How Springs Work

A Journey of Discovery…

Todd Kincaid, Ph.D.
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Ever swam against the flow of a strong Florida Spring?

Guessing many of you have..
My first time was at Wakulla Springs in ~ 1973.
Later on, Wekiwa became my favorite place on Earth.

I was one of those kids you probably still see…
lined up along the edge
of what I still believe
must surely be one of the greatest wonders of world.

Where does the water come from?

You can't help but wonder
when you're holding yourself against the flow
struggling to get just a little farther in…

I remember stories of divers using anchors to pull themselves deeper into Blue Springs, past a constriction at ~120 feet deep. I also remember that some of them died trying…

There were, and still are loads of crazy ideas
- from the Appalachian Mountains…
- from the Great Lakes…
- from a deep great lake that Florida floats on top of…
- from a pure and ancient source impervious to harm.

Where does the water come from?

The question that sparked my career…

My presentation –

- *What I was taught…*
- *What I've learned since…*
- *How have the springs and caves come to be…*
- *Why springs are important…*
- *What needs to be done to protect them…*

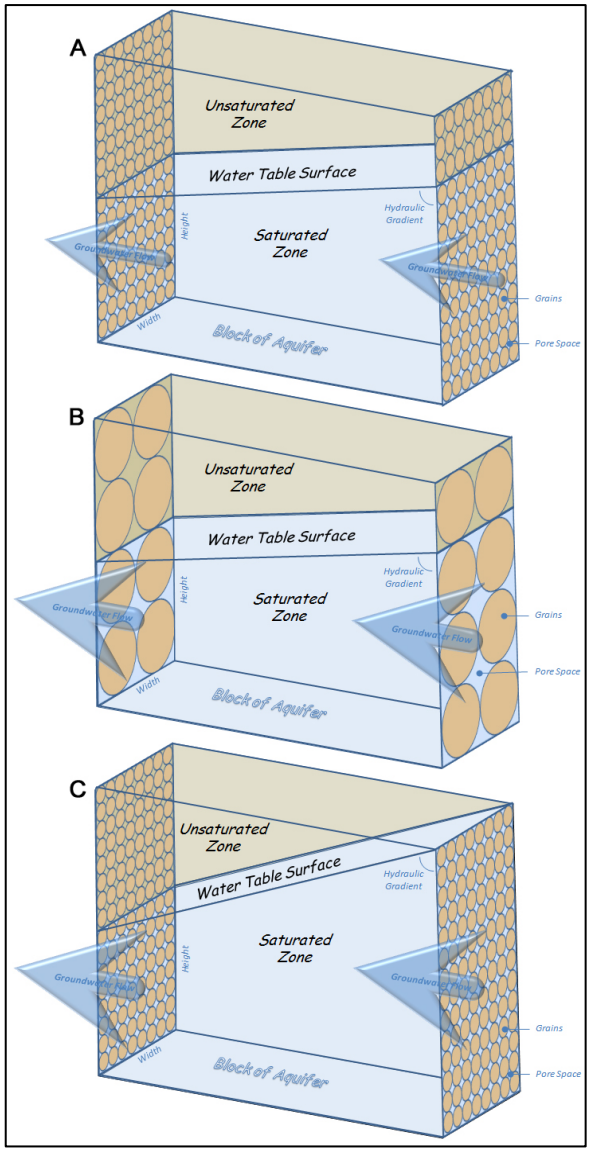
- *Where does the water come from…*

What I was taught …

(4 years in 6 bullets)

"There are no such things as underground rivers"

- Groundwater flows through the spaces between rock grains.
- Groundwater flow is a diffuse slow process.
- Velocities tend to be on the order of feet per year or less.
- Mathematical concepts that evolved for America's great sandstone aquifer underlying the mid-west (the Ogallala Aquifer) render groundwater movement, aquifer storage, and contaminant movement very predictable.
- Amateurs study springs, whereas professionals study wells
- No caves in Florida / if there are they're not significant & too hard to deal with anyway



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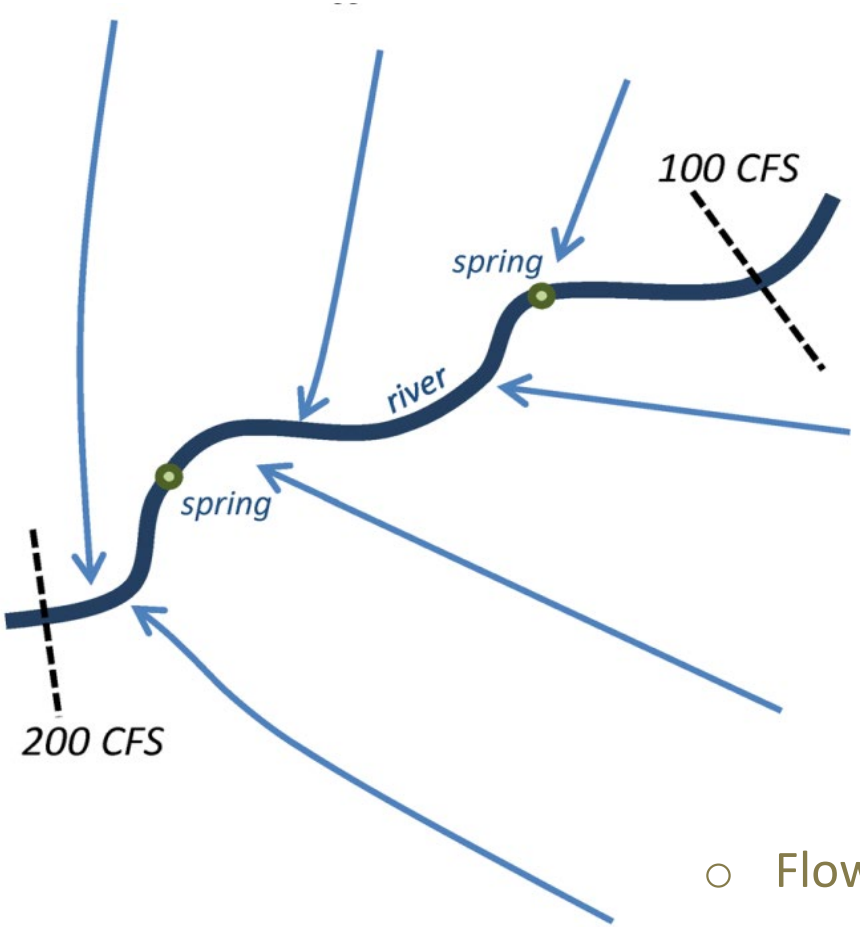
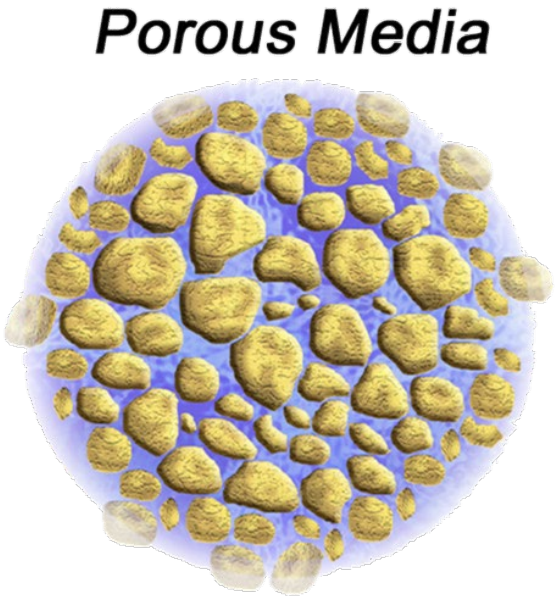
Groundwater Moves by Diffuse Flow





sand / sandstone
easy to characterize
simplest math

- Flow is between the grains
- Discharge dispersed evenly along river
- Space between grains (effective permeability) is highly heterogeneous

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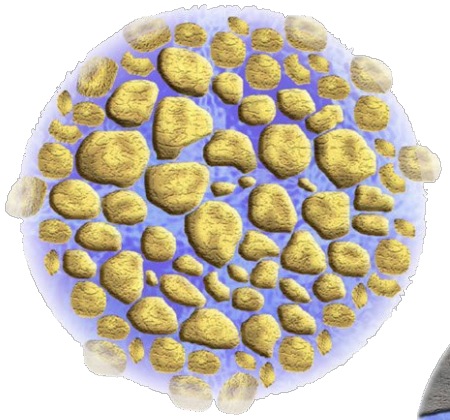
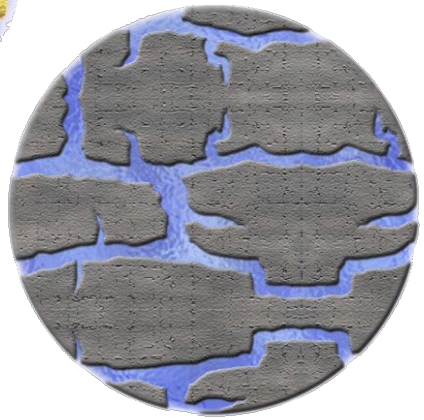
Types of Permeability

Porous Media



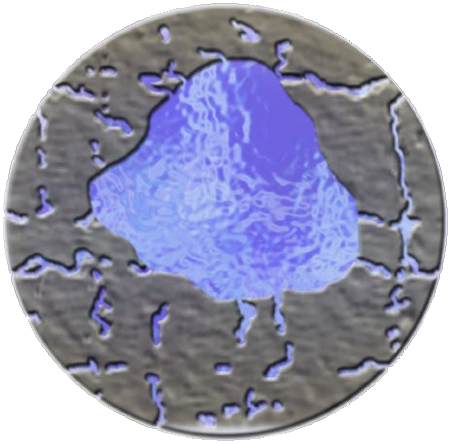
sand / sandstone
easy to characterize
simplest math

Fractered Rock



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

Karst (Conduits)



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

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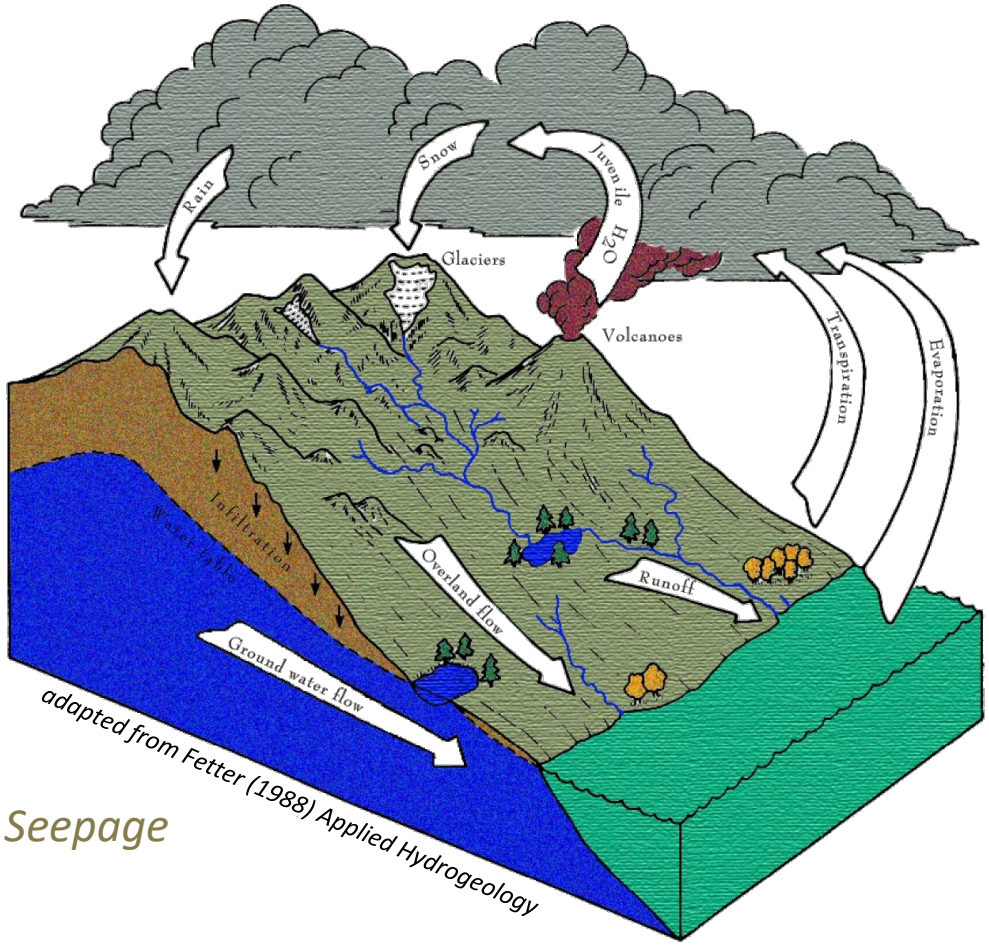
Hydrologic Cycle

- Water flows down gradient
- Inflows equal outflows



adapted from Fetter (1988) Applied Hydrogeology

Discharge = Precipitation – Runoff – Evapotranspiration + Change in Storage

- *Recharge = Precipitation – Runoff – ET*
- *Discharge = Spring flow + Extractions + Seepage*

1st Principles of Science – Mass Balance

- *No such thing as magic*
- *Pollutants don't just go away*
- *Water pumped out is captured from some natural discharge*

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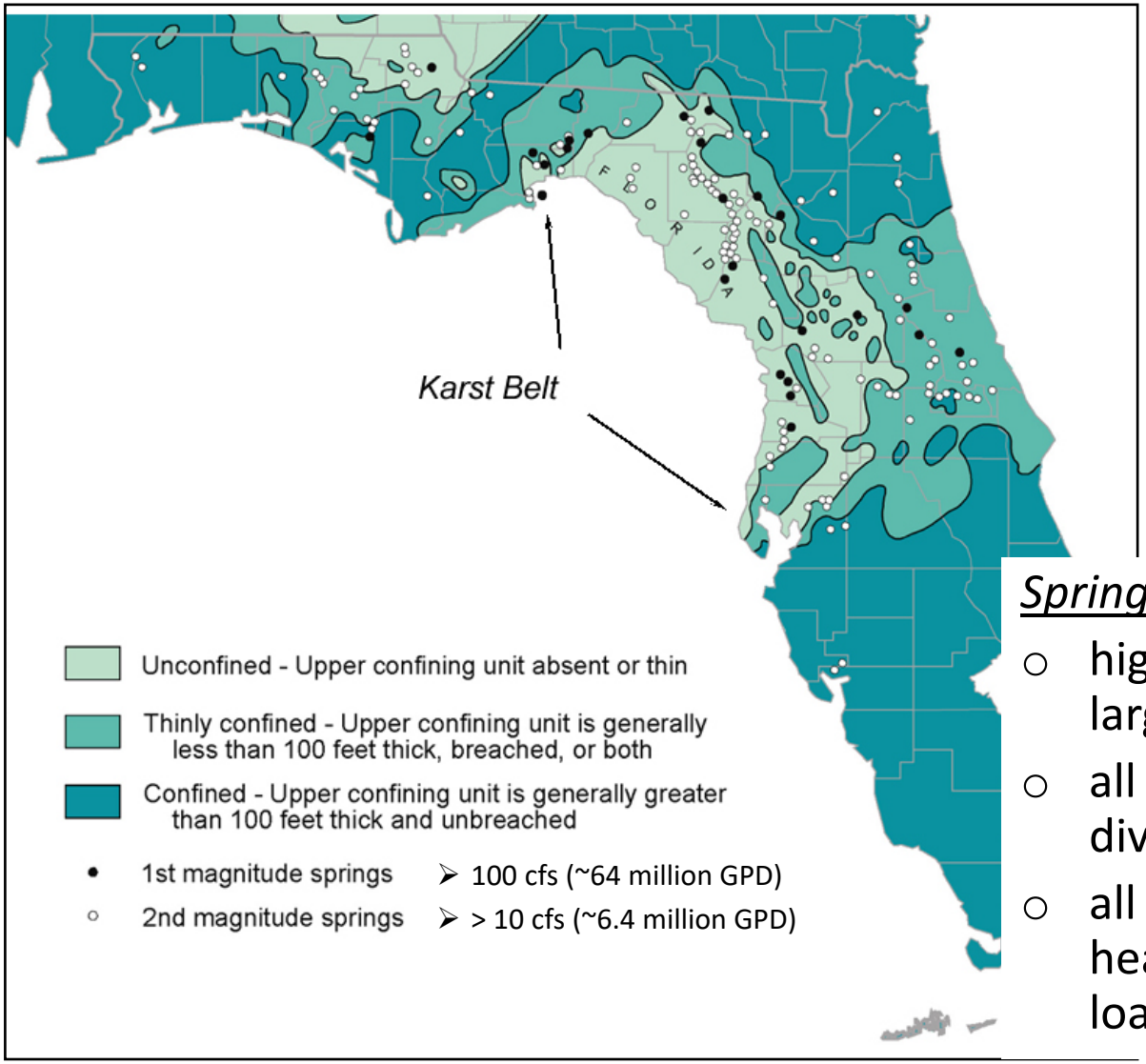
What I learned later on …



Sinkholes, Springs
Caves, & Swallets
disappearing streams

All the defining features that all the world's karstic areas have in common!

Springs

- highest concentration of very large springs in the world
- all big springs discharge from big dive-able cave systems
- all but a few of the springs are heavily impacted from nutrient loading

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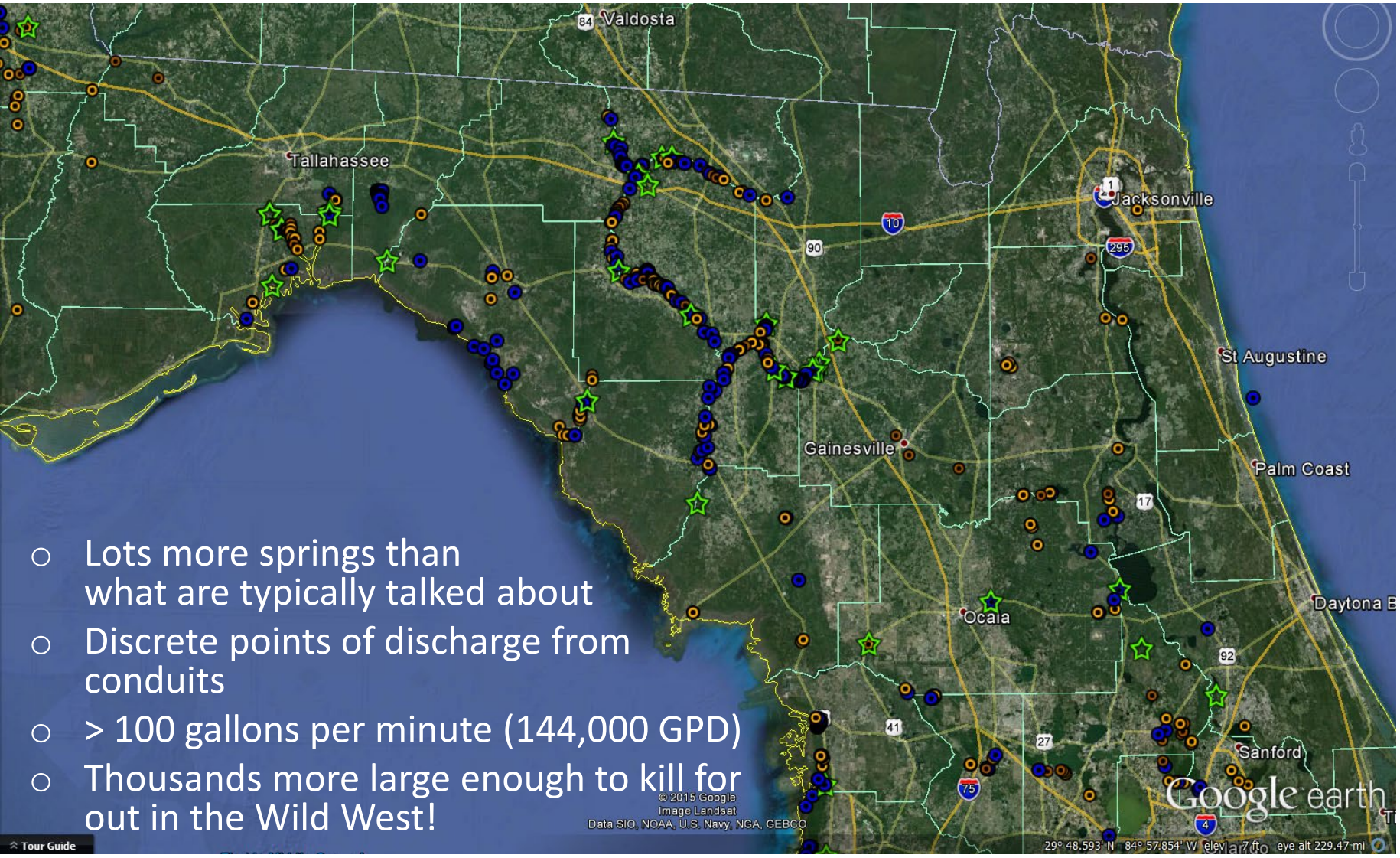
Springs in Florida

Mapped Springs 1st – 4th Magnitude



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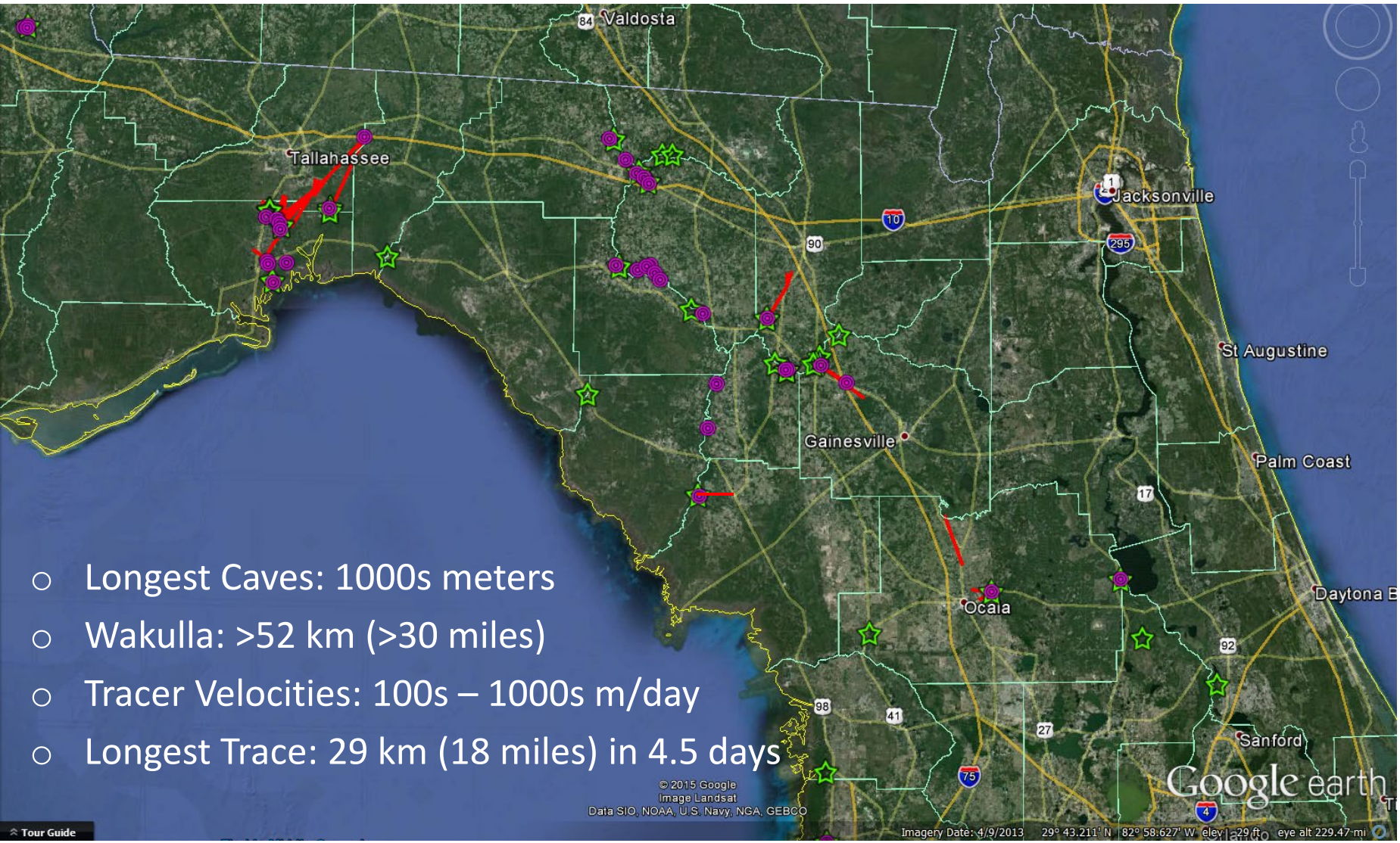
Caves in Florida

1st Magnitude Springs, Long Mapped Caves, Long Traces



- Longest Caves: 1000s meters
- Wakulla: >52 km (>30 miles)
- Tracer Velocities: 100s – 1000s m/day
- Longest Trace: 29 km (18 miles) in 4.5 days

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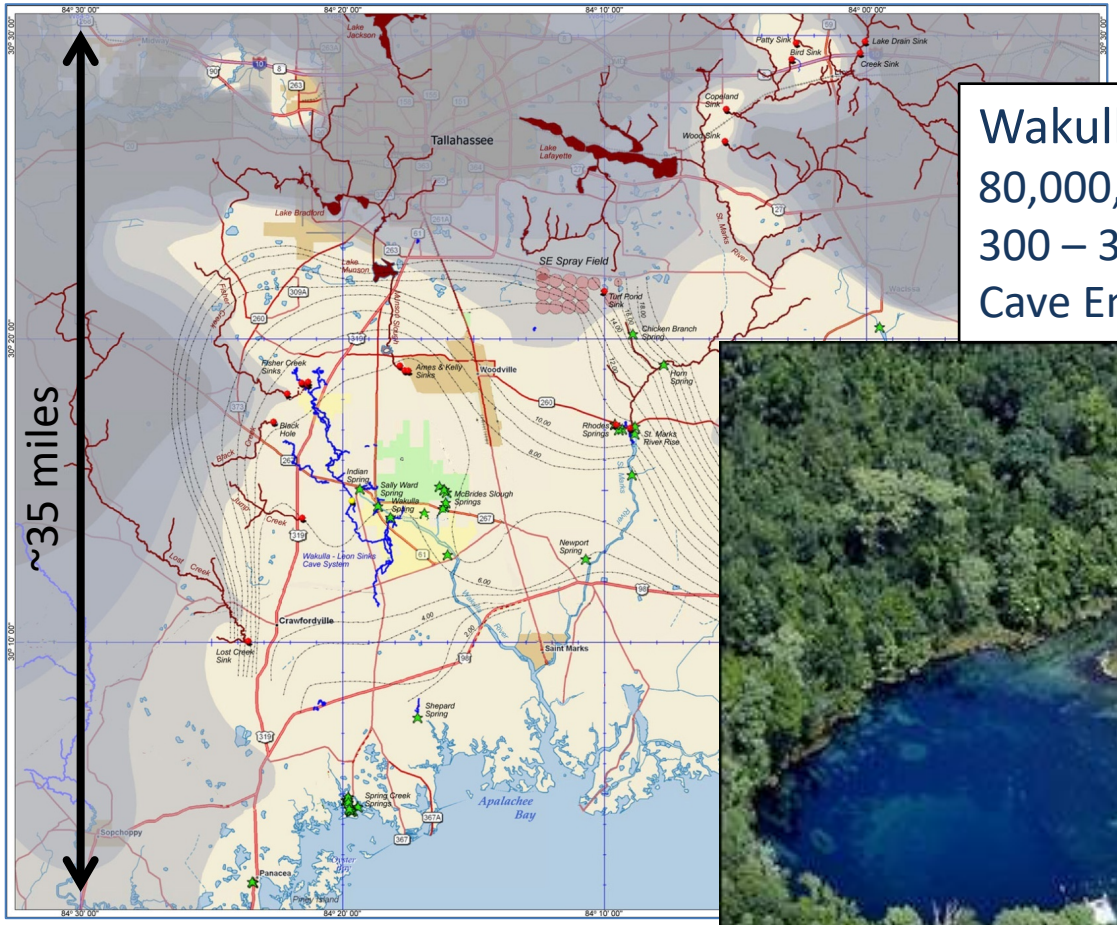
Wakulla Springs & The Woodville Karst Plain

Woodville Karst Plain – Focus of Cave Exploration Since



Wakulla Springs
80,000,000 – 1,000,000,000 gal/day
300 – 3,800 olympic swimming pools per day
Cave Entrance: ~40m high, 60-80m wide

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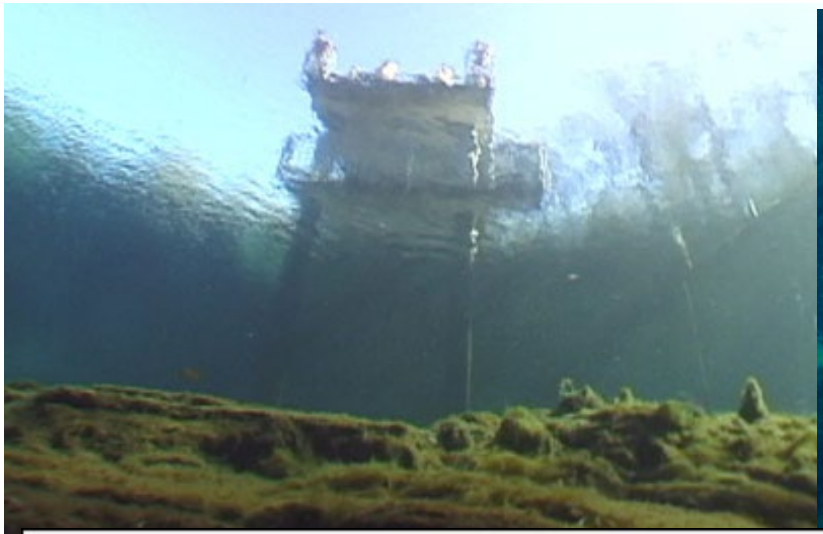
Ecological Decline



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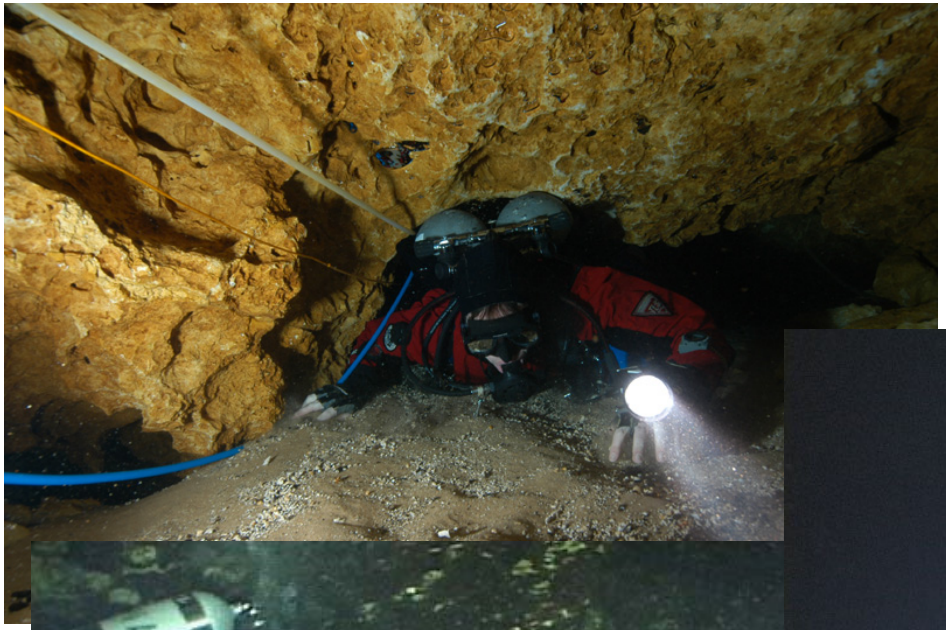
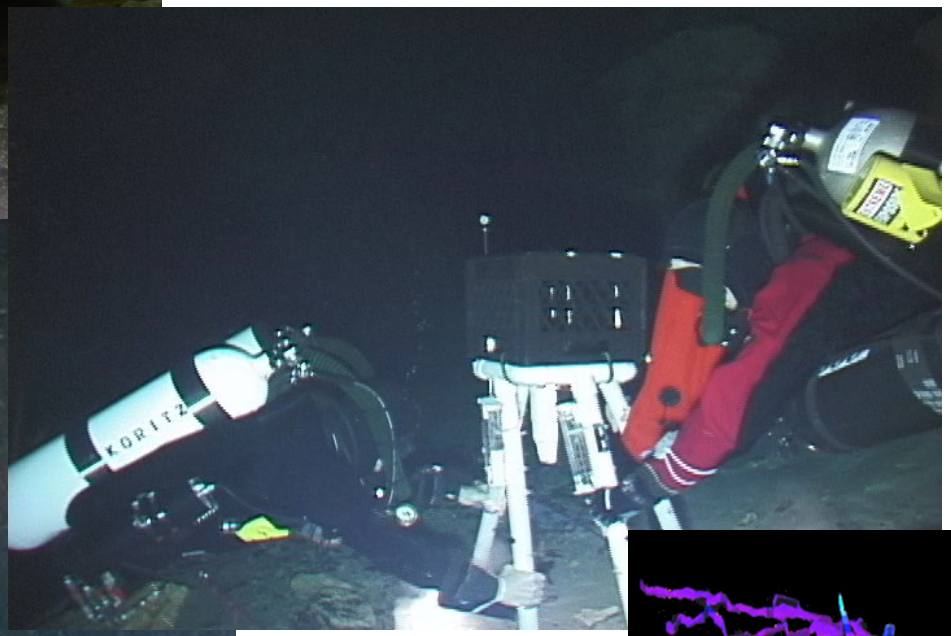
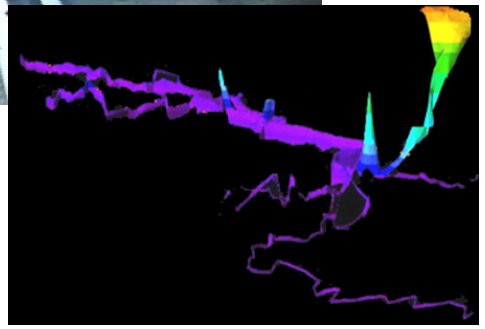
Engaging Divers and Scientists



- previously unimagined access
- tubing for tracing & sampling
- meter installation
- cave radio location (wells & maps)
- detailed survey data – 3D visualization





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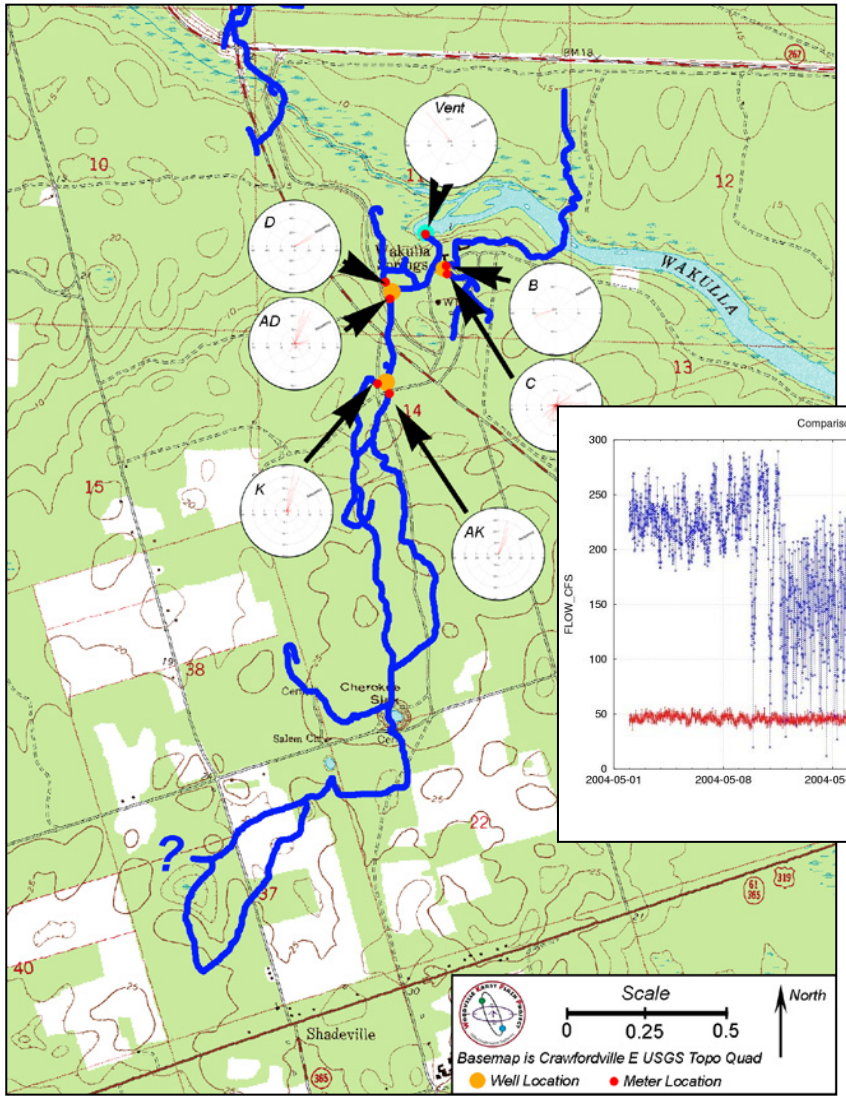
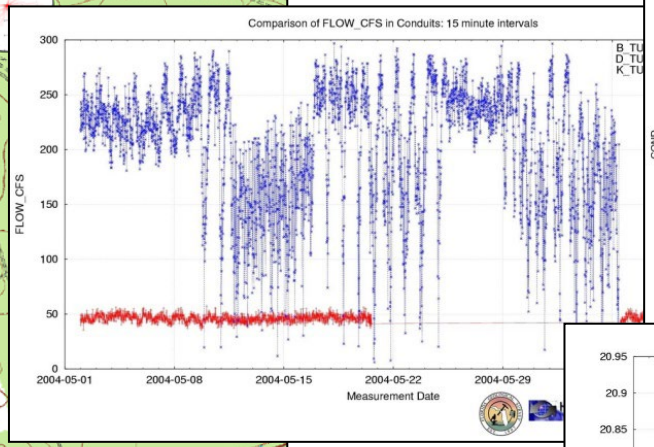
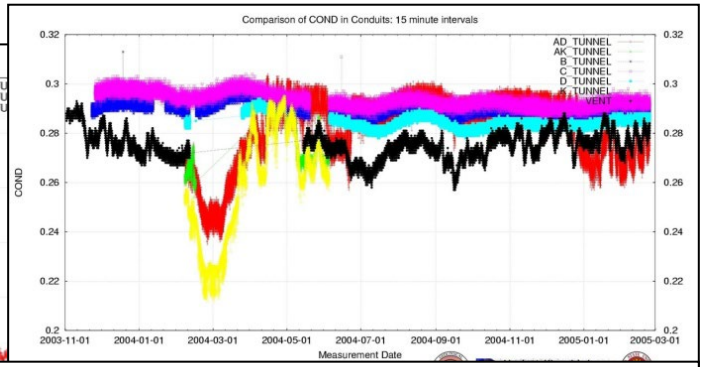
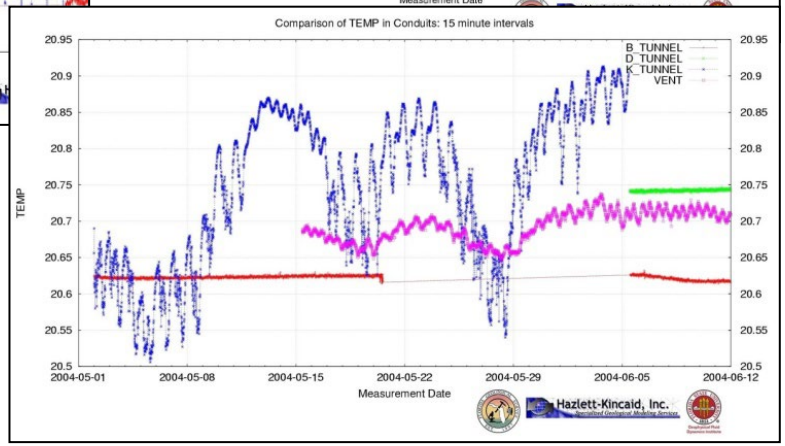
World's Most Instrumented Cave



- seven stations
- conduit junctions
- flow, temperature, conductivity
- 15 minute intervals – available online
- mixing - water from different sources







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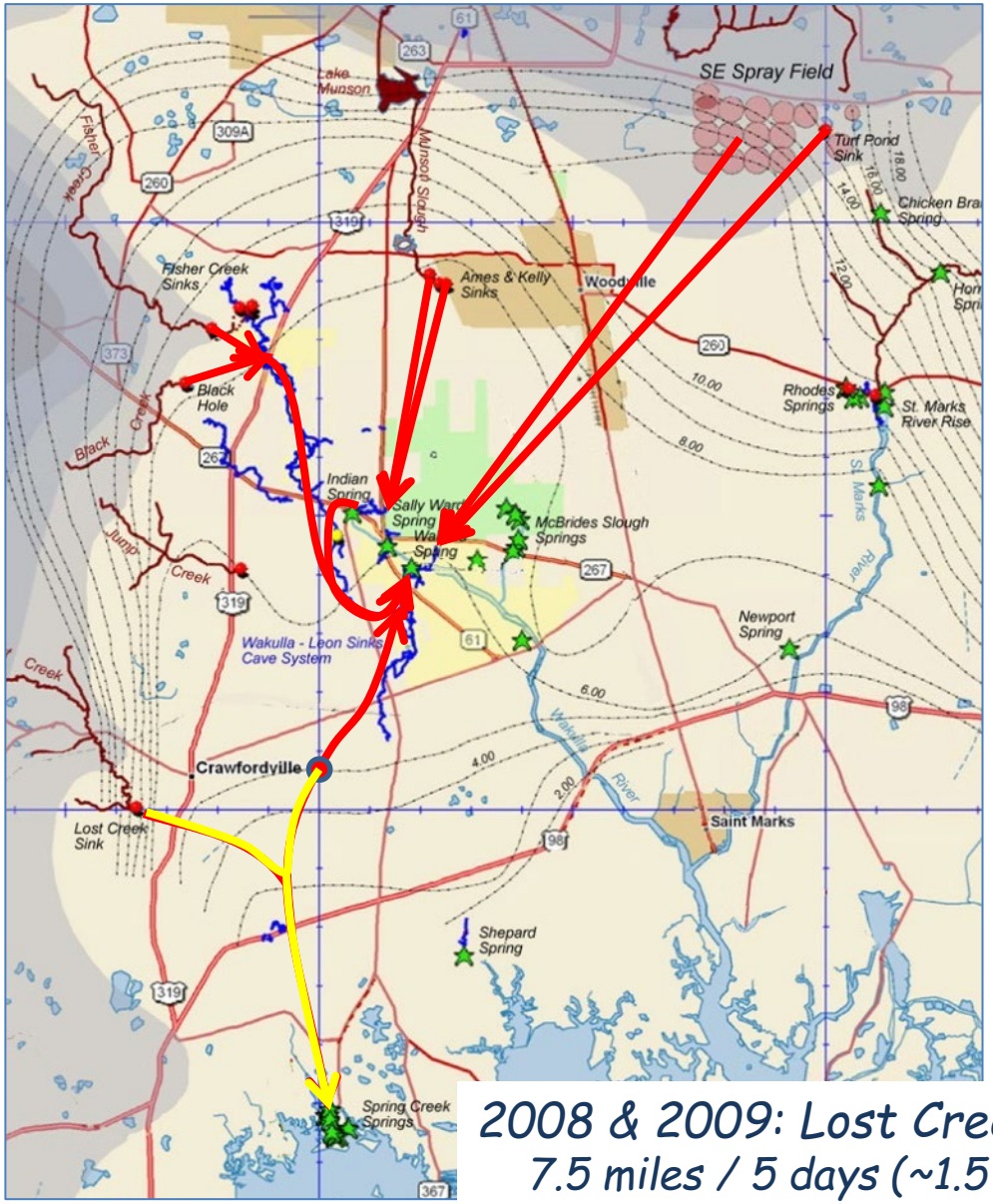
Groundwater (Dye) Tracing



2002: Fisher Creek – Emerald Sink
1.7 miles / 1.7 days (3,770 ft/day)

2003: Black Creek – Emerald Sink
1.6 miles / 1.6 days (2,670 ft/day)

2004: Emerald Sink – Wakulla Spring
10.3 miles / 7.1 days (7,650 ft/day)

2005: Kelly Sink – Indian Spring
5.2 miles / 13.5 days (2,040 ft/day)

2005: Ames Sink – Indian Spring
5.2 miles / 17.2 days (1,600 ft/day)

2005: Indian Spring – Wakulla Spring
5.5 miles / 5.9 days (4,890 ft/day)

2006: Wells – Wakulla Spring
10.4 miles / 66.5 days (830 ft/day)
10.4 miles / 56 days (980 ft/day)

2006: Turf Pond – Wakulla Spring
10.9 miles / 56 days (1,030 ft/day)

2008 & 2009: Lost Creek – Spring Creek & Wakulla Spring
7.5 miles / 5 days (~1.5 miles/day)

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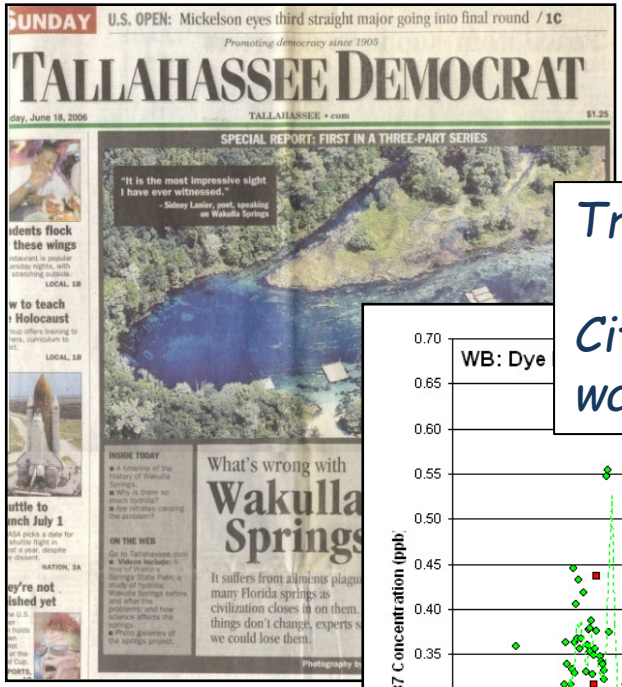
Making a Difference

Education + Science + Press = Results

$200 Million Dollar Breakthrough Curve


SUNDAY U.S. OPEN: Mickelson eyes third straight major going into final round /1C

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SPECIAL REPORT: FIRST IN A THREE-PART SERIES

"It is the most impressive sight I have ever witnessed."
- Sidney Lanier, poet, speaking on Wakulla Springs

What's wrong with Wakulla Springs

It suffers from ailments plagu many Florida springs as civilization closes in on them. things don't change, experts s we could lose them.


FRIDAY JANUARY 27, 2006

Local&State

Family mourns the seven children killed in Wednesday crash. 3B

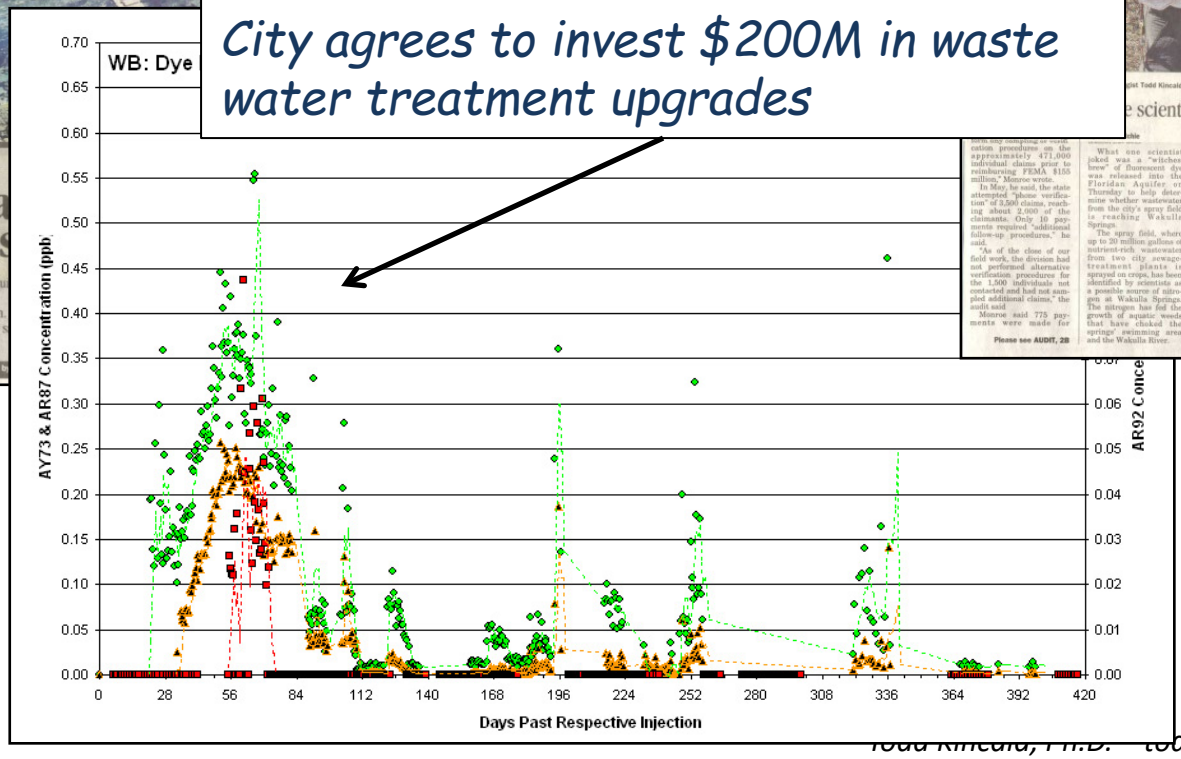
Storm victims given extra car aid

'They took on an unpopular

Test to check spray field's impact

scientists say site is source of springs pollution

ONLINE



Tracer arrives at Wakulla: ~60 days

City agrees to invest $200M in waste water treatment upgrades

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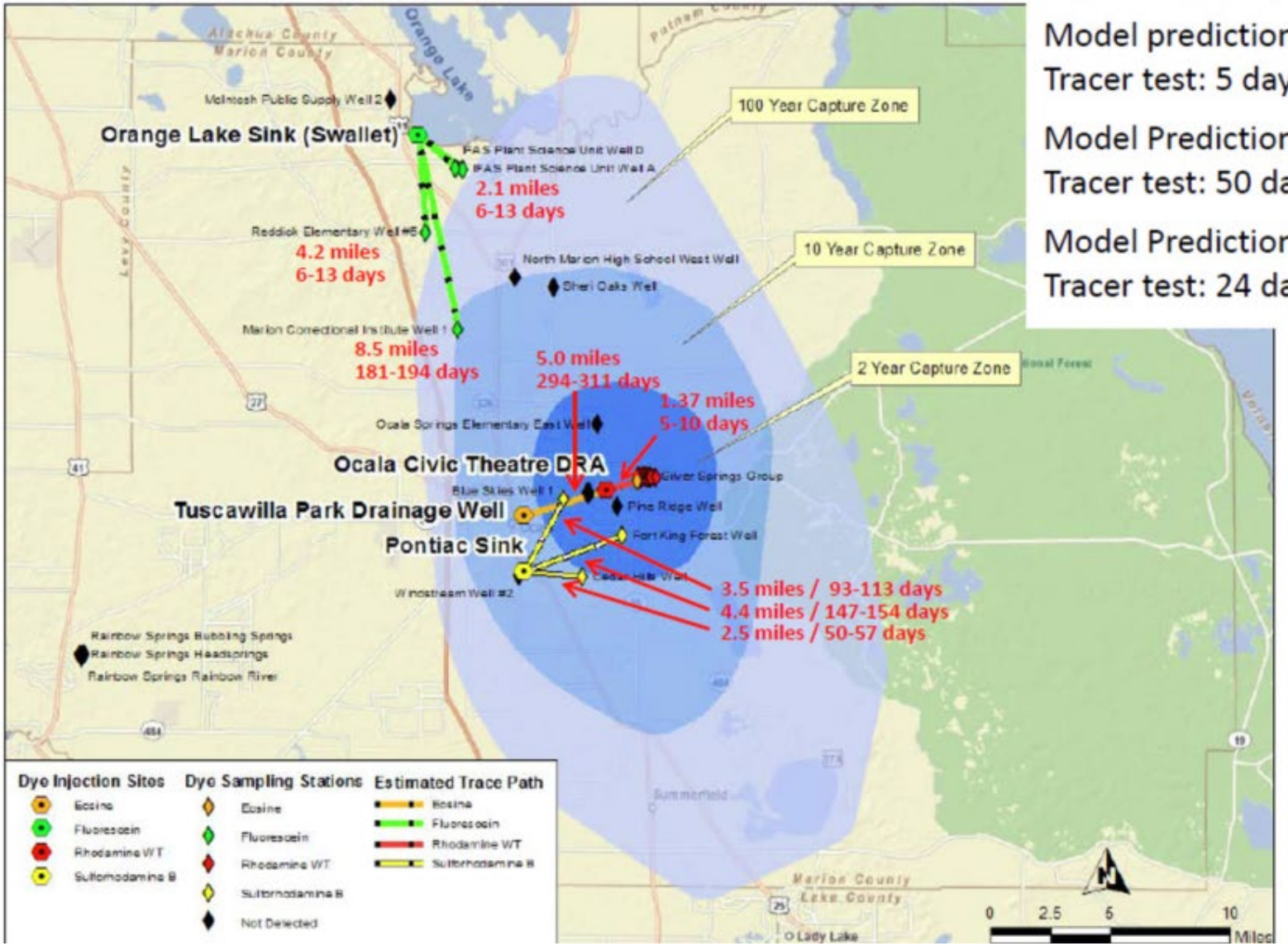
Caves in Florida: Traced Flow Paths to Silver Spring



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

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No 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!*

- 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"

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What I've Learned …

© JP Bressor

What I’ve Learned …

There


What I’ve Learned …
There Really
© Kirill Egorov

What I've Learned …

There Really Are


What I’ve Learned …
There Really Are Such
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What I've Learned …

There Really Are Such Things

What I've Learned …

There Really Are Such Things As

What I’ve Learned …

There Really Are Such Things As Underground

What I've Learned …

There Really Are Such Things As Underground Rivers

What I've Learned …

There Really Are Such Things As Underground Rivers

- We keep finding more and more caves & the ones we thought were fully explored keep getting longer and longer

Todd Kincaid, Ph.D. – todd.kncaid@shanwil.com

What I've Learned …

There Really Are Such Things As Underground Rivers

- Longest caves span 10s of miles across a basin
- We keep finding more and more caves & the ones we thought were fully explored keep getting longer and longer

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What I've Learned …

There Really Are Such Things As Underground Rivers

- Cave passages can vary greatly in size even within a single system
- Longest caves span 10s of miles across a basin
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What I've Learned …

There Really Are Such Things As Underground Rivers

- Biggest caves are more than 200 feet across / Smallest are too small to fit through
- Cave passages can vary greatly in size even within a single system
- Longest caves span 10s of miles across a basin
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What I've Learned …

There Really Are Such Things As Underground Rivers

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What I've Learned …

There Really Are Such Things As Underground Rivers

- Caves carry loads of sediment and debris
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What I've Learned …

There Really Are Such Things As Underground Rivers

- Caves carry a lot of water very quickly from upland recharge areas to springs
- Caves carry loads of sediment and debris
- Big caves = slower flow / Small caves = faster flow
- Biggest caves are more than 200 feet across / Smallest are too small to fit through
- Cave passages can vary greatly in size even within a single system
- Longest caves span 10s of miles across a basin
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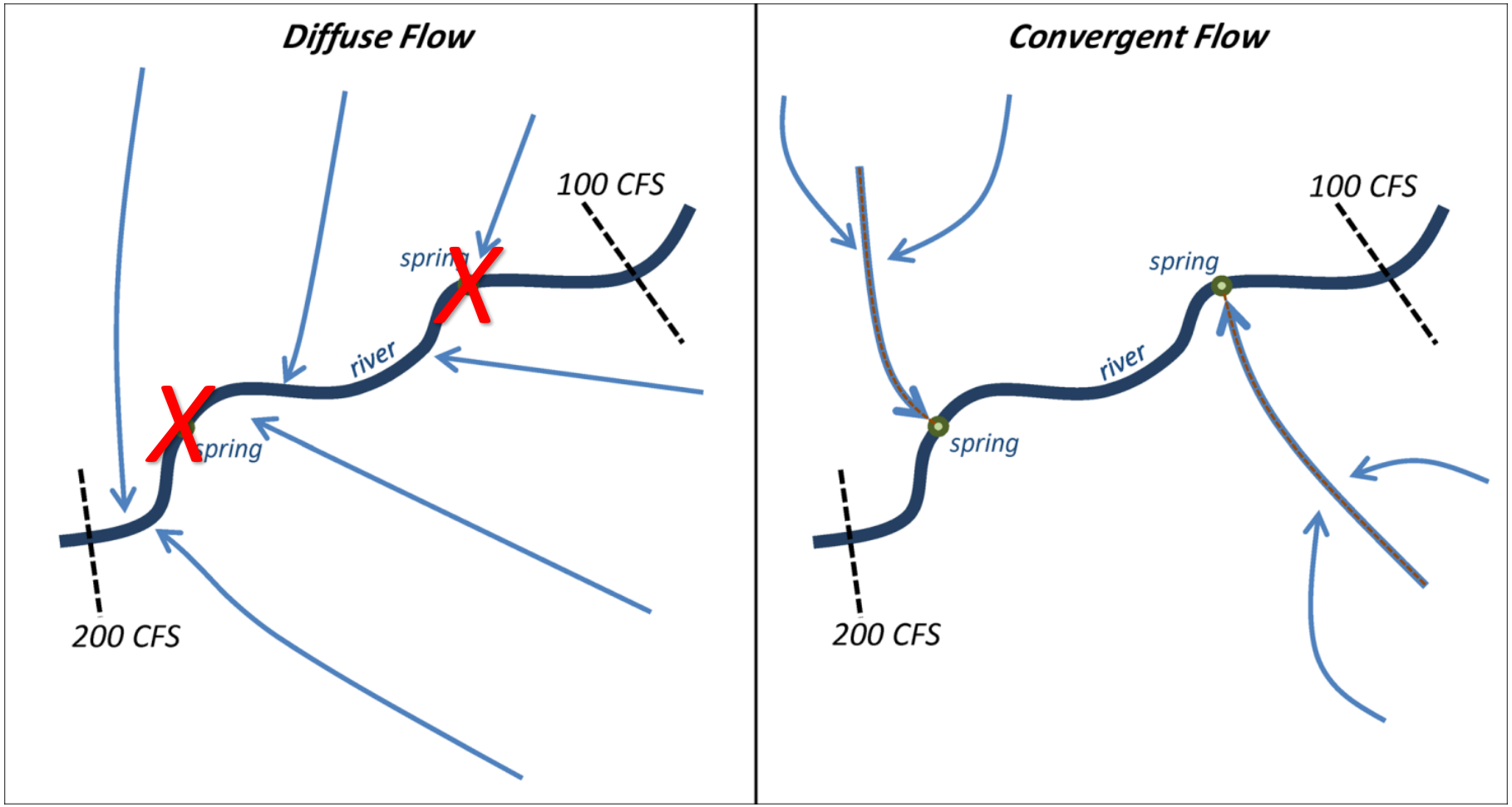
Ideal vs Real Conditions



- Can't have big springs
- Only seepage faces

- Springs require conduits
- Only way the math really works

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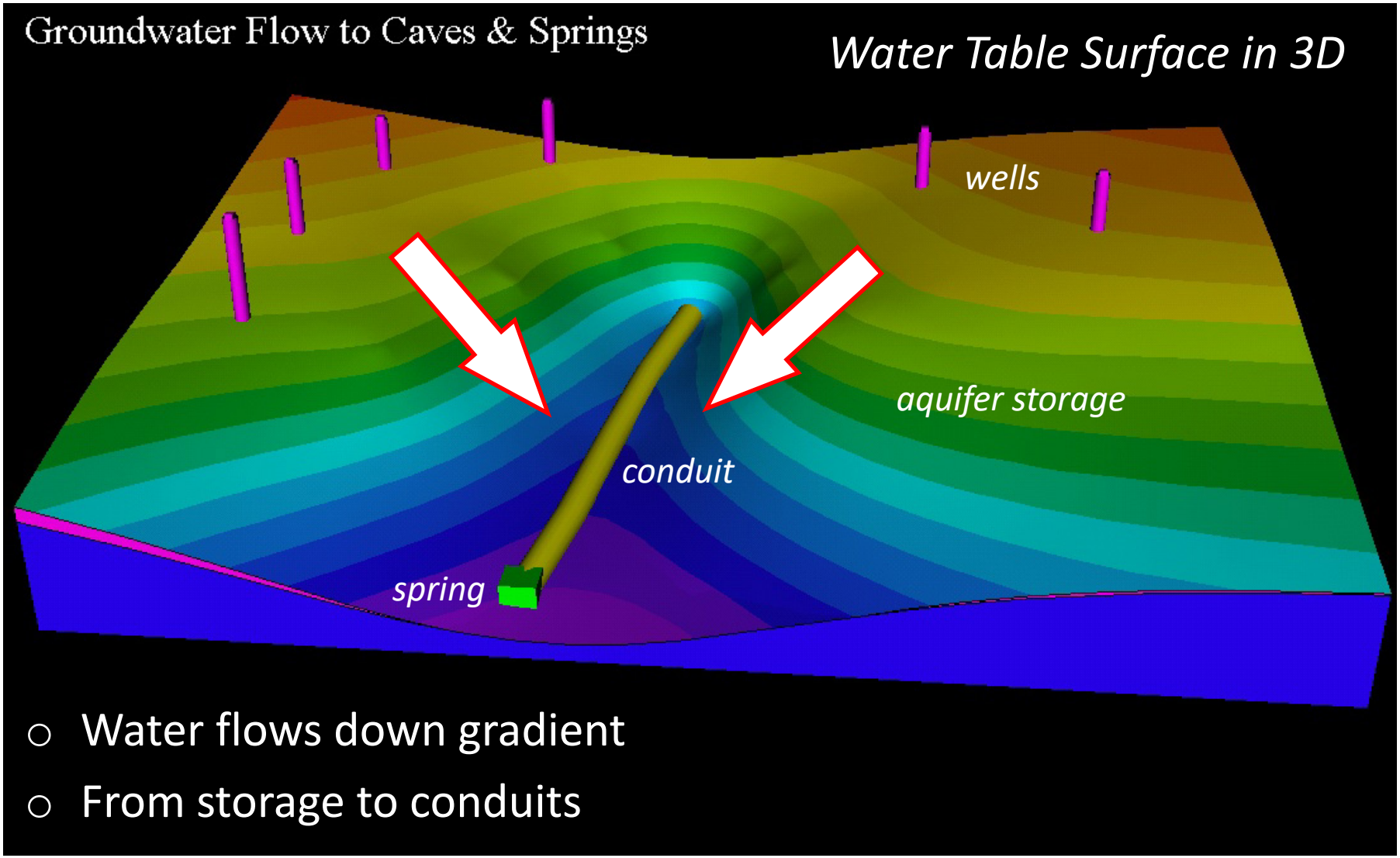
Caves in Florida



- Water flows down gradient
- From storage to conduits

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How do Caves get Made?

Two easy steps in 5 quick slides!

1. Expose soluble rocks to meteoric circulation
   aka: rain on limestone
2. *Engage positive feedback between dissolution and flow*
   aka: caves increase flow, which increase caves

- *Wolfgang Dreybrodt, Will White, Many Others…*
  Chemical reactions for dissolution of calcite in water with CO_2
  - $CaCO_3 + H^+ \Leftrightarrow Ca^{2+} + HCO_3^-$
  - $CaCO_3 + H_2CO_3 \Leftrightarrow Ca^{2+} + 2HCO_3^-$
  - $CaCO_3 + H_2O \Leftrightarrow Ca^{2+} + CO_3^{2-} + H_2O$ *Limestone + Rain*
  - $CO_2{}^g + H_2O \Leftrightarrow CO_2{}^{aq} + H_2O$
  - $(CO_2{}^{aq}) = K_H \times P_{CO2}$

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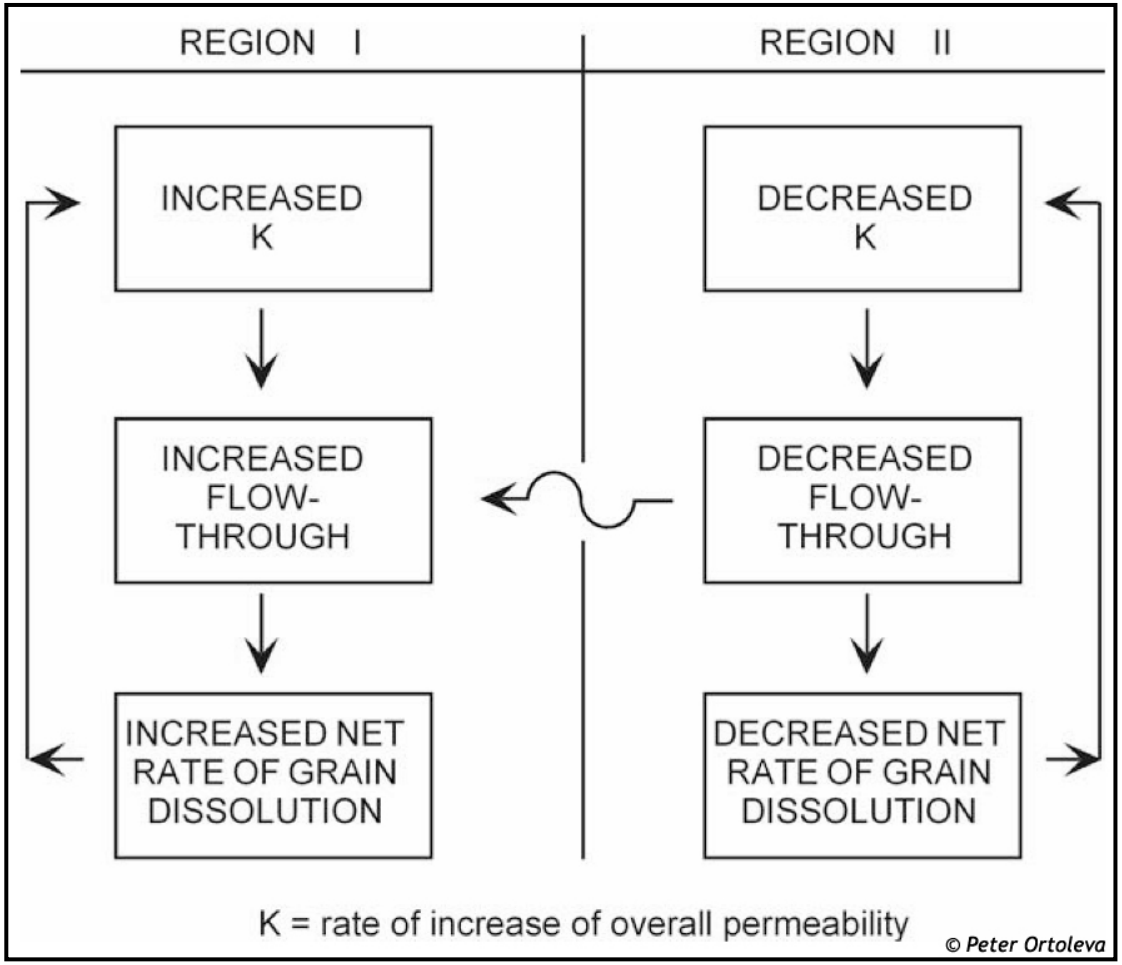
How do Caves get Made?

- *Peter Ortoleva*
  Dissolution Fingering
- "Feedback System"
- Region I = positive
  more and more caves
  faster & faster flow
- Region II = negative
  no caves
  less and less flow



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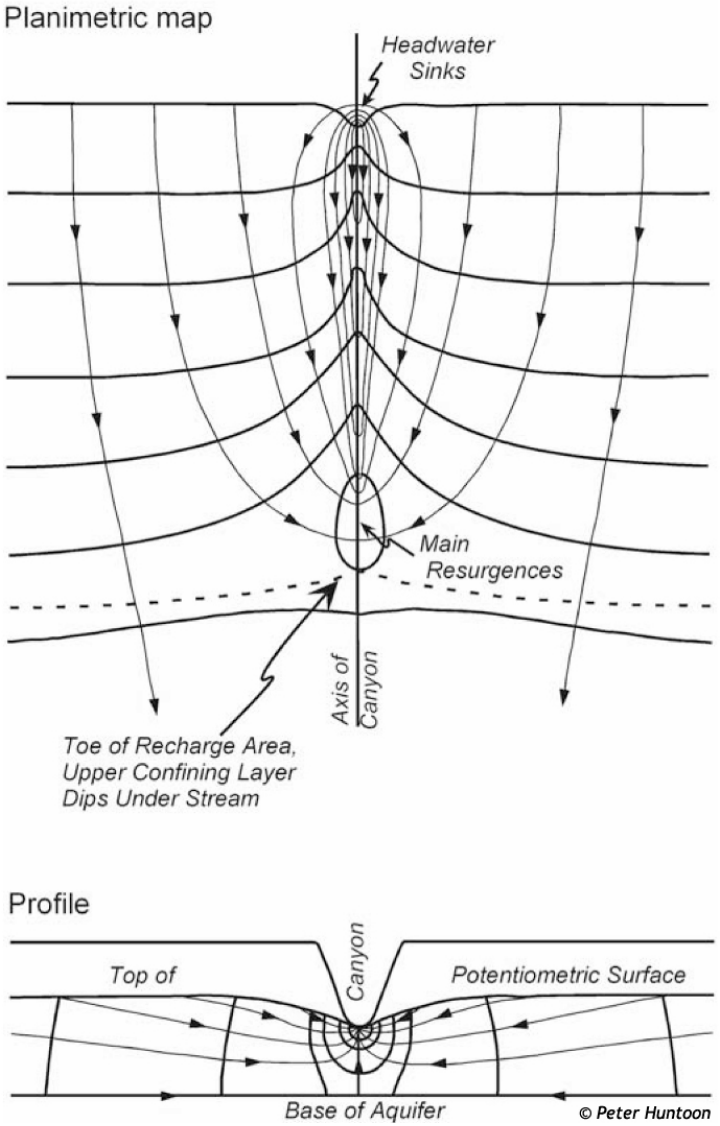
How do Caves get Made?

Peter Huntoon - Where Caves Form…

- Caves are a direct consequence of flow through soluble rocks
- Controlling variable is hydraulic gradient
- Caves form fastest in regions where flow is focused
- Probable cave paths can be mapped from hydrogeological investigation
  - Recharge / Discharge
  - Hydraulic Gradient
  - Surface Expressions
  - *Modeling that puts all of these together*



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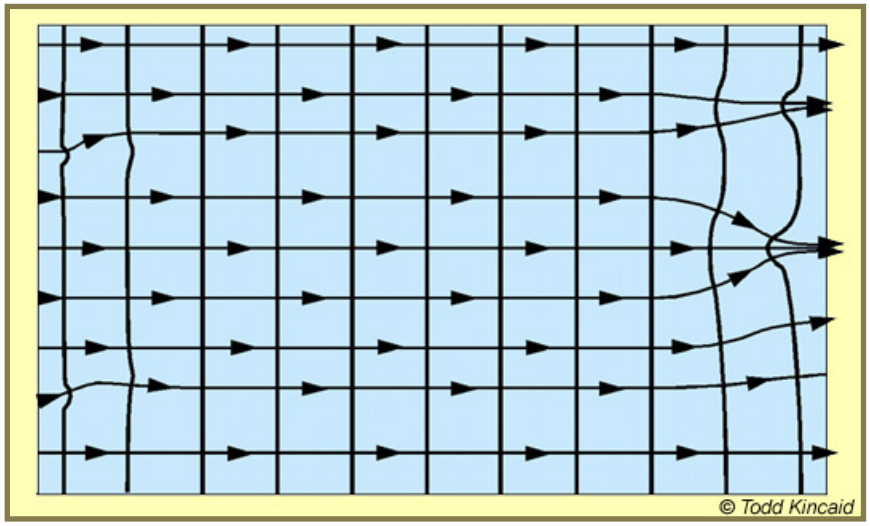
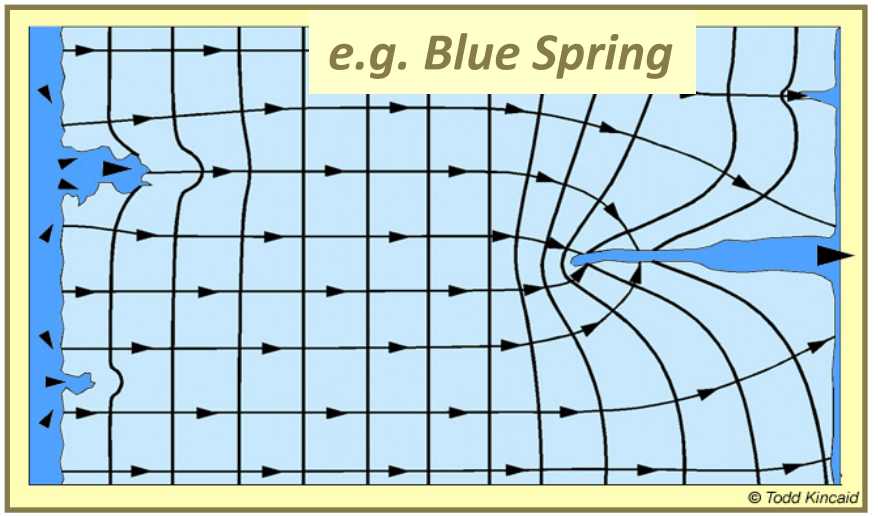
How do Caves get Made?

Todd Kincaid – How Caves Evolve

1. Cave development is initiated by positive feedback loops between flow and dissolution that exploit random variations in permeability.

2. Dissolution fingering occurs upstream and downstream. Dissolution is faster downstream due to higher velocities caused by discharge to springs. Large irregular chambers develop upstream while long tubular conduits develop downstream. Gradients adjust due to cave development.





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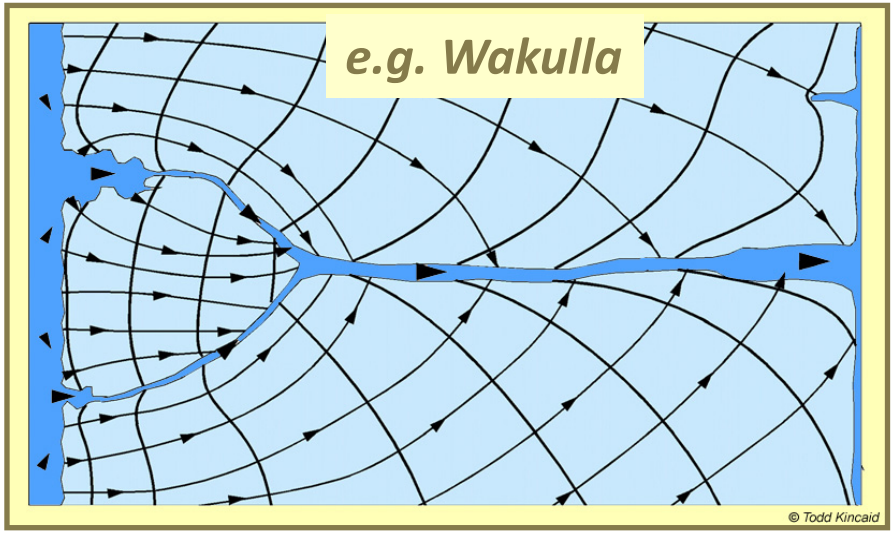
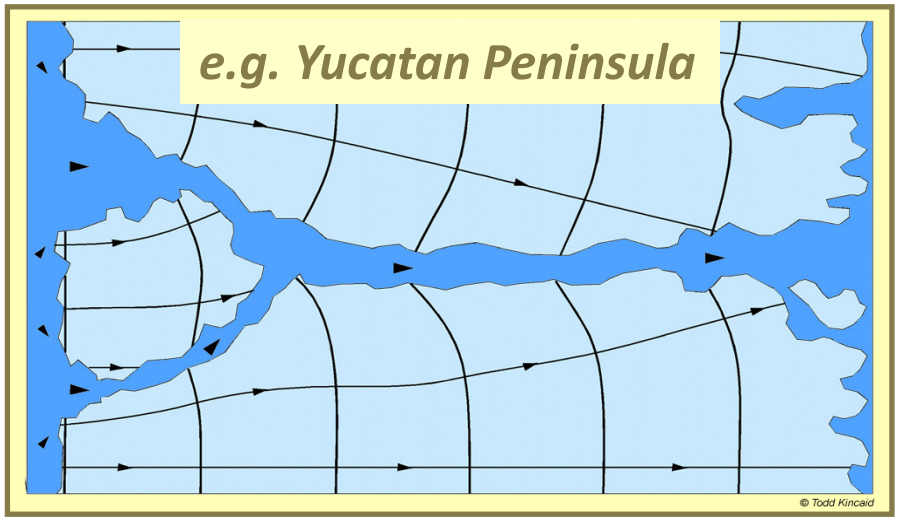
How do Caves get Made?

3. Cave expansion progresses fastest in the downstream tubular caves. The two cave types eventually join establishing a preferential flow path from recharge to springs. Fastest flow rates are through conduits.

4. Velocities drop as caves expand. Conduit flow reaches a balance with local recharge after which caves become significant storage features.





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Springs, Caves, & Springsheds

Springs are discrete large magnitude groundwater discharges.

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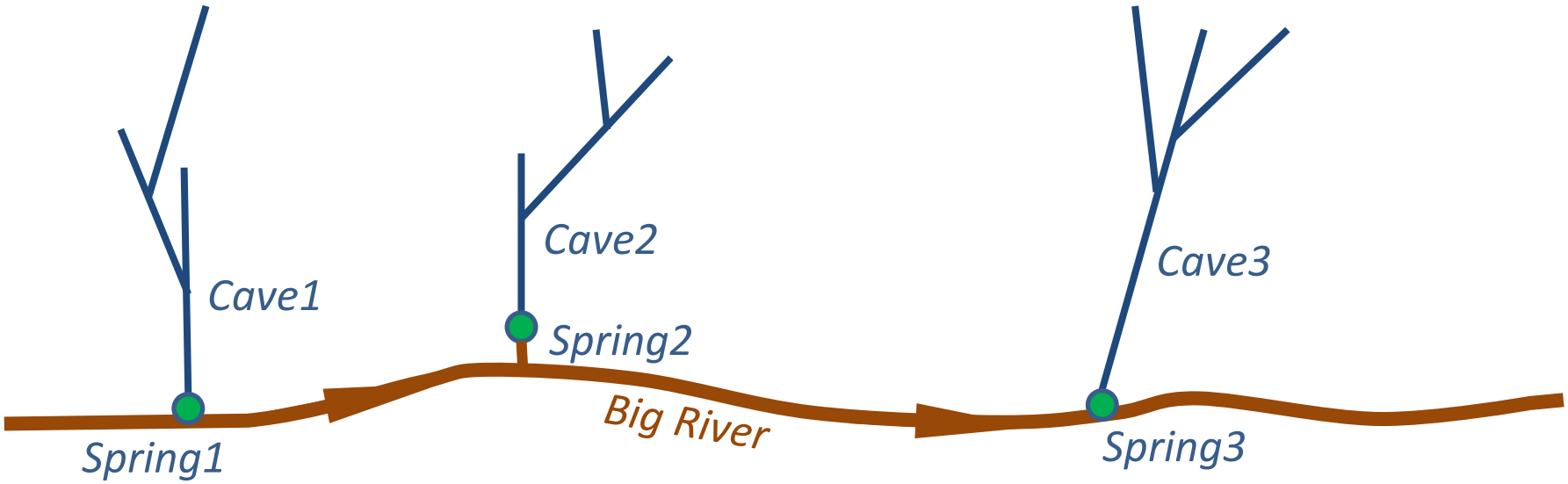
Springs, Caves, & Springsheds

Caves of different sizes connect to every spring.



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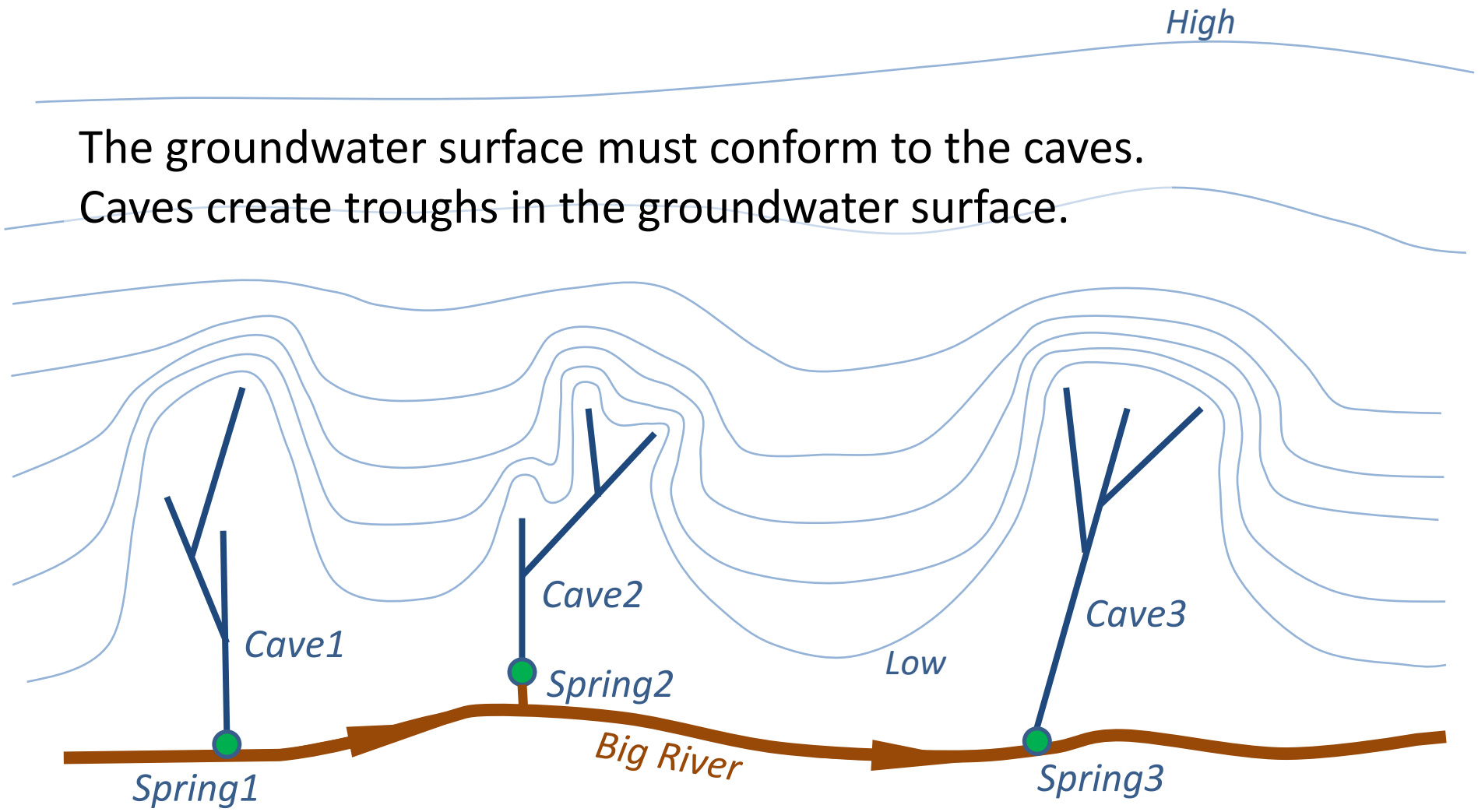
Springs, Caves, & Springsheds



The groundwater surface must conform to the caves.
Caves create troughs in the groundwater surface.

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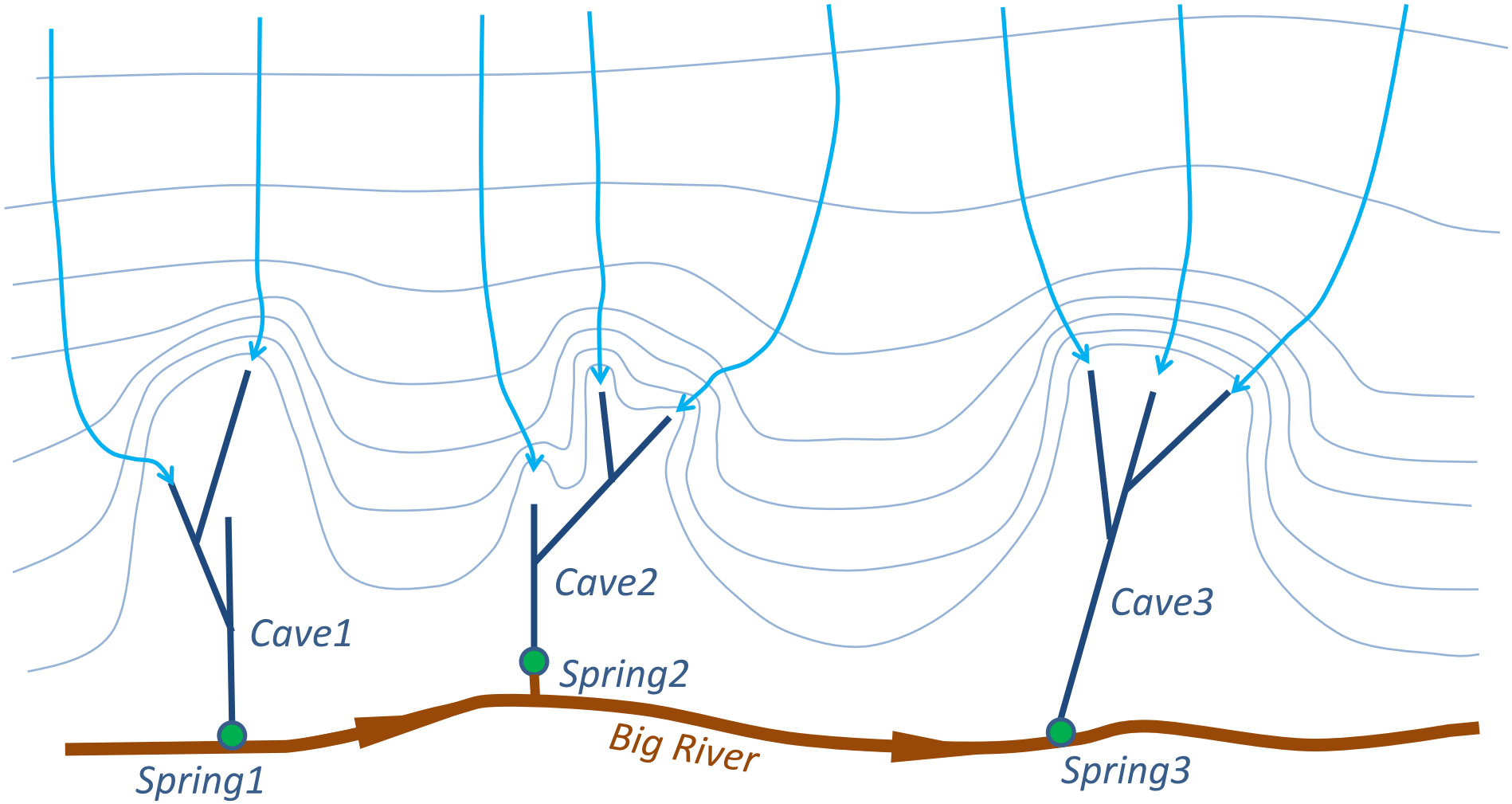
Springs, Caves, & Springsheds



Caves capture groundwater flow from broad areas.

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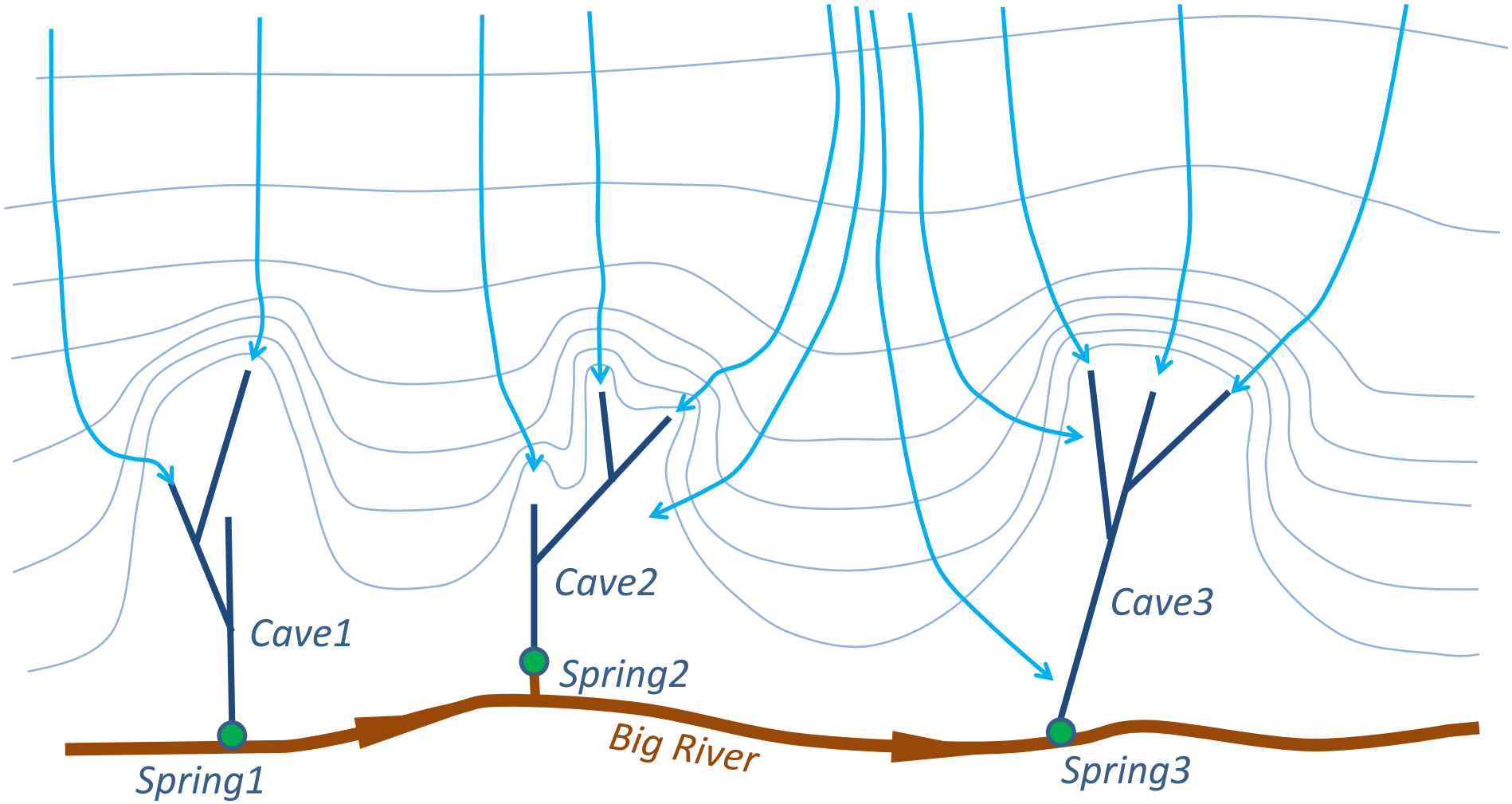
Springs, Caves, & Springsheds



The vast majority of the flow goes to springs.

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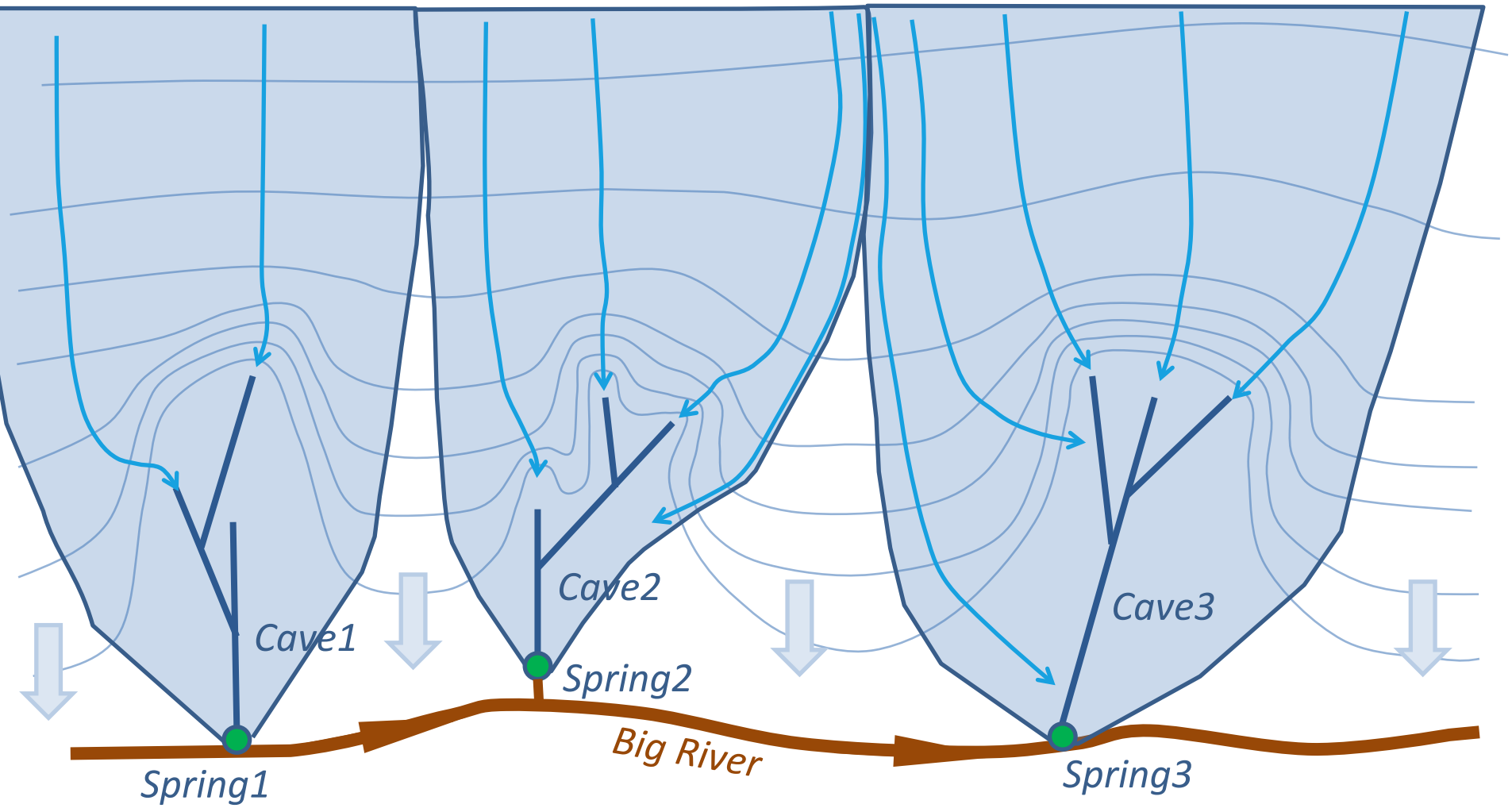
Springs, Caves, & Springsheds



Not much diffuse flow passes between the springsheds.

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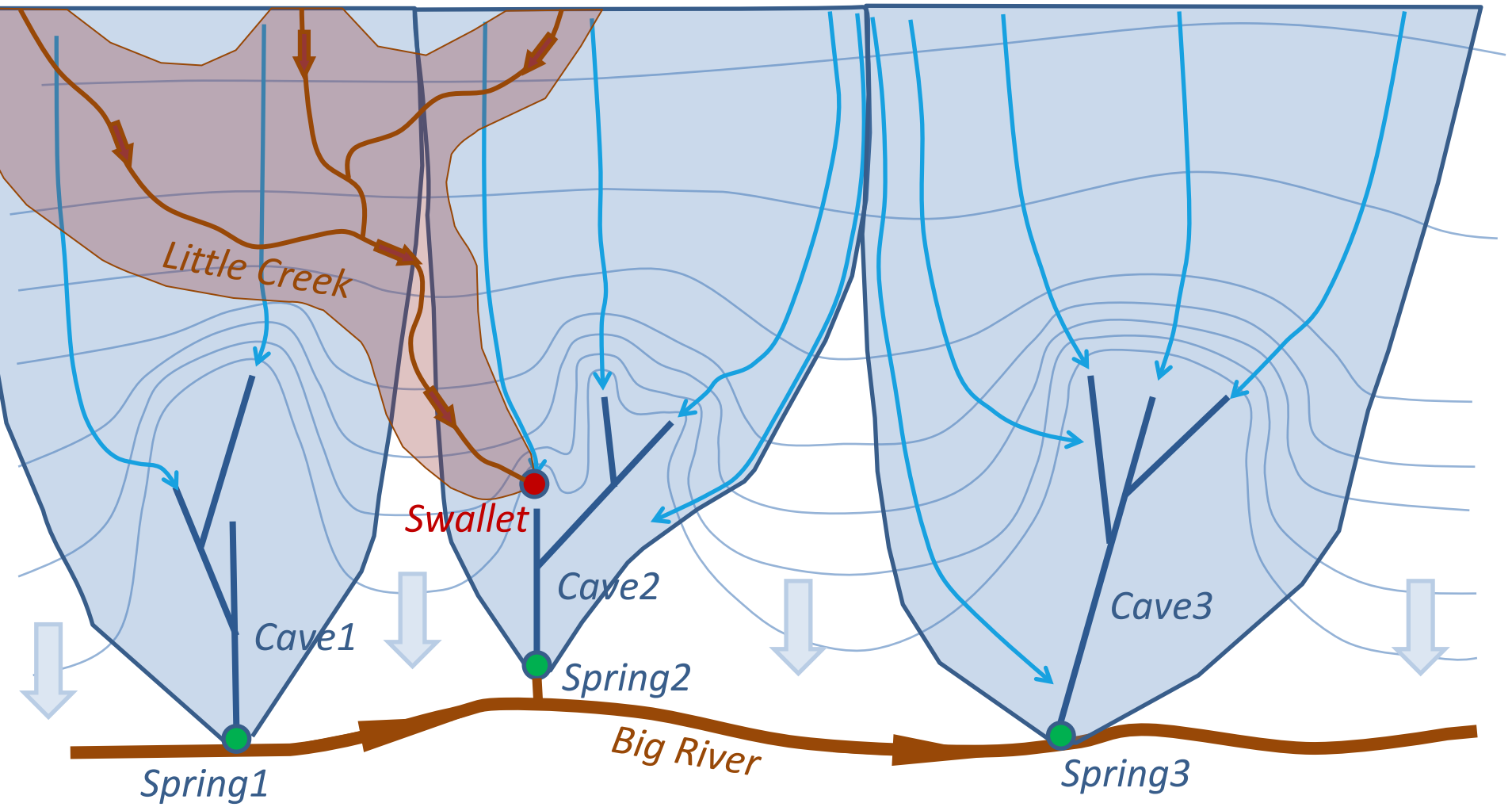
Springs, Caves, & Springsheds



Springs can also receive water from surface rivers and streams
- *from areas outside of the groundwater basins.*

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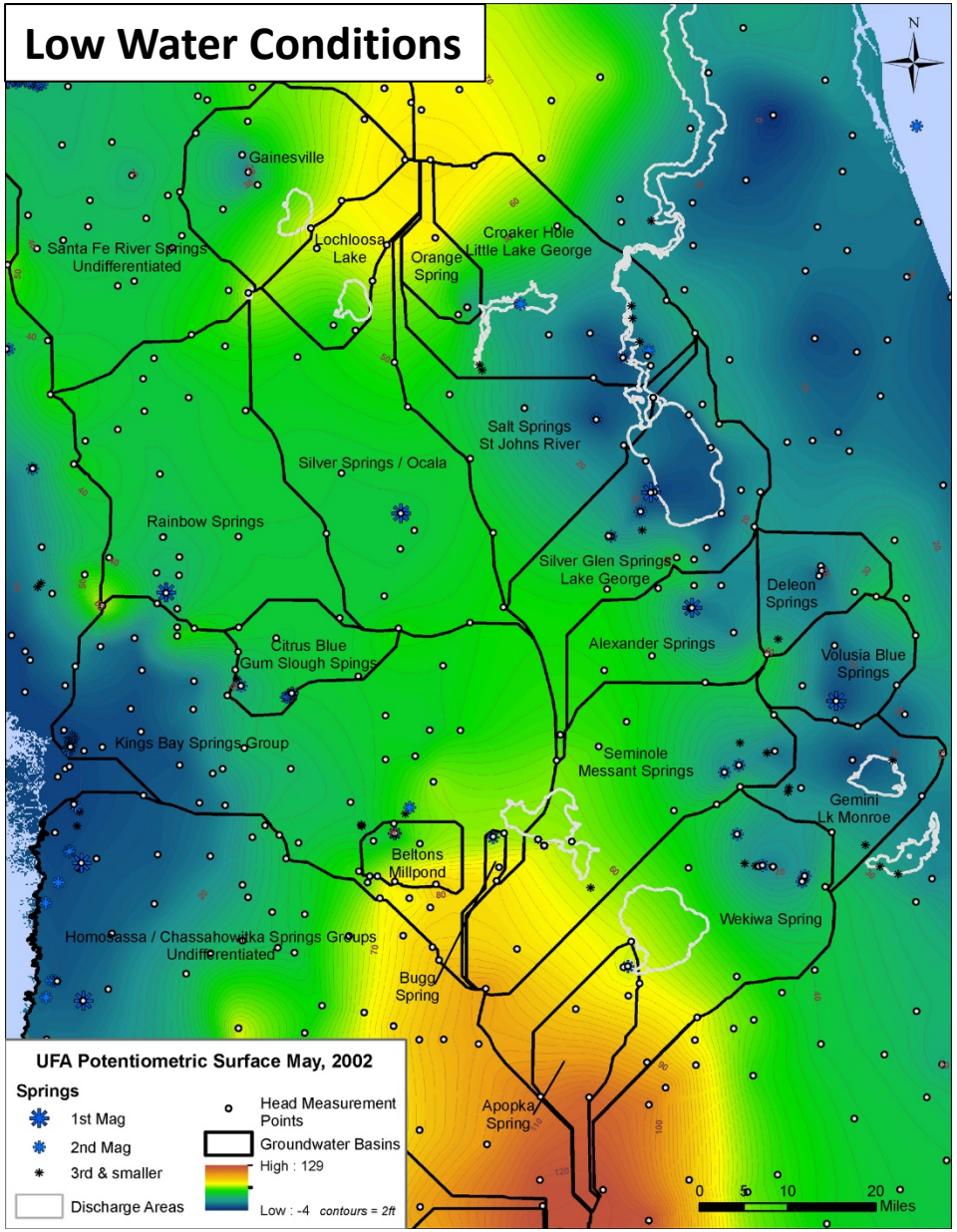
Springsheds: Where the water comes from…



- springsheds defined from potentiometric surface data
- abut each other
- consume most of the area between coasts
- precludes diffuse flow to coast from substantive distances
- springshed boundaries change under differing hydraulic conditions & due to pumping
- vast majority of flow through Floridan aquifer is to springs

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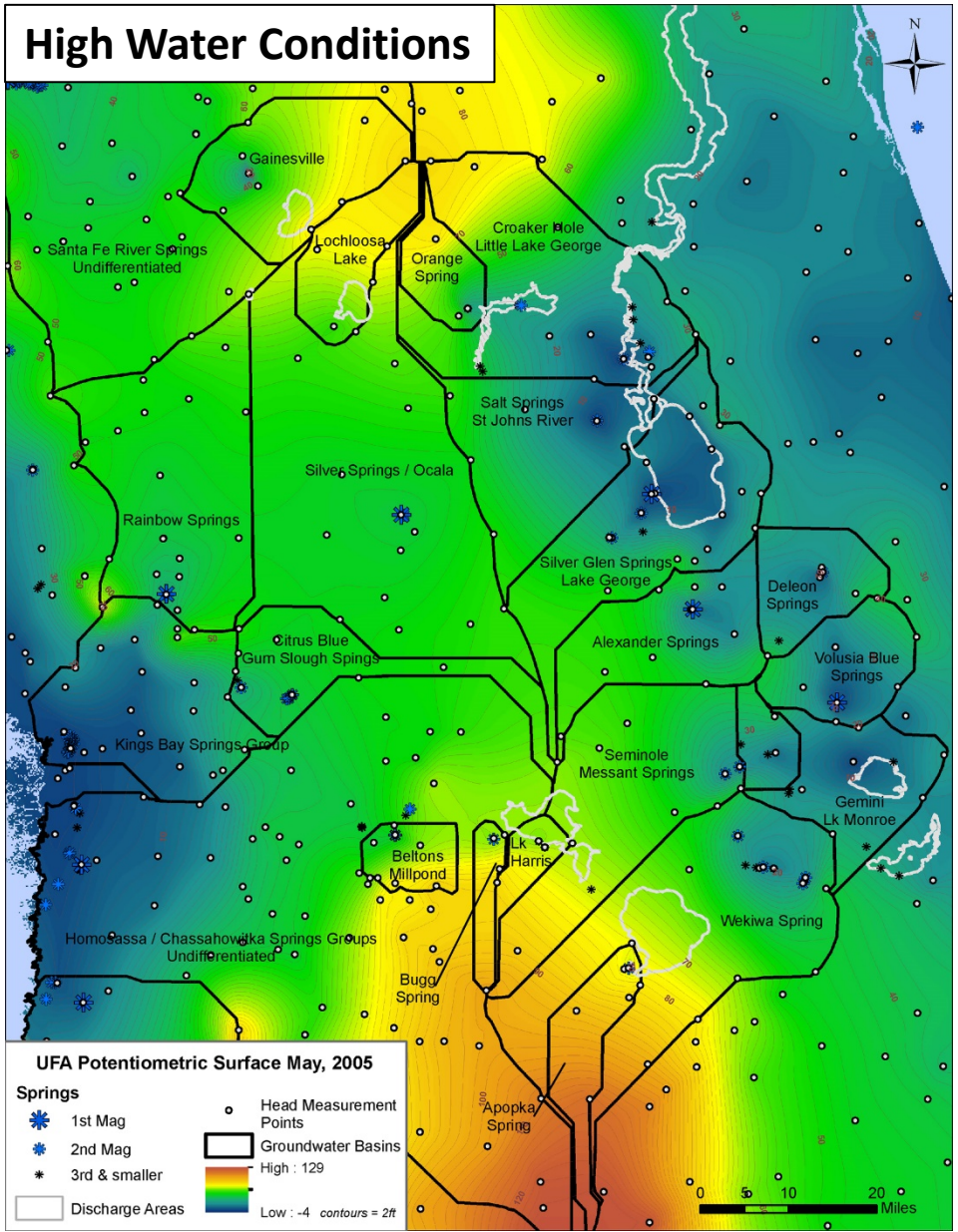
Springsheds: Where the water comes from…



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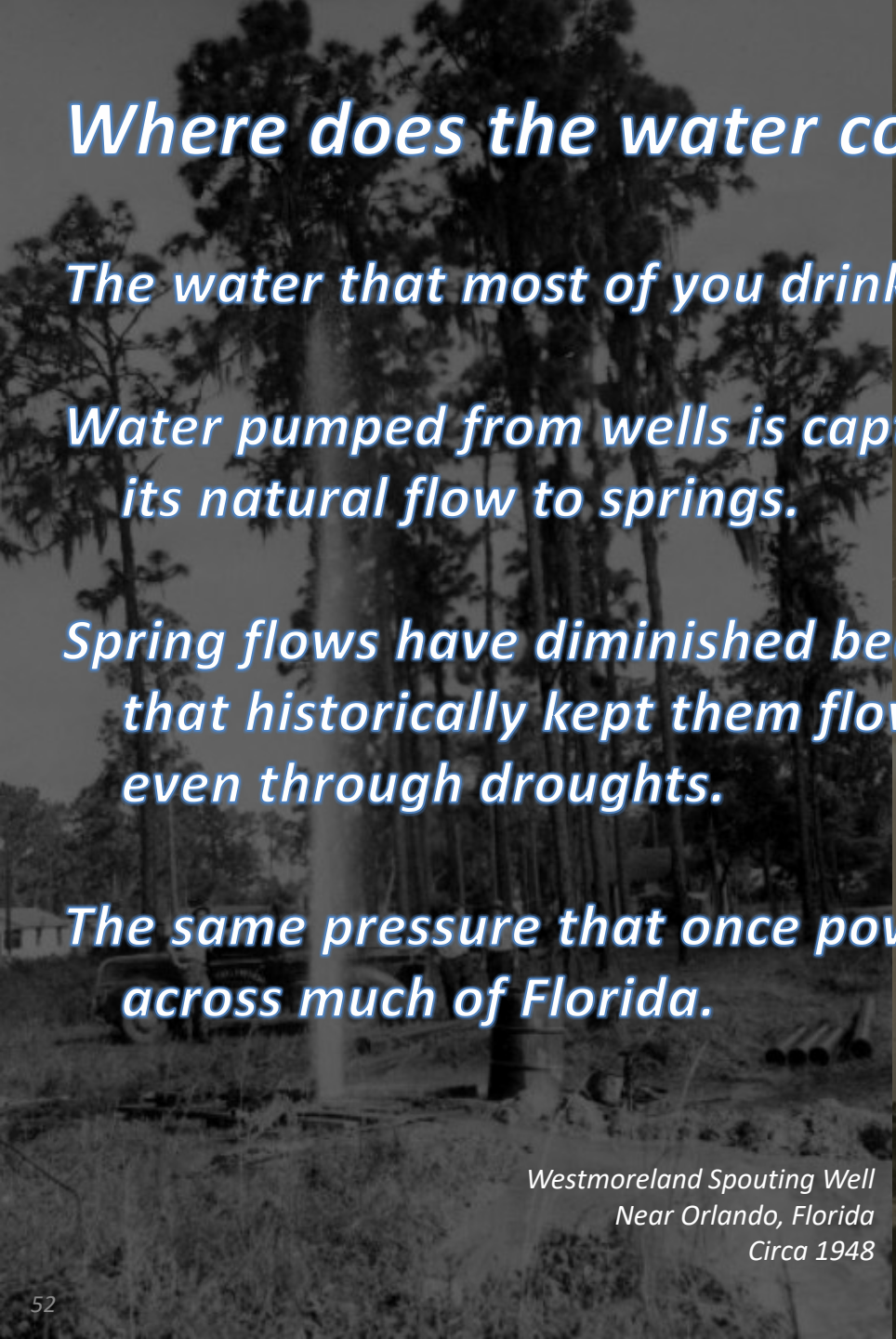
Where does the water come from?

The water that most of you drink comes from the springs.

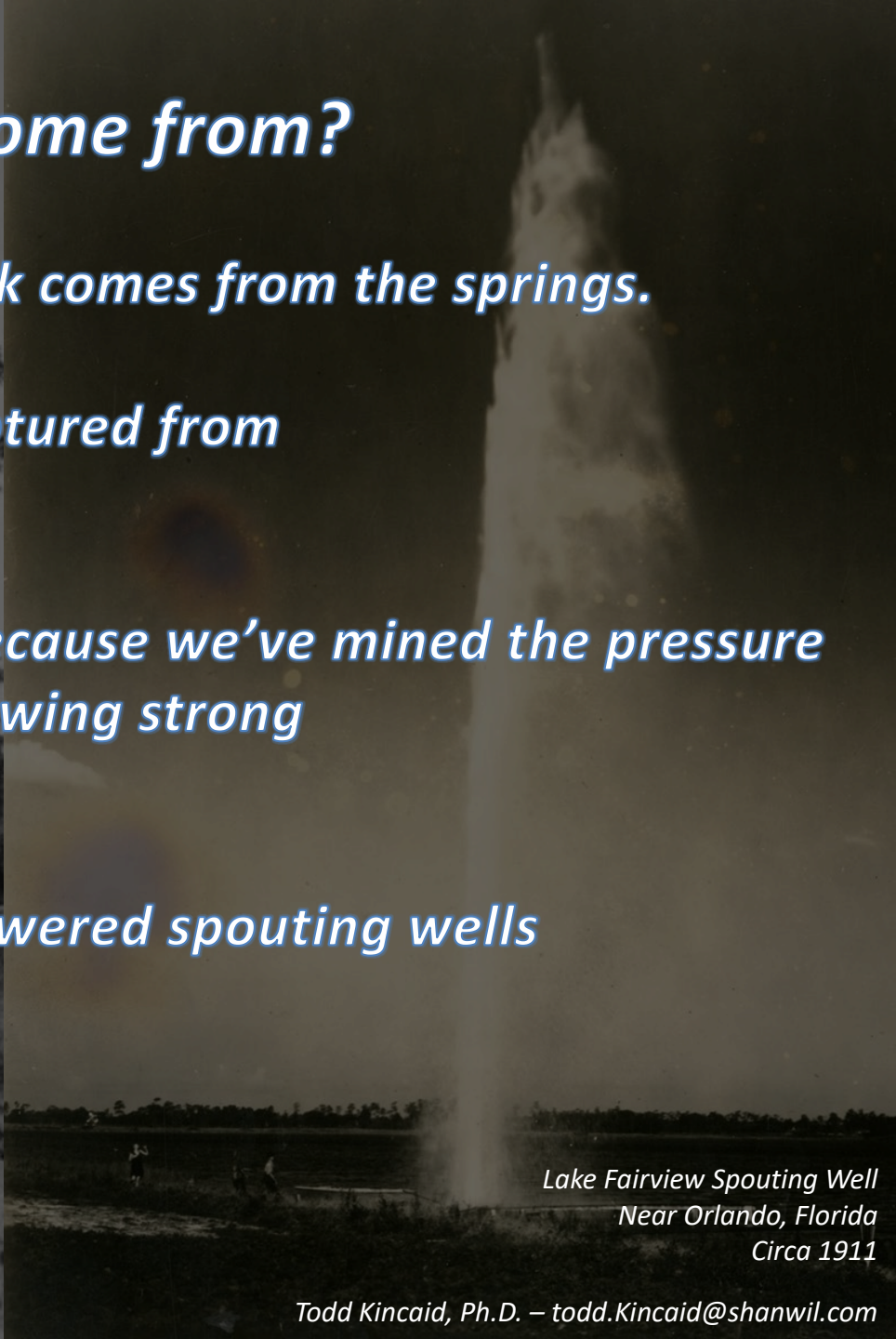
Water pumped from wells is captured from its natural flow to springs.

Spring flows have diminished because we've mined the pressure that historically kept them flowing strong even through droughts.

The same pressure that once powered spouting wells across much of Florida.



Westmoreland Spouting Well
Near Orlando, Florida
Circa 1948



Lake Fairview Spouting Well
Near Orlando, Florida
Circa 1911

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Where does the water come from?

Spring water isn't as old as we'd like to believe…

The springs are green because we're contaminating groundwater

- with our wastewater
- with our fertilizers
- with the things we discard to the land surface thinking that they'd never reach the springs…

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Where does the water come from?

From your own back yard – metaphorically…

Beyond their beauty and their ability to inspire…
Springs are important because
- they are the measure of your aquifer's health
- of how much water you have
- of how clean that water is.

Strong clean spring flows are the earmark of a healthy aquifer
- one that can sustainably supply clean freshwater forever
- one that is intelligently managed.

Diminished and contaminated spring flows
- mark the beginning of the end of your water resource.

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What must be done…

Reject the myths about slow moving ancient groundwater.

Look beyond your friends that care deeply about springs and build alliances with a broader group of Floridians who share a common desire / a common need…

Protecting Your Water Resource.

Todd Kincaid, Ph.D. – todd.Kincaid@shanwil.com

What must be done…

Substantially reduce and cap nutrient releases.

- *advanced wastewater treatment*
- *artificial wetlands*
- *reduced use of fertilizers*

Achieving the needed reductions will likely take all three and more.

It won't be popular and it won't be cheap but…

It's the only solution to the eutrophication problem.

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What must be done…

Establish caps on groundwater consumption.

Need to be less than what you currently use…

Springs don't care what you use the water for!

Artificial recharge…

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What must be done…

Consider water footprints when establishing policies - personal and public

It takes about 400 bottles of water to make one bottle of milk…

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What must be done…

Consider water footprints when establishing policies - personal and public

Save > 15,000 gal/year
- if you switch to beer!
- for each glass/day!

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Thank You!

Contact me…
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