# Developing a Groundwater Flow Model for Slough Management in Sauk County, WI

Sauk County CPZ, March 14th, 2017

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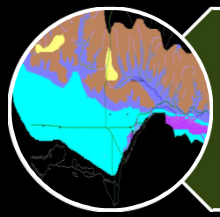
**Jean Bahr** University of Wisconsin-Madison, Geoscience

**Ken Wade** Kenneth Wade Consulting LLC

**Study motivation**

**Study Site:** Hydrogeology, field data

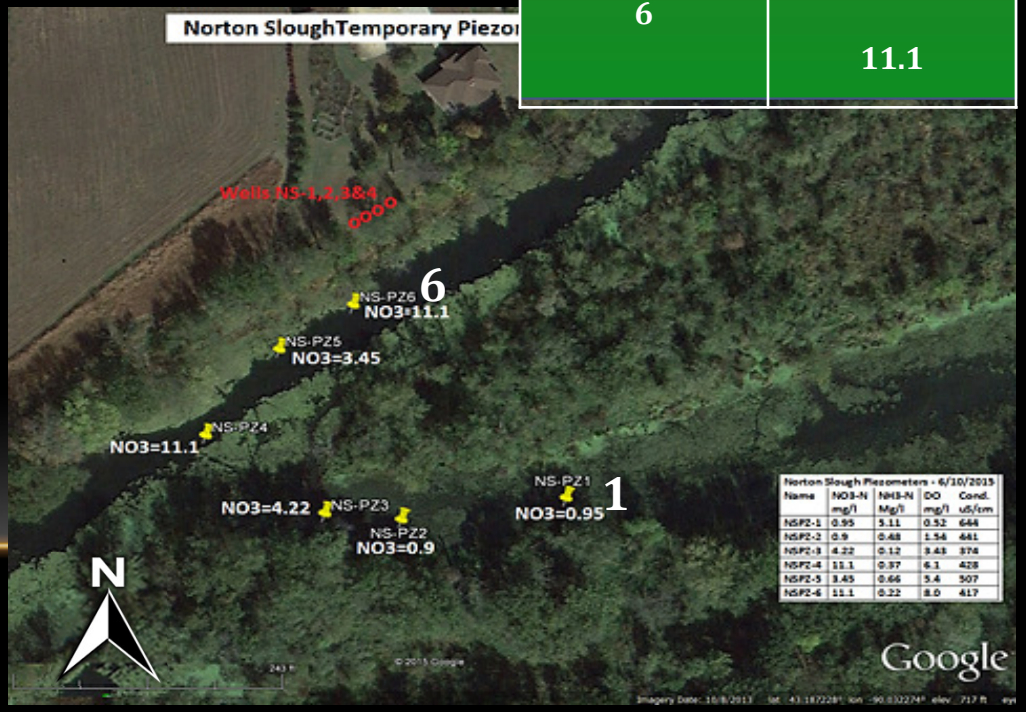


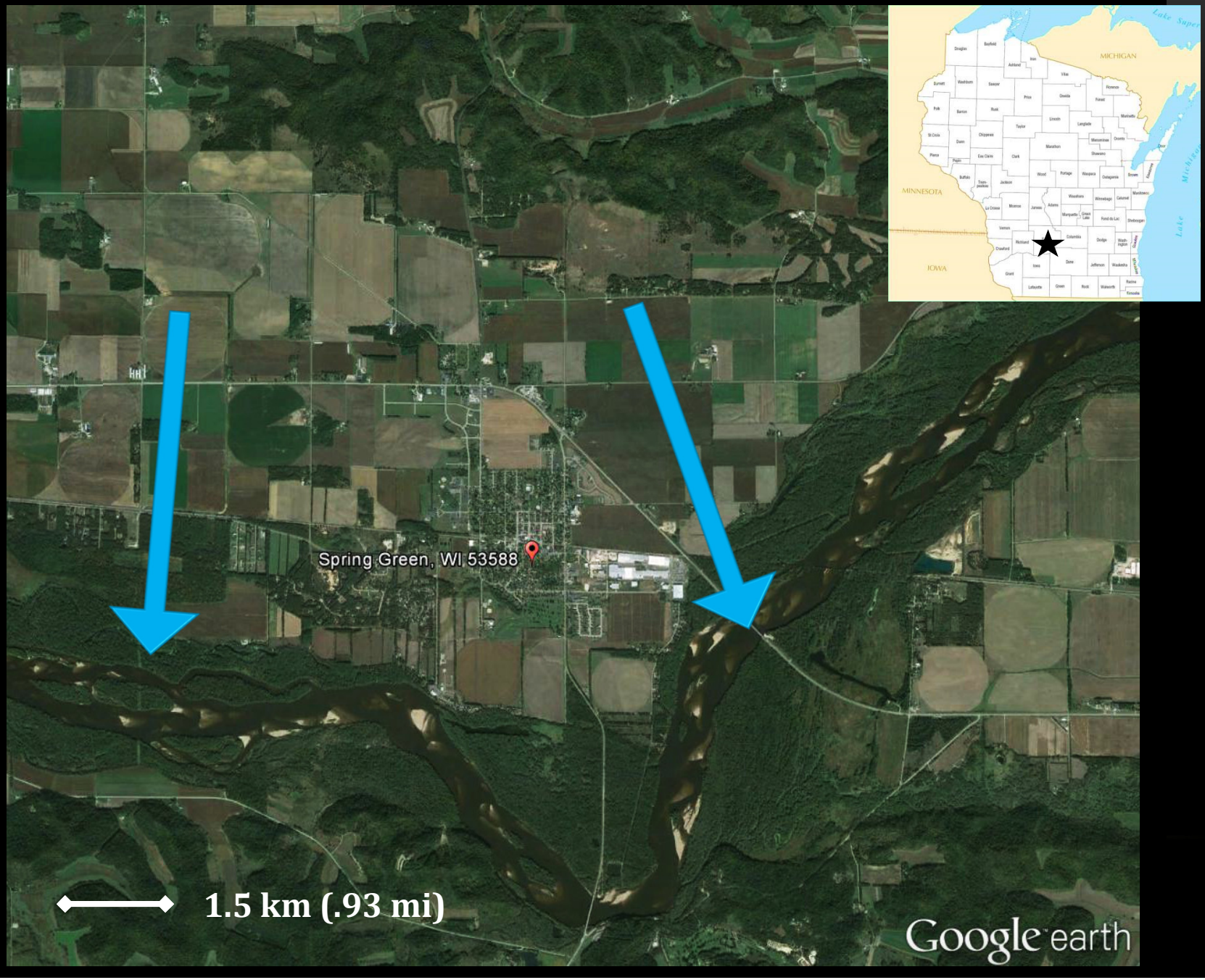
**Groundwater Flow Model;** building on the past

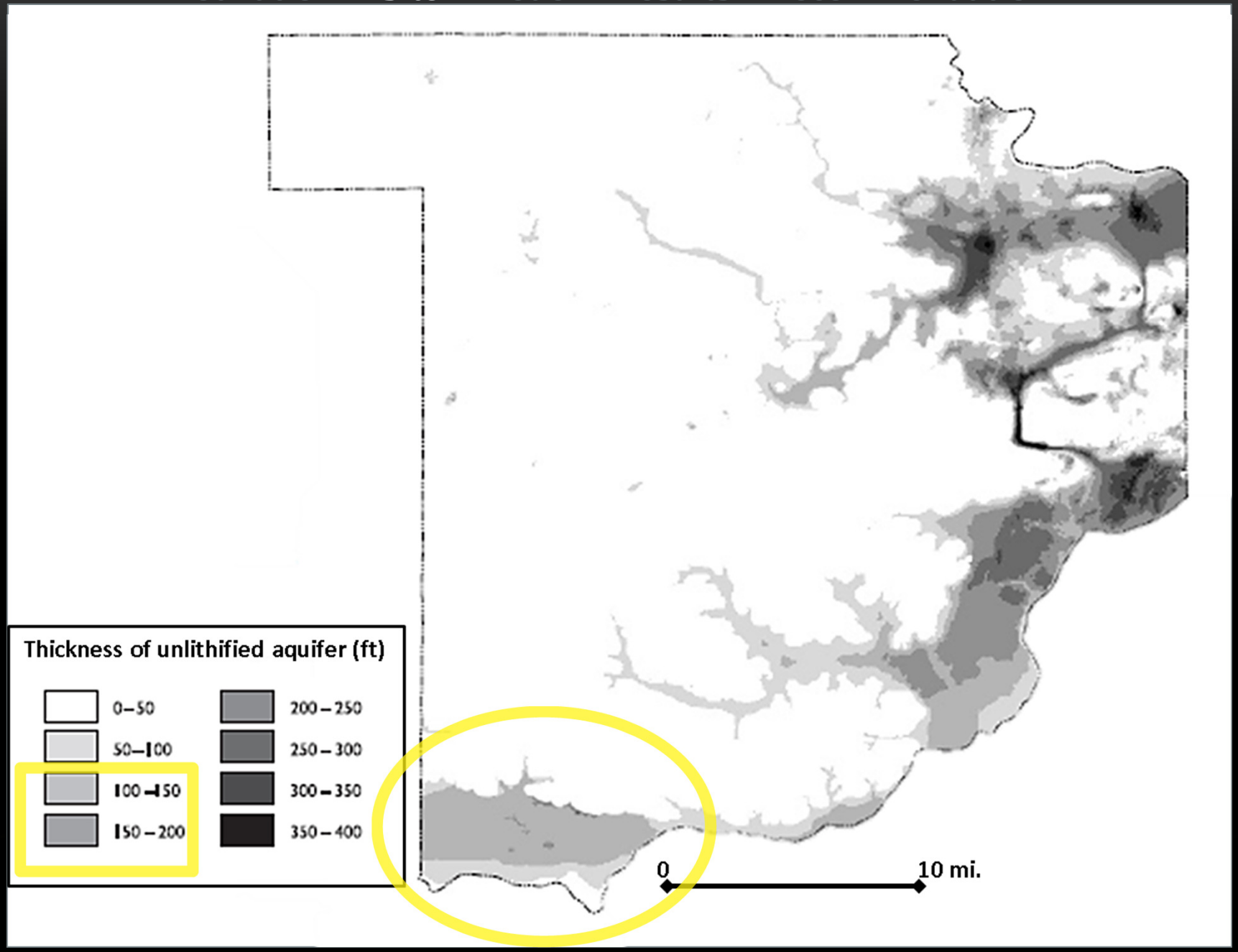
**Model Results:** recharge sites and travel times

**Recommendations**

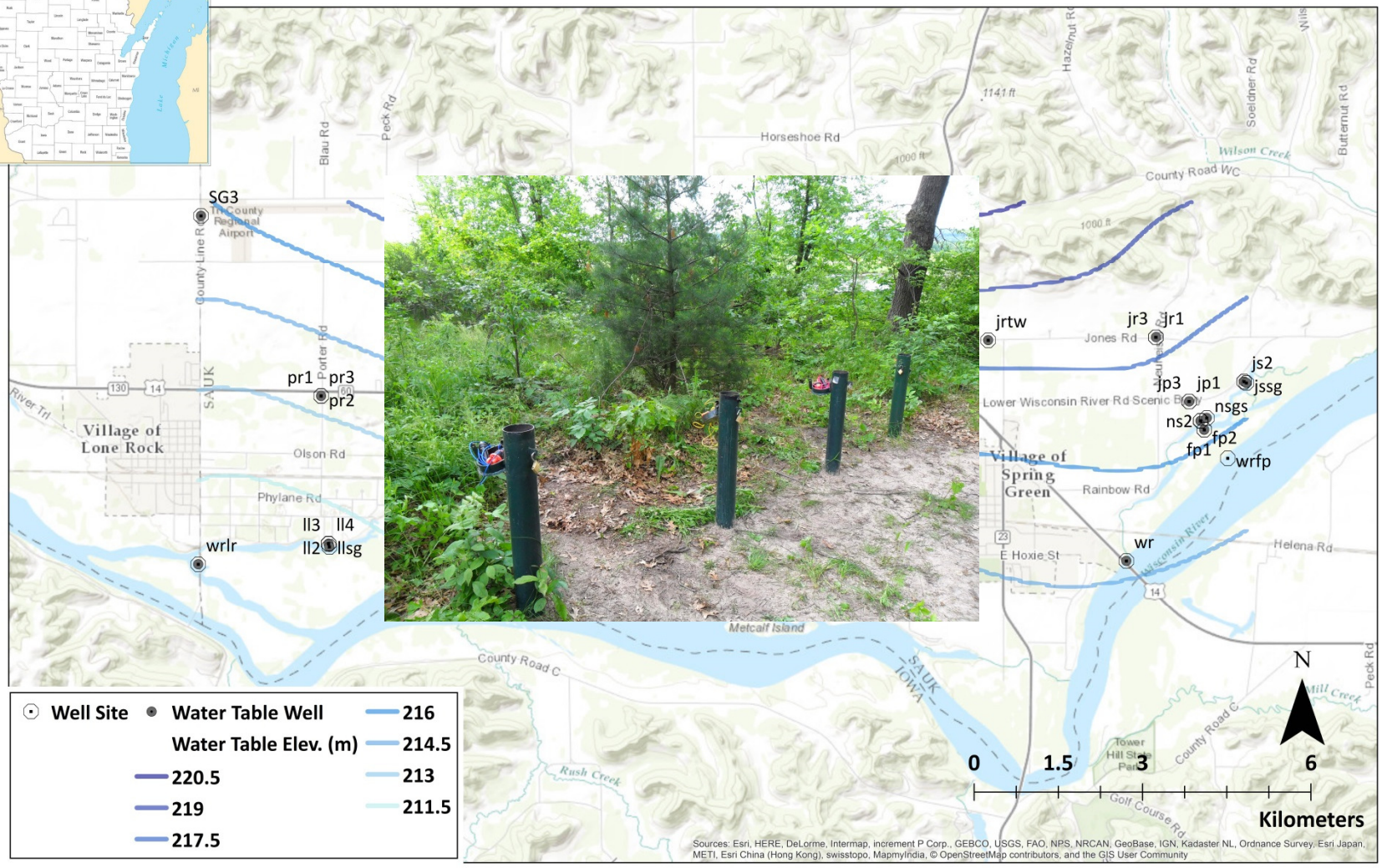
| Site | Piezometer $NO_3$-N mg/l |
|---|---|
| 1 | 0.95 |
| 2 | 0.9 |
| 3 | 4.22 |
| 4 | 3.45 |
| 5 | 11.1 |
| 6 | 11.1 |

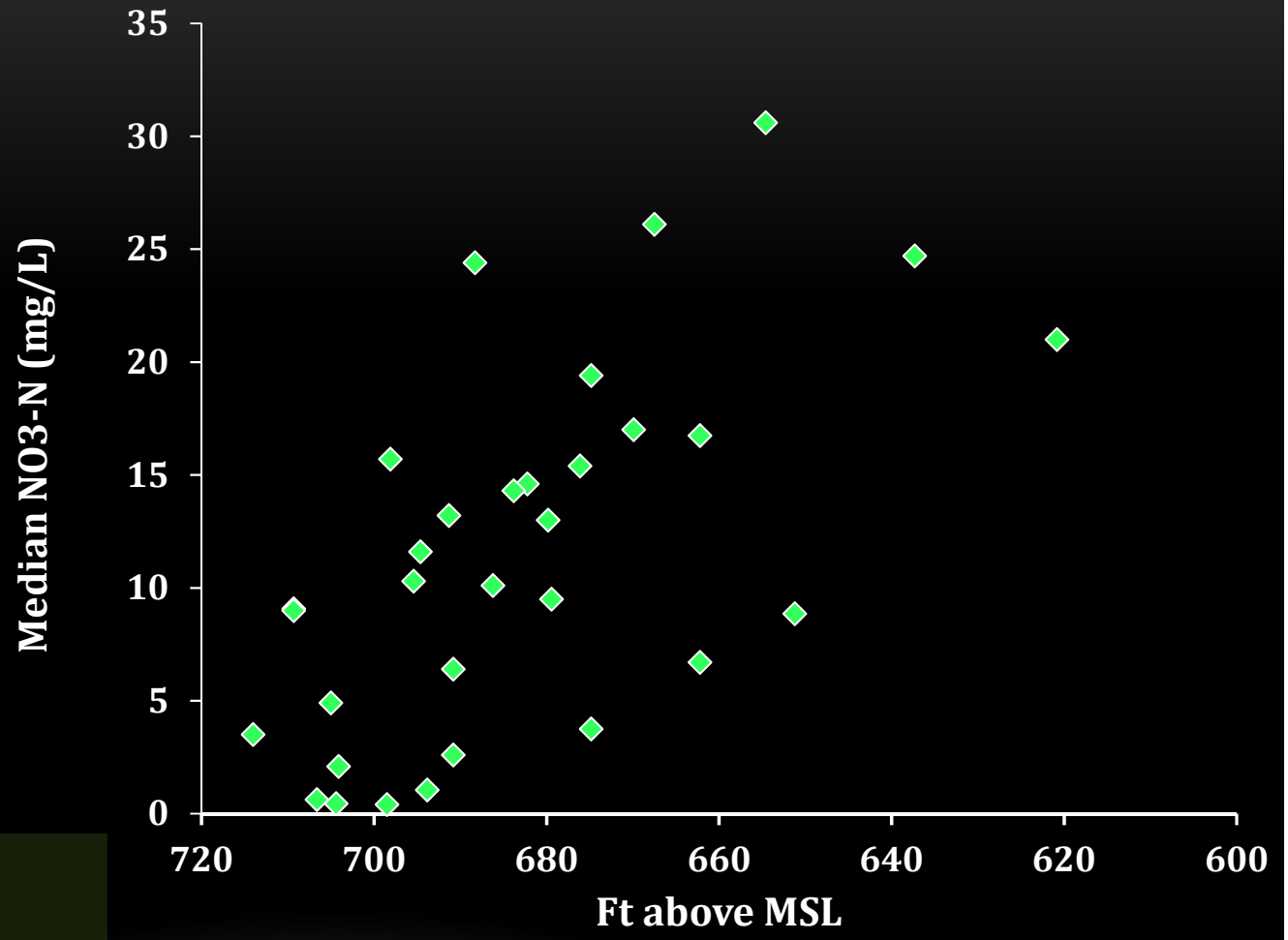



Spring Green, WI 53588
1.5 km (.93 mi)
Google earth
MICHIGAN
MINNESOTA
IOWA
Lake Superior
Lake Michigan

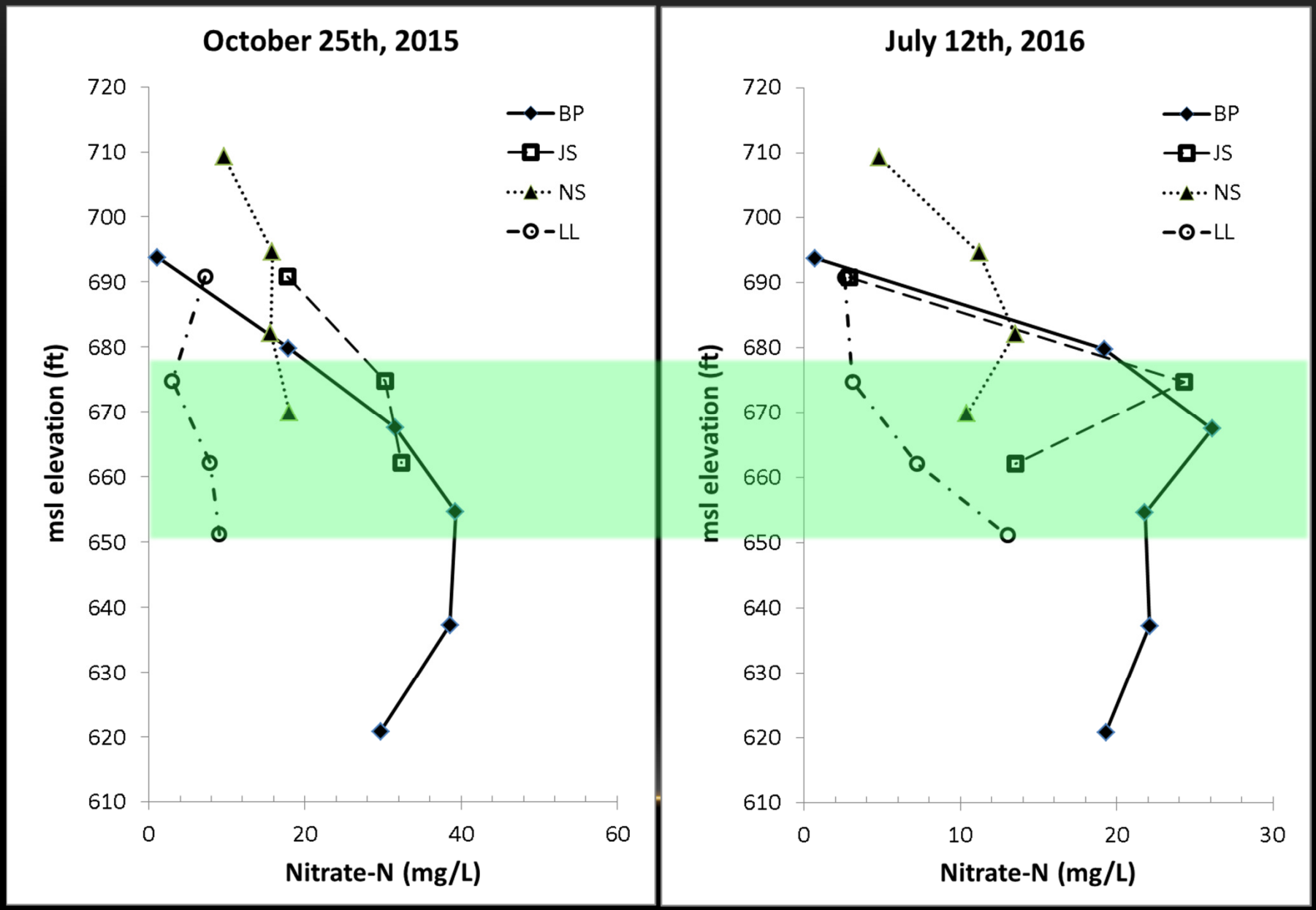

Thickness of unlithified aquifer (ft)
0–50
50–100
100–150
150–200
200–250
250–300
300–350
350–400
0
10 mi.

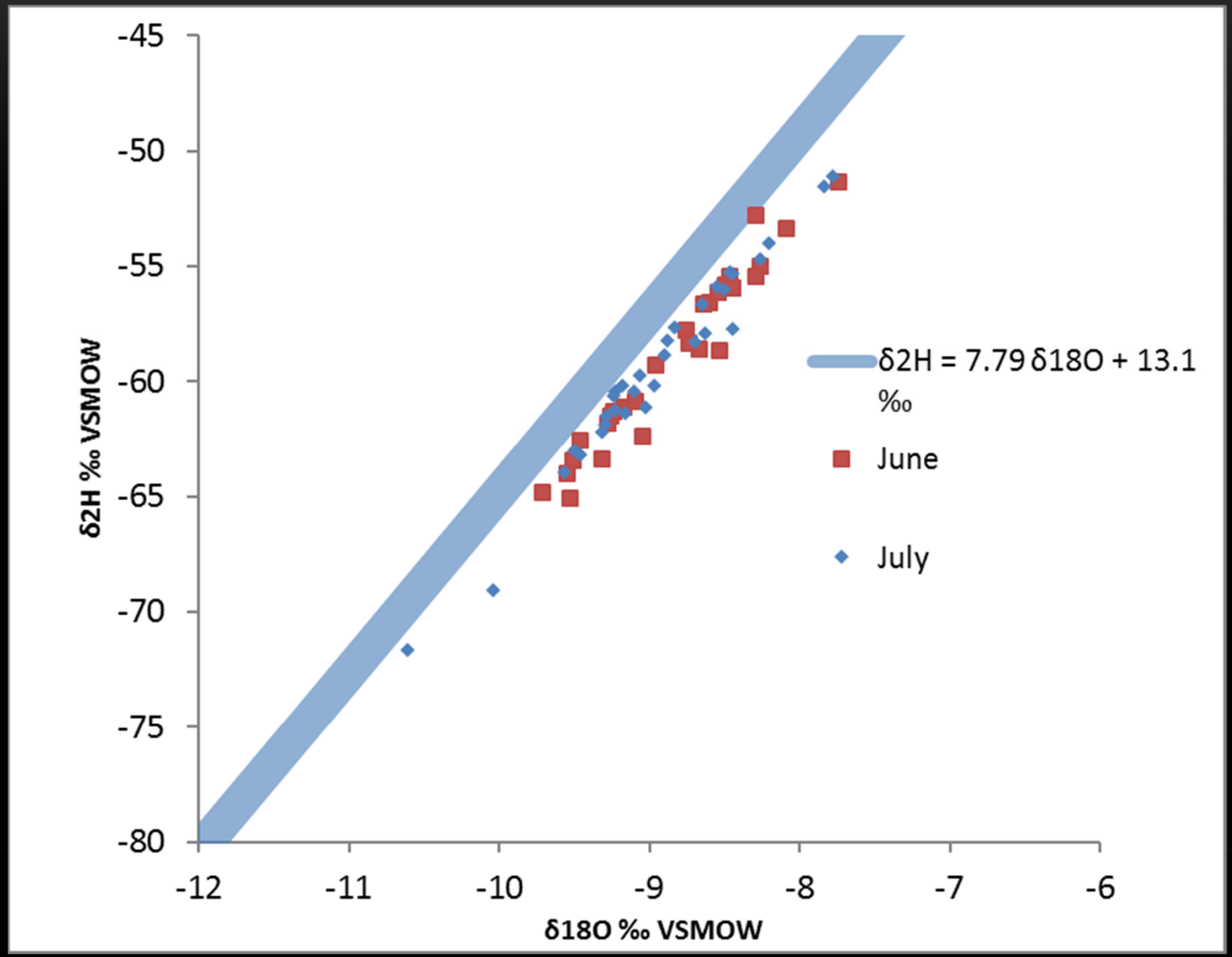

Lake Superior
MICHIGAN
MINNESOTA
IOWA
Lake Michigan

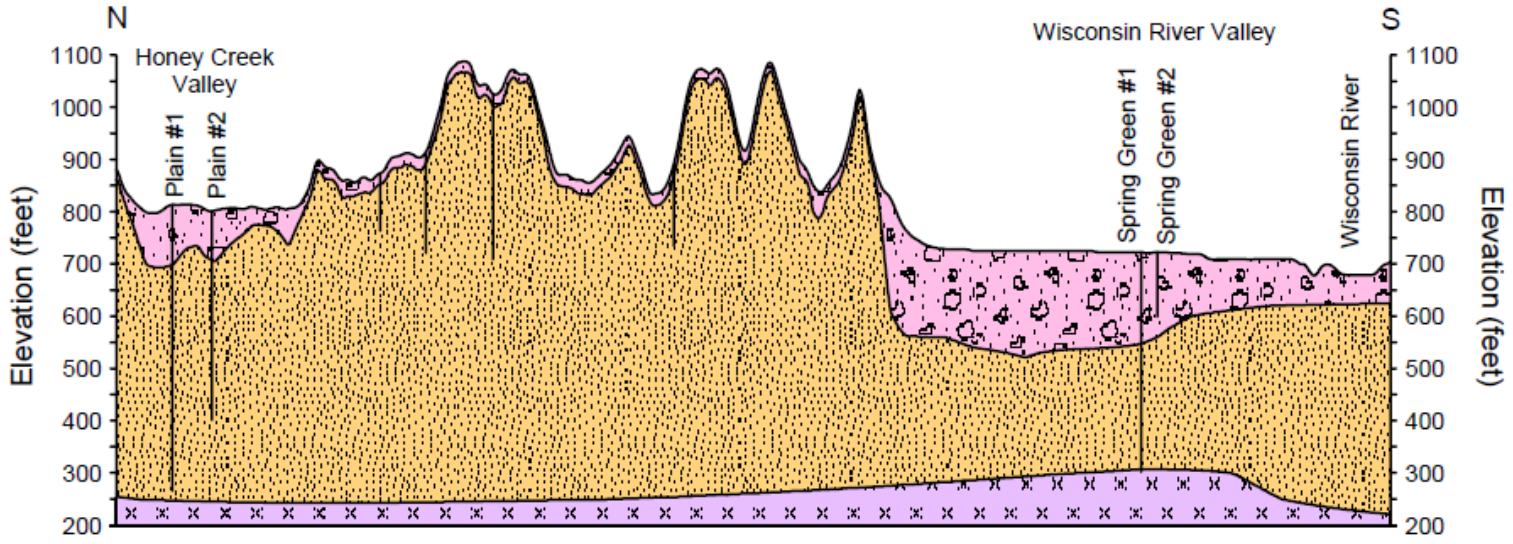

SG3
Tri County Regional Airport
County Line Rd
Blau Rd
Peck Rd
Horseshoe Rd
1141 ft
1000 ft
Hazelnut Rd
Soeldner Rd
Wilson Creek
County Road WC
Butternut Rd
Porter Rd
SAUK
pr1
pr3
pr2
130
14
River Trl
Village of Lone Rock
Olson Rd
Phylane Rd
ll3
ll4
ll2
llsg
wrlr
jrtw
jr3
jr1
Jones Rd
jp3
jp1
js2
jssg
Lower Wisconsin River Rd Scenic Bi
nsgs
ns2
fp2
fp1
wrfp
Village of Spring Green
Rainbow Rd
23
E Hoxie St
wr
Wisconsin River
Helena Rd
Metcalf Island
County Road C
SAUK
IOWA
Mill Creek
Peck Rd
Rush Creek
Tower Hill State Park
Golf Course Rd
N
0
1.5
3
6
Kilometers
Well Site
Water Table Well
Water Table Elev. (m)
220.5
219
217.5
216
214.5
213
211.5
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



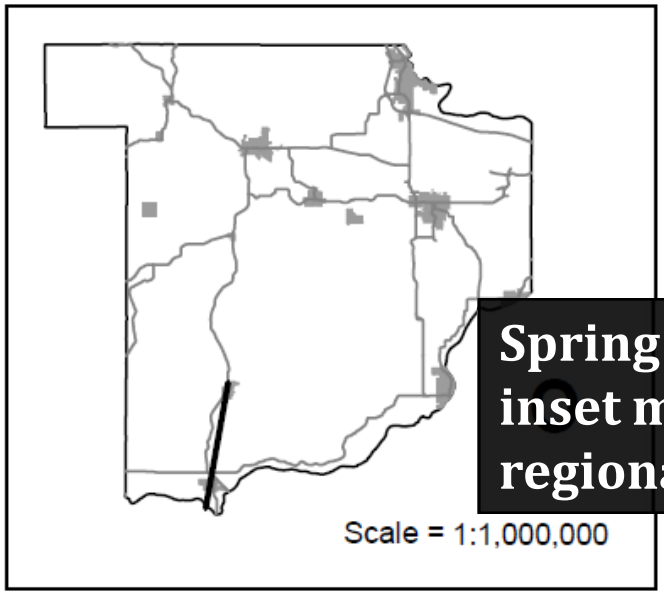

- 7/2014-7/2016
- 32 wells
- 4 well nests


October 25th, 2015
msl elevation (ft)
720
710
700
690
680
670
660
650
640
630
620
610
0
20
40
60
Nitrate-N (mg/L)
BP
JS
NS
LL
July 12th, 2016
msl elevation (ft)
720
710
700
690
680
670
660
650
640
630
620
610
0
10
20
30
Nitrate-N (mg/L)
BP
JS
NS
LL


-45
-50
-55
-60
-65
-70
-75
-80
δ2H ‰ VSMOW
-12
-11
-10
-9
-8
-7
-6
δ18O ‰ VSMOW
δ2H = 7.79 δ18O + 13.1 ‰
June
July




Cross-Section Location




**Explanation**

- Unconsolidated Aquifer
- Bedrock Aquifer
- Precambrian Bedrock

Horizontal Scale = 1:100,000

Kilometers

**Spring Green MODFLOW model: finite-difference inset model based on the larger Sauk County regional GFLOW model**

**Gotkowitz et al., 2002**

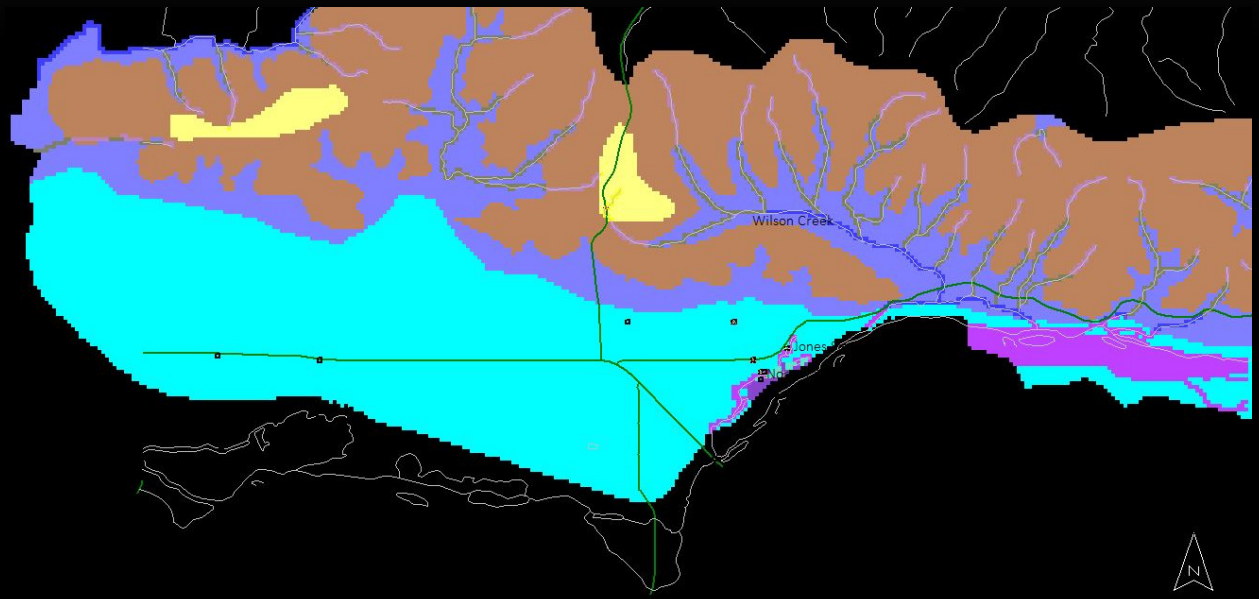
20x Vertical Exaggeration

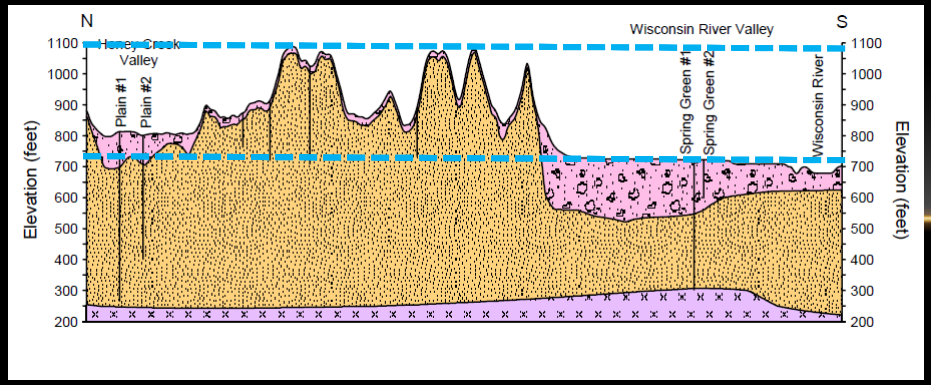
# NUMERICAL STEADY-STATE MODEL

- 3-Dimensional, 9 layers.
- Steady state; simulating base-flow conditions (~July- October).
- Transport model – chemical reactions not considered.
- Boundaries; constant head and no-flow.

# NUMERICAL STEADY –STATE MODEL

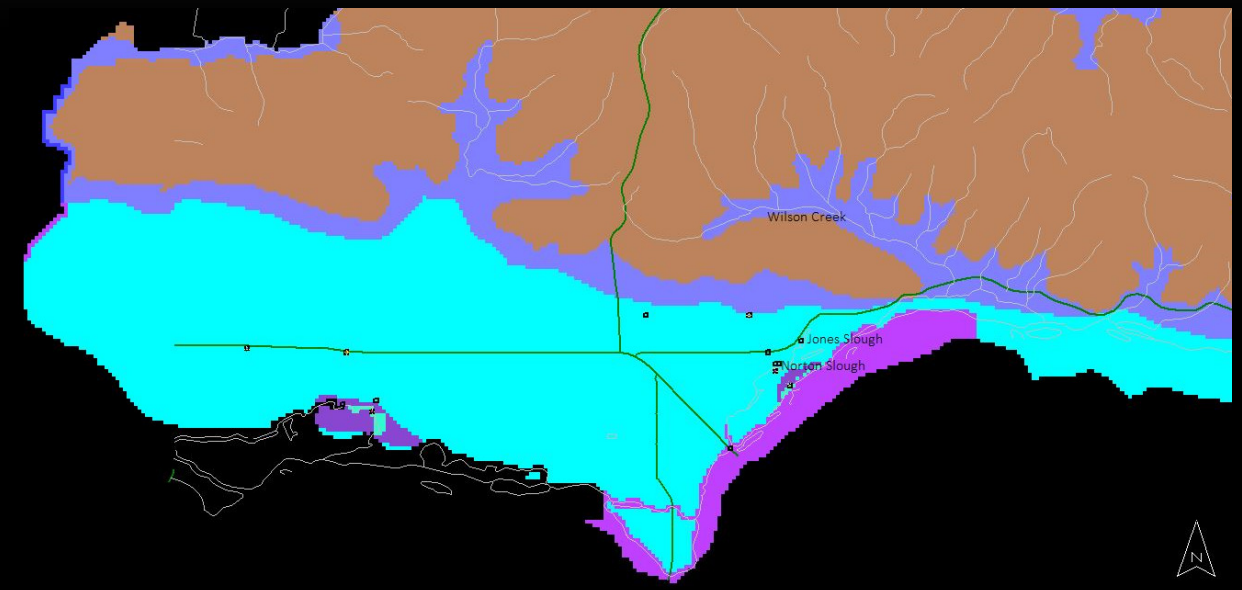
1

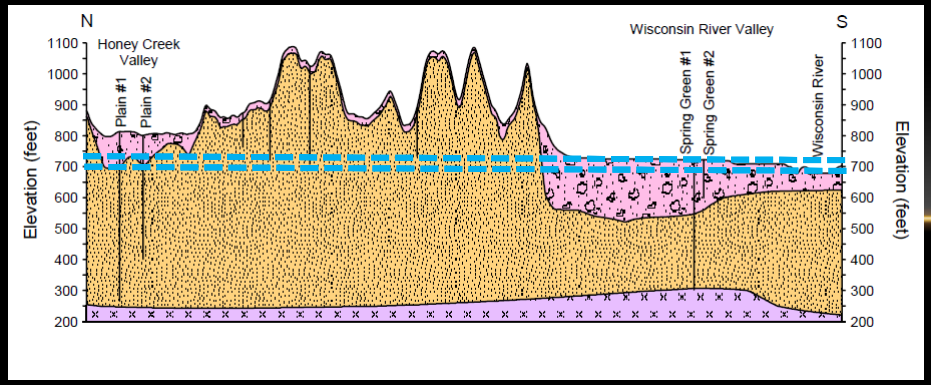


# NUMERICAL STEADY –STATE MODEL

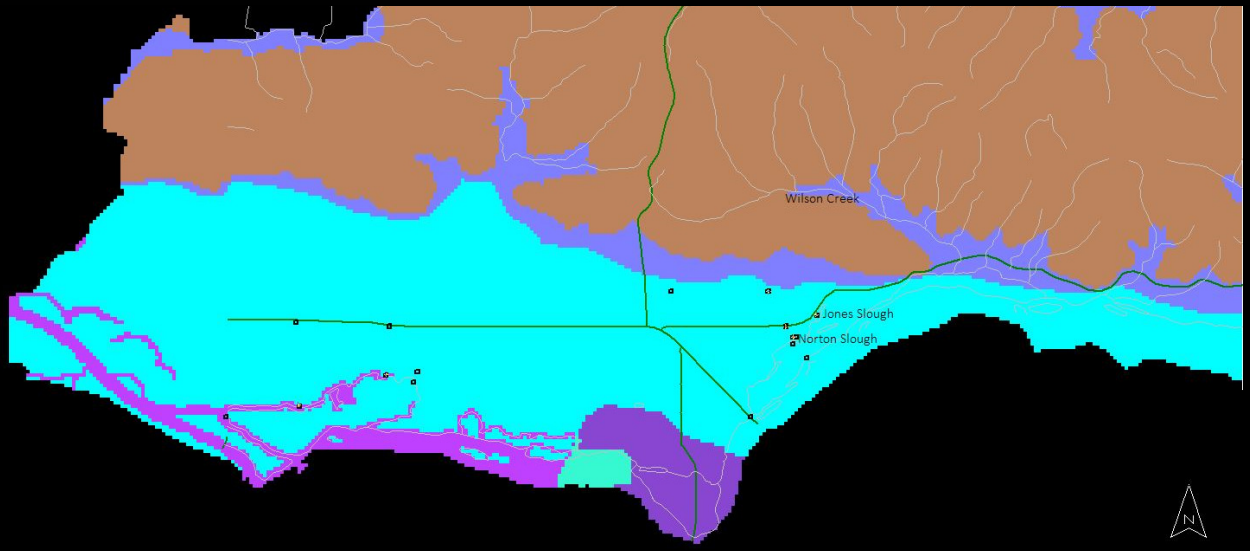
**2**

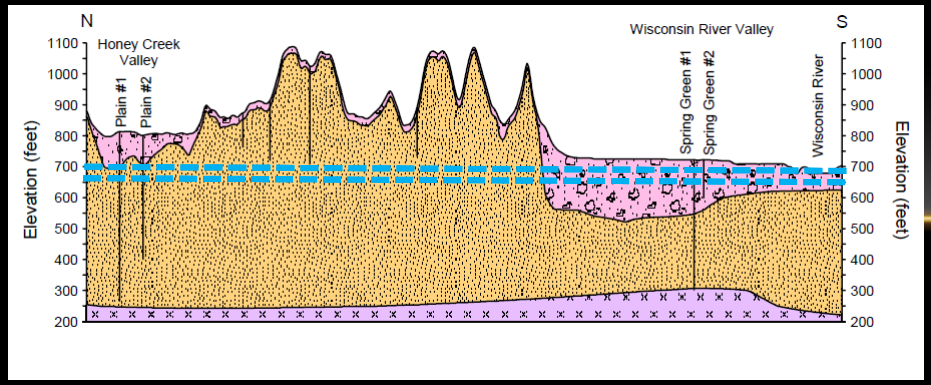


# NUMERICAL STEADY –STATE MODEL

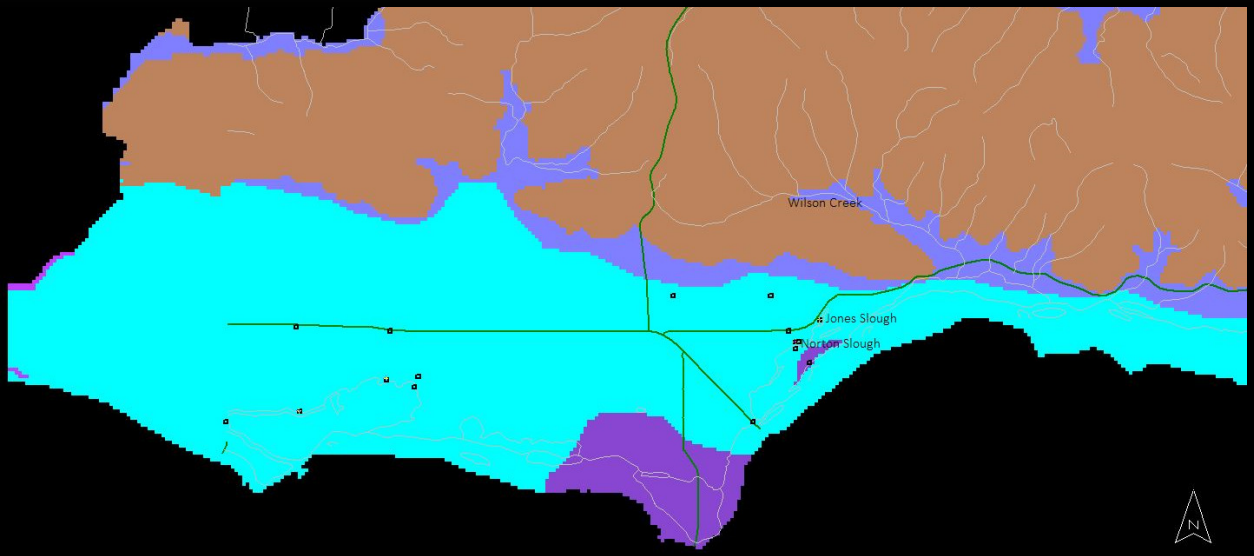
3

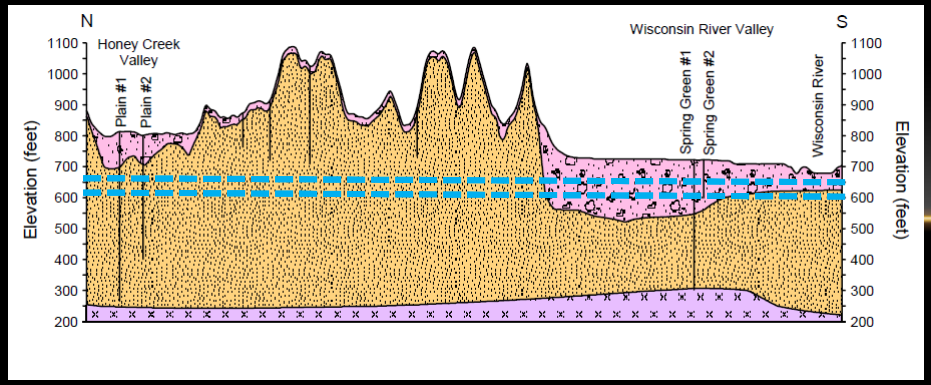


# NUMERICAL STEADY –STATE MODEL

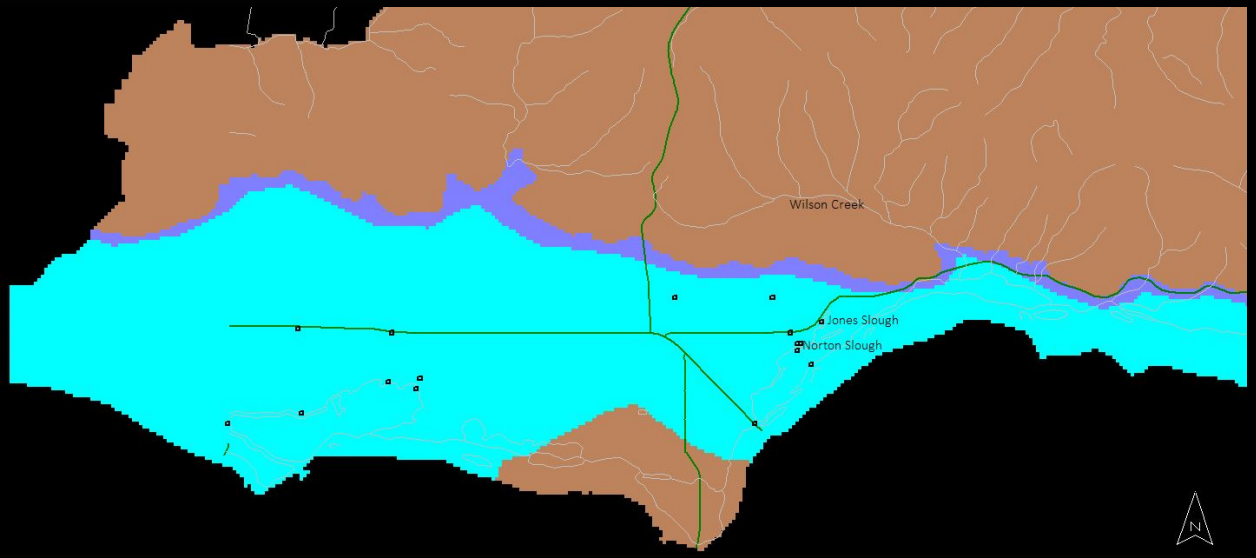
**4**

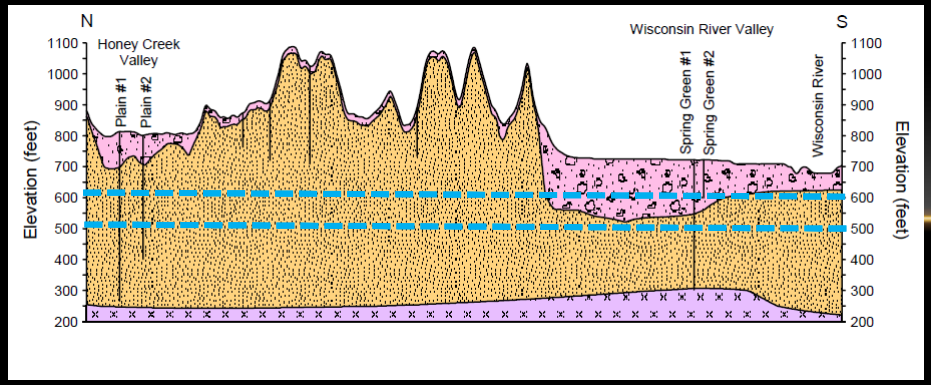


# NUMERICAL STEADY –STATE MODEL

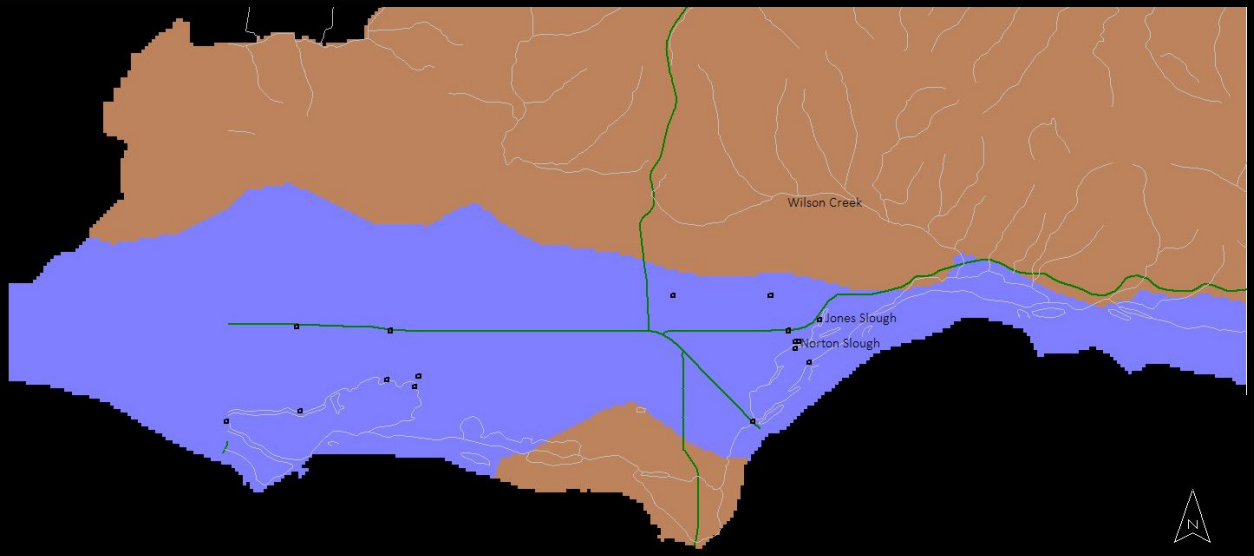
5

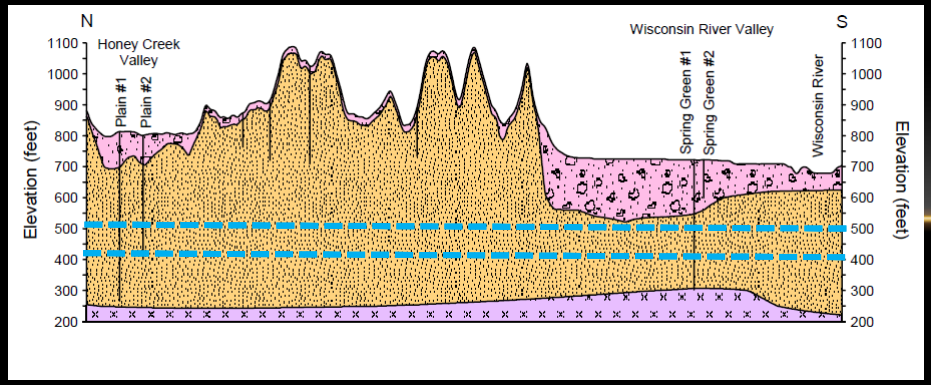


# NUMERICAL STEADY –STATE MODEL

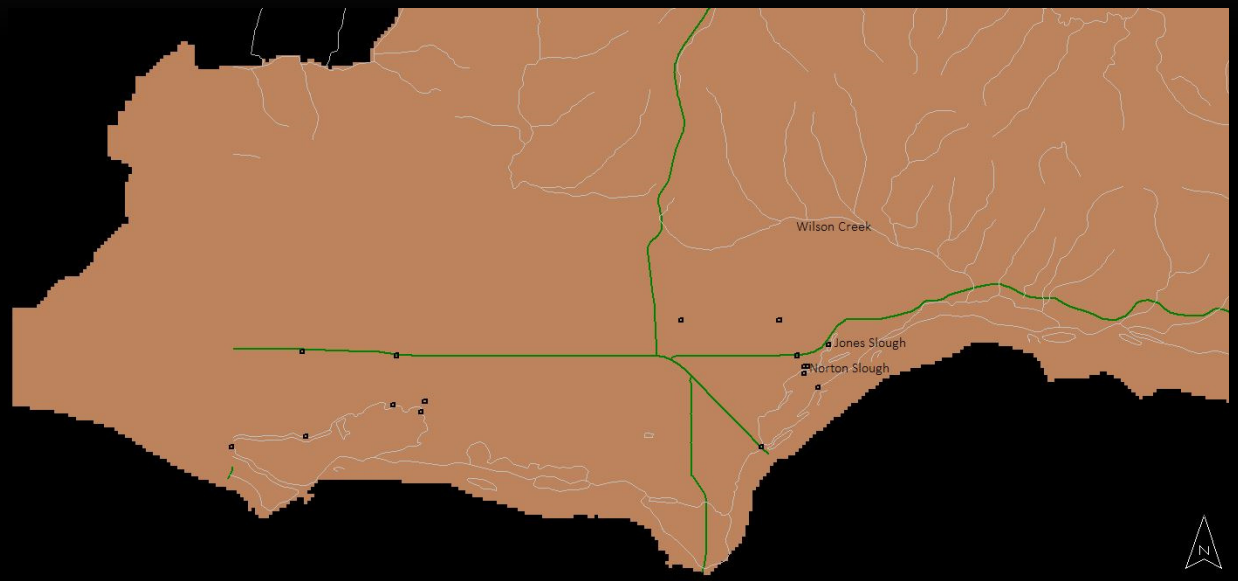
6

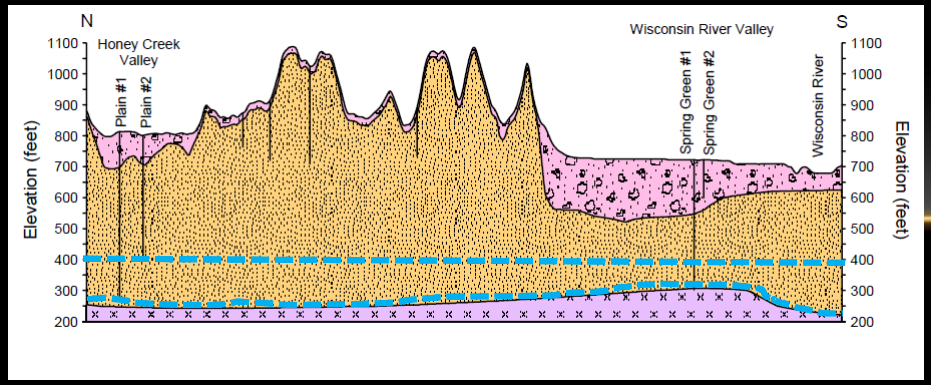


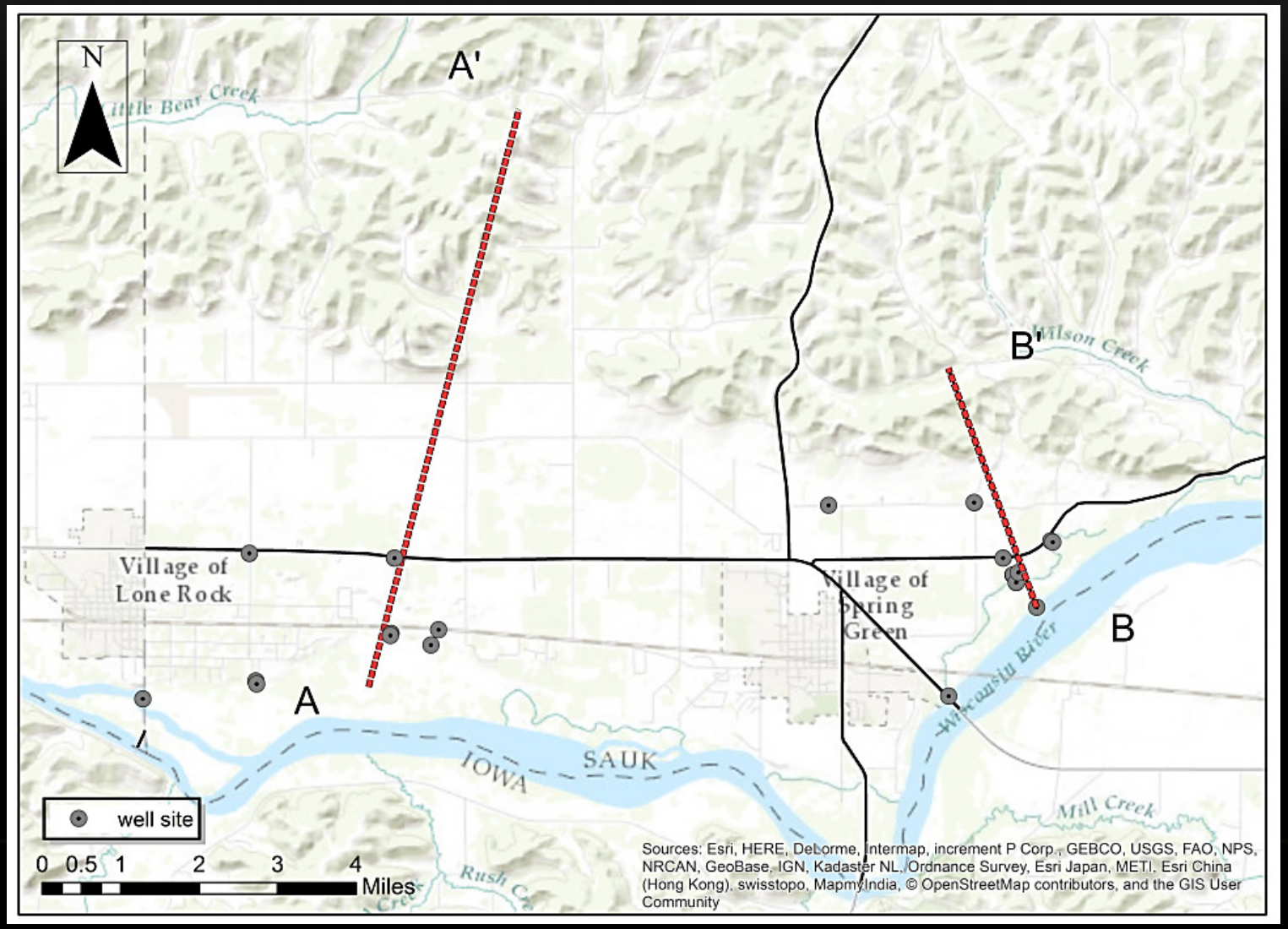



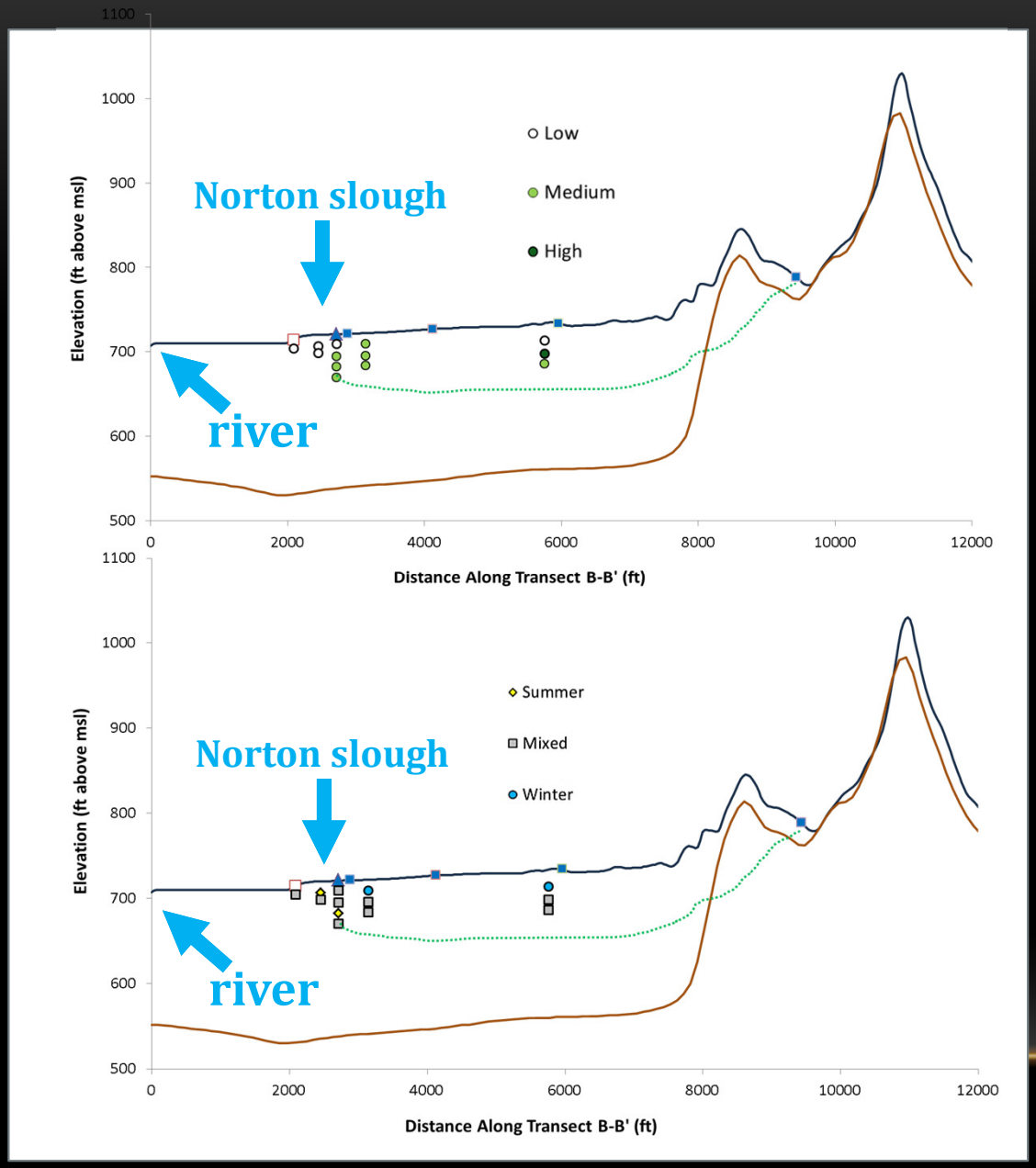
# NUMERICAL STEADY –STATE MODEL

**7-9**




N
A'
B'
A
B
Village of Lone Rock
Village of Spring Green
IOWA
SAUK
Wilson Creek
Mill Creek
well site
0 0.5 1 2 3 4
Miles
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



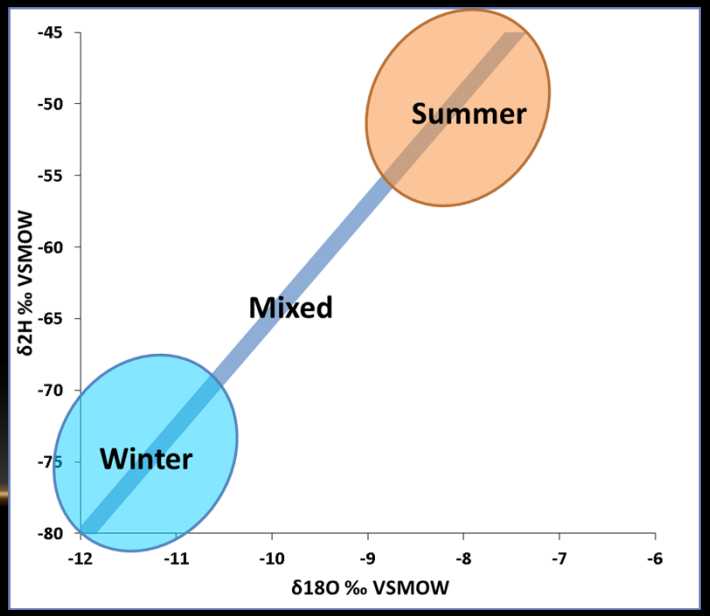

# Transect B-B'

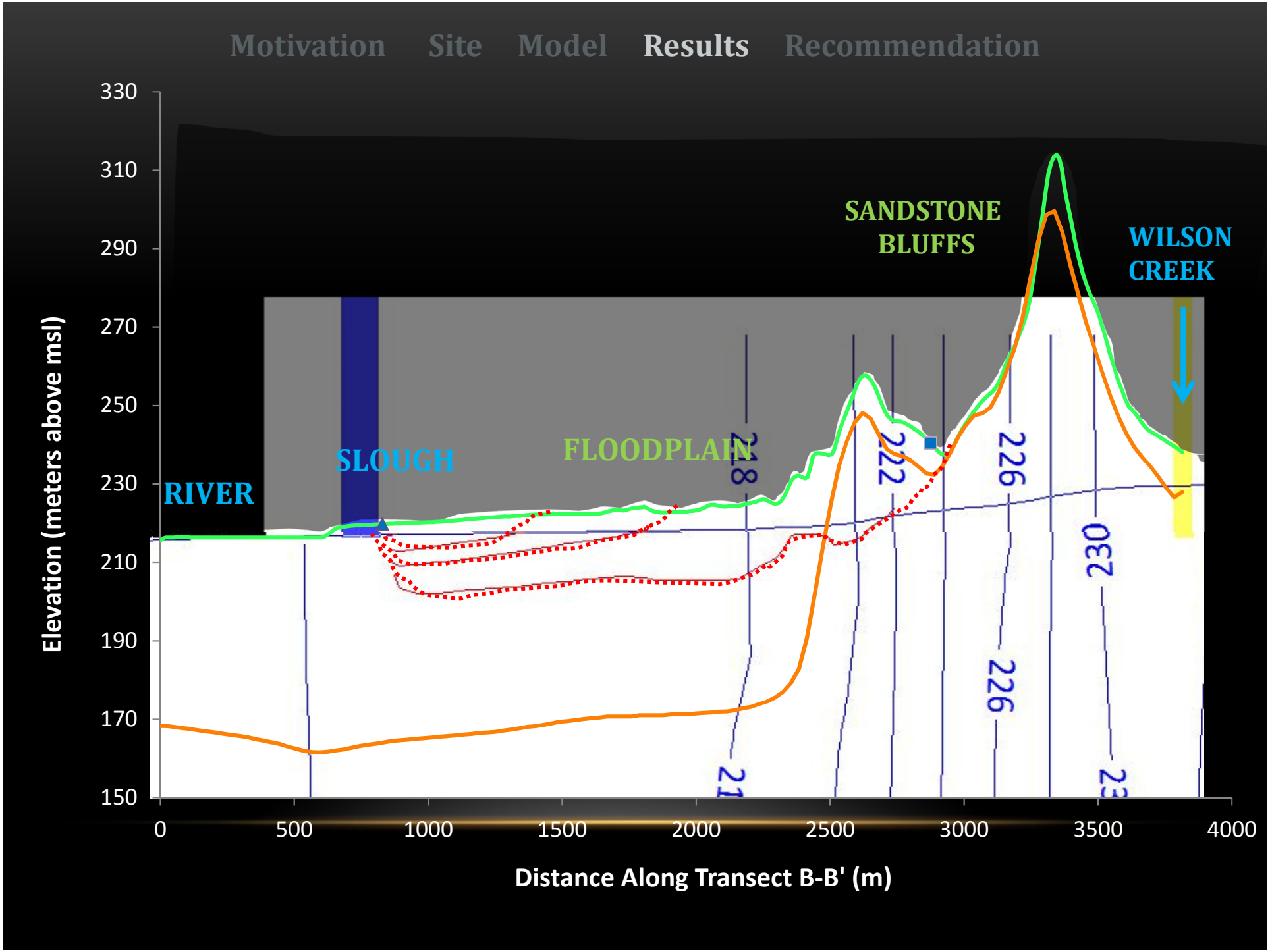
**Nitrate –N (mg/L) - July '16**

Low = 0.4-7

Medium = 7.1-15

High = 15.1-26.1

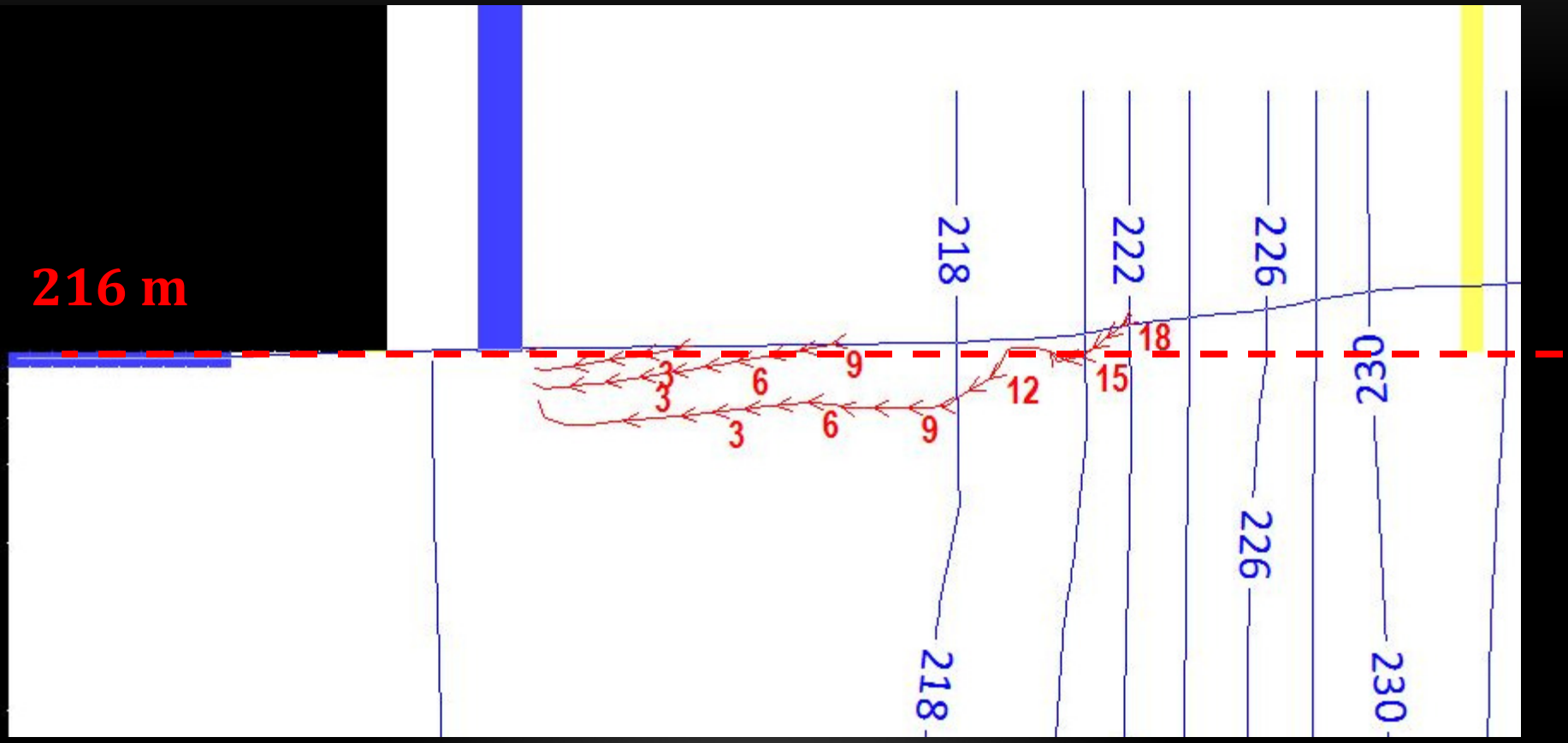



SANDSTONE BLUFFS
WILSON CREEK
SLOUGH
FLOODPLAIN
RIVER
218
222
226
230
226
Elevation (meters above msl)
330
310
290
270
250
230
210
190
170
150
0
500
1000
1500
2000
2500
3000
3500
4000
Distance Along Transect B-B' (m)

B’
South

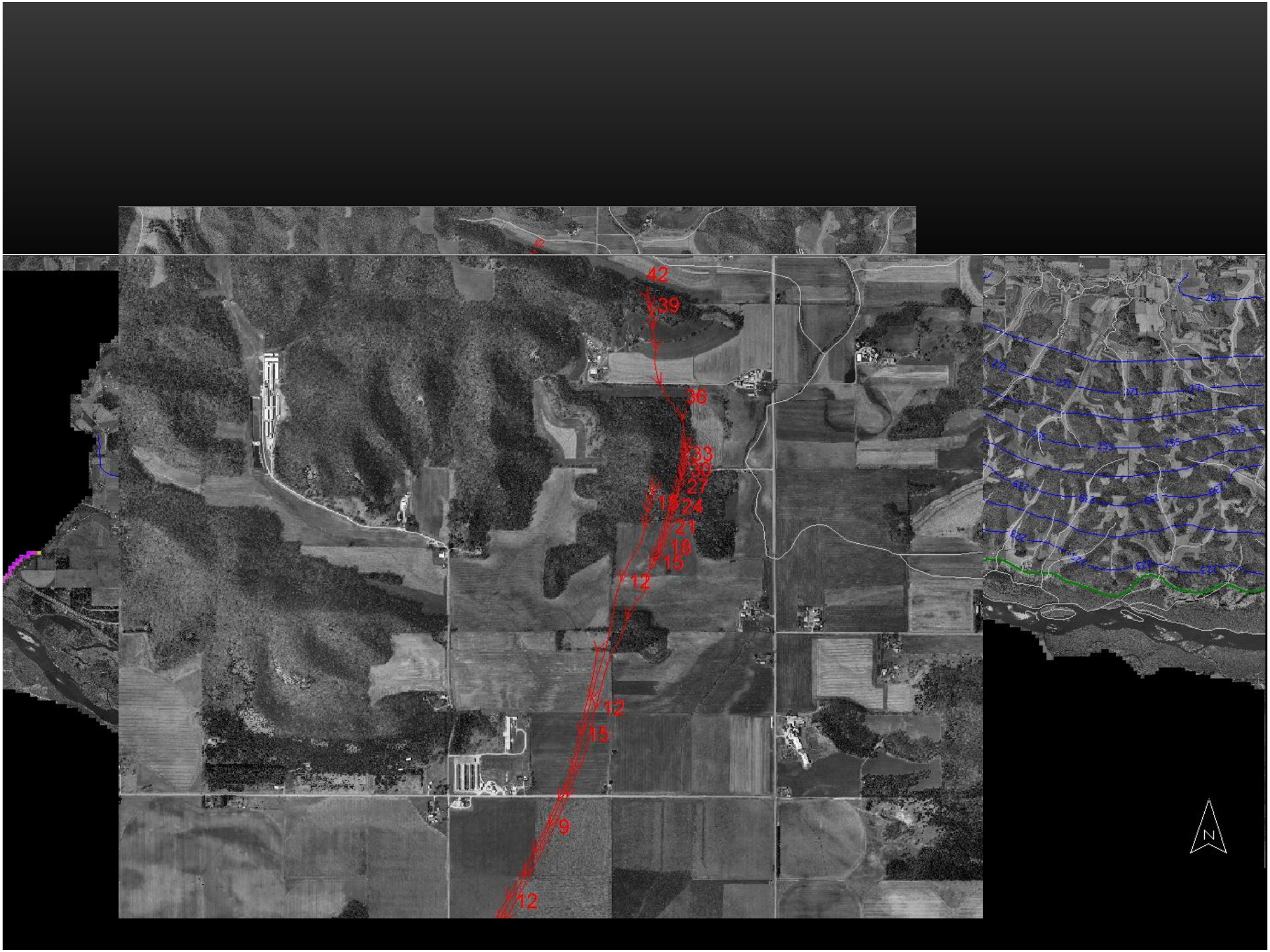
Norton slough

B
North

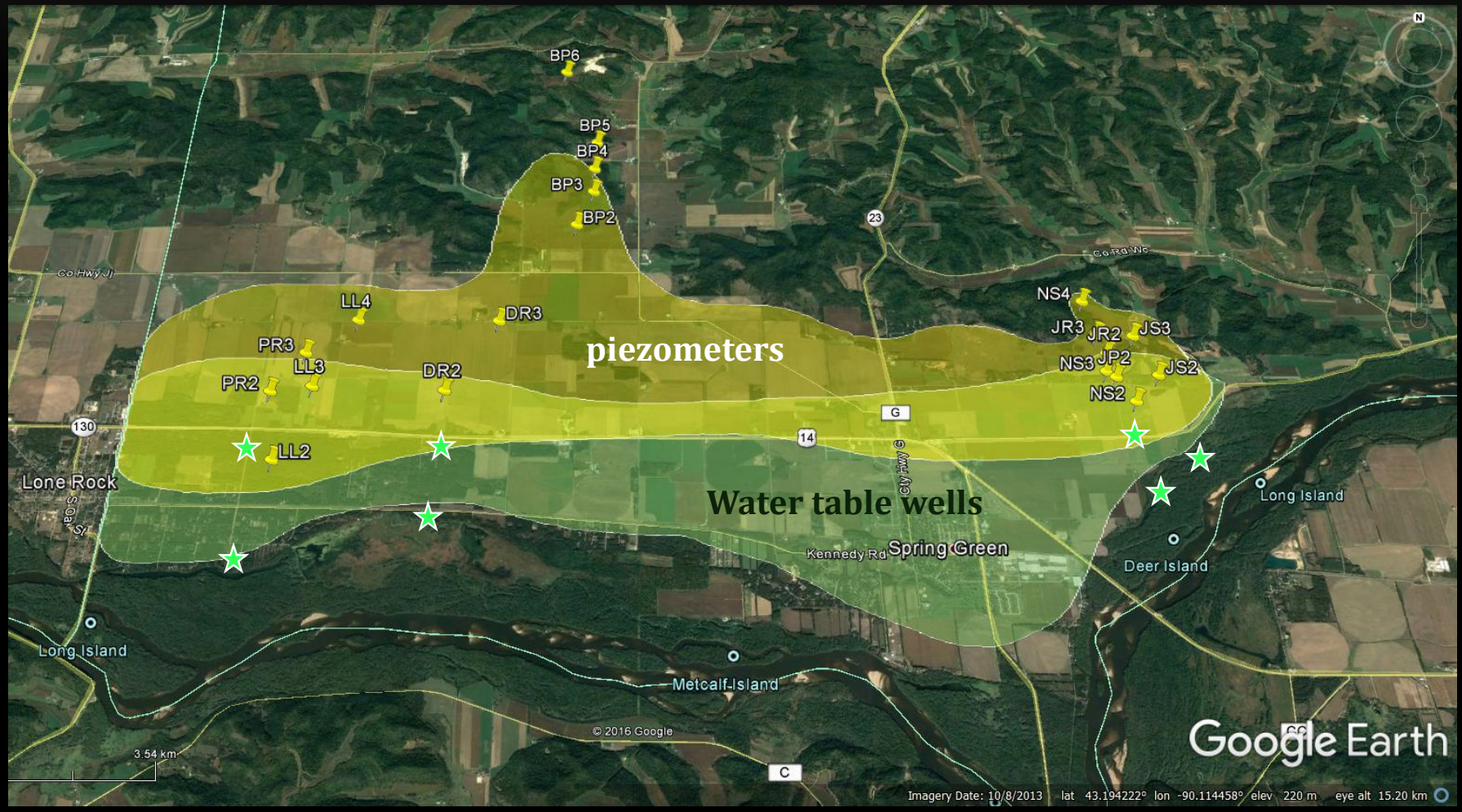



Results for reverse particle tracking near Norton Slough

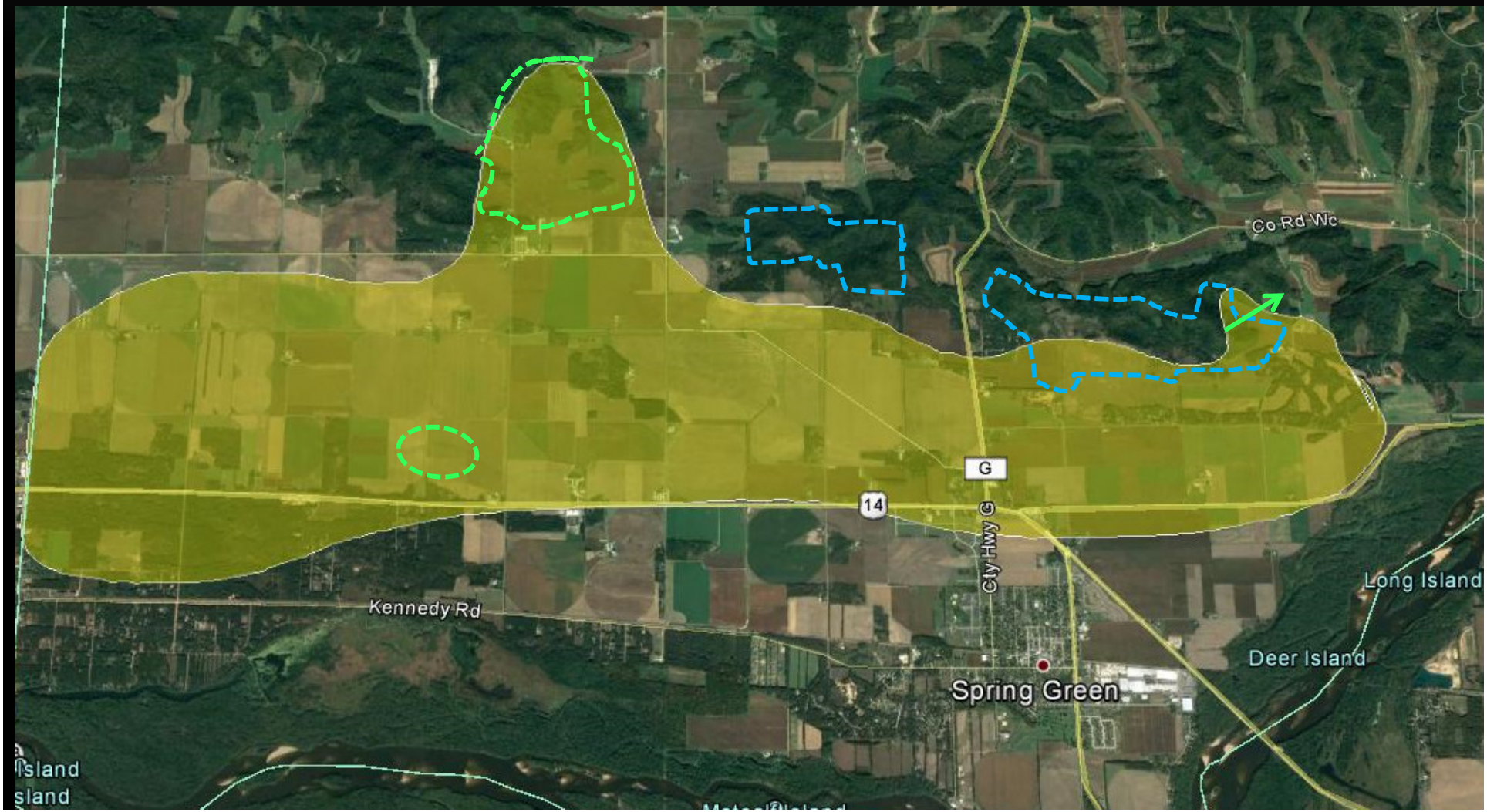

Wilson Creek
18
15
12
9
9
6
6
3
33
Jones Slough
Norton Slough
N


42
39
36
33
30
27
24
21
18
15
12
12
15
9
12
N

# RECHARGE ZONES



# REMEDIATION



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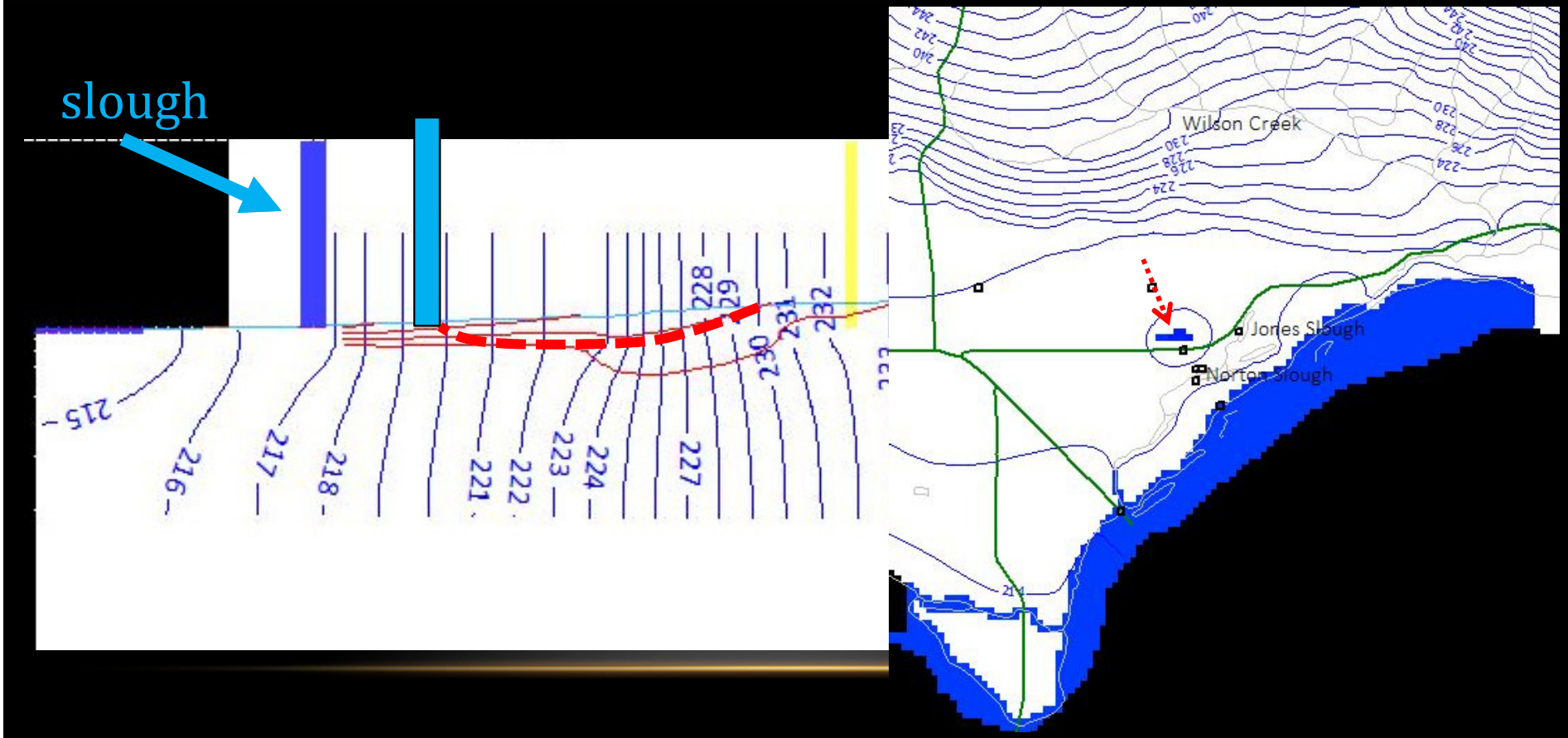

## Special thanks to my advisor, Dr. Jean Bahr

**&**

**Ken Wade, Dave Marshall, Timm Zumm, Doug and Sheryl Jones, Madeline Gotkowitz, and many more!**

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- Sauk County Dept. of Zoning and Conservation
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- Minnesota Groundwater Association Scholarship Foundation




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- Gotkowitz, M. B., Zeiler, K. K., Dunning, C. P., Thomas, J. C. and Lin, Y-F. 2005. *Hydrogeology and simulation of groundwater flow in Sauk County, Wisconsin*, Madison, WI: Wisconsin Geological and Natural History Survey. (Wisconsin Geological and Natural History Survey Bulletin 102)

- http://md.water.usgs.gov/waterdata/index%20images/freshwater.jpg

# QUESTIONS?

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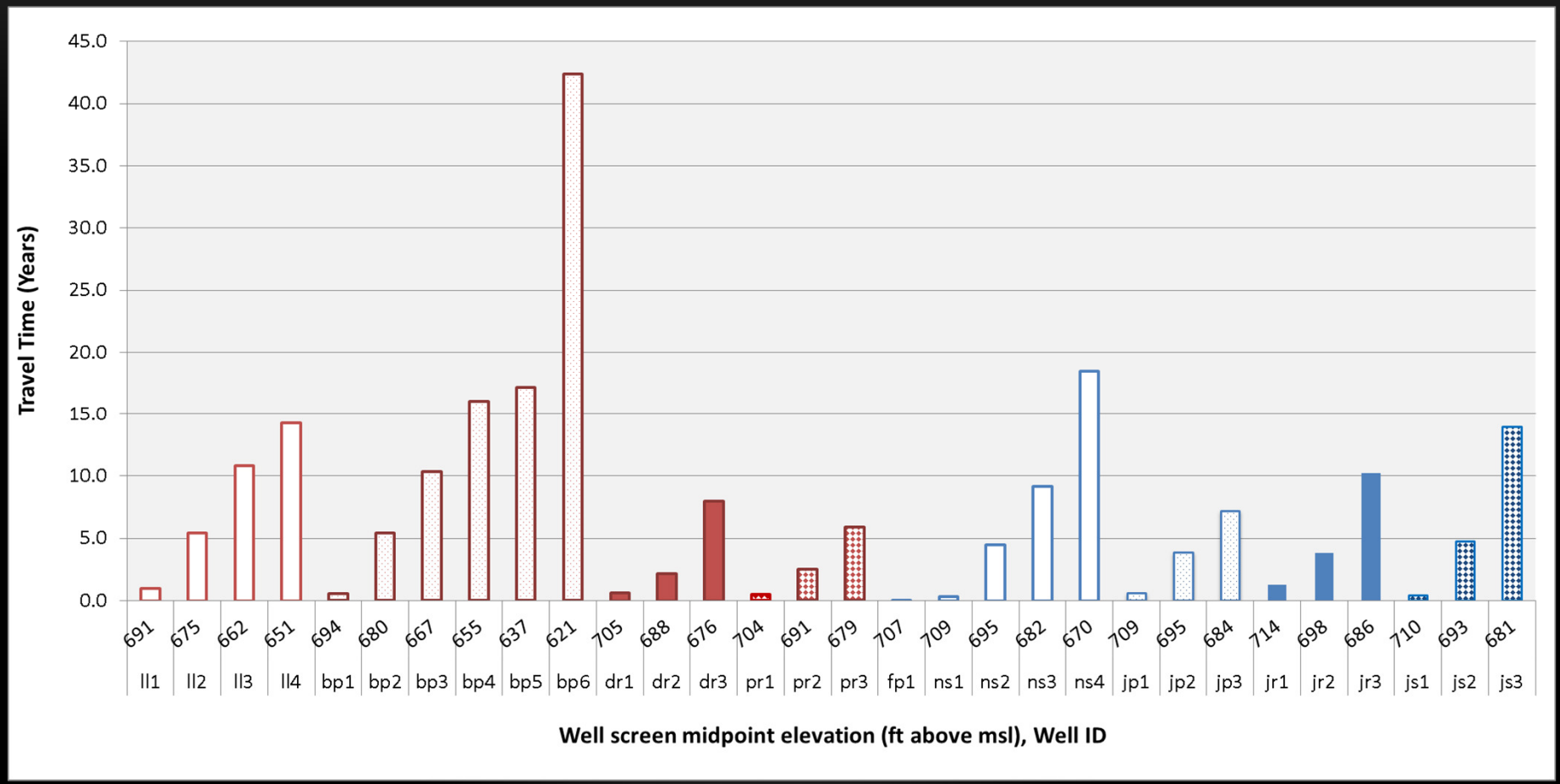
**schlaudt@wisc.edu**

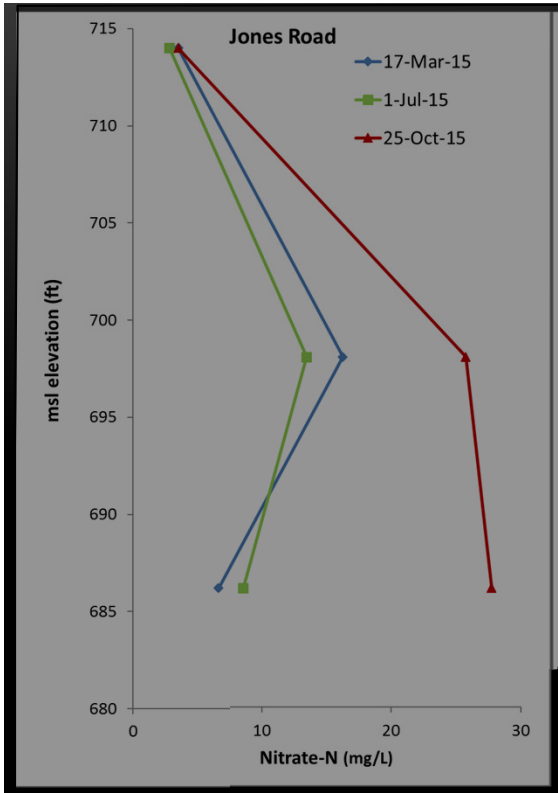
# HYDRAULIC CONDUCTIVITIES

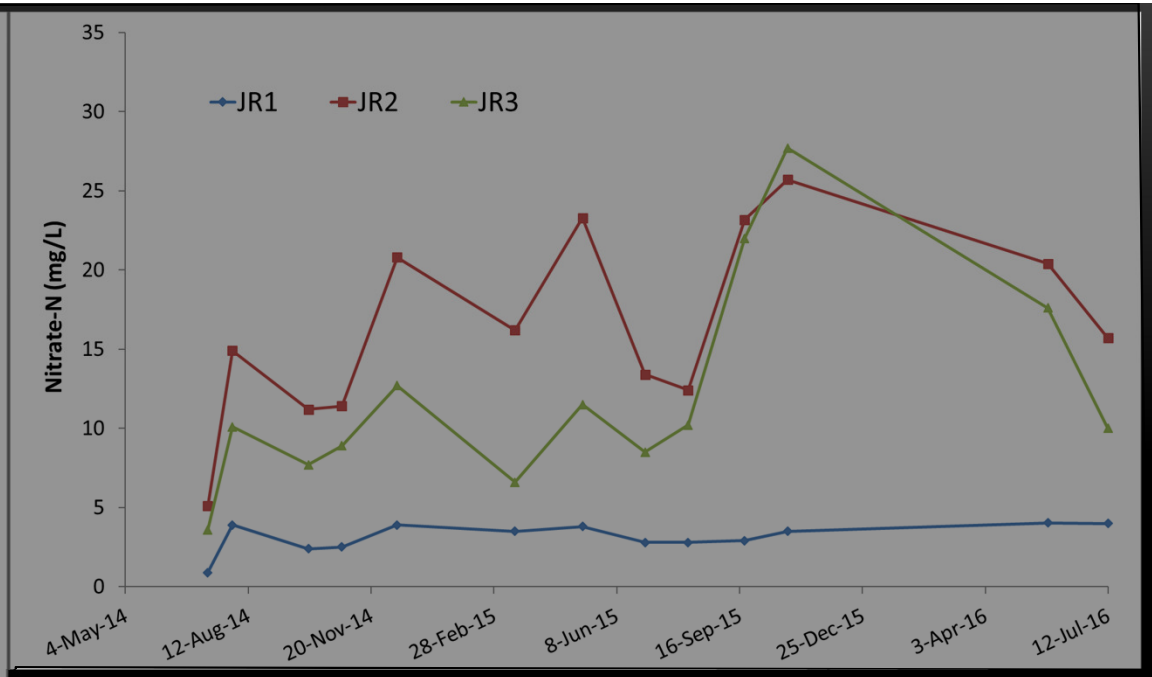
| Hydraulic Conductivity | | Zone | |
|---|---|---|---|
| (m/d) | (ft/d) | (Kx, Ky, Kz) | # |
| 90, 90, 9.0 | 297, 297, 29.7 | Wisconsin River Valley | 3 |
| 45, 45, 4.5 | 148, 148, 14.8 | Modern Floodplain - Silt | 4 |
| 25, 25, 2.5 | 82, 82, 8.2 | Uplands Alluvium | 2 |
| 1, 1, 0.1 | 3.3, 3.3, .33 | Sandstone Bedrock Aquifer | 1 |
| 0.25, 0.25, 0.0025 | 0.82, 0.82, 0.0082 | Dolomite Capped Bluffs | 5 |

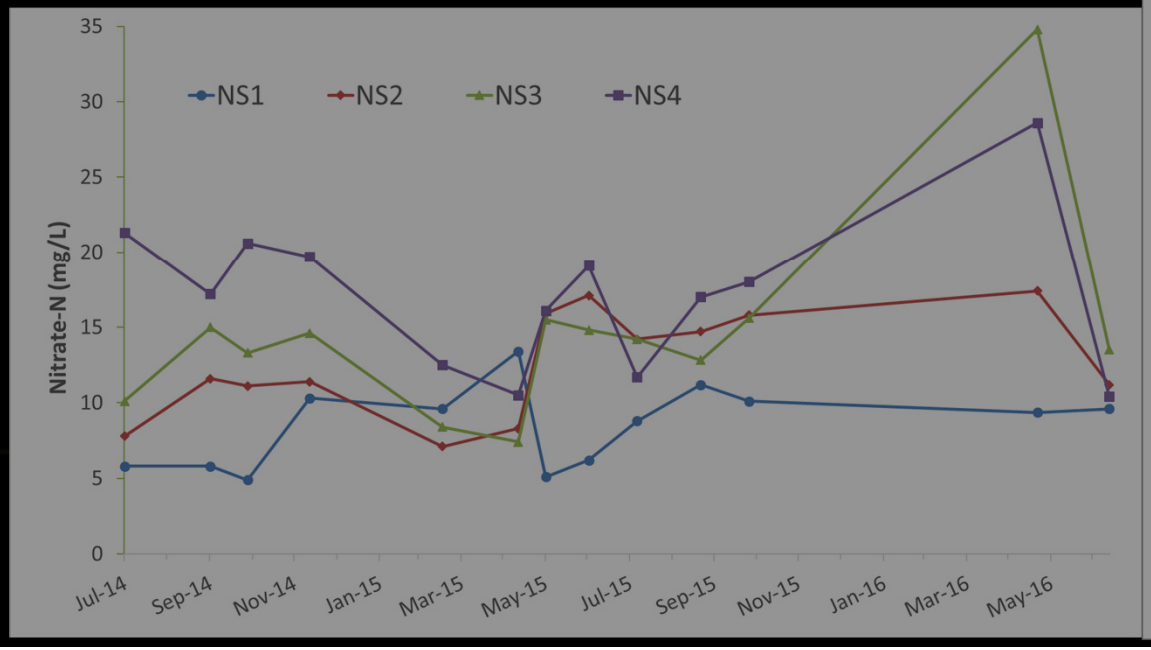
| | Kx | Ky | Kz | | Color |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 0.1 | 0 | |
| 2 | 25 | 25 | 2.5 | 0 | |
| 3 | 90 | 90 | 9 | 0 | |
| 4 | 45 | 45 | 4.5 | 0 | |
| 5 | 0.25 | 0.25 | 0.0025 | 0 | |

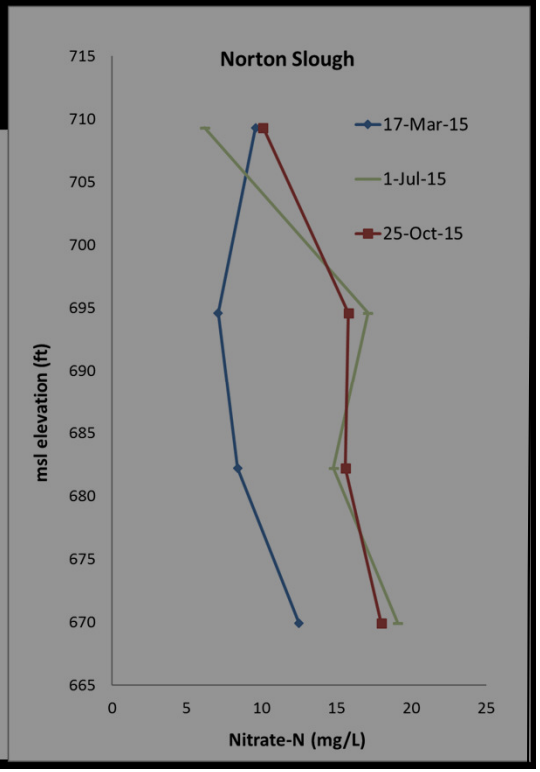
| Recharge Rate | | |
|---|---|---|
| Zone | (m/day) | (ft/day) |
| 1 - sandstone & dolomite bluffs | 8.90E-04 | 2.92E-03 |
| 2 - floodplain | 5.90E-04 | 1.94E-03 |

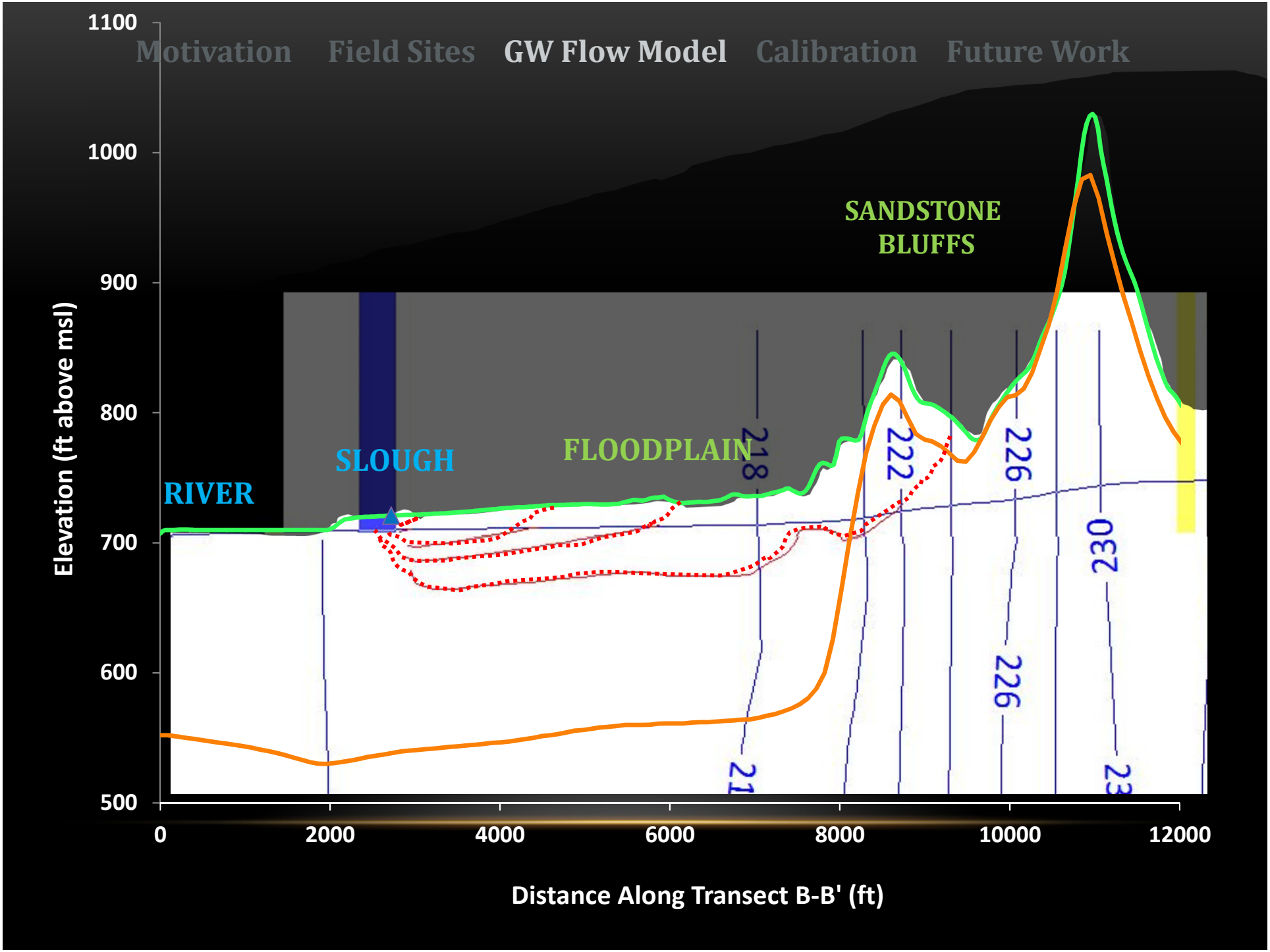

Travel Time (Years)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
691 675 662 651 694 680 667 655 637 621 705 688 676 704 691 679 707 709 695 682 670 709 695 684 714 698 686 710 693 681
ll1 ll2 ll3 ll4 bp1 bp2 bp3 bp4 bp5 bp6 dr1 dr2 dr3 pr1 pr2 pr3 fp1 ns1 ns2 ns3 ns4 jp1 jp2 jp3 jr1 jr2 jr3 js1 js2 js3
Well screen midpoint elevation (ft above msl), Well ID

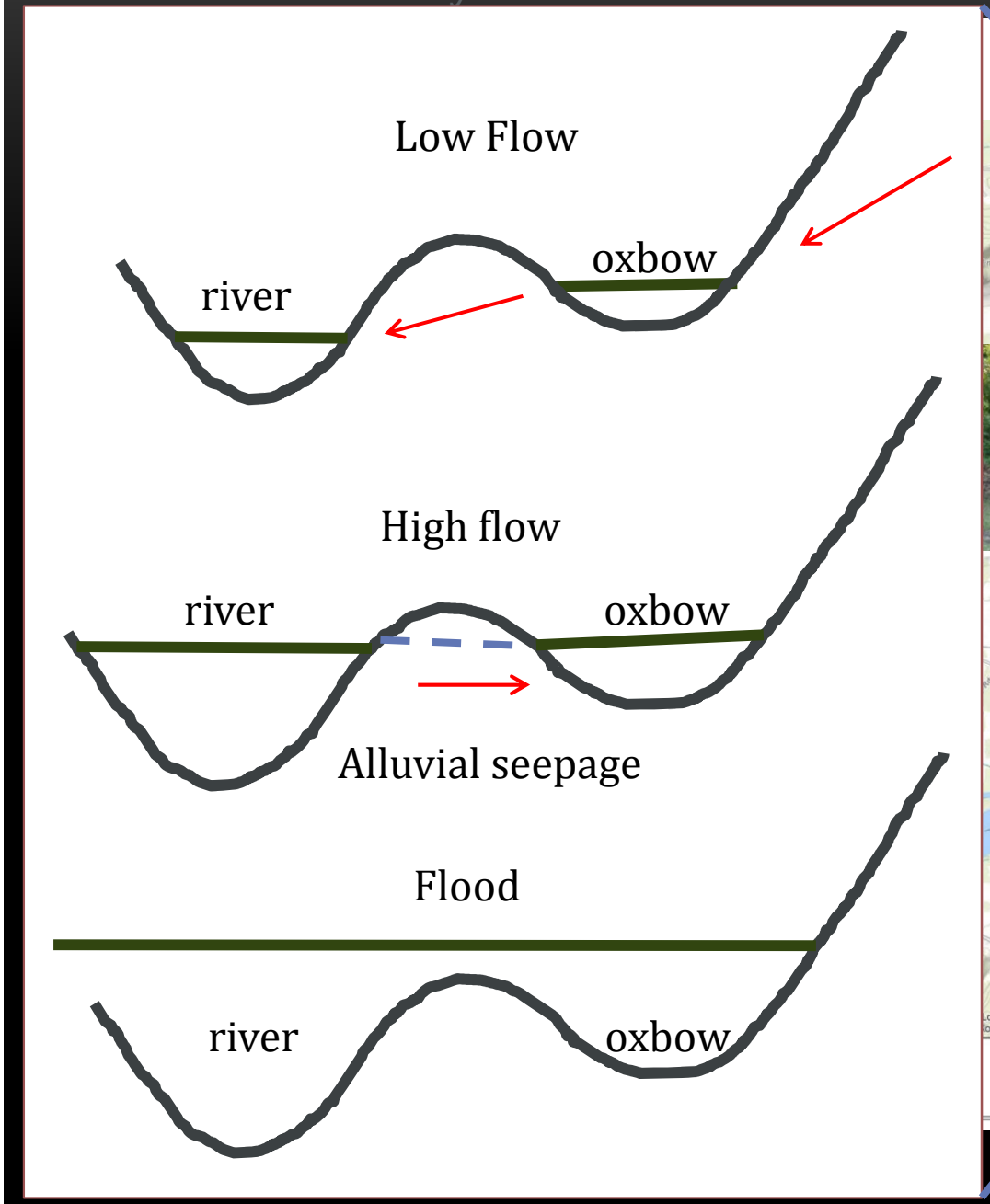

Jones Road
17-Mar-15
1-Jul-15
25-Oct-15
msl elevation (ft)
715
710
705
700
695
690
685
680
0
10
20
30
Nitrate-N (mg/L)

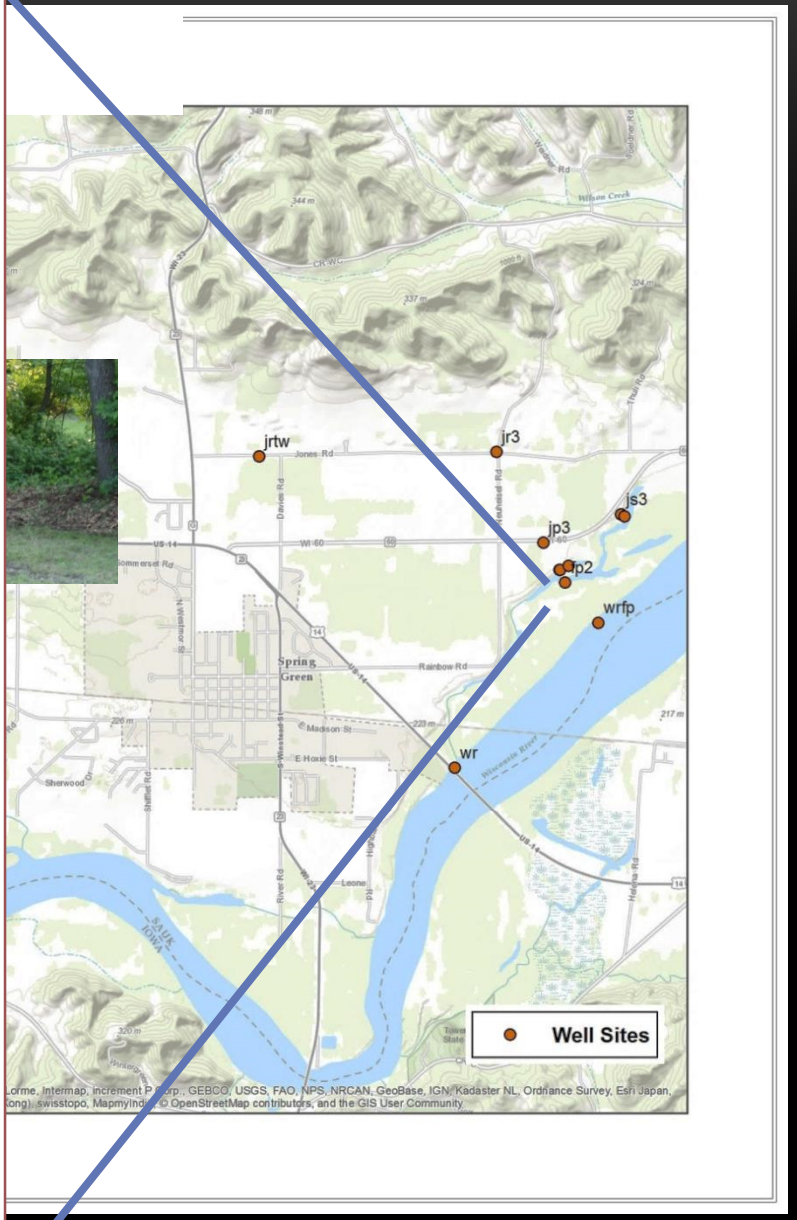

JR1
JR2
JR3
Nitrate-N (mg/L)
35
30
25
20
15
10
5
0
4-May-14
12-Aug-14
20-Nov-14
28-Feb-15
8-Jun-15
16-Sep-15
25-Dec-15
3-Apr-16
12-Jul-16


NS1
NS2
NS3
NS4
Nitrate-N (mg/L)
35
30
25
20
15
10
5
0
Jul-14
Sep-14
Nov-14
Jan-15
Mar-15
May-15
Jul-15
Sep-15
Nov-15
Jan-16
Mar-16
May-16


Norton Slough
17-Mar-15
1-Jul-15
25-Oct-15
msl elevation (ft)
715
710
705
700
695
690
685
680
675
670
665
0
5
10
15
20
25
Nitrate-N (mg/L)

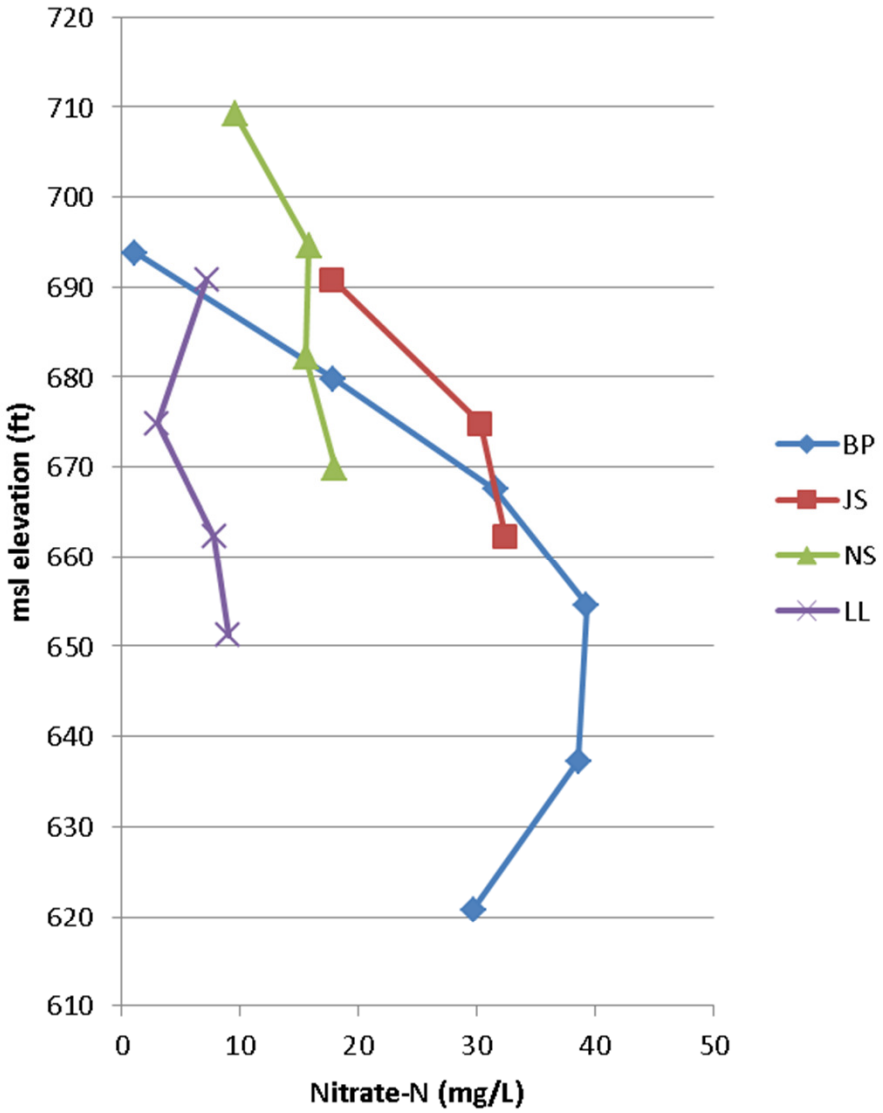

1100
1000
900
800
700
600
500
Elevation (ft above msl)
SANDSTONE BLUFFS
SLOUGH
FLOODPLAIN
RIVER
218
222
226
226
230
0
2000
4000
6000
8000
10000
12000
Distance Along Transect B-B' (ft)

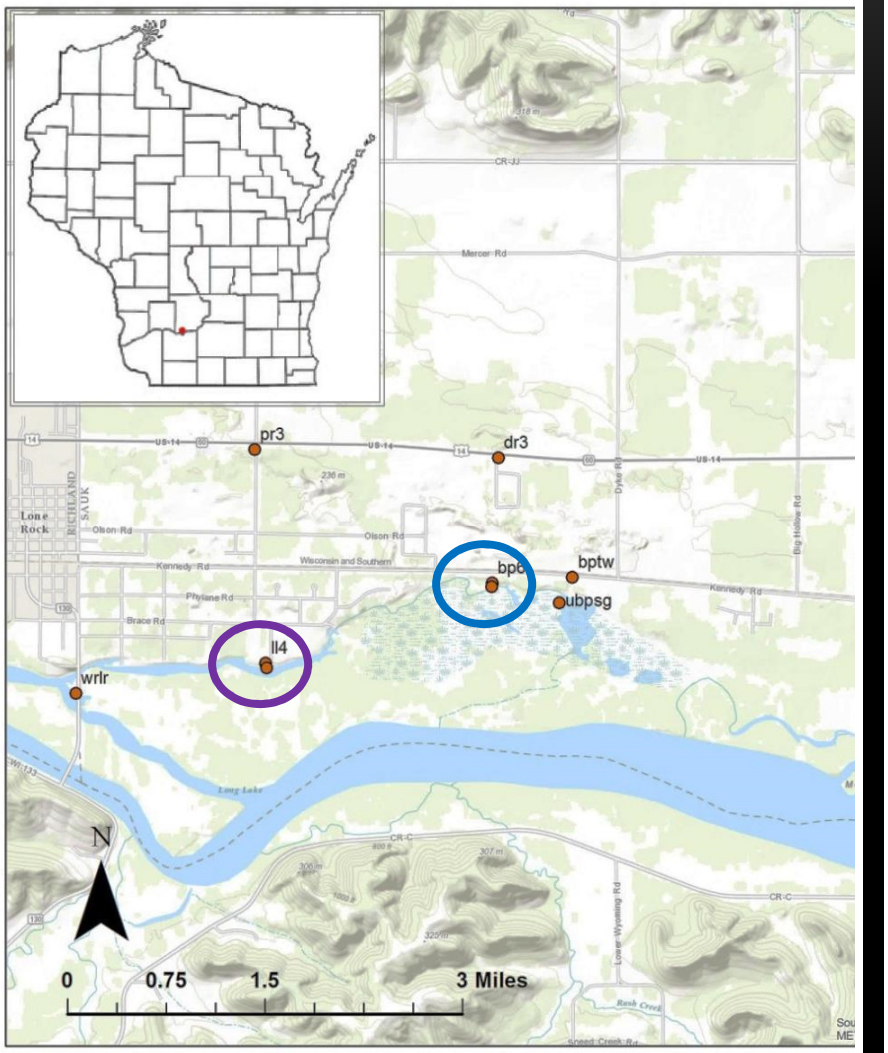


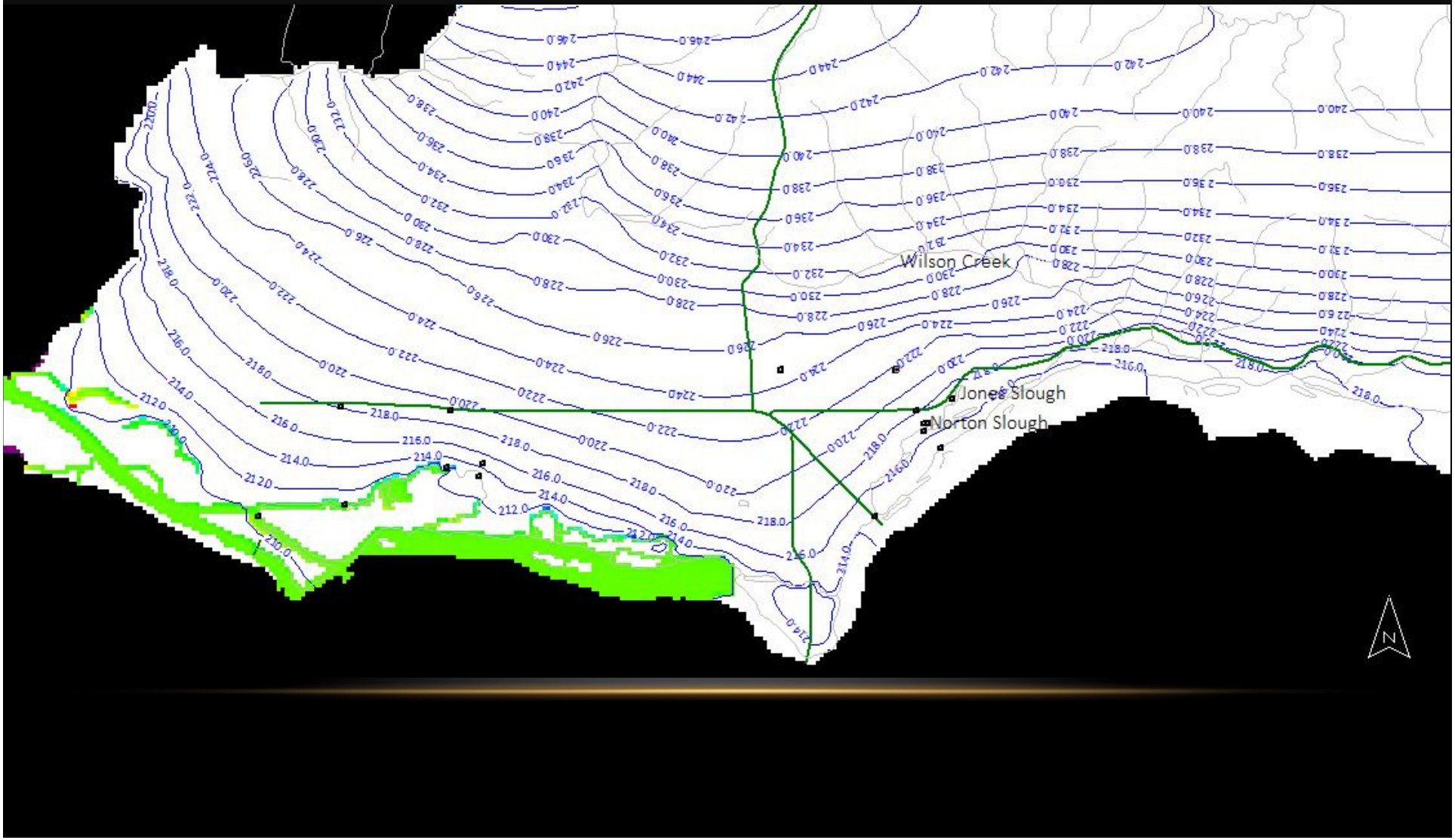

Adapted from Amoros and Bornette, 2002.

# Site Comparison of Nitrate-N

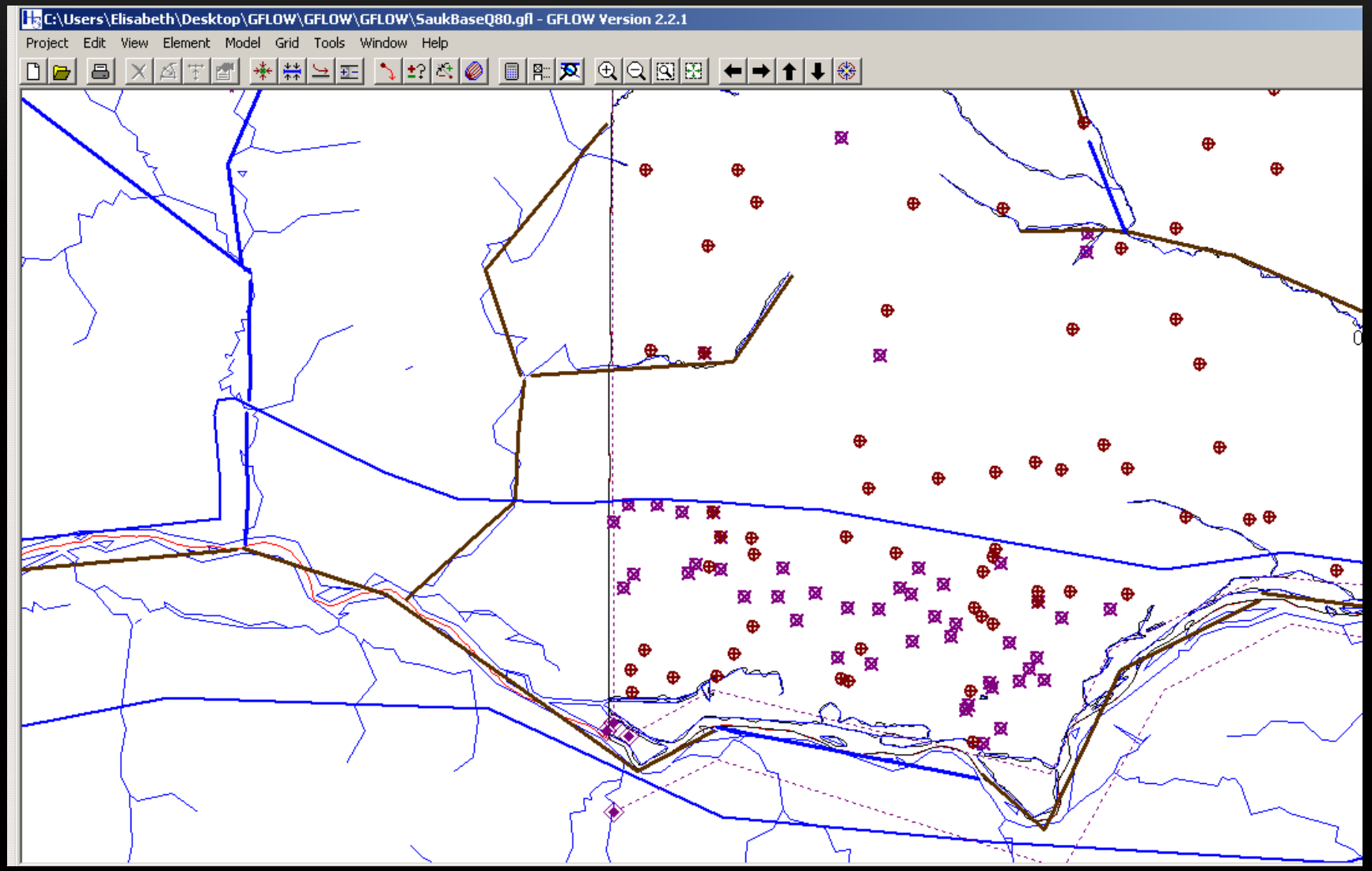


# LAYER 3



# SAUK COUNTY GFLOW



Model Specs:

- The real-world areal extent of the model is approximately 424.7 $km^2$, centered on the town of Spring Green, WI
- 172 rows, 388 columns, and 9 layers with 80 m grid spacing
- Each layer of constant thickness except bottom of layer 9 where the variable elevations represent the contact of sandstone bedrock with Precambrian rock. Layer thicknesses were determined based on the location of the sloughs and the river, the features of focus. More layers with narrower thicknesses were created around these surface water bodies to allow for greater detail in particle tracking and flow path analysis
- Boundaries: bluffs, which act as a regional groundwater divide, define the northeastern boundary of the model and the Wisconsin River the southern boundary. They are represented by a no-flow boundary in layer 1 and multimode wells in layers 2-9 to represent the regional flux in the deeper portion of the unconfined aquifer. Bear Creek and Little Bear Creek make up the west and northwestern boundaries respectively. The Lower Wisconsin River and perennial rivers/ streams were treated as constant head boundaries. Springs and ephemeral streams (determined by USGS topographic maps of the region) were treated as drains. This distinction between perennial and ephemeral streams was made as a way to check model validity by observing at what point the drains became active during model calibration.
- Steady State: All water levels in the model represent baseflow conditions which were determined to occur, on average, between the months of July and October. Water elevations for the constant heads and multi-node well boundary conditions were extracted from the results of the Sauk County GLFOW model and calibrated with the monitoring wells' water level data.