

- I would like to share with you today 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
- I’ve split this into two presentations:
  - Today I will provide an overview of findings and address in detail the first research question: What are the light-absorbing substances responsible for the dark water conditions?
  - In December I will explore in detail the other two research questions:
    - What are the sources of those light-absorbing substances?
    - Why have the frequency and duration of dark water conditions increased?
- I will be drawing on research conducted by the US Geological Survey and other hydrogeologists and a recently completed WSA 4.5-year project funded with three Protect Florida Springs tag grants from the Fish and Wildlife Foundation of Florida [\[click\]](#).
- Also essential to the project’s success was the support provided by the Wakulla Spring State Park administration, in particular, former park manager Pete Scalco and current manager, Amy Conyers, who arranged for weekly boat access to the spring boil for sampling. [\[click\]](#)
- Principal contributors to the project include
  - McGlynn Laboratories Inc. which collected and analyzed the weekly water quality and light data that are the backbone of the study, as well as dye studies and water quality analyses of karst lakes and sinking streams that are sources of the light-absorbing substances responsible for the dark water conditions in the spring
  - Dr. Akshinthala Prasad of the FSU Department of Biology who conducted algal taxonomic analysis for the project
  - Drs. Richard Long and Thomas Sawicki and graduate student Kaylee Castle of the FAMU Dept of Biology who completed environment DNA analyses
  - Dr. Ethan Deyle of the Boston University Dept of Biology who conducted advanced statistical analyses of some of the data
  - And a host of volunteers who assisted with field work at the spring and the karst lakes, most notably Cal Jamison, Sophie Wacongne-Speer, Emily Speer, Andreas Hagberg, and Bob Thompson



- When I moved to Tallahassee in 1991 you could see all the way to the bottom of the spring from a boat or the top of the dive tower through aqua blue water “as clear as gin” and “sapphire blue,” as one British travel writer once described it
- **[CLICK]** Historically, the water turned tea-colored after major rain events.
- Typically the spring would clear after a few weeks, unless we had prolonged periods of rain.
- But now the spring stays dark most of the time
- The periods of time when the water is brown have increased in duration and frequency
- **[click to next slide]** In addition, during times when the water has historically cleared, i.e. when you could see all the way to the bottom, the water is now green, with varying degrees of intensity

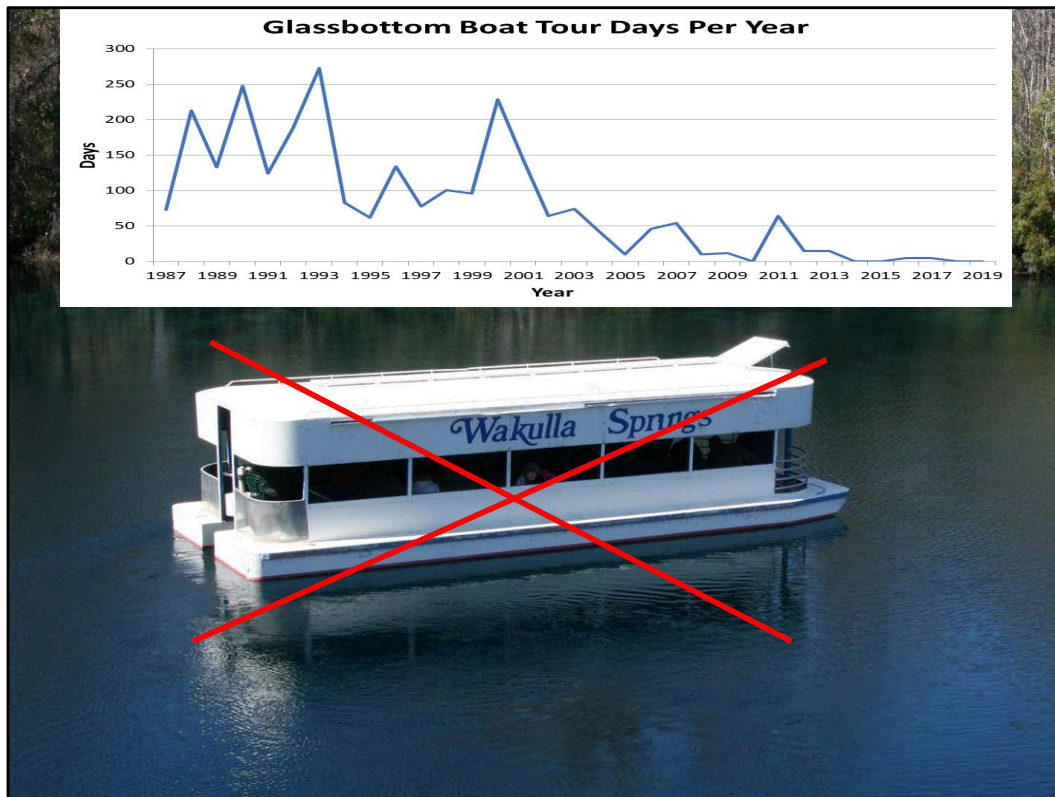


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- The change is dramatically shown by comparing this low-altitude air photo from 1967 with the current Google Earth image that I downloaded a few weeks ago. [\[click\]](#)





- Glass-bottom boat tours have been the most obvious casualty of the more frequent dark water conditions
  - The park has typically suspended glass-bottom boat tours when the visibility is less than 75 feet because there's not much to see if the visibility depth is any less
- **[CLICK]** As shown on this chart, in the late 1980s and early 1990s we typically ran GBB tours 150 or more days a year
  - But that number fell off dramatically in 1994 (83)
  - It recovered briefly in 2000 and 2001; then fell off sharply again and has trended downward since
  - In 2012 and 2013 the park conducted tours for only 15 days
  - None in 2014-2015
  - 5 each in 2016 and 2017
  - **[CLICK]** None since 2017

## Research Questions

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

- Here again are the three research questions. I'm going to start with a summary of what I think we have learned about each and then move into a detailed exploration of the first question.

## Causes: What Have We Learned?

- Three light-absorbing substances are present in the spring:
  - Colored Dissolved Organic Matter (CDOM): measured as “true color” (tannins)
  - Chlorophyll a: measured as corrected chlorophyll a and pheophytin a
  - Suspended particulates: measured as turbidity

- **[click]** Three color-absorbing substances are present in the spring:
  - **[click]** Colored dissolved organic matter referred to as CDOM of which tannins are the predominant form in freshwater springs in Florida
  - **[click]** Chlorophyll a, the predominant form of chlorophyll in algae and vascular plants
    - Pheophytin a is a degraded form of chlorophyll a that can occur when algal cells are damaged or die
    - Corrected chlorophyll a is total chlorophyll a minus pheophytin a
  - **[click]** Suspended particulates tend to be very low in most freshwater springs;
    - the common metric, turbidity, however, captures more than suspended inorganic particles
    - turbidity is an aggregate measure that reflects the presence of algae cells as well as colored dissolved organic matter
    - Therefore it is not very helpful in differentiating the individual causes of dark water conditions

## Causes: What Have We Learned?

- Two have significant negative impacts on visibility depth:
  - CDOM measured as “true color” (tannins)
  - Corrected chlorophyll a

Statistical analysis reveals that

- **[click]** Two color-absorbing substances have significant negative impacts on visibility depth:
  - **[click]** CDOM measured as true color
  - **[click]** Corrected chlorophyll a
- Turbidity has no significant effect
- Pheophytin has a statistically significant positive impact at the 90<sup>th</sup> percentile of visibility depth, i.e. when visibility depth is greater than 90% of the other observations. I am unable to fashion a logical explanation for this finding.

## Causes: What Have We Learned?

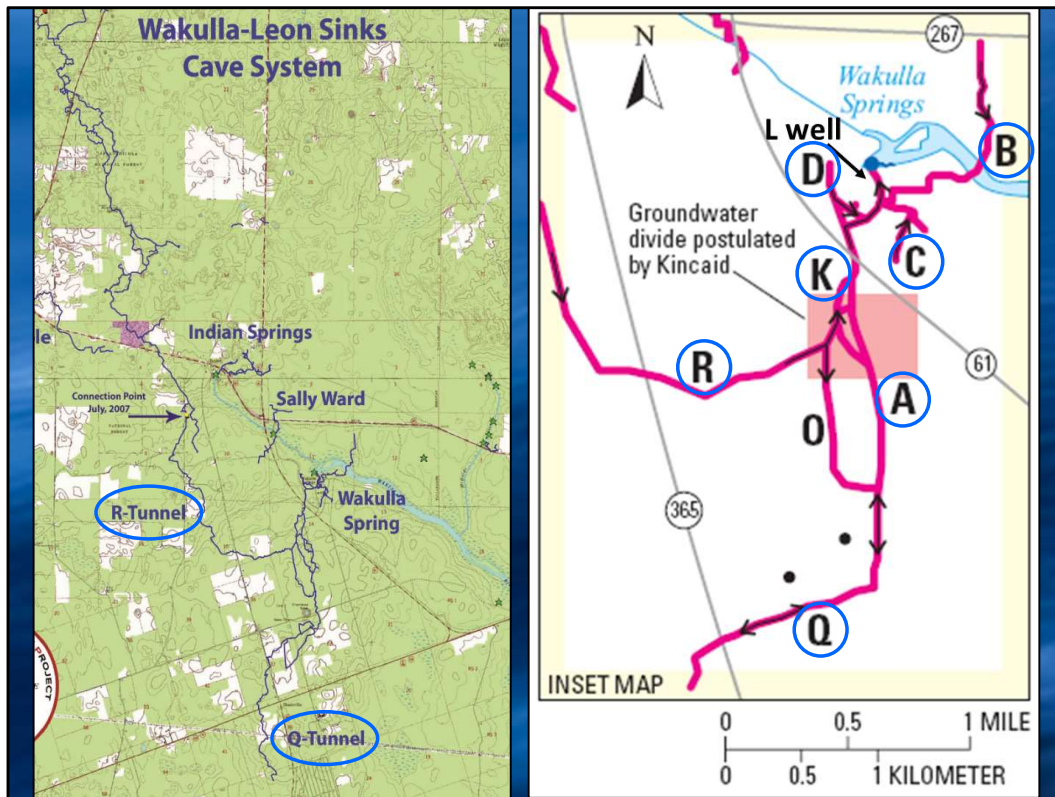
- CDOM and corrected chlorophyll a contribute to dark water conditions when
  - visibility depth is greatest
  - apparent color is green rather than brown
- Small increases of each have a greater impact when visibility is greater

- **[click]** CDOM and corrected chlorophyll a contribute to dark water conditions when
  - visibility depth is greatest and
  - the apparent color is green rather than brown
- **[click]** Small increases of each have a greater impact when visibility is greater

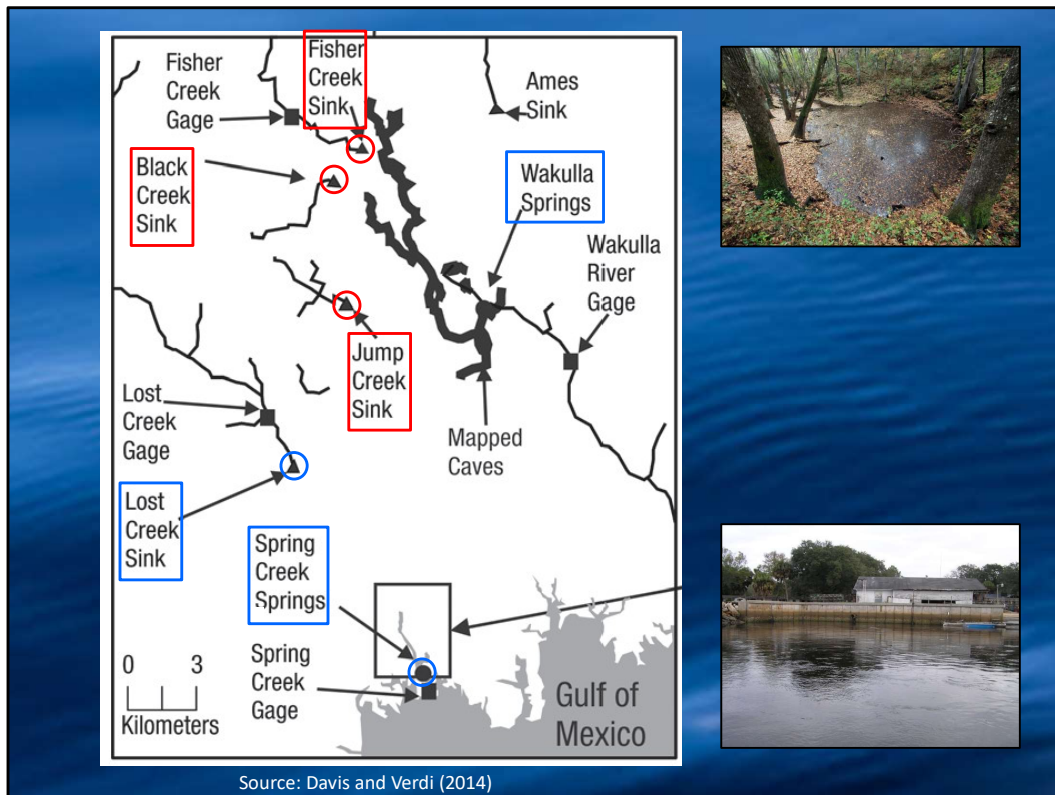
## Sources: What Have We Learned?

- CDOM (tannins) and chlorophyll are delivered to the spring through all major caves

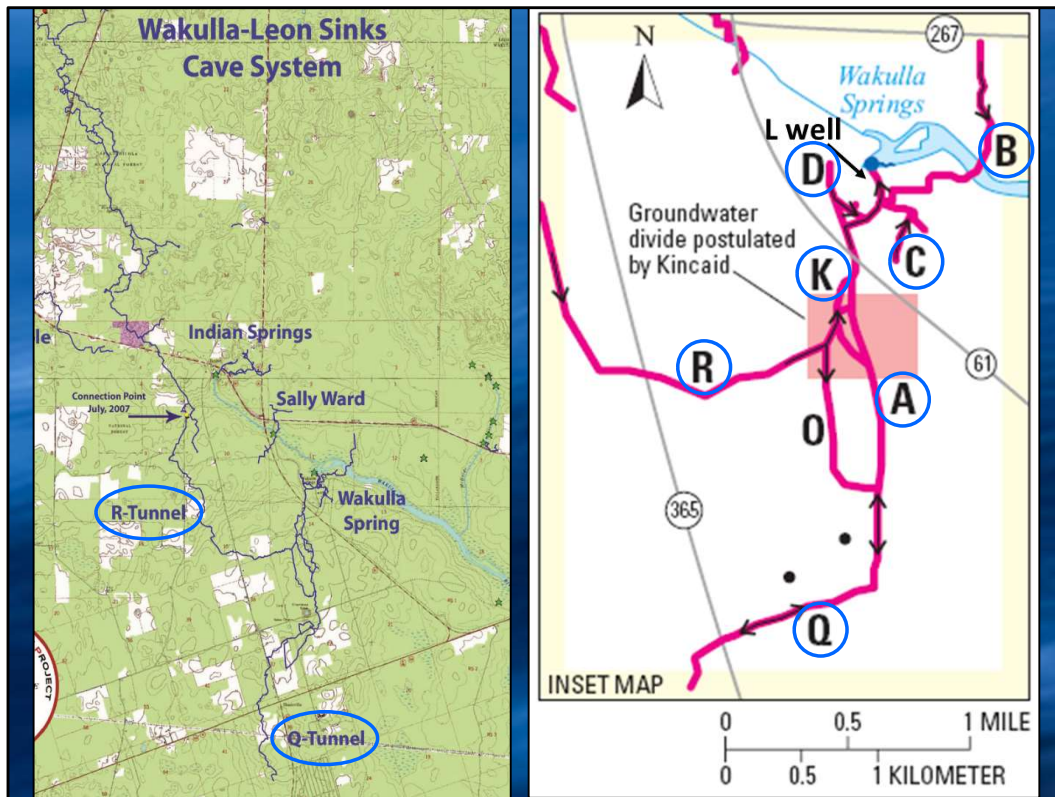
- CDOM (tannins) and chlorophyll are delivered to the spring in ground water flowing through all the major caves that converge upstream of the spring vent



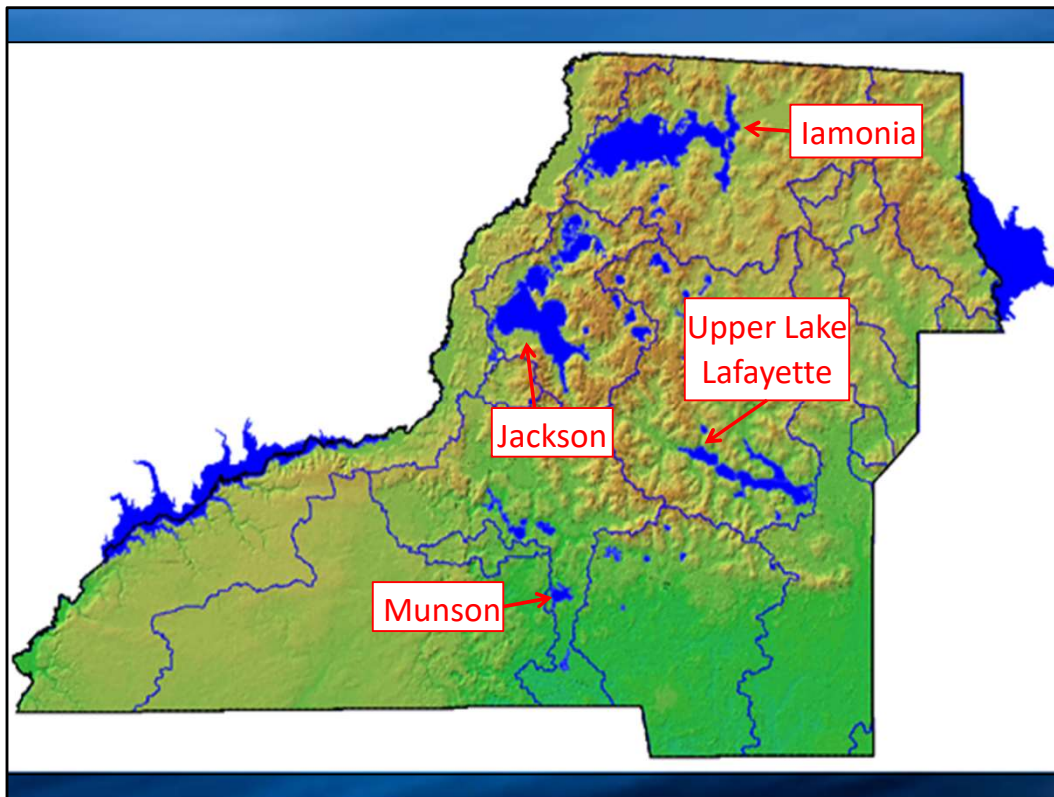
- The largest loads of both CDOM and chlorophyll a are carried via the K [\[click\]](#) and A [\[click\]](#) caves which convey about 80 percent of the total inflow to the spring
- The K cave receives flow from the R tunnel which connects to the Leon Sinks cave system to the north [\[click\]](#)
- The A cave receives flow from the Q tunnel which flows north to the spring [\[click\]](#)



- The principal source of tannic water inputs to the R tunnel are three sinking streams in the Leon Sinks area of Apalachicola National Forest that flow into sinkholes, referred to as swallettes **[click]**, north of the spring **[3 clicks]**:
  - Fisher Creek
  - Black Creek
  - Jump Creek
- When rainfall is scarce these may stop flowing altogether; that is when the spring has historically cleared
- The principal source of tannic inputs to the Q tunnel is flow from a fourth sinking stream, Lost Creek, which also flows out of the National Forest, but its swallette lies southwest of the spring **[click]**
  - Lost Creek's discharge formerly flowed predominantly to caves connected to the Spring Creek springs at the coast **[click]**
  - Since 2006, flow at Spring Creek has occasionally stopped or reversed
  - When this happens the Lost Creek discharge into the aquifer can flow north into the Q tunnel and contribute tannic inflows to the spring



- Additional CDOM inputs to the R and Q tunnels, as well as the B, C, and D caves near the spring, originate from the many smaller sinks that pock-mark the area, flowing through smaller conduits or as matrix flow through the karst limestone



- The sinking streams are not significant sources of chlorophyll
- It most likely originates from one or more karst lakes in the springshed which discharge to the aquifer via bottom seepage into the karst limestone matrix and through sinkholes in the lake bottoms:
  - **[click]** Iamonia
  - **[click]** Jackson
  - **[click]** Upper lake Lafayette
  - **[click]** Munson
- Chlorophyll likely travels to the Wakulla cave system from these sources via both conduit and matrix flow
- However, prior to this study no one had demonstrated hydrogeologic connections between Wakulla Spring and Iamonia, Jackson, or Upper Lake Lafayette

## Sources: What Have We Learned?

- Previous dye studies
  - Leon Sinks swallets: 9-10 days
  - Lost Creek swallet: 45-47 days
  - Lake Munson via Ames Sink: 22-23 days
- Dye studies conducted by MLI
  - Lake Jackson: 35 days
  - Upper Lake Lafayette: 30-35 days
  - Lake Iamonia: 11 days

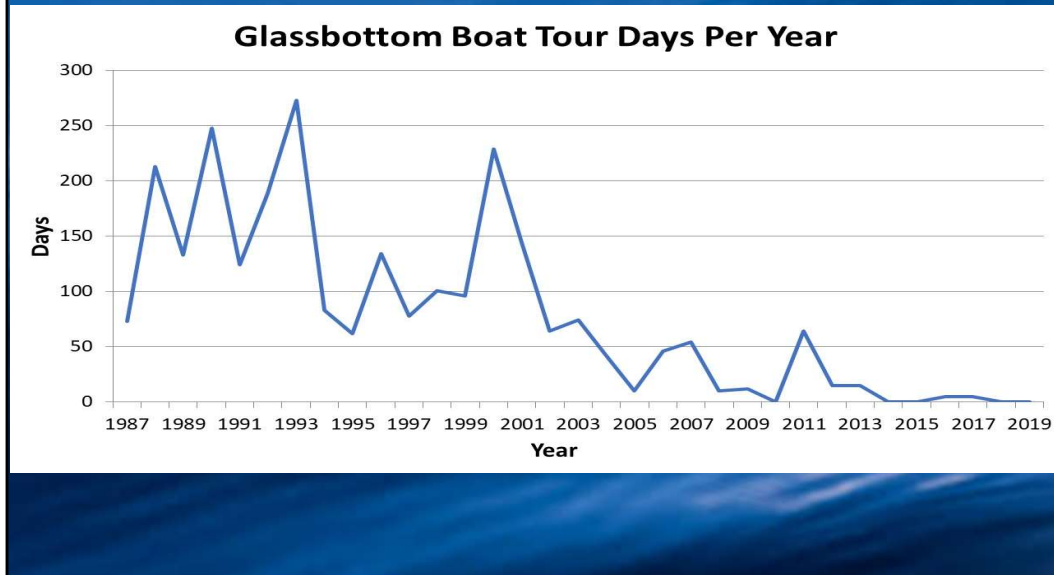
- Previous dye studies have documented connections to Wakulla Spring from
  - **[click]** the Leon Sinks swallets with a travel time of 9-10 days
  - **[click]** Lost Creek swallet in 45-47 days
  - **[click]** Lake Munson in 22-23 days
- **[click]** Dye studies conducted by MLI for the first time have shown connections between Wakulla Spring and the other large karst lakes in the springshed:
  - **[click]** Lake Jackson in 35 days
  - **[click]** Upper lake Lafayette in 30-35 days
  - **[click]** Lake Iamonia in 11 days

## Sources: What Have We Learned?

- Unique algal taxa at the L well and
  - Lake Jackson: 2
  - Upper Lake Lafayette: 1
- eDNA surveys identified unique algal OTUs at the L well and
  - Lake Jackson: 4
  - Upper Lake Lafayette: 4
  - Lake Munson: 5

- **[click]** Algae taxonomic analyses conducted by Dr. Prasad at FSU in 2017 of samples collected by MLI from Lakes Jackson, Munson, and Upper Lafayette and the L well identified three taxa at the L well that were only present in Lake Jackson or Upper Lake Lafayette **[click]**
  - None of the algal taxa identified at the L well were unique to Lake Munson
  - The L well is situated about 430 feet from the spring vent; it was installed in 2015 to supply water to the lodge AC system
- A second round of algal taxonomic analyses in 2018 was indeterminant because the L well sample yielded no algae
- **[click]** Environmental DNA analyses conducted by Dr. Long and his colleagues at FAMU in 2017 and 2018 identified 13 operational taxonomic units at the genus and/or species level that were only present in Lake Jackson, Upper Lake Lafayette, or Munson
  - Similarity indexes for the whole array of eDNA OTUs found in the four lakes indicate that Lake Jackson is most similar to the L well followed by ULL and then Munson
  - None of the OTUs identified at the L well were unique to Lake Iamonia and it was consistently the least similar in total diversity to the L well
- These findings, combined with the dye studies, provide some evidence that lakes Jackson, Upper Lafayette, and Munson are each likely sources of the chlorophyll observed at Wakulla Spring

## Changes in Frequency and Duration: What Have We Learned?



- As previously notes, our proxy for changes in visibility over time is annual frequency of GBB tours
- While we know that both CDOM and chlorophyll have been present right along, something has obviously changed
- The third research question is, Why have the frequency and duration of dark water conditions increased?
- **[ Part II show rainfall and partitions with regression results]**

## 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

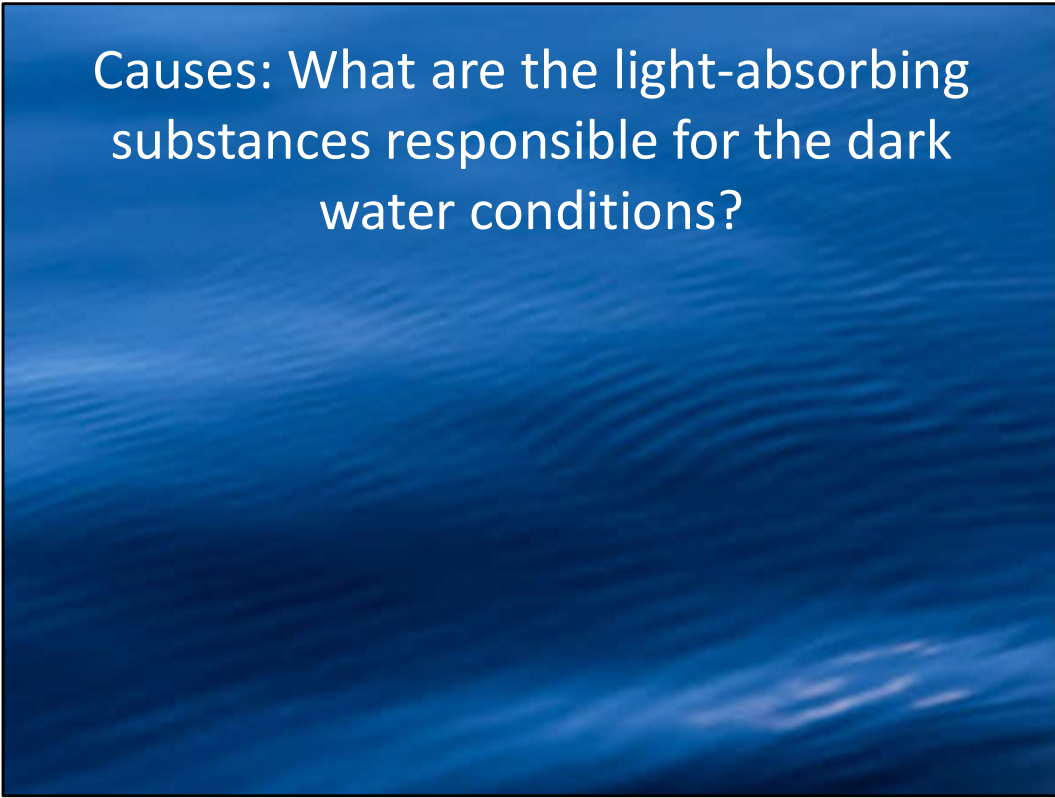
- **[click]** Comparing current CDOM levels, measured as true color, with historic data reveals they may have increased
  - **[click]** Average level measured during this project is 3 times greater than that for data reported between 1966 and 2006
- **[click]** On the other hand, chlorophyll levels, 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

## Changes in Frequency and Duration: What Have We Learned?

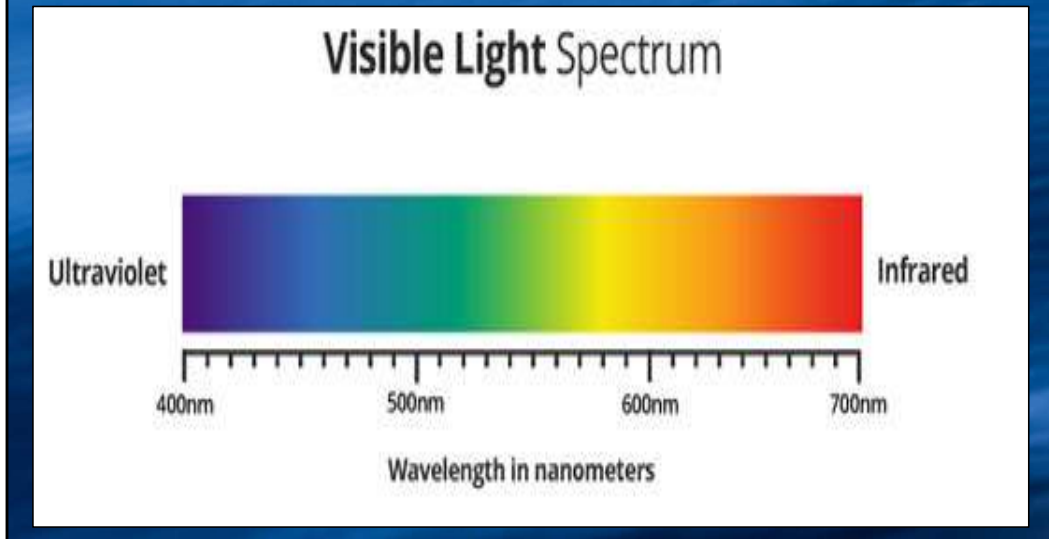
- Changes in rainfall patterns
- Changes in ground water withdrawals within the springshed
- Changes due to sea level rise
- Resulting changes in Wakulla Spring - Spring Creek dynamics
- Declining spring pool stage elevation

- Other possible factors that have been identified by other researchers include
  - Changes in rainfall patterns
  - Changes in ground water withdrawals within the springshed
  - Changes due to sea level rise
  - Resulting changes in the dynamics between Wakulla Spring and Spring Creek
- A newly recognized factor that also may be playing a role is the decline in spring pool stage elevation
- I will dig into these in the Part II presentation
- At this point, I want to return to the first question and unpack that **[click to next slide]:**  
“

Causes: What are the light-absorbing substances responsible for the dark water conditions?

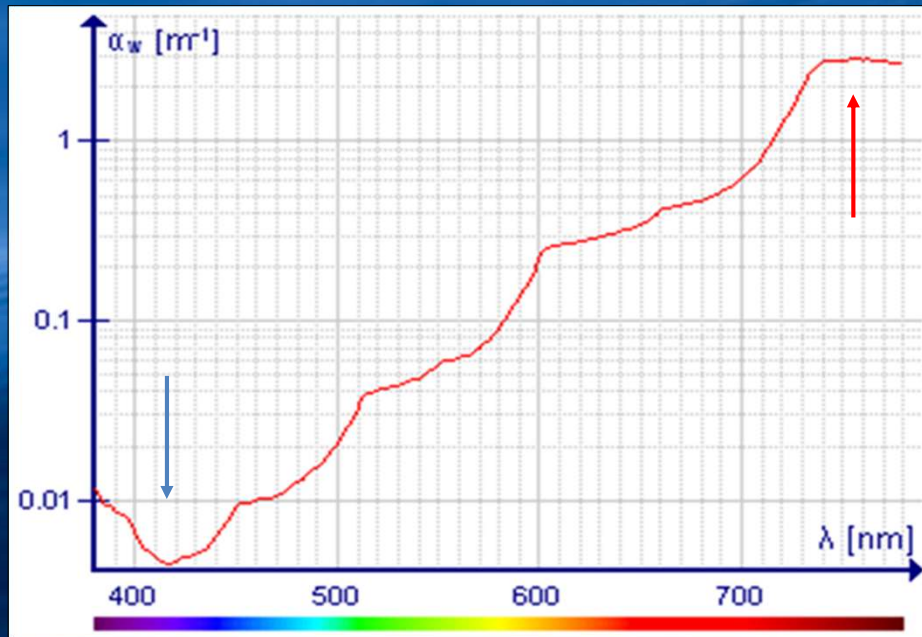


## Visibility Depth: 0% PAR Depth Limit



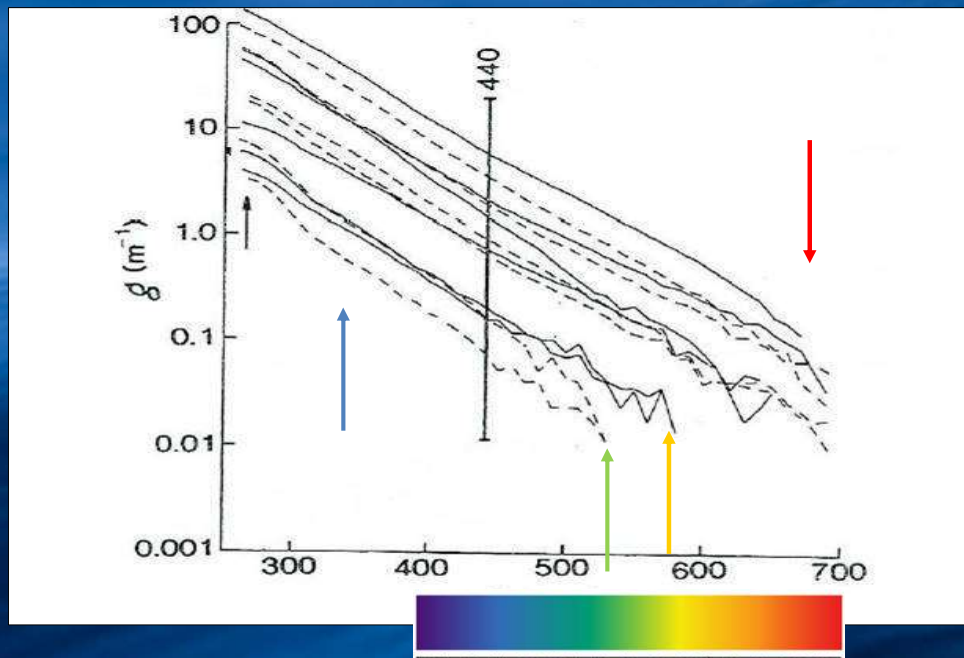
- Dr. McGlynn defined visibility depth as the depth at which all photosynthetically active radiation or PAR is extinguished by absorption or the 0% PAR depth limit
- The PAR spectrum is equivalent to the spectrum that humans can see, what we call "visible light" with wavelengths ranging from 400 to 700 nanometers

## Water Light Absorption Spectrum

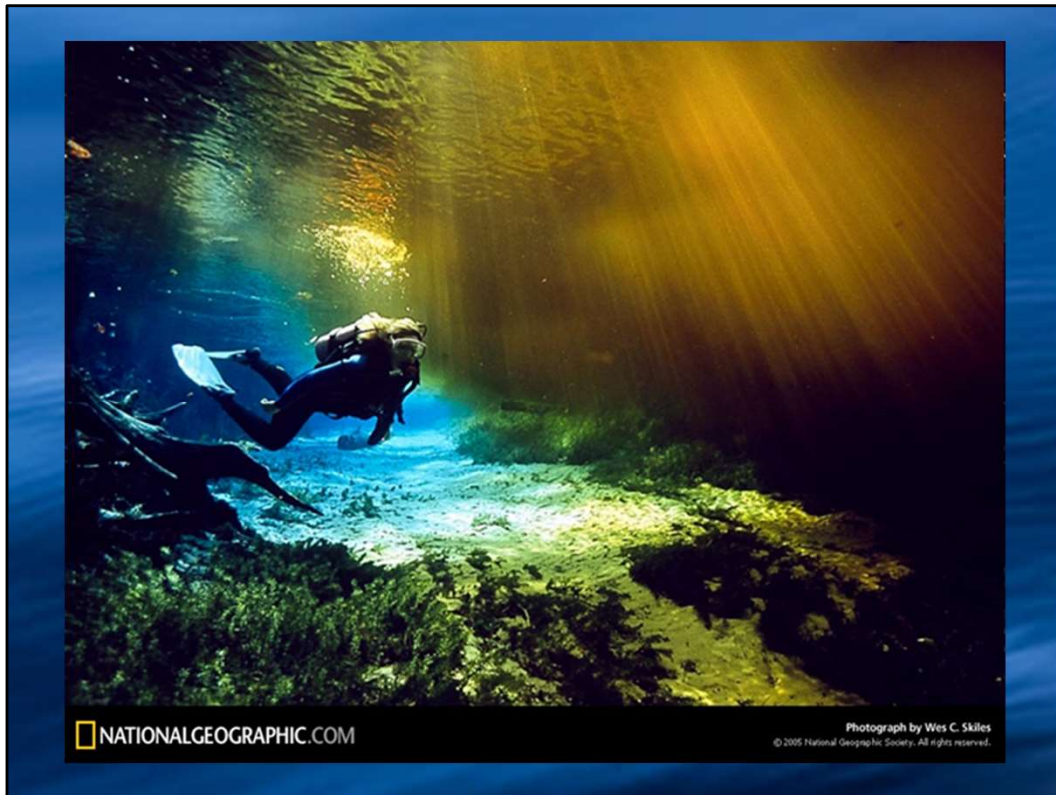


- Pure water absorbs light most strongly at the higher wavelengths in the red range **[click]**
- Thus it's the shorter blue light wavelengths that are most fully transmitted, hence clean water looks blue **[click]**

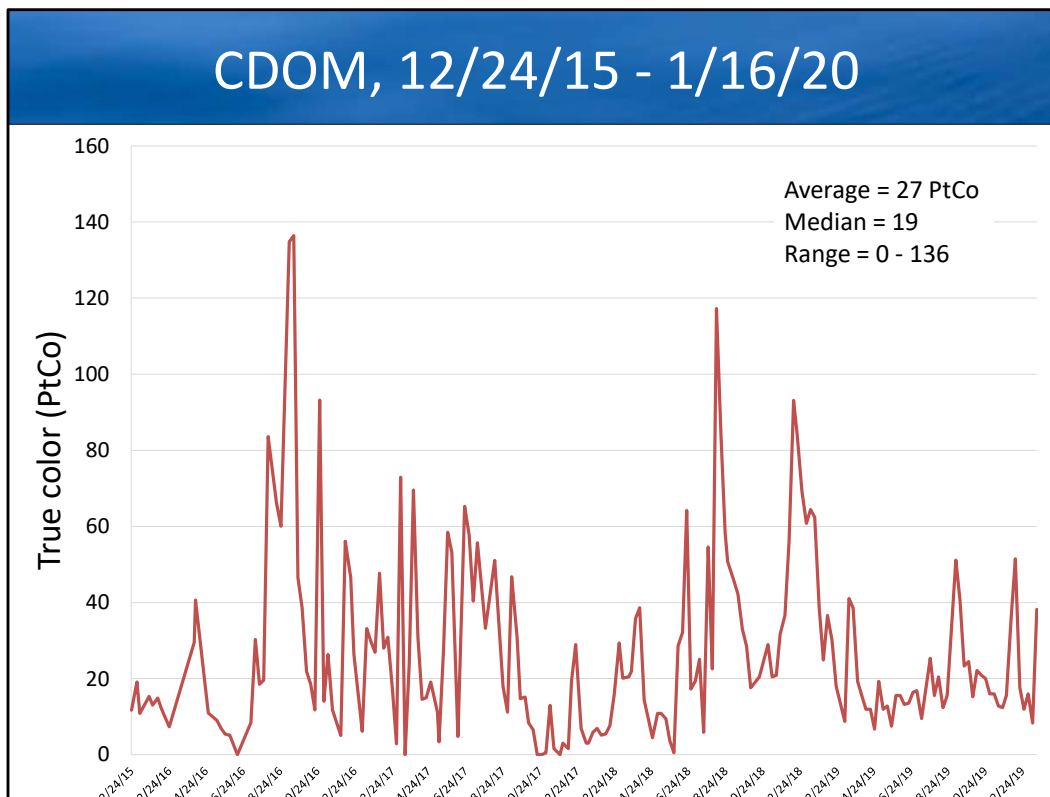
## CDOM Light Absorption



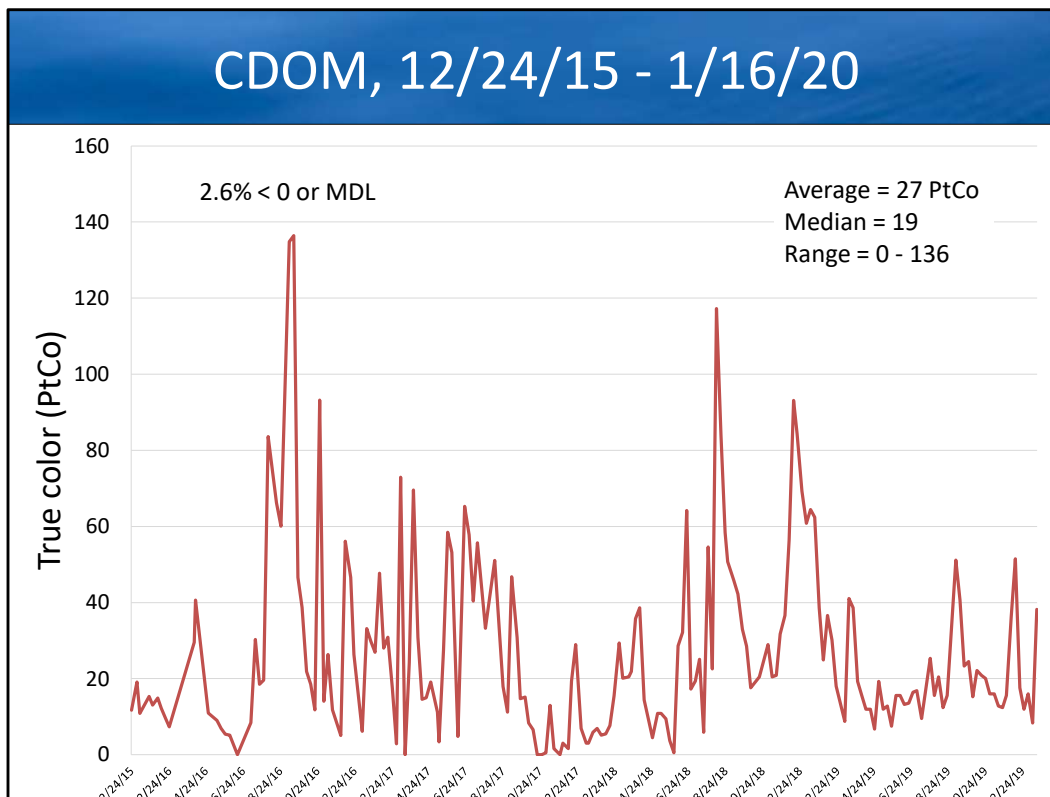
- When colored dissolved organic matter, CDOM, is added to water, it absorbs predominantly the shorter blue as well as ultra-violet wavelengths less than 400 nm which is outside the visible range **[click]**
- This shifts the dominant light transmission back to the right **[click]**
- High concentrations of CDOM absorb enough of the blue light to make the water appear reddish brown
- At lower concentrations, less blue light is absorbed and the transmitted wavelengths shift to the left
- Intermediate concentrations can yield a yellow to orange color **[click]**
- Low concentrations can produce an apparent green color **[click]**
- This is nicely illustrated in the next slide



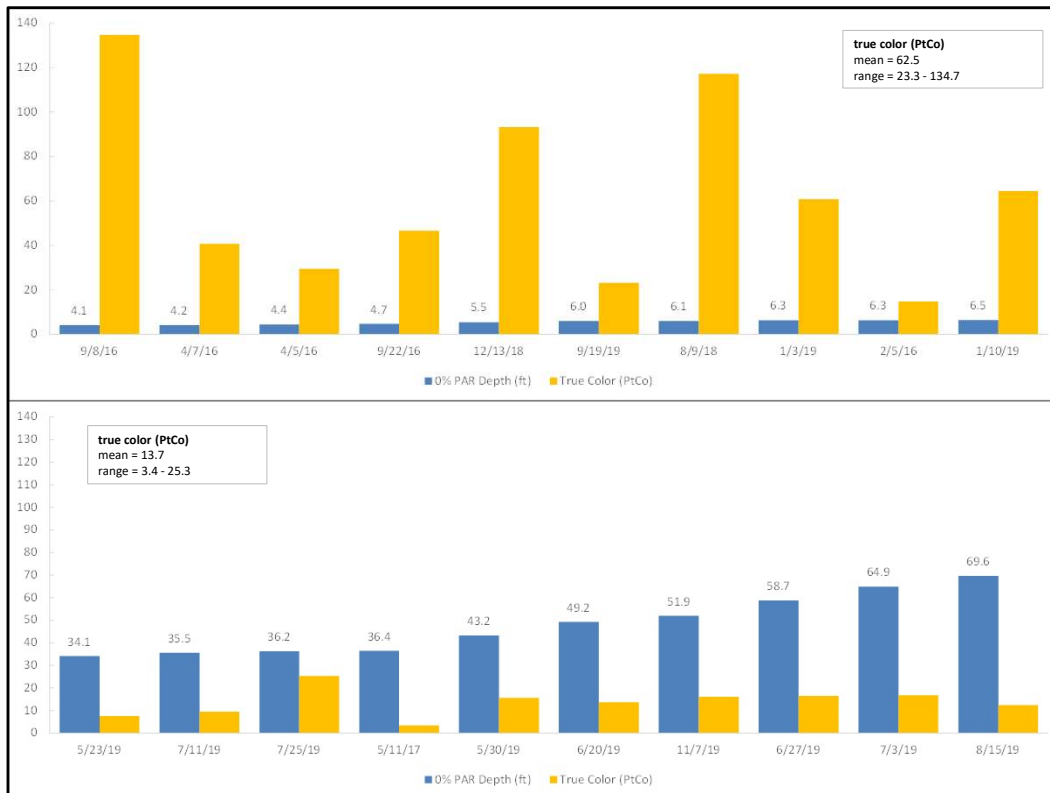
- This National Geographic photo depicts highly tannic water from the Santa Fe river flowing into the Ginnie Spring run
  - You can see the color shifts with decreasing concentrations of CDOM in the area above the diver



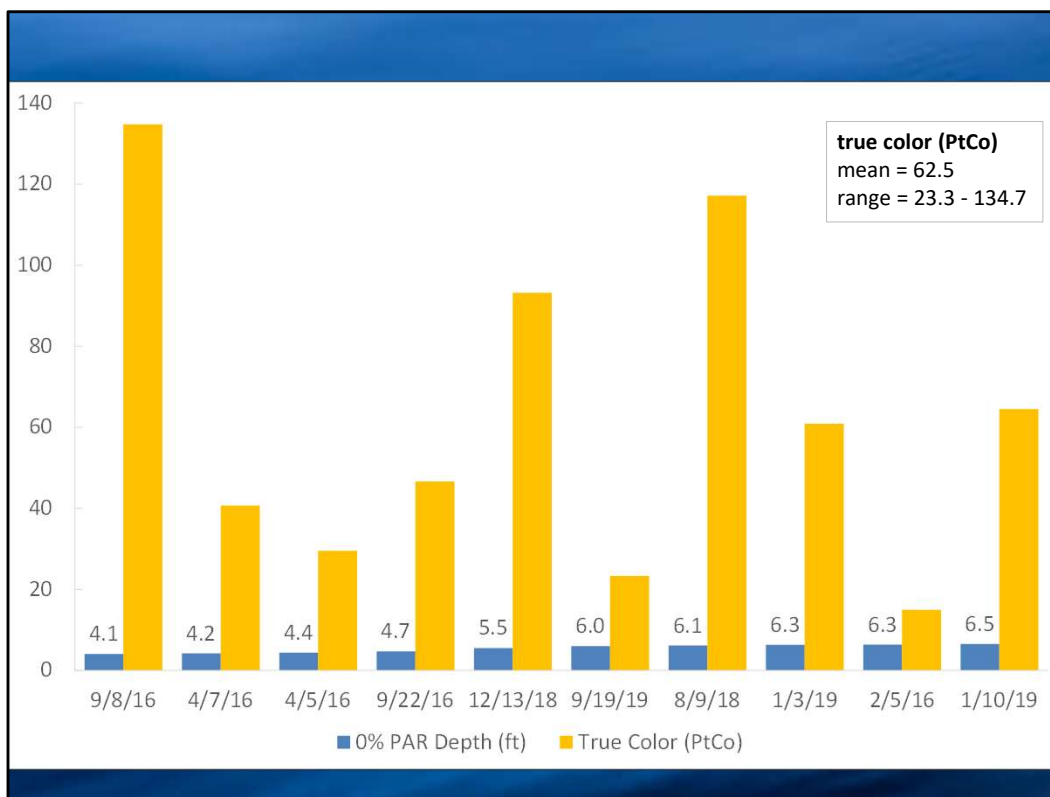
- Let's take a look now at the individual light-absorbing substances
- CDOM measured as true color (tannins) over the 4.5-year study period, from Dec 24, 2015 to Jan 16, 2020 averaged 27 Platinum-Cobalt units
  - With a median of 19
  - And a range of 0 to 136
- True color was zero or less than the method detection limit (0.19 PtCo) for only 5 of the 189 weekly samples (2.6%)



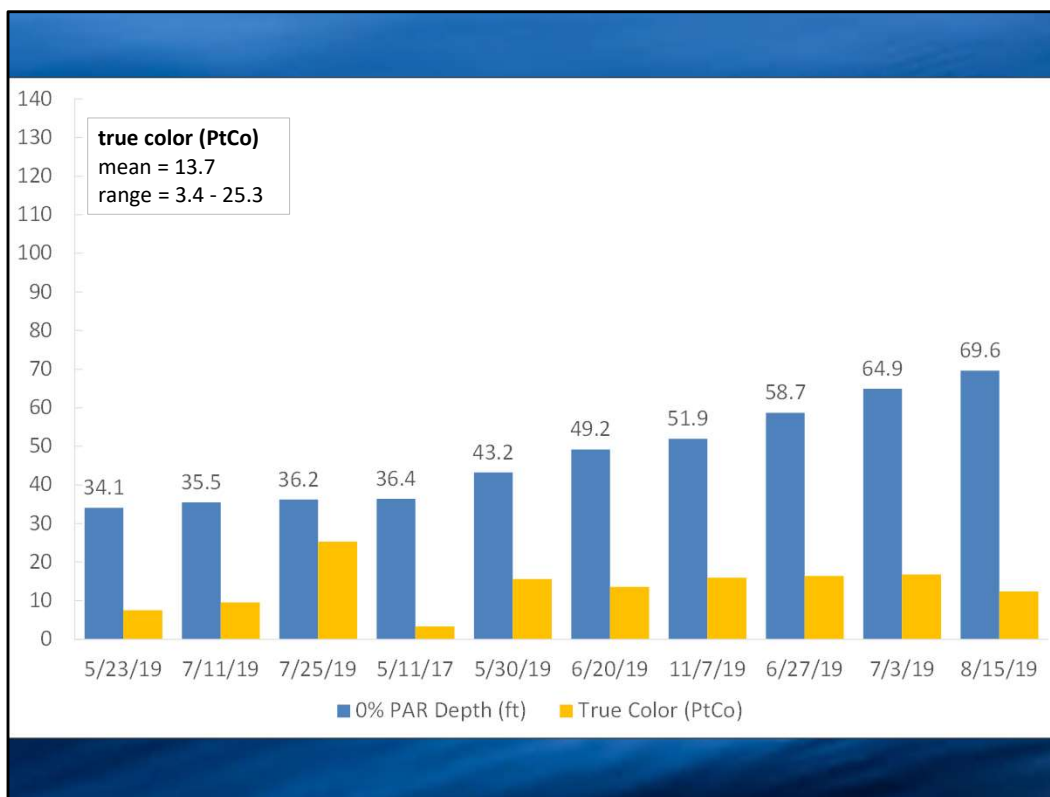
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- If we examine the 10 dates when visibility was lowest during the study period, what we might call “dark water events,” we encounter visibility depths ranging from 4.1 feet on the left to 6.5 feet on the right **[hidden enlarged slide follows]**
  - true color values range from 23 to 135 PtCo but do not appear to be directly correlated with the shift in visibility
- If we examine the 10 dates when visibility was highest, what we might call “light water events” we encounter visibility depths ranging from 34 feet on the left to 70 feet on the right **[hidden enlarged slide follows]**
  - true color values range from 3 to 55 PtCo but again do not appear to be directly correlated with the shift in visibility
  - Note however, that CDOM is present on each of these dates when the perceived color of the water would have been green or greenish brown

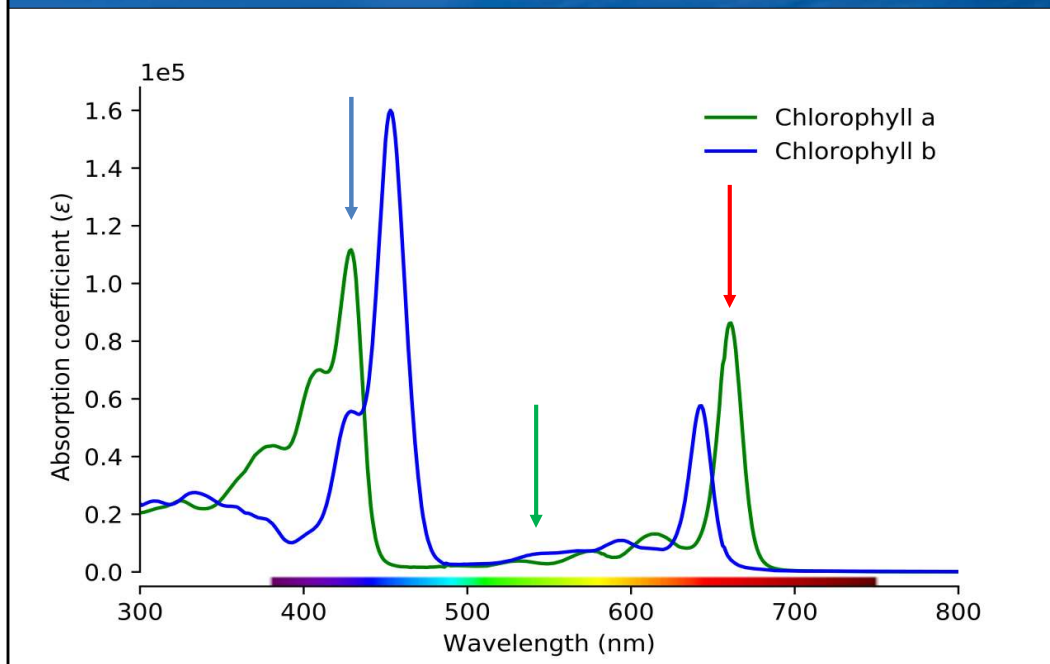


- CDOM dark events enlarged



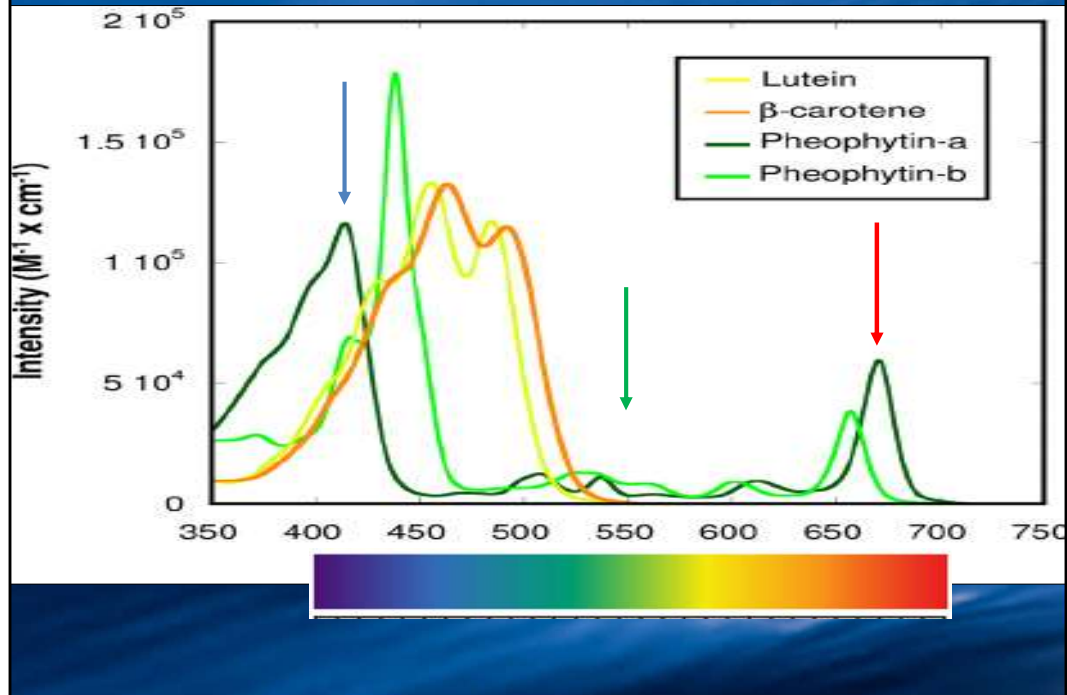
- CDOM light events enlarged

## Chlorophyll a Light Absorption



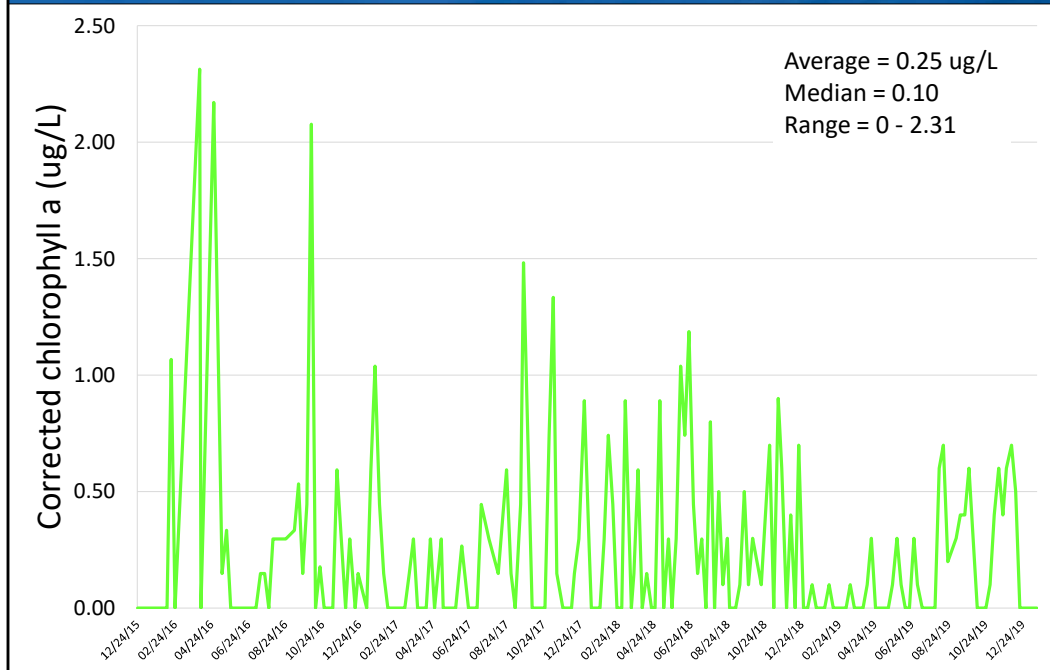
- The chlorophyll a absorption spectrum is bi-nodal with one peak in the blue range at 430 nm **[click]** and a second in the red range at 665 nm **[click]**
- If we just introduce chlorophyll a to clean water the transmission peak shifts to the middle of the visible light spectrum and the apparent color is green **[click]**

## Pheophytin a Light Absorption



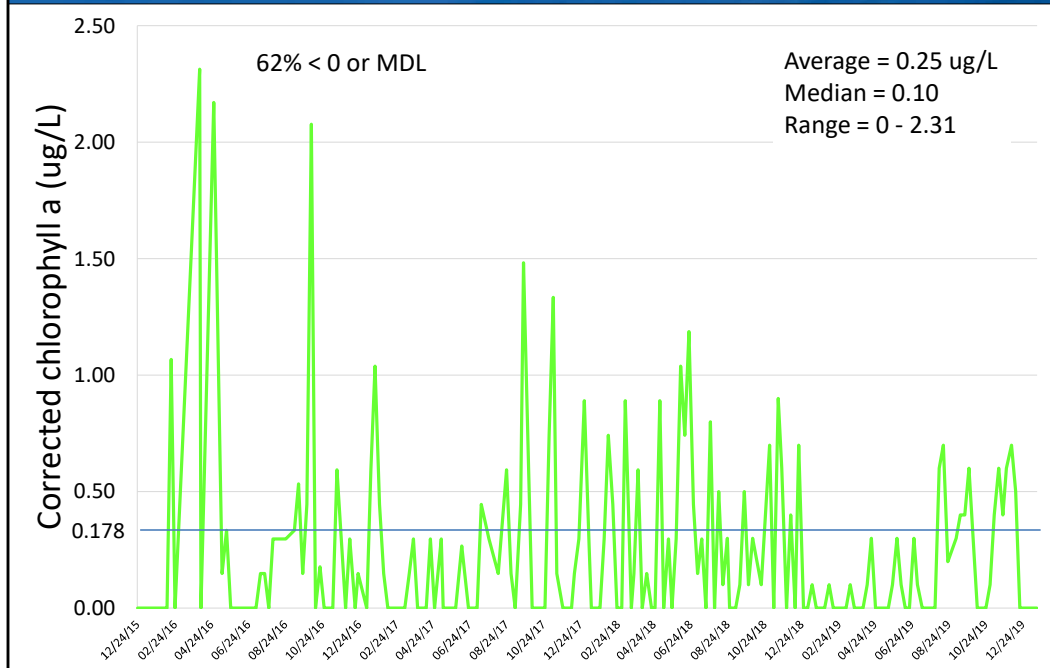
- Pheophytin a has a similar absorption spectrum with slightly different peaks: a blue range peak at 420 nm [\[click\]](#) and a red-range peak at 654 nm [\[click\]](#)
- Again yielding an apparent color that is green [\[click\]](#)

## Chlorophyll a, 12/24/15 - 1/16/20



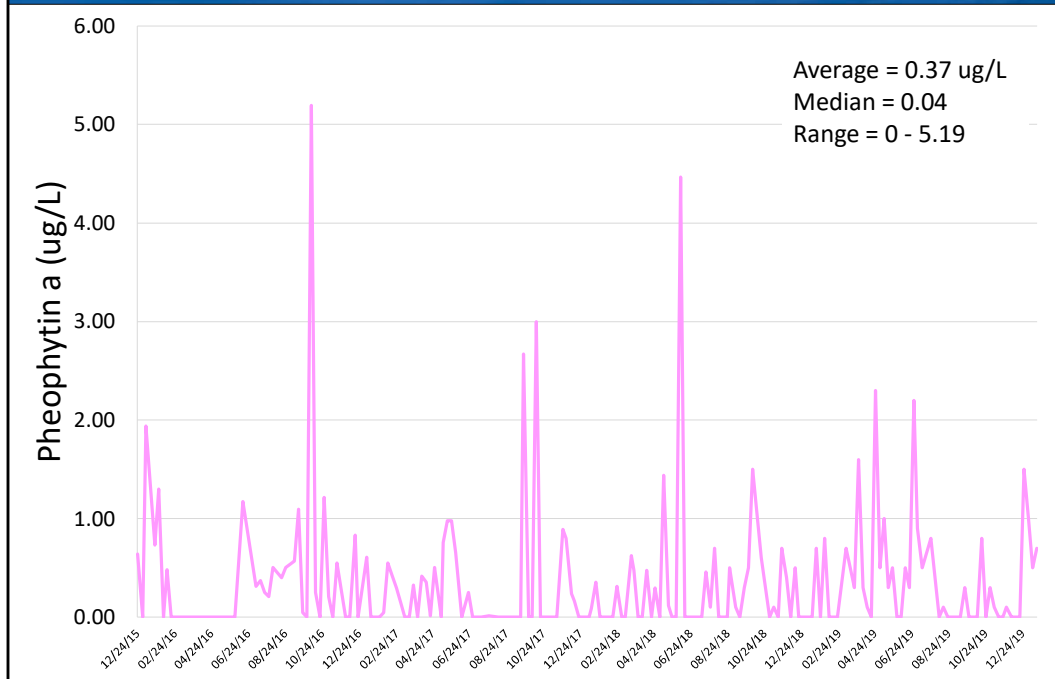
- Chlorophyll a, measured as corrected chlorophyll a, over the 4.5-year study period, from Dec 24, 2015 to Jan 16, 2020 averaged 0.25 ug/L
  - With a median of 0.10
  - And a range of 0 to 2.31
- **[click]** Corrected chlorophyll a was zero or less than the method detection limit (0.178 ug/L) for 62% of the 189 weekly samples

## Chlorophyll a, 12/24/15 - 1/16/20



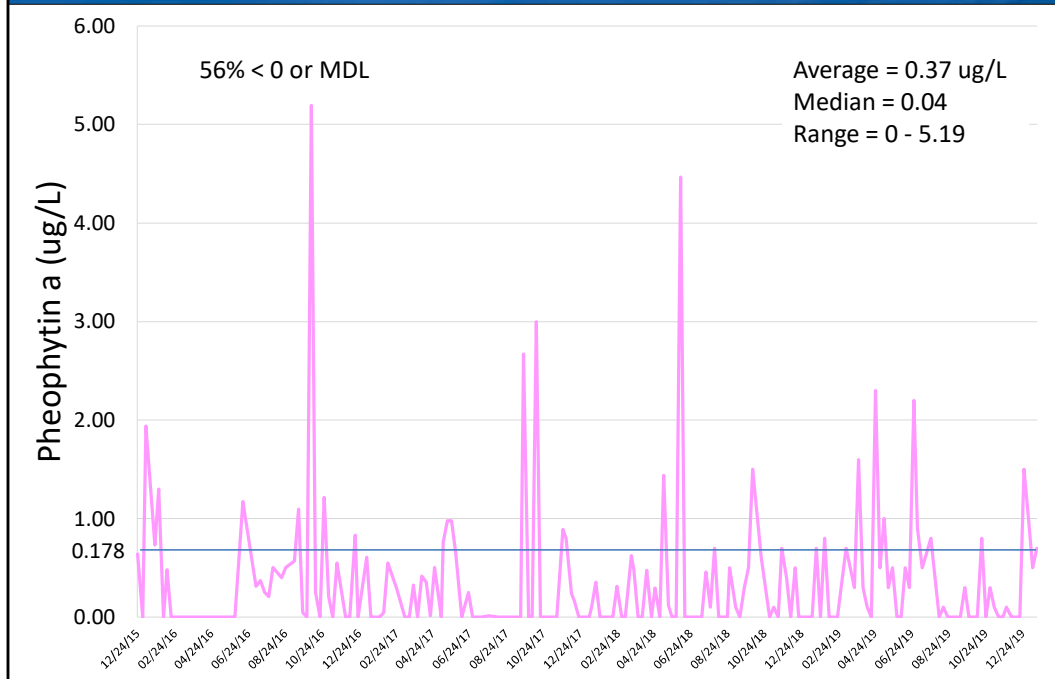
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## Pheophytin a, 12/24/15 - 1/16/20

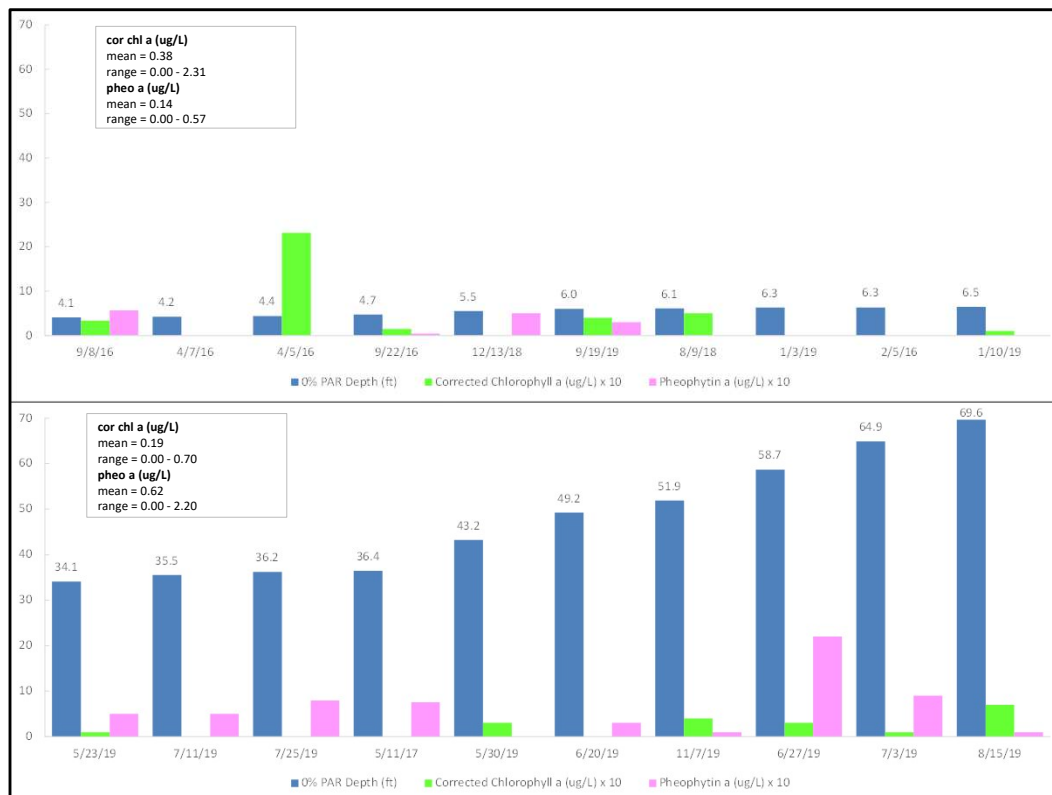


- Pheophytin a measured over the 4.5-year study period, from Dec 24, 2015 to Jan 16, 2020 averaged 0.37 ug/L
  - With a median of 0.04
  - And a range of 0 to 5.19
- **[click]** Pheophytin a was zero or less than the method detection limit (0.178 ug/L) for 56% of the 189 weekly samples

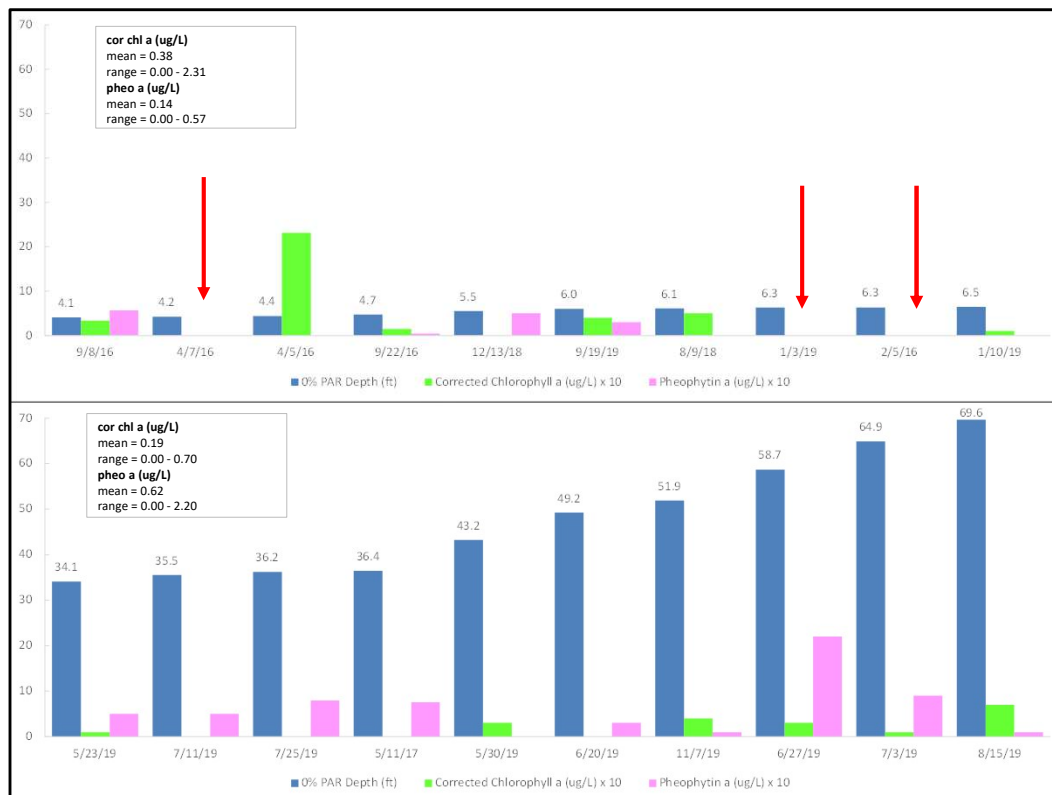
## Pheophytin a, 12/24/15 - 1/16/20



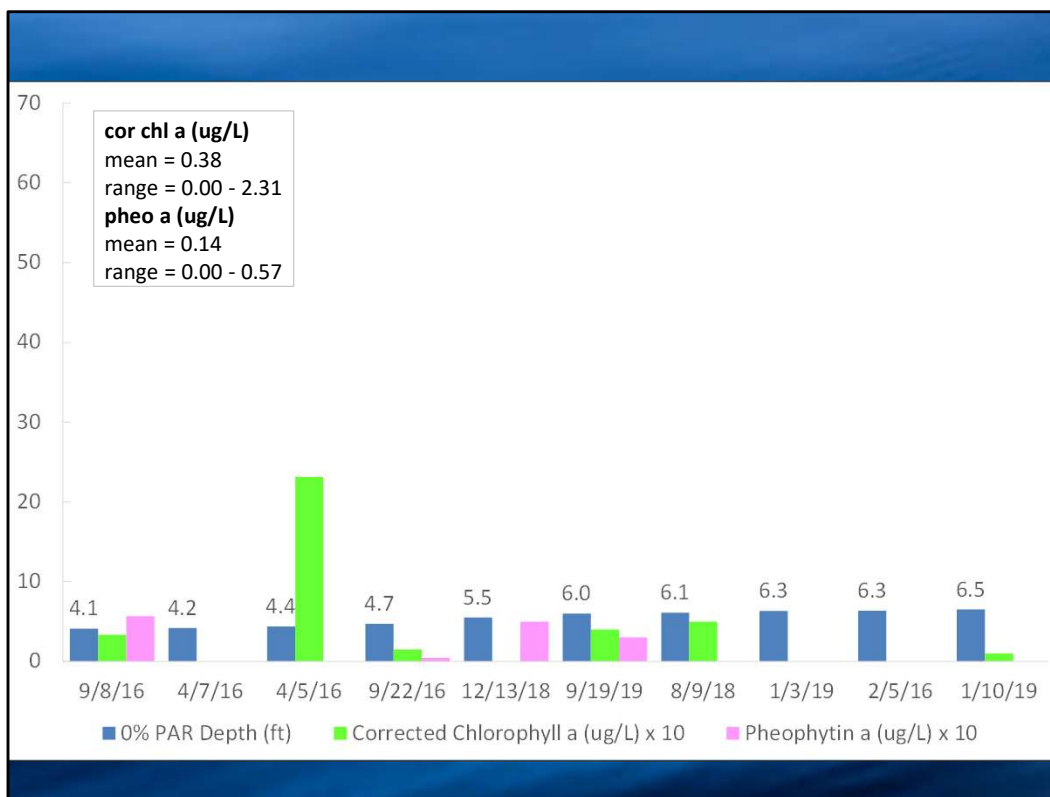
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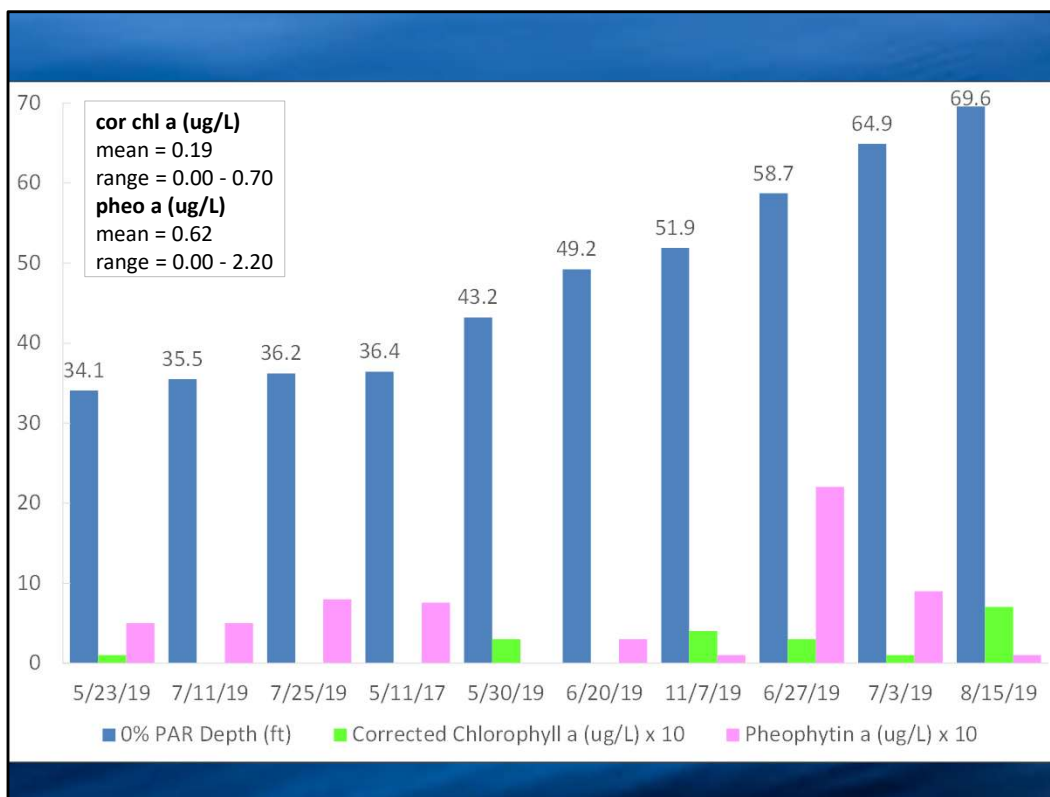
- Looking at the 10 dates when visibility was lowest during the study period: **[hidden enlarged slide follows]**
  - corrected chlorophyll a values range from 0.00 to 2.31 ug/L but show no evidence of being directly correlated with the shift in visibility
  - neither does pheophytin a which ranges from 0.00 to 0.057 ug/L
  - On three dark event dates **[click]**, neither form of chlorophyll a is present above the method detection limit of 0.178 ug/L
- Examining the 10 dates when visibility was highest during the study period: **[hidden enlarged slide follows]**
  - corrected chlorophyll a values range from 0.00 to 0.70 ug/L but show no evidence of being directly correlated with the shift in visibility
  - neither does pheophytin a which ranges from 0.00 to 2.20 ug/L
  - One or the other form of chlorophyll a is present above the method detection limit of 0.178 ug/L on each light event date



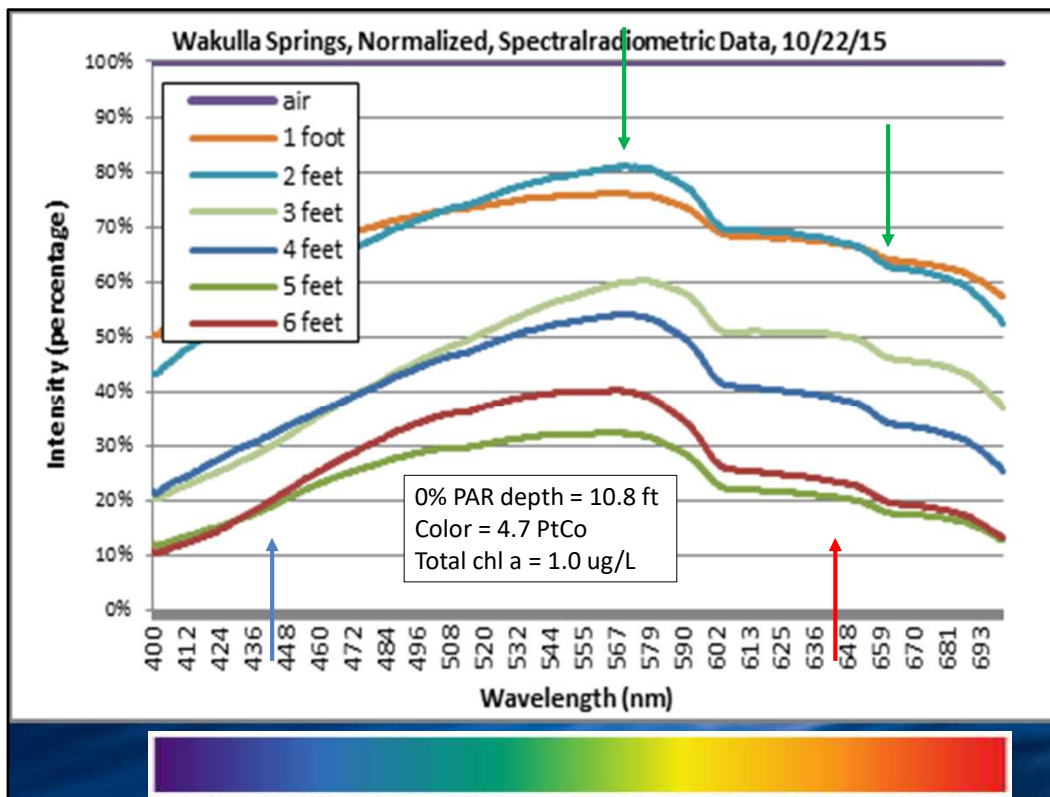
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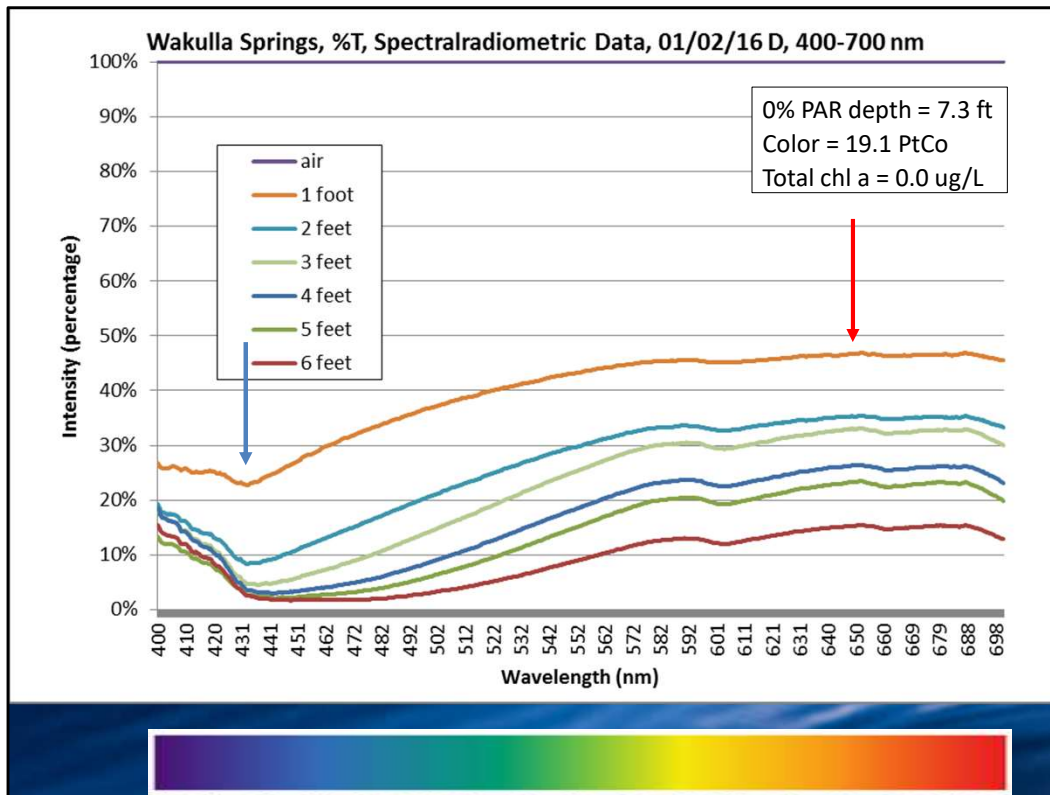
- Dark events enlarged



- Light events enlarged

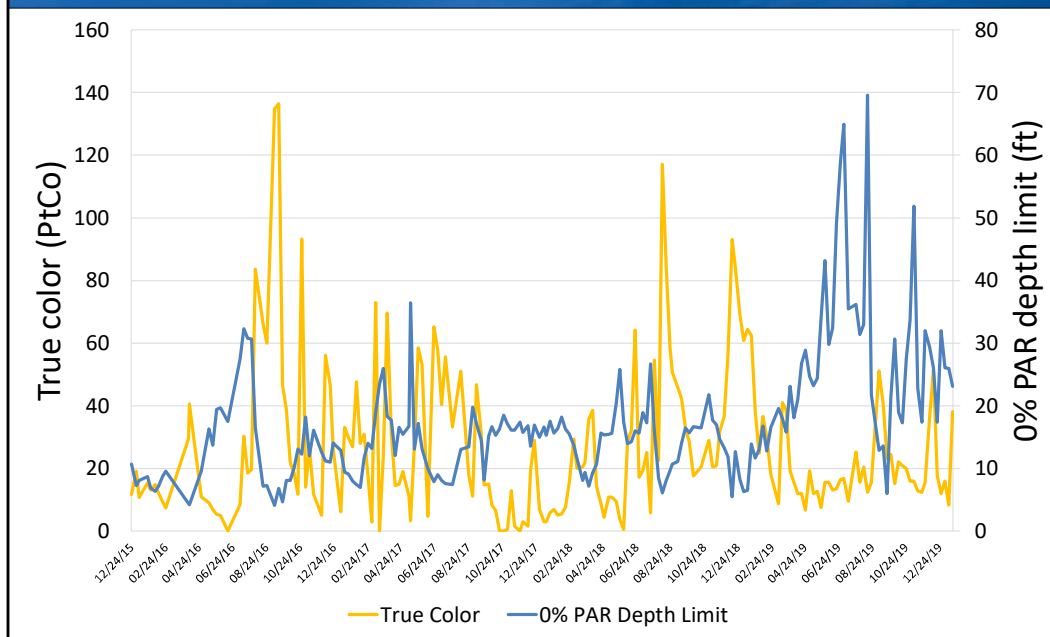


- As we've just seen, chlorophyll, measured as corrected chlorophyll a and pheophytin a, is present in the spring boil, and therefore must be contributing to some degree to the absorption of PAR/visible light and reduced visibility along with CDOM measured as true color.
- This is demonstrated by graphs of visible light transmission created by Dr. McGlynn from spectral radiometric readings taken at the spring boil at one-foot intervals
- This normalized graph compares light transmission at each depth at each wavelength with transmission measured in the air just above the water surface – the purple line at the top
  - Visibility depth was 10.8 ft
  - Color was 4.7 PtCo
  - Total chlorophyll a (sum of corrected chlorophyll a + pheophytin a) was 1.0 ug/L
- As is to be expected, transmission decreases with depth: as light passes through more water, more light is absorbed by the water itself and any light-absorbing substances that are present
- This specrad graph illustrates the typical profile of a so-called "light event" when visibility depth is greater and the apparent color is green rather than the reddish brown associated with high tannin levels
- Both the shortest wavelengths (< 470 nm) **[click]** and the longer wavelengths (>590 nm) **[click]** were being absorbed
- Greatest transmittance is in the middle at about 500-590 nm, i.e. greens and yellows at 75-80% **[click]**
- Each curve displays a dip in transmittance at about 665 nm which corresponds to the chlorophyll a longer wavelength absorbance peak **[click]**



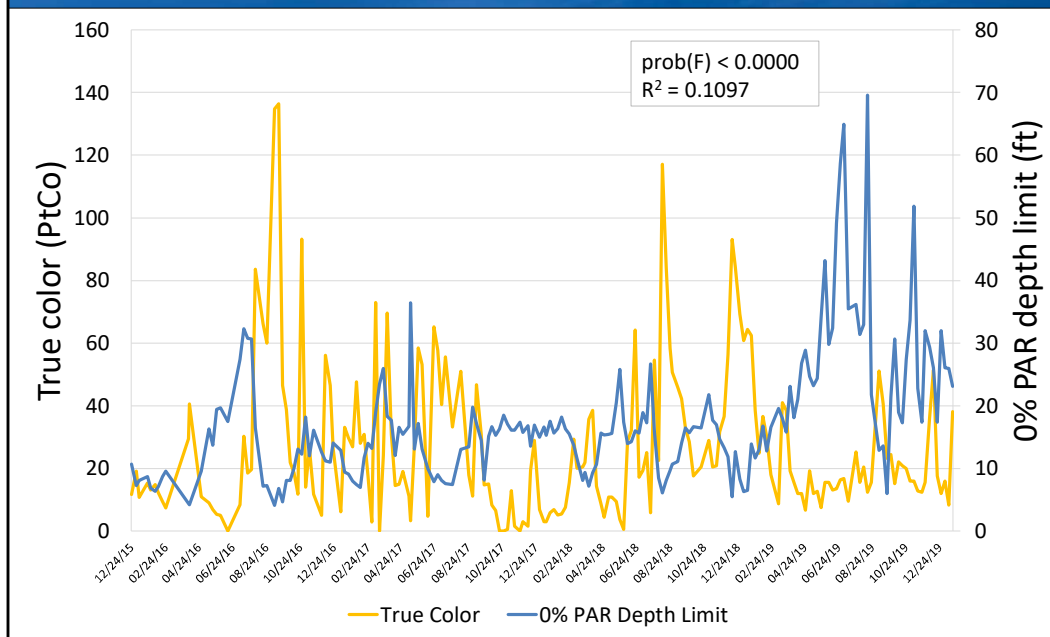
- This specrad graph illustrates the typical profile of a so-called “dark event” when visibility depth is less and the apparent color is reddish brown associated with high tannin levels
- The shortest wavelengths (< 470 nm) were strongly absorbed **[click]**
- While the longer wavelengths (>590 nm) were being more fully transmitted at about 45% at one-foot depth **[click]**

## CDOM with Visibility Depth, 12/24/15 - 1/16/20



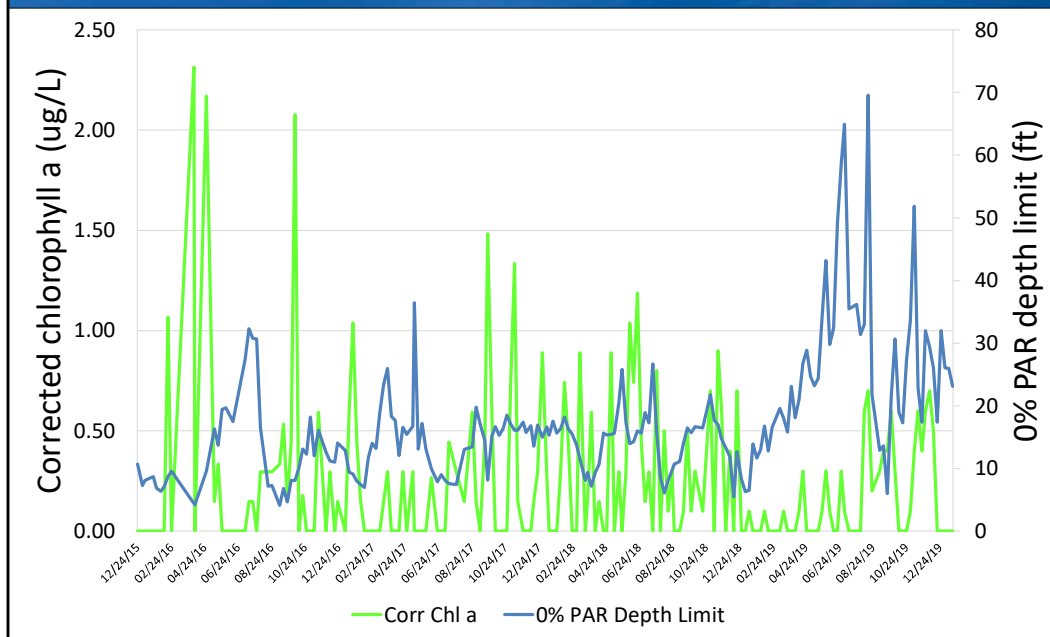
- If we plot CDOM measured as true color with visibility measured as 0% PAR depth limit for the study period, we see evidence of an inverse relationship, i.e. higher levels of CDOM are associated with reduced visibility
- **[click]** Ordinary least squares regression confirms this apparent relationship with a model that is statistically significant at better than 99.99%
  - However, true color only explains about 11% of the observed variation in visibility depth ( $R\text{-squared} = 0.1097$ )

## CDOM with Visibility Depth, 12/24/15 - 1/16/20



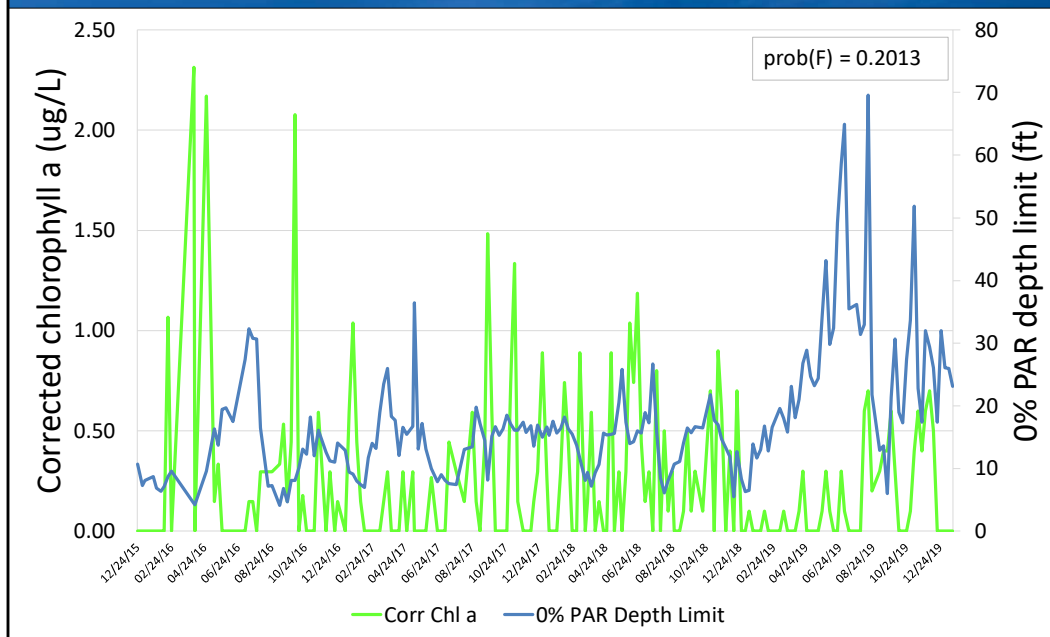
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## Chlorophyll a with Visibility Depth, 12/24/15 - 1/16/20



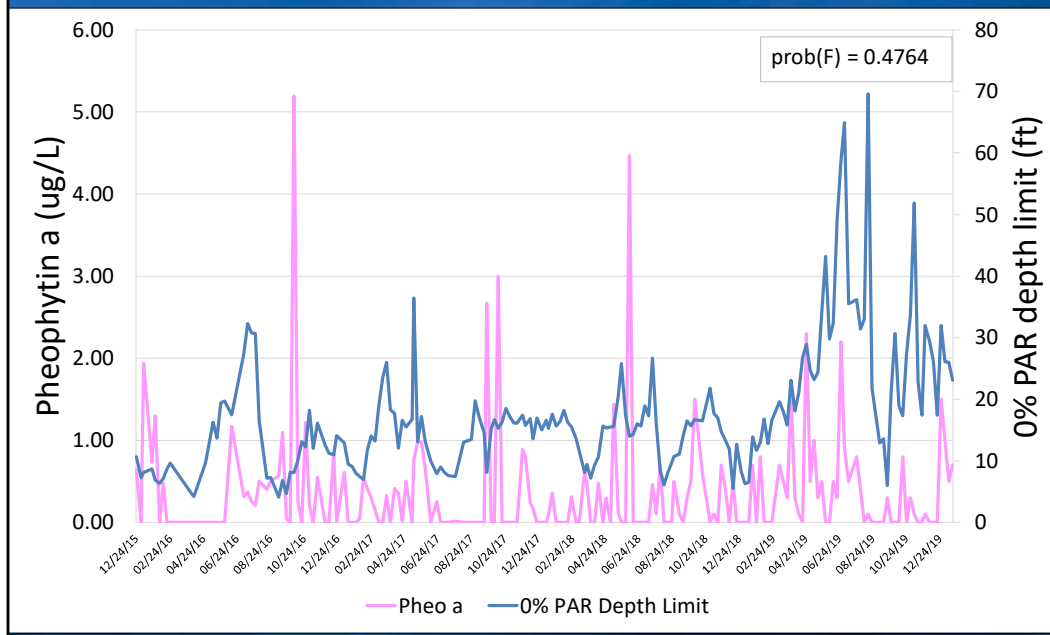
- When we plot chlorophyll a measured as corrected chlorophyll a with visibility, we see no evidence of a consistent relationship
- **[click]** An ordinary least squares regression model is not statistically significant at the 90% level or better, so the R-squared value is irrelevant

## Chlorophyll a with Visibility Depth, 12/24/15 - 1/16/20



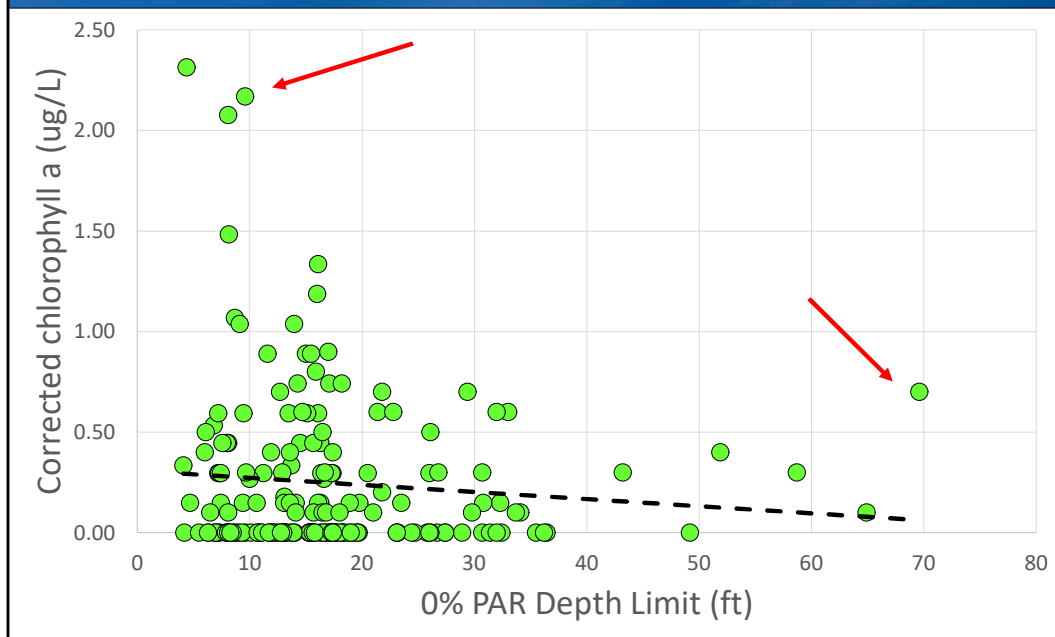
- When we plot chlorophyll a measured as corrected chlorophyll a with visibility, we see no evidence of a consistent relationship
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## Pheophytin a with Visibility Depth, 12/24/15 - 1/16/20



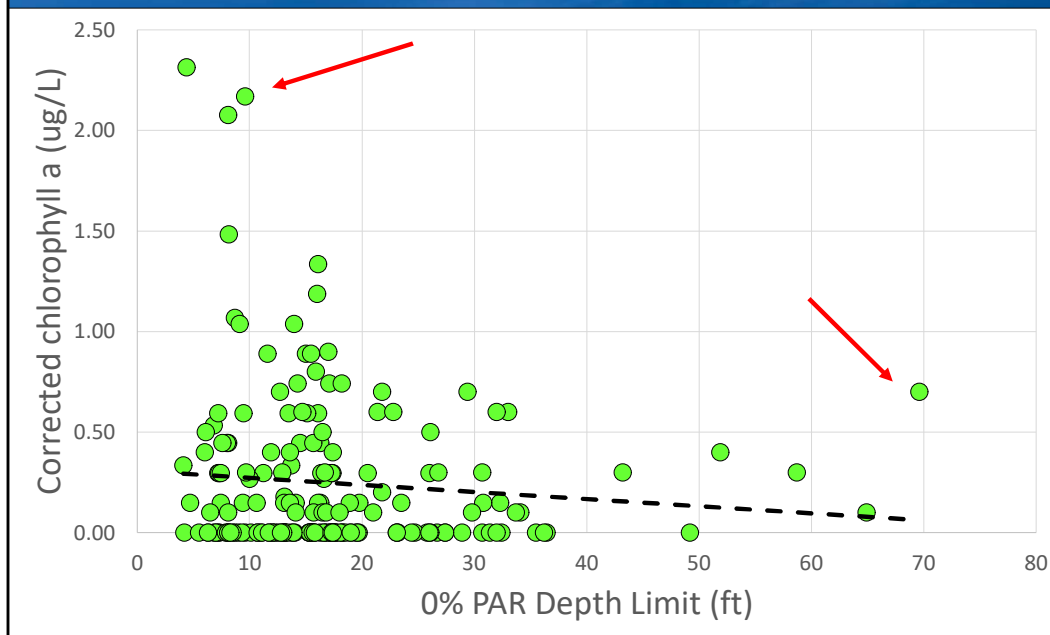
- We get similar results when we plot pheophytin a with visibility

## Scatter Plot of Chlorophyll a and Visibility, 12/24/15 – 01/16/20



- An examination of scatterplots for the two chlorophyll variables, corrected chlorophyll a shown here, reveals that ordinary least square regression is not the most effective way to analyze possible relationships between these two variables and visibility depth
- Values are not linearly distributed and there are a number of outlying values **[click]**
- My statistical consultant, BU quantitative ecologist Dr. Ethan Deyle, recommended quantile regression as a more suitable alternative approach
  - Rather than estimating the mean expected value of visibility depth for each corrected chlorophyll a observation, quantile regression estimates the expected value for a given quantile or percentile
  - For example, one can apply quantile regression to estimate the expected value of the 50<sup>th</sup> percentile of visibility depth, i.e. the median, or any other percentile of interest
  - I engaged Dr. Deyle to conduct quantile regression for CDOM measured as true color as well as corrected chlorophyll a and pheophytin a. The results are presented in the next slides

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Quantile and OLS Regression Results				
Light Absorbing Substance	Visibility Depth Model	Coefficient*	t Statistic**	Prob(t)***
CDOM (true color)	OLS	-0.1414	-4.80	< 0.0000
	25 <sup>th</sup> percentile	-0.1120	-7.28	< 0.0000
	50 <sup>th</sup> percentile	-0.0968	-4.42	<0.0000
	75 <sup>th</sup> percentile	-0.1240	-3.07	0.0025
	90 <sup>th</sup> percentile	-0.2190	-9.89	<0.0000

- The coefficient is the slope of the regression line for a given independent variable.
  - If the coefficient is negative there is an inverse relationship between the independent variable and the dependent variable.
  - Therefore, in these models, a negative coefficient indicates that the higher the level of the light-absorbing substance, the shallower the visibility depth.
  - So in the OLS model, a one unit increase in true color results in a 0.14 ft decrease in 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.
- Here we see the results for CDOM measured as true color
  - The coefficient is significant for the OLS regression as we saw earlier
  - They also are significant for all four quantiles tested
- Notice that the 90<sup>th</sup> percentile coefficient is almost twice as large as that for the 75<sup>th</sup> percentile [click]
  - That tells us that when visibility depth is greater than 90% of the other observations, a one unit increase in CDOM measured as true color has twice the impact that it has when visibility depth is greater than 75% of the other observations

## Quantile and OLS Regression Results

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Corrected chlorophyll a	OLS	-2.4713	-1.28	0.2013
	25 <sup>th</sup> percentile	-2.4000	-1.36	0.1740
	50 <sup>th</sup> percentile	-3.1300	-3.50	0.0006
	75 <sup>th</sup> percentile	-3.7000	-1.20	0.2320
	90 <sup>th</sup> percentile	-10.3000	-1.77	0.0783

- Looking at corrected chlorophyll a, the 50<sup>th</sup> percentile model, i.e. the median, is significant at the 99.94% level
- And the 90<sup>th</sup> percentile model is significant at the 92.17% level
- Comparing the coefficients for the 50<sup>th</sup> and 90<sup>th</sup> percentiles we see that visibility depth at the 90<sup>th</sup> percentile **[click]** is more than 3 times as sensitive to a one ug/L increase in corrected chlorophyll a than at the 50<sup>th</sup> percentile **[click]**
  - i.e. at the 90<sup>th</sup> percentile of visibility depth, a 1 ug/L increase in corrected chlorophyll a will lead to a 10.3-foot decrease in visibility

## Quantile and OLS Regression Results

Light Absorbing Substance	Visibility Depth Model	Coefficient*	t Statistic**	Prob(t)***
CDOM (true color)	OLS	-0.1414	-4.80	< 0.0000
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	90 <sup>th</sup> percentile	-10.3000	-1.77	0.0783
Pheophytin a	OLS	0.7809	0.71	0.4764
	25 <sup>th</sup> percentile	-0.5890	-1.10	0.2720
	50 <sup>th</sup> percentile	-0.4220	-0.46	0.6260
	75 <sup>th</sup> percentile	4.2000	1.12	0.2630
	90 <sup>th</sup> percentile	11.0000	1.77	0.0791

- Looking at pheophytin a, only the 90<sup>th</sup> percentile model is significant at the 90% level or better
- BUT note, the 90<sup>th</sup> percentile coefficient is positive
- That means that a 1 ug/L increase in pheophytin is associated with an 11-foot INCREASE in visibility
- I cannot think of a plausible explanation for this result

## Research Questions

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

- Having established that CDOM 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
- We will move on to the other two research questions in a follow-up presentation which I have tentatively scheduled for our next meeting on December 18th