DIGITAL MAPPING TECHNIQUES 2016

The following was presented at DMT'16
(May 22-25, 2016 - Florida Geological Survey,
Tallahassee, FL)

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Big Data Hydrogeology and the Woodville Karst Plain

By Seth Willis Bassett, GISP and Scott Barrett Dyer

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In an abstract sense, the practice of science is an endeavor to create a structured narrative supported by data. The challenge for the researcher in the modern age of computers often lies not in collecting project related data, but rather in interpreting the enormous amounts of data in a manner that constructs a meaningful narrative without getting lost in the 'noise.'

This presentation relates to research conducted by the authors in the western portion of the Woodville Karst Plain region of Florida. In particular, the relationship between Wakulla Spring – one of the largest and best known of Florida's springs – and the Spring Creek Spring Complex is explored. These two springs represent a coupled spring system, where conditions at one spring are both dependent upon and drive changes at the other spring. A brief narrative of subject-oriented slides is presented below:

- Slides 3 – 5 introduce the study area within a mature karstic plain where the unconfined Upper Floridan Aquifer is at a shallow depth. The western Woodville Karst Plain (WKP) is bordered to the west and north by two distinctly different physiographic provinces where the Upper Floridan Aquifer is confined or semi-confined (Apalachicola Coastal Lowlands and the Tallahassee Hills). The differences in surface sediments, topography and the limited interaction between surface waters and groundwater in the provinces to the west and north compared to that of the Woodville Karst Plain and work to determine the flow dynamics present in the WKP. An idealized cross section is presented to give the reader a perspective of the characteristics of the Woodville Karst Plain and its positon between the Tallahassee Hills and the Gulf of Mexico.
- Slides 6 – 9 highlight the complexity of flow dynamics within the Woodville Karst Plain. An example of the "flashy" flow of Wakulla Spring and the enormity of water that can be conveyed through the mature karstic area following Tropical Storm Debby is presented. Wakulla Spring and Spring Creek Springs Complex are introduced.
- Slides 10 – 14 elucidates the prevalence of conduits and karst windows within the study area and the monitoring that has been conducted to document, understand and determine the cohesive response the conduit system exhibits to flow regime changes within the basin. The karst windows monitored (except Tobacco Sink) have all been verified by divers and or dye tracing experiments to be connected to the underlying conduit system. The conduits proximal to the vent (B, C, D, AD, K, AK) that are being monitored represent the aggregate contribution of the major conduits supplying the water discharged through the main vent at Wakulla Spring.

- Slides 15 and 16 propose and demonstrate the data prompting the two most important questions asked in regards to the flow-regime changes observed at Wakulla Spring over the past two decades. The top figure on slide 16 illustrates the increase in average discharge at the main vent at Wakulla measured in cubic feet per second. The bottom figure indicates the declining visibility of the water at Wakulla spring as the percentage of the year that glass-bottom boat tours were run by the park service, as these tours are not offered when visibility is poor.
- Slides 17 – 19 reveal the enormous amount of data an extended study can generate and the tools employed to address the archiving, analysis and presentation of such a large data set in a cohesive, interpretable and presentable manner.
- Slides 20 – 26 present the water level elevation data obtained through the karst window monitoring and a two stage flow regime that was differentiated based on the positive or negative discharge at Spring Creek Springs Complex. The salinity of Spring Creek Springs Complex was correlated with the water level elevation at the karst windows. The two stage system is shown in slides 24 and 26 to manifest a gradient reversal that is capable of redirecting ground water and allogenic recharge (typically tannic and dark in color) from the western and southern portions of the basin that traditionally flow south to Spring Creek Springs Complex; when Spring Creek Spring complex is no longer discharging, this water is rerouted northward to Wakulla Spring. This demonstrates that the two first magnitude springs share or compete for groundwater depending on the varying hydrological conditions. This also demonstrates why the discharge is increasing at Wakulla Spring and why the clarity of the water has decreased.
- Slides 27 – 32 present conductivity and directional flow data obtained by conduit monitoring at six conduits proximal to the main vent at Wakulla Spring, Revell Sink and Spring Creek vent 10 to demonstrate a spatial and temporal migration of more conductive water (presumably mixed and diluted seawater) northward during specific periods of sustained negative flow (high conductivity) at Spring Creek Springs Complex. Slide 28 demonstrates that the south facing conduits (AD, AK, K and C) proximal to the Wakulla Spring vent and Revell sink experience a rise in conductivity following the sustain negative flow and high salinity at Spring Creek Springs Complex. Slide 29 demonstrates that the same south facing conduits proximal to the vent at Wakulla Spring also show a more defined azimuthal direction of flow from the south to the north during the same periods. Slides 30 and 31 explore the possibility that the increase in conductivity documented in the conduit flow meter monitoring are due to anthropogenic runoff (Tallahassee, Spray fields or landfills) or connate water. Slide 31 explores the possibility that the rise in conductivity during the periods examined is associated with analytes typical of anthropogenic sources (those plotted with red data points), connate water (those plotted with bright green data points) or analytes typical of saltwater (those plotted with blue data points). Slide 32 demonstrates that the molar ratios of Na/Cl analytes are within the ratios typical of saltwater, indicating that trace amounts of seawater are being conveyed inland from the Spring Creek vents to Wakulla Spring vent during periods of flow reversal at Spring Creek.

- Slide 33 and 34 provide key lessons learned by the authors relating to collecting, archiving, analyzing and presenting large volumes of scientific data.
- Slide 35 provides links by which readers can learn more about the project.

In order to build a narrative that explain the complex and dynamic relationships explored during the project, the authors embarked on a multi-year project of organizing and analyzing multiple sources of data that eventually totaled millions of rows in a PostgreSQL database. Critical to advancing their project was the realization that neither author could have completed this work on their own. Thus, in the author's view, research that is predicated on 'big' data requires a team of at least two personnel: the domain expert (i.e., geologist) who is able to create meaning out of raw data, and a data expert who is able to organize, manipulate, and visualize the data to support the geologist and their interpretative efforts.

Florida Department of Environmental Protection

Florida Geological Survey

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Digital Mapping Techniques

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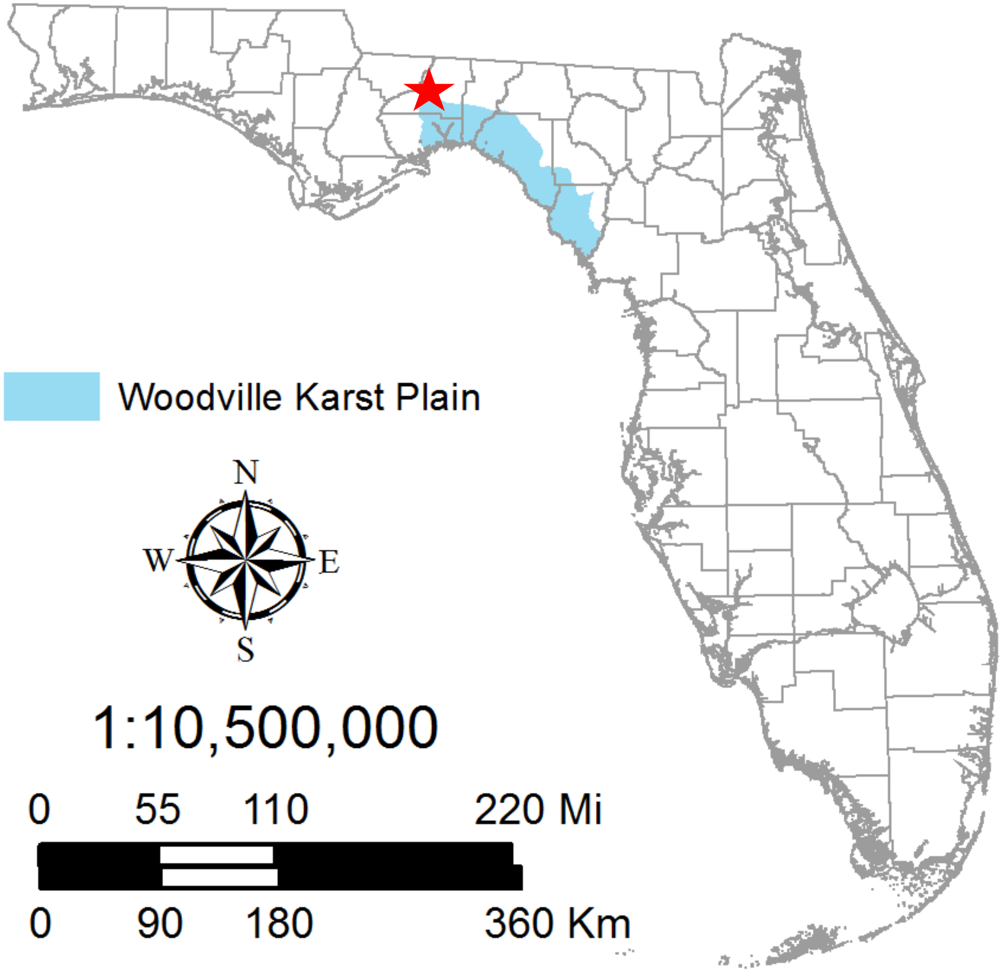
Woodville Karst Plain

Scott Barrett Dyer

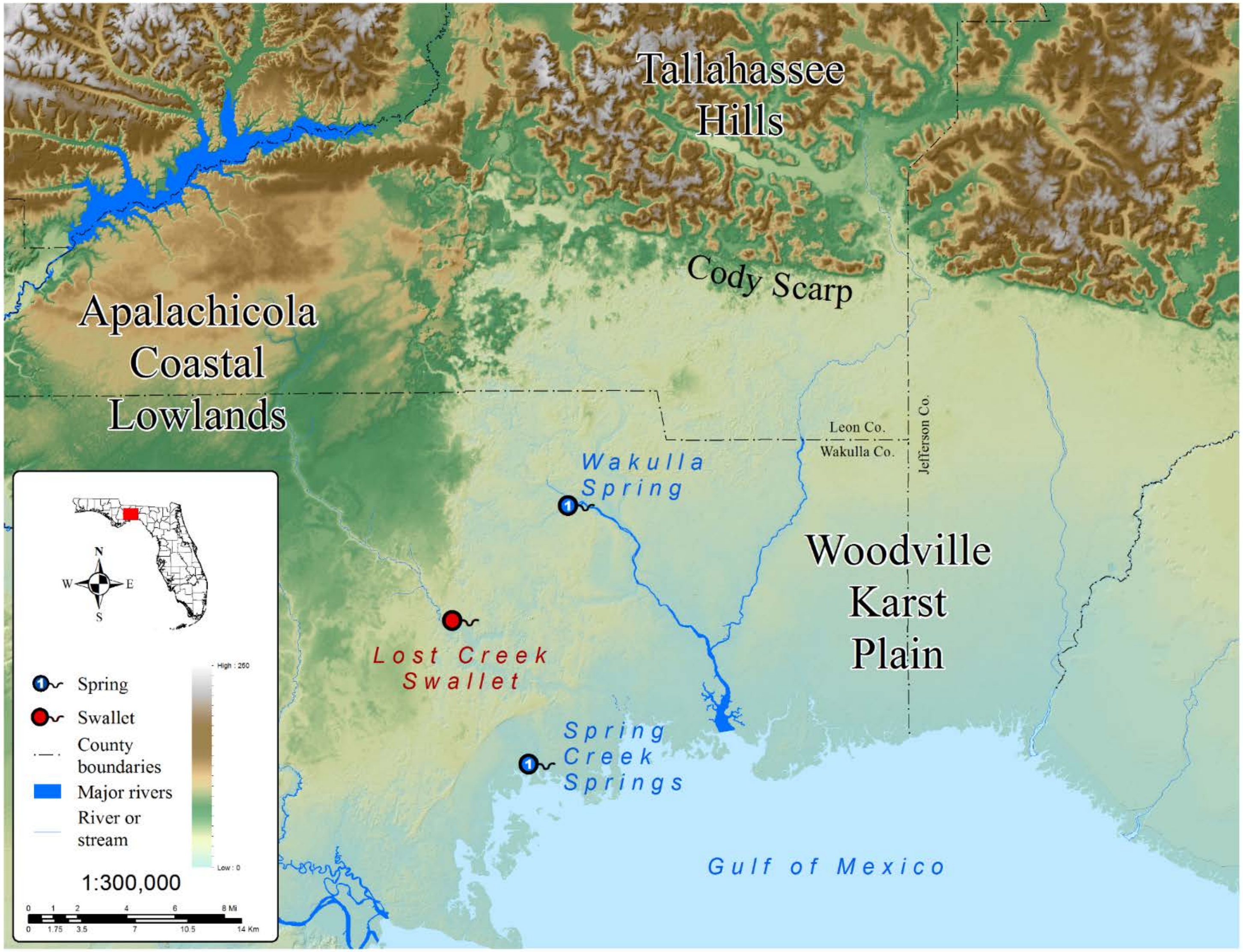




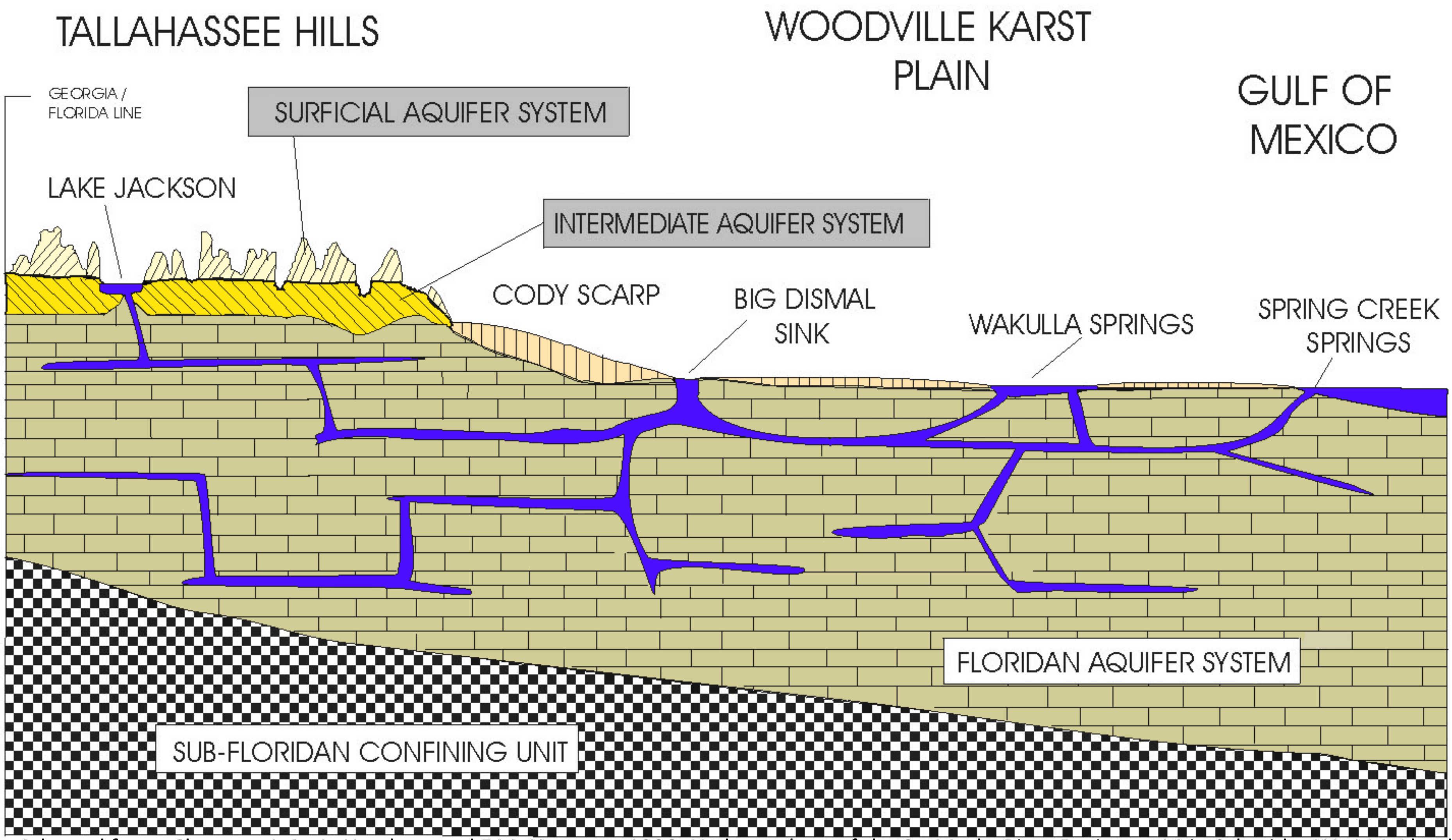
The Woodville Karst Plain



Physiography



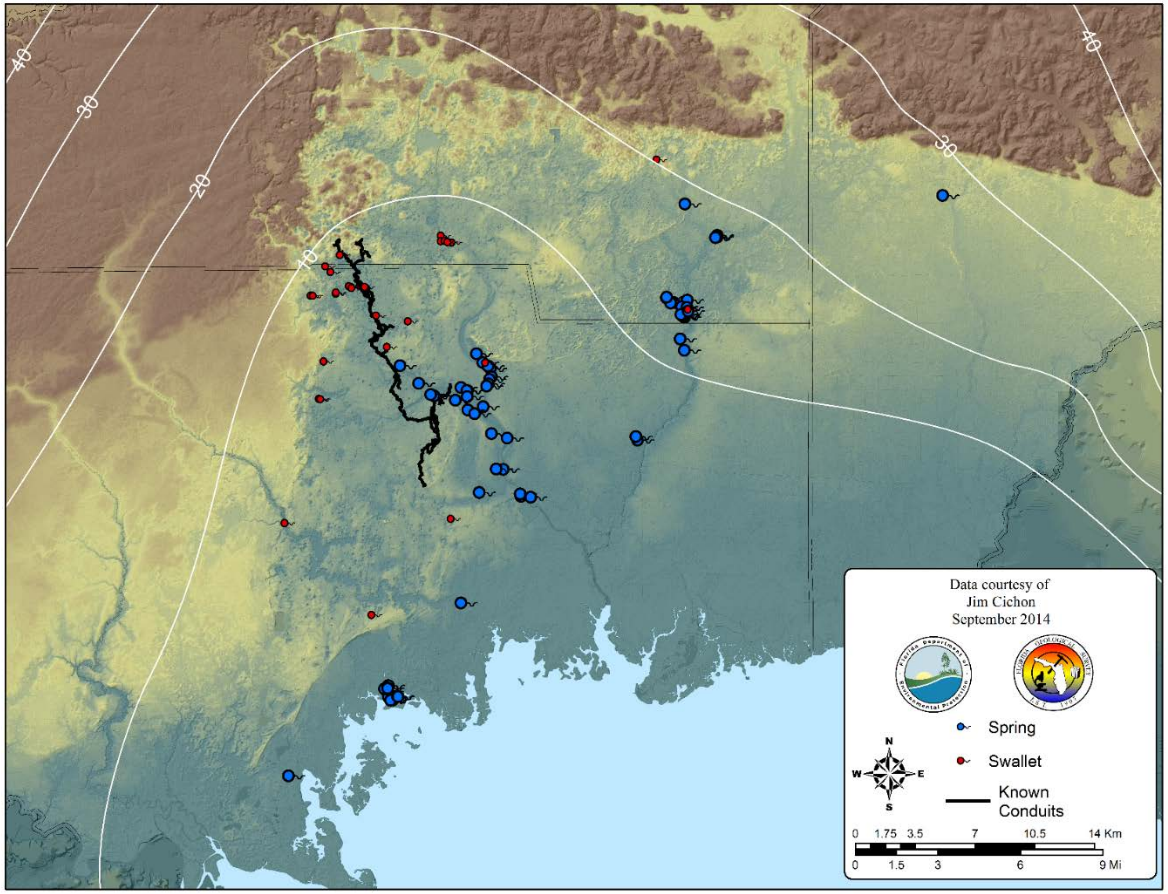
Idealized Cross Section



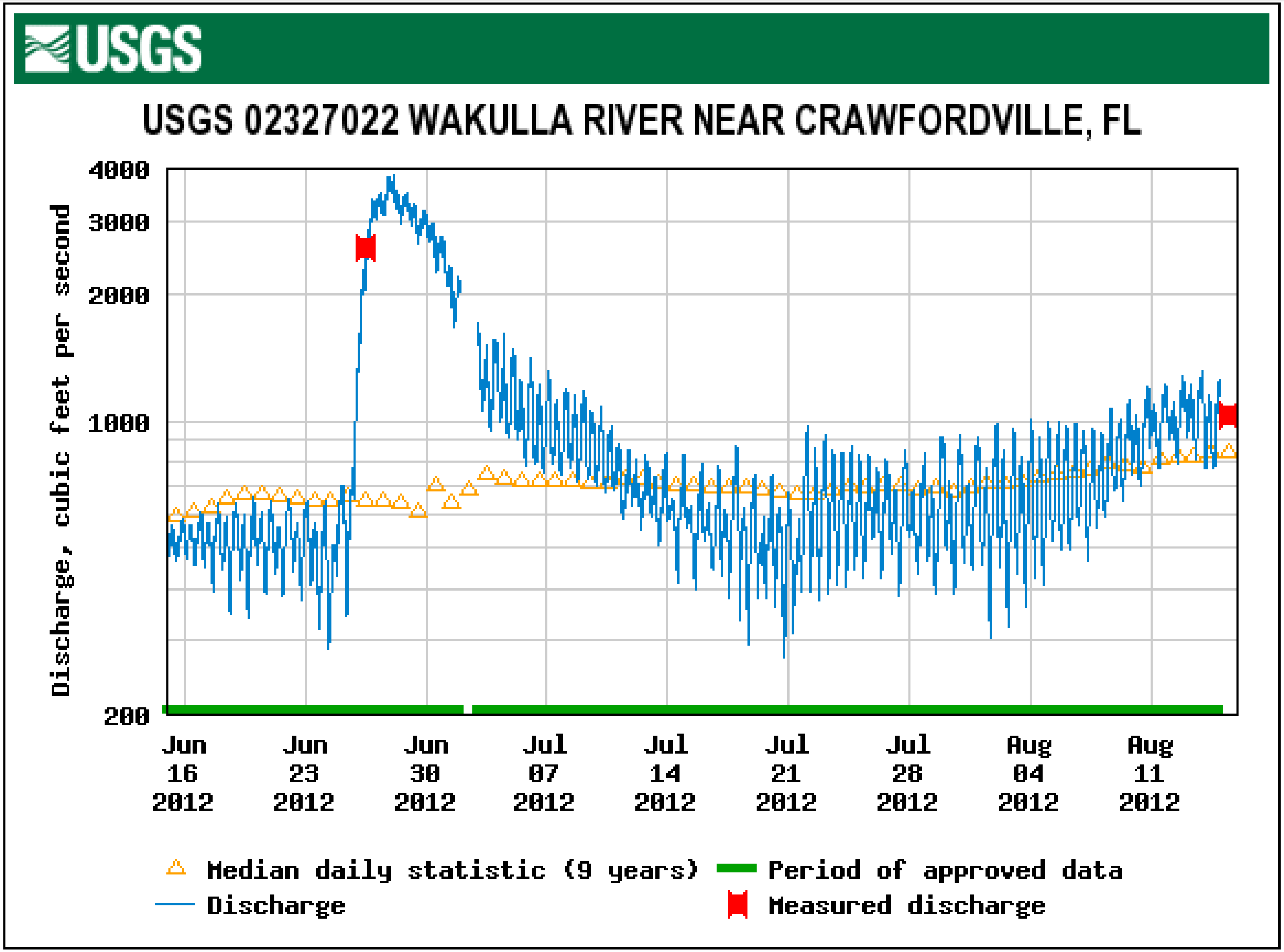
Adapted from: Clemens, L.A., L. Hatchett and F.M. Hartnett. 1998. Hydrogeology of the St. Marks River Basin. pp 14 in Schmidt., W., J.M. Lloyd and C. Collier. Bulletin 56: *The Wakulla Springs Woodville Karst Plain Symposium*. Florida Geological Survey. Tallahassee, Fl.

Flow Dynamics

- Convergence of flow in/out UFA
- Multiple components of water: Regional GW, Autogenic and Allogenic Recharge
- Regional GW discharge UFA
- Highly Karstified, Highly transmissive
- Mature/well developed conduits system/ Preferential flow paths
- 14 springs: 1st - 3rd magnitude; Three first magnitude Q> 2.83 m^3/s (Scott et al., 2004
- Fast-Active Flow and Slower In-Active flow



Tropical Storm Debby



Wakulla Spring

- One of Florida's largest and well known springs
- Main vent / subordinate springs form Wakulla River
- Discharge varies, responsive to precipitation, "flashy"
- Extraordinary quantity of discharge in Wakulla County
  - 88% of the **total** discharge for the 'groundwater area'
  - 16% of **total** discharge for the **entire** Upper Floridan Aquifer

Source: Johnston et al., 1988

Spring Creek Spring Complex (SCSC)

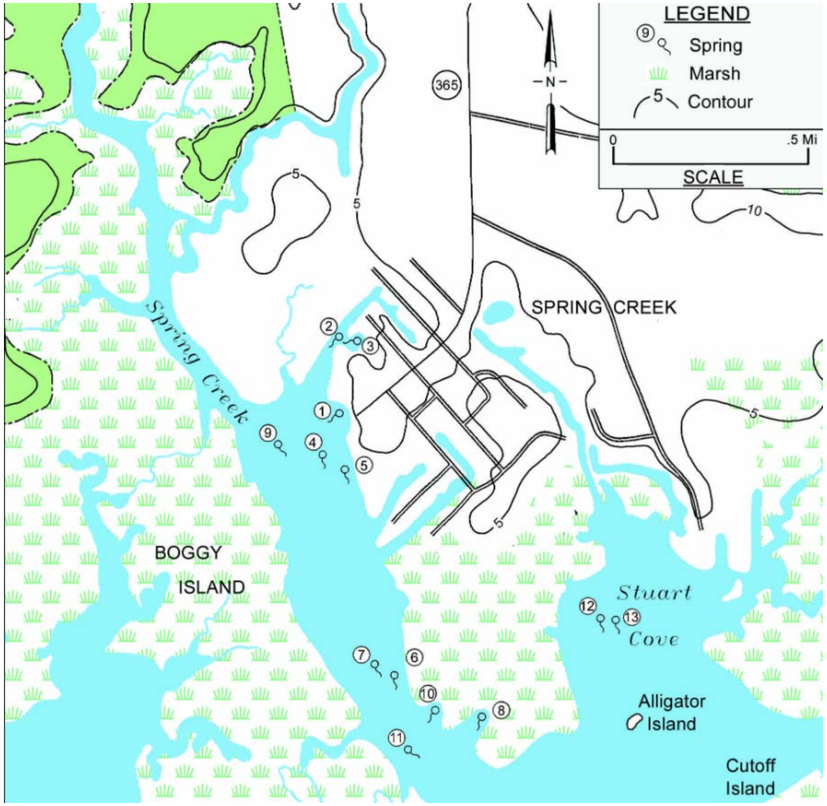
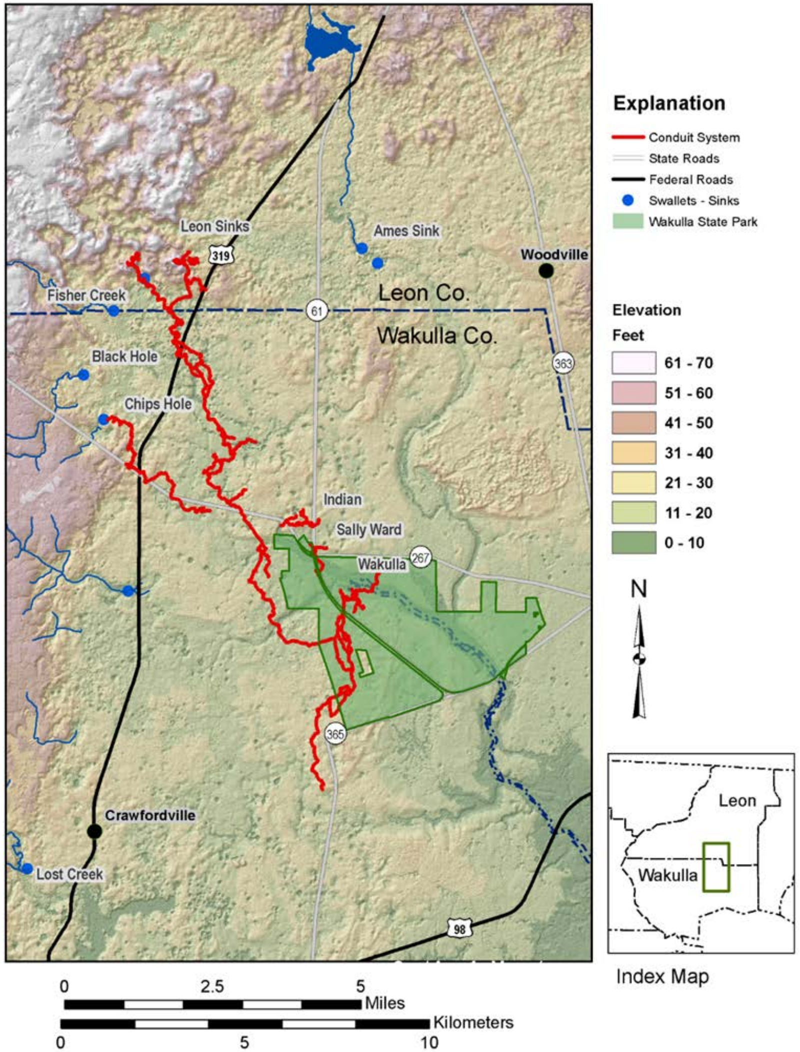


Image Credit: Lane 2001

Image Credit: Tom Scott & Hal Davis

Woodville Karst Plain Project – GUE Conduit mapping and exploration

- Founded in 1987 responsible for most of the known characteristics of the conduit system
- December 2007 formally connected the Leon Sinks – Wakulla Spring cave system
- South 6.3 km in Q tunnel toward Spring Creek Springs
- Contributed indispensable efforts to this study
- Exploration continues



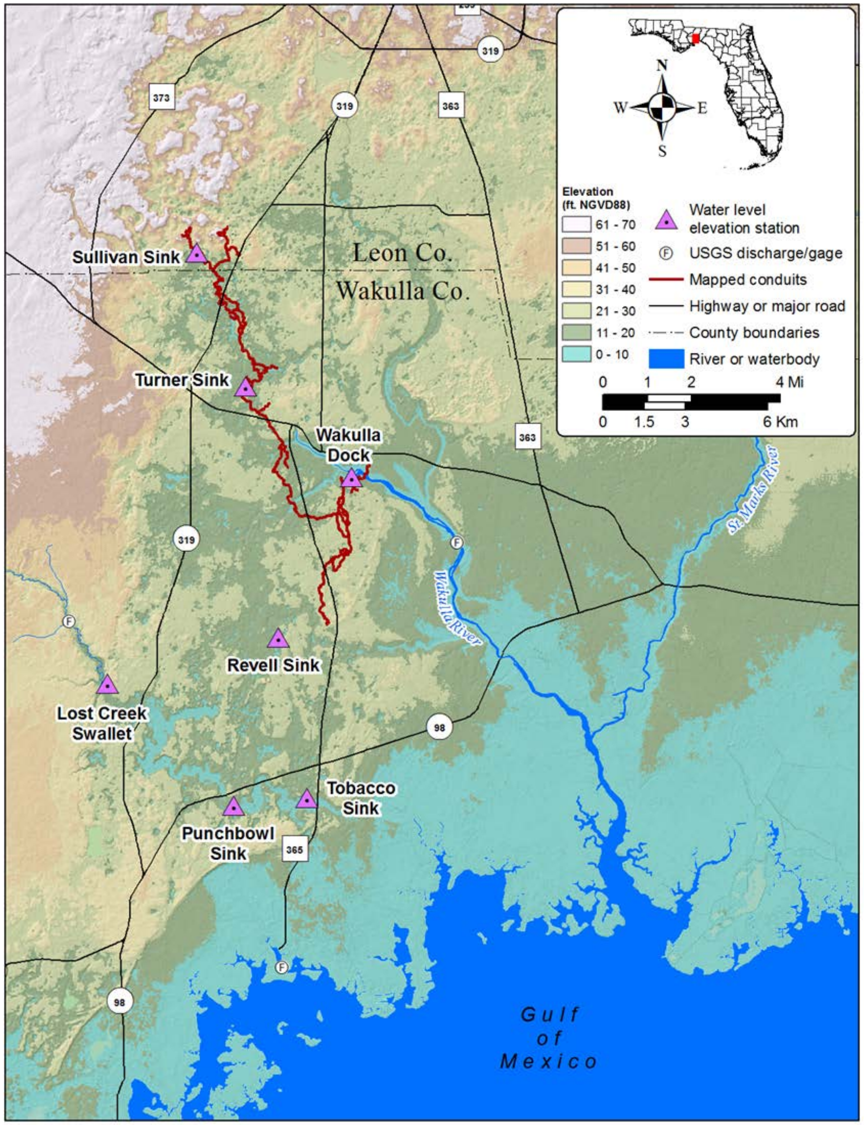
Karst Windows

Sullivan Sink. Image Credit: Seth Bassett / FGS

Punchbowl Sink. Image Credit: Seth Bassett / FGS

Water Level Elevation Stations at Karst Windows

- Monitor water level elevation
- Deployed along North – South Transect
- Monitor conduit system response to flow regime changes
- Exhibit cohesive conduit system response to hydraulic pressure



Conduit Instrumentation

Image credit:
Falmouth Scientific, Inc.

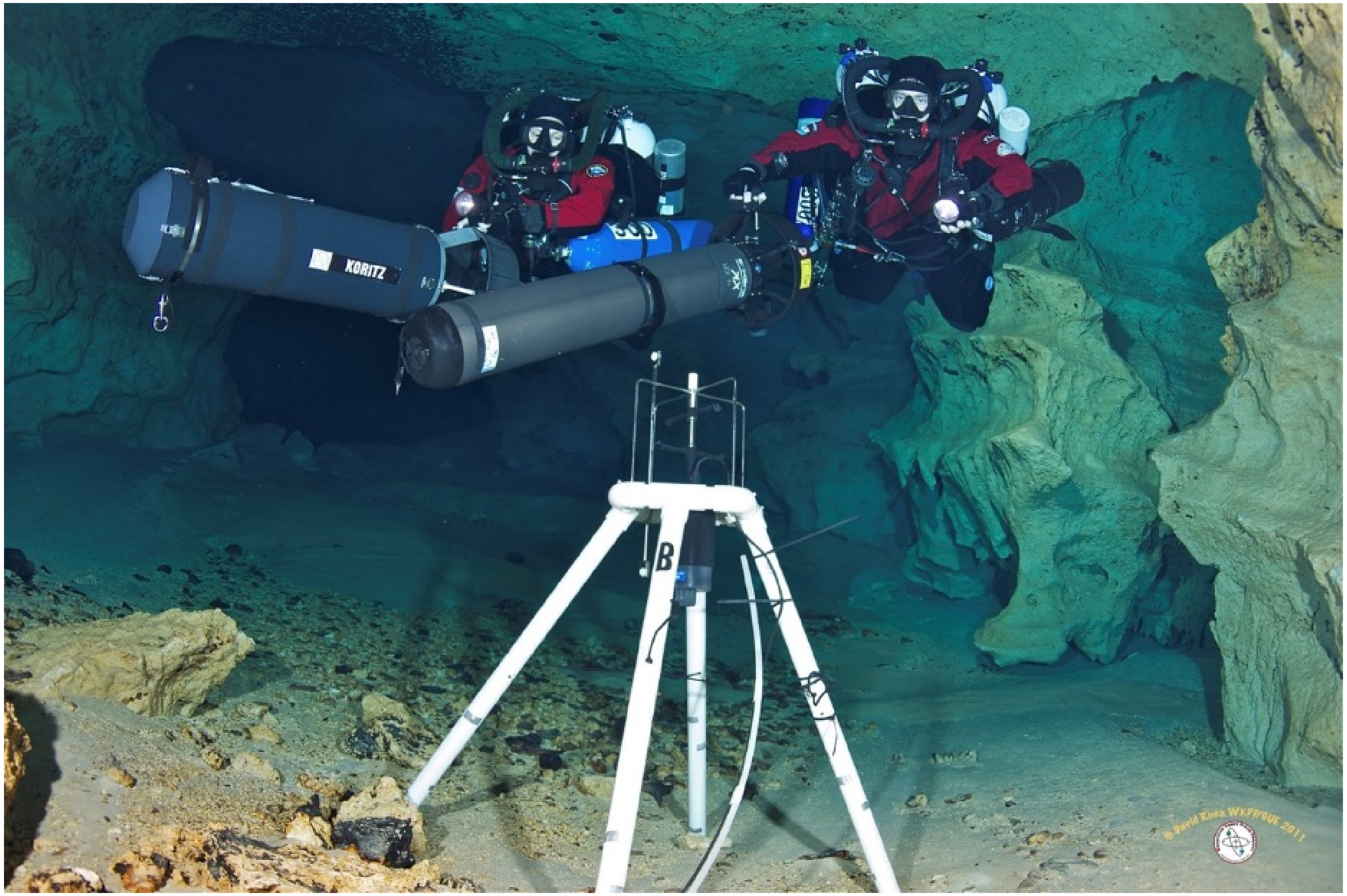
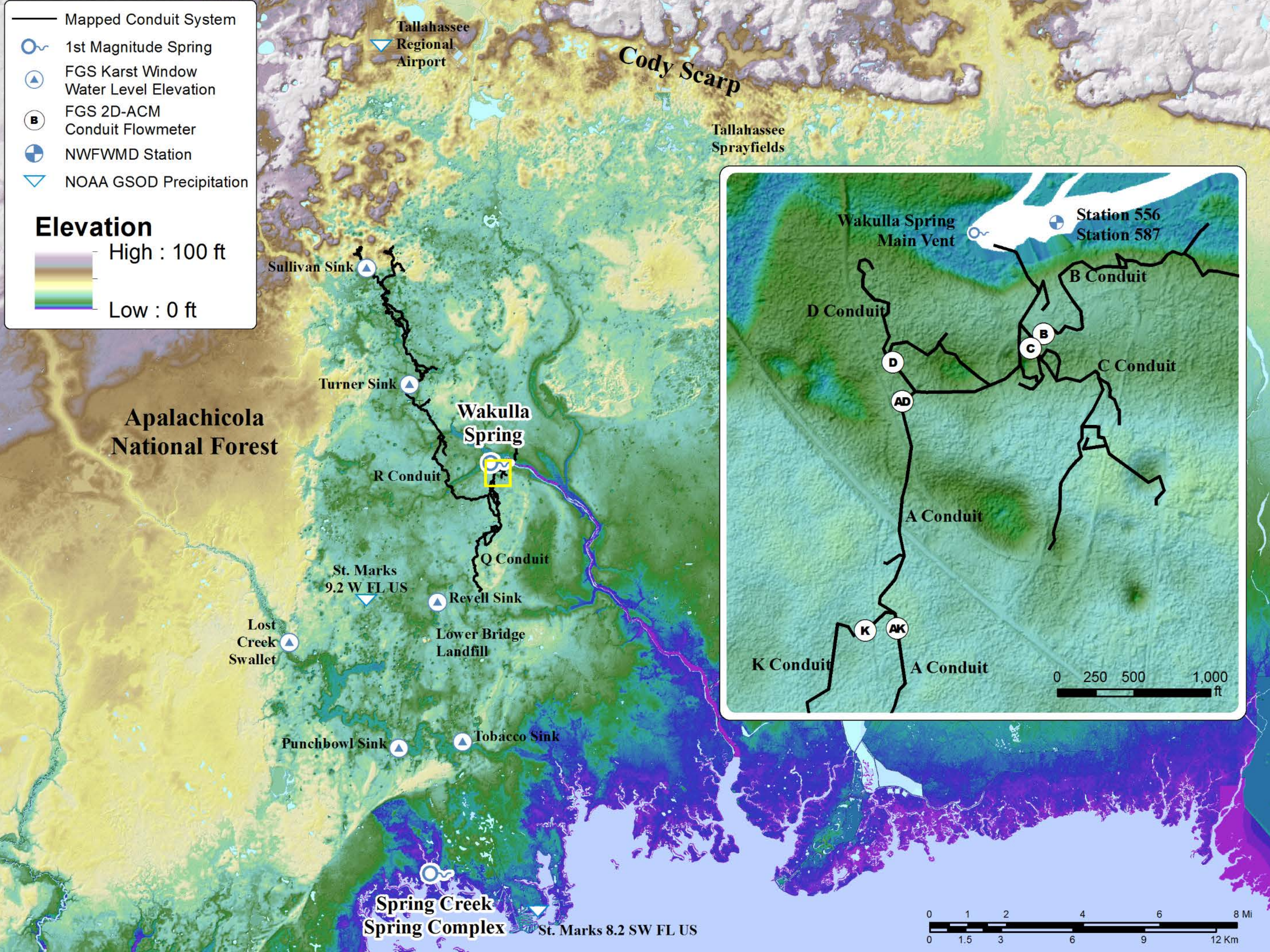


Image Copyright: David Rae and the Global Underwater Explorers/Woodville Karst Plain Project.



Mapped Conduit System
1st Magnitude Spring
FGS Karst Window Water Level Elevation
FGS 2D-ACM Conduit Flowmeter
NWFWMD Station
NOAA GSOD Precipitation
Elevation
High : 100 ft
Low : 0 ft
Tallahassee Regional Airport
Cody Scarp
Tallahassee Sprayfields
Sullivan Sink
Turner Sink
Apalachicola National Forest
Wakulla Spring
R Conduit
Q Conduit
St. Marks 9.2 W FL US
Revell Sink
Lost Creek Swallet
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Spring Creek Spring Complex
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Wakulla Spring Main Vent
Station 556
Station 587
B Conduit
D Conduit
C Conduit
A Conduit
K Conduit
B
C
D
AD
K
AK
0 250 500 1,000 ft
0 1 2 4 6 8 Mi
0 1.5 3 6 9 12 Km

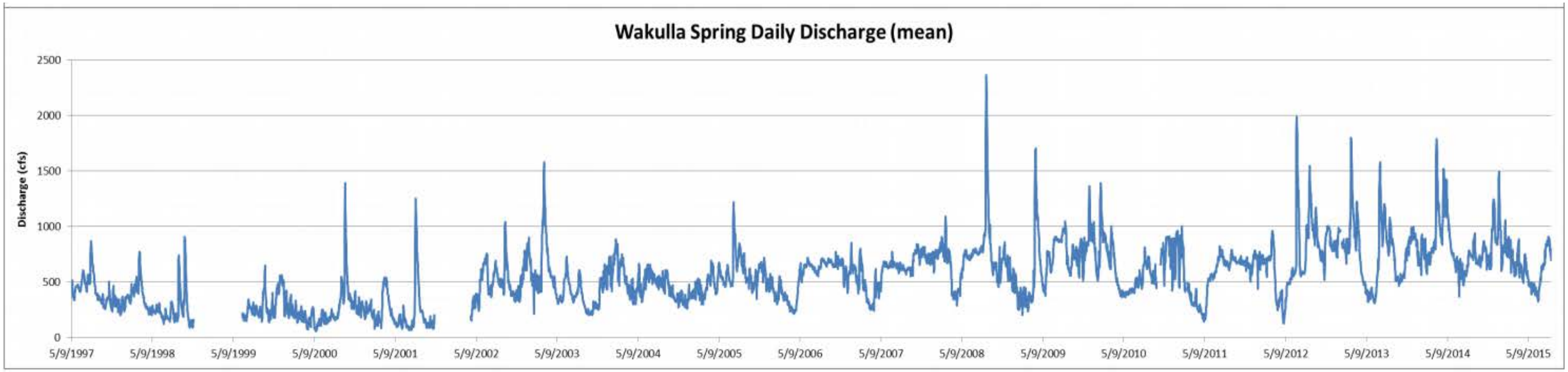
Two most important questions??

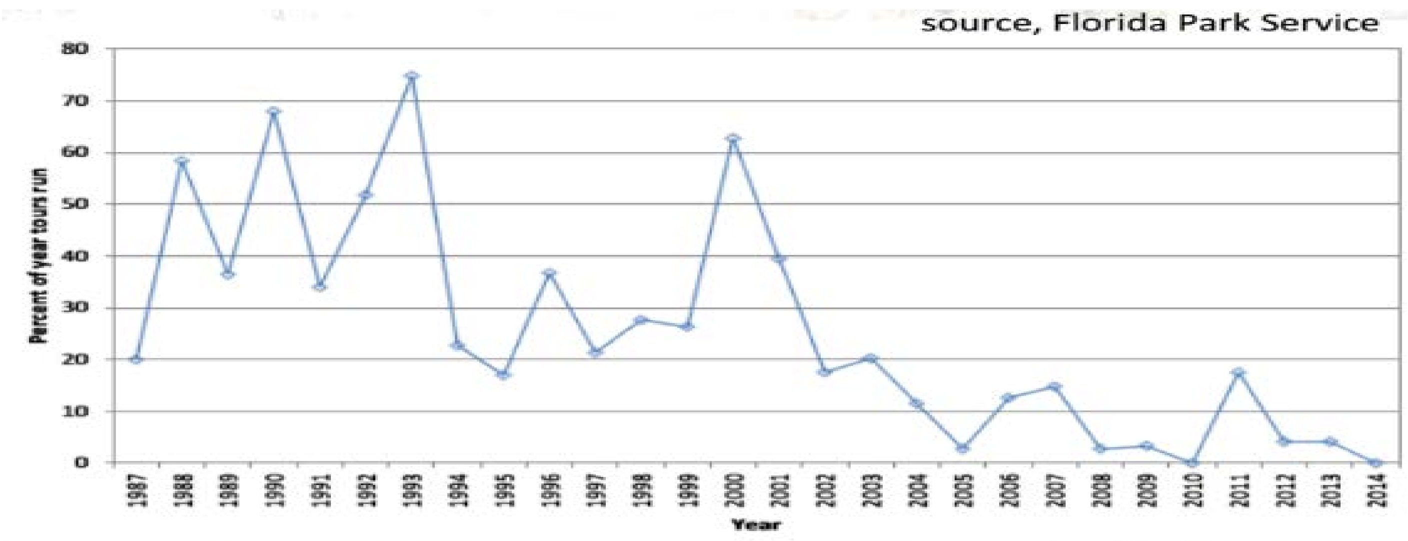
- Proposed by the two most notable Hydrologist involved in Woodville Karst Plain research (Barrios & Davis)

  - Why is discharge at Wakulla Springs on the increase?

  - Why is clarity at Wakulla Springs decreasing?

Two Questions





Source: Kristopher Barrios, Northwest Florida Water Management District

Big Data

Site	Start Timestamp	End Timestamp	Device	Rows	Parameters	Total
AD (Deep)	2004-02-08 02:15:00+00	2013-12-02 18:00:01+00	Falmouth 2D-ACM	311833	28	8731324
AK (Deep)	2004-02-07 22:15:00+00	2008-05-14 18:45:00+00	Falmouth 2D-ACM	79052	28	2213456
AK (Deep)	2008-05-18 17:45:00+00	2013-12-02 17:00:01+00	Falmouth 2D-ACM	156346	28	4377688
B (Deep)	2003-11-23 02:32:23+00	2013-12-02 18:00:00+00	Falmouth 2D-ACM	342020	28	9576560
C (Deep)	2003-11-25 23:00:58+00	2013-01-10 15:15:00+00	Falmouth 2D-ACM	311542	28	8723176
D (Deep)	2007-12-17 17:45:00+00	2009-07-08 18:15:00+00	Falmouth 2D-ACM	53193	28	1489404
D (Deep)	2004-02-08 02:15:00+00	2007-07-05 18:00:00+00	Falmouth 2D-ACM	116041	28	3249148
D (Deep)	2011-07-12 16:06:00+00	2013-12-02 18:00:01+00	Falmouth 2D-ACM	56775	28	1589700
K (Deep)	2008-05-18 18:00:00+00	2013-12-02 17:00:00+00	Falmouth 2D-ACM	157757	28	4417196
K (Deep)	2004-02-07 22:15:00+00	2008-05-14 18:45:00+00	Falmouth 2D-ACM	98964	28	2770992
Revell Sink (Deep)	2010-09-17 17:45:00+00	2014-01-23 19:00:01+00	Falmouth 2D-ACM	84089	28	2354492
Spring Creek 10 (Deep)	2009-05-28 17:15:00+00	2014-01-23 18:00:01+00	Falmouth 2D-ACM	131433	28	3680124
Spring Creek 1 (Deep)	2009-05-20 21:45:00+00	2011-11-02 15:15:00+00	Falmouth 2D-ACM	79165	28	2216620
Vent (Deep)	2003-10-30 03:50:57+00	2006-08-10 14:00:00+00	Falmouth 2D-ACM	9684	28	271152
Vent (Deep)	2007-02-15 15:05:00+00	2007-05-19 16:45:00+00	Falmouth 2D-ACM	8932	28	250096
Vent (Deep)	2008-05-16 14:51:24+00	2009-05-24 04:08:40+00	Falmouth 2D-ACM	1832	28	51296
Vent (Deep)	2007-12-16 23:05:00+00	2008-03-29 09:05:00+00	Falmouth 2D-ACM	9929	28	278012
Lost Creek (Surface)	2009-01-26 17:30:00+00	2012-11-11 18:27:35+00	Level Troll 500	130648	5	653240
Revell Sink (Surface)	2008-12-15 19:45:00+00	2010-03-18 18:45:00+00	Level Troll 500	39838	5	199190
Revell Sink (Surface)	2010-08-19 17:00:00+00	2013-02-20 17:00:00+00	Level Troll 500	85996	5	429980
Revell Sink (Surface)	2013-02-20 18:00:00+00	2013-03-07 18:04:31+00	Level Troll 500	362	5	1810
Revell Sink (Surface)	2013-07-24 16:00:00+00	2014-02-24 19:00:00+00	Level Troll 500	5164	5	25820
St. Marks River Rise (Surface)	2008-12-16 00:00:00+00	2010-08-23 17:30:00+00	Level Troll 500	55380	5	276900
Sullivan Sink (Surface)	2013-02-20 20:00:00+00	2014-02-24 20:00:00+00	Level Troll 300	8856	3	26568
Sullivan Sink (Surface)	2008-12-10 18:00:07+00	2013-02-20 19:00:00+00	Level Troll 500	145574	5	727870
Tobacco Sink (Surface)	2008-12-15 17:15:00+00	2013-02-20 16:00:00+00	Level Troll 500	144141	5	720705
Tobacco Sink (Surface)	2013-10-02 17:00:00+00	2015-01-23 00:00:00+00	Level Troll 500	3481	5	17405
Turner Sink (Surface)	2012-04-11 18:15:00+00	2013-02-20 18:00:00+00	Aqua Troll 200 CTD	27797	5	138985
Turner Sink (Surface)	2008-12-16 19:59:59+00	2010-03-26 01:45:00+00	Level Troll 500	43855	5	219275
Turner Sink (Surface)	2010-08-25 16:15:00+00	2011-09-16 18:45:00+00	Level Troll 500	37163	5	185815
Vent (Surface)	2013-02-21 14:45:00+00	2013-05-23 14:00:00+00	Aqua Troll 200	2179	3	6537
Vent (Surface)	2011-04-14 00:00:00+00	2012-11-27 17:00:00+00	Level Troll 500	52331	5	261655
Vent (Surface)	2013-07-24 17:00:00+00	2014-02-24 17:00:00+00	Level Troll 500	5161	5	25805
Vent (Surface)	2008-08-14 15:00:00+00	2011-02-15 18:00:00+00	Level Troll 500	92237	5	461185
				2,888,750		60,619,181

Florida Department of Environmental Protection

Florida Geological Survey

WKP Data & Analysis

Seth Willis Basset, GISP





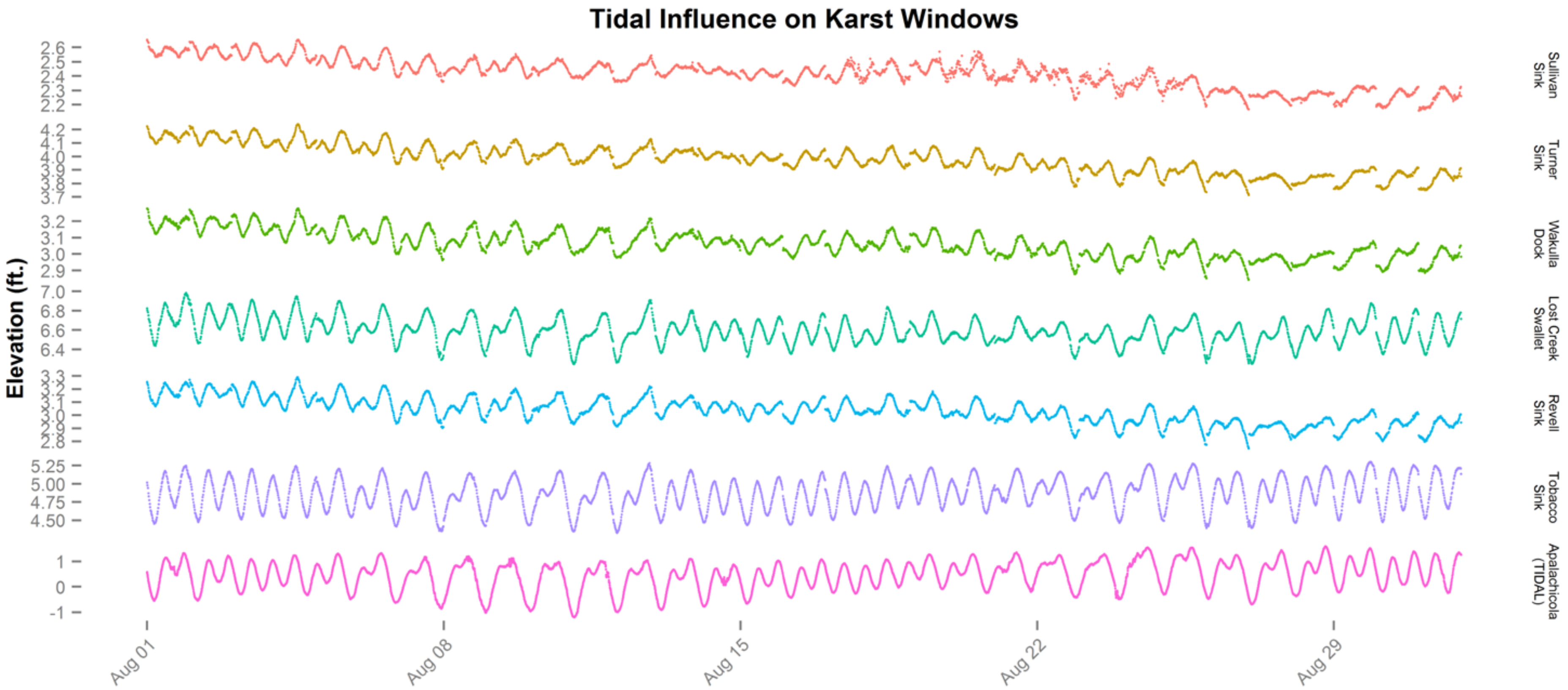
Solutions:
Dealing with the Data Flood

- Processing and Storage
  - Python
  - PostgreSQL
  - PostGIS

- Plotting and Analysis
  - R

- Communication & Distribution
  - Github
  - Shiny Server

Karst Window Tidal Signatures

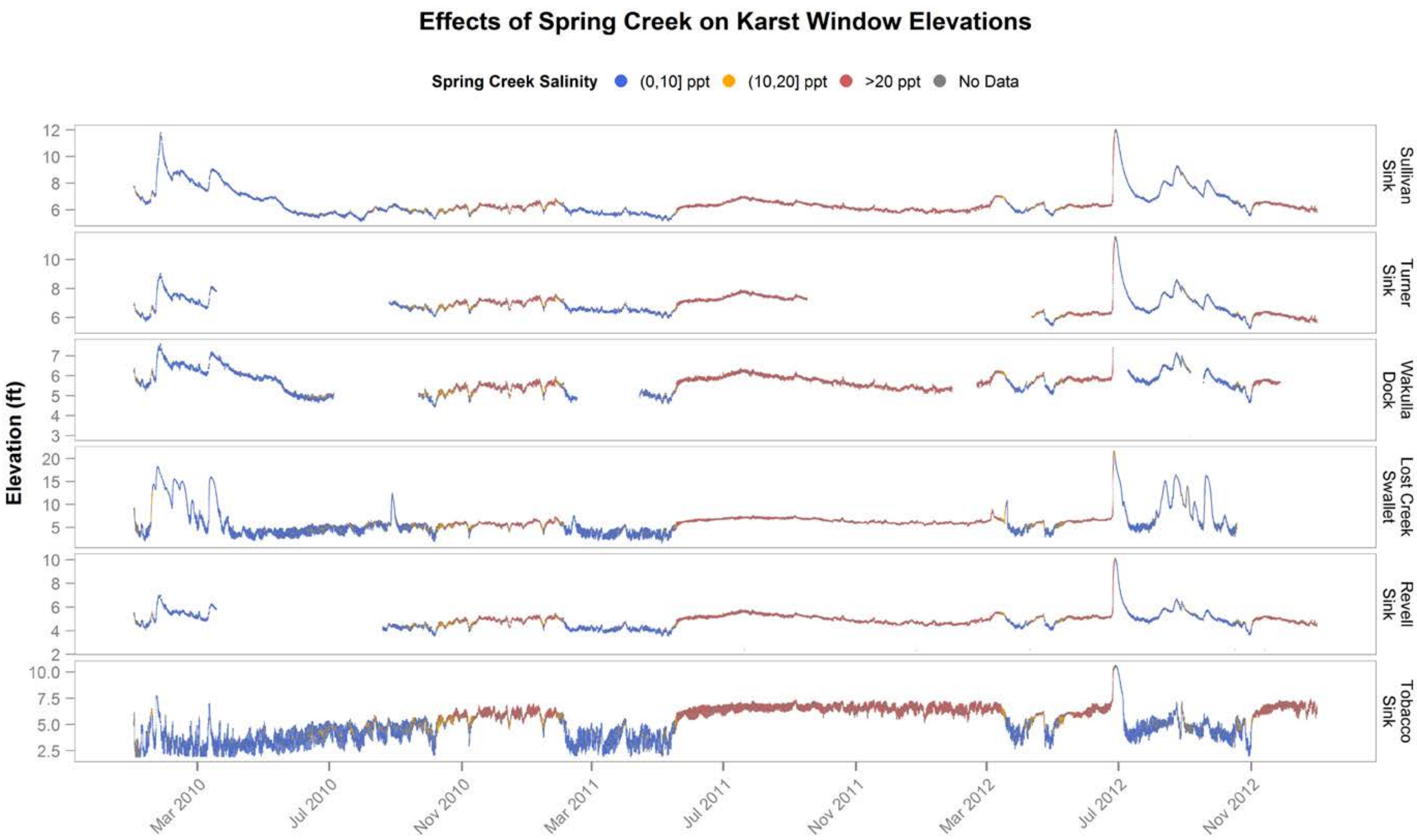


Loper, D., and E. Chicken. 2005. "Analysis and Discussion of Karst Conduit Waves." *Sinkholes and Engineering and Environmental Impacts of Karst*, 454–66. doi:10.1061/41003(327)43.

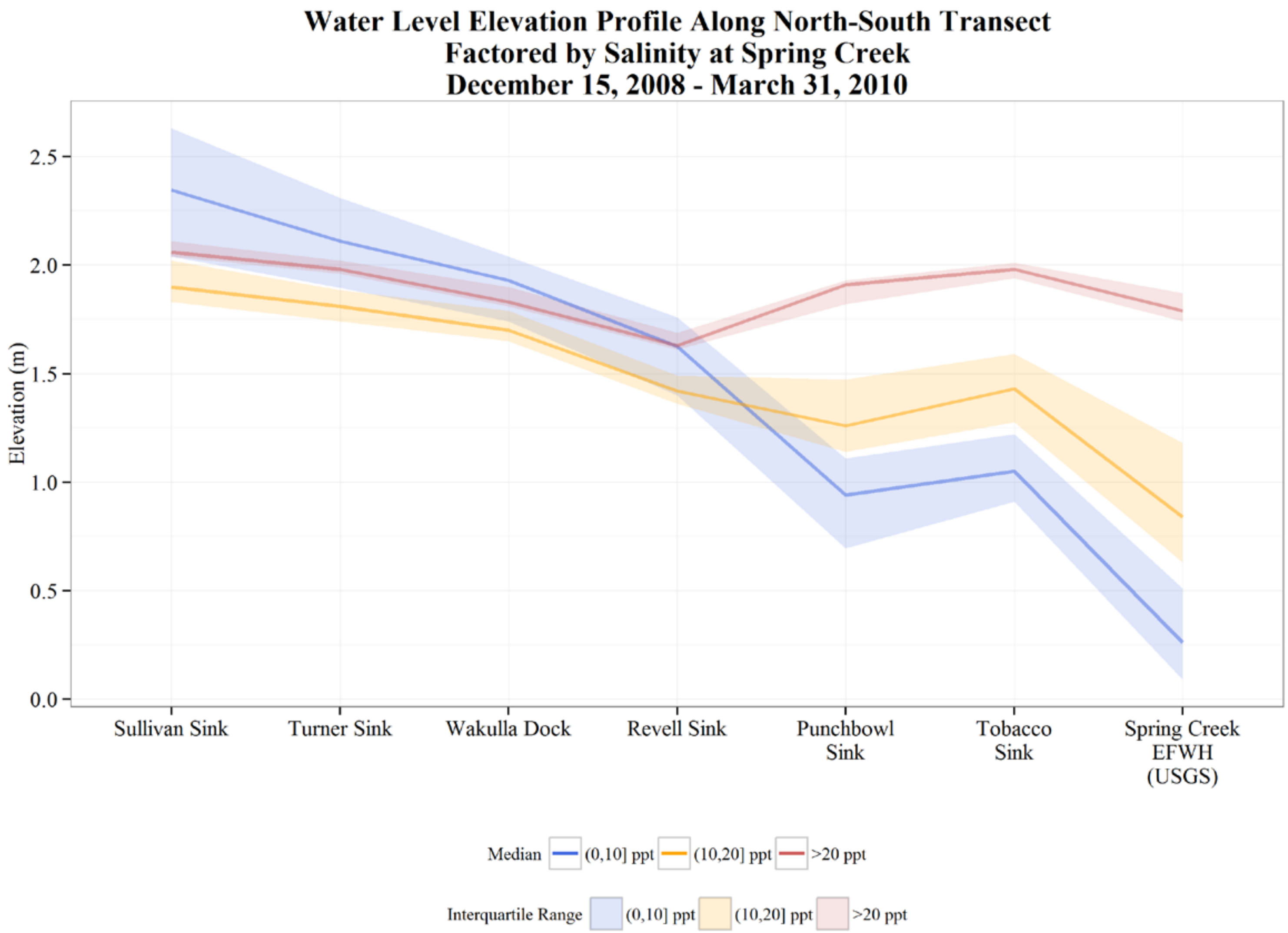
Loper, D.E., C.L. Werner, E. Chicken, G. Davies, and T. Kincaid. 2005. "Coastal Carbonate Aquifer Sensitivity to Tides." *Eos, Transactions, American Geophysical Union* 86 (39): 353–57.

Chicken, Eric, and David E. Loper. 2007. "Estimating Tidal Effects in Spring Discharge: A Multiscale Method Using Correlated Phenomenon." *Water Resources Research*, no. 43. http://onlinelibrary.wiley.com/doi/10.1029/2006WR005117/full.

Two-Stage System

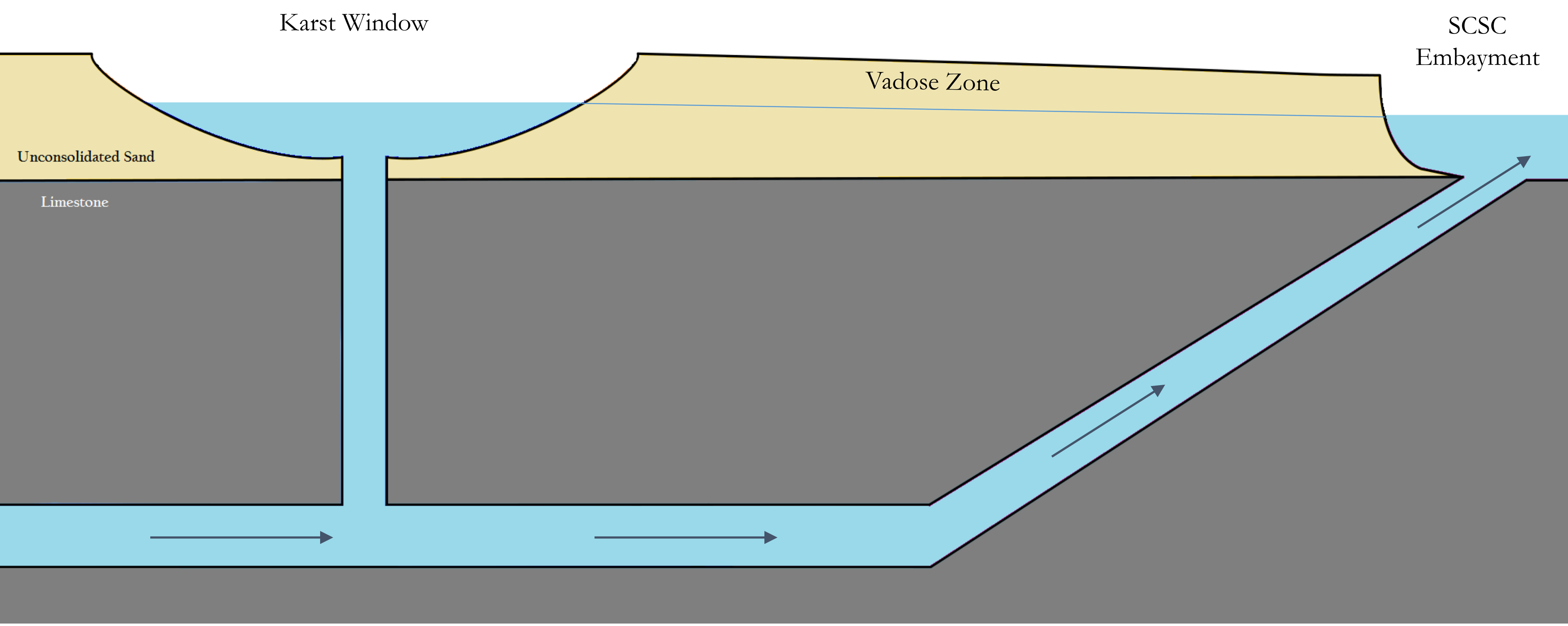


Gradient Segmentation

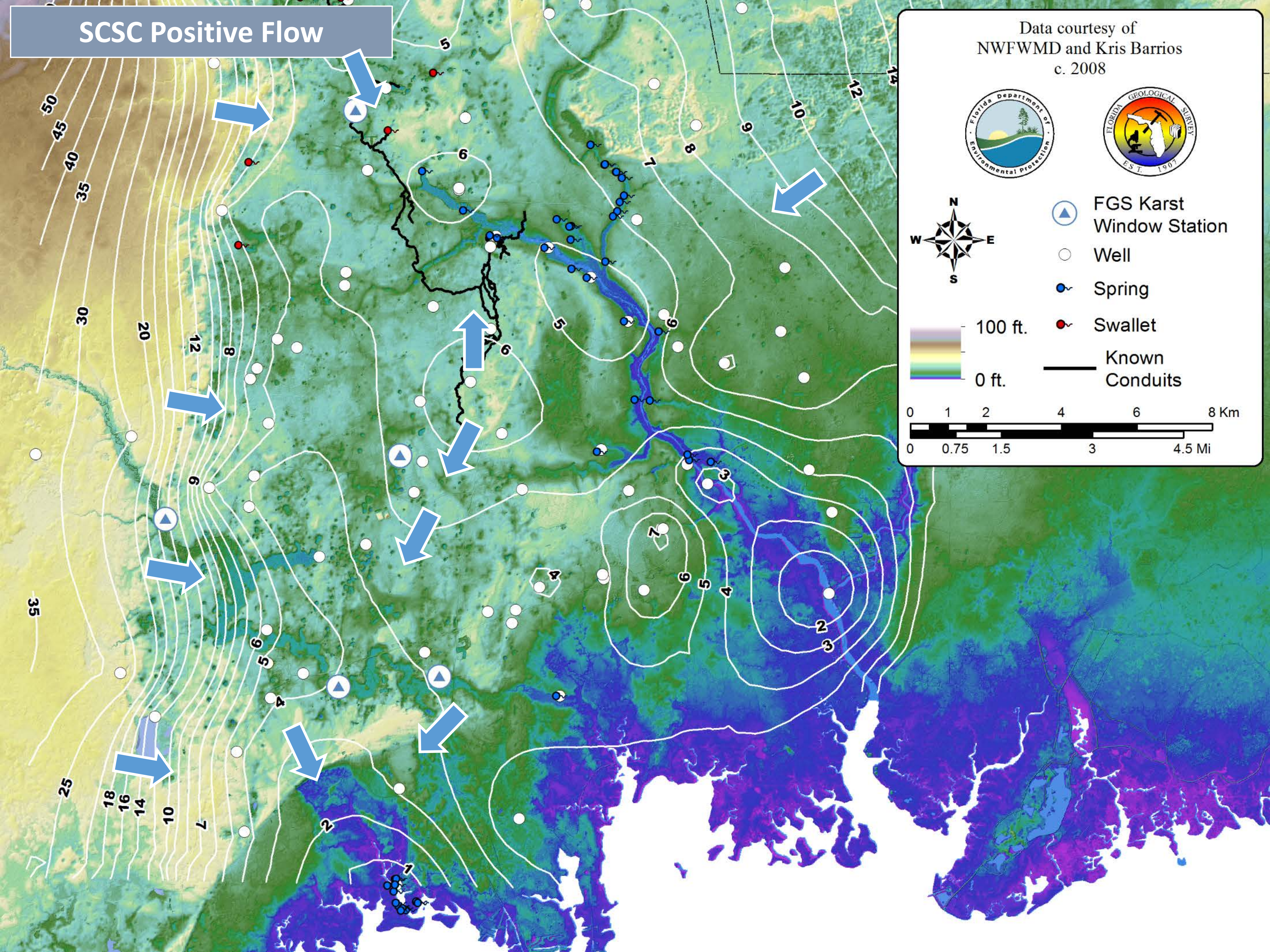


Two-Stage Mechanics

SCSC Positive Flow

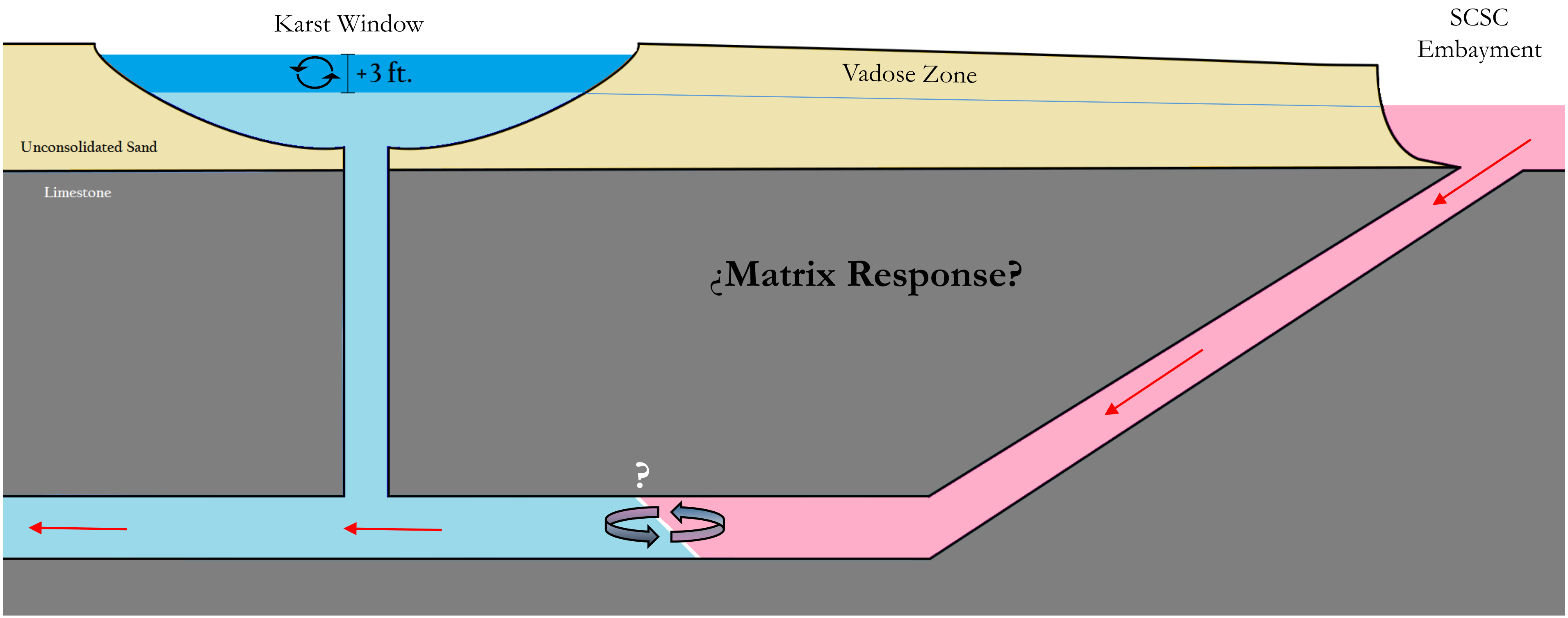


SCSC Positive Flow



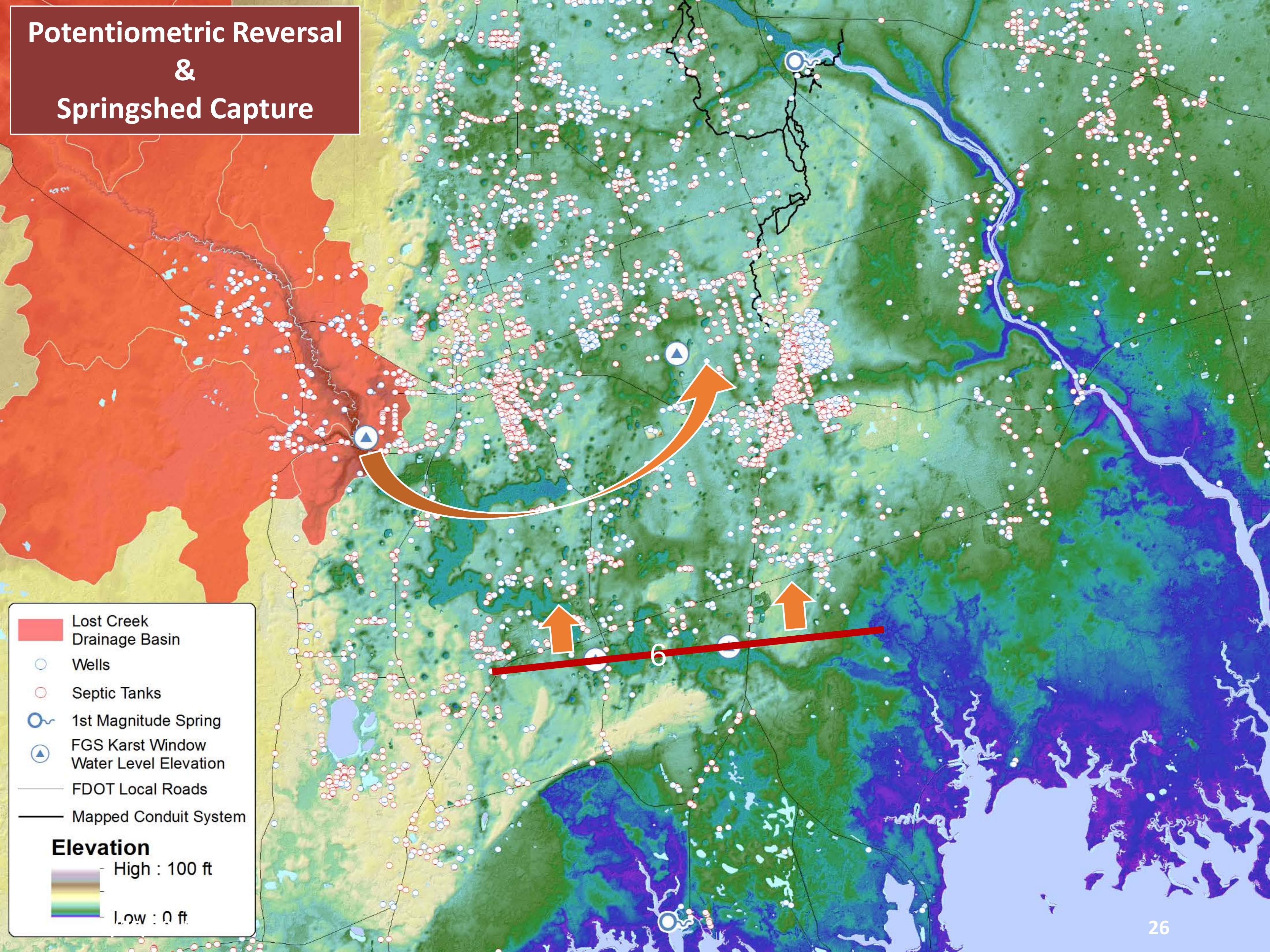
Two-Stage Mechanics

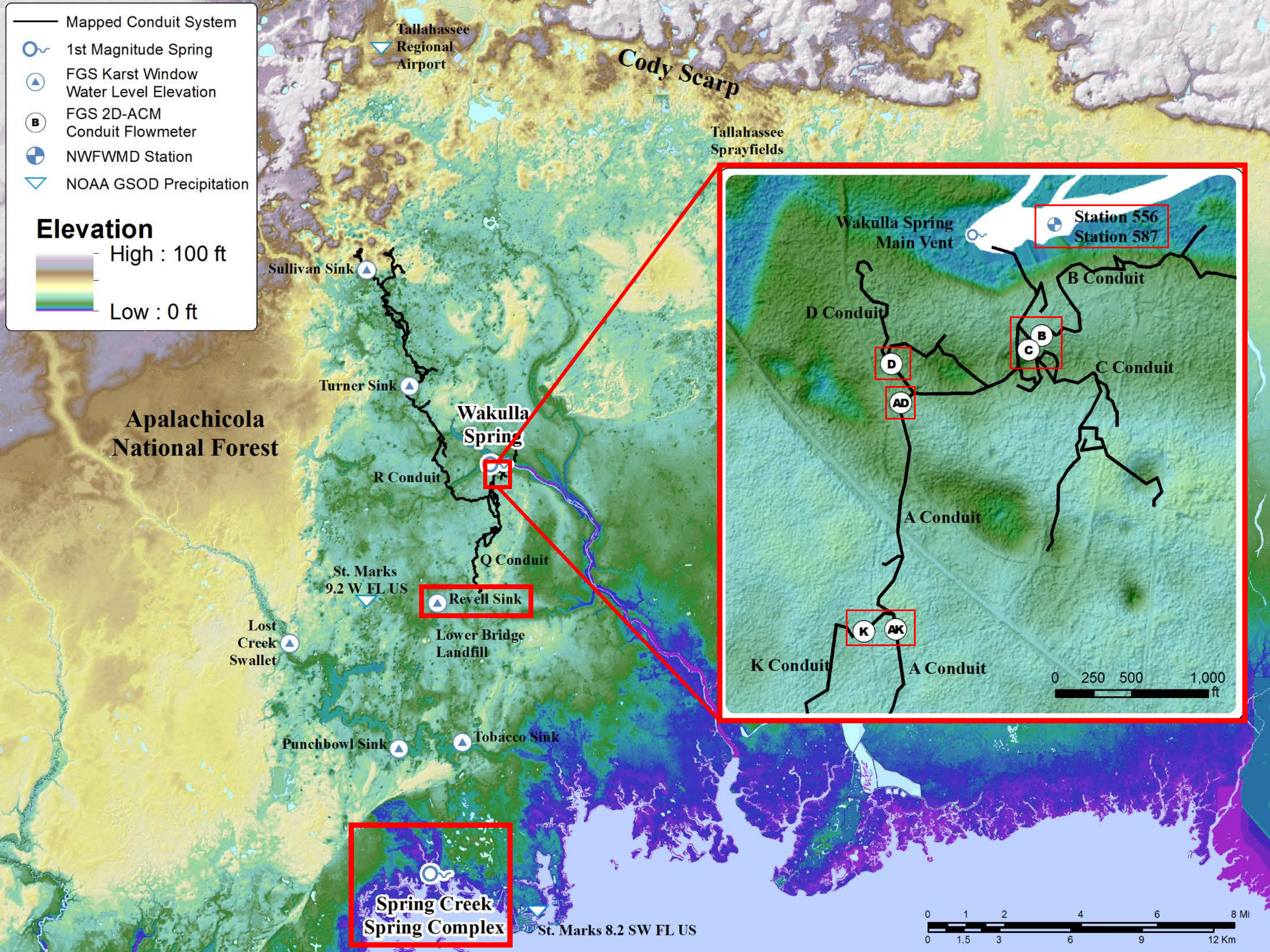
SCSC Negative Flow



Extension of Davis, Hal. 2011. "The Interconnectedness Between Spring Creek Springs and Wakulla Spring and the Effects on Flow at Wakulla Spring." http://www.floridasprings.org/downloads/florida_113_qg5bjxw6.pdf.

Potentiometric Reversal & Springshed Capture





Mapped Conduit System
1st Magnitude Spring
FGS Karst Window Water Level Elevation
FGS 2D-ACM Conduit Flowmeter
NWFWMD Station
NOAA GSOD Precipitation
Elevation
High : 100 ft
Low : 0 ft
Tallahassee Regional Airport
Cody Scarp
Tallahassee Sprayfields
Sullivan Sink
Turner Sink
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R Conduit
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Tobacco Sink
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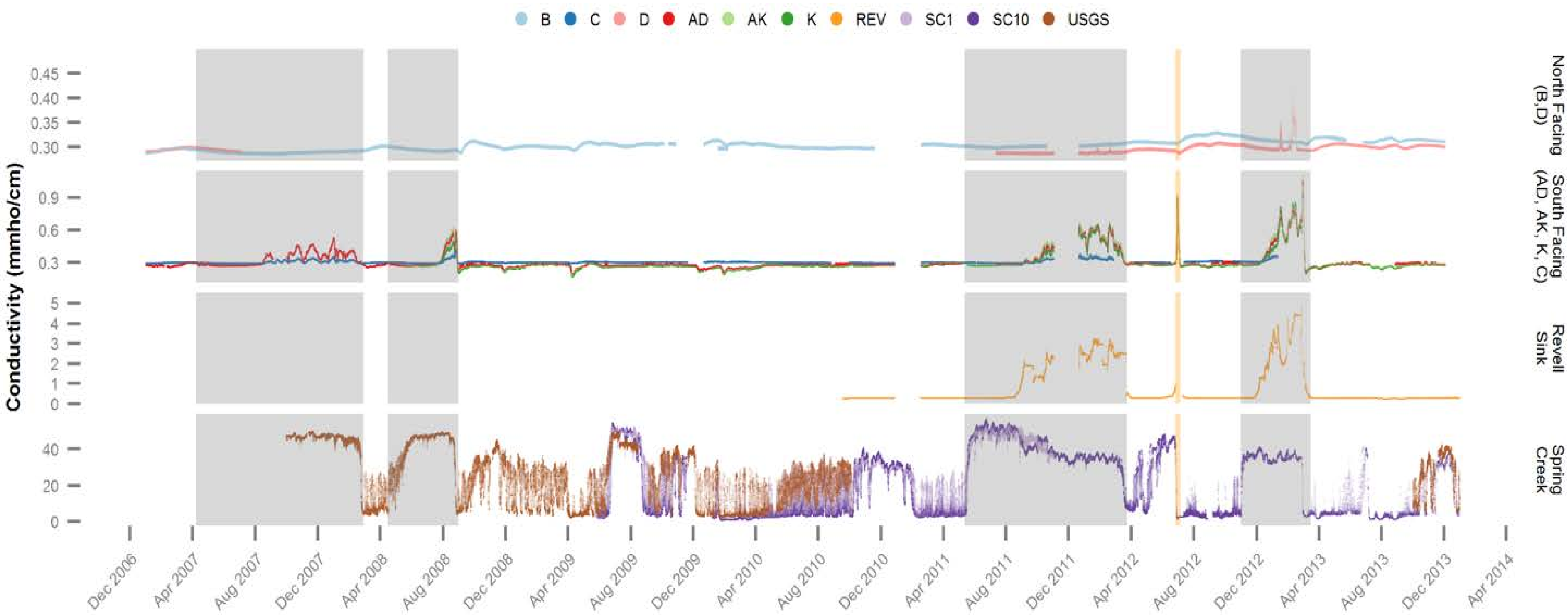
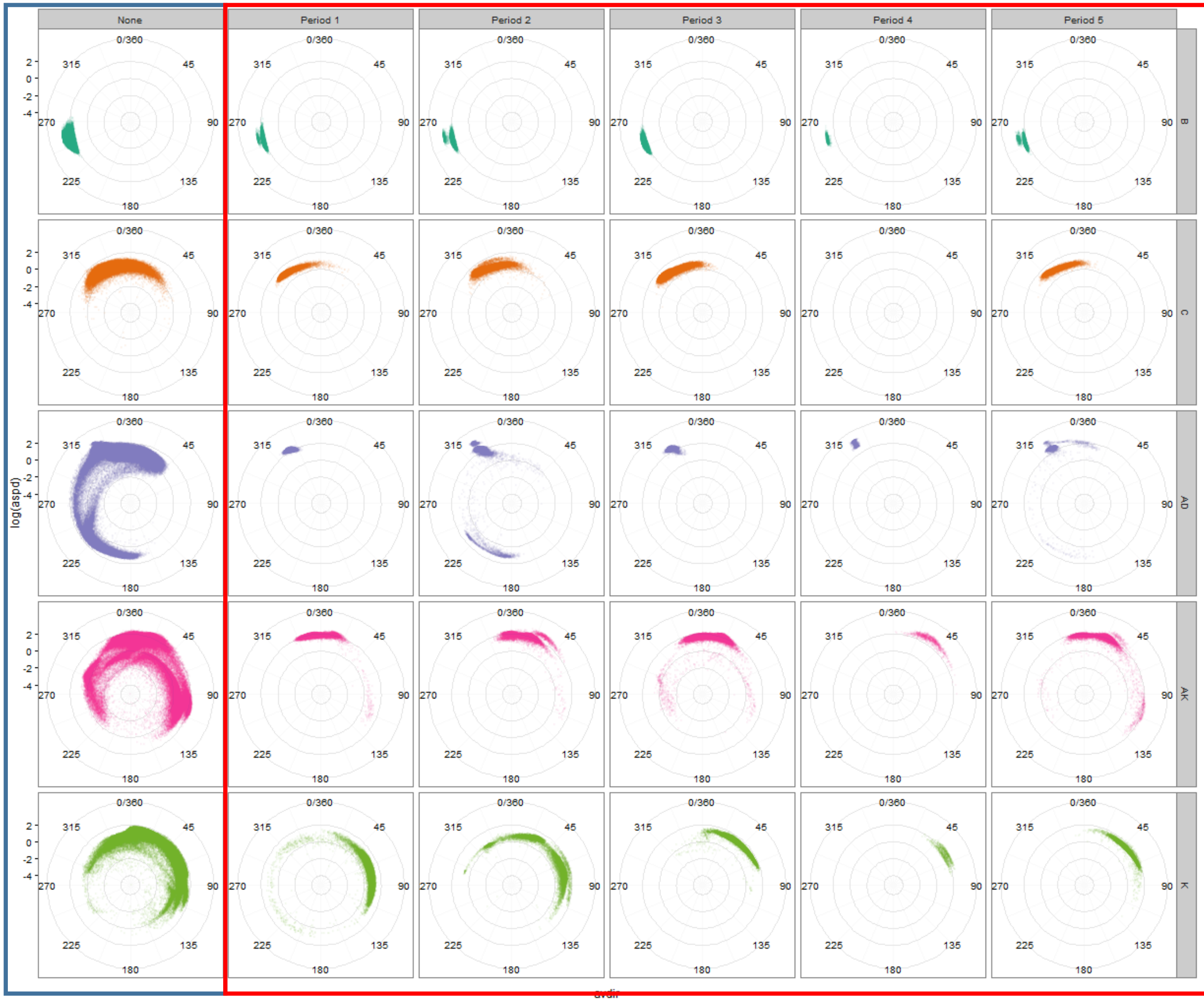
St. Marks 8.2 SW FL US
Wakulla Spring Main Vent
Station 556
Station 587
B Conduit
D Conduit
C Conduit
A Conduit
K Conduit
0 250 500 1,000 ft
0 1 2 4 6 8 Mi
0 1.5 3 6 9 12 Km

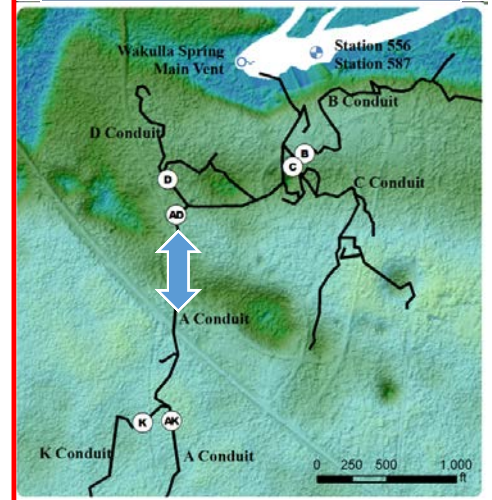
Conductivity Rises at the Vent



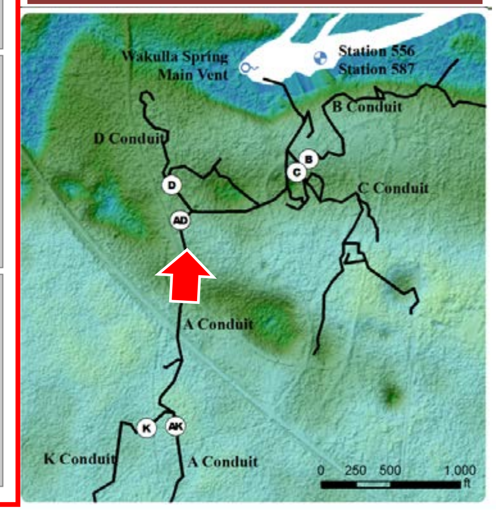
Flow Directions

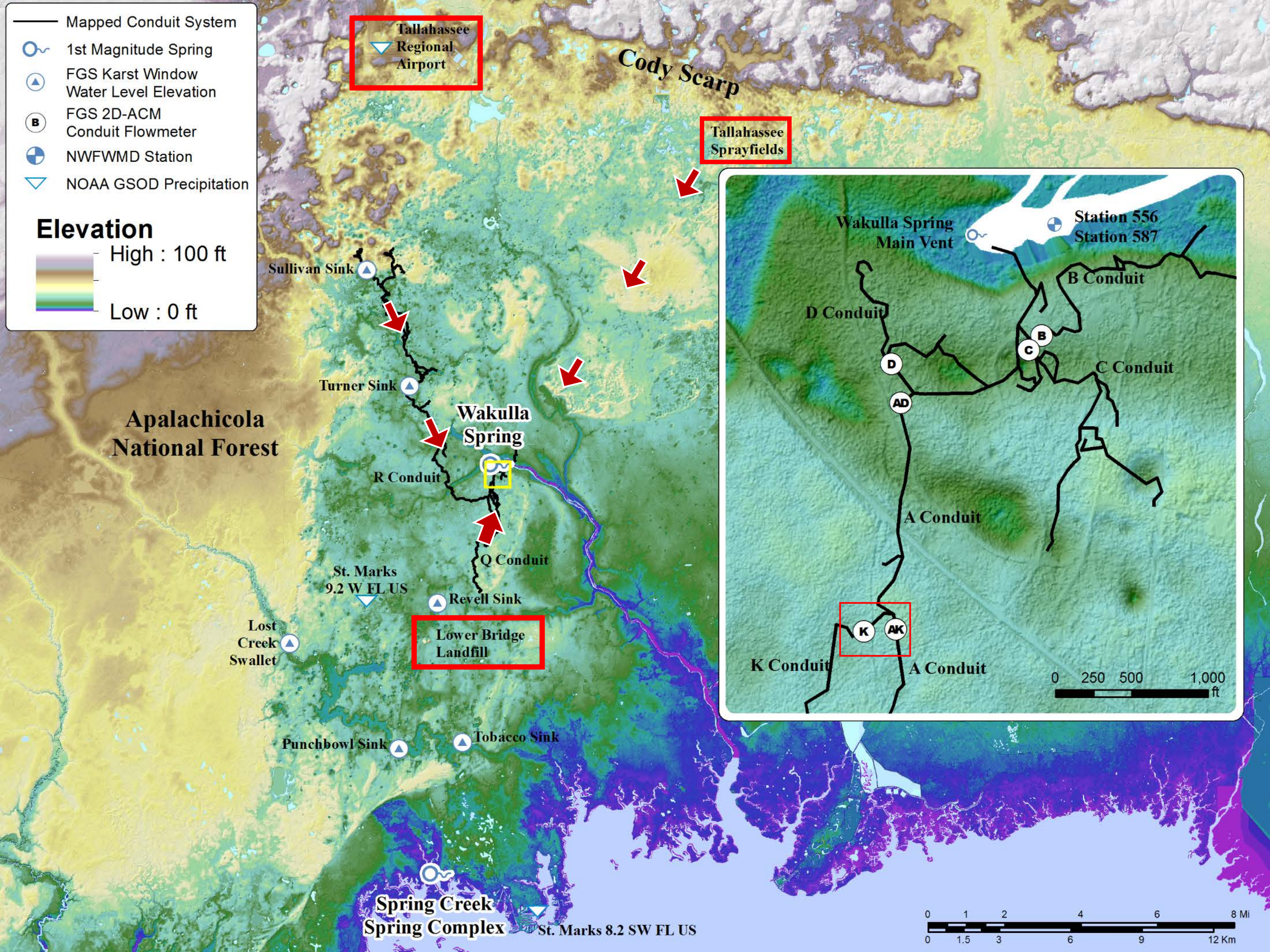


SCSC Positive Flow



SCSC Negative Flow





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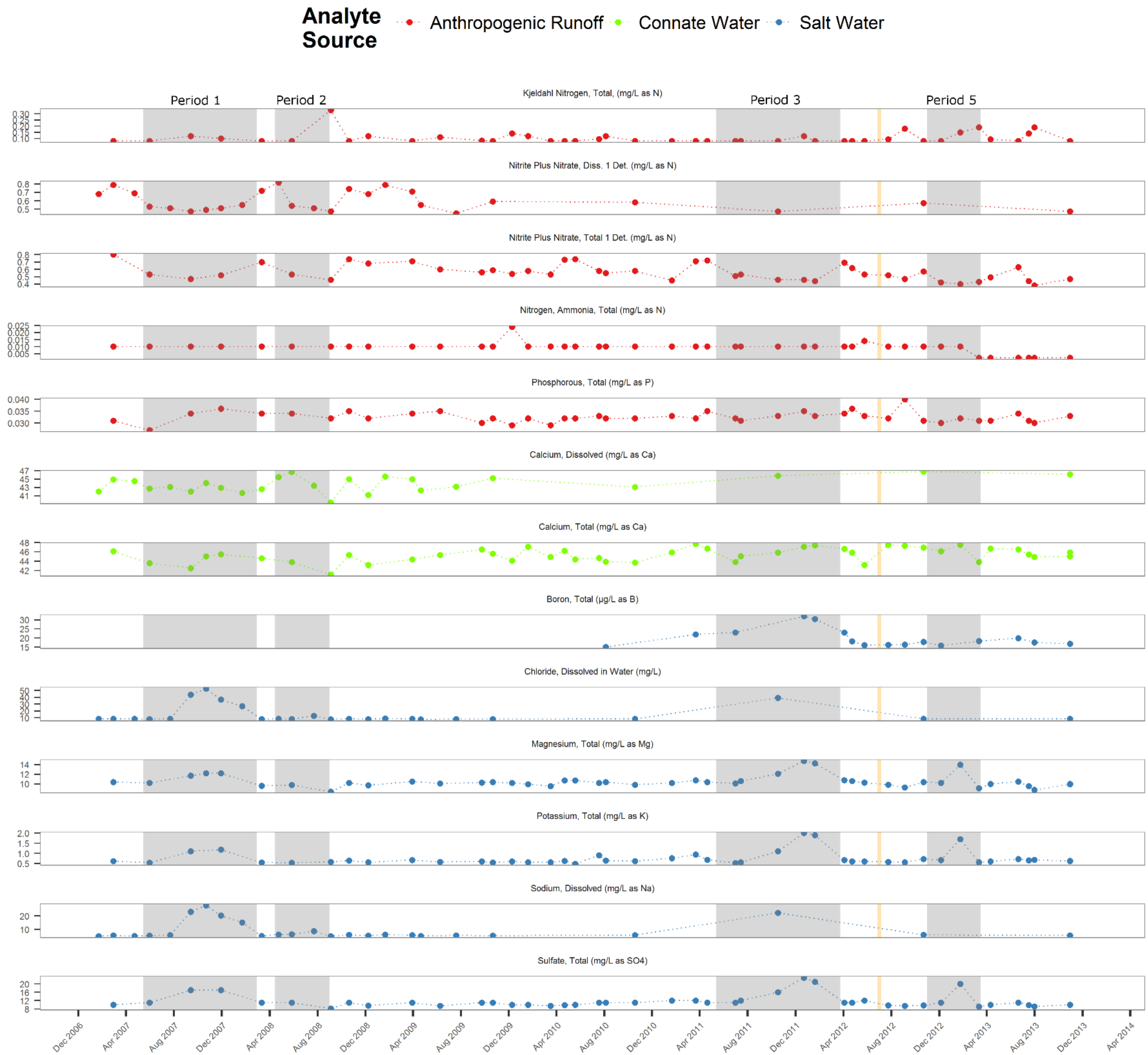
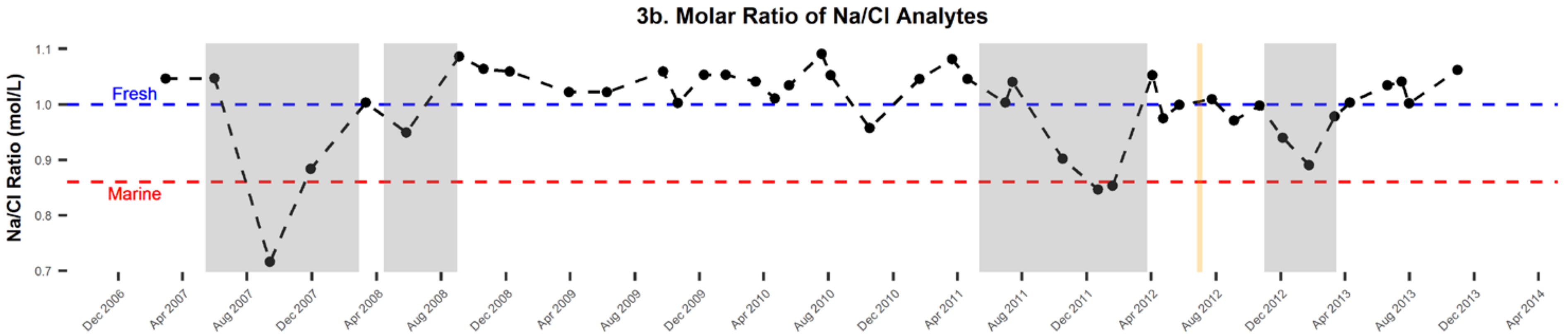
Tobacco Sink
Spring Creek Spring Complex
St. Marks 8.2 SW FL US
Wakulla Spring Main Vent
Station 556
Station 587
B Conduit
D Conduit
C Conduit
A Conduit
K Conduit
0 250 500 1,000 ft
0 1 2 4 6 8 Mi
0 1.5 3 6 9 12 Km


Analyte Source
Anthropogenic Runoff
Connate Water
Salt Water
Period 1
Period 2
Period 3
Period 5
Kjeldahl Nitrogen, Total, (mg/L as N)
Nitrite Plus Nitrate, Diss. 1 Det. (mg/L as N)
Nitrite Plus Nitrate, Total 1 Det. (mg/L as N)
Nitrogen, Ammonia, Total (mg/L as N)
Phosphorous, Total (mg/L as P)
Calcium, Dissolved (mg/L as Ca)
Calcium, Total (mg/L as Ca)
Boron, Total (µg/L as B)
Chloride, Dissolved in Water (mg/L)
Magnesium, Total (mg/L as Mg)
Potassium, Total (mg/L as K)
Sodium, Dissolved (mg/L as Na)
Sulfate, Total (mg/L as SO4)
Dec 2006
Apr 2007
Aug 2007
Dec 2007
Apr 2008
Aug 2008
Dec 2008
Apr 2009
Aug 2009
Dec 2009
Apr 2010
Aug 2010
Dec 2010
Apr 2011
Aug 2011
Dec 2011
Apr 2012
Aug 2012
Dec 2012
Apr 2013
Aug 2013
Dec 2013
Apr 2014

Molar Ratios of Analytes



Lessons Learned

- Big data requires a **team**
  - Domain expert
  - Data expert
- Effective analysis relies on **intra-team education.**
- Write-only data is **useless.**
- It is easier to teach a data expert basic domain knowledge than it is to teach a domain expert advanced data manipulation techniques

Lessons Learned

- **ALWAYS** keep the original data
- **ALWAYS** archive a copy of your processed data in a "flat" format for future recovery and use: CSV, TSV, JSON, or GEOJSON
- **NEVER** rely on proprietary formats to archive data.
- Pick **ONE**:
  - High personnel costs, low software costs
  - Low personnel costs, high software costs
- **Open source solutions** can replace expensive proprietary software at the cost of training

See the Project!

- https://github.com/FloridaGeologicalSurvey/KORI/wiki
- https://floridageologicalsurvey.shinyapps.io/wakulla_conduits/
- http://www.nature.com/articles/srep32235
- The Florida Geological Survey: National Leader in Karst Hydrology companion poster (this conference)