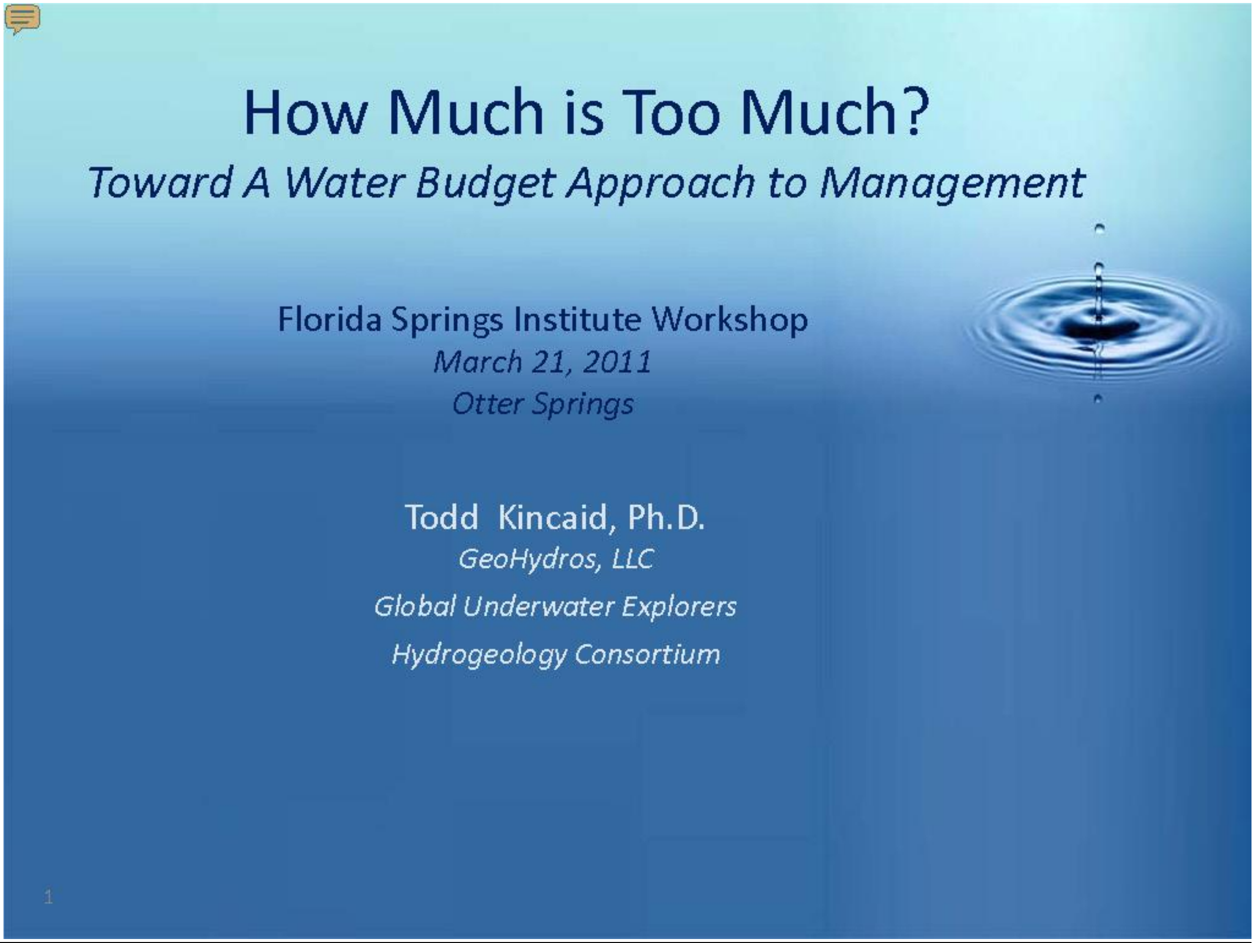
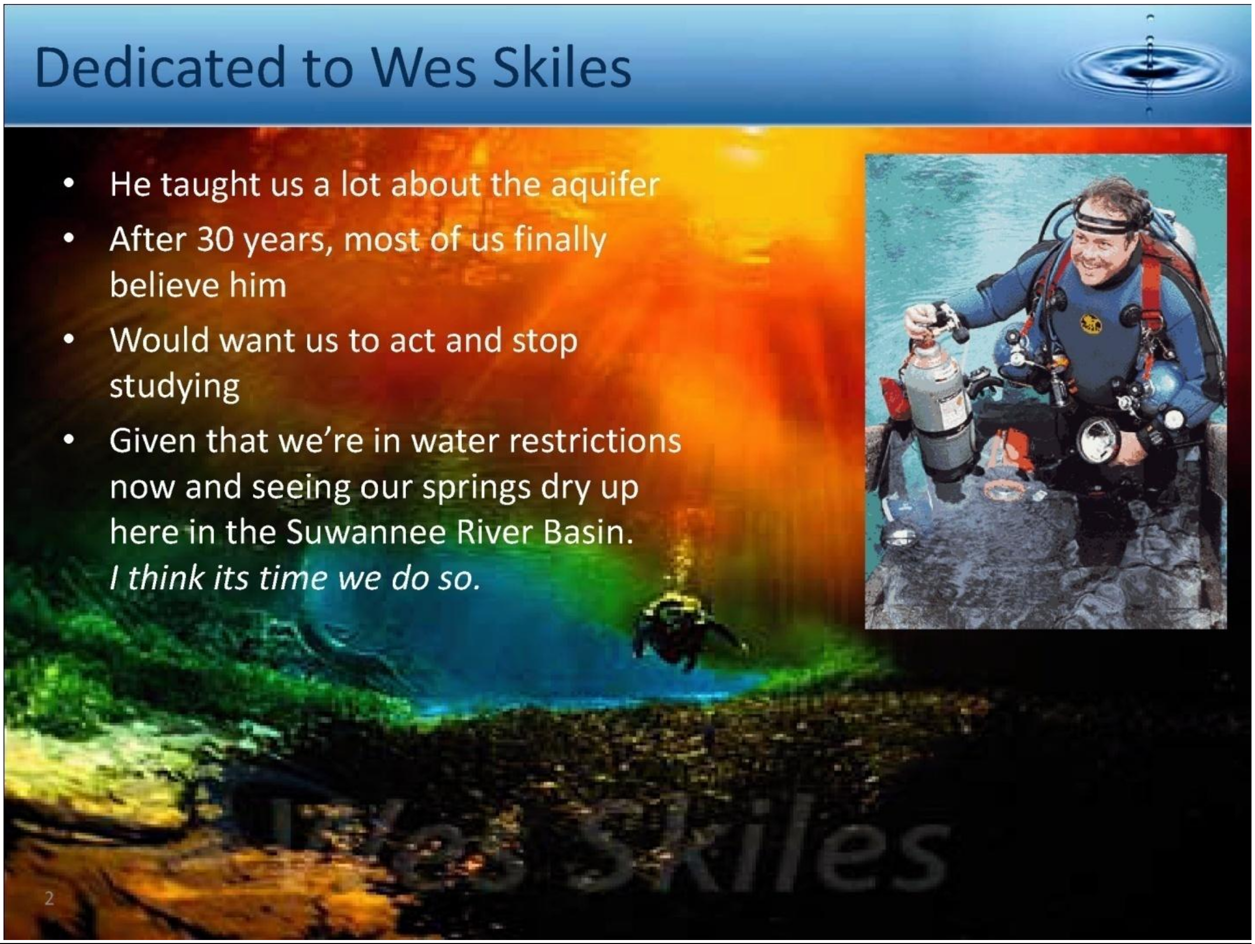


Thank you for joining this presentation. My name is Todd Kincaid. I am a hydrogeologist and long-time Florida cave diver. I started a geological modeling company 12 years ago so that I could focus my work as much as possible on understanding and protecting Florida Springs. I have been working with many fine people on this effort ever since including the non-profit organizations Global Underwater Explorers and the Hydrogeology Consortium as well as the Florida Geological Survey and the Florida DEP. I'm very happy to join Bob Knight and the Florida Springs Institute in continuing that work.



I think if Wes was here with us, he'd tell us that the time for study, review, and consideration is long past – that it is time to act. He'd say what we all know – that our springs and rivers are severely impacted, that in their former state, they are jewels unique to the world, and that we as stewards of these natural gems are obligated to protect them such that our children and children's children can experience them the same way that we have.

I met Wes for the first time nearly 25 years ago. I was an undergraduate geology student at the University of Florida taking my first groundwater classes. Our professor invited him to come in and share some of his videos with us. He wasn't there to talk about the science of groundwater. He was simply there to show us what the aquifer really looked like – from inside – and I could tell that he was there because he knew these places were threatened and he hoped that by showing us what they really looked like, that we may one day help save them. I probably appreciated those videos more than most of my fellow students because by that time I was an avid cave diver myself and was diving in some of the same caves in his videos 3-4 times per week.

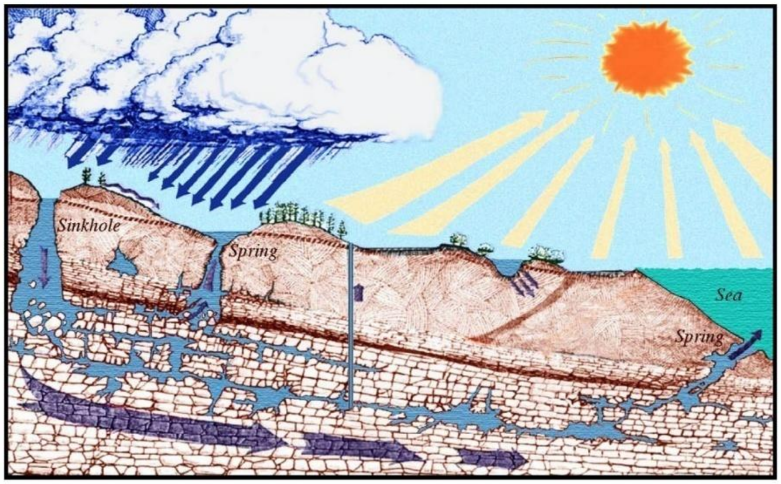
Our professor also invited respected groundwater professionals to our class from many of the agencies that are tasked with managing groundwater in Florida. The most significant thing I remember from those presentations is that when asked about caves, many dismissed them as irrelevant and some even claimed that Wes had fabricated his videos – "Hollywood style" and that those caves simply didn't exist.

So, throughout most of the past 25 years, the groundwater profession has treated caves in the Floridan aquifer as either irrelevant or non-existent despite being repeatedly wrong about predictions of groundwater flow directions and velocities – the most fundamental variables in groundwater management. Thankfully, most of us finally believe what Wes knew and had been showing us for so long. But even still, most of our groundwater management efforts continue to be based on theories and techniques that disregard the caves.

It is terribly unfortunate that we treated caves as irrelevant for so long, but even worse, if we don't change our ways – in terms of how we measure, manage and model groundwater in north Florida, to address the caves that we now all know exist, we'll loose our springs forever.

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.

3 GeoHydros

The total amount of groundwater available in any springshed is only equal to the amount of recharge that occurs within its boundaries. Measuring that recharge directly is difficult but we can know what it must be at a minimum by measuring the spring discharge. Groundwater levels within the springshed mark the amount of storage available to the springs when recharge is diminished. All extractions that occur within a springshed diminish the available storage by the amount of water withdrawn, which will then diminish the spring flow. If this process is not managed sustainably, we will mine all of the storage and ultimately all of the spring flow as well.

Significance of a Water Budget

Inputs – Outputs = Change in Storage

- How do you know how much money you can spend?
  - Income
  - 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 = recharge
  - Expenses = all discharge and extractions
  - Available cash = storage
- One difference
  - There is no such thing as a water surplus
  - Every drop of water entering that recharges the aquifer flows eventually to springs and rivers
  - Management falls to deciding which uses will be impacted by new extractions & devising creative ways of recycling the extracted water
- Our problem is that we don't effectively measure income or expenses

4

GeoHydros

A water budget is exactly like a financial budget. The amount we make equals the amount we spend + the change in our savings. If we spend more than we make, we deplete our savings. If we continue that practice long enough, we go broke.

In groundwater, the amount we receive in recharge = the total amount of discharge (spring flow + extractions) + the change in aquifer storage. If we extract more than we receive in recharge, we will deplete storage. If we continue that trend long enough, we will mine all of the groundwater out of the aquifer. During droughts, continued spring flow depletes aquifer storage. As the storage goes down, so does the pressure in the aquifer that drives the spring flow. The loss in pressure reduces the spring flow and if the drought persists, groundwater levels (aquifer pressure) will fall far enough to cause the springs to stop flowing.

Any extractions beyond the natural spring discharge will deplete aquifer storage causing a decrease in spring flows. If we manage our extractions such that the total discharge is less than or equal to recharge, we will achieve a balance in the aquifer such that water levels and spring flows do not continue to decline. If on the other hand, we extract too much, both will continue to decline until both the storage and the spring flows are depleted.

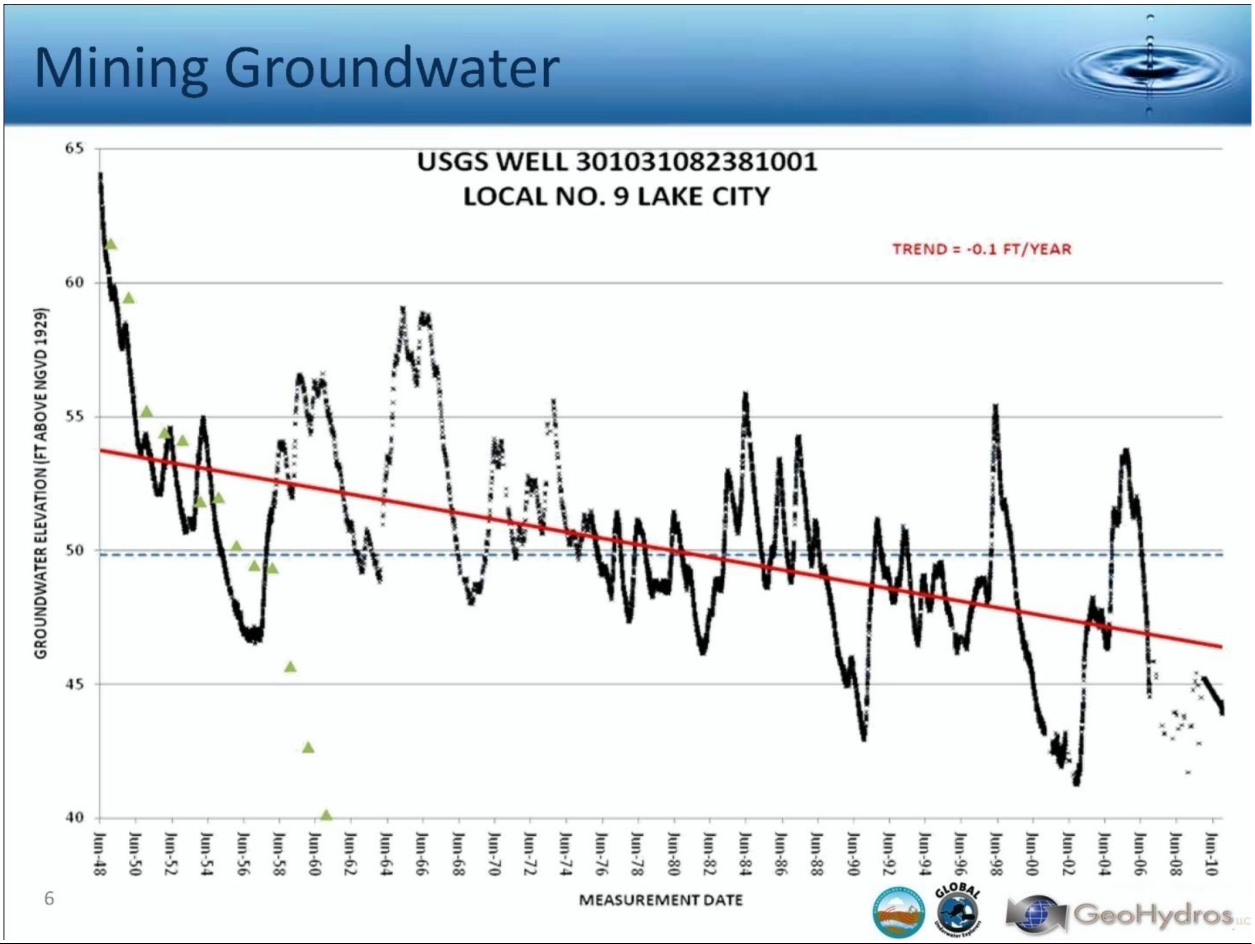
Problems

- We're using too much water - Mining water from the aquifer
- We 're not adequately measuring / monitoring our water supply
- We're not adequately measuring / monitoring consumption
- We're using the wrong tests to evaluate consumption & impacts
- We're not adequately reporting our water status
- We're not adequately educating ourselves on how we interact with our aquifer
- We haven't clearly defined what we want in terms of water availability – competing objectives (environmental vs. social)

5

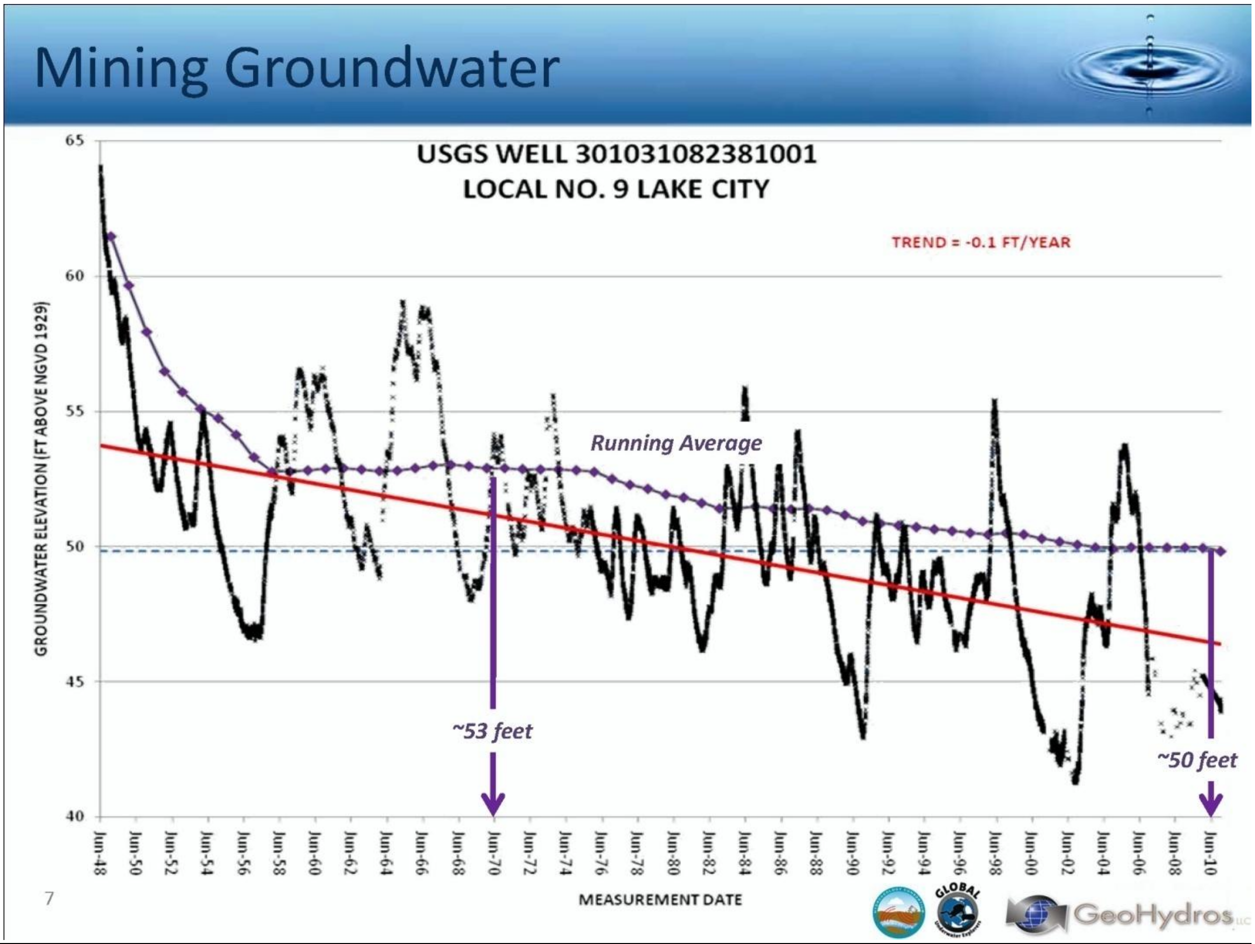
GeoHydros

These are the problems I believe we are currently experiencing and must confront. The rest of the presentation elaborates on each challenge that we must play a part in overcoming.

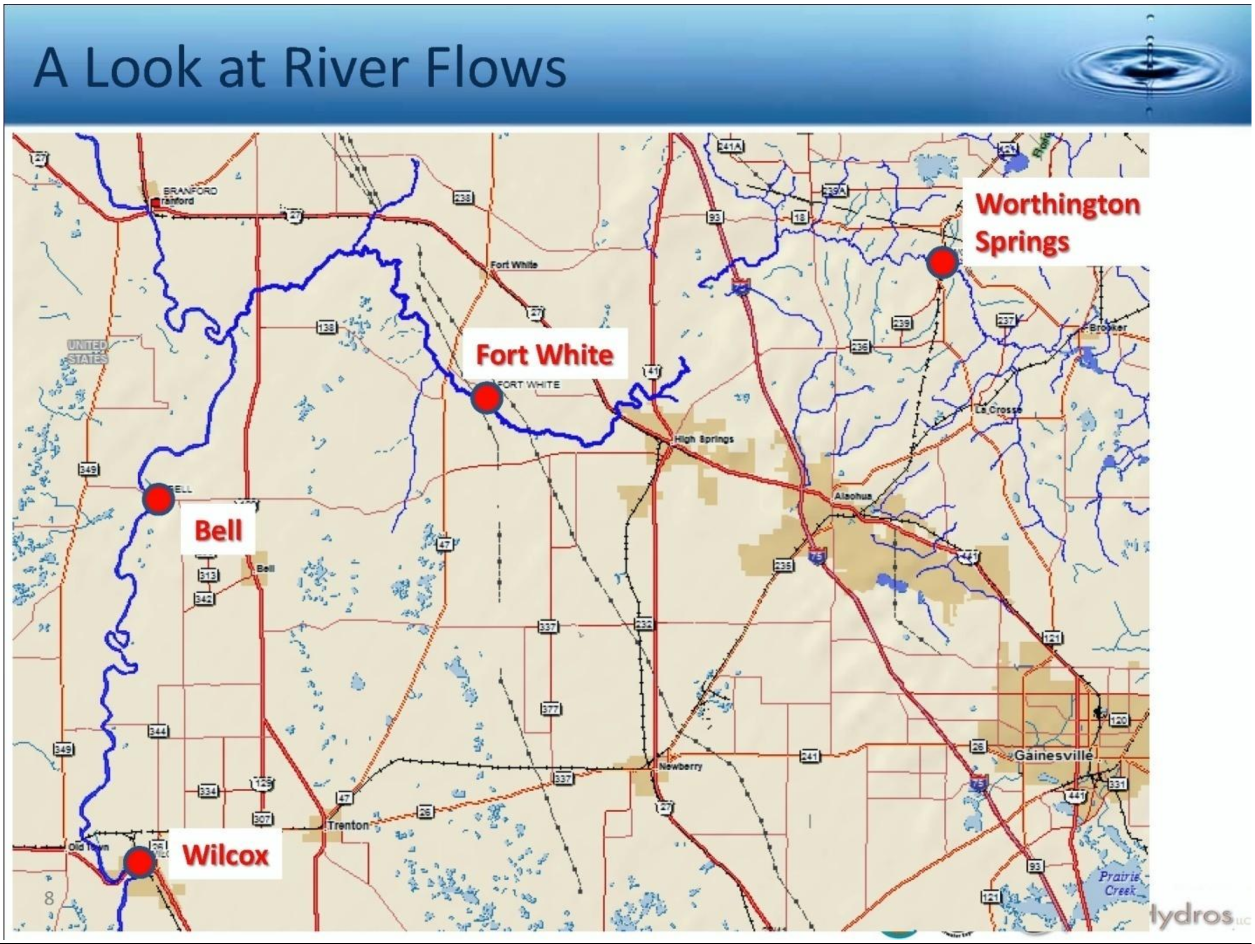


This is a historical record of groundwater levels at a USGS monitoring well in Lake City Florida that extends from 1948 through 2010. The ups and downs mark seasonal variability created by the storm-driven precipitation in the Suwannee River Basin. The troubling trend is marked by a continuous overall decrease that can be easily and intuitively discerned by simply tracing your finger along all the peaks or troughs in the seasonal fluctuations.

We can also apply a trend fit to the data, which reveals a consistent overall decline of 0.1 feet per year throughout the record. Another way to look at the data, although inaccurate, is to calculate and plot a simple average for the data and then falsely note that there are still some parts of the seasonal fluctuations that plot above average. The reality however is that if left unchecked, we will need to see bigger and bigger storms to achieve groundwater levels that plot above this average. Inaccurate data analysis will not change the fact that this graph clearly shows – we're mining groundwater in the Suwannee River basin and have been doing so for quite a while.

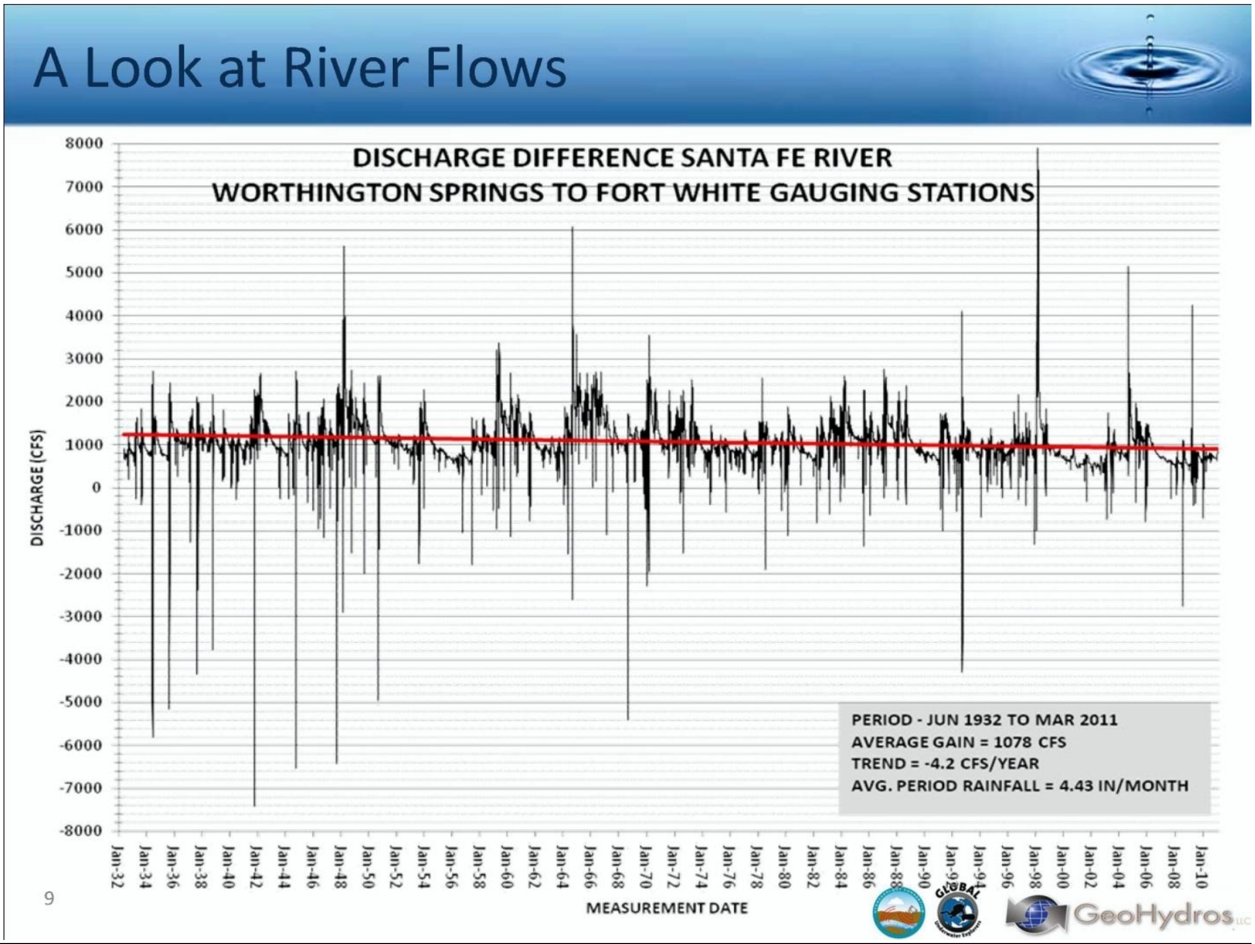


Here's another way to look at the same chart in which I've plotted the running average (average groundwater level to the given year) as purple dots on top of the graph. Here we can see a nearly continuous decline in the average groundwater level in the well as time progresses and that we've lost nearly 3 feet of storage (groundwater level) since 1970.

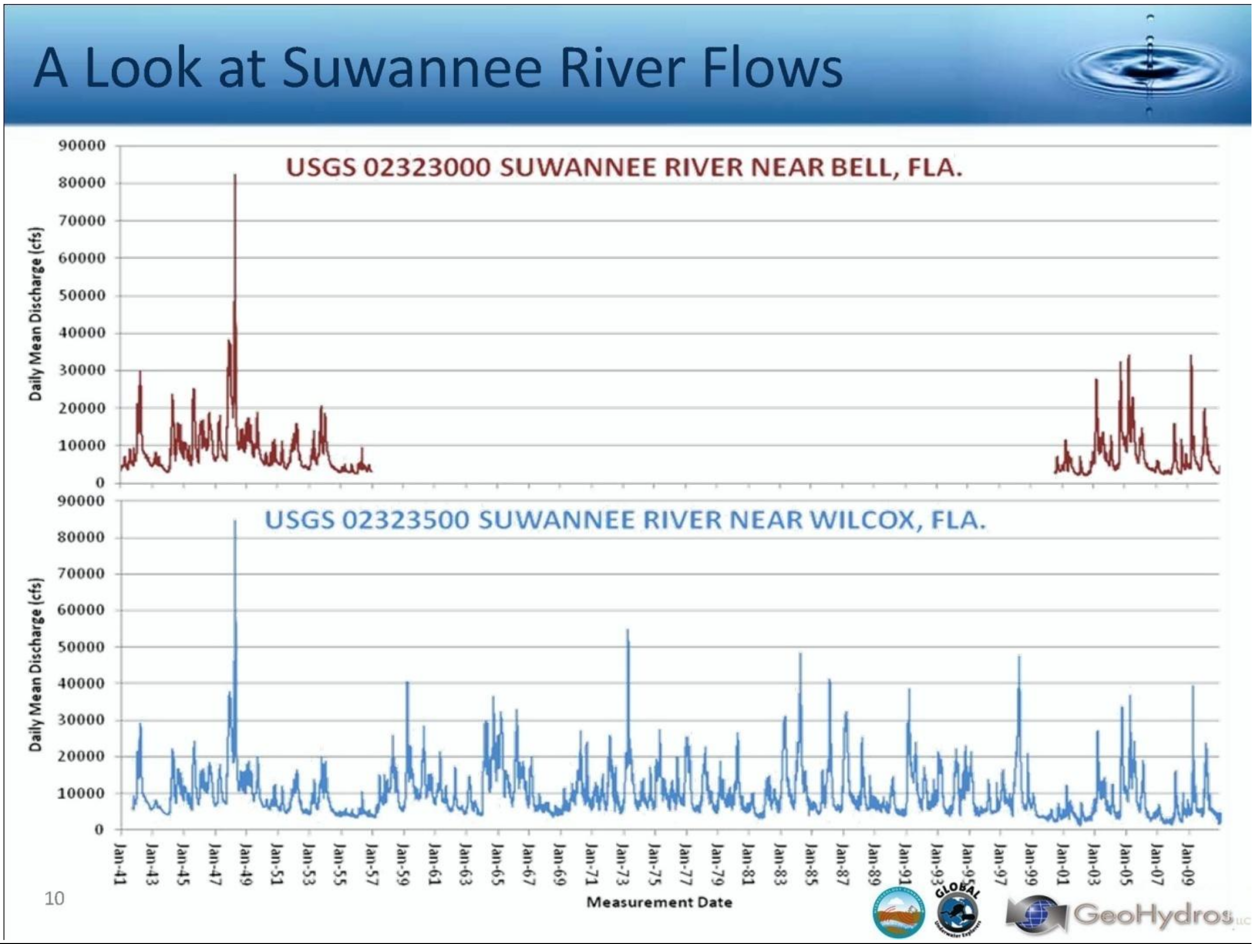


Another way to assess our water budget performance is to look at long-term records of river flows. Instead of looking at the flow directly though, we'll look at how the river flow changes between upstream and downstream stations through time. If flow in the downstream station is greater than the upstream station, we describe the river as gaining (receiving spring flow). If the reverse is true, we describe the river as loosing. By comparing the historical records, we can learn how the degree to which the rivers gain or lose water has changed through time.

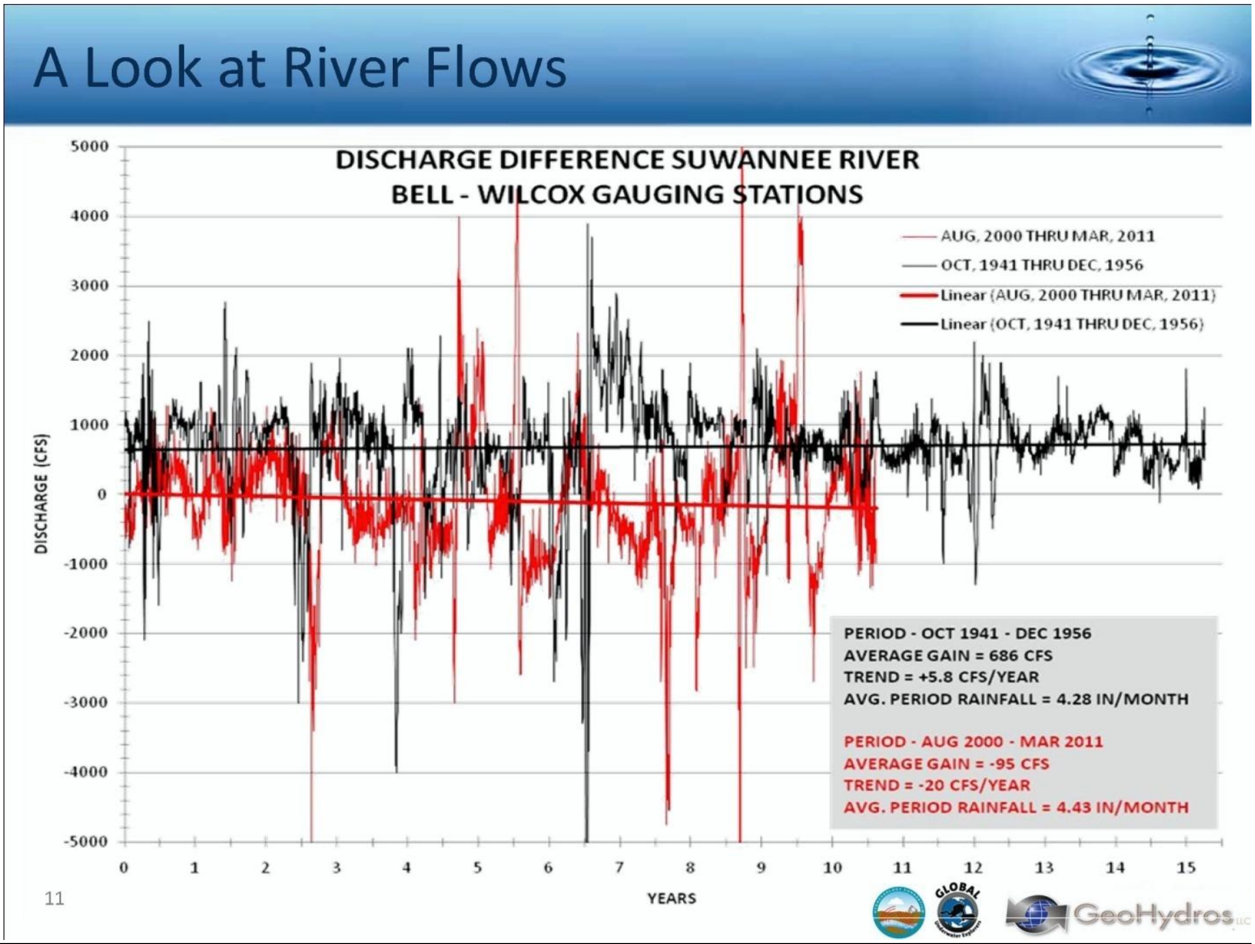
Worthington Springs and Fort White are upstream and downstream stations on the Santa Fe River. Bell and Wilcox are upstream and downstream stations on the Suwannee River.



This plot shows the difference between flow measured at the upstream and downstream stations on the Santa Fe River (Worthington Springs – Fort White). Though the numbers fluctuate, the bulk of them consistently plot above 0 revealing that the Santa Fe River has been a gaining stream overall throughout the historical record. The plot also shows however, that the amount of gain has consistently declined throughout the record – by approximately 4.2 cfs per year from 1932 to 2010. If we compare the average gain during the first 20 years of the record with the average gain for the last 20 years of the record, we would see that the Santa Fe River has lost 285 cfs – or the equivalent of almost 3 first magnitude springs.



The record in the Suwannee River is not as complete at the upstream (Bell) gauge so we'll compare the early-time record (1941-1956) with the late-time record (2000-2011).

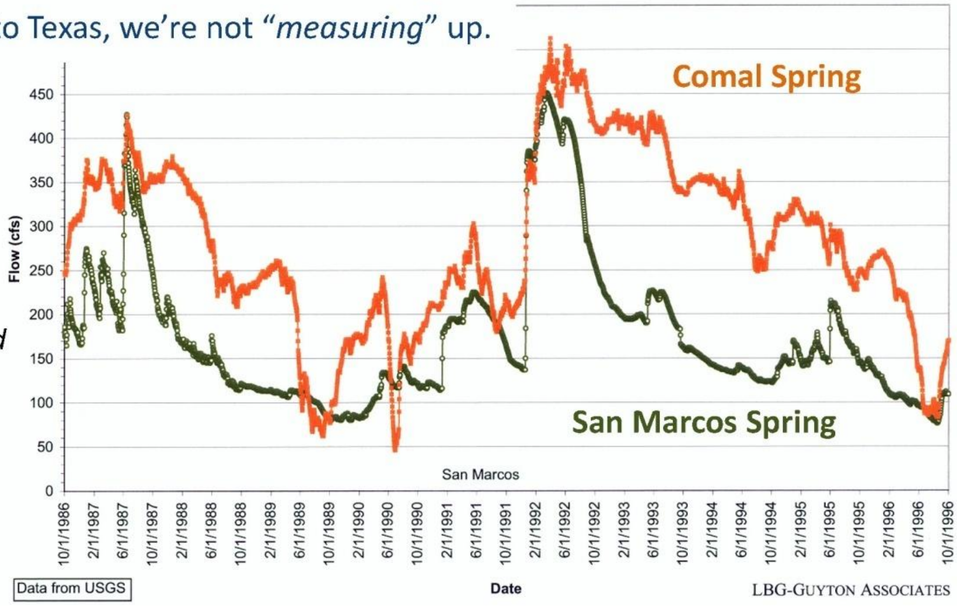


This plot shows the difference between the upstream and downstream gauging stations for the early-time record (black) and the late-time record (red). During the early-time period, this section of the Suwannee River was a gaining stream with an average gain of 686 cfs/year and it was, on average, increasing in gain at a rate of 5.8 cfs/year. The late-time record shows quite the opposite where this section of the river has become a losing stream with an average loss of -95 cfs and it is losing more through time at an average rate of -20 cfs/year. That's a total loss of almost 800 cfs from the river between the two time periods wherein the average rainfall for the two periods was essentially the same.

What Have We Lost?

- Know we've lost substantial river flow
- Presume that the loss is in spring flows
- Which ones?
- Don't really know because we don't have good data.
- Compared to Texas, we're not "*measuring*" up.

Continuous Record
1986 - 1996



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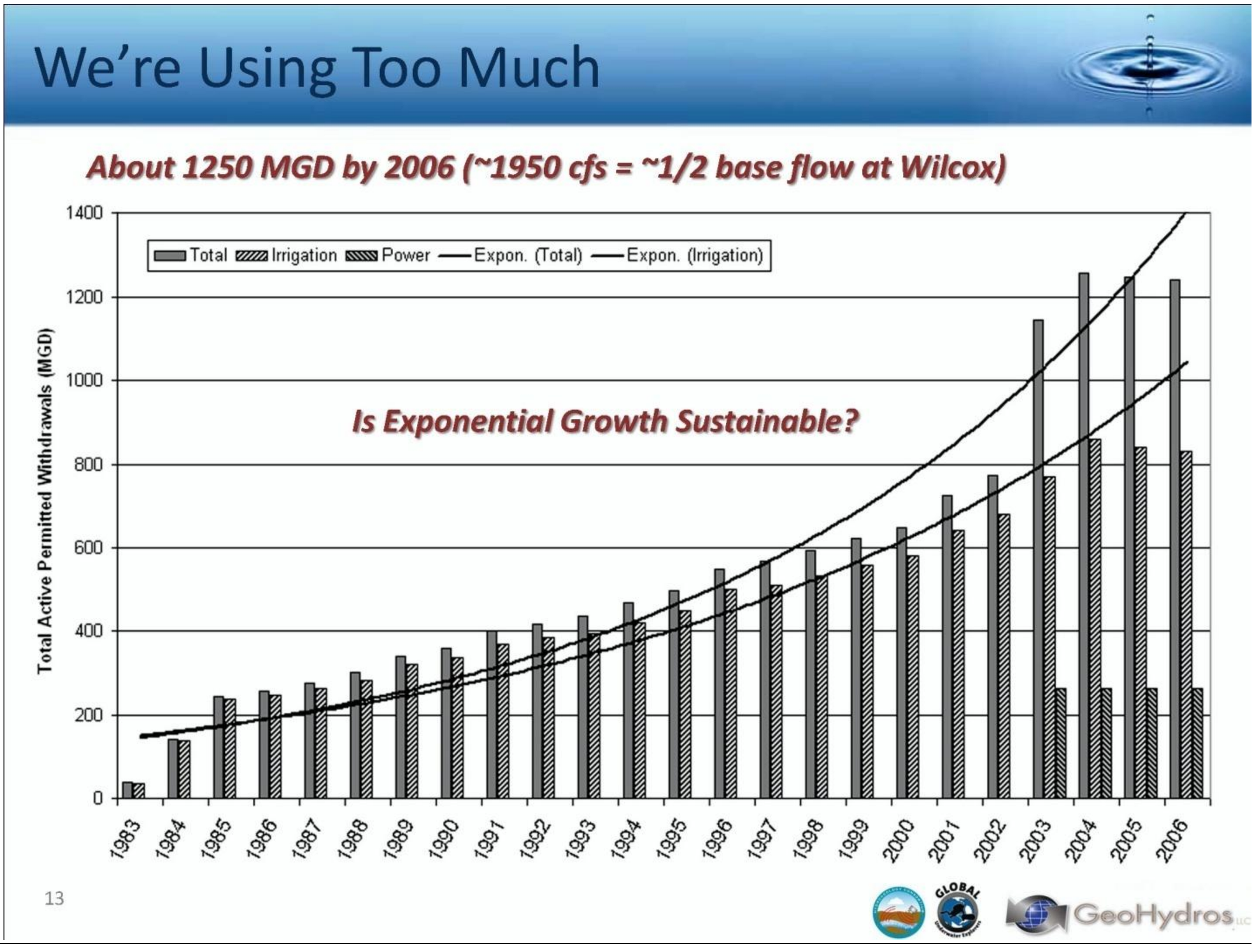
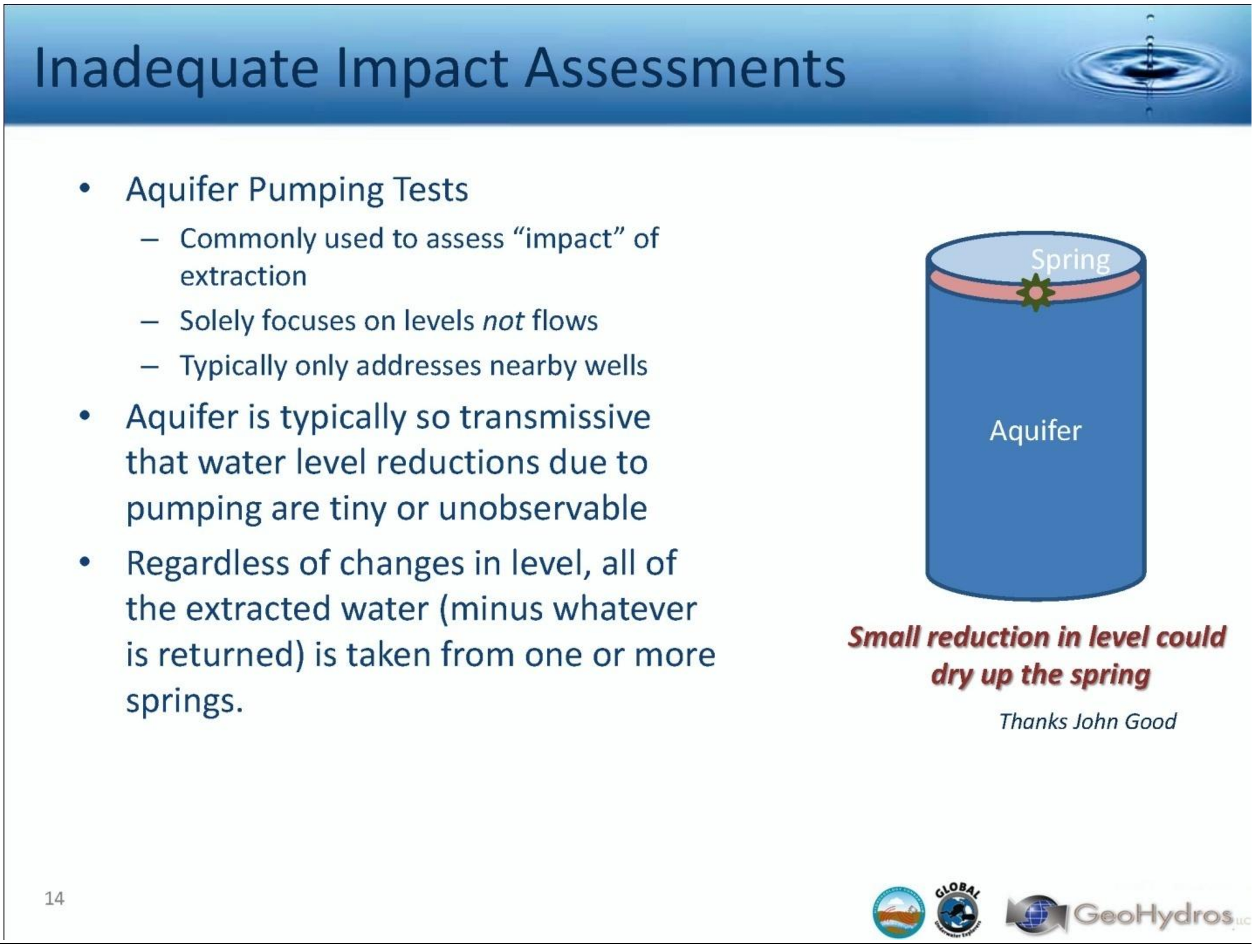
The previous plots clearly show an impact to groundwater levels and river flows but we cannot discern where the impacts are occurring because we are not collecting sufficient spring flow data. This plot shows what such data would look like. It provides two continuous records of spring flows in the Edwards aquifer of Texas. This is the kind of continuous data we need if we are going to be able to understand how our actions (groundwater pumping) are impacting specific springs. If water resources managers are progressive enough to implement this data into the state's long term water budget planning in Texas, we can, and should do the same in Florida.



We've now seen that both aquifer storage and spring flows are in decline. We cannot definitively say that those declines are due to pumping but … we do know that permitted pumping extractions from the Floridan aquifer in the Suwannee River Basin have risen exponentially since the early 1980's and are currently about 1950 cfs, which is approximately ½ the base flow of the Suwannee River at the Wilcox station.



One of the fundamental problems we must confront is the manner by which groundwater withdrawals are typically evaluated. Aquifer pumping tests are designed to evaluate how pumping from a well impacts groundwater levels in the aquifer around the well. The basic premise is that pumping will cause a conical depression or "drawdown" in the natural groundwater surface, often called the water table or potentiometric surface, and the depth and spread of that depression defines the impact of the pumping. When this is true, the "cone of depression" defines the area that is impacted by the pumping – broader the cone – broader the area of impact.

The Floridan aquifer has such a high capacity for water flow, however, that most of all the pumping tests ever performed show very little to no drawdown whatsoever. From that perspective, it can be presumed that pumping rarely has a significant impact on the aquifer.

As we've seen in the previous plots however, all pumping depletes storage and potentially spring flows by the amount extracted. The problem is that the pumping test is not an appropriate manner by which the impacts from pumping can be measured. This realization is proving to be a difficult, yet crucial concept to convey to water resource managers and policy makers.

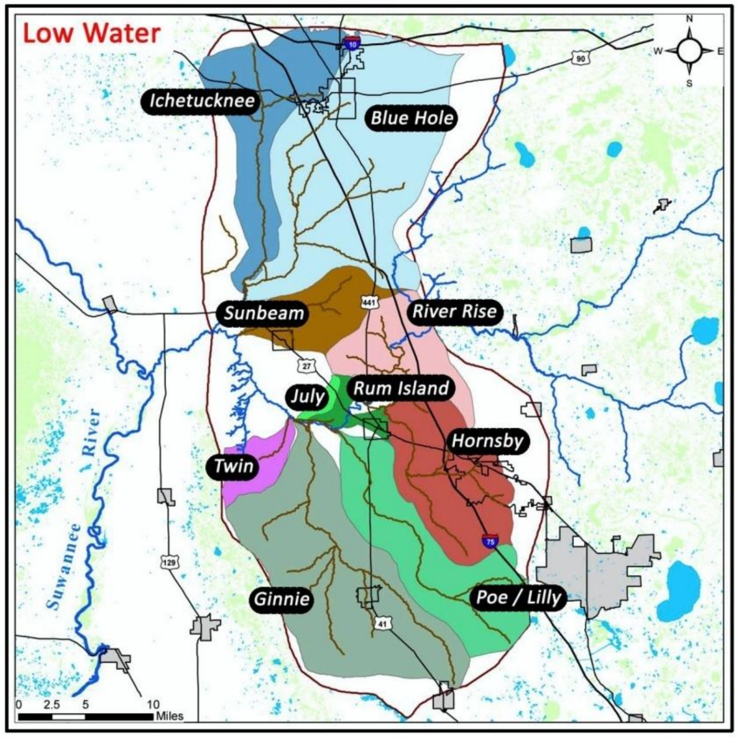
This idealized bucket demonstrates the problem. The bucket represents the aquifer, which can be hundreds of feet thick. The springs are like the spout in the top of the bucket. When the bucket is full or nearly full, the springs will flow. However, a relatively small depression in the water level in the bucket will cause the springs to stop flowing.

In the real world, a small depression in groundwater levels reduces the pressure in the aquifer resulting in a loss of spring flow. The smaller springs go first then the larger ones. Unfortunately, we have already lost many of the smaller ones throughout Florida and even some in the Suwannee River Basin.

Modeled 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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Groundwater models are another tool used to predict the impacts from groundwater pumping. They're also used to predict flow paths and velocities in order to determine where springs are vulnerable to contamination.

It has been said that all models are wrong and, to a point, that is certainly true – they are just models. But some are much more wrong than others. The test of wrongness is the degree to which they simulate observable conditions.

Most models are based on an assumption that the aquifer is essentially a sand box with no caves and no springs. Such models cannot accurately simulate the flow paths or velocities that they were designed to predict. And, if they fail to do that, they cannot accurately predict springshed boundaries, which in turn, means that they cannot predict the impacts of pumping on the springs.

The solution is simple. We need to construct models such that they include the caves and springs and swallets that we know exist. This slide shows the results from such a model that we created for Coca-Cola. The model simulates conduit networks and the springsheds associated with them. The model includes and reasonably simulates all of the most significant observable conditions in the region: springs, swallets, caves, groundwater/surface water mixing, and conduits.

It probably isn't exactly accurate but – it isn't very wrong. The model wasn't easy to build. We had to work out new methods and non-standard software because it turns out that all the standard methods and software – though easier to use – cannot really address karst. But, Coca-Cola supported us for four years because they understood that if their access to clean fresh water was to be preserved, groundwater in the Santa Fe River basin had to be better managed.

Modeled 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
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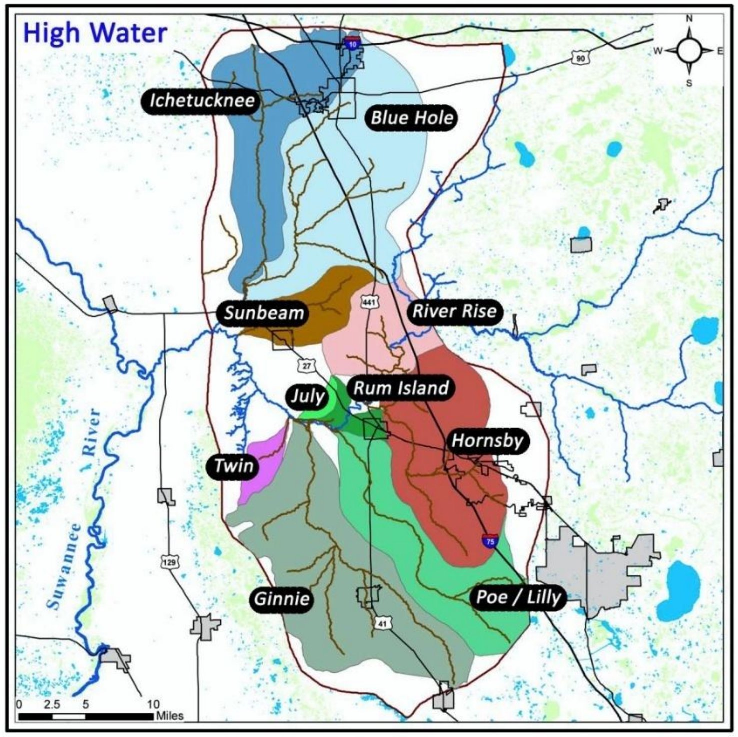

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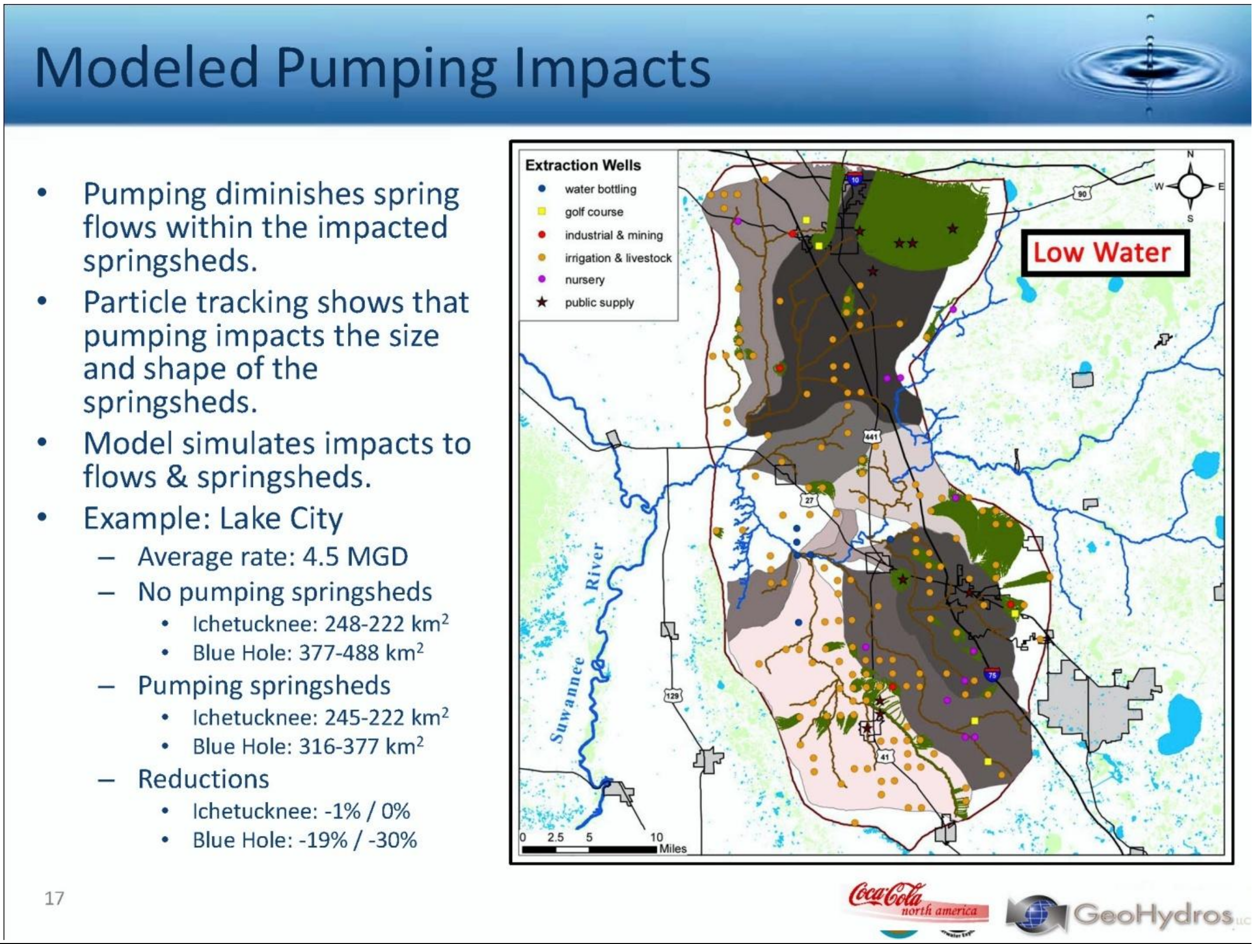
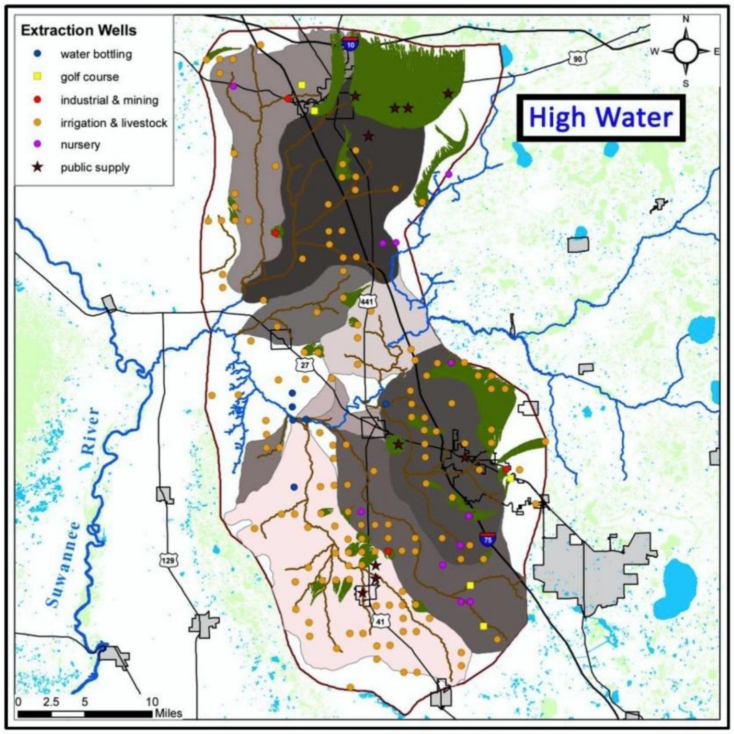
The same model results but for high water conditions. You can see how the sprinshed boundaries change due to elevated rainfall and therefore recharge.



The green lines trace the model-simulated flow of groundwater to the largest pumping wells in the western Santa Fe River Basin. The springsheds in which the lines originate are those that contain the springs that are impacted by the pumping. The amount of pumping in those springsheds depletes the aquifer storage that would otherwise deliver flow to the springs.

Modeled 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 km²
    - Blue Hole: 377-488 km²
  - Pumping springsheds
    - Ichetucknee: 245-222 km²
    - Blue Hole: 316-377 km²
  - Reductions
    - Ichetucknee: -1% / 0%
    - Blue Hole: -19% / -30%



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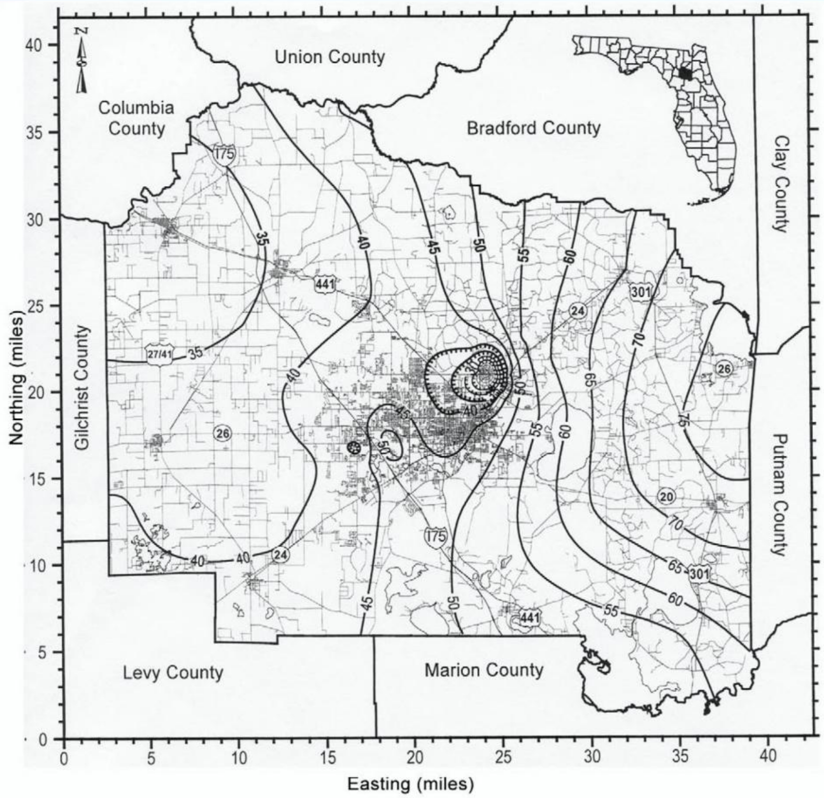
The same model showing which springsheds are impacted by pumping under high water conditions.

Gainesville's Water?

May 2000



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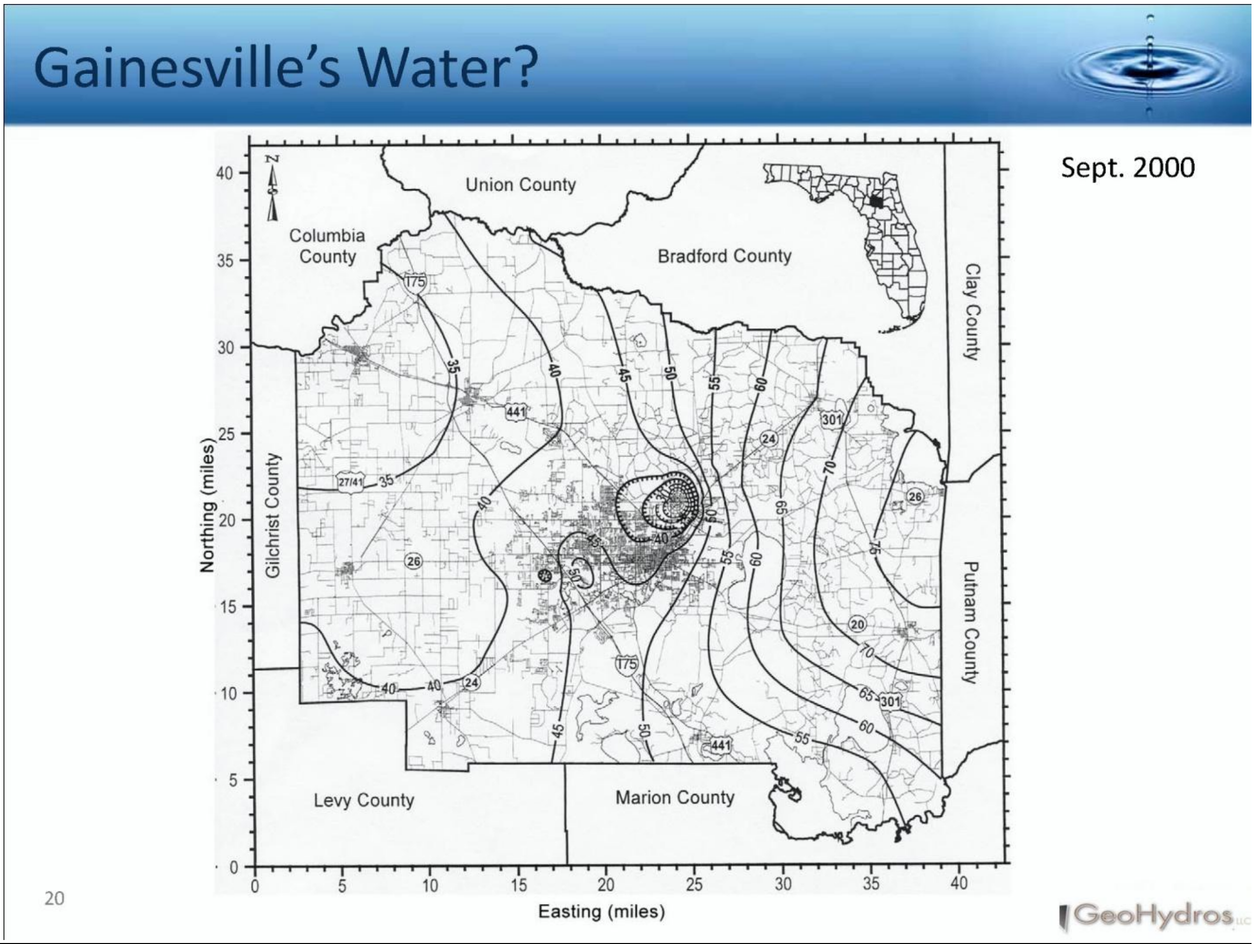
GeoHydros

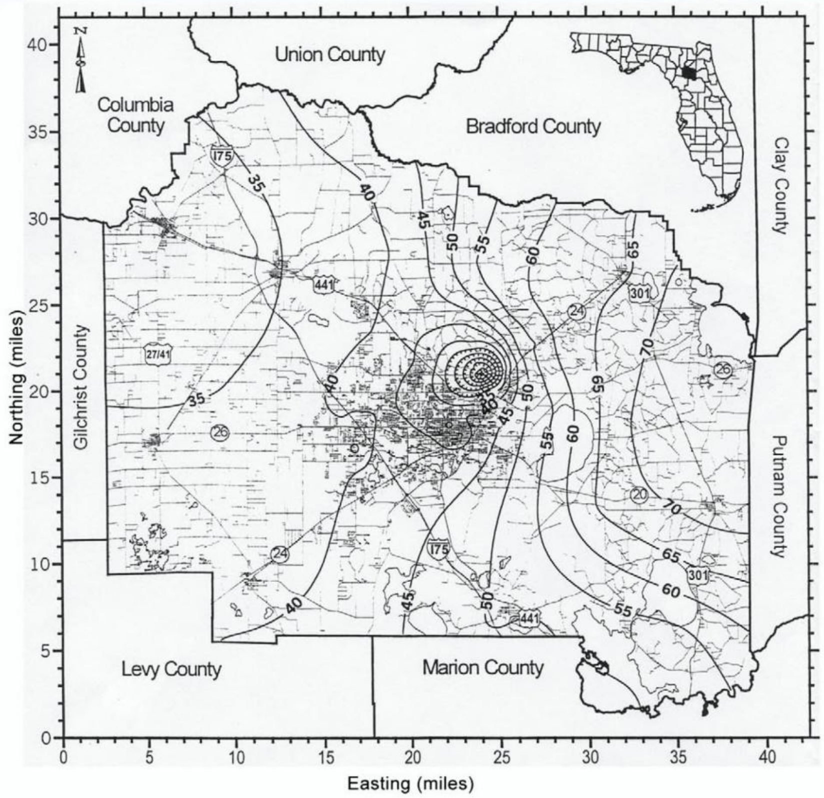
A potentiometric surface map of the upper Floridan aquifer showing the cone of depression associated with pumping at the City of Gainesville's water supply wells. The numbers on the lines mark the elevation of the groundwater surface in the aquifer where flow is from high to low. If you put your thumb over Gainesville's cone of depression, it would appear that flow is generally from east to west to the Santa Fe River, which makes the border of Columbia and Alachua Counties. Remove your thumb and you'll see that Gainesville is intercepting flow that would otherwise flow to the river – to springs such as the River Rise and Hornsby springs.



The same potentiometric surface but for September 2000. The cone of depression is still intercepting Santa Fe River flow.

Gainesville's Water?

May 2001



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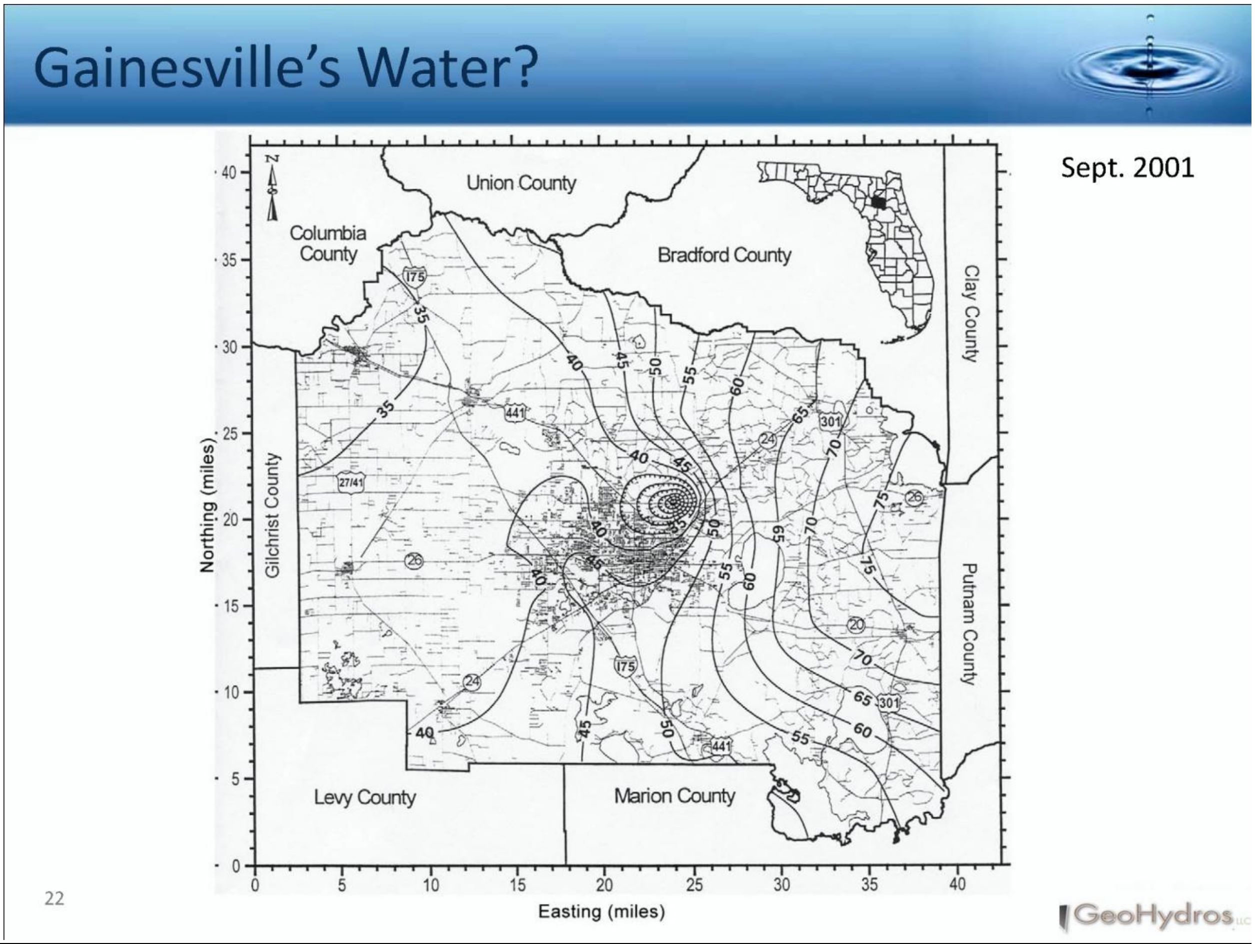
GeoHydros

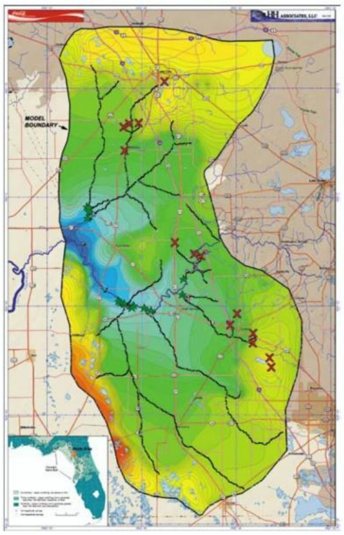
The same potentiometric surface but for May 2001. The cone of depression is still intercepting Santa Fe River flow.



The same potentiometric surface but for September 2001. The cone of depression is still intercepting Santa Fe River flow.

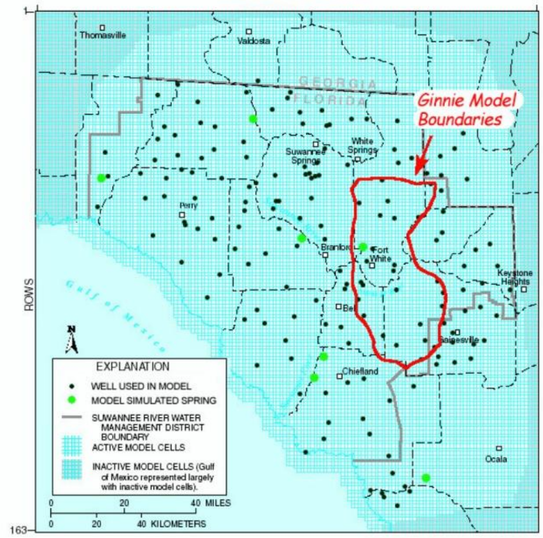
Battle of the Models

CCNA Model



- 13 springs
- 14 swallets
- conduits
- element size ~5 -100 ft

USGS Model



- 1 spring
- 0 swallets
- 0 conduits
- element size ~1 mile

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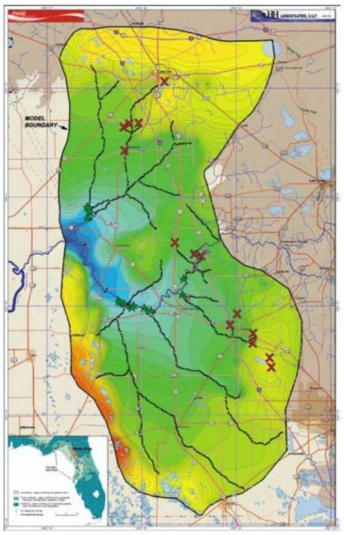
GeoHydros

A comparison of two models. One represents most of what we know is true. The other doesn't.

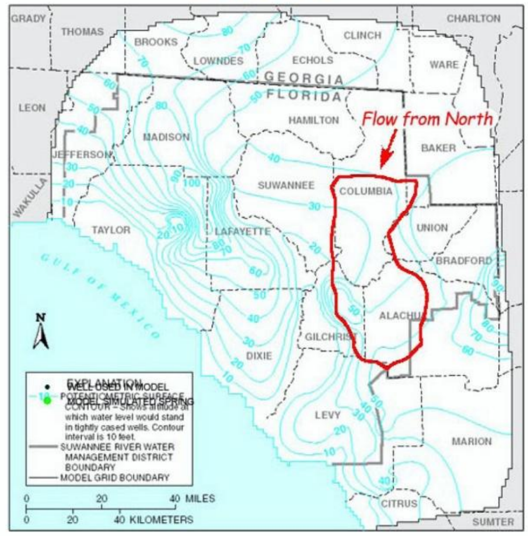
Battle of the Models

CCNA Model



- closed to flow from north
- predicts less water available
- predicts large springsheds
- low rock permeability + conduits

USGS Model

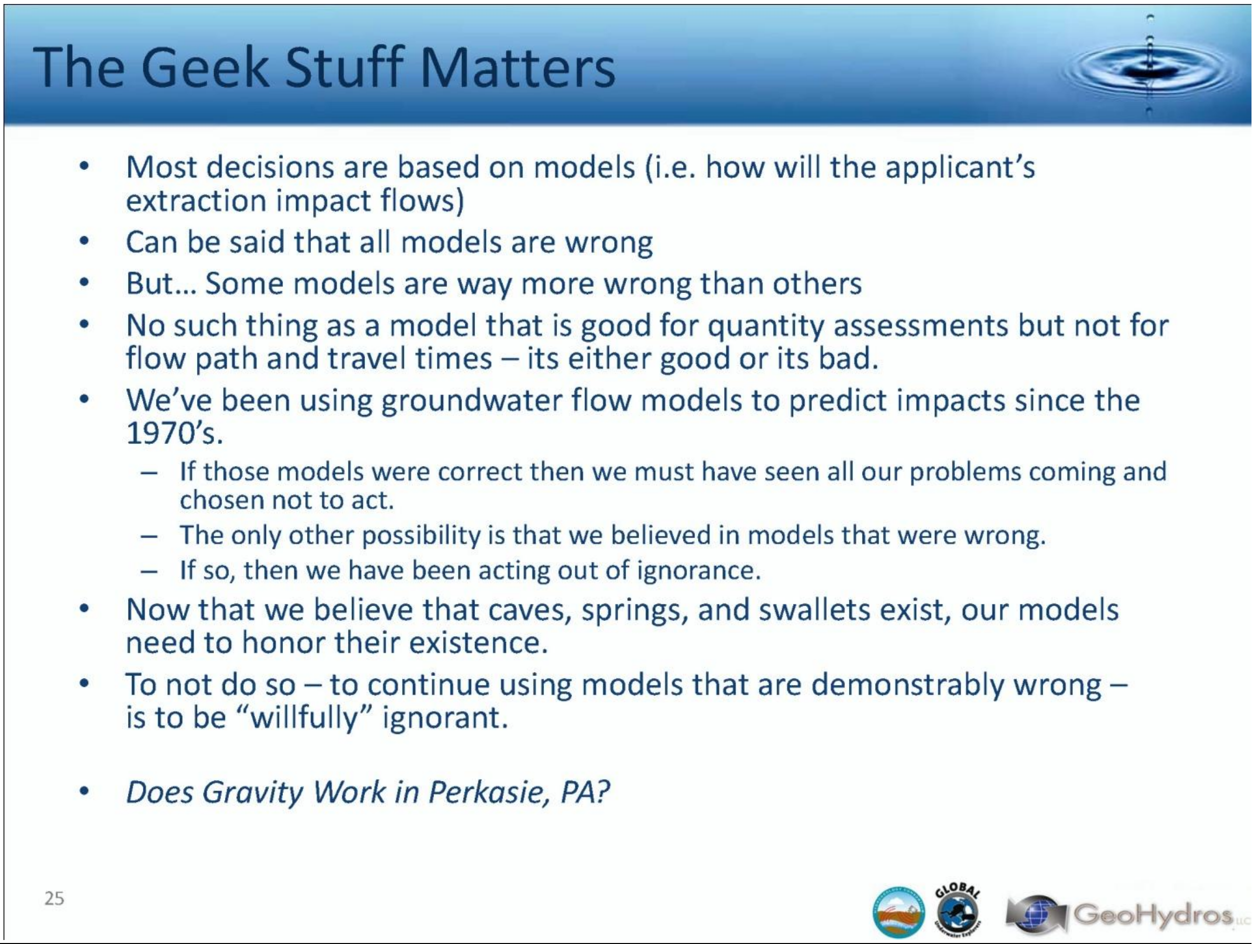


- open to flow from north
- predicts more water available
- predicts small springsheds
- high rock permeability

24

GeoHydros

A comparison of results from the same two models. The one that more closely represents reality (left) is closed to the north thereby predicting that all the flow available to Santa Fe River Springs must come from no farther north than Lake City. The other one is open to flow from Georgia thus predicting much more available water.



The message I hope to convey is that the technical details matter greatly. Unfortunately these technical details are often glossed over and disregarded. Presentations that include modeling often gloss over the whole effort with one slide then jump to the conclusions that we're asked to accept. And, when the modeling geeks start arguing, most of us stop listening. That needs to change.

I recently worked on a groundwater model for southeastern Pennsylvania. A city engineer from one of the municipalities (Perkasie Borough) in our model domain disputed our simulated wellhead protection zones (like a springshed for municipal wells). He argued that the concept of a water budget, which is the fundamental principal on which models are built, was not valid in Perkasie. In essence he believed that more water comes into Perkasie than goes out, which is tantamount to not believing in gravity. To my dismay, the City manager gave equal weight to both arguments.

Everyone does not need to be a math wizard nor do they need to understand all of the details wrapped up in the various technical methods used to support decisions. But – everyone should, by now, given our water crisis, be wise enough to know when one position fails to pass the laugh test. Think of the cost in time and money – and harm to the resource – associated with failing to dismiss positions and proposals that are demonstrably wrong at the most basic levels.

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"

26 GeoHydros

An example of how wrong models can be and how consequential blind faith in them can be can be found by looking to a recent problem in Miami-Dade County. There are large quarries near the Miami-Dade well field. These quarries excavate limerock from open water-filled pits. Because of the proximity of the pits to the well field, water quality is closely monitored. At one point, cryptosporidium was found in the pit water, which raised significant concern that it might live in the groundwater long enough to enter the wells. The biologists say that if the travel time for the bacteria in the ground is 30 days or more, then it will die and not be a problem.

Miami-Dade has a model in place that use as the basis for many water resource decisions. The model indicated that the travel time between the quarry pit and the wells would be much longer than required to kill the bacteria. A dye tracing test was commissioned however to verify the model predictions. The plan called for injecting dye into wells near the quarry and sampling for it in the water supply wells. The geologist advocated for a conservative step-wise approach to the test starting with very small quantities of dye and progressing to larger amounts if needed. The stepped approach was specifically designed to test the model-predicted travel times where shorter travel times require less dye.

Believing in the model, the officials refused the recommended approach and ordered one large quantity injection. The dye traveled to the water supply wells in hours rather than days (1.5 orders of magnitude faster than predicted). The large flush of red dye into the wells was rapidly distributed out into the system and into peoples homes. Anyone washing their clothes that day ended up with pink whites. The mines were shut down pending further study.

Resource managers went on to acknowledge the problem and work with the mine to fix the cryptosporidium problem. But, nobody has addressed the bigger issue. – If the model is 1.5 orders of magnitude in error in the prediction of groundwater velocities, then it is simply wrong. Wrong models promote bad decisions. I think it is safe to conclude that all decisions rendered on the basis of that model should now be considered unsupported and reevaluated.

The Springs Don't Care …

- Water is valuable to us and to the ecosystems
- If its cheap or free it will be wasted
- There is no longer enough for everyone to use as they please
- Riparian vs. First in Time (east vs. west)
- Water Use – bad or good – judge by consumption alone
- The springs don't care what we use their water for
  - Tomatoes
  - Houses
  - Lawns
  - Beer
  - Bottled water
- Ideally, water users should have a long-term stake in the water quantity and quality

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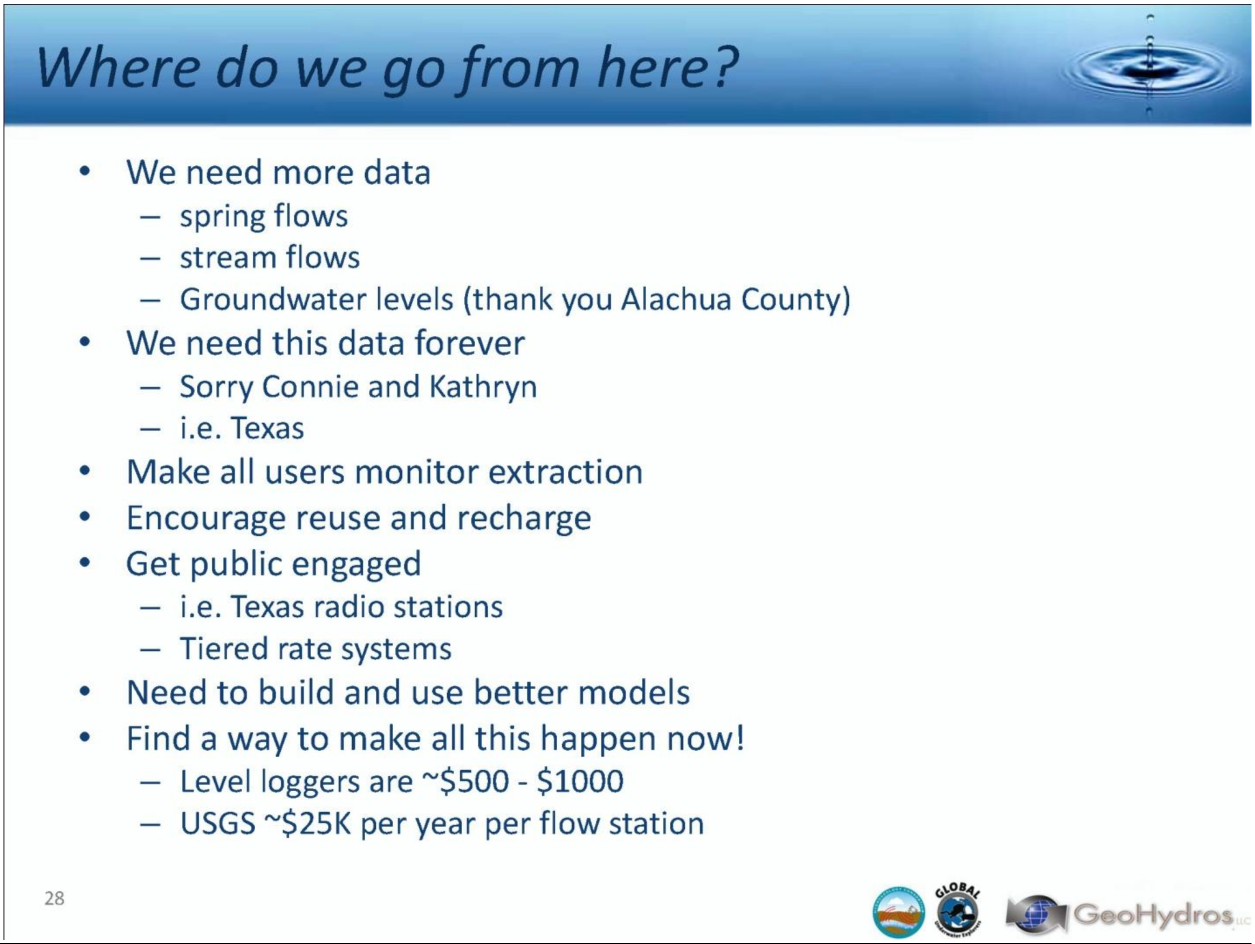
GeoHydros

Another issue we must confront is the manner in which we evaluate and regard withdrawals. Simply put, the springs do not care what we use the water for – homes, tomatoes, beer, water, lawns – doesn't matter to the springs. All that matters is the quantity.

By focusing our efforts on reducing use by the largest consumers of this precious resource – agriculture and municipal supply, we will be one critical step closer to a sustainable water management solution. We should also prefer users that stay in the basins from which they extract the water and maintain an economic interest in preserving flows and quality.



In summary …

We need more data and we need to support long-term (perpetual) data collection efforts.

- We need to expand and sustain river and spring flow gauging.
- We need to expand and sustain groundwater level gauging such as the effort being pursued by Alachua County.
- We need to sustain these efforts for the long haul – just like they do in Texas.

We need to monitor extractions (municipal use and agricultural use) as they are beginning to do in Georgia. But, we need to go another step further and make that data public so it can be used to more accurately assess aquifer impacts.

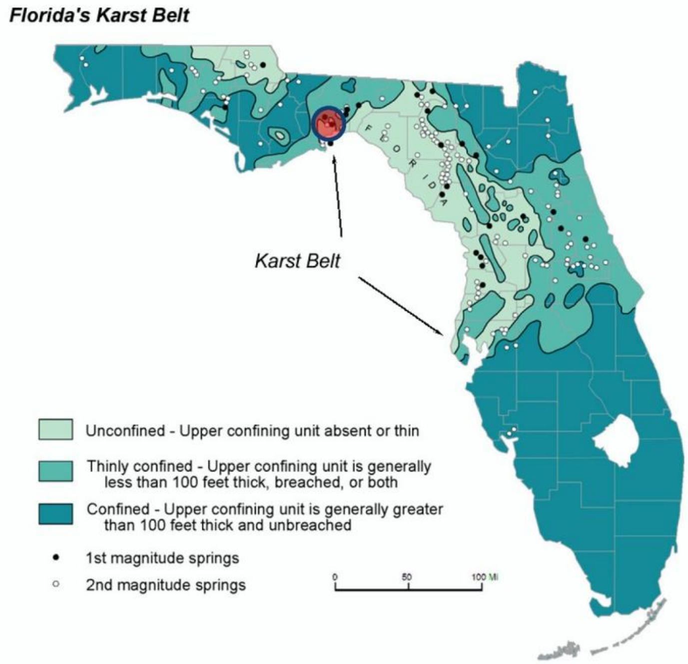
We need to get the public more engaged in water resource conservation and the status of our aquifer and springs. In Texas, they announce the aquifer water levels on the radio stations every day. We need to be doing the same.

We need to engage in and encourage reuse and recharge.

We need to build and use better models to support decisions.

We need to make these things happen now. Gauges are not that expensive. If the State cannot or will not do it, then we need to find another route. Perhaps non-profit organizations like the Florida Springs Institute.

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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We must remember that Florida is unique to the world in terms of having so many very large clear springs in such close proximity.

We must act to protect them.