Comments on the Northwest Florida Water Management District
Draft Wakulla and Sally Ward Springs MFL Technical Report

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I believe it is premature for the Northwest Florida Water Management District to be recommending allowable flow reductions for the Wakulla Spring – Sally Ward Spring system. The district's decision to limit the scope of the Wakulla and Sally Ward Springs MFL study to setting a minimum flow for the springs rather than addressing both minimum flow and minimum level (head) as has been done by some other districts, results in an incomplete assessment of the potential significant harms of additional ground water withdrawals on the water quality of the Wakulla Spring and River, its ecosystem, and recreational use of the spring.

I urge the district to extend the MFL study to address establishing a minimum level (head) through additional research and ground water modelling that accounts for accelerating sea level rise, worst-case drought scenarios, and the effects of alternative withdrawal scenarios on shifting head gradients and resulting impacts on the occurrence of salinity spikes, the frequency and duration of dark water conditions due to CDOM/tannins, and the continuation of excessive nitrate concentrations and associated biological impairment of the spring and upper river.

The draft technical report fails to convey or adequately address the severity of the water quality and ecological degradation of the Wakulla Spring and River. Prolonged periods of dark water conditions and excessive levels of nitrate nitrogen have already resulted in significant harm to the spring and river ecosystem and recreational use of the spring. Wildlife monitoring conducted by the State Park has documented a long-term decline in total abundance of the species surveyed and the continued decline despite the cessation of herbicide treatments of the spring and river in 2013 and reductions in nitrate levels attributed to modifications of the City of Tallahassee's wastewater treatment processes. The recent advent of salinity spikes and the prospect of their more frequent occurrence as sea level continues to rise at an accelerated rate pose the most serious threat of significant harm. There is some evidence that recent salinity spikes may already have adversely affected some upper river habitat.

The report suggests that an apparent pattern of declining time-adjusted nitrate concentration residuals versus flow may indicate the presence of a dilution effect with a high degree of variability. This may be the result of increasing occurrences of Spring Creek Spring Group reversals due to reduced head gradients between Wakulla Spring and Spring Creek, but the report does not pursue this question because of its restricted focus on minimum flow.

The technical report acknowledges the role of changing head gradients between Wakulla Spring and the Spring Creek Spring Group in the occurrence of salinity spikes associated with periods of decreased rainfall. It attributes these to lower than average precipitation since 1995 and rising sea level. However, the evidence of a significant decline in rainfall since 1995 is not robust, and the assessment of sea level rise fails to account for the evidence that the rate is accelerating.

The technical report describes a trend of decreasing spring/river stage but does not offer a convincing explanation for why it is occurring. The report acknowledges that the declining stage contributes to the decreasing head difference between Wakulla Spring and the Spring Creek Spring Group as well as between the spring and the Floridan Aquifer to the north. It does not, however, recognize the links between those conditions and more frequent and prolonged periods of dark water conditions at Wakulla Spring.

The available data on changes in ground water levels within the Wakulla Spring contribution area are limited. The report downplays the significance of ground water trends, despite the fact that those data show declining ground water levels at all four of the wells due north of the spring with statistically significant trends. The report suggests that declining ground water levels are not unexpected at two of those wells which are described as being near production wells (Lafayette Park and Lake Jackson). However, the analysis in Appendix A does not explicate the relationships between ground water levels at those wells, actual withdrawals from the nearby production wells, and recharge. The report also concludes that withdrawals are inconsequential because they comprise such a small percentage of the combined discharge of Wakulla Spring and the Spring Creek Spring Group. Again, the focus solely on spring flow neglects the implications for shifting head gradients.

Most importantly, because of its restricted focus on spring flow, the technical report does not address the potential for ground water withdrawals north of the spring to contribute to the observed decline in spring/river stage, the associated changes in head gradients, and the associated water quality and ecological impacts.

I elaborate on these issues in the following sections.

1. **The technical report fails to convey or adequately address the severity of the water quality and ecological degradation of Wakulla Spring and River.**

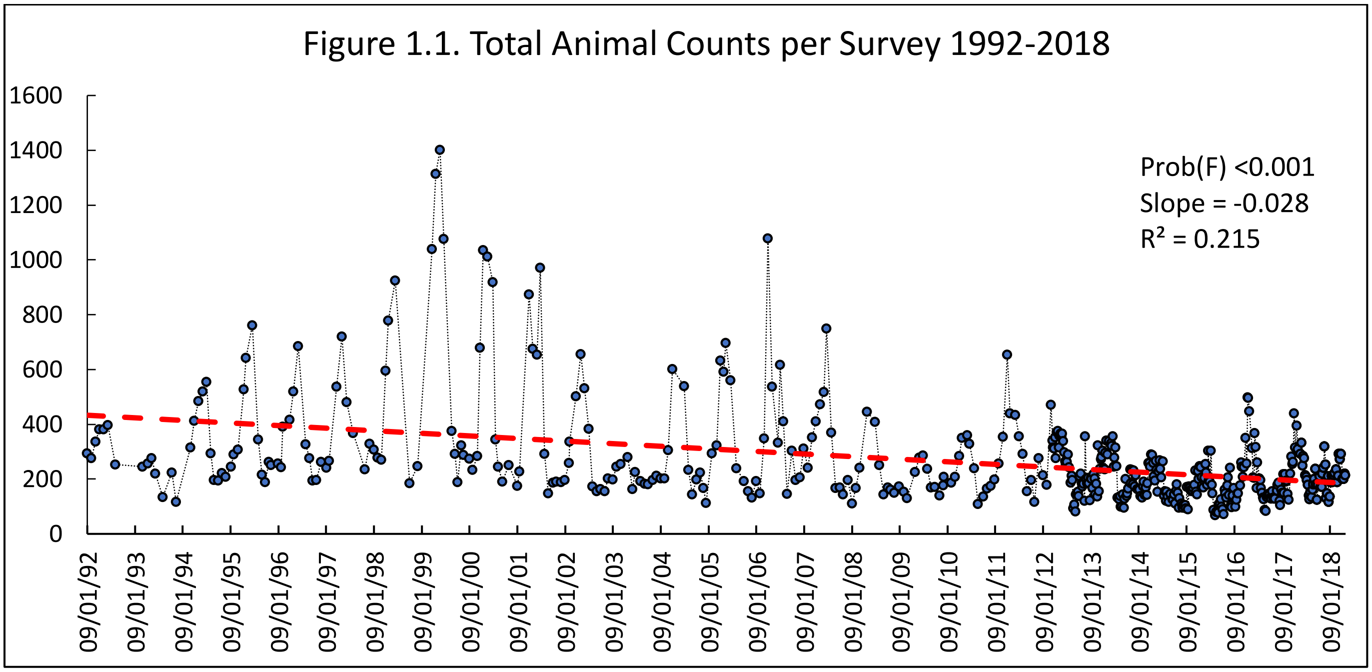
   - **The executive summary (p. 11)** states that "The majority of the Wakulla River and Sally Ward spring run, in addition to their respective floodplains, remains in a relatively natural condition."

     This statement overlooks the designation of the upper Wakulla River as a biologically impaired water in 2008, the occurrence and impacts of the hydrilla invasion and the use of herbicides to control it, the documented long-term declines in wildlife abundance, the drastic reduction in water clarity which has resulted in the cessation of glass bottom boat tours, one of the principal recreational uses of Wakulla Spring, or the onset of increased salinity and salinity spikes that can affect freshwater species in the river.

   - **Section 1.7.3 Wildlife** overlooks the long-term decline in wildlife abundance documented by the State Park's wildlife monitoring program (1987-present).

     The State Park wildlife monitoring program (Thompson, 2017; Deyle, 2019) has documented statistically significant long-term declines in the total abundance of wildlife species surveyed (figure 1.1). Deyle (2019) has presented evidence that these declines have been associated with the hydrilla invasion and the use of herbicides to control it as documented by Savery (2005) and Van Dyke (2019).

     Four species increased in abundance over this period or record, fourteen decreased, and six exhibited no statistically significant long-term trend. Total wildlife abundance and nine species increased in abundance during the hydrilla invasion (1992-2000), probably because of increased food supply.



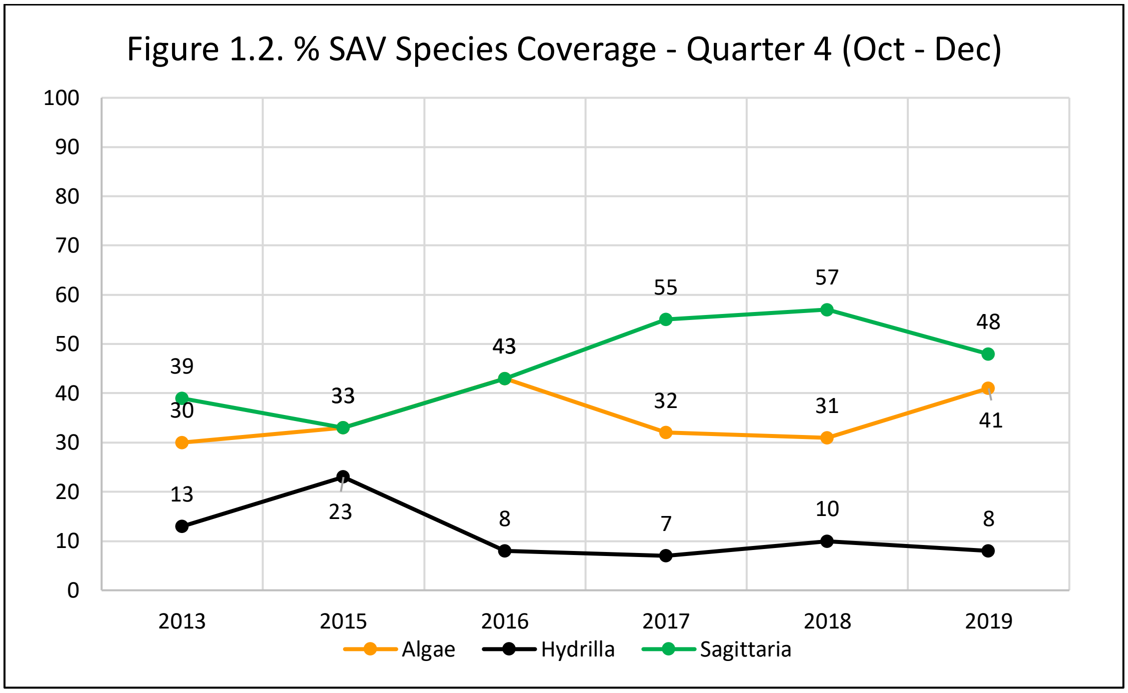
During the hydrilla management period (2000-2012), total wildlife abundance decreased as did twelve species, most likely because of the disruptions of mechanical harvesting, the loss of total plant biomass, and/or the decrease of some native submerged aquatic plants resulting from herbicide treatments.

Quarterly vegetation surveys conducted during the post-hydrilla management period (2012-2018) document a decline in hydrilla balanced by an increase in spring tape grass (*Sagittaria kurziana*) but a stubborn persistence of algal mats (figure 1.2). Total wildlife abundance continued to decrease during this period as did three species, while a fourth began to decline for the first time. Seven species increased during this period, including three that had decreased during the hydrilla management period, possibly signaling emergence of an alternative food web.

- **Section 1.6.** does not convey the seriousness of nor does it adequately address the causes of the impairments posed by **increasing frequency of salinity spikes** at Wakulla Spring or the **more frequent and prolonged periods of dark water conditions**.

  The introductory paragraph of section 1.6 Water Quality (p. 35) presents a misleading summary of the water quality of Wakulla Spring and the upper Wakulla River: “Most of the Wakulla River watershed has good water quality (NWFWMD 2017). Additionally, the Wakulla River is designated as an Outstanding Florida Water (OFW) (Section 62-302.700, F.A.C.).”

  Section 1.6 fails to clearly state that FDEP designated the upper Wakulla River as an “impaired water” in 2008 based on low stream condition index values due to excessive growth of hydrilla and algal mats caused by high levels of nitrate nitrogen (Gilbert, 2012) and that this situation was the basis for adopting the monthly average 0.35 mg/L nitrate TMDL.



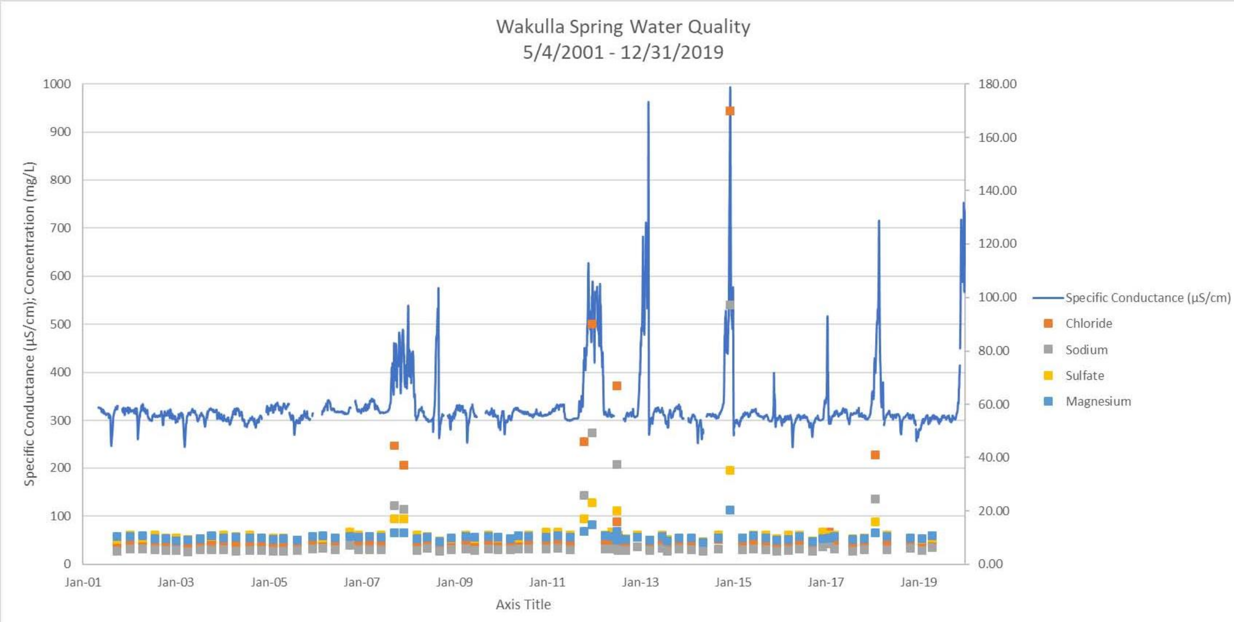
Section 1.6.2 neglects additional Wakulla Spring water quality data available in FDEP's WIN database collected by McGlynn Laboratories Inc (MLI) including weekly true color, chlorophyll a, pheophytin a, nitrate, and specific conductivity. Table 4 of the technical report does not include statistics for CDOM/true color and chlorophyll/pheophytin a which have been demonstrated to be the principal causes of dark water conditions at the spring (Kulakowski, 2010; Luzius et al., 2018; McGlynn and Deyle, 2019; Deyle, in preparation).

- **Section 1.6.6** does not convey the seriousness of the impairments resulting from the **advent and increasing frequency of salinity/specific conductivity spikes**.

The technical report (p. 41) attributes salinity/specific conductivity increases at Wakulla Spring to reversals of the flow at the Spring Creek Spring Group, but states that specific conductivity displayed no statistically significant trend from October 22, 2004 to December 31, 2019. Figure 22 (p. 43) as well as slide #8 in Sutton (2020) (figure 1.3) show that the first departures from the long-term average of 330 micro Siemans occurred in 2007, one year after the first year in which Spring Creek Springs Group reversals were reported by Kincaid (2011). Nine spikes have occurred since then through 2019.

In his comments on the draft technical report, Douglass Barr (2021) makes a compelling argument that the greatest long-term threat of significant harm to the Wakulla Spring and River ecosystem is the trend of **increasing frequency of salinity spikes** associated with reversals in the discharge of the Spring Creek Spring Group. Barr demonstrates that the spikes have been associated with periods of drought, and he emphasizes that the accelerating rate of sea level rise foretells increasing occurrences.

Fig. 1.3. Wakulla Spring Water Quality 5/4/2001 – 12/31/2019



Average Wakulla Spring Conductivity= 330 uS/cm

Source: Sutton (2020).

Salinity spikes are more important than trends in average or median salinity because many freshwater plants and animals are stenohaline with limited tolerance for higher salinity. The recent breakup of the so-called bulrush island at the downstream end of the river boat tour route may be the result of the intolerance of the California bulrush (*Schoenoplectus californicus*) to elevated salinity. Bulrush generally cannot tolerate chloride concentrations greater than 45 mg/L (Neubauer et al., 2012). Sutton's slide #8 (figure 1.3) records eight instances (orange squares) where chloride levels have exceeded that threshold, including a very high spike of about 170 mg/L in January 2015.

I and several other tour guides began to notice a decline in the density of bulrush on the island circa 2016-2017. Portions of the island began to disappear, eventually fragmenting the island into three separate sections. Google Earth air photos from 2016 and 2018 show the onset of the fragmentation (figures 1.4 and 1.5). The two areas of open water marked in Figure 1.5 have now broken through. Loss of this habitat is concerning because it provides nesting habitat for several species including common gallinule, pied-billed grebe, and least bittern which is designated as a "species of greatest conservation need" by the Florida Fish and Wildlife Conservation Commission (2019).

Fig. 1.4. "Bulrush Island," Wakulla Springs State Park Tour Boat Route, 9/25/16.

Source: Google Earth

Fig. 1.5. "Bulrush Island," Wakulla Springs State Park Tour Boat Route, 10/11/18.

Source: Google Earth

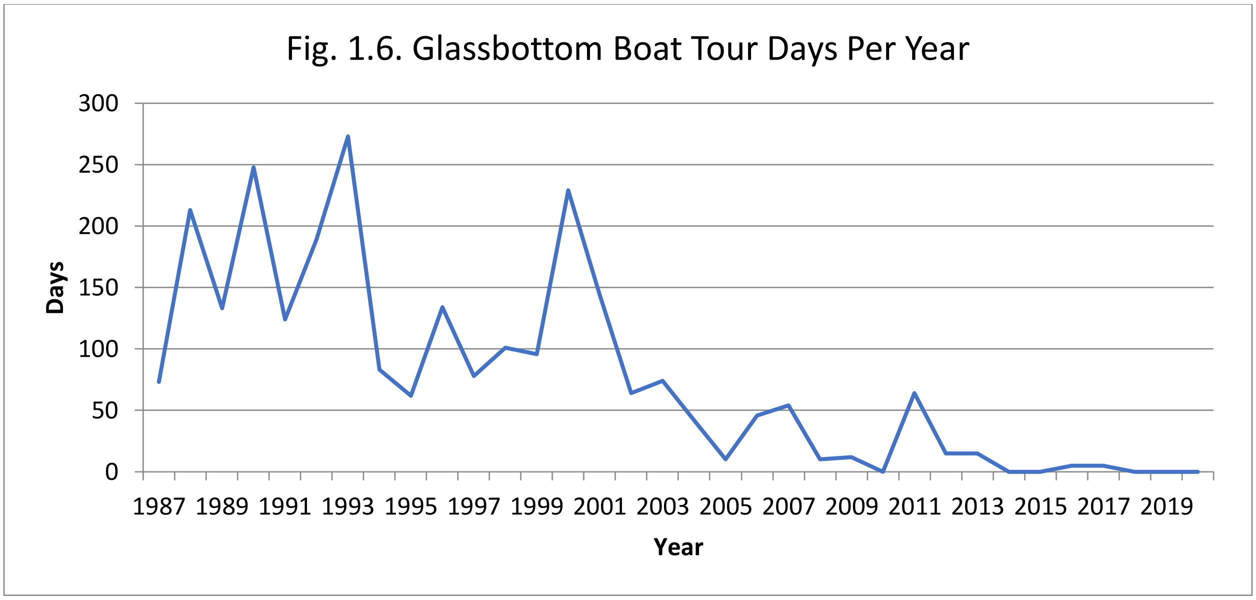
- **Section 1.6.5 Trends in Water Clarity** does not document the **long-term trend in declining visibility depth** at Wakulla Spring, fails to convey the **significance of the decline in water clarity** and its **implications for both the spring and river ecosystem and recreational use**, and neglects the role of Spring Creek Spring Group flow reversals on loadings of CDOM/tannins to Wakulla Spring.

  The opening sentence (p. 39) states that "The clarity of water emerging from Wakulla Spring is quite variable, ranging from the clear blue associated with many springs to darker, more tannic stained water." In fact, clear blue conditions with visibility to the deepest visible point in the spring bowl at approximately 90 feet, have occurred only a few days if at all since August 2013 when I began working as a volunteer at the State Park. The average weekly visibility depth observed by McGlynn Laboratories Inc. between August 2014 and May 2020 was 19.5 feet with a maximum of 71 (McGlynn, 2020). Apparent color has ranged from tannic brown to various shades of greenish brown.

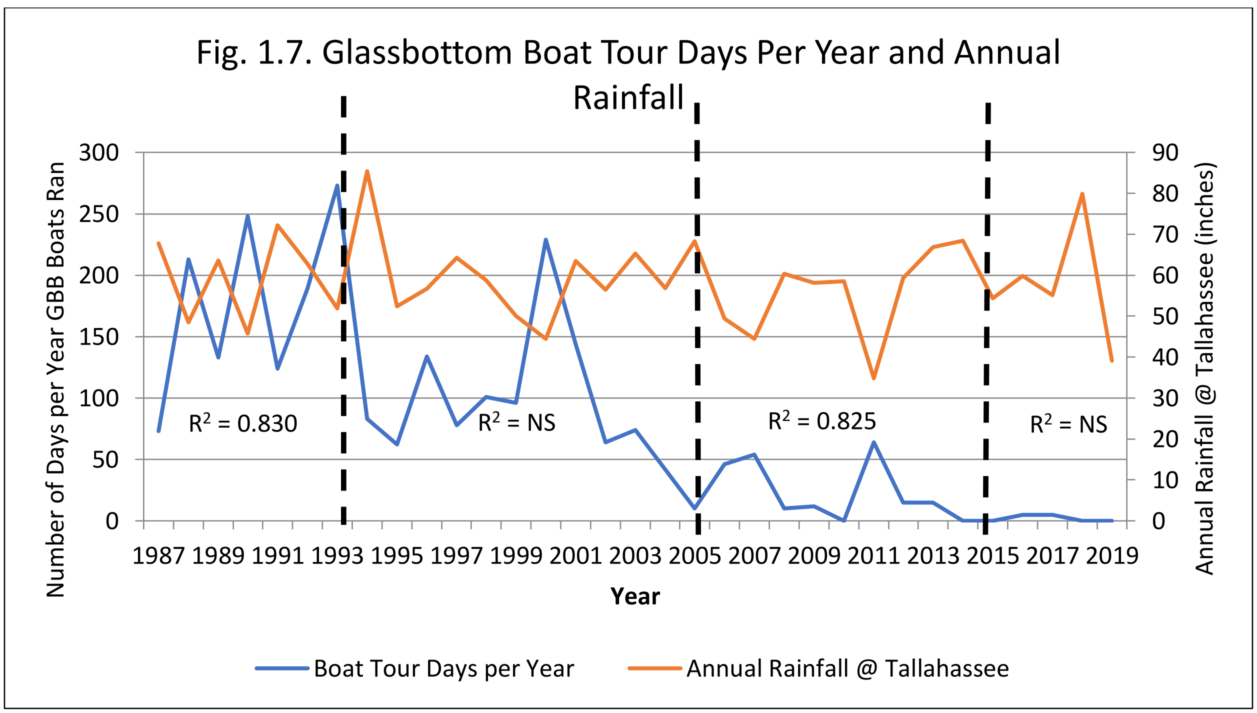
  Prolonged dark water can limit the depth at which submerged aquatic vegetation (SAV) can survive, i.e. the compensation point, the depth at which a plant receives just enough photosynthetically active radiation (PAR) to produce by photosynthesis the amount of sugar needed to offset the amount consumed by respiration. This is 10 percent of PAR at the surface for the two dominant submerged aquatic grass species in the spring bowl and Upper Wakulla River, American eelgrass (*Vallisneria americana*) and springtape (*Sagittaria kurziana*) which are likely keystone species for the spring and river aquatic ecosystem (Hauxwell et al., 2004; Szafraniec, 2014). The average depth of the 10 percent PAR compensation point measured during 2015 and 2016 was about 10 feet, suggesting that survival of the native submerged aquatic grasses may be limited at greater depths (McGlynn and Deyle, 2019). While low-level air photos from the late 1960s show SAV at greater depths in the spring bowl, 15 feet was the maximum depth at which submerged aquatic grasses were growing in the spring bowl in 2016. These are predominantly if not exclusively patches of transplanted *Vallisneria* introduced circa 2005.

  Visibility depth also constrains operation of glass-bottom boat tours, one of the key recreational activities for which Wakulla Spring has been known for over 150 years (Revel, 2002). Section 3.6 Aesthetic and Scenic Attributes states that "In recent years, reduced water clarity in Wakulla Spring and a decrease in the number of days that glass bottom boat tours have been conducted near the spring vent have been reported." In fact, concern with the increased frequency and duration of dark water conditions dates to at least the early 1990s. As early as 1991, tour boat operators observed that the water was remaining dark at times when there had been little rain (Dodrill, 1992).

  Several researchers have used the frequency of glass-bottom boat tours as a proxy for dark water condition trends (Loper et al., 2005; Kulakowski, 2010; McGlynn and Deyle, 2019). As shown in Figure 1.6, the decline began in 1994, The **frequency of glass-bottom boat tours dropped** from over 200 tour days per year in the early 1990s to zero to five tour days per year since 2014. Previous park manager Sandy Cook (1994-2008) 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 (cook, 2020).



Loper et al. (2005) and Kulakowski (2010) observed an apparent inverse relationship between annual glass-bottom boat tour days and rainfall, however, Kulakowski noted that the two variables appeared to uncouple after 1994. Figure 1.7 extends this analysis through 2019. Simple linear regression analysis indicates that the relationship broke down between 1994 and 2005 and then again between 2014 and 2019 suggesting that other forces may be involved. More recent research indicates that **altered head differences between Wakulla Spring and the Floridan aquifer to its north and between the spring and the Spring Creek Springs Group may be involved**.



Spectral radiometric analysis (McGlynn and Deyle, 2019) and quantile regression (Deyle in preparation; Deyle, 2020a) show that **both chlorophyll a and CDOM/tannins measured as true color contribute to reduced visibility depth** measured as the depth at which visible light transmission falls to zero percent of that at the surface. True color levels on the 10 samples dates with the lowest visibility ranged from 23.3 to 134.7 PtCo with a mean of 62.5, while those of 10 dates with highest visibility ranged from 3.4 to 25.3 PtCo with a mean of 13.7. **Low levels of both chlorophyll a and CDOM/tannins have a greater impact when visibility is greatest** (table 1.1).

Comparison of chlorophyll a and true color levels from 2015-2019/2020 with those reported in the WIN data base and other sources (Deyle, in preparation) indicate that chlorophyll a levels have not changed (table 1.2) but CDOM/tannin levels may have increased (table 1.3). Thus **changes in CDOM/tannin levels may be the principal cause of the increased frequency and duration of dark water conditions at the spring.**

Table 1.1. OLS and quantile regression results for visibility depth versus true color, corrected chlorophyll a, and pheophytin a, 12/24/15 – 01/16/20.

Light Absorbing Substance	Visibility Depth Model	Coefficient*	t Statistic**	Prob(t)***
CDOM (true color)	OLS	-0.1414	-4.80	< 0.0000
	0.25 quantile	-0.1120	-7.28	< 0.0000
	0.50 quantile	-0.0968	-4.42	<0.0000
	0.75 quantile	-0.1240	-3.07	0.0025
	0.90 quantile	-0.2190	-9.89	<0.0000
Corrected chlorophyll a	OLS	-2.4713	-1.28	0.2013
	0.25 quantile	-2.4000	-1.36	0.1740
	0.50 quantile	-3.1300	-3.50	0.0006
	0.75 quantile	-3.7000	-1.20	0.2320
	0.90 quantile	-10.3000	-1.77	0.0783
Pheophytin a	OLS	0.7809	0.71	0.4764
	0.25 quantile	-0.5890	-1.10	0.2720
	0.50 quantile	-0.4220	-0.46	0.6260
	0.75 quantile	4.2000	1.12	0.2630
	0.90 quantile	11.0000	1.77	0.0791

* The coefficient in OLS is the slope of the regression line for a given independent variable. If the coefficient in negative there is an inverse relationship between the independent variable and the dependent variable. In these models, the higher the level of the light-absorbing substance, the shallower the visibility depth.

** The t statistic tests the hypothesis that the actual value of the coefficient is zero. The higher the t statistic value, the lower the probability that the actual value is zero.

*** The prob(t) value is the probability that the actual value of the coefficient is zero. The lower the prob(t) value, the greater the probability that the coefficient is NOT equal to zero. Values highlighted in green are significant at the 95 percent level or higher, i.e. prob(t) is less than or equal to 0.0500. Values highlighted in yellow are significant at the 90 percent level or higher, i.e. prob(t) is less than or equal to 0.1000.

Table 1.2. Corrected chlorophyll a concentrations (ug/L) for the study compared to other Wakulla Spring and River data and other springs.

Source	Sample Station	Dates	Sample Size	Range	Average	Median
Current Study*	Wakulla boil	12/24/15 - 12/05/19	29	0.59 - 2.31	0.96	0.74
FDEP STORET	Wakulla boat dock (#44061)	06/10/14 - 04/26/17	7	0.55 - 1.50	0.90	0.77
FDEP STORET	Wakulla tram (#44059)	10/30/13 - 7/26/17	10	0.55 - 2.10	0.98	0.90
Howard T. Odum Florida Springs Institue (2014)	Wakulla boil	4/10/06 - 11/28/06	12	1.00 - 5.30	1.63	n/a
Gilbert (2012)	Wakulla boil	1996 – 2008	21	1.0 - 7.2	1.8	1.0

*Values below FDEP STORET MDL of 0.55 ug/L excluded to conform with other data sets.

Table 1.3. True color (PtCo units) for the study compared to other Wakulla Spring data and other springs.

Source	Sample Station	Dates	Sample Size	Range	Average	Median
Current Study*	Wakulla spring boil	12/24/15 - 1/16/20	180	0.0 - 136.4	26.7	19.1
FDEP STORET	Wakulla boil (#9695)	09/23/09 - 12/2/14	26	0.0 - 82.0	18.7	5.0
FDEP STORET	Wakulla boat dock (#44061)	10/31/13 - 8/18/15	23	23.0 - 56/0	16.5	9.3
Howard T. Odum Florida Springs Institute (2014)	Wakulla boil	5/19/66 - 12/5/06	108	0.0 - 40.0	4.2	n/a
Gilbert (2012)	Wakulla boil	1966 - 2006	50	5.0 - 30.0	8.7	5.0

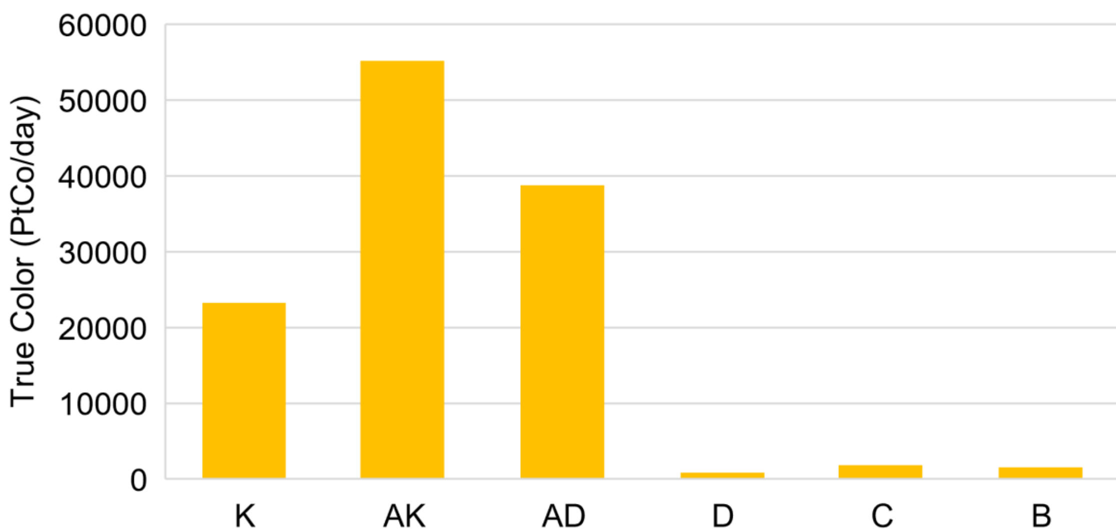
* Values below FDEP STORET MDL of 2.5 PtCo set to zero to conform to other data sets.

Section 1.6.5 fails to identify Lost Creek as an important source of CDOM/tannins when the Spring Creek Spring Creek flows reverse. The technical report acknowledges that discharges from sinking stream swallets and sinkholes "to the north and west of the spring" (p. 39) can contribute to reduced visibility at Wakulla Spring, but does not address the evidence that sources south of the spring, most notably Lost Creek, also contribute to dark water conditions at the spring.

As discussed above in the context of salinity/specific conductivity trends**, reversals in the flow at the Spring Creek Spring Group** have been documented and shown to likely be the cause of increasingly frequent periods of elevated salinity observed at Wakulla Spring. These dynamics also very likely play a role in the increased frequency and duration of dark water conditions at the spring. Dyer (2015) documented ground water flows from the Lost Creek swallet to Wakulla Spring in dye studies in 2008 and 2009. Analysis of true color loadings at the K and AK wells (Deyle in preparation; Deyle, 2020b) using weekly true color data for the period Aug 2016 – Aug 2017 posted by MLI to WIN and cave well flow data for the period Feb 2004 – Dec 2013 available from the Florida Geological Survey indicates that at times more CDOM/tannins may be entering the spring from the south via the Q tunnel than from the north via the R tunnel which receives inflows from the Leon Sinks sinking stream swallets, i.e. Black, Fisher, and Jump Creeks (see figures 1.8 and 1.9).

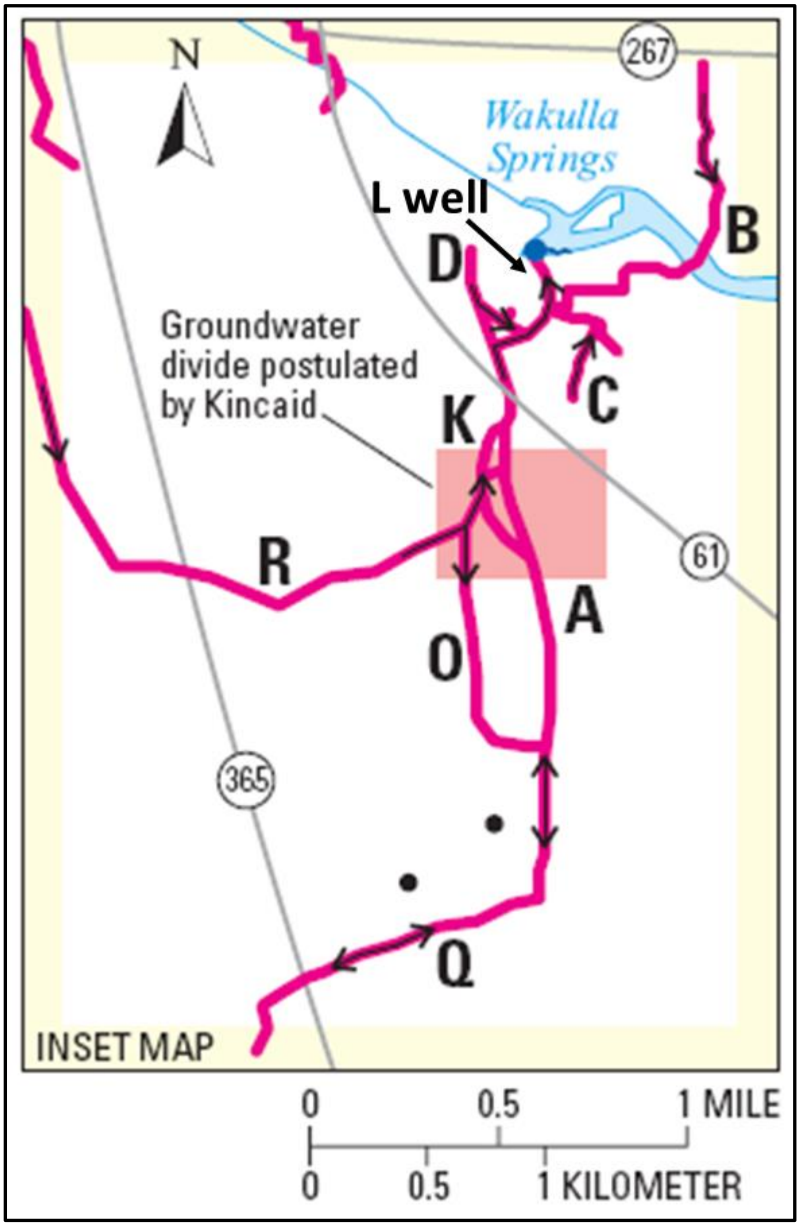
The observed but not fully explained **trend of decreasing stage elevation** described in Sections 2.6 and 2.7 of the technical report and discussed further below in section 4 contributes to periods of reduced head difference between Wakulla Spring and the Spring Creek Springs Group (section 2.7, p. 79). It also may result in an increased head difference between the spring and the Floridan aquifer to the north. During times when discharges from the Leon Sinks sinking streams via their swallets cease, this increased head differential may have led to increased discharge of tannins from the surrounding matrix thereby contributing to an influx of low levels of CDOM/tannins at times when in the past the spring was clear (Deyle, in preparation).

Fig. 1.8. Mean true color loadings at K, AK, AD, D, C, and B wells, 8/17/16-8/10/17



- The apparent pattern of **declining time-adjusted nitrate concentration residuals versus flow** shown in Figure 15 of the technical report (p. 38), which the technical report suggests may indicate the presence of a dilution effect with a high degree of variability, may be the result of increasing occurrences of Spring Creek Spring Group reversals due to reduced head gradients between Wakulla Spring and Spring Creek. This hypothesis could be further assessed by comparing nitrate loads at the AK well and the K well using weekly nitrate data for the period Aug 2016 – Aug 2017 posted by MLI to WIN and cave well flow data for the period Feb 2004 – Dec 2013 available from the Florida Geological Survey.

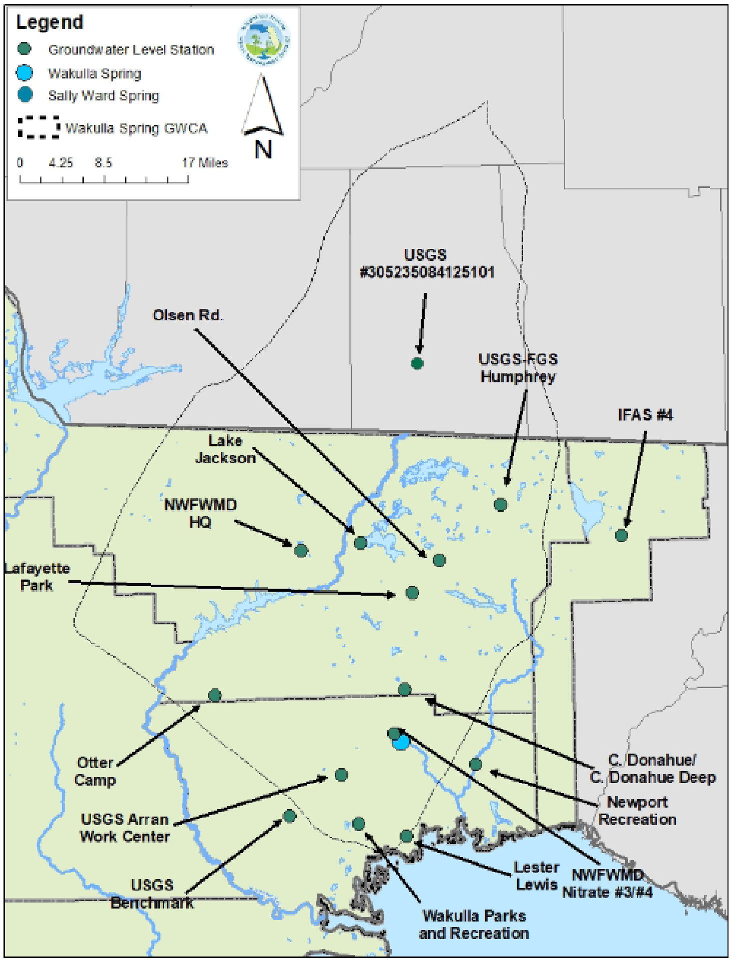
Fig. 1.9. Wakulla Spring cave system detail (Davis et al., 2010).



2. **The assumption of stable ground water levels within the springshed north of Wakulla Spring does not appear to be supported by the evidence.**

- **Long-term ground water elevation data are limited for the Wakulla springshed**. Section 4.2.2 of Appendix A analyses data for 16 wells, 10 of which are north and presumably upgradient of Wakulla Spring (figure 2.1). Periods of record as well as sampling intervals vary among these wells. The District installed 15 additional monitor wells during 2014-2015 but did not include data from those wells in the analysis because of the short period of record (Appendix A, p. 48).

Fig. 2.1. Appendix A Figure 46: Location of Ground Water Wells Investigated for Long-Term Trends



- **The report dismisses ground water level changes as a forcing function** based on a visual inspection of near-term trends at the two wells closest to the spring, Nitrate #3 and #4, and the small extent of ground water level decreases over the periods of record of the other individual wells (Appendix A, pp. 47, 48).

  Nitrate #3 and #4 had insufficient numbers of observations to support statistical trend analysis, so findings are based solely on visual inspection of the graphs in Appendix A figure 52. The next nearest up-gradient wells to the north are C. Donahue and C. Donahue Deep (POR = 1995 and 1989 to 2018, respectively)

  Seven of the 16 wells had ground water level trends that were statistically significant at the 95% level (see table 2.1). Appendix A reports that three of these experienced decreases of less than one foot over their periods of record, while three others experienced decreases in excess of two feet (see Appendix A figures 47-52).

  Both of the C. Donahue wells show declines beginning in 2003 (App A, Figure 47), and the deep well has a statistically significant negative trend (table 2.1). Two of the three wells due north of

C. Donahue also have significant negative trends: Lafayette Park (POR analyzed = 1960-2018) and Lake Jackson (POR analyzed = 1966-2019). The report suggests that declining ground water levels are not unexpected at those wells which are described as being near production wells. However, the analysis in Appendix A does not explicate the relationships between ground water levels at those wells, actual withdrawals from the nearby production wells, and recharge.

USGS #305235084125101 in south Georgia also exhibits a significant negative trend (POR = 1964-2020). It has the greatest negative slope of all the wells listed in Appendix A table 11 (see table 2.1 here). The only wells with positive significant trends are Otter Camp and Wakulla Parks and Recreation. Otter Camp is in the SW corner of Leon County. The Wakulla Parks and Recreation is well south of the spring.

- Given these findings and the limited data record available, **it seems premature to rule out declining ground water levels as a forcing function** that may be affecting head gradients in the Wakulla Spring – Spring Creek Spring Group springshed.

Table 2.1. Technical Report Appendix A Table 11: Seasonal Kendall Trend Test Results

Station Name	p-value	Slope
C. Donahue	0.297	-0.014
C. Donahue Deep	0.036*	-0.027
IFAS #4	0.369	-0.075
Lafayette park	0.027*	-0.057
Lake Jackson	0.016*	-0.090
Lester Lewis	0.222	n/a
Newport Recreation	0.003*	-0.010
Nitrate #3	n/a	n/a
Nitrate #4	n/a	n/a
NWFWMD HQ	0.514	0.044
Olson Rd.	0.095	-0.078
Otter Camp	0.035*	0.039
USGS #305235084125101	0.020*	-0.118
USGS Arran Work Center/Nitrate Pot	0.597	0.027
USGS Benchmark	0.096	-0.007
Wakulla Parks and Recreation	0.009*	0.078

3. **The technical report does not address the effects of withdrawals on ground water levels or the resulting effects on head gradients.**

- The technical report states (p. 81) that "Withdrawals within the Wakulla Spring groundwater contribution area have remained relatively stable since 1995, during which time the daily discharge at Wakulla Spring displayed an increasing trend . . . ."

  The report also maintains that the effects of withdrawals are minimal in terms of Wakulla Spring discharge (p. 81): "A water budget developed for the combined groundwater contribution area .

. . indicates that groundwater extractions comprised less than 1% of total inflows in 2009 and 2014. During 2011, which was a drought period, groundwater withdrawals comprised 2% of the total inflow."

However, **the report does not address the effects of withdrawals on ground water levels or the resulting effects on head gradients** between Wakulla Spring and the Upper Floridan Aquifer to the north or the Spring Creek Spring Group to the south.

- Starting from the premise that salinity spikes comprise the most severe potential cause of significant harm to the spring and river ecosystem, Barr argues that **the effects of ground water withdrawals should be modelled for worst-case drought conditions**. The Eastern District Model (EDM) ground water model is calibrated for three steady-state periods using 2011 to represent drought conditions (Coates et al., 2019).

4. Continuing decline in the Wakulla Spring pool elevation (stage) may be a critical forcing function and must be properly accounted for.

- Technical report figure 40 (p. 77) reveals a general pattern of declining stage at times when discharge was 500 cfs. A linear regression trend line for this period has a statistically significant (prob(F) < 0.0009) negative slope (figure 4.1 below). The report, however, offers **no compelling explanation for the observed long-term decline in spring/upper river stage** measured at the boat tram gauge over the period of record 12/5/87 – 5/19/20.

  The technical report (p. 77) suggests that the decline in stage was initiated by the large-scale herbicide treatment of hydrilla that occurred April 2002, citing Van Dyke (2019) who describes a damming effect and resulting raised pool stage from the hydrilla proliferation between 1997 and 2000, followed by a surge and decreased stage resulting from the massive die-off after the April 15-17, 2002 herbicide treatment. However, the stage data for those time periods show **no evidence of a damming effect as the hydrilla spread** between 1997 and 2000 from the boat dock to the tour boat turnaround about one mile downstream (figure 4.2): Stage exhibits no statistically significant trend. There also is **no evidence of an abrupt drop in stage following the herbicide treatment in April 2002** (figure 4.3). Van Dyke reports (2091, p. 4) that "[f]rom April 1-29 to May 5-23, the average water levels measured at the park declined 1.4 feet." Figure 4.3 reveals that the stage decrease over that time was the continuation of a decrease after a major peak of 7.58 feet on 3/8/02 resulting from a 5.98-inch rainfall event on 3/3/02. The technical report also describes a **sharp decline in stage following Hurricane Michael** in October 2018, but I cannot find any evidence of such a decline in the data (see figure 4.5).

  Partitioning the data before (1987-1996), during (1996-2002), and after the hydrilla invasion (2002-2020) reveals the following:

  - 1987-1996 – significant increasing trend (figure 4.4)
  - 1996-2002 – no significant trend (figure 4.2 above)
  - 2002-2020 – significant decreasing trend (figure 4.5)

  Further partitioning the data between 2002 and 2020 by 2006, the year Spring Creek Spring Group reversals apparently began (Kincaid, 2011), reveals significant decreasing trends for each time period.

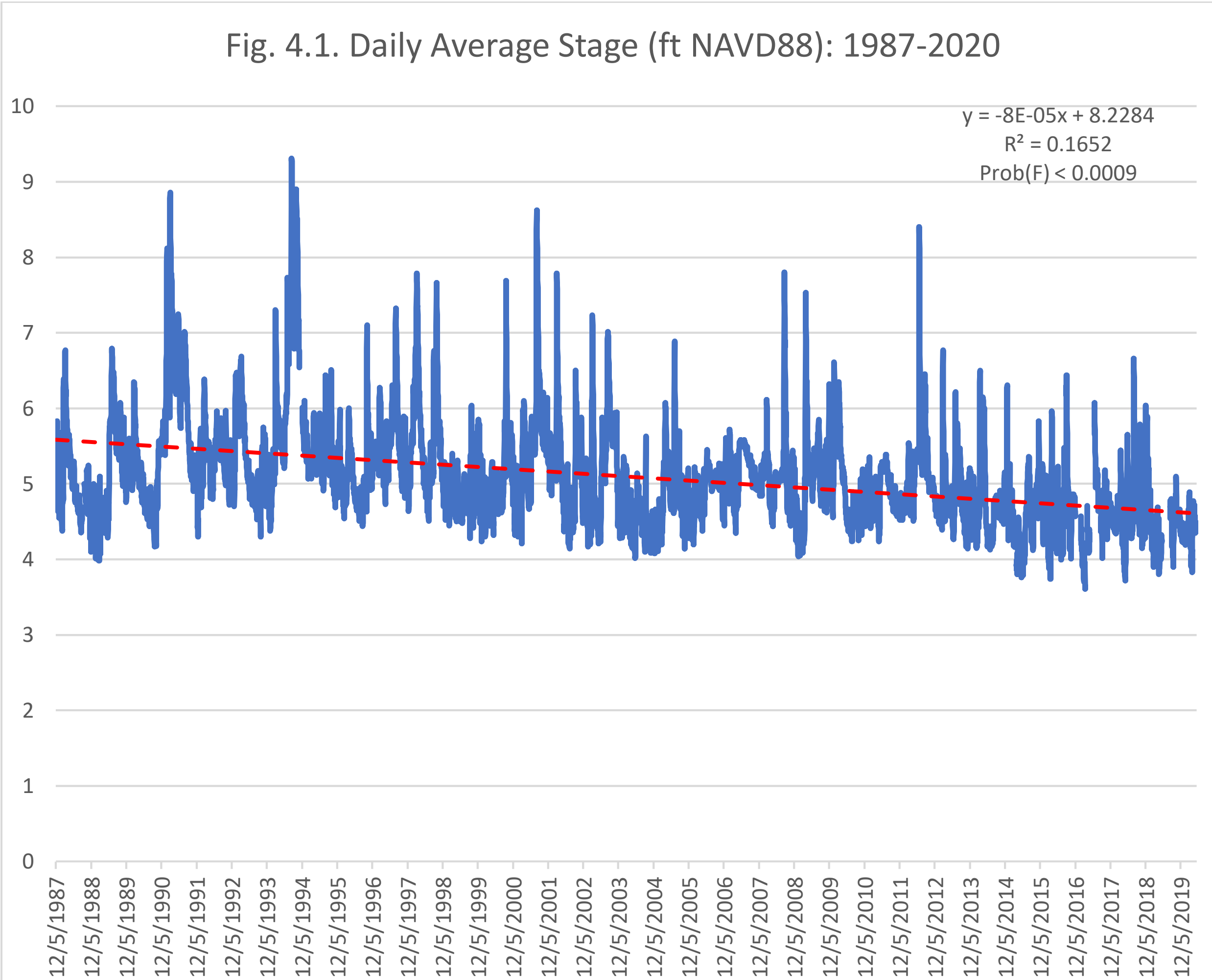


Fig. 4.1. Daily Average Stage (ft NAVD88): 1987-2020

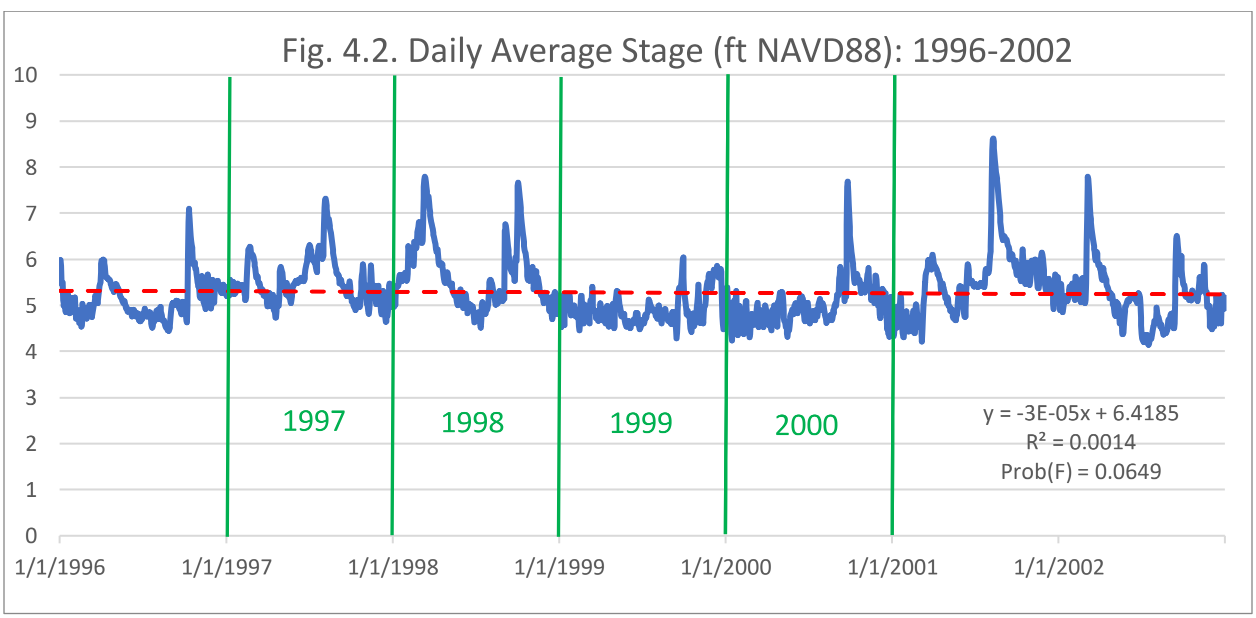


Fig. 4.2. Daily Average Stage (ft NAVD88): 1996-2002

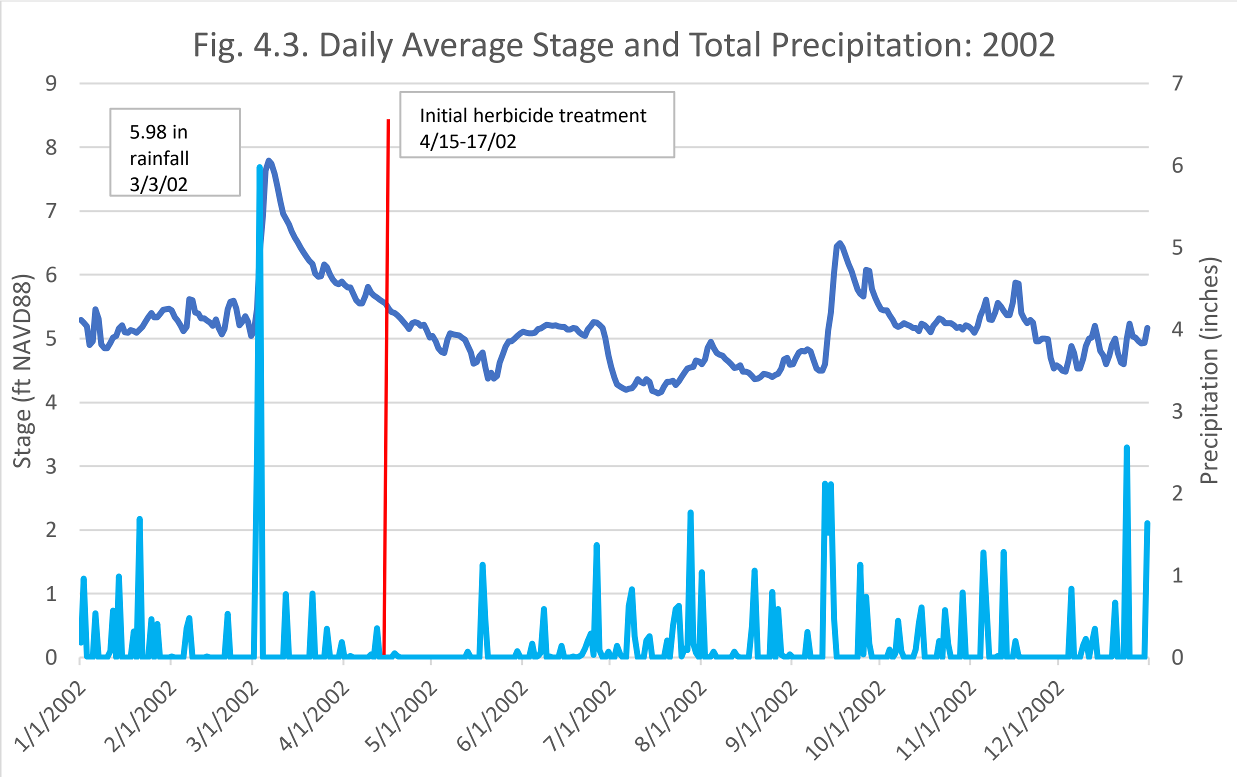


Fig. 4.3. Daily Average Stage and Total Precipitation: 2002
5.98 in rainfall 3/3/02
Initial herbicide treatment 4/15-17/02
Stage (ft NAVD88)
Precipitation (inches)
9
8
7
6
5
4
3
2
1
0
7
6
5
4
3
2
1
0
1/1/2002
2/1/2002
3/1/2002
4/1/2002
5/1/2002
6/1/2002
7/1/2002
8/1/2002
9/1/2002
10/1/2002
11/1/2002
12/1/2002

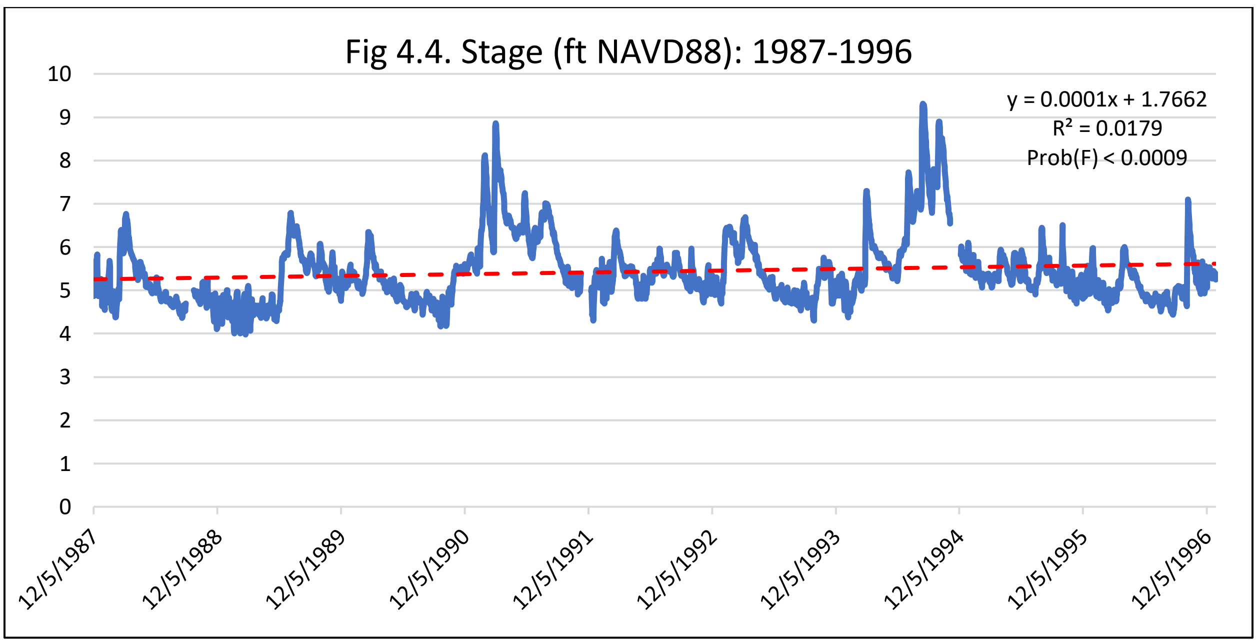
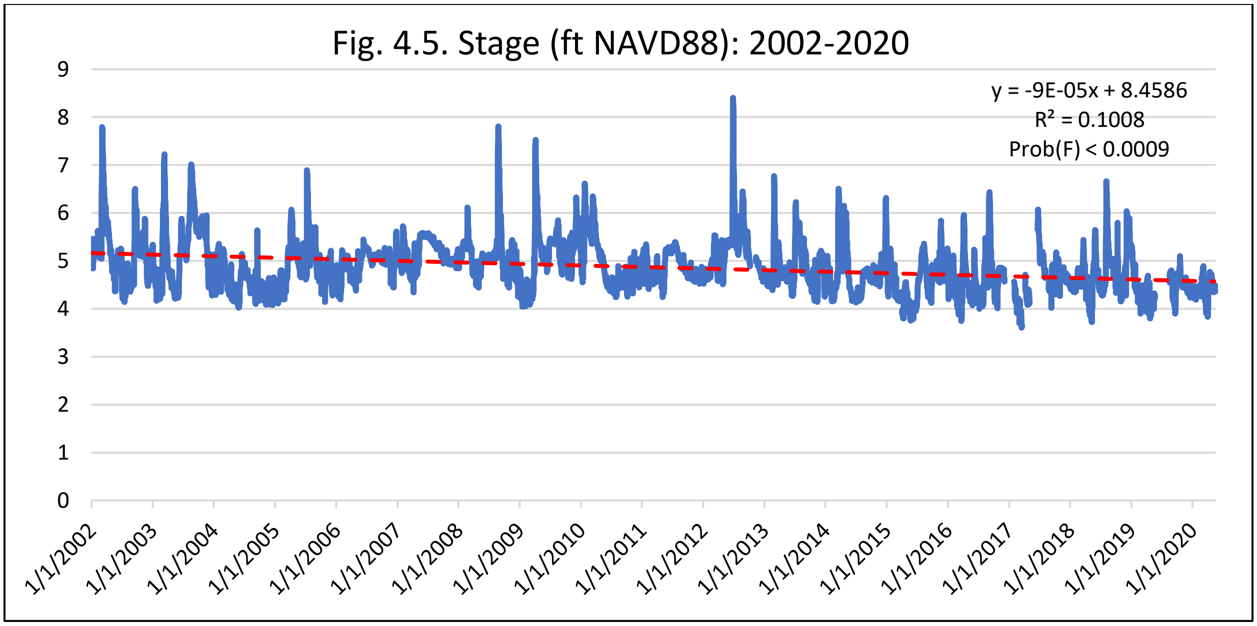
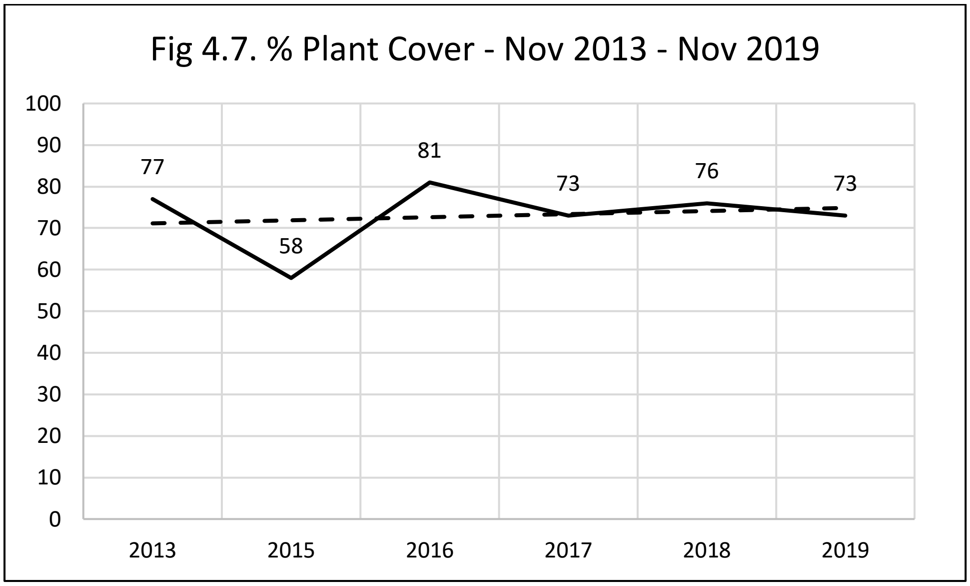


Fig 4.4. Stage (ft NAVD88): 1987-1996
y = 0.0001x + 1.7662
R² = 0.0179
Prob(F) < 0.0009
10
9
8
7
6
5
4
3
2
1
0
12/5/1987
12/5/1988
12/5/1989
12/5/1990
12/5/1991
12/5/1992
12/5/1993
12/5/1994
12/5/1995
12/5/1996



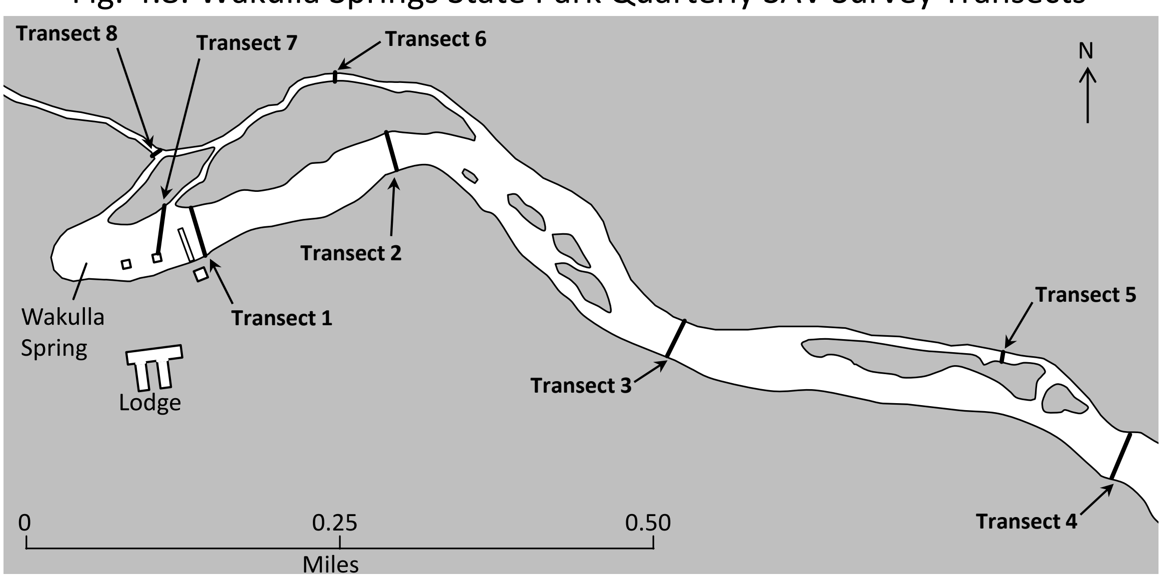
- **This phenomenon requires further examination**. One possible explanation is that the massive removal of hydrilla along with several inches of organic sediments resulted in prolonged exposure of bare sediments to **erosion**. We know from low altitude photos of the river just below the spring in the late 1960s, as well as first-hand accounts, that the river channel was densely vegetated with submerged aquatic vegetation (SAV) prior to the hydrilla invasion (figure 4.6) and that since its removal, large areas of bare sediment have persisted. Quarterly SAV surveys since 2013 (Thompson, 2020) show the average percent of plant cover over all transects in November ranging from 58 to 81 with no sign of improvement (figure 4.7).

Fig. 4.6. Low-Altitude Aerial Photo of Wakulla Spring and Upper River circa 1967



Examination of water depth measurements [relative to long-term mean stage of 5.10 ft NAVD88] taken during the quarterly SAV surveys between 2013 and 2020 at the deepest positions along transects #2 and 3 (figure 4.8) show evidence of continuing erosion at transect #2 just before the first turn (figure 4.9), where current is the fastest (based on my boat driving experience) and bare limestone is now visible that was not exposed when I began driving tour boats in 2013. The trend at transect #3, which is about 10 feet downriver of the boat tram gauge, reveals some evidence of erosion at plot 5 (150 feet from the south bank) but a slight increase in water depth at plot #1 (30 ft from south bank) (figure 4.10). I should note that the transect positions are determined using a range finder, so position is not exactly the same from one survey to the next.

Fig. 4.8. Wakulla Springs State Park Quarterly SAV Survey Transects



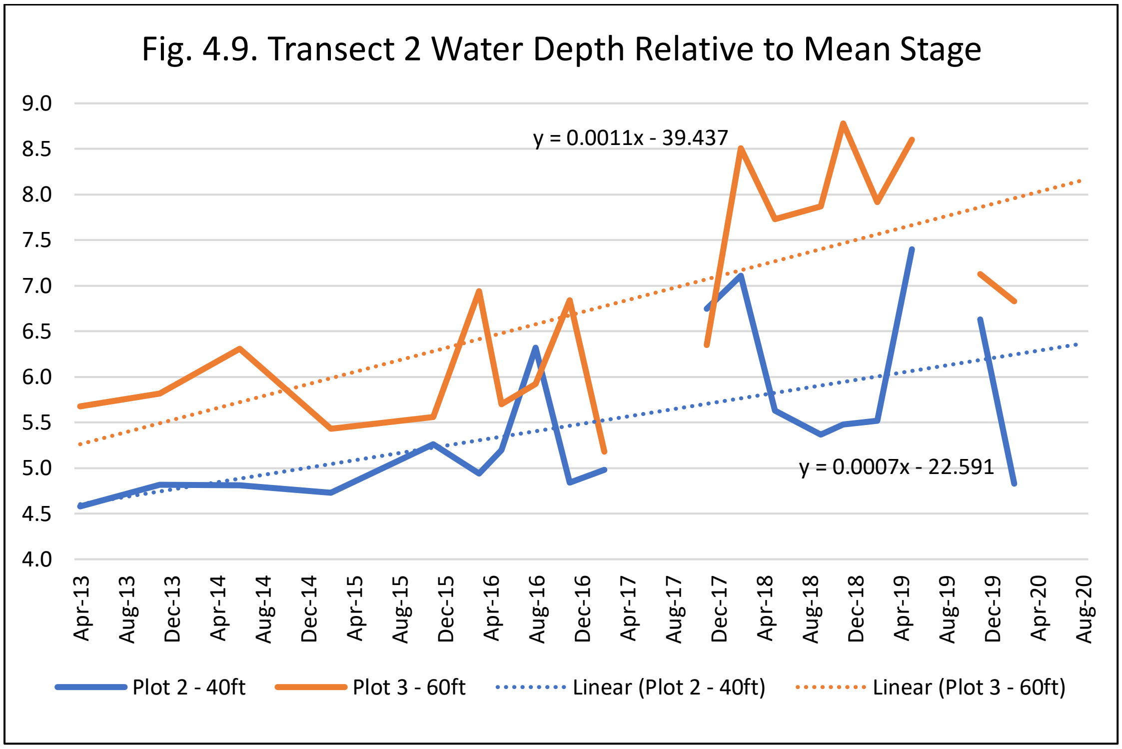


Fig. 4.9. Transect 2 Water Depth Relative to Mean Stage
y = 0.0011x - 39.437
y = 0.0007x - 22.591
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
Apr-13
Aug-13
Dec-13
Apr-14
Aug-14
Dec-14
Apr-15
Aug-15
Dec-15
Apr-16
Aug-16
Dec-16
Apr-17
Aug-17
Dec-17
Apr-18
Aug-18
Dec-18
Apr-19
Aug-19
Dec-19
Apr-20
Aug-20
Plot 2 - 40ft
Plot 3 - 60ft
Linear (Plot 2 - 40ft)
Linear (Plot 3 - 60ft)

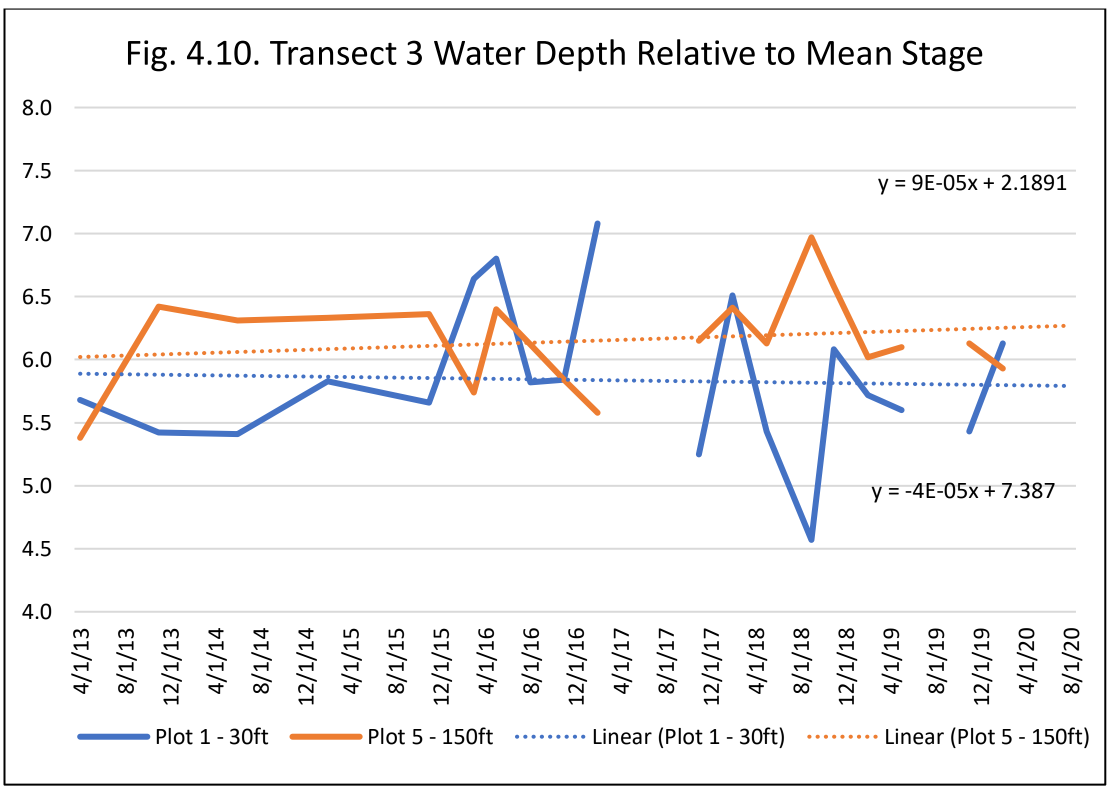


Fig. 4.10. Transect 3 Water Depth Relative to Mean Stage
y = 9E-05x + 2.1891
y = -4E-05x + 7.387
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
4/1/13
8/1/13
12/1/13
4/1/14
8/1/14
12/1/14
4/1/15
8/1/15
12/1/15
4/1/16
8/1/16
12/1/16
4/1/17
8/1/17
12/1/17
4/1/18
8/1/18
12/1/18
4/1/19
8/1/19
12/1/19
4/1/20
8/1/20
Plot 1 - 30ft
Plot 5 - 150ft
Linear (Plot 1 - 30ft)
Linear (Plot 5 - 150ft)

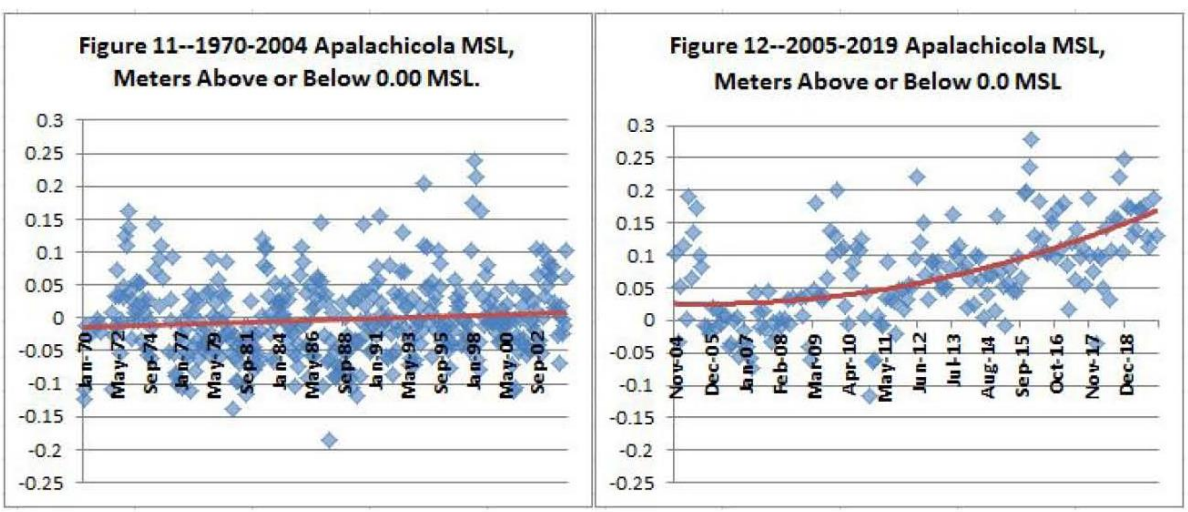
- One other hypothesis not addressed in the technical report is that **a long-term trend in declining ground water elevation in the springshed north of Wakulla Spring** is contributing to and/or primarily responsible for the observed decline in stage. See section 2 above for a further discussion.

5. **Accelerating sea level rise is an inescapable forcing function and must be properly accounted for.**

- The technical report (p. 79) acknowledges that "[l]ong-term sea level rise . . . affects the equivalent freshwater head at the coast, and thus influences inland head gradients and flow directions" and therefore "may be reducing freshwater discharge from the Spring Creek Spring Group." The report does not, however, explicitly recognize that **sea level rise is**, therefore, **an important forcing function for salinity spikes** occurring at Wakulla Spring, **as well as northward flows of tannic waters from the Lost Creek swallet** and other swallets and sinkholes south of the spring when Spring Creek Spring Group flows are reversed for sufficiently long periods of time.

- As Douglas Barr emphasizes in his comments on the draft technical report, it is essential to **base projections of the effects of future sea level rise on the more recent rate of sea level rise rather than the long-term average** described in section 5.4 (p. 130). The technical report employs an average of 2.38 mm/yr while Barr calculates an average for the period 2005 to 2019 of 0.42 inch/yr or 10.67 mm/yr. Barr demonstrates that the rate is accelerating, partitioning the data for the Apalachicola tide gauge into two periods: 1970-2004 and 2005-2019. He fits a straight line to the 1970-2004 data and a second-order polynomial to the latter period (figure 4.1). This is consistent with the findings of climate change researchers. See for example, IPCC (2019) which states "with high confidence" that global sea level rise is accelerating (p. 4-3).

Fig. 5.1. Partitioned Sea Level Rise Charts, Apalachicola Tide Gauge, 1970-2019



Source: Barr (2020).

6. **The evidence for a trend of decreasing precipitation is unconvincing.**

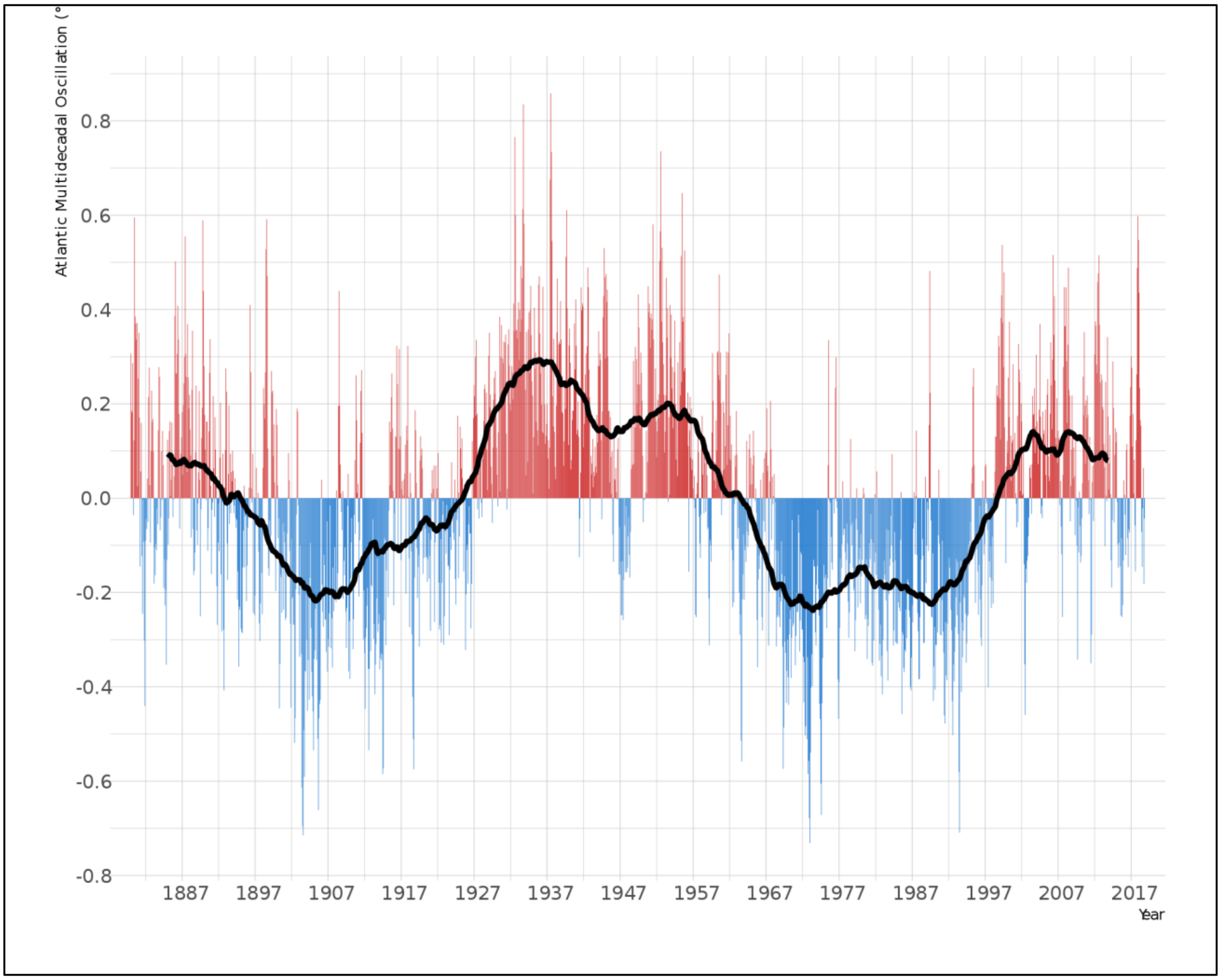
- The technical report identifies precipitation as one of the principal forcing functions for spring discharge (p. 75) and periods of **low precipitation as a forcing function for reversals of the**

Spring Creek Spring Group flows and associated increases in salinity/specific conductivity at Wakulla Spring (pp. 32; 64).

- The report hypothesizes (p. 79) that "**below average rainfall since approximately 1996 . . . may be reducing freshwater discharge from the Spring Creek Spring Group**." However, the evidence of such a decreasing trend is unconvincing.

  Referring to figure 43 in section 4.2.2 of Appendix A, the technical report states (p. 43) that "[t]he ten-year moving average annual precipitation indicates precipitation has been below the long-term average since 1999 . . . . This indicates that the area has been in a precipitation deficit for an extended period, possibly associated with the AMO cycle." As shown in figure 6.1 the current AMO warm period began in 1995, while the preceding cool period began in 1965 (Wikipedia, 2020).

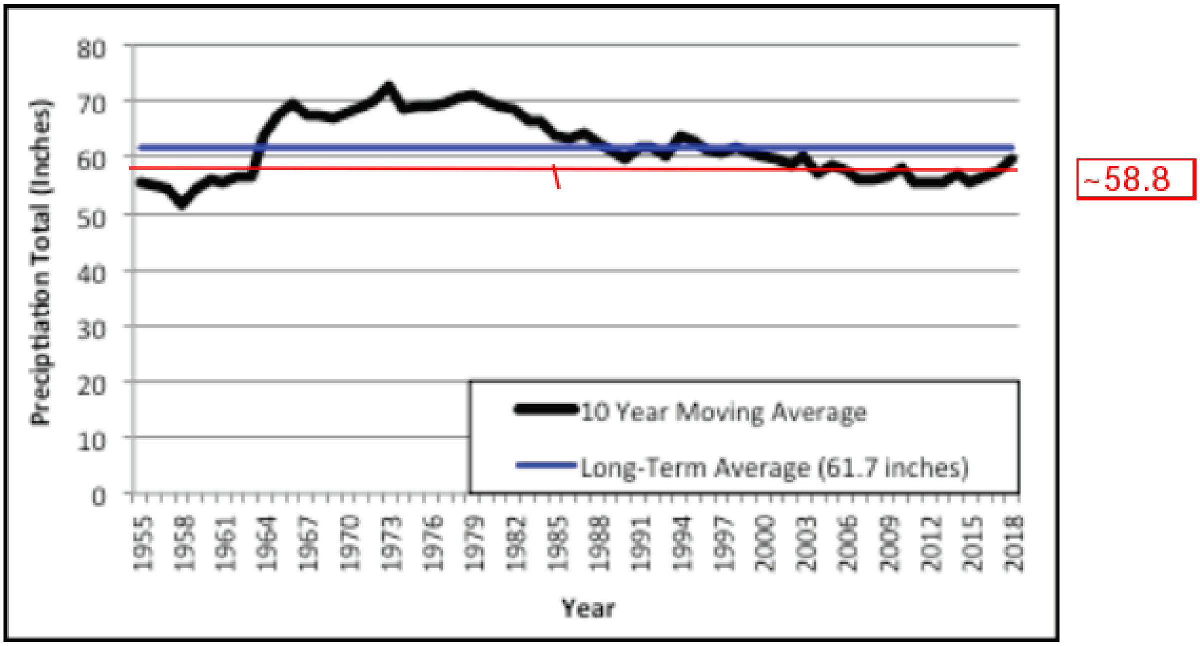
Fig. 6.1. Atlantic Multidecadal Oscillation, 1887 – 2017.



Source: Wikipedia (2020).

The technical report finding is based on the long-term average from 1946-2019 of 61.7 in/yr. The National Weather Service reports Tallahassee rainfall for a longer period of record, 1889-2019, with an average of 58.8 in/yr. If that average is applied in figure 43, the ten-year moving average has not definitively gone below the long-term average yet (figure 6.2).

Fig. 6.2. Technical Report Appendix A Figure 43: Average Annual Precipitation Totals for the Prior Decade



Appendix A figure 43 (figure 6.2 here) also is not completely consistent with the AMO cycle. The ten-year moving average begins to exceed both long-term averages circa 1963 well ahead of the onset of the AMO cool cycle in 1965.

- In the absence of robust evidence of a trend of declining precipitation, **other forcing functions deserve a closer look including ground water withdrawals.**

7. **Shifts in head gradients appear to be the major forcing function behind salinity and dark water threats.**

- The technical report (p. 79) acknowledges that **continuing sea level rise plus the unexplained trend of decreasing spring pool/river stage are the principal drivers of the declining head difference** between Wakulla Spring and the Spring Creek Spring Group.

  The report also acknowledges that the unexplained **decreasing stage trend "may be increasing the local head gradient between Wakulla Spring and the Florida aquifer**." However, it is possible that a regional decrease in ground water levels is at least in part responsible for the declining pool/river stage, in which case the head difference between the spring and the aquifer may not be increasing or may be increasing less than might otherwise occur if other forces also are at work, e.g. continuing erosion of the upper river stream channel (see section 4 above).

- The technical report advances Davis and Verdi's (2014) explanation of **rainfall as the principal driver of Spring Creek Spring Group flow reversal events** (p. 32) which in turn can cause inflows of higher salinity ground water to Wakulla Spring from the south, and, as I've argued in section 1 above, also can cause inflows of tannic water from the Lost Creek swallet and other swallets and sinkholes south of the spring.

- In the absence of compelling evidence of a trend of decreasing rainfall as the explanation for the decreasing pool/river stage, and with no robust evidence that ground water levels north of Wakulla Spring are stable, I believe **it is critical that further analysis be conducted of the effects of ground water withdrawals** on the declining Wakulla Spring/River stage and the effect of that trend on head differences between the spring and the Floridan aquifer to north as well as the Spring Creek Spring Group to the south.

8. No increase in permitted withdrawals should be allowed until (a) the MFL study is extended to address establishing a minimum level (head) through ground water modelling that accounts for accelerating sea level rise, worst-case drought scenarios, and the effects of alternative withdrawal scenarios on shifting head gradients and (b) the need for a prevention or recovery strategy is reassessed.

- While the report states (p. 16) that "This assessment focuses on determining the threshold at which additional withdrawals would cause significant harm to ecology and water resources of the area," **limiting the analysis to minimum flows without also considering minimum ground water level/head neglects the possible effects of additional withdrawals on critical water quality parameters**, i.e. salinity, dark water conditions, and possibly nitrates, **which pose the greatest threats of significant harm** to the Wakulla Spring and River ecosystem and recreational use of the spring.

- **The applicable statute (section 373.042(2)(a) FS) explicitly requires adopting both minimum flows and levels**:". . . the Northwest Florida Water Management District, which shall use such authority to adopt minimum flows <u>and</u> [emphasis added] minimum water levels for Outstanding Florida Springs no later than July 1, 2026."[1]

- **Three other water management districts have adopted minimum spring or aquifer levels.** Two have adopted both minimum flows and levels for one or more springs: Suwanee River WMD for Fanning Spring (40B-8.041 FAC) and St. Johns River WMD for Wekiwa Springs and seven smaller springs (40C-8 FAC). The Southwest Florida WMD has adopted minimum aquifer levels to minimize saltwater intrusion (40D-8.626 FAC).

[1] Sec 373.042(1) FS defines the two metrics as follows: "(a) Minimum flow for all surface watercourses in the area. The minimum flow for a given watercourse is the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area. (b) Minimum water level. The minimum water level is the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources or ecology of the area.

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