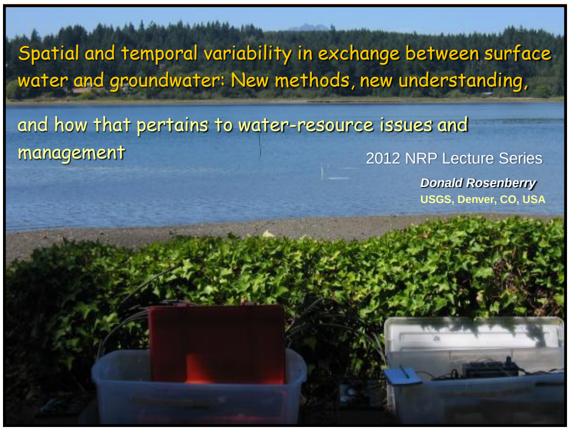
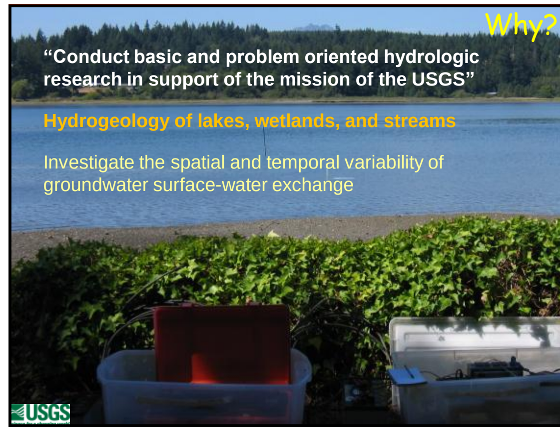
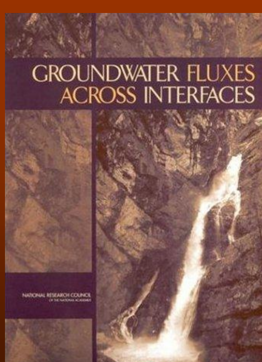




Why?



NRC Committee – New/recent challenges

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JOHN L. WILSON, New Mexico Tech, Socorro, New Mexico

NRC Staff

WILLIAM S. LOGAN, Project Director, Water Science and Technology Board
ANITA A. HALL, Senior Project Assistant, Water Science and Technology Board

USGS

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

USGS

Geological controls

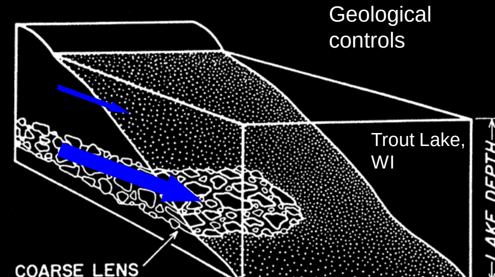
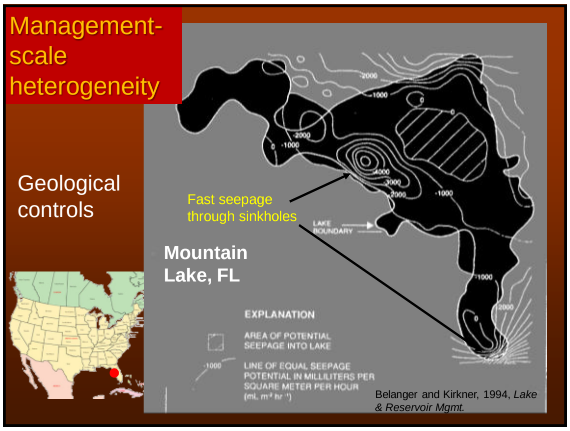
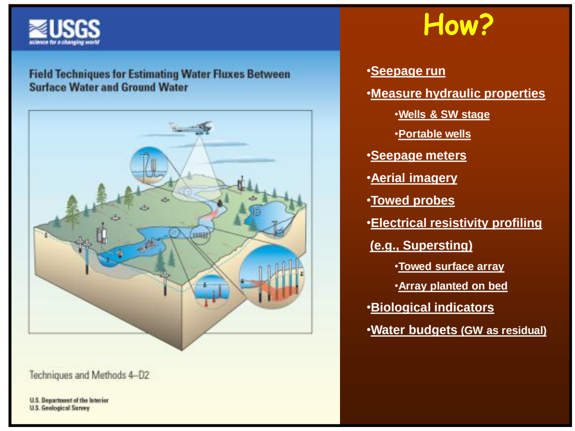
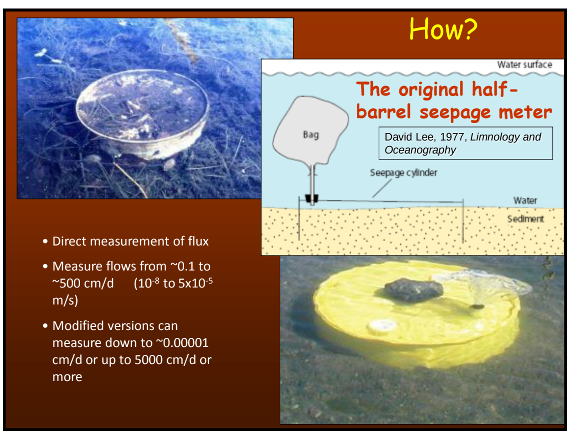


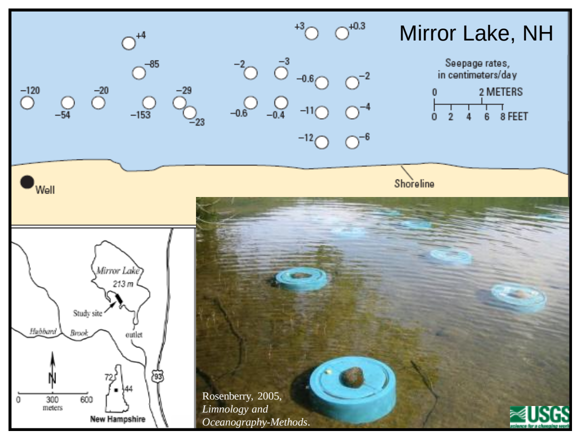
Fig. 5. Three-dimensional schematic drawing of the hypothesized situation at Trout Lake showing a coarse lens intersecting the lakebed.

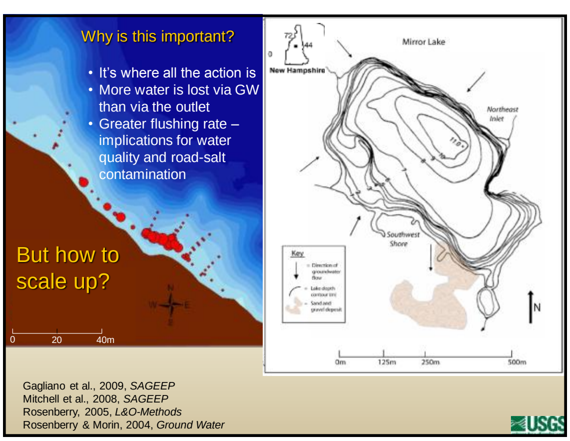
Krabbenhoft and Anderson, 1986, *Ground Water*

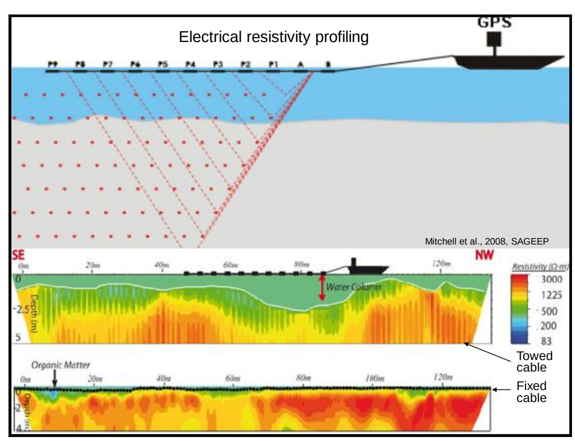

Management-scale heterogeneity
Geological controls
Fast seepage through sinkholes
Mountain Lake, FL
LAKE BOUNDARY
EXPLANATION
AREA OF POTENTIAL SEEPAGE INTO LAKE
LINE OF EQUAL SEEPAGE POTENTIAL IN MILLILITERS PER SQUARE METER PER HOUR (mL m⁻² hr⁻¹)
Belanger and Kirkner, 1994, Lake & Reservoir Mgmt.

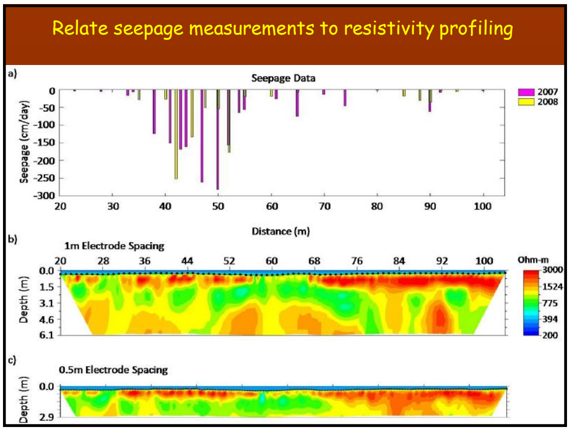

USGS
science for a changing world
Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water
Techniques and Methods 4–D2
U.S. Department of the Interior
U.S. Geological Survey
How?
•Seepage run
•Measure hydraulic properties
•Wells & SW stage
•Portable wells
•Seepage meters
•Aerial imagery
•Towed probes
•Electrical resistivity profiling (e.g., Superstring)
•Towed surface array
•Array planted on bed
•Biological indicators
•Water budgets (GW as residual)

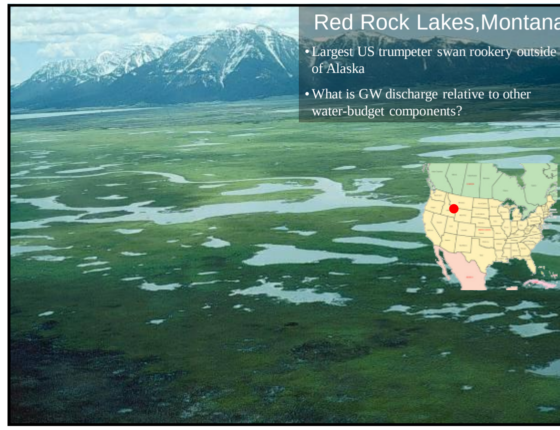

How?
Water surface
The original half-barrel seepage meter
David Lee, 1977, Limnology and Oceanography
Bag
Seepage cylinder
Water
Sediment
• Direct measurement of flux
• Measure flows from ~0.1 to ~500 cm/d (10⁻⁸ to 5x10⁻⁵ m/s)
• Modified versions can measure down to ~0.00001 cm/d or up to 5000 cm/d or more

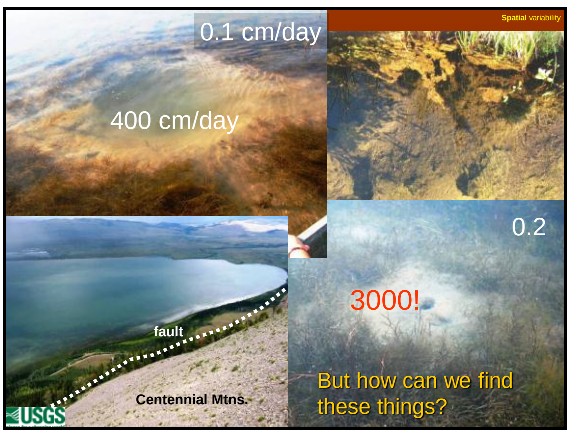

Mirror Lake, NH
Seepage rates, in centimeters/day
0 2 METERS
0 2 4 6 8 FEET
Well
Shoreline
Mirror Lake
213 m
Study site
outlet
Hubbard Brook
N
0 300 600 meters
New Hampshire
Rosenberry, 2005, Limnology and Oceanography-Methods.
USGS


Why is this important?
• It's where all the action is
• More water is lost via GW than via the outlet
• Greater flushing rate – implications for water quality and road-salt contamination
But how to scale up?
0 20 40m
Mirror Lake
New Hampshire
Northeast Inlet
Southwest Shore
Key
0m 125m 250m 500m
N
Gagliano et al., 2009, SAGEEP
Mitchell et al., 2008, SAGEEP
Rosenberry, 2005, L&O-Methods
Rosenberry & Morin, 2004, Ground Water
USGS


Electrical resistivity profiling
GPS
Mitchell et al., 2008, SAGEEP
SE
NW
Water Column
Depth (m)
Resistivity (Ω-m)
3000
1225
500
200
83
Towed cable
Organic Matter
Fixed cable

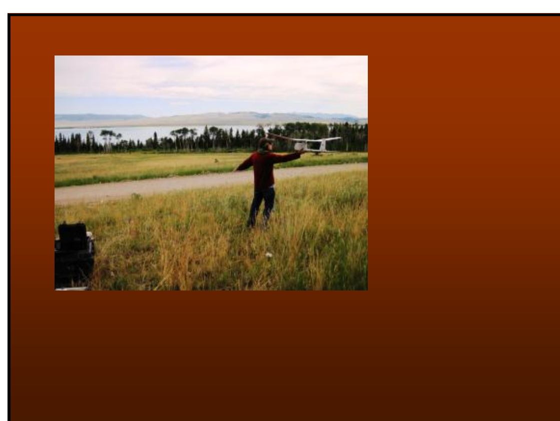

Relate seepage measurements to resistivity profiling
a)
Seepage Data
Seepage (cm/day)
0
-50
-100
-150
-200
-250
-300
20 30 40 50 60 70 80 90 100
Distance (m)
2007
2008
b)
1m Electrode Spacing
20 28 36 44 52 60 68 76 84 92 100
Depth (m)
0.0
1.5
3.1
4.6
6.1
Ohm-m
3000
1524
775
394
200
c)
0.5m Electrode Spacing
Depth (m)
0.0
2.9

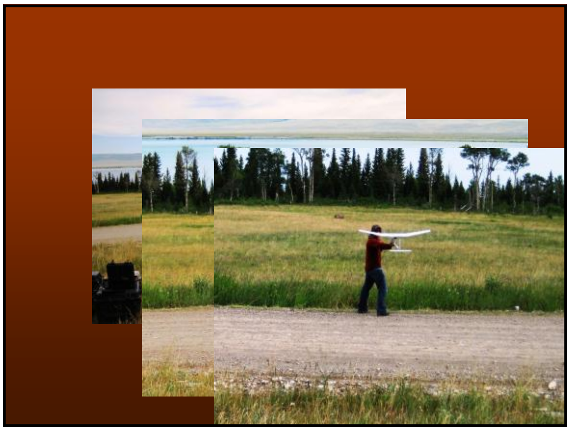

Red Rock Lakes,Montana
• Largest US trumpeter swan rookery outside of Alaska
• What is GW discharge relative to other water-budget components?

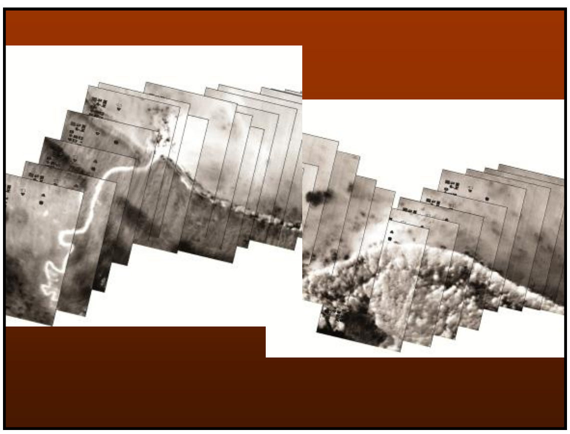

0.1 cm/day
Spatial variability
400 cm/day
0.2
3000!
fault
Centennial Mtns.
USGS
But how can we find these things?

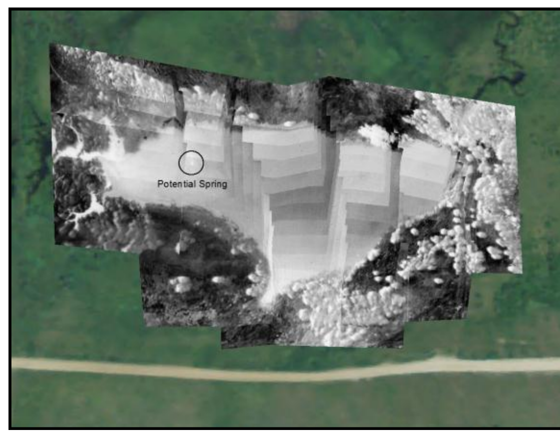

USGS "Air Force"
USGS

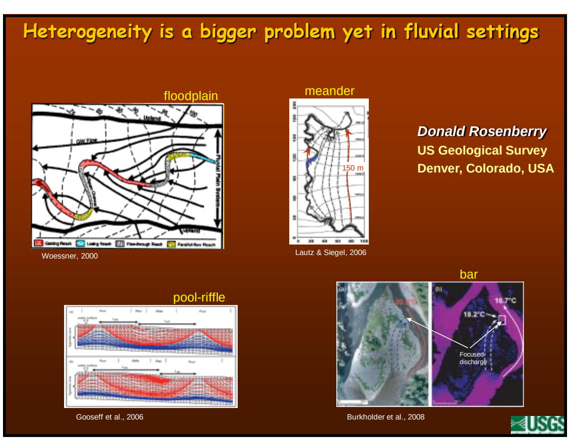

Todd Preston
Nose cone – front, side, or bottom-view
color or IR camera

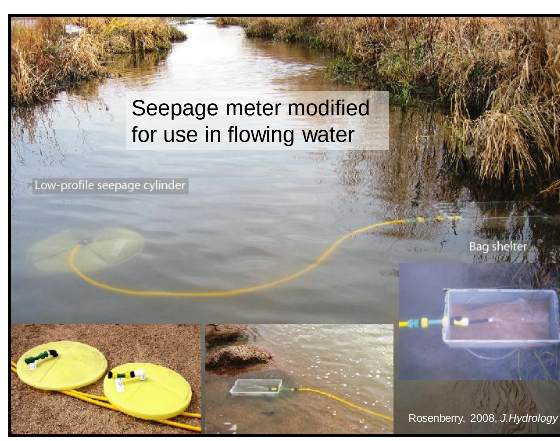


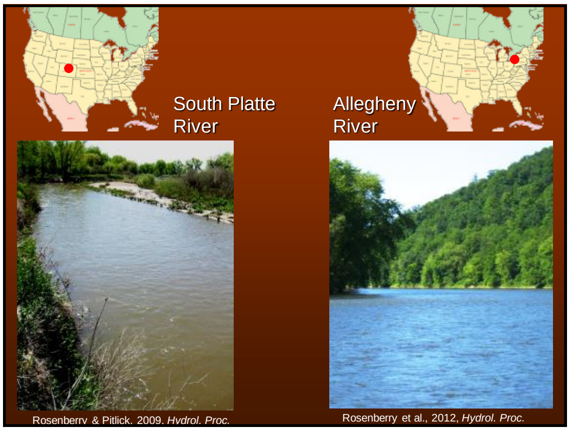


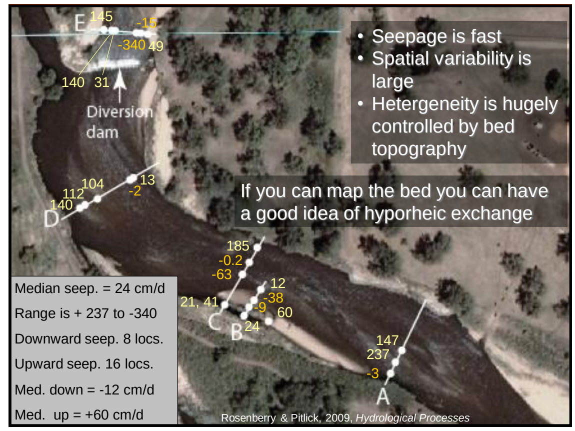


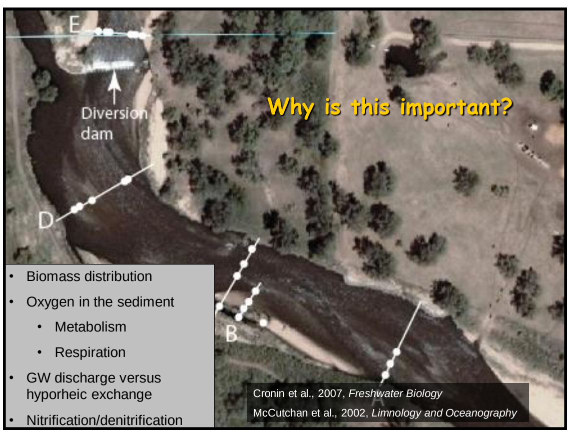

Potential Spring

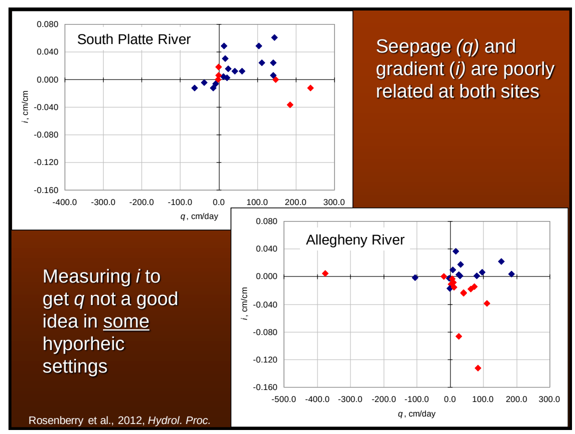

Heterogeneity is a bigger problem yet in fluvial settings
floodplain
Woessner, 2000
meander
Lautz & Siegel, 2006
Donald Rosenberry
US Geological Survey
Denver, Colorado, USA
pool-riffle
Gooseff et al., 2006
bar
Burkholder et al., 2008
USGS

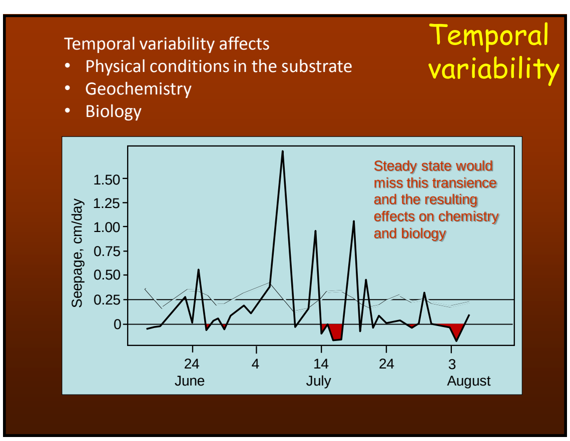

Seepage meter modified for use in flowing water
Low-profile seepage cylinder
Bag shelter
Rosenberry, 2008, J.Hydrology

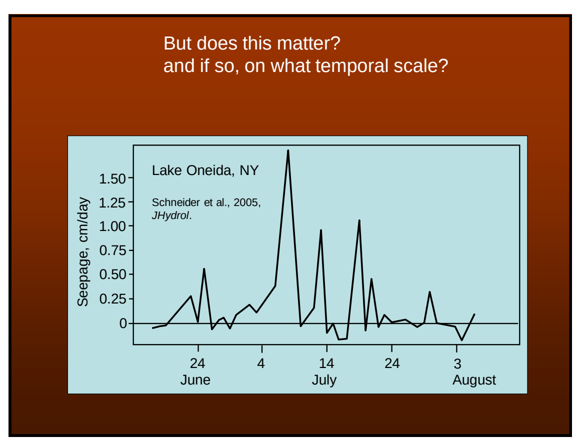

South Platte
River
Allegheny
River
Rosenberry & Pitlick, 2009, Hydrol. Proc.
Rosenberry et al., 2012, Hydrol. Proc.

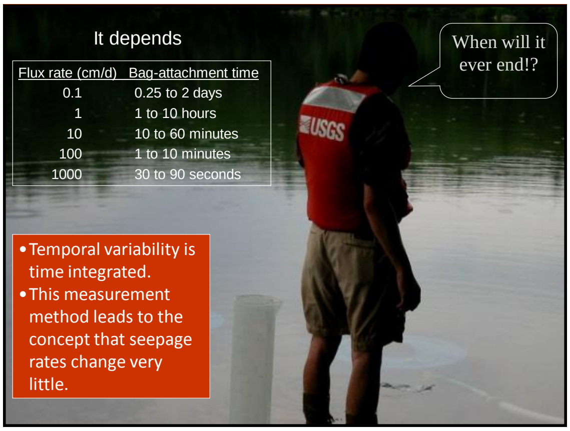

• Seepage is fast
• Spatial variability is large
• Hetergeneity is hugely controlled by bed topography
If you can map the bed you can have a good idea of hyporheic exchange
Diversion dam
Median seep. = 24 cm/d
Range is + 237 to -340
Downward seep. 8 locs.
Upward seep. 16 locs.
Med. down = -12 cm/d
Med. up = +60 cm/d
E
D
C
B
A
Rosenberry & Pitlick, 2009, Hydrological Processes


Why is this important?
Diversion dam
E
D
B
• Biomass distribution
• Oxygen in the sediment
• Metabolism
• Respiration
• GW discharge versus hyporheic exchange
• Nitrification/denitrification
Cronin et al., 2007, Freshwater Biology
McCutchan et al., 2002, Limnology and Oceanography

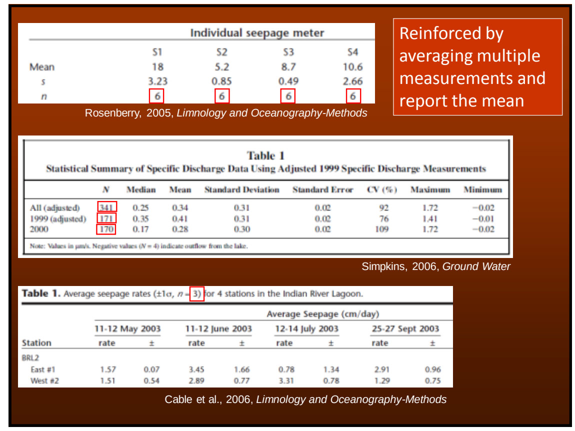

South Platte River
i, cm/cm
q, cm/day
Seepage (q) and gradient (i) are poorly related at both sites
Measuring i to get q not a good idea in some hyporheic settings
Allegheny River
Rosenberry et al., 2012, Hydrol. Proc.


Temporal variability affects
• Physical conditions in the substrate
• Geochemistry
• Biology
Temporal variability
Steady state would miss this transience and the resulting effects on chemistry and biology
Seepage, cm/day
24
June
4
14
July
24
3
August


But does this matter?
and if so, on what temporal scale?
Lake Oneida, NY
Schneider et al., 2005, JHydrol.
Seepage, cm/day
24
June
4
14
July
24
3
August



Flux rate (cm/d)	Bag-attachment time
0.1	0.25 to 2 days
1	1 to 10 hours
10	10 to 60 minutes
100	1 to 10 minutes
1000	30 to 90 seconds



	Individual seepage meter			
	S1	S2	S3	S4
Mean	18	5.2	8.7	10.6
s	3.23	0.85	0.49	2.66
n	6	6	6	6

Rosenberry, 2005, *Limnology and Oceanography-Methods*

Table 1
Statistical Summary of Specific Discharge Data Using Adjusted 1999 Specific Discharge Measurements

	N	Median	Mean	Standard Deviation	Standard Error	CV (%)	Maximum	Minimum
All (adjusted)	341	0.25	0.34	0.31	0.02	92	1.72	−0.02
1999 (adjusted)	171	0.35	0.41	0.31	0.02	76	1.41	−0.01
2000	170	0.17	0.28	0.30	0.02	109	1.72	−0.02

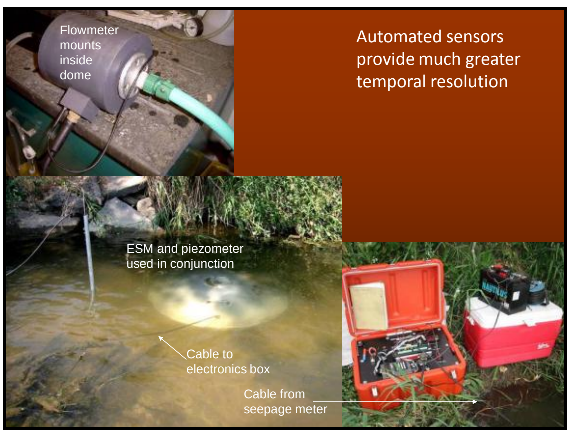
Note: Values in μm/s. Negative values ($N = 4$) indicate outflow from the lake.

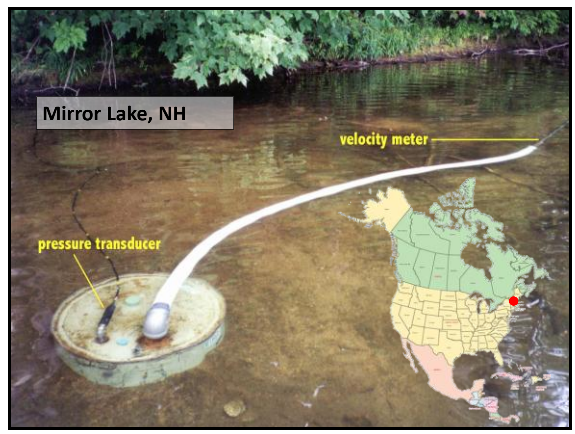
Simpkins, 2006, *Ground Water*

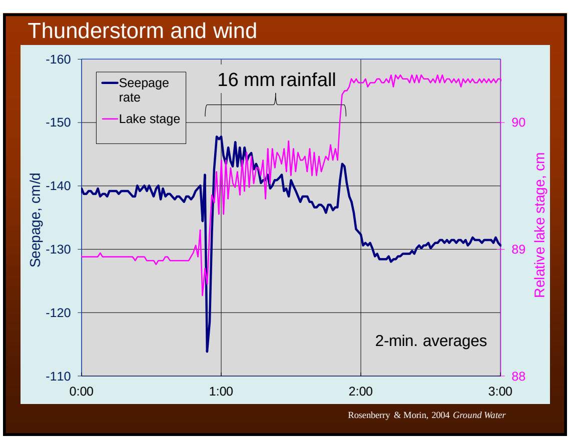
Table 1. Average seepage rates (±1σ, $n = 3$) for 4 stations in the Indian River Lagoon.

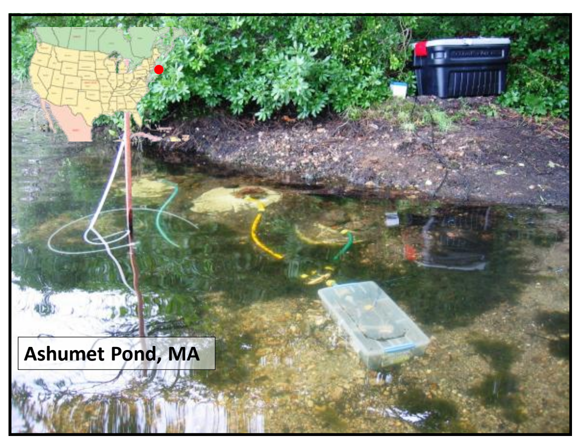
	Average Seepage (cm/day)							
	11-12 May 2003		11-12 June 2003		12-14 July 2003		25-27 Sept 2003	
Station	rate	±	rate	±	rate	±	rate	±
BRL2								
East #1	1.57	0.07	3.45	1.66	0.78	1.34	2.91	0.96
West #2	1.51	0.54	2.89	0.77	3.31	0.78	1.29	0.75

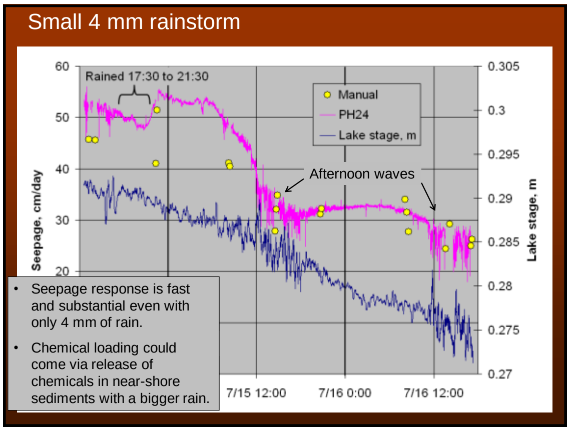
Cable et al., 2006, *Limnology and Oceanography-Methods*



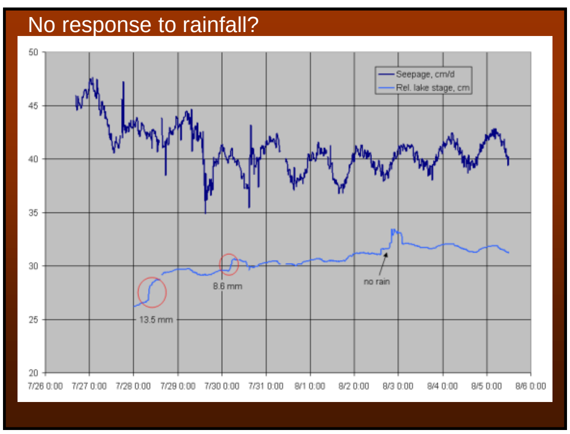


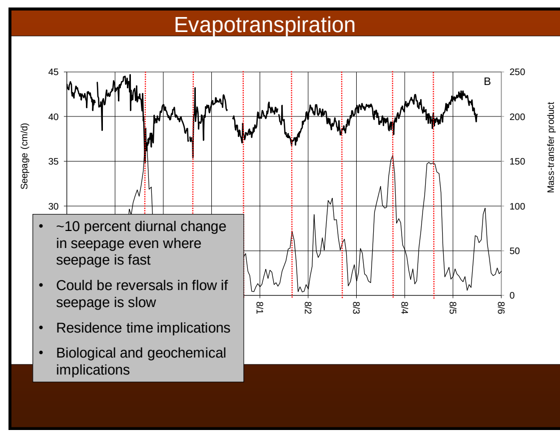




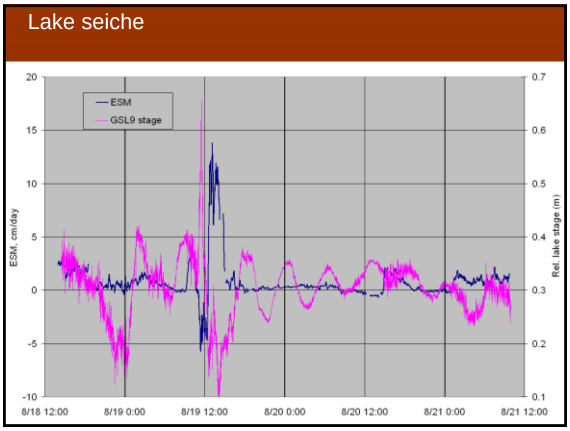

Small 4 mm rainstorm
Rained 17:30 to 21:30
Manual
PH24
Lake stage, m
Afternoon waves
Seepage, cm/day
Lake stage, m
60
50
40
30
20
0.305
0.3
0.295
0.29
0.285
0.28
0.275
0.27
7/15 12:00
7/16 0:00
7/16 12:00
Seepage response is fast and substantial even with only 4 mm of rain.
Chemical loading could come via release of chemicals in near-shore sediments with a bigger rain.


Shingobee Lake, MN

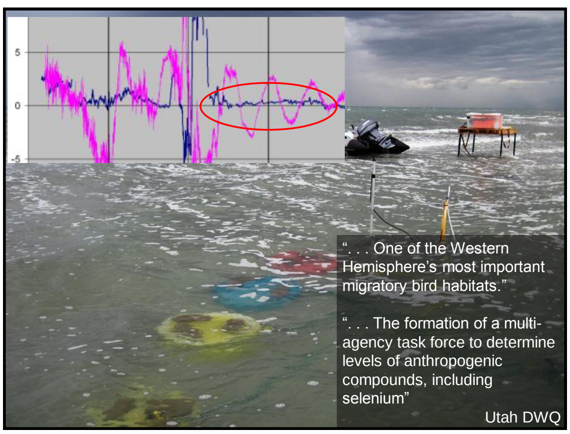

No response to rainfall?
Seepage, cm/d
Rel. lake stage, cm
13.5 mm
8.6 mm
no rain
50
45
40
35
30
25
20
7/26 0:00
7/27 0:00
7/28 0:00
7/29 0:00
7/30 0:00
7/31 0:00
8/1 0:00
8/2 0:00
8/3 0:00
8/4 0:00
8/5 0:00
8/6 0:00

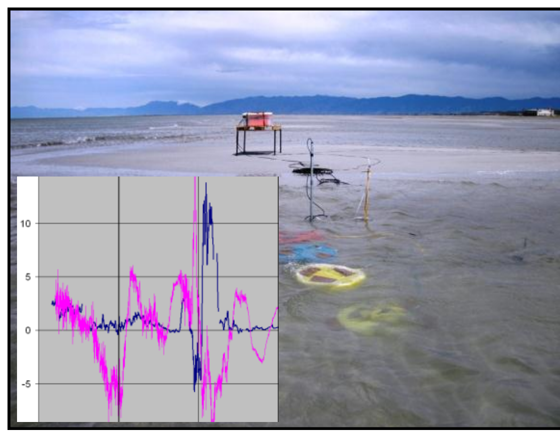

Evapotranspiration
Seepage (cm/d)
Mass-transfer product
B
45
40
35
30
250
200
150
100
50
0
8/1
8/2
8/3
8/4
8/5
8/6
~10 percent diurnal change in seepage even where seepage is fast
Could be reversals in flow if seepage is slow
Residence time implications
Biological and geochemical implications

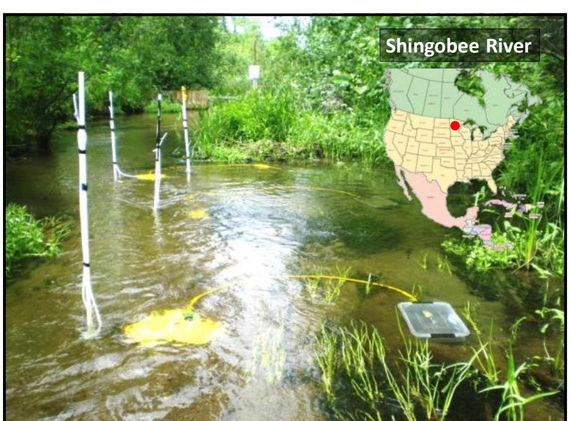

Great Salt Lake, UT

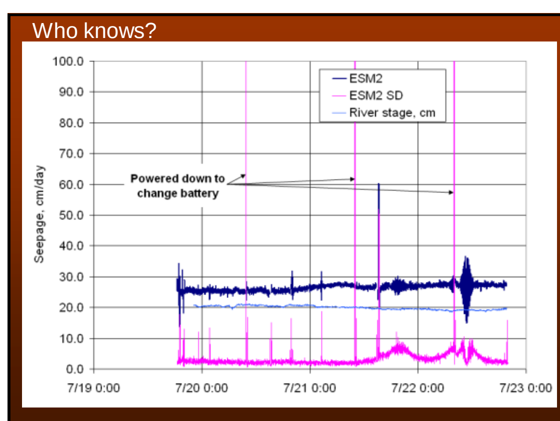

Lake seiche
ESM
GSL9 stage
ESM, cm/day
Rel. lake stage (m)
20
15
10
5
0
-5
-10
0.7
0.6
0.5
0.4
0.3
0.2
0.1
8/18 12:00
8/19 0:00
8/19 12:00
8/20 0:00
8/20 12:00
8/21 0:00
8/21 12:00

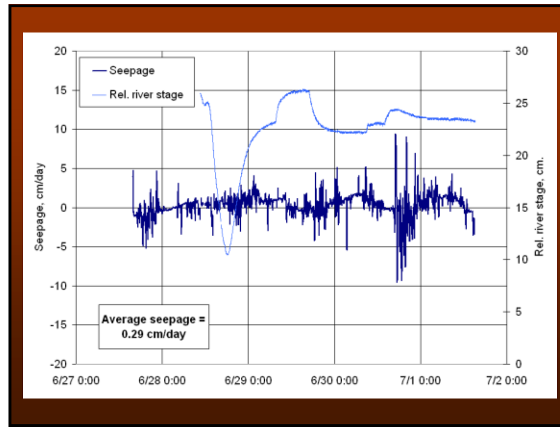

Selenium in the Great Salt Lake
So what?
USGS

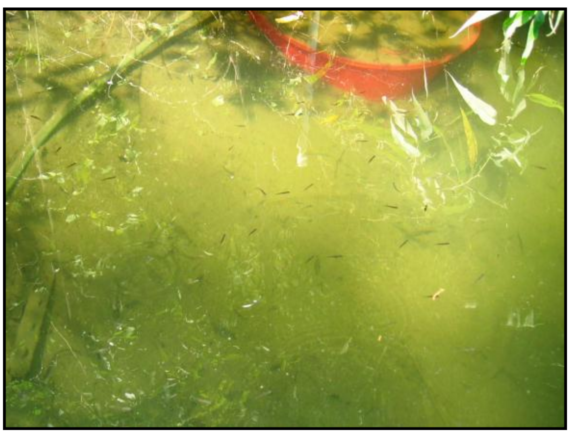

5
0
-5
". . . One of the Western Hemisphere's most important migratory bird habitats."
". . . The formation of a multi-agency task force to determine levels of anthropogenic compounds, including selenium"
Utah DWQ

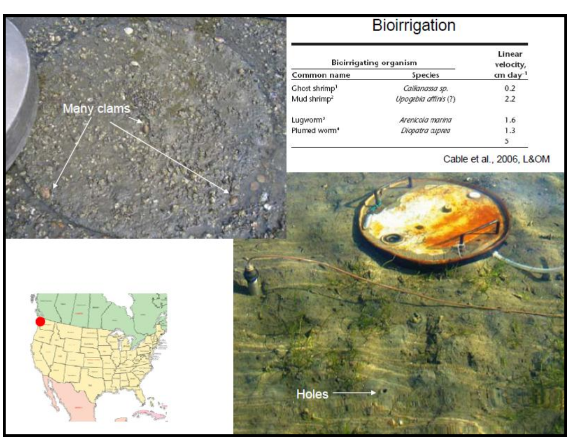

10
5
0
-5


Shingobee River

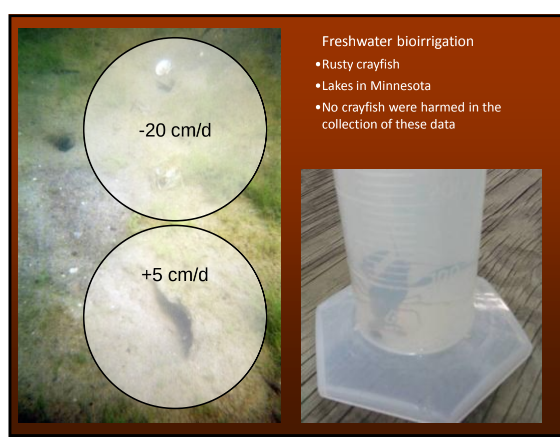

Who knows?
ESM2
ESM2 SD
River stage, cm
Powered down to change battery
Seepage, cm/day
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
7/19 0:00
7/20 0:00
7/21 0:00
7/22 0:00
7/23 0:00





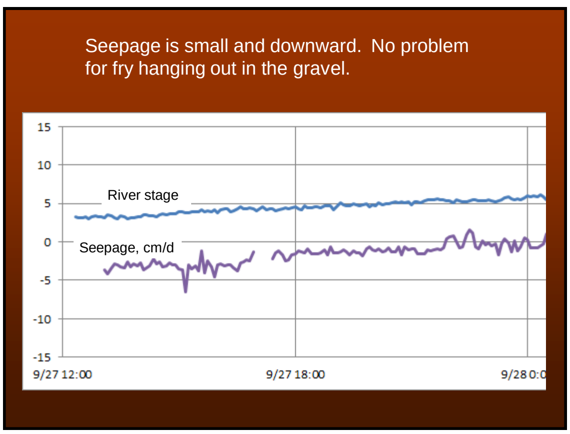


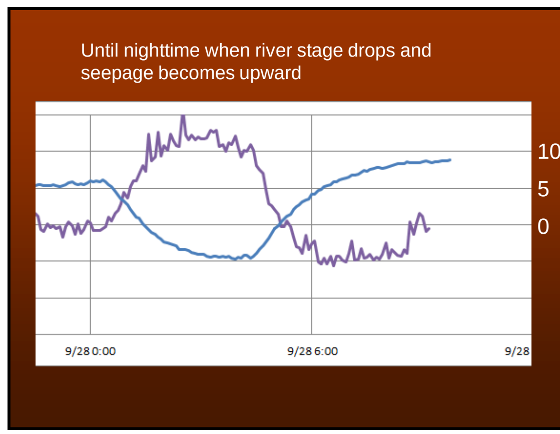
Biorrigating organism		Linear velocity, cm day⁻¹
Common name	Species	
Ghost shrimp[1]	*Callianassa sp.*	0.2
Mud shrimp[2]	*Upogebia affinis* (?)	2.2
Lugworm[3]	*Arenicola marina*	1.6
Plumed worm[4]	*Diopatra cuprea*	1.3
		5



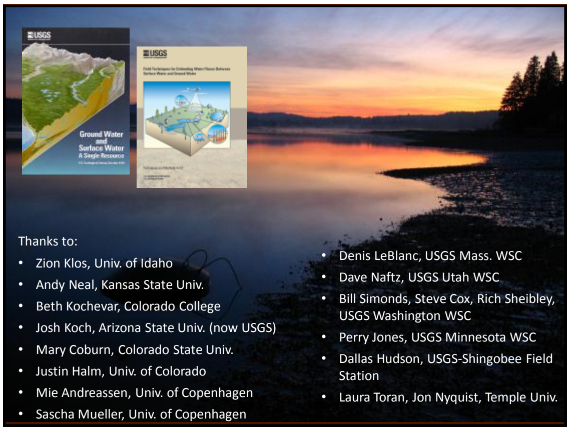

Spawning redds
Alexander and Caissie. 2003. *Ground Water*
Brown and Ford. 2002. *River Research and Applications*
Moir et al. 2002. *Geomorphology*
Morrison et al. 2002. *Journal of Hydrology*
Soulsby et al. 2001. *Regulated Rivers: Research & Management*
Baxter and Hauer. 2000. *Journal of Fisheries and Aquatic Science*
Baxter and McPhail. 1999. *Canadian Journal of Zoology*
Garrett et al. 1998. *Journal of Fisheries Management*
Pitlick and Van Steeter. 1998. *Water Resources*


If sediments are contaminated, can discharging groundwater expose fry to contaminants?


Seepage is small and downward. No problem for fry hanging out in the gravel.
15
10
5
0
-5
-10
-15
River stage
Seepage, cm/d
9/27 12:00
9/27 18:00
9/28 0:0


Until nighttime when river stage drops and seepage becomes upward
10
5
0
9/28 0:00
9/28 6:00
9/28


So who cares?
Plants
Benthic invertebrates
Endangered species
Fish
Ecologists
Geochemists
Geomorphologists
Engineers (and water suppliers)
Hydrologists and hydrogeologists
Resource managers
The public!


Thanks to:
Zion Klos, Univ. of Idaho
Andy Neal, Kansas State Univ.
Beth Kochevar, Colorado College
Josh Koch, Arizona State Univ. (now USGS)
Mary Coburn, Colorado State Univ.
Justin Halm, Univ. of Colorado
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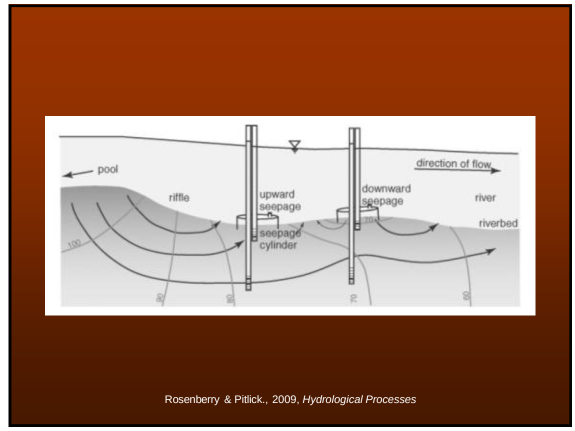
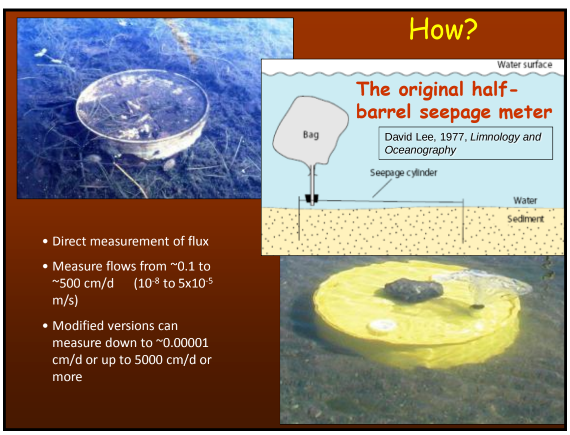
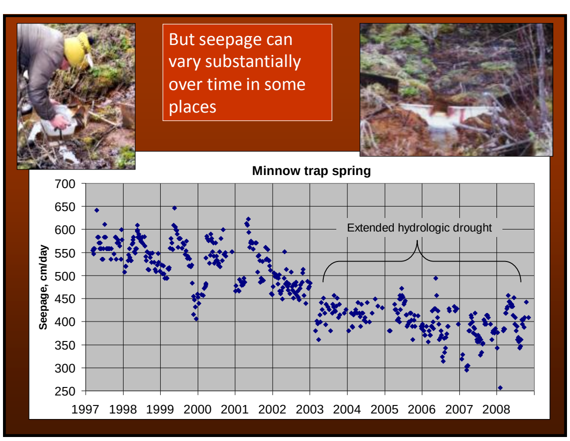
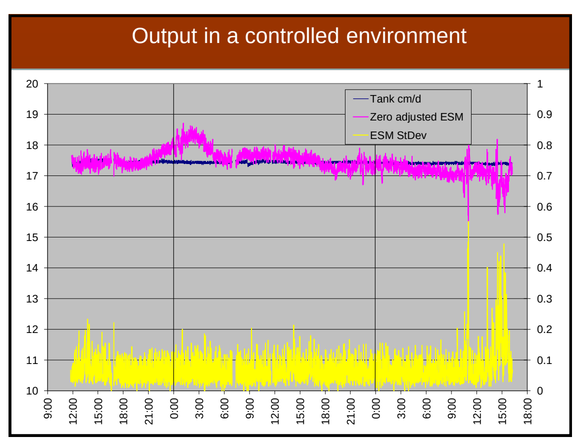
Denis LeBlanc, USGS Mass. WSC
Dave Naftz, USGS Utah WSC
Bill Simonds, Steve Cox, Rich Sheibley, USGS Washington WSC
Perry Jones, USGS Minnesota WSC
Dallas Hudson, USGS-Shingobee Field Station
Laura Toran, Jon Nyquist, Temple Univ.
Ground Water and Surface Water A Single Resource


pool
direction of flow
riffle
upward seepage
downward seepage
river
riverbed
seepage cylinder
Rosenberry & Pitlick., 2009, Hydrological Processes


How?
Water surface
The original half-barrel seepage meter
David Lee, 1977, Limnology and Oceanography
Bag
Seepage cylinder
Water
Sediment
• Direct measurement of flux
• Measure flows from ~0.1 to ~500 cm/d (10-8 to 5x10-5 m/s)
• Modified versions can measure down to ~0.00001 cm/d or up to 5000 cm/d or more


Great Salt Lake, UT


But seepage can vary substantially over time in some places
Minnow trap spring
Seepage, cm/day
700
650
600
550
500
450
400
350
300
250
Extended hydrologic drought
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008


Output in a controlled environment
Tank cm/d
Zero adjusted ESM
ESM StDev
20
19
18
17
16
15
14
13
12
11
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
9:00 12:00 15:00 18:00 21:00 0:00 3:00 6:00 9:00 12:00 15:00 18:00 21:00 0:00 3:00 6:00 9:00 12:00 15:00 18:00