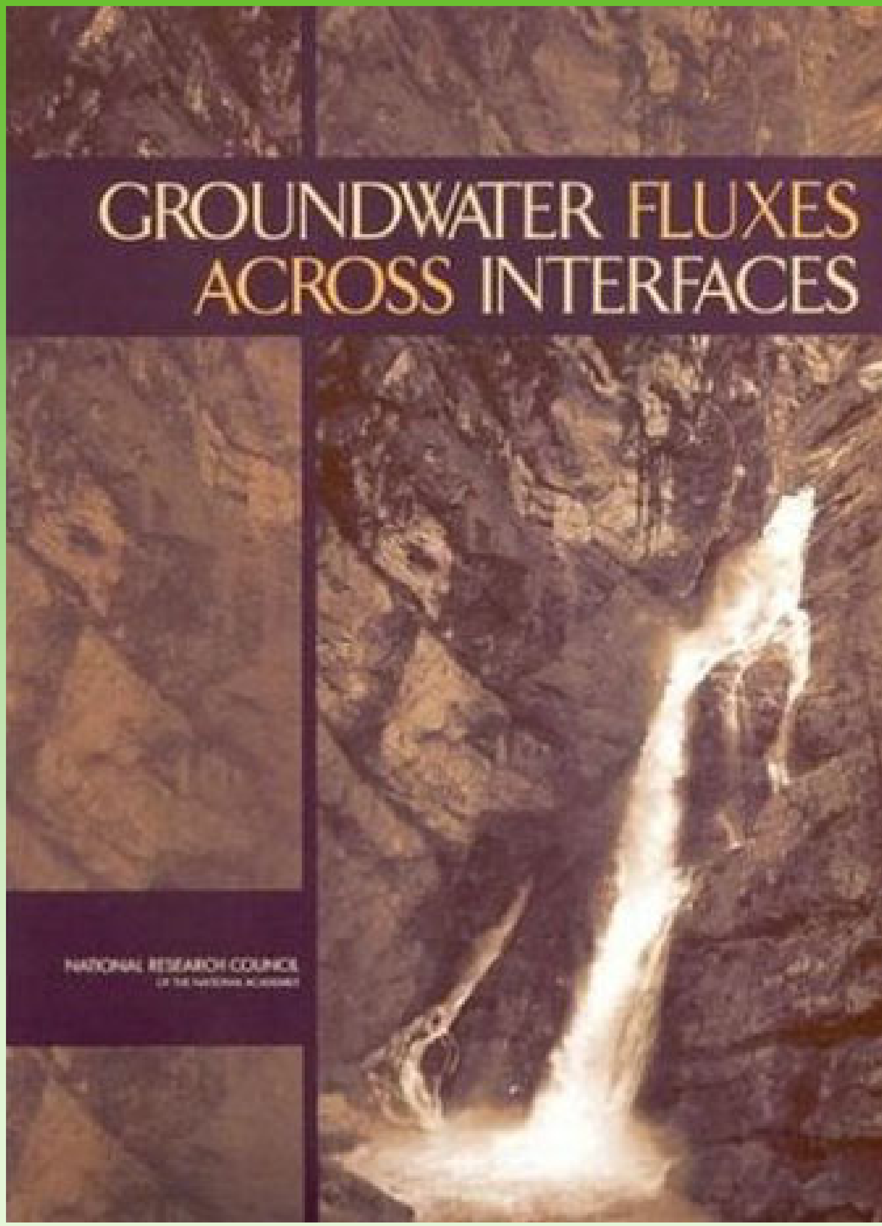
Groundwater-surface-water-atmosphere interactions

Research at the sediment-water interface

Don Rosenberry
USGS, Denver

NRC Committee – New/recent challenges



COMMITTEE ON HYDROLOGIC SCIENCE[1]

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National Research Council Major Findings

1. Our ability to quantify spatial and temporal variability in recharge and discharge is inadequate and must be improved.
2. The roles of groundwater storage, and recharge and discharge fluxes in the climate system are poorly understood.
3. Better measurements are needed as well as better ways to scale measurements

NRC 2004

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NRC No. 1
Spatial and temporal variability

- Establish experimental benchmark sites (watersheds) where measurement techniques and understanding of processes can be improved
  - Sites should include a wide range of geologic, climatic, and landscape types
  - Sites should be integrated with existing experimental watersheds
- Initiate a workshop to guide development of scientific and implementation plans for establishment of benchmark sites

NRC 2004

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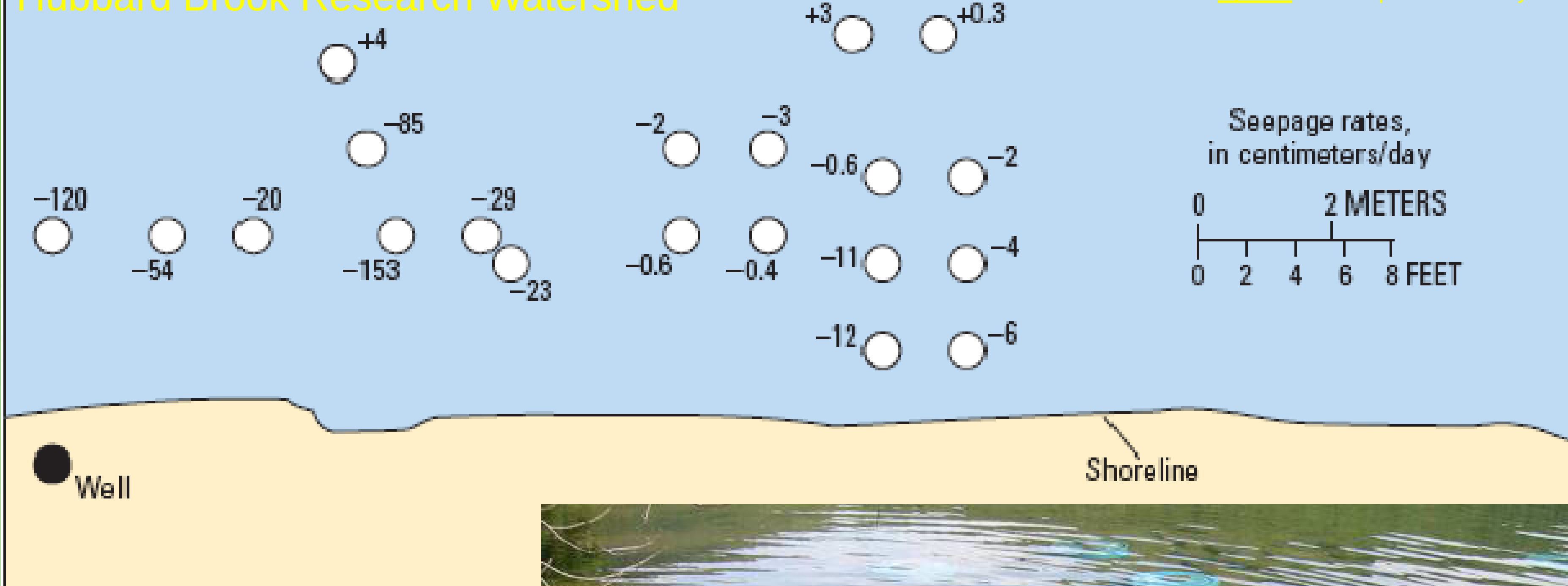
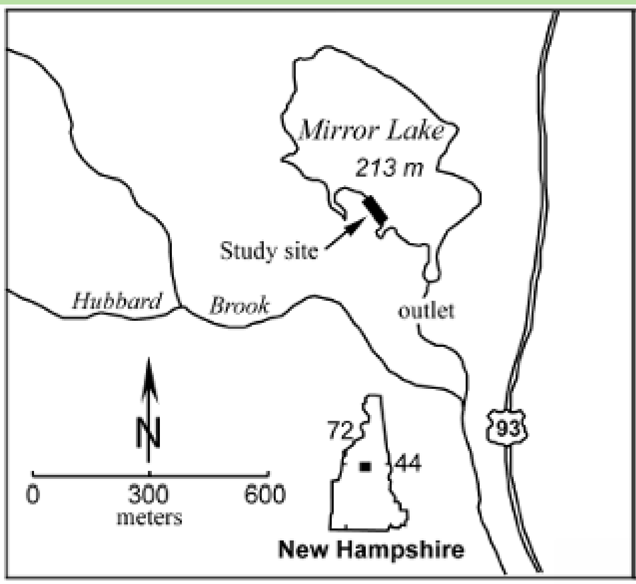
Hubbard Brook Research Watershed

Spatial and temporal variability





Rosenberry, 2005, *Limnology and Oceanography-Methods*.

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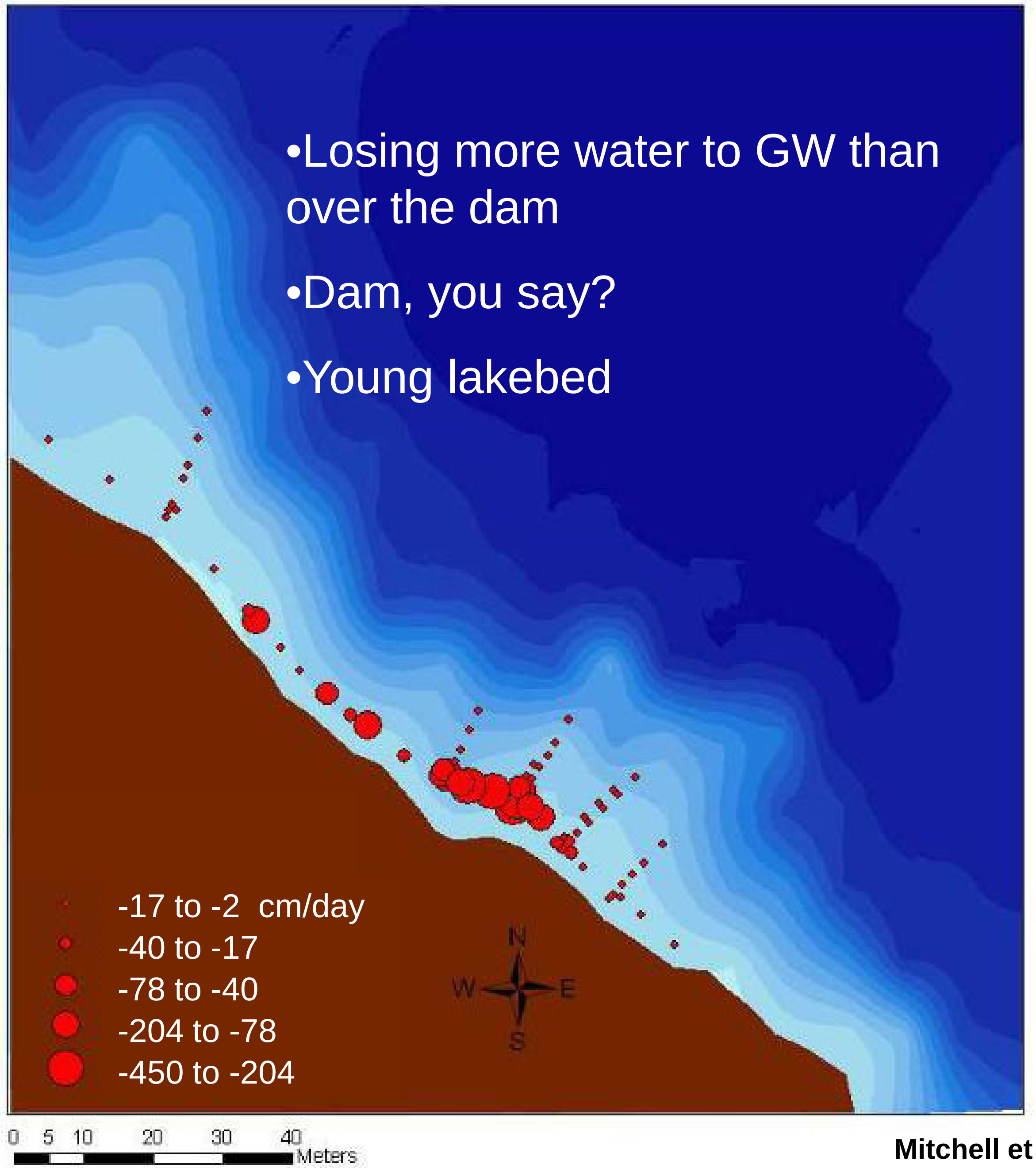
Rosenberry, 2005, *Limnology and Oceanography-Methods*.

Spatial variability

Southwest Shore Seepage Rates and Bathymetry
Mirror Lake, NH

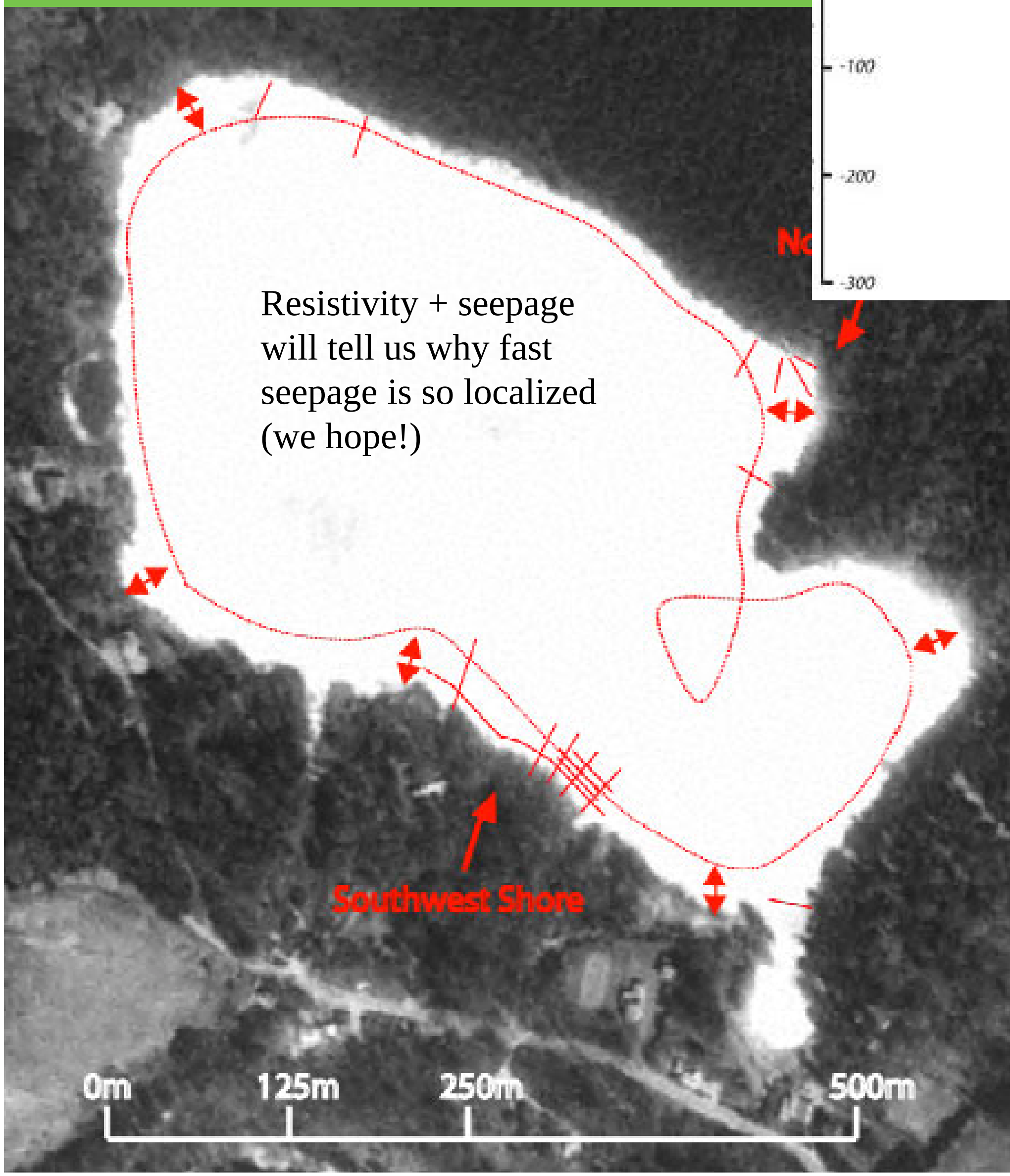
- Losing more water to GW than over the dam
- Dam, you say?
- Young lakebed



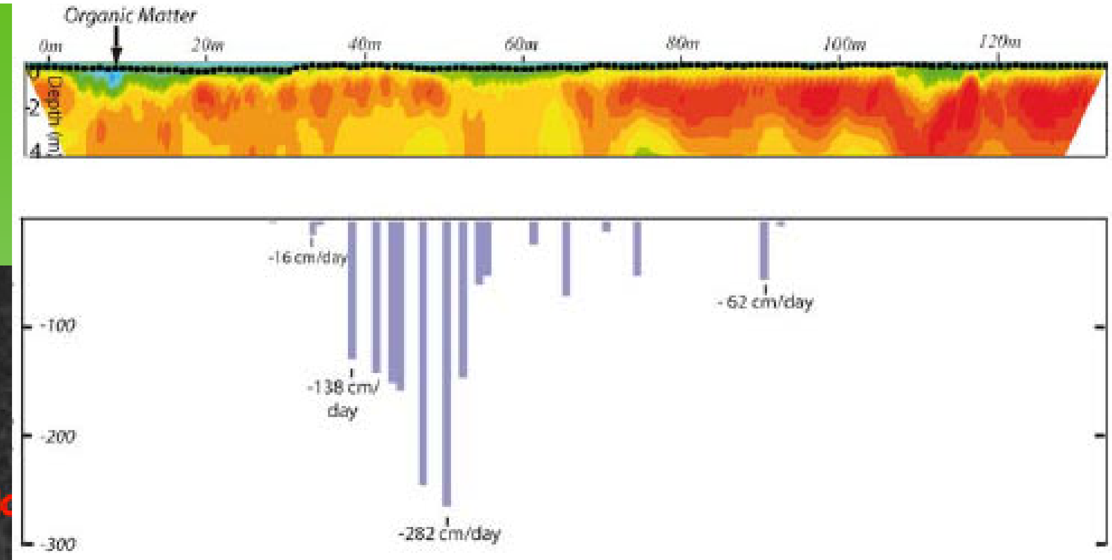
Mitchell et al., 2008, *SAGEEP*

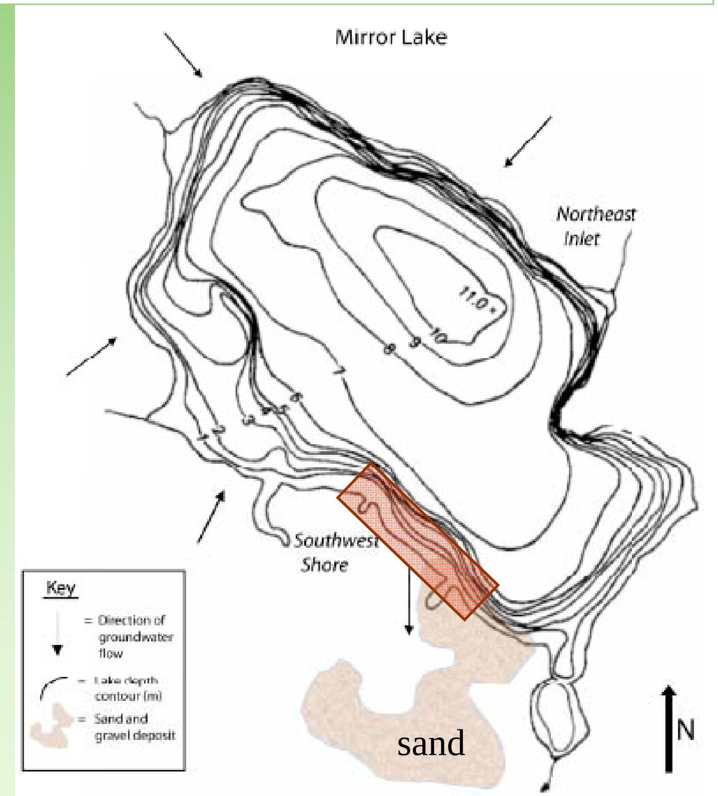
But why here?

Relate seepage to geology



Resistivity + seepage will tell us why fast seepage is so localized (we hope!)

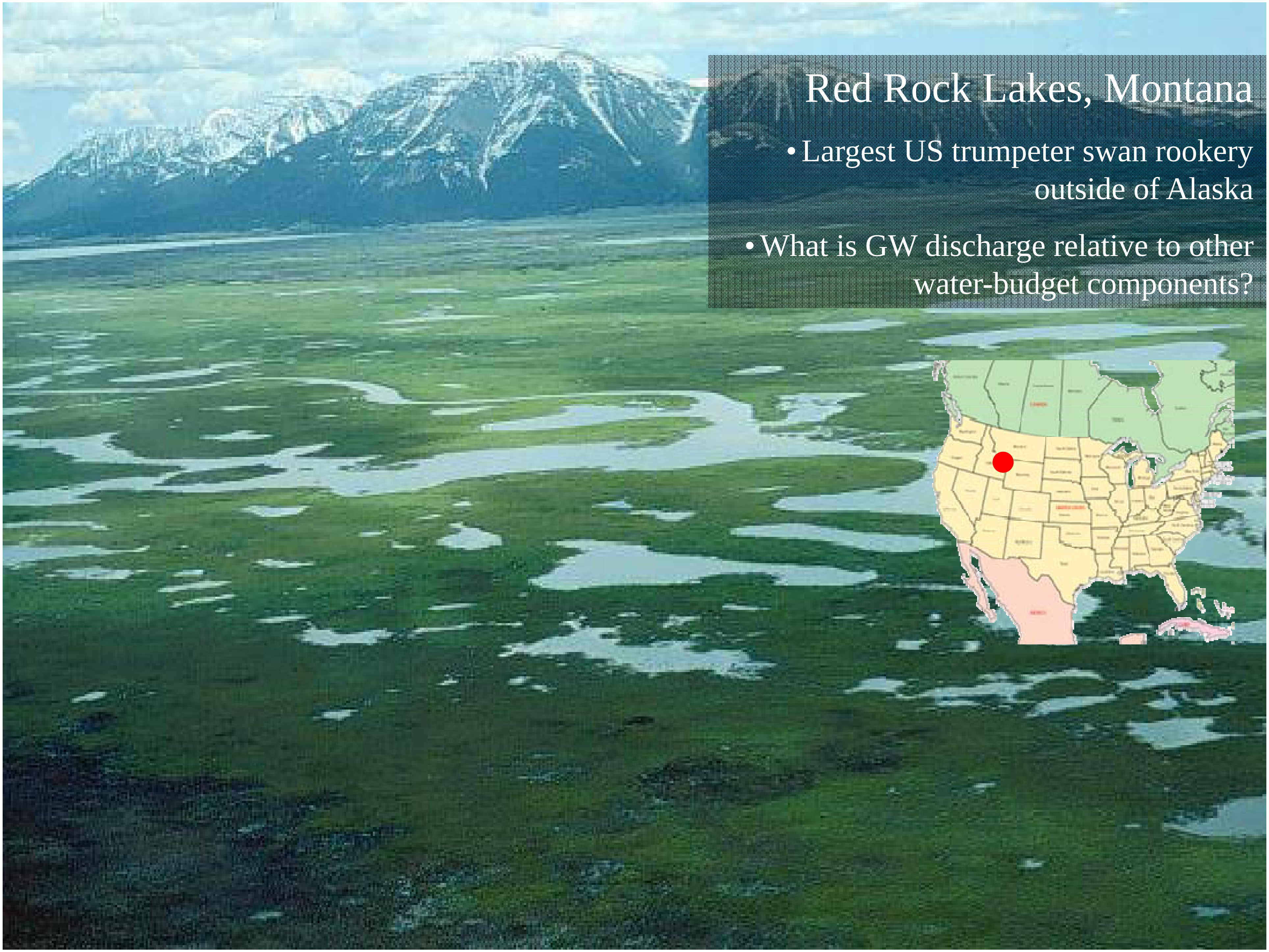




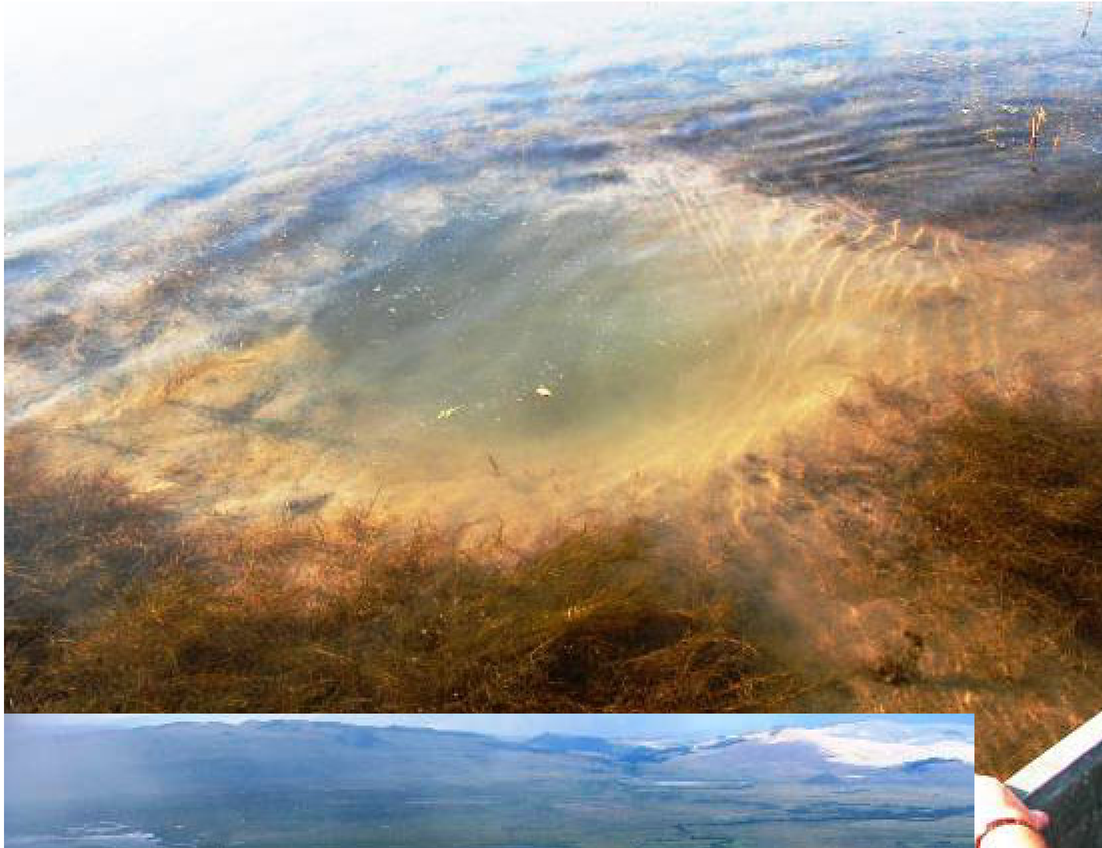
Mitchell et al., 2008, *SAGEEP*

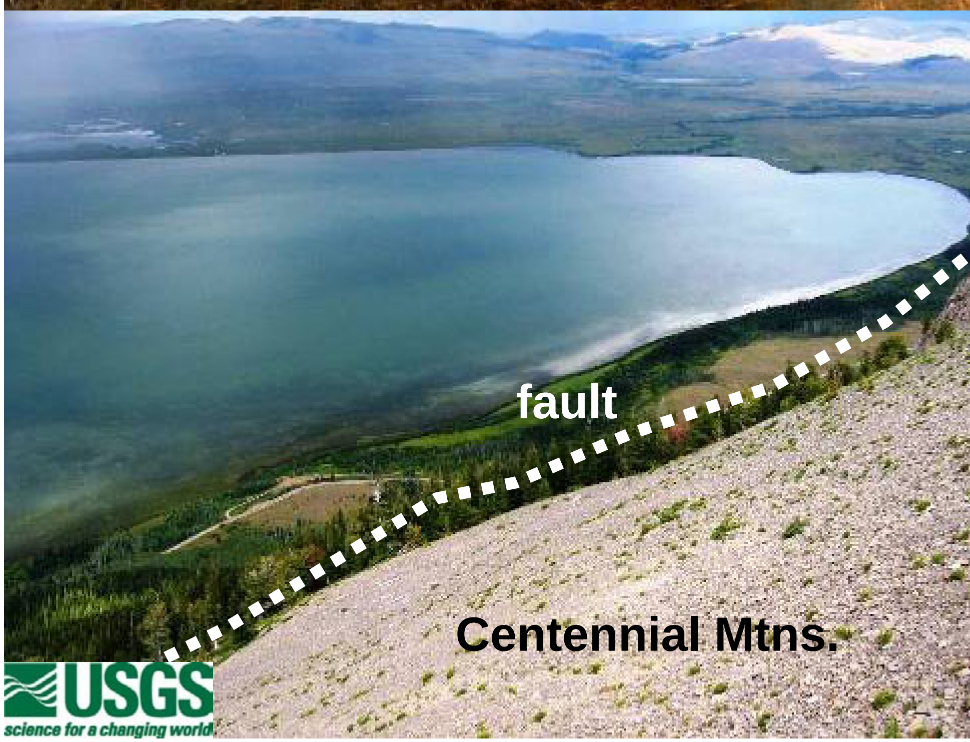
Red Rock Lakes, Montana

- Largest US trumpeter swan rookery outside of Alaska
- What is GW discharge relative to other water-budget components?

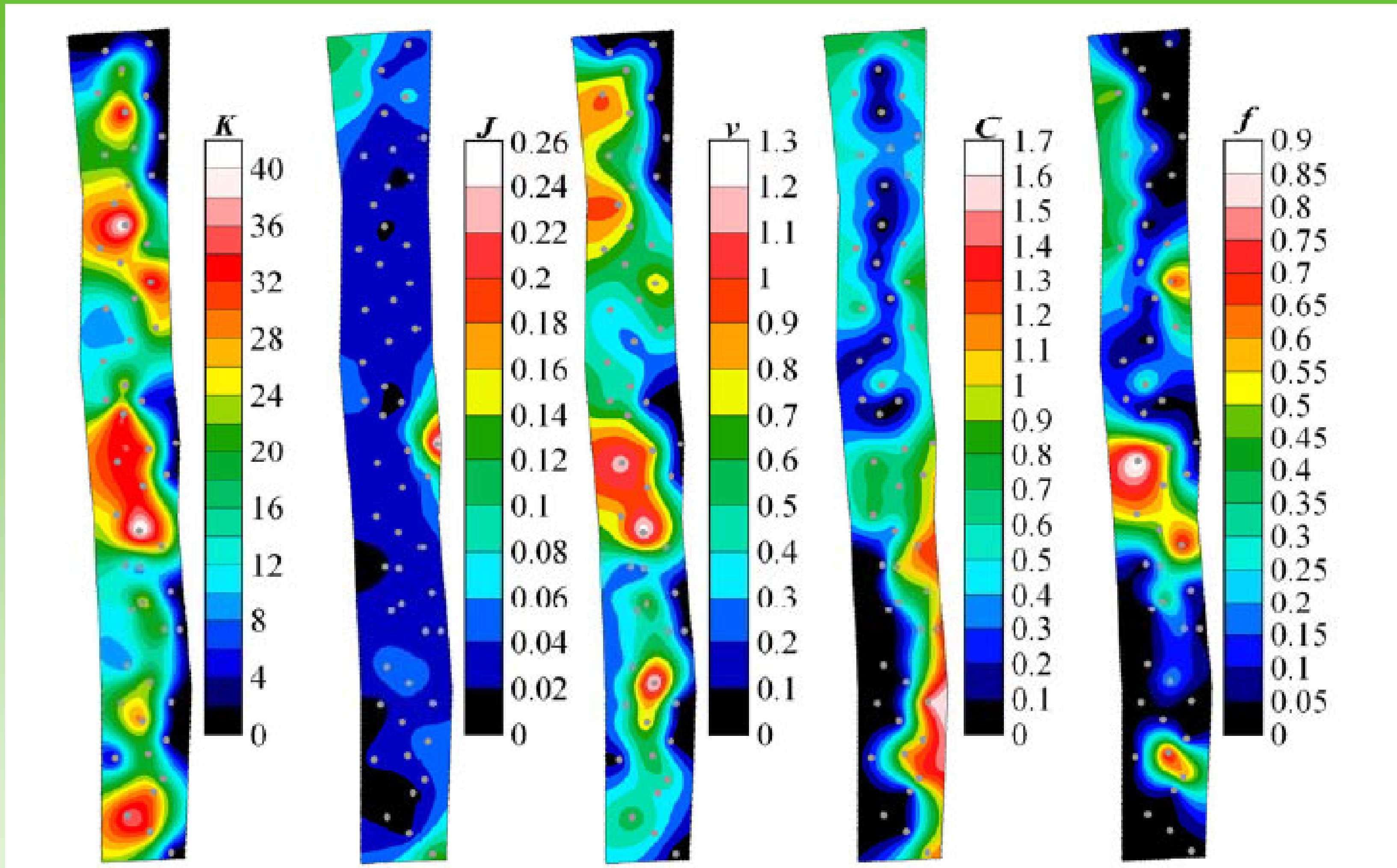


Spatial variability





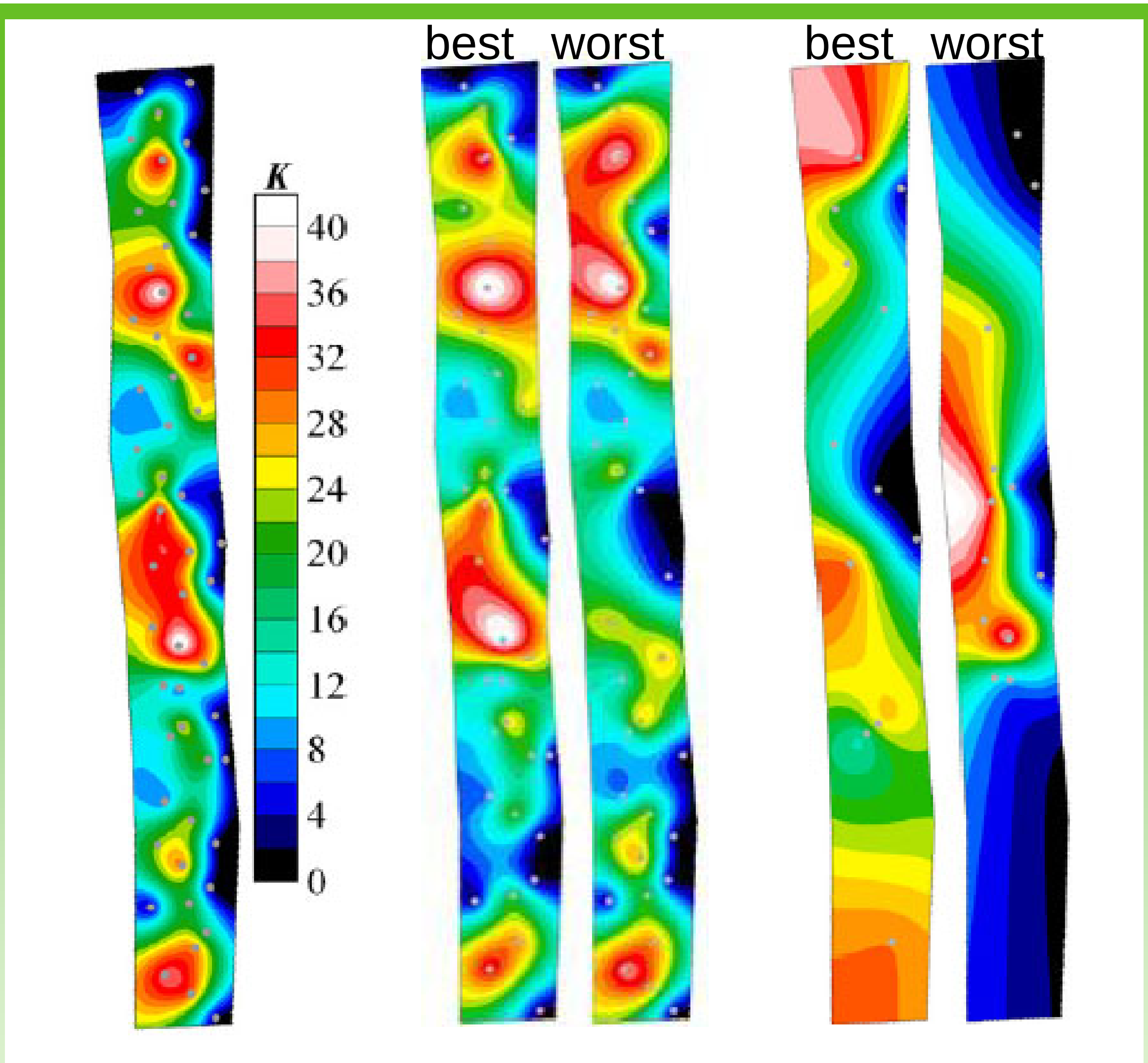
West Bear Creek, North Carolina



54 meas. locs.

K = hydraulic conductivity
J = hydraulic gradient
v = seepage velocity
C = nitrate concentration
f = nitrate seepage flux

Kennedy et al., 2008, *Journal of Hydrology*



54 meas points "true" meas.
36 meas points
12 meas points

Best and worst of 120 alternate maps based on random sub-sampling distrubutions

Kennedy et al., 2008, *Journal of Hydrology*

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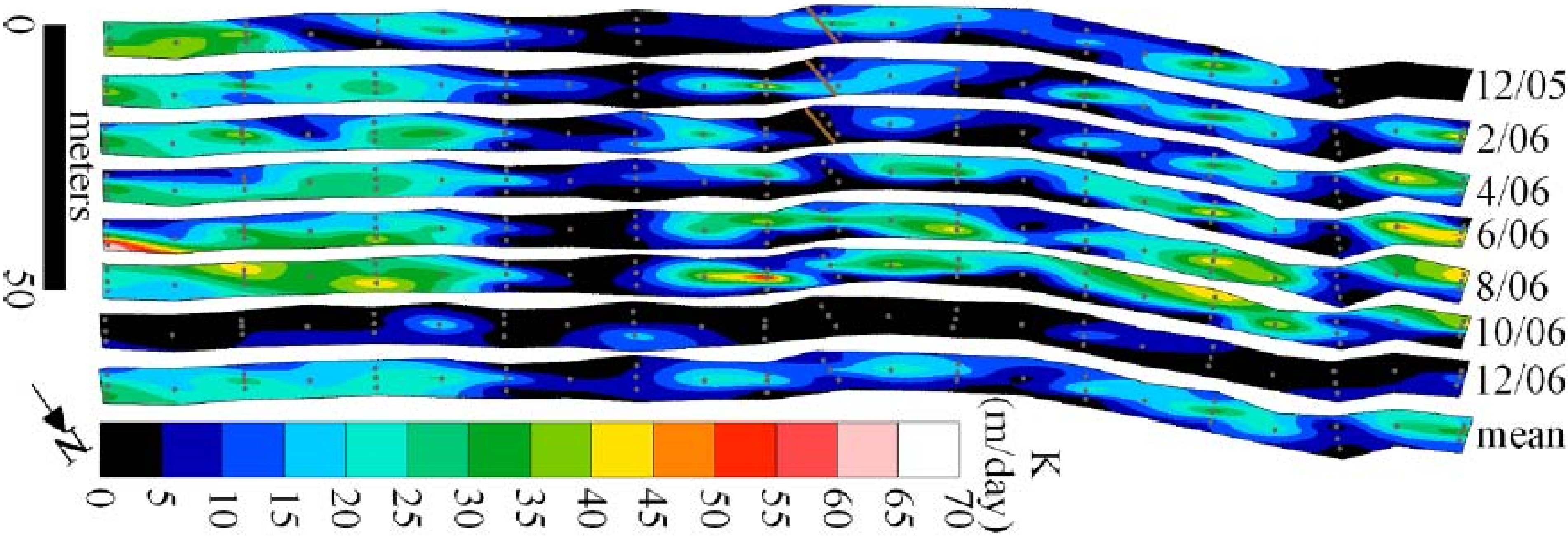
Seasonal

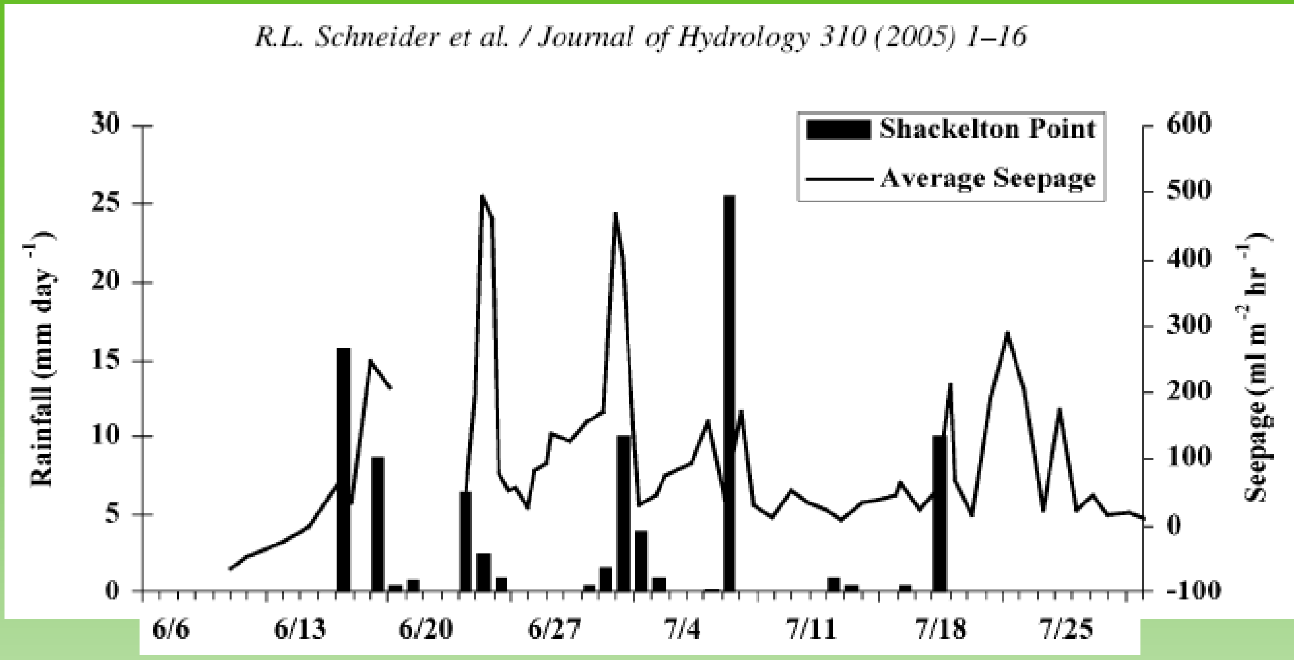
West Bear Creek, North Carolina

flow

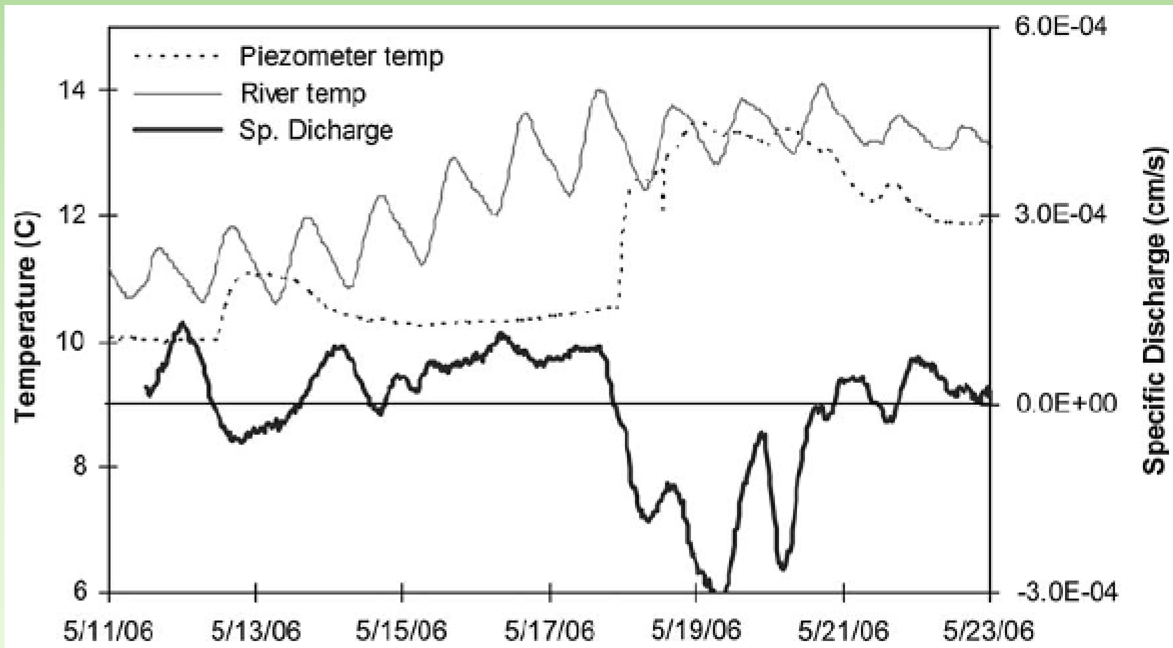


Genereux et al., 2008, *Journal of Hydrology*

Weekly to daily

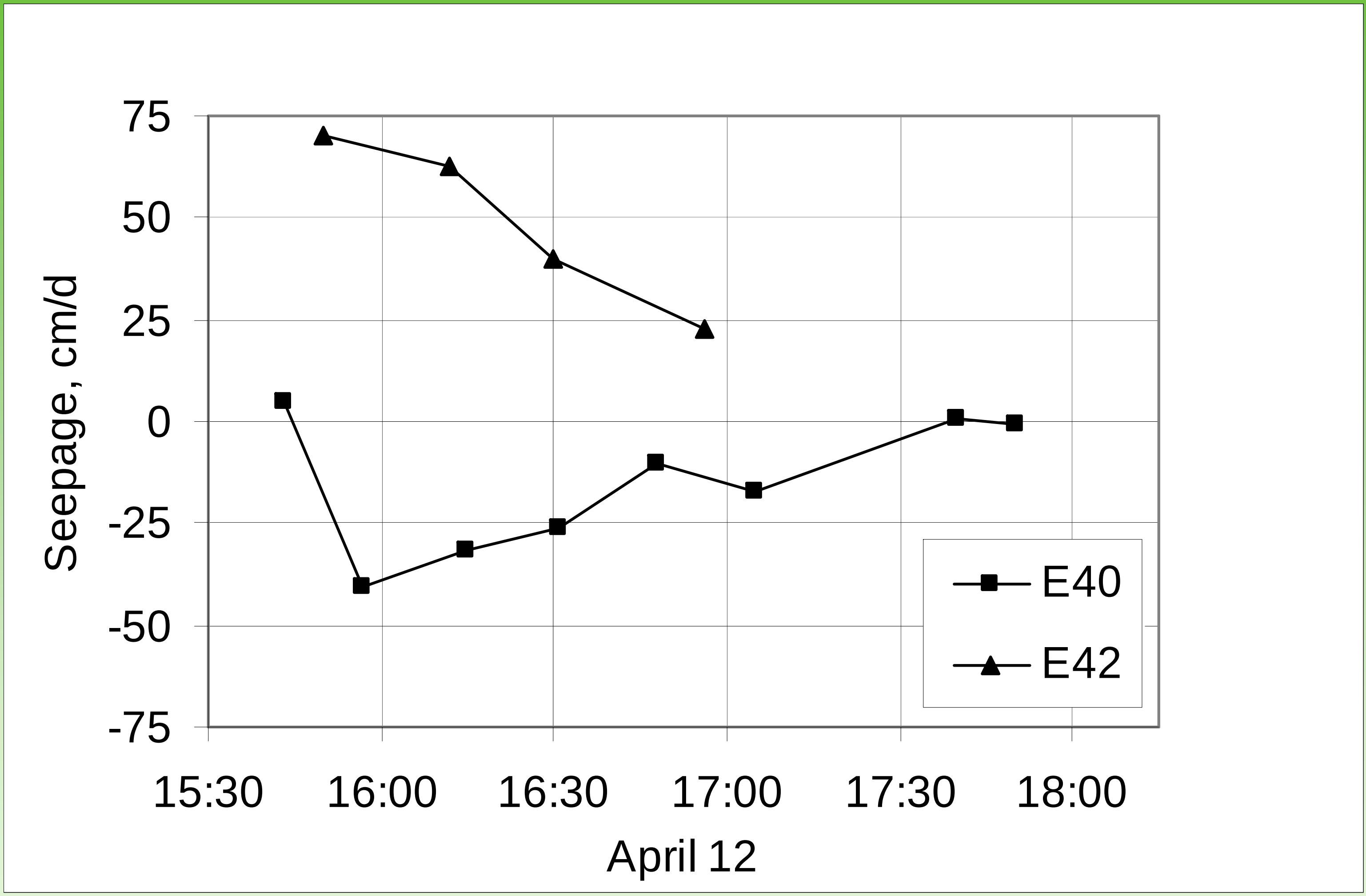


Hanford, WA



Fritz et al., 2009, *Ground Water*

Hourly



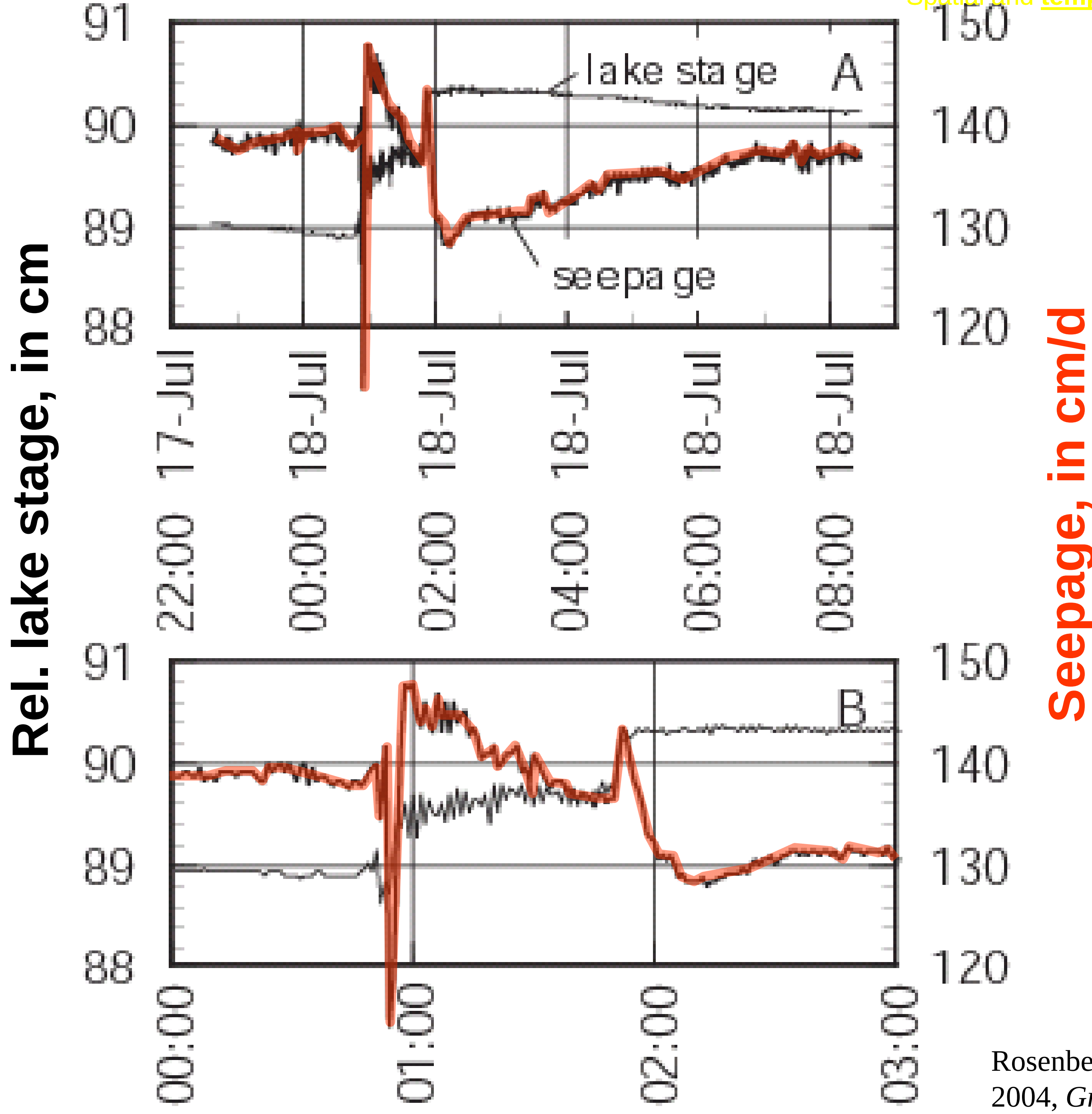
Rosenberry, 2008, *Journal of Hydrology*

- $5 to $50 per measurement
- Time

Spatial and **temporal** variability

Minute by minute

$3 to $7 per meas.

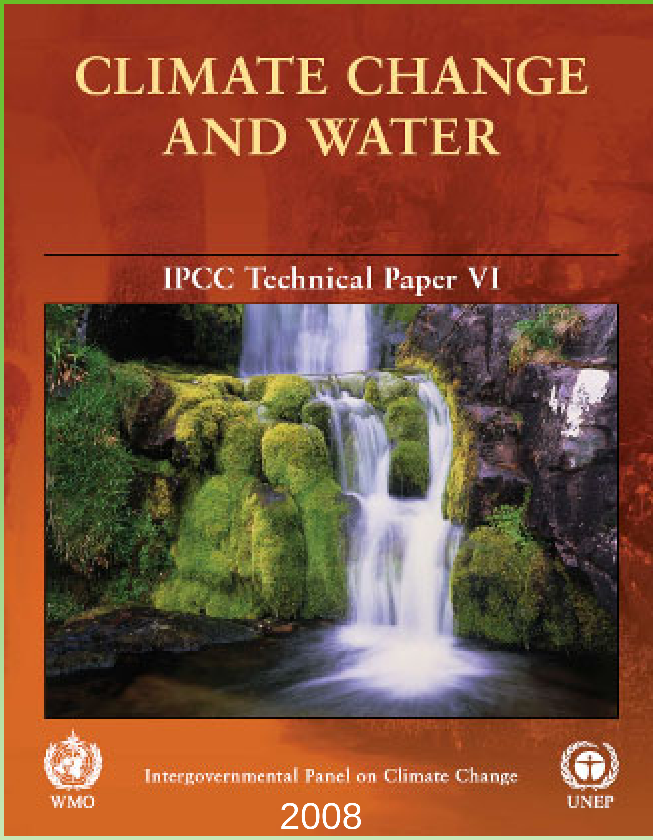


Rosenberry & Morin, 2004, *Ground Water*

NRC No. 2
Groundwater and climate change

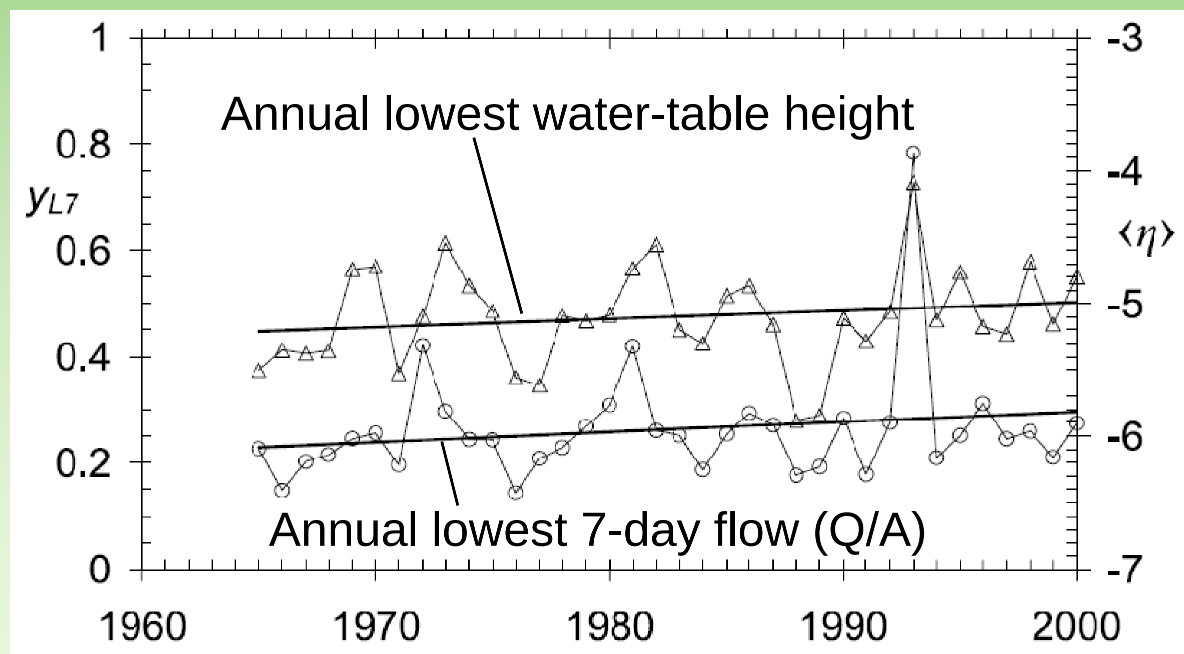
- Look at long-term fluctuations in GW relative to climate indicators (in undisturbed areas)
  - GW is the largest reservoir of fresh water in the hydrologic cycle
- Better represent GW in climate models
  - More realistic storage parameters
  - GW uptake by vegetation
  - Fluxes to (and from) lakes, wetlands, and streams
- Study the effects of human use of GW for water supply on climate
  - Regional, continental, global assessments of GW withdrawals
  - Assessments of wetlands drained
  - Link withdrawals and drainages with climate

NRC 2004



Numerous examples of relevance of groundwater to climate change and vice versa

Illinois and Rock Rivers



Brutsaert, 2008, *Water Resources Research*

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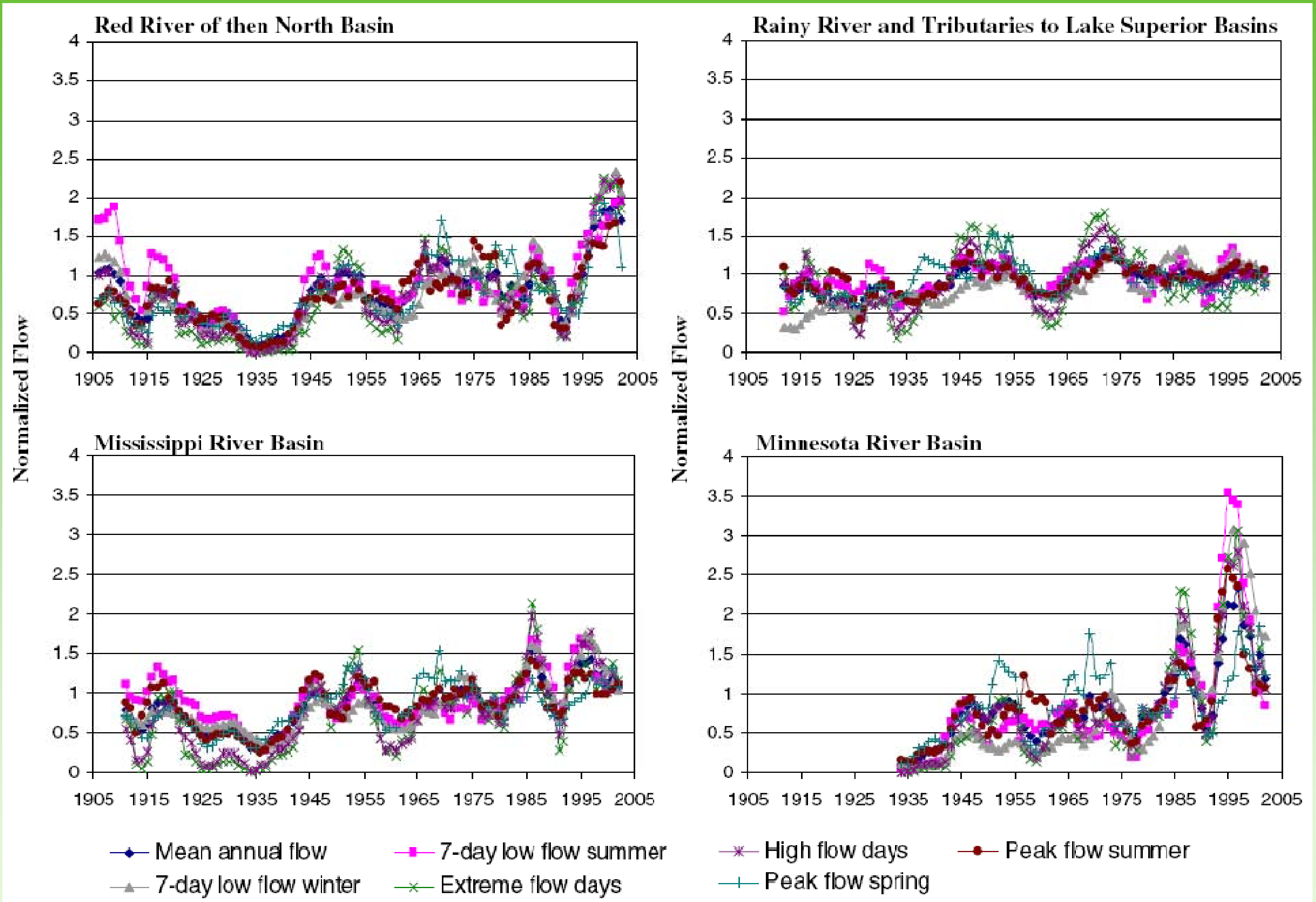
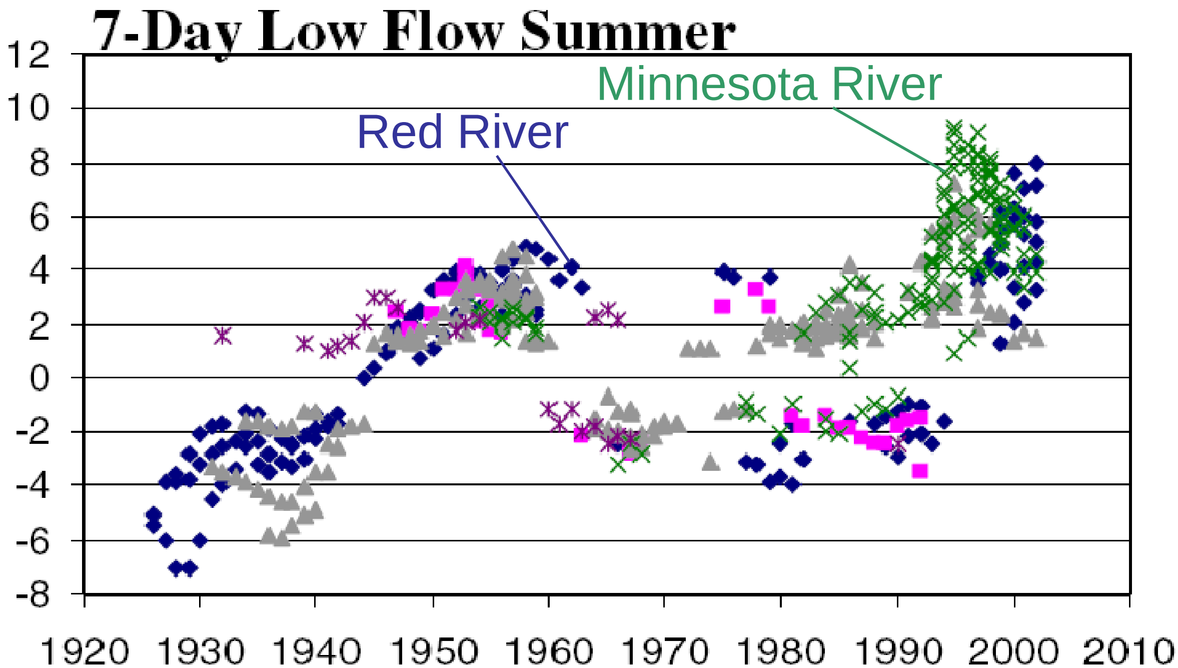
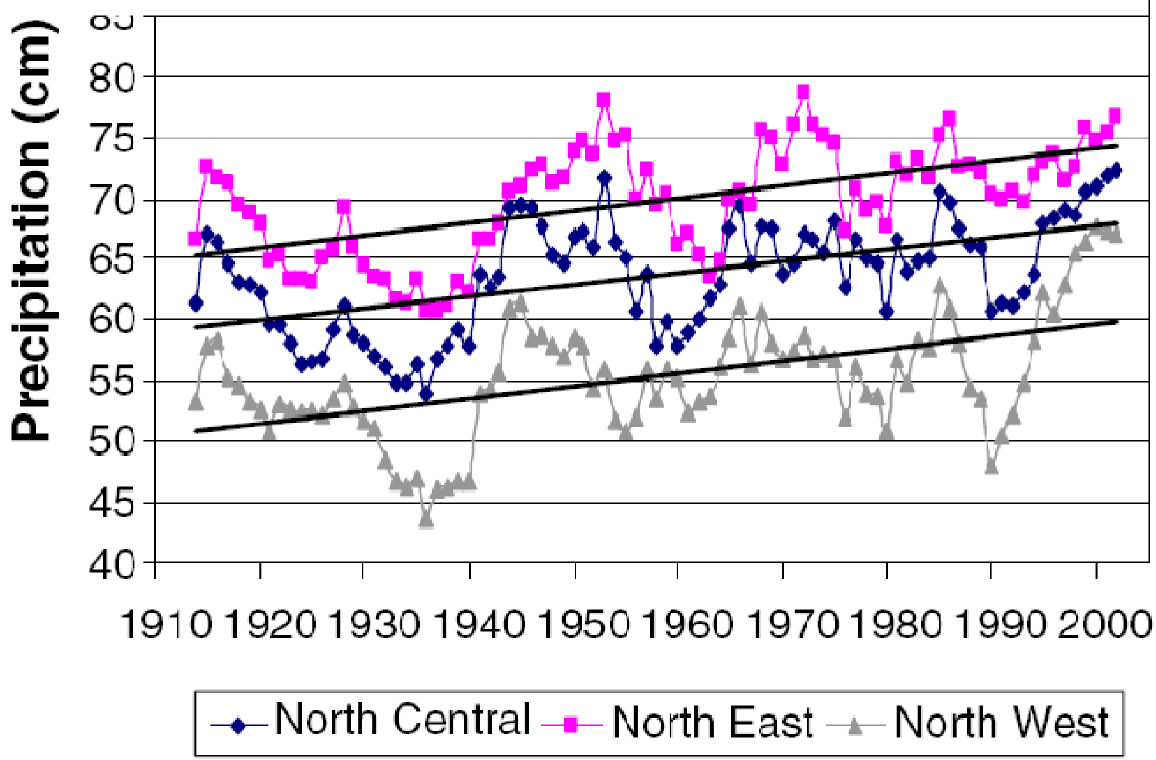
7-day low flow indicates strongest trend
7-day low flow ≈ baseflow ≈ groundwater discharge



Novotny & Stefan, 2007, *Journal of Hydrology*

Groundwater and climate change

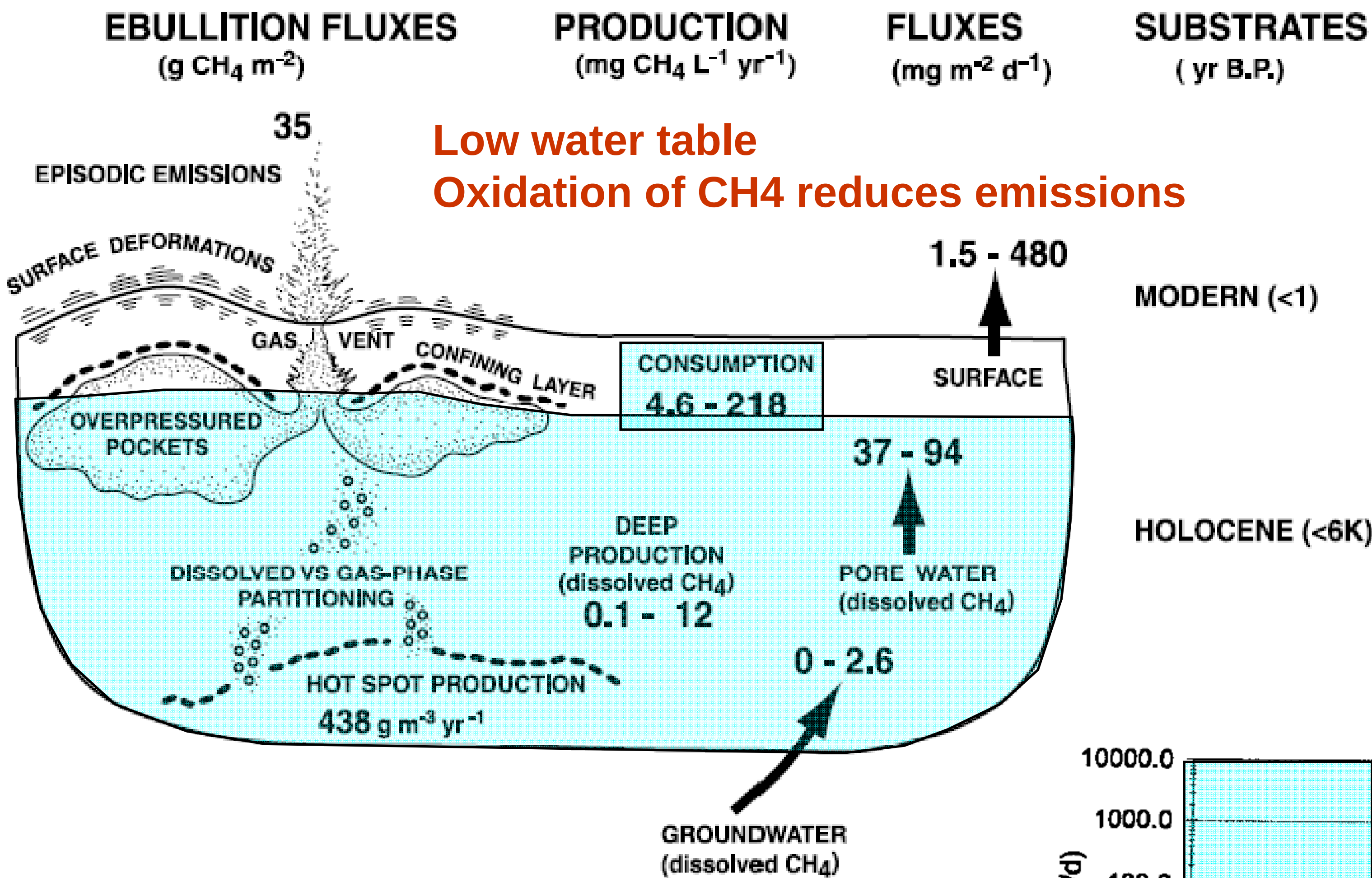




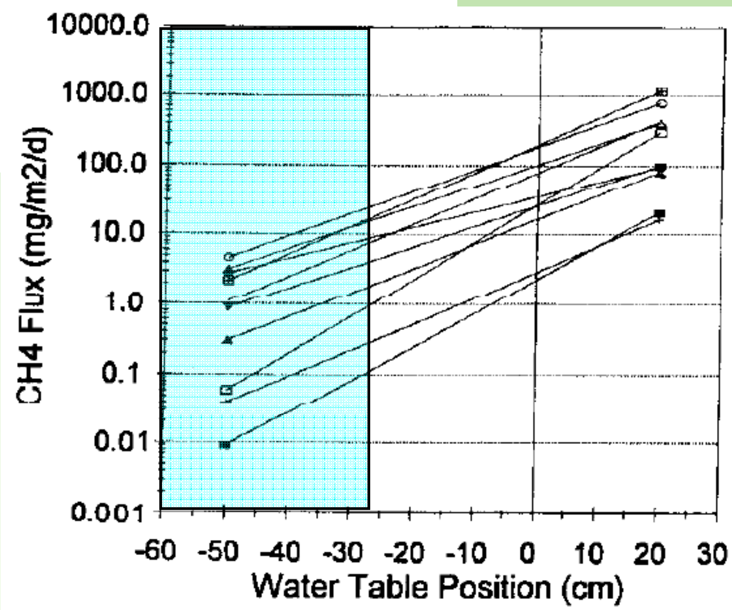
Novotny & Stefan, 2007, *Journal of Hydrology*

Goundwater and greenhouse gases

Low water table
Oxidation of CH4 reduces emissions



Glaser et al., 2004, *Global Biogeochemical Cycles*



Moore et al., 1998, *Climatic Change*

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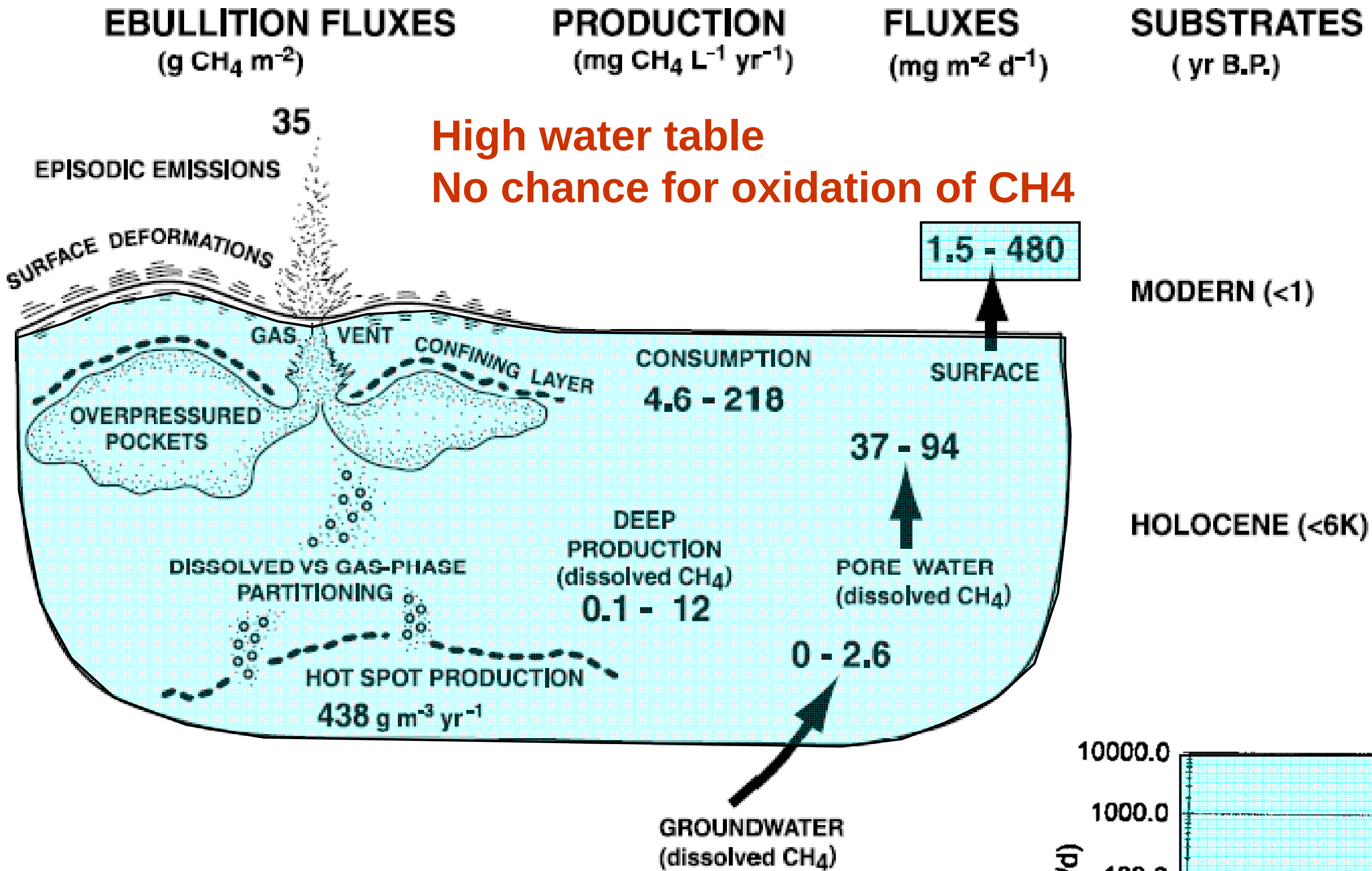
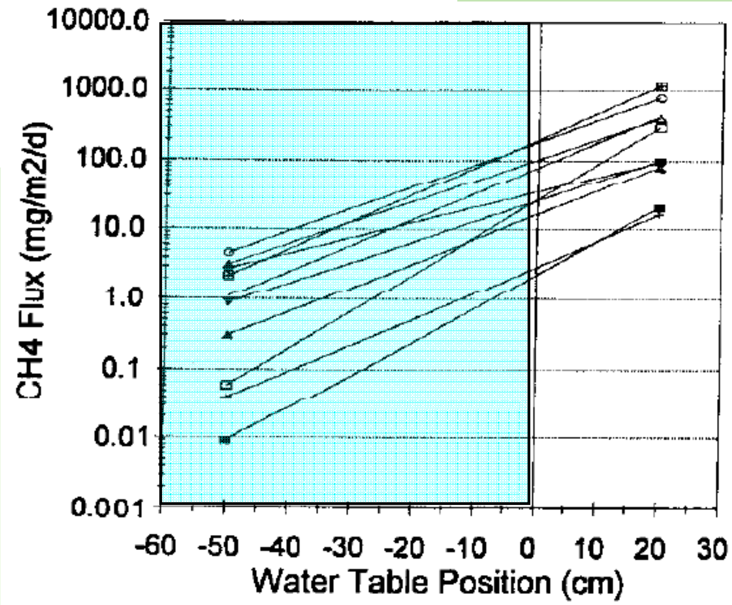
Groundwater and climate change

High water table
No chance for oxidation of CH_4



Glaser et al., 2004, *Global Biogeochemical Cycles*



Moore et al., 1998, *Climatic Change*

Groundwater and climate change

Sudden decrease of water table leads to ebullition

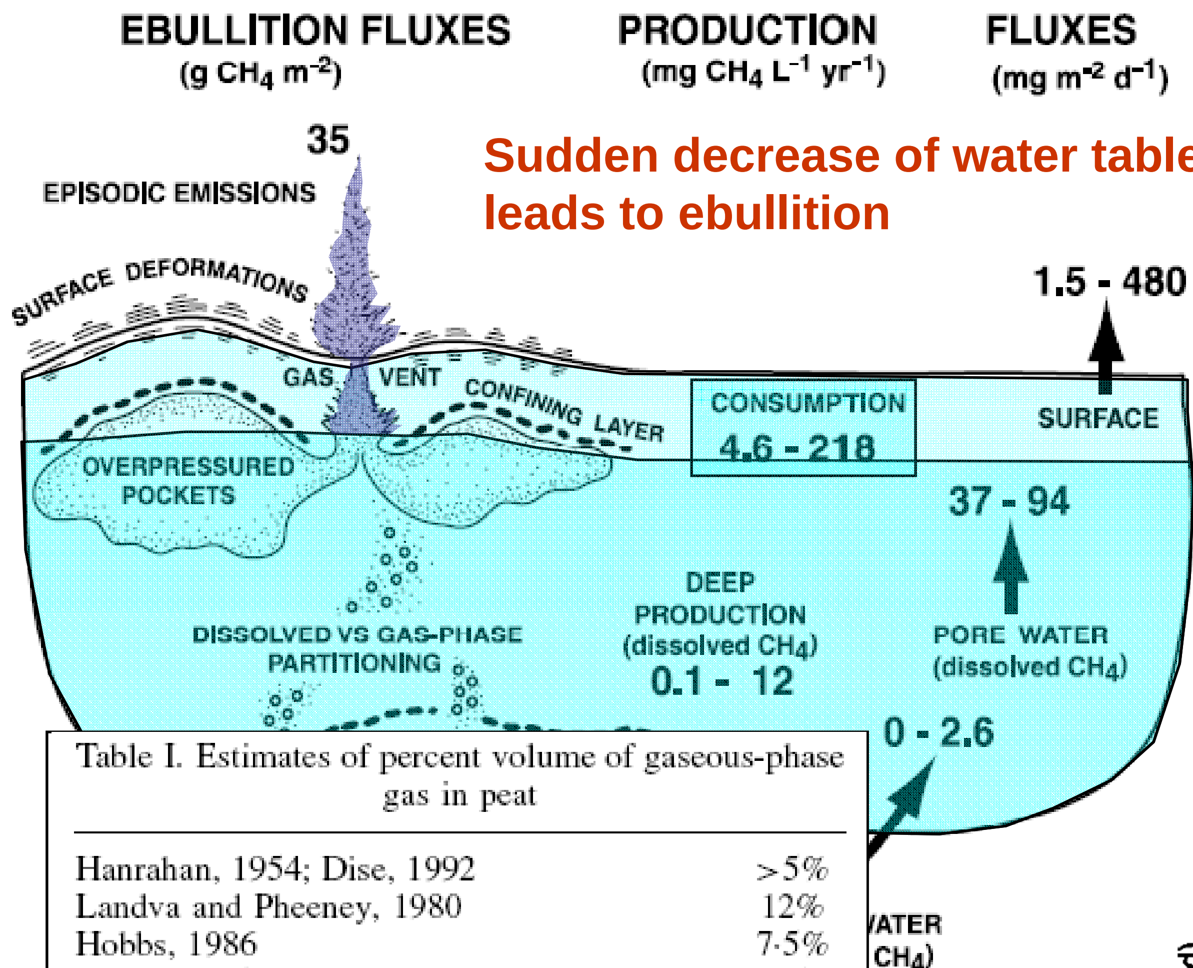
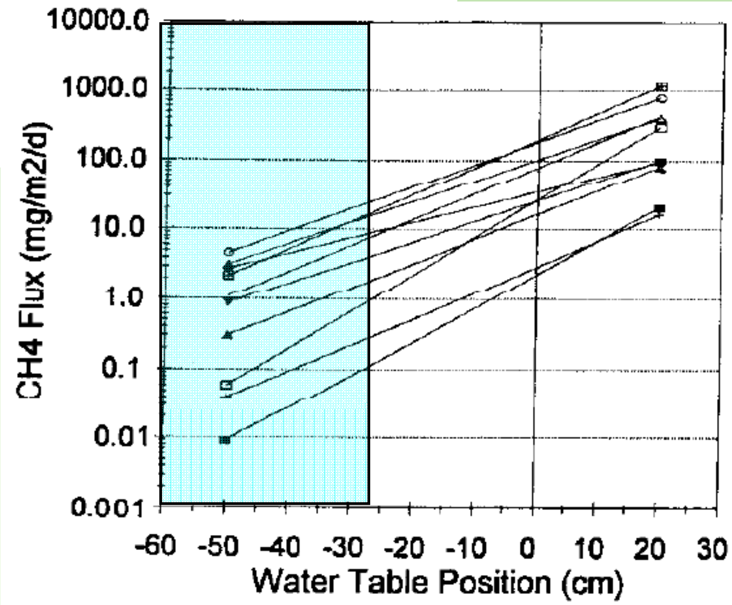
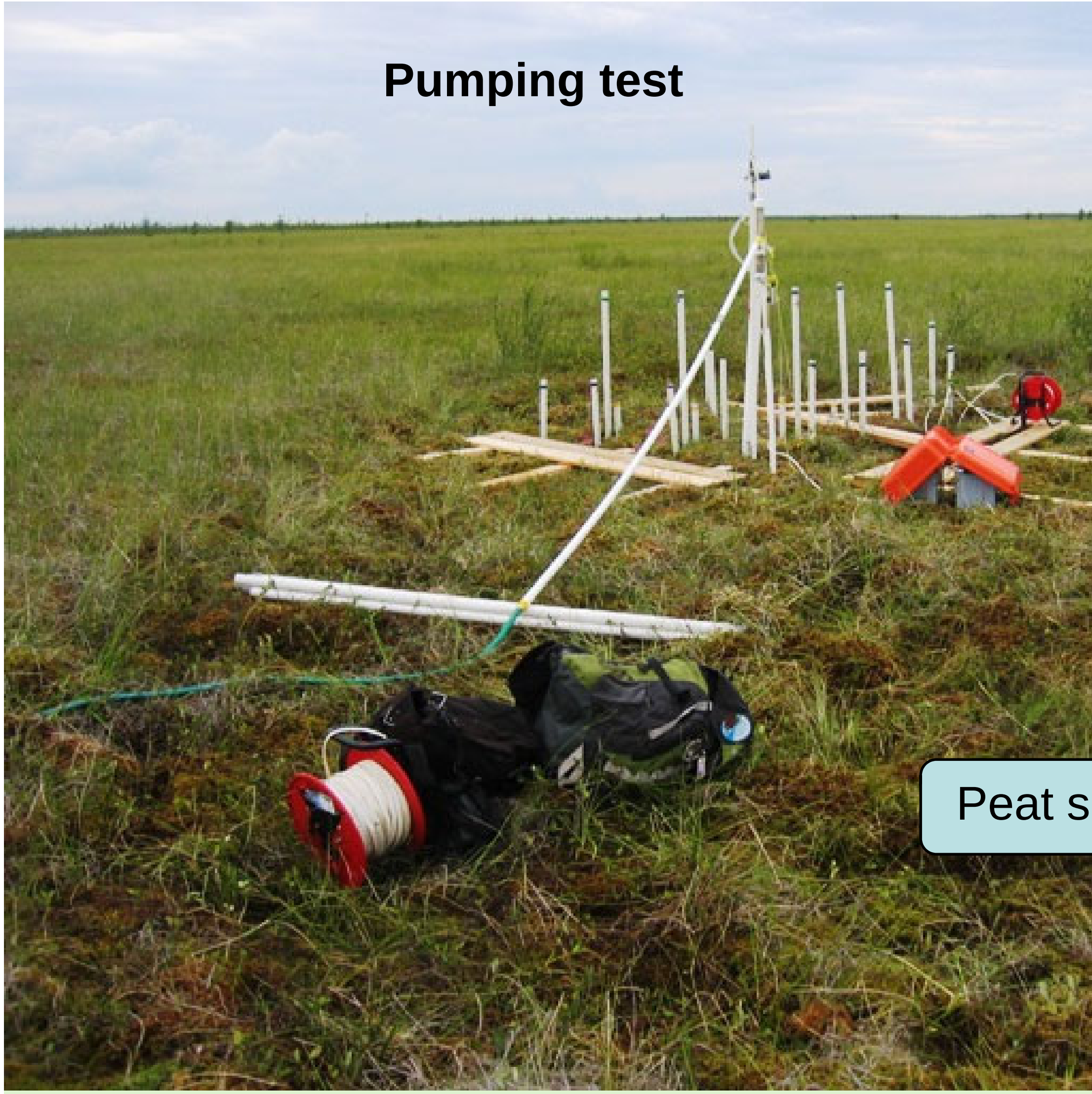


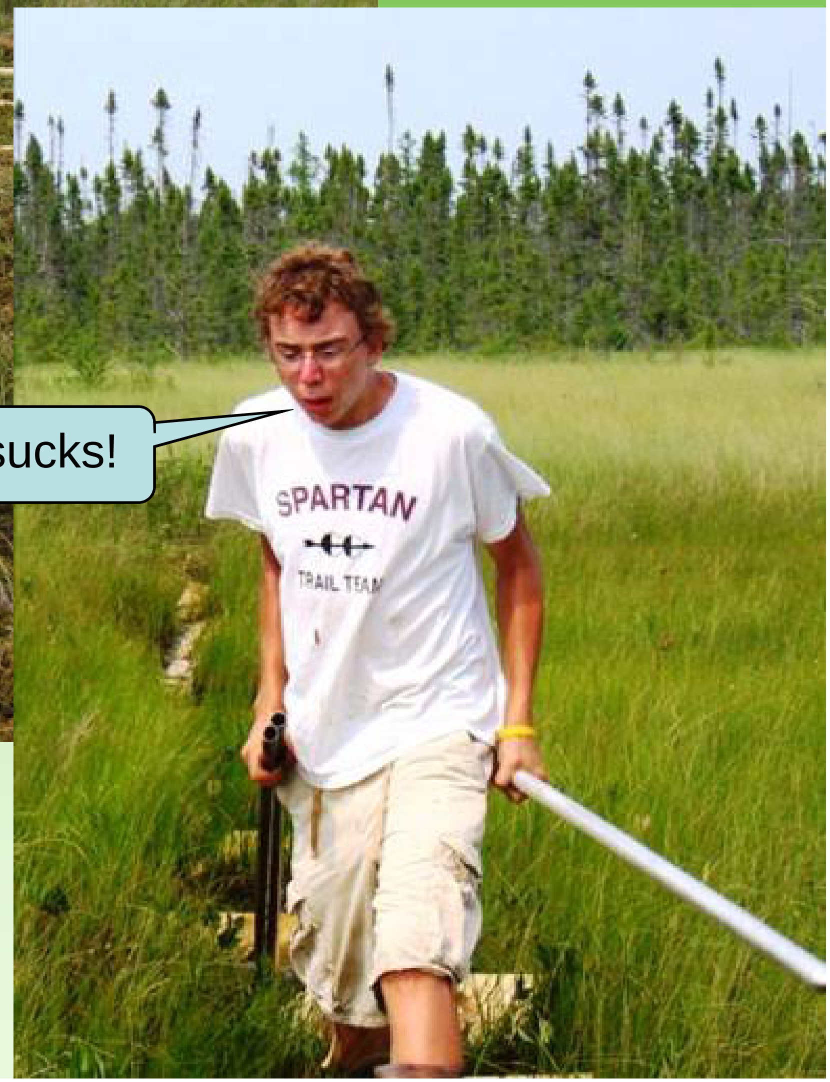
Table I. Estimates of percent volume of gaseous-phase gas in peat

Hanrahan, 1954; Dise, 1992	>5%
Landva and Pheeney, 1980	12%
Hobbs, 1986	7·5%
Brown *et al.*, 1989	2–5%
Fechner-Levy and Hemond, 1996	8–15%
Beckwith and Baird, 2001	5–10%
Rosenberry *et al.*, 2003	9–13%
Baird *et al.*, 2004	4–15%
Kellner *et al.*, 2004	~10%
Comas *et al.*, 2005	0–10%
Kellner *et al.*, 2005	0–15%
Strack *et al.*, 2005	5–15%
Tokida *et al.*, 2005b	0–19%

Rosenberry et al., 2006, *Hydrological Processes*







Relate gas generation, storage, and release to peat hydrogeology

NRC No. 3
Groundwater measurements

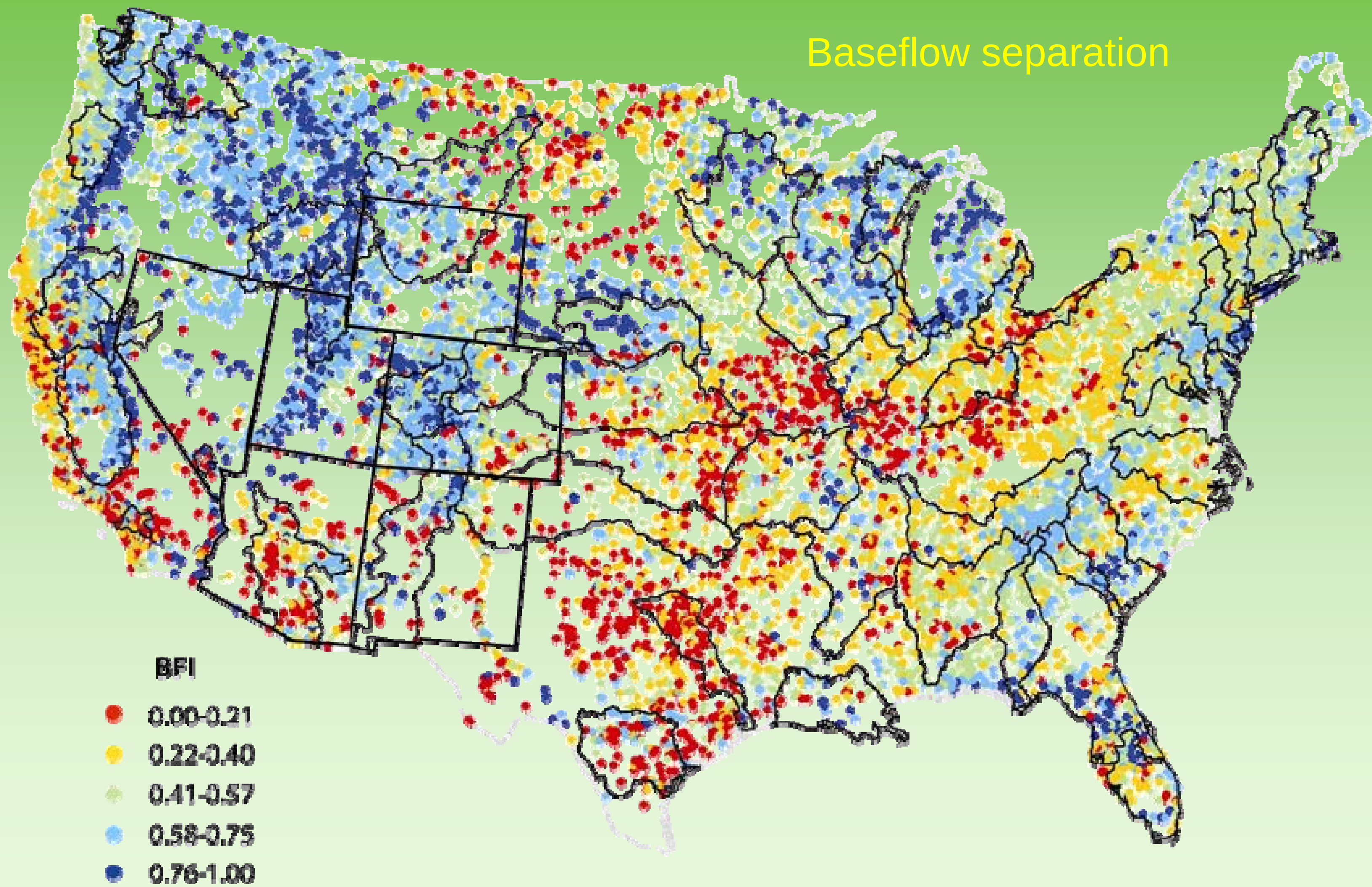
- Better understanding of processes associated with scaling of these measurements
- Development of sensors that measure recharge and discharge at specific points

NRC 2004

Need to scale measurements and methods to match the scale of concern

Nationwide scale

Baseflow separation



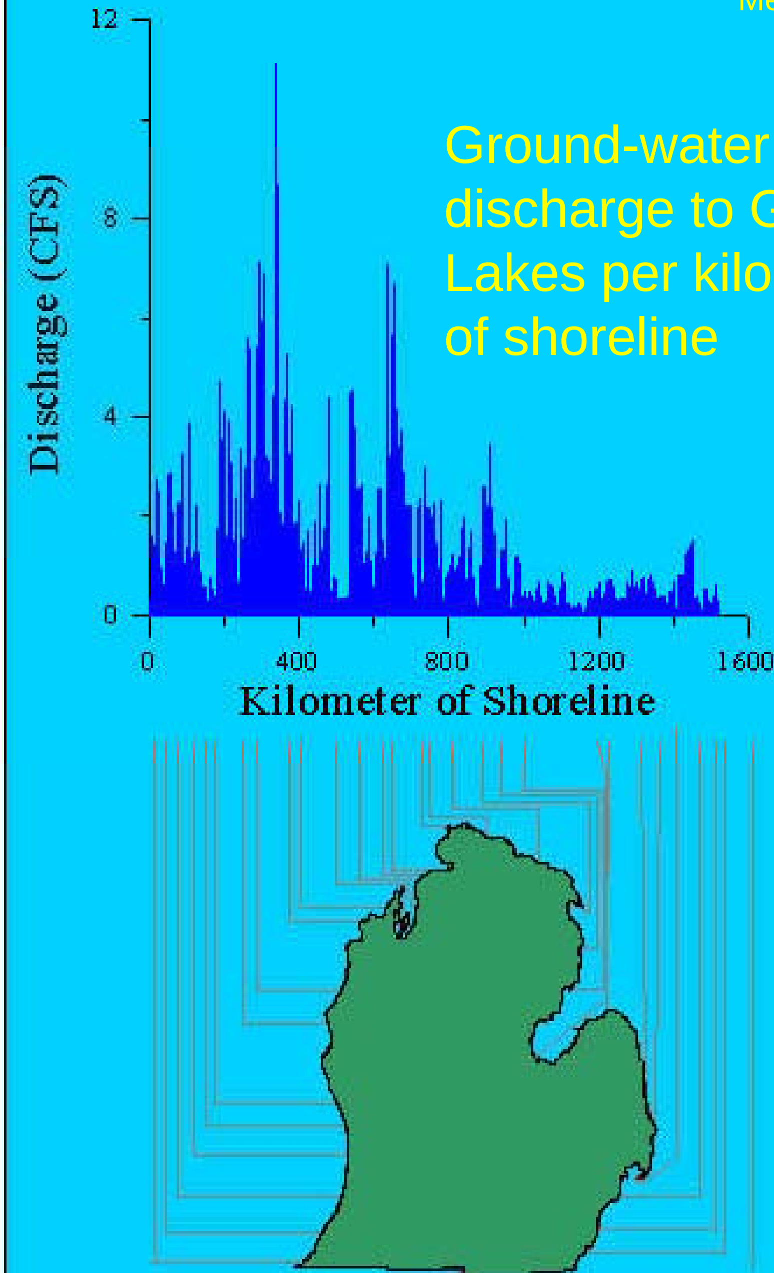
Wolock, 2003, USGS OFR 03-146

Regional scale

MODFLOW model

Measurements and **scale**

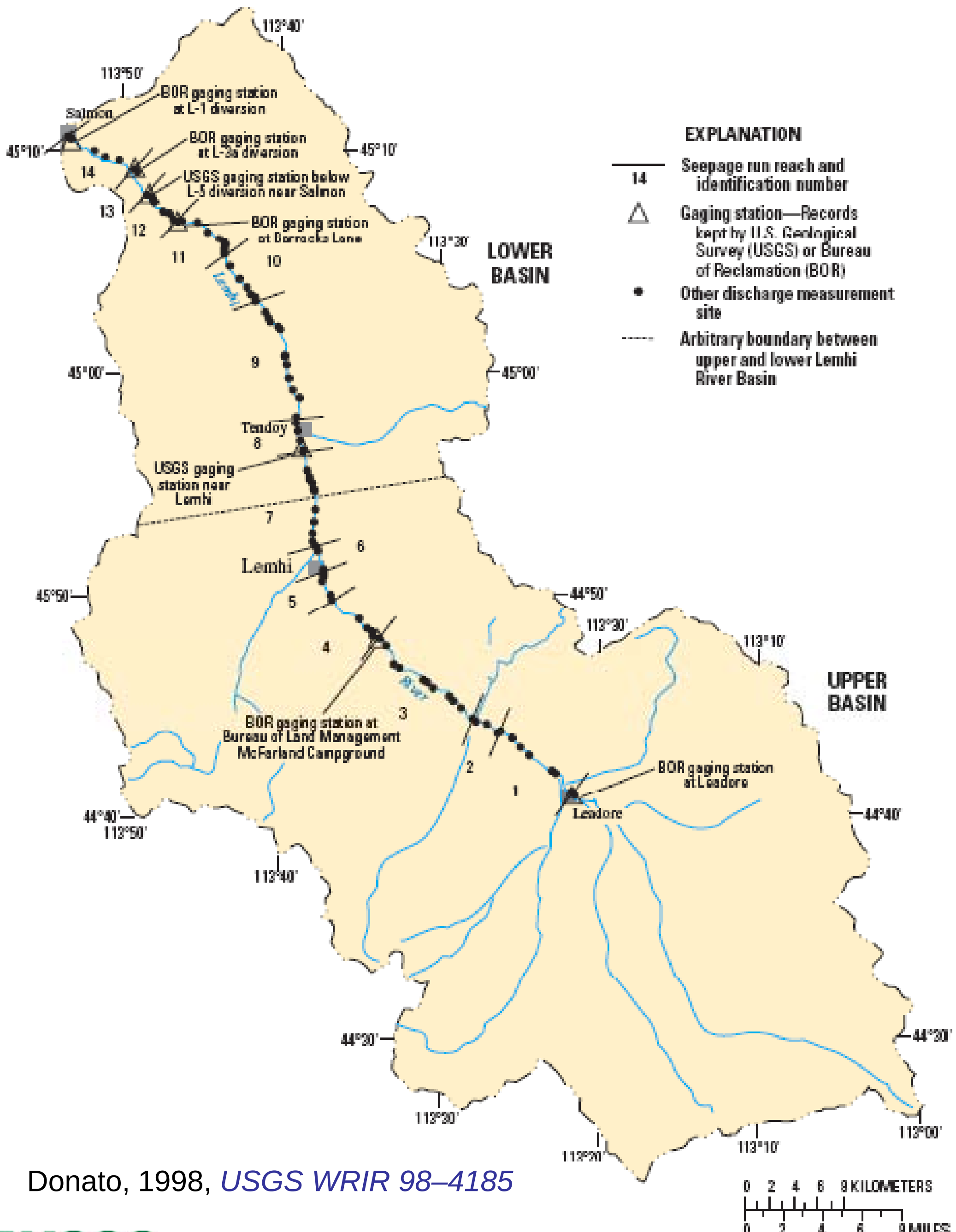
Ground-water discharge to Great Lakes per kilometer of shoreline



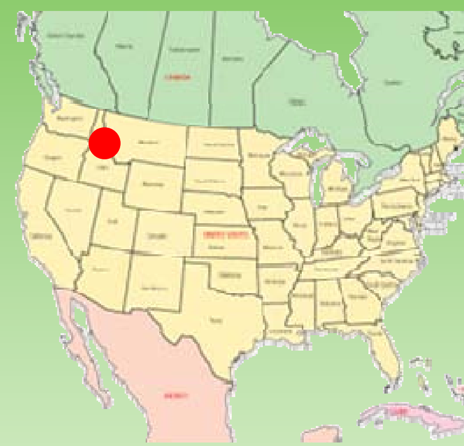
Hoaglund et al., 2002, *Ground Water*

Watershed scale

Seepage run



Donato, 1998, *USGS WRIR 98–4185*



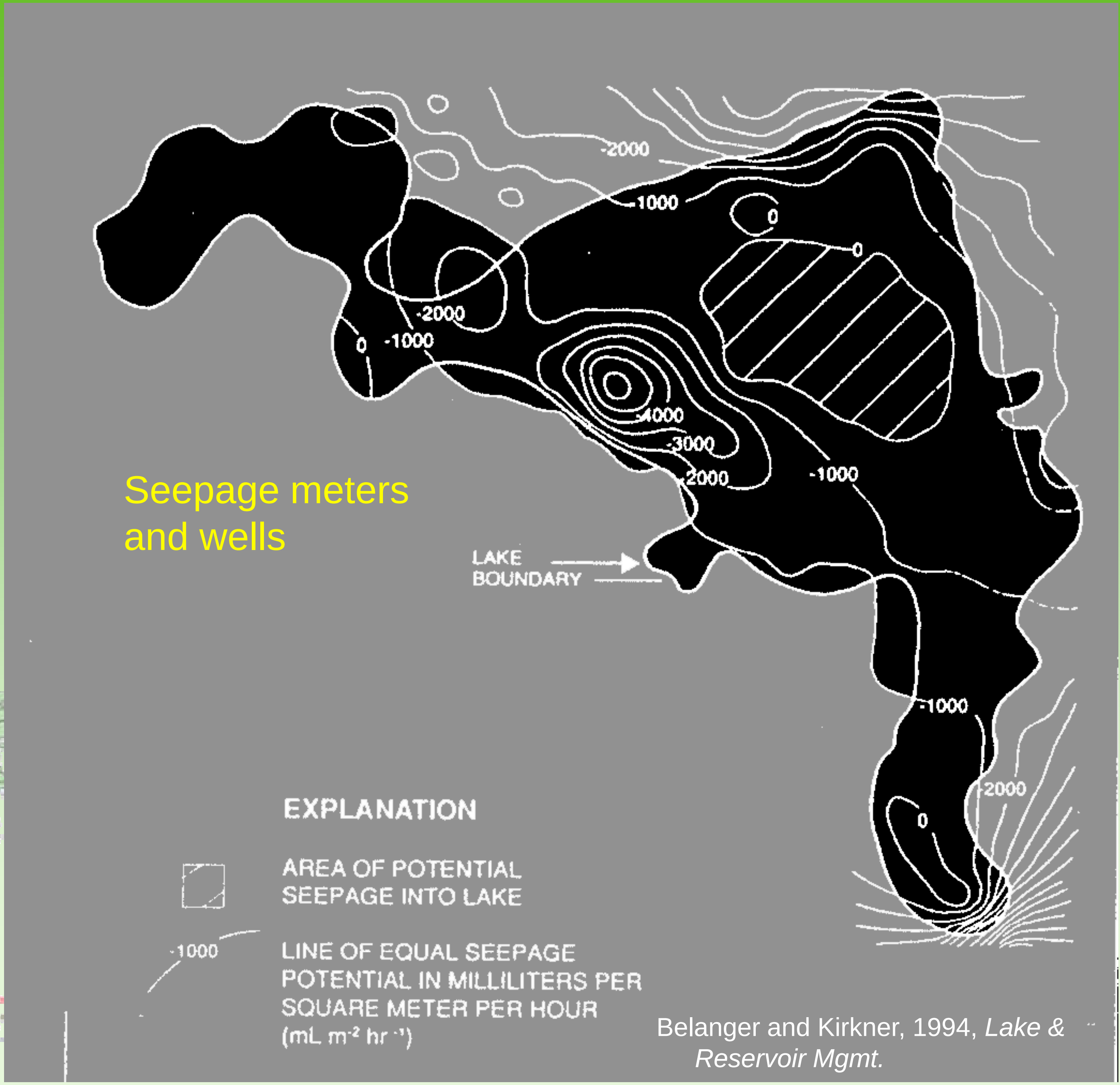
Lakebed scale

Karst

Mountain Lake, FL

Belanger and Kirkner 1994

very labor intensive



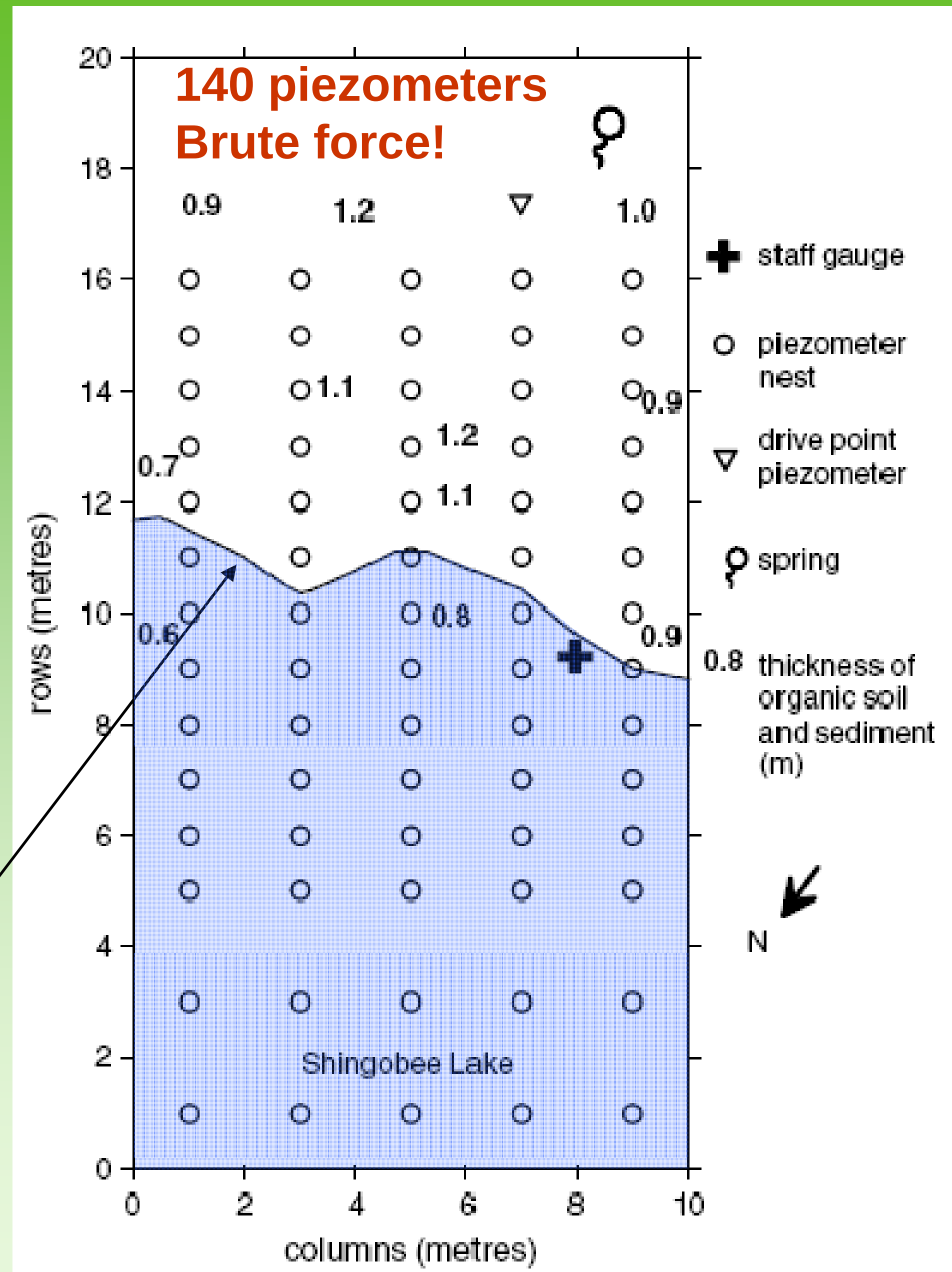
Seepage meters and wells

Belanger and Kirkner, 1994, *Lake & Reservoir Mgmt.*

Local scale

Shingobee Lake, MN, USA – GW flow heterogeneity based on *K* and gradients

Shoreline



Kishel & Gerla, 2002, *Hydrological Processes*

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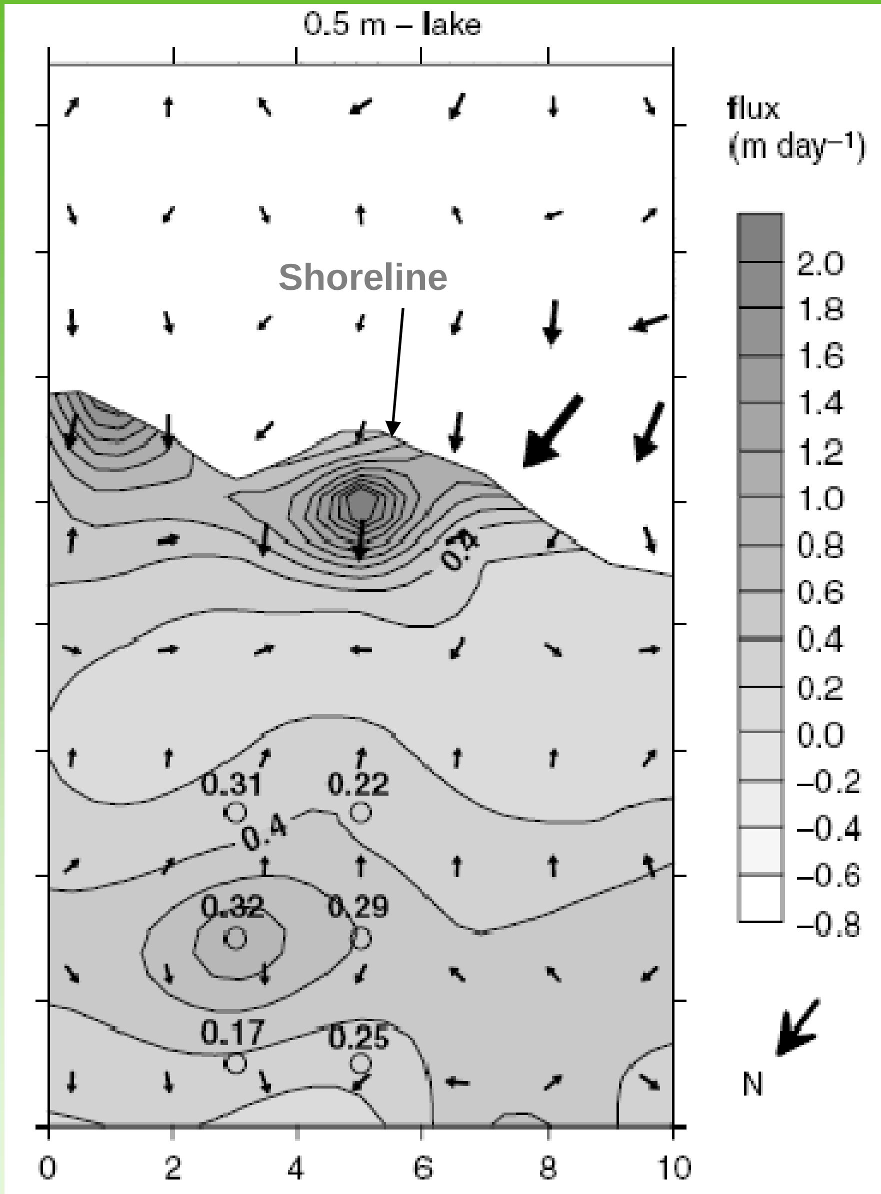
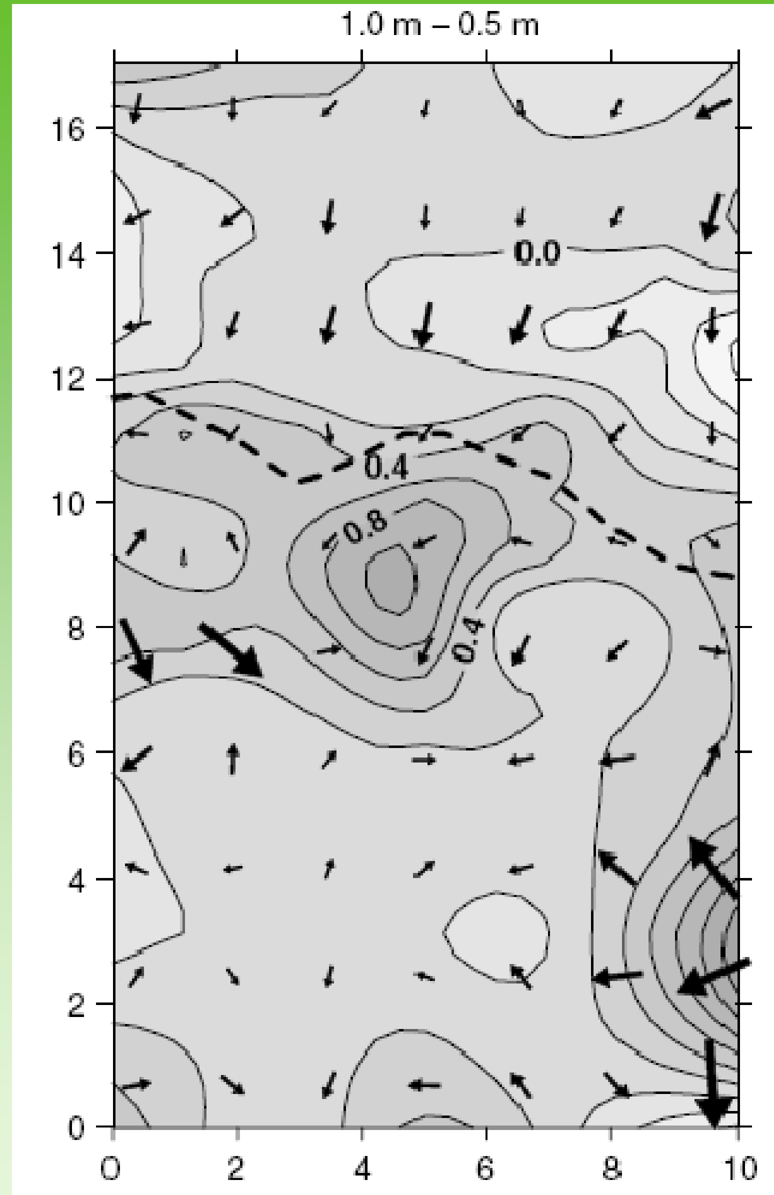




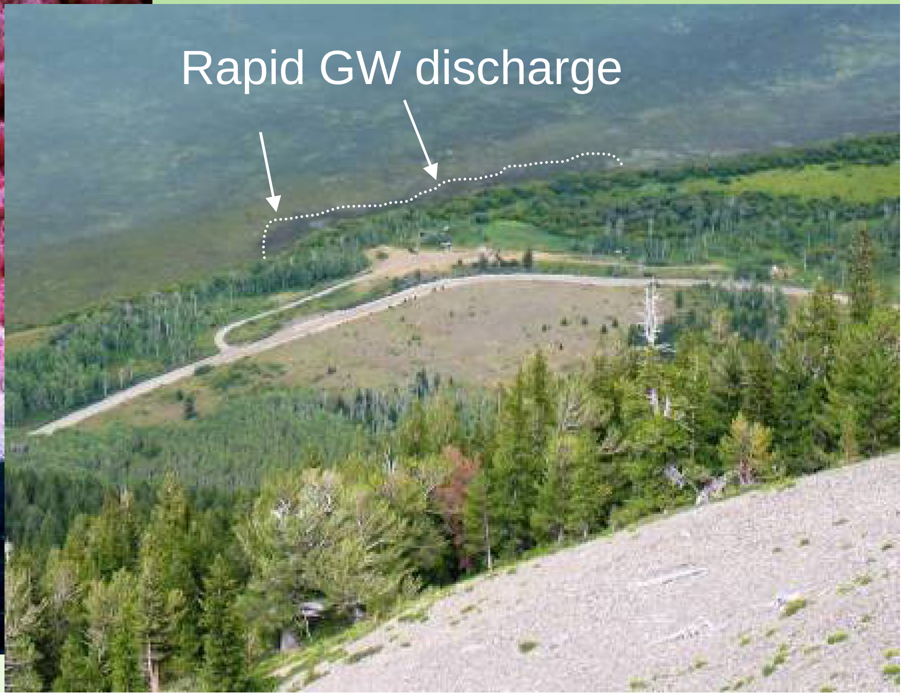
Contours indicate vertical GW flow. Arrows indicate horizontal GW flow.

Kishel & Gerla, 2002, *Hydrological Processes*

But how to integrate scales?

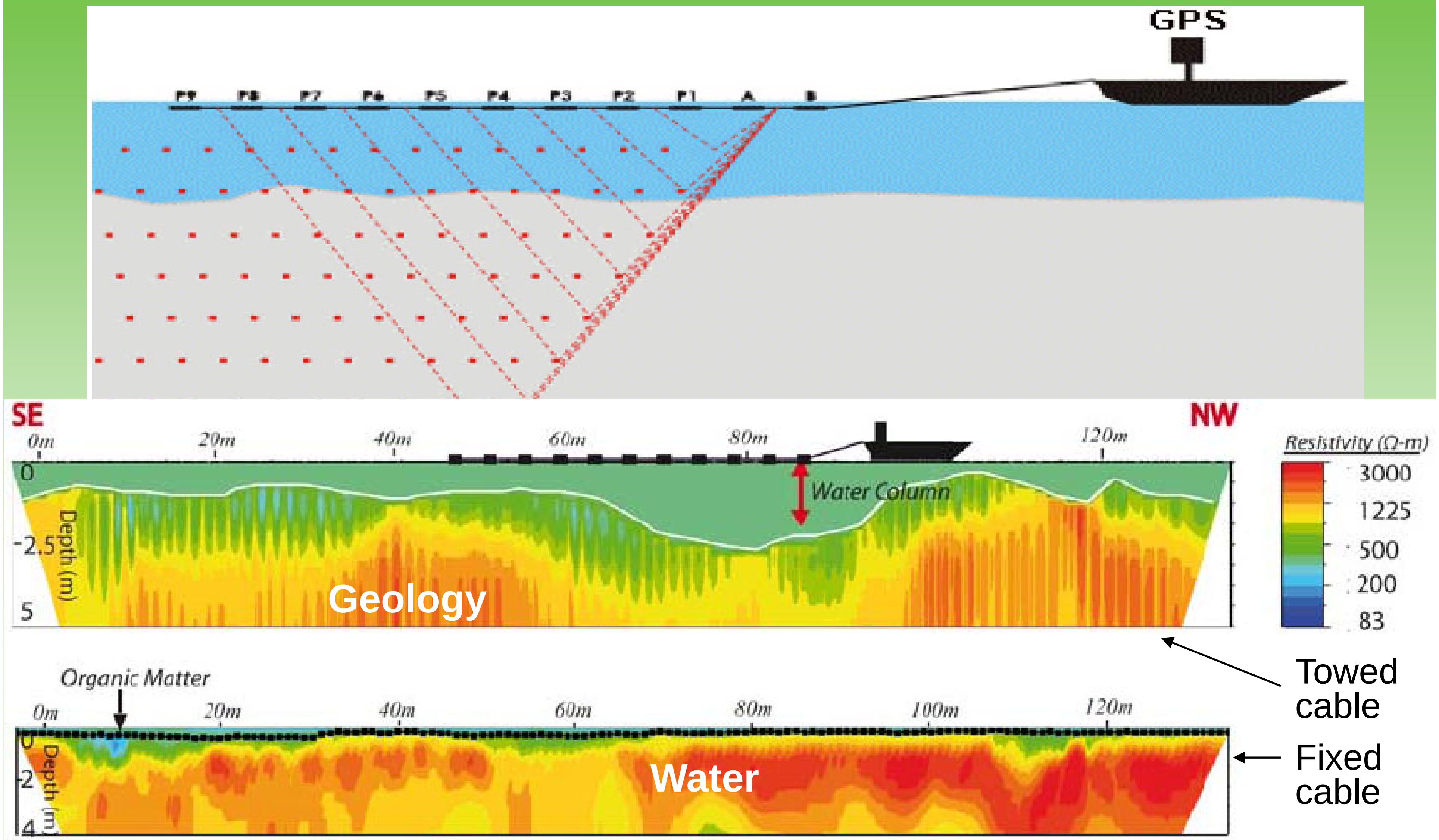
Aerial imagery

- Usually thermal IR
- Temperature difference between SW and GW needs to be greater than sensitivity of the film or sensor
- Satellite imagery (spatial and thermal resolution)
- Sometimes GW discharge can be seen with visible spectrum imagery



Scaling up

Electrical resistivity profiling



Mitchell et al., 2008, SAGEEP

Hood Canal, Puget Sound, WA

Courtesy of Bill Simonds

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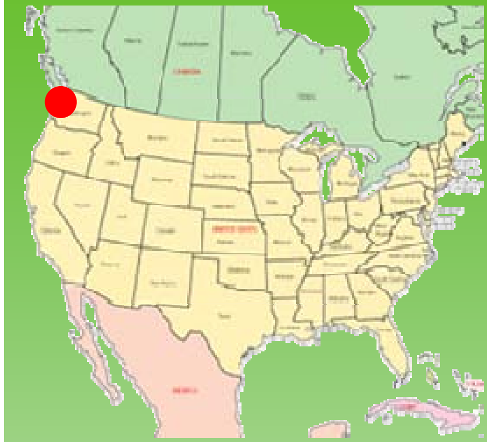
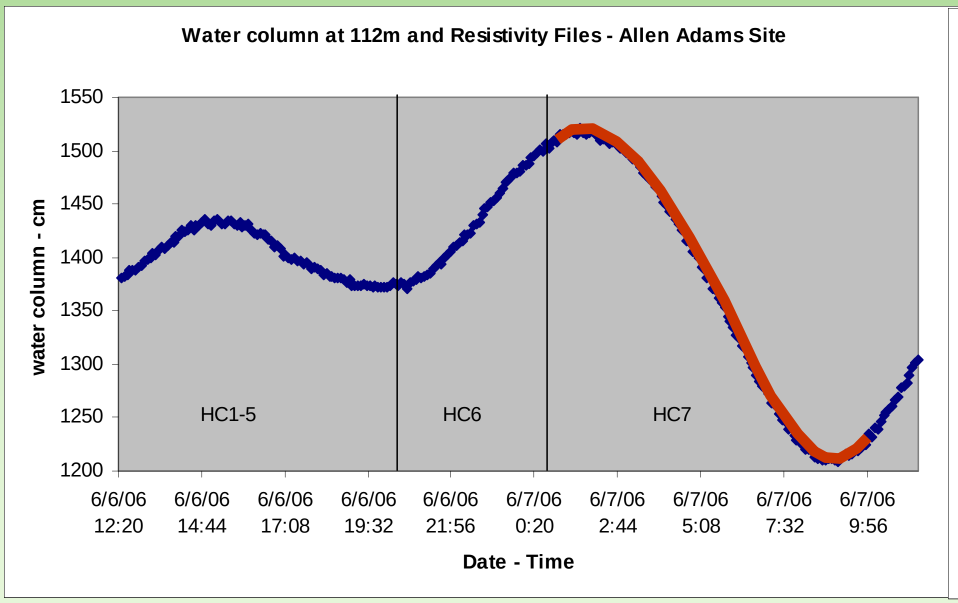


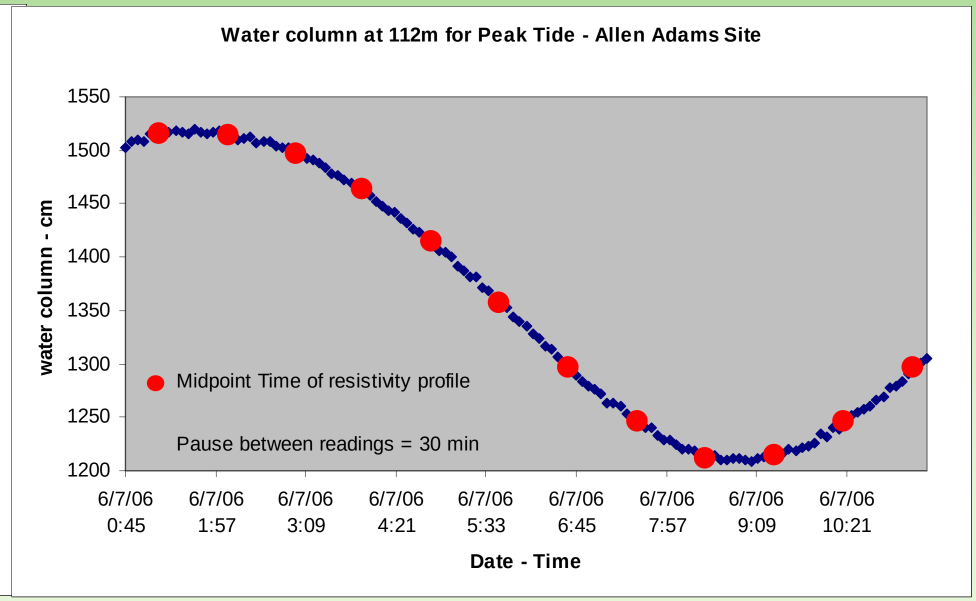
High Resolution Underwater Resistivity

Hood Canal, WA

Entire Time Series



Peak Tide Time Series



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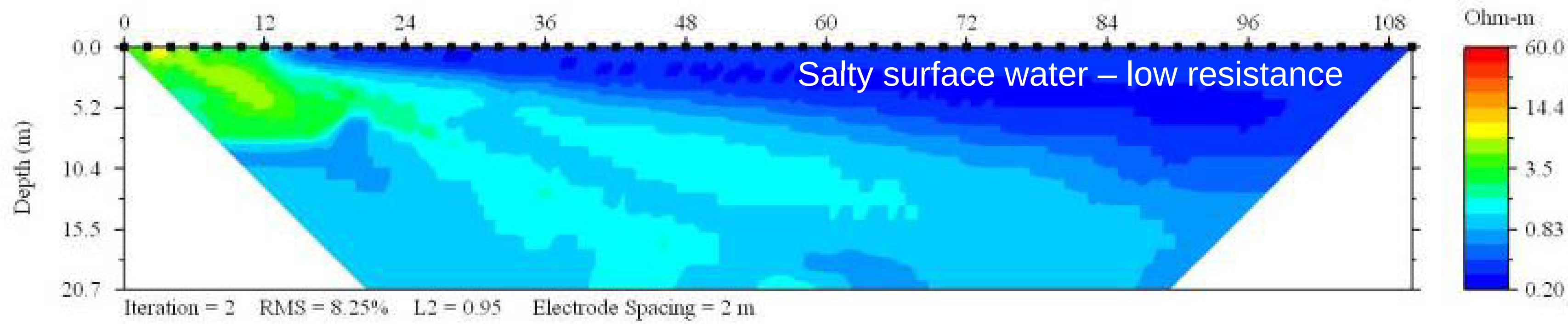
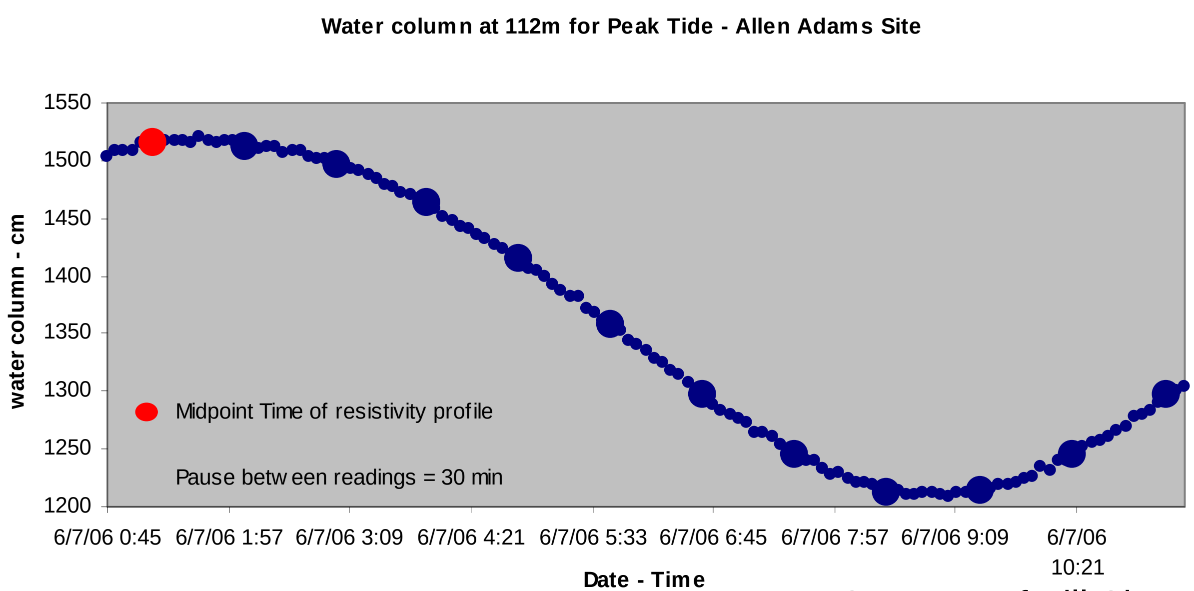
1:12





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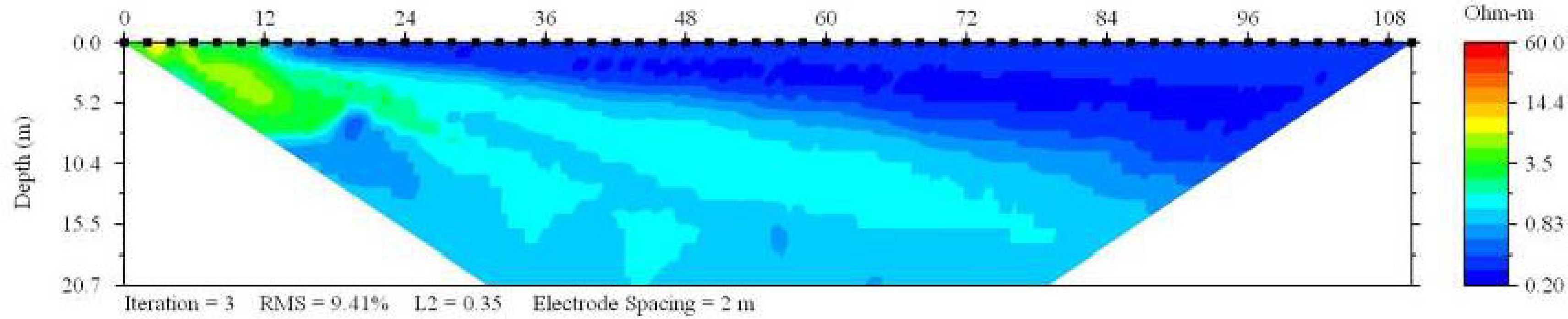
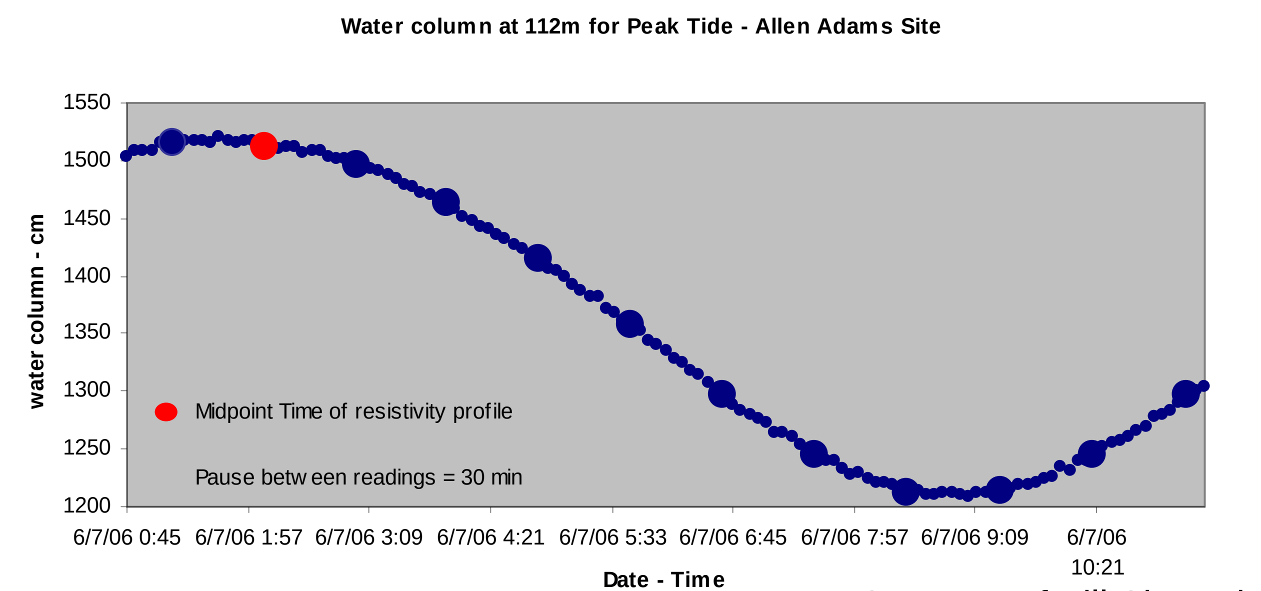
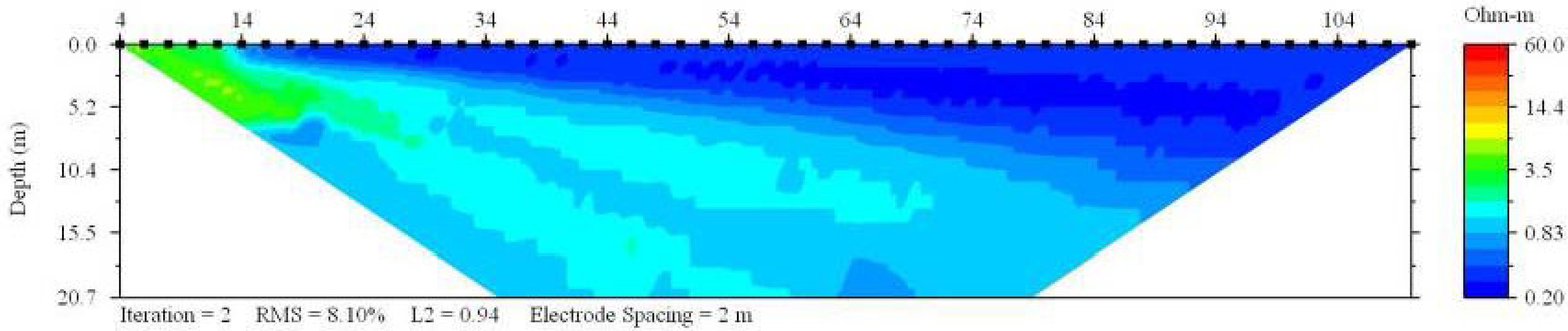
2:07

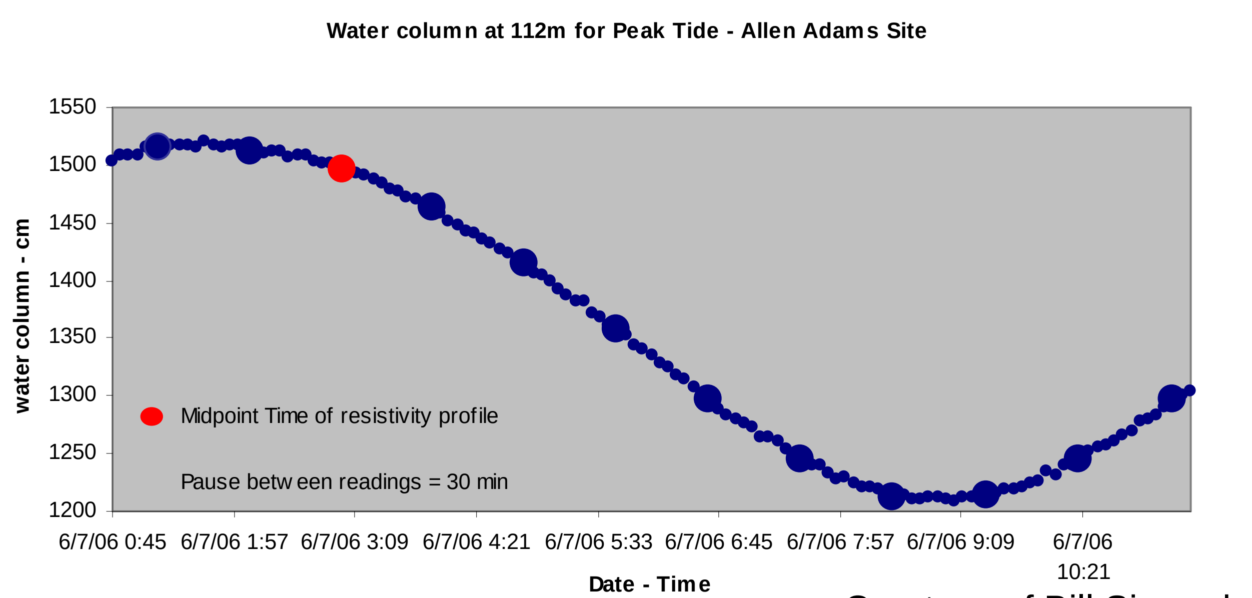




Courtesy of Bill Simonds

3:01





Courtesy of Bill Simonds

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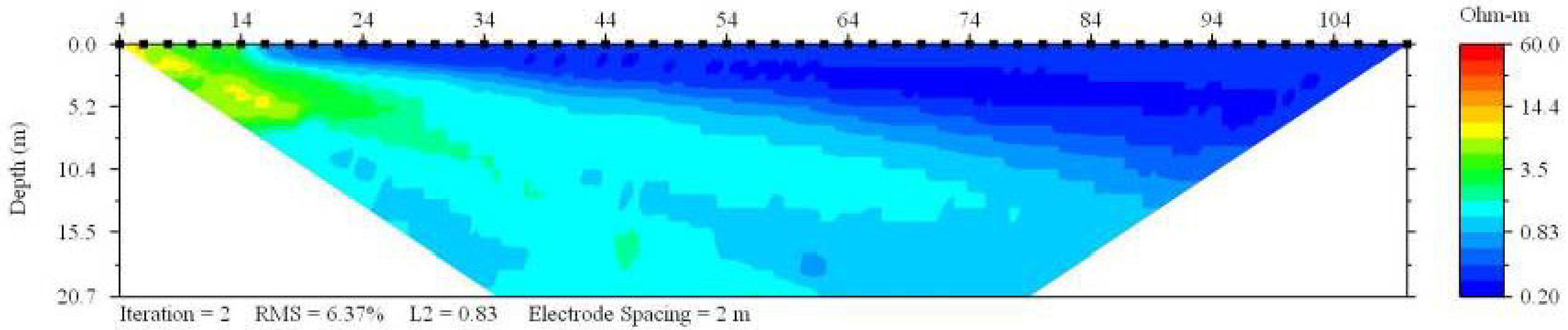
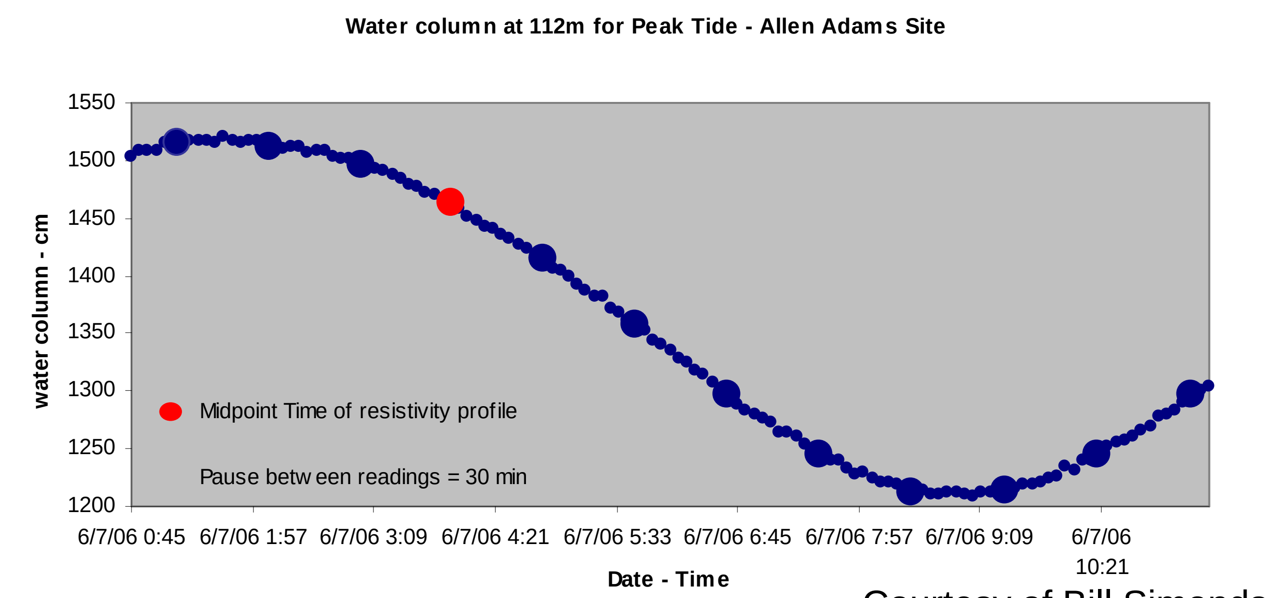
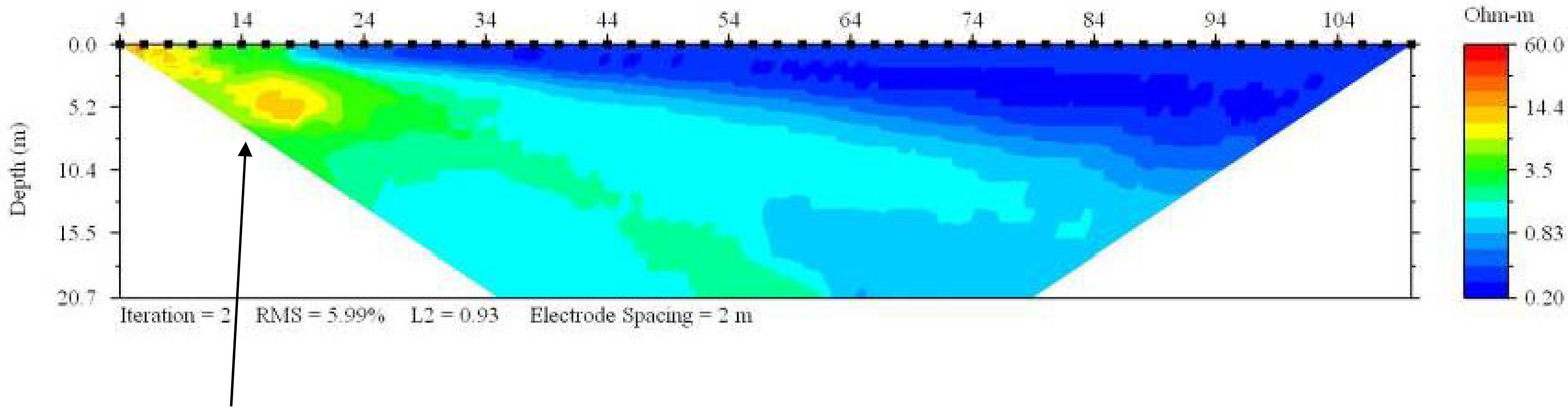


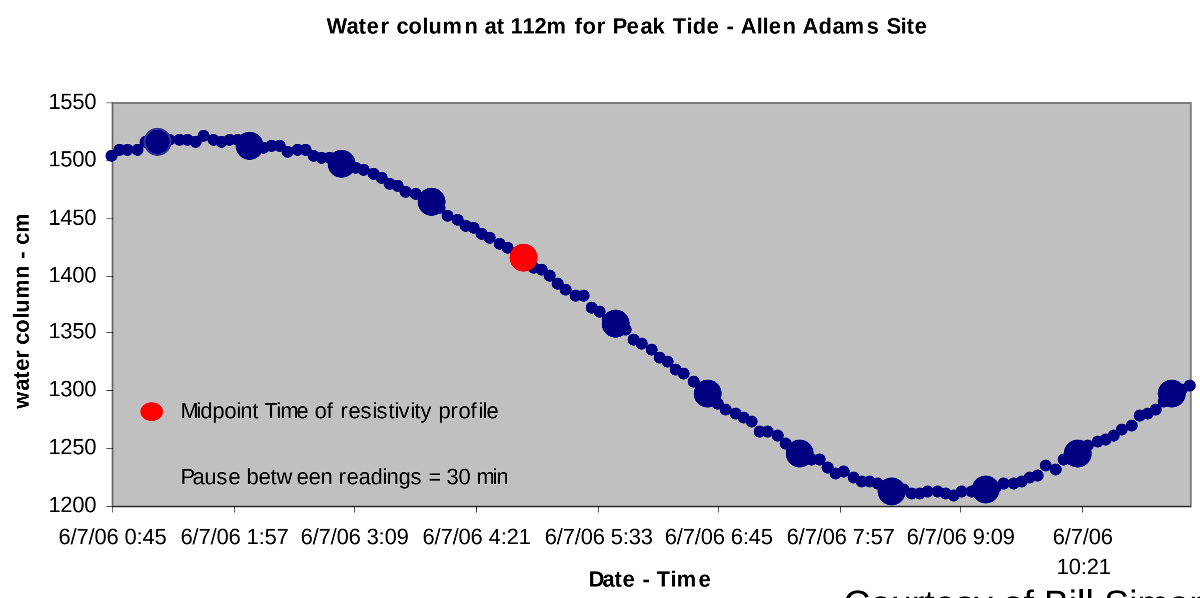


Courtesy of Bill Simonds

4:50



Tide going out, fresh-water moving in



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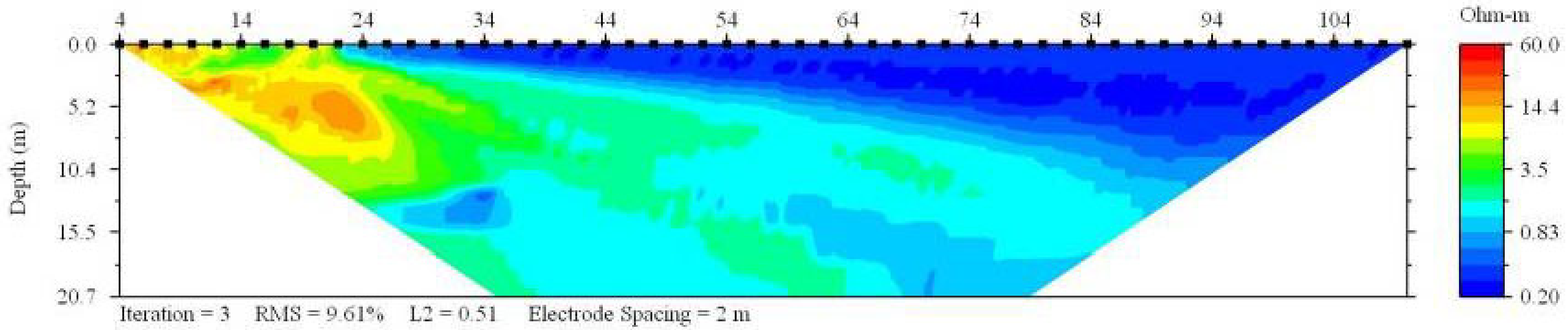
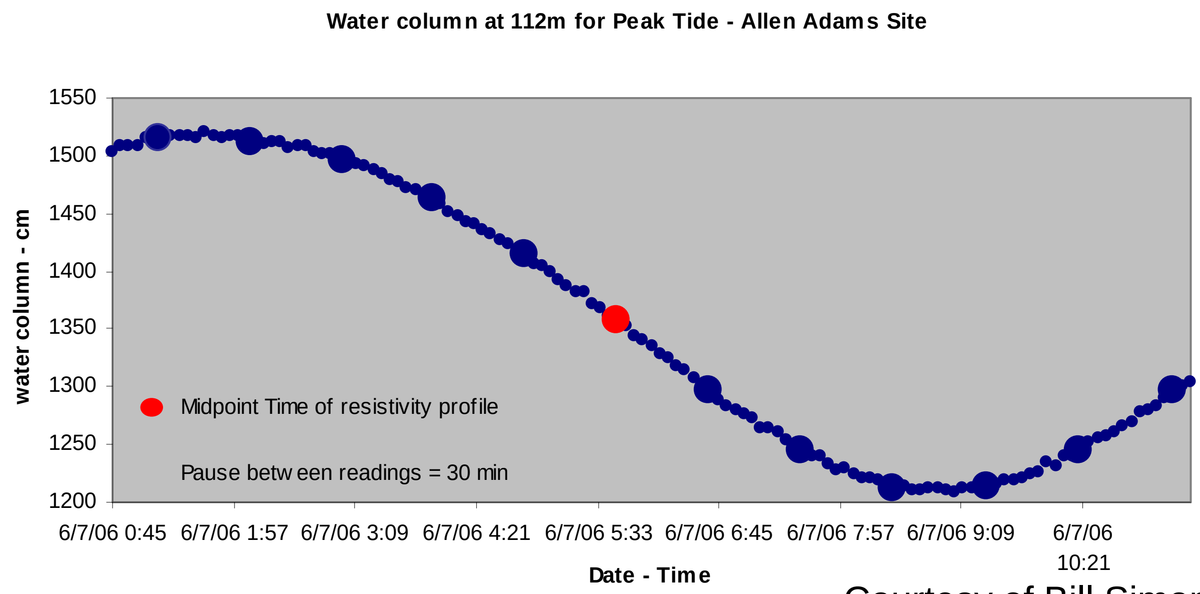
5:44





Courtesy of Bill Simonds

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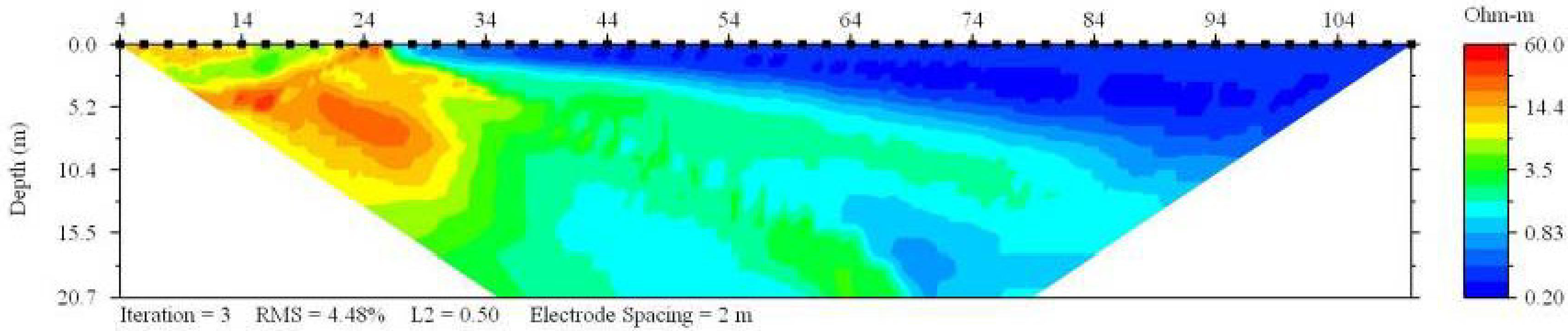
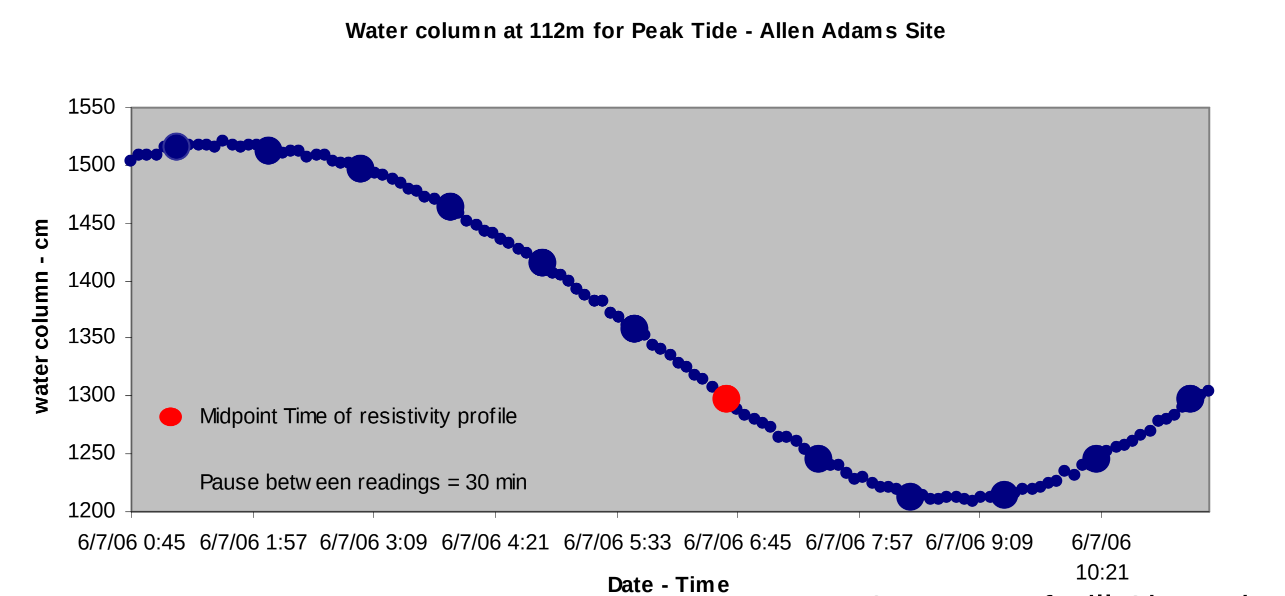
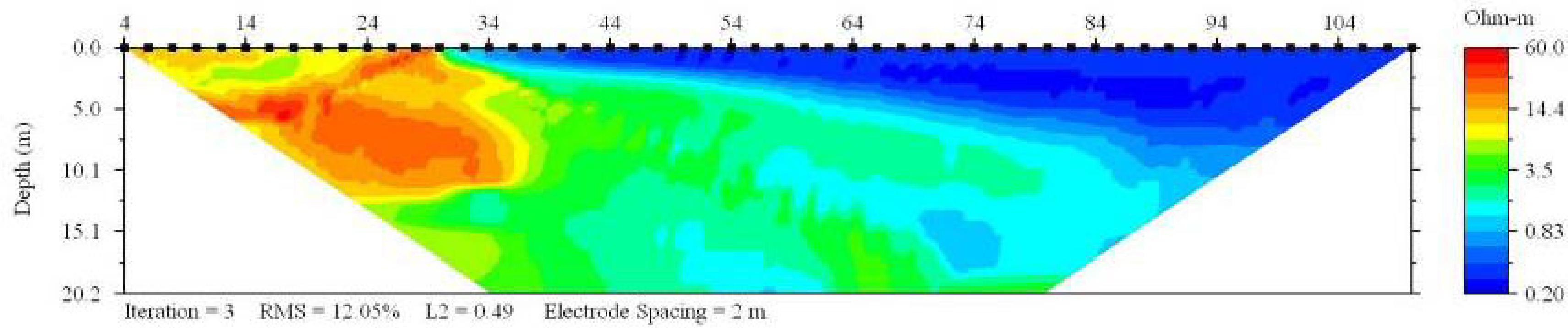
6:38

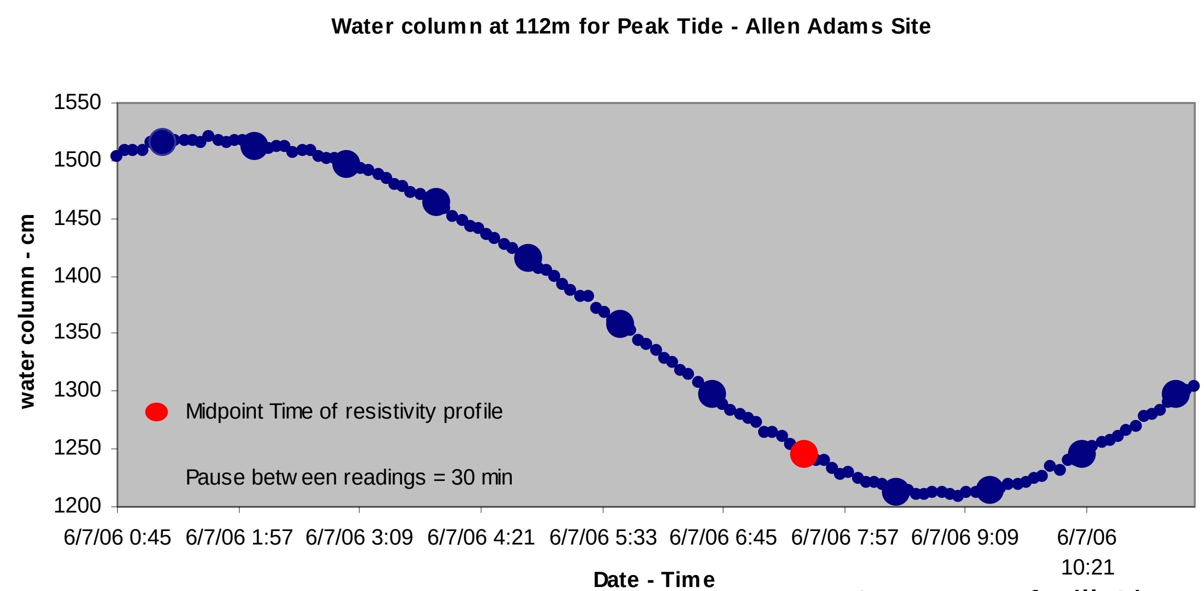




Courtesy of Bill Simonds

7:34





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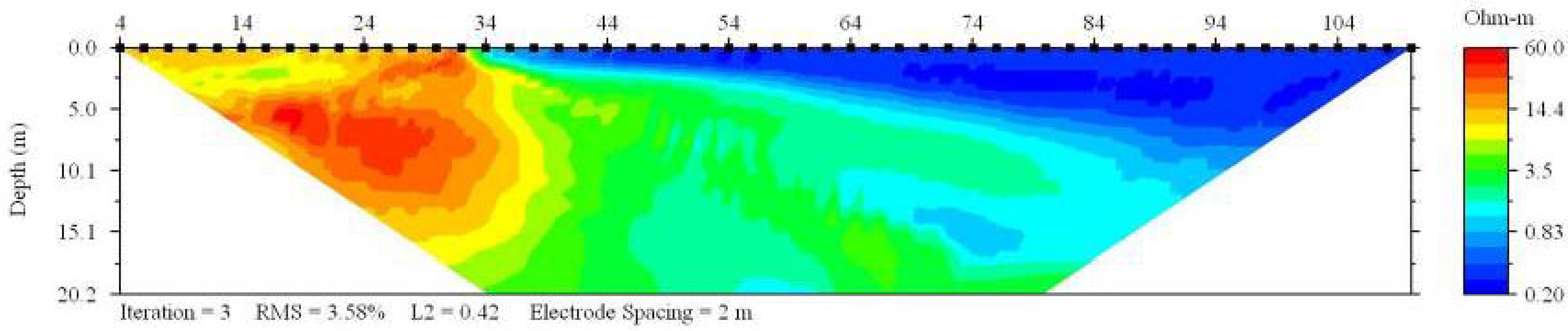

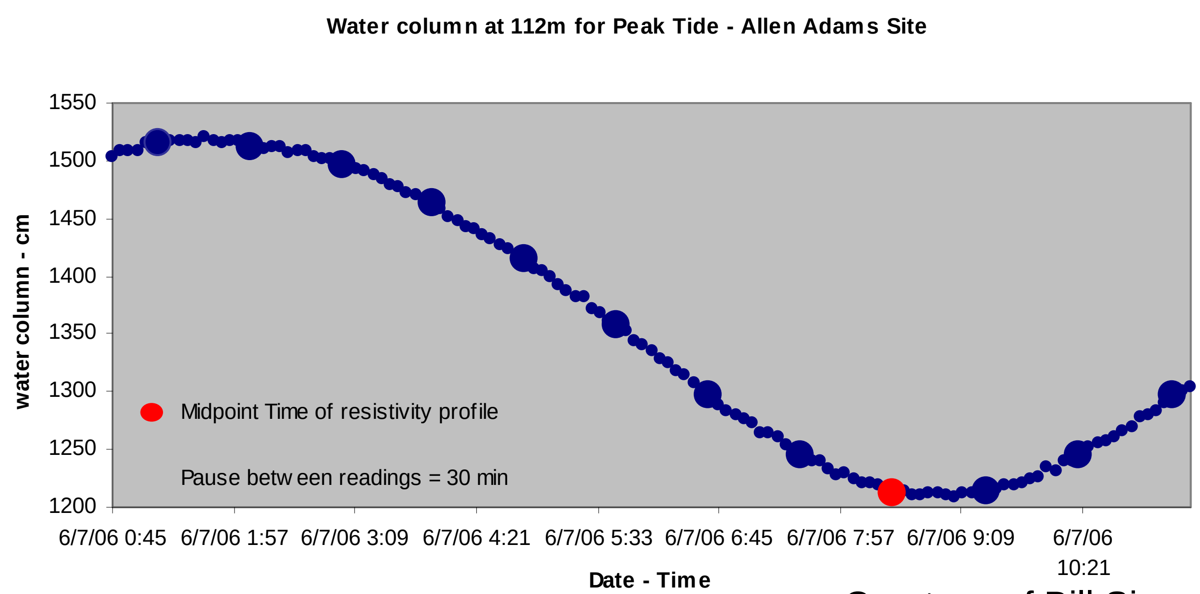

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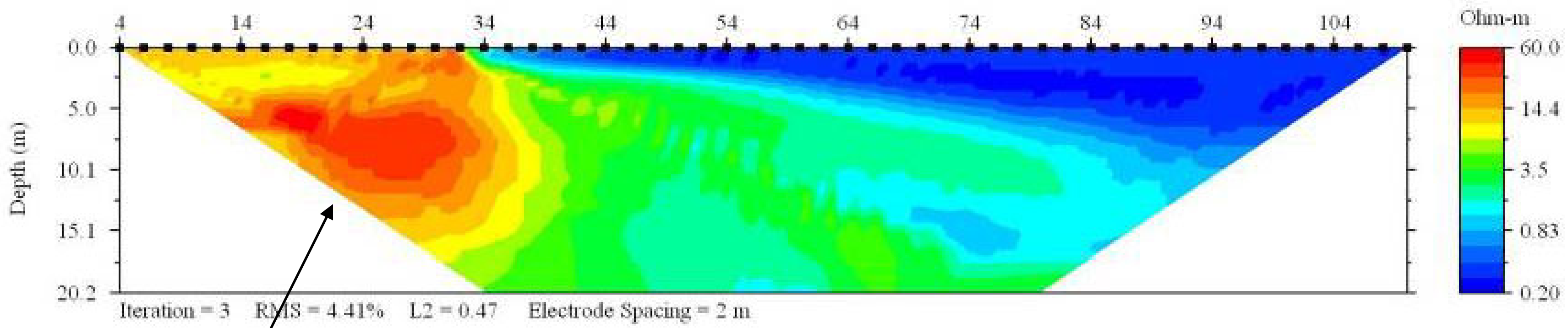
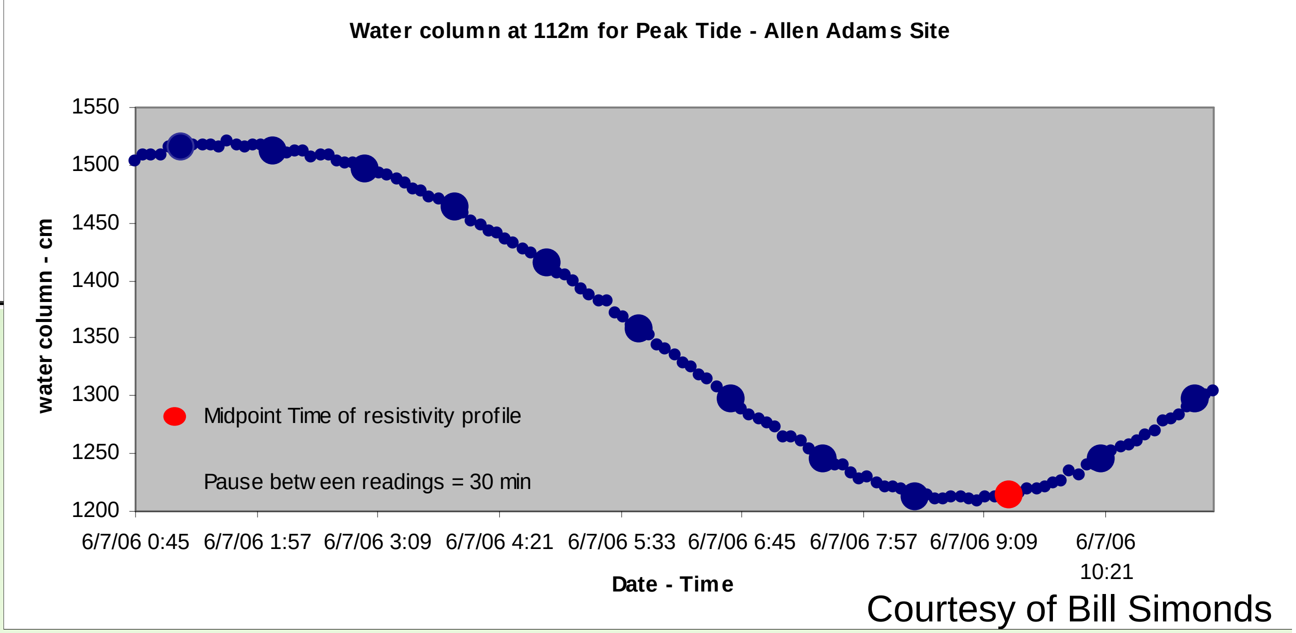


Maximum extent of fresh water



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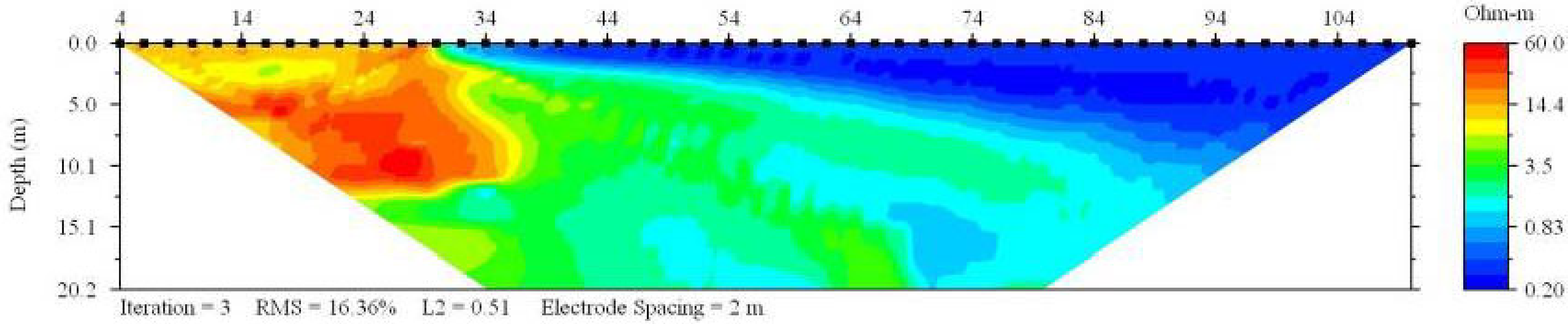

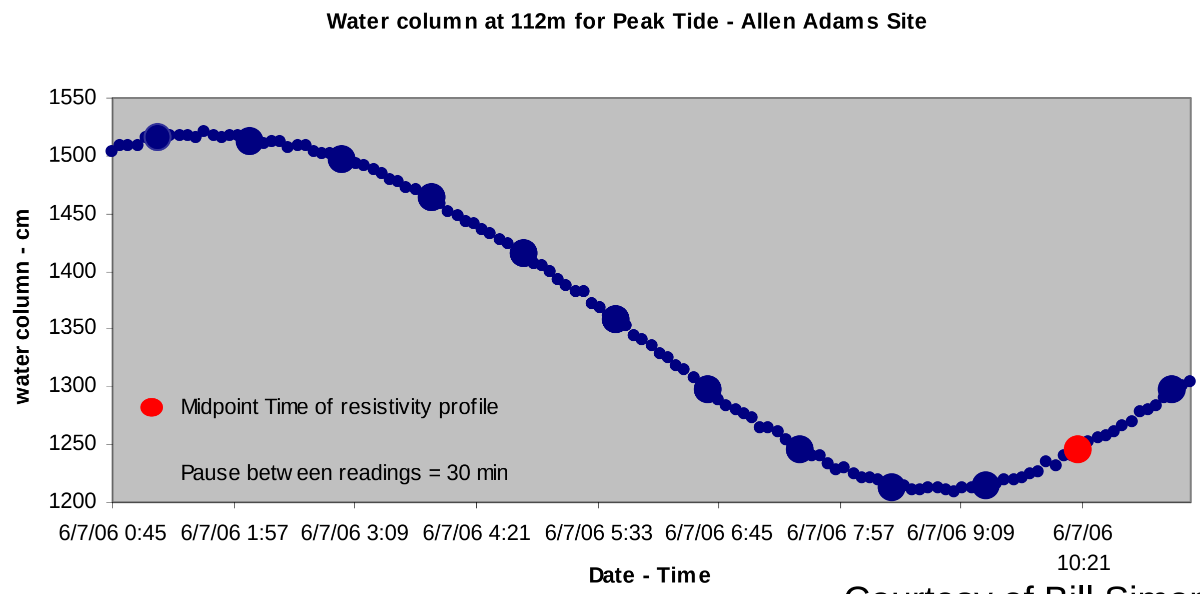

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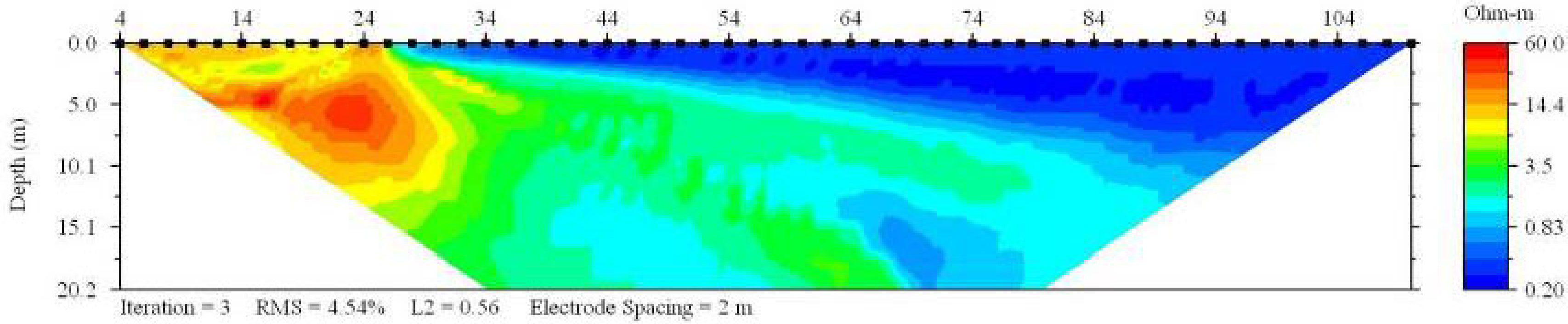

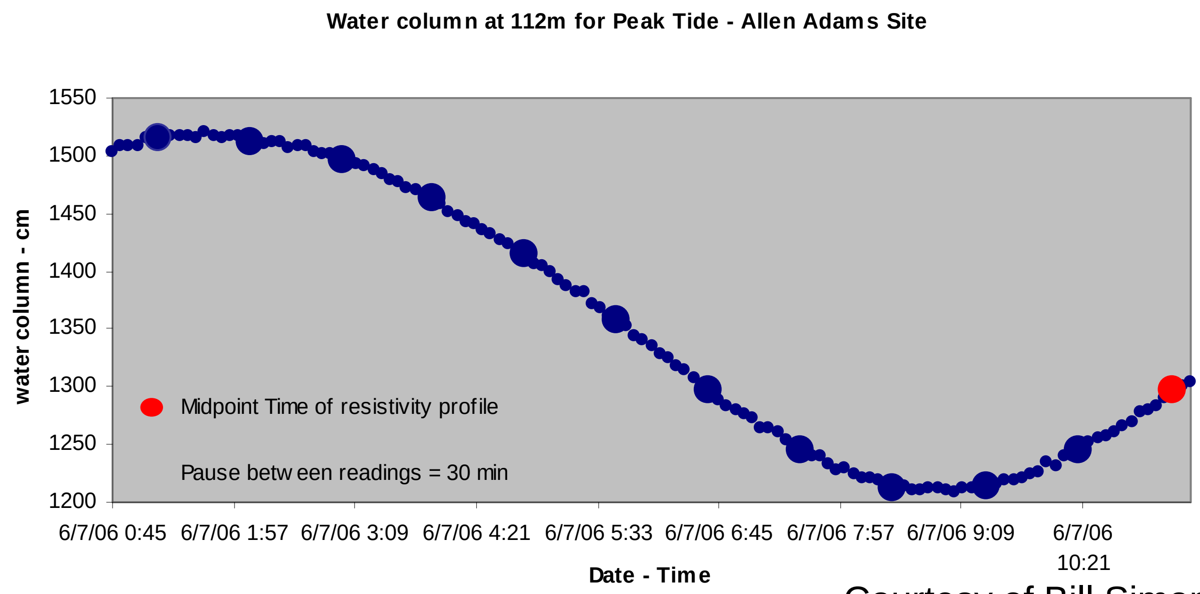

Courtesy of Bill Simonds

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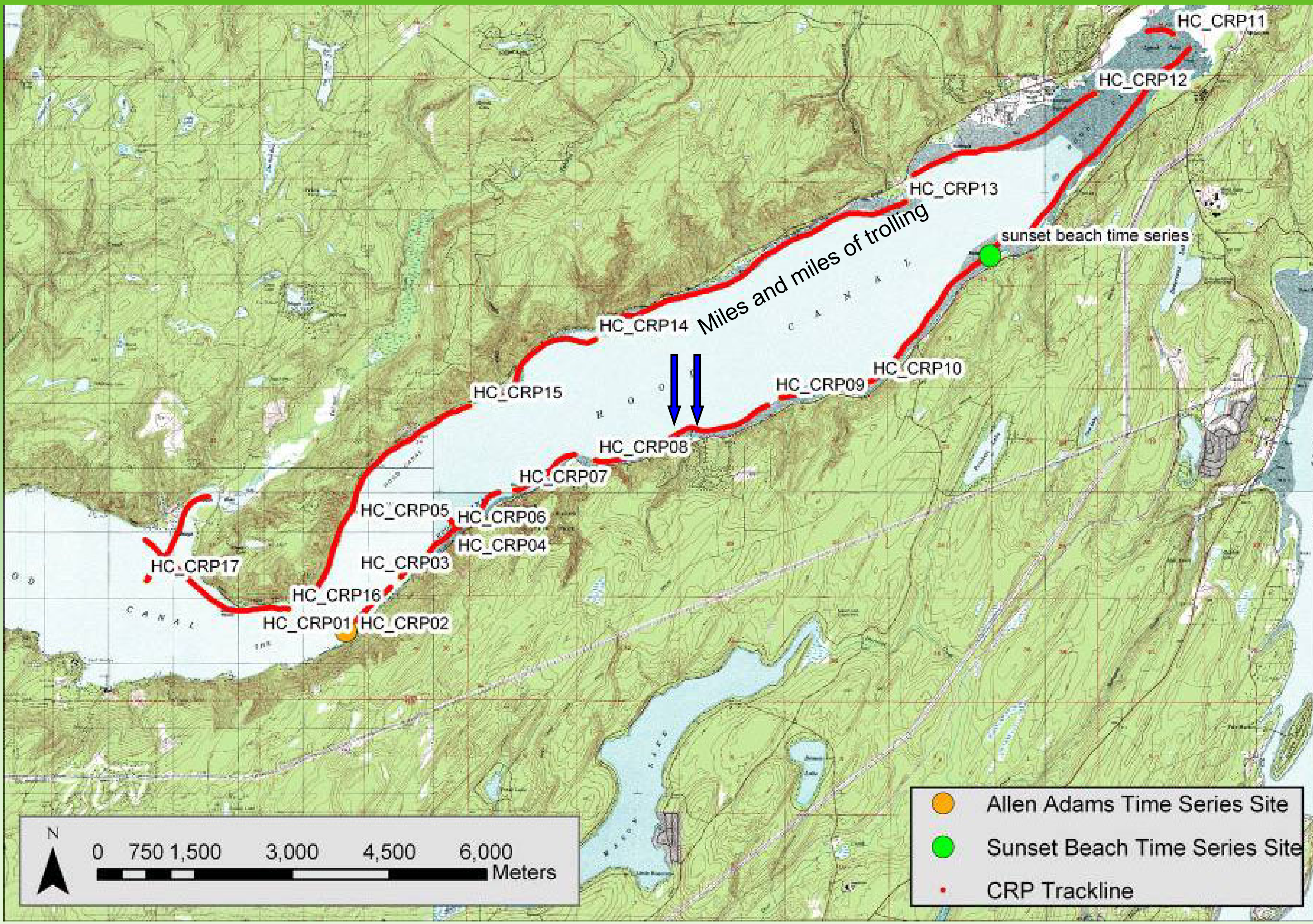
Collected Streaming Resistivity Profiles and continuous Radon along a transect parallel to the shoreline

Courtesy of Bill Simonds



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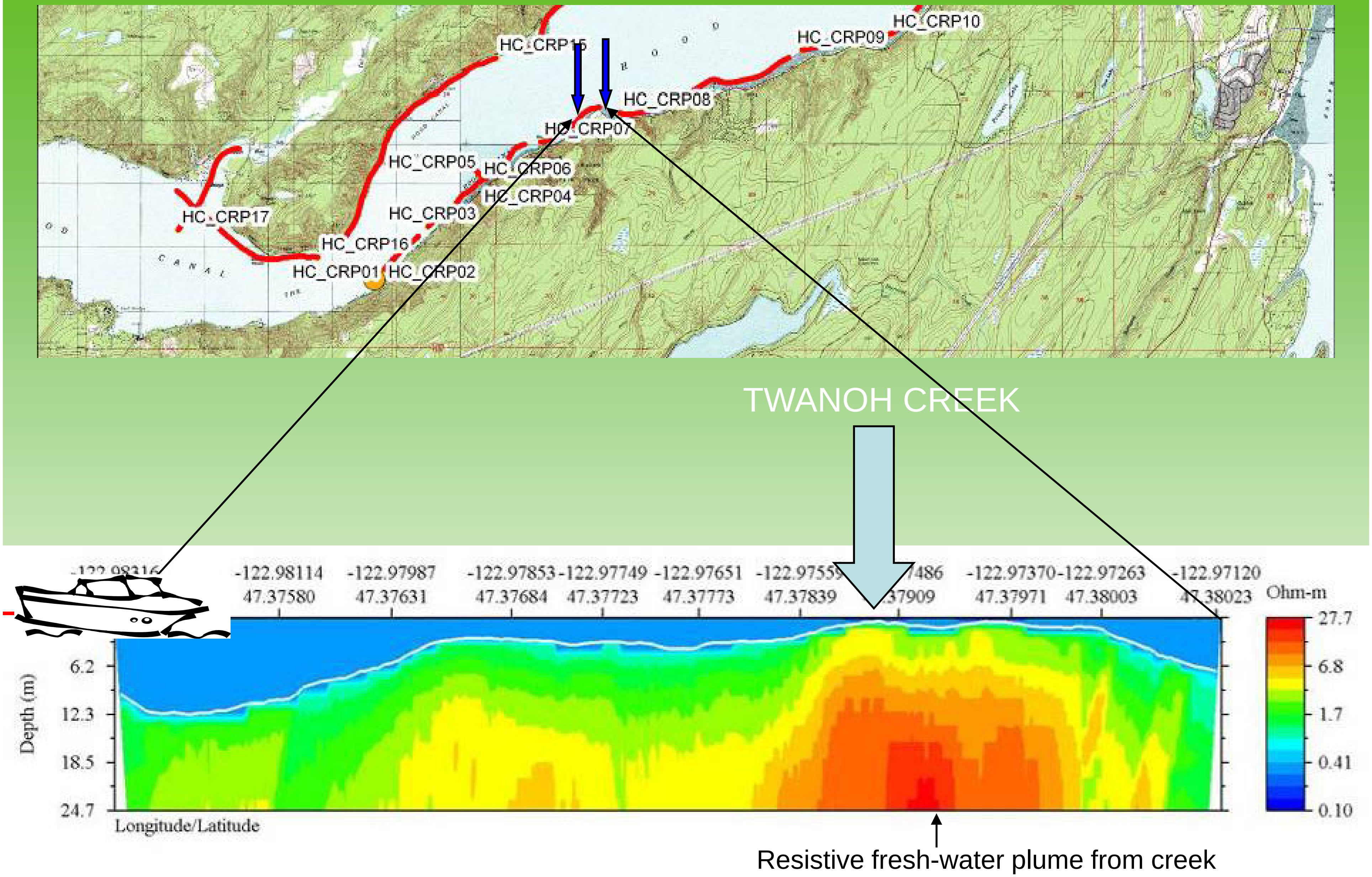
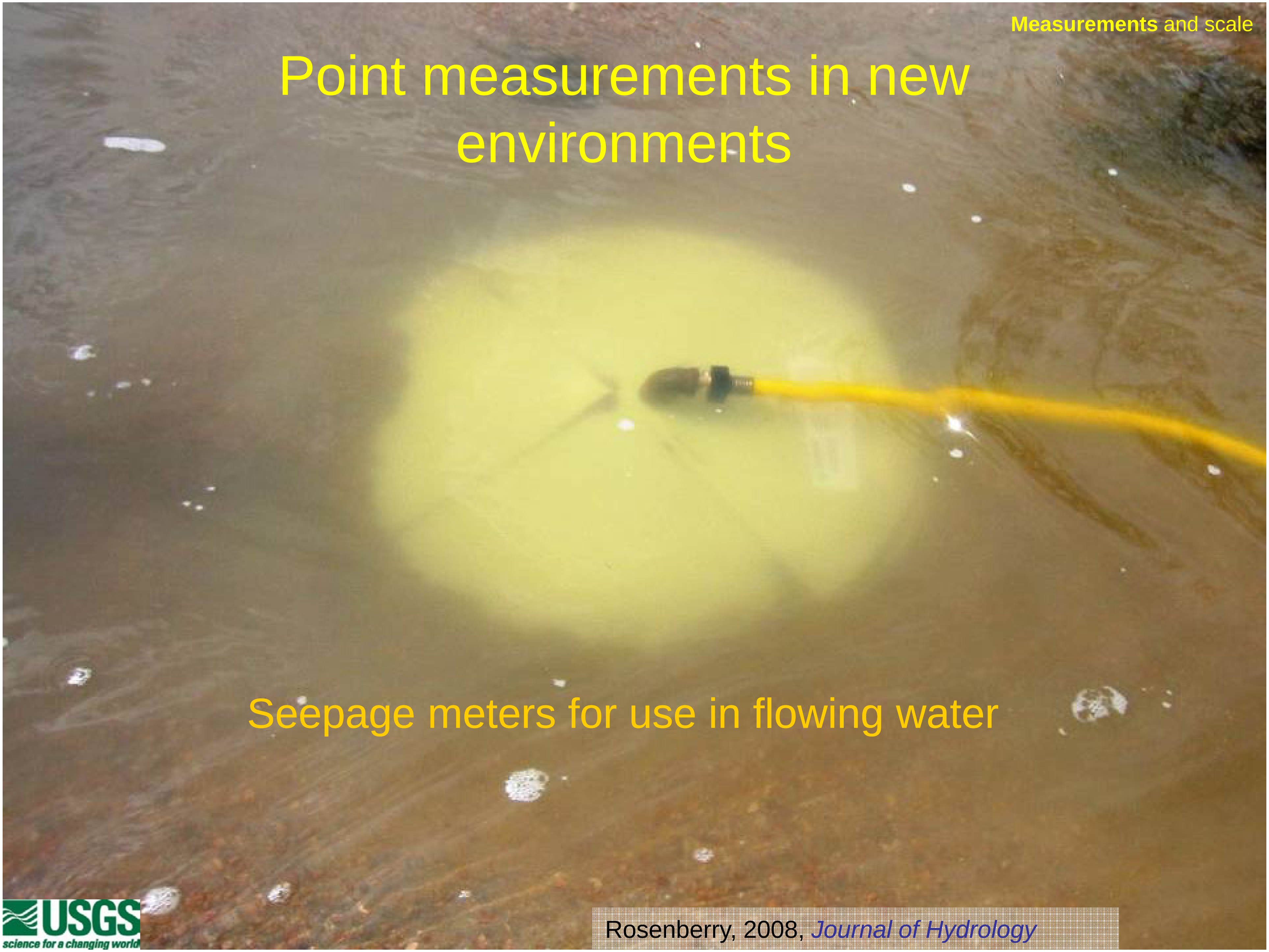
Simonds et al., 2008, *USGS SIR 2008-5078*



Courtesy of Bill Simonds

Point measurements in new environments



Seepage meters for use in flowing water

Rosenberry, 2008, *Journal of Hydrology*

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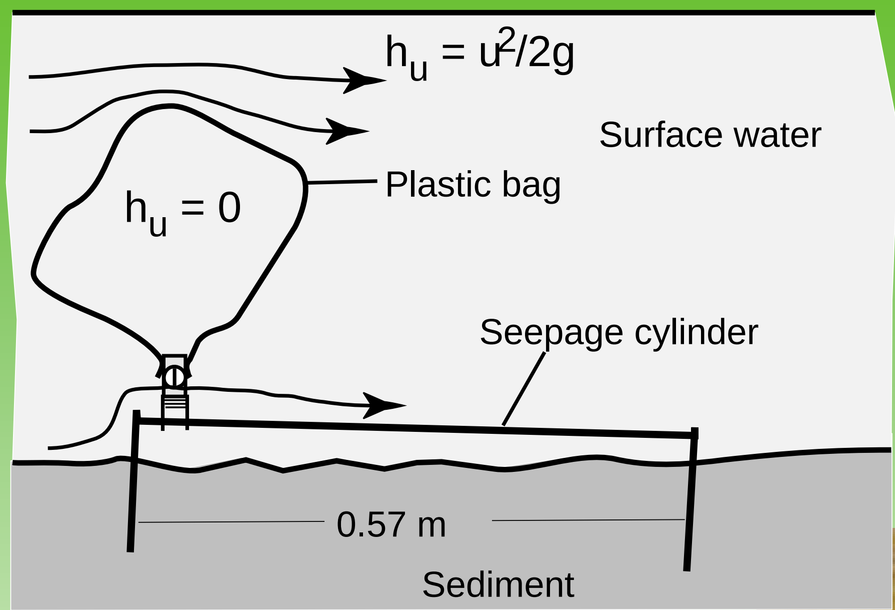
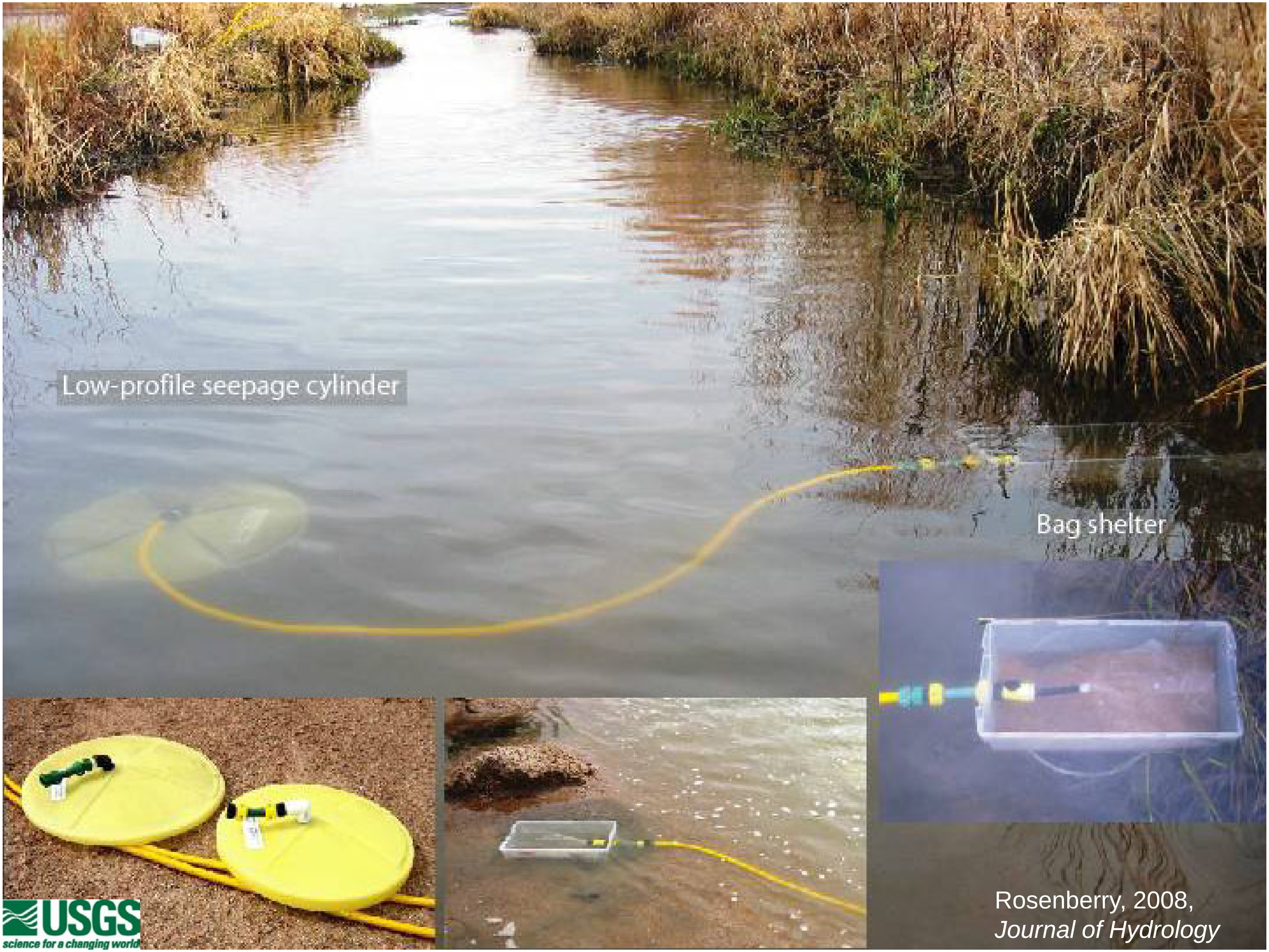
$h_{in} = h_{out} - u^2/2g$

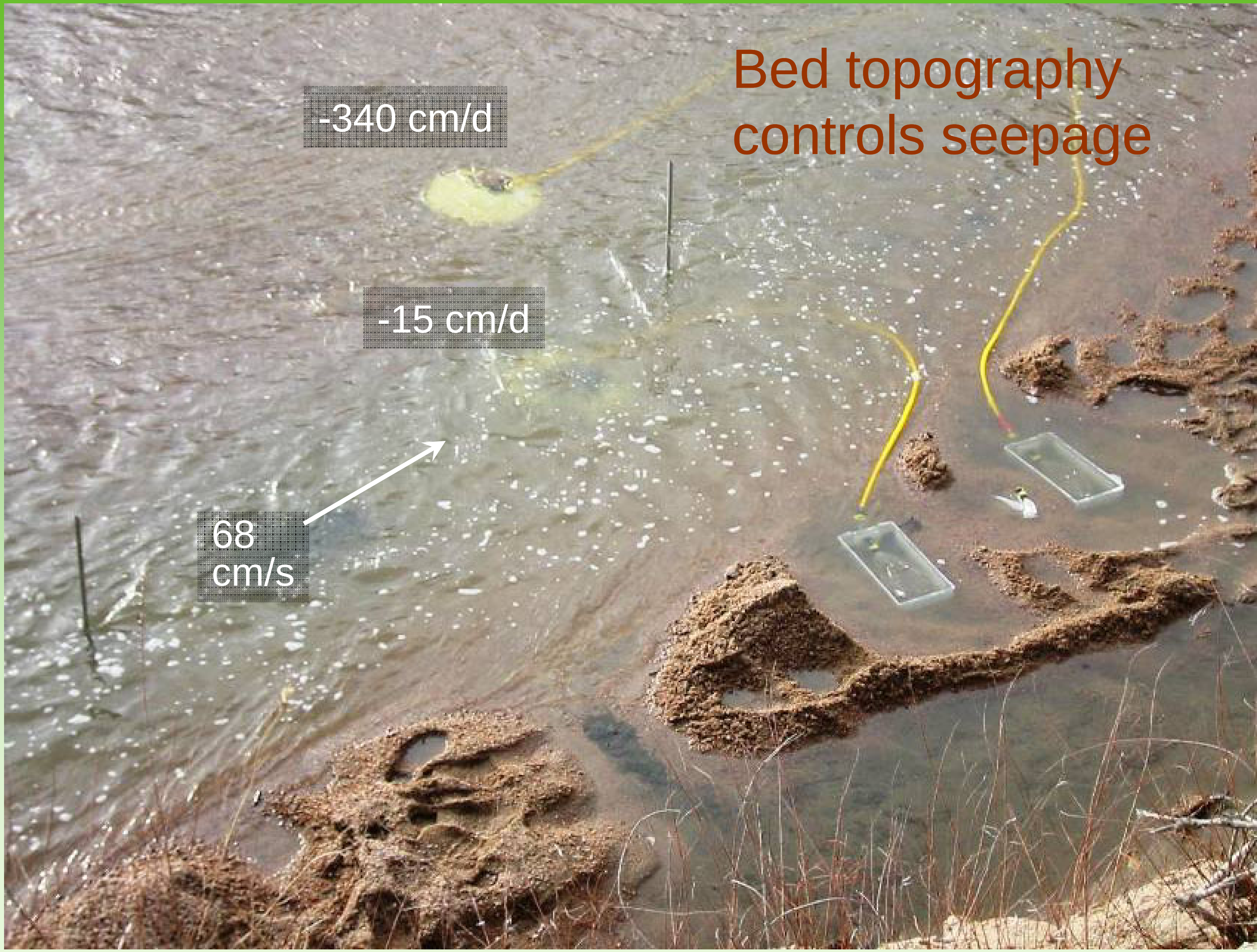


"Seepage meters and Bernoulli's revenge"

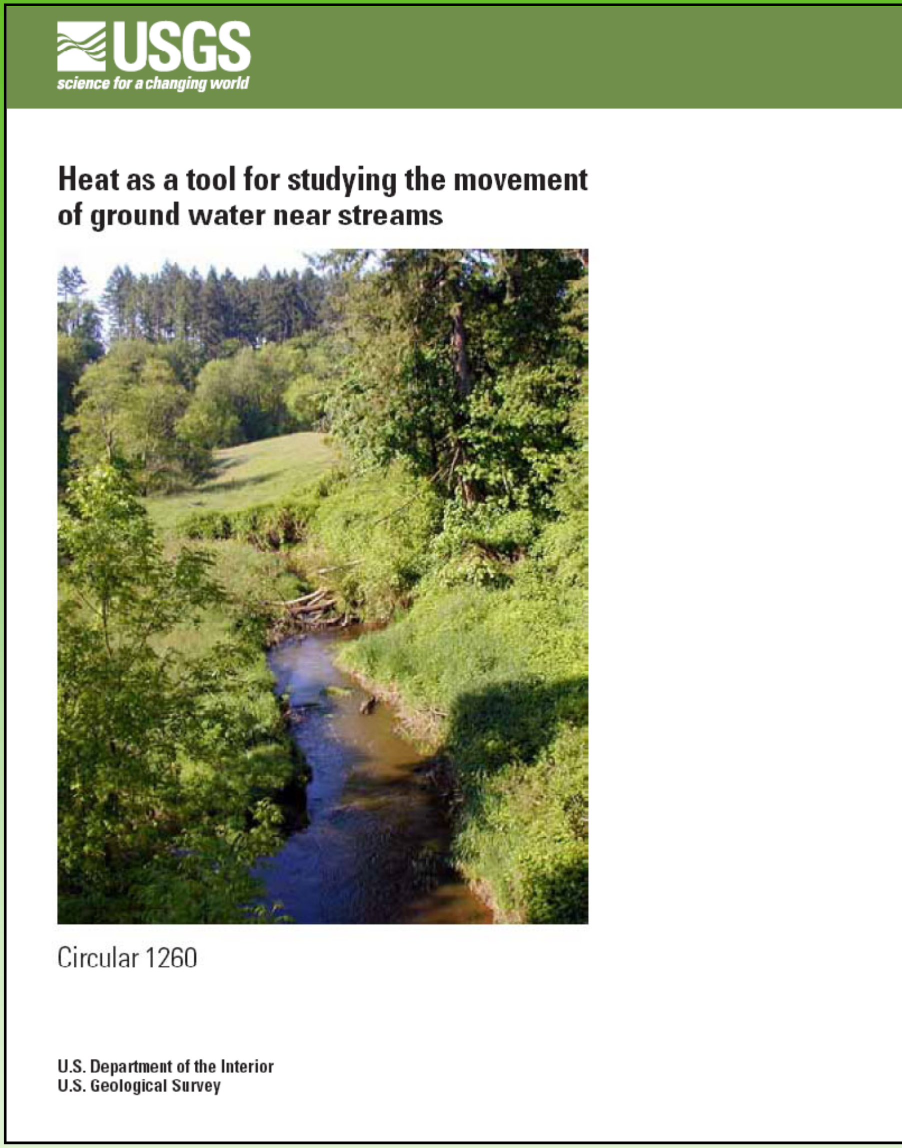
Shinn et al., 2002, *Estuaries*

- "Comment on Bernoulli's revenge" – Corbett & Cable, 2003, *Estuaries*
- "Exonerating Bernoulli?" – Cable et al., 2006, *L&O*


Low-profile seepage cylinder
Bag shelter
USGS
science for a changing world
Rosenberry, 2008,
Journal of Hydrology



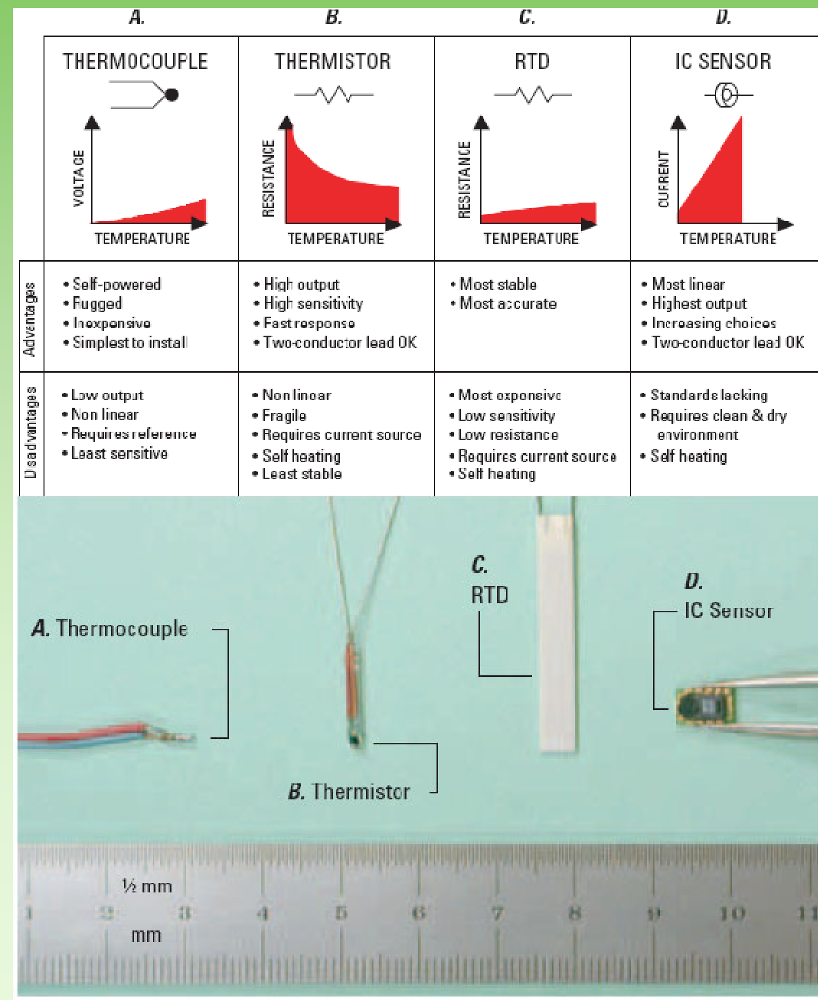
Rosenberry, 2008, *Journal of Hydrology*



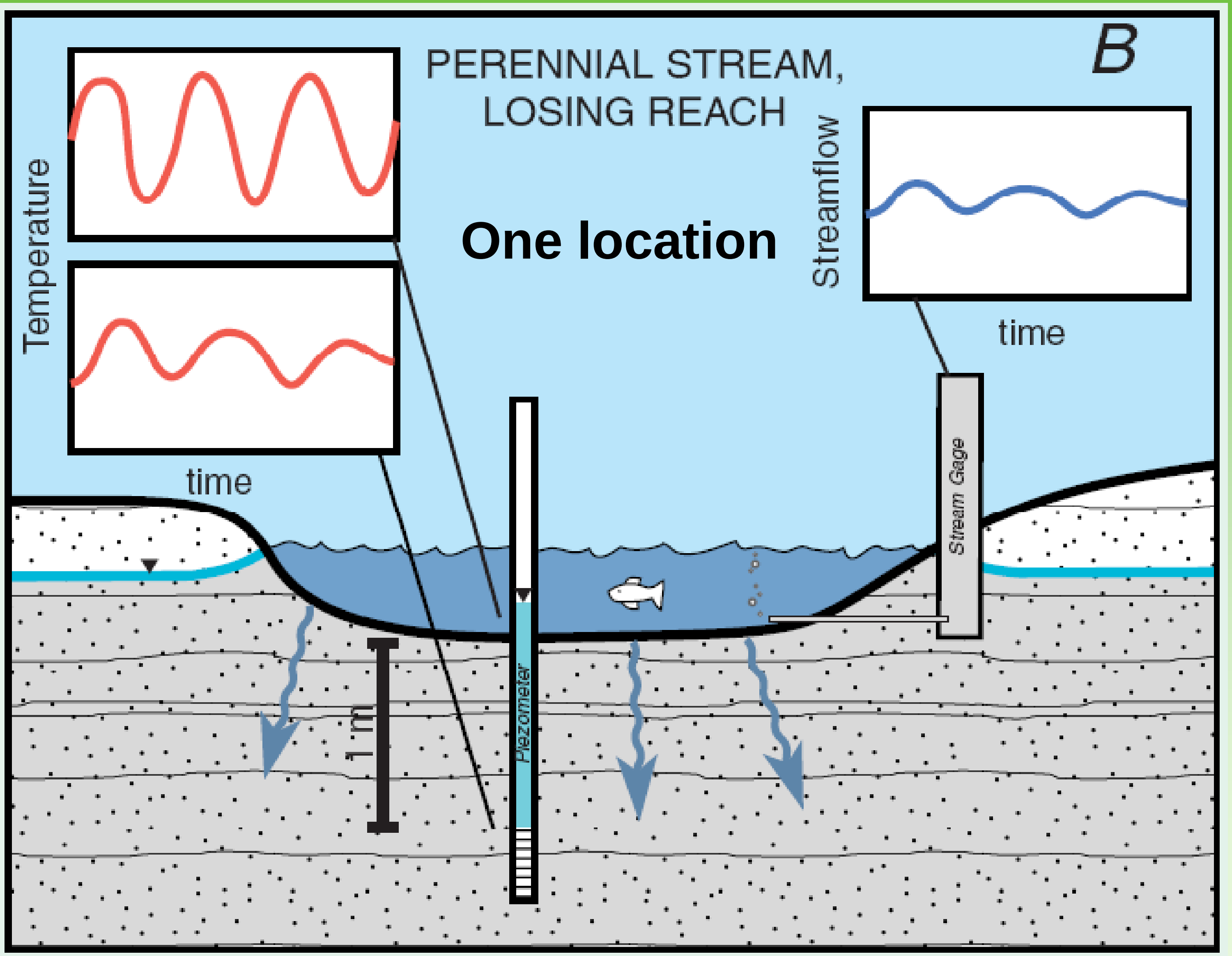
Heat as a Tool for Studying the Movement of Ground Water near Streams

Stonestrom and Constantz, 2003, *USGS Circular*

Very inexpensive measurement

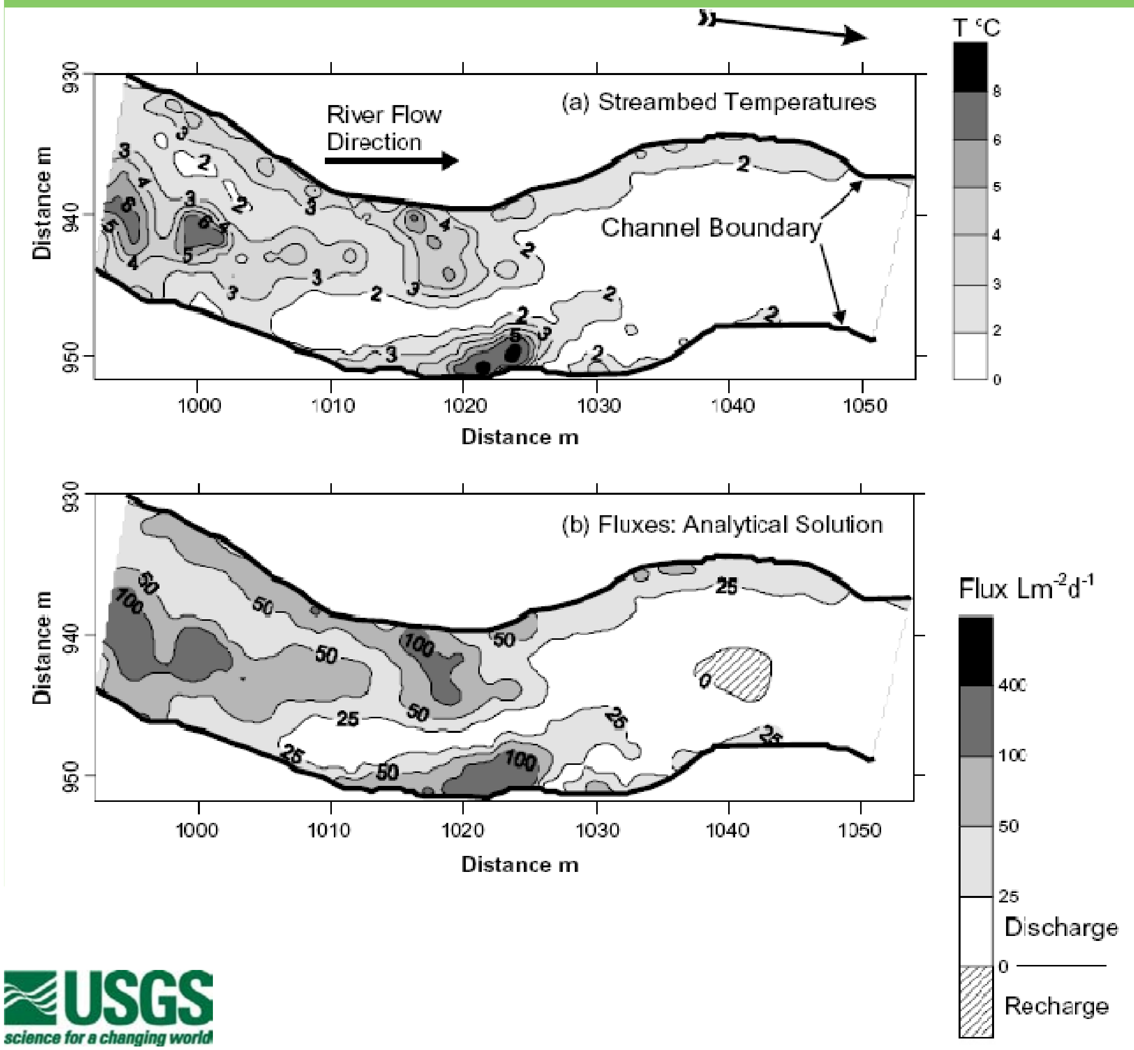


Example showing expected temperature response when stream is losing (Chapter 4, Rosenberry and LaBaugh, 2008, *USGS T&M 4-D2*)



Another method using temperature mapping of bed

Used the Turcotte and Schubert (1982) analytical solution to the one-dimensional steady-state heat-diffusion–advection equation



$$q_z = -\frac{K_{fs}}{\rho_f c_f z} \ln \frac{T(z) - T_L}{T_0 - T_L}$$

q_z = Seepage velocity

$T(z)$ = streambed temperature at depth z

T_L = fixed temperature at bottom of aquifer

T_0 = temperature at depth 0

κ_{fs} = thermal conductivity

$\rho_f c_f$ = volumetric heat capacity of the fluid

z = depth beneath the sediment-water interface

Schmidt et al., 2007, *Journal of Hydrology*

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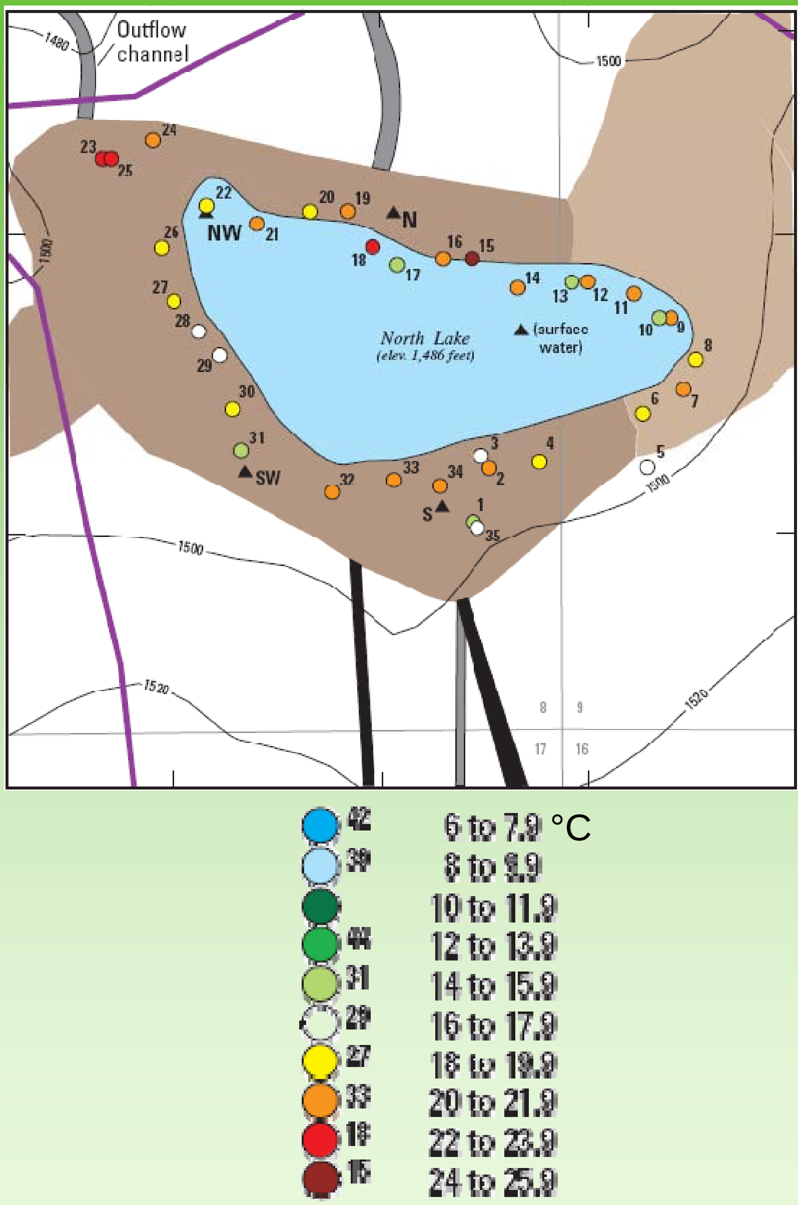
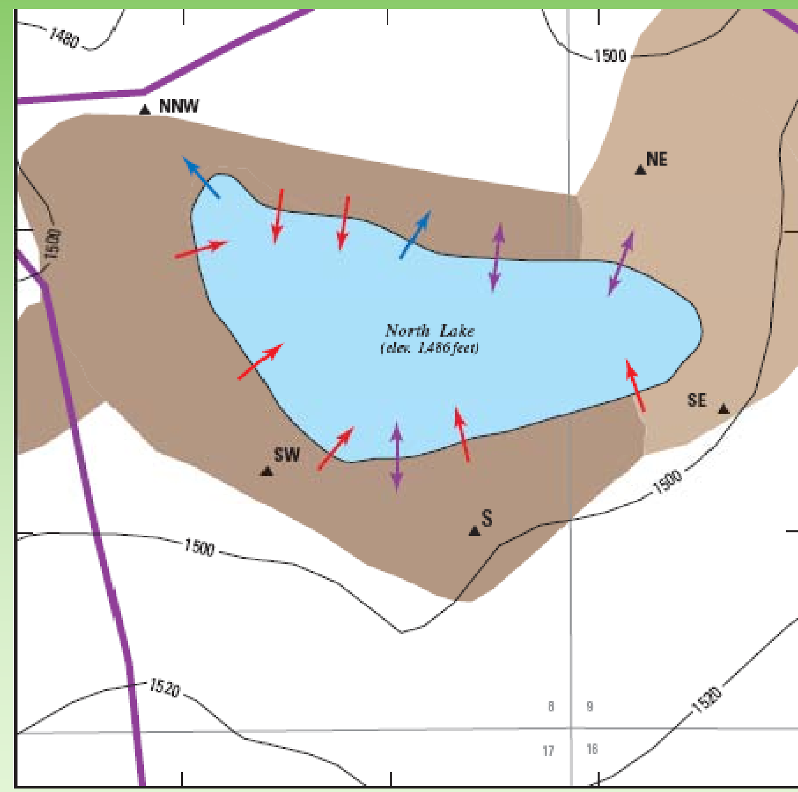
Grand Portage Reservation, MN



- Used temperature, isotope ratios, water chemistry, nutrients to assess GW-SW exchange
- Temperature was easiest and worked the best



Perry Jones, *USGS SIR2006-5034*

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What’s next?

Biological effects

- Bioturbation
  - Benthic invertebrates can manipulate sediment
  - In some cases, burrow tubes and fecal pellets have higher *K* than sediment (e.g., Nogaro et al., 2006, *Freshwater Biology*)
  - Fish work the sediment, disturb algal growth, contribute to sediment transport (e.g., Statzner, 2003, *WRR*)
- Bioirrigation
  - Filter feeders can create their own seepage

Bioirrigation

Bioirrigating organism		Linear velocity, cm day^{-1}
Common name	**Species**	
Ghost shrimp[1]	*Callianassa sp.*	0.2
Mud shrimp[2]	*Upogebia affinis* (?)	2.2
Lugworm[3]	*Arenicola marina*	1.6
Plumed worm[4]	*Diopatra cuprea*	1.3
		5

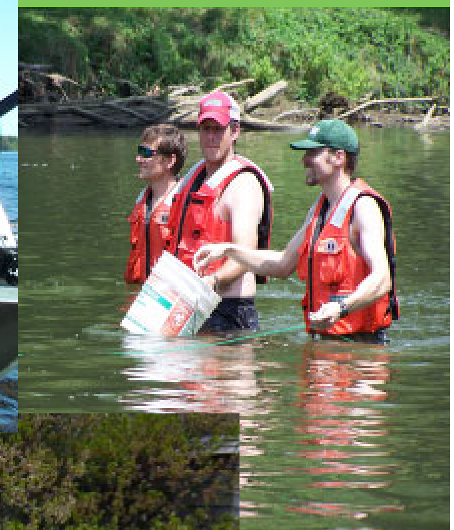
Cable et al., 2006, *Limnology and Oceanography Methods*

Freshwater bioirrigation

- Rusty crayfish
- Lakes in Minnesota
- ~25 cm/d
- Watch for holes in bed beneath and adjacent to seepage meter

Fiber Optic – Distributed temperature system (DTS)

- High spatial resolution (~0.5 to 1 m)
- High precision (0.01 degC)
- Large scale (10's of km possible)
- Continuous measurement (in time and space)
- Continuous data download (no retrieval/disturbance)
- Long-term installation possible



Courtesy of Fred Day-Lewis

Waquoit Bay, Cape Cod, MA

FO-DTS Study Area

- DTS Cable zig-zags over a 80-m by 60-m area
- As configured:
  - Spatial resolution along cable = ~1 m
  - Temporal resolution = ~1 min
  - Thermal resolution = 0.1 deg C

Courtesy of Fred Day-Lewis

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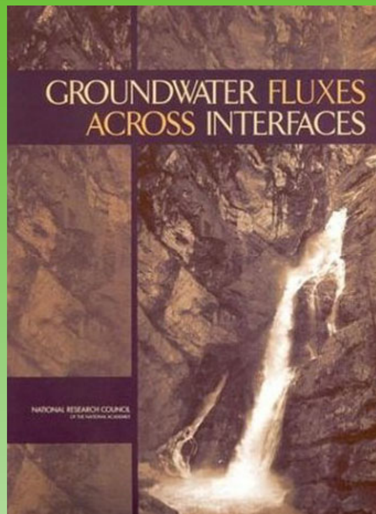
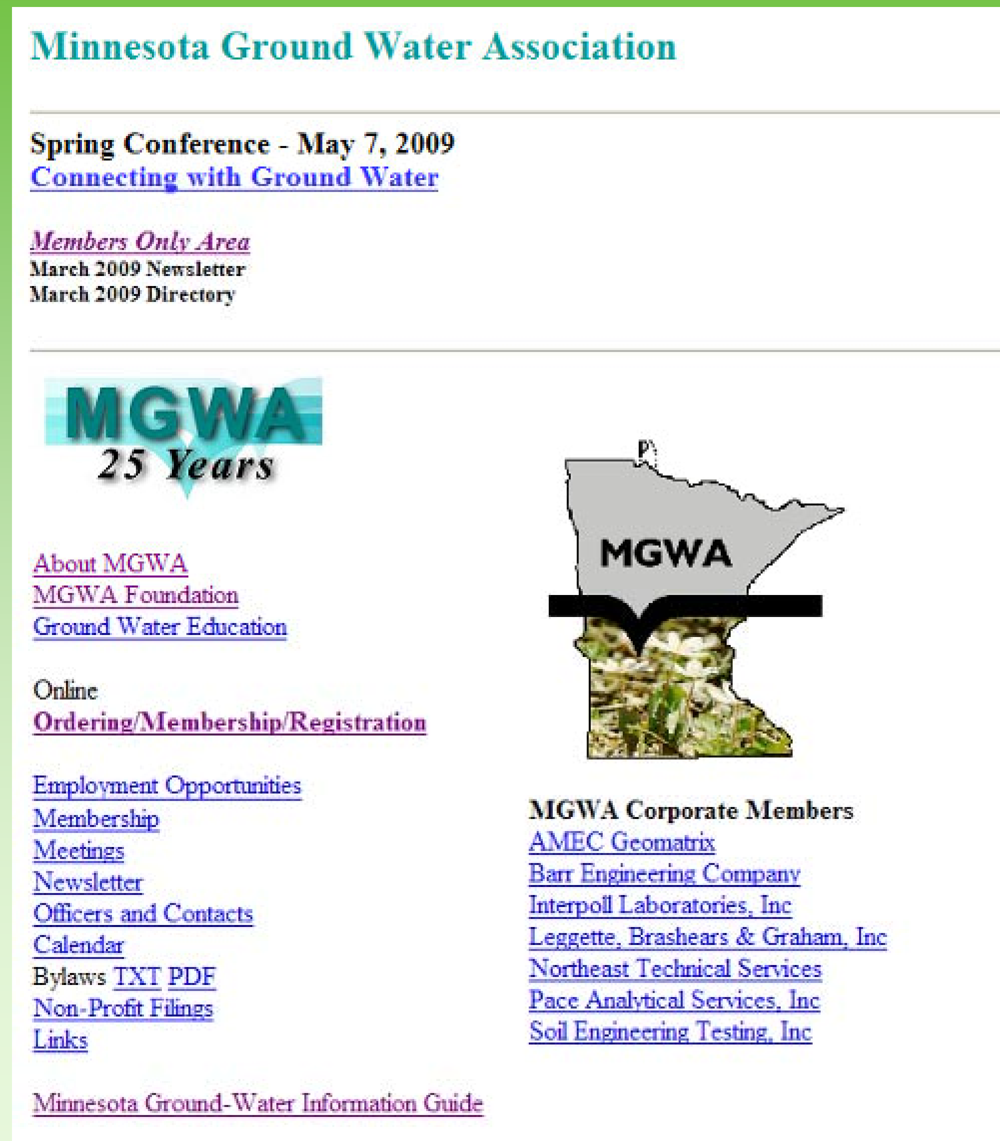
Minnesota is leading the way



NRC Major Findings

1. Quantify spatial and temporal variability
2. Groundwater and climate change
3. Better measurements and deal with temporal and spatial scales


Minnesota Ground Water Association

Spring Conference - May 7, 2009
Connecting with Ground Water

Members Only Area
March 2009 Newsletter
March 2009 Directory

MGWA
25 Years

About MGWA
MGWA Foundation
Ground Water Education

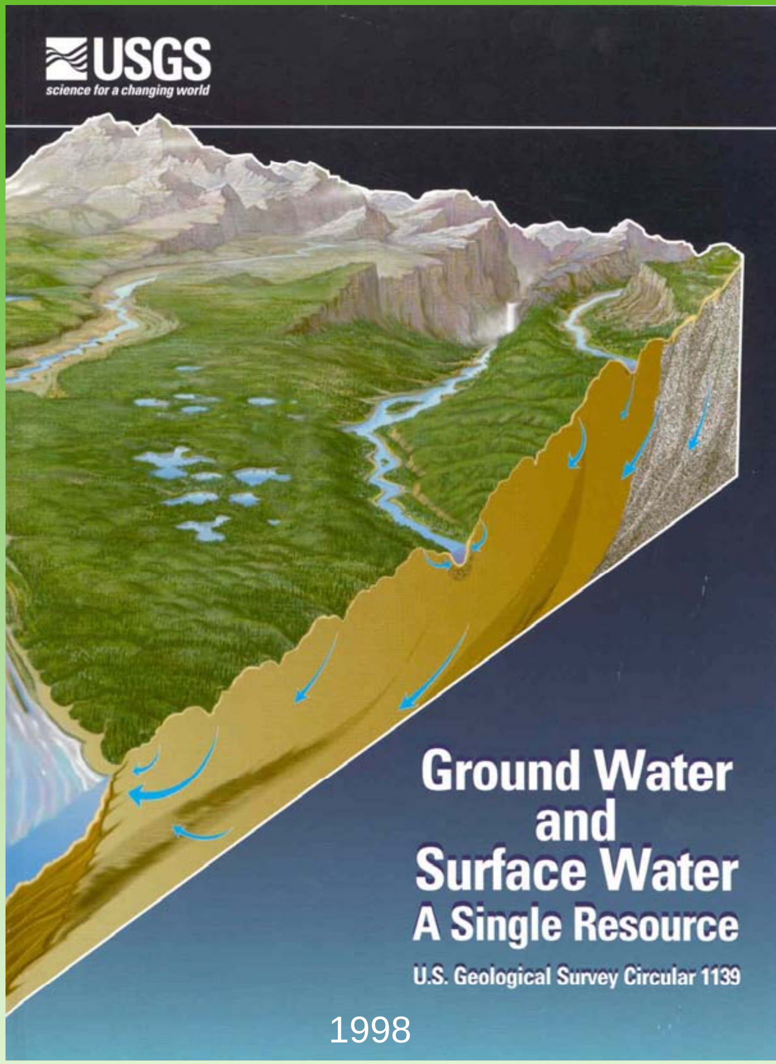
Online
Ordering/Membership/Registration

Employment Opportunities
Membership
Meetings
Newsletter
Officers and Contacts
Calendar
Bylaws TXT PDF
Non-Profit Filings
Links

Minnesota Ground-Water Information Guide

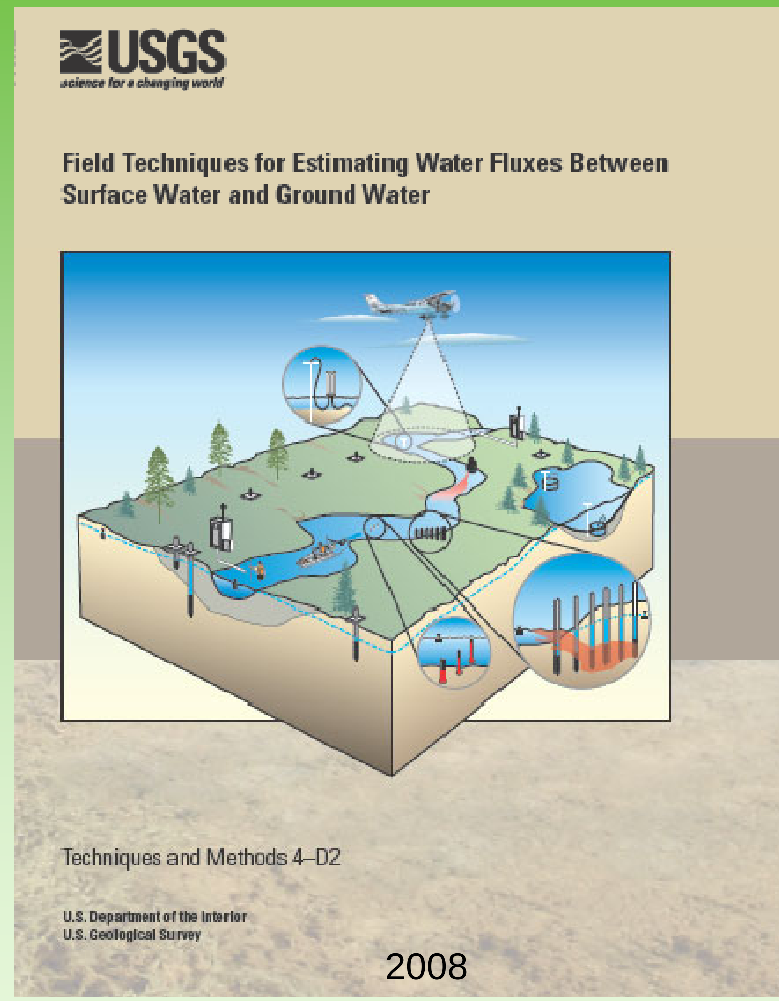
MGWA

MGWA Corporate Members
AMEC Geomatrix
Barr Engineering Company
Interpoll Laboratories, Inc
Leggette, Brashears & Graham, Inc
Northeast Technical Services
Pace Analytical Services, Inc
Soil Engineering Testing, Inc



Why

How



Thanks, Jim Lundy!

Questions?


I sure hope this slug test finishes before Shamu's cousin finds me!

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