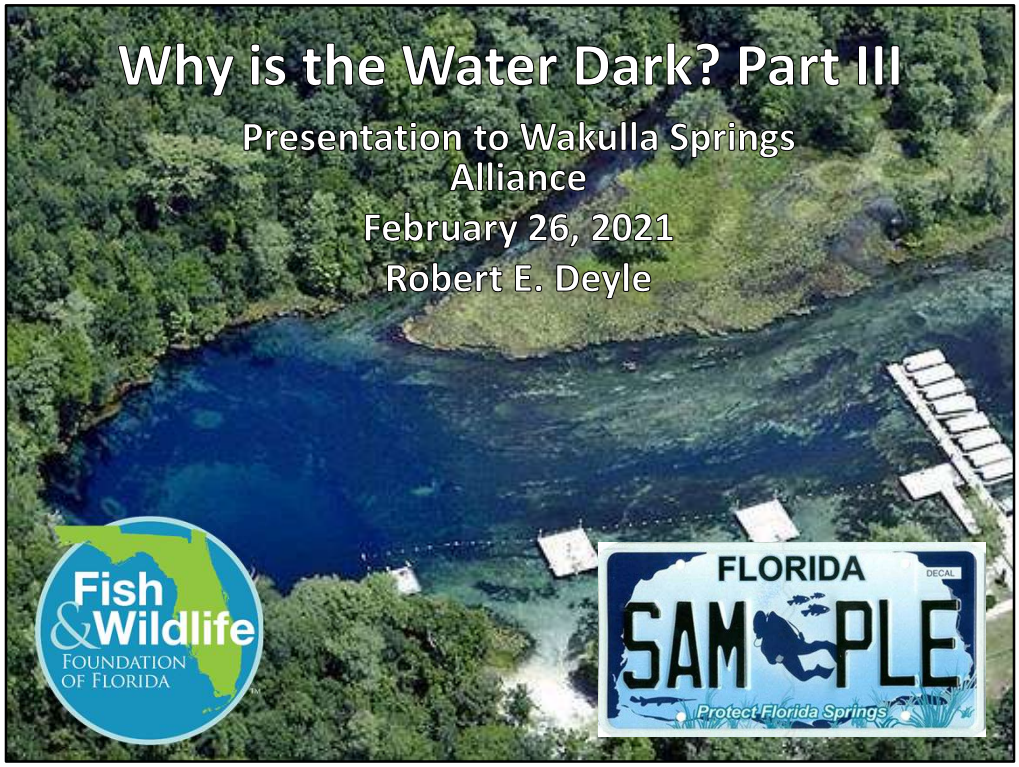


• This is the penultimate presentation in a four-part series sharing what I believe we now know about why the water in the spring is "dark" so much more often than in the past, resulting in the almost complete cessation of glass-bottom boat tours and contributing to the decline of the submerged aquatic vegetation that forms the foundation of the spring food web

• This presentation takes us beyond an analysis of the light absorption and water quality data collected by McGlynn Labs Inc during the WSA's 4.5-year project that was funded with three Protect Florida Springs tag grants from the Fish and Wildlife Foundation of Florida **[click]**

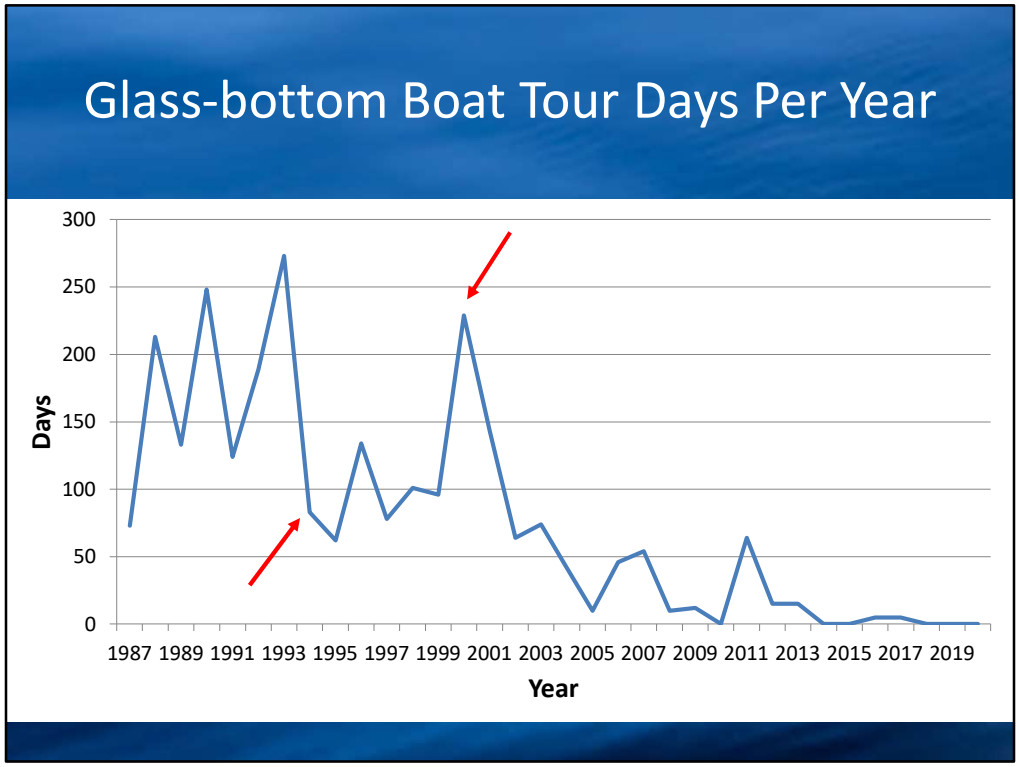
• to explore hypotheses about what has changed in the Wakulla Spring springshed and ecosystem that might explain why we have low visibility dark water conditions nearly all the time. **[click to next slide]**

- This is very much a work in progress.
    - I've discussed some of these hypotheses with Kathleen Coates and her colleagues at the Water Management District.
    - And Hal Davis has agreed to review them for me
- Some loose ends remain. Because of that and because we have other important issues to discuss today, I've split this presentation into two parts.
- Hence today's presentation is Part IIIA with Part IIIB to follow in March. **[click]**

Research Questions

- ✓ What are the light-absorbing substances responsible for the dark water conditions?
- ✓ What are the sources of those light-absorbing substances?
- 3. Why have the frequency and duration of dark water conditions increased?

- Part I in November established that CDOM measured as tannins and chlorophyll a measured as corrected chlorophyll a contribute to reductions in spring visibility
    - and that the spring is especially sensitive to these substances when visibility is higher
- Part II in December documented that
    - CDOM and chlorophyll are delivered to the spring through all major caves
    - CDOM originates primarily from sinking streams
    - Dye studies show that Wakulla Spring receives ground water that originates from each of the four major karst lakes in the springshed: Iamonia, Jackson, Upper Lafayette, and Munson
    - Algae taxonomic analyses and environmental DNA analyses indicate that chlorophyll discharged at the spring vent likely comes from all four lakes
- Today we tackle the question of why. What has changed that might explain the increased frequency and duration of dark water conditions at the spring?
- But let's start by reminding ourselves about the changes that have been observed in dark water conditions.
- Our best proxy is the record of glass-bottom boat tour days **[click to next slide]**



- The initial drop occurred in 1994 **[click]** starting a trend that has declined to 5 to 0 days per year since 2014, with the exception of the peak in 2000 **[click]**.
- Sandy Cook, who served as park manager from 1994 to 2008 has indicated that the decline in glass-bottom boat tour frequency was not due to changes in staffing, equipment, or the visibility criterion for conducting tours.

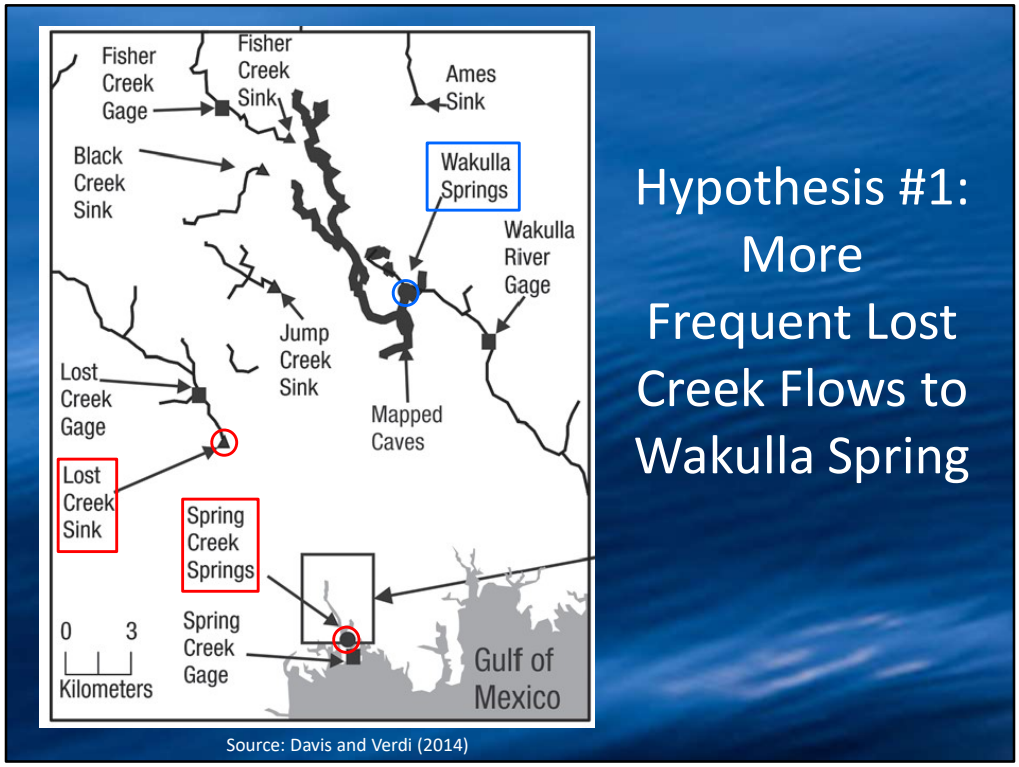
Changes in Frequency and Duration: What Have We Learned?

- CDOM levels may have increased
  - 2015-2020 average three times > 1966-2006 average
- Chlorophyll levels may have decreased
  - 2015-2020 average = 53% of 1996-2008 average

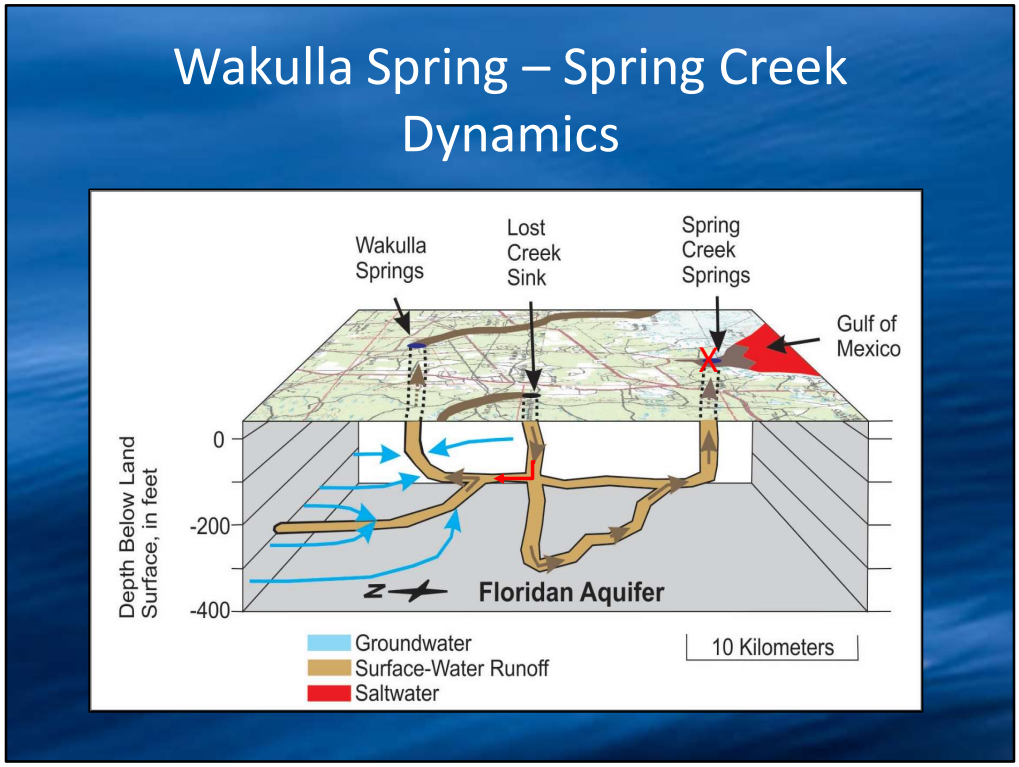
- **[click]** Comparing current CDOM levels, measured as true color, with historic data from DEP's WIN data base and other sources reveals they may have increased
  - **[click]** The average level measured during this project is 3 times greater than that for data reported between 1966 and 2006
- **[click]** On the other hand, chlorophyll levels, measured as corrected chlorophyll a, may have decreased
  - **[click]** Average concentration measured during this project is 53% of that for data reported between 1996 and 2008
- The question is why?
- I'm going to approach this by examining a series of hypotheses **[click for next slide]**

Hypotheses

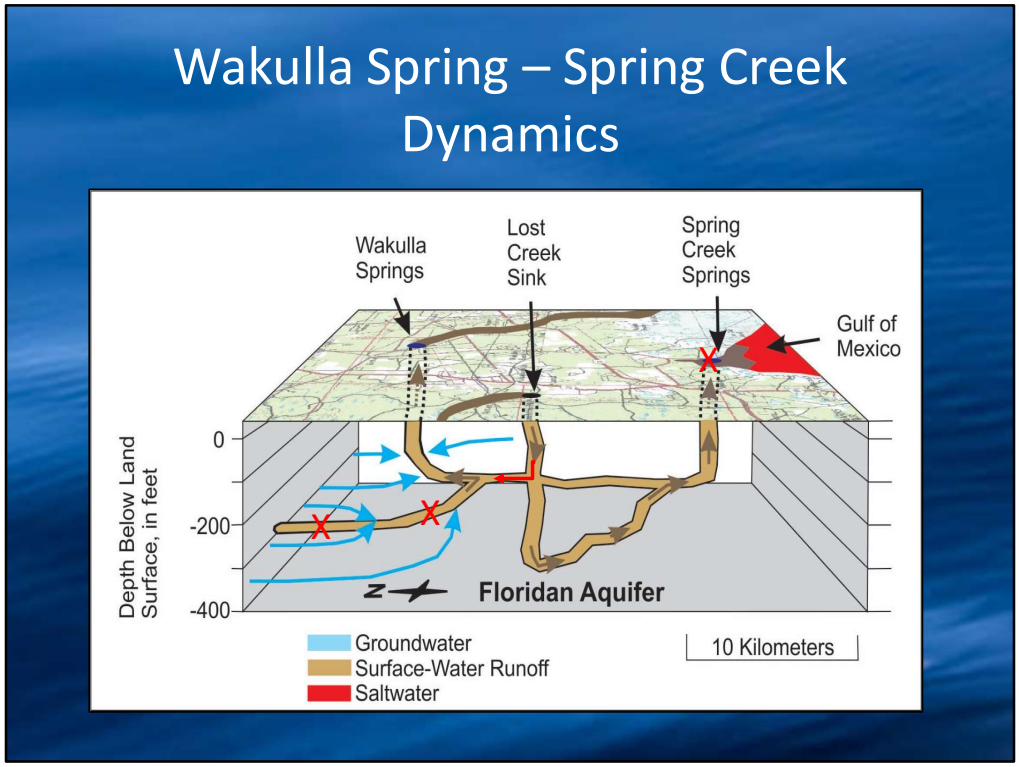
1. Hypothesis #1: More Frequent Lost Creek Flows to Wakulla Spring
2. Accelerating sea level rise and head gradients
3. Changes in rainfall patterns
4. Declining spring pool stage (head)



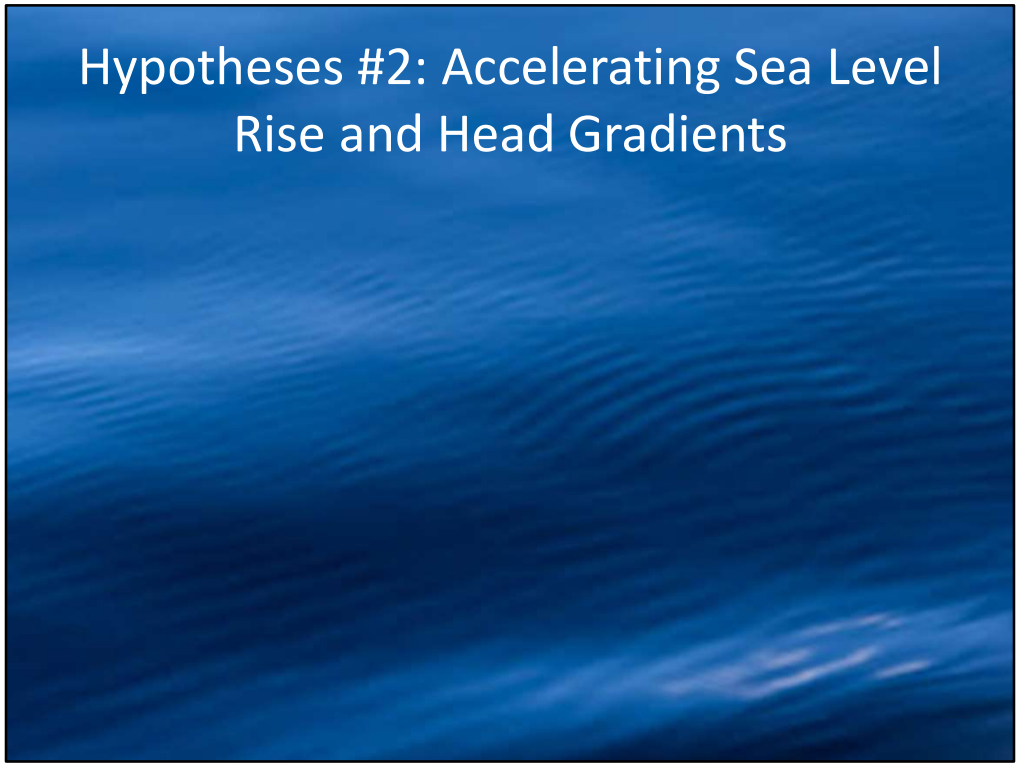
- Hypothesis #1: The first suspect is more frequent diversion of Lost Creek flows north to Wakulla Spring during periods of flow reversals at the Spring Creek Springs Group.
- That would likely contribute to more prolonged dark water episodes associated with some rainfall events during those times when Spring Creek is still backed up but not enough increase in head difference has been generated to return Spring Creek to positive flow.



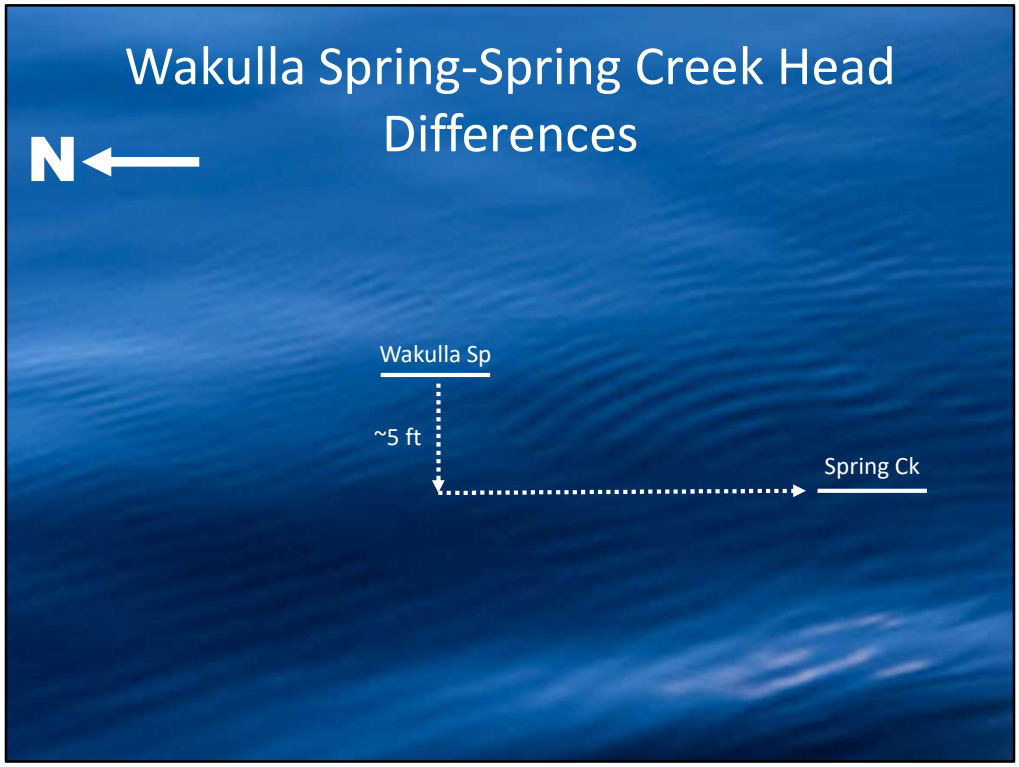
- You may recall from my presentation in December that I suggested that there is a transition period between when the Spring Creek Springs are backed up after periods of low rainfall and this scenario where, after sufficient rainfall, the sinking streams, including Lost Creek, begin to flow again as shown in this figure
- During the transition period, the saltwater plug at Spring Creek still holds back the southward flow **[click]**
- And tannic water from Lost Creek flows north to Wakulla adding to the dark water load **[click]**



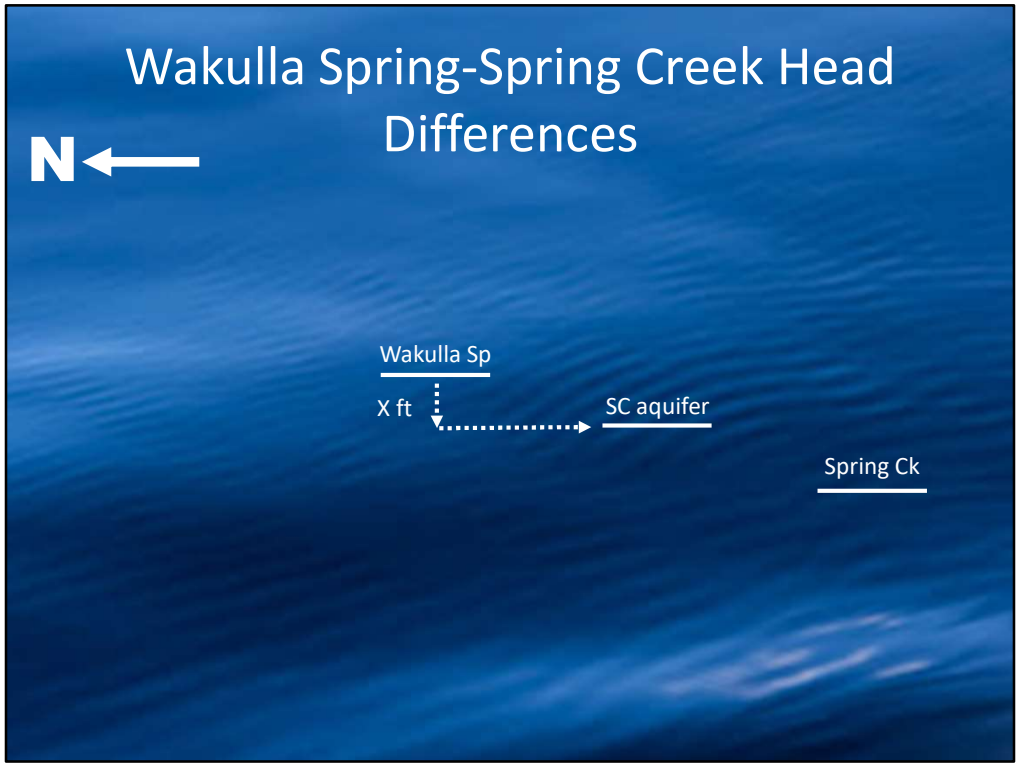
- The more perplexing question is what is contributing to prolonged periods of low levels of tannins of sufficient magnitude to keep visibility well below the glass bottom boat tour threshold of 70-75 feet.
    - You may recall from my December presentation that quantile regression analysis of data from the WSA study indicates that the 90th quantile of visibility depth values is more sensitive to small increments in true color (and chlorophyll) than for lower quantiles:
    - In other words, a small amount of tannins can have a substantial impact on visibility depth.
- It is likely that a variant of this transitional scenario also sometimes occurs when rainfall is not sufficient to unplug Spring Creek during which
    - tannic flows from the Leon Sinks sinking streams cease **[click]**
    - but Lost Creek continues to flow and its tannic discharge continues to enter Wakulla Spring,
        - albeit at lower concentrations,
        - perhaps contributing to the apparent green dark water conditions at the spring



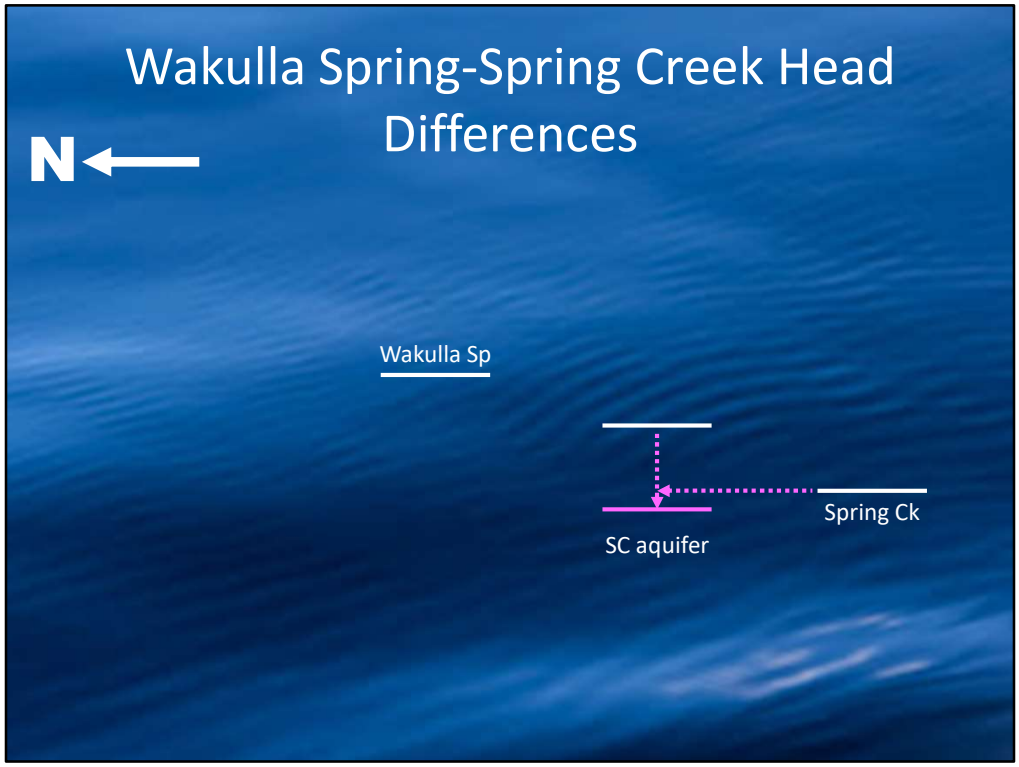
- So the question is why have reversals occurred in the Spring Creek Springs Group discharge and why might they be happening more often
- The primary suspect identified by Davis and Verdi is sea level rise.



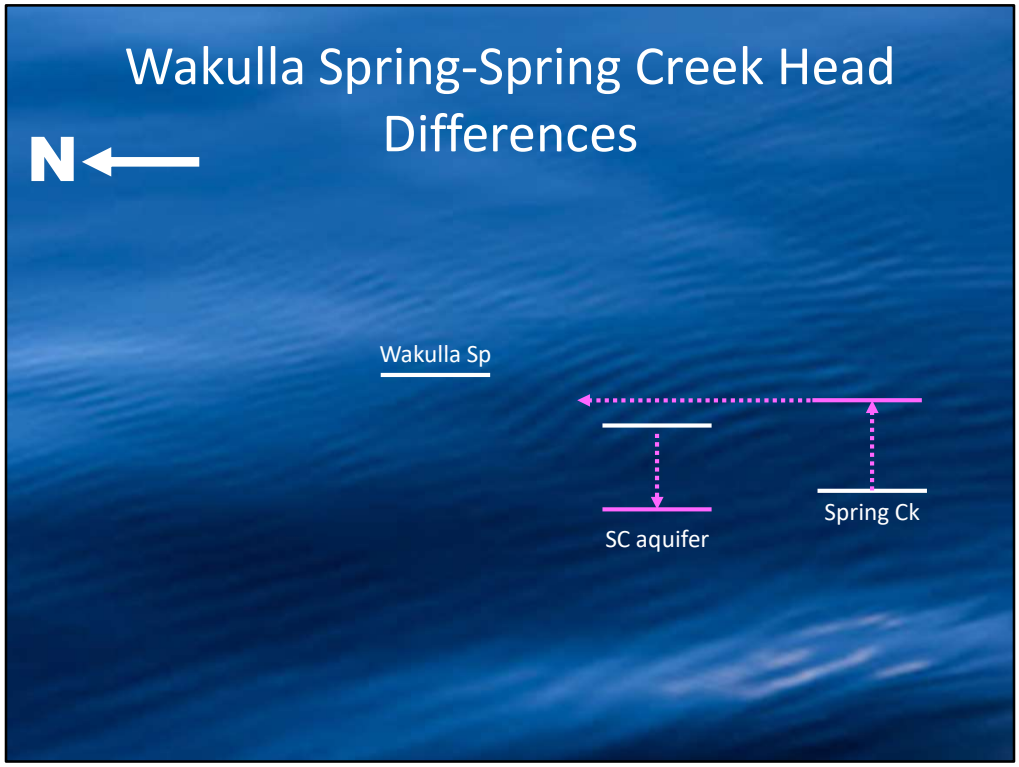
- The head difference in fresh groundwater systems is essentially the difference in elevation between two hydrologic features
- As shown here, the approximate head difference between the Wakulla Spring pool elevation or stage and the Gulf of Mexico at the Spring Creek Springs Group is about 5 feet **[click to next slide]**
- At some intermediate location between Wakulla Spring and Spring Creek the elevation of the piezometric surface within the aquifer will be somewhere in between



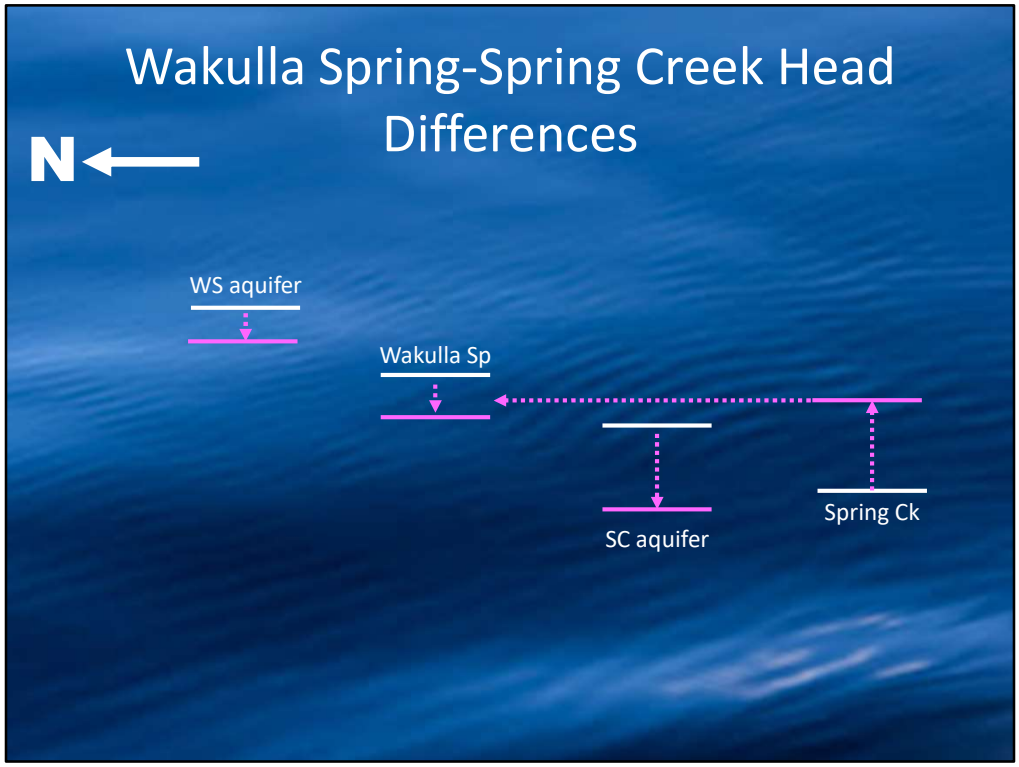
- At some intermediate location between Wakulla Spring and Spring Creek the elevation of the water table within the aquifer will be somewhere in between



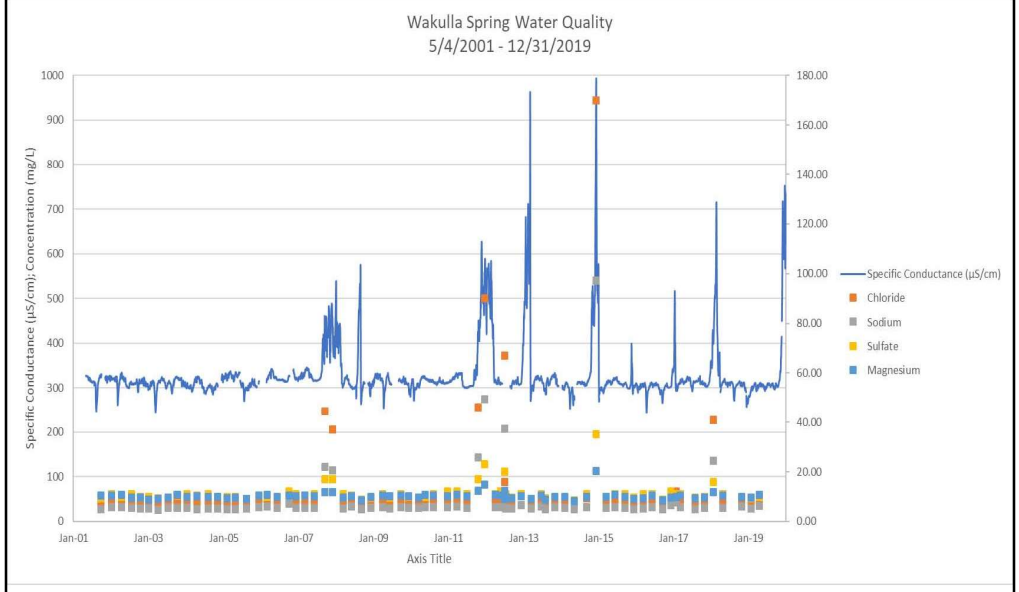
- Spring Creek reversals begin when decreasing rainfall within the Spring Creek Springs Group springshed causes a reduced head in the aquifer **[click]** and an associated decrease in discharge from the Spring Creek Springs Group
- This allows salt water to flow into the Spring Creek aquifer **[click]**



- The higher density saltwater produces a further increase in the effective head at the Spring Creek springs
- This causes salt water to flow <u>further north</u> through the aquifer pushing lower density freshwater upgradient

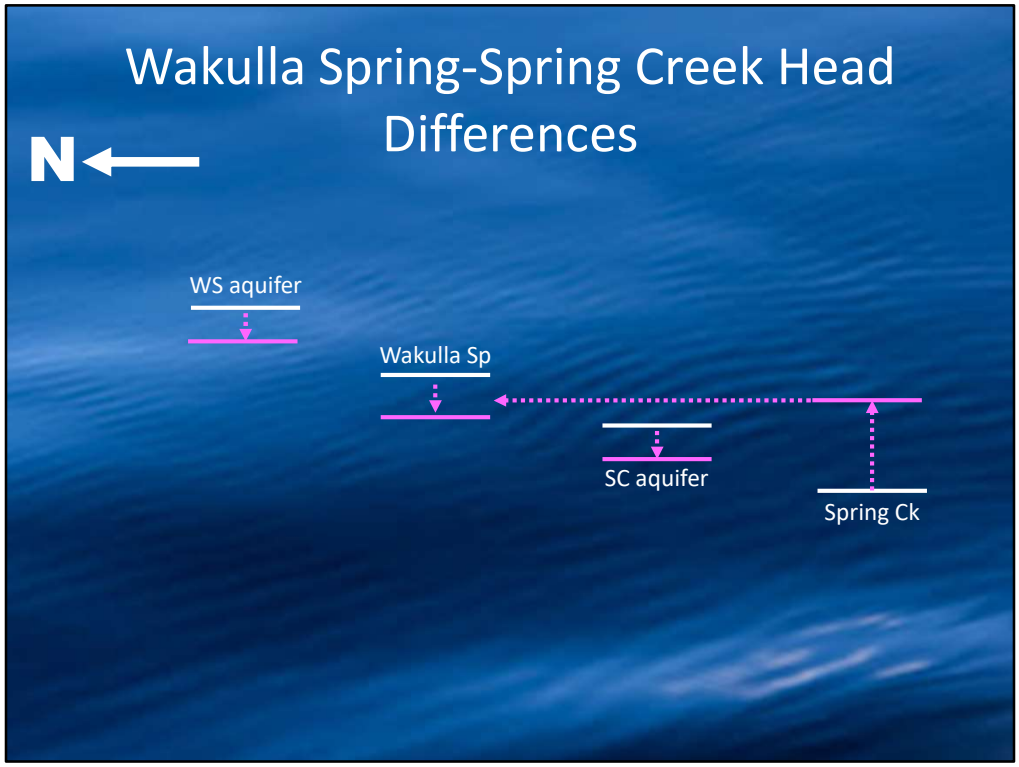


- If the area of no rainfall includes Wakulla Spring and the aquifer to its north,
    - the water table drops in the Wakulla Spring aquifer
    - as does the pool stage at the Spring
- At some point the reverse flows from Spring Creek may reach all the way to Wakulla Spring resulting in detectable salinity spikes

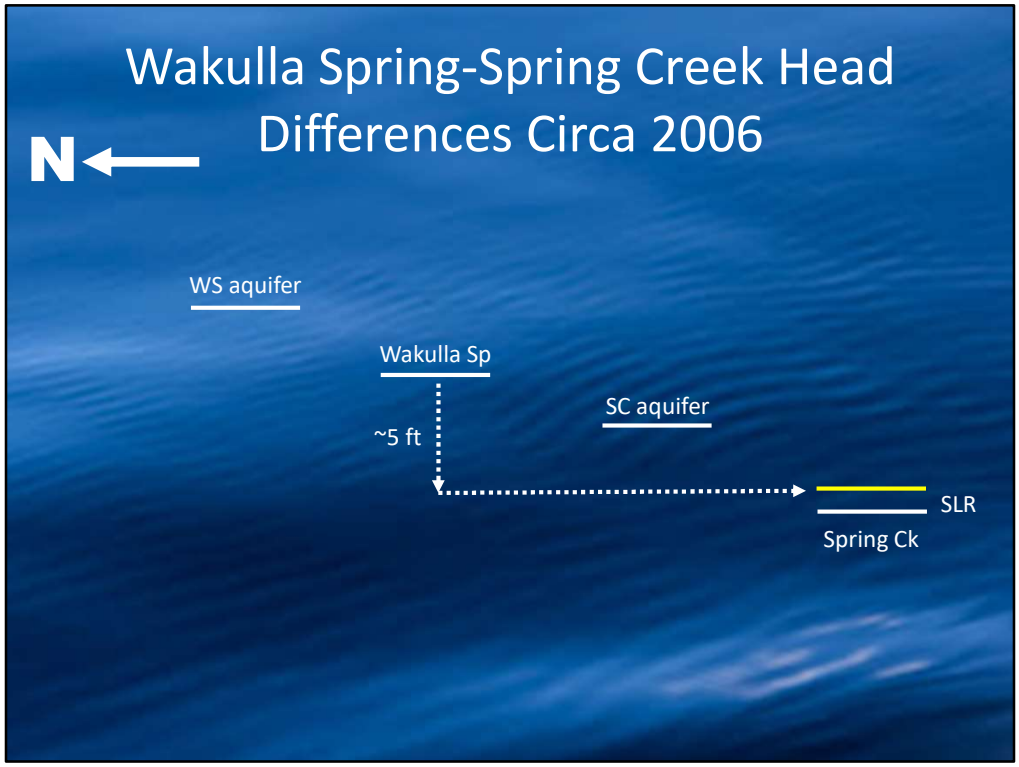


Average Wakulla Spring Conductivity= 330 uS/cm

- The recent trend of episodic salinity spikes, measured as specific conductivity, in the Upper Wakulla River would seem to fit this pattern
- These first occurred in 2007, shortly after Spring Creek Springs Group flow reversal were first observed

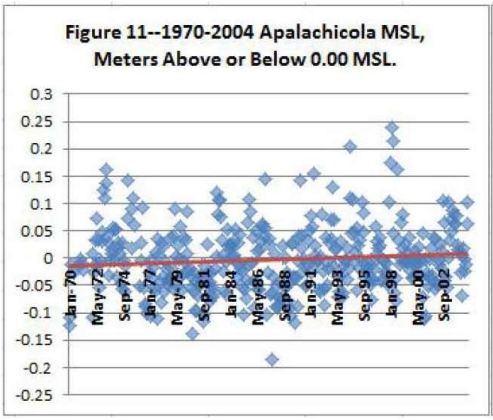


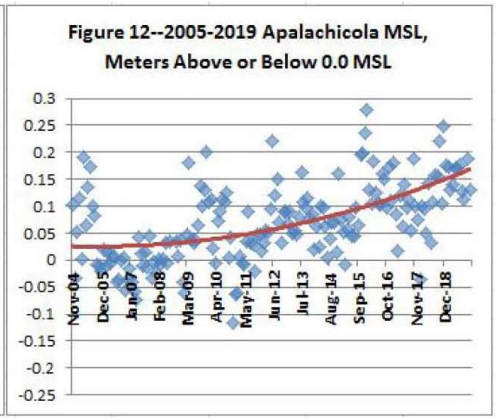
- At intermediate points in this dynamic, the shifting head difference will be sufficient to push water within the Spring Creek aquifer into Wakulla Spring carrying with it tannins from smaller swallets and sinkholes
- And at other points the shifting head difference will be such that the tannic discharge from the Lost Creek swallet flows north to Wakulla as well



- Todd Kincaid has reported that the first known instances of Spring Creek reversals occurred in 2006.
- Apparently some threshold in head difference between the aquifer north of the Spring Creek spring group and the Gulf of Mexico was first crossed at that time due to continuing sea level rise. **[click to next slide]**

Hypotheses #2: Accelerating Sea Level Rise

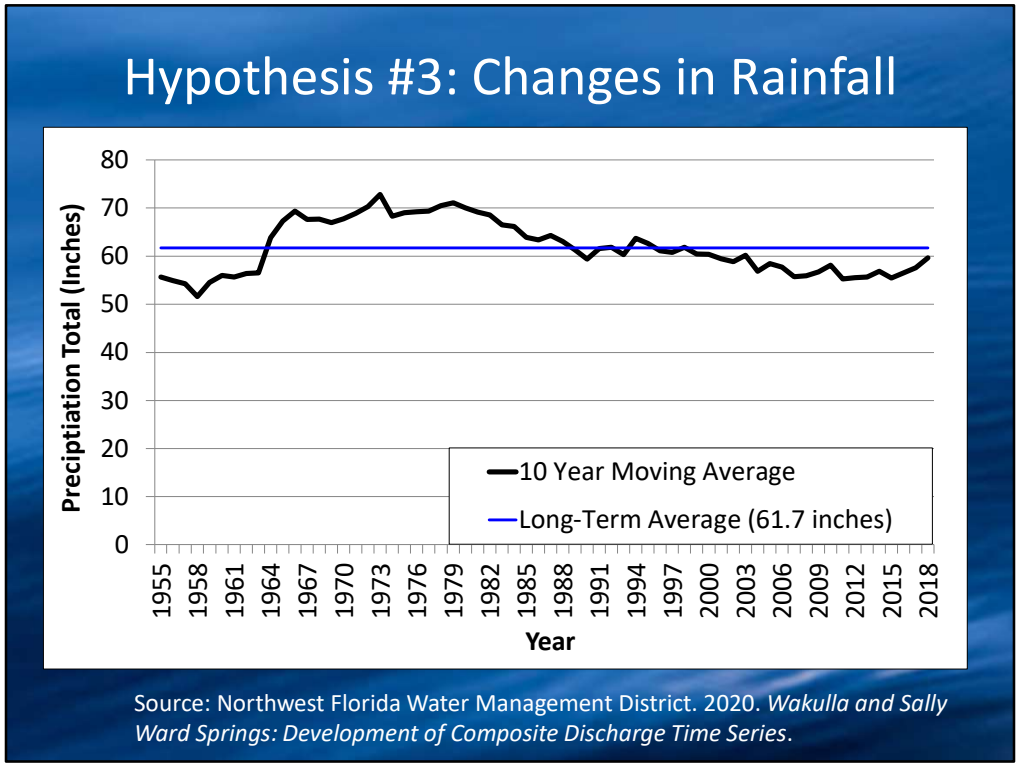




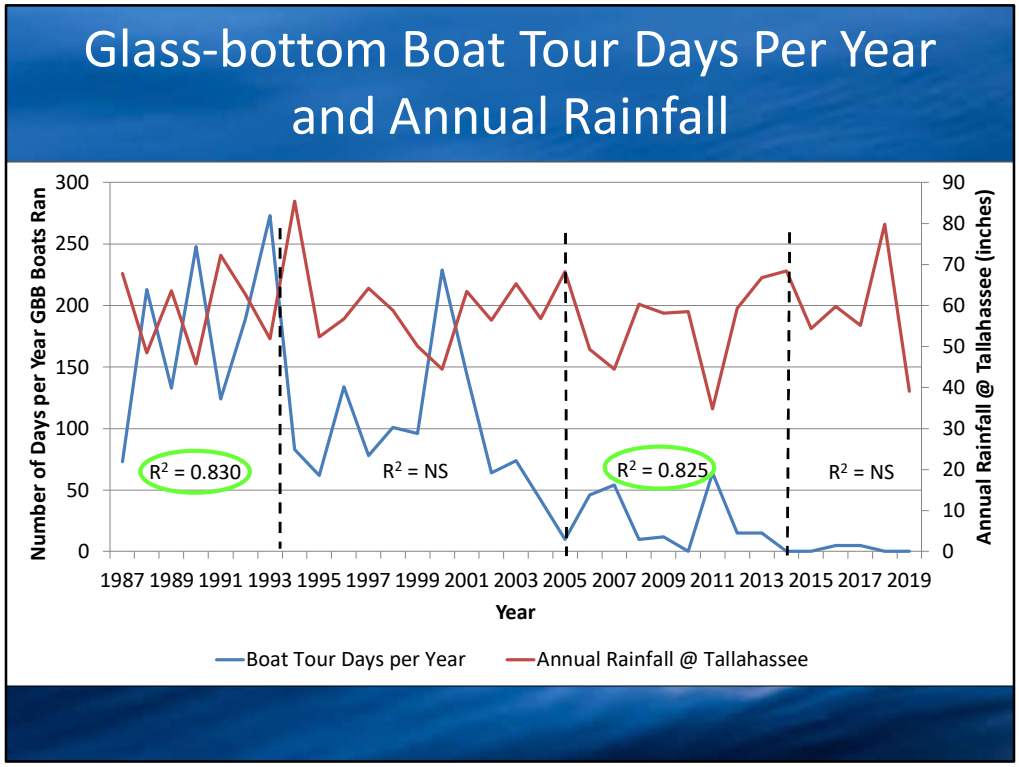
Partitioned Sea Level Rise Charts, Apalachicola Tide Gauge, 1970-2019 (Barr, 2020)

- As Doug Barr pointed out in his comments on the Water Management District's draft Wakulla and sally Ward Spring MFL Technical Report
    - The rate of sea level rise is accelerating
- Therefore, we should anticipate that Spring Creek Spring Group reversals will occur more frequently all else being equal
    - It will take less of a rainfall decline to set up a sufficient head difference between the Spring Creek aquifer and the springs group for reversals to occur

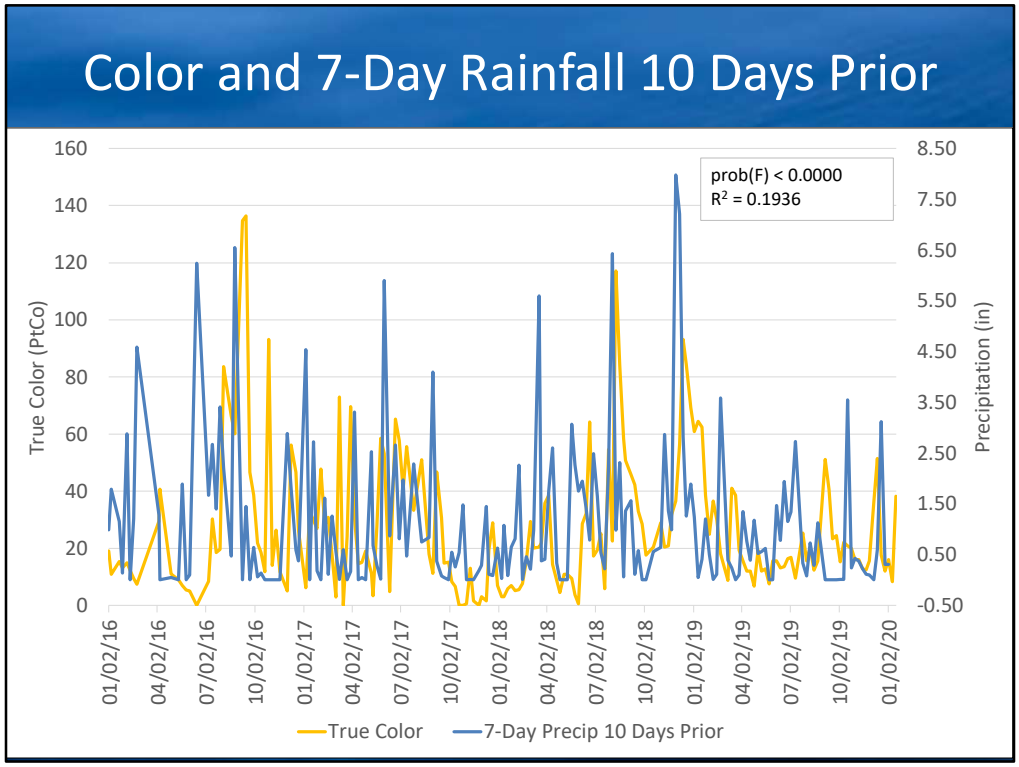
- Hypothesis #3 is that changes in rainfall patterns may be a forcing function that affects the frequency and duration of dark water conditions at the spring
- Since the occurrence of Spring Creek Spring Reversals is associated with periods of lower rainfall, a trend of decreasing rainfall may be contributing to more frequent and more prolonged reversals. **[click]**



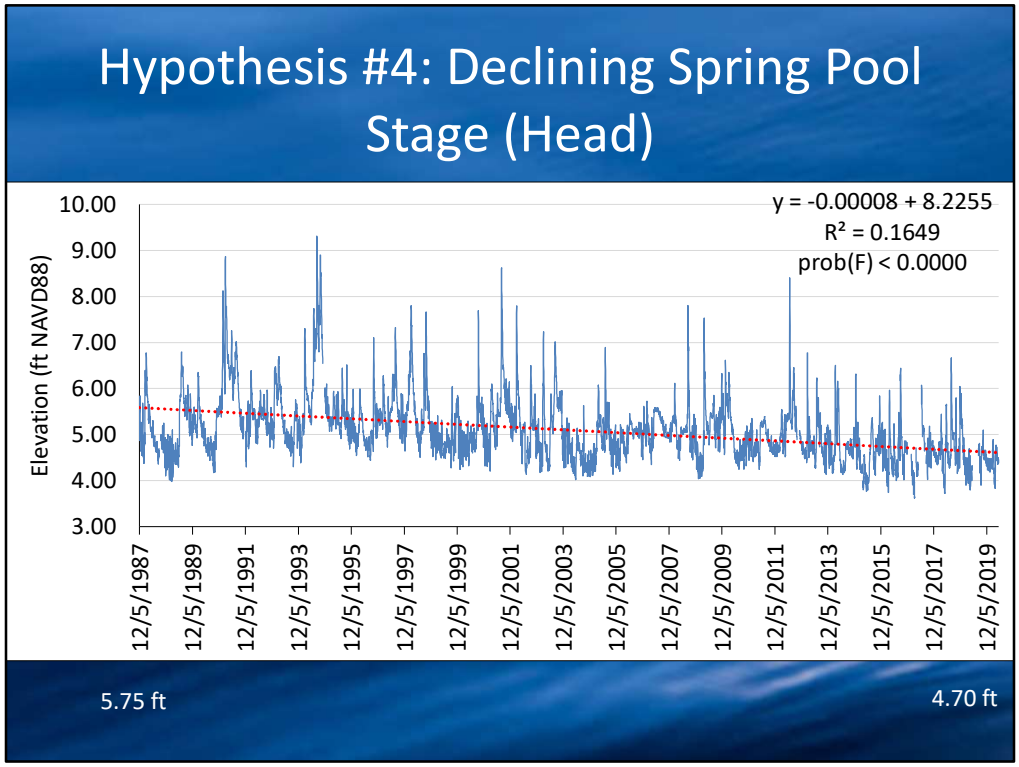
- The authors of the Water Management District's draft MFL Technical Report indicate that there has been a trend of decreasing annual rainfall since the late 1980s based on the 10-year moving average
- This trend likely has contributed to the occurrence and increasing frequency of Spring Creek Spring Group flow reversals along with sea level rise
- However, the relationship between rainfall and dark water conditions is quite complex.



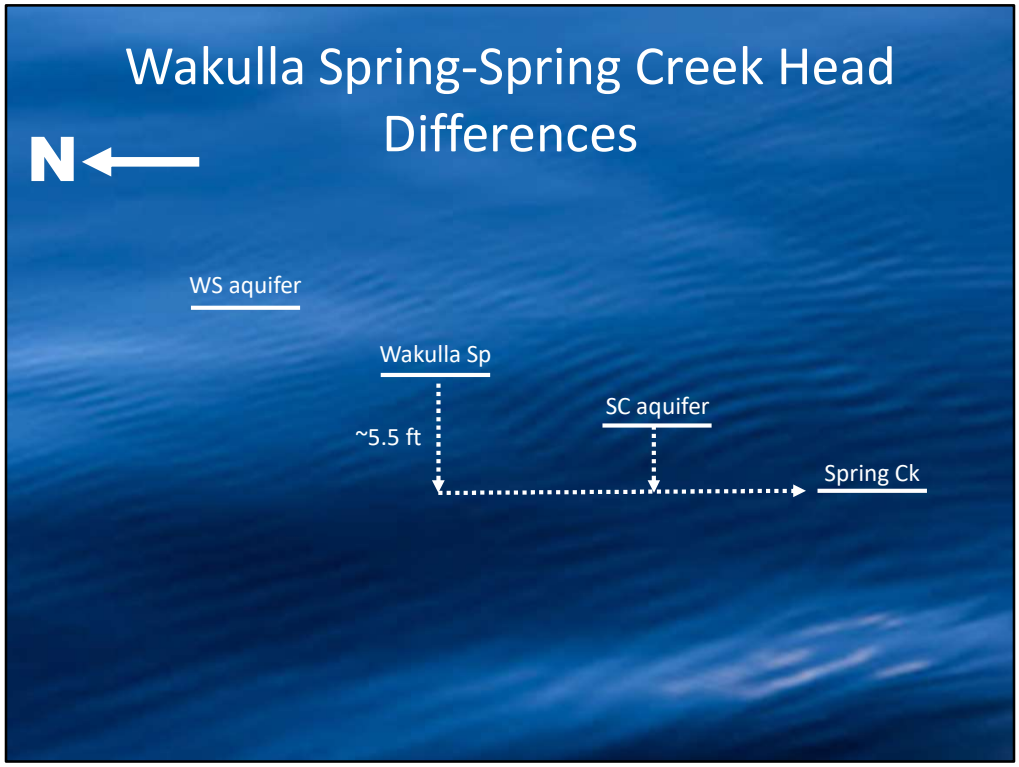
- Graphing annual glass bottom boat tour days with annual precipitation at the Tallahassee airport reveals a strong <u>inverse</u> relationship during two periods
- Consistent with the historical pattern of dark water conditions being associated with prolonged rainfallL
    - **[click]** 1987 – 1994
    - **[click]** 2005-2014



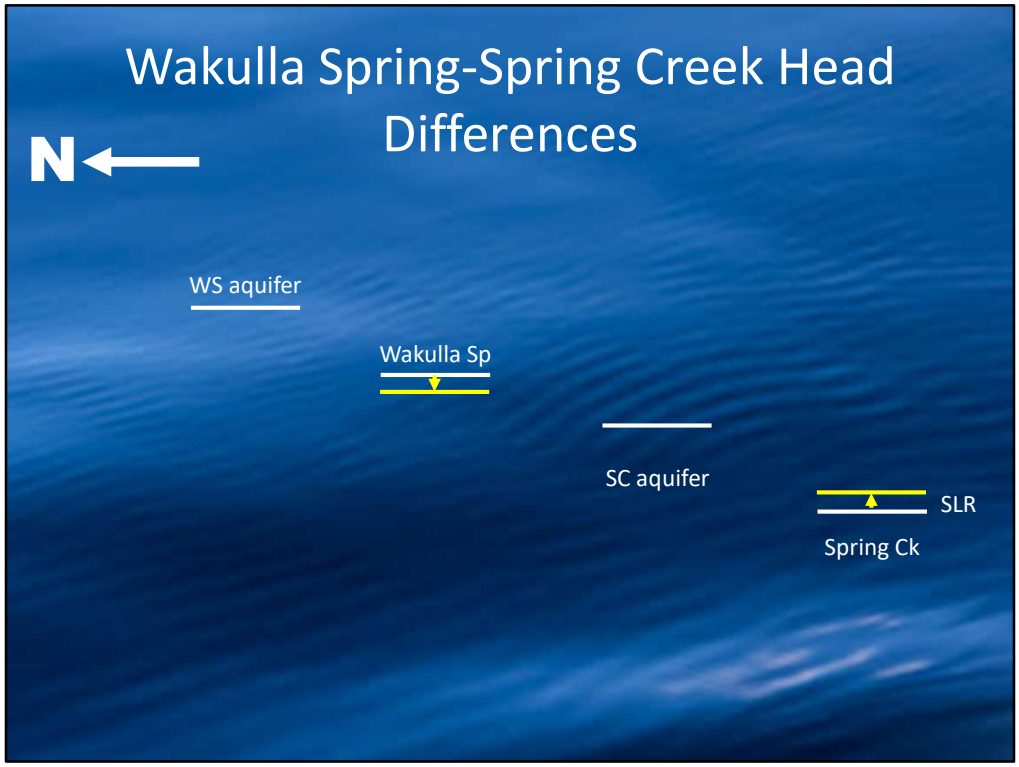
- Indeed, true color at the spring boil over the WSA study period 2016 and 2020 is <u>positively correlated</u> with 7-day rainfall 10 days prior
    - The 10-day interval was selected to reflect the travel time between the Leon Sinks sinking stream swallets and the spring calculated from dye studies.
- A regression model of the relation is significant at better than the 99.99% level and explains 19 percent of the observed variation in true color at the spring
- Thus a trend of declining rainfall would be expected to reduce the frequency and duration of dark water events due to inflows of tannins from the skinning streams to the north
    - But declining rainfall also may be associated with more frequent Spring Creek springs group reversals and associated dark water impacts on Wakulla Spring



- Hypothesis #4: The other trending phenomenon has been a progressive decrease in the spring pool stage as measured by the WMD for the period December 1987 through May 2020 at their gauge at the boat tram about 0.57 mile downstream from the spring boil.
- Comparing the end points of the trend line shown here, pool stage has decreased from a predicted value of about
    - **[click]** 5.75 ft North American Vertical Datum 88 (NAVD88) in 1987 to
    - **[click]** 4.70 ft NAVD88 in 2019
- The elevation of the USGS gauge at Spring Creek is 0 ft NAVD88



- In the late 1980s, when the Spring Creek springs were flowing, there was about a 5.5-foot head difference between the pool stage or head at Wakulla Spring and mean sea level at Spring Creek **[click]**
    - There also is a positive head difference between the water table in the aquifer and Spring Creek **[click]**

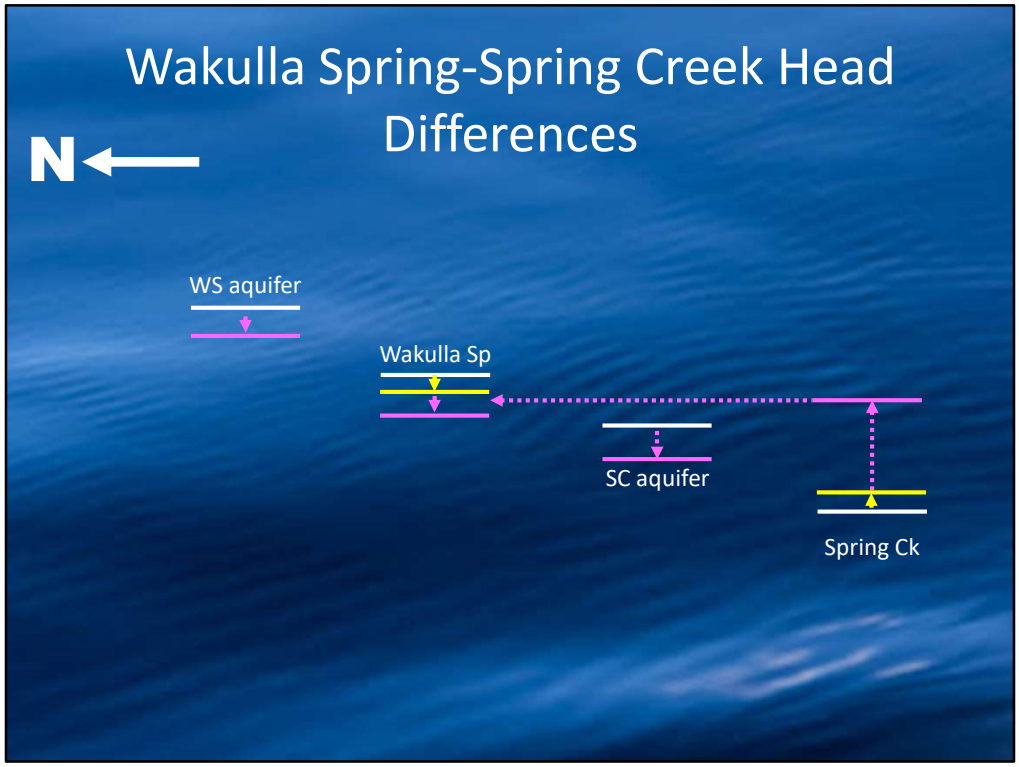


- Thus while SLR is reducing the head difference in one direction **[click]**,
    - declining stage at Wakulla Spring is further reducing the difference from the other direction **[click]**

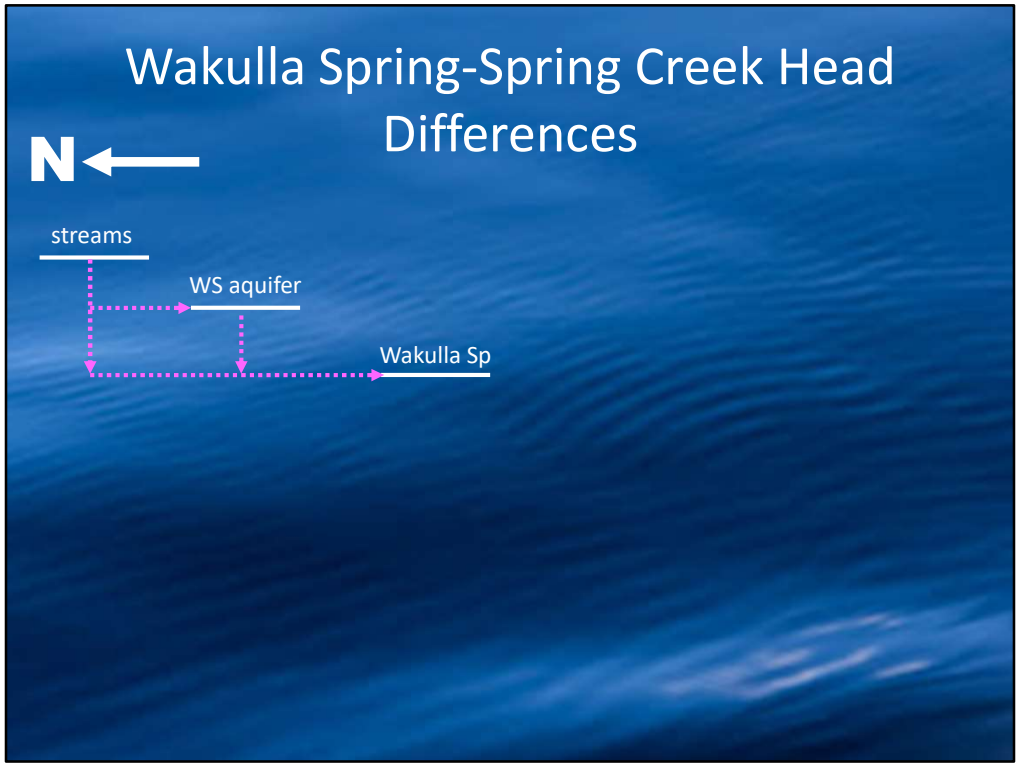
SCSG Reversal Events

Event	Date of beginning of reversal event at SCSG	Date of end of reversal at Wakulla Spring	SCSG under reversal conditions (Days)	Wakulla Spring with high specific conductance (days)
1	5/7/2007	2/27/2008	296	203
2	4/15/2008	8/31/2008	138	42
3	5/4/2011	3/27/2012	328	207
4	10/27/2012	3/3/2013	127	87
5	4/22/2014	12/30/2014	252	116
6	9/25/2016	1/17/2017	114	42
7	9/10/2017	3/26/2018	197	105
		Total	1452	802
			36%	20%

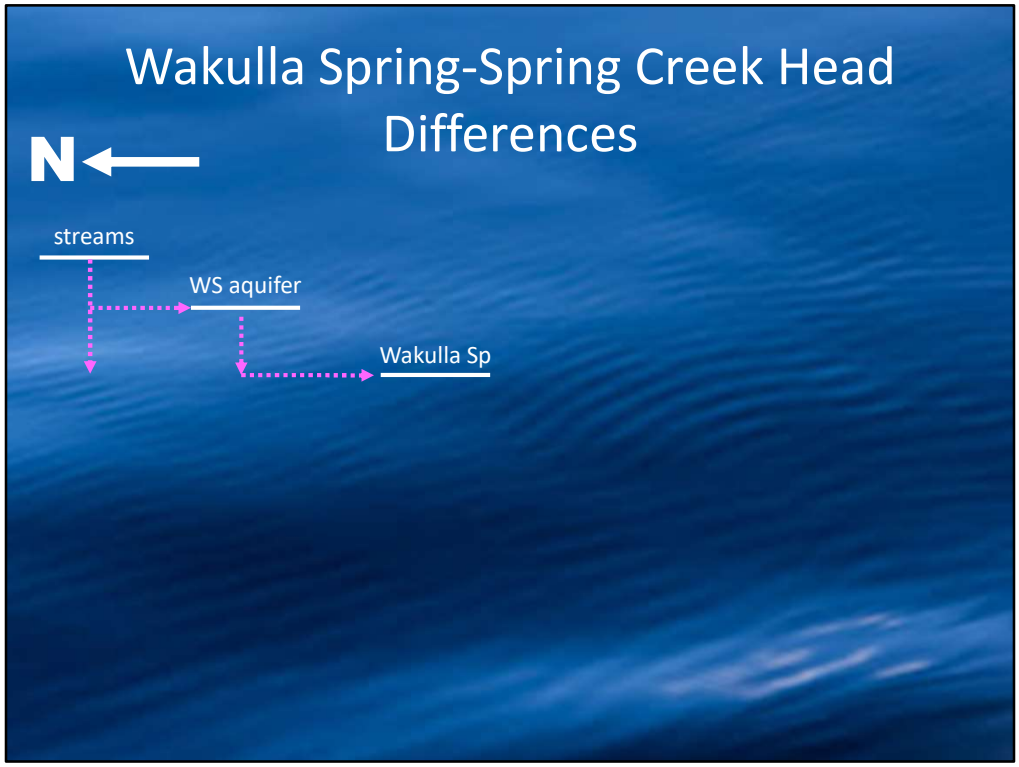
- Some flow of tannic water north from the Spring Creek aquifer to Wakulla Spring likely occurs under reversal conditions when saline water from Spring Creek does not penetrate all the way to the spring
- Based on James Sutton's recent presentation specific conductance at Wakulla Spring was greater than "normal" for about 20% of the time (802 days) between 5/7/2007 and 3/26/18 (4062 days)
- But reversal conditions occurred about 36% of the time (1452 days)



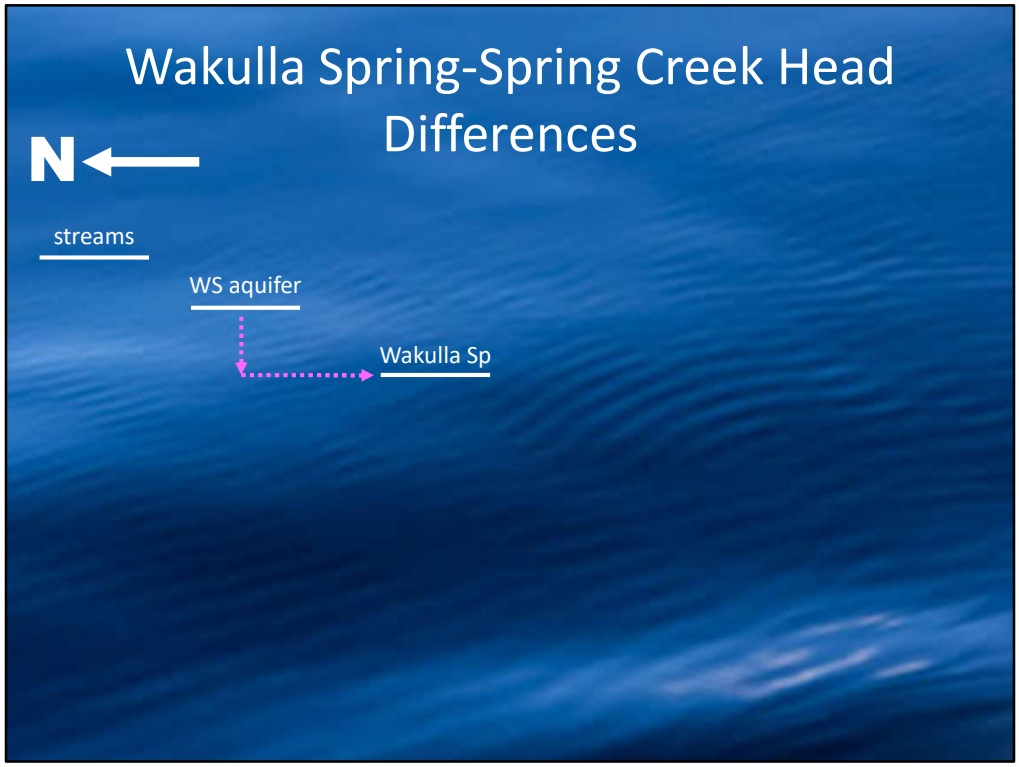
- I'm hypothesizing that the resulting decrease in head difference between Wakulla Spring and Spring Creek Spring Group makes Wakulla Spring more susceptible to
    - inflows of higher salinity water from the Spring Creek Spring Group
    - and tannin-laden water from Lost Creek and karst window sinks and smaller swallets in the Spring Creek aquifer with a lesser rainfall deficit
- Which in turn result in more frequent and/or more prolonged periods of dark water at Wakulla Spring



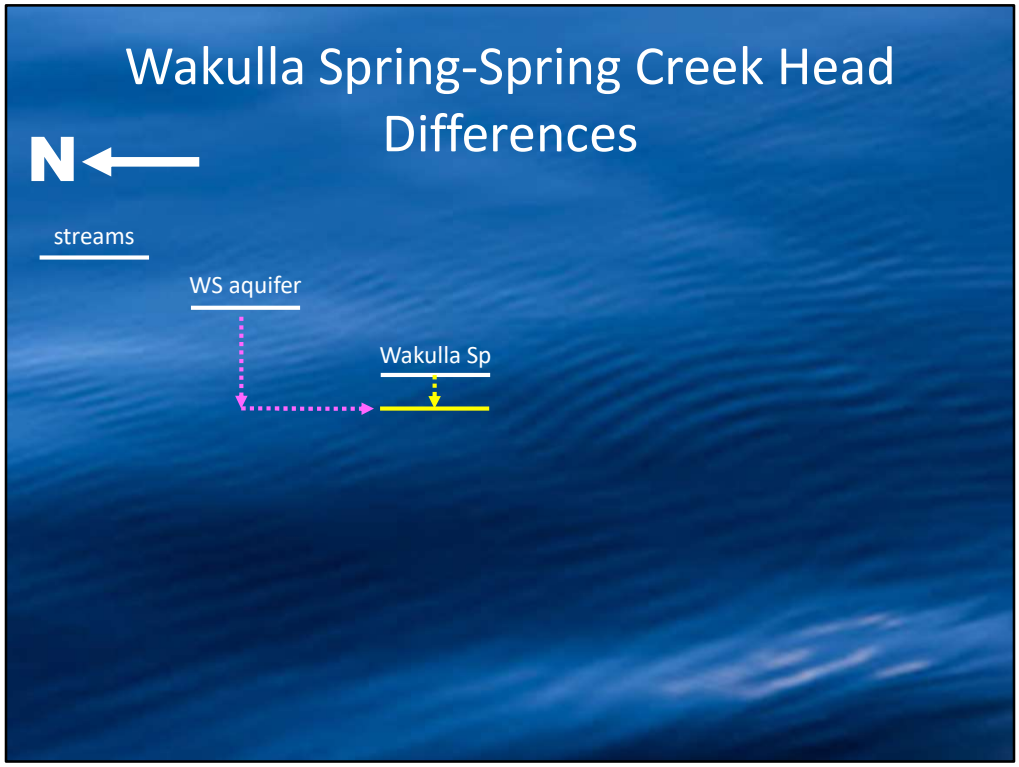
- The trend of declining pool stage at Wakulla Spring also may result in more frequent and/or prolonged inflow of tannins from the aquifer to the north of the spring
- After periods of sufficiently long rainfall the major sinking streams in the Leon Sinks area, Black, Fisher, and Jump Creeks, begin to flow **[click]**
- That water travels through caves to Wakulla Spring which is down gradient from the streams, i.e. there is a negative head difference between the creeks and the spring **[click]**
- At the same time, some of that tannic water will move from the caves into the aquifer because the water table head also is lower than that of the creeks **[click]**
- Some of that tannic water flows through the aquifer matrix to the spring as well **[click]**
- When the creeks stop flowing, no new tannic water is flowing to Wakulla via the caves **[click to next slide]**



- Or to the aquifer **[click to next slide]**



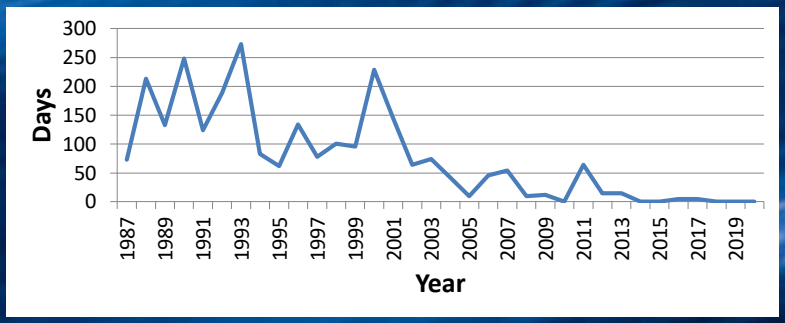
- But tannic water will continue to flow from the aquifer matrix into Wakulla Spring



- As the spring pool stage drops, increasing the head difference between the spring and the aquifer, tannic water in the deeper reaches of the aquifer matrix may be able to flow into the spring thereby prolonging dark water conditions
- This sets up two more questions that I am still working on **[click to next slide]**

Next Questions

- Why is the Wakulla Spring Pool Stage (Head) Dropping?
- What happened circa 1994 to trigger the decline in visibility?



- What explains the observed decline in spring pool stage/head?
- What happened circa 1994 to trigger the decline in visibility?
- I'll plan to make a final presentation of alternative hypotheses in March, hopefully informed by further conversations with WMD staff and Hal Davis.