How Much is Too Much?

Toward A Water Budget for Wakulla Spring

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Abstract: *Drying up the Spring?*

Recent hydrologic studies in the Wakulla springshed (conducted or supported by the FGS/DEP, GeoHydros, the Woodville Karst Plain Project, the Florida State University, US Geological Survey, and the City of Tallahassee) give rise to concerns about groundwater availability in the Wakulla springshed. These include the groundwater tracer tests that have connected many of the sinking streams in the springshed to Wakulla spring, hydrologic metering of the tunnels within Wakulla cave that discriminate between groundwater and surface water components of the spring flow, and tracer tests and metering at the Spring Creek springs that show Wakulla and Spring Creek to be connected by large underwater conduits. Collectively, these studies reveal that the groundwater budget for Wakulla Spring is susceptible to harm from upland groundwater consumption and sea-level rise.

The Wakulla springshed, like all springsheds and stream basins in the world, has a water budget. Like a financial budget, the water budget defines the total inflow, the total outflow, and the change in water storage, which is like a savings account for water. Total inflow is primarily composed of all the rain that falls in the sprinshed plus any stream flow from streams that originate outside the springshed. Total outflow includes all of the water that flows out to the Gulf of Mexico in the Wakulla / St Marks River, all of the spring flow that enters the bay directly, all of the water that either evaporates or is used by plants, and all of the water that is pumped out of the ground and not returned to the aquifer in the springshed.

In order to utilize water resources for human needs, the supply of water must be ecologically sustained for the long term within the confines of the water budget. To maintain a sustainable water budget, total usage cannot exceed the total amount of water received. When it does, storage is reduced, water levels fall, and spring flows decline, which if continued unchecked can result in dried up spring basins, lakes, sinkholes, and rivers. If the total usage is less than the total inflow the amount of storage will increase, groundwater levels will rise, and spring flows will increase, which over a long enough period can result in flooding. Our status with respect to the water budget fluctuates seasonally, even monthly, depending on how much rain we receive and how much we're using so an effective gauge of our status must be based on long-term trends.

The water budget for the Wakulla springshed contains two major components that each have their own budget, groundwater and surface water. Groundwater is the relatively older clear water that reaches Wakulla Spring and is the primary component of the spring flow when the spring is clear and the glass-bottom boats are running. It consists of all the rain that falls on the ground in the upper reaches of the springshed that infiltrates into the aquifer, and flows through the rocks into the caves and out to the springs. This is the only source of water to the spring during dry periods when the streams stop flowing and also supplies nearly 100% of the water consumed in the springshed from groundwater wells.

Surface water is the dark tea-colored water that flows through the creeks and streams and is ultimately funneled rapidly into the aquifer through the swallets or sinkholes located at the end of the streams. We now know from the tracer tests and hydrologic metering that this water travels very quickly (days or weeks) to Wakulla spring is responsible for the dark water days that keep the glass-bottom boats at the dock. This new knowledge is critical to understanding our relationship to the Wakulla's water budget because we are not currently using surface water to any significant extent for water supply and our usage therefore primarily impacts only the groundwater component of the total water budget.

In order to ensure that we do not overdraft Wakulla's groundwater account, we must accurately measure and compare the total groundwater consumption in the springshed with only the groundwater component of the spring flow. To date these measurements have not been performed but we are able to make an educated guess as to where we stand. A reasonable estimate of the groundwater component of the discharge from both Wakulla and Spring Creek

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Abstract: *Drying up the Spring? – Cont.*

springs is roughly 400 million gallons per day where as the total permitted groundwater extraction in only the northern section of the Wakulla springshed exceeded 25% of that value in 2007. While this does not account for returns to the aquifer as for instance those that occur at the Tallahassee spray field, the value is large enough to warrant a closer analysis of the current and projected groundwater withdrawals as well as the plan for sustaining adequate groundwater (clear water) flow to Wakulla and the neighboring springs.

The consequences of over consumption in the Wakulla springshed would likely be dire. We know from the recent history of Florida's west coast and now even the Santa Fe river basin in north central Florida that over-pumping the Floridan aquifer can result in a complete loss of flow to smaller springs. The analog in the Wakulla springshed would be a loss of discharge from the smaller springs like Sally Ward, McBrides, Sheperd, and the springs along the middle section of the Wakulla River. Diminished groundwater levels will also decrease the already sporadic number of clear water days at the spring vent. Even more significantly though, because Wakulla and Spring Creek are physically connected, diminished groundwater levels in the northern part of the springshed will foster an increase in the duration and magnitude of the spring flow reversals in Spring Creek that have been occurring every summer since 2006. We know from recent studies that these reversals drive salt water into the aquifer conduit system and push it significantly inland. That influx of salt water results in higher than normal water levels in the south and increased salinities in the deeper part of the aquifer. If the duration and/or magnitude of these reversals increases, it is likely that the ecosystem in the southern part of Wakulla County and even the potability of the Floridan aquifer in that region will be jeopardized.

Sea level in the northern Gulf of Mexico is rising. On that, there is no dispute. There is little available long-term data on groundwater levels in the springshed. The longest records that do exist show a slow but consistent decline in aquifer water levels since the 1960's. Apparent flow at Spring Creek has changed significantly since 2006 but we are just now learning to what degree conditions have and are changing. We do know that for the first time in the memory of the oldest native residents in the Spring Creek region, boats need special paint to keep barnacles from growing on their bottoms. We also know that conditions at Wakulla spring have changed as well. When the Spring Creek springs reverse in summer, Wakulla's flow dramatically increases and the water clarity drops resulting in fewer clear-water days in the basin. In total, these data and observations are at very least ample cause for a closer and more serious look at the groundwater budget and groundwater consumption in the springshed.

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Groundwater Protection *– the real problem*

Lack of funding > > Funding driven by public interest

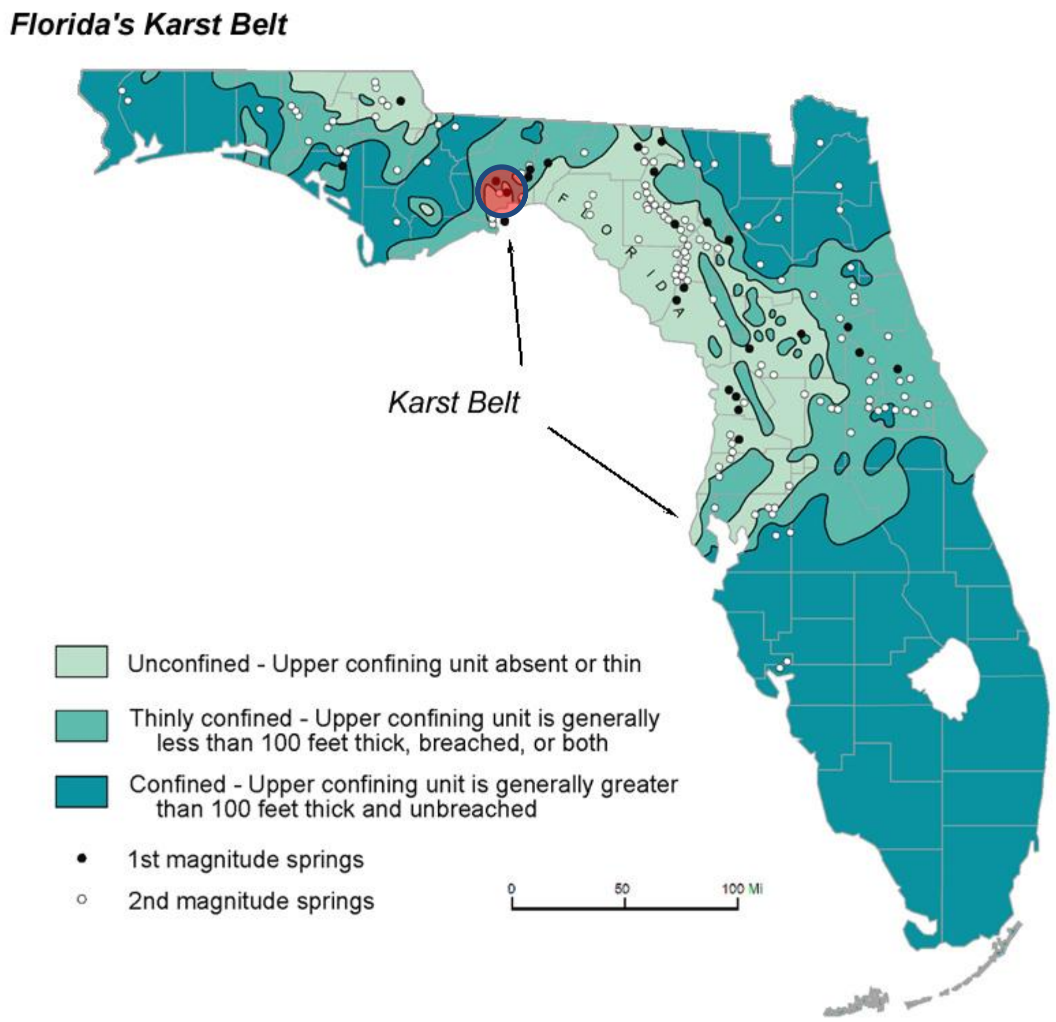
> > Measure of Interest?

Topic	*Internet Hits*
• global water resources:	24,800,000
• aquifer protection:	1,350,000
• water shortage:	8,130,000
• water crisis:	27,900,000
• water pollution:	34,400,000
• bottled water:	10,100,000
• Florida springs:	40,900,000
• Florida springs decline:	651,000
• Britney Spears:	49,800,000
• free porn:	188,000,000
• free sex:	366,000,000

Clean Water / Free Sex = < 10%

Clean Water / Britney Spears = 68%

The Floridan Aquifer



- 27 (>1/3) of the largest springs in North America discharge from the Floridan Aquifer
- Average discharge from those springs > 6.5 billion gpd
- All of those springs discharge from mapped underwater cave systems
- >90% of inhabitants use groundwater from Floridan Aquifer
- Conduit-dominated flow in unconfined sections
- Less known under confining layer

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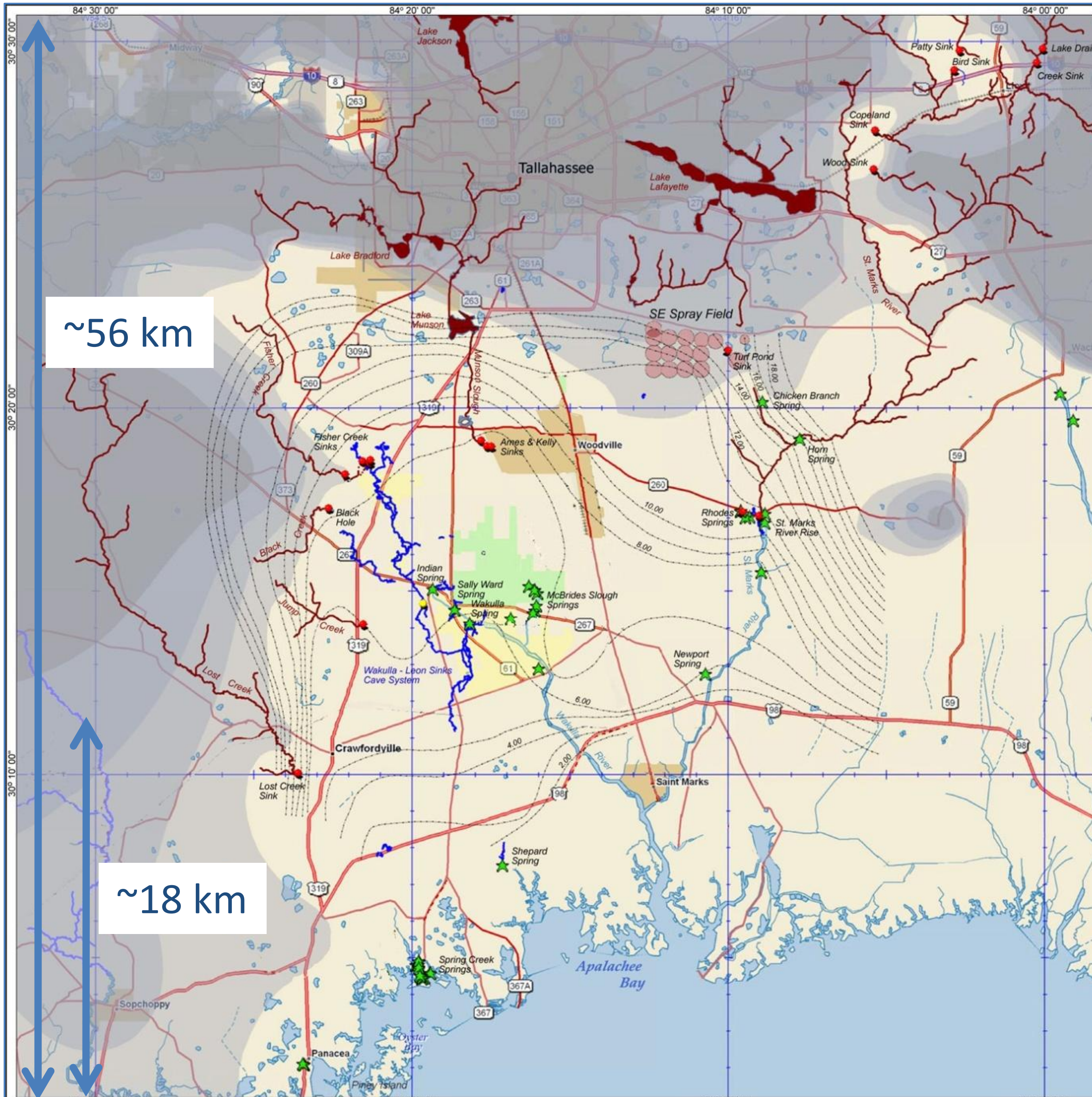
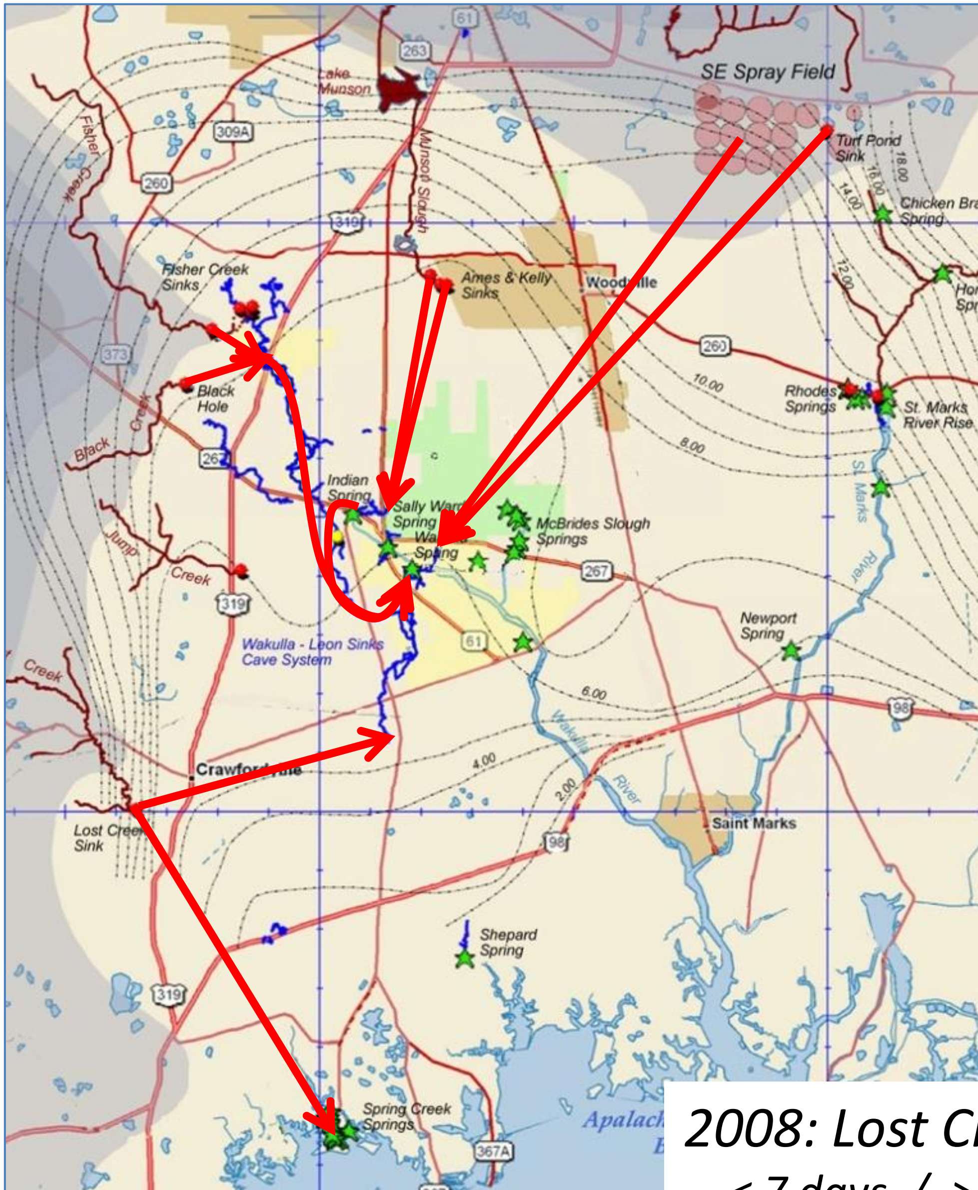
Caves in the WKP



	feet	*meters*
Wakulla Springs	168,900	51,484
Chip's Hole	22,292	6,795
Natural Bridge	12,108	3,691
Indian Springs	11,897	3,626
Sally Ward	6,857	2,090
Shepard's	5,689	1,734
Bird Sink	4,839	1,475
Little Dismal	2,968	905
McBride's	2,166	660
Church's	2,108	642
Rat Sink	1,463	446
Hideaway	1,228	374
Hatchet	1,120	341
Spring Creek 2	810	247
Meetinghouse	769	234
Farrell Shallow	566	173
Ventana Azul	363	111
TOTAL	**246,143**	**75,025**

Groundwater Tracing



2002: Fisher Creek – Emerald Sink
2,680 m / 56 hours (820 m/day)

2003: Black Creek – Emerald Sink
2,576 m / 76 hours (810 m/day)

2004: Emerald Sink – Wakulla Spring
16,550 m / 7.1 day (2,337 m/day)

2005: Kelly Sink – Indian Spring
8,400 m / 13.5 days (622 m/day)

2005: Ames Sink – Indian Spring
8,400 m / 17.2 days (506 m/day)

2005: Indian Spring – Wakulla Spring
8,790 m / 5.9 days (1,490 m/day)

2006: Wells – Wakulla Spring
16,800 m / 66.5 days (252 m/day)
16,800 m / 56 days (300 m/day)

2006: Turf Pond – Wakulla Spring
17,500 m / 56 days (312 m/day)

2008: Lost Creek – Spring Creek & Wakulla Spring
< 7 days / > 2 weeks

Comparison of Calculated Groundwater Velocities

Woodville Karst Plain, North Florida

Method	Velocity (m/day)	Assumptions	Source
Tracing	252-2,337 m/day	none	5
Pumping Test Transmissivities	0.03-0.23 m/day	Calculated Gradient Aquifer b = 100m	1
Model Derived Transmissivities	0.03 – 1.17 m/day	Calculated Gradient Aquifer b = 100m	3
Geochemical age dates	7.5 – 15 m/day	Age ~20-40 years 100% of Recharge derived from top of basin (~110 km to north)	2, 4

1. Bush, P.W., and Johnston, R.H., 1988. Ground-water hydraulics, regional flow, and ground-water development of the Floridan aquifer system in Florida and parts of Georgia, South Carolina and Alabama: U.S. Geological Survey Professional Paper 1403-C, 80 p.
2. Chanton, J. 2002. Unpublished data and report on stable isotopic age dating of waters in the Woodville Karst Plain, Florida for the Florida Geological Survey, Tallahassee, FL.
3. Davis, H. 1996. Hydrogeologic Investigation and Simulation of Ground-Water Flow in the Upper Floridan Aquifer of North-Central Florida and Delineation of Contributing Areas for Selected City of Tallahassee, Florida, Water Supply Wells: USGS Water-Resources Investigation Report 95-4296.
4. Katz, B.G., Chelette, A.R., and Pratt, T.R., 2004. Use of chemical and isotopic tracers to assess nitrate contamination and ground water age, Woodville Karst Plain, USA: Journal of Hydrology, v. 289, no. 1 /4, p. 36-61.
5. Kincaid, T.R. and Werner, C.L., 2008. Conduit Flow Paths and Conduit/Matrix Interactions Defined by Quantitative Groundwater Tracing in the Floridan Aquifer, in Lynn Yuhr, Calvin Alexander, and Barry Beck editors, *Sinkholes and the Engineering and Environmental Impacts of Karst: Proceedings of the 11th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst*, American Society of Civil Engineers.

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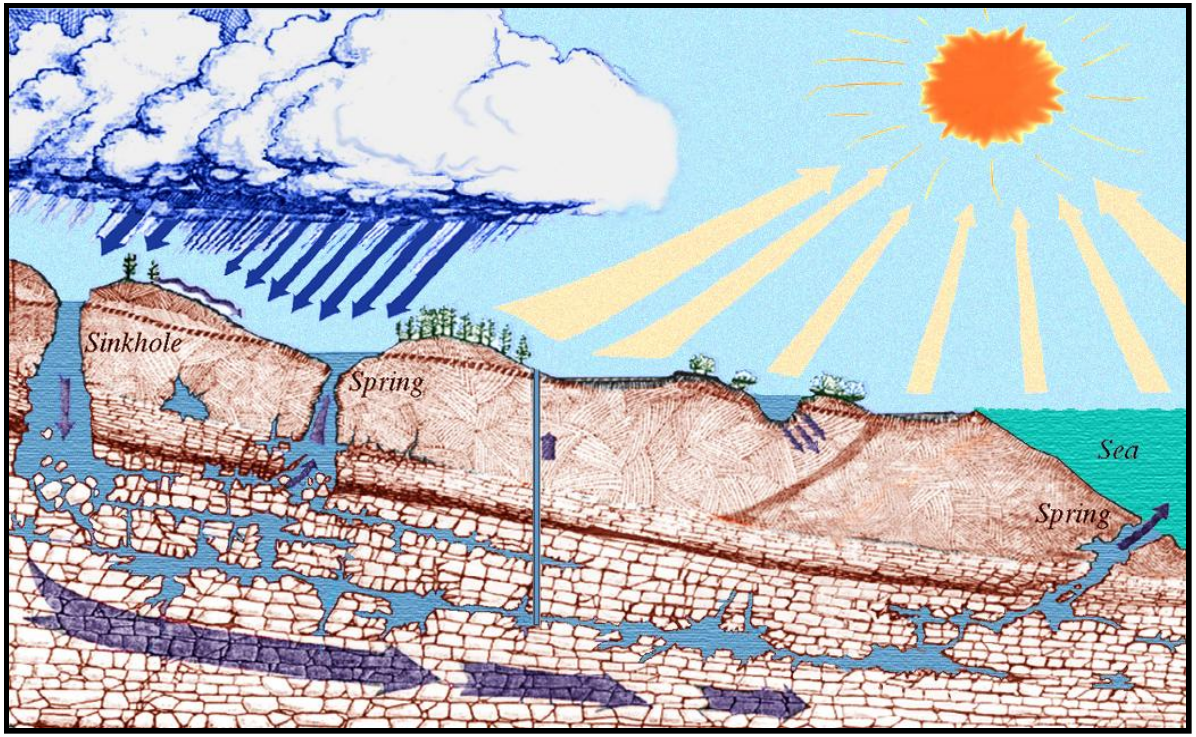
Significance of a Water Budget

Inputs – Outputs = Change in Storage

- How do you know how much money you can spend?
  - Income
  - Fixed expenses
  - Balance = surplus money = available cash to spend
  - *Credit – provides immediate benefit but adds to fixed expenses*
- Water availability is governed by the same basic rules
  - Income = rain
  - Fixed expenses = all current extractions
  - Available cash = storage
- One difference
  - There is no such thing as a water surplus
  - Every drop of water entering the Wakulla Springshed is already being used
  - Management of that water falls to deciding which users will be impacted by new extractions & devising creative ways of recycling the extracted water

Hydrologic Cycle

How much groundwater do we have?



Water Budget

- Sustainable
  total use = recharge
- Surplus Storage
  total use < recharge
- Declining Storage
  total use > recharge
- ***Just like your check book***

- Water is in constant motion moving from rain to the sea.
- Many different users (humans, plants, animals, rivers, streams, springs, estuaries, etc).
- Groundwater withdrawals intercept part of that flow and return it along a different path (typically surface flow).
- Quality & Quantity are impacted by how much we use, how we impact the quality of recharge, and how the water flows underground.

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Hydrogeology of the WKP

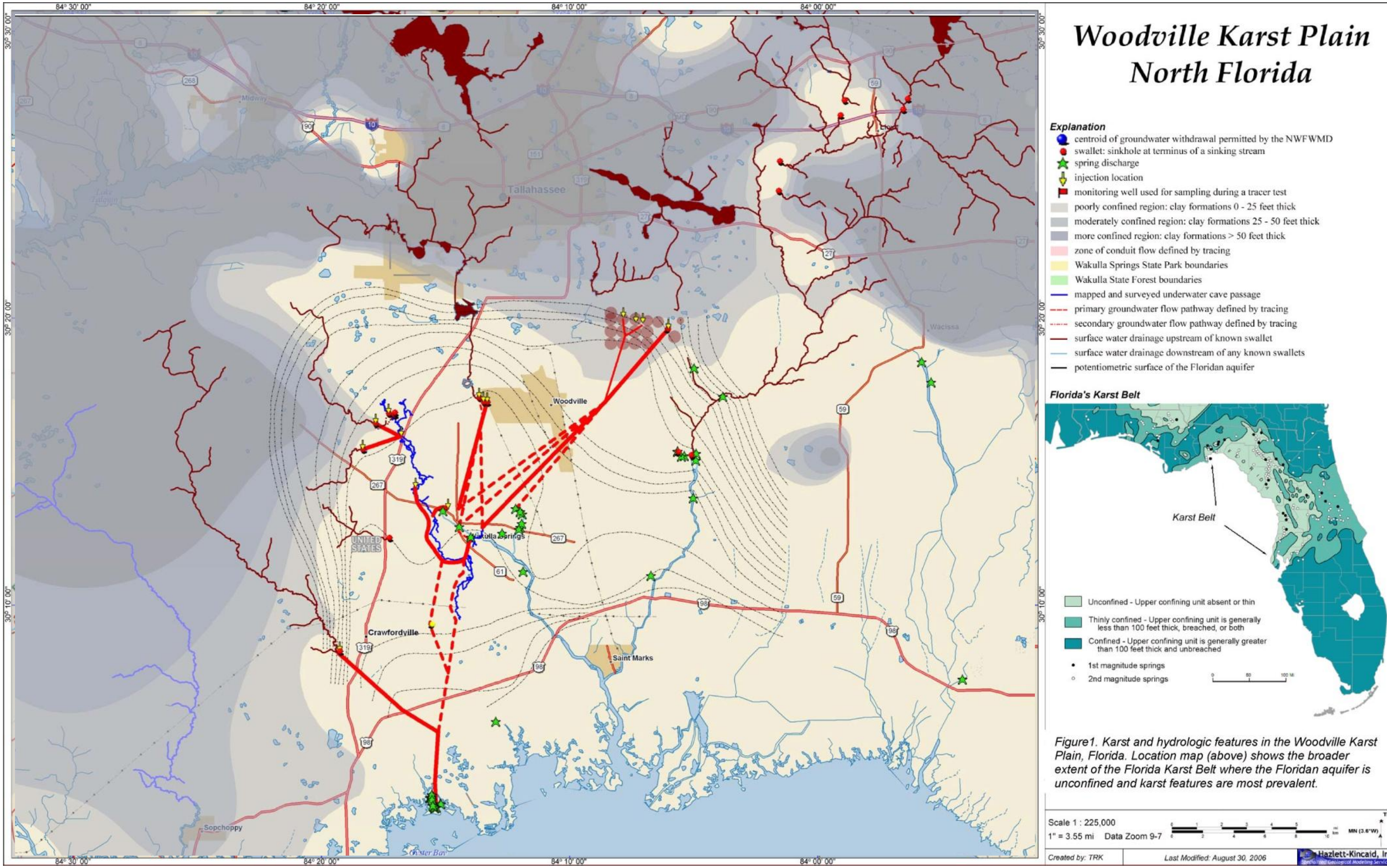
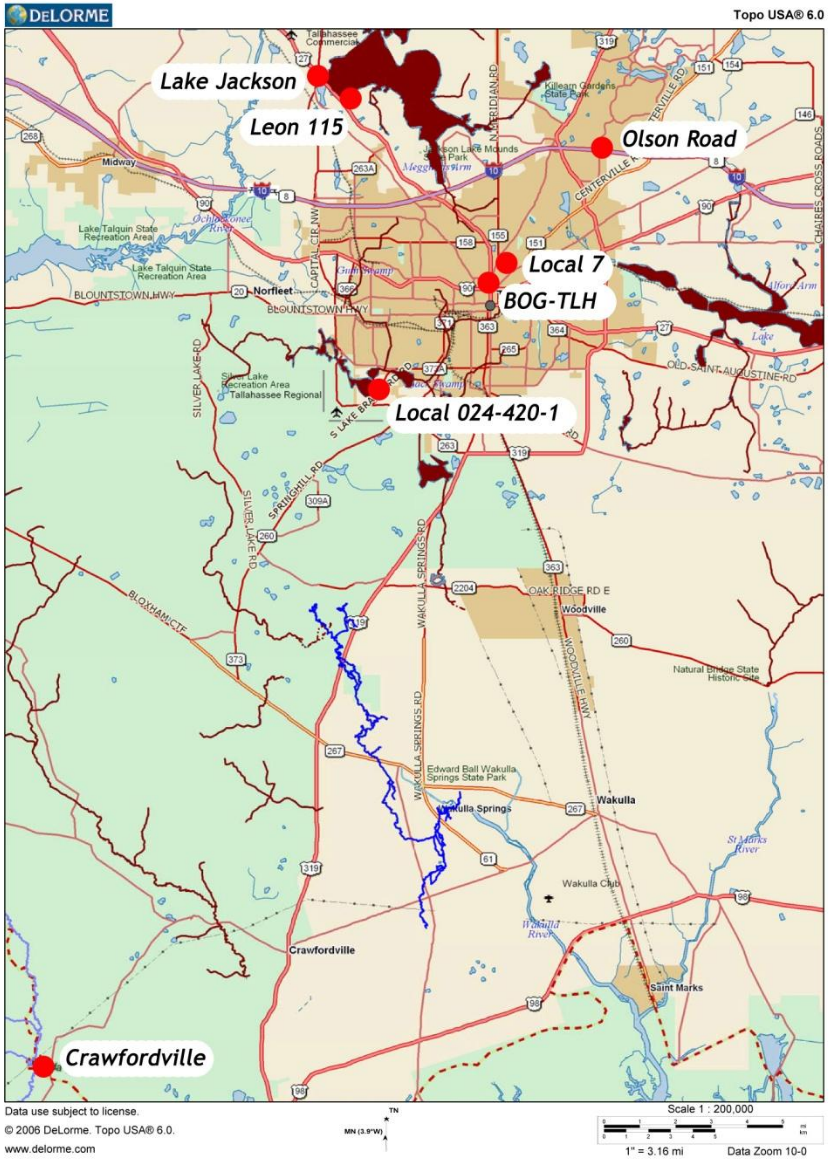


Figure1. Karst and hydrologic features in the Woodville Karst Plain, Florida. Location map (above) shows the broader extent of the Florida Karst Belt where the Floridan aquifer is unconfined and karst features are most prevalent.

Disconcerting Hydrologic Trends



- Groundwater levels appear to be declining since the 1970's
  Data from the USGS & NWFWMD
- Extractions are rising
- Sea level in the Gulf of Mexico is rising by 1.5 to >4 mm/yr
  Douglas, 2005 – Geophysical Monograph vol. 161, pp. 111-121

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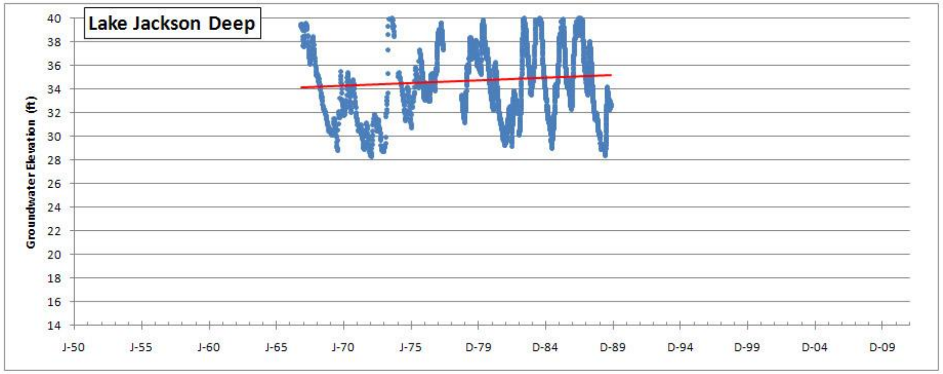
Lake Jackson Deep
Groundwater Elevation (ft)
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36
34
32
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16
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J-50
J-55
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J-70
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D-04
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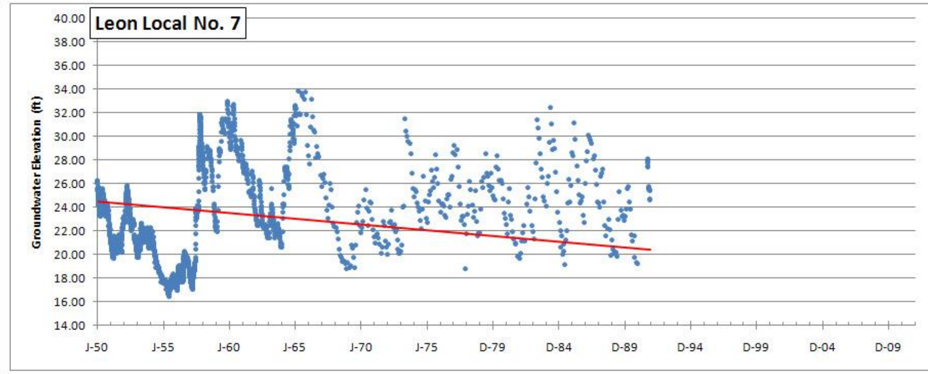
Leon Local No. 7
Groundwater Elevation (ft)
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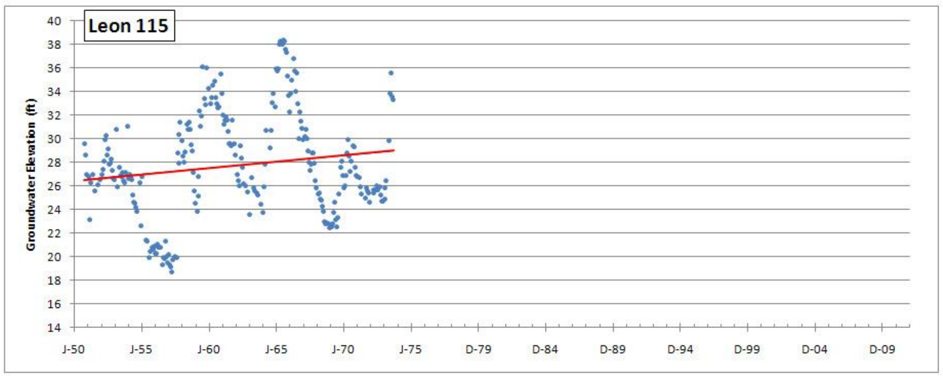
Leon 115
Groundwater Elevation (ft)
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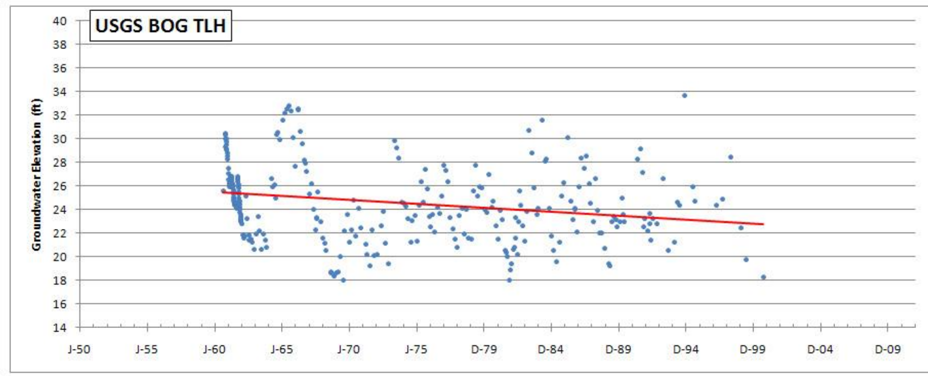
USGS BOG TLH
Groundwater Elevation (ft)
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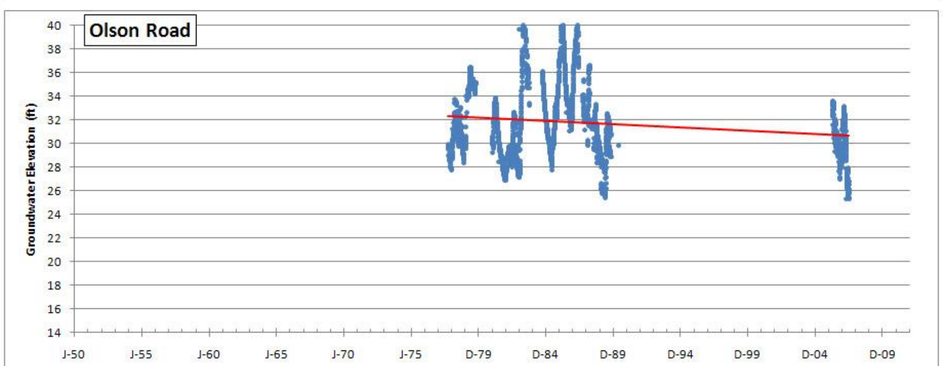
Olson Road
Groundwater Elevation (ft)
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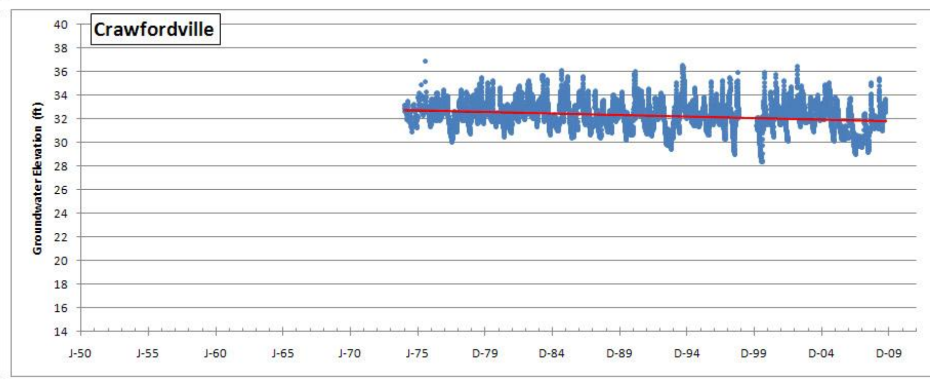
Crawfordville
Groundwater Elevation (ft)
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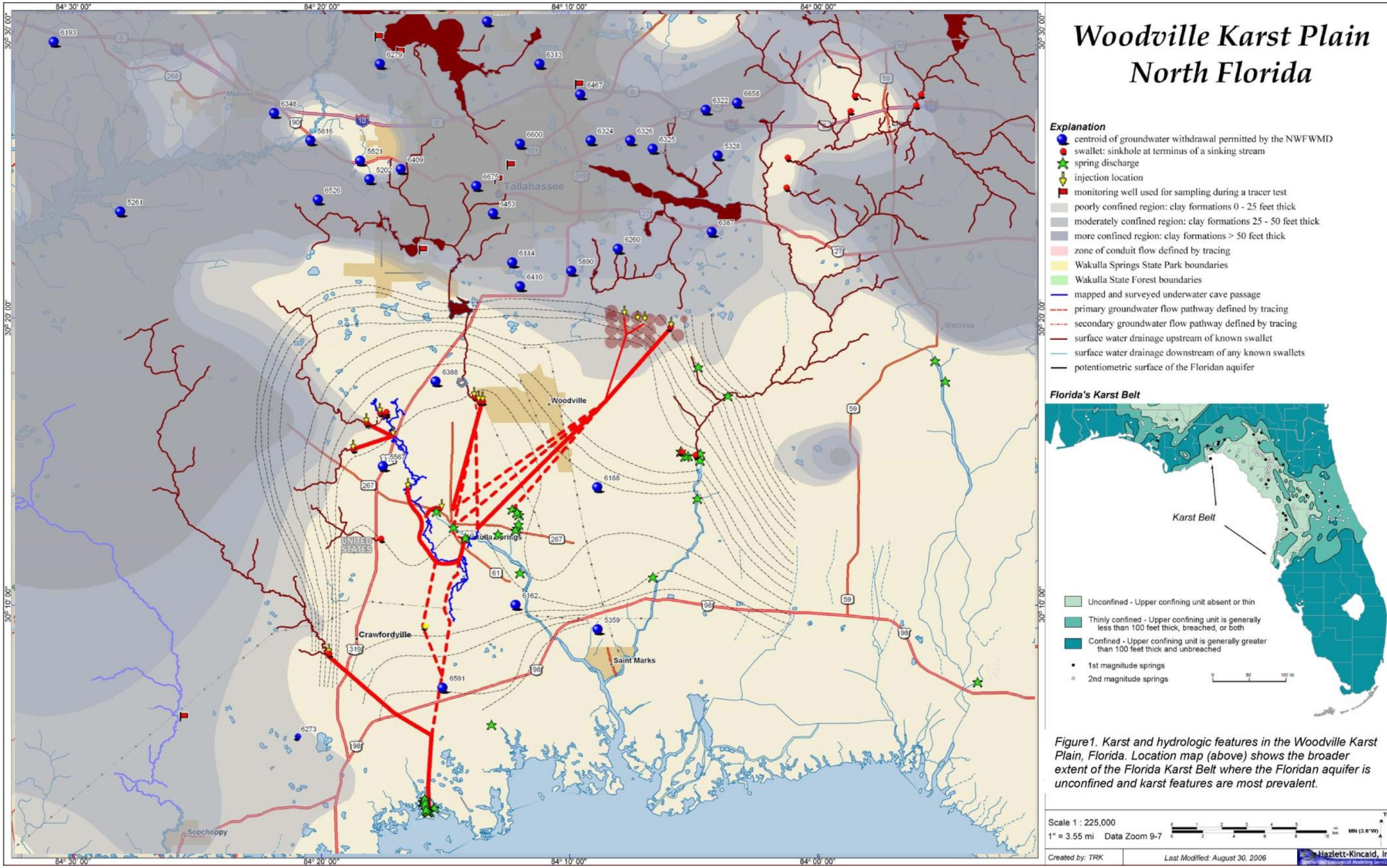
Extractions in the WKP



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Permitted Groundwater Withdrawals

Average Allowable Withdrawals

Legend

Well System Centroid

•

Center points of some of the consumptive use wells/sites within the NWFWMD. These are not actual well locations, but an average center point based on actual locations of all the wells under a consumtive use permit number.

Average Permitted Pumprate

- 100 - 1000
- 1001 - 5000
- 5001 - 10000
- 10001 - 50000
- 50001 - 100000
- 100001 - 500000
- 500001 - 1000000
- 1000001 - 5000000
- 5000001 - 10000000
- 10000001 - 40000000

Circle size represents the average amount of water, in gallons per day, permitted to be pumped from the system

Size of Consumptive Use Well System

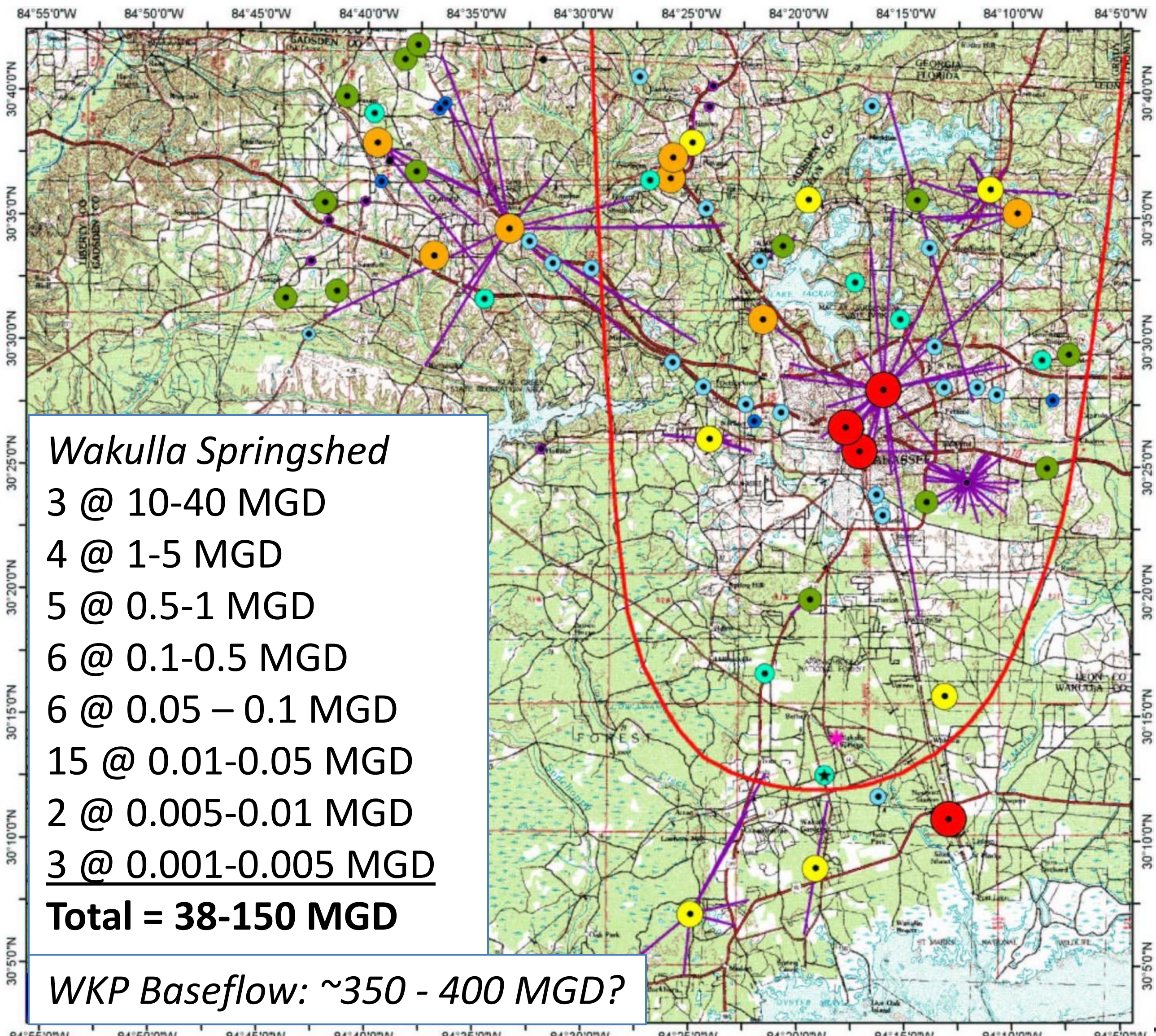
Lines represent the distance from the centroid to wells under the same consumptive use permit

- Wakulla Springshed Boundary
- Wakulla Springs
- Proposed Water-Bottling Operation

0 2.5 5 10 15 Miles

Scale - 1:275,000

Projection - GRS 1980 Albers



Wakulla Springshed

3 @ 10-40 MGD

4 @ 1-5 MGD

5 @ 0.5-1 MGD

6 @ 0.1-0.5 MGD

6 @ 0.05 – 0.1 MGD

15 @ 0.01-0.05 MGD

2 @ 0.005-0.01 MGD

<u>3 @ 0.001-0.005 MGD</u>

Total = 38-150 MGD

WKP Baseflow: ~350 - 400 MGD?

Most Recent Tracing Results …

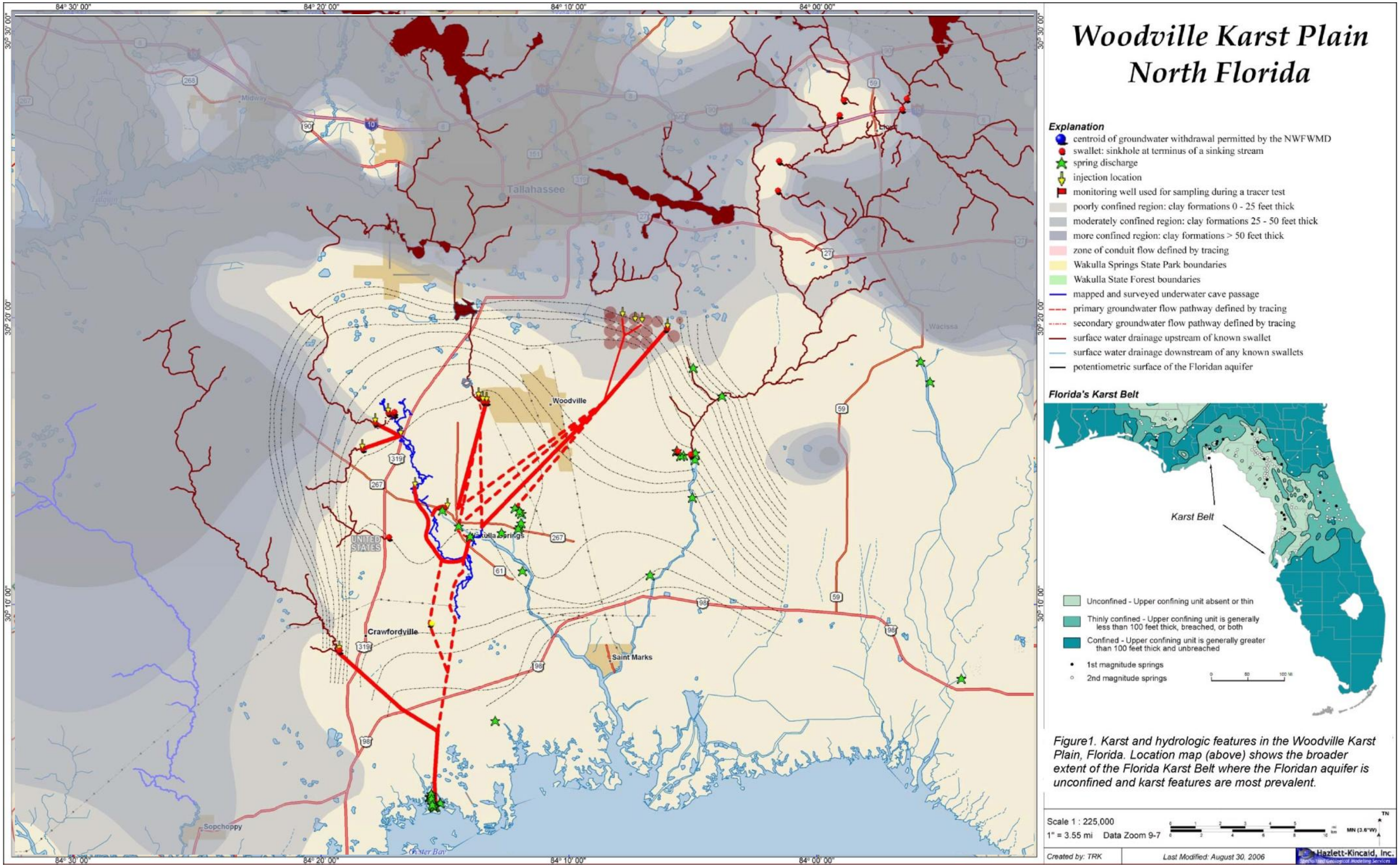


Figure1. Karst and hydrologic features in the Woodville Karst Plain, Florida. Location map (above) shows the broader extent of the Florida Karst Belt where the Floridan aquifer is unconfined and karst features are most prevalent.

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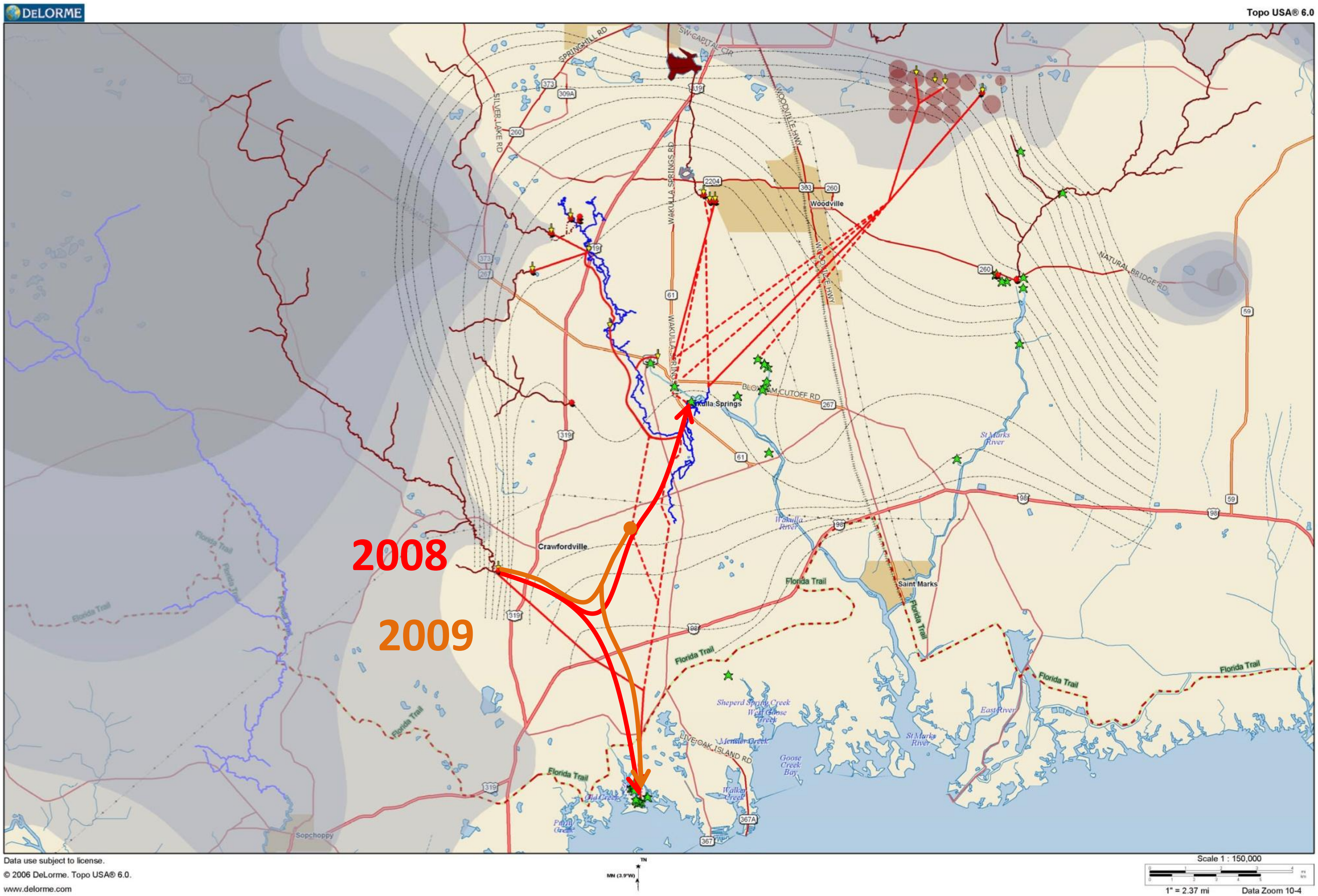
Timeline …

- May 4, 2007: Inject 10 kg Uranine into Turner Sink
  - Travels rapidly to Wakulla Spring
  - 8 & 19 days after injection
  - Turns Wakulla green
  - No recovery at Spring Creek

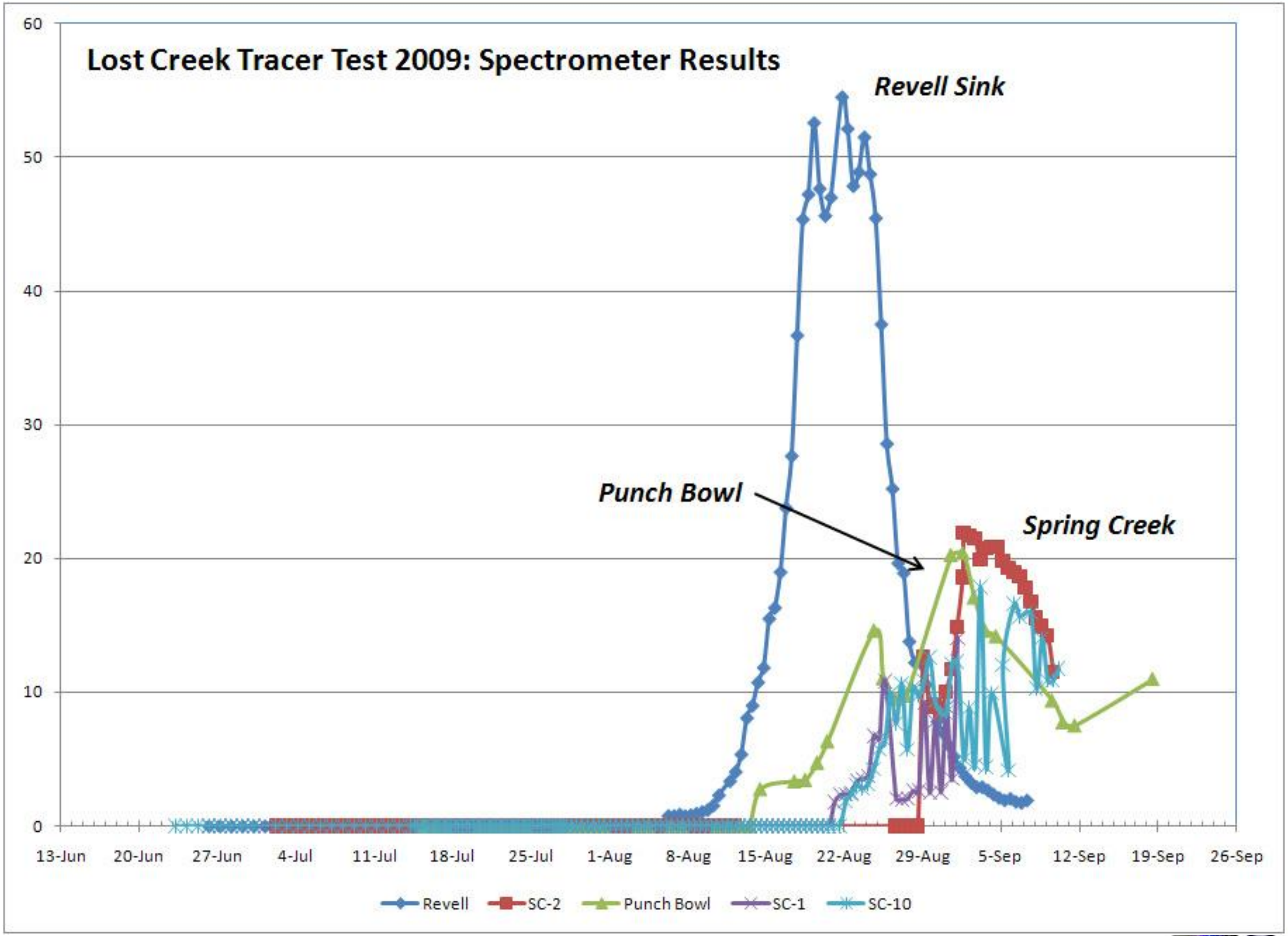
- May 29, 2008: Inject 10 kg Uranine into Lost Creek Sink
  - Travels rapidly to Spring Creek Vent #10
  - Less than 5 days travel time
  - Recovery curve stops shortly afterward – Spring Creek Reversing
  - Subsequent recovery at Revell (~50 days after injection)
  - Subsequent Recovery at Wakulla Spring (~56 days after injection)

- July 14, 2009: Inject 15 kg Uranine into Lost Creek Sink
  - Spring Creek reversing
  - First detection @ Revell Sink
  - Changed direction toward Spring Creek (Spring Creek Flowing)
  - Detection @ Punch Bowl
  - Recovery at all major Spring Creek Vents

New Confirmed Pathways



Tracer Detections



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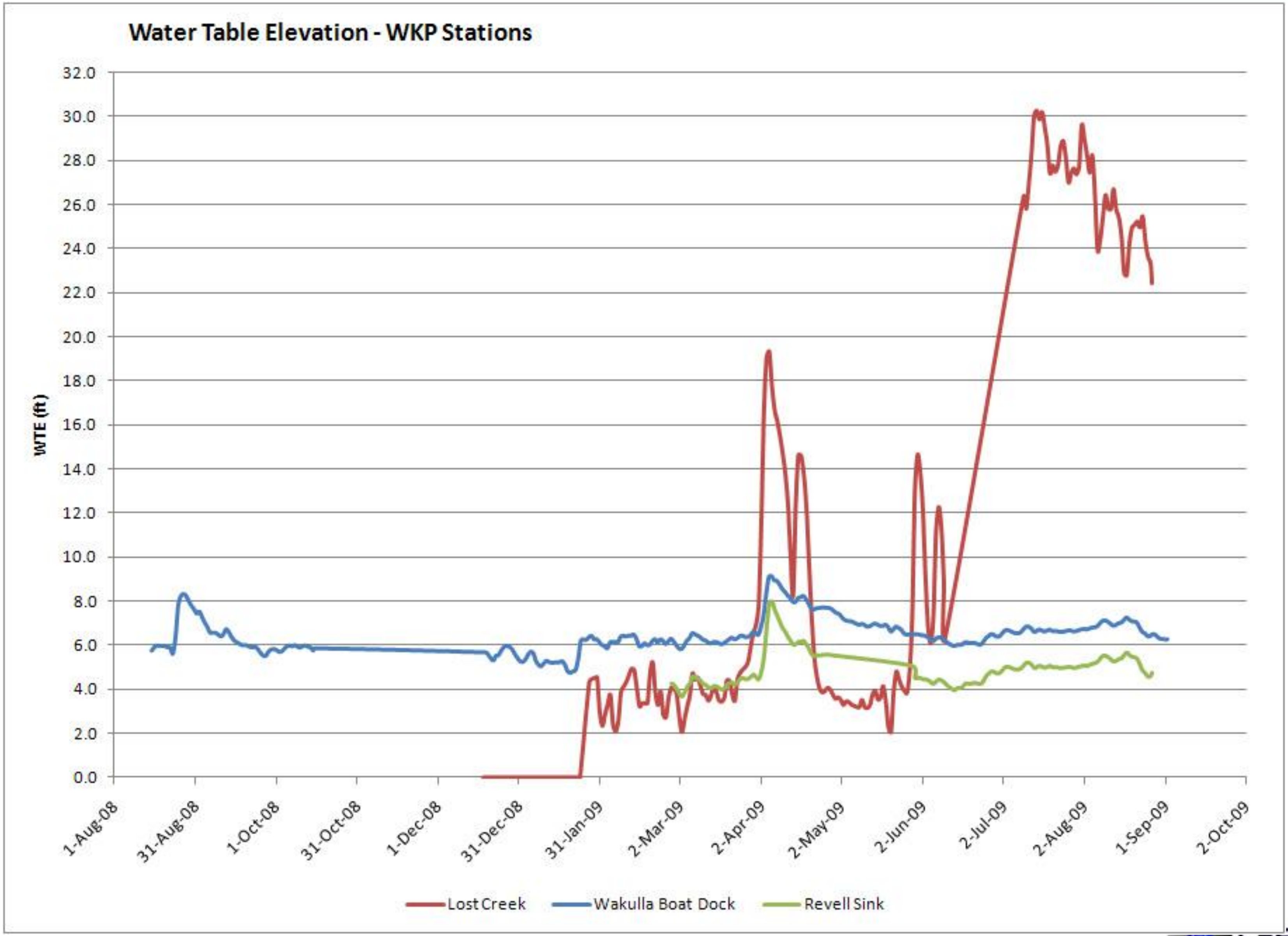
Water Table Elevations



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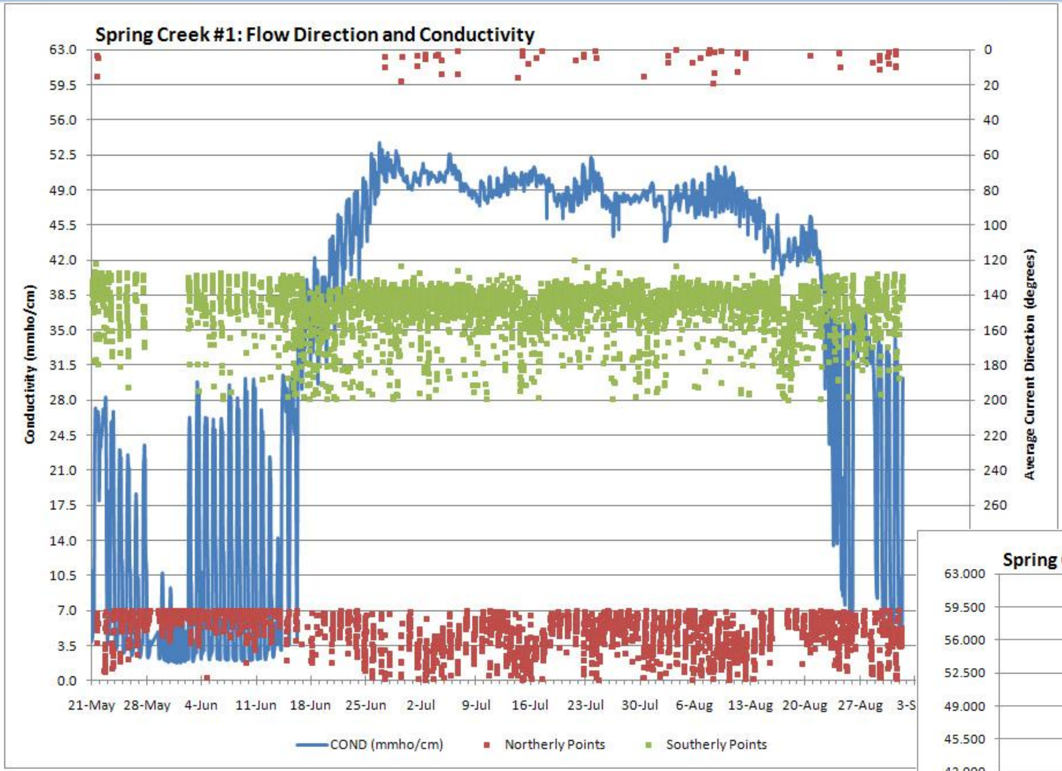
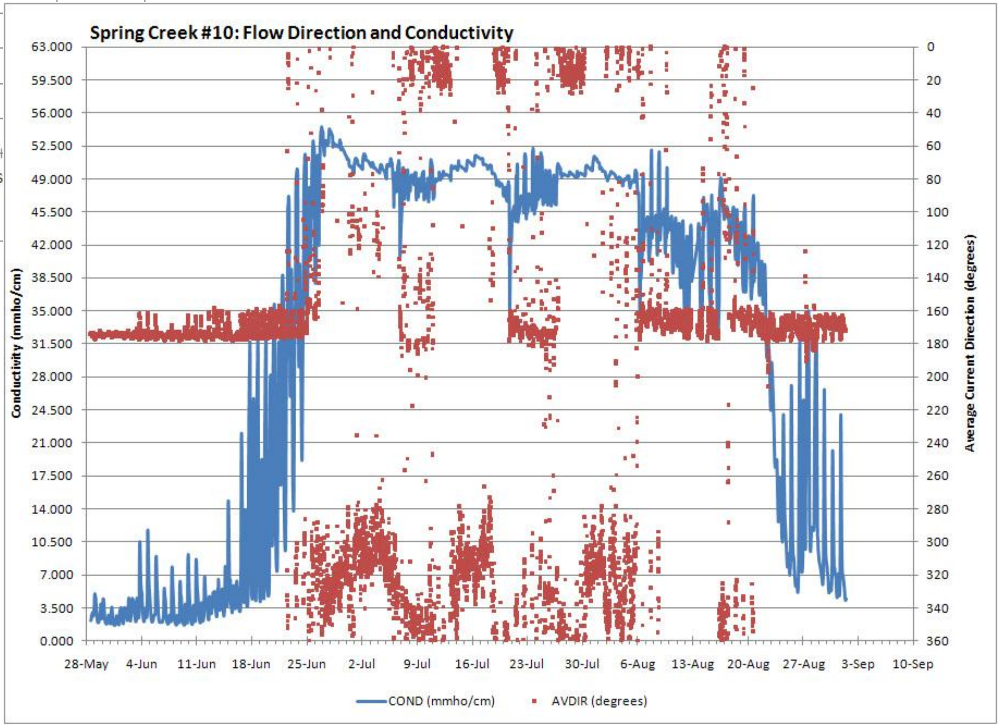
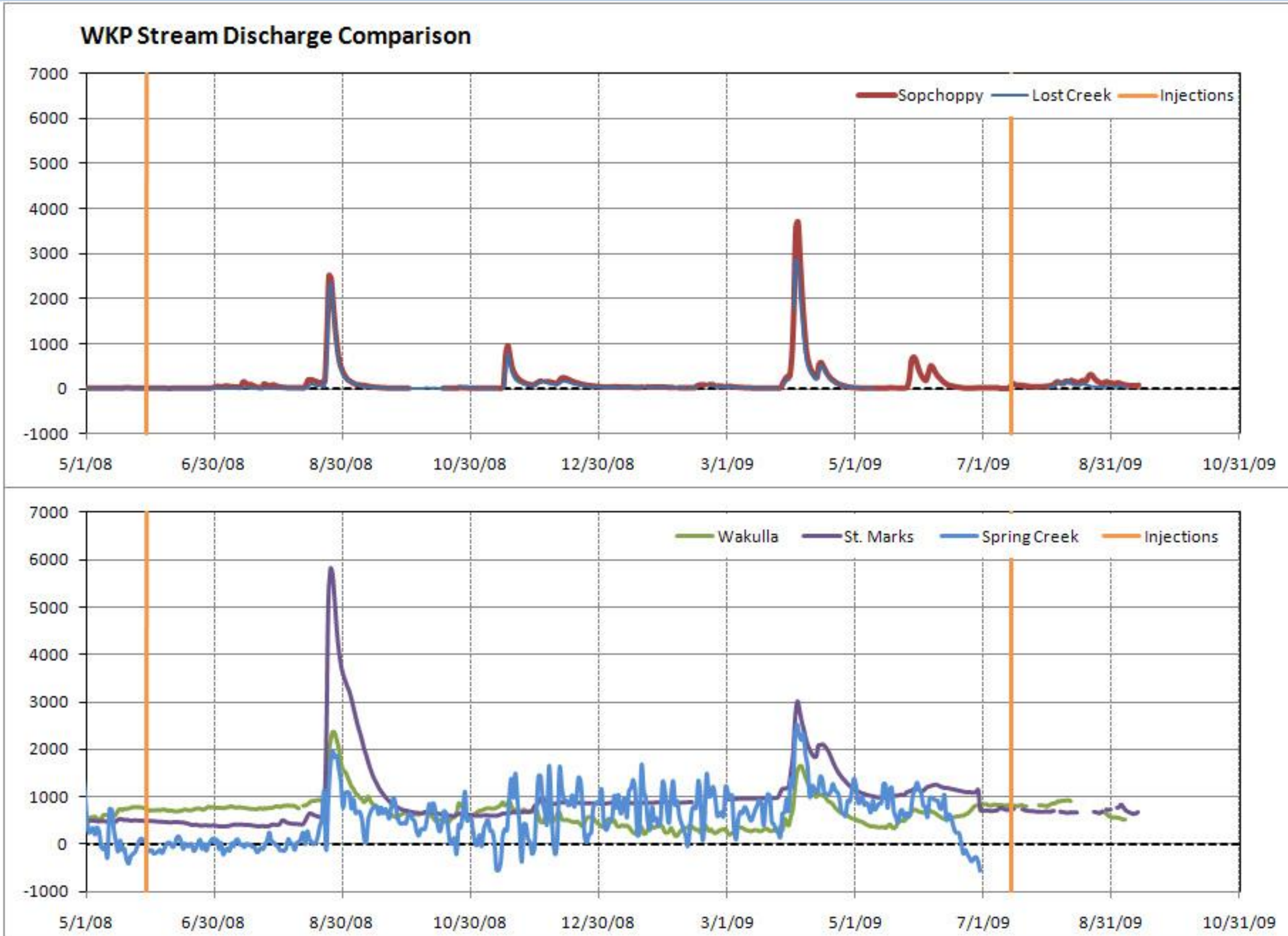
Spring Creek Reversals





River Flow Trends



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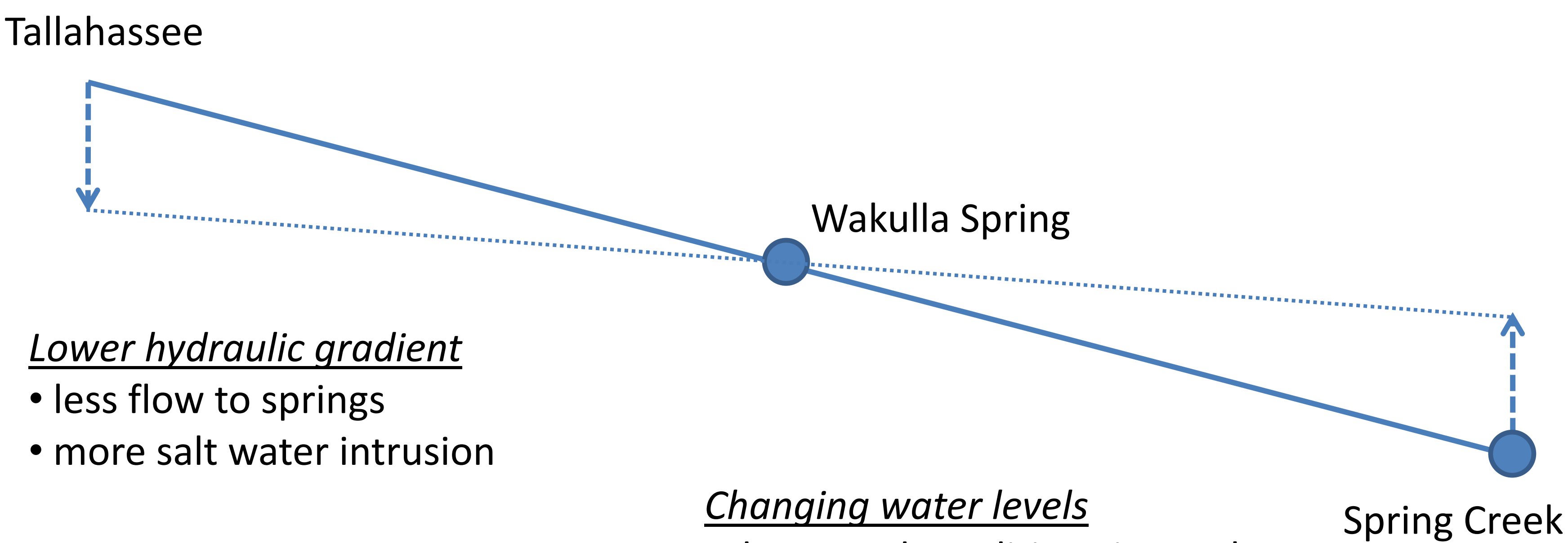
Hydraulic Gradient



Lower hydraulic gradient

- less flow to springs
- more salt water intrusion

Changing water levels

- depressed conditions in north
- deeper unsaturated zone
- elevated conditions in south
- reduced unsaturated zone

Summary - 1

- Wakulla and Spring Creek are connected by one or more large conduits.
- When Spring Creek reverses, Wakulla takes it's groundwater flow – i.e. the Wakulla Springshed expands to include all of the area that formerly contributed to Spring Creek.
- Diminished water clarity conditions in summer at Wakulla are likely due to water quality of Spring Creek water.

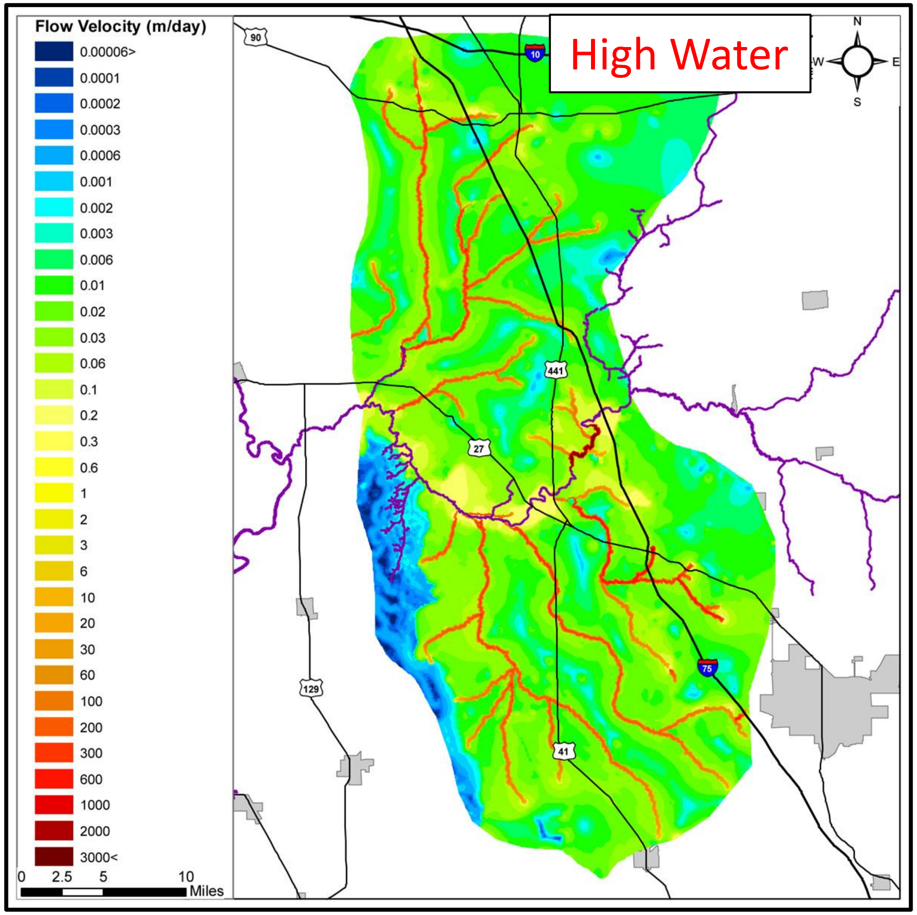
Why does Spring Creek reverse?

- Not sure – but trying to find out…
- Consensus focuses on depressed groundwater gradients and tide.
- Under low flow conditions, high tides likely reverse gradient at spring Creek.
- Denser salt water flows into the large caves.
- Denser water requires relatively larger gradient to drive it out.
- Water levels in the southern part of the WKP stay high (flooded sinks…) until the groundwater gradient rises sufficiently to drive the salt water out of the Spring Creek caves.
- When the gradient reaches the critical level, the Spring Creek vents begin to flow, the elevated water levels in the south fall, and Wakulla's flow drops.

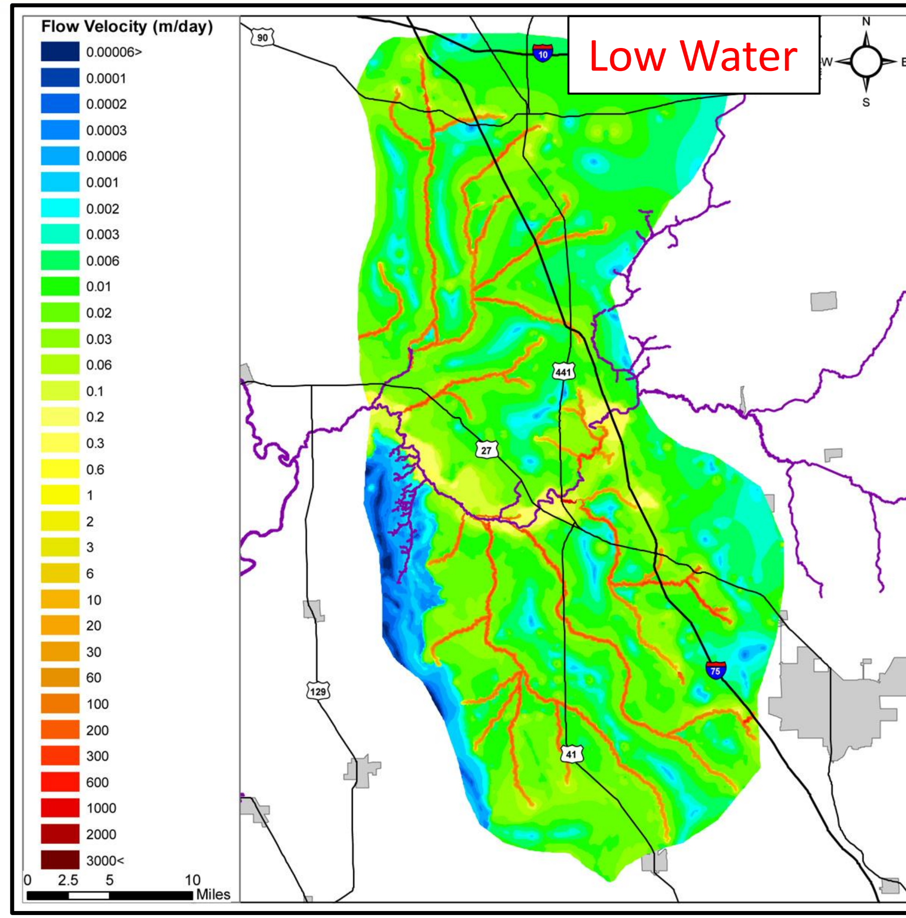
Summary - 2

- Water clarity at Wakulla is, in part, dependent on the duration of the Spring Creek reversals.
- If trends continue (sea-level rise & groundwater level declines), the duration of Spring Creek reversals will increase.
- Reducing upland groundwater declines would contribute to reducing the duration of the Spring Creek reversals.
- Protecting water clarity requires an understanding of the groundwater budget and how extractions impact that budget.
- Achieving these protections will require continued (probably expanded) data collection.
  - Groundwater levels
  - Flows
  - Spring Creek variability

Model Calibration: *Groundwater Velocities*



- Conduits model: ~ 100 to ~3000 m/day
- Conduits observed: ~ same
- Matrix model: ~ 10^{-3} to 10^{-1} m/day
- Matrix observed: ~ $10^{-?}$ To $10^{-?}$ m/day



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- Conduits observed: ~ same
- Matrix model: ~ 10^{-3} to 10^{-1} m/day
- Matrix observed: ~ $10^{-?}$ To $10^{-?}$ m/day

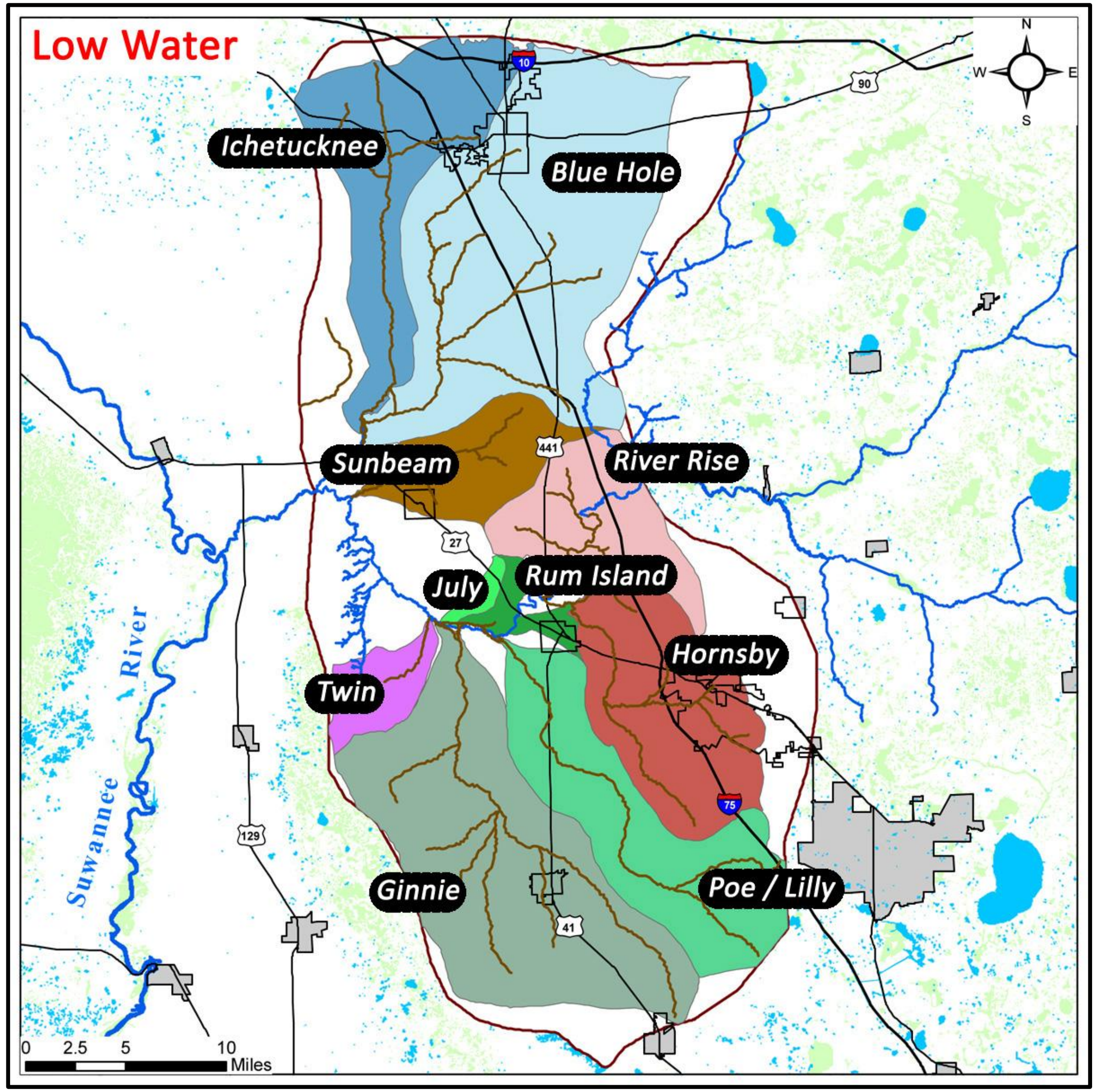
Coca-Cola north america

GeoHydros

Applications: *Springshed Delineations*

- Defined from forward particle track analysis
- Boundaries change between high water & low water conditions

Spring Group	High (km^2)	Low (km^2)
Ginnie / Blue	395	414
Blue Hole Group	377	488
Hornsby	274	210
Ichetucknee	248	222
Poe / Lilly	237	241
River Rise	116	134
Sunbeam	80	103
Twin	29	49
Rum Island	24	26
July	12	11



GeoHydros

Applications: *Springshed Delineations*

- Defined from forward particle track analysis
- Boundaries change between high water & low water conditions

Spring Group	High (km^2)	Low (km^2)
Ginnie / Blue	395	414
Blue Hole Group	377	488
Hornsby	274	210
Ichetucknee	248	222
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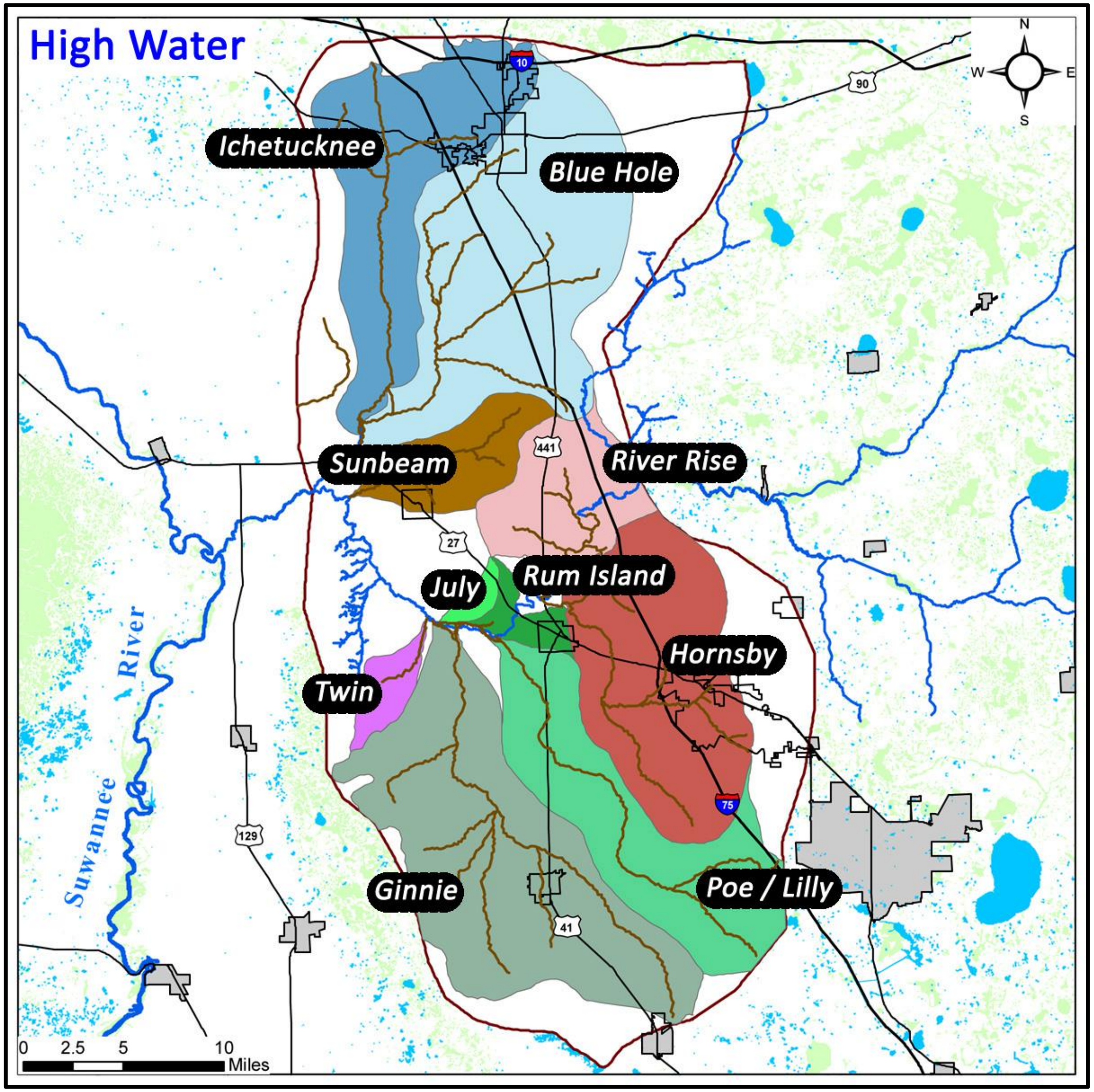
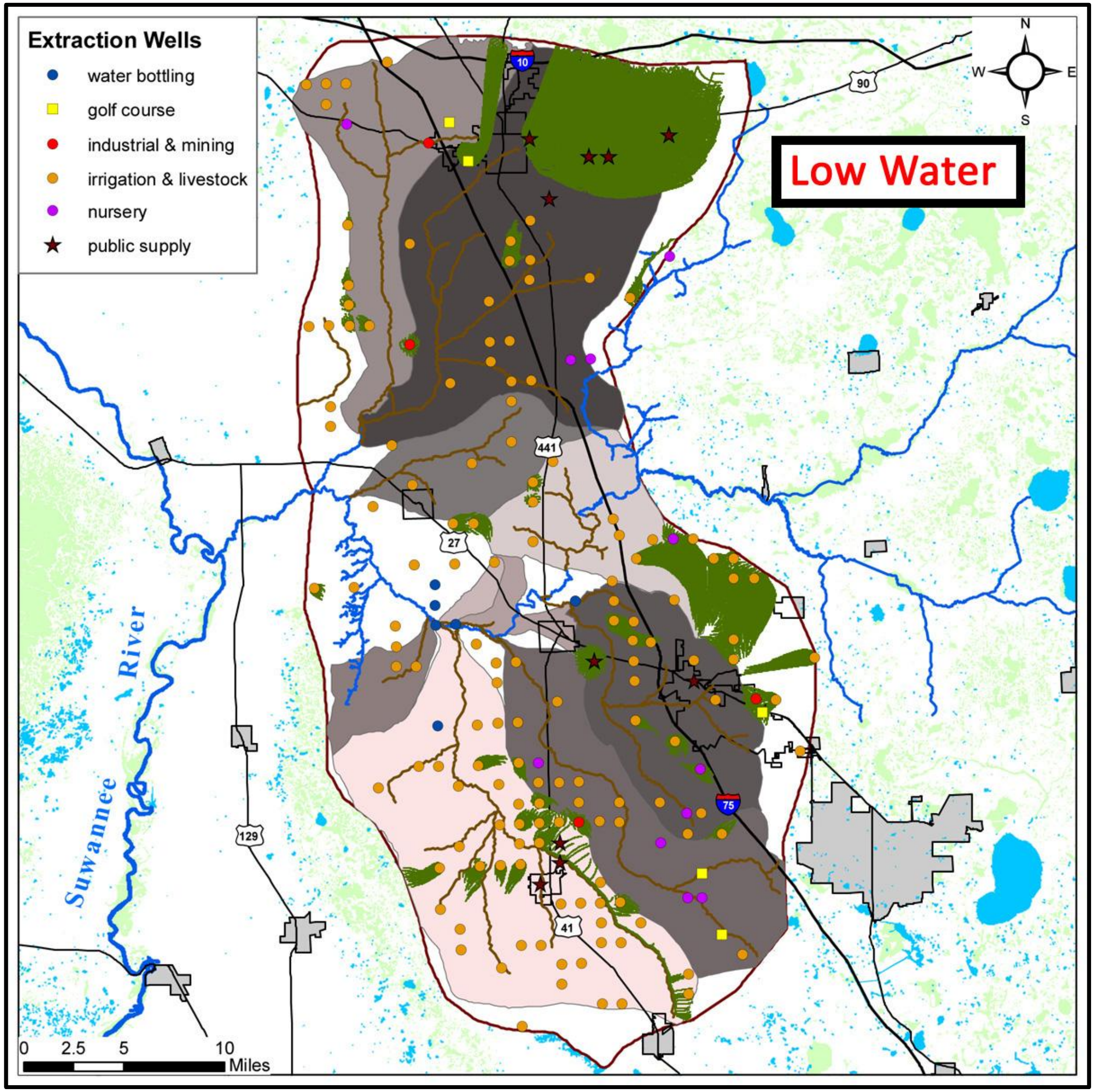


GeoHydros

Applications: *Pumping Impacts*

- Pumping diminishes spring flows within the impacted springsheds.
- Particle tracking shows that pumping impacts the size and shape of the springsheds.
- Model simulates impacts to flows & springsheds.
- Example: Lake City
  - Average rate: 4.5 MGD
  - No pumping springsheds
    - Ichetucknee: 248-222 km^2
    - Blue Hole: 377-488 km^2
  - Pumping springsheds
    - Ichetucknee: 245-222 km^2
    - Blue Hole: 316-377 km^2
  - Reductions
    - Ichetucknee: -1% / 0%
    - Blue Hole: -19% / -30%



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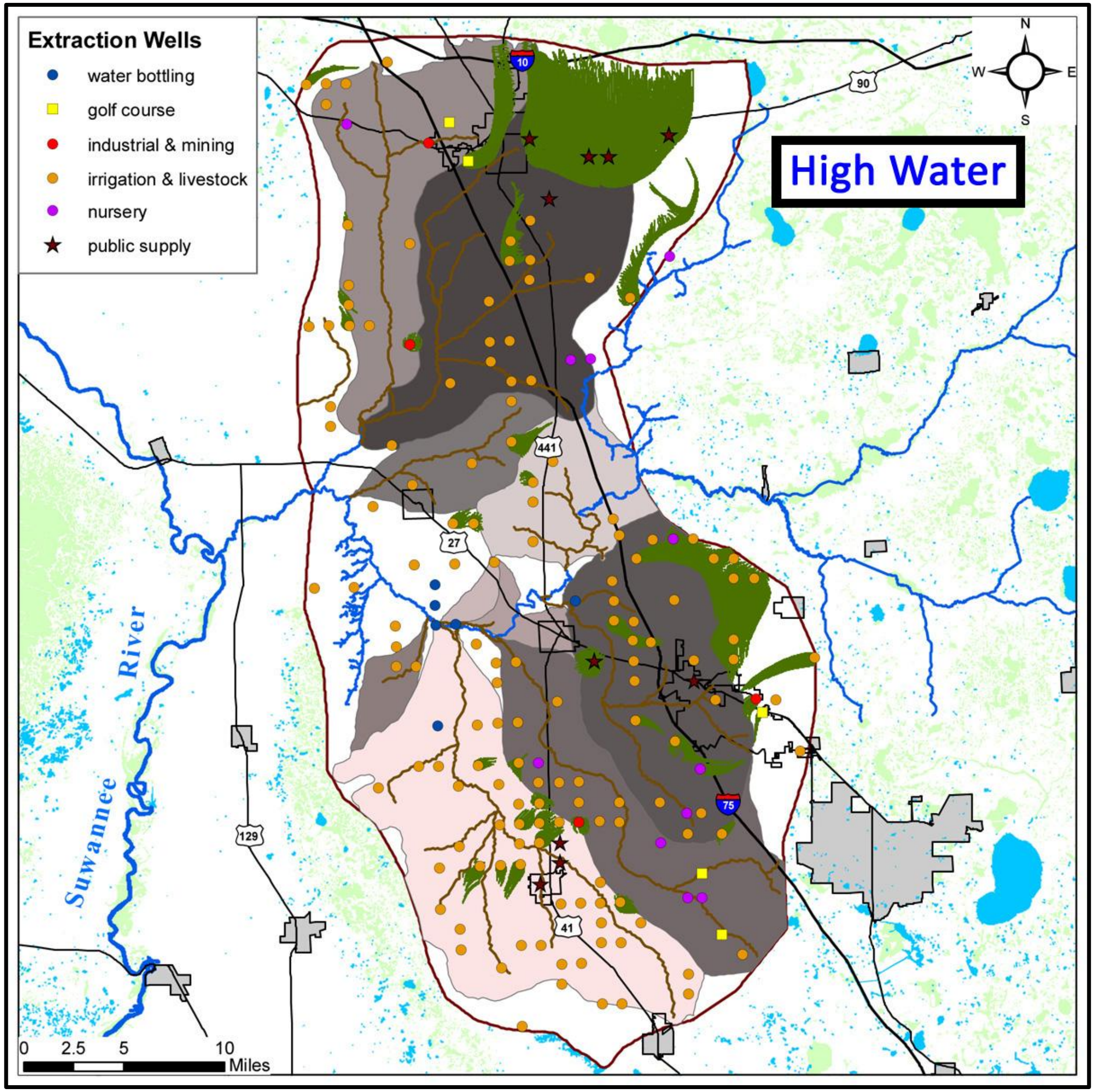


Applications: Aquifer Vulnerability

Flow is to closest conduits

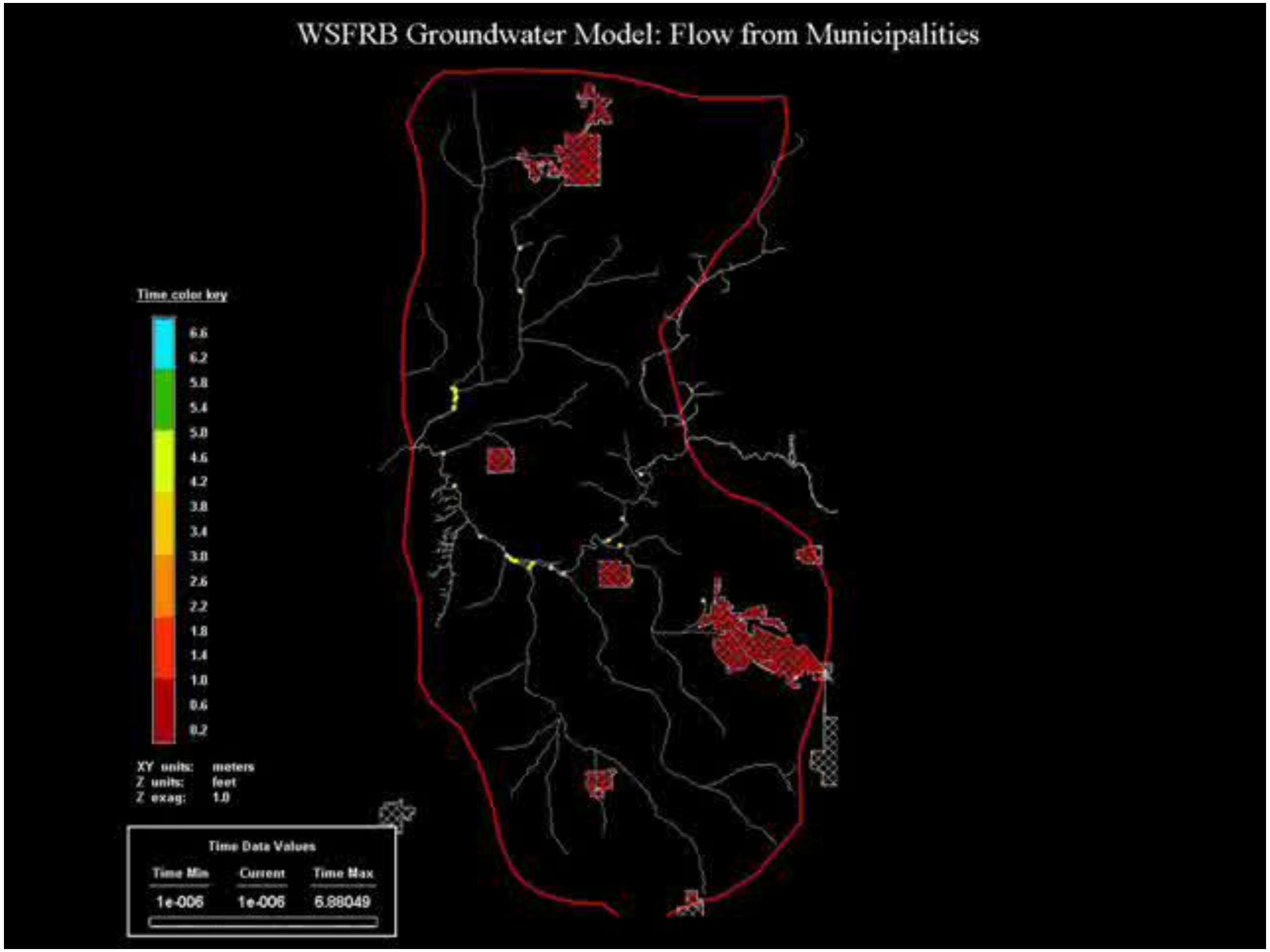
Closest towns not always of most concern

Newberry – Ginnie Spring
- *~12 miles*
- *~1000 days*
- *conduit flow*

Alachua – Hornsby Spring
- *~7 Miles*
- *~500 days*
- *conduit flow*

High Springs – River
- *~2 miles*
- *~10,000 days*
- *no conduit*

Municipalities: Santa Fe River Basin, Florida

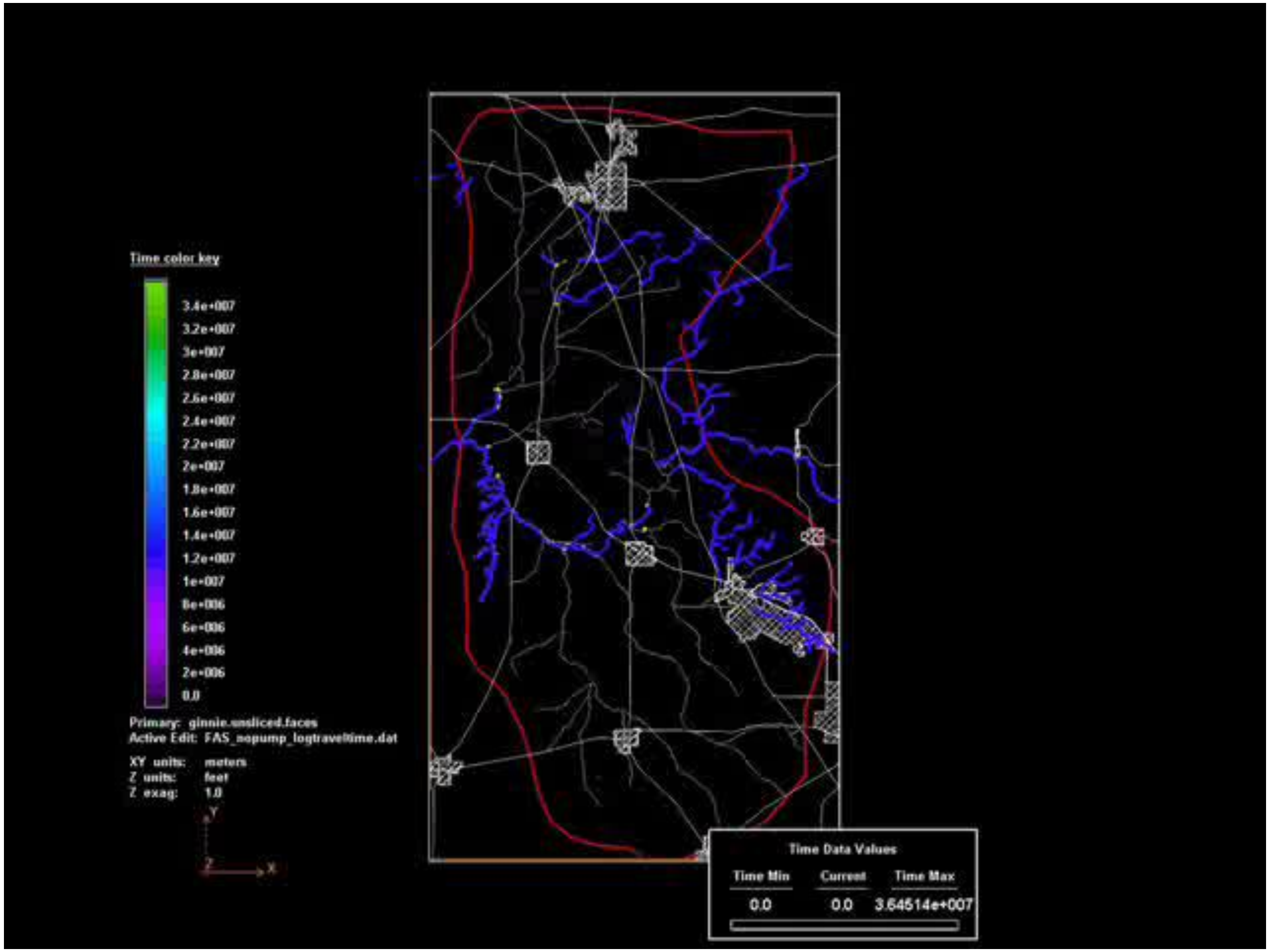


Applications: Source Water Protection

Controlled by conduits

Simulated velocity range
- *10^2 m/day*
- *10^{-3} m/day*

Springs Vulnerability: Santa Fe River Basin, Florida



How should we address quantity issues?

- Establish & publicize the water budget
  - Immediately initiate continuous flow measurements
  - Immediately initiate continuous water level measurements
- Finish establishing pathways
- Develop a basin-scale groundwater model that accurately simulates flows and heads
- Use the model to evaluate impacts of development scenarios
  - Increased water extractions
  - Reuse and returns
  - Landuse changes
- Issue and manage permits based on a holistic assessment of impacts to the water budget
- Educate the public

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Karst in my County?

Beneath the Pink Underwear

Water pollution is more serious than the WASD plan would have you believe

BY STEVEN DUDLEY
steven.dudley@miaminewtimes.com

miaminewtimes.com | originally published: June 5, 2003

- *No caves?*
- *No big springs?*
- *No sinking streams?*
- *Can still have conduit flow!*

Alex Barrera

- Quarries located close to Northern Miami-Dade well field
- Potential source of contamination to the wells
- Conventional wisdoms "models" state that groundwater travel times are slow (many days)
- Dye tracing – on the other hand – showed that travel times are hours: *1.5 orders of magnitude higher!*
- *Problem was that the trace was designed assuming the slower rate and as a result the wells were flooded with red dyed water turning people's underwear pink*
- Lesson: limestone + rain = karst
- Adequate protection measures must be based on accurate conceptualizations "models"

GeoHydros

More Information

- Wakulla Research
  - www.geohydros.com/FGS/
- Santa Fe River Model
  - www.geohydros.com/CCNA/