Coca-Cola north america

Western Santa Fe River Basin Groundwater Resource Model

Results & Applications

September 30, 2009

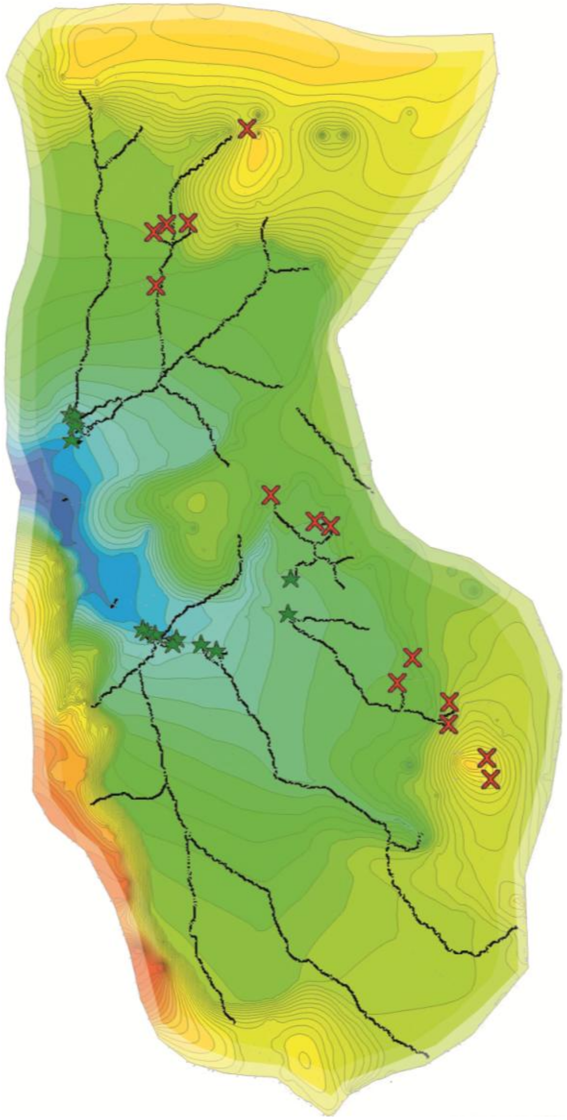
Santa Fe Springs Working Group

Poe Springs, Florida

GeoHydros, LLC

Coca-Cola North America

CCDA Waters, LLC



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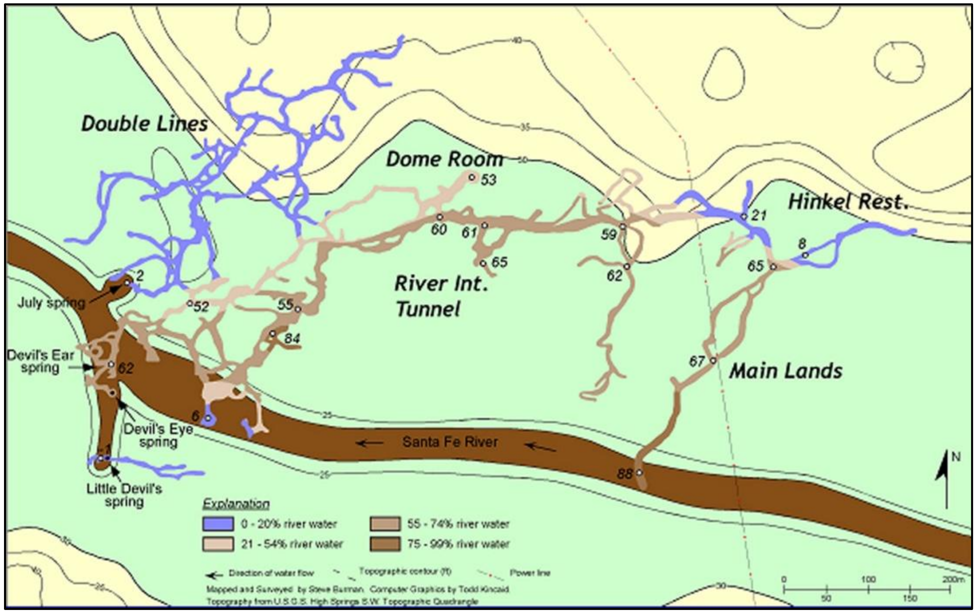
Our Background with this Project

Todd Kincaid, Ph.D.
Group Leader - H2H Specialized Geological Modeling Group
Reno, NV

Ph.D. – Univ. of Wyoming
M.S. & B.S. – Univ. of Florida
Modeling & Karst Work for 16+ years



- Cave diving & exploration
  - 20+ years in FL, Mexico, Turkey
- Lack of professional knowledge
  - Common hydrogeological practices assume no karst
- Improving understanding
  - Tracing & cave mapping
- Reliance on modeling
  - Management stems from model predictions
- Modeling limitations
  - Most models assume no karst (few or no springs, no swallets, no caves)
- Opportunities for improvement
  - New technology & better use of data yields better results

What is a groundwater model?

- Computer generated simulation of groundwater flow patterns & rates.
- Used to make predictions about impacts to flow and quality stemming from specific actions or conditions.
  - Development
  - Contaminant spills
  - Drought
- Confidence in predictions stems from the model's ability to simulate real-world conditions *(calibration).*
  - Models that accurately simulate present or past conditions are deemed to be reliable predictors of future conditions.
  - Models that calibrate to more and varied types of data are more unique than those that calibrate to small sets of similar types of data.
- In order to be reliable, modeling assumptions must be valid or applicable to the environment being modeled.

Project Objectives

- Develop a model that calibrates to high and low water conditions in the western Santa Fe River Basin.

  Most models only address average conditions

- Define all springsheds that may interact under varying conditions and contribute water to Ginnie Springs & CCNA's well.

  We know that springsheds change and interact under different conditions

- Develop a model that incorporates karst features and conduit flow patterns.
- Develop a model that will deliver reliable predictions of travel-times to springs.

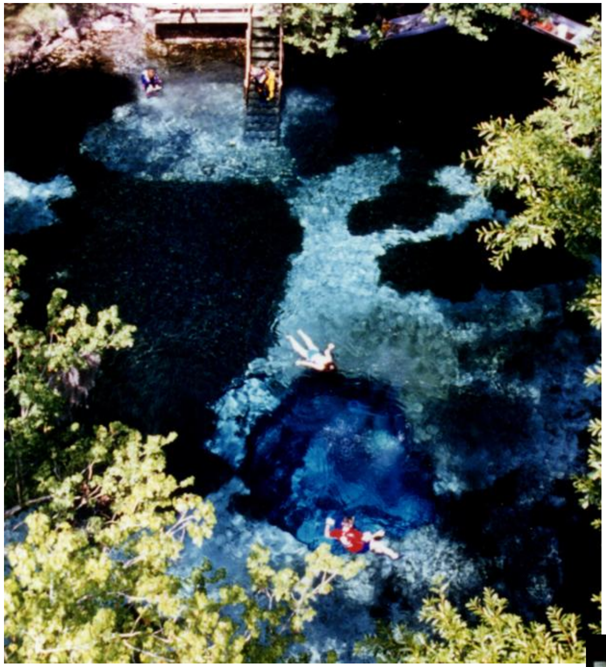
  Use model results to develop spring/aquifer vulnerability maps

- Develop a model that can be trusted by government resource managers.
- Share the model and model results with government resource managers and the public.

Important Hydrogeologic Complexities

Springs

large magnitude discrete discharges

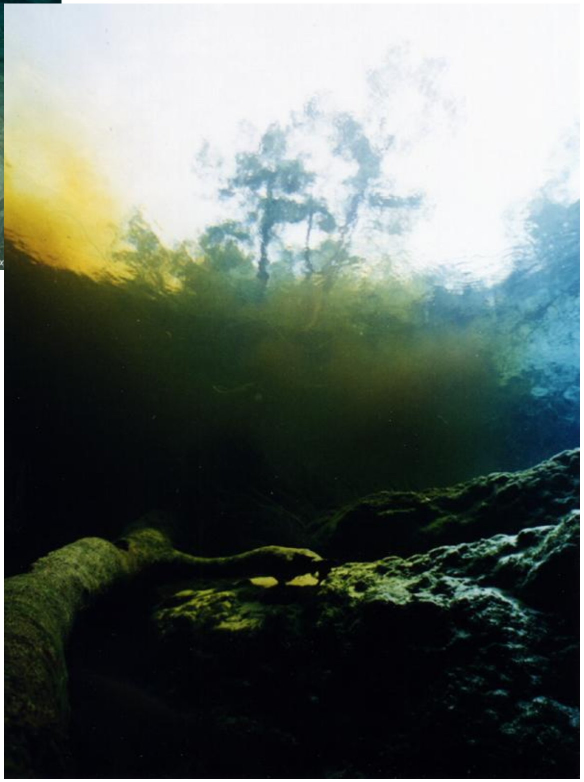


Conduits

Very significant preferential flow paths

GW / SW Mixing

Impacts water budget



Swallets

Large magnitude discrete recharge

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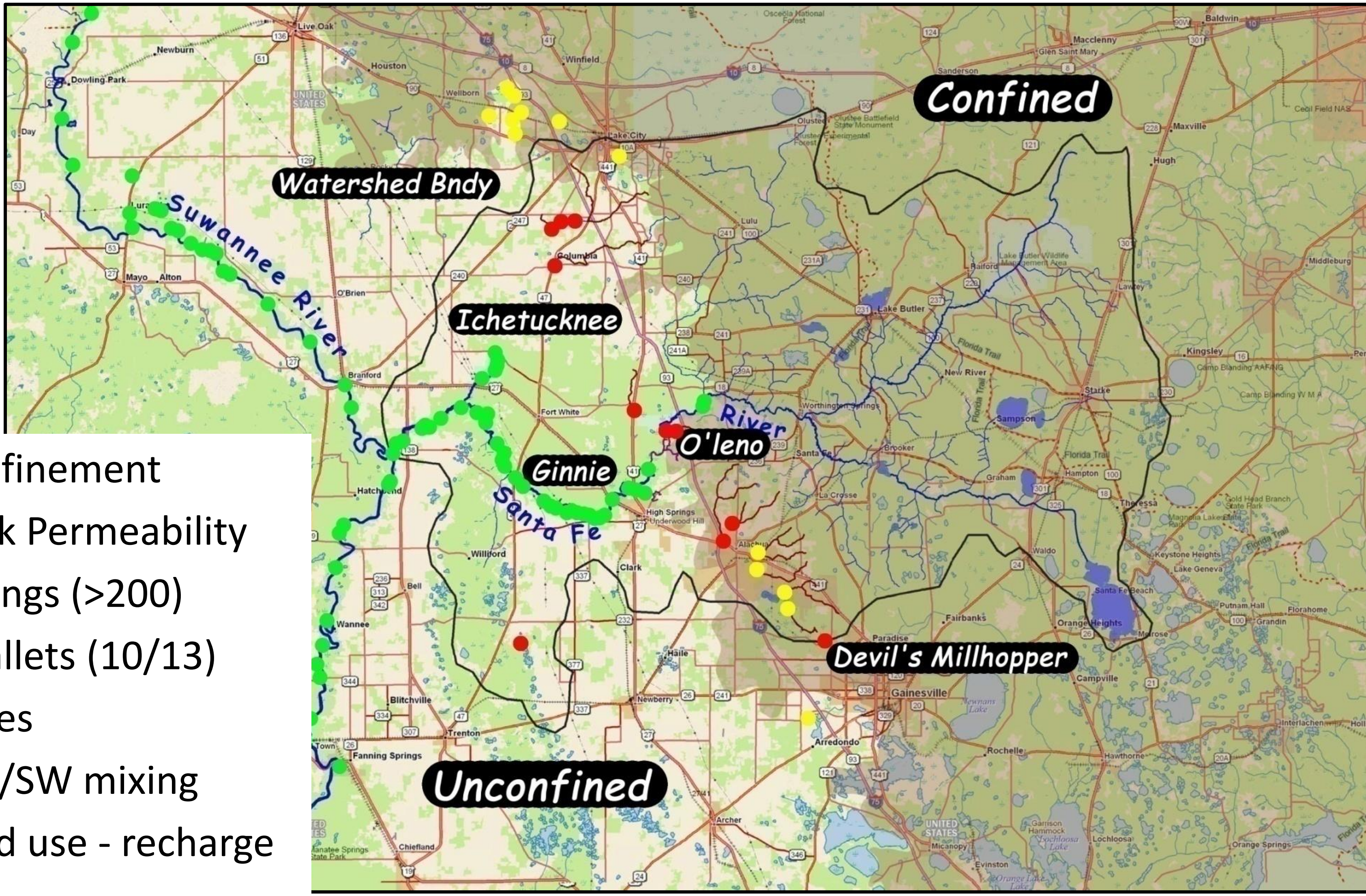
Important Hydrogeologic Complexities



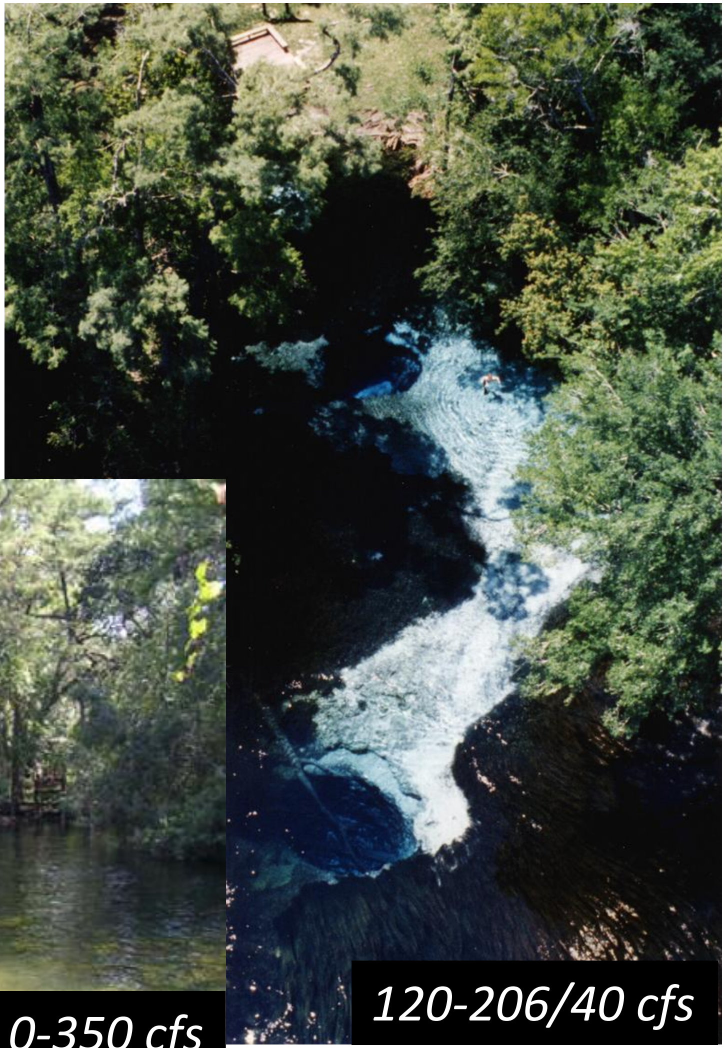
- Confinement
- Rock Permeability
- Springs (>200)
- Swallets (10/13)
- Caves
- GW/SW mixing
- Land use - recharge

Karst features create the dominant controls on flow

Springs: *Primary Groundwater Discharge*

- More than 200 springs in the SRWMD
  - 1st Mag (>= 100 cfs): 18
  - 2nd Mag (10-100 cfs): 81
  - 3rd Mag (1-10 cfs): 60
  - 4th Mag (.1-1 cfs): 37
- 81 in the Santa Fe River Basin
  - 1st Mag: 9
  - 2nd Mag: 36
  - 3rd Mag: 23
  - 4th Mag: 8
- Not all springs are the same
  - *Some get water from rain seeping into rocks*
  - *Some get water from drainage into swallets*

Devil's Ear / Devil's Eye Springs

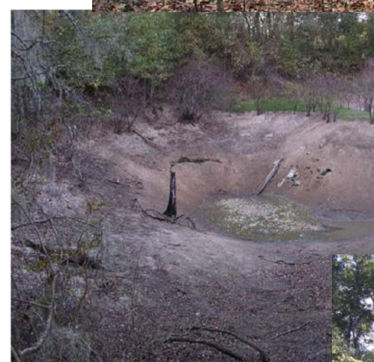


Hornsby Spring

Must properly address springs & spring types

Swallets: *High Volume Rapid Recharge*

- Swallets: disappearing streams that fully connect the land surface to the FAS.
  - 11 known & documented features
  - O'leno Sink, Clay Hole Group (3), Rose Creek, Mill Creek (2), Hammock, Pareners Branch, Waters Lake, Devil's Millhopper
- Swallet-Seeps: basins containing perched water above FAS that deliver high recharge.
  - 13 features
  - Burnett's Lake, Lee Creek Sink, Turkey Creek Sink, Blues Creek Sink, Alligator Lake, Lake Luna, Lake Ogden, Lake Wilson, Hancock Lake, Orange Pond, "String of Ponds, " Lake Jeffrey, Hogtown Prairie



Swallets are significant components of the water budget

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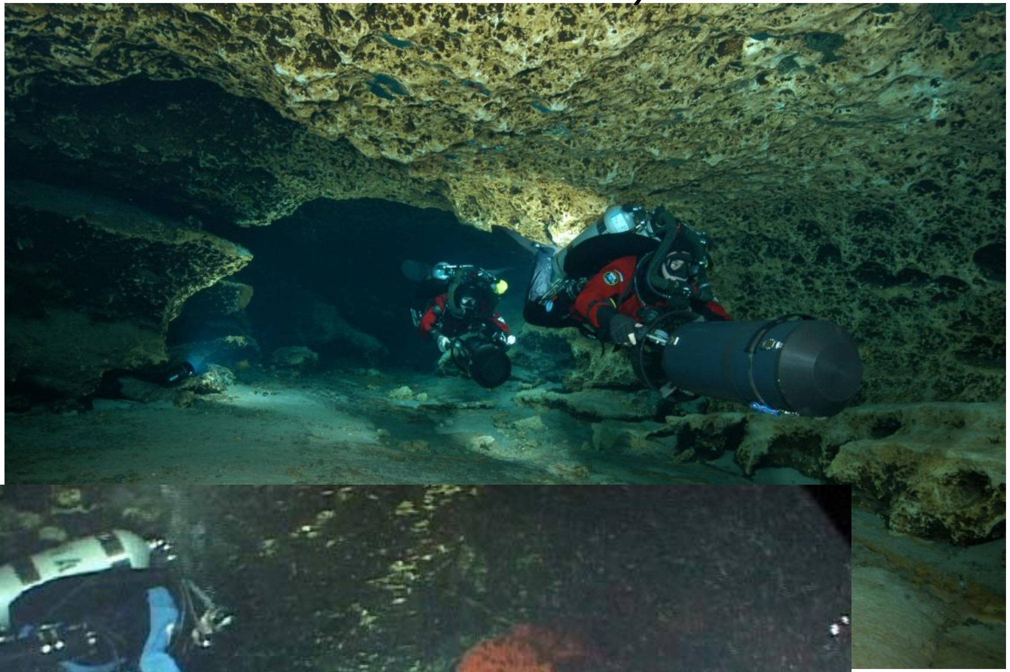
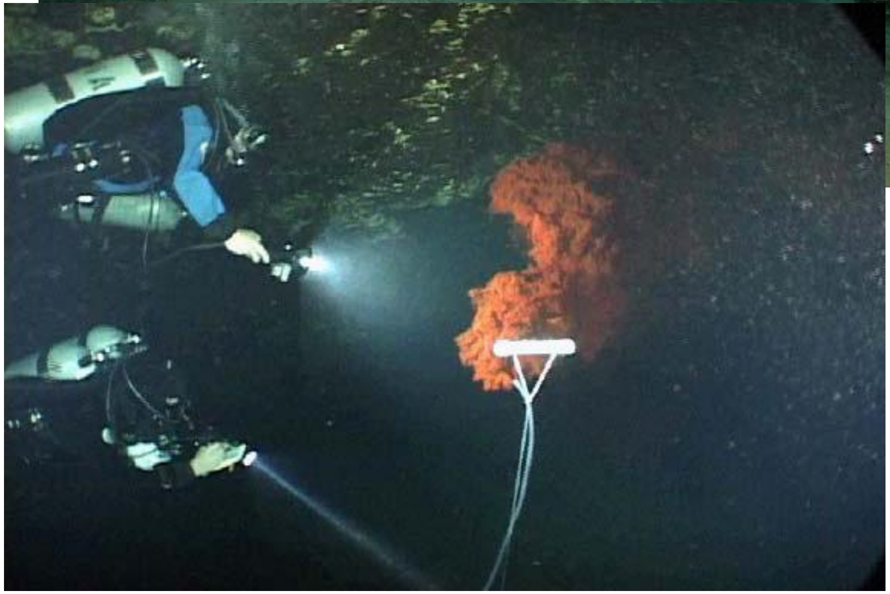
Caves: *Groundwater Highways*

- Numerous explored & mapped caves
  - Old Bellamy, Hornsby, Devil's Ear, Mill Creek, Rose Sink, Ginnie, etc.
  - Depths trend 75 – 150 ft
  - Diameters: ~3 – 30 ft
- More traced caves
  - Rose Creek, Clay Hole, Mill Creek, San Felasco, Ichetucknee, Ginnie
  - ~200 – 750 m/day
- Probably many more that have not been documented
- Large flow & velocity range
  - Spring caves
  - Sinkhole caves

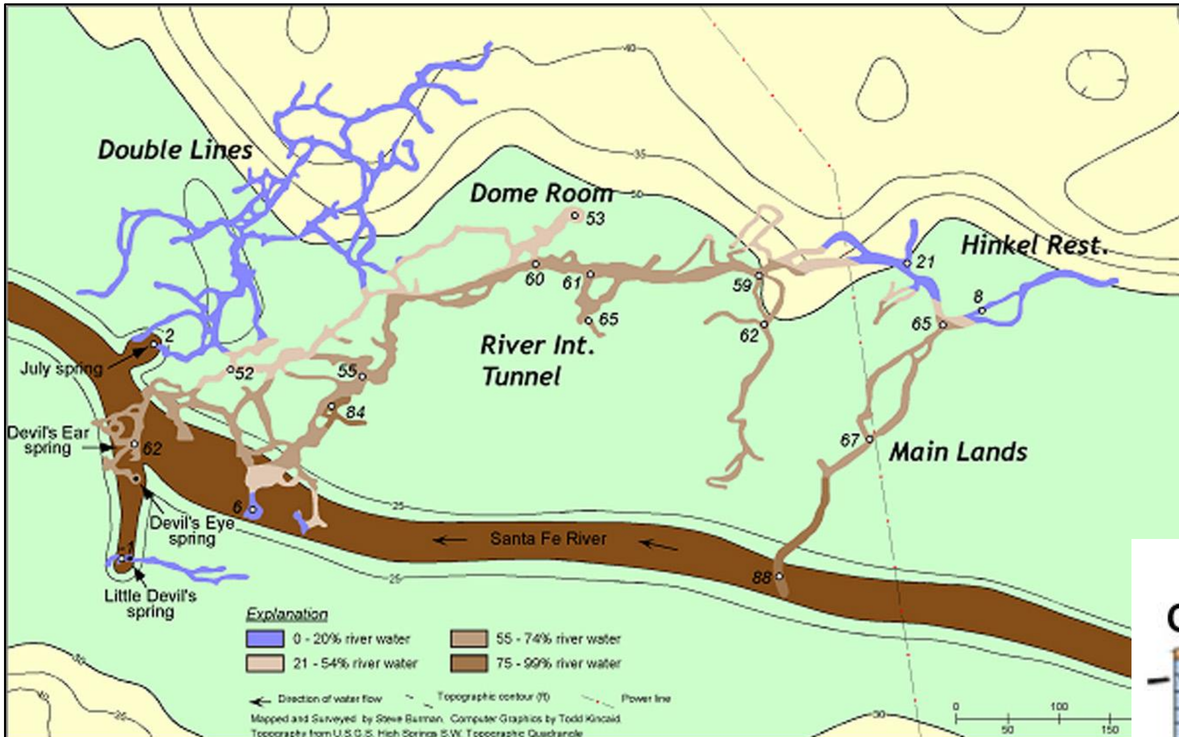
Devil's Ear Cave System

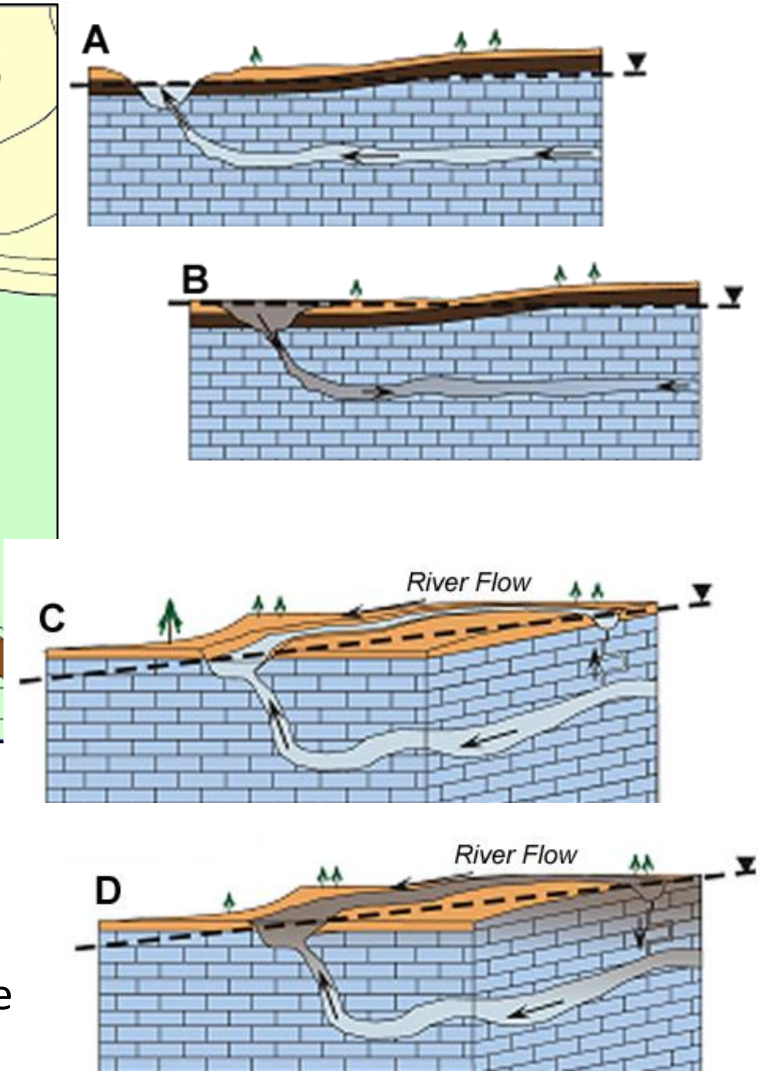




Must adequately address conduit control on flow patterns

Groundwater / Surface Water Mixing

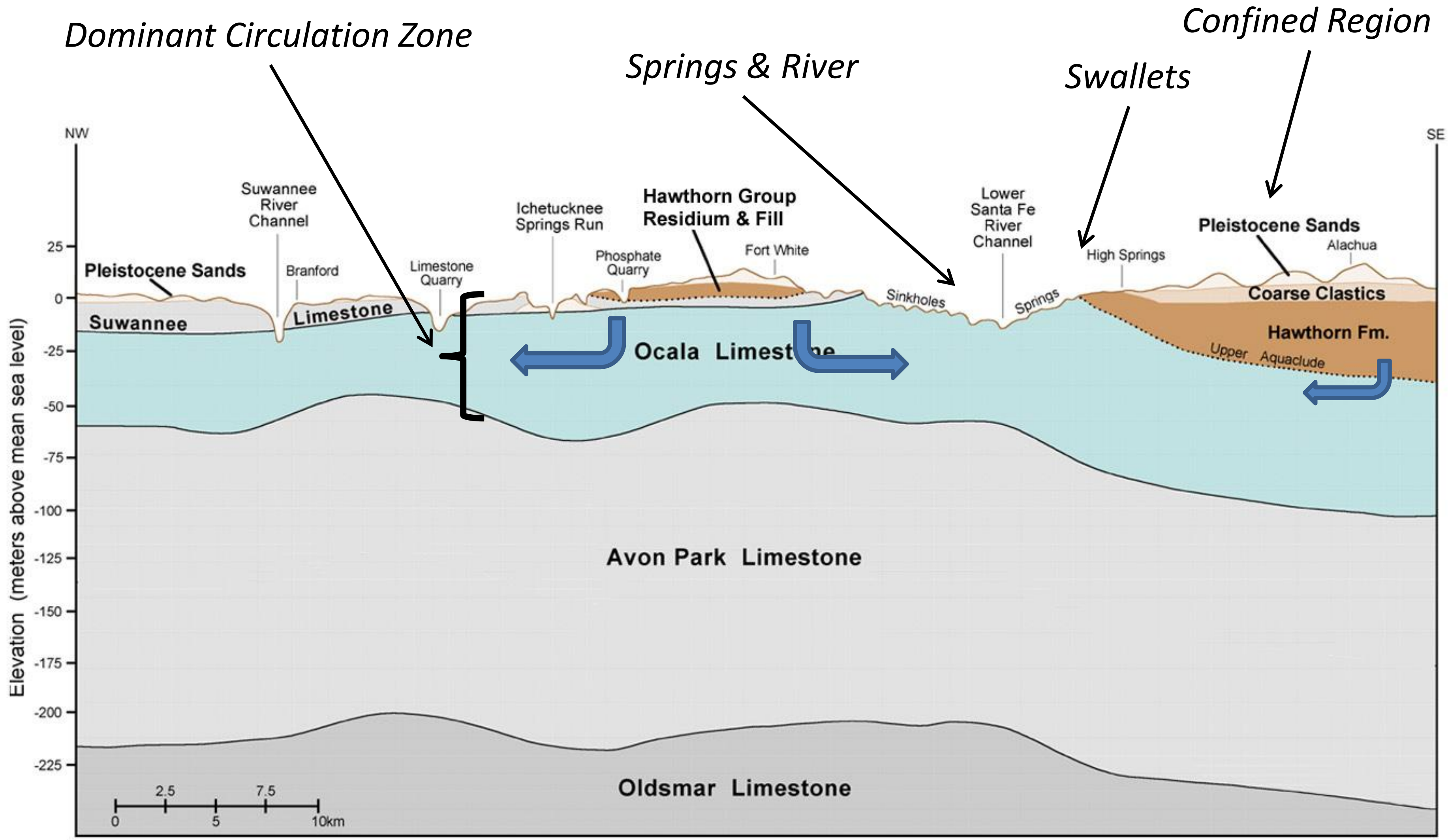




- Mixing occurs over very rapid time scales
  - *days rather than years*
- Can account for 50 – 100% of flow
- Degree of mixing is reflected by color of the discharge
- Need to constrain mixing in order to establish an accurate water budget

Mixing impacts the water budget

Geologic Controls on Groundwater Flow



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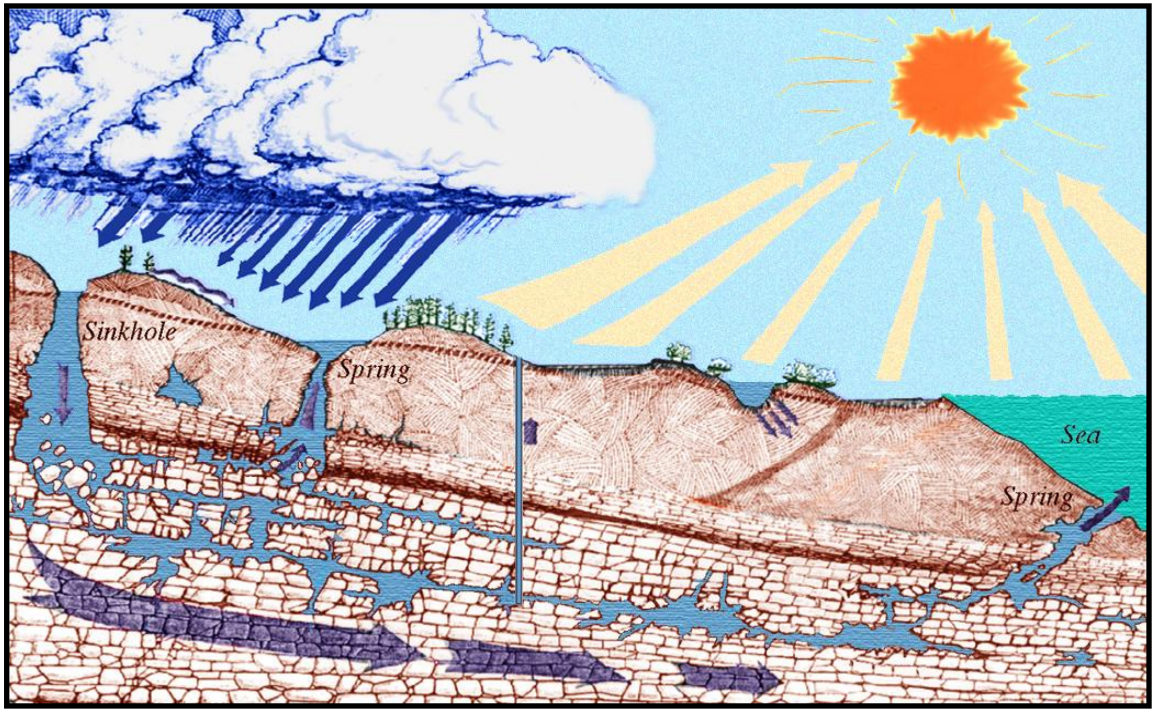
What is a Water Budget?

How much groundwater do we have?



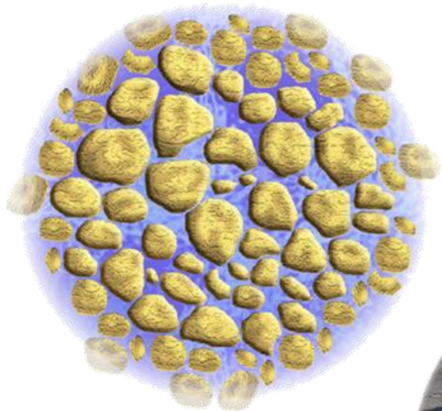
Water Budget

- 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.

Basic Conceptualization Options

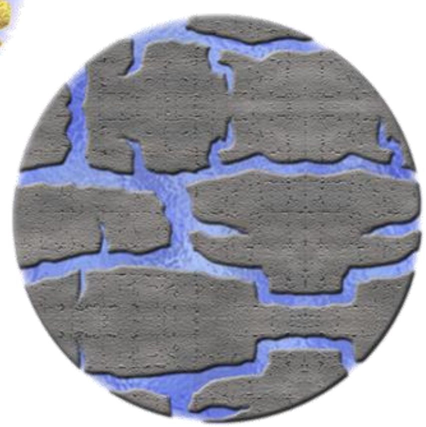
Porous Media



Most commonly assumed

sand / sandstone
easy to characterize
simplest math

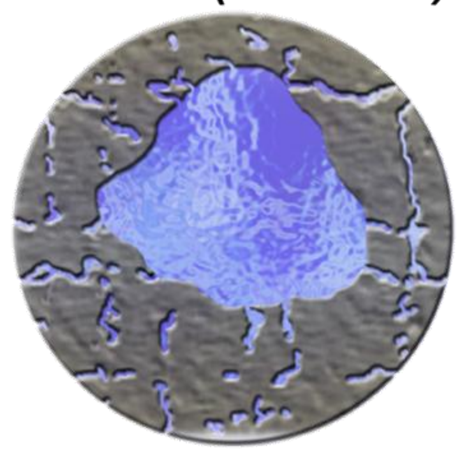
Fractered Rock



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

Most commonly true

Karst (Conduits)

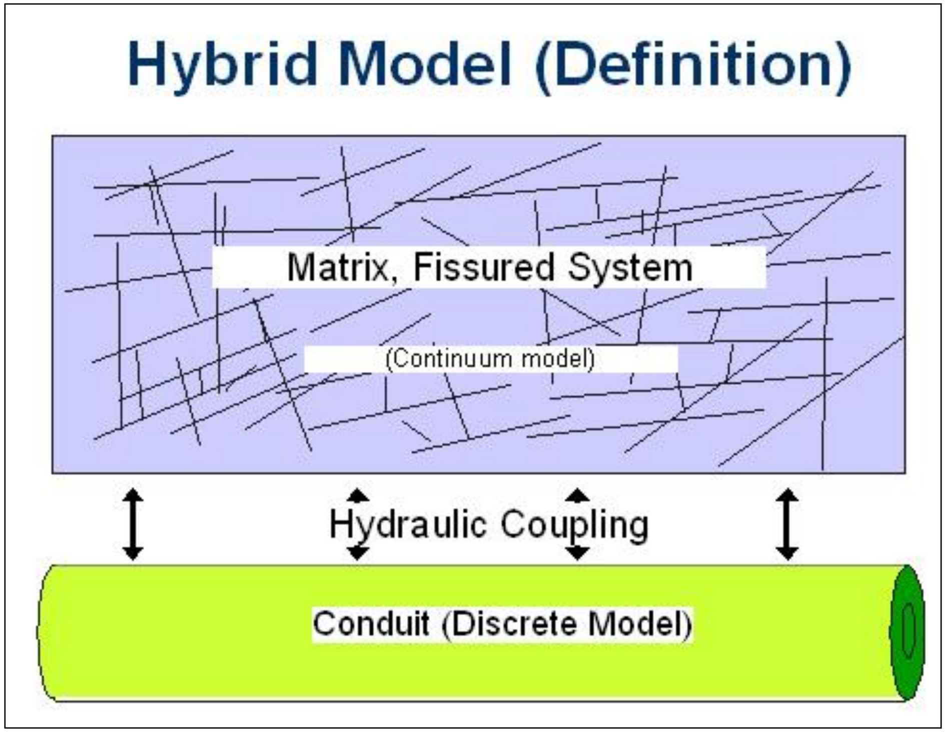


Limestone (Floridan Aquifer)
cannot typically be mapped
hardest to characterize
most difficult math

Start with an accurate conceptualization

Numerical Approach & Software

- 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^{TM}
  - Commercially available (DHI-WASY)
  - Commonly used by national laboratories & research institutions.
  - Discrete element features allow for hybrid model design.



WASY Software FEFLOW WASY

http://www.feflow.info/

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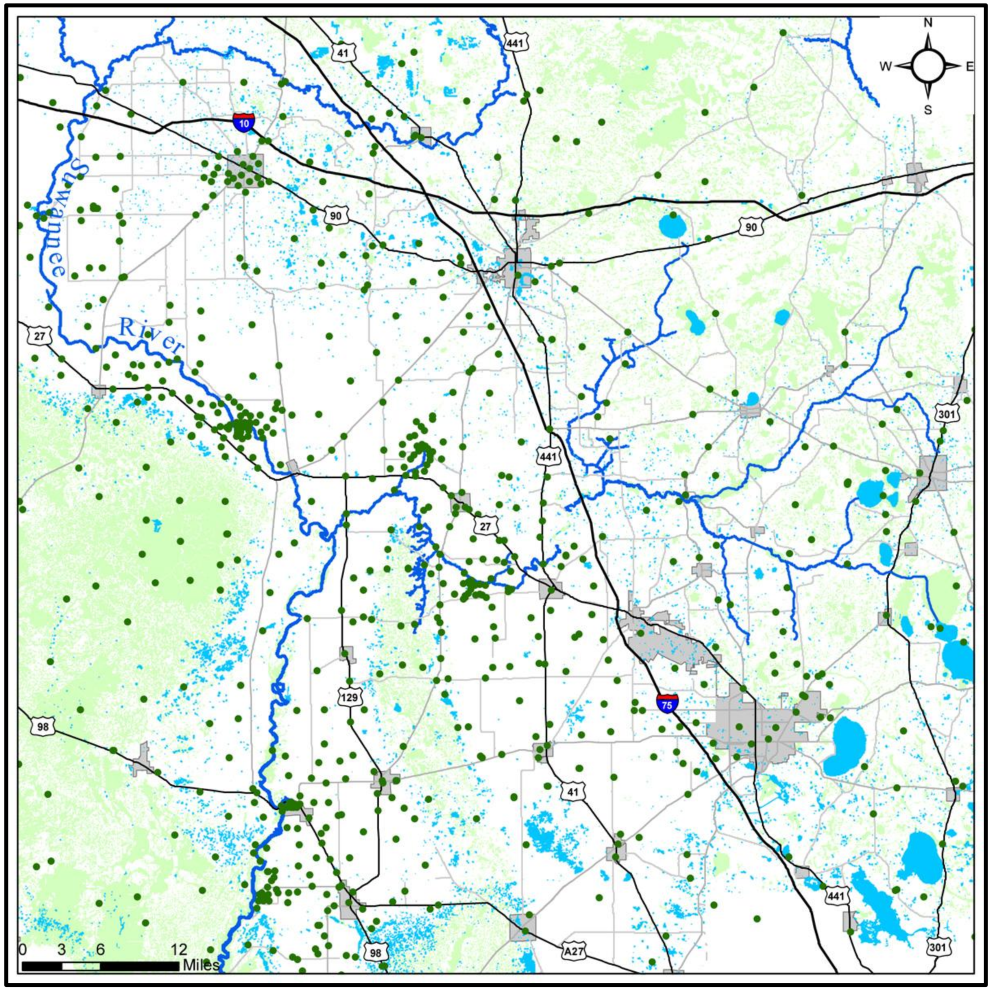
Data Compilation: *Groundwater Levels*

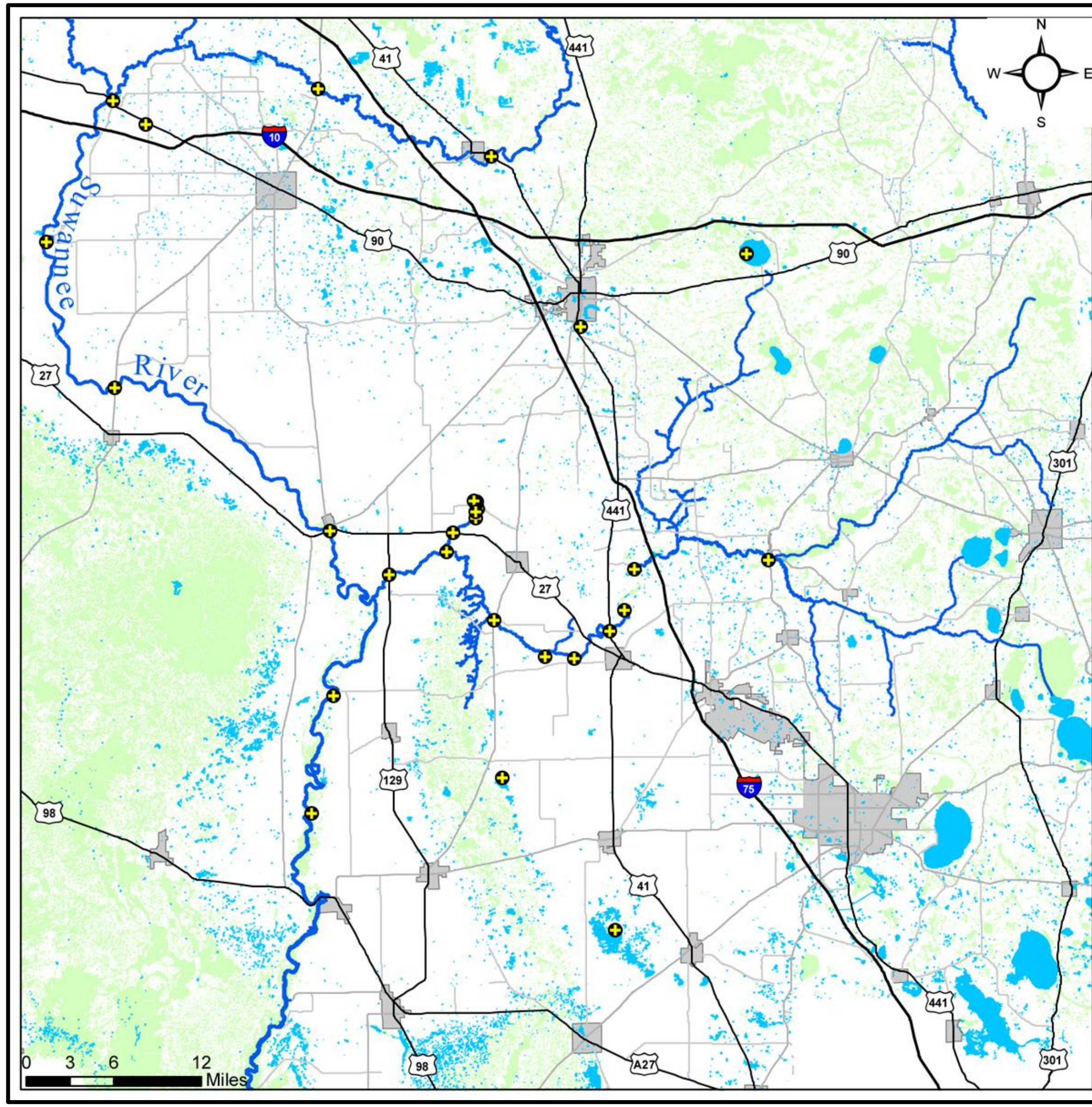
- Wells east of Suwannee River = 691
  - SWRWM = 484
  - ACEPD = 174
  - KES = 21
  - SRWMD & ACEPD = 6
  - ACEPD & KES = 6
- Wells in model area = 250
- Identified highest water periods as:
  - Jan 1998 – May 1999
  - Oct 2004 – Dec 2005
- High water period wells = 396
- Identified lowest water periods as:
  - Jan 2001 – Dec 2002
  - May 2007 – Oct 2007
- Low water period wells = 571



Data compiled from area much broader than model area

Data Compilation: *River, Lakes, & Springs*

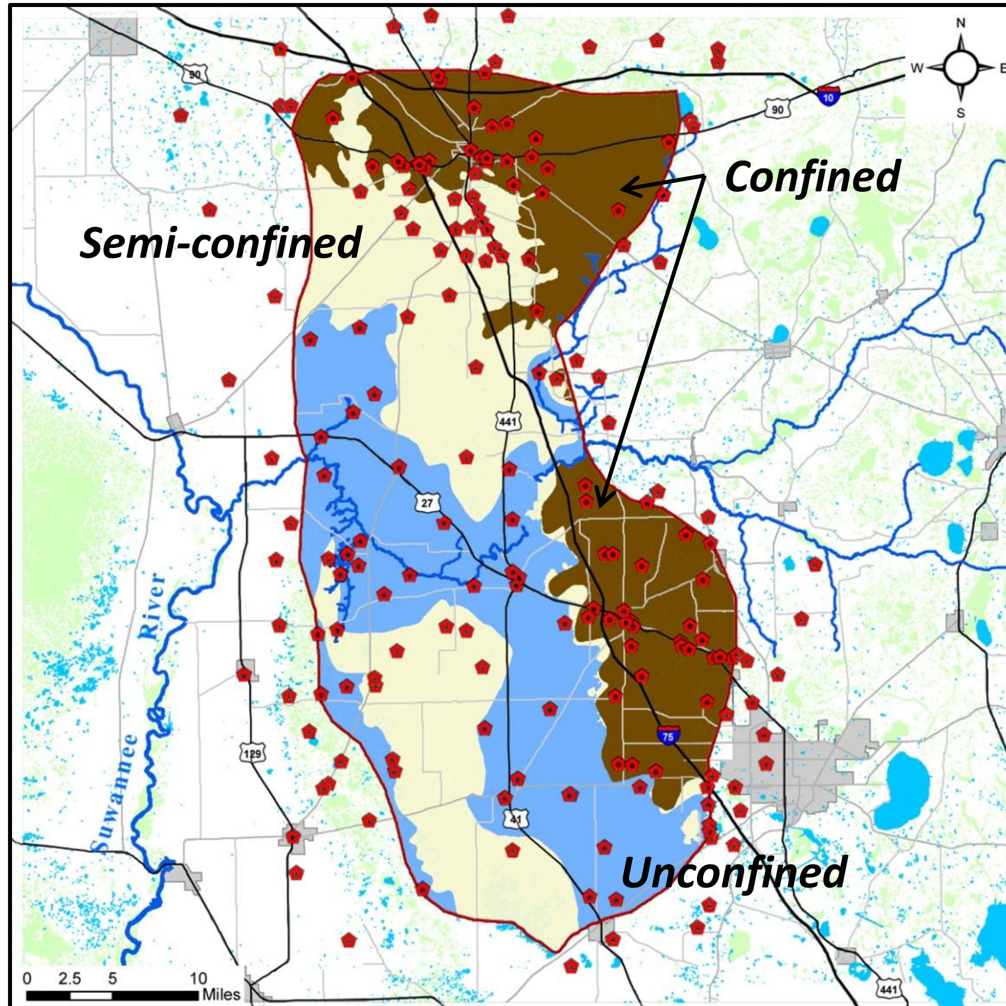
- Total stations = 30
  - Lakes: 4
  - Rivers: 14
  - Springs: 12
- Data sources
  - SRWMD
  - USGS
  - ACEPD



Stage data used to constrain head fields

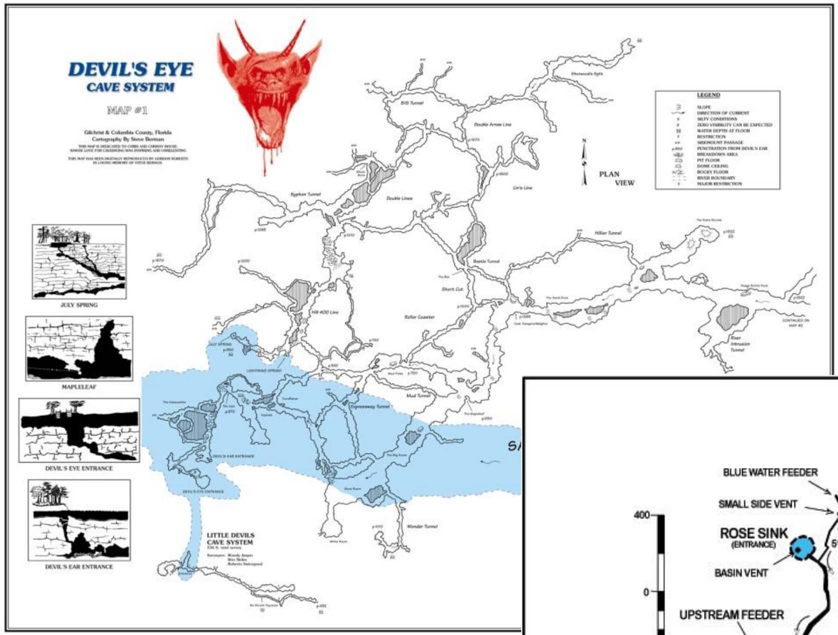
Data Compilation: *Geology*

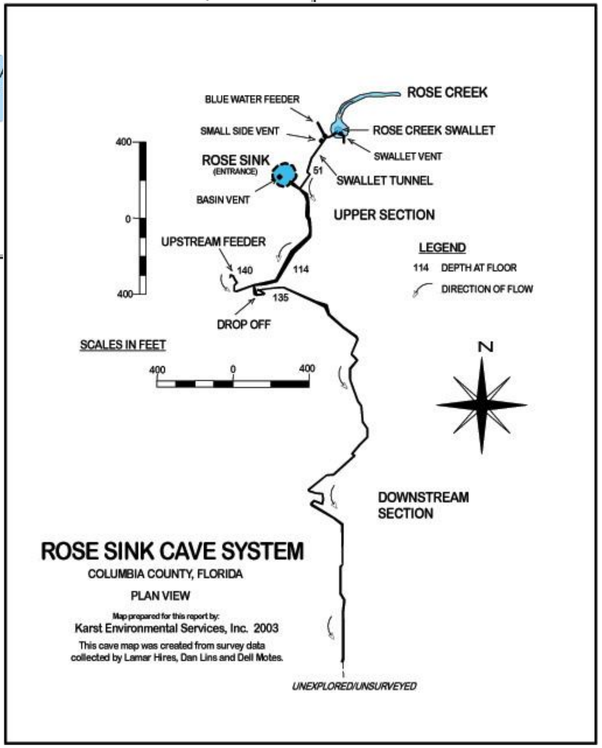
- Compilation of maps (layer extent) and boreholes (layer thickness)
- Surficial aquifer
  - Semi-confining unit
  - Sand covering limestone & clay
  - Moderate recharge / permeability
- Confining unit
  - Predominantly clay
  - Very low recharge / permeability
- Upper Floridan Aquifer
  - Limestone
  - High recharge / permeability
- Sources
  - FGS lithprog database: 198 boreholes
  - Geologic Map of Florida (FGS, 2001)
  - Env. Geology of Florida (FGS, 2001)
  - Alachua County Aquifer Confinement (FGS, 1998)



Data Compilation: *Known Caves in Area*

- Prevalence of known caves indicates pervasive conduit development.
- Spring Caves
  - Devil's Ear / Devil's Eye / July
  - Ginnie
  - Hornsby
  - Blue Hole
- Swallet Caves
  - Mill Creek Sink
  - Rose Creek Sink

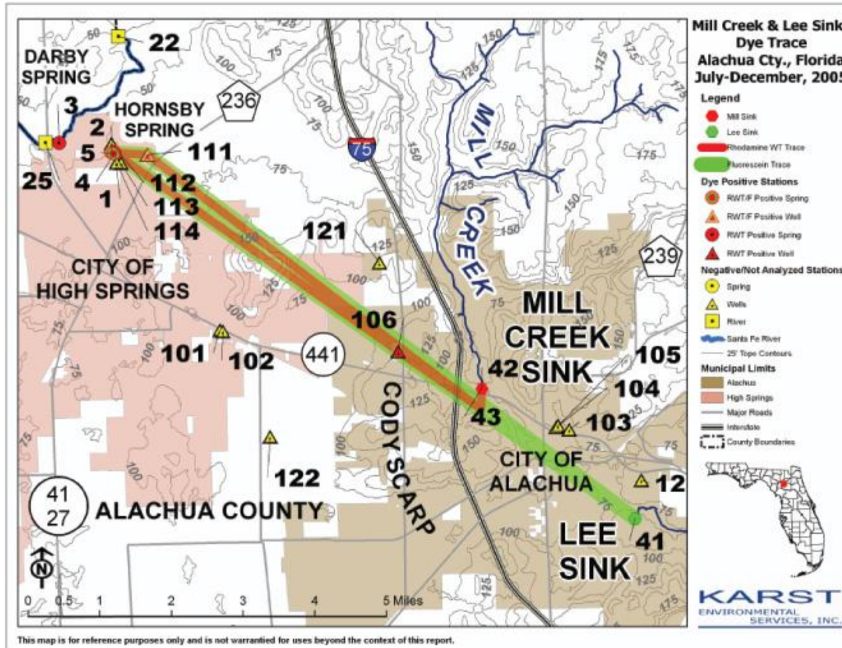


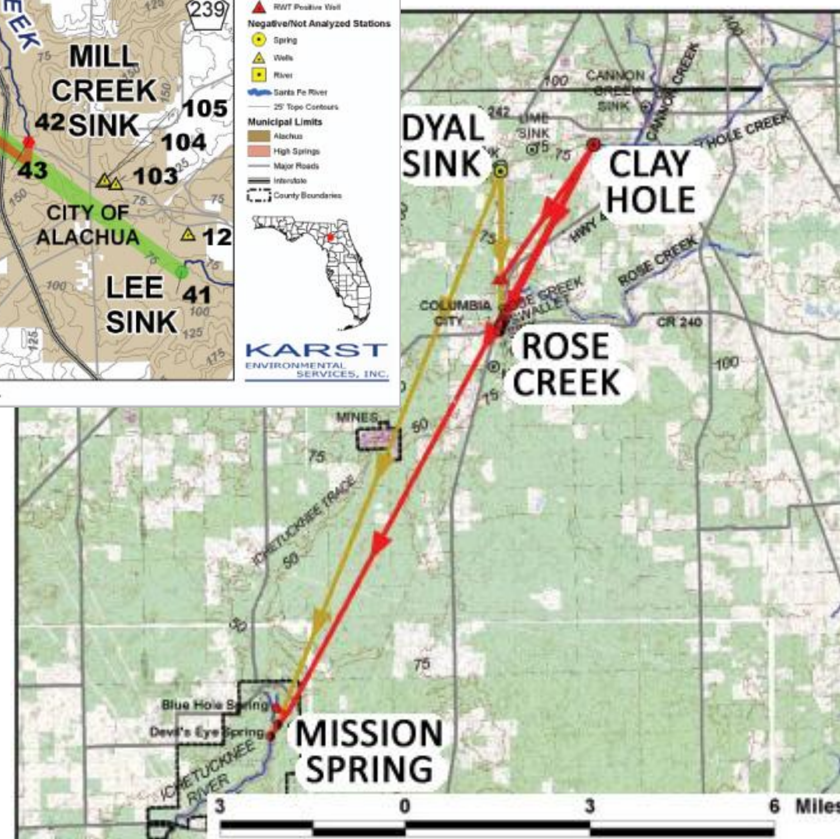


Non-standard data & observations critical to model

Data Compilation: *Groundwater Tracing*

- Clay Hole - Mission
  - Inj. 5/15/03
  - Dry conditions
  - Rainfall fills sink on 6/4/03
  - Dye arrives at Blue Hole & Mission
    - 1st detect: 7/31
    - Peak arrival: 8/14
  - Distance: >= 50,000 ft
  - Travel time: 46 – 72 days
  - Velocity: 690 – 1090 ft/day (210-330 m/day)
- Mill Creek – Hornsby
  - Inj. 7/26/05: wet conditions
  - Velocity: 1400 – 2400 ft/day (430-730 m/day)





Non-standard data & observations critical to model

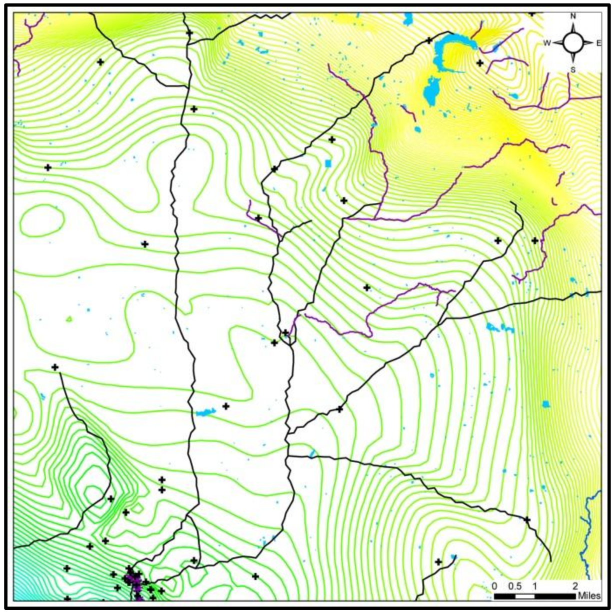
Groundwater Modeling Process

- Design model to match known physical conditions
  - geology, caves, well & spring locations, swallet inputs
  - Recharge ranges (bounded by rainfall data & land use)
- Define physics of groundwater flow
  - Porous media in rock / Pipe flow in caves
- Run model and compare results against data
  - Groundwater levels, Springs, Groundwater velocities (tracing)
- Adjust model parameters *(within reasonable limits)*
  - Rock permeability, Cave locations & dimensions
  - Recharge *(bounded by data and zones defined by land use)*
- Rerun model with new settings
- Repeat process until simulation matches data
- Run model with low water recharge (only adjust recharge)
- Compare results against data
- Adjust model parameters and rerun as necessary
- Repeat whole process until model simulates both high water and low water conditions with same parameter settings

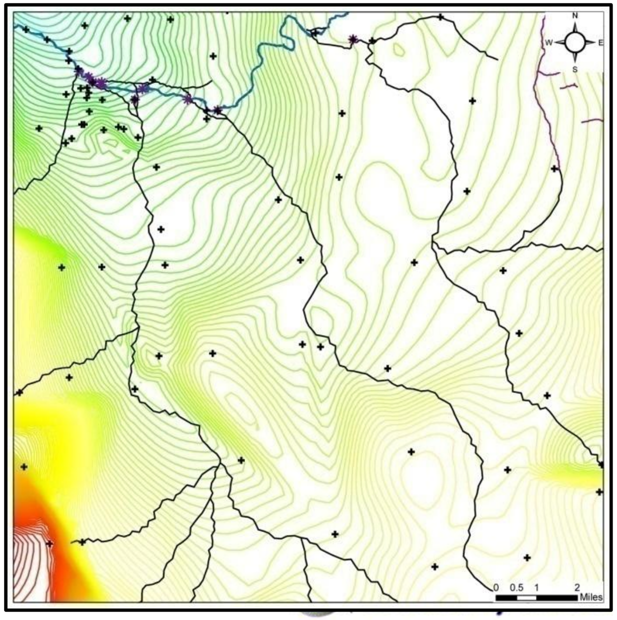
Conduit Locations & Assignments

- 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)

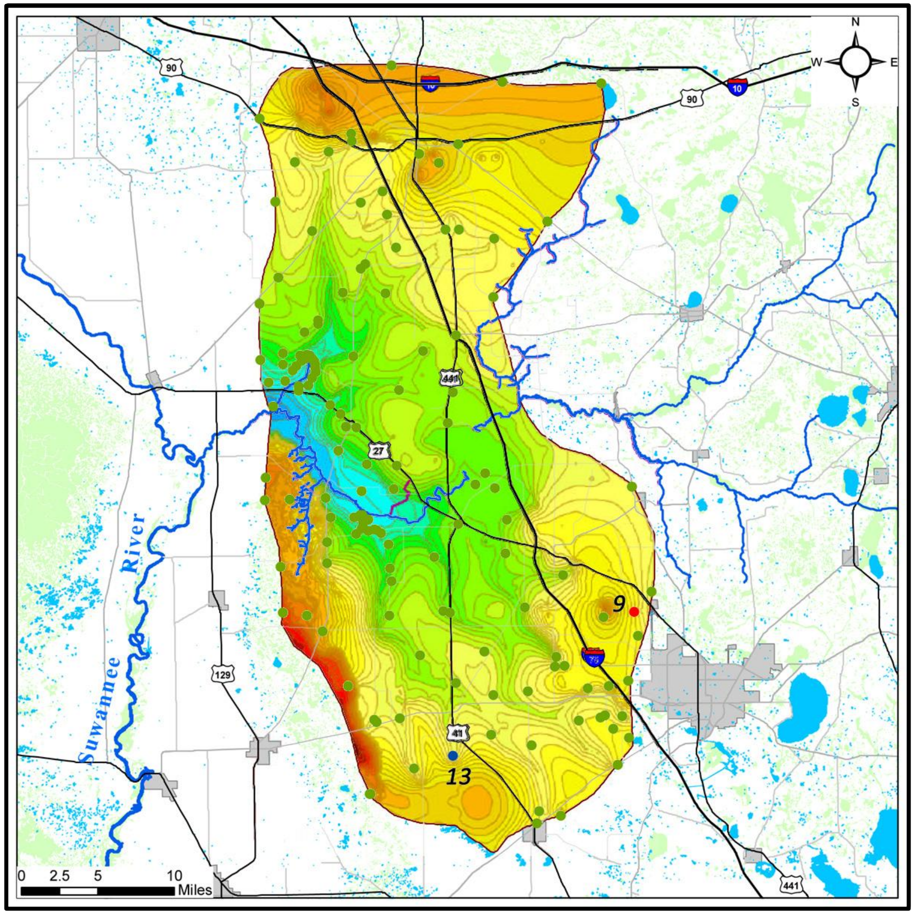
Northern Region

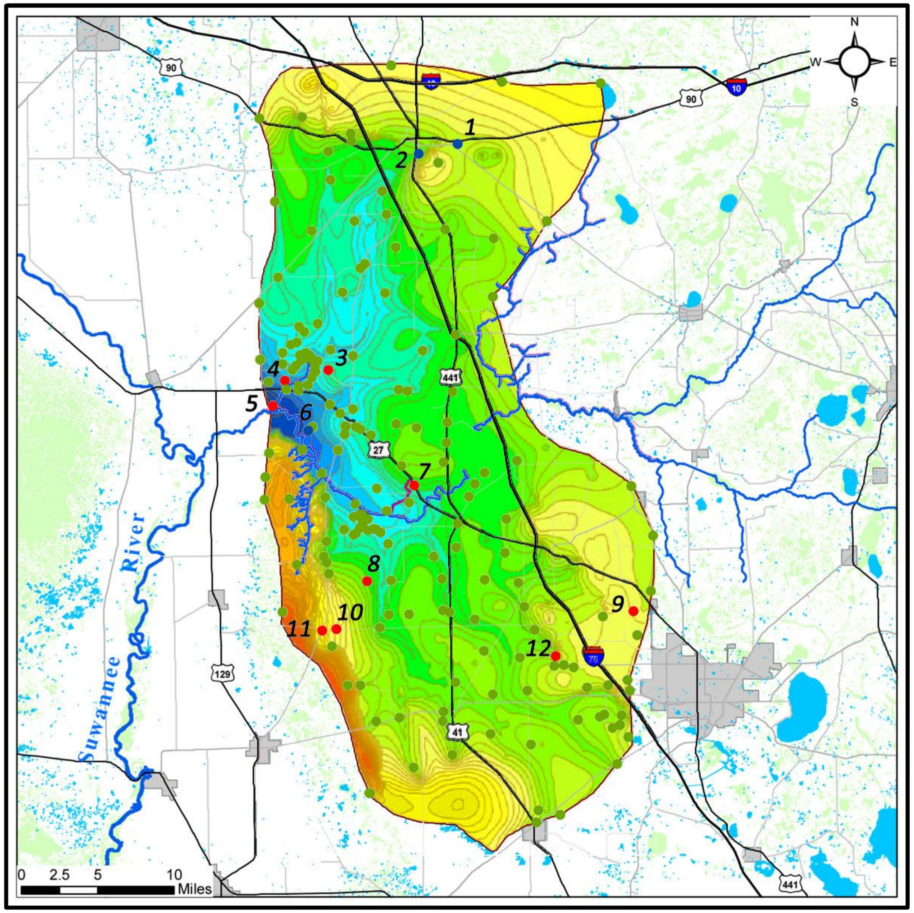


Southern Region



Model Calibration: *Groundwater Levels*





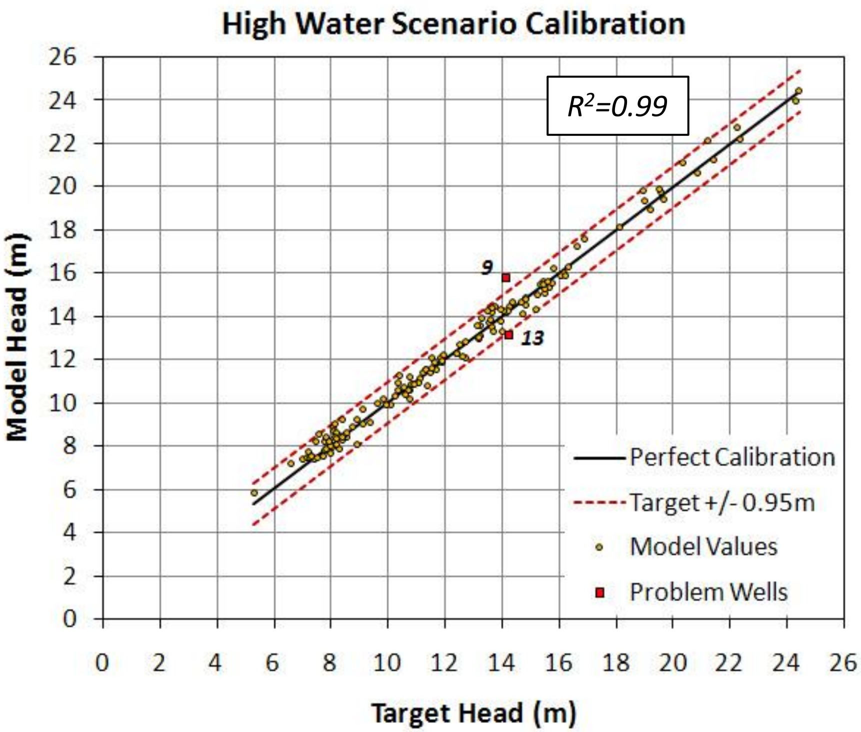
Green = calibrated (Red = high / Blue = low)

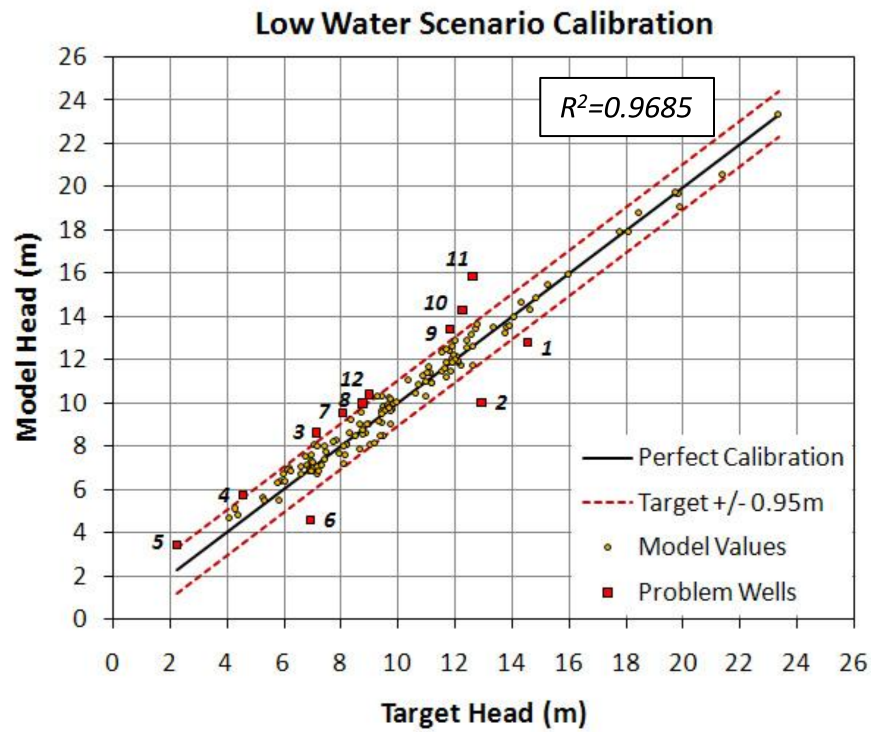
- High water: 143/145 wells calibrated
- +/- 0.95 m (~3 ft)
- Problems near mounds & conduits

- Low water: 176/188 wells calibrated
- +/- 1.05 m (~3ft)
- Problems near mounds & conduits

Both scenarios are very well calibrated

Model Calibration: *Groundwater Levels*





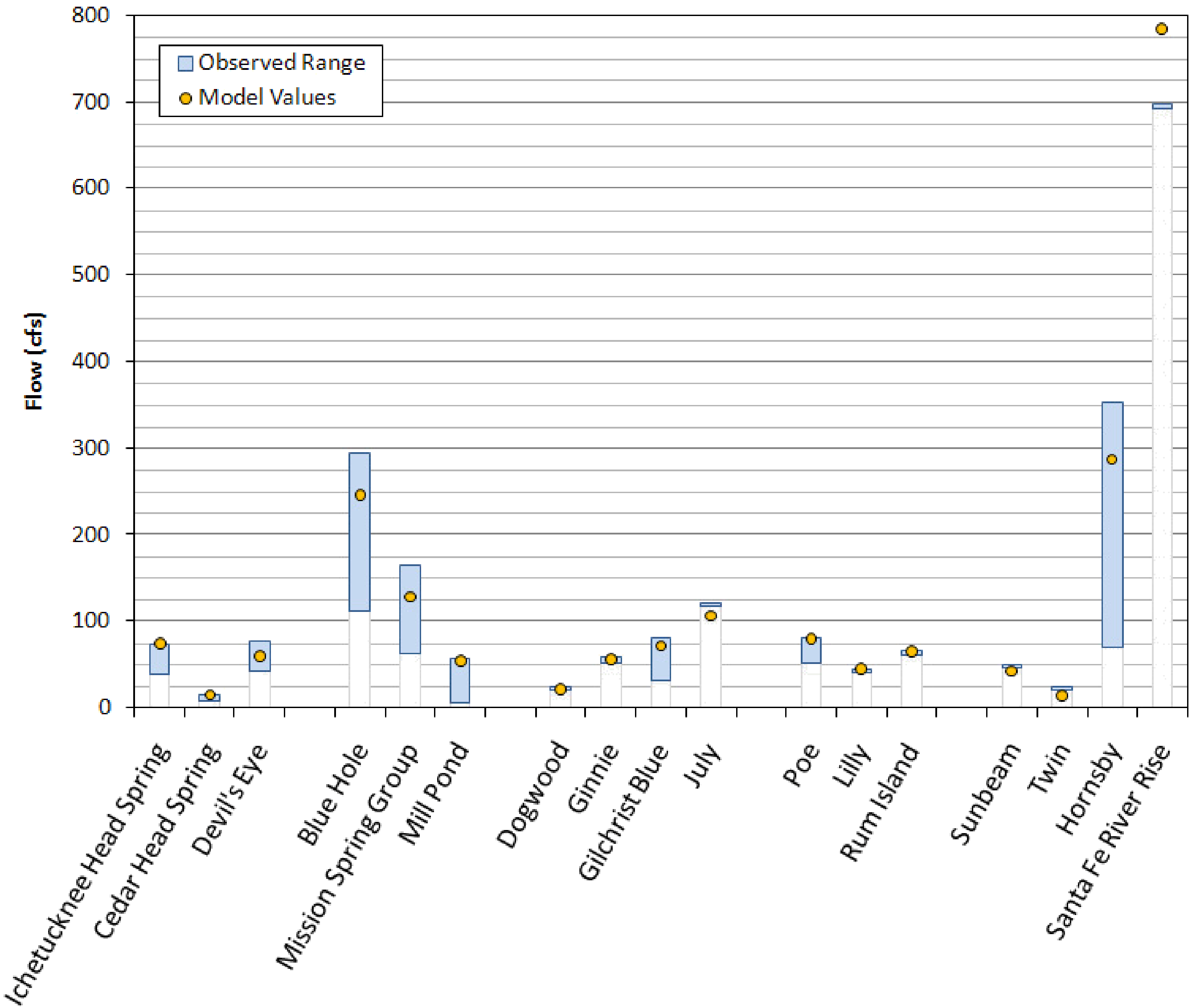
- Plots show how well the model simulates known groundwater levels.
- Perfect match would be the black line.
- All points within the red dashed lines are “calibrated.”
- Could not achieve this good of a match if it were not for including the conduits.
- Even the points that fall outside the red lines 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.

Both scenarios are very well calibrated

Model Calibration: *Spring Flows*

High Water Simulation

- 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

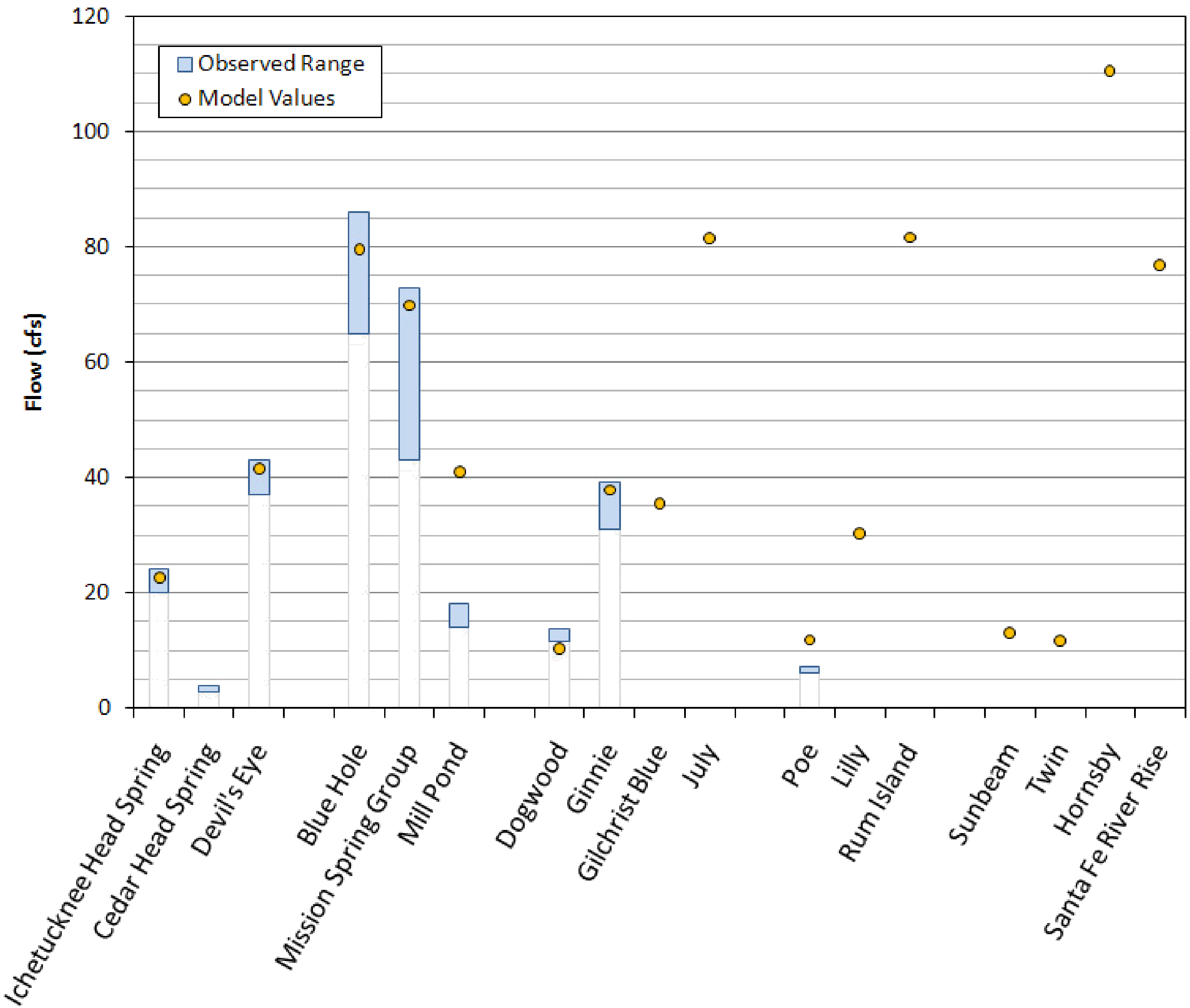


High Water Scenario is Very Well Calibrated

Model Calibration: *Spring Flows*

<u>*Low Water Simulation*</u>

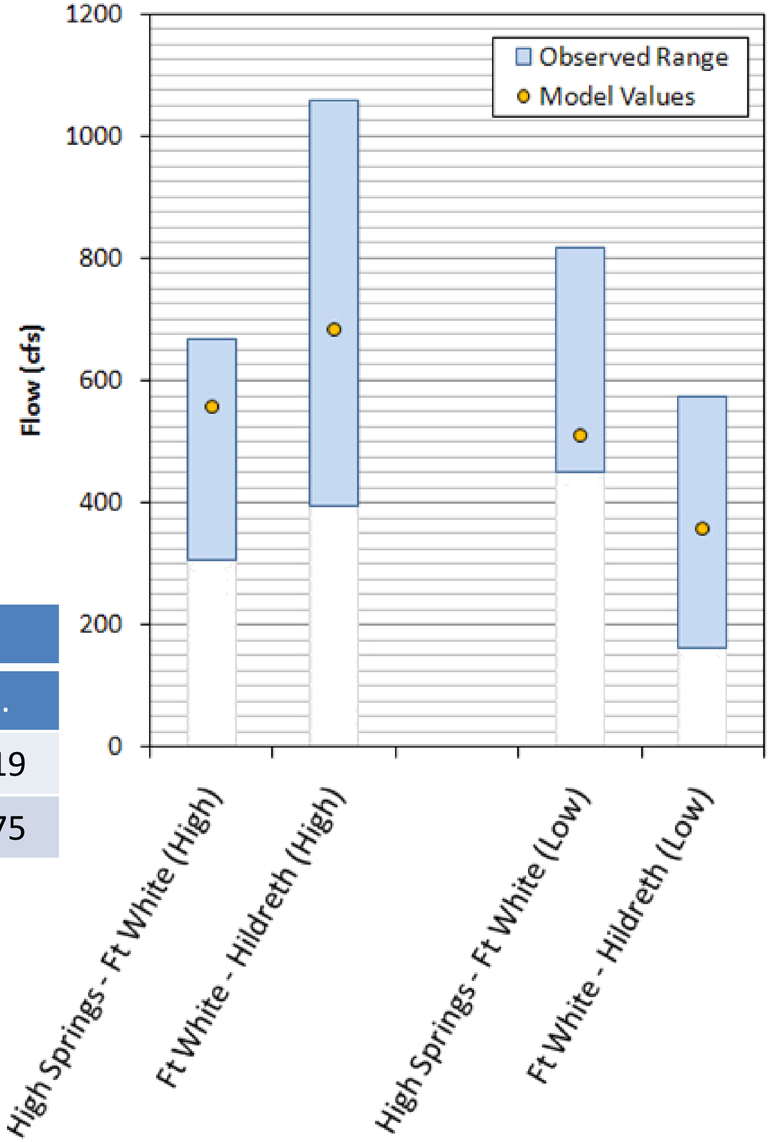
- Data for 9 springs
- Model within observed range at 5
- Model very close at 3
- Over estimated Mill Pond
- Still within “reasonable range” for average low conditions
- Might impact springshed estimates in Ichetucknee area



Low Water Scenario is Well Calibrated

Model Calibration: *River Gains*

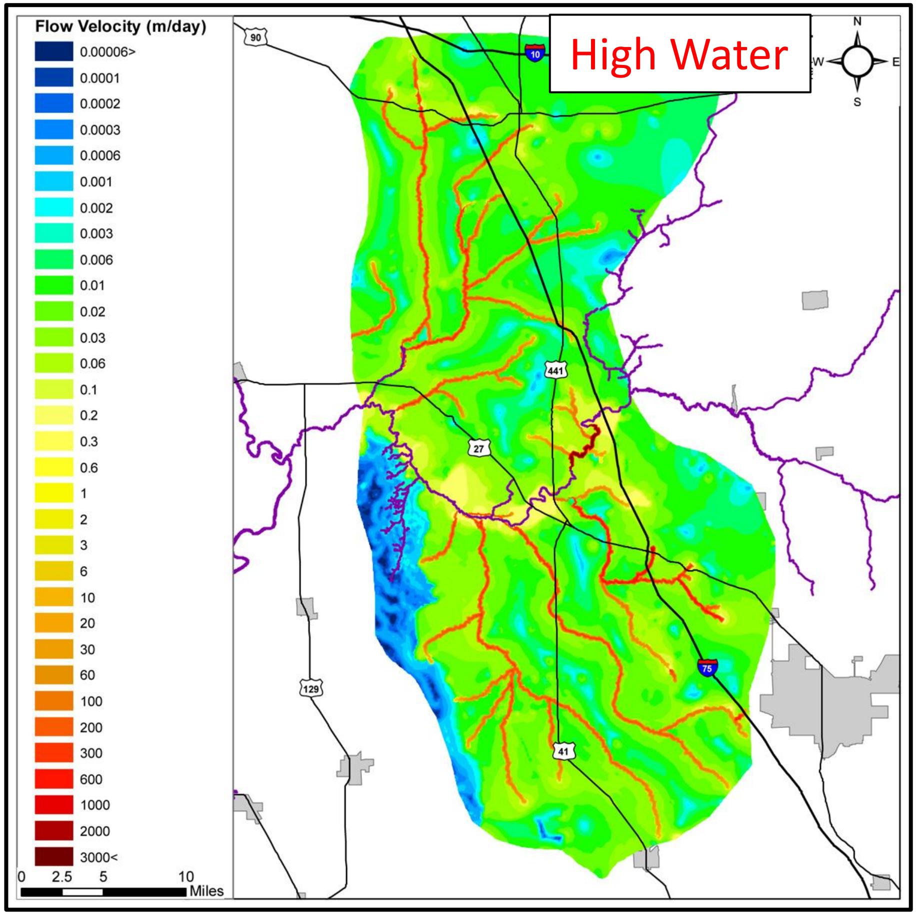
- Aggregate river gains also used as calibration targets
- Accounts for springs and diffuse flow to rivers
- Model matches observed ranges

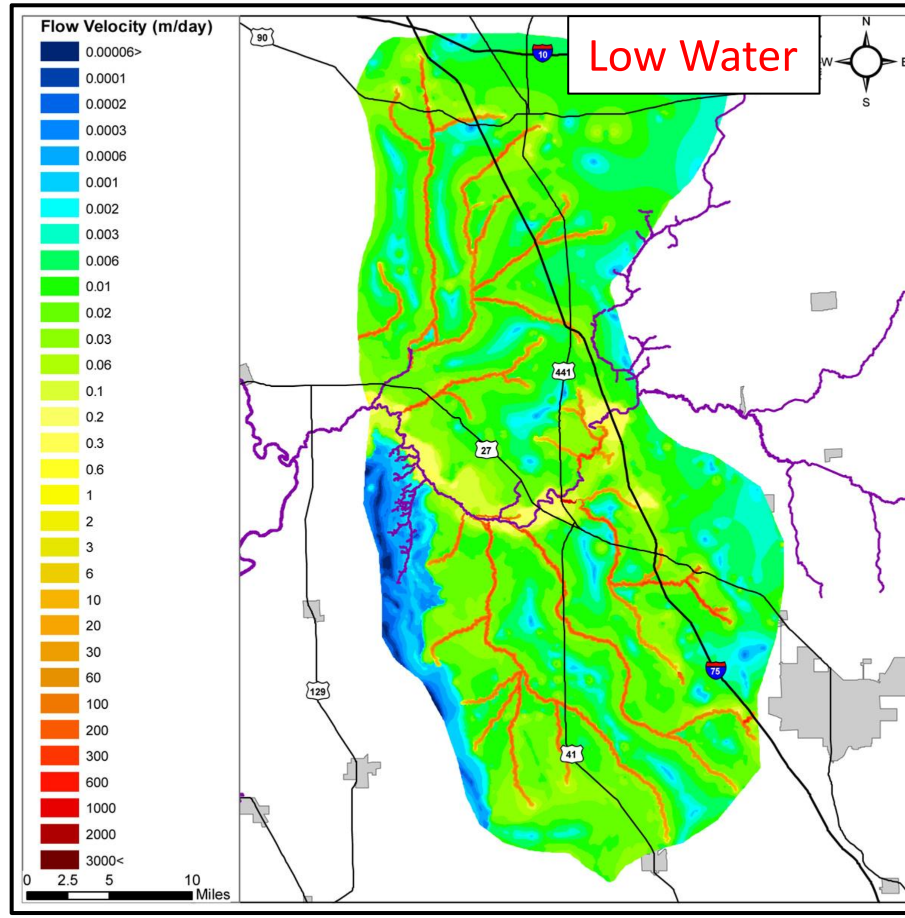


	High Water		Low Water	
River Stretch	Model	Meas.	Model	Meas.
High Springs – Ft. White	557	307-669	511	449-819
Ft. White - Hildredth	685	395-1059	357	162-575

Matches both spring flows & aggregate river gains

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

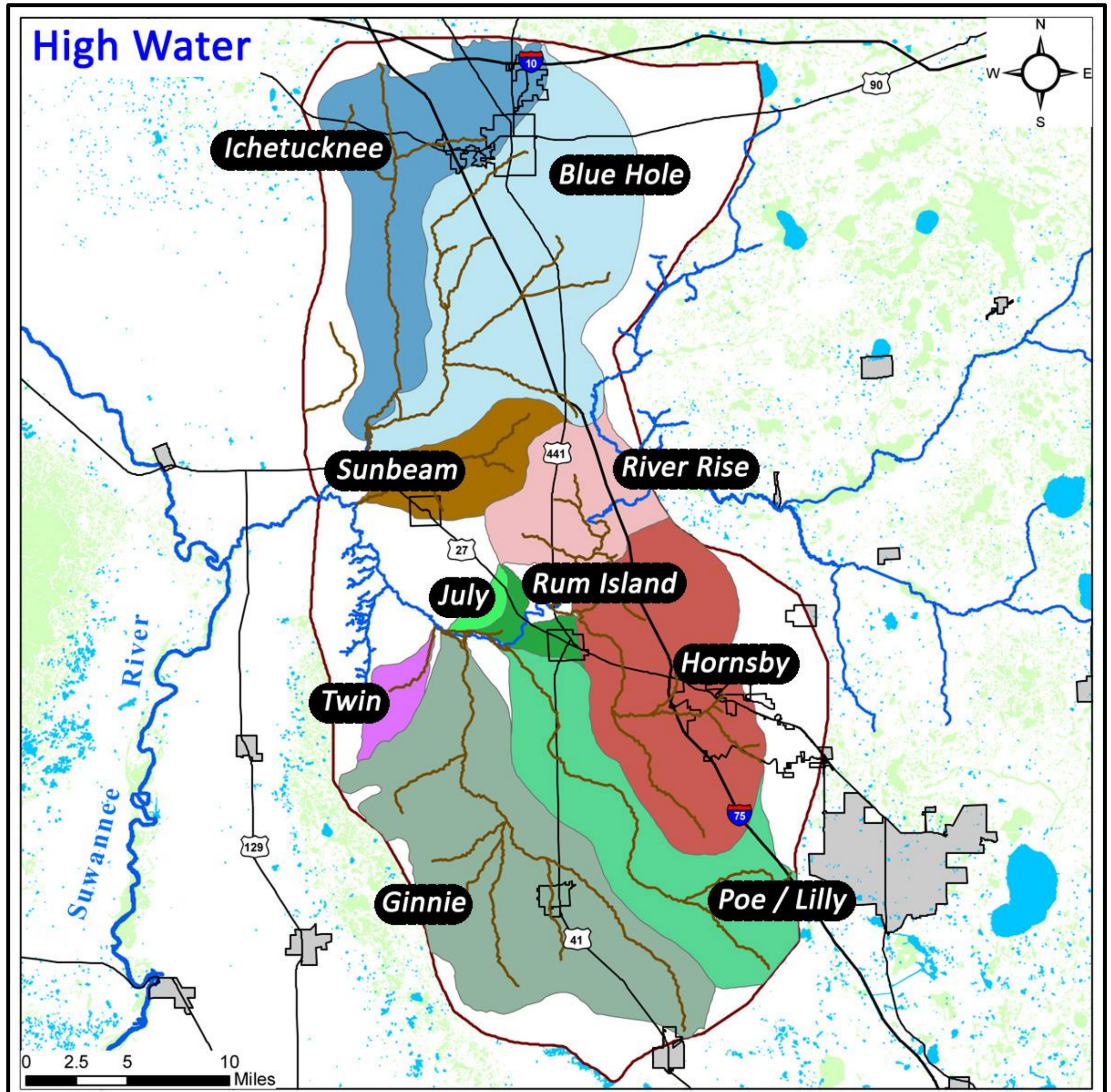
- Conduits model: ~ 100 to ~1000 m/day
- Conduits observed: ~ same
- Matrix model: ~ 10^{-3} to 10^{-1} m/day
- Matrix observed: ~ $10^{-?}$ To $10^{-?}$ m/day

Both scenarios are very well calibrated

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



Model has defined springsheds based on flow

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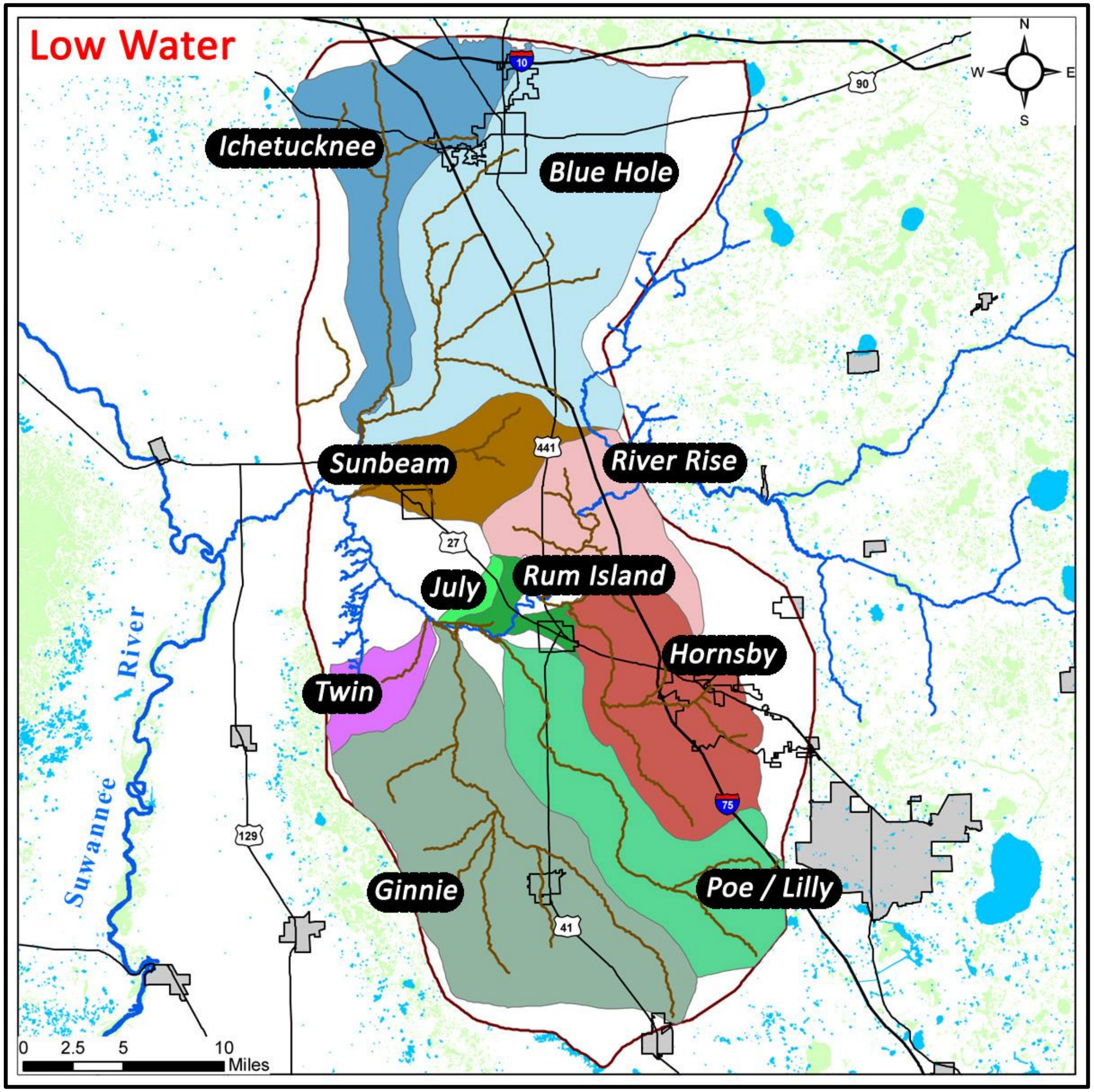


Model has defined springsheds based on flow

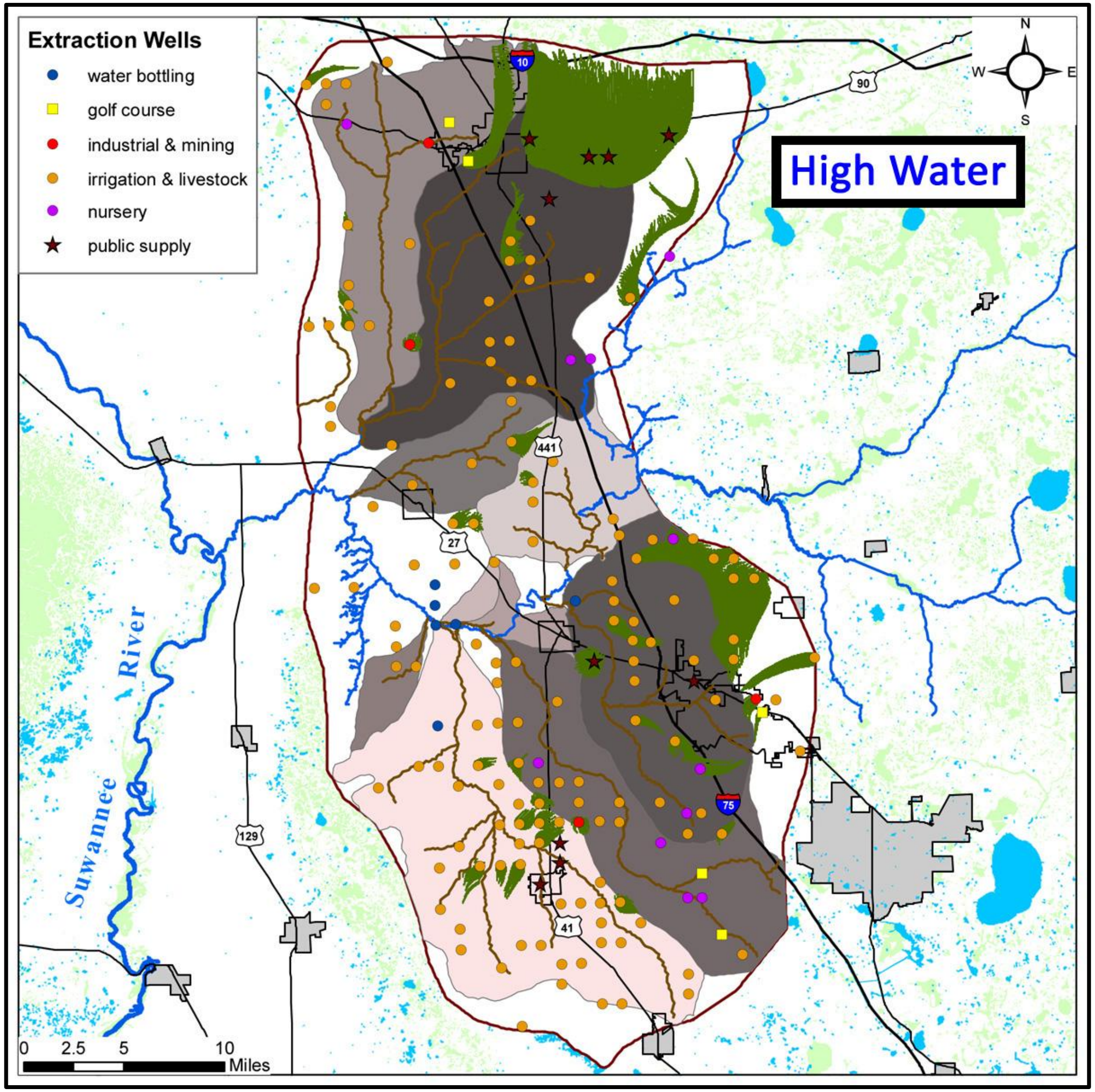
Applications: *Springshed Delineations*

Spring Group	High Water Area/Flow (km^2/cfs)	Low Water Area/Flow (km^2/cfs)	Change (km^2/cfs)	% Change
Ginnie / Blue / July	407/253	425/165	+18/-88	+4/-35
Blue Hole Group	377/427	488/190	+111/-237	+29/-55
Hornsby / Columbia	274/286	210/110	-64/-176	-23/-62
Ichetucknee	248/147	222/64	-27/-83	-11/-56
Poe / Lilly / Rum Island	261/188	267/124	+5/-64	+2/-34
River Rise	116/784	134/77	+18/-707	+15/-90
Sunbeam	80/42	103/13	+23/-28	+28/-68
Twin	29/13	49/12	+21/-2	+73/-11

Loosing swallet inflows significantly impacts springsheds

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%



Model simulates pumping impacts under varying conditions

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
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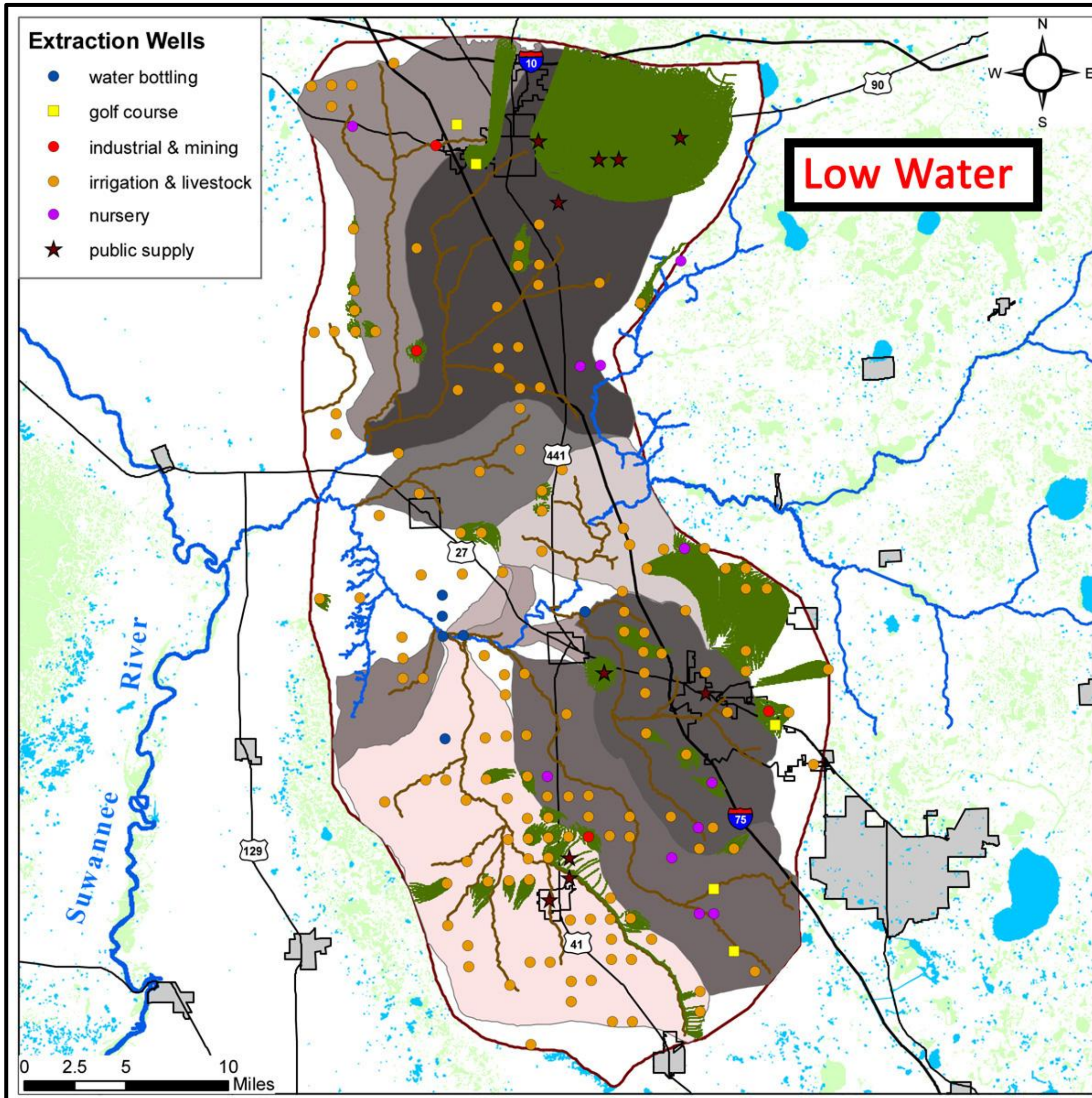
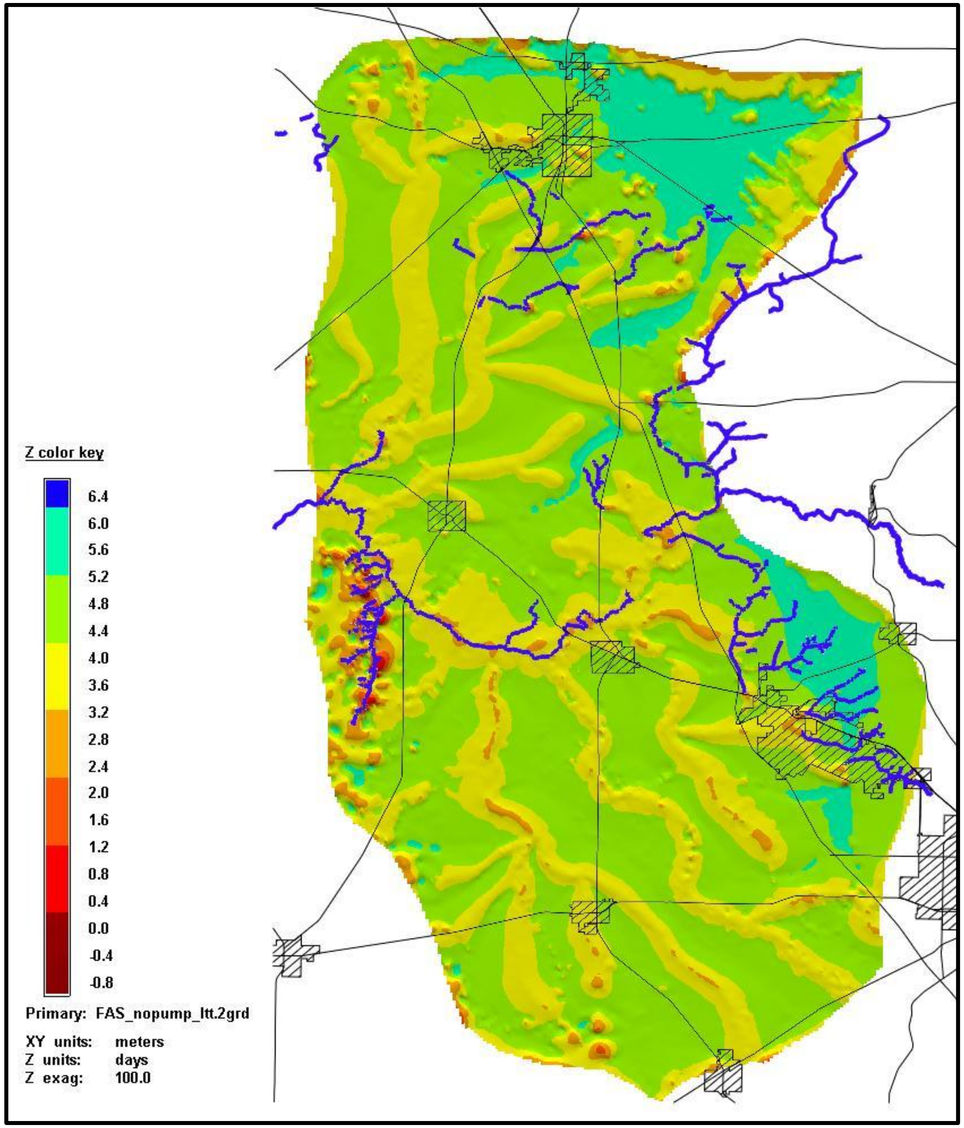


Model simulates pumping impacts under varying conditions

Applications: *Aquifer Vulnerability*

- Forward particle tracks used to delineate time of travel in FAS from all points in springsheds to the springs.
- No perceptible change from high water to low water conditions.
- Highest vulnerability zones (fastest travel-times) create zone around conduits.
- Distance to conduits far more important than distance to spring.



Model travel-times equate to aquifer vulnerability

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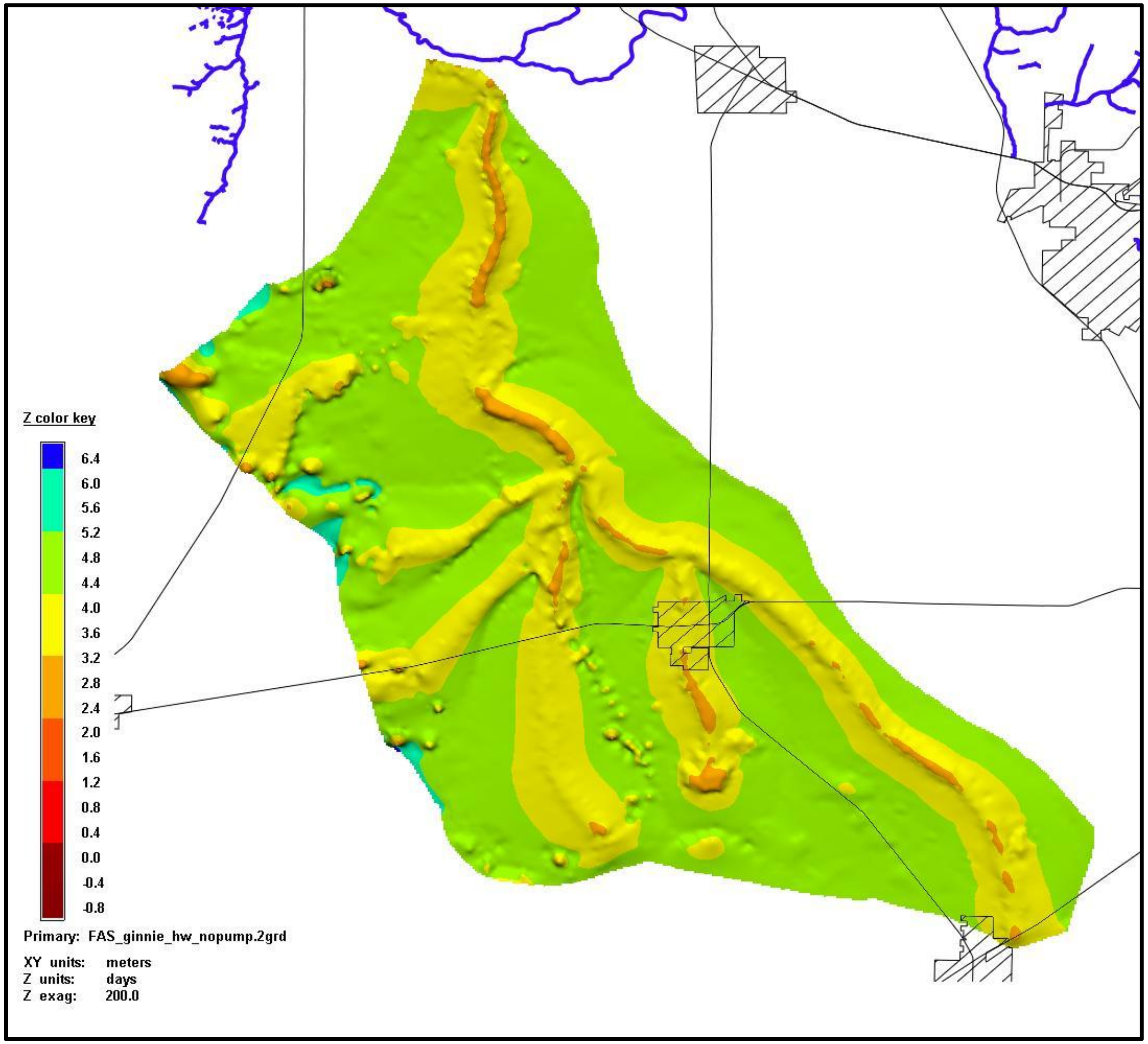
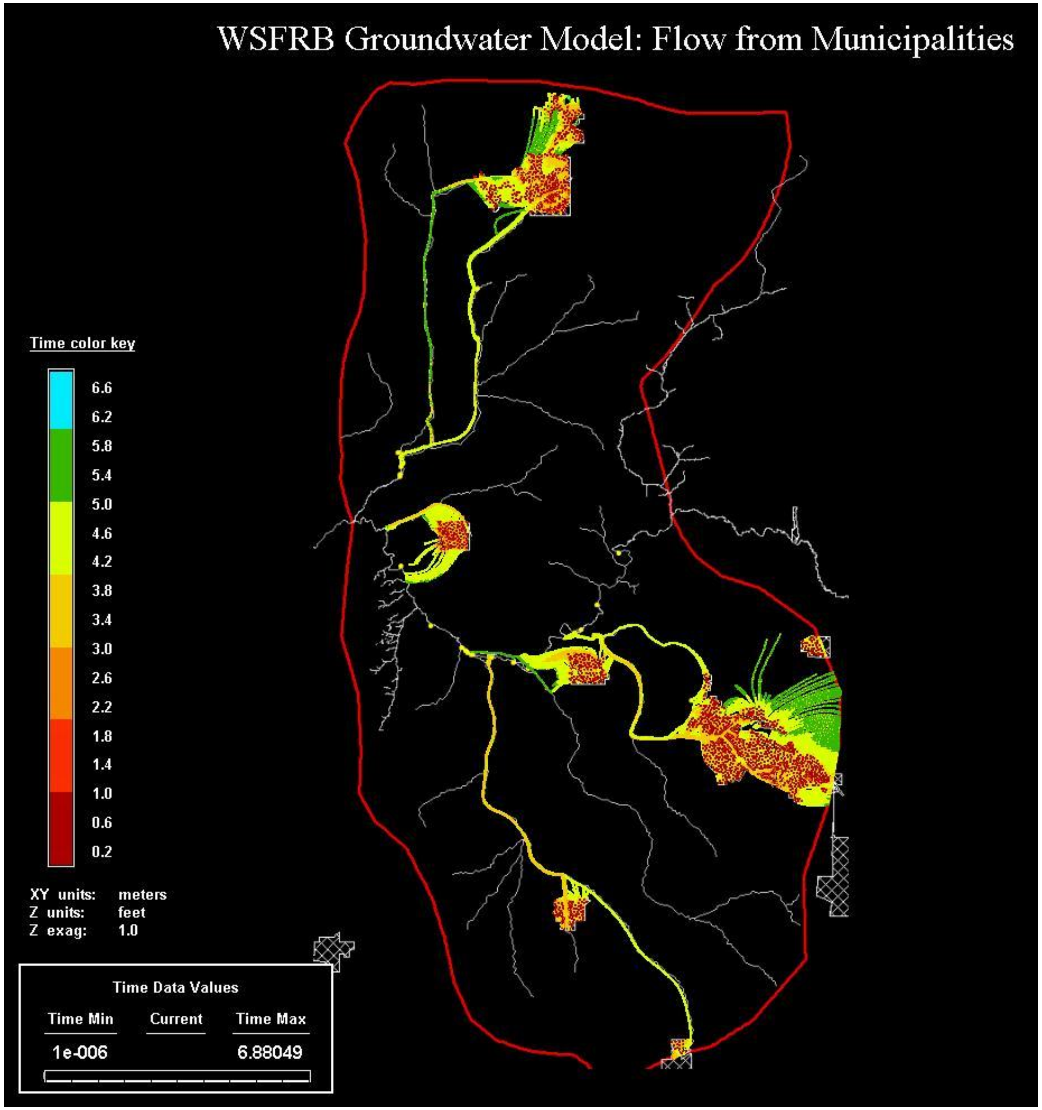


Model travel-times equate to aquifer vulnerability

Coca-Cola north america

Applications: *Particle Tracking- Transport*

- 3D Particle tracks used to evaluate transport from specific locations.
- 3D particle tracks exported from FEFLOW to EarthVision for visualization & analysis.
- Emphasizes significance of conduits – distance from spring far less important than distance from conduits.
- Visualizations created by seeding area municipalities and evaluating particle tracks / time of travel.
- Produces worst-case scenario – no dilution or retardation.
- Some tracking problems associated with dual permeability architecture.



Flow model can be used to evaluate potential transport

GeoHydros

Applications: *Particle Tracking - Transport*

Tracking water flow from municipalities in the Santa Fe River Basin, Florida

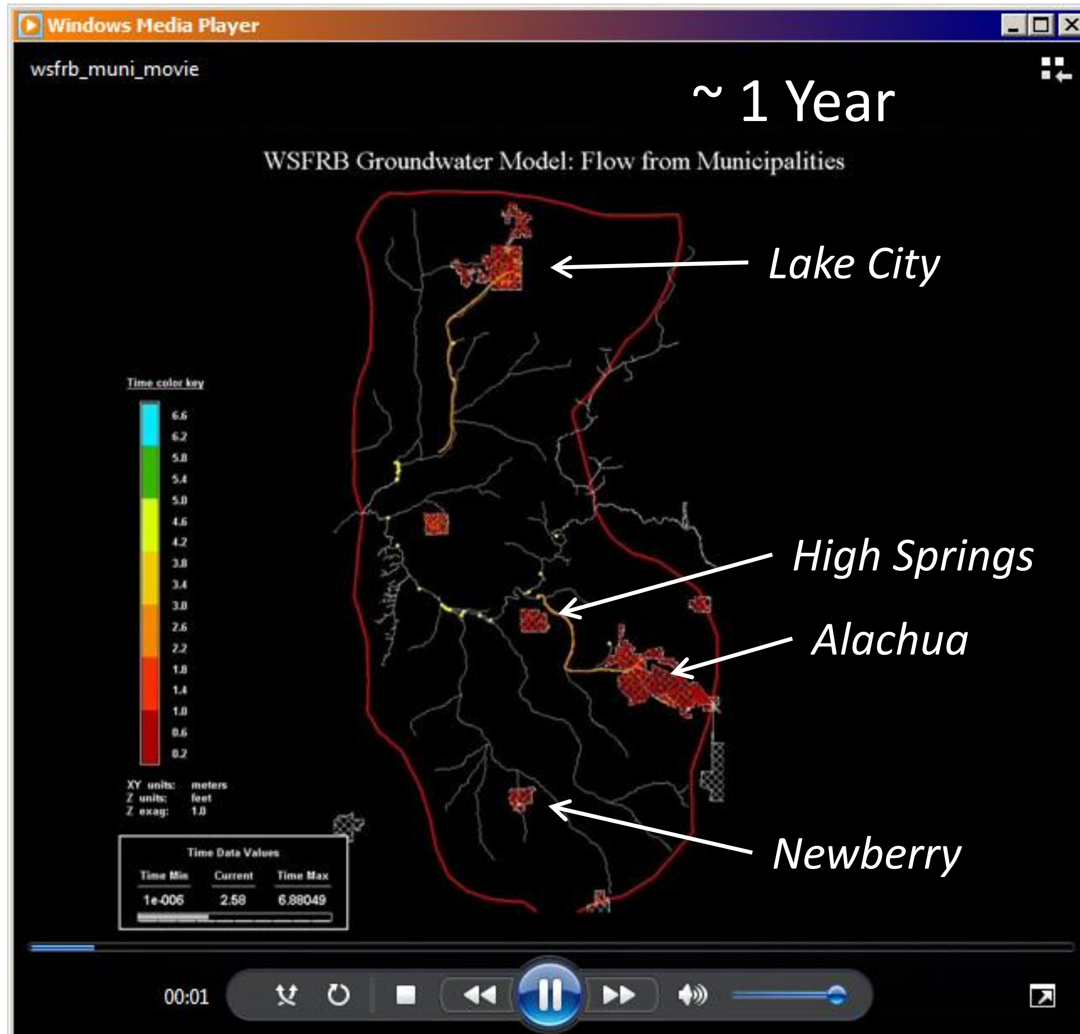
Flow is to closest conduits

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*



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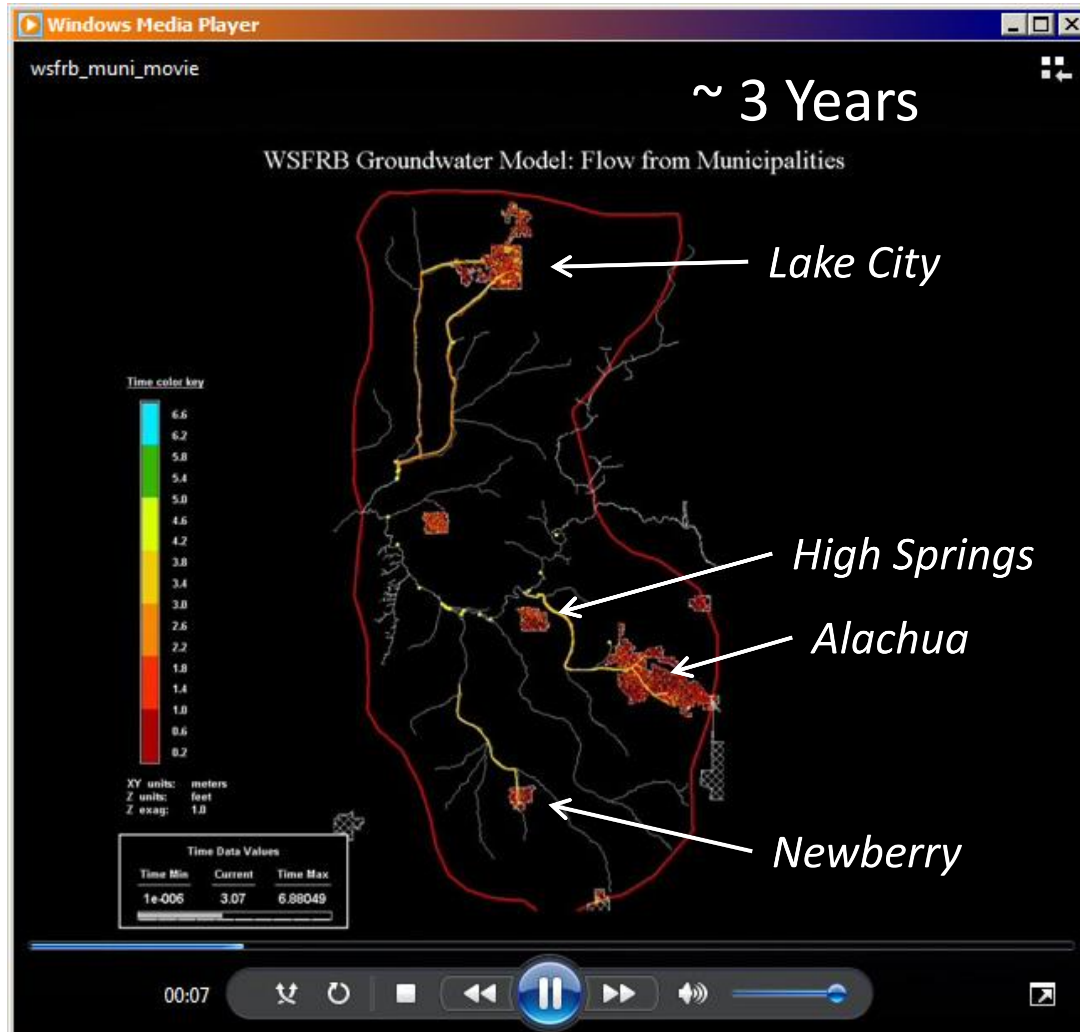

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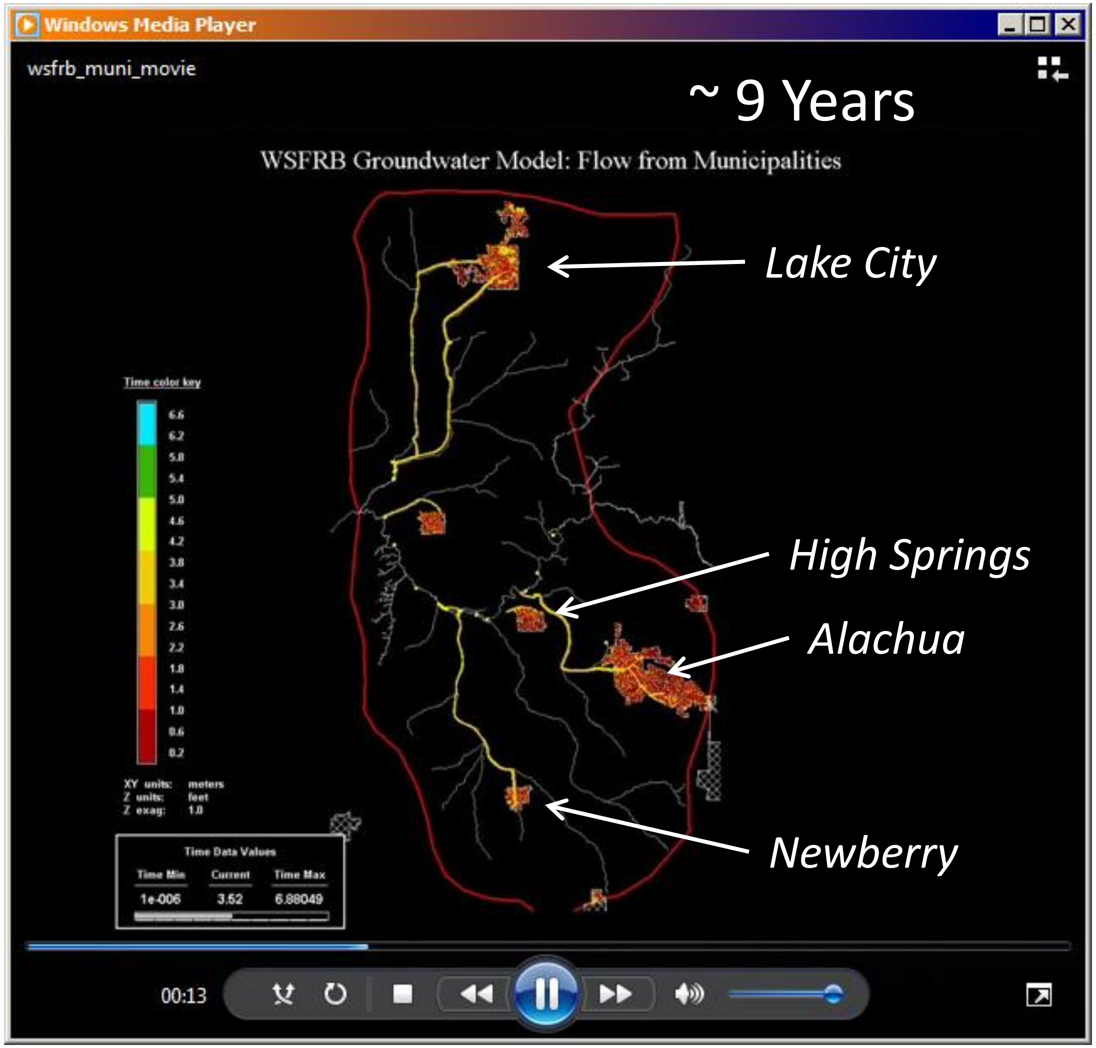

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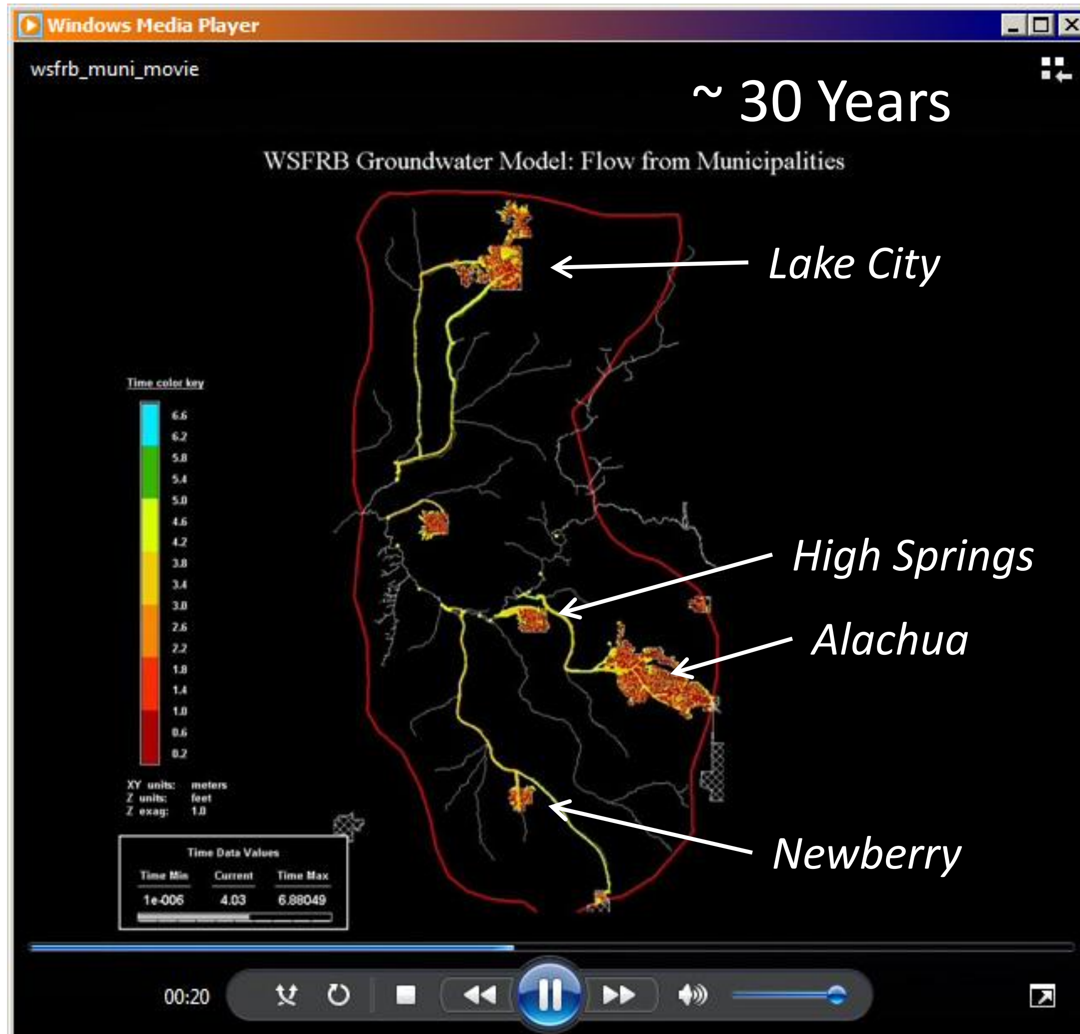

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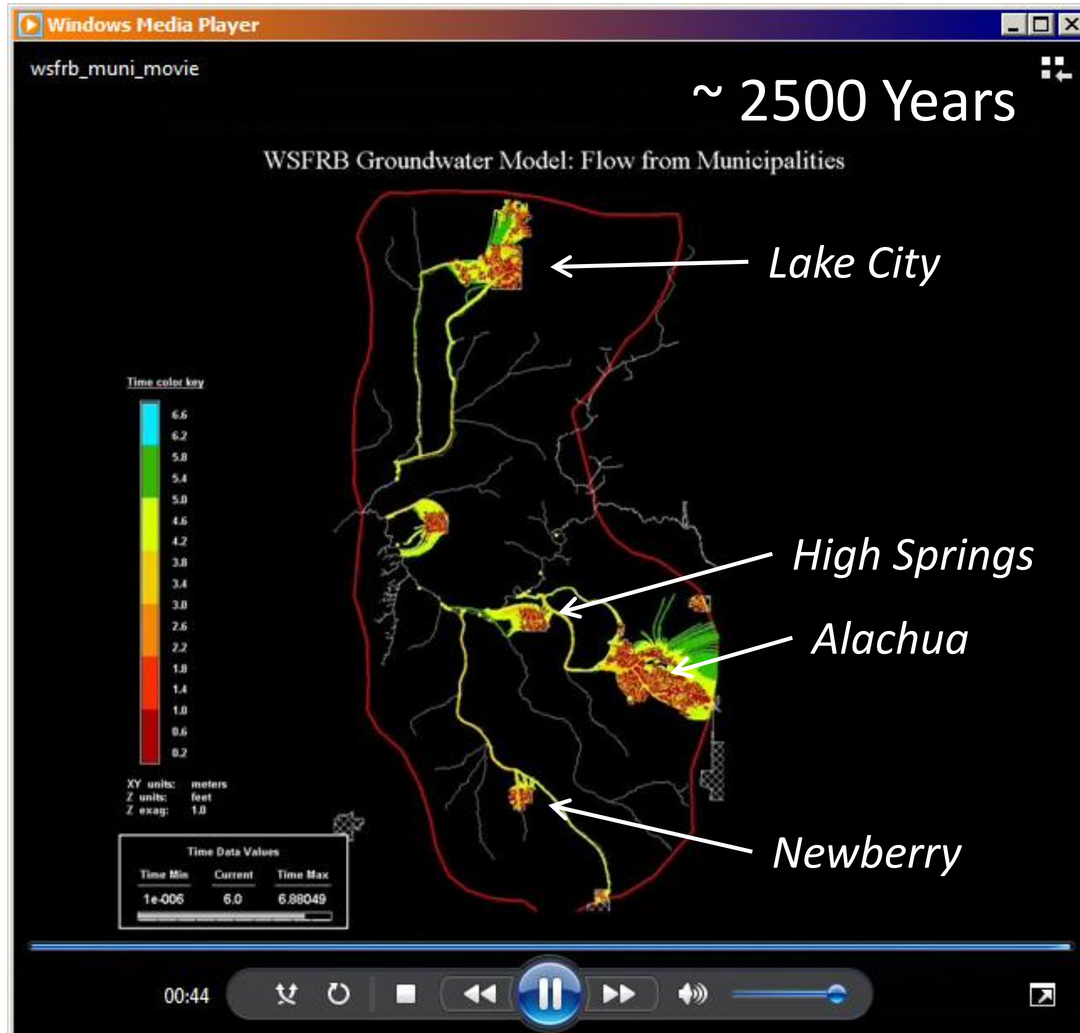

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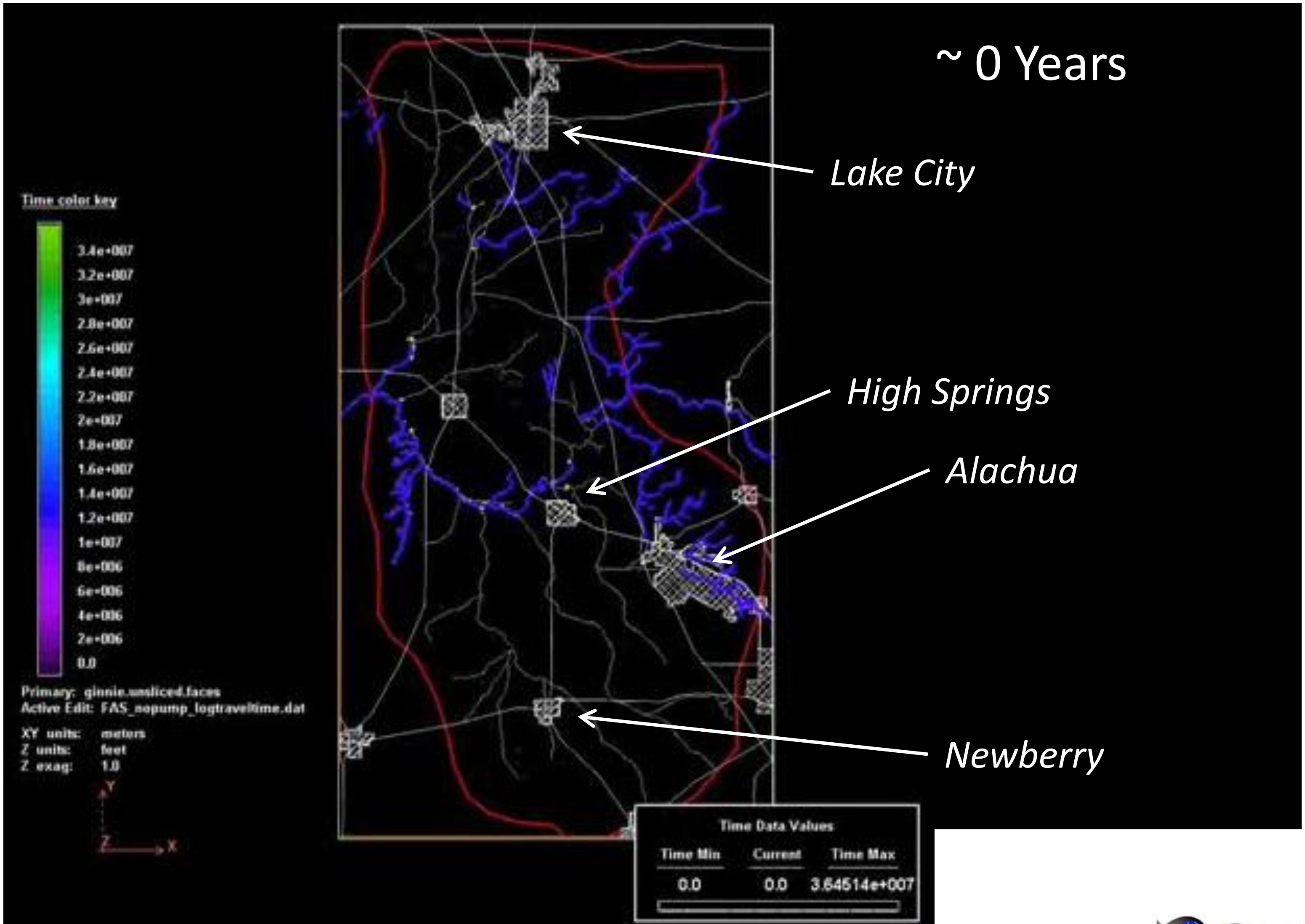
Applications: Springs Vulnerability

Travel-time to discharge from points within the Santa Fe River Basin, Florida



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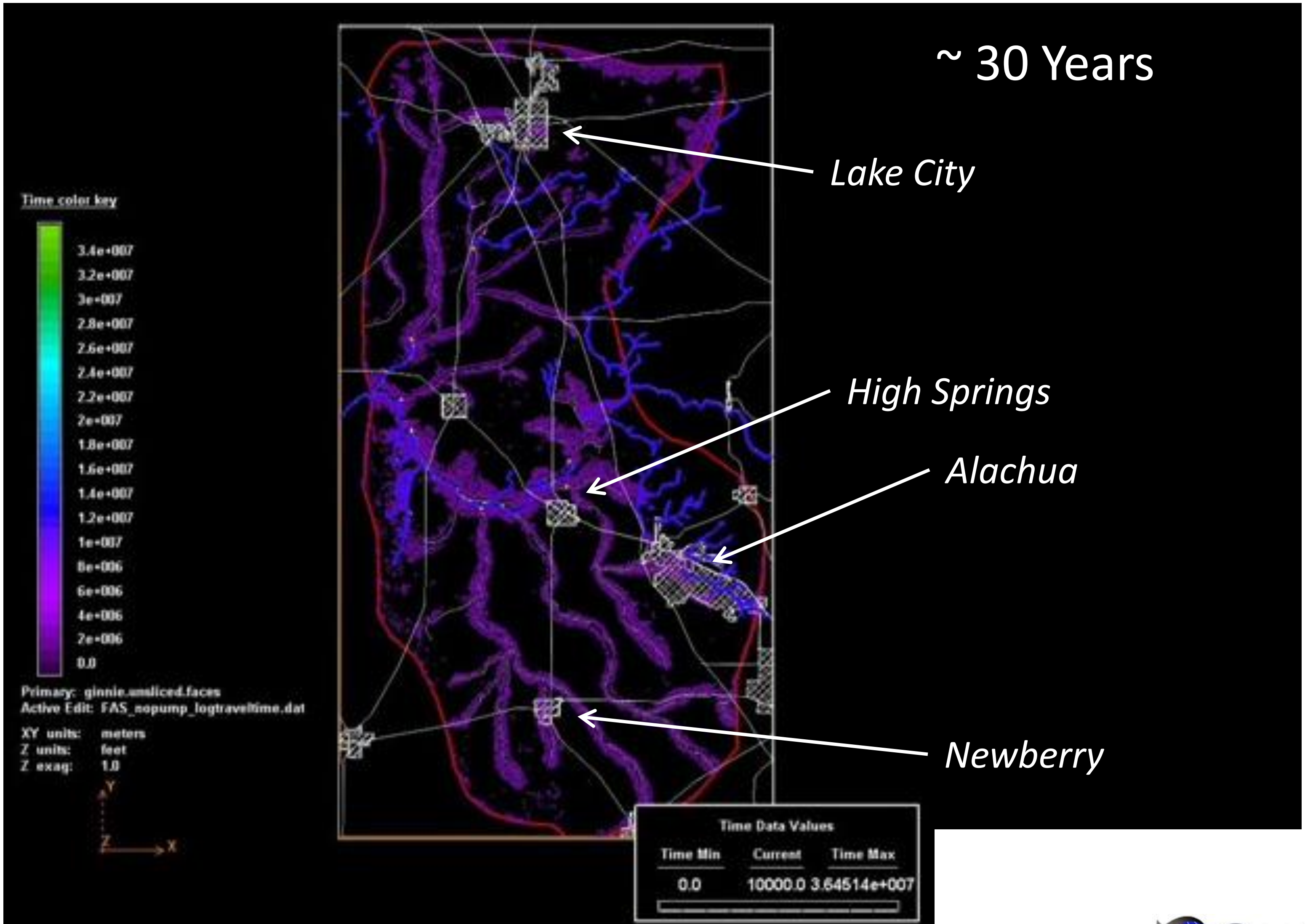

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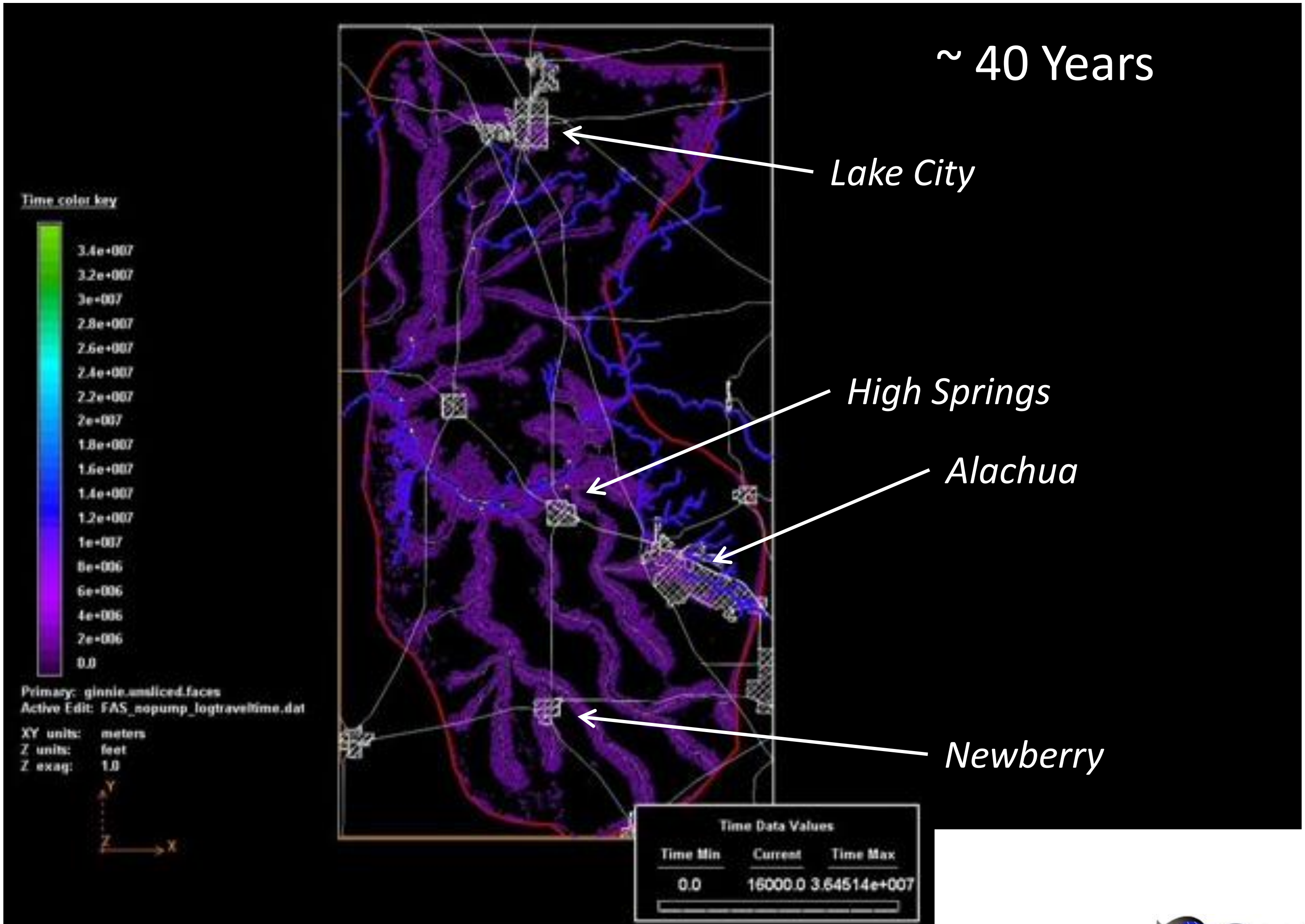

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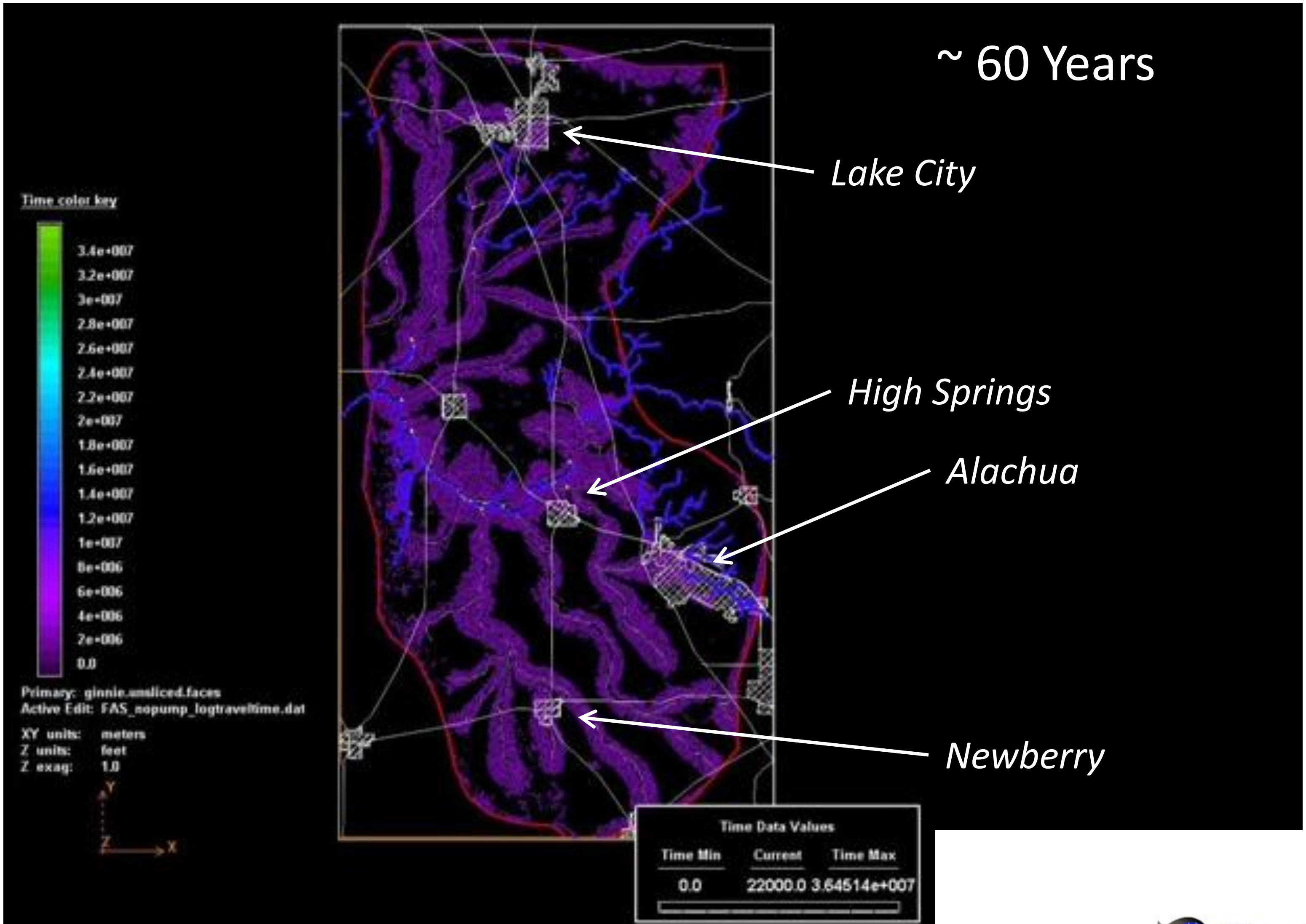

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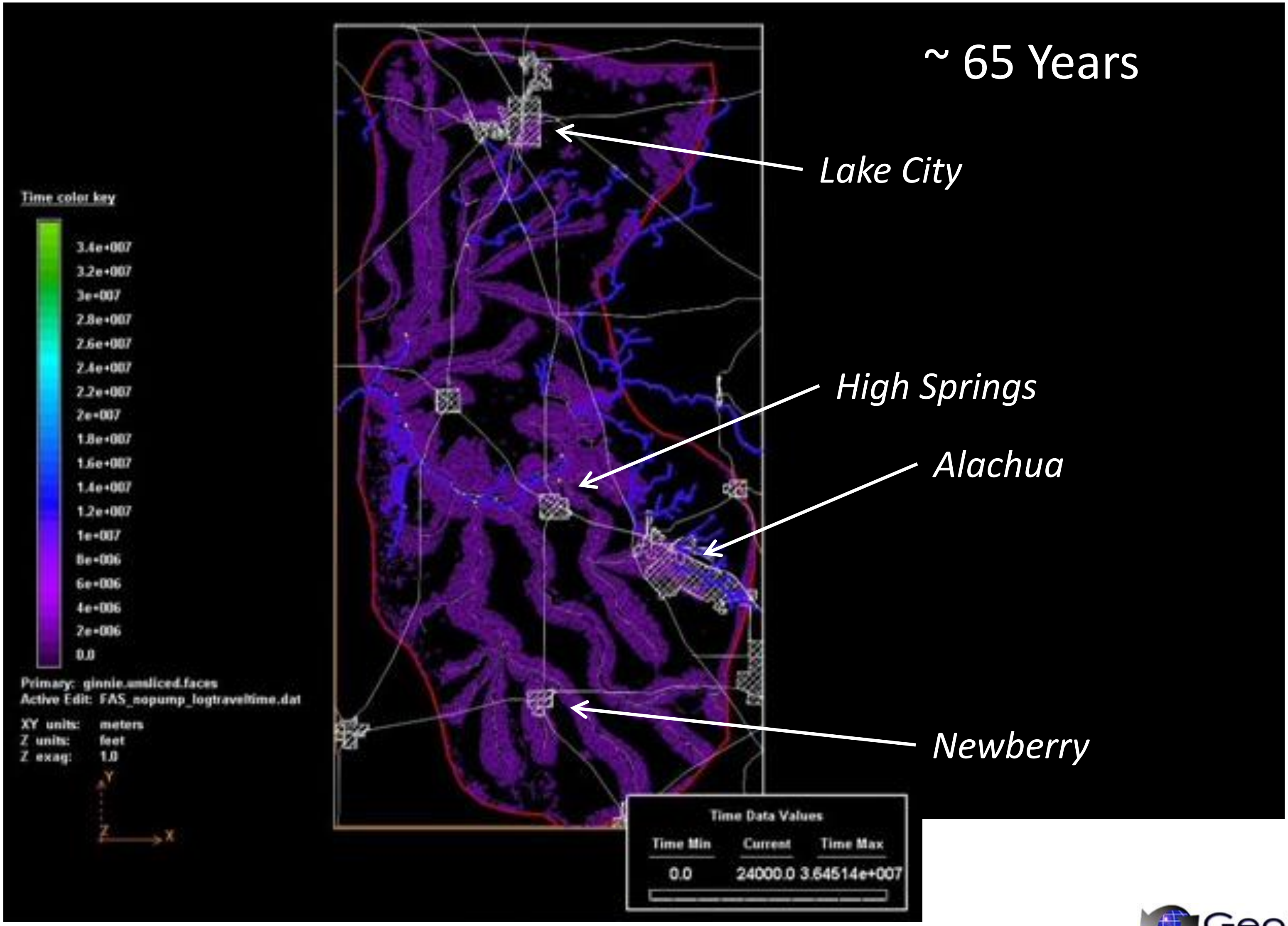

Coca-Cola north america

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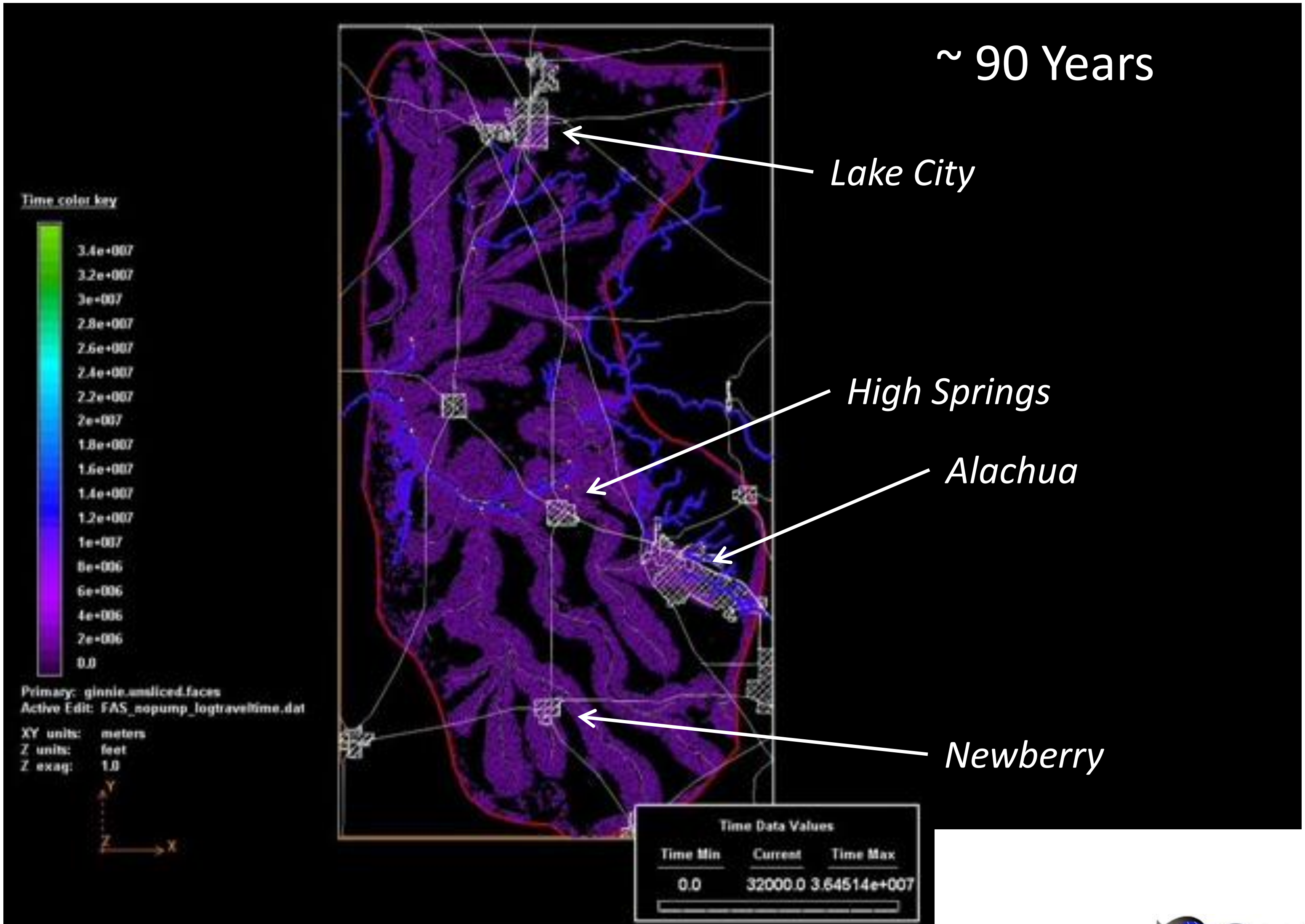

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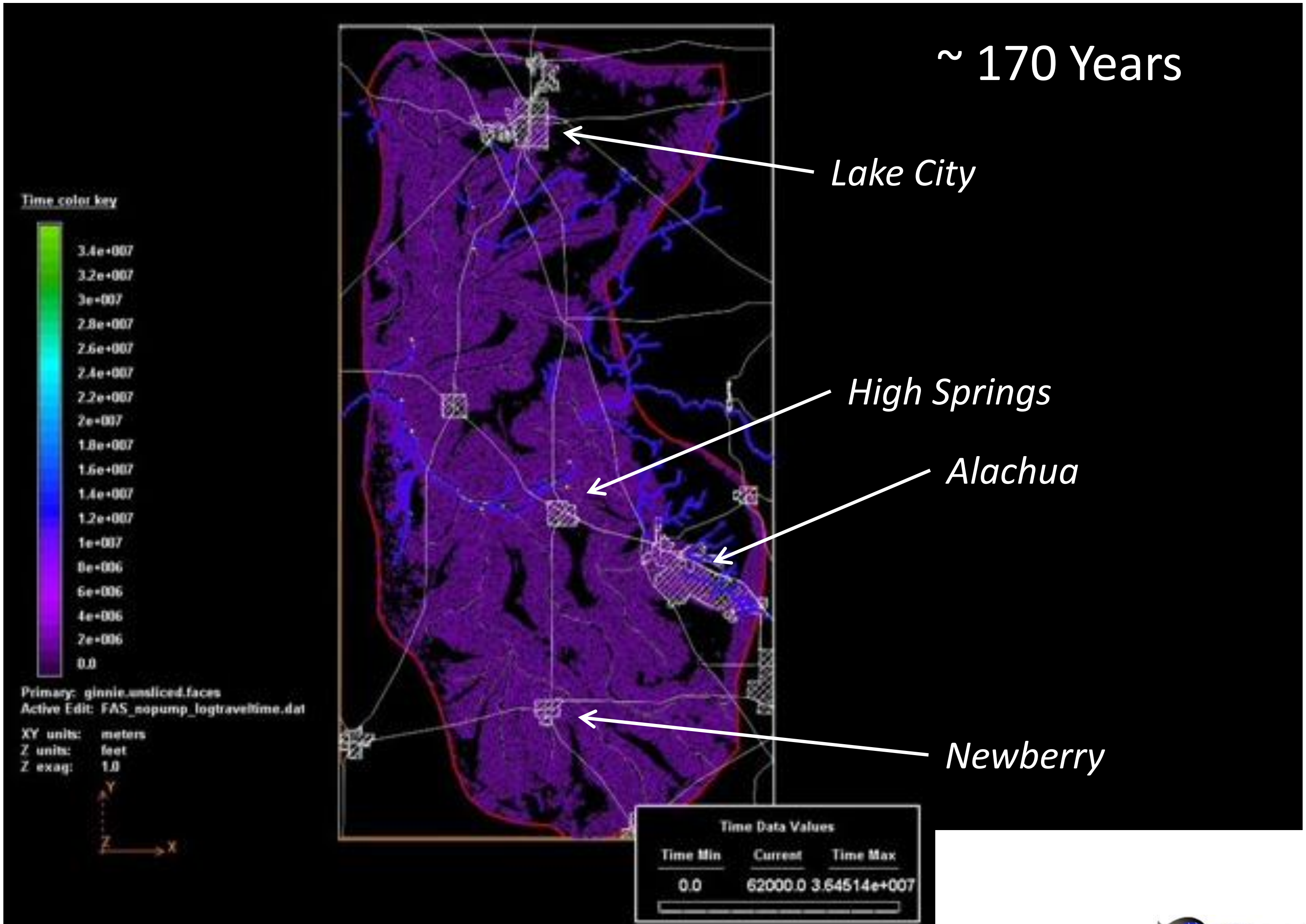

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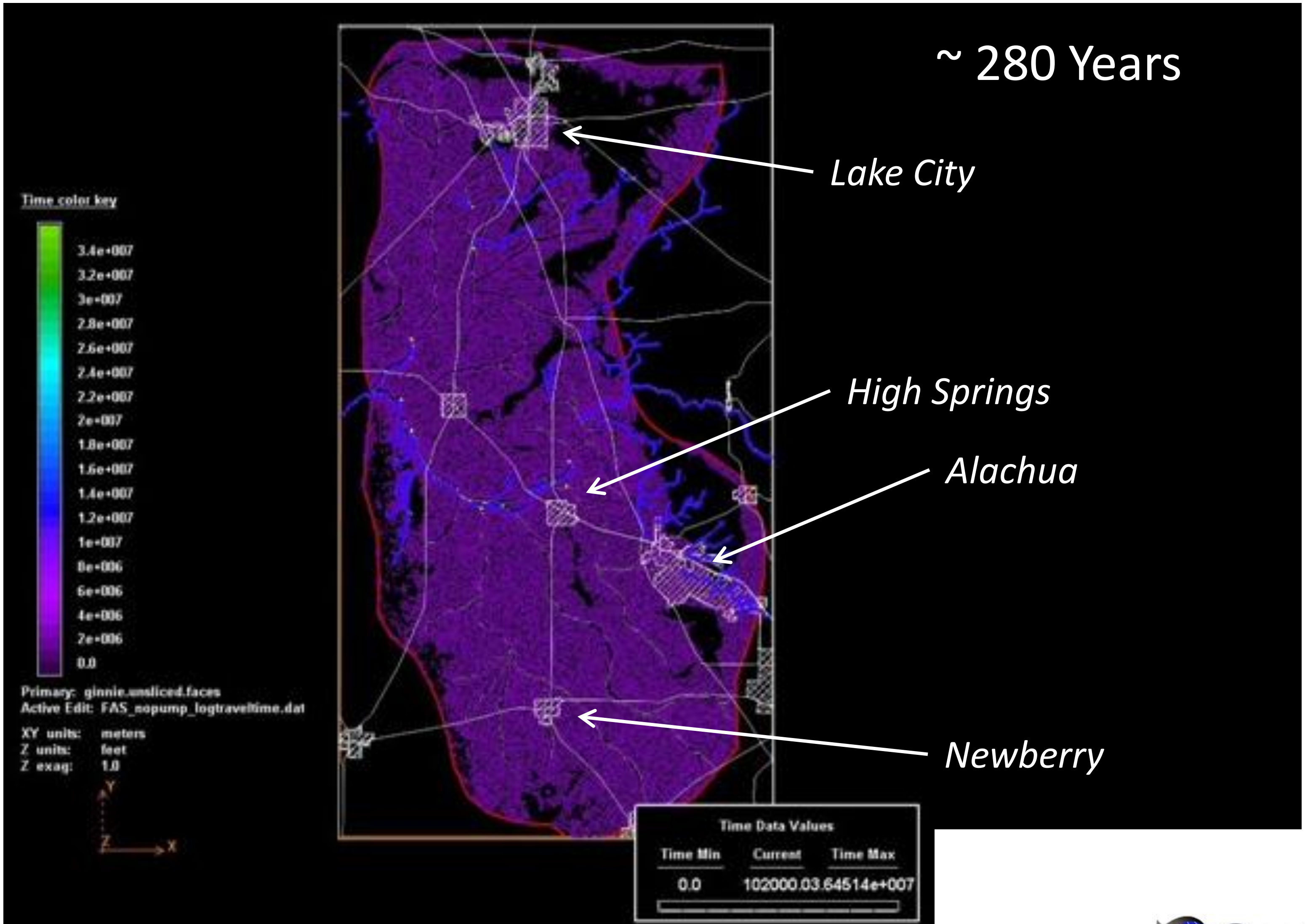

Summary & Conclusions

- Model successfully simulates realistic flow conditions to springs in the WSFRB.
- Model can be used to evaluate both water quantity and quality issues and concerns relative to springs protection.
- Model is now publically available.
- Provided technical presentation to SRWMD, SJRWMD, & FLDEP.
- CCNA wants local governments to use this model to support water resource protection in the WSFRB.

- www.geohydros.com/CCNA/

GeoHydros LLC

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