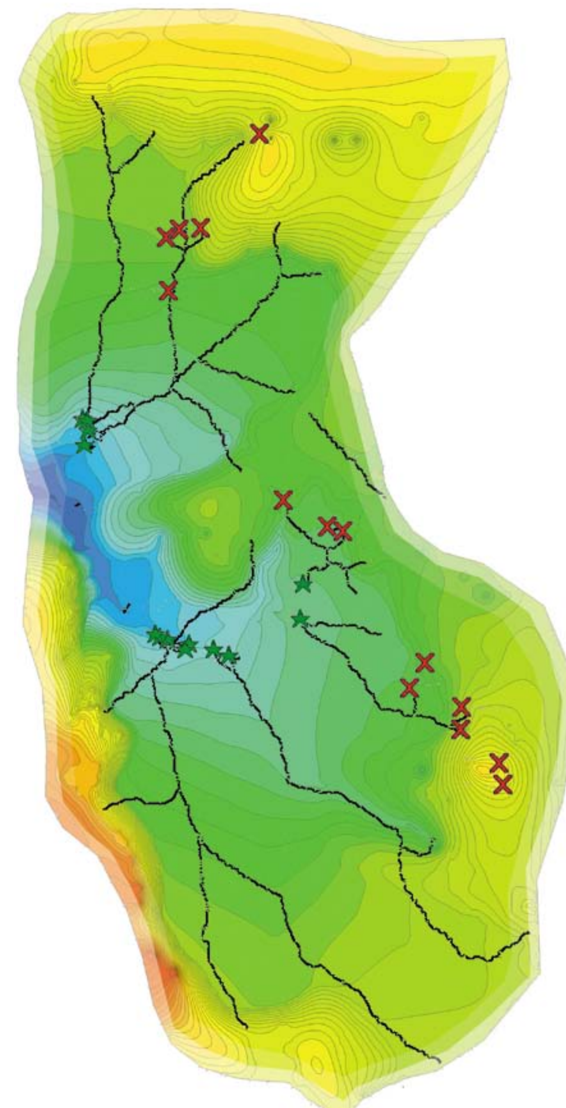
MODELING SPRINGSHEDS AND SPRING VULNERABILITY IN THE KARSTIC FLORIDAN AQUIFER



Florida Geological Survey Meeting

Tallahassee, Florida

November 16, 2012

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GeoHydros, LLC

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GeoHydros, LLC

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What is a groundwater model?

- Computer generated simulation of groundwater flow patterns & rates.
- Confidence in predictions stems from the model's ability to simulate real-world conditions *(calibration).*

  If we can accurately simulate what we see today or have documented in the past, we can reliably predict what will happen tomorrow.
- We've been using groundwater models in Florida since at least the 1970's to predict the impacts of development on groundwater levels and groundwater quality.
- Our predictions haven't been very good.
  - Inaccurate springsheds delineations
  - Very inaccurate transport predictions
- *Why & what can we do about it?*

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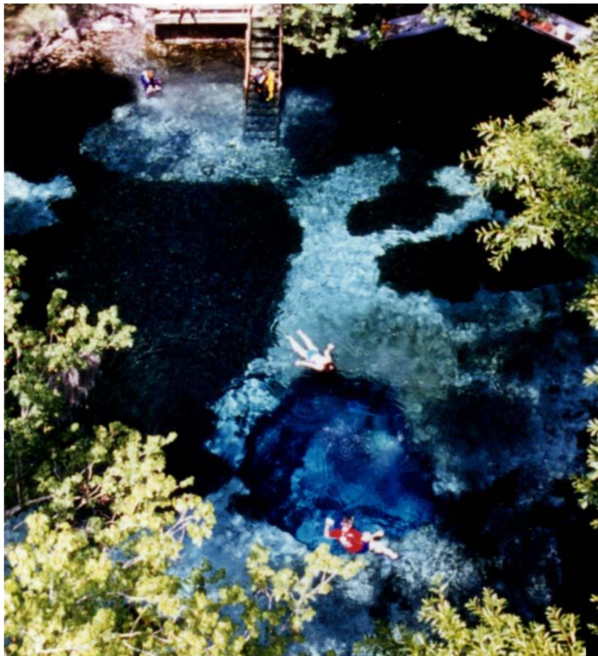
Section – 1
Western Santa Fe River Basin
and
The Suwannee River Water Management District Model

Important Hydrogeologic Complexities

Springs

large magnitude discrete discharges

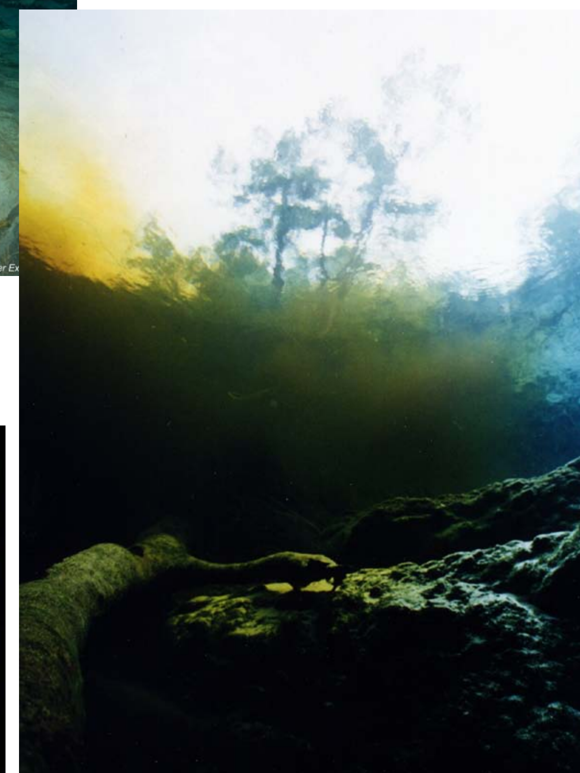


Conduits

Very significant preferential flow paths

GW / SW Mixing

Impacts water budget



Swallets

Large magnitude discrete recharge

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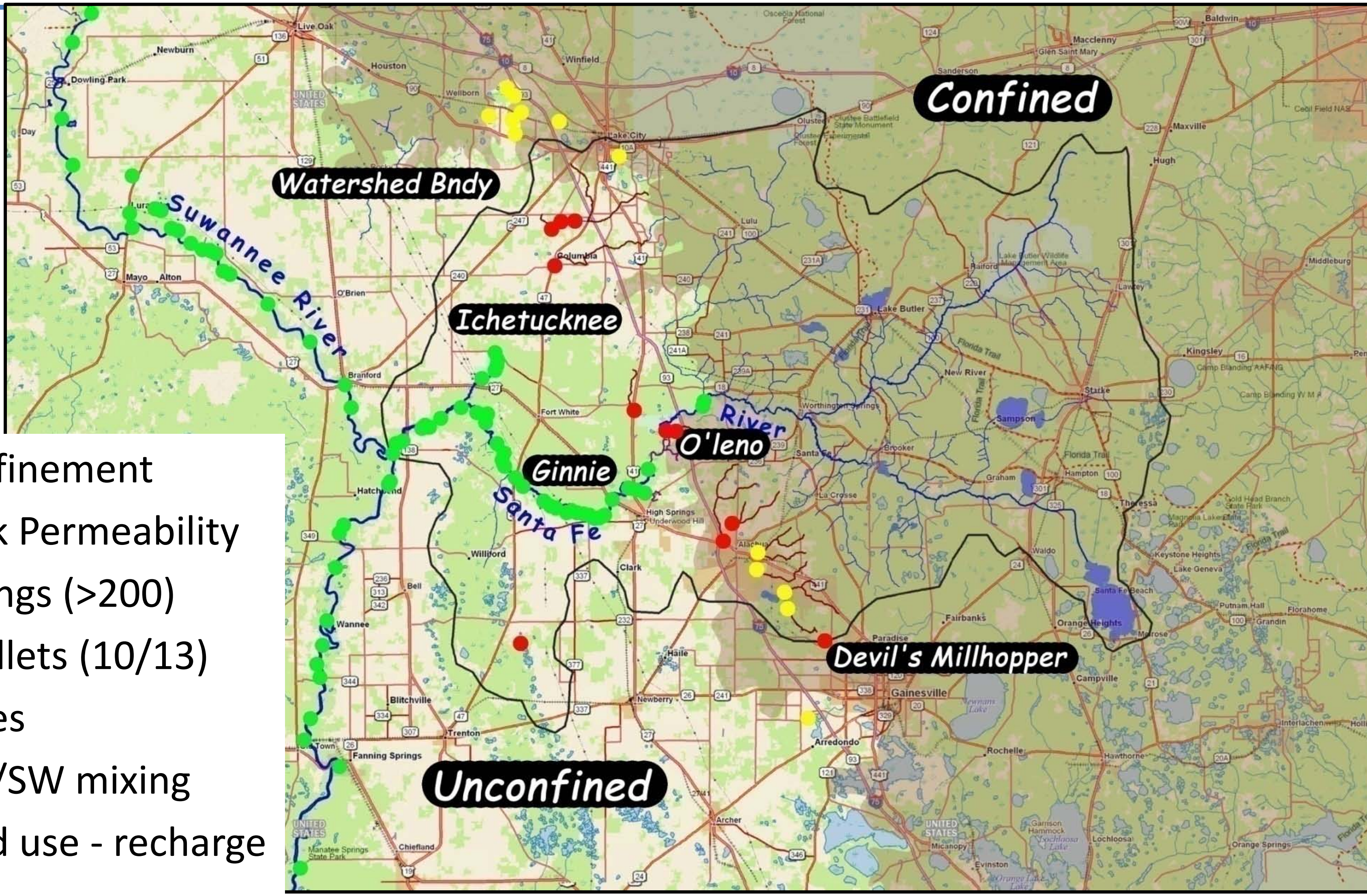
Important Hydrogeologic Complexities



- Confinement
- Rock Permeability
- Springs (>200)
- Swallets (10/13)
- Caves
- GW/SW mixing
- Land use - recharge

Karst features create the dominant controls on flow

Desirable Modeling Applications

- Predict impacts of groundwater extraction on spring flows
  - Simulate springshed boundaries and how they interact
  - Simulate specific spring discharges
  - Simulate magnitude and spatial location of pumping
  - Simulate specific groundwater extractions
- Predict impacts of changing recharge conditions on spring flows
  - Simulate land use and land use changes
  - Simulate 3D hydrostratigraphic framework
- Map spring and well vulnerability to contamination
  - Simulate groundwater flow patterns to springs
  - Simulate groundwater velocities
- Identify sources of contamination to springs

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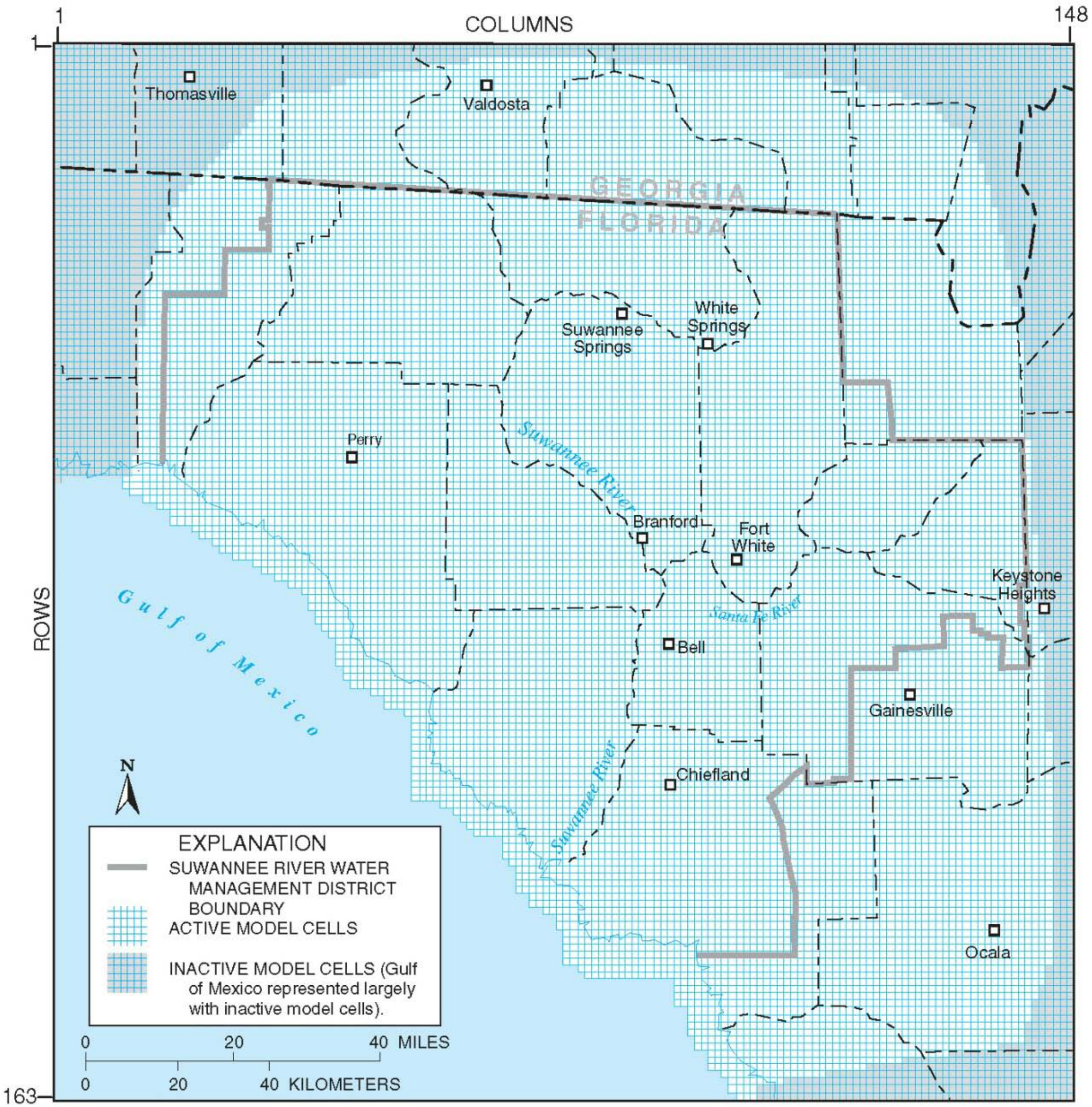
SRWMD Model - Design



- USGS – Planert, 2007
- MODFLOW
- 163 rows
- 148 columns
- Cell size = 5000 feet
- Calibrated to September, 1990 conditions
- Assumes that the aquifer is a porous media – no conduit or fracture flow

Cannot simulate any interactions occurring at less than ~ 1 square mile scale

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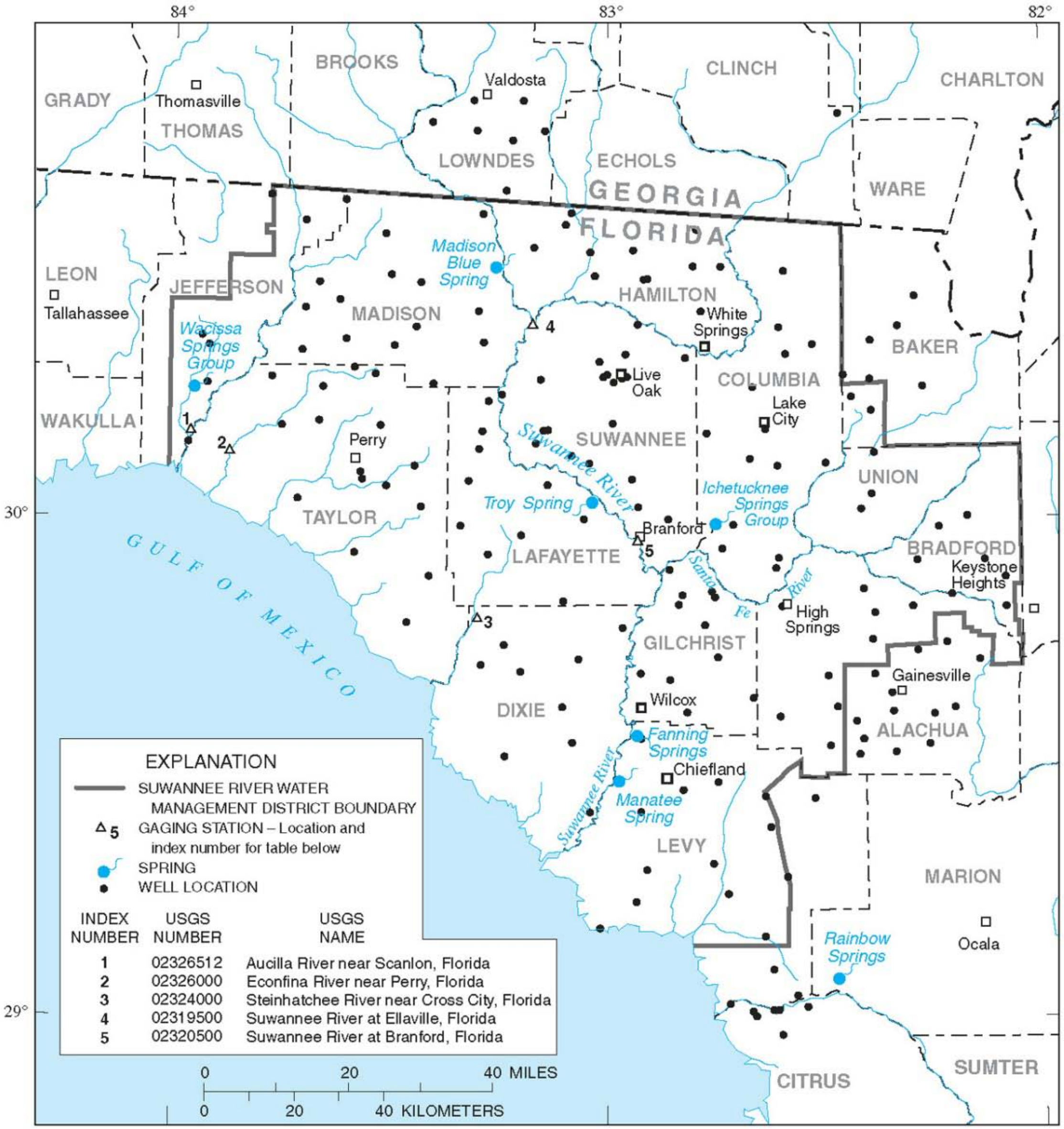
SRWMD Model - Calibration



- Calibration targets
  - 190 wells
  - 5 stream reaches
  - 7 springs
- Swallets not included
- Traced flow paths not included

Fewer calibration targets = less unique answer = less confidence

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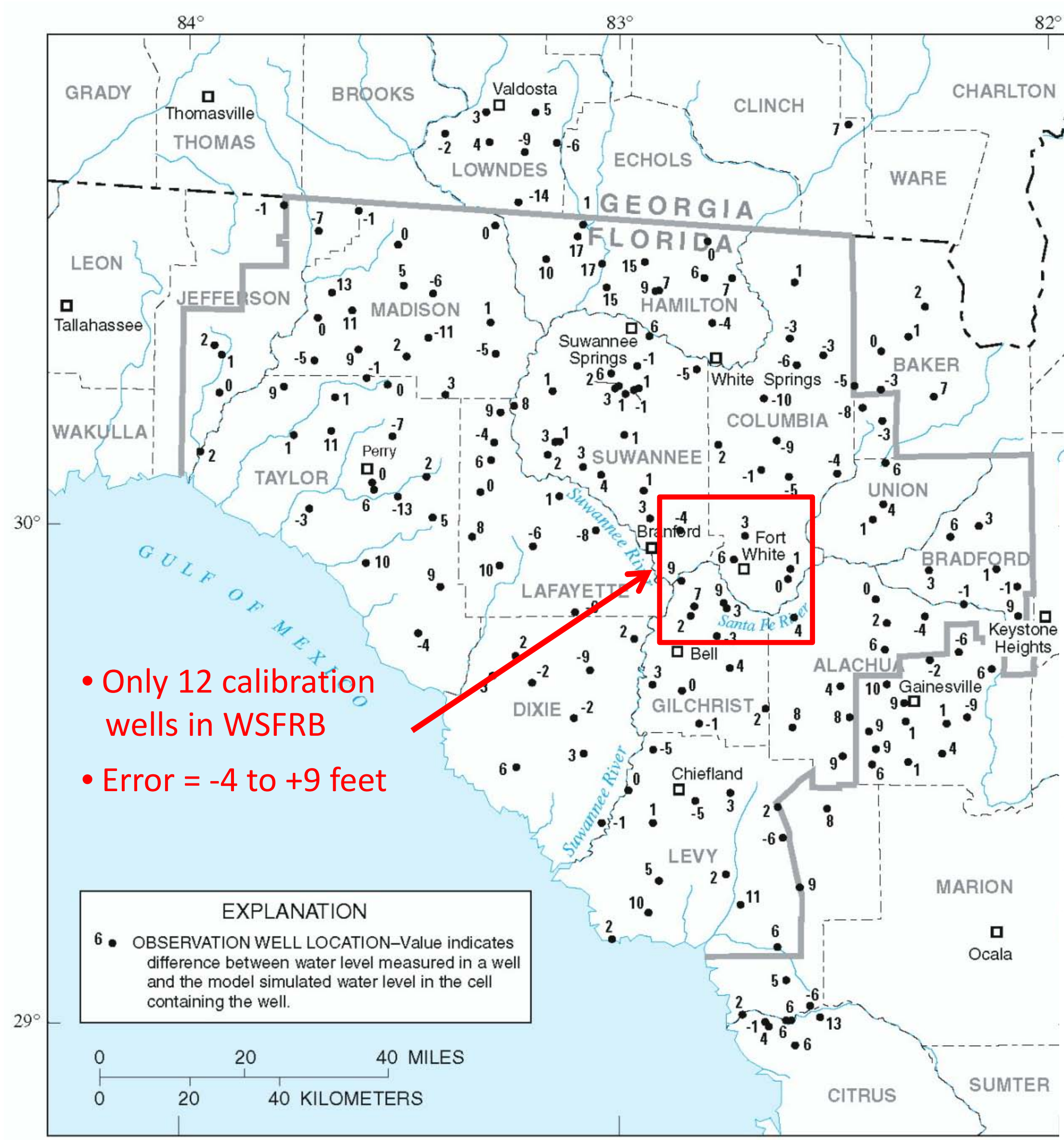
SRWMD Model - Reliability



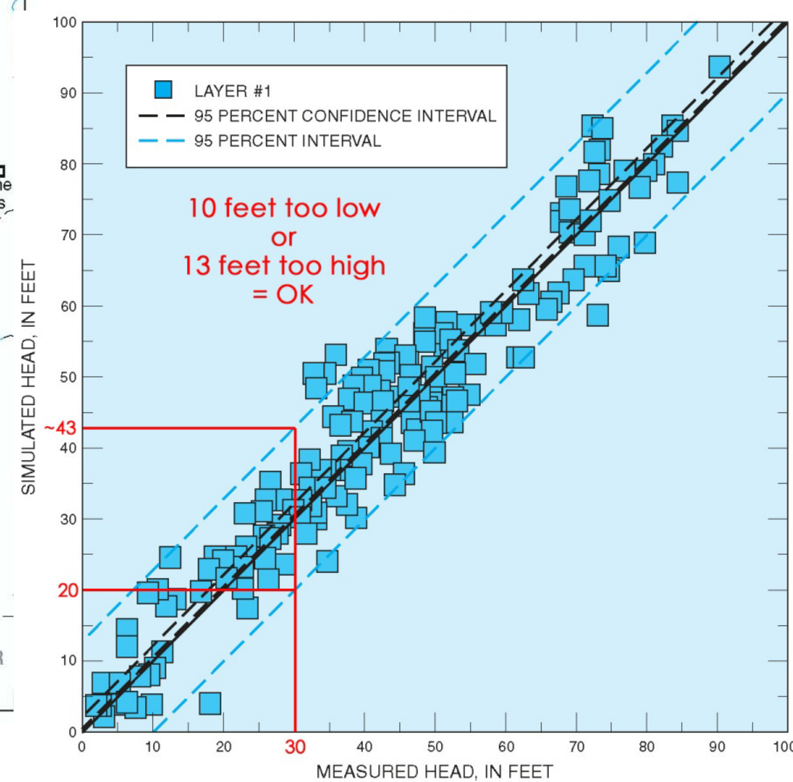
- Only 12 calibration wells in WSFRB
- Error = -4 to +9 feet

Residuals

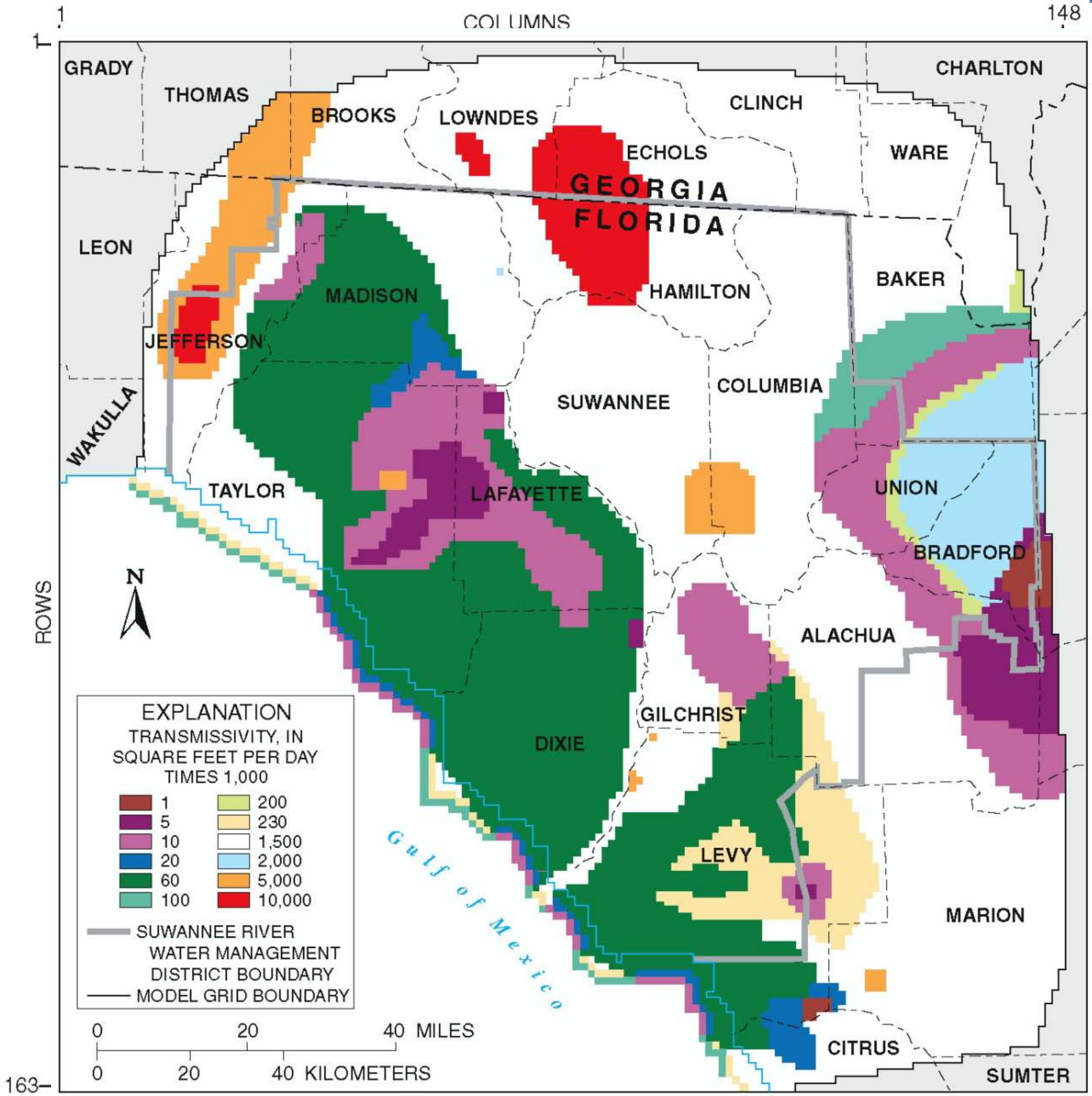
How good is the model?

Not very good

+/- 10-13 feet in Florida is a big deal

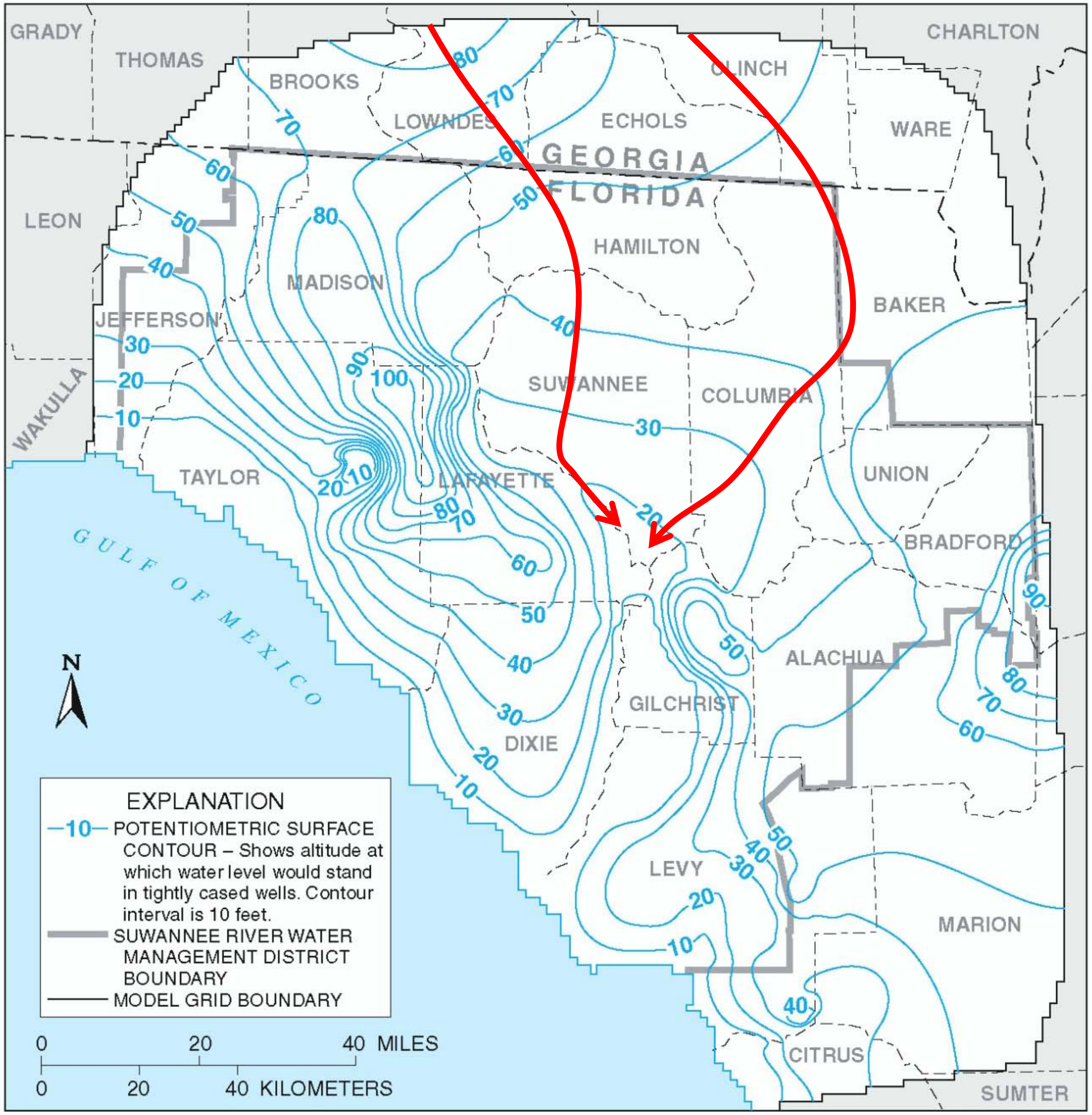


SRWMD Model - Conceptualization



- Assumes that the aquifer is a porous media – no conduit or fracture flow
- Big blocky transmissivity zones
- Not geologically supported
- Highly unrealistic permeability values
  - 10,000,000 ft2/day *~ 28,500 ft/day K*
  - 1,500,000 ft2/day *~ 4,285 ft/day K*
  - 60,000 ft2/day *~ 171 ft/day*

SRWMD Model – Application - Regional



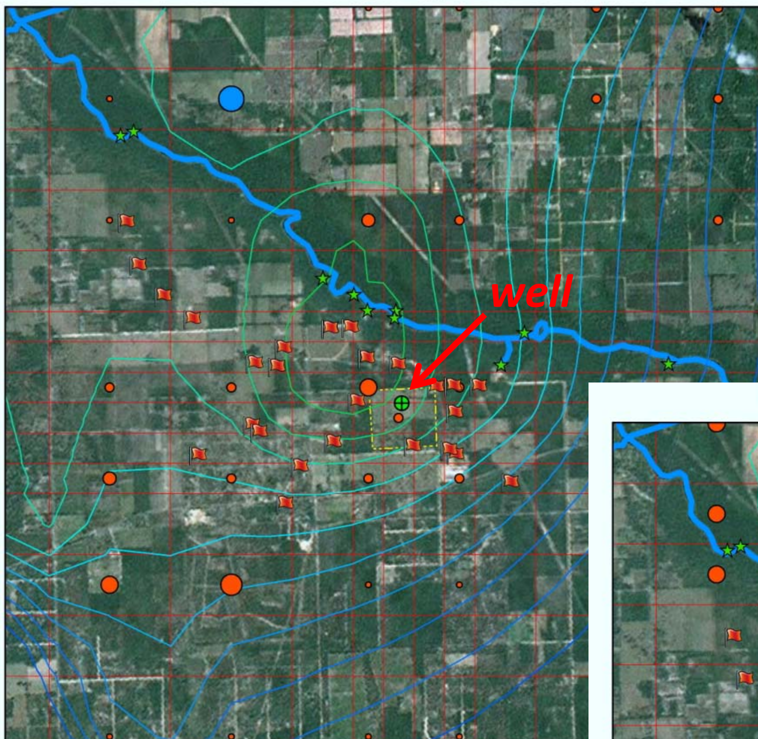
Broad open basins contribute water to Suwannee & Santa Fe springs

Lots of available water

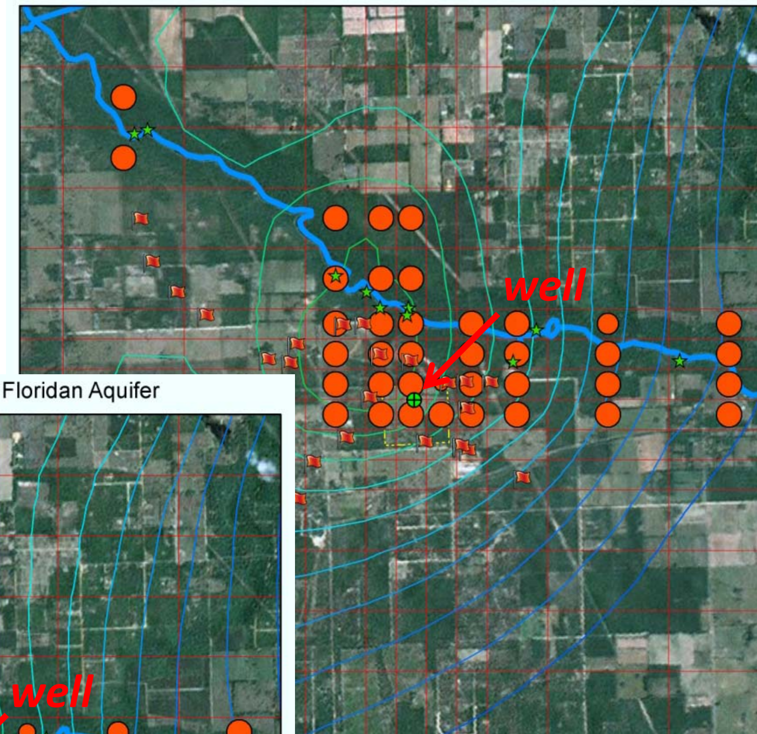
- No indication of convergent flow
  - no springs
  - no conduits
- No springshed delineations

SRWMD Model – Application - Local

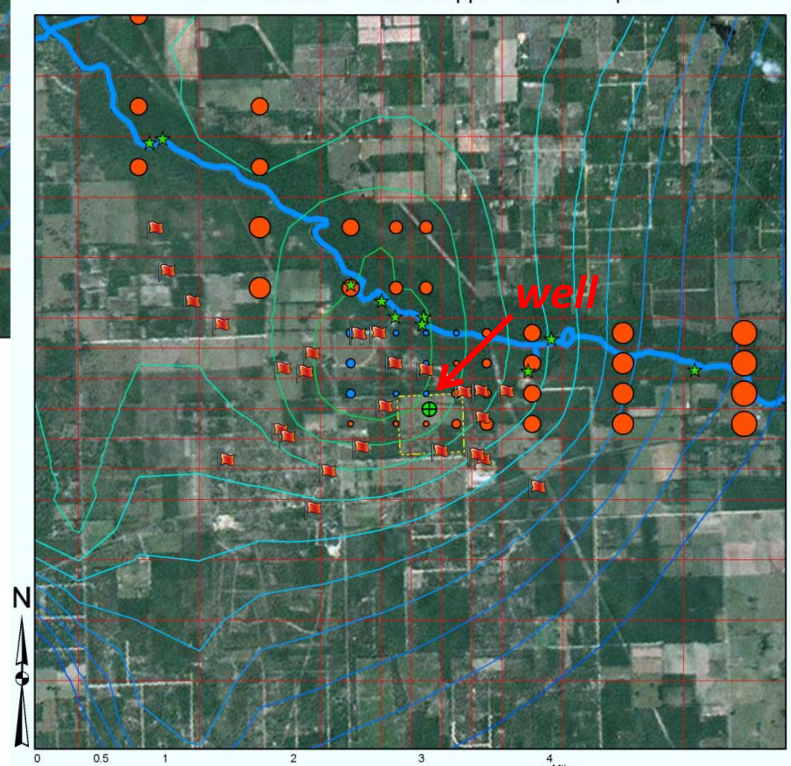
MODFLOW Well Flux in Upper Floridan Aquifer



MODFLOW Drain Flux in Upper Floridan Aquifer



MODFLOW River Flux in Upper Floridan Aquifer



- Way too coarse for detailed analyses
- Overlapping assignments
- travel times in error by orders of magnitude

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Section – 2

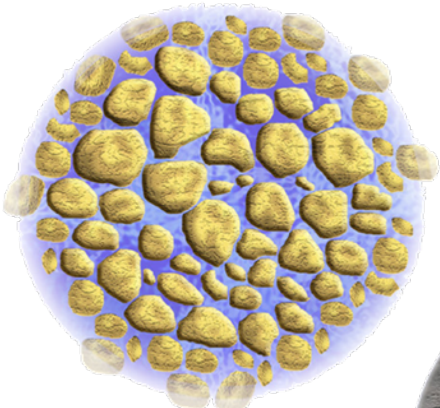
Western Santa Fe River Basin

and

The Hybrid Karst Model

We Can do Better…

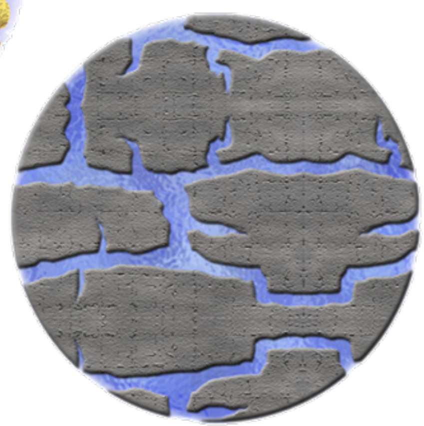
Porous Media



sand / sandstone
easy to characterize
simplest math

Most commonly assumed

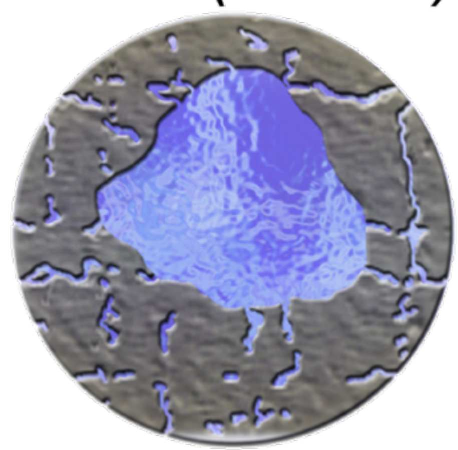
Fractered Rock



hard rocks (shale, granite, etc)
can map from surface
harder to characterize
more difficult math

Most commonly true

Karst (Conduits)



Limestone (Floridan Aquifer)
cannot typically be mapped
hardest to characterize
most difficult math

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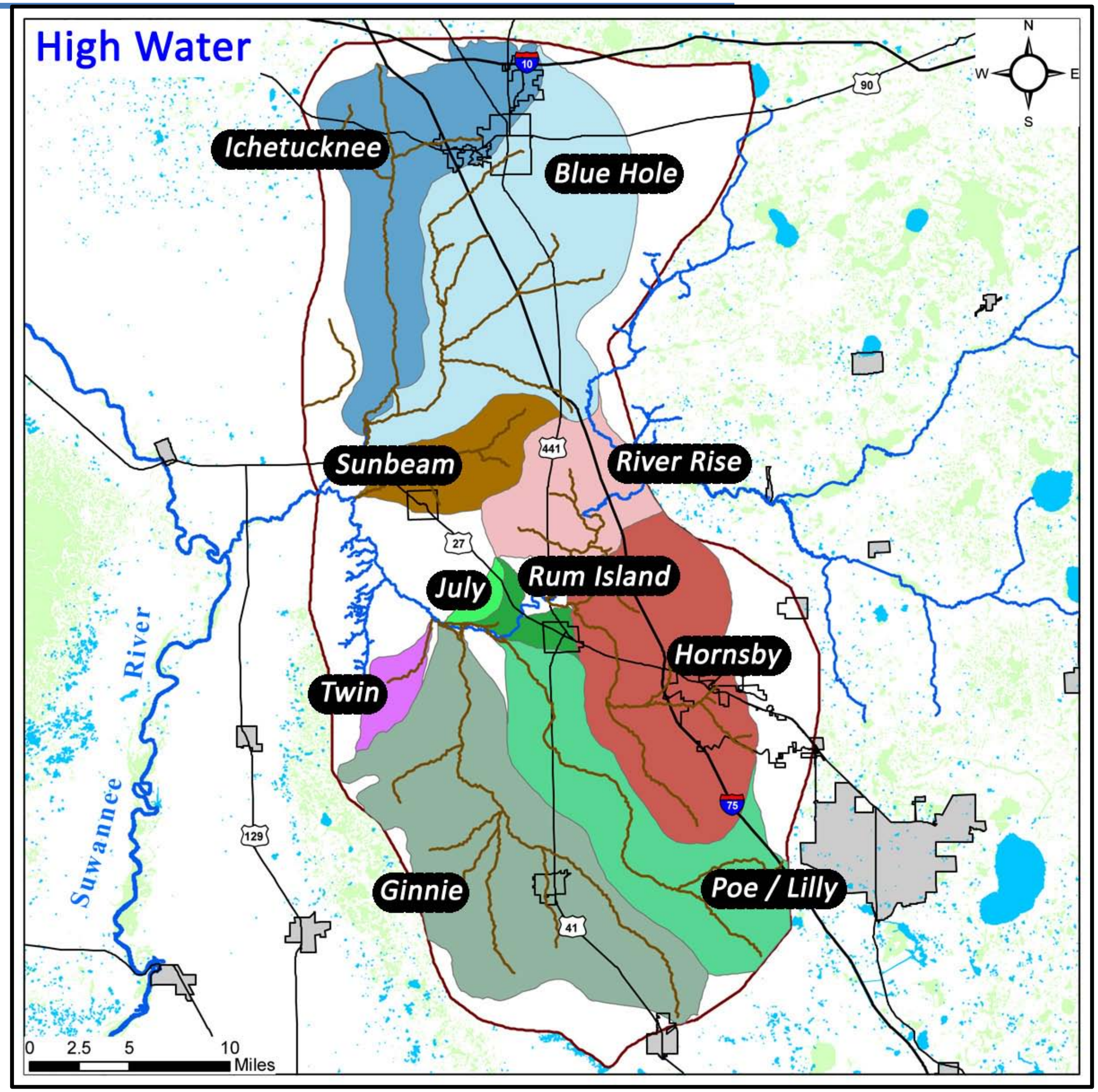
We Can Delineate Reasonable *Springsheds*

- 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



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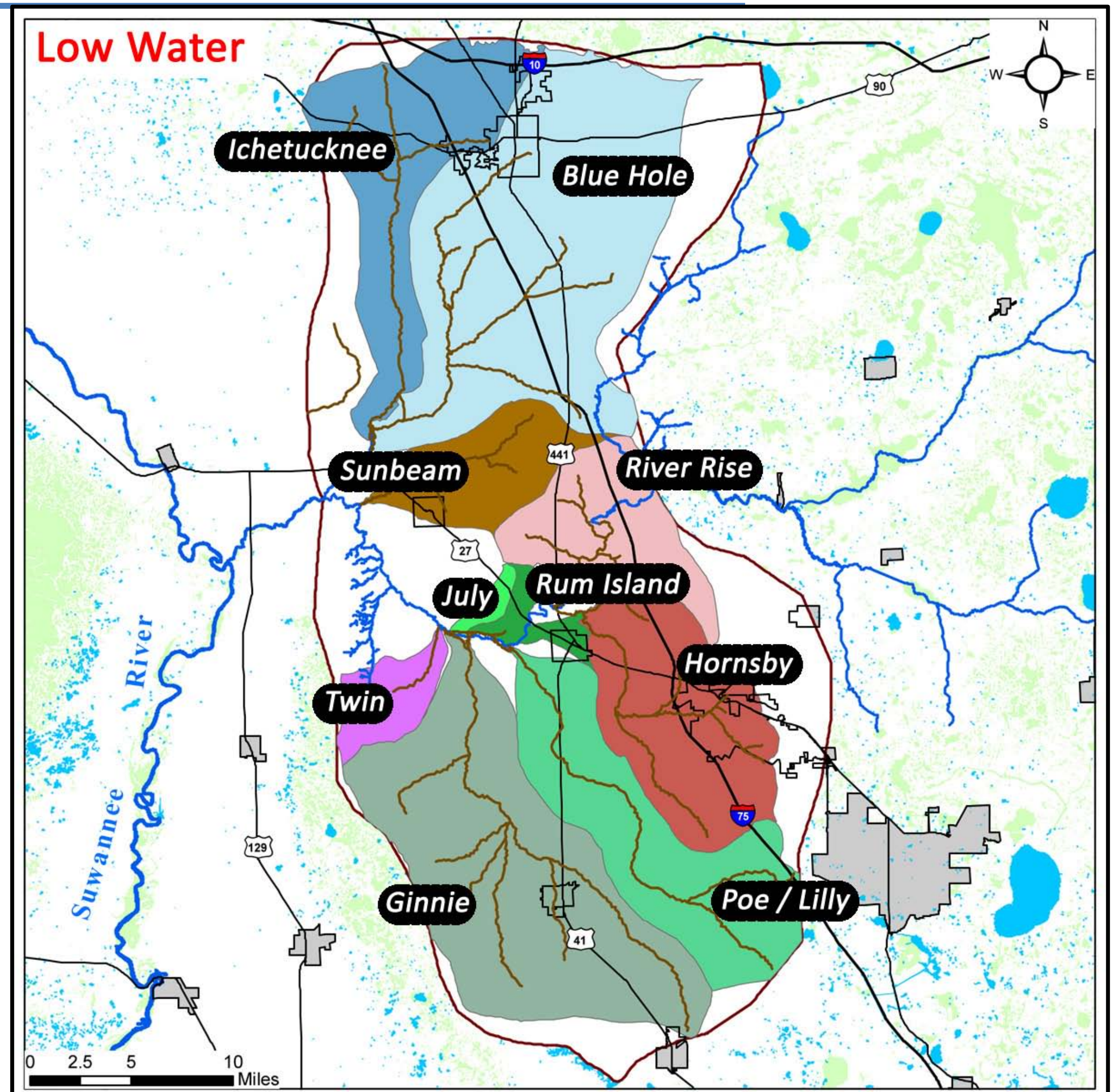

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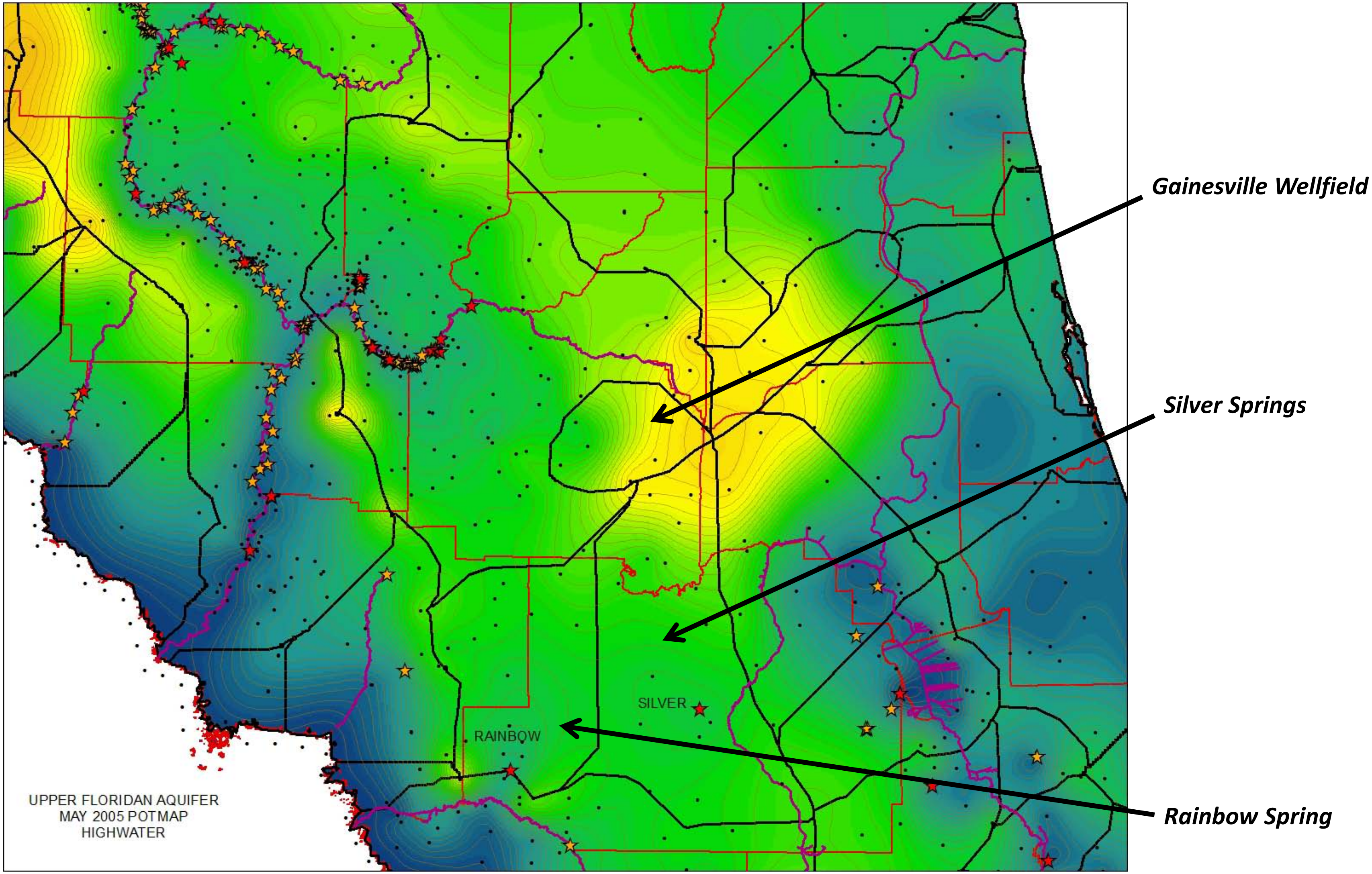
Silver Springs – From Data - 2005



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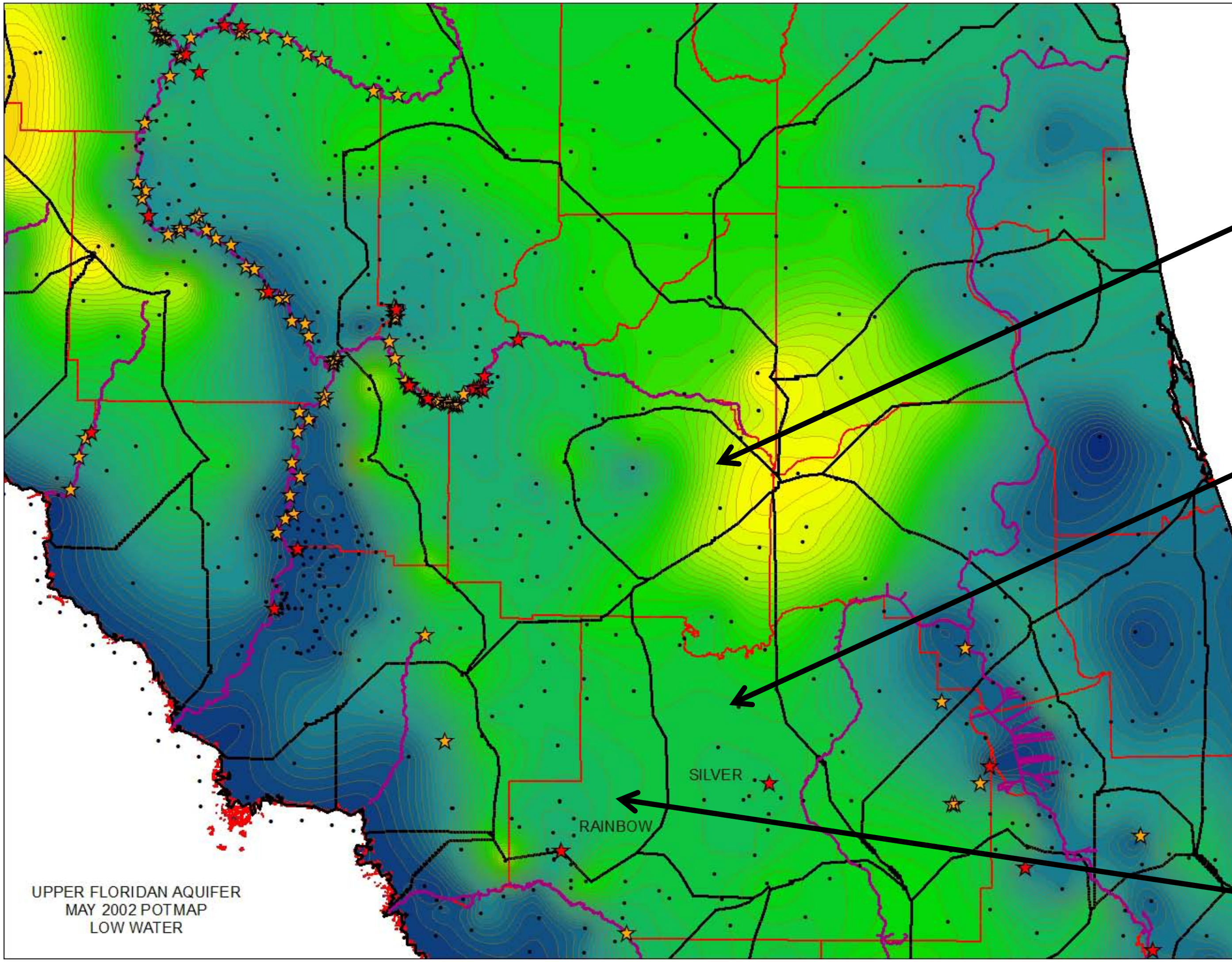
Silver Springs – From Data - 2002



Gainesville Wellfield

Silver Springs

Rainbow Spring

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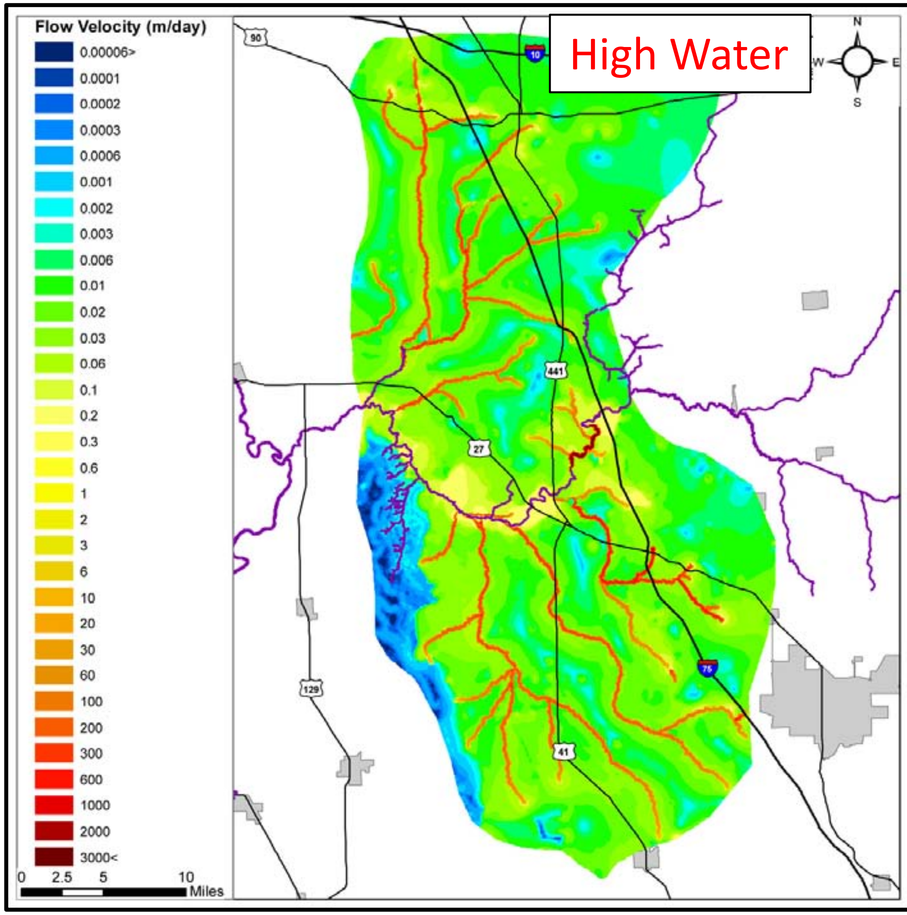
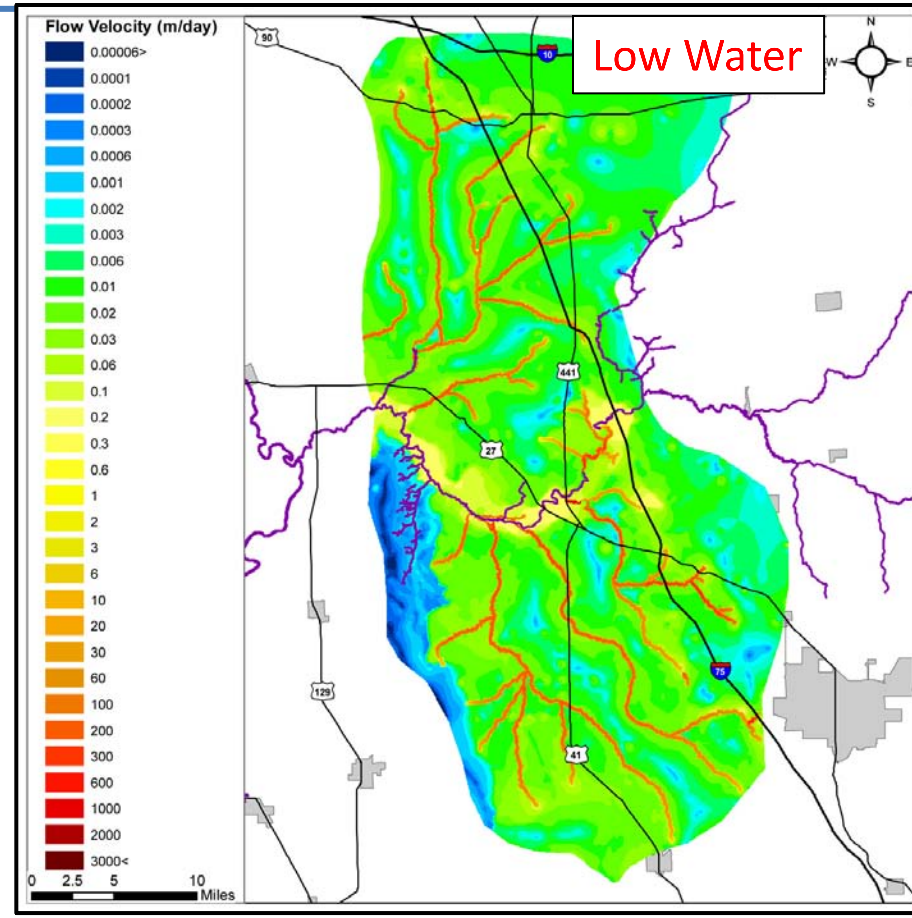
We Can Simulate Reasonable Velocities



- Conduits model: ~ 100 to ~3000 m/day
- Conduits observed: ~ same
- Matrix model: ~ 10^{-3} to 10^{-1} m/day
- Matrix observed: ~ 10^{-6} To 10^{-3} m/day



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Excellent basis for defining vulnerability

GeoHydros
Specialized Geological Modeling

We Can Simulate Travel Times

Flow is to closest conduits

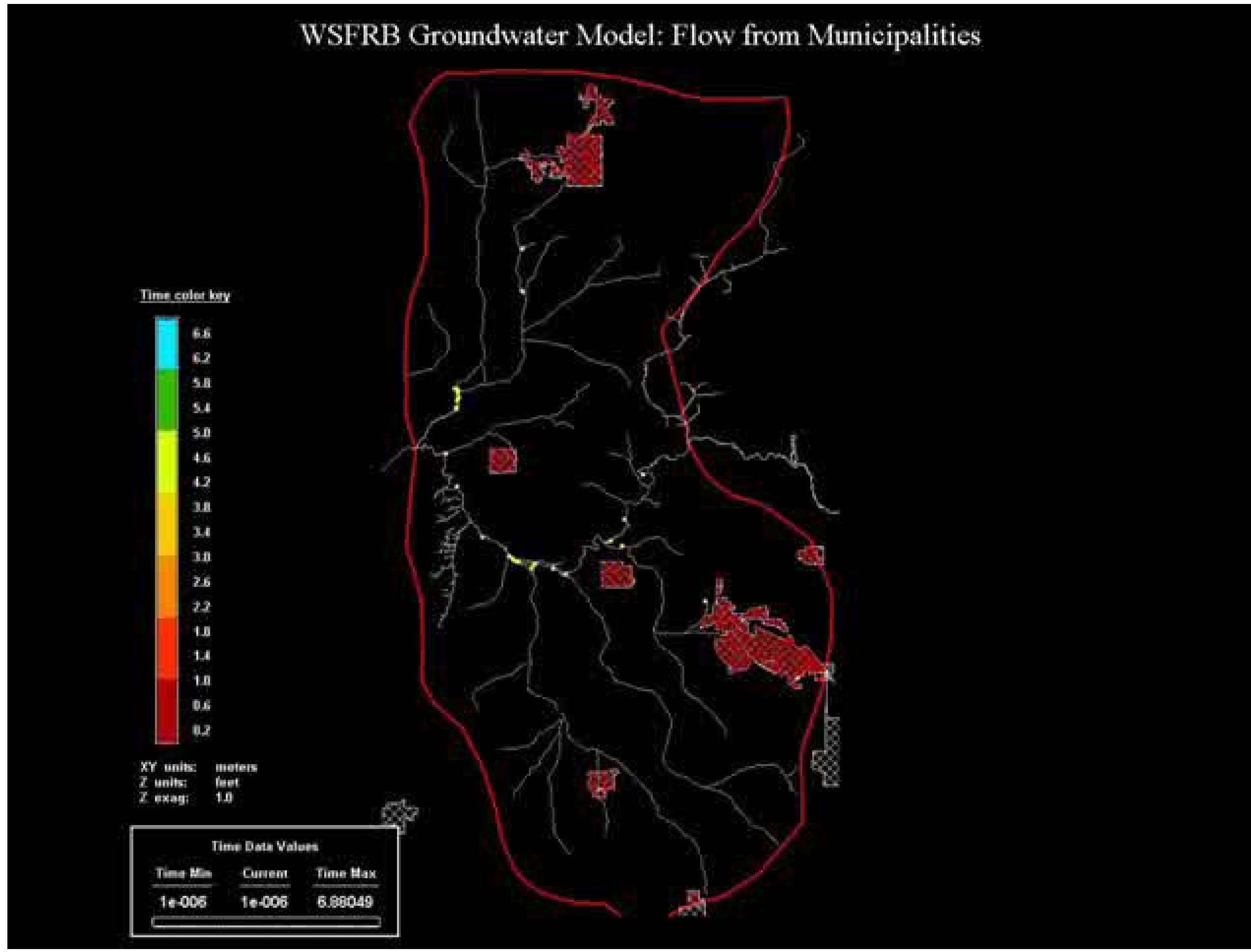
Closest towns not always of most concern

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



Simulating Travel Times - Municipalities

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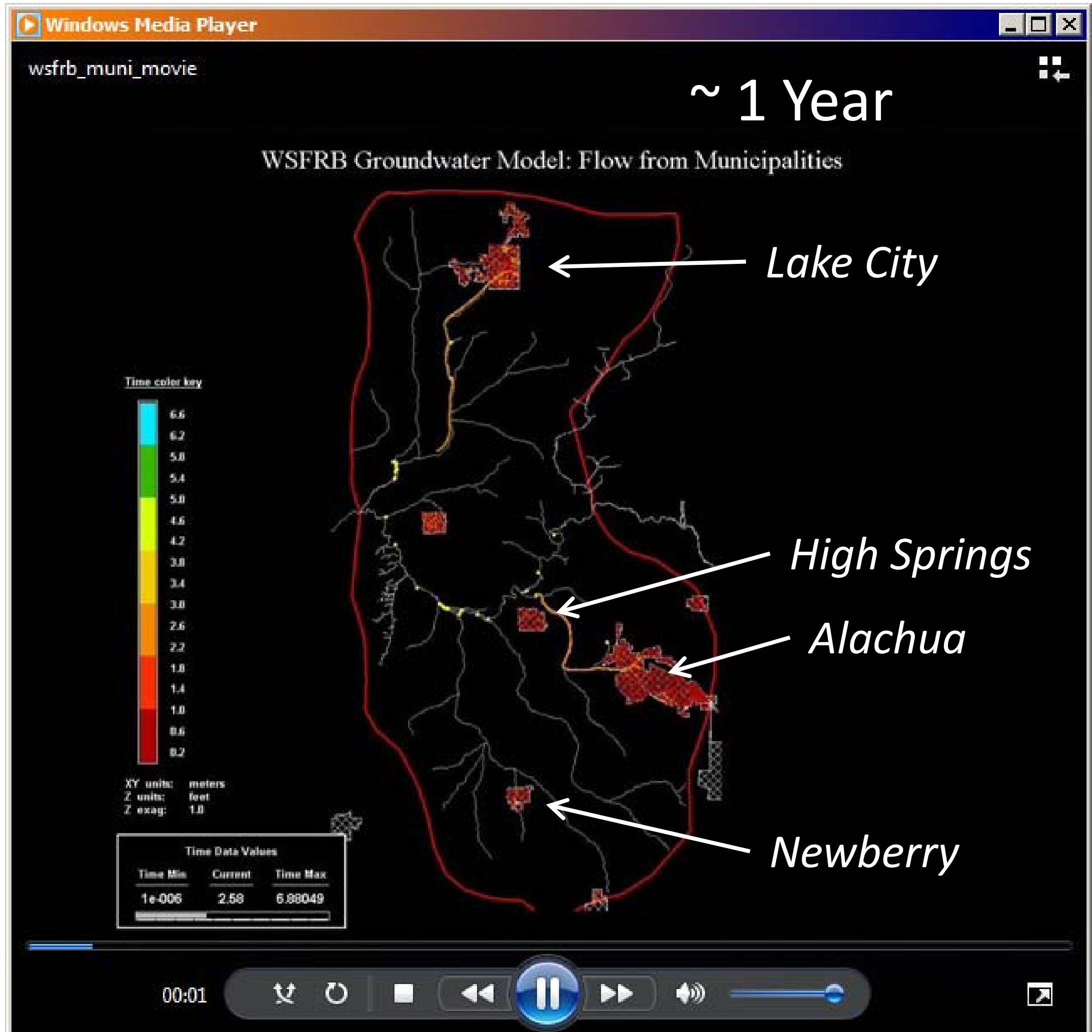

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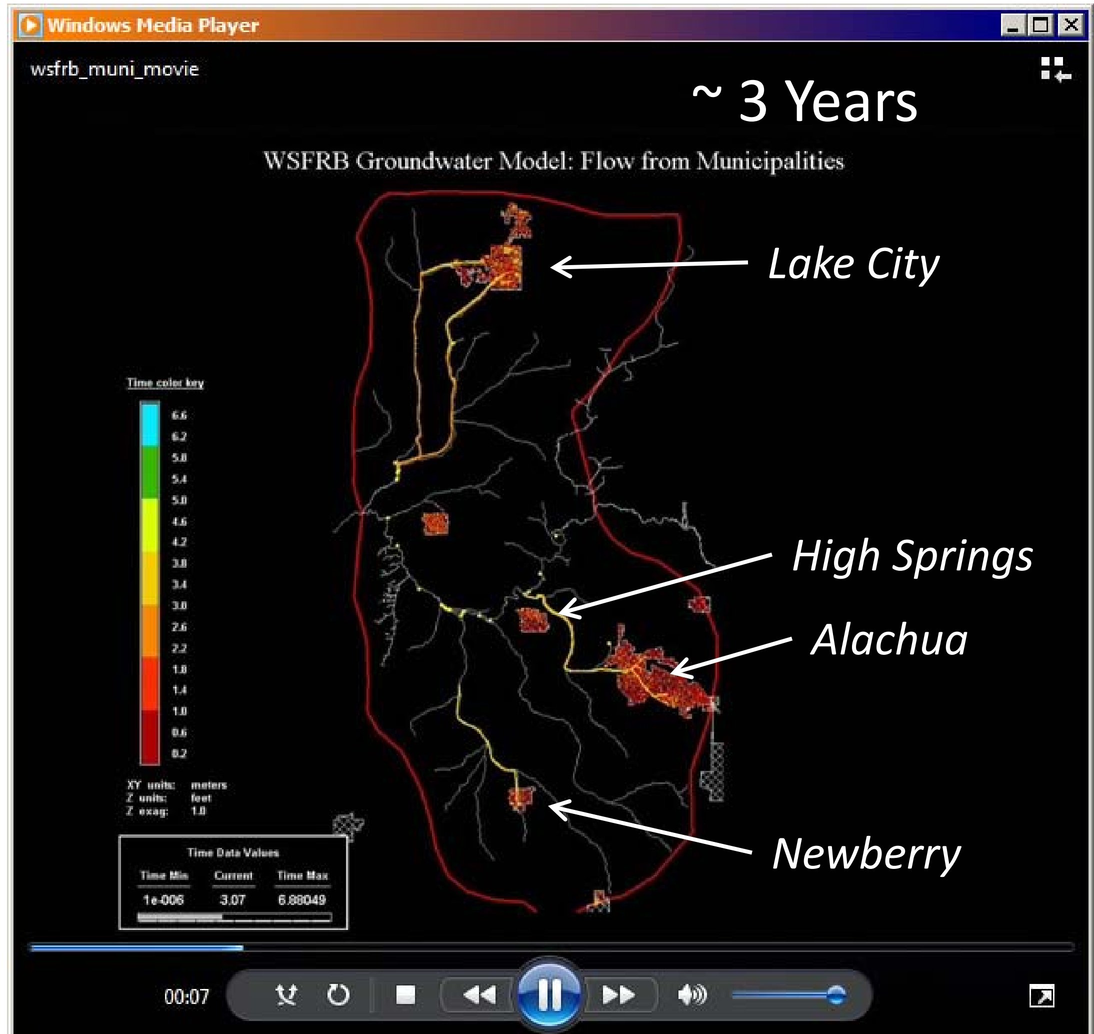

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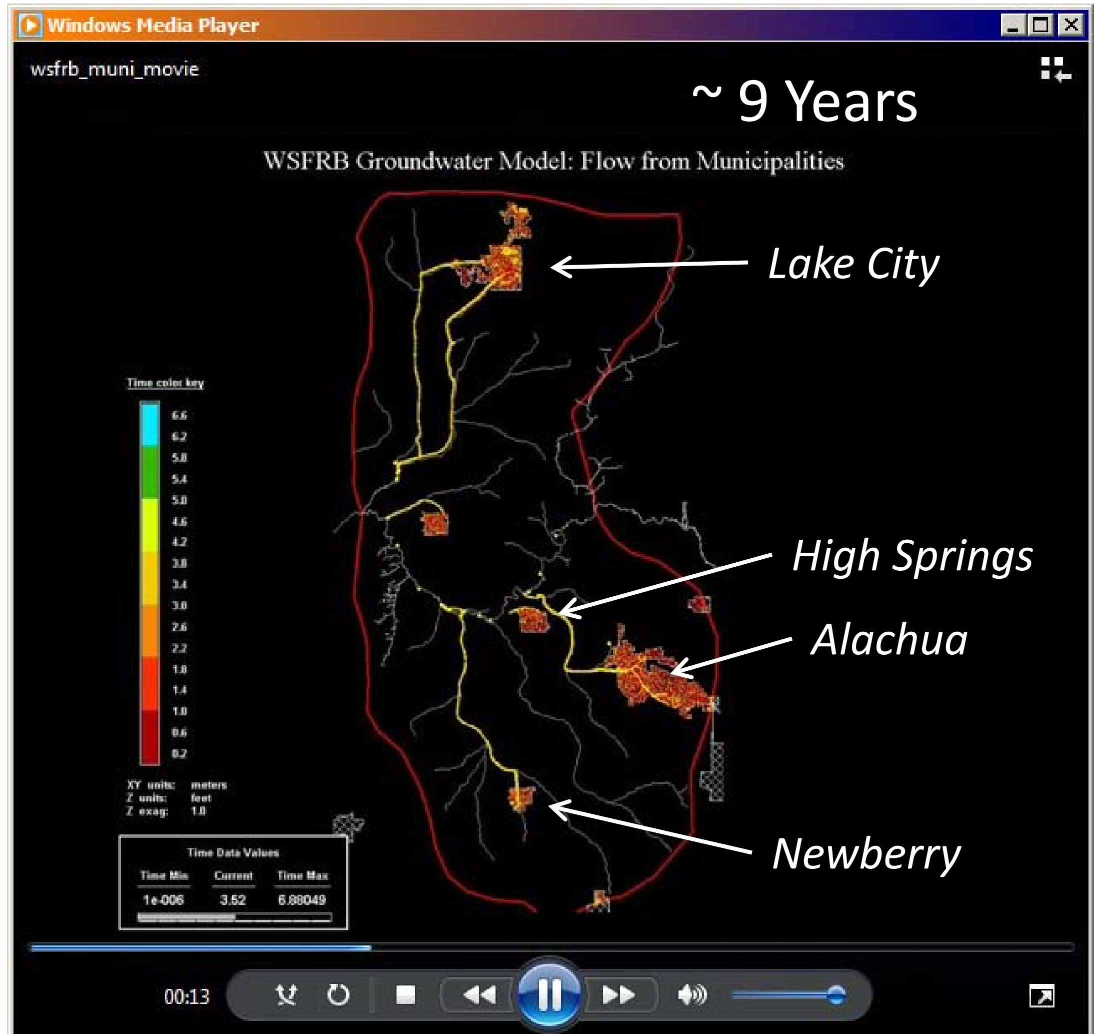

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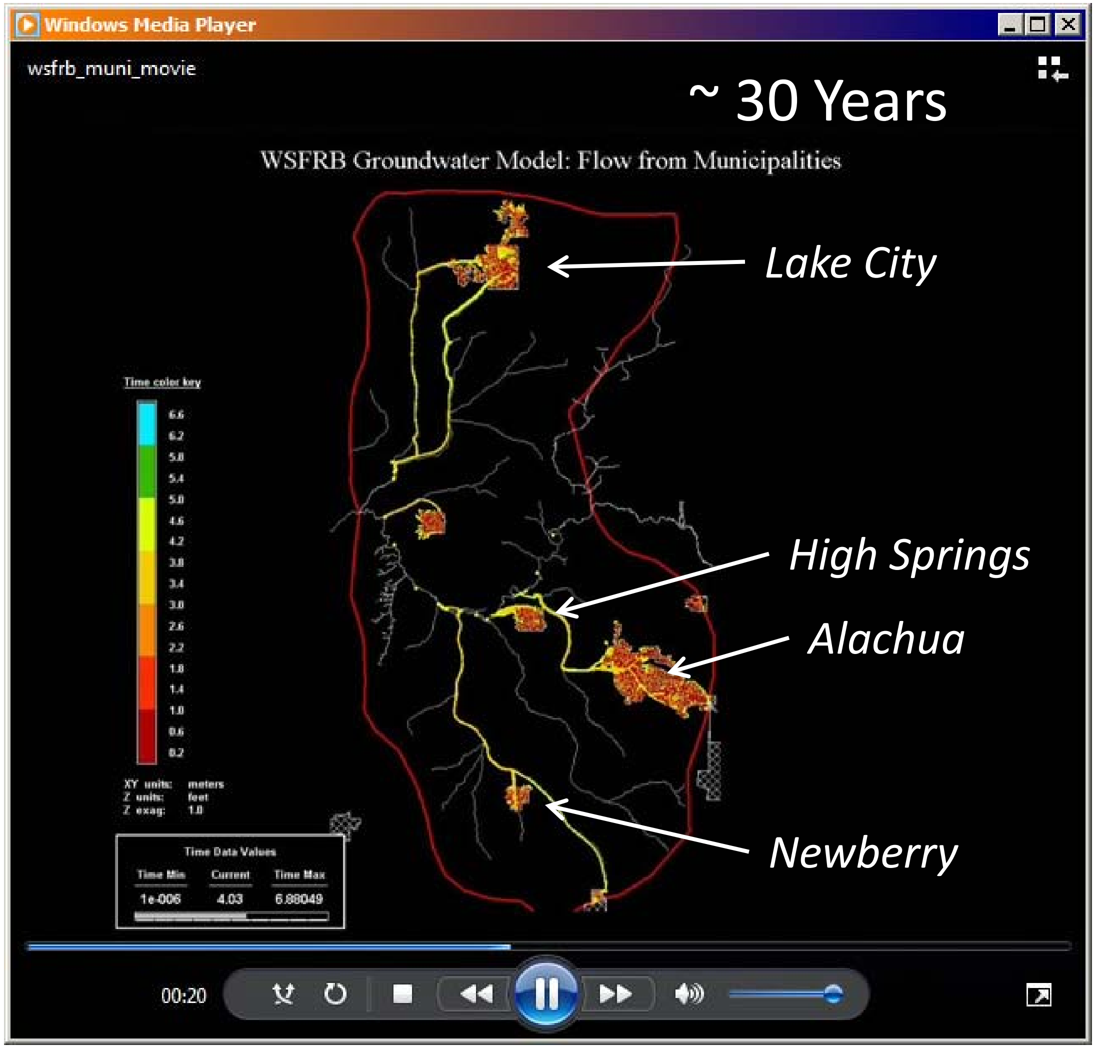

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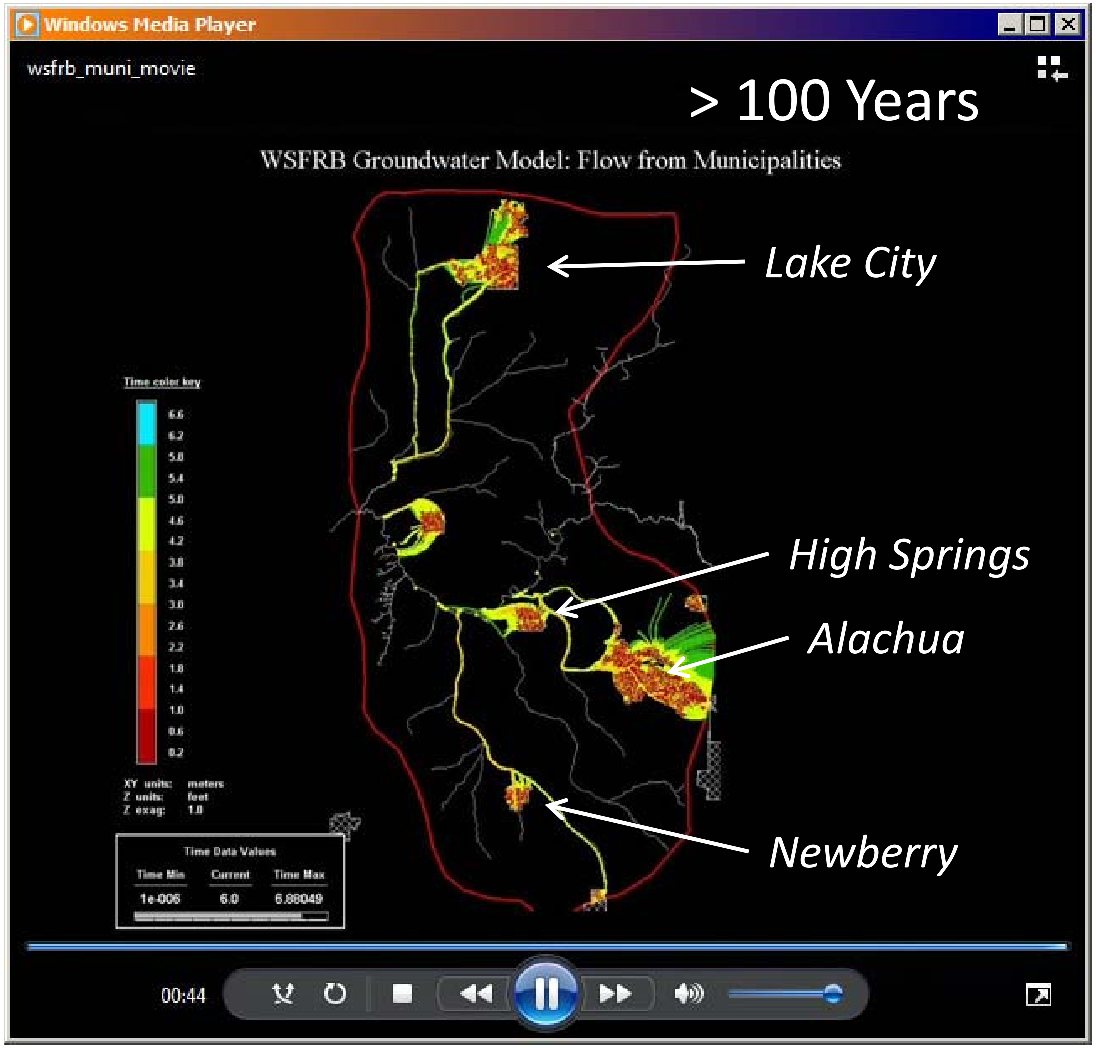

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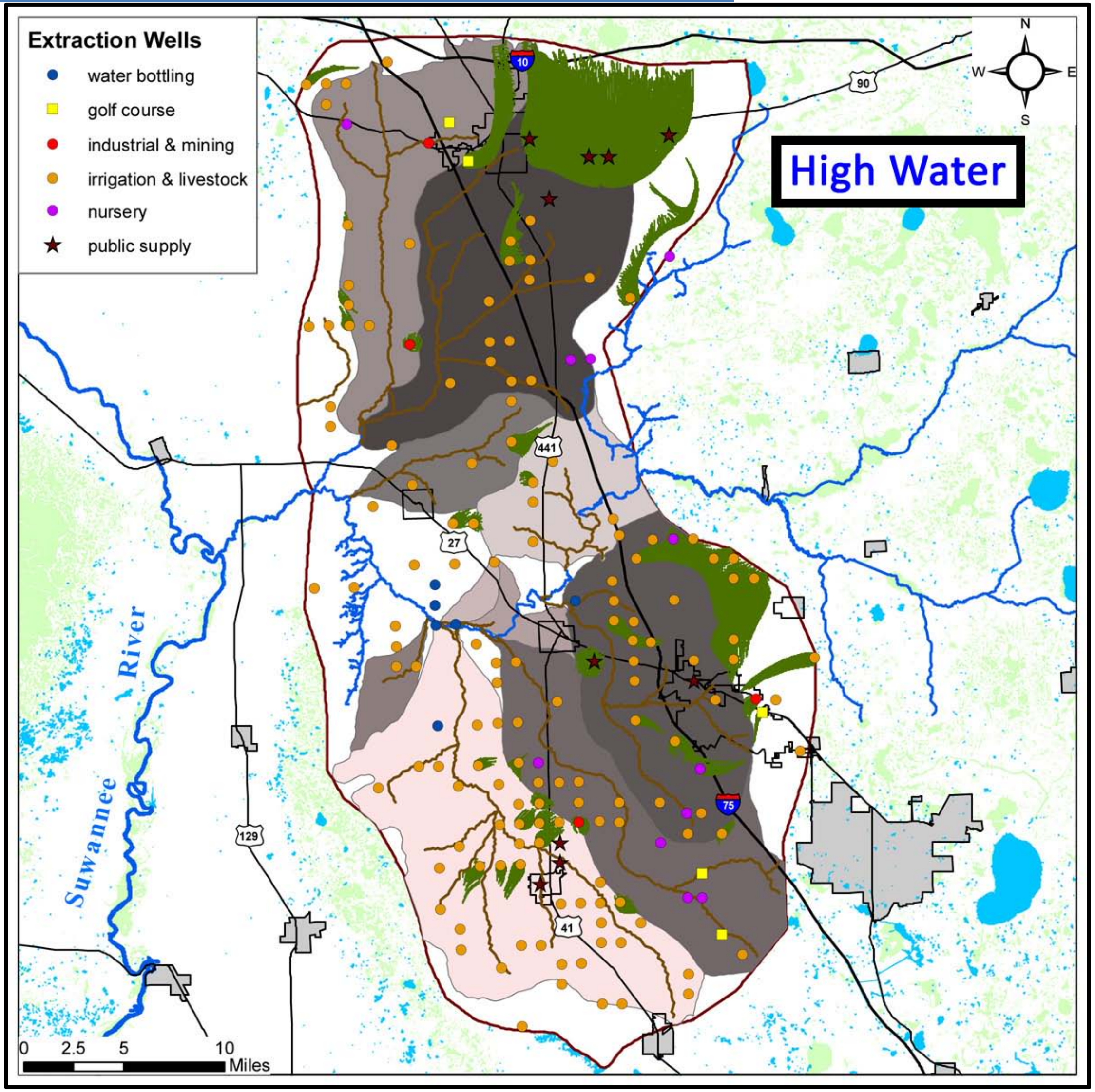
We Can Simulate the Impacts of Pumping

- 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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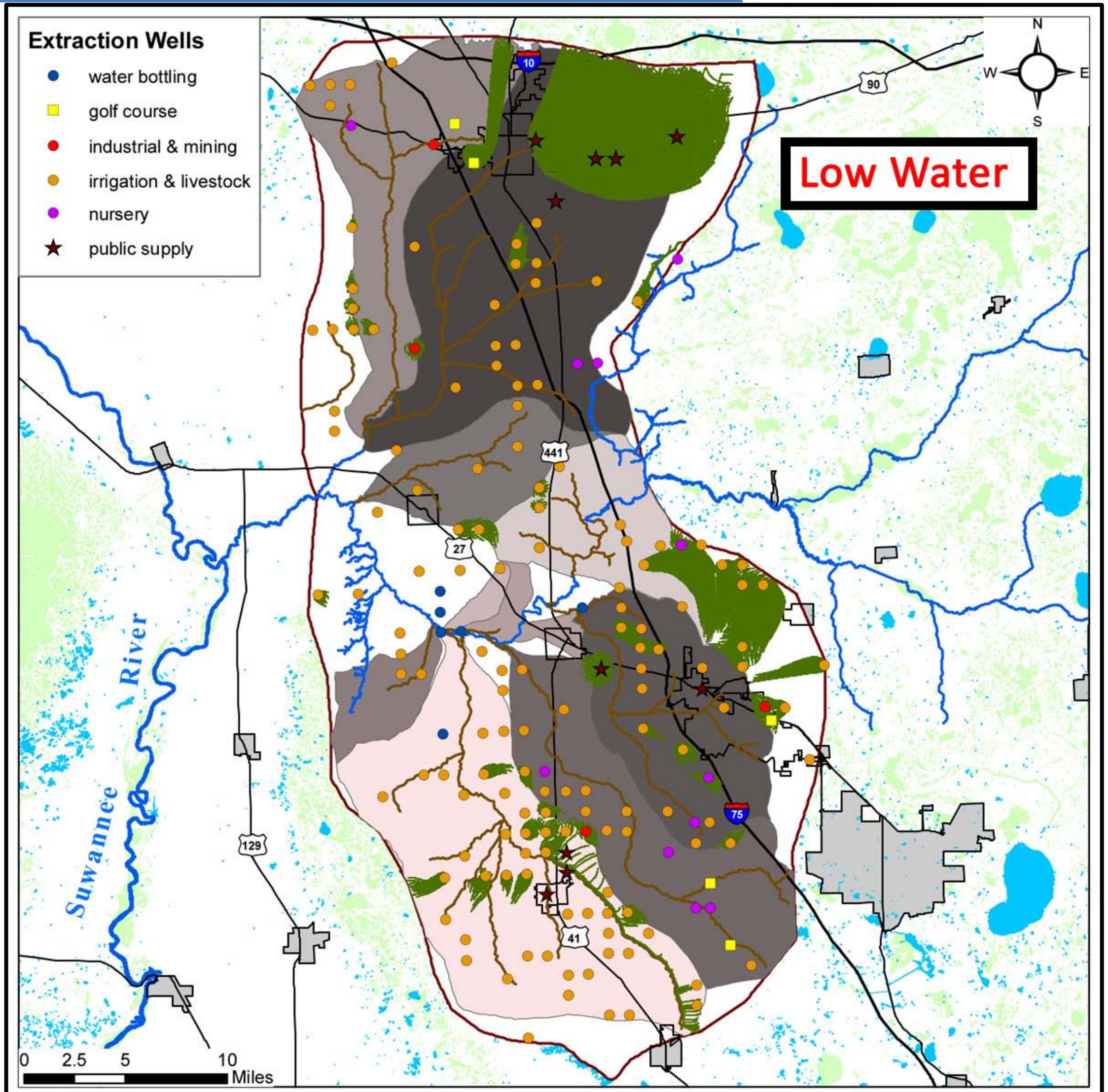

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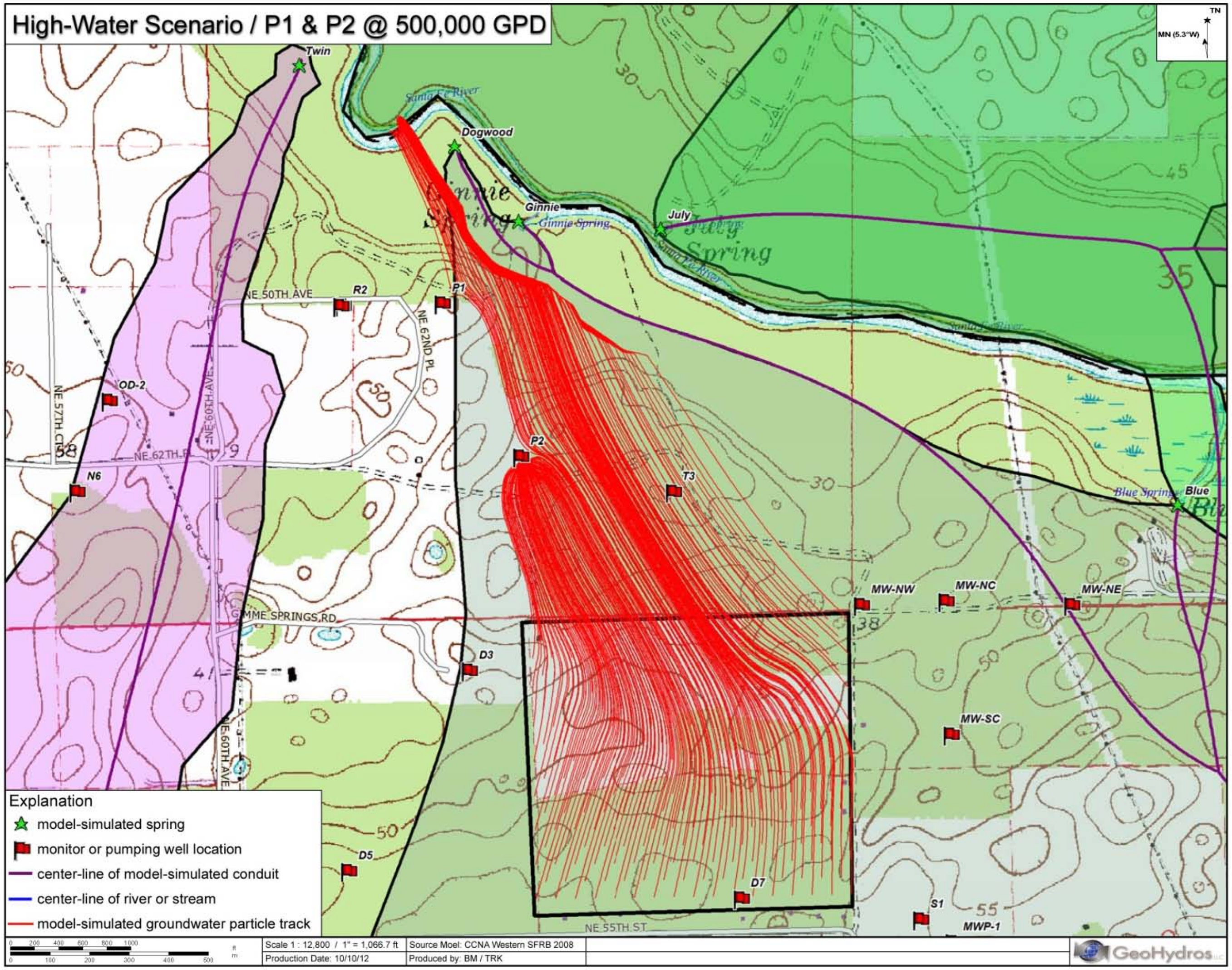
We Can Simulate Impacts of Land Use



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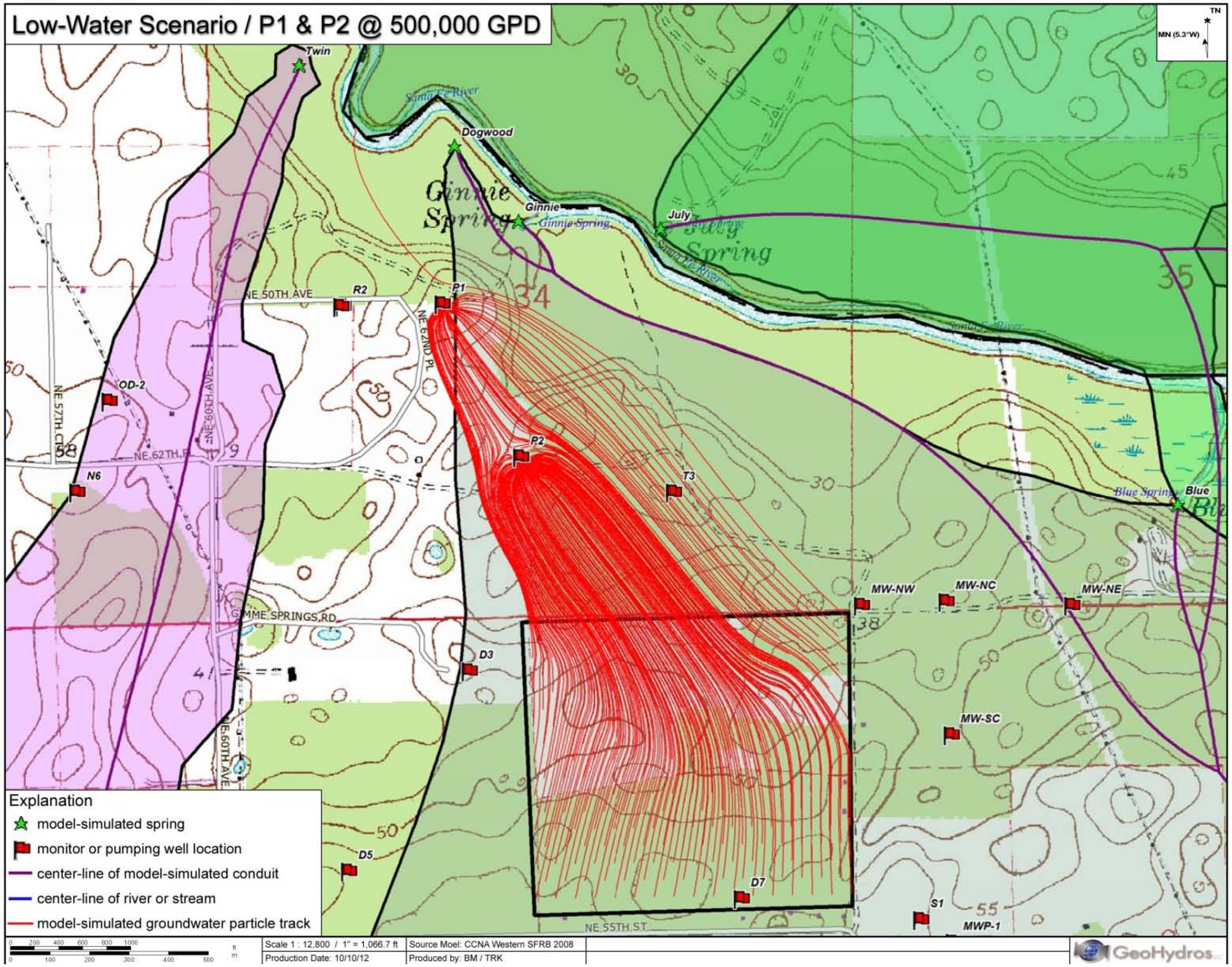

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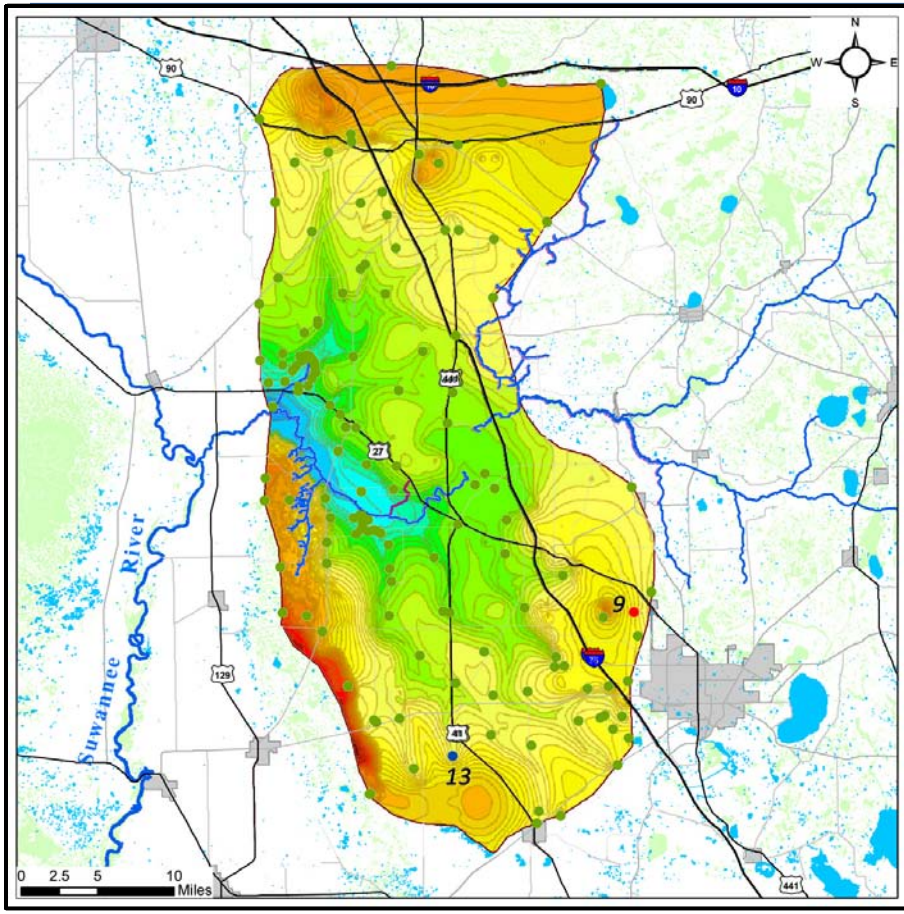
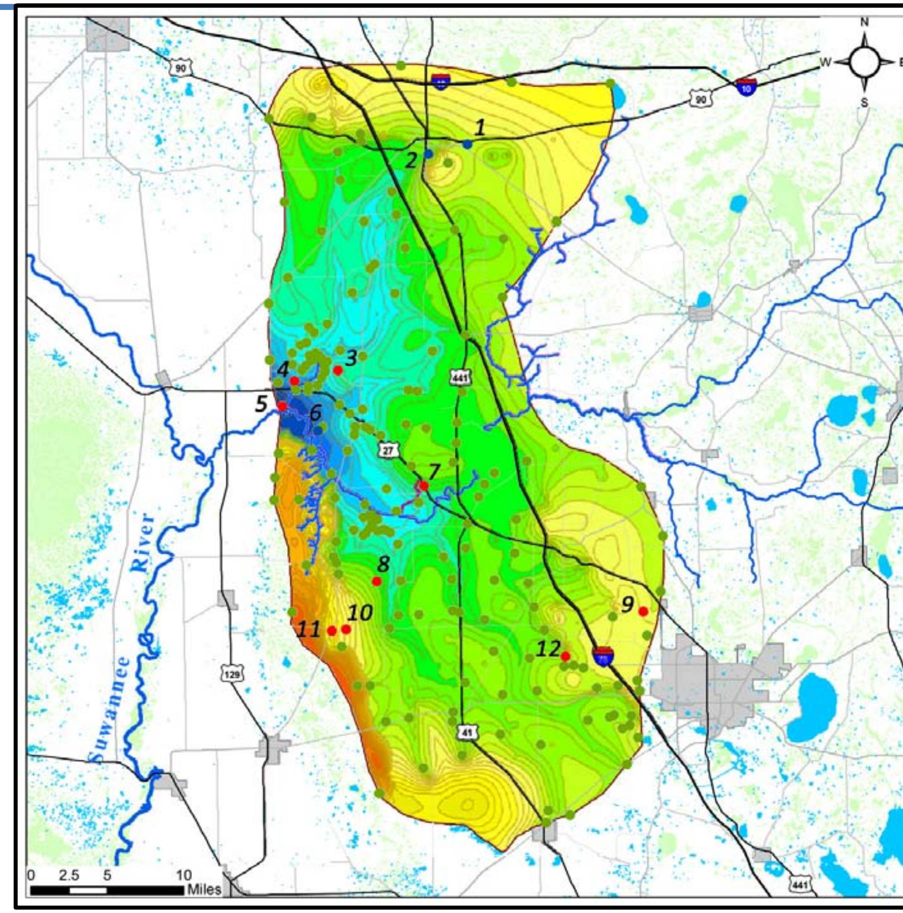
To Do This – *We Must Use a Higher Standard*



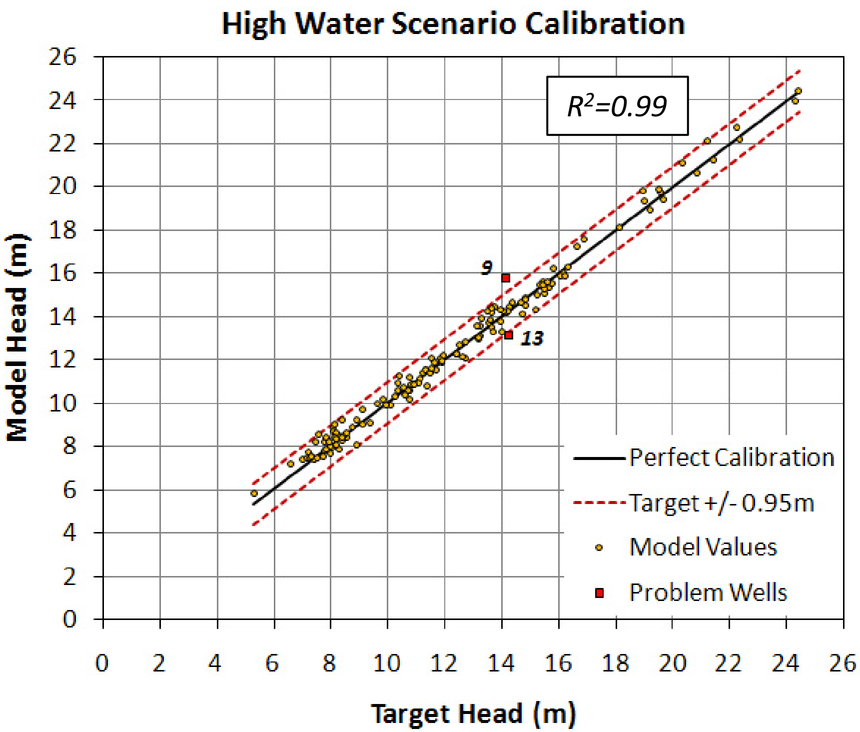


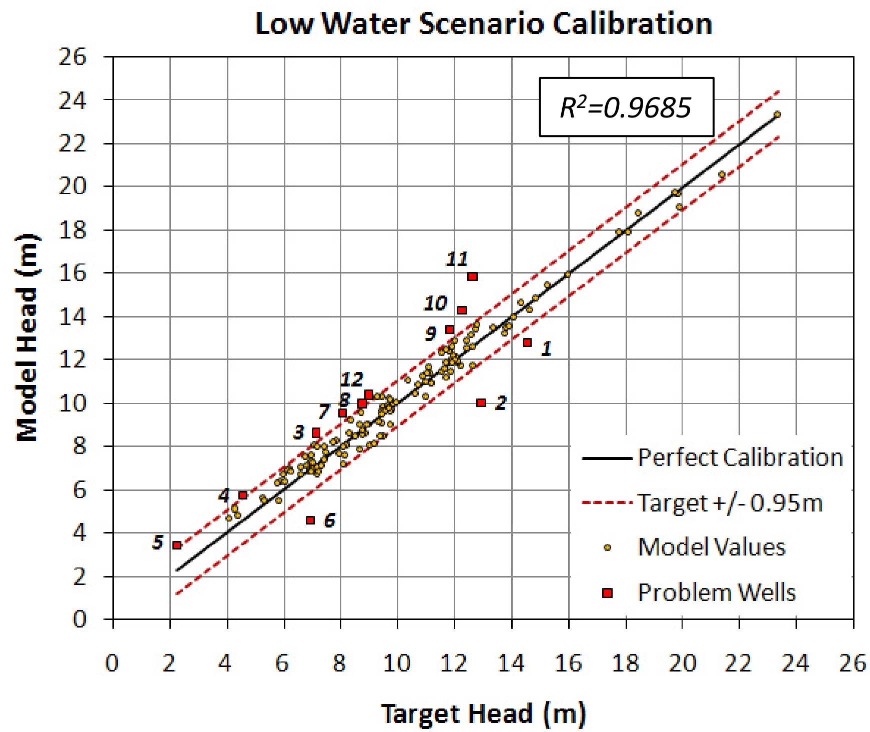
Green = calibrated (Red = high / Blue = low)

- High water: 143/145 wells calibrated
- 1998/1999; 2004/2005
- +/- 0.95 m (~3 ft)

- Low water: 176/188 wells calibrated
- 2001/2002; 2007
- +/- 1.05 m (~3ft)

To Do This – *We Must Make Better Use of Data*





- Plots show how well the model simulates known groundwater levels.
- Perfect match would be the black line.
- All points within the red dashed lines are “calibrated.”
- Could not achieve this good of a match if it were not for including the conduits.
- Even the points that fall outside the red lines are close to target levels.
- Additional small adjustments to the conduit locations could probably get all points within range.
- Those adjustments will not significantly impact the model predictions.

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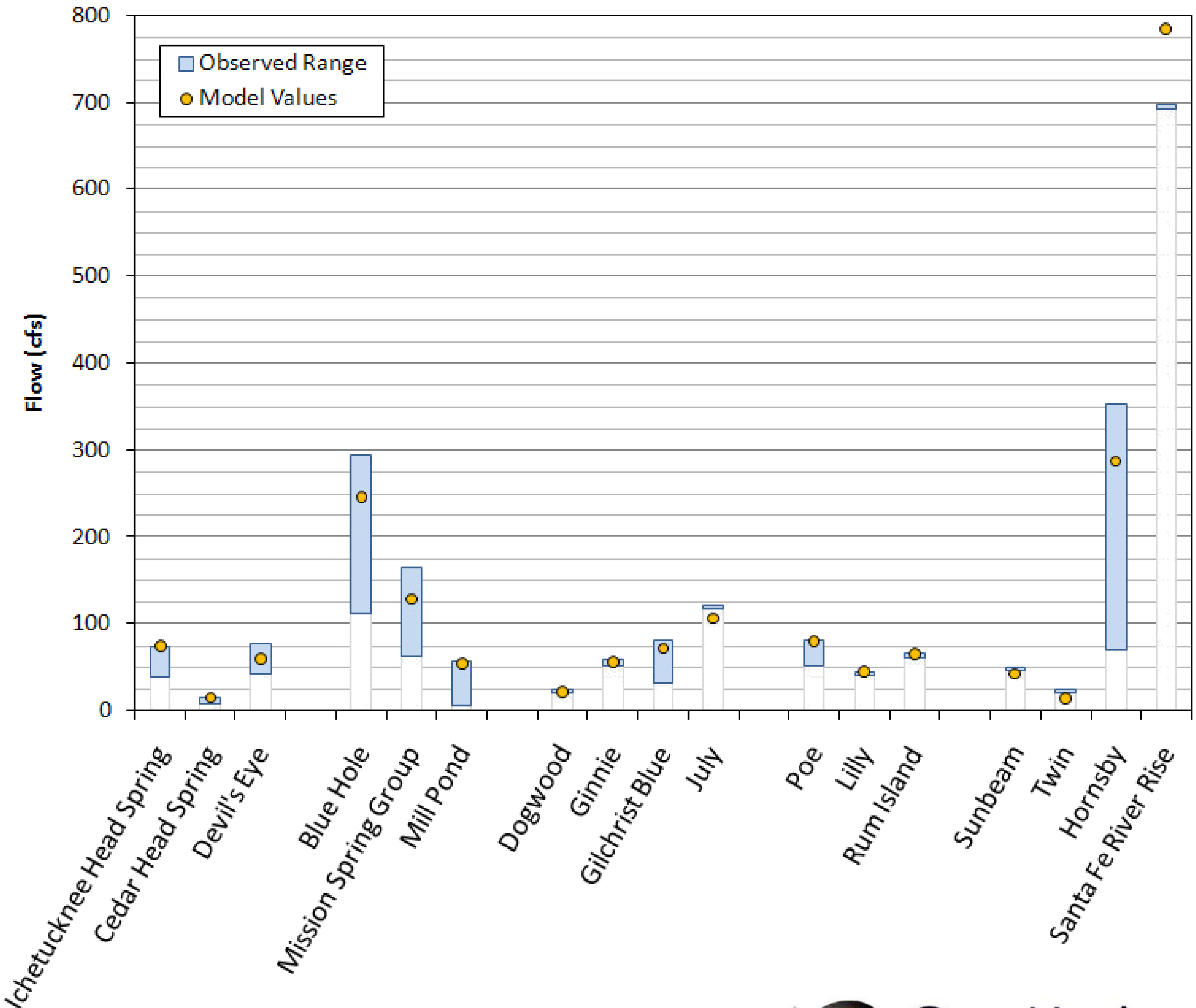
To Do This – *We Must Calibrate to Spring Flows*

<u>*High Water Simulation*</u>

- Data for 17 springs
- Model within observed range at 13
- Model very close at 3
- Over estimated Santa Fe River Rise
- Does not impact groundwater flow because the conduit is mostly surface water



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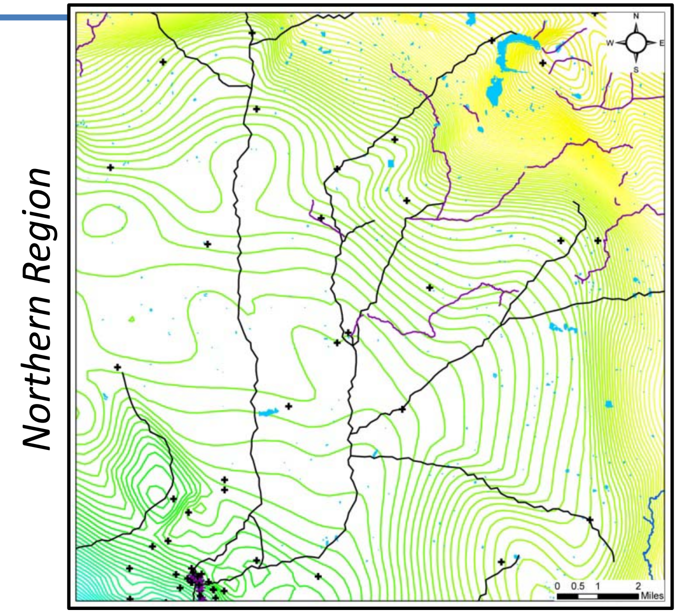
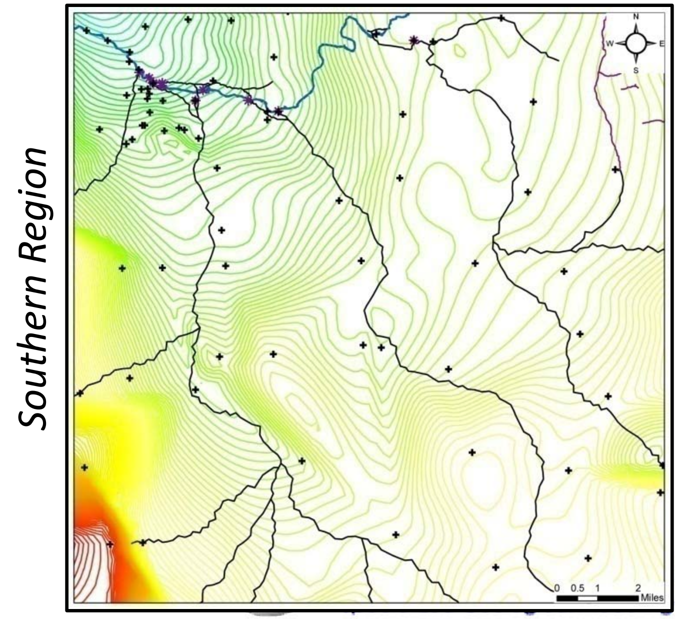
To Do This – *We Must Simulate Conduits*

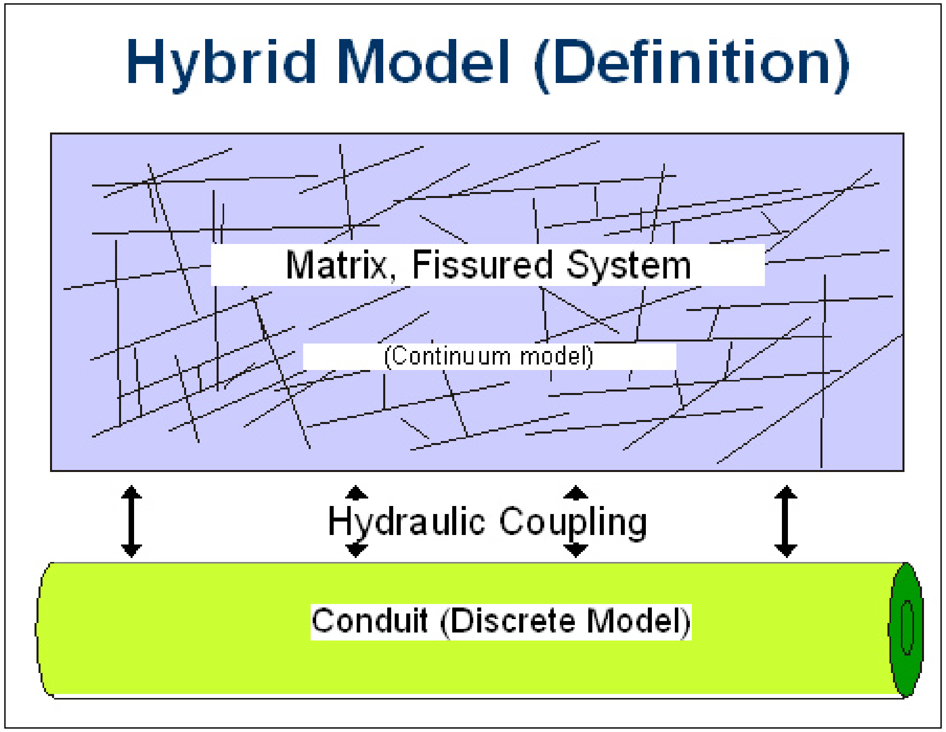
- What we know…
  - Conduits convey water rapidly to springs
  - Groundwater surface around conduits is depressed
  - Groundwater surface in sand would be smooth
  - Groundwater surface has troughs & ridges in the SFRB
  - The rocks are fairly similar across the region
- Assumptions …
  - Complexity in groundwater surface is due to conduits
  - Conduits follow troughs in the groundwater surface
- Step-1: Assign conduits to known locations
  - Mapped caves / Tracer defined pathways
- Step-2: Assign conduits along troughs
  - Between known connected points
  - Up-gradient from springs
  - Down-gradient from swallets
  - To unexplained closed depressions
- Step 3: Modify conduits to match data
  - Simplest possible pattern (low water conditions)
  - Dimensions set to carry necessary water to springs (high water conditions)





To Do This – *We Must Use Better Tools*

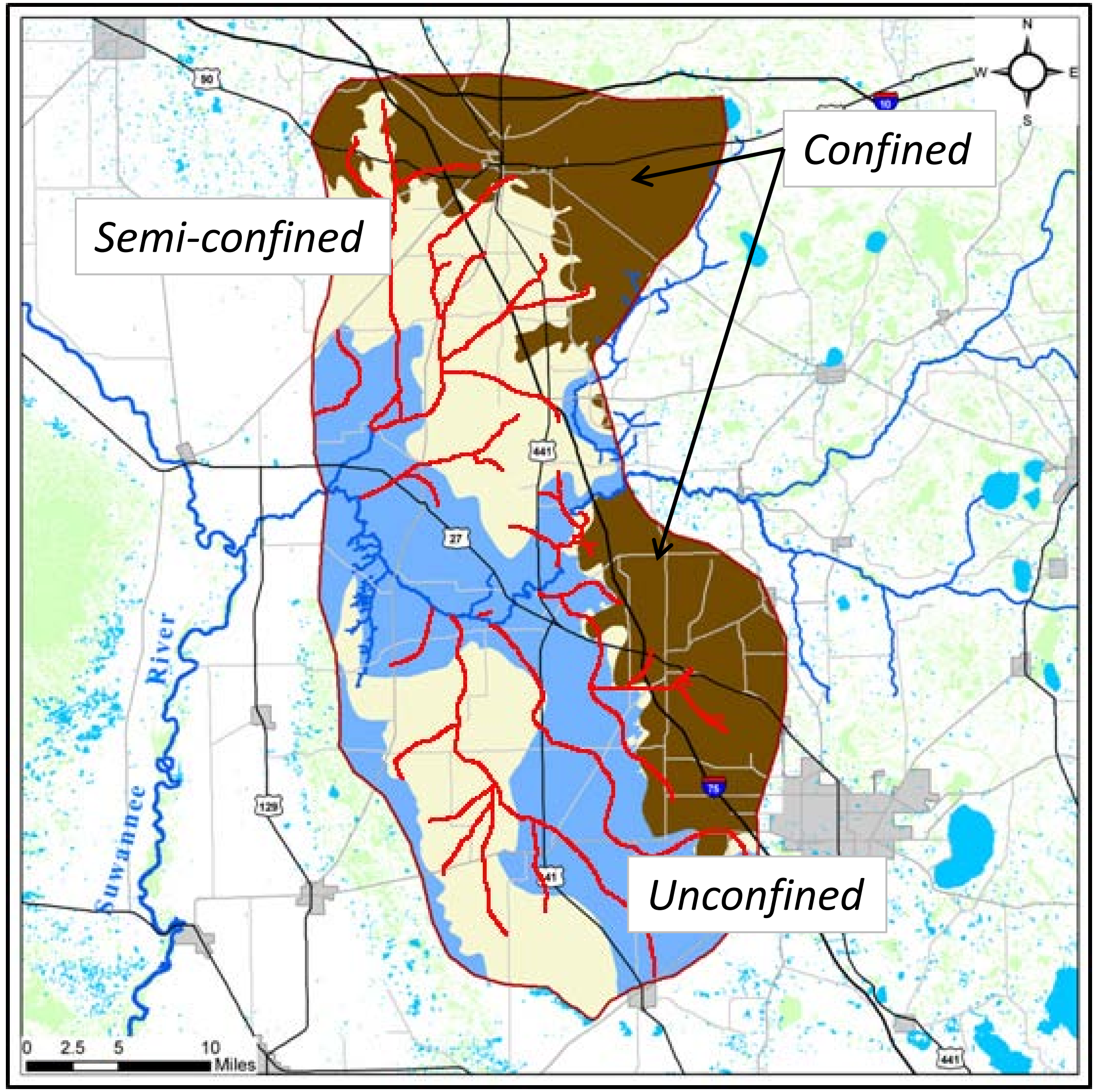
- Hybrid Model (Dual Permeability)
  - Continuum model for matrix
    porous media > Darcy flow
  - Discrete model for conduits
    Pipe flow
  - Flow can exchange between the two media
- Finite-element formulation
  - Maximum flexibility for geometric design
  - Computational efficiency
    more model runs = higher confidence
- FEFLOW™
  - Commercially available (DHI-WASY)
  - Commonly used by national laboratories & research institutions.
  - Discrete element features allow for hybrid model design.



http://www.feflow.info/

To Do This – The Model Geology Must be Reasonable

- Compilation of map delineations and unit thicknesses from borehole logs.
- Confining unit
  - Clay K
  - Overlain by surficial aquifer with sand K
- Semi-confining unit
  - Mixed silt & clay K
  - Overlain by surficial aquifer with sand K
- Unconfined
  - Normal limestone K
  - Surficial aquifer merges with FAS



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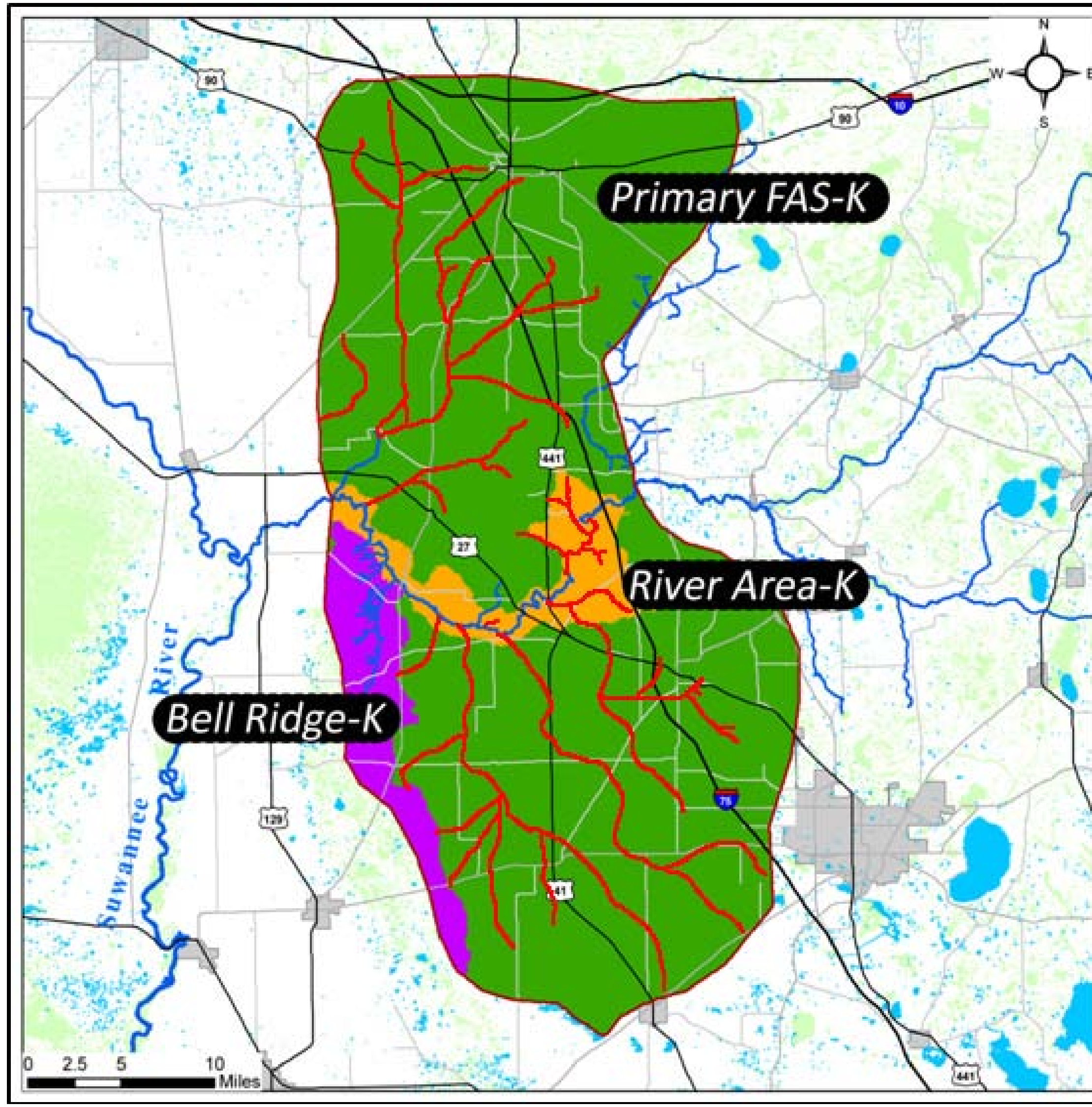
To Do This – The Model Geology Must be Reasonable

- Primary FAS
  - Relatively high K
  - Similar to high end of range for medium to fine sand.
  - K = 57 ft/day
- FAS under Bell Ridge
  - 2 orders of magnitude lower K
  - Similar to low end of range for fine sand with considerable silt.
  - K = 0.57 ft/day
- FAS near river
  - Developed a buffer around known caves to establish a high K zone near the river.
  - More fracturing and caves
  - K = 1133 ft/day



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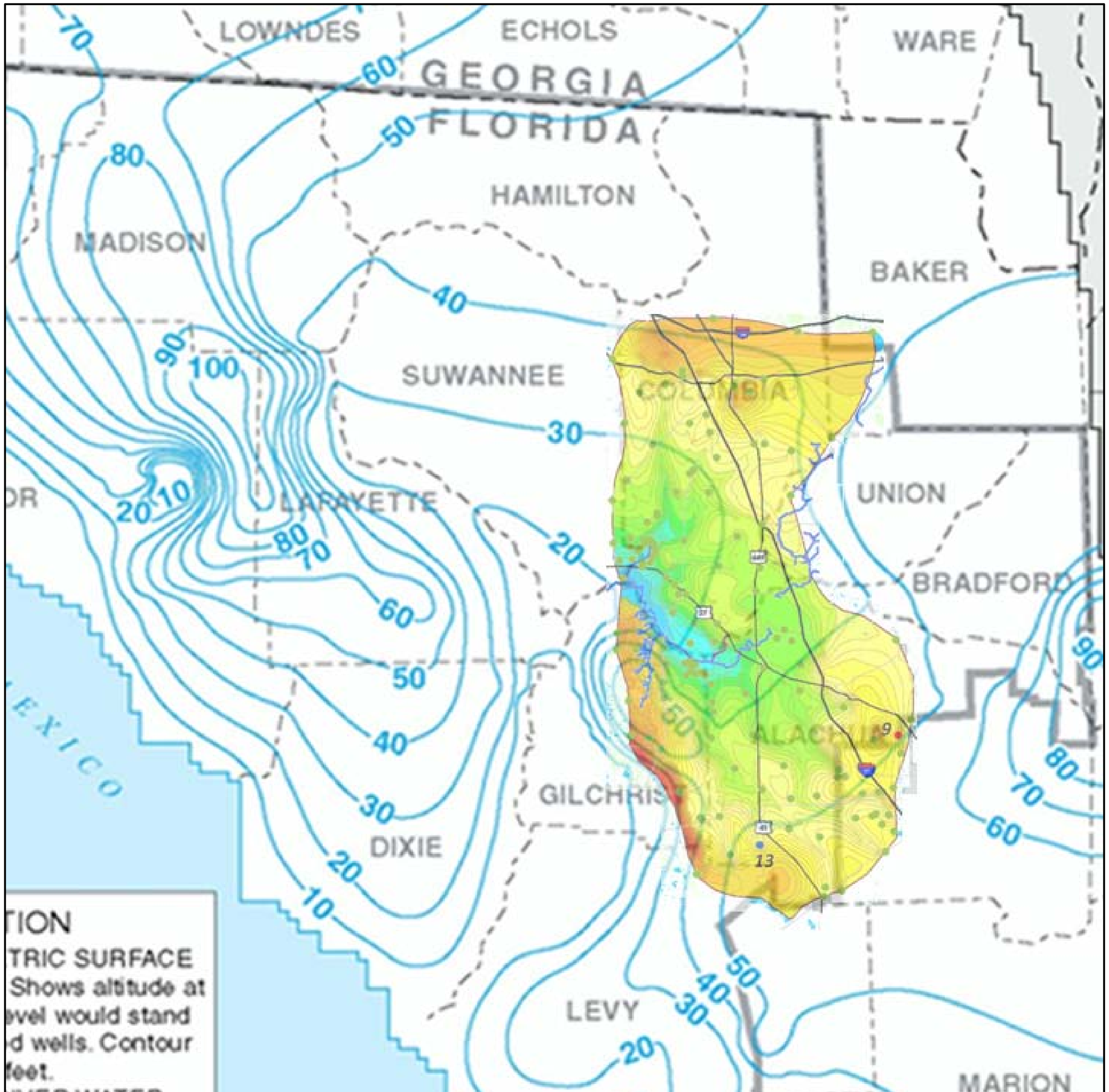
It Makes A Difference



- Much smaller basin
- Smaller water resource

- *Reasonable springsheds*
- *Reasonable velocities*
- *Reasonable water level scenarios*
- *Reasonable impact assessments*
- *Contaminant transport*

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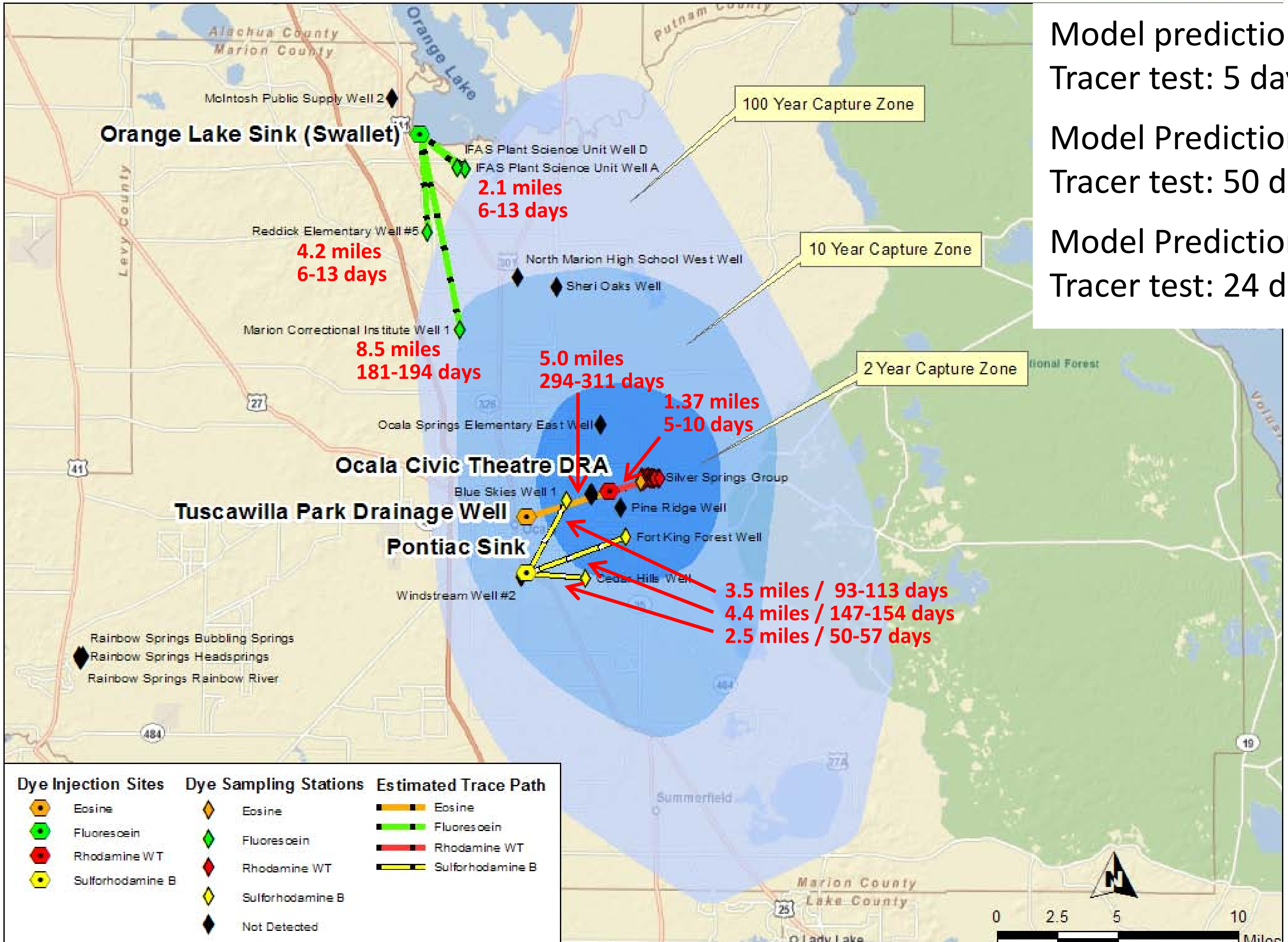
It Makes a Difference



Model prediction: 2 years
Tracer test: 5 days – 10.5 months

Model Prediction: 10 years
Tracer test: 50 days – 10.5 months

Model Prediction: 100 years
Tracer test: 24 days – 12.5 months

Courtesy Karst Environmental Services

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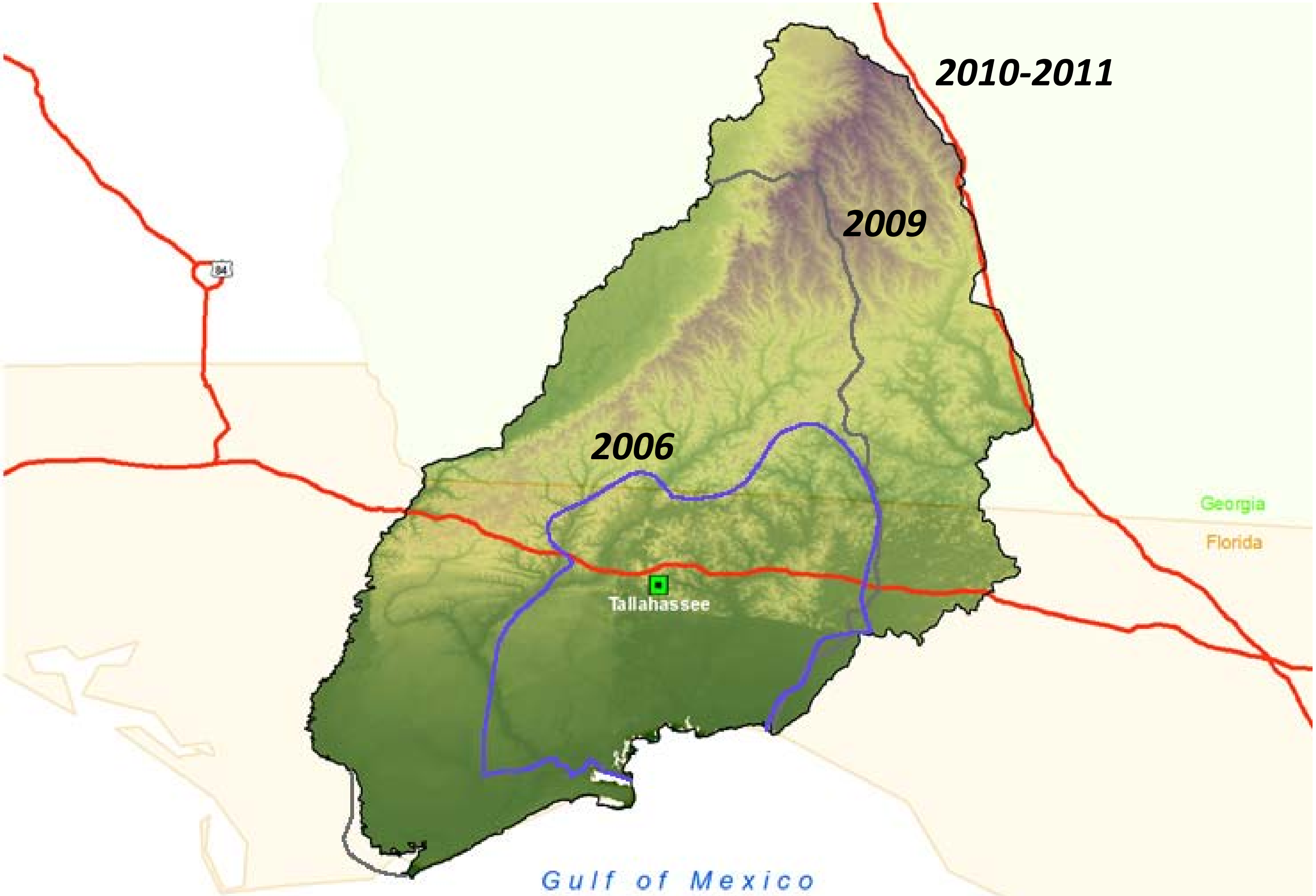
Section – 3
The North Florida Hybrid Karst Model

WAKULLA-SPRING CREEK-ST MARKS-WACISSA SPRINGSHEDS MODEL



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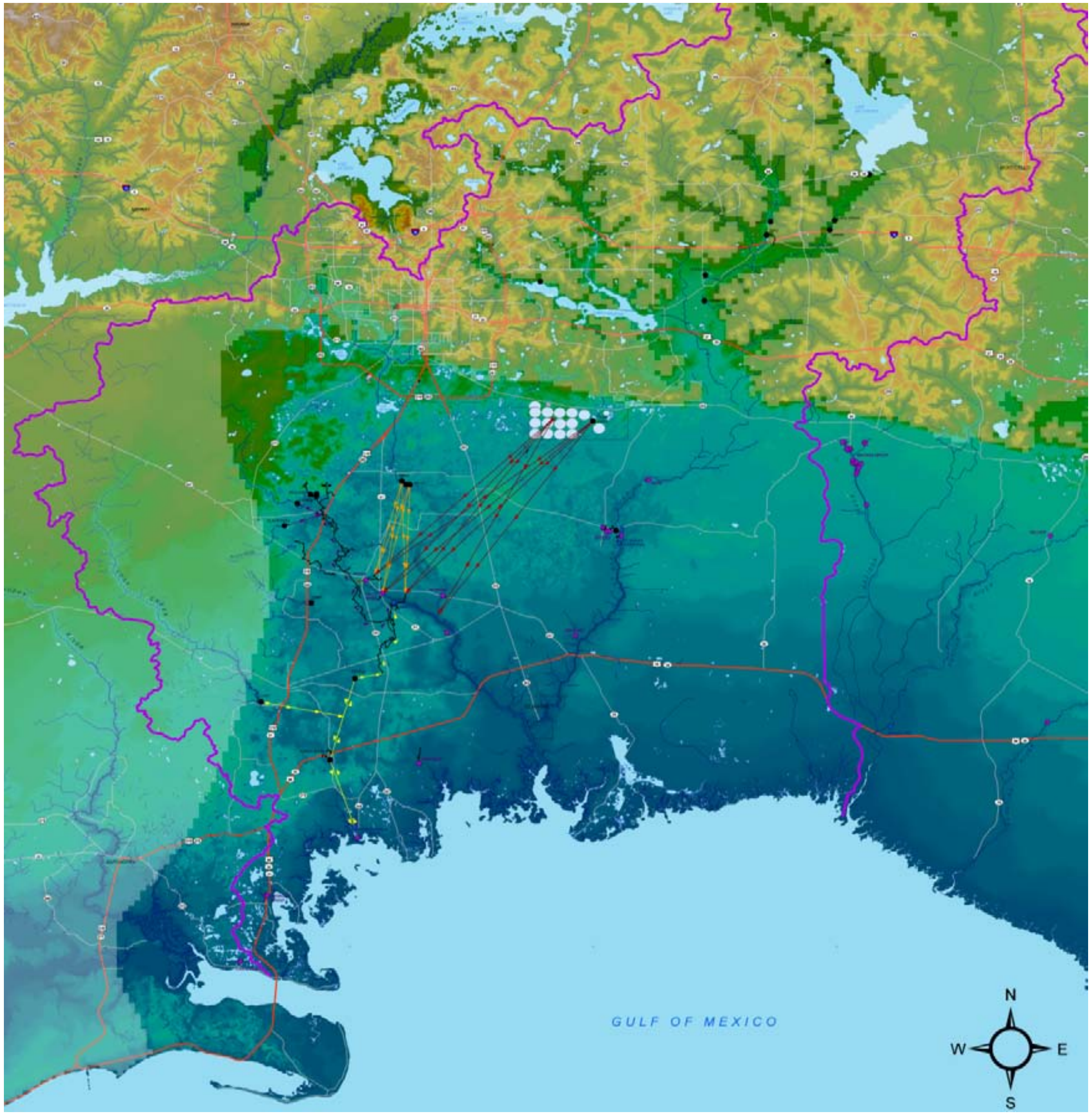
Hydrogeologic Complexities



- Confinement
- 1st Mag. Springs
  - Wakulla
  - Spring Creek group
  - St. Marks
  - Wacissa group
- 2nd Mag. Springs
  - Many
  - Not addressed yet
- Swallets
  - 12 primary
  - At least 5 secondary
- Caves
  - Mapped (~47 miles)
  - Tracer-defined
  - Inferred

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Model Boundaries

Surficial

Gulf of Mexico (CH)

Aucilla Watershed (NF)

Withlacoochee (CH)

With. Watershed (NF)

Flint/Apalachicola (CH)

IAS

Same as SAS

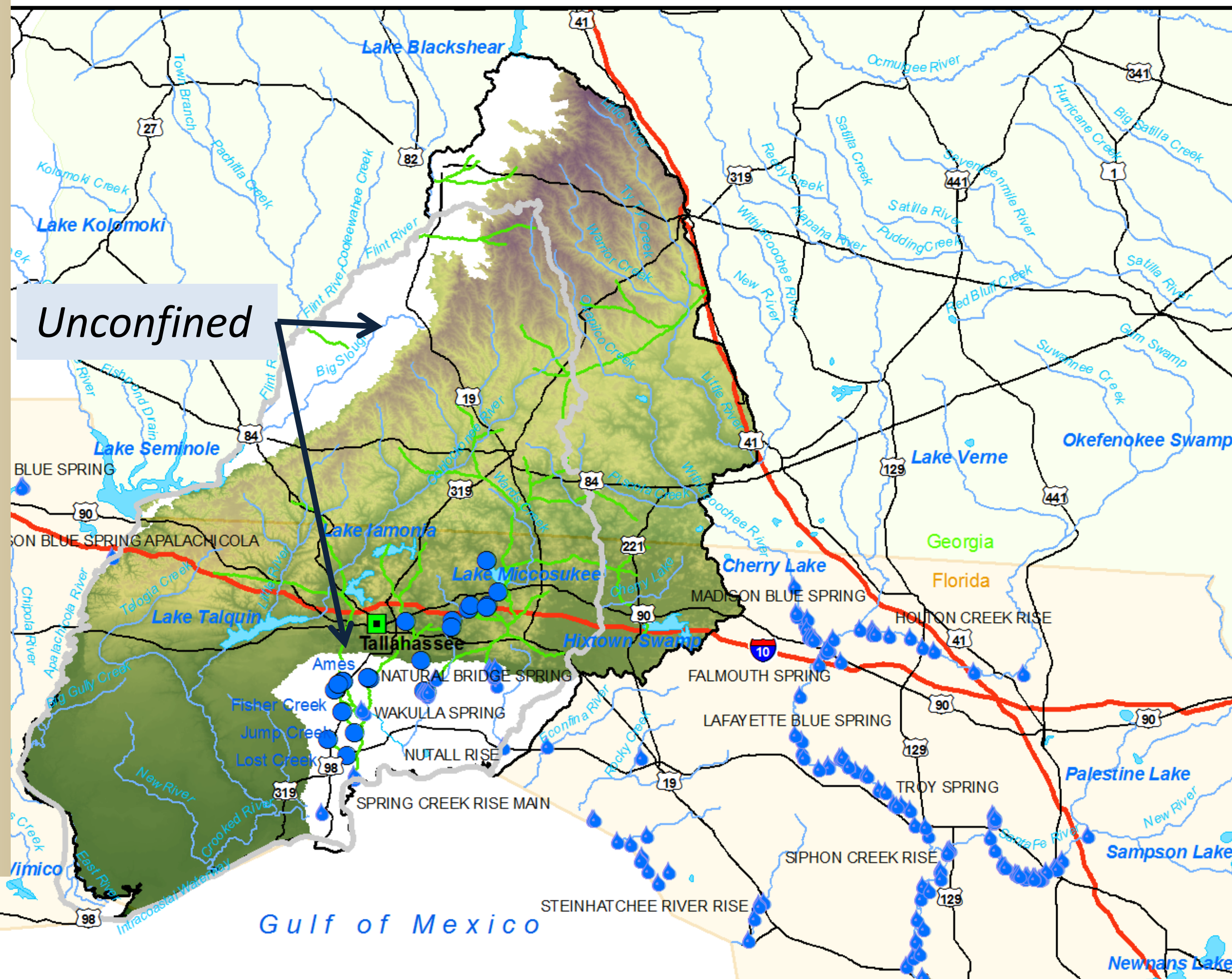
FAS

Gulf of Mexico (CH)

Interp. Pot. Sur. (CH)

Flint/Apalachicola (CH)

Ground Water Model Regional Topography and Hydrology



CH = constant head

NF = no flow

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Model Construction

Similar to the Western Santa Fe Model Process

- Layers
  1. Surficial (SAS)
     discontinuous
  2. Confining Layer (IAS)
     discontinuous
  3. Upper Floridan
     Suwannee Limestone
     discontinuous
  4. Upper Floridan
     numerical layer for conduits
  5. Upper Floridan
     Ocala limestone
- Conductivity
  - SAS: ~120 ft/day
  - IAS: ~5.7 ft/day
  - FAS: ~57 – 5670 ft/day
    geologically defined zones

Chronostratigraphic Units			Lithostratigraphic Units		Hydrostratigraphic Units
Era	System	Series			
CENOZOIC	QUARTERNARY	RECENT	Alluvium		Surficial Aquifer
		PLEISTOCENE	Terrace Sands		
	TERTIARY	PLIOCENE	Miccosukee / Citronelle		Confining Unit / Intermediate Aquifer
			Jackson Bluff		
			Tamiami		
		MIOCENE	Hawthorn	Hawthorn	
				Torreya/Arcadia	
			Chattahoochee / St. Marks		Floridan Aquifer
		OLIGOCENE	Suwannee		
		EOCENE	Ocala		
			Avon Park		

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Model Construction

- Swallets: *~260 cfs total*
  Lost Creek, Jump Creek, Black Creek, Fisher Creek, Ames, St. Marks River, Natural Bridge, Still Creek, Lake Drain Creek, Lloyd Creek, and Burnt Mill Creek
- Swallet-Seeps: all major lake basins in north Florida section of the domain
- Springs: *target ~5,050 cfs total*
  Wakulla, Spring Creek, St Marks, Wacissa
  Cray's Rise, Natural Bridge, Rhodes, and Horn
- Caves & Traced Pathways
- Pumping
  - Florida
    - Defined by NFWMD permitted pumping (average)
    - 49 wells
  - Georgia
    - Data not as good / compiled by county
    - Decatur = 32-42 MGD
    - Grady = 5-8 MGD
    - Thomas = 15-20 MGD
    - Mitchell = 30-40 MGD
    - Brooks = 3-5 MGD
    - Colquitt = 9-18 MGD
    - Worth = 7-10

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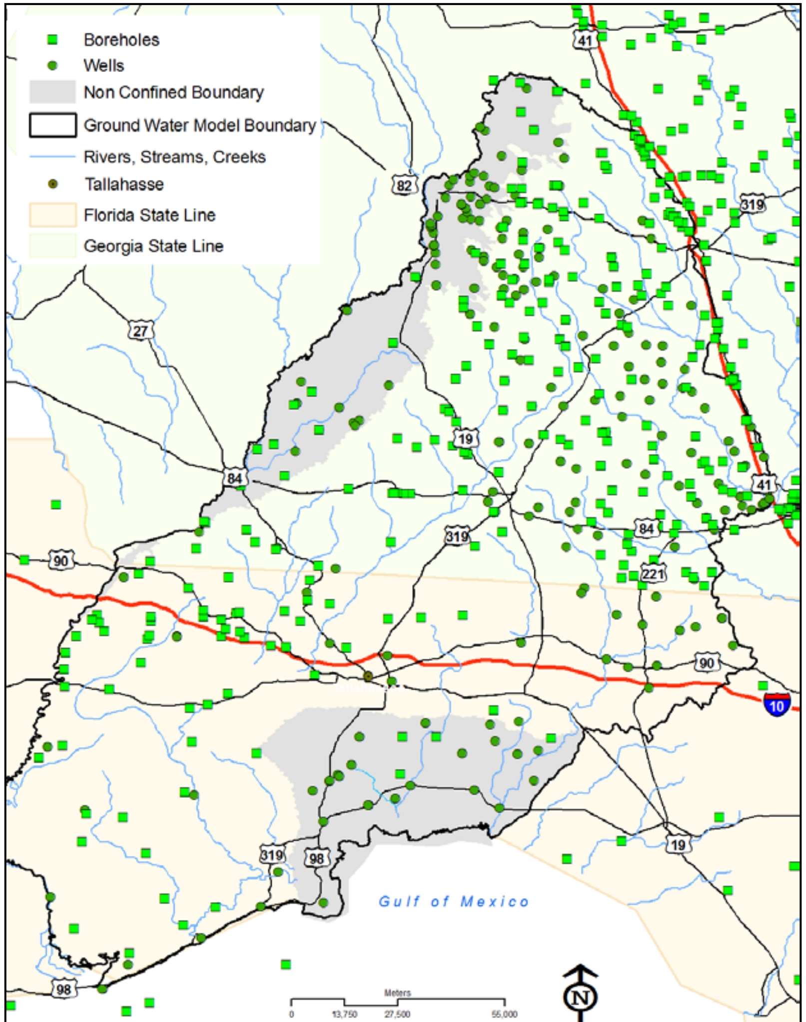
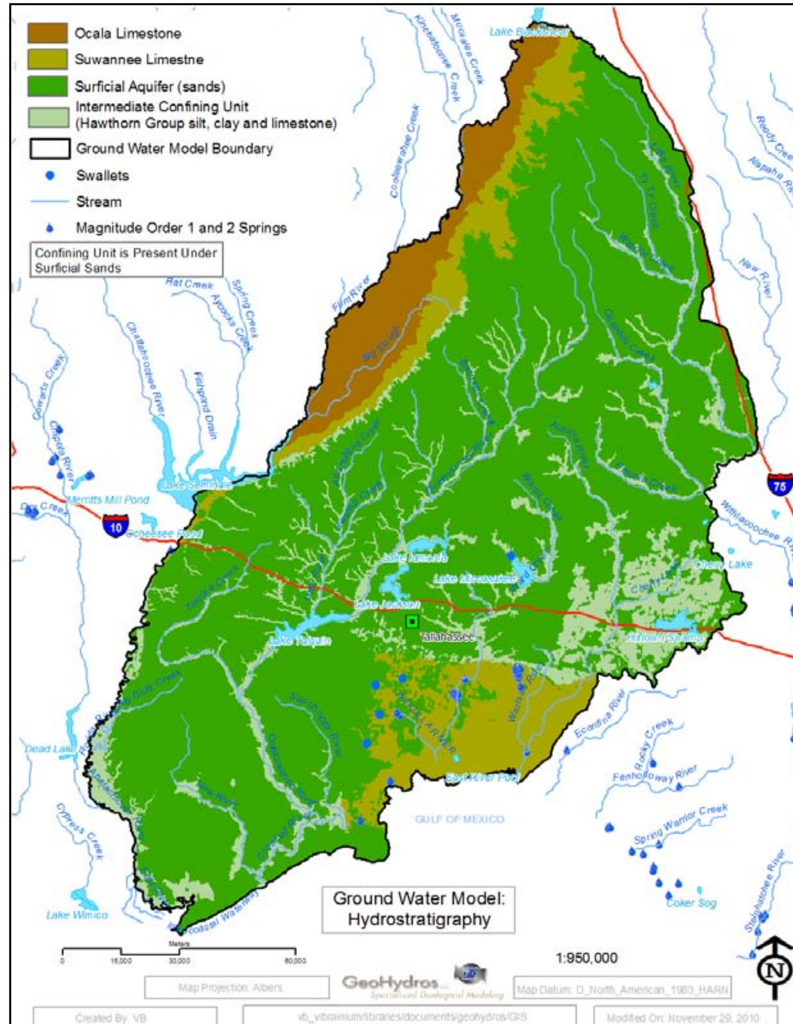
Model Framework

- ~900 wells and boreholes





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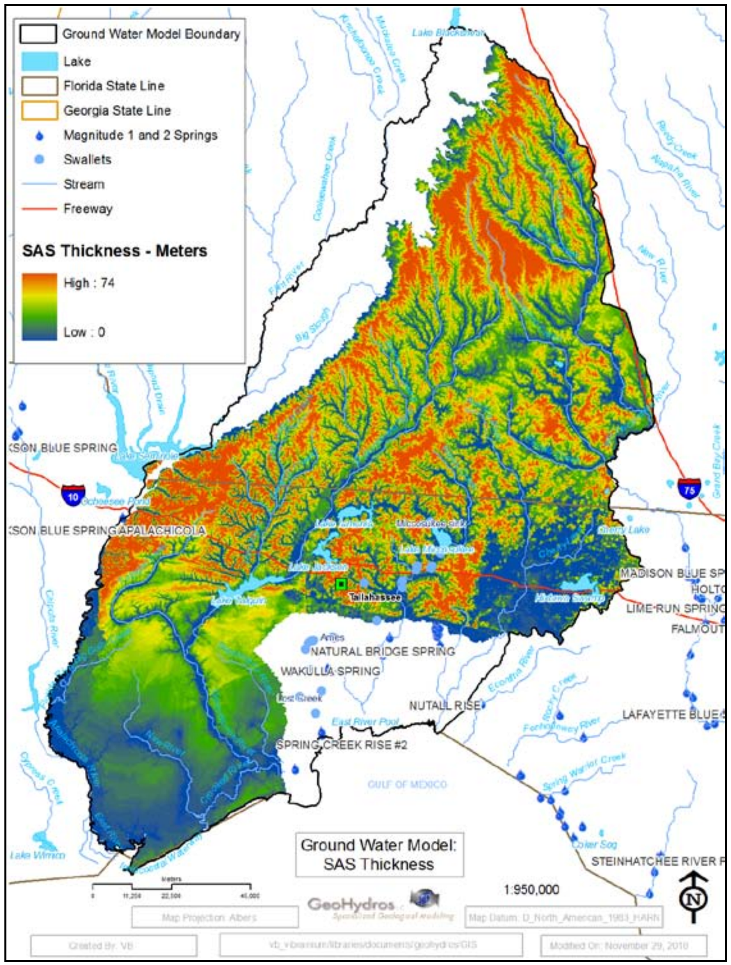
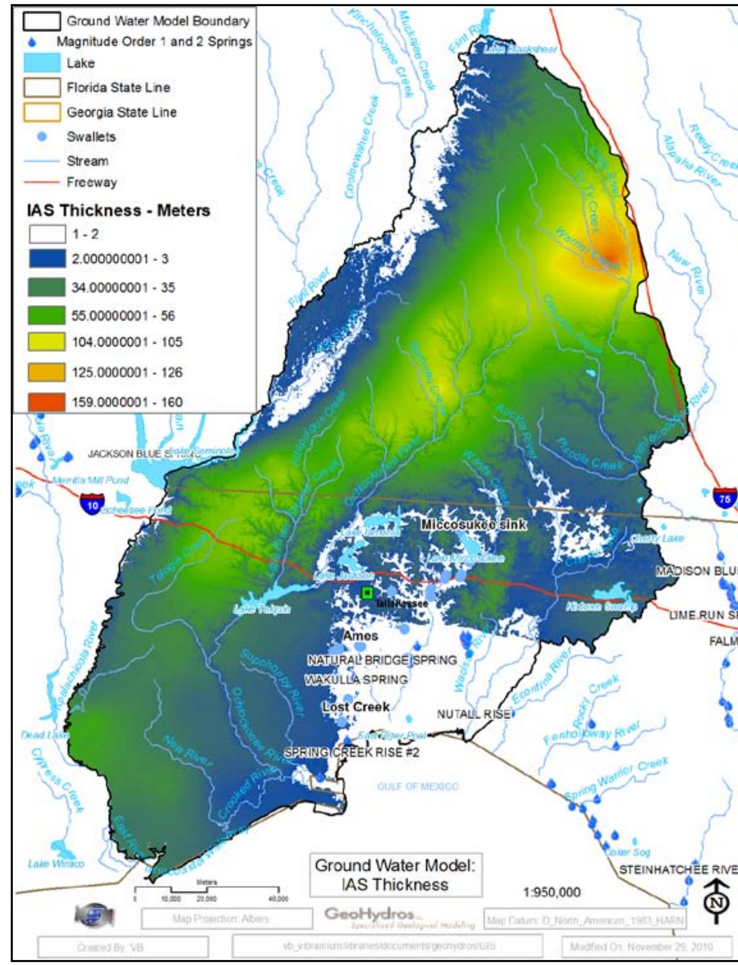
Model Framework

Surficial Thickness



Confining Unit Thickness



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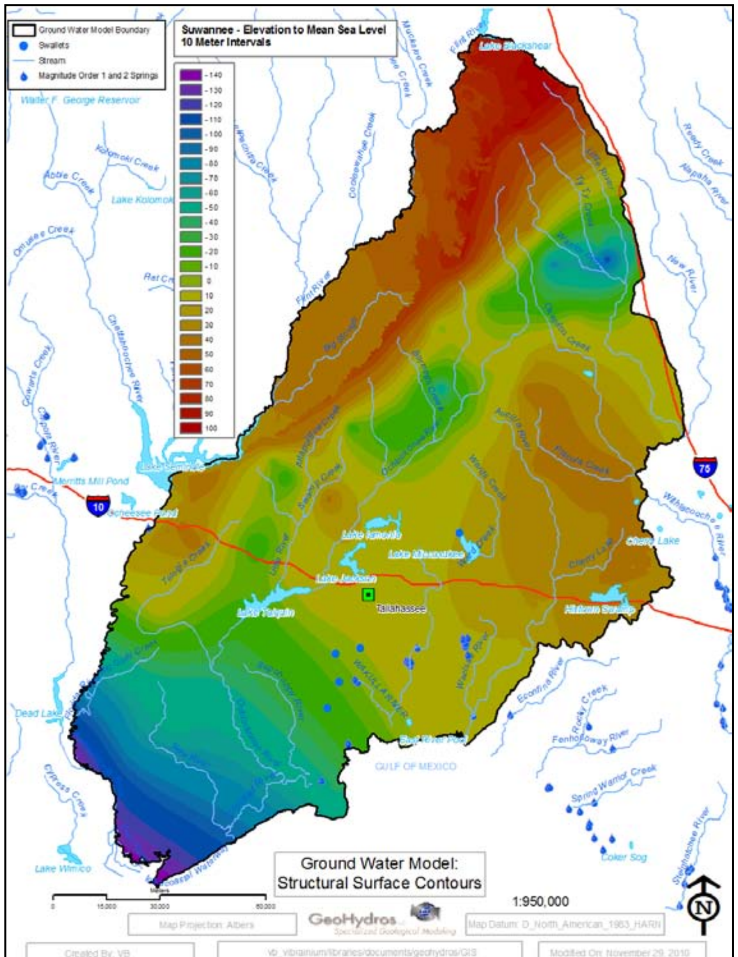
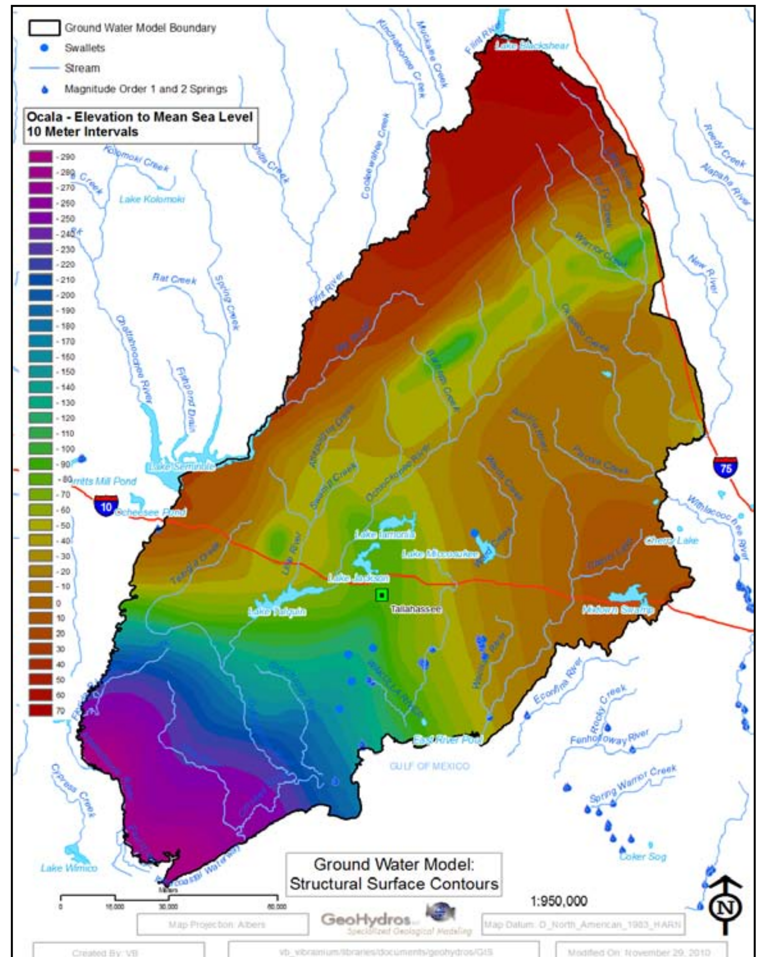
Model Framework

Suwannee Surface



Ocala Surface



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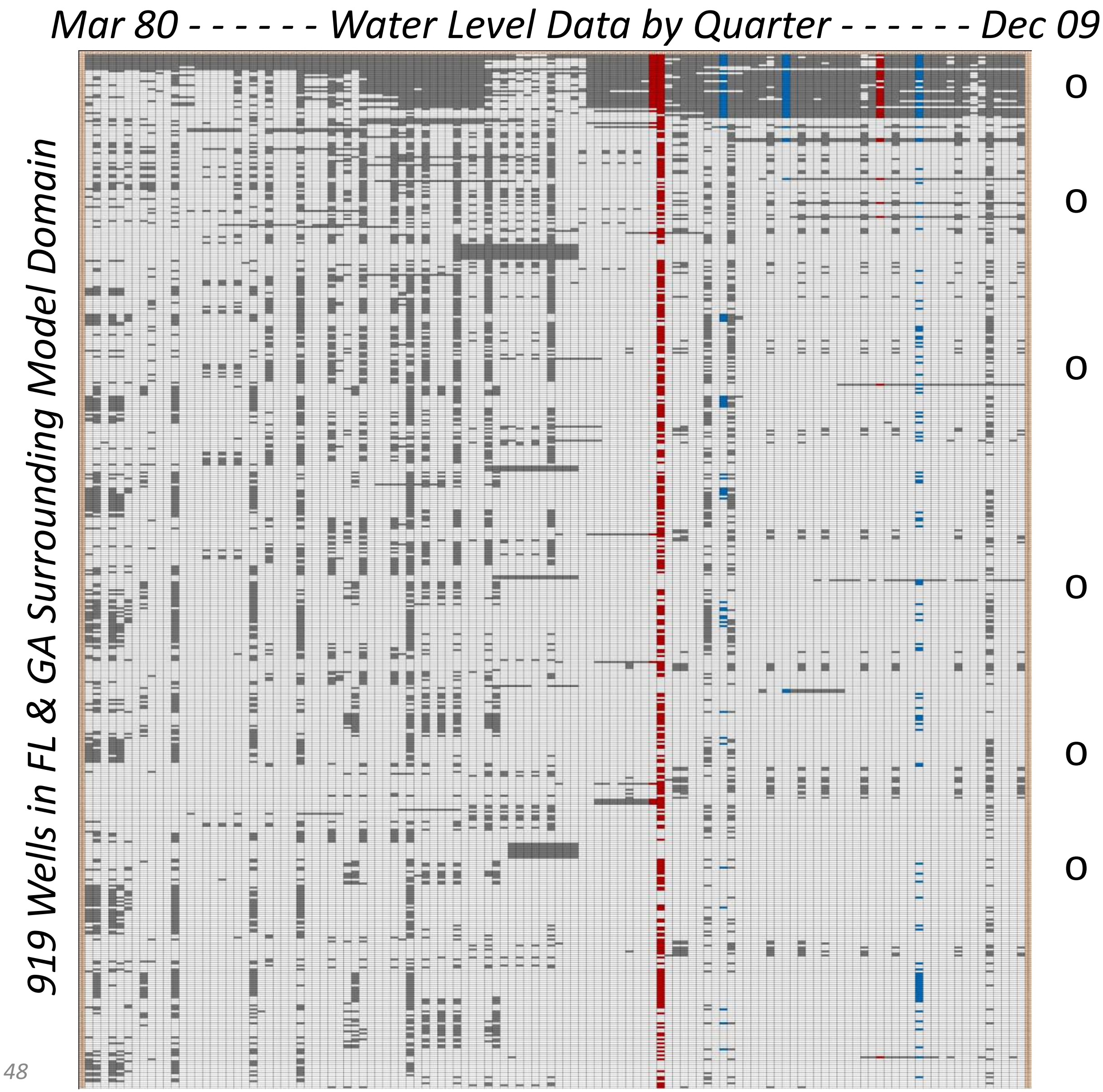
Developing a Calibration Dataset



- Dramatically increases data density for calibration
- Analyze data and bin into groups representative of high & low water periods
- Use well-well regression analyses on all wells to expand datasets with data from wells that correlate
- Use grouped data to develop high-water and low-water potentiometric surface maps
- Use pot surface maps to define initial conduit layout
- Use high-water and low-water datasets for model calibration

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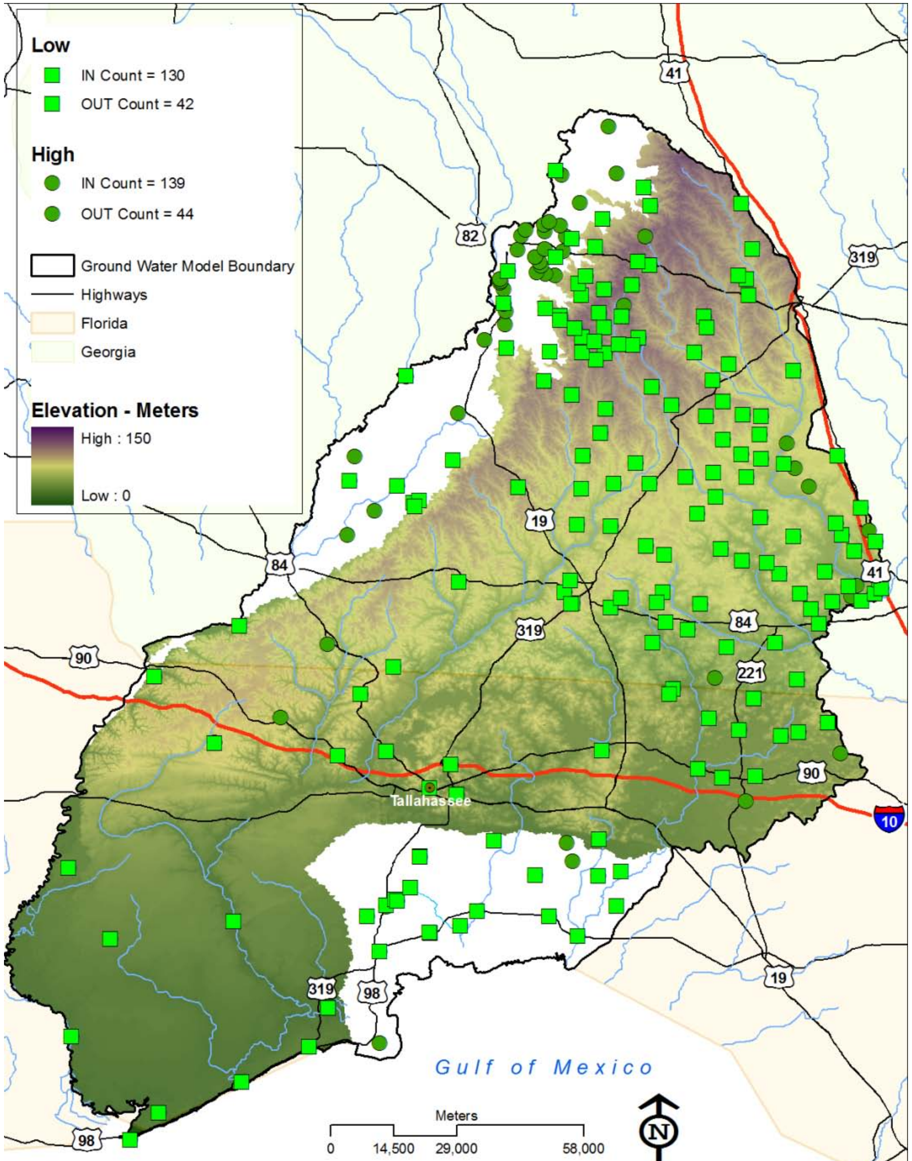
Calibration Datasets



- High Water
  - 1998 2nd quarter - *GA & NFWMD*
  - 2005 2nd quarter – *SRWMD*
- Low water
  - 2002 2nd quarter – *SRWMD*
  - 2000 2nd quarter – NFWMD
  - 2006 3rd quarter – Georgia
- *Boxes are low-water data points*
- *Circles are high-water data points*
- *Shared points are not distinguished.*

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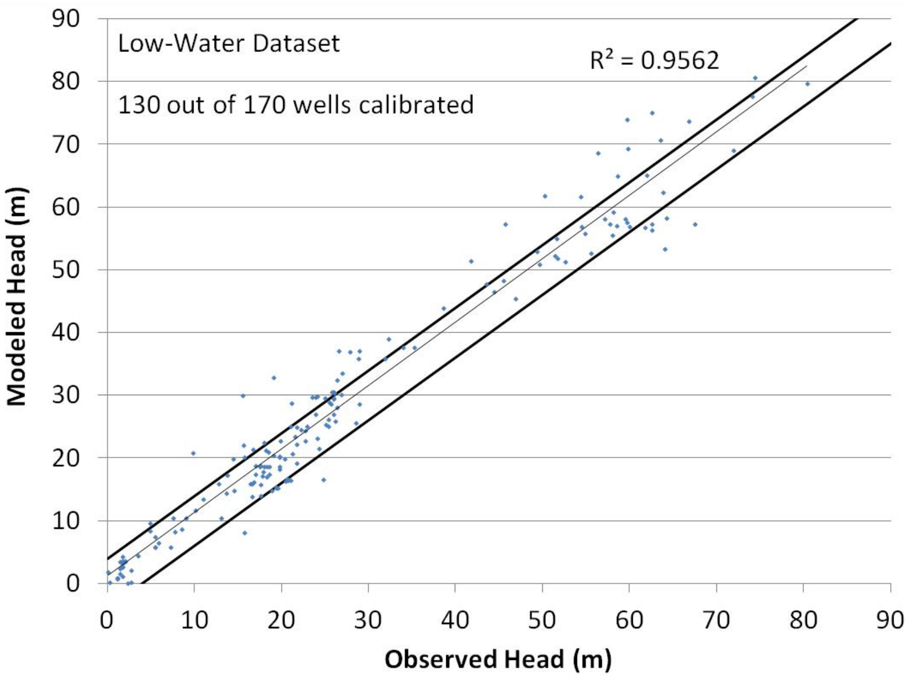
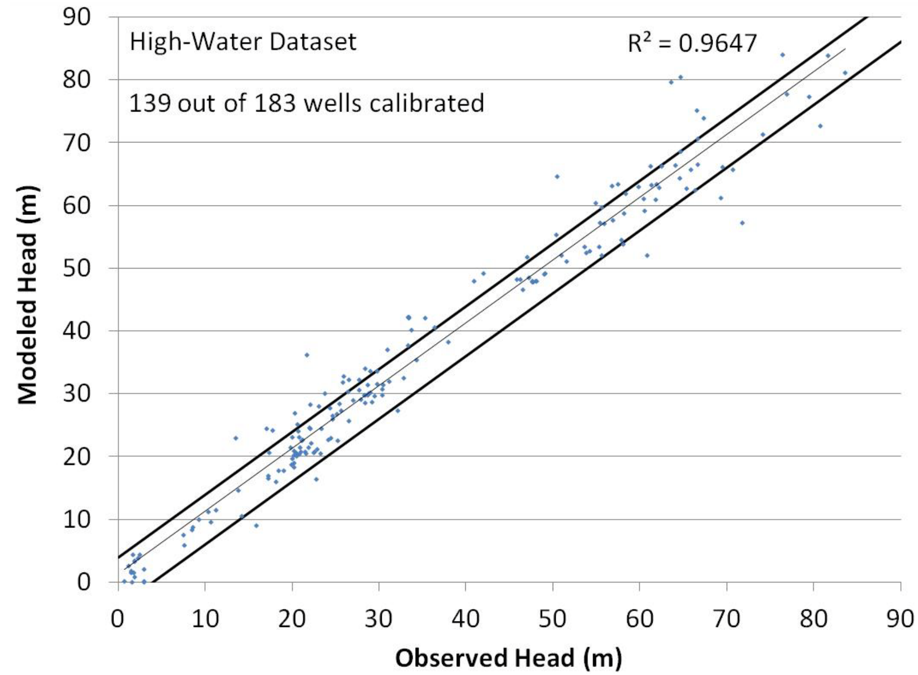
Calibration - Heads





<u>Low-Water Dataset</u>

- Target criteria: confined = +/- 4 m
- Target criteria: unconfined: +/- 0.3 m
- 130/170 wells calibrated
- R^2 = 0.9562

<u>High-Water Dataset</u>

- Target criteria: confined = +/- 4 m
- Target criteria: unconfined: +/- 0.3 m
- 139/183 wells calibrated
- R^2 = 0.9647

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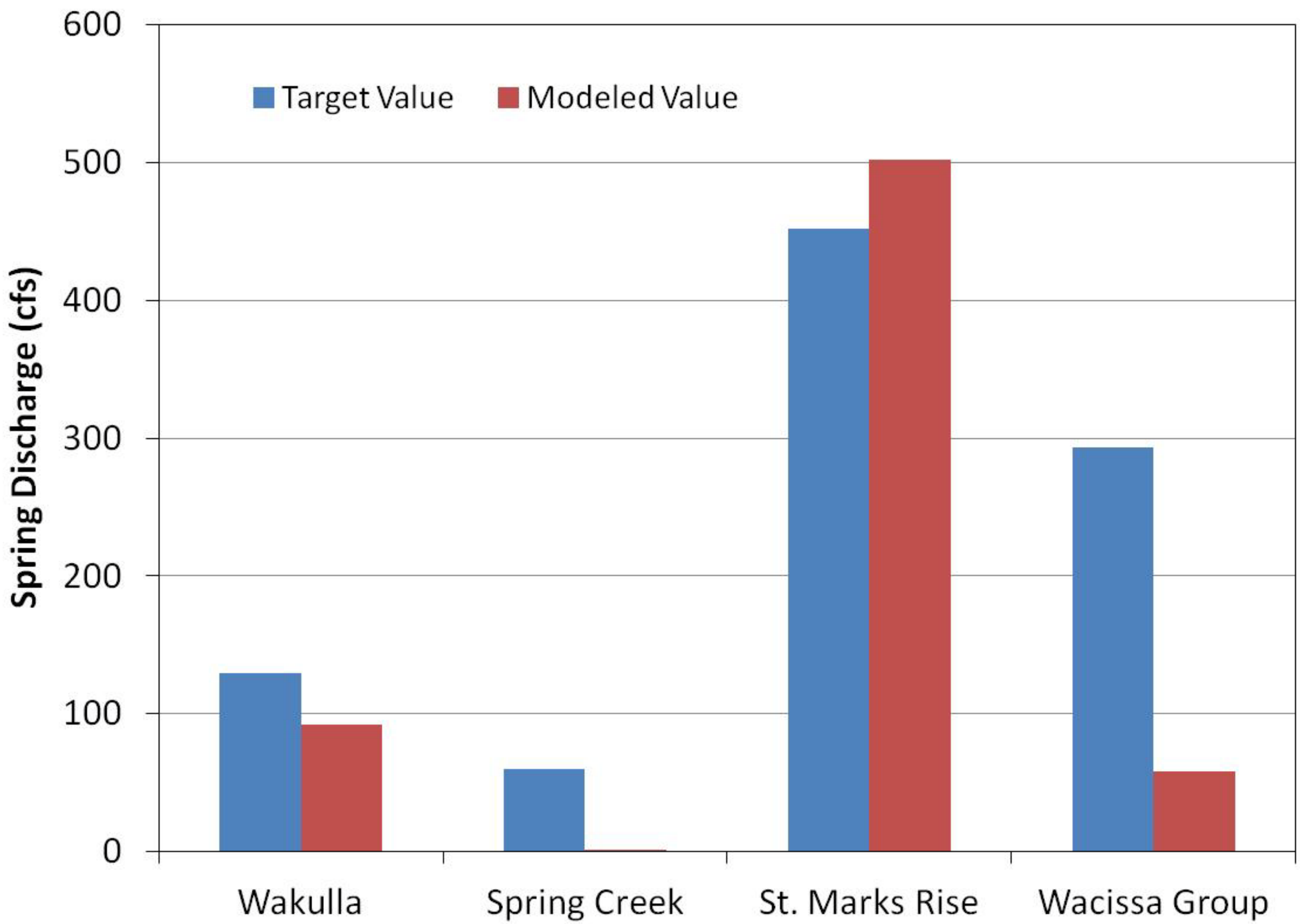
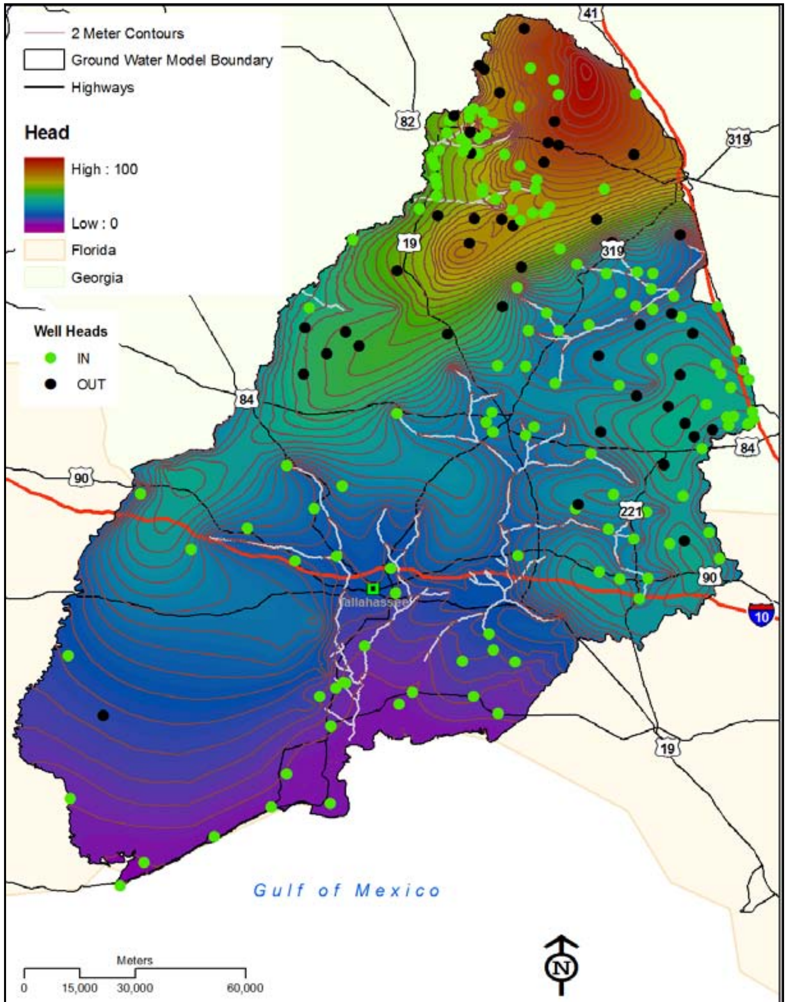
Calibration – Springs

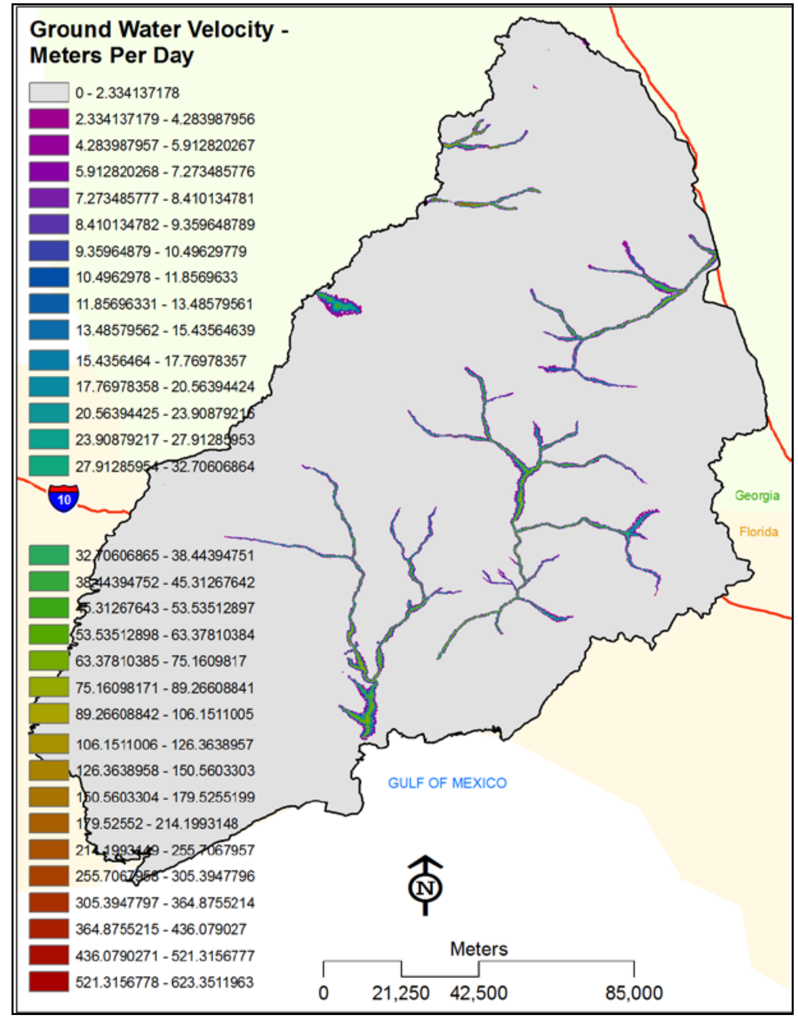


2010 Model Results

Potentiometric Surface



Velocities



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2011 Modeling Objectives

- Add tracer-defined pathway from NE Tallahassee swallets
  - Bird Sink Trace performed 2012
  - Connected to St. Marks River Rise (< 2 weeks travel time)
  - Also to Wakulla (~ 50 days travel time – very low concentration)
- Evaluate impact of sea level rise
- Evaluate effect of pumping
  - Needed to develop a more detailed accounting of pumping magnitudes and locations
  - Particular focus on Georgia
    not as well documented in 2010 modeling effort

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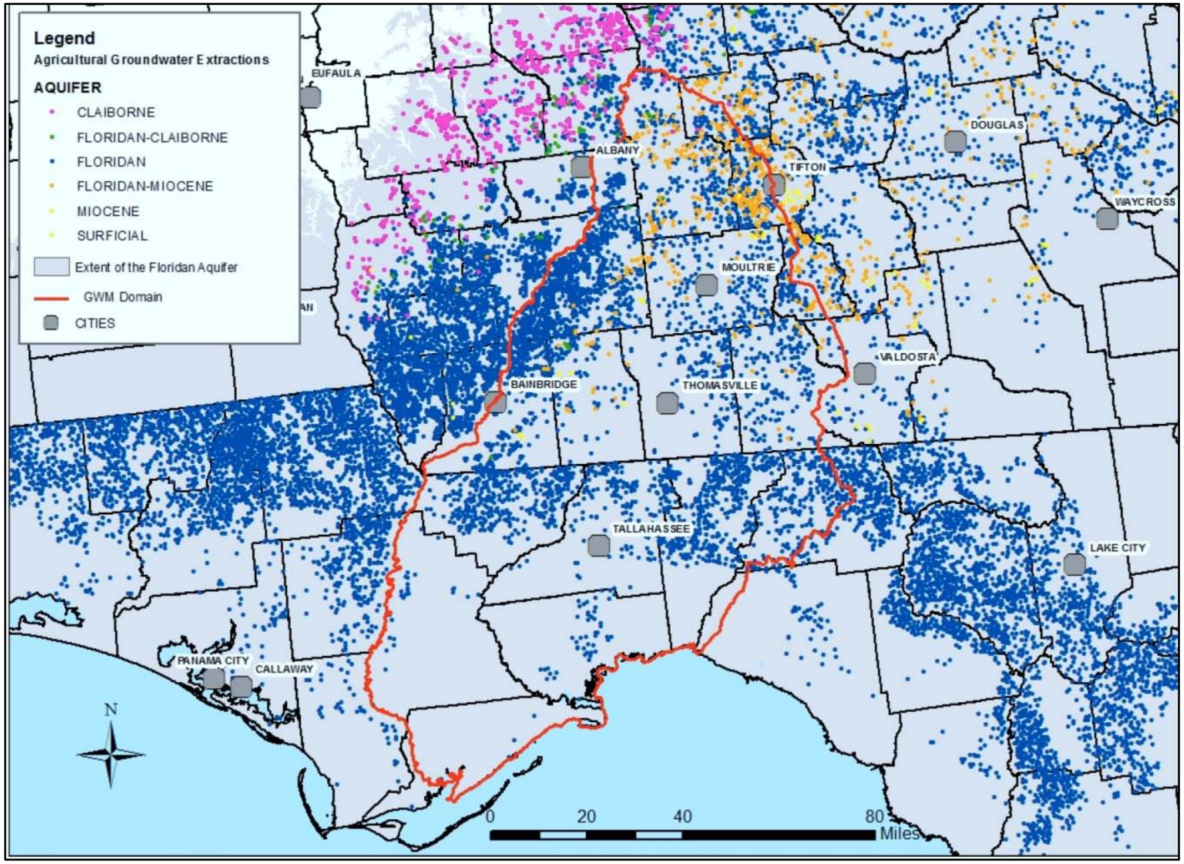
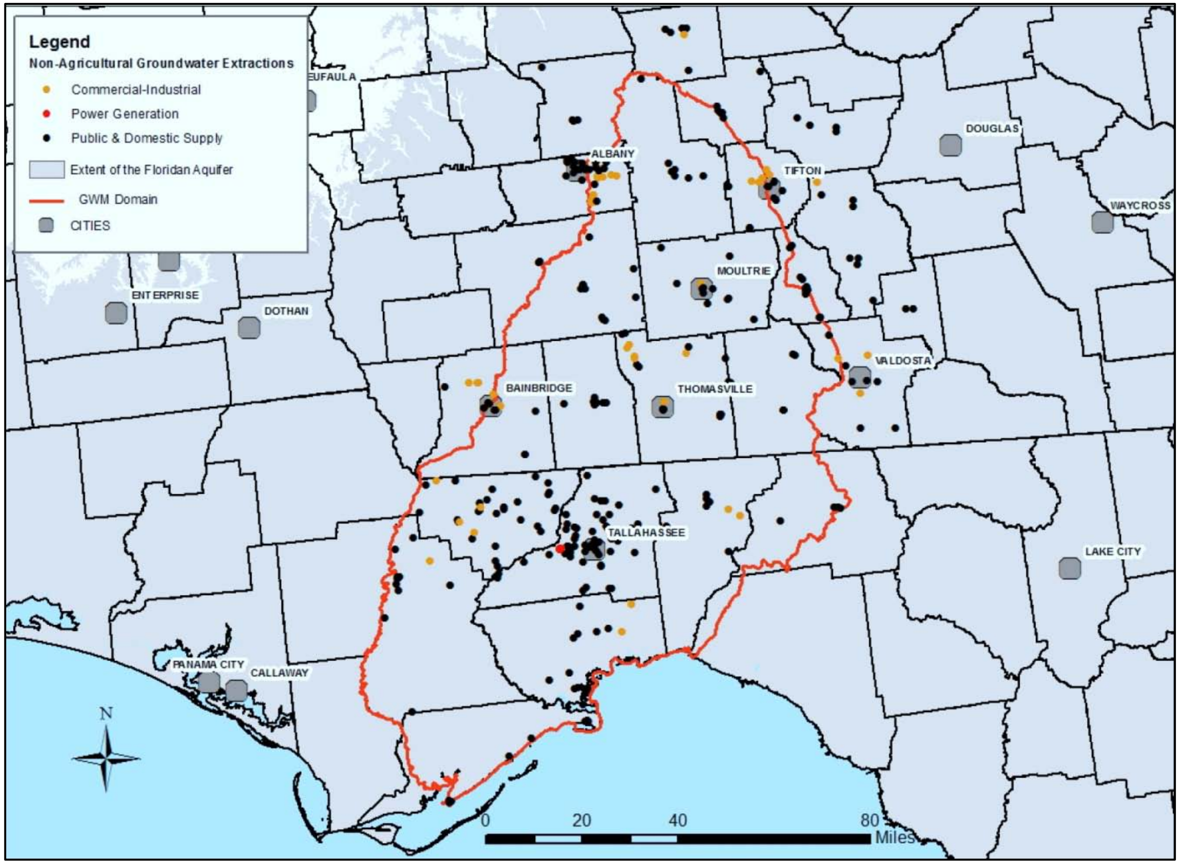
Agricultural Pumping



- National Environmentally Sound Production Agriculture Laboratory (NESPAL) - University of Georgia's College of Agricultural and Environmental Sciences
- Georgia EPD
- NWFWMD
- SRWMD

GA: 183 MGD – Contributing Counties / 93 MGD Model Domain
FL: 29 MGD – Contributing Counties / 21 MGD Model Domain

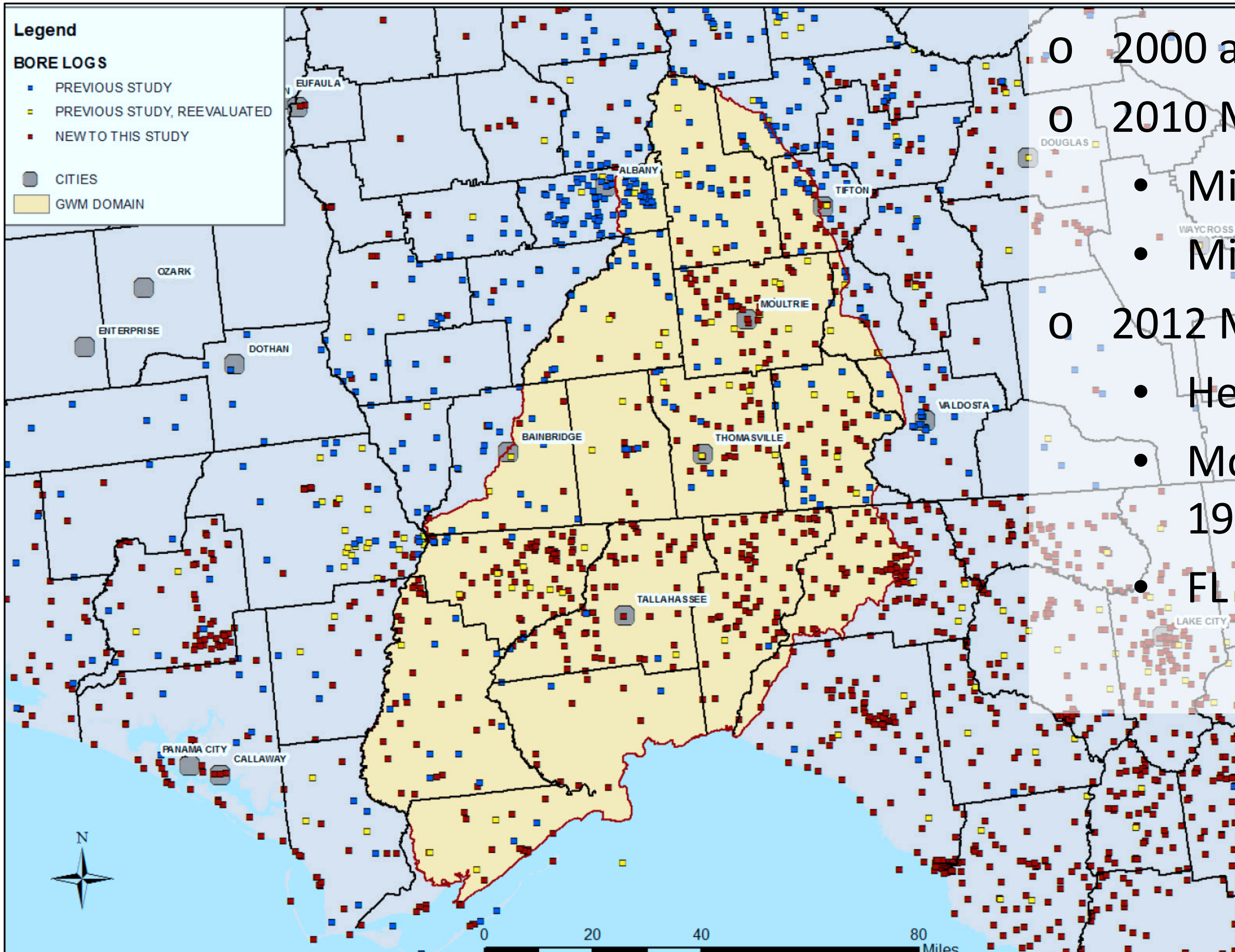
Municipal Pumping



- GA: Fanning & Trent 2009
- FL: Maralla 2009
- FL: NWFWMD

GA: 54 MGD – Contributing Counties
FL: 24 MGD – Contributing Counties

Revised Geology



- o 2000 additional borelogs
- o 2010 Model
  - Miller 1986
  - Miller 1988
- o 2012 Model - *added*
  - Herrick 1961
  - McFadden & Others 1986
  - FL LithProg Database

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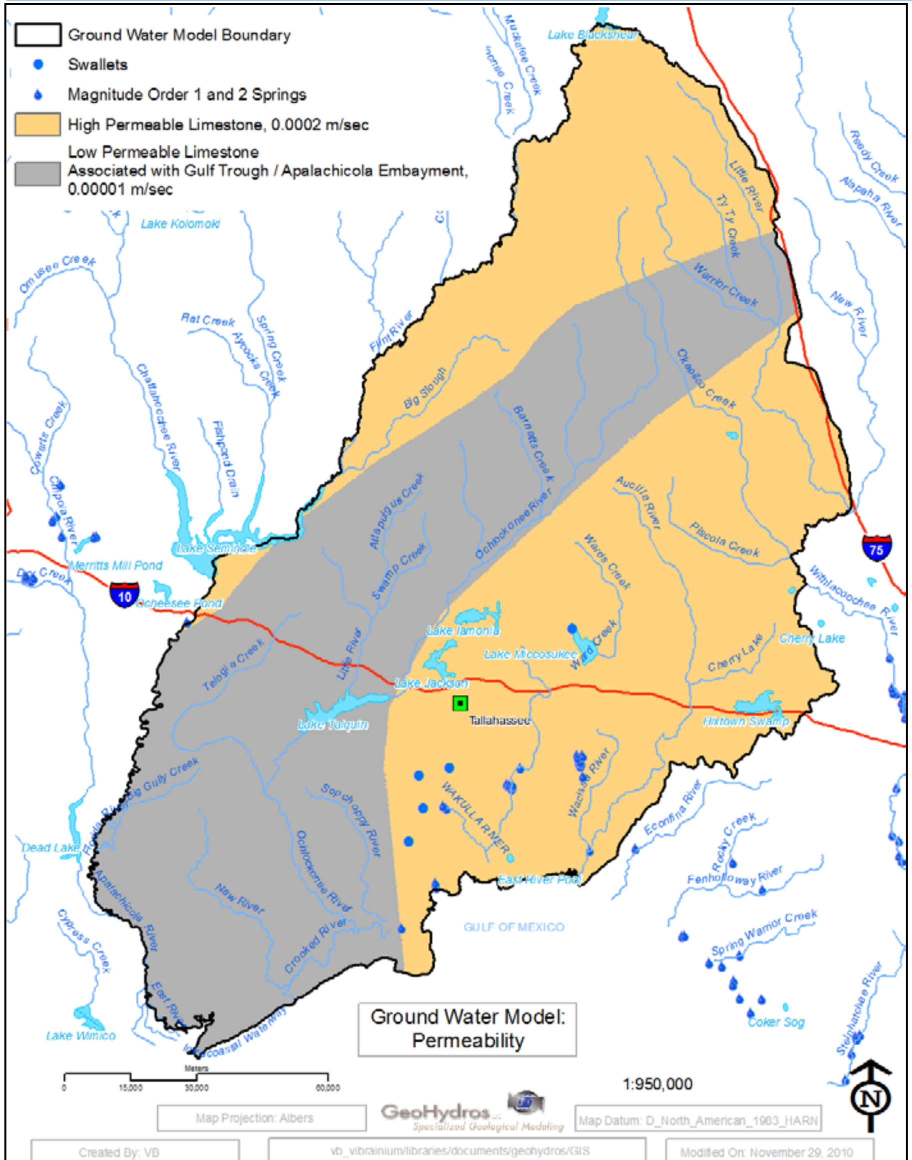
Focus on Delineation of Gulf Trough



- Lost Calibration
  - 2010 Model relied on conduits to explain low head regions
  - Pumping negated those
  - Removing conduits forced re-interpretation of geology
  - Primarily Gulf Trough
- Expanded geologic dataset
- Re-designed layer configurations

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Revised Hydrostratigraphic Framework

- Expanded Model to bottom of Oldsmar or equivalent
- 9 model layers (expanded from 5)
- Divisions set to describe lateral and vertical heterogeneity in Floridan aquifer system units

GWM LAYER	AGE	HIGH PERM	LOW PERM	NOTE
1	Post Miocene	Undif. sand & clay		Continuous, vertical K will define where Hawthorn present
	Miocene	Altamaha	Hawthorne	
2	Miocene	Chattahoochee / Tampa / St. Marks		Discontinuous, all Miocene limestones where present
3	Upper Oligocene	Suwannee		Discontinuous, all Suwannee where present
4	Lower Oligocene		Marianna / Undif.	Discontinuous, all Marianna where present
5	Upper Late Eocene	Ocala	Cooper Marl	Discontinuous, all Ocala where present
6	Lower Late Eocene	Wilson	Undif. / Barnwell	Discontinuous, horizontal K will define Wilson / Undifferentiated division
7	Upper Middle Eocene	Avon Park	Lisbon	Continuous, horizontal K will define Avon Park / Lisbon division
8	Lower Middle Eocene	Lake City	Tallahatta	Continuous, horizontal K will define Lake City / Tallahatta division
9	Early Eocene	Oldsmar	HTGB	Continuous, horizontal K will define Oldsmar / HTGB division
-	Paleocene	Cedar Key	Cedar Key	Top of the layer is bottom slice of model

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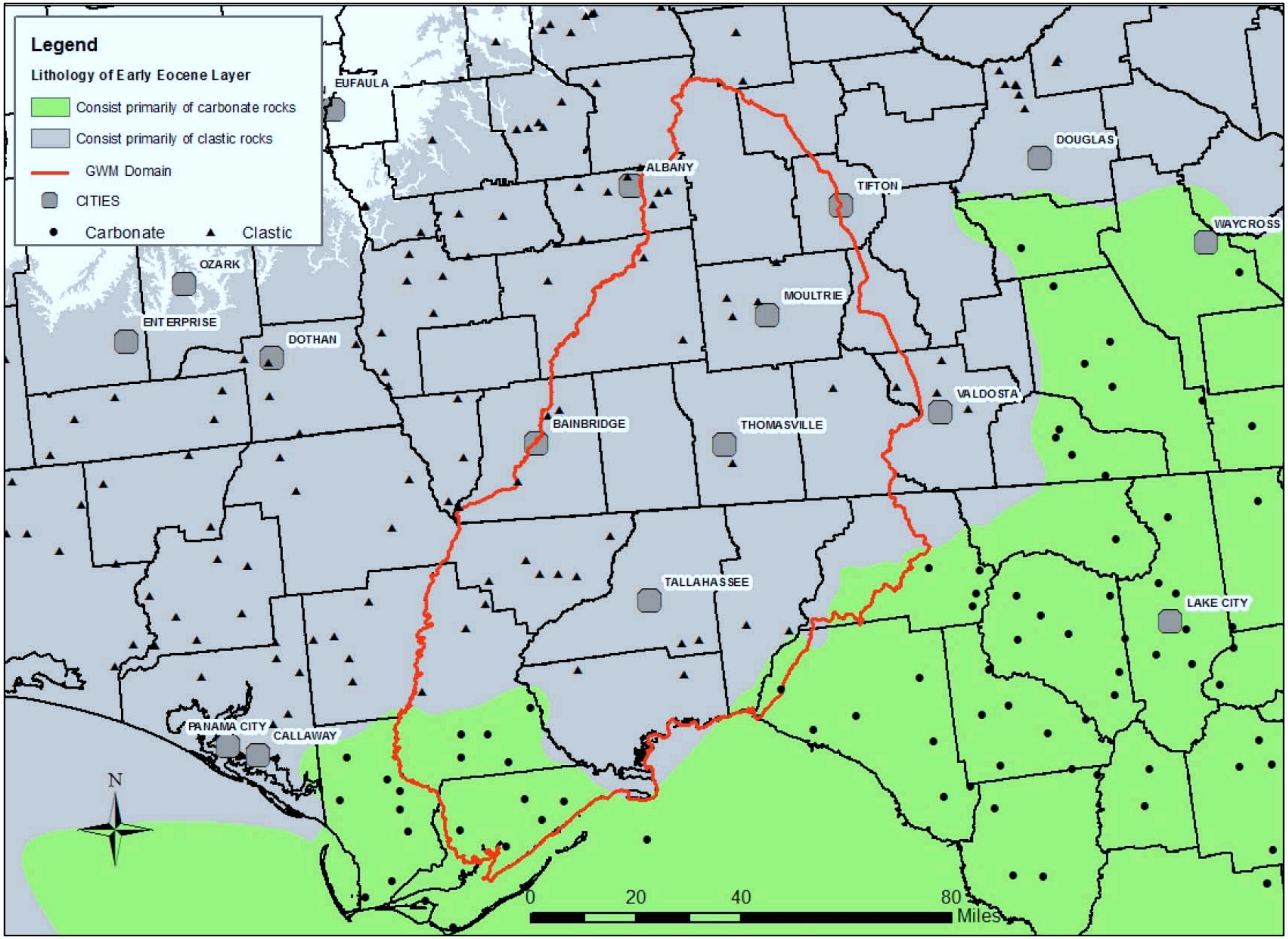
Revised Framework – Early Eocene Layer



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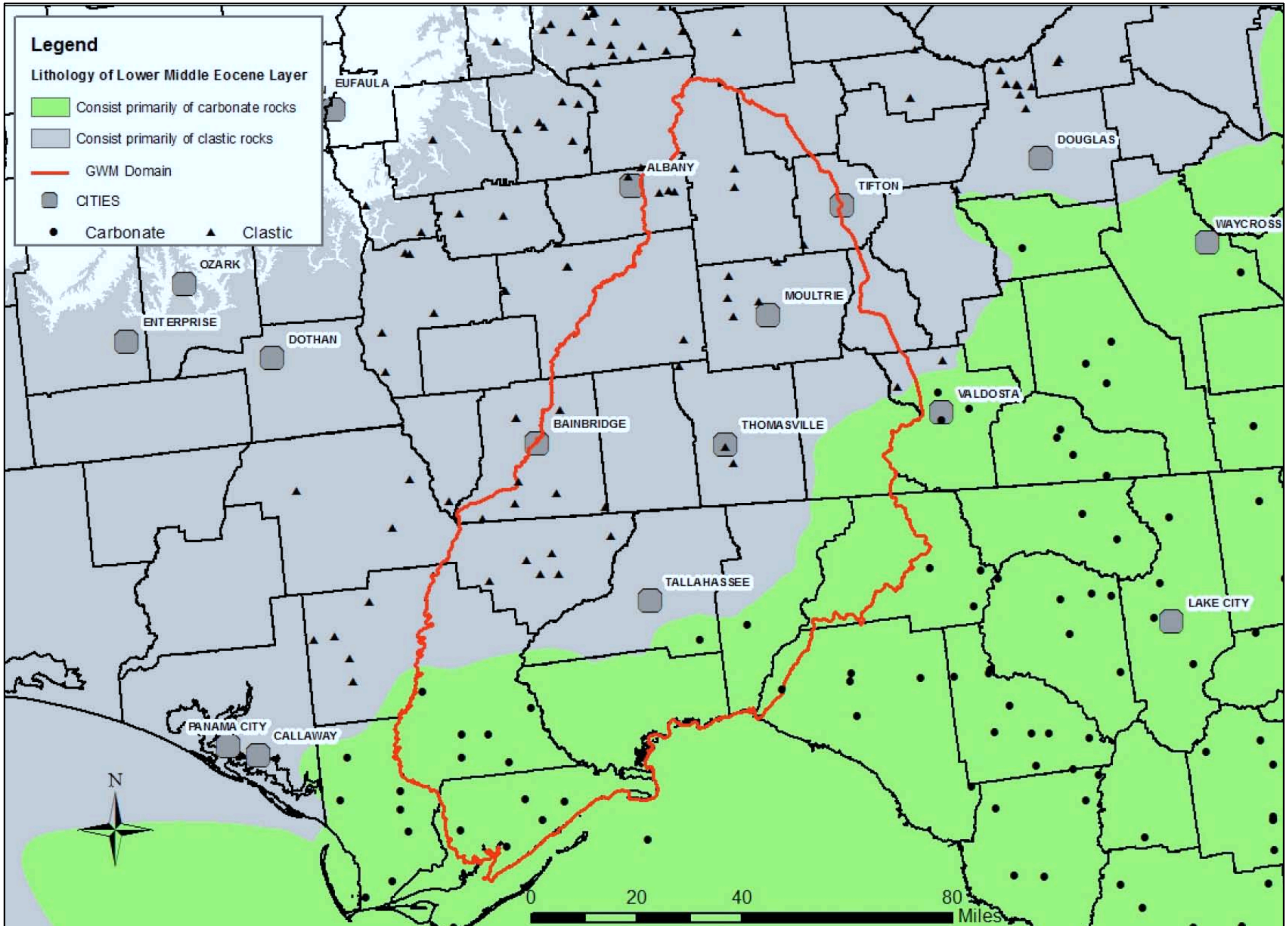
Revised Geology – Lower Middle Eocene Layer



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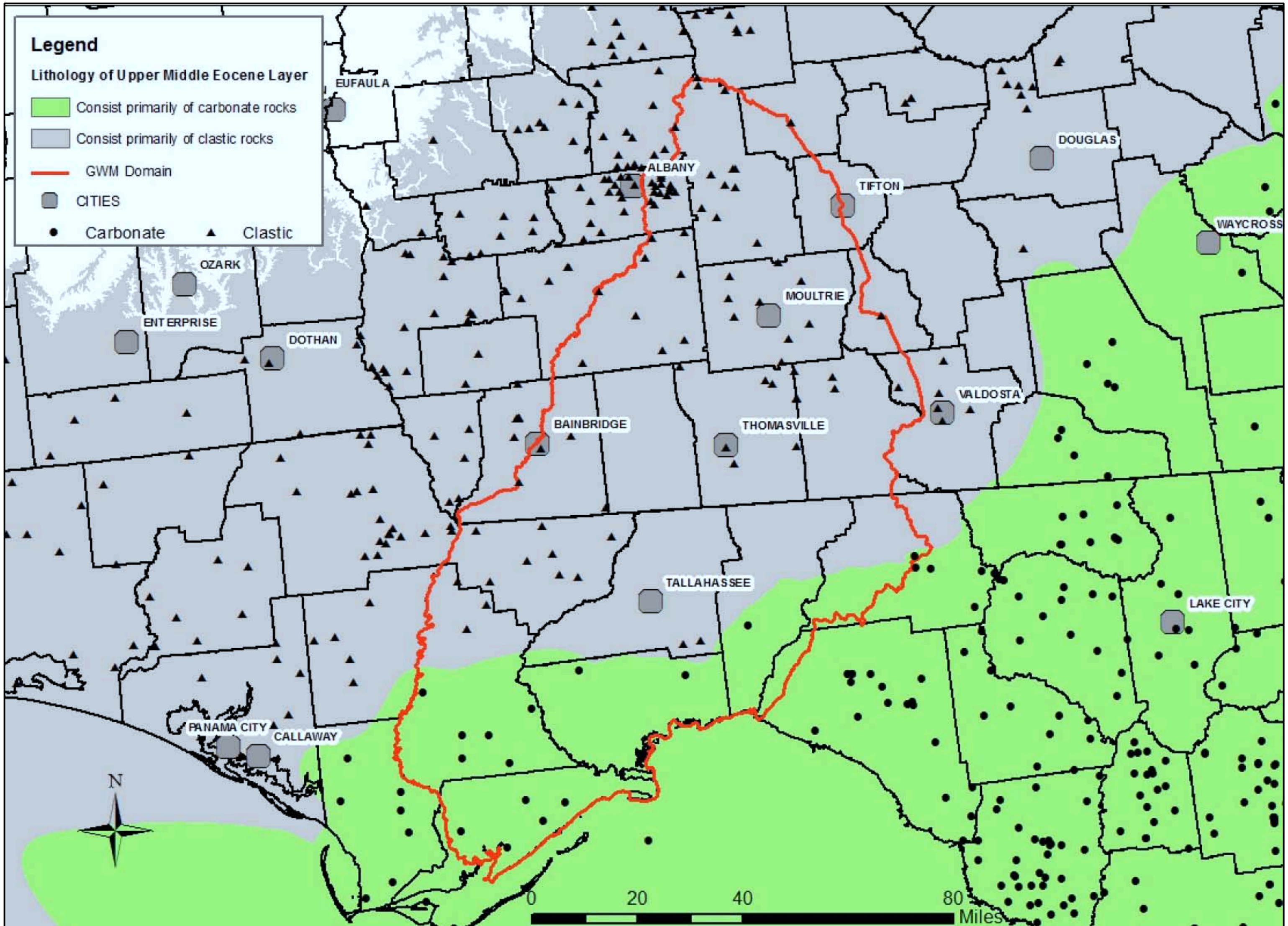
Revised Geology – Upper Middle Eocene Layer



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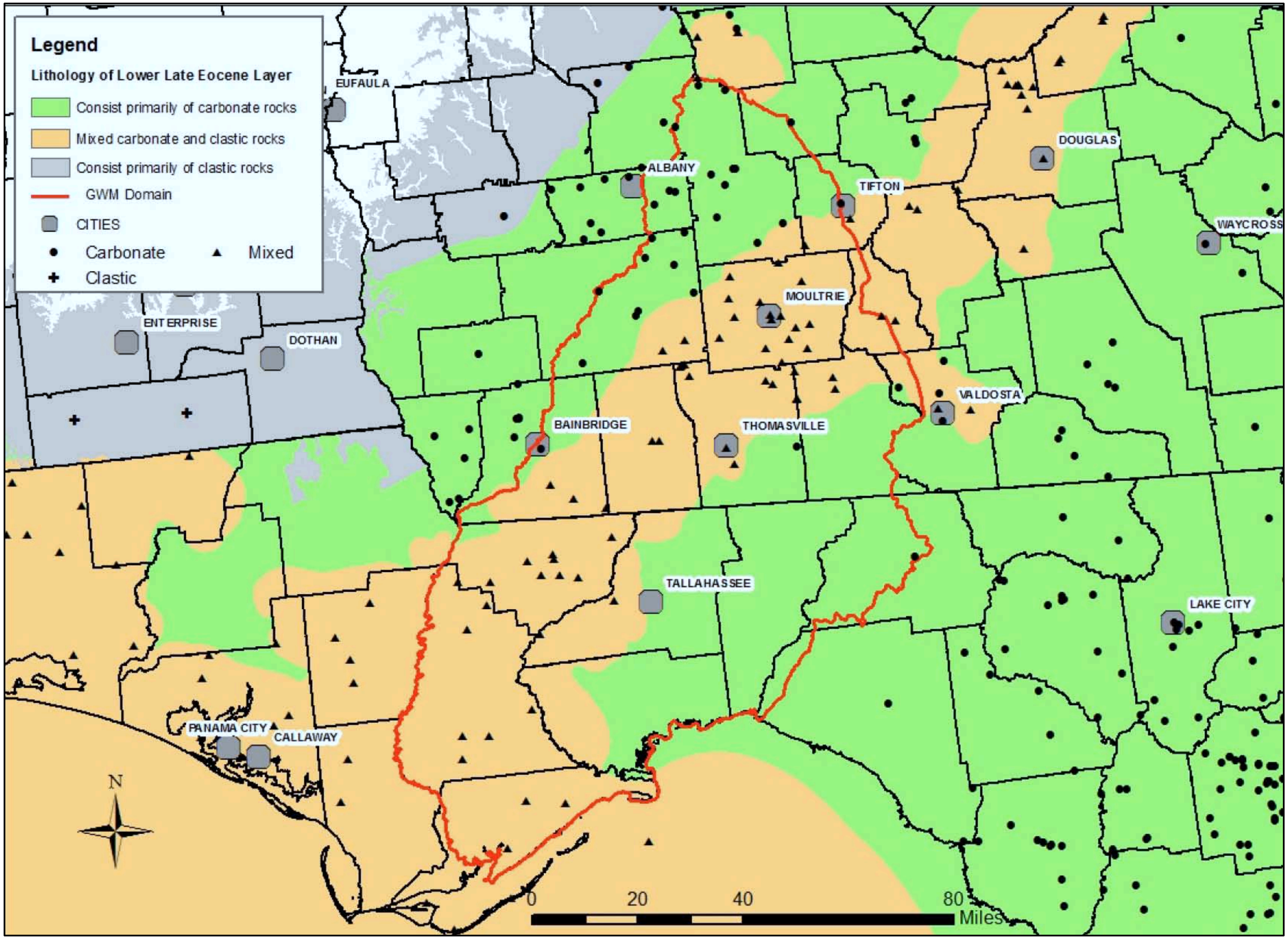
Revised Geology – Lower Late Eocene Layer



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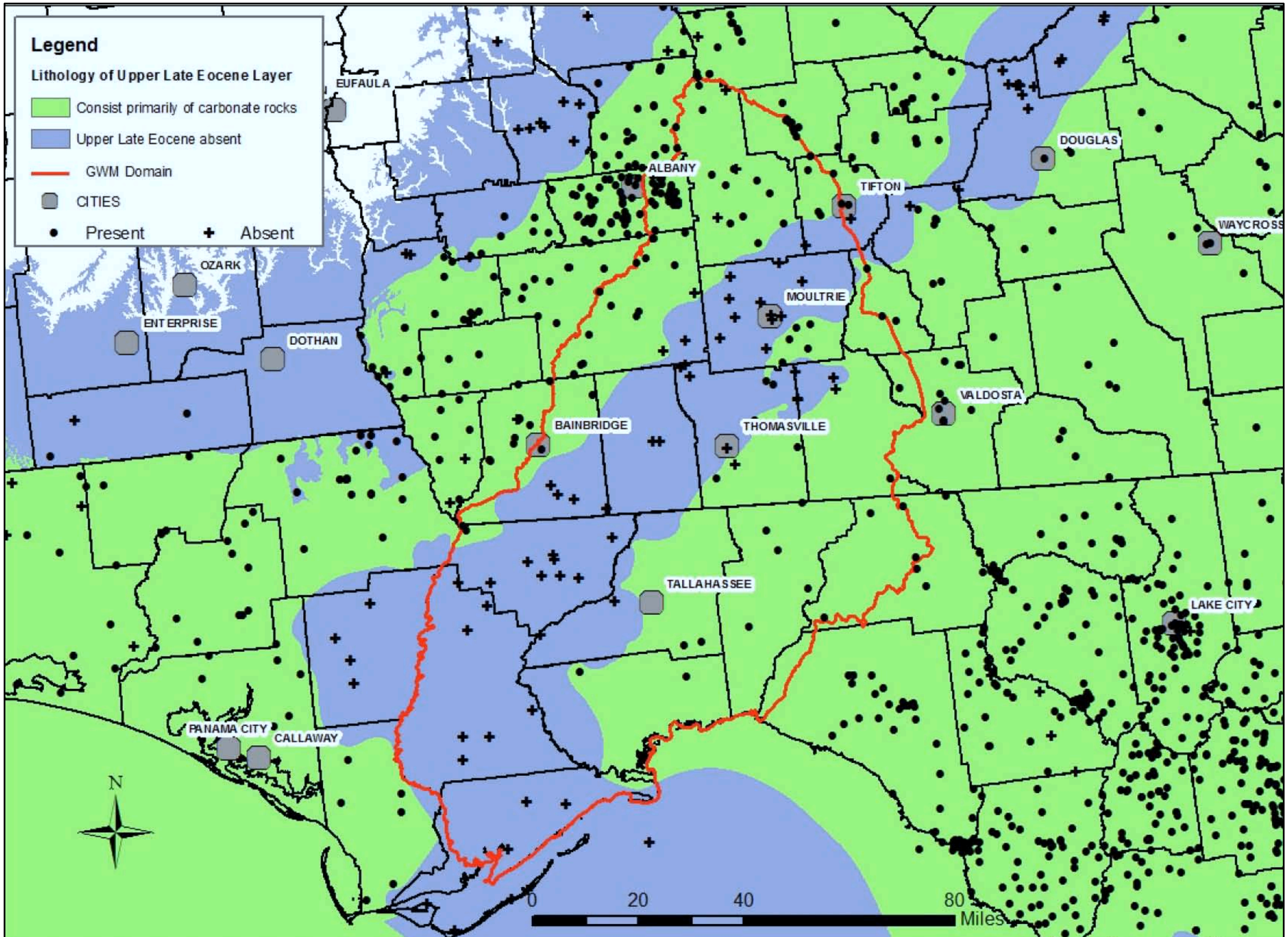
Revised Geology – Upper Late Eocene Layer



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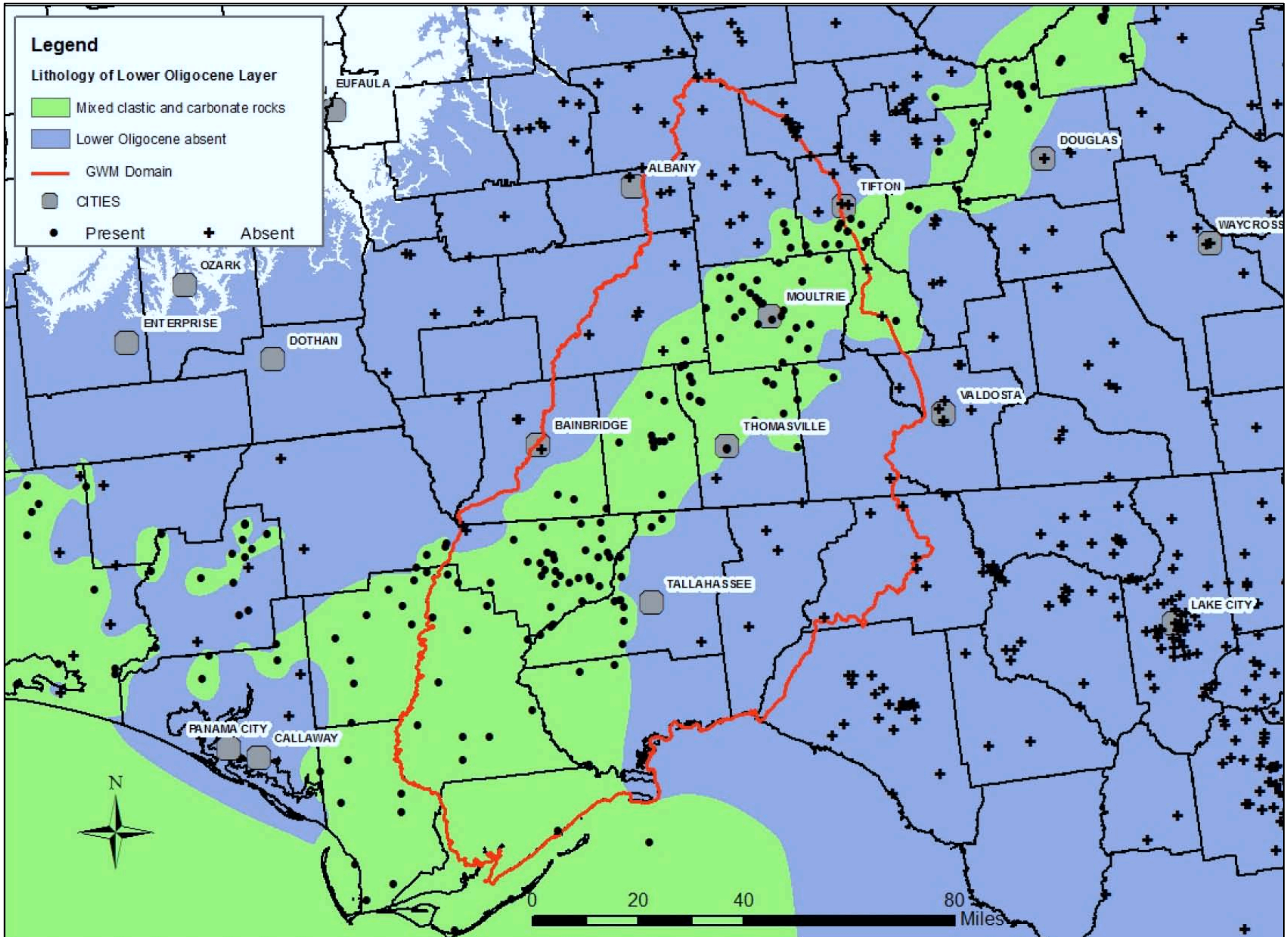
Revised Geology – Lower Oligocene Layer



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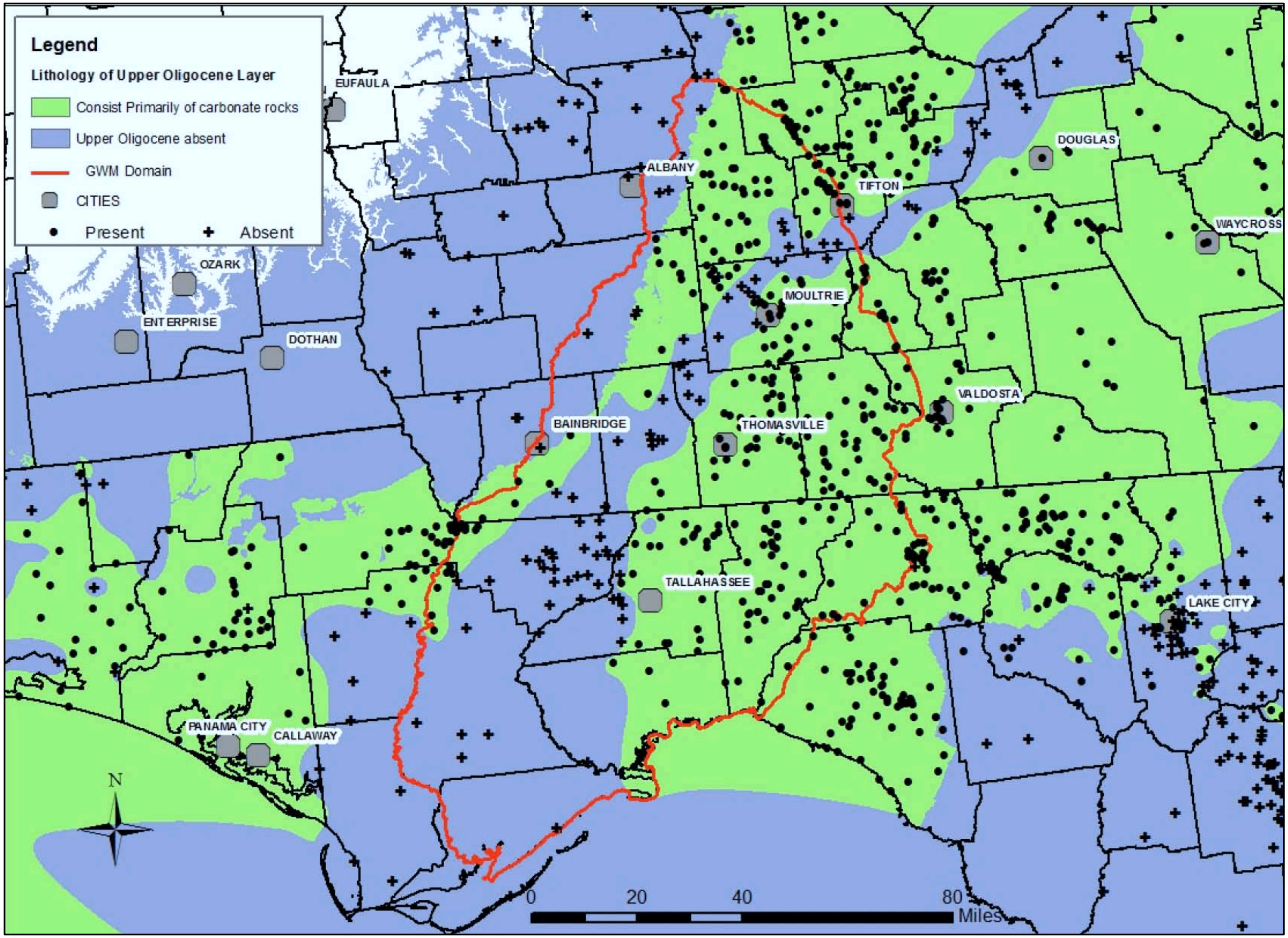
Revised Geology – Upper Oligocene Layer



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2012 Summary

- 2012 revisions were unexpected but necessary
  - Completed compilation and delineation of pumping
  - Completed revision of geologic layers
    - Synthesizes all available borehole data
    - Georgia and Florida
    - Formerly disjoint datasets
- The revised model has not been calibrated
- In order to complete the model …
  - Port the revised framework into FEFLOW
  - Recalibrate model to heads and spring flows
    - High-water & low-water head datasets
    - Revised assessment of Wakulla and St. Marks flows based on USGS gauging data
  - Projected timeline for recalibration: ~ 1 year
- Once completed, the north Florida hybrid model will be capable of producing reliable water supply and water quality assessment as well as environmental and development scenario analyses relatively quickly

Program Applications

- MFL
  - Delineate springsheds and boundary fluctuations
  - Define water budget for high and low water conditions
  - Quantify impacts of pumping
  - Quantify impacts of reuse and return flows
- TMDL
  - Delineate springsheds and boundary fluctuations
  - Define groundwater flow patterns and travel times
  - Define vulnerability zones
  - Define contaminant loading and breakthrough profiles

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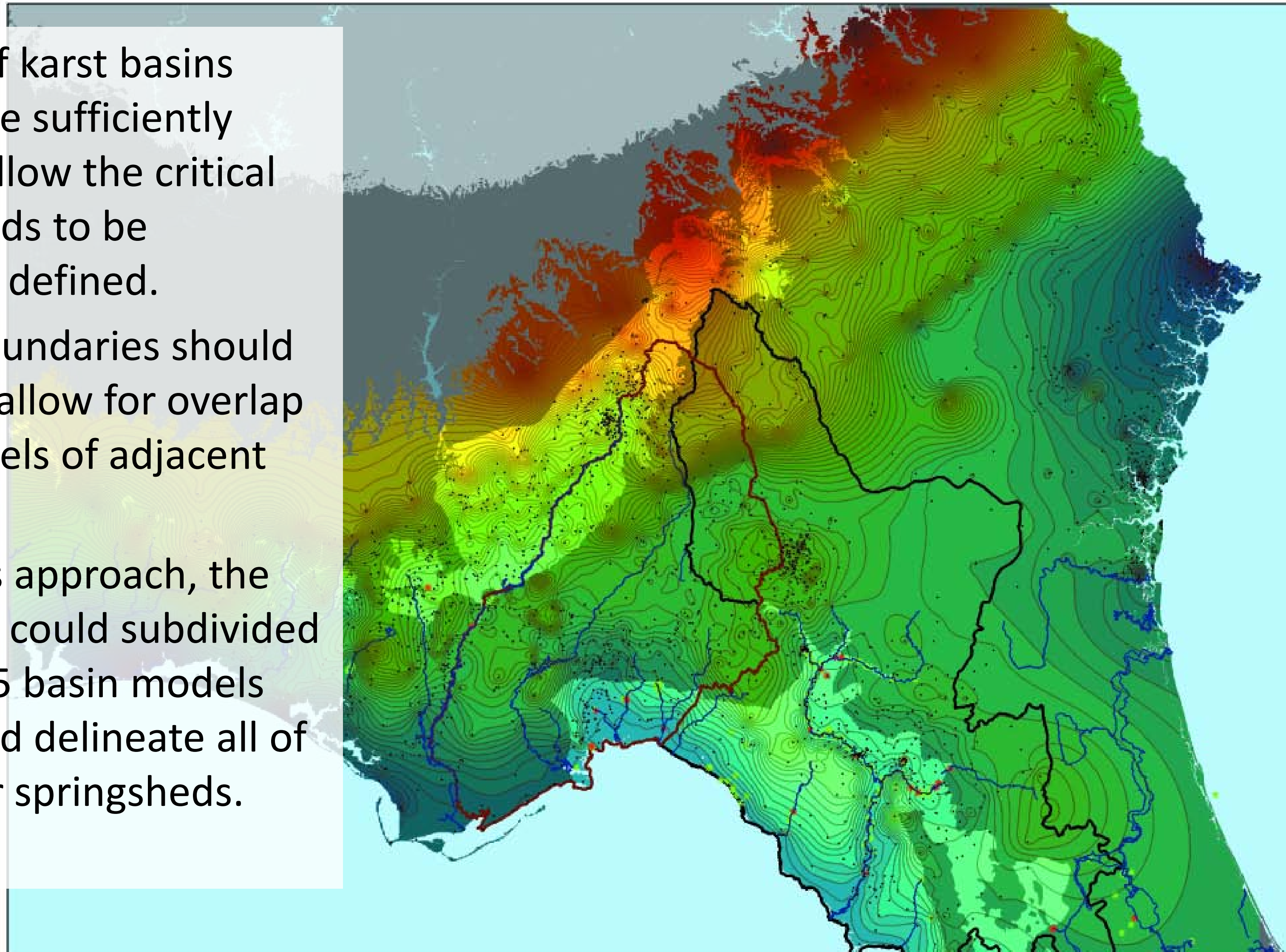
Broader Applications – *Florida's Karst Regions*

- Models of karst basins need to be sufficiently large to allow the critical springsheds to be internally defined.
- Model boundaries should be set to allow for overlap with models of adjacent basins.
- Using this approach, the Karst Belt could subdivided into 4 or 5 basin models that would delineate all of the major springsheds.



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Thanks for Listening

Acknowledgements

- *Florida Geological Survey*
  - Rodney DeHan, Jon Arthur, Scott Dyer, Tom Greenhalgh, Harley Means
  - FGS Staff
  - Applied research to solve problems
  - www.geohydros.com/FGS/

- *The Coca-Cola Company*
  - Vested interest in sustained clean freshwater discharge to the Western Santa Fe River
  - "Diminished water quality & quantity diminishes our business and their brand"
  - *www.geohydros.com/CCNA/*

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