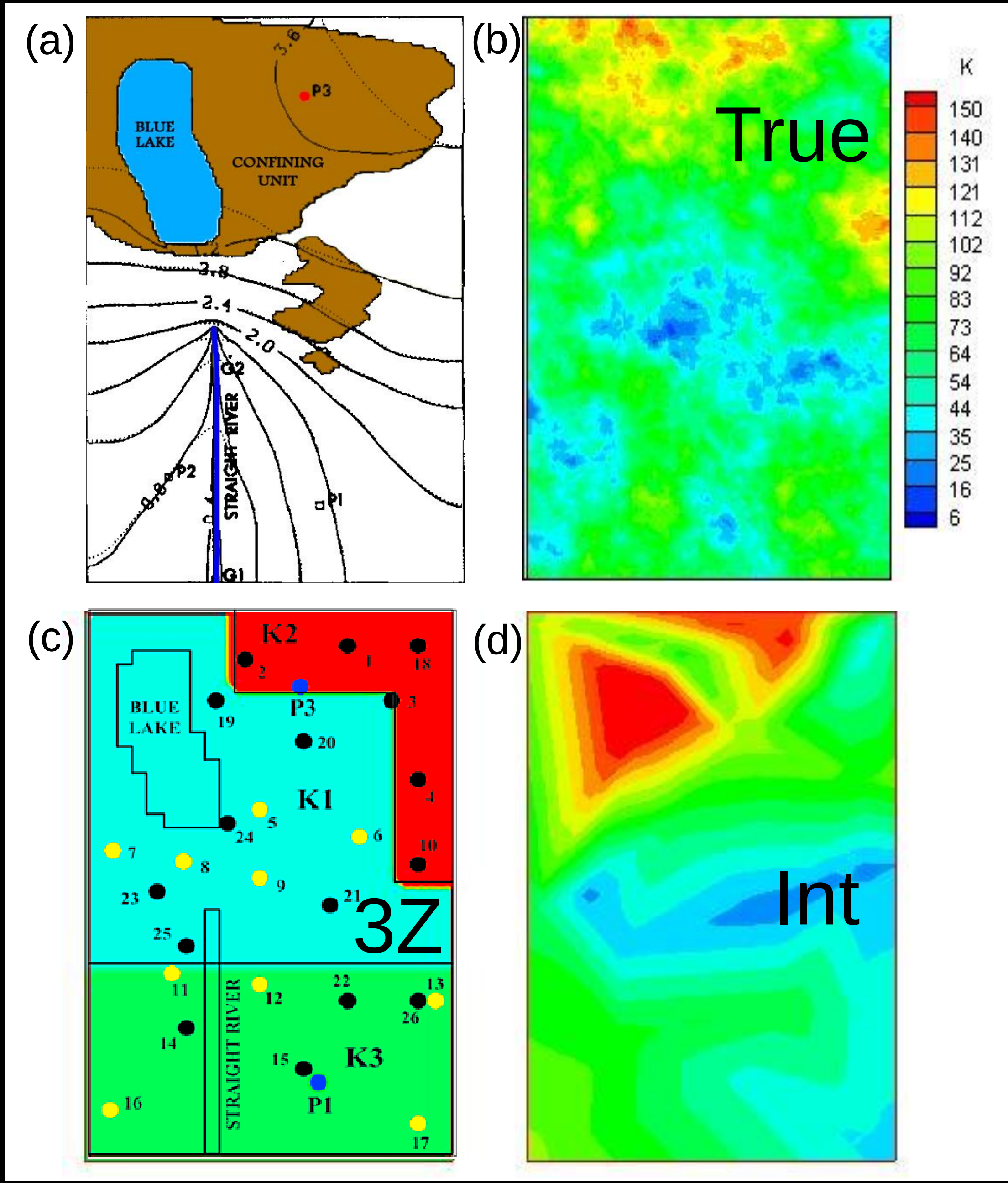
- Use simple test cases to understand
- Models vary in how the spatially distributed parameter K is represented.

HO: homogeneous

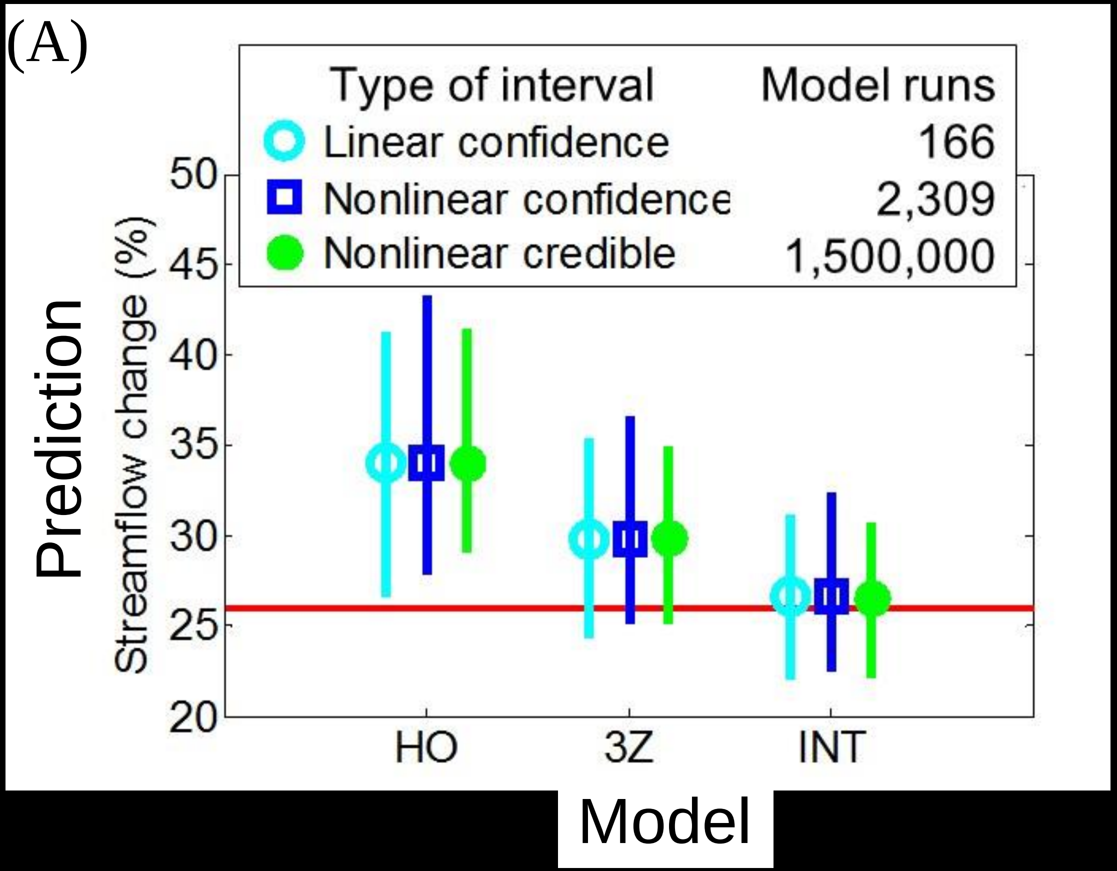
3Z: 3 zones

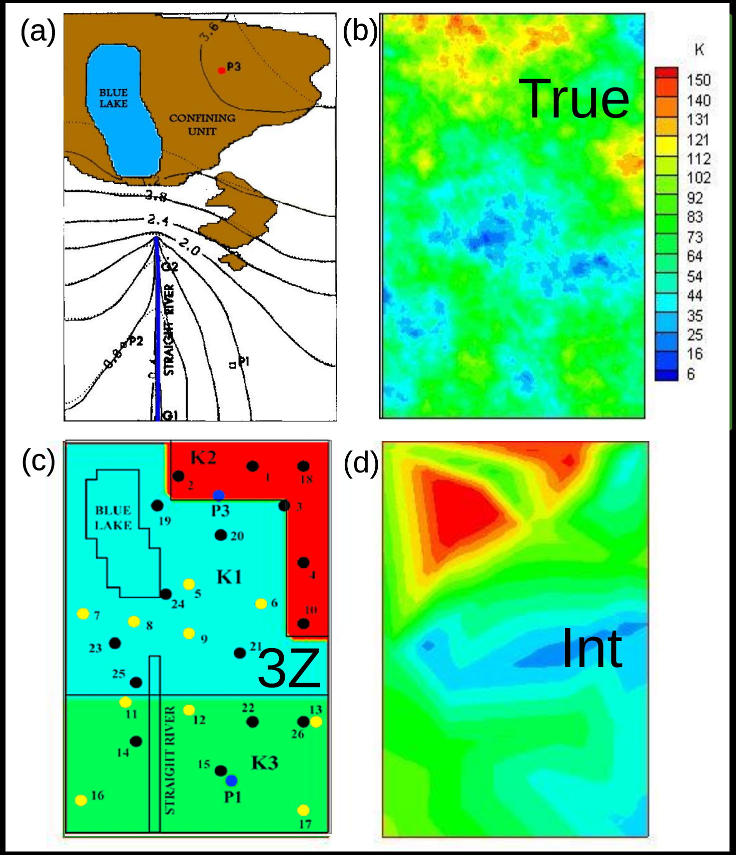
INT: interpolated

Predict flow to stream under pumping conditions



Regression and Bayesian uncertainty intervals for a groundwater investigation

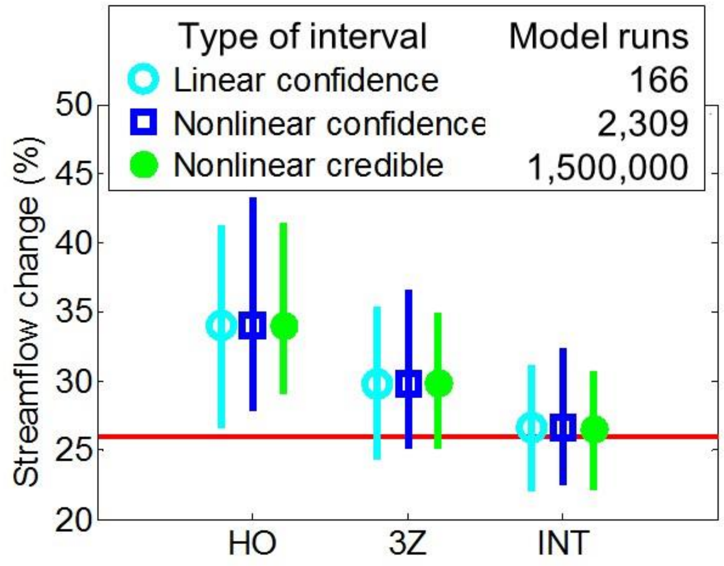




Lu et al. 2012 Water Resources Research

Diagnostic Tests for Computationally Frugal Methods

(A)



(B)

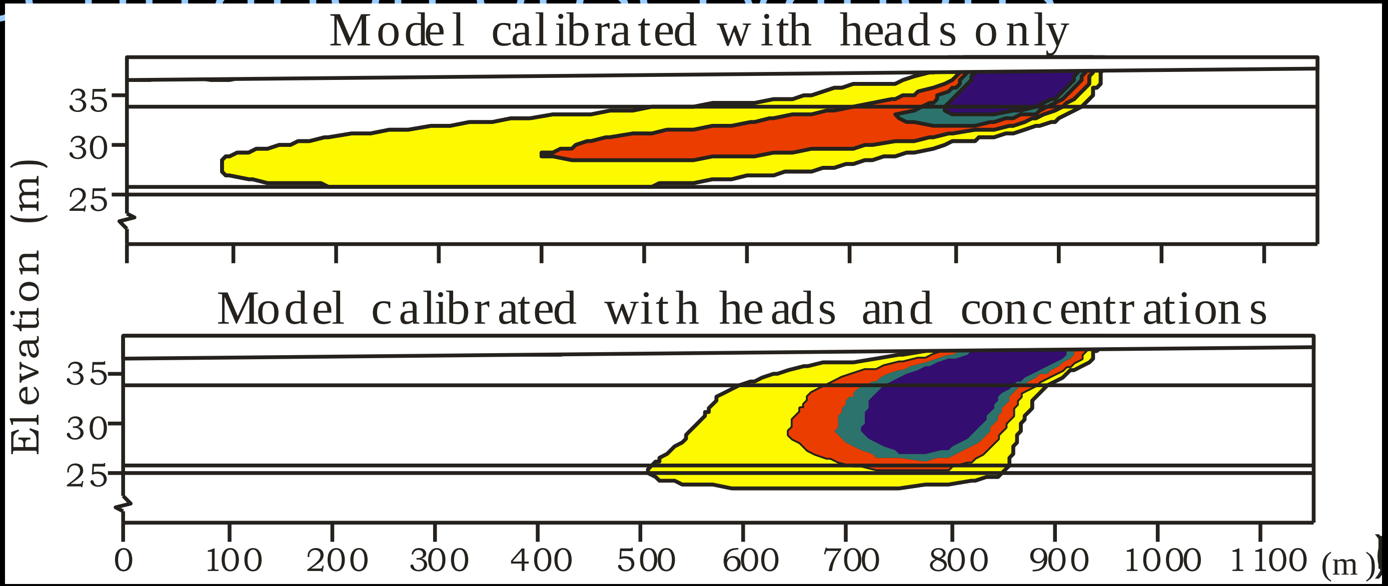
	Model	
HO	3Z	INT
Test model adequacy using $s_{(n-p)}^2$		
1.49 (1.25-1.84)	1.27 (1.06-1.57)	1.05 (0.88-1.30)
Test model linearity using intrinsic nonlinearity		
0.54	0.04	0.18
Test for Gaussian independent weighted residuals using		
0.989(0.96)	0.986(0.96)	0.989(0.97)

Model runs
to understand model results

Calibration with heads only and with concentration observations

Here, explore what difference does one type of observation make to predictions?

Plume lengths differ by a about a factor of 2.



Barlebo Hill Rosbjerg Jensen 1998 Nordic Hydrology