# TURBIDITY, NITROGEN, AND DISSOLVED OXYGEN ABNORMALITIES IN THE ATCHAFALAYA BASIN 2016-2019 – A WORKING PAPER.

## Prepared for the Atchafalaya Basinkeeper

## Abstract

Mississippi River nutrient  levels three times higher than pre-1975 leads to eutrophication and hypoxia in Atchafalaya Floodway swamps during River floods. External pressures are exacerbating internal eutrophication events, leading to hypoxia and its attendant negative impacts socioeconomically as well as to the fragile ecology. The latter recognizing how the natural hydrology of the Basin has been modified by human activity and interference, such as oil and gas exploration, navigation, sediment dispersal projects and such. Additionally, highly mobile suspended sediment is rapidly infilling the swamps being mostly flood induced. The present management of the Basin (Floodway and original Basin elements outside the Floodway) is exacerbating these detrimental processes as the safety floodway rapidly loses its capacity to absorb floodwaters – it original purpose. A totally new management strategy is needed or else this Basin, this ecological wonder, will be lost within a few years and flooding of the built environment will become more acute.

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## SUMMARY

The period 1 January 2016 to 31 December 2019 was chosen for this report as this matches measurements that have been acquired in the central part of the Basin, in the vicinity of the proposed East Grande Lake (EGL) project. This thesis will look at the changing water quality cycles in the Basin as against the major source of the nutrients and suspended sediments, namely the Mississippi River. Data at a Big-Picture river scale is reduced and then compared to in-basin and specific monitoring sites - at a small picture scale. Both sets of data independently reveal the role highly nutrient-rich Mississippi River floodwaters play in Eutrophication and Hypoxia in the Basin Floodway.

The main conclusion is that eutrophication and hypoxic events principally owe their origin to Atchafalaya River floodwater entering the wetlands, aided in a large part by manmade canals, channels and cuts. This aspect of the physics that drives the unnatural responses in the basin strongly reveals that future proposed management should not involve "so-called flushing projects." Rather this points to the need to think outside the box and recognize that this Basin, although three separate parts due to levees, could well be managed as one unit – the original Atchafalaya Basin. Management such as the proposed EGL project are not the solution to dealing with eutrophication and hypoxia.

Van Heerden (2020), in a sister thesis, addresses the suspended sediment impacts and rapid infilling of the Floodway Basin as a consequence of present management plans. The reader is encouraged to read that thesis in addition to this manuscript.

# CHAPTER 1. TURBIDITY, NITROGEN AND DISSOLVED OXYGEN ABNORMALITIES IN THE ATCHAFALAYA BASIN 2016-2019 – A WORKING PAPER.

## INTRODUCTION AND TERMINOLOGY

This thesis will discuss data obtained by review of the scientific literature; data from the USGS National Water Information System web pages; academic thesis; and, obtained from the state of Louisiana being data collected by The Nature Conservancy (TNC) under contract to the state. The study period is 1 January 2016 through to 31 December 2019 being the interval during which data from various sources were collected in the Basin swamps. However, there will be references to other prior reports and data sets where these are applicable. As the Atchafalaya River is a distributary of the Mississippi the primary source of turbidity and associated nutrients is the latter. As will be shown in this report, what characterizes the Mississippi River ‘input’ into the Basin is somewhat different to what ‘exits’ the Basin, at Morgan City. Some transformations and modifications occur as the nutrient rich Mississippi waters traverse the Atchafalaya Floodway Basin. These modifications reflect the consequence of eutrophication due to nutrient loading that exacerbates the hypoxia events that occur with more and more frequency.

The Atchafalaya River Basin, Louisiana, coincides with the natural basin formed by alluvial ridges that relate to present and former Mississippi River courses (Plate 1). The Basin extends inland from the Gulf of Mexico for a distance of 125 miles to the former confluence of the Mississippi River and Red River. Continuity of the Basin is only interrupted by an alluvial ridge, the Teche Ridge, that crosses the Basin at the latitude of Morgan City, Louisiana. Central to the Basin is the Atchafalaya River, which connects the Mississippi River and Red River to the Gulf of Mexico and flows through the Teche Ridge at Morgan City where it becomes the Lower Atchafalaya River. Until 1928 the entire Basin functioned as the Atchafalaya River flood plain or Basin and afforded a natural outlet for Mississippi and Red River floodwaters to the Gulf of Mexico. Since then major changes have evolved. In 1928 and 1956, respectively, Congress authorized the construction of a floodway through the Basin and the construction of a control structure at Old River to regulate the diversion of Mississippi River flow into the Atchafalaya River (Plate 1). To provide a defined floodway, guide levees were constructed east and west of and parallel to the Atchafalaya River and at an average distance of 15 miles apart. Flood flows as well as the annual overflow of the Atchafalaya River thus became confined to the central part of the natural basin as far south as the Teche Ridge – the Basin Floodway. Through the ridge, flows are temporarily further confined to only the channels of the Lower Atchafalaya River and the constructed Wax Lake outlet until the guide levees terminate and water escapes the channels into adjacent wetlands and the Gulf of Mexico.

Despite the many adverse changes that have taken place as a result of indiscriminate use of the Atchafalaya Basin's water- and land-related resources, the Basin still constitutes a resource complex of exceptional recreational, ecological, and commercial significance. The floodway system above the Teche Ridge is one of the largest remaining alluvial flood plain hardwood swamps in the United States. It contains more than 700,000 acres of hardwoods, nearly one-third of which are cypress-tupelo swamps, and 53,000 acres of water bodies. To this must be added the hardwood swamps of the Basin outside the floodway. Below the Teche Ridge the Basin environment becomes one of fresh and brackish water marshes and bays, with the development of the Atchafalaya and the Wax Lake Deltas the most important process. These deltas offer the potential aggradation and accretion of a 300 to 350 mi2 area of new wetlands in a state where the loss of wetlands is staggering.

Use of the Atchafalaya Basin for flood control has significantly affected the integrity of the Basin's waters physically, biologically, and chemically. Most drastic has been the segmentation of the natural basin and associated modification of the overflow regime. Floodway guide levees have divided the Basin into the central Basin Floodway and two sub basins, the Verret sub basin on the east side and Fausse Point sub basin on the west side (Plate 1). The resultant restriction of the active flood plain has intensified riverine processes within the floodway area while it has eliminated annual overflow in the marginal areas. Within the floodway, the overflow regime was further modified as a result of partial channelization of the Atchafalaya River and associated spoil disposal along its lower course from Interstate Highway 10 to Morgan City. In combination with other actions related to navigation and oil and gas extraction, the modification of the hydrologic regime has had a major adverse impact (EPA 1979).

In the mid-1500s, the Atchafalaya River started to capture flow from the Mississippi River due to a distinct gradient advantage because of a shorter course to the Gulf (van Heerden 1983). With capture of Mississippi flow came Mississippi sediment and the Basin started to slowly fill with sediments from the north. By the early 1960’s the Atchafalaya had captured 30% of the Mississippi flow creating concerns about how long New Orleans could operate as a port. The federal government then constrained the Atchafalaya distributary by building a structure at the point of diversion from the Mississippi in 1963, artificially controlling the flow down the Atchafalaya at 30% of the combined Red River and Mississippi discharges. They also constructed guide levees to contain Atchafalaya Floods within a Floodway basically cutting the size of the receiving Basin by 50% (Plate 1). The Atchafalaya Basin, preconstruction of the Atchafalaya flood control levees (the so-called M R & T guide levees), was almost twice its present size. As depicted in Plate 1, the guide levees crossed open water and swamp. Basically, it would appear that two lines were drawn on a map, each being a guide levee, without any consideration of the environmental and ecological impacts. Thus, construction of the control structure at Old River and the flood control 'role' given the Basin has meant that the sediment load of the Atchafalaya River has now only half the area it used to have to be ‘spread out,’ thus significantly enhancing the average annual sediment deposition rate in the Basin. Half the area with the same load as before means twice the potential sedimentation rate across the Basin. Additionally, the guide levees cut off the Basin Floodway from beneficial low sediment freshwater inputs from surrounding areas, resulting from precipitation events, by closing channels, slews and such, with the solid levee system. Thus, disruption of the natural hydrology dramatically reduced the benefits of these low sediment and nutrient inputs, while undoubtedly contributing to the occurrence of hypoxia events.

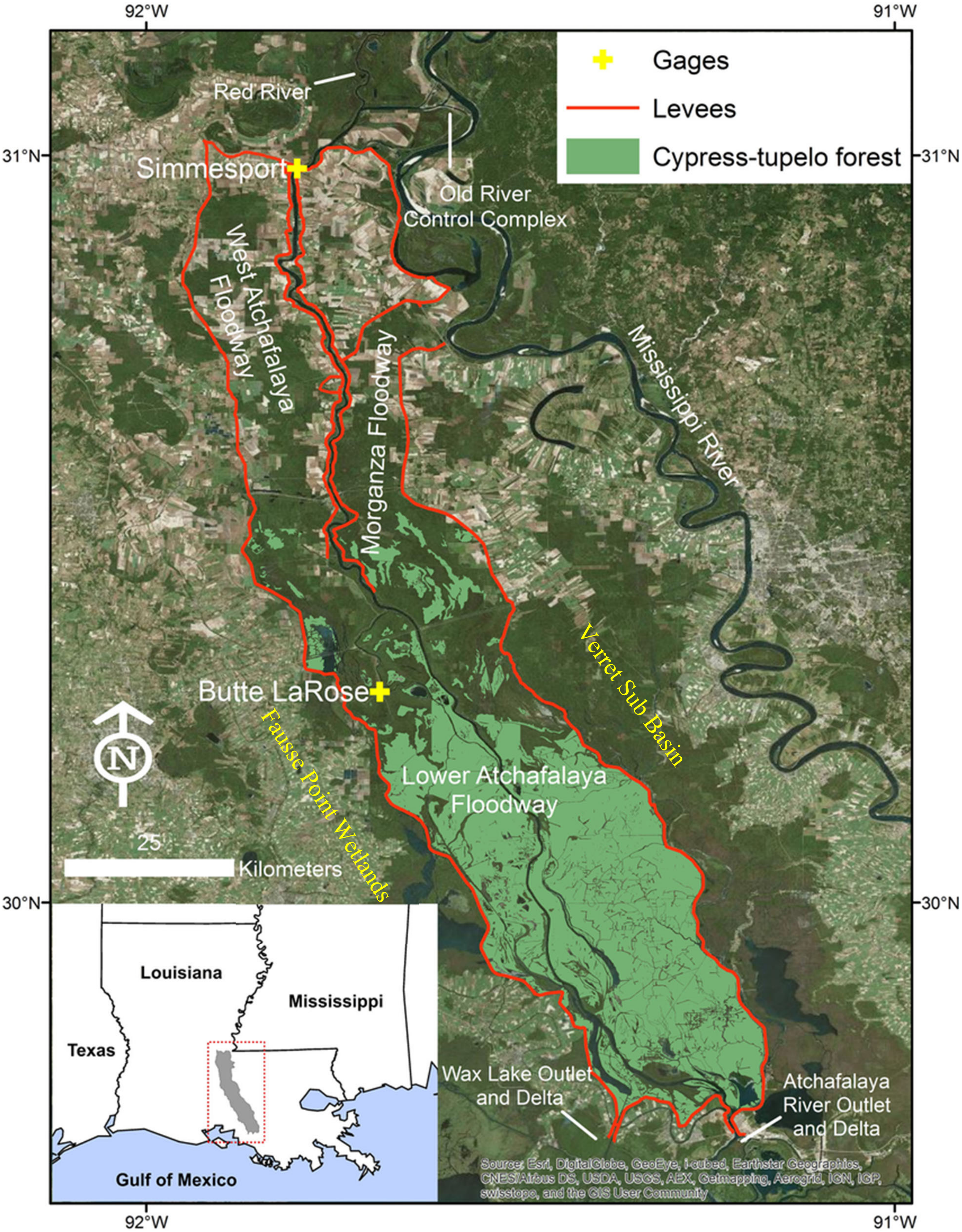

*Plate 1. Physiographic setting of the Atchafalaya Basin with the guide levees shown in red. Notice that outside the Floodway are sections (dark green) of the original swamp Basin, the Verret sub basin on the east side and Fausse Point sub basin on the west side*

The Corps very effectively altered the physics, setting up a change in the physical environment with its attendant biological responses. It constructed projects that resulted in enhanced sediment infilling of the Floodway Basin, reducing its capacity, decreasing the efficiency and potential for the floodway to hold flood waters – a real public safety issue (See van Heerden 2020).

a. **Eutrophication** is an enrichment of water by nutrients that causes structural changes to the ecosystem such as: increased production of algae and aquatic plants, depletion of fish species, general deterioration of water quality and other effects that reduce and preclude use. The chemical nutrients are typically compounds containing nitrogen, phosphorus, or both. Eutrophication can be a natural process in lakes. While annual reduction of dissolved oxygen values is in part a natural phenomenon resulting from large organic litter input and the organic nature of stillwater swamp sediments, at present, given the cutting up of the Basin with canals and pipeline cuts and oil/gas access channels, spoil piles blocking natural slews, etc.; the oxygen values in large swamp areas as well as streams are depressed for periods in excess of one month to levels where water can no longer support fish and other aquatic life.

b. **Hypoxia**, or oxygen depletion, is an environmental phenomenon where the concentration of dissolved oxygen in the water column decreases to a level that can no longer support living aquatic organisms. **Hypoxia** in the northern Gulf of Mexico is defined as a concentration of dissolved oxygen less than 2 mg/L (2 ppm). Oxygen depletion and "hypoxia" develop wherever the consumption of oxygen by organisms or chemical processes exceeds the supply of oxygen from adjacent layers of water, from the atmosphere, and from photosynthesizing organisms. Hypoxia is often associated with very high, non-normal, nutrient loading of aquatic environments, which leads to a consumption frenzy by microorganisms and algae which in turn greatly reduce the oxygen concentrations.

## TURBIDITY, NUTRIENTS AND DISSOLVED OXYGEN.

### a. Turbidity.

Turbidity is the quality of a fluid being cloudy, opaque, or thick with suspended matter; "the measurement of turbidity is a key test of water quality. Or said slightly differently; Turbidity is the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid include clay, silt, very tiny inorganic and organic matter, algae, dissolved colored organic compounds, and plankton and other microscopic organisms. Turbidity, which is measured by shining a light through the water is reported in Formanzin Nephelometric Units (FNU). High numbers mean low water clarity and vice versa.

### b. Nitrogen.

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. The nitrate ion ($NO3^-$) is the stable form of combined nitrogen for oxygenated systems. Although chemically unreactive, it can be reduced by microbial action. The nitrite ion ($NO_2^-$) contains nitrogen in a relatively unstable oxidation state. Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (ICAIR Life Systems, Inc., 1987).

Nitrate is used mainly in inorganic fertilizers. It is also used as an oxidizing agent and in the production of explosives, and purified potassium nitrate is used for glass making. Sodium nitrite is used as a food preservative, especially in cured meats. Nitrate is sometimes also added to food to serve as a reservoir for nitrite. Nitrates occur naturally in plants, for which it is a key nutrient. Nitrate and nitrite are also formed endogenously in mammals, including humans. Nitrate is secreted in saliva and then converted to nitrite by oral microflora.

Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater treatment and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks.

In this study the combination of Nitrate and Nitrite data is reference as Nitrogen, for simplicity reasons.

### c. Dissolved Oxygen

Dissolved Oxygen (DO) refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water. In limnology (the study of lakes), dissolved oxygen is an essential factor second only to water itself. A dissolved oxygen level that is too high or too low can harm aquatic life and affect water quality.

Non-compound oxygen, or free oxygen ($O_2$), is oxygen that is not bonded to any other element. Dissolved Oxygen is the presence of these free $O_2$ molecules within water. The bonded oxygen molecule in water ($H_2O$) is in a compound and does not count toward dissolved oxygen levels. One can imagine that free oxygen molecules dissolve in water much the way salt or sugar does when it is stirred.

Dissolved Oxygen is necessary to many forms of life including fish, invertebrates, bacteria and plants. These organisms use oxygen in respiration, similar to organisms on land. Fish and crustaceans obtain oxygen for respiration through their gills, while plant life and phytoplankton require dissolved oxygen for respiration when there is no light for photosynthesis. The amount of dissolved oxygen needed varies from creature to creature. Bottom feeders, crabs, oysters and worms need minimal amounts of oxygen (1-6 mg/L), while shallow water fish need higher levels (4-15 mg/L) (www.fondriest.com).

Microbes such as bacteria and fungi also require dissolved oxygen. These organisms use DO to decompose organic material at the bottom of a body of water. Microbial decomposition is an important contributor to nutrient recycling. However, if there is an excess of decaying organic material (from dying algae and other organisms), in a body of water with infrequent or no turnover (also known as stratification), the oxygen at lower water levels will get used up quicker.

Dissolved oxygen enters water through the air or as a plant byproduct. From the air, oxygen can slowly diffuse across the water's surface from the surrounding atmosphere, or be mixed in quickly through aeration, whether natural or man-made. The aeration of water can be caused by wind (creating waves), rapids, waterfalls, ground water discharge or other forms of running water.

A waste product of photosynthesis from phytoplankton, algae, seaweed and other aquatic plants, DO is also produced. While most photosynthesis takes place at the surface (by shallow water plants and algae), a large portion of the process takes place underwater (by seaweed, sub-surface algae and phytoplankton). Light can penetrate water, though the depth that it can reach varies due to dissolved solids and other light-scattering elements present in the water. Depth also affects the wavelengths available to plants, with red being absorbed quickly and blue light being visible past 100 m. In clear water, there is no longer enough light for photosynthesis to occur beyond 200 m, and aquatic plants no longer grow. In turbid water, this photic (light-penetrating) zone is often much shallower.

Regardless of wavelengths available, the cycle doesn't change. In addition to the needed light, CO2 is readily absorbed by water (it's about 200 times more soluble than oxygen) and the oxygen produced as a byproduct remains dissolved in water. As aquatic photosynthesis is light-dependent, the dissolved oxygen produced will peak during daylight hours and decline at night.

In a stable body of water with no stratification, dissolved oxygen will remain at 100% air saturation. 100% air saturation means that the water is holding as many dissolved gas molecules as it can in equilibrium. At equilibrium, the percentage of each gas in the water would be equivalent to the percentage of that gas in the atmosphere – i.e. its partial pressure. The water will slowly absorb oxygen and other gasses from the atmosphere until it reaches equilibrium at complete saturation. This process is sped up by wind-driven waves and other sources of aeration.

Two bodies of water that are both 100% air-saturated do not necessarily have the same concentration of dissolved oxygen. The actual amount of dissolved oxygen (in mg/L) will vary depending on temperature, pressure and salinity (Diagram 1).

The solubility of oxygen decreases as temperature increases. This means that warmer surface water requires less dissolved oxygen to reach 100% air saturation than does deeper, cooler water. For example, at sea level (1 atm or 760 mmHg) and 4°C (39°F), 100% air-saturated water would hold 10.92 mg/L of dissolved oxygen. But if the temperature were raised to room temperature, 21°C (70°F), there would only be 8.68 mg/L DO at 100% air saturation.

In this study this temperature related property of dissolved oxygen is considered in the results discussion, but it is important to note that a literature search concerning Eutrophication in the Atchafalaya Floodway has revealed no realization of this temperature relationship of collected data in management decisions or project justifications! This is a real failing in many management decisions of the past where low dissolved oxygen levels have been used to justify swamp 'infilling' projects.

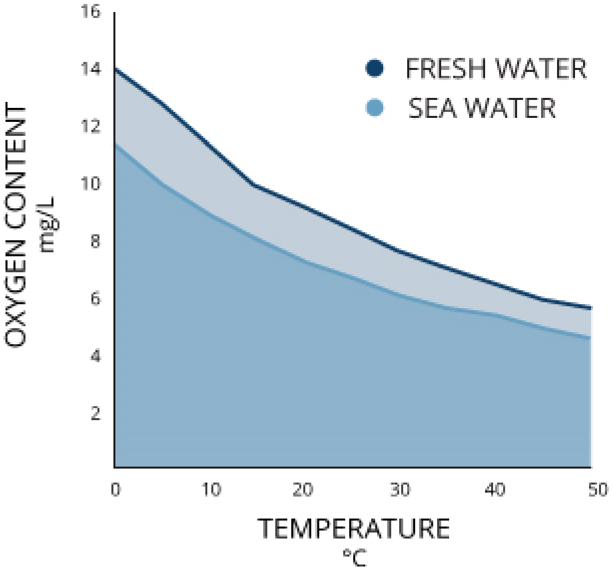

*Diagram 1. Dissolved Oxygen content as a function of temperature*

## SOURCE OF TURBIDITY IN THE ATCHAFALAYA BASIN

### a. Sediments

Van Heerden (2020) discusses the nature of the sediments in the basin, as well as sedimentation, sediment transport and suspended load and impacts for the Basin. Thus, there is no sediment discussion herein. The van Heerden (2020) report is a sister to this report.

### b. Nutrients

Human population growth and its associated activities have altered landscapes, hydrologic cycles, and the flux of riverine constituents at accelerating rates over the last several centuries (Galloway and Cowling 2002). Significantly increasing loads of nutrients, particularly nitrogen and phosphorus, have found their way to the coastal ocean, especially during the last half of the 20th century (Figure 1). There are thresholds of nutrient loading above which the nutrient inputs no longer stimulate entirely positive responses from the ecosystem, such as increased fisheries production (Rabalais 2002). Instead changes in land-based sources of nutrients are leading to eutrophication of coastal waters with symptoms of poor water quality, noxious algal blooms, oxygen depletion, and, in some cases, loss of fisheries production (Rabalais et al, 2007). Eutrophication is becoming a major environmental problem in estuarine and coastal waters throughout the world (Nixon 1995), even in inner to mid-continental shelf waters (Rabalais 2005). Estuarine and coastal riverine systems with high water residence time such as the Atchafalaya Basin are susceptible to eutrophication, given adequate light conditions (Cloern 2001). In contrast, coastal ecosystems adjacent to large rivers with swift currents that move materials away from the river mouth that deter the development of stratification are not conducive to the accumulation of biomass or depletion of oxygen, as for example in the Amazon and Orinoco River plumes.

The Mississippi River forms the largest watershed on the North American continent. It discharges on average 580 $km^3$ of fresh water per year to the northern Gulf of Mexico through two main distributaries: the birdfoot delta southeast of the city of New Orleans, Louisiana, and the Atchafalaya River Basin deltas, Lower Atchafalaya mouth and Wax Lake Outlet, 200 km to the west that carries about one-third of the flow (van Heerden 1983, Meade 1996). The Mississippi River system discharges sediment yields of $210 * 10^6$ Mg/yr., $1.6 * 10^6$ Mg/yr. nitrogen, of which $0.95 * 10^6$ Mg is nitrate and $0.58 * 10^6$ Mg is organic nitrogen, $0.1 * 10^6$ Mg/yr. phosphorus, and $2.1 * 10^6$ Mg/yr. silica (Milliman and Meade 1983, Meade 1996, Goolsby et al. 1999). The Louisiana coastal ecosystem is productive (~300 g $Cm^2yr^1$; Turner and Allen 1982, Lohrenz et al. 1990) and the location of the second largest zone of coastal hypoxia (defined here as dissolved oxygen <2 mg/L) in the world's oceans (Rabalais et al. 2002).

Figure 1 aptly reveals the uncoupled relationship, before 1975, between the mean annual concentration of nitrate and silicate in the Mississippi River at New Orleans and the coherent changes after 1980 (Rabalais 2007). In other words, mean annual concentration of nitrate and silicate in the Mississippi River at New Orleans were not linked in the pre-heavy use of industrial fertilizer in the Mississippi River's catchment. Once commercial fertilizer use became widespread the concentrations of these variables became linked, the suspended sediment of the Mississippi River (represented by the silica concentration), and nutrient loading became coupled. Thus, measurements of turbidity then become a good measure of the ever-changing suspended sediment and coupled nutrient loads. Present day nutrient loads, as represented by Nitrate, are three-times what they were prior to about 1973 (Figure 1).

Welch et al (2014) present data related to nutrient loading of the Atchafalaya Basin during the 2011 flood. It is important to note that Welch et al (2014) only sampled main river channels and not any swamp sites. They point out that Nitrate composed about 70% of the total Nitrogen Flux and that there were no substantial losses or gains in the Atchafalaya or Lower Mississippi River channels themselves. However, as will be shown shortly there is a marked

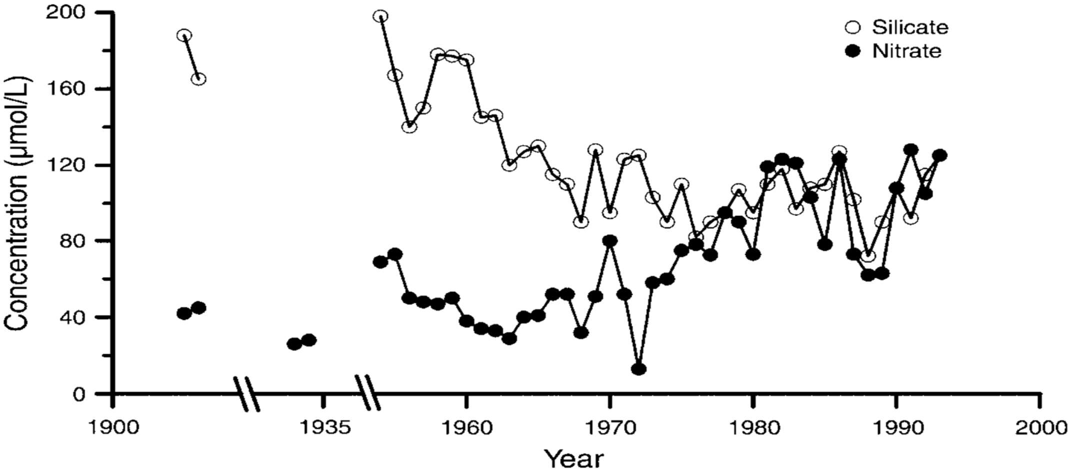

*Figure. 1. The mean annual concentration of nitrate and silicate in the Mississippi River at New Orleans. Note the uncoupled relationship between the two variables before 1975 and the coherent changes after 1980 (Rabalais. 2007).*

modification, lowering, of the Nitrogen levels as the Mississippi sourced waters flow through the Basin, and the Welsh etal (2014) results will be explained shortly.

But what happens to the Nitrogen when it enters the still water of an interior swamp? It has nowhere to go so potentially Nitrogen loading of the swamp takes place – loading that could cause hypoxia. As will be presented below there is a marked difference in the N levels as well dissolved Oxygen between the Mississippi River input and Atchafalaya waters leaving the Basin at its coastal exits. Welch et al (2014) point out that when suspended sediment fluxes increase, agricultural chemicals attached to sediment can be readily transported downstream and may further exacerbate water quality problems in receiving surface-water bodies. So, if you increase the discharge (flux) of suspended sediments into Atchafalaya Basin interior swamps you are going to exacerbate water quality problems and hence potential lowering of oxygen concentrations and hypoxia. Horowitz (2010) concludes that suspended sediments delivers about 85% of the annual phosphorous flux and 30% of the annual Nitrogen flux to the region.

As streamflow was decreasing in the 2011 flood in the Lower Mississippi River - Atchafalaya River sub basin (Welch etal 2014), orthophosphate composed an increasing percentage of the total phosphorous concentration, probably because of return of waters low in oxygen concentration from stillwater areas such as inundated lands, backwater streams, and floodways. Poorly oxygenated waters promote the release of sediment-bound phosphorous into the more readily available dissolved form. So, the data collected by Welch etal (2014) suggest that a low oxygen concentration promotes the release of phosphorous.

There are those that have advocated that to reduce the hypoxia in the northern Gulf of Mexico one should try to capture the nutrients before such exit the Atchafalaya and Mississippi Rivers. A thought has been that projects such as the Louisiana Coastal Protection and Restoration Authority's (CPRA) East Grande Lake (EGL) project will lead to capture of these nutrients and help the Gulf to the detriment of the Basin. However, if one really wants to capture the nutrients one needs to attack them at their source – heavy use of industrial fertilizers on upcountry farmlands. The political will does not seem to be there to achieve this so instead we should concentrate on building as many Atchafalaya and Wax Lake deltas along our coast as possible to try to reduce or stem coastal land loss (so necessary for coastal Louisiana's future) and tie up the nutrients here where they will stimulate marsh growth, instead of filling up the Atchafalaya Basin with suspended sediments. The Basin once lost will never be returned or restored. It will be lost forever.

Cypress swamps are fragile, require unique conditions of hydrology, geomorphology and dry periods to germinate, sprout and grow. If the environment is kept pristine in that the physics do not change then these swamps can survive for thousands of years. Louisiana was blessed with hundreds of thousands of acres of these biological wonders, but man through altering the physics and the physical environment has destroyed most of these swamps. The Atchafalaya

Swamps are under direct threat as the physics of the environment undergoes dramatic changes. These swamps survived by limited suspended sediment being deposited on the natural Basin levees and some fine-grained clays, organic matter and nutrients would through overbank flow enter the basin and slowly drain out at its seaward ends, maintaining the health and integrity of the system. Sixty plus inches of rain p.a. aided the natural hydrology. That is not the case today.

The Corps of Engineers' management of the Basin (van Heerden 2019, 2020) is accelerating the physical change due to significantly enhancing sedimentation rates within the Basin. This infilling is aided by oil and gas canals/excavations such as pipeline canals, as well as large scale 'restoration' projects implemented to improve water quality but instead lead to eutrophication and swamp destruction. This is the death knell of cypress swamps – it is also precipitating a substantial public safety issue as we fill the "tank" that is supposed to hold Mississippi and Atchafalaya flood waters – the Floodways purpose – that is being accelerated by rapidly rising sea levels off the Louisiana coast. All decreasing the functionality of the Floodway each year—a looming public safety issue!

1. Sources for Turbidity Data

This thesis will discuss data obtained by review of the scientific literature; data from the USGS National Water Information System web pages; academic thesis; and, obtained from the state of Louisiana. Unfortunately, the dataset is not complete due to state entities not releasing requested data. The study period is 1 January 2016 through to 31 December 2019 being the interval during which data from various sources were collected in the Basin.

Data was also obtained by review of a master's thesis from Nichol's State University. Kong's 2017 thesis titled "Population characteristics of red swamp crayfish *Procambarus clarkii* from hydrologically impaired locations in the Atchafalaya River *Basin*" presents data from locations in the central part of the eastern half of the Floodway for Atchafalaya River for flood events in 2016 and 2017. Unfortunately, her University, although funded by state dollars, would not make available the original data. It appears that The Nature Conservancy (TNC) funded her work. So, where necessary Kong's data as presented in her thesis has been subjected to different plots, and other data sets have been incorporated to further interpret the data. Missing from her thesis is any quality control or assessment of the accuracy of her measurements, no calibration data, and the actual measurements. So, in this respect this thesis is still a working draft as we await Nicholls State University to respond to our requests. van Heerden (2019) discusses Kong's thesis in depth.

Lastly, since 2016 TNC has been collecting data under contract to Louisiana Department of Natural Resources (DNR) and then CPRA. The 2016 to 2018 final reports were made available to us by DNR. The 2019 data collected by TNC, requested through a FOIA application have recently been supplied by the CPRA. Unfortunately, that data does not cover the whole year.

## NATURE OF THE RIVER FLOODS 2016 through 2019

### a. Characteristics of 2016 Flood versus the 2017 Flood as Sampled by Kong (2017) and TNC.

Plate 2 depicts the Mississippi Catchment and location of its main distributaries. Suspended sediment and nutrient loads for each Mississippi/Atchafalaya flood are controlled in part by which Mississippi upstream tributaries are in flood. Reference was made in this phenomenon above when discussing the extreme flood on the Mississippi River of 2011 when the major contributor of streamflow to the lower Mississippi-Atchafalaya River sub basin during April and May was the Ohio River, whose water contained lower concentrations of suspended sediment, pesticides, and nutrients than water from the upper Mississippi River (Welch et al 2014).

Figure 2 represents the daily Floodway stage at Butte la Rose recorded for 2016 and 2017. The Figure also reveals the rather short time period that Kong sampled her sites in the Basin (Kong's 3.5 m line shown, discussed later). The 2016 flooding on the Missouri and Upper Mississippi Rivers which included extensive snow melt would have contributed very high levels of suspended sediment (Plate 2) during the period of Kong's sampling. By contrast, the 2017 flood peak sampled by Kong in 2017 represented the result of 1:1000-year rainfall in a relatively narrow east-west band from Joplin MO to New Albany IN the lower half of the Mississippi catchment across a portion of the Mississippi and Ohio Rivers (Plates 3 and 4). This was a sudden rainfall induced flood peak and not fed by the upper reaches of any of the main Mississippi River catchment feeders such as the Missouri River - a very different kind of flood and not a great suspended sediment producer. So, suspended sediment loads reaching the Atchafalaya Floodway were lower than normal for the flood peak on the Atchafalaya River associated with this 1:1000-year rainfall event south of St Louis MO, to be discussed below.

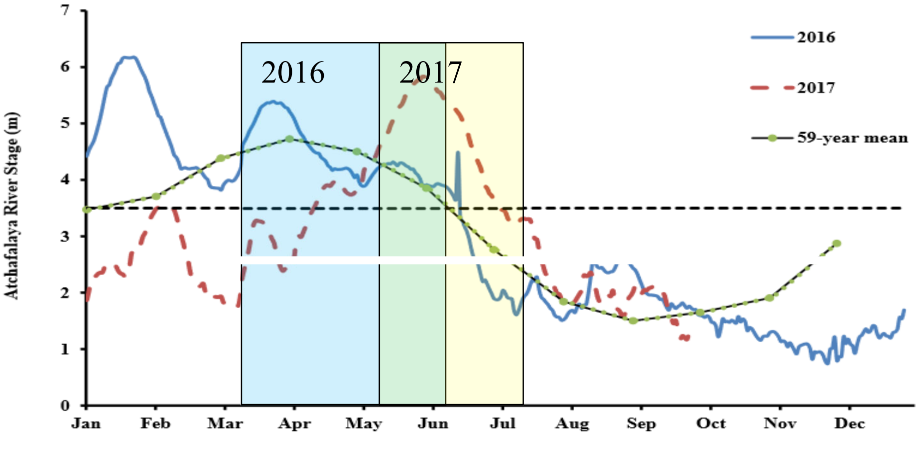

*Figure 2. Daily Atchafalaya River stage at Butte La Rose for 2016 and 2017 and the 59-year monthly mean. Also shown are Kong's sampling period for each of the years. Note the relatively narrow flood band of the 2017 rain induced flood, which was sampled in its ebbing stages.*

What is evident is that for each of Kong's sampling periods is that she did get data during a flood peak, part of the overall Atchafalaya flood of each year (Figure 2).

*Plate 2. Tributaries of the Mississippi River and its catchment.*

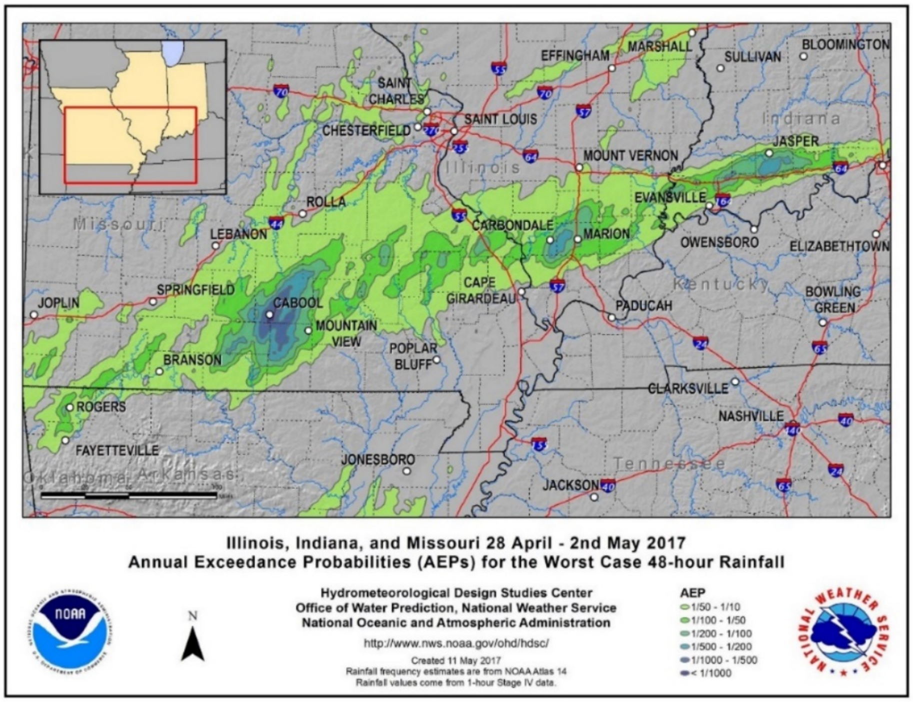

*Plate 3. The catastrophic 1:1000-year rainfall event that precipitated a 2017 flood peak event on the Atchafalaya.*

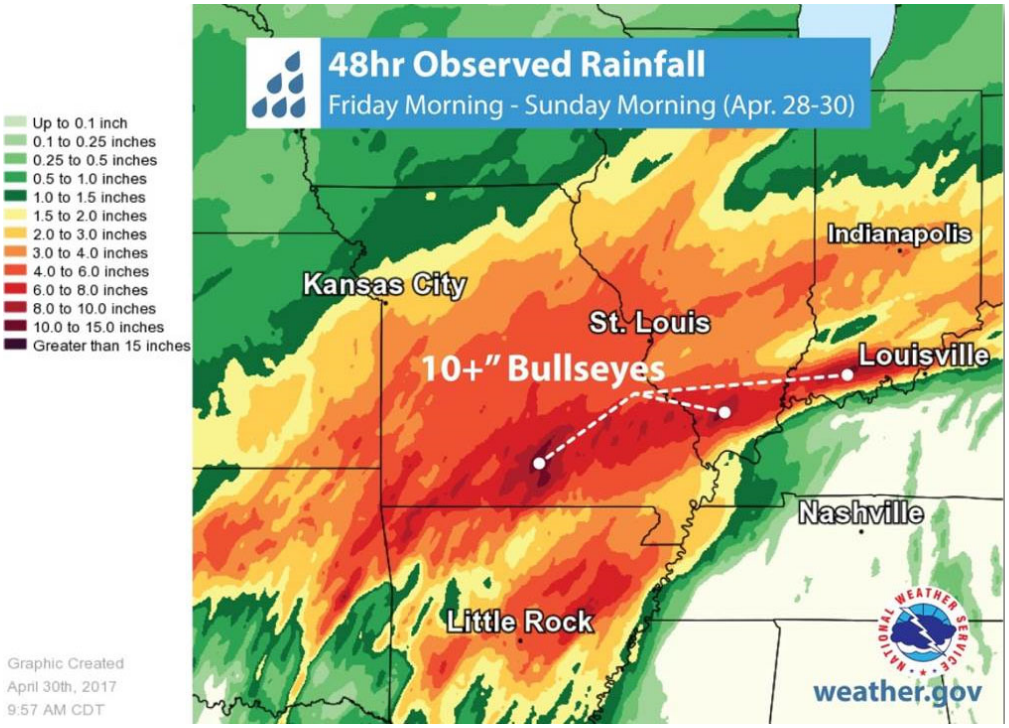

*Plate 4. 48 Hour Observed Rainfall during 1:1000- year event, April 2017.*

As previously presented turbidity (suspended sediment) and nutrient levels are coupled (Rabalais 2007). Higher the turbidity the higher the nutrient concentrations being carried by the flood water.

b. 2018 and 2019 Mississippi River Floods

Initial review of flood literature suggests the early 2018 flood (February through mid-June) was a Mississippi Catchment flood with an apparent strong contribution from the Upper Mississippi and Missouri Rivers. During major floods, the Bonnet Carre Spillway can be utilized to divert part of the flow of the Mississippi River into Lake Pontchartrain, being operated to limit the Mississippi River flow passing New Orleans, Louisiana, to the project design flood discharge of 1.25 million cubic feet per second (cfs).The Bonnet Carre Spillway was opened for 23 days from March 8th through March 30th. A total of 168 gates was opened by March 15th, 48% of capacity. The River was in flood at Baton Rouge for 67 days (6th longest since 1927) and Red River Landing was above flood stage for 74 days (7th longest since 1927). Additionally, there were several major rainfall events in Louisiana during the year and some severe flooding when a drain system 'stalled.'

The 2019 Mississippi River flood was the longest known flood of record on the lower Mississippi River (Figure 3), flooding during the winter, spring, and summer of 2019; caused at least 12 deaths and economic losses in excess of $20 billion. Estimated damages in the Midwestern United States alone had reached $12.5 billion by April 2019. Flooding along the Mississippi River was not the result of a single weather event. Instead, a series of flood events in tributary basins produced Mississippi River flooding of record duration. Flooding along the Tennessee and Ohio Rivers in the winter was followed by catastrophic floods in portions of the Midwestern United States in the early spring and record flooding along the Arkansas River in late May. While the Mississippi River flood of 2019 set records for duration and total volume, only a few locations along the Mississippi River saw record stages or flows.

In late May 2019, the U.S. Army Corps of Engineers announced plans to operate the Morganza Control Structure in early June to prevent overtopping of the structure and reduce river stages along Mississippi River levees. The proposed operation would have diverted 150,000 cfs from the Mississippi River into the Morganza Floodway, thence into the Atchafalaya Floodway. The planned operation was postponed (and eventually cancelled) when subsequent forecasts indicated that stages would be lower than originally predicted.

The Bonnet Carre' Spillway was opened on 27 February 2019 for the first time in two consecutive years. The peak diversion discharge through the Spillway of 213,000 cfs occurred on 19 March 2019. The Spillway was closed on 10 April 2019. The average diversion discharge was approximately 140,000 cfs.

The Bonnet Carre' Spillway was reopened on 10 May 2019 marking the first time that the Spillway has been operated twice in the same year. The peak diversion discharge of 161,000 cfs occurred on 21-22 May 2019. The Spillway was closed on 27 July 2019. The average diversion discharge was approximately 120,000 cfs.

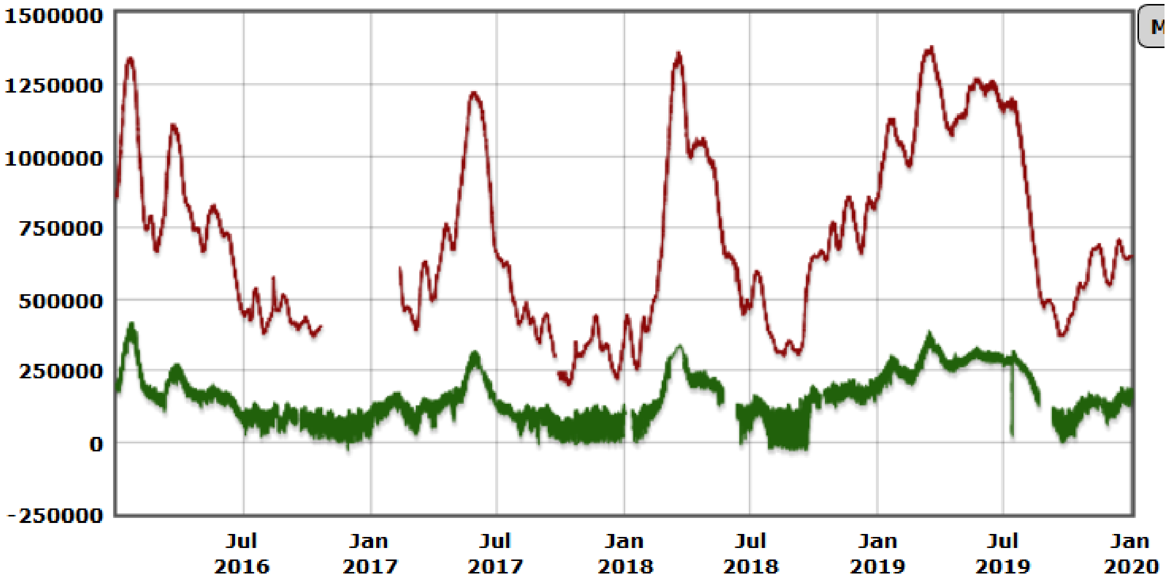

*Figure 3. Mississippi discharge (Brown) vs Atchafalaya Discharge (Green) in cfs. 2016 to 2019*

Turbidity and nutrient related algae and bacteria blooms were recorded from Texas through the Florida Panhandle. Even bathing was restricted or stopped because of the toxicity of the waters. This simply represents that the environment is having a hard time trying to adjust to the highly elevated nutrient loading of the Mississippi River. Unless the federal government steps in with a strong hand, this toxicity issue will only get worse!

# 2016 TO 2019 TRENDS IN DISCHARGE, NUTRIENT LOADING, AND DISSOLVED OXYGEN IN THE MISSISSIPPI AND ATCHAFALAYA RIVERS - The Big Picture.

This chapter will review the overall system, the big picture so to speak. Following sections will then focus in on selected areas of the Floodway associated with the CPRA proposed EGL project. Recently it has become much easier to access data from the USGS National Water Information System web page (https://nwis.waterdata.usgs.gov/nwis). This allows multi year comparisons of different water quality measures as well as comparisons of basin to basin. The following discussions will specifically review and compare data from the Mississippi River at Baton Rouge and the Atchafalaya at Morgan City. The Baton Rouge site was chosen as being representative of the inflow from the Mississippi via the Old River diversion into the upper part of the Atchafalaya Basin Floodway – in other words what is coming in at the top. The Morgan City gauging station is representative of what is flowing out of the bottom of the Basin and thus, in comparison to the Baton Rouge data, allows a quantification and assessment of water quality changes occurring as the flow moves through the Basin. It must be noted, Welch etal (2014) stated that in the 2011 flood there was little change in the Nitrogen levels in the channels as they transvers the Basin Floodway. The data presented below reveals that there is a strong modification of nutrient levels as evidence by the flood waters leaving the Floodway for the period 2016 to 2019. However, in the 2011 flood the Morganza Spillway was opened allowing a flush of the eastern half of the Basin and could well have skewed her results. In the present study the Morganza Spillway was never opened and the Nitrogen levels, comparing the Mississippi input to the seawards Atchafalaya export, underwent some meaningful modifications with ramifications for the health of the Basin.

## a. Turbidity Data

Turbidity measurements in the Mississippi at Baton Rouge and at Atchafalaya at Morgan City reflect a point in the stream, it is not a cross section. However, as it is a well-mixed turbulent flow regime, it is an indicator of potential flux. The latter depends on the net concentration of nutrients and the total suspended sediment loads from all the Mississippi Catchment tributaries. The contribution from each tributary is unique to itself reflecting size of the catchment area, farming acreage, number and size of cities, discharge regime, and individual weather patterns and conditions. As a result, the turbidity is not a straight line.

Figure 4 is a plot of 2016 to 2019 Mississippi River discharge and associated turbidity measured in FNU units. What is very apparent is that there does not seem to be a correlation between the discharge rate and the turbidity; the range seems to be about 25 FNU to a high of around 175 FNU with an eyeball average of about 60 units but that over time the turbidity trend appears to be downwards. For this discussion the seeming straight-line peaks are ignored as possible abnormalities. The major flood of 2019 appears to have the lowest turbidity measurements of the 4-year period. The lowering of the turbidity measurements in 2019 may actually be a response to ‘dilution’ due to the vast volume of water, in excess of 900,000 cfs, that characterized at least 7 months of this flood (Figure 4). The discharge in 2019 far exceeded the previous three years.

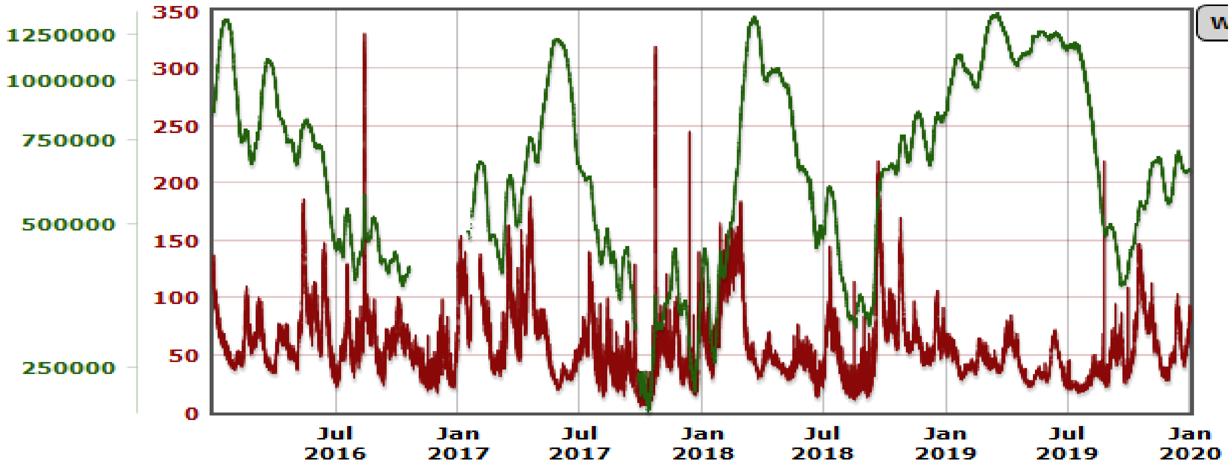

*Figure 4. Mississippi River Discharge (Green) vs Turbidity (Brown), 2016 -2019. Discharge in cfs, Turbidity FNU.*

Discharge in the Atchafalaya River for the 4-year period, 2016 to 2019, varied from about 90,000 to 420,000 cubic feet per second (cfs), about the federal mandated 30% of the Mississippi flow upstream of Old River (Figure 5). Ignoring the straight-line peaks, the turbidity seems to have varied from about 50 FNU to about 275 FNU and like the Mississippi case, the turbidity seems to be below the long-term trend for at least part of the 2019 flood possible due to some dilution. In due course we will look into the turbidity picture more closely.

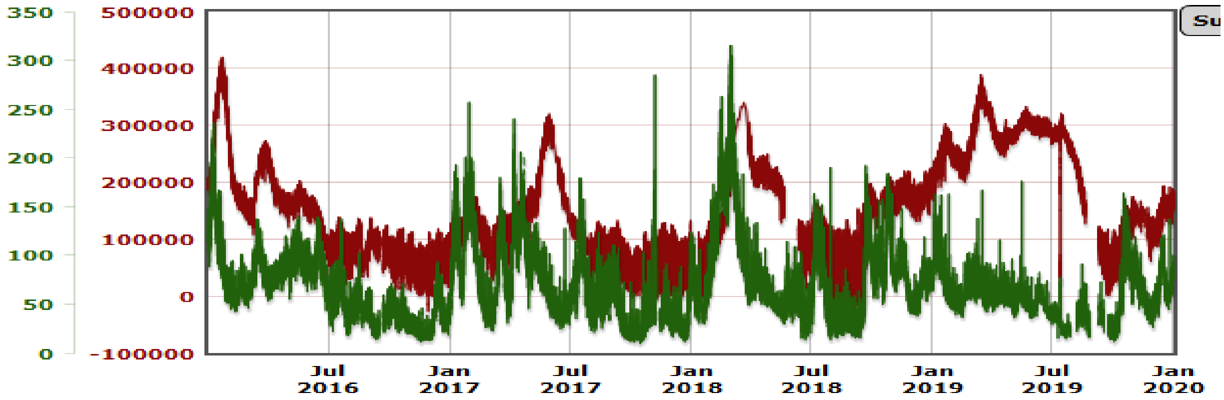

*Figure 5. 2016 - 2019 Lower Atchafalaya River at Morgan City River Discharge (Brown) vs Turbidity (Green).*

The 2016 Turbidity comparison between the Mississippi and Atchafalaya Rivers is presented in Figure 6. During the winter/spring months (January to July) the Atchafalaya Turbidity is higher than the Mississippi; seems the reverse for the rest of the year. So, what is the pattern for the rest of the study period? In 2017 (Figure 7) a similar pattern appears to be present in that the Atchafalaya Turbidity is higher than the Mississippi, January to July, but thereafter they appear similar. As pointed out earlier in late April/early May 2017 a major rainfall event occurred in a small section of the Mississippi Catchment. The nature of the flood meant it had a lower than normal nutrient load and that is discernable in Figure 7 as the turbidity levels fell from late April through July of that year. Figure 8 reveals the 2018 Turbidity plots for both rivers. In this year

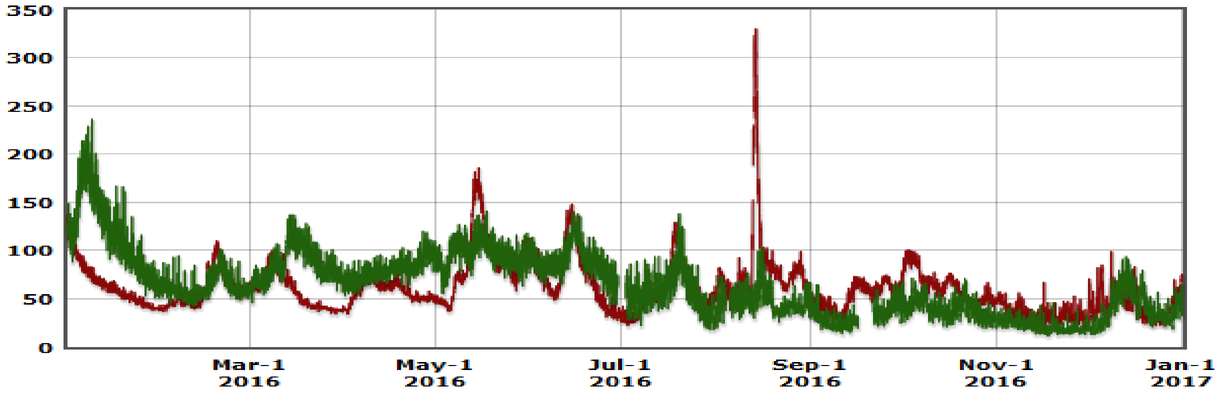

*Figure 6. 2016 Mississippi (Brown) and Atchafalaya (Green), Turbidity in FNU*

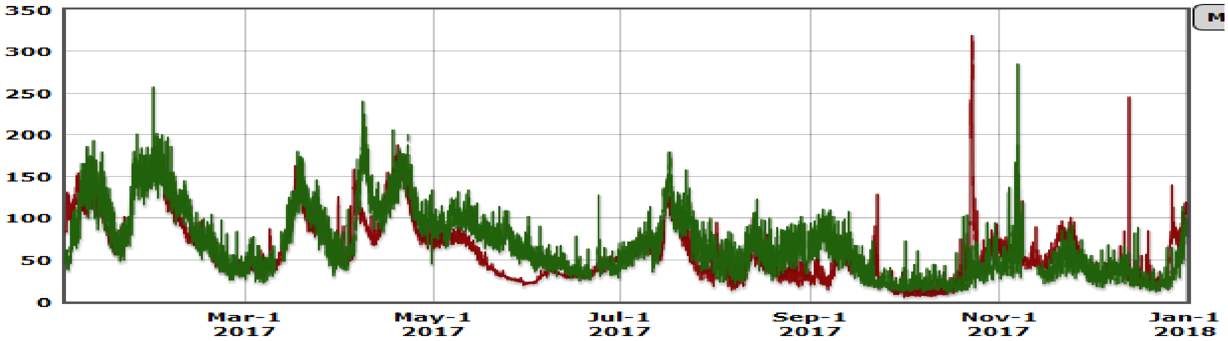

*Figure 7. 2017 Mississippi (Brown) and Atchafalaya (Green), Turbidity (FNU).*

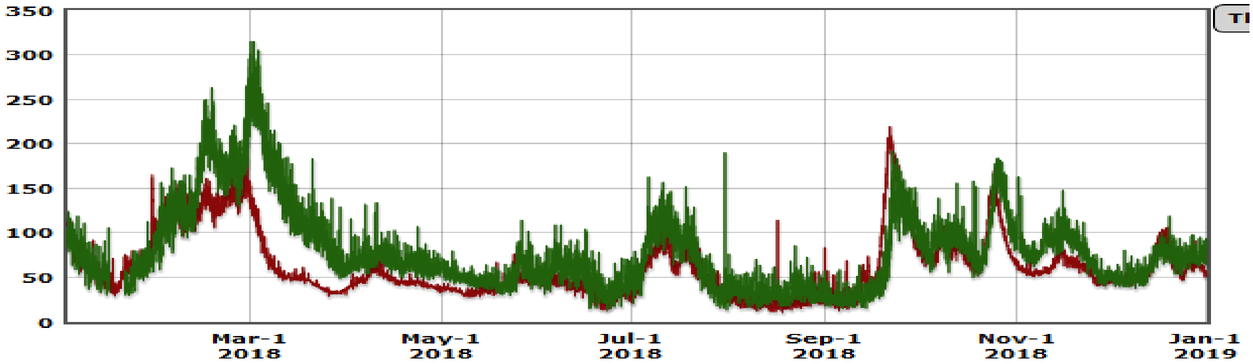

*Figure 8. 2018 Mississippi (Brown) and Atchafalaya (Green) Turbidity (FNU).*

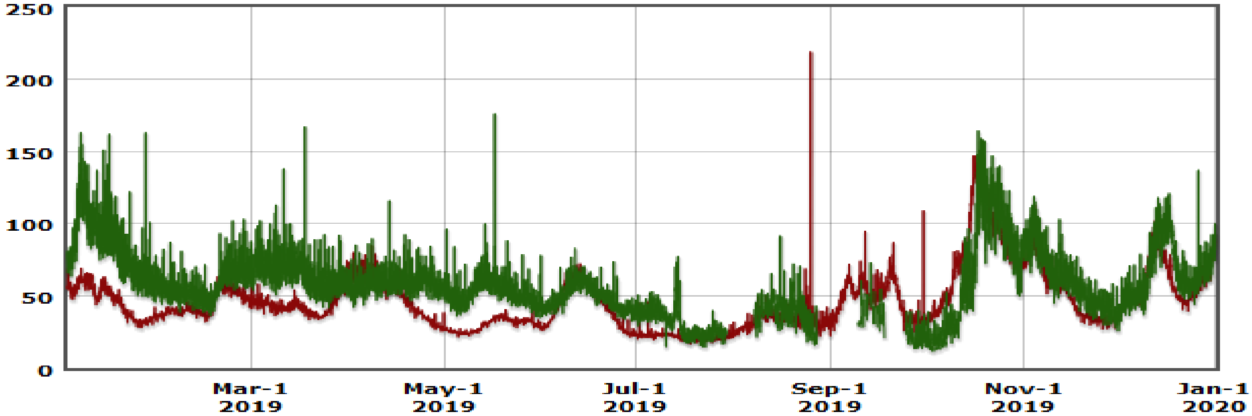

*Figure 9. 2019 Mississippi (Brown) and Atchafalaya (Green) Turbidity (FNU).*

the Turbidity in the Atchafalaya River at Morgan City (southern end of Basin) is generally higher in January to July, but the pattern  seems to hold through the year. A similar pattern holds for 2019 (Figure 9). This may reflect that from 1 March 2018 through to January 2020 the Mississippi River was basically flooding except for two months of the summer of 2018

So, in general, Turbidity in the Atchafalaya River at its lowest end, where it exits the Basin heading to the coast and Atchafalaya Bay, exceeds that of the Mississippi when the River is in flood. Why, they both have the same source?

b. Nitrogen Data, 2016 to 2019.

Figure 10 represents the plot of discharge as against the Nitrate plus Nitrite (hereafter referred to as N) concentrations measured for the Mississippi River at Baton Rouge for the period 2016 – 2019. Generally, the N concentration mirrors the discharge regime but not always; at times there being mark variances. It varied from a low of 0.5 mg/l in the winter of 2017/2018 to a narrow peak high of 3.0 mg/l in July 2018. As the N concentrations are point measurements, they are not necessarily an expression of the flux of nutrients. The actual concentration may reflect the source of the flood waters (i.e. from which major tributary did flow originate) as well as dilution in major floods.

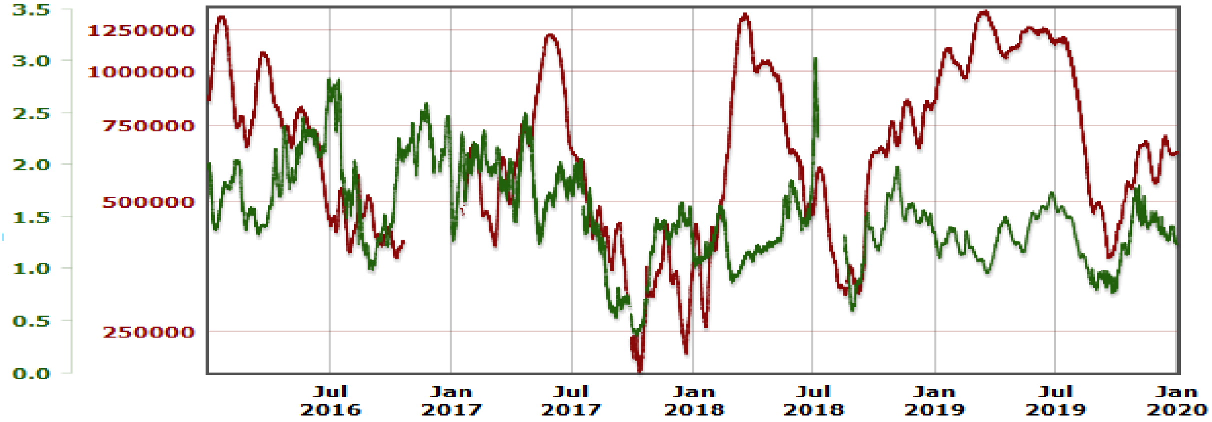

*Figure 10. 2016 – 2019 Mississippi River Discharge (Brown) vs Nitrate plus Nitrite (Green), discharge in cfs, N in mg/l.*

The Atchafalaya discharge variance plot as against the Nitrogen concentration for 2016-2019 is presented in Figure 11. There is a striking difference as compared to the Mississippi (Figure 10). The N levels generally appear to be lower in the Atchafalaya River than the Mississippi for most of the year (compare Figures 10 and 11). We will now examine each year individually in order to try to understand these variances. N levels fluctuate independent of discharge reflecting the source of the Mississippi flood waters in its catchment.

Figures 12 a, b, c, and d for the years 2016 through 2019 reveal that in general the N concentration in the Atchafalaya tracks that of the Mississippi, although there are differences. Higher N in the Mississippi River January to August, except for the major flood year of 2019. (Figure 12d). This year was marked by a major long duration flood with discharges rising again in October and it would appear as a consequence the Mississippi N levels were always higher

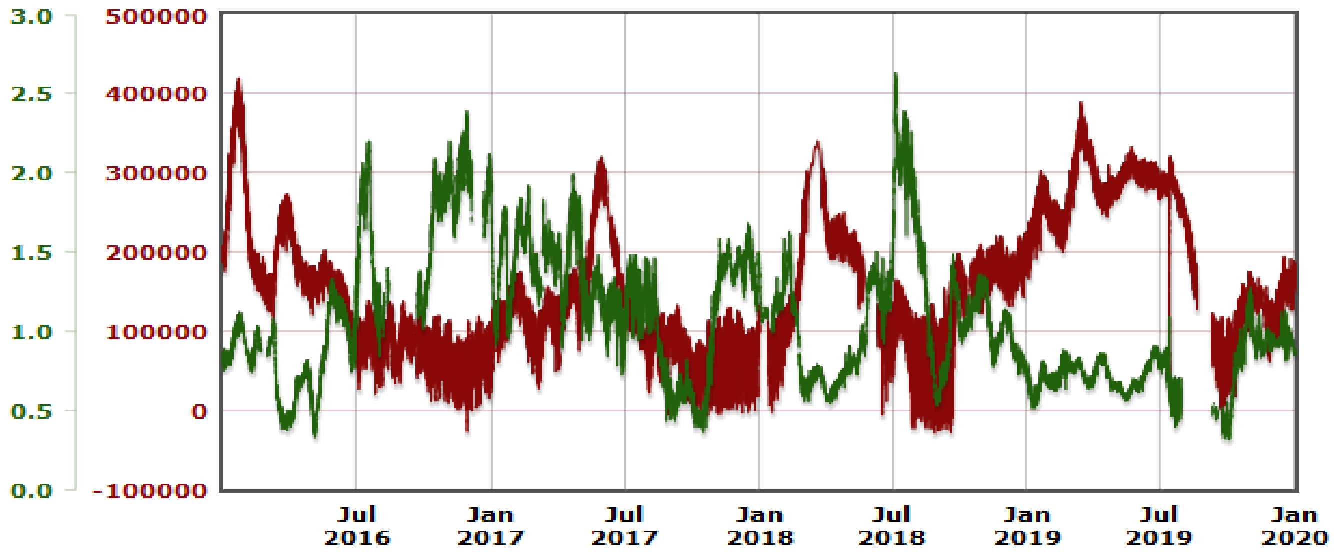

*Figure 11. 2016-2019 Lower Atchafalaya River at Morgan City River Discharge cfs (Brown) vs Nitrate plus Nitrite in mg/l (Green).*

than those of the lower Atchafalaya River. In some years the N concentration is the Atchafalaya is half that of the Mississippi River. Why the difference one would ask, where is the Nitrogen going; or in other words, what is absorbing or consuming the Nitrates and Nitrides as the Atchafalaya River flood water cross the swamp Basin from the North to the South? The Nitrogen levels fall as the flood waters from the Mississippi passing down and through the Atchafalaya Basin increase in Turbidity! Intuitively this does not make sense. Now we need to see what is happening to the dissolved Oxygen concentrations as the flood waters cross the Basin from the Mississippi River water input at Old River, to exiting of the Basin at Morgan City.

c. Dissolved Oxygen concentrations, 2016 to 2019.

In general, the dissolved Oxygen levels in the Atchafalaya River, at its southern end once crossing the Basin, are lower than that of the Mississippi River; its original source (Figure 13). This may be key to understand the N variances. The biggest difference is when the river flood is waning and temperatures are on the increase, May to August.

Figure 14 a, b, c, and d represent the USGS data for the Mississippi River location of dissolved Oxygen (brown) vs Nitrogen (Green) for the full study period, 2016 through 2019. There is a seasonal variation in the Oxygen with a high of about 12 mg/l in the colder winter months and a low of about 6 mg/l in the summer. During the 4-year study period the temperature of the Mississippi varied from a winter low of about 5 deg C (41 deg F) to a summer high of about 30 Deg C (86 deg F). According to dissolved oxygen versus temperature curves found at www.fondriest.com for this temperature range the data in Figure 14 a-d imply the Mississippi River is at or close to total saturation in terms of dissolved Oxygen as it flows past Baton Rouge in the confined river channel.

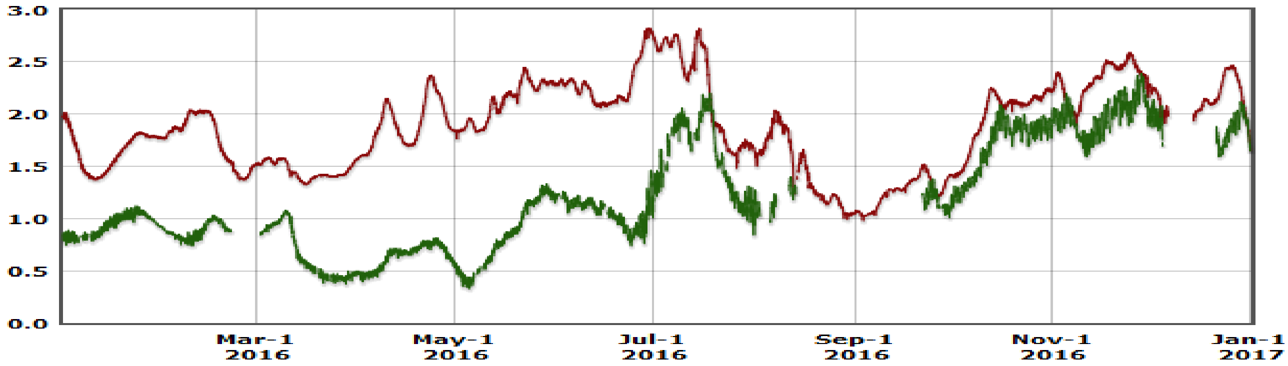

*Figure 12a. Mississippi (Brown) and Atchafalaya Rivers (Green) Nitrate plus Nitrite mg/l, 2016.*

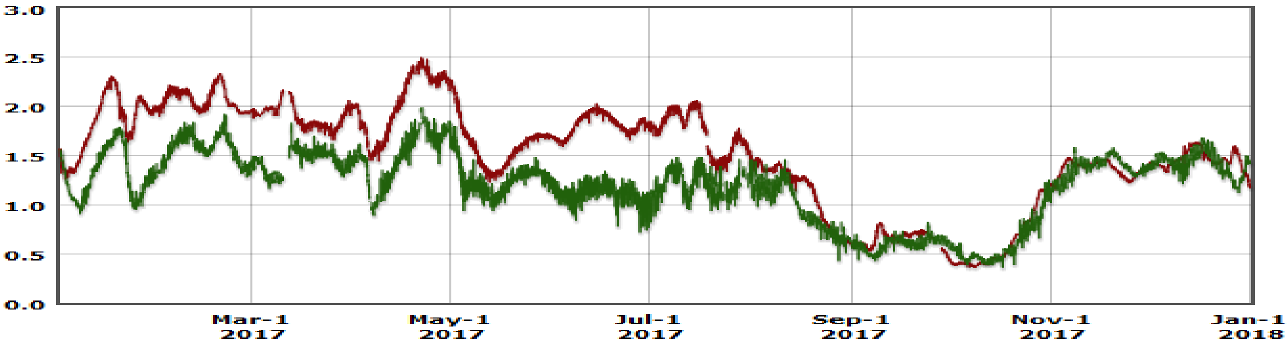

*Figure 12b. Mississippi (Brown) and Atchafalaya Rivers (Green) Nitrate plus Nitrite mg/l, 2017.*

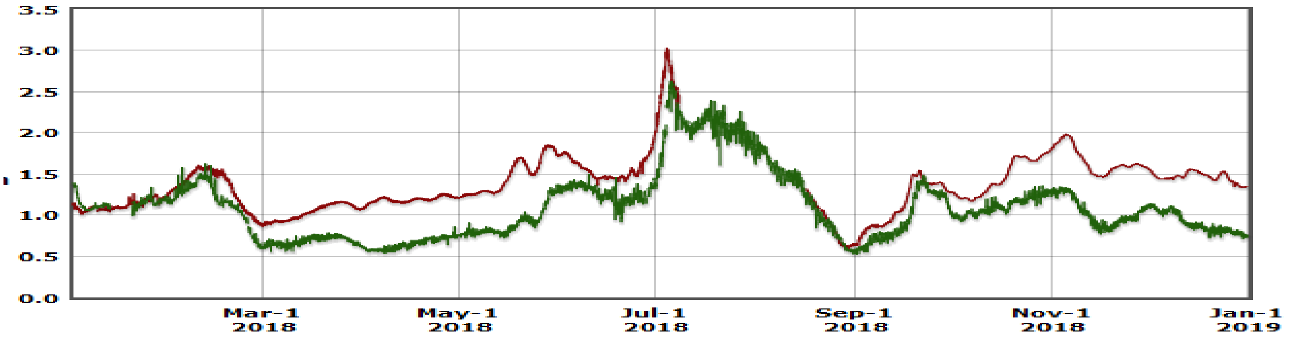

*Figure 12c. Mississippi (Brown) and Atchafalaya River (Green) Nitrate plus Nitrite mg/l, 2018.*

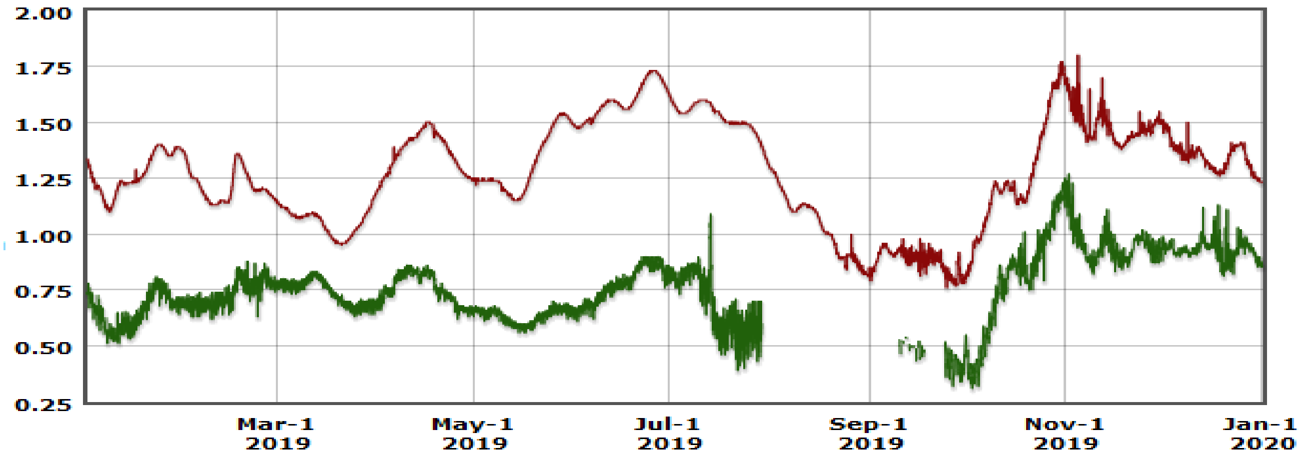

*Figure 12d. Mississippi River and Atchafalaya River Nitrate plus Nitrite mg/l, 2019. Brown is Miss at Baton Rouge, green Atchafalaya River at Morgan City.*

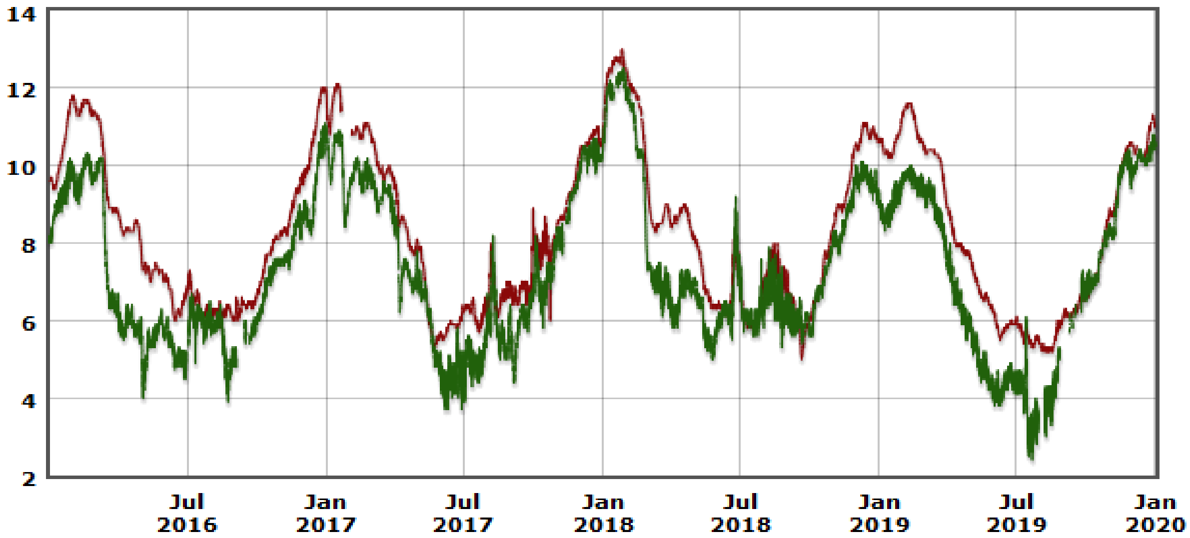

*Figure 13. Dissolved oxygen Mississippi (Brown) vs Atchafalaya Rivers at Morgan City (Green), 2016 -2019.*

The Atchafalaya Picture is different. Figures 15 a-d reveal a time series, broken into calendar years, of Nitrogen and Oxygen measurements as collected by the USGS for 2016 through 2019. Again there seems to be a seasonal variation in Oxygen high of about 10 mg/l in the colder months and an average low of 4-5 mg/l with 2019 being marked by lows of 2.5 mg/l. Two mg/l is considered the lowest the dissolved Oxygen can get to before Hypoxia sets in, so the winter of 2019 was close to this cut off. So once again it raises the question, is flushing of Atchafalaya Swamps with Atchafalaya flood water the best management tool to prevent eutrophication and hypoxia in these regions of the swamp. The 2019 flood was a monster with very high flood levels, strong flows yet the Oxygen got down to 2.5 mg/l (Figure 15d). By comparison the Mississippi low was 5.5 mg/l.

Considering seasonal temperature differences as measured by the USGS at Morgana City we can explain the seasonality in the drop of Oxygen levels but not the much lower dissolved Oxygen levels as compared to the source Mississippi waters. If all things are equal, then the Oxygen levels should exactly follow the trend and values of Oxygen in the Mississippi River (Figures 14 a-d).

During the summer warmth the Atchafalaya Oxygen levels should be about 8 mg/l, not the 4-5 mg/l and the 2019 low of 2.5 mg/l as displayed in Figure 15 a-d. Why this huge difference in Oxygen levels in the flow exiting the Basin at Morgan City? Something is ‘sucking’ the oxygen out of the water. In the shallow waters of the Basin swamps and lakes photosynthesis is taking place so one would expect, as explained in the introduction, that Oxygen levels would be helped by Photosynthesis. Why are the Oxygen levels in the range of 4-5 with a 2019 low of 2.5mg/l being half of what one would expect based on the source water (Figures 15 a-d)?

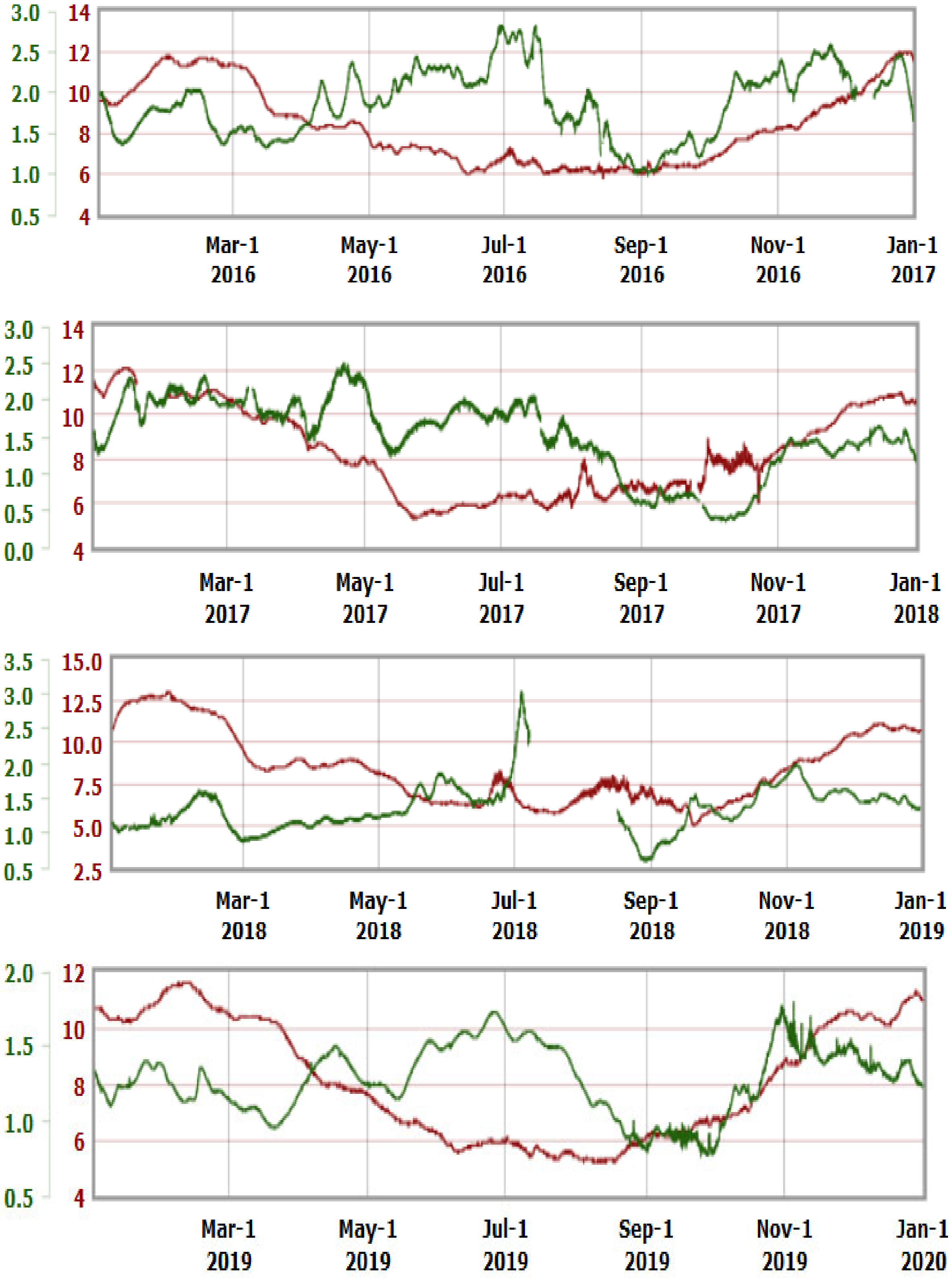

*Figure 14 a, b, c, and d. Mississippi River dissolved Oxygen (brown) vs Nitrogen (Green) 2016 through 2019.*

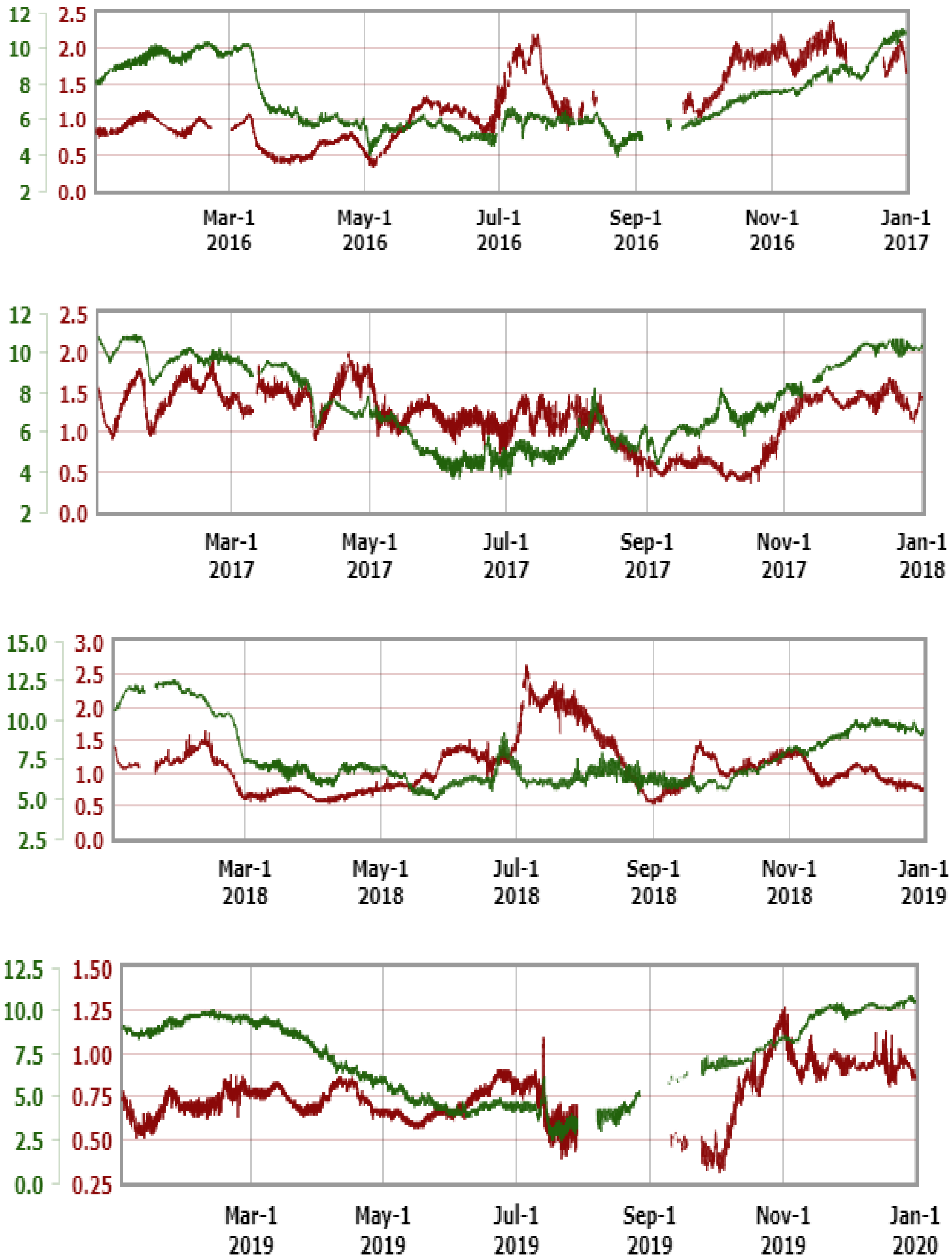

*Figure 15 a, b, c, and d. Atchafalaya River Nitrogen (brown) vs dissolved oxygen (green). 2016 through 2019*

Figures 16 a-d summerizes the differenece between the Mississippi River water quality as input to the Basin and the manipulations characterizing the flow through the Floodway Basin. The extremely high nutrient (N amongst others) loaded Atchafalaya floodwaters that overtops levees or exits the River via manmade channels, becomes fodder for various organisms such as algae, bacteria, fungi and other microbes and allows such to have a massive feast and in the process utilize a huge amount of the available DO. This consumption of DO is so pervasive that even photosynthesis and natural physical aeration process such as wavelets and rain splatter do not make up for that which is consumed.

What these figures reveal that for most of any caleneder year, Atchafalaya DO levels are mostly lower than those of the Mississippi feeder. Interestingly, the curves do show contemporaneous spikes in the DO of both rivers. Hurricanes, thunderstorms, cold front passages and other windstorms do through surface aeration increase DO levels. Some aquatic plants may utilize the excess N.Unfortunately the scope of this study would not allow the author the opportunity to chase down the origins of some of the DO spikes revealed in Figures 16 a, b, c and d.

## CONCLUSIONS - BIG PICTURE

1. In general, Turbidity in the Atchafalaya River at its lowest end, where it exits the Basin heading to the coast and Atchafalaya Bay, exceeds that of the Mississippi when the River is in flood. Both have the same source (van Heerden (2020) explores this further).
2. N levels fluctuate independent of discharge reflecting the source of the Mississippi flood waters in its catchment. The N levels generally appear to be lower in the Atchafalaya River outflow than the Mississippi input for most of the year (compare Figs 10 and 11).
3. The Mississippi River is at or close to total saturation in terms of dissolved Oxygen as it flows past Baton Rouge
4. During the summer warmth the Oxygen levels in the Atchafalaya Basin waters should be about 8 mg/l, not the 4-5 mg/l and the 2019 low of 2.5 mg/l as displayed in Figure 15 a-d. Why this huge difference in Oxygen levels in the flow exiting the Basin at Morgan City? Something is ‘sucking’ the oxygen out of the water. In the shallow waters of the Basin swamps and lakes photosynthesis is taking place so one would expect, as explained in the introduction, that Oxygen levels would be helped by Photosynthesis.
5. The Atchafalaya Nitrogen levels are lower that the Mississippi River especially during the the spring and summer months when the temperature is rising and the days getting longer. The Mississippi River is a confined channel, as against the Atchafalaya where flood waters spread laterally over a vast shallow area, In the Atchafalya Basin shallows, billions of microorganisms and some alage and aquatic plants suck up (ingest) Nitrogen ,and flourish; depressing the DO levels.
6. The DO levels in Atchafalaya, as evidenced where the waters leave the Basin at its southern end, are at times half that of the basically saturated DO Mississippi flow inputs to the Basin. The drop in DO levels cannot be explained by seasonal temperatutre differeneces. Instead this is classical eutrophication. Micro organisms and such are

having a huge feast due to the heavy nutrient loads of the Mississippi River precipitating marked lowering of DO, as the consume the DO – a real management consideration!

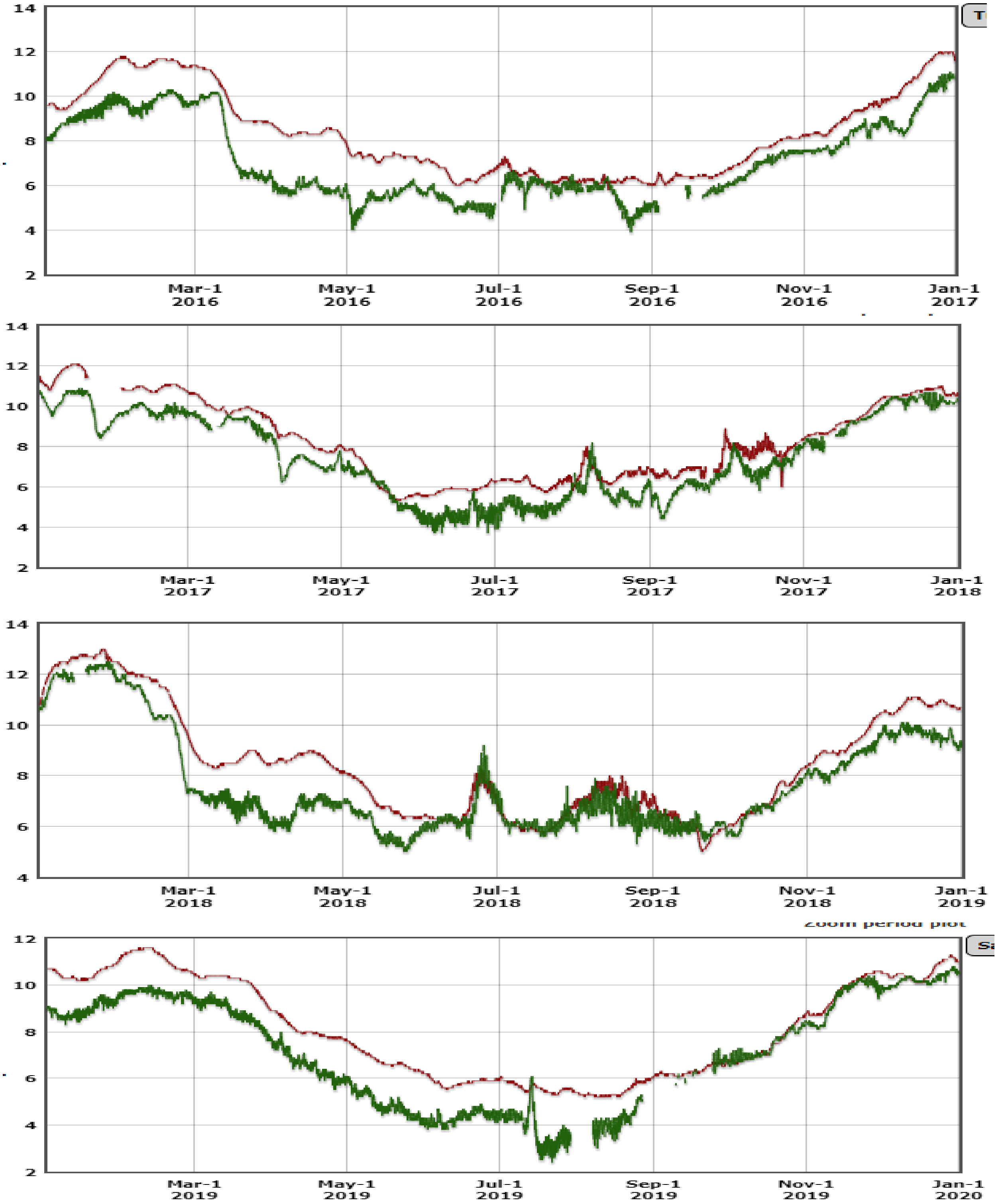

*Figure 16 a, b, c, and d. Mississippi River (Brown) vs Atchafalaya (Green) DO mg/l 2016 through 2019.*

## CHAPTER 2. TURBIDITY, NUTRIENT, AND DISSOLVED OXYGEN PROCESSES IN THE SWAMPS AND THEIR CONSEQUENCES – the inner basin picture.

### a. Data Sources

In trying to better understand the causes of hypoxia an intensive literature search was undertaken. This section will discuss data obtained by review of a master's thesis from Nichol's State University, as well as data collected by the state in the Basin. Kong's 2017 thesis titled, "Population characteristics of red swamp crayfish *Procambarus clarkii* from hydrologically impaired locations in the Atchafalaya River Basin," presents data from locations in the central part of the eastern half of the Floodway for Atchafalaya River flood events in 2016 and 2017. Her thesis was basically aimed at measuring various environmental and water quality parameters in a section of the Atchafalaya Floodway in order to try to determine if there was a relationship between water quality and crawfish production. Temperature, Dissolved Oxygen (DO), pH, Secchi depth (a simple measure of turbidity), and, specific conductance was recorded at all sample locations on every sample date and various parameters were collected from red swamp crayfish. Unfortunately, her University, although funded by state dollars, would not make available the original data (two requests). It appears that Royal Dutch Shell also funded her work through TNC. In general Kong presented means or averages and not temporal data at each site. Kong's sites for this analysis were chosen on their proximity to the various elements of the proposed EGL project (Figure 17).Where necessary Kong's data has been subjected to different plots and other data sets have been incorporated to further interpret the data. Missing from her thesis is any quality control or assessment of the accuracy of her measurements, no calibration data.

Kong's study reflects data that was collected only during a specific flood peak of the Atchafalaya River for each sample site. There was no data collected for the rest of the hydrologic year, so flood vs non-flood comparisons are not possible. She sampled flood peaks in 2016 and one in 2017 (Figure 2, page 12). Very fortunately each of the flood peaks origin and characteristics were quite different as discussed above (Plates, 2, 3 and 4).

Since 2017 The Nature Conservancy (TNC) have collected water quality data in the same region of the Basin although not at the same locations. Figure 17 depicts the location of TNC data collection sites although there is no GPS data, location or environment setting data. On 3/1/2019 a crew from the Atchafalaya Basinkeeper, who, as commercial fishermen and longtime residents know the swamp like the back of their hands, could not locate any of the TNC sites even though they should be readily noticeable. Sites AU1 and AU6 both appear to be on the back slope of a high spoil pile along the bank of an excavated channel. If so, not an ideal situation to be collecting 'swamp' data. This review will focus on the Kong sites that cluster closest to the TNC sites (Blue box in Figure 17).

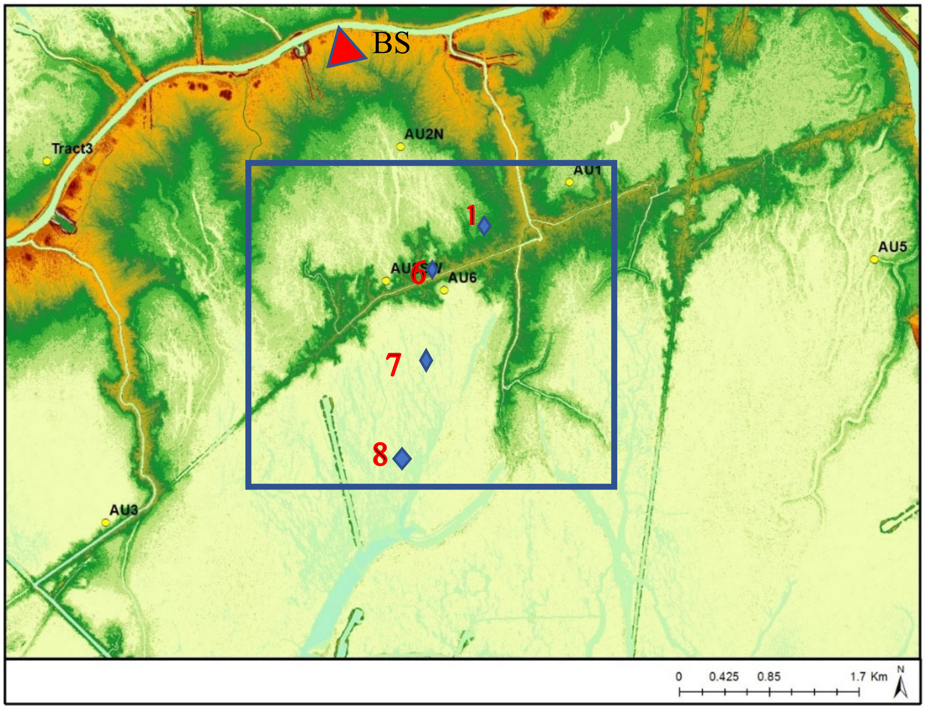

*Figure 17. Kong's 2016 sampling sites 1, 6, 7, and 8, same region of the Basin as TNC sites AU1, AU6, and AU2SW in 2017 and 2018. LiDAR image, richer the color higher the elevations. TNC sites and Kong's 1, 6, and 7 are on the edges of levees even if they are subaqueous, higher elevations than interior backswamps. Kong's site 8 is more of a backswamp location. All site location interpolated from small scale diagrams in Kong and TNC reports. No GPS data available. Note the location of gauging station Bayou Sorrel (FWS) marked red diamond BS to be discussed later.*

### b. Kong's 2016 data explained

In interpreting Kong (2017) data it is very important to recognize that the 2016 flood water is sourced from the greater Mississippi catchment (Plate 2, page 13); as compared to the 2017 flood which reflected a rainfall induced flood pulse with the flood source being the flooding of land and subsequent runoff water from a narrow portion of the lower Mississippi River (Plate 3 and 4, pages 13 and 14). The 2016 flood was a catchment flood with high turbidity (Figure 18) whereas the 2017 flood peak sampled by Kong (2017) was basically a 'clean water' flood with low turbidity (Figure 19). As the need is to understand hypoxia in swamps rather than levee locations, 4 swamp locations were chosen (Figure 17).

*Ground Elevations*

As discussed by van Heerden (2019a), Kong (2107) does not present any elevation data (nor does TNC) at any of her sites. This is of critical importance in trying to understand flooding and duration of inundations, amongst other issues. The measure she uses to determine inundation of her sites is based on an unofficial crawfish season, namely:-

*"Intensive and extensive sites were sampled twice a month during the crayfish seasons from 19 March to 9 June 2016 and from 7 May to 3 July 2017. There is no official crayfish season set by resource managers in Louisiana, instead, wild crayfish harvest is determined by Atchafalaya River water level. The crayfish season began when the Atchafalaya River level at Butte La Rose, Louisiana (U.S. Army Corps of Engineers gauge 03120, 30°16'57" N, 91°41'17" W) was greater than 3.5 m, which resulted in floodplain inundation at intensive site locations."*

So, Kong (2017) seems to be suggesting that the ground elevation, or perhaps the average ground elevation of her sites is 3.5 m or lower as relates to the Butte La Rose gauging station. There is no real or hard data to support her 3.5 m (11.48 ft) assertion. In discussion with commercial crawfishermen in the Basin I am told that they start commercial harvesting once the stage at Butte la Rose has exceeded 7.0 ft for a week. In their experience this inundation level and overtopping takes about a week to fill the swamp so that they can get boat access. Generally, they need about 18 inches of water to move their boats to their trap sites. This suggests about 5 feet (1.5 m) elevation where they fish. There is no scientific justification for Kong's 3.5 m assertion, a major flaw of this study. She gives no indication of the elevations of her sample sites other than water depths must have exceeded 18 inches for her to have boat access and collect crawfish at her sites each time they were sampled. This lack of data becomes critical as we further discuss Kong (2017) thesis and the TNC data.

Van Heerden (2019a) took a first stab at getting an indication of the elevation of her sites, but all interpretations were based on the stage data from Butte La Rose, 15 miles away and further up Basin – not ideal at all. Figure 2 from Kong (2017) presents Butte La Rose daily water level stage data for 2016 and 2017 with her assumed 3.5 m 'line.' TNC for some reason also only utilize the Butte La Rose gage in all their reports, rather than the gage say at Bayou Sorrel locks which is much closer to the TNC and Kong's sampling sites, and, at about the same latitude (understand there may be a datum issue at this gauging site?).

As van Heerden (2019) pointed out TNC do, however, supply data from which it is possible to get a rough representation of the ground elevation at their sites. Using the Butte la Rose gauge data van Heerden (2019) used two different techniques to determine ground elevations in Kong's study area. Figure 20 is TNC representation of the daily mean water stage for 2017 at Butte La Rose and Figure 21 represents mean daily water levels at their 7 monitoring sites for the same time period. TNC verbal communication via email 01/28/2019 informed that the water levels presented in Figure 21 are as follows; "The depth sensor on the Sonde (instrument) is about 15 cm off of the sediment surface, so these data … would be the water levels above the sensor, which is 15 cm above the soil surface." Thus, if one knows the river stage and one knows the water depth at each sample site; by simple subtraction and then subtracting the instruments height above ground of 15 cm, one can get the elevation of each site as it relates to the datum for the closest gauging station. TNC (2017) state that Sonde water level data track the stage at Butte La Rose.

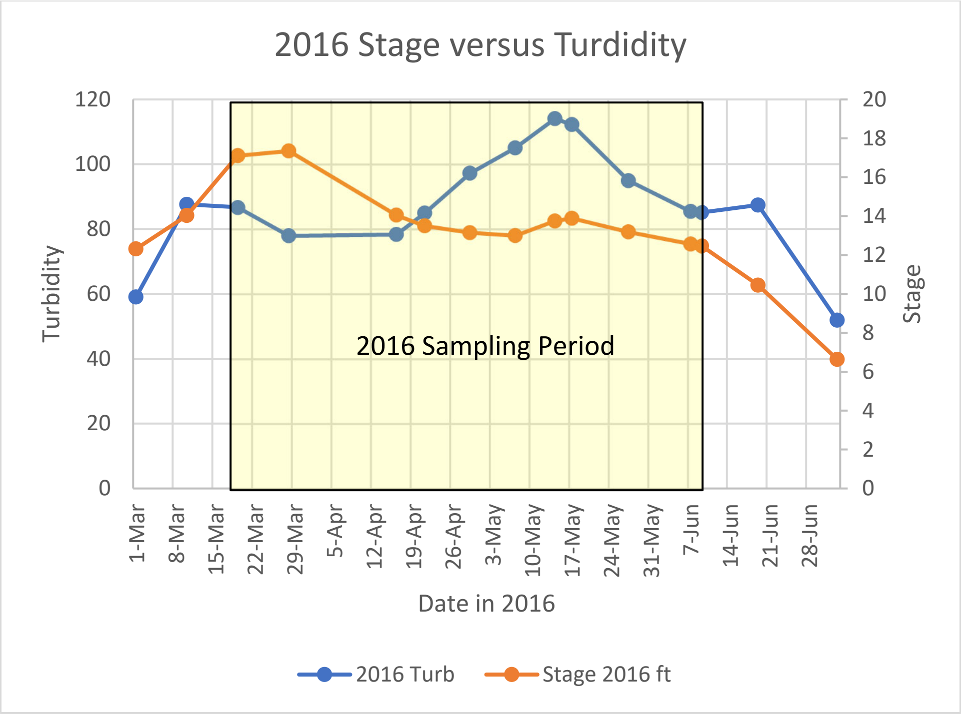

*Figure 18. Stage and turbidity comparison of the 2016 flood peak sampled by Kong (2017).*

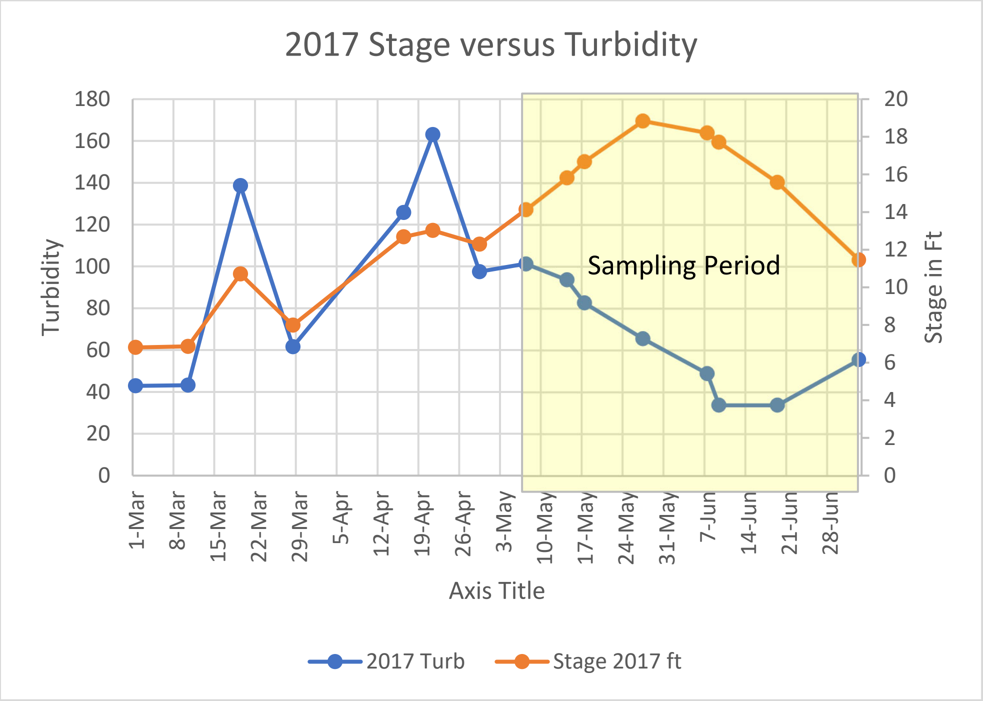

*Figure 19. Stage and turbidity comparison of the 2017 flood peak sampled by Kong (2017).*

Van Heerden (2019) recognising that the head or fall of water from the Butte La Rose gauge to the study area (about 15 miles (to the North West) at high or peak stages is most likely to be the greatest; so his calculations were based on stages of 3 m (9.8 ft) and lower. This was done to minimize any slope over the 15 ml during the fall of the peak flood. Even though there is a low probability that the water surface at Butte La Rose gauge and the study site were at the same elevation,  he proceeded in the face of a lack of any other data. SIGMA, the engineering company contracted by the state to design the EGL project subsequently claimed, without any supportive data, that the EGL project area the stages were 6.5 feet below Butte la Rose (van Heerden 2019b). As we will see below that was way off and raises questions about the whole design process.

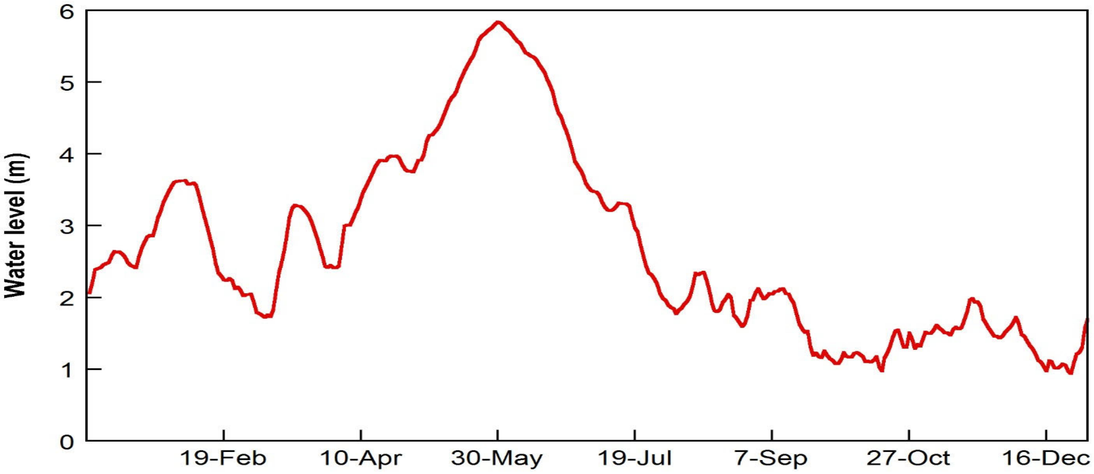

*Figure 20. Daily mean water levels at Butte La Rose during 2017. Preliminary data from USGS gage 07381515 Atchafalaya River at Butte La Rose, LA (TNC 2017).*

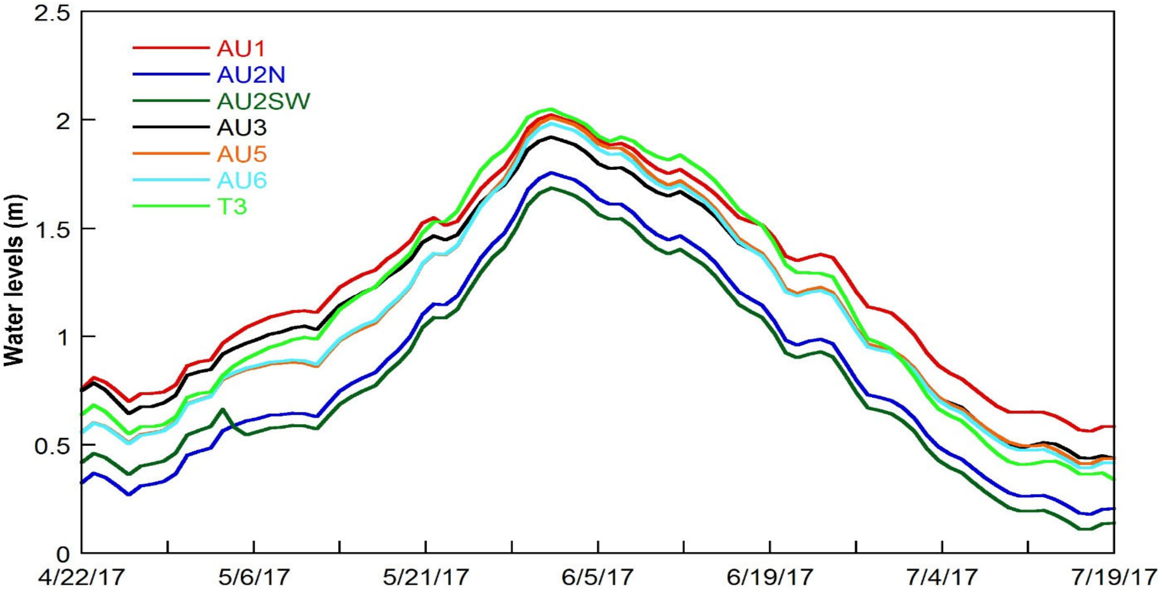

*Figure 21. Daily mean water levels during the 2017 flood pulse at the seven TNC (2017) monitoring sites.*

Doing the subtraction for the TNC sites AU1, AU6, and AU2S gives a ground elevation for each sampling data sites and then calculating the average gives a ground elevation at Kong's and TNC sites, as relates to the Butte La Rose gauge datum, of 2.47 meters (8.1 ft), which is 1.0 meter (3.28 ft) lower than the 3.5 m unscientific assumption made by Kong (2017).

A second method became available on receipt of the TNC 2018 data 1st March 2019. Here the TNC sites AU2S and AU6 were utilized from 6/3/18 to 10/8/18 when the Butte La Rose gauge showed a leveling off of the water level from a peak through to the beginning of another peak – a time with very little if any surface slope. Doing the calculations in a similar manner to that above gives elevations of 8.7 ft at AU2S and 8.5 ft at AU6. Not much different from the 8.1 feet found using the first method. However, these are at best approximates, used in van Heerden's 2019a and b reports, until new data became available as will be discussed next.

Late 2019, after a field trip to the area, van Heerden noted a gauging station on Bayou Sorrel very close to the proposed EGL project (Figure 17, page 28). After an extensive internet search the Bayou Sorrel (FWS) (49615) site was located (Figure 17) with a datum of 0.0 NGVD. Figure 22 is a plot of Bayou Sorrel (FWS) gauge superimposed on the Butte la Rose gauge, using the same axes for the period 12/10/2018 through 03/31/2020. What is strikingly obvious is the Butte La Rose gauge stages are not representative of the Bayou Sorrel - EGL project area, at all. In the flood of 2019, the Butte la Rose gauge was up to 13 feet higher than that at Bayou Sorrel and during low flows is only a few feet higher than at Bayou Sorrel (Figure 22).

As mentioned earlier the SIGMA engineering team claimed a 6.5 feet difference in stage elevations between the two sites, not real except at a very certain stage in 2019, maybe for a day or two. What is clearly demonstrated in Figure 22 is that the variances in stage between the two sites is totally depended on river regime factors such as discharge and internal Basin hydrodynamics.

Now in order to get a representative elevation for the Kong and TNC suites a similar analysis to van Heerden (2109a) was undertaken using the stage data from the Bayou Sorrel (FWS) gauge. The period 06/10/2019 to 07/10/19 was chosen being a period when the hydrograph was relatively flat (Figure 22). The range in water depths above the instruments at the various TNC sites (on average) for this period was 2.3 m to 1.7 m (Figure 23), while the Bayou Sorrel (FWS) gauge height varied from 3.96 m (13 ft) to 3.35 m (11 ft). By adding the 0.15 m instrument height above the ground (TNC pers comm) to the water depth measured by the instrument and then subtracting that sum from the gauge height on get an elevation of the ground at each site, 3.96 –(2.3 + 0.15) = 1.51 m and 3.35 – (1.7 +.15) = 1.5 m!

So, the general elevation at the TNC and Kong's sites chosen for this analysis is NGVD 1.5 m or NGVD 5 feet. Now finally we have a real and defensible elevation for the ground elevation at the relevant Kong and TNC sites, using stage data from a nearby gauging station, one can proceed with the assessment of the data collected and the implications thereof. Importantly this new elevation data strengthens van Heerden (2019a, 2019b) conclusions.

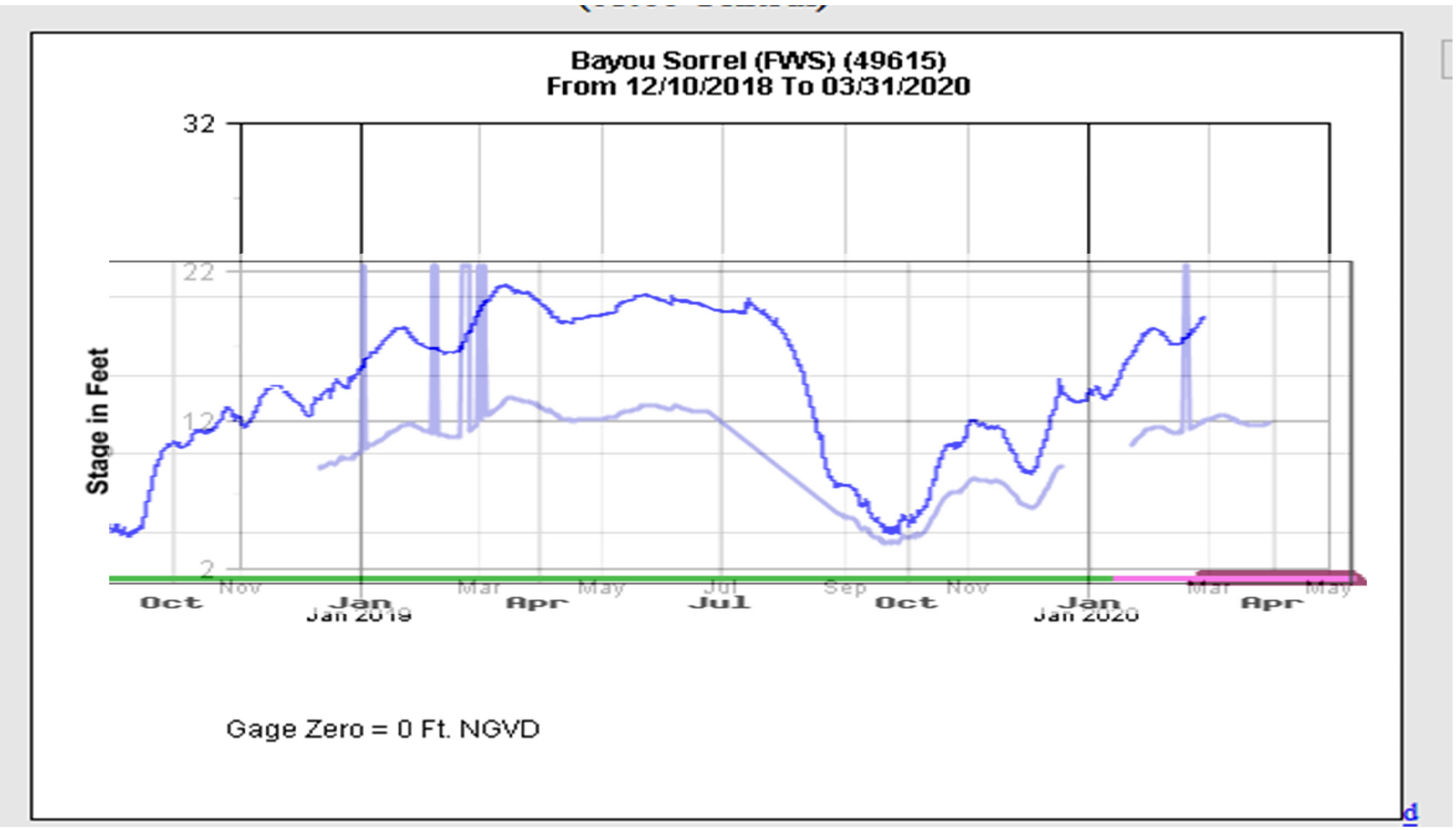

*Figure 22. Butte La Rose gauge overlaid on Bayou Sorrel (FWS) late 2018 through early 2020. Butte La Rose the upper darker blue*

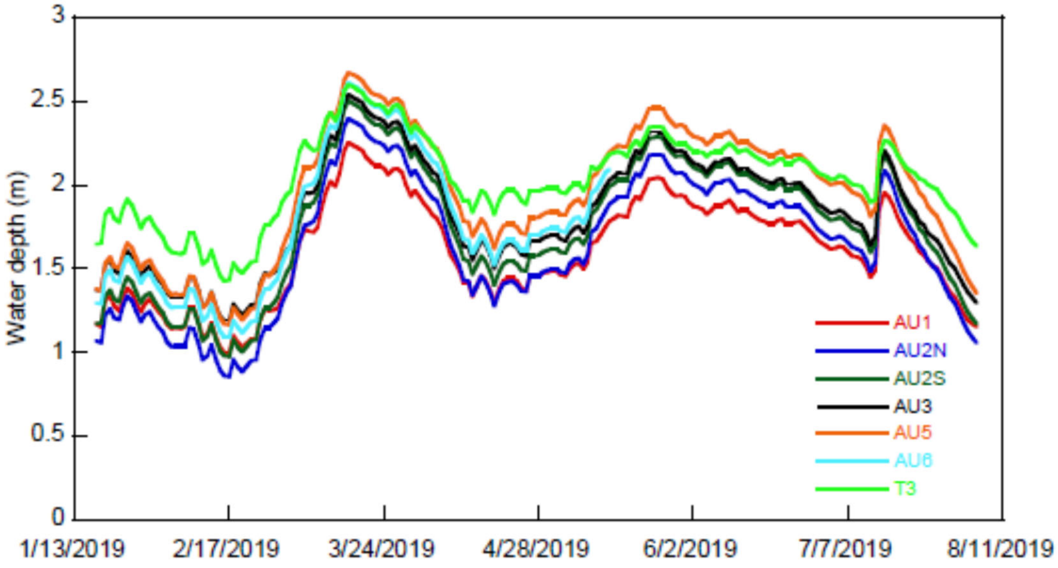

*Figure 23. Mean Daily water levels at TNC monitoring stations 2019.*

*Dissolved oxygen implications*

The only time series (temporal) data in Kong's thesis is fortunately oxygen concentrations (Figure 24). The replot of the Kong data for Site 1 (Figure 25) reveals that for the full study period the site was flooded with at least 7 feet of water using a ground elevation of 5.0 feet as determined for this site based on the TNC and Bayou Sorrel (FWS) gauge data. It was being flushed by Atchafalaya River flood waters. So, there was a hydrologic connection to a channel somewhere. If such is good for improving Dissolved Oxygen levels for the system, then there is obviously something else going on that is driving down the oxygen levels as the flood progresses as depicted in Figure 25. If connectivity to a channel and flushing were healthy for this site, then The DO should remain above the hypoxic zone. Kong (2017) states categorically without any justification that there was no hydrologic connection from at least 04/29/2016 onwards! Figure 25 reveals otherwise! This misrepresentation and conclusion seem random and no scientific basis or explanation is presented. The question at this site then becomes; what is driving down the oxygen concentrations as the flood progresses? Kong's sites 6, 7, and 8 all repeat the same pattern of DO falling over time (Figure 24).

What about seasonal temperature corrections? Kong's data shows temperatures during her sampling varying from 18 C to 24 C which means about a 1 mg/l drop in DO – does not explain what observed. TNC 2017 shows temps from 22.8 C to 25.7 C so less than 1 mg/l DO drop. TNC 2018, the data is a bust as in one figure the May temps are 15 C while the next 25 C – so what is real? TNC 2019 has a warming from 14 C to 24 C which would have resulted in a 2 mg/l DO drop. So, even though there are issues, temperature data from Kong and TNC cannot account for more than a 2 mg/l drop in DO levels.

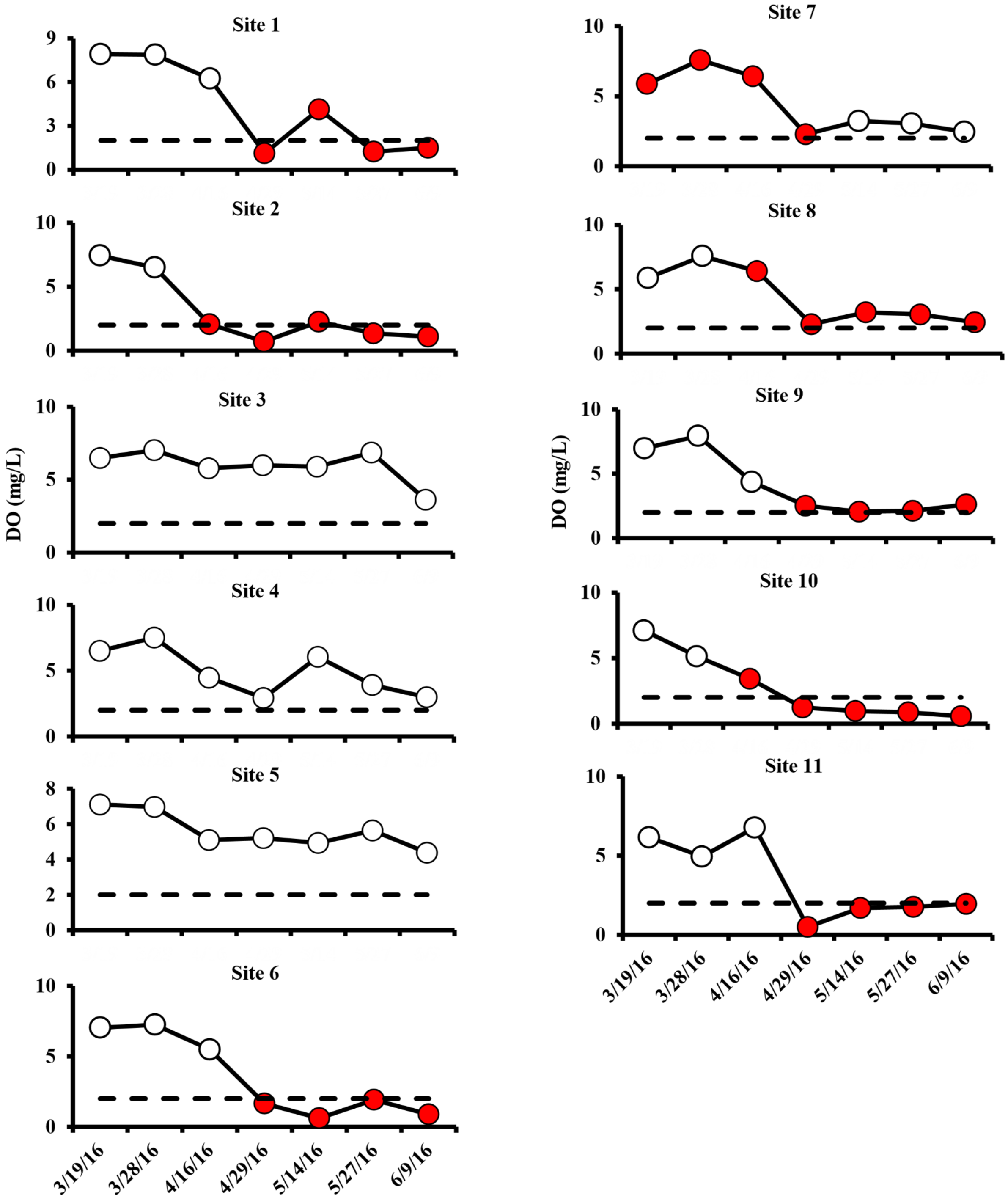

*Figure 24. Dissolved oxygen (DO) concentration and hydrologic connectivity at Atchafalaya Basin Preserve sample locations during the 2016 sample season (Kong 2017). The red dots indicate when Kong assumes the site is hydrologically disconnected from flood water input, an invalid conclusion as this manuscript reveals.*

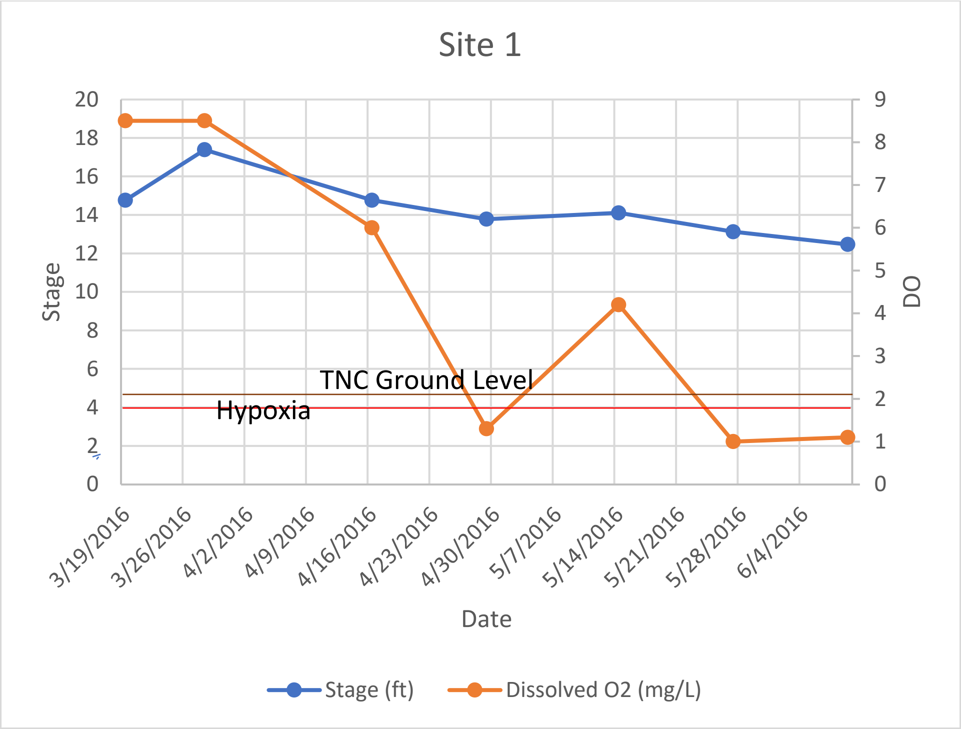

*Figure 25. Site 1 - Plot of data from Kong (2017) of Butte la Rose stage and DO over the time data was collected for Site 1. See Figure 24 for comparison.*

Thus, based on Kong's 2016 data, the explanation of the impacts of allowing suspended sediment laden flood waters to enter swamp and pond environments is that, these waters bring in vast amounts of nutrients that result in a rapid lowering of oxygen concentrations from background levels and lead to hypoxia – due to microorganisms having a glutenous feast. Kong's data bears this out very clearly and raises questions about the viability of using channel cuts as a means to flush backswamp environments to improve water quality. This 2016 data set does not support this hypothesis as advocated by those who believe opening up the Basin to Atchafalaya flows will improve water quality.

One important management consequence of flooding back swamps with suspended sediment laden water that Kong (2017) did not consider is the infilling and eventual loss of these unique forested wetlands.

### c. Discussion of Kong's 2017 data and results

The first question is what about the river turbidity while she was sampling – what was the river supplying to her study sites by way of nutrients and suspended sediments? Unfortunately, data on turbidity or suspended sediment loads is not recorded at Butte La Rose, but turbidity data is collected (mostly hourly) on the Atchafalaya River at Morgan City (Figure 19). The higher the turbidity number the greater the concentration of suspended material in the water column. Figure 18 reveals that the turbidity ranged from 86.7 to 114.1 during Kong's 2016 flood sampling. In contrast during the peak of the 2017 flood (Figure 19, page 30) the turbidity was constantly dropping from 100 to a low of 33.8; reflecting that this river flood pulse was a rainfall induced event (Plates 3 and 4) and the sediment and nutrient load reflected by the turbidity measurements was very low.

The only data that Kong (2017) presents for actual measurements over time at each of her sample sites is dissolved oxygen (Figure 26). The replot of the Kong data for Site 1 (Figure 27) reveals that for the full study period the site was flooded with at least 6 feet of water using a ground elevation of 5.0 feet determined for this site. Maximum flooding would have been at least 13 feet above ground! It was being flushed by Atchafalaya River flood waters for the duration of Kong's 2017 study. So, there was a hydrologic connection to a channel somewhere. As this was a low turbidity rainwater induced flood the lack of nutrients is reflected in that the DO concentration rises from being hypoxic early May 2017 to 5 mg/l at the peak of the flood, but then drops back to hypoxic once this "clear" water flush has past (Figure 27). This is strong proof that Atchafalaya River turbidity is directly coupled with DO concentration. Kong (2017) states categorically without any justification that there was no hydrologic connection 5/7/2017 and 7/3/2017. Figure 27 reveals otherwise. Site 2,6, 7, 8,9, 11 all follow the same pattern over time (Figure 26) (van Heerden 2019).

Unfortunately, Kong (2017) only presents means (with standard deviations) for turbidity data for each of her 14 sites. In 2017 the means for the sites under consideration, namely 1, 6, 7, and 8, the Secchi Disk readings range from 30.6 – 36.0 cm. By contrast the 2016 data ranged from 17.7 to 24.0 cm being far more turbid than the 2017 sampling at the same sites, reflecting the 2017 1:1000-year rain induced flood peak versus the Mississippi catchment flood of 2016 (See Figures 10, page 19, and 19, page 30 for comparison).

This data strongly points to the impacts of allowing suspended sediment laden Mississippi catchment (the norm) flood waters to enter swamp and pond environments; these waters bring in vast amounts of nutrients associated with suspended sediments that result in a rapid lowering of oxygen concentrations from background levels and lead to hypoxia. Kong's data bears this out very clearly and raises questions about the validity of using channel cuts to flush back swamp environments to improve water quality. This data set does not support this hypothesis as advocated by those who wish to flush the swamp with Atchafalaya River flood water.

One important management consequence of flooding back swamps with suspended sediment laden water that Kong (2017) did not consider is the infilling and eventual loss of these unique forested wetlands.

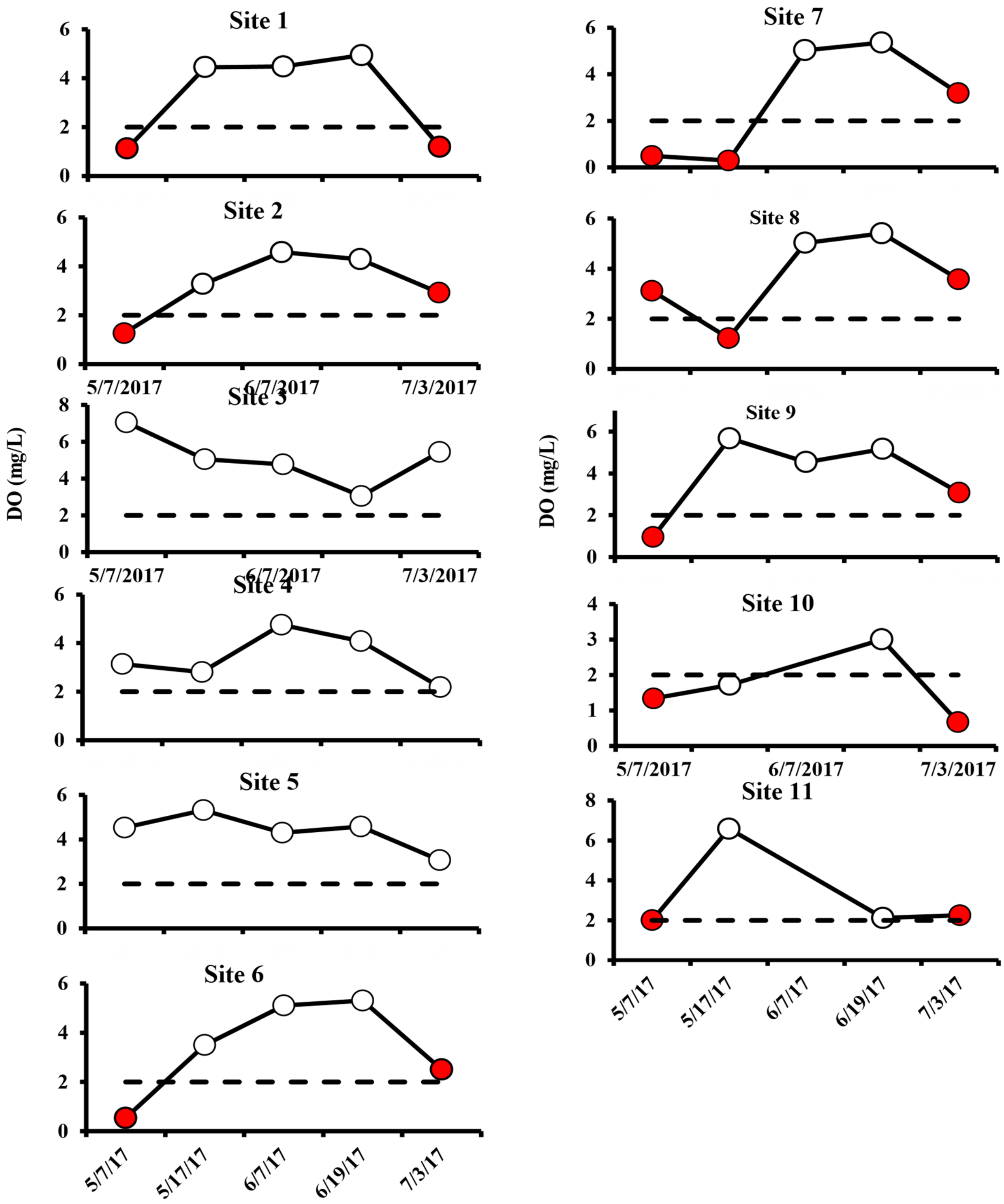

*Figure 26. Dissolved oxygen (DO) concentration and hydrologic connectivity at Atchafalaya Basin sample locations during the 2017 sample season (Kong 2017). The red dots indicate when Kong assumes the site is hydrologically disconnected from flood water input which this manuscript proves is an invalid conclusion. The dashed horizontal line on the graphs indicates hypoxic level (DO < 2 mg/l).*

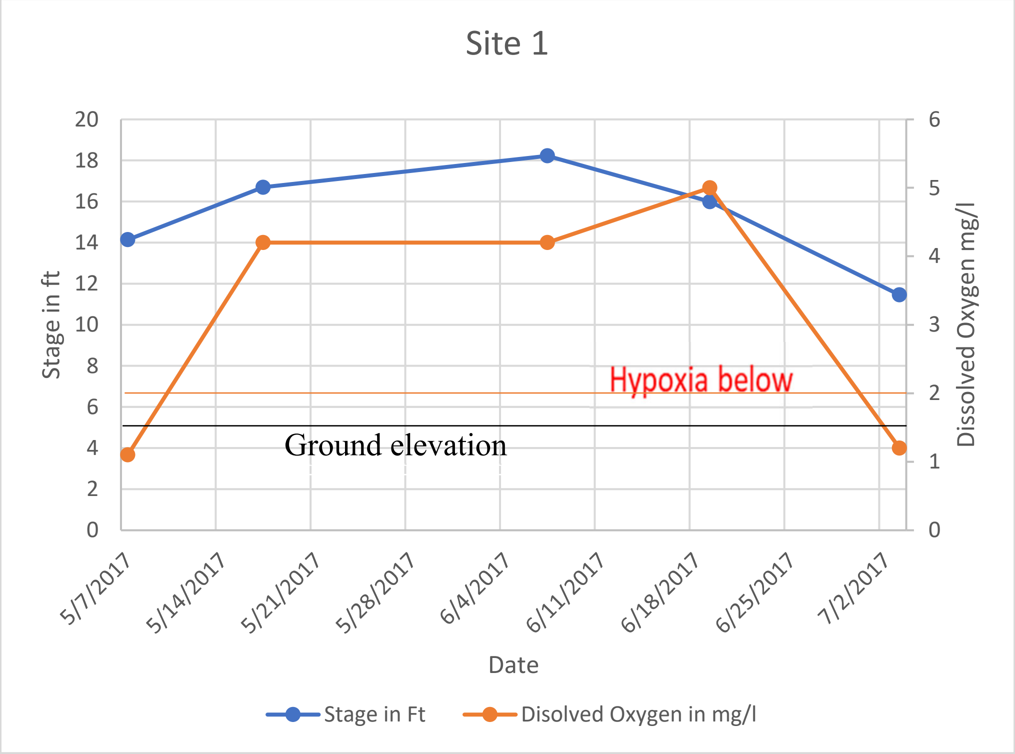

*Figure 27. Site 1, Stage at Butte La Rose in feet and Dissolved Oxygen collected by Kong (2017). See  Figure 26 by comparison.*

So, in summary, 2016's flood was a catchment flood peak with high turbidity; in contrast 2017 was a rain induced flood with much lower turbidity (Figure 19, page 30)). Kong's data collected within a Basin swamp for the flood peak in 2016 reveal that as the flood starts peaking DO levels are high and as the flood progresses, they decline to hypoxic conditions. For 2017 it was almost the opposite. The DO levels rose as the flood progressed, reflecting that a low turbidity rainfall induced flood peak crossed her study area in 2017. This data is strong evidence that Eutrophication and eventually Hypoxia are the result of the very high Mississippi nutrient loads entering the swamps and the rapid reduction in DO follows as microorganisms feast and consume the DO, except very unique flood peaks.

## DISCUSSION OF THE NATURE CONSERVANCY DATA COLLECTED FOR LaDNR/CPRA 2017 to 2019.

The Nature Conservancy (TNC), since 2017 collected water quality data for the LaDNR in the same region of the Basin as Kong (2017), although not at the same locations (Figure 17, page 28). There is no GPS position data to make a determination where the sites were located, was it on a levee or was it in an open pond or in a forested swamp? There is no weather data either.

Strong winds, rain, other boat traffic etc. before or during a sample event can markedly change the readings.

## The TNC Data for 2017

The TNC data was collected from 04/22/2017 till 07/19/2017 – a 3-month period that included the time Kong (2017) was sampling around the same flood peak (Figure 28). A comparison is thus possible between the two data sets. Figure 28 reveals that the flood rose to its peak on 28th May 2017, during the sampling period, and then fell thereafter. TNC state "During the passage of the flood pulse dissolved oxygen levels increased at all sites, but the magnitude and duration of that response varied from site to site" (TNC 2017). This is a result that matches Kong data and strengthens the argument that a low turbidity flood is far better for the system than a high turbidity flood which is the norm.

### a. Synoptics of DO levels at the 2017 TNC sites.

The TNC data do reveal that there is a marked temporal fluctuation in the DO against the background of a general rise during the flood (Figure 29 and 30). The sites displayed in Figure 22 , AU6 and AU2SW are close together being on either side of a pipeline canal (Figure 17, page 28). Depending on prevailing wind direction; major wind storms; major rainfall events; and, the stage of river flooding; water flow direction at these sites could be from all points of the compass and vary almost from day to day and as these waters flow back and forth, here and there, they occasionally bring in pockets of low DO waters from stagnant areas. Stagnation possibly due to impoundment, or biological degradation of submerged plant matter, or both. However, the overall DO picture, as TNC stated, is for the DO to increase as the 2017 flood progressed.

### b. Comparison of TNC Site AU6 to Kong's Sites 6, 7, and 8 For 2017 (Figures 29 to 34).

The turbidity at TNC AU6 (Figure 29) is lower than that in the Atchafalaya River (Figure 31) around 05/07/17 but rises up to the same level as the River at its peak of 34 FNU mid-June and then falls rapidly thereafter. The River turbidity at the lower end of the Basin for the period is almost a reverse mirror image, being highest (100 FNU) in early May falling to a low of 34 FNU around 20 June 2017 and thereafter rising again to the end of the record. Kong's data was not measured daily by rather fortnightly, so it lacks the synoptics of the TNC data. But comparisons of the two data sets are permissible. Notably the DO rises faster at Kong 6 (Figure 32) as compared to AU6 (Figure 29) as the 2017 flood progresses.

Kong 7 (Figure 33) and Kong 8 (Figure 34) more resemble AU 6 as they appear to be in the same general water body.

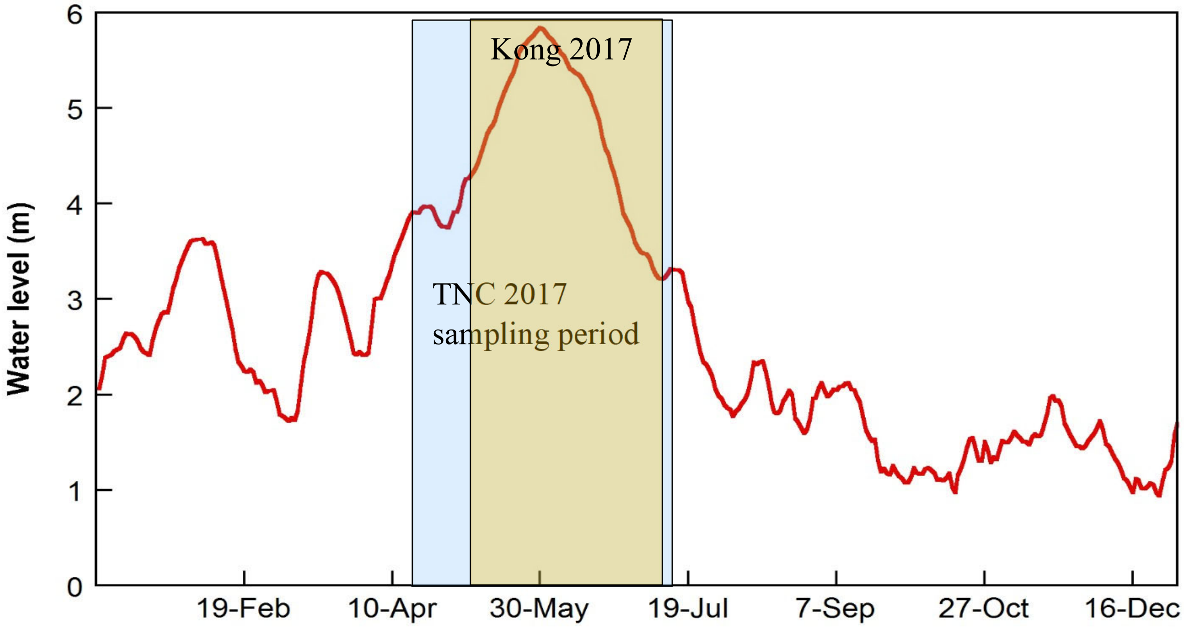

*Figure 28. Daily mean water levels at Butte La Rose during 2017. Preliminary data from USGS gage 07381515 Atchafalaya River at Butte La Rose, LA.*

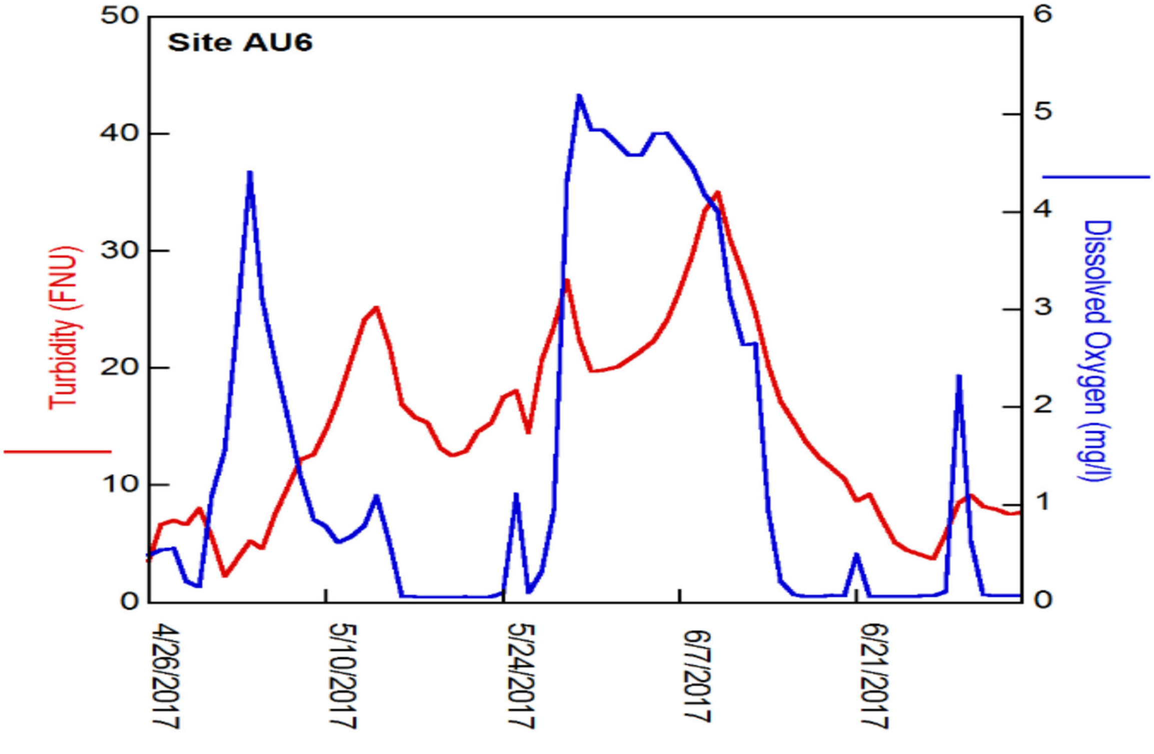

*Figure 29. Turbidity and dissolved oxygen from April to July 2017. TNC Sites AU6*

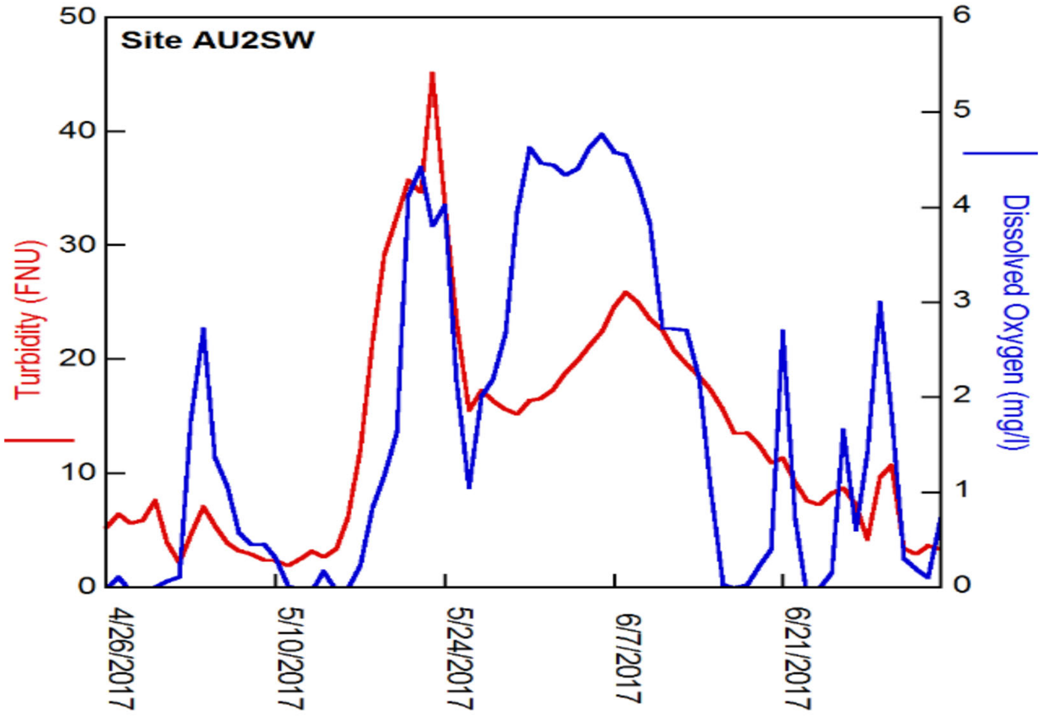

*Figure 30. Turbidity and dissolved oxygen from April to July 2017. TNC Sites AU2SW*

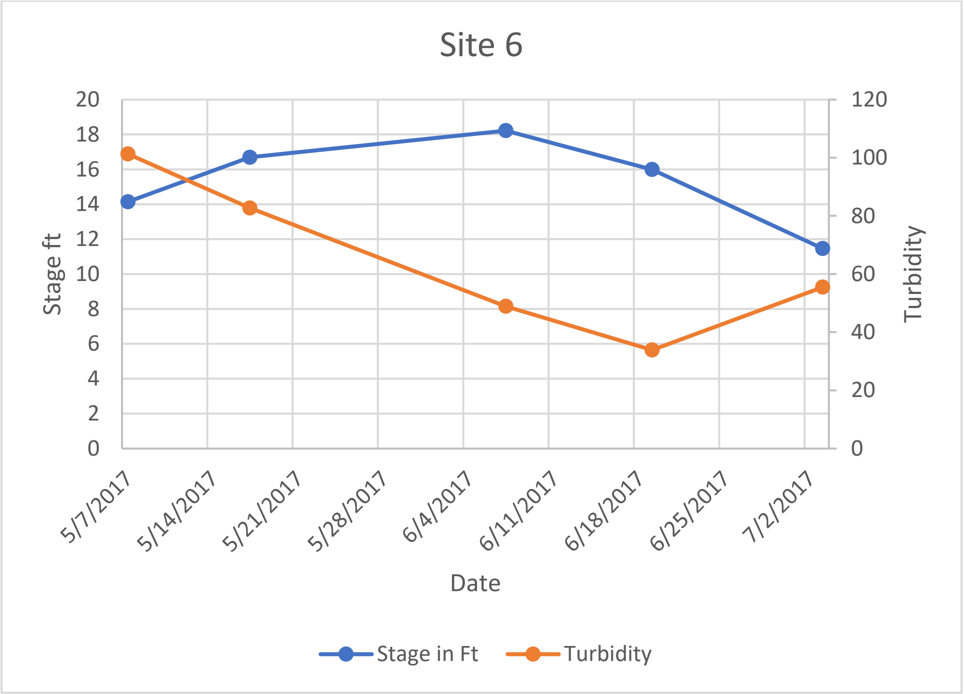

*Figure 31. Kong 6. Stage in feet at Butte La Rose and Morgan City Turbidity for duration of 2017 study*

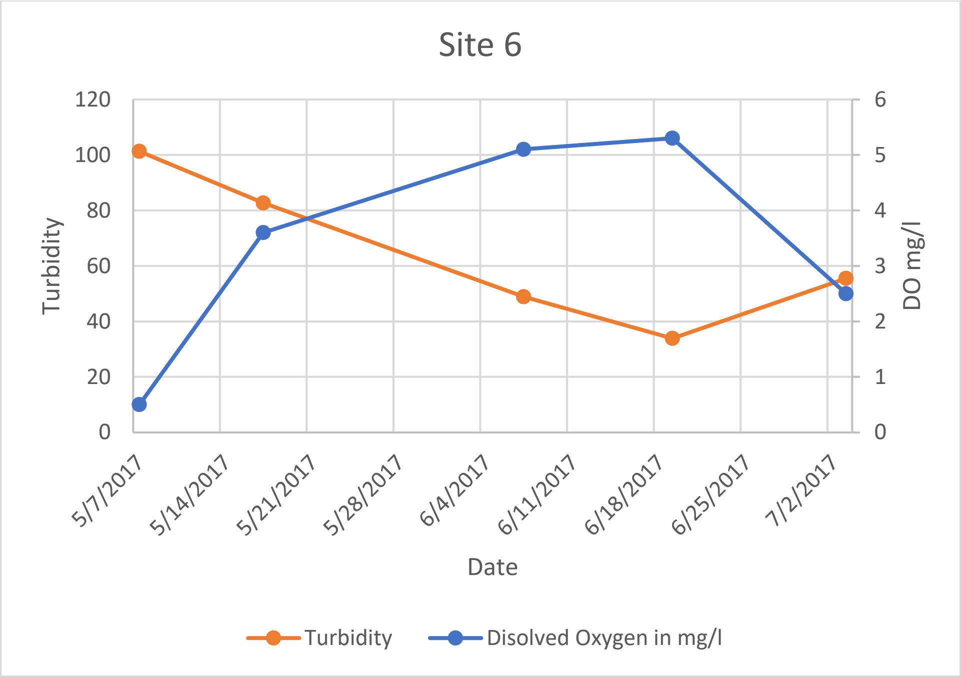

*Figure 32. Site 6 Plot of Dissolved Oxygen from Kong (2017) and Turbidity from Morgan City over the time data collected in 2017.*

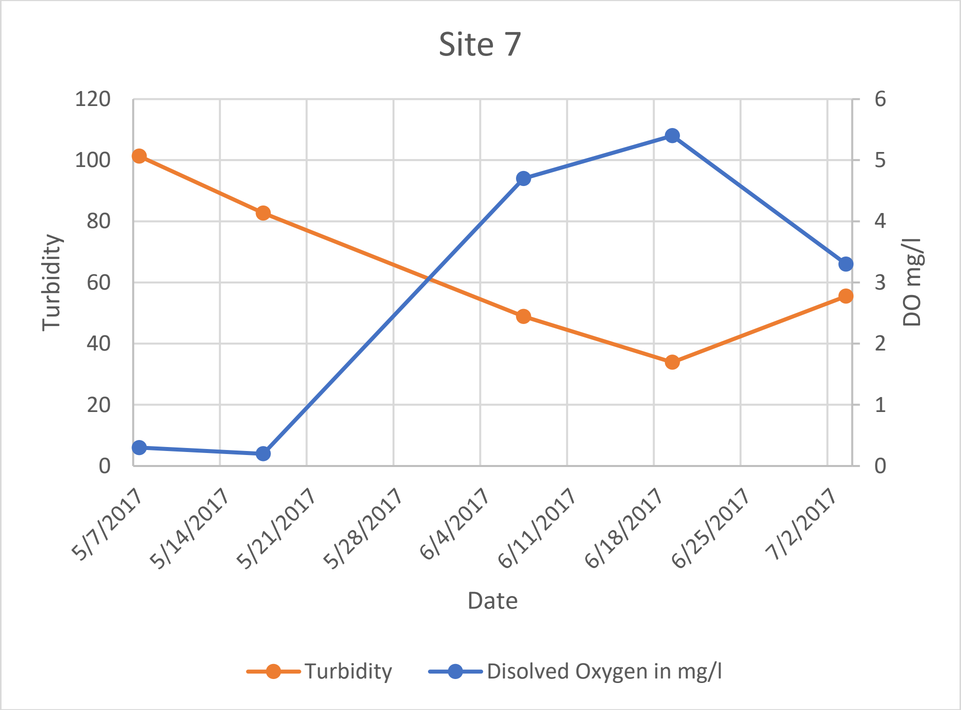

*Figure 33. Site 7 Plot of Dissolved Oxygen from Kong (2017) and Turbidity from Morgan City over the time data was collected in 2017.*

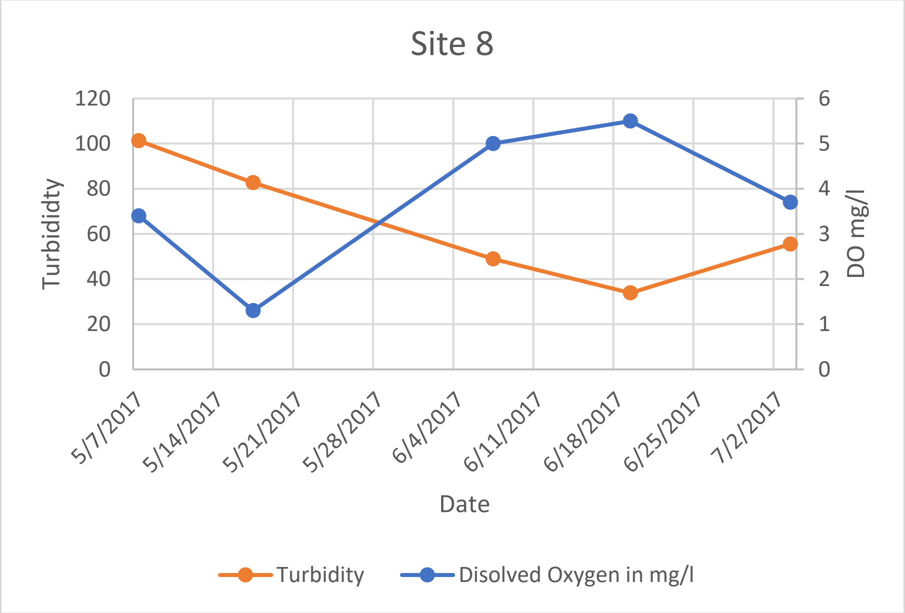

*Figure 34. Site 8. Plot of Dissolved Oxygen from Kong (2017) and Turbidity from Morgan City over the time data was collected for Site 8 in 2017.*

So, in summary, 2017 was a rain-induced flood with much lower turbidity than a regular flood such as 2016 (Figures 18 and 19). Kong's data for the flood peak in 2017 reveal that the DO levels rose as the flood progressed, reflecting a low turbidity rainfall induced flood peak. During the flood eutrophication and hypoxia were not an issue. The TNC 2017 data support and parallel the Kong data. Suffice to say, Low turbidity floods (unique, very rare since 1973) drive up the DO in contrast to high turbidity floods (the norm) where often Hypoxia results due to the rapid reduction in DO, as microorganisms feast on the abundant nutrients especially N, and consume the DO.

### c. The TNC Data for 2018

The Butte la Rose stage data indicate that there were only about three months of low water (less than 3 m or 9.8 ft) (Figure 35). Initial review of flood literature suggests the early flood from February through mid-June was a Mississippi Catchment flood with an apparent strong contribution from the Upper Mississippi and Missouri Rivers. For ease of discussion this will be referred to as the 5-month duration "Spring" flood while that from October through the end of the year the "Fall" flood. Turbidity data from Morgan City (Figure 36) supports this view in that turbidities peaked at about 320 and were high for most of the early flood and rose again with the late flood. An eyeball average of about 100 appears fair for both floods. So, the 2018 flood from early February through mid-June was carrying high suspended sediment loads as well as nutrients.

Figure 37 from TNC (2018) shows that at most of the TNC sites the DO rose in sympathy with the Spring flood but at half the sites the DO fell precipitously after a month (AU5, AU6, T3), started falling at the time the flood peak. So, is fresh flood water improving DO; why did the DO levels fall while the flood was still going strong? The rest of the TNC sites stayed elevated until end of April for another month (A1, AU2S, AU3). Can this discrepancy be explained? The upper DO sites, AU1, AU2S and AU3, are aligned along the Florida Gas pipeline canal a major flood feeder into these swamp areas (Figure 17, page 28). The close proximity would have maintained higher DO levels (for a month longer) until the consequences of eutrophication due to nutrient loading took its toll on the DO. TNC present evidence of algal blooms at site AU1, a reflection of the nutrient loading. The rest of the sites (AU5, AU6, T3) appear show a dramatic reduction in DO late March even though there is still about 3 feet of water over the bottom of the sites. Why? Site AU2N is not shown on Figure 37 but review of the data collected at this site shows that from

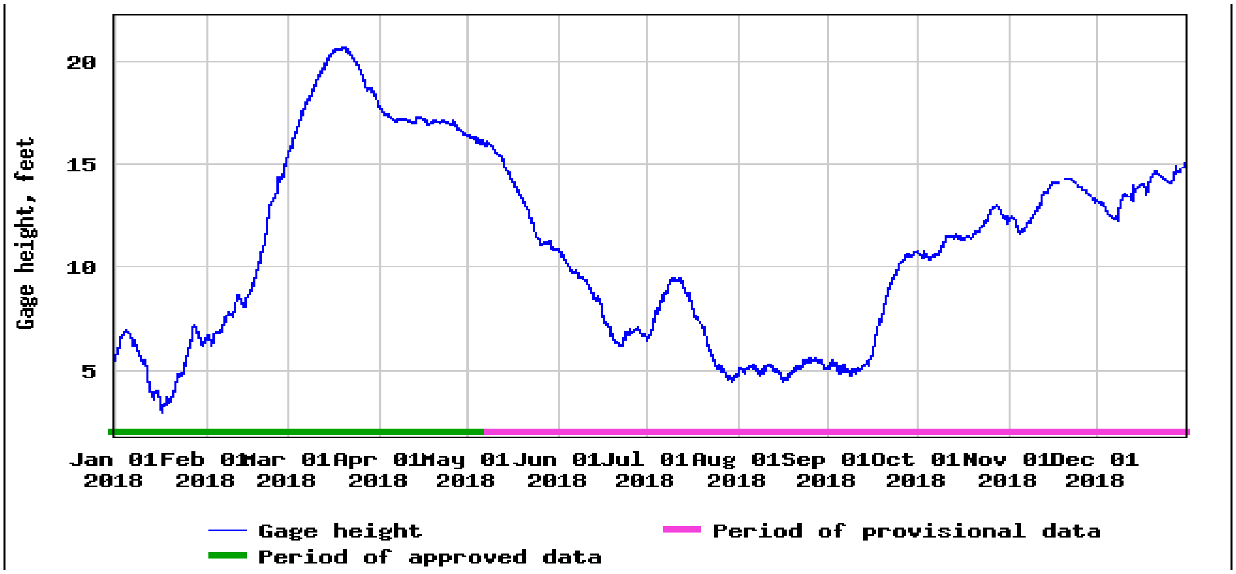

*Figure 35. Atchafalaya River water levels at Butte La Rose (USGS Gage 07381515) in 2018*

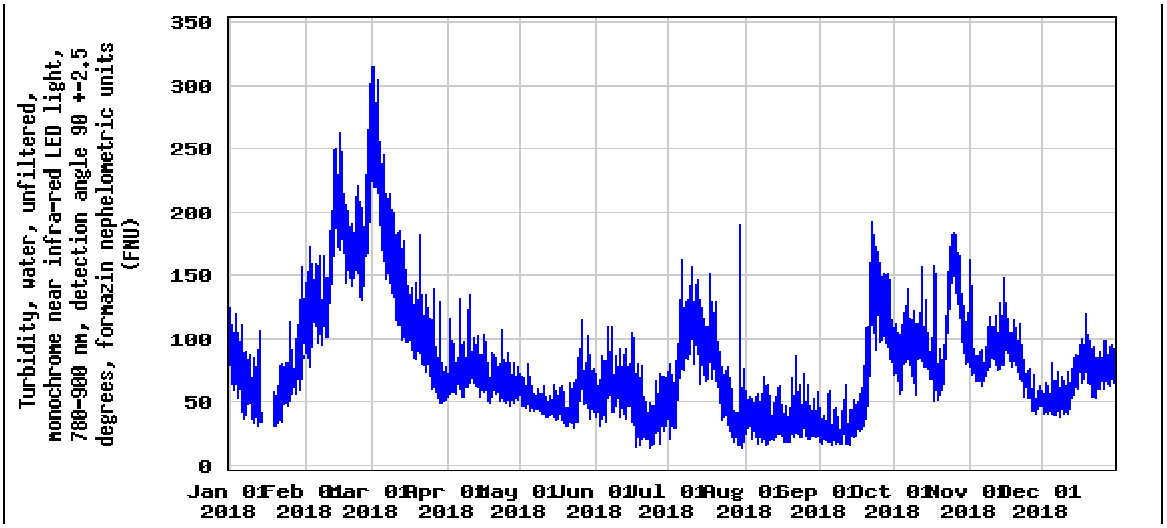

*Figure 36. Turbidity data for Morgan City for the year 2018.*

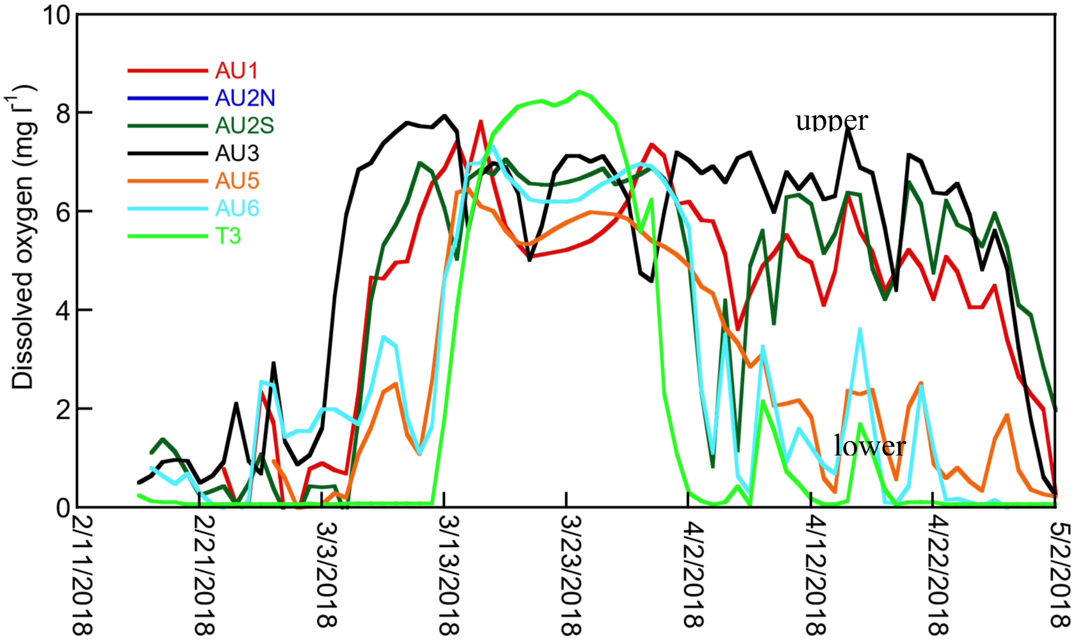

*Figure 37. Mean daily dissolved oxygen concentrations at the backswamp monitoring stations for three months from February to May 2018. (From TNC 2018).*

4/10/18 to 6/23/18, when the site became dry, it was Anoxic. It joins the lower group above. The data difference between the 'upper' and 'lower' group reveal that location is important in trying to understand the data and that the upper group are closer to a direct source of river flood water. The lower group because of the flood induced nutrient loading become Anoxic very rapidly. If flooding with river water was healthy for the maintenance of oxygen levels in the swamps, then this precipitous fall in DO should not occur.

Figure 38 is a plot of turbidity for the whole of 2018 (12 months) for sites AU2S (upper) and AU6 (lower) while Figure 39 is a plot for the two same stations of DO. What is readily apparent in Figure 39 is that towards the end of the year the DO at AU6 (lower group) is better than AU2S (upper group), why one might ask? On 1 March 2019 an ABK crew went to try to find these two sites but were not successful. However, they did spend some time in the general area of these two instrument sites and reported that there was a strong south wind and waves were breaking on water areas south of the Florida Gas canal that were not heavily vegetated. Anyone who has spent any time in the Basin knows that wind causes ripples at the very least but can be rough when the wind is strong. They also noticed that near to AU2S water was flowing north into the Florida Gas canal being pushed by the wind.

Site AU2S is located north of the Florida Canal, which is lined by high spoil banks, while AU6 is south of the is canal (Figure 17). The canal has an SW-NE orientation and south of it are a number of open water bodies with a fetch of about 4 miles before the next pipeline canal. A quick review of local weather data indicates that October through December were wet months with a total rain fall in excess of 18 inches, about 4 inches above normal, reflecting that a number of cold fronts crossed the area. Such would have produced strong south to southeasterly to east winds, so the raindrop splatter and the wind waves would have enhanced the dissolved oxygen content of these areas resulting in the DO measurements being non-Anoxic for those three months. If this increase in DO was due to flood waters, then the AU2S site would have had a similar DO response.

This very quick initial review and attempt to interpret the TNC data reveal two very important aspects of the Basin. Firstly, flood water will locally improve DO for a short period but then the nutrient loading leads to eutrophication and eventually anoxic conditions develop. Secondly, other factors such as storm and wind events can have a dramatic impact on DO, raising levels above the anoxic condition.

TNC do not give an explanation why the turbidity at site AU1 has spikes of up to 350 from 4/7/2018 to at least 5/2/2018 (Figure 40). Was this an instrument problem or was there some external process forcing this very high turbidity. Boat traffic maybe?

The bottom line is that this quick initial review shows the complexity of the Basin and that introduction of flood waters even with moderate floods will enhance Eutrophication and lead to anoxic conditions.

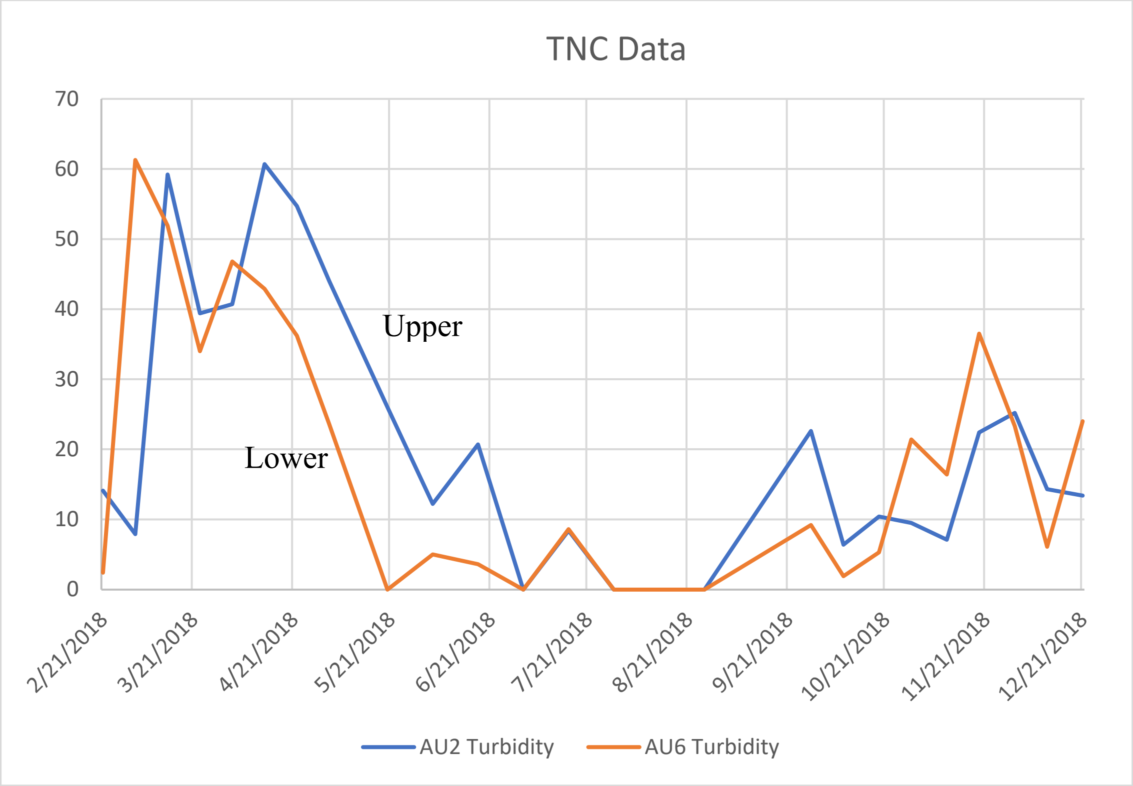

*Figure 38. Turbidity plots for sites AU2S and AU6 for the 2018-year (Source TNC 2018). Upper and Lower based on Fig 37 for period 2/2018 to 5/2018 – 3 months.*

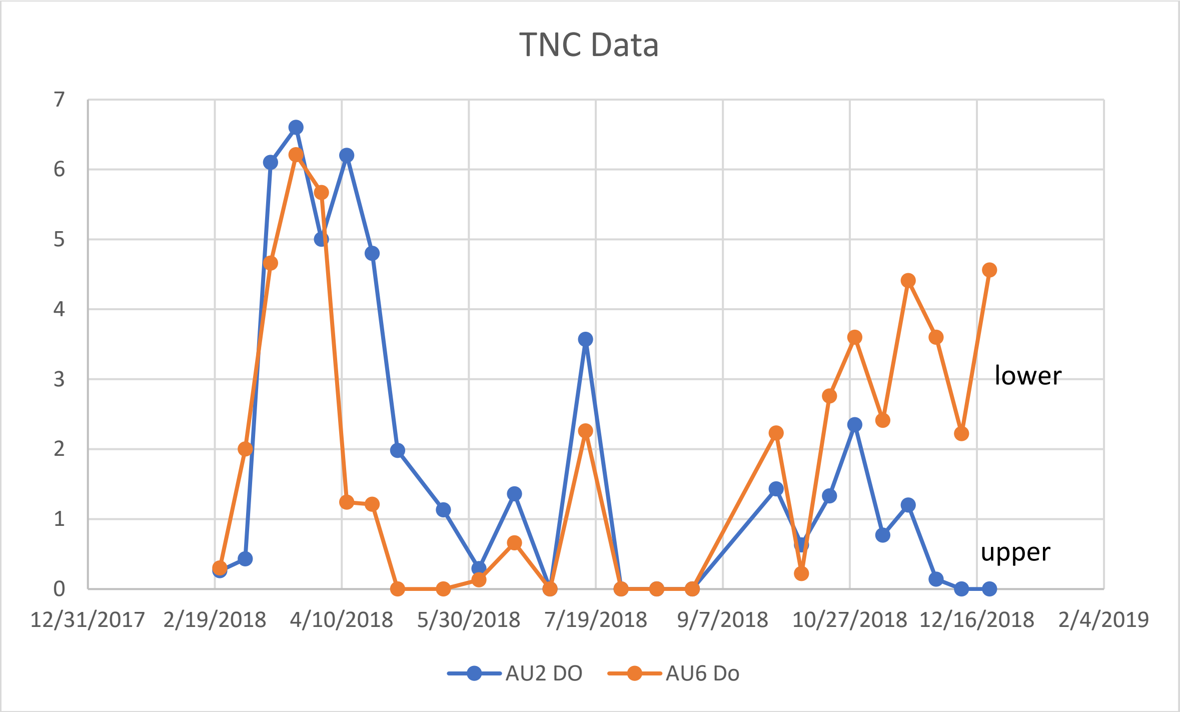

*Figure 39. Dissolved oxygen plots for sites AU2S and AU6 for the 2018 year.(Source TNC 2018). Upper and Lower based on Fig 37 for period 2/2018 to 5/2018 – 3 months.*

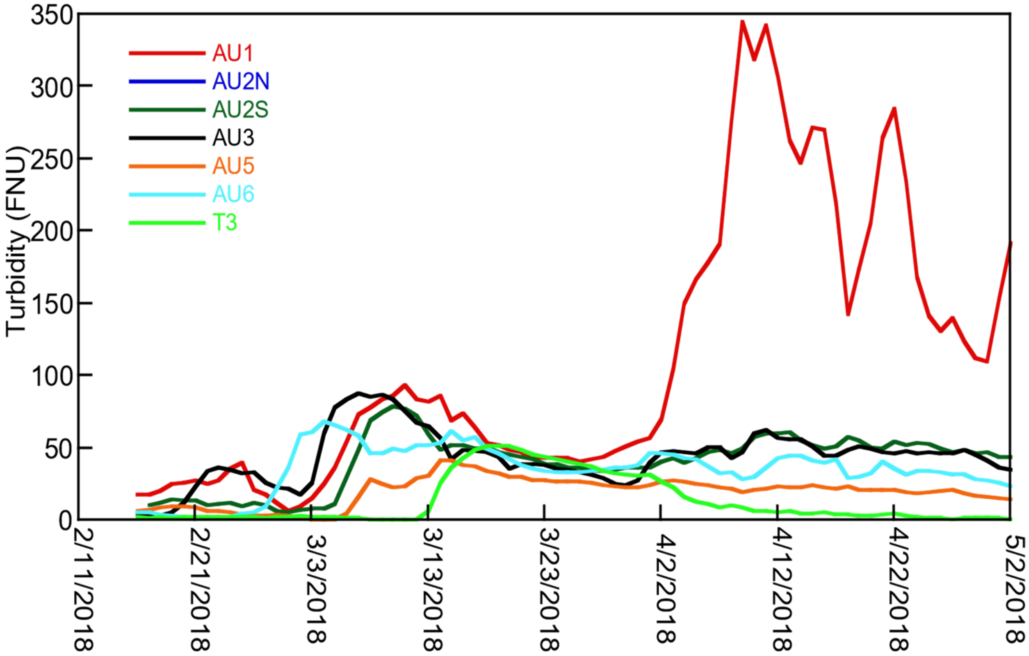

*Figure 40. Mean daily turbidity at the backswamp monitoring stations from February to May 2018.*

d. The TNC 2019 Data.

As previously discussed, the 2019 Mississippi flood was of long duration (Figure 41) and precipitated two openings of the Bonnie Carre' Spillway.

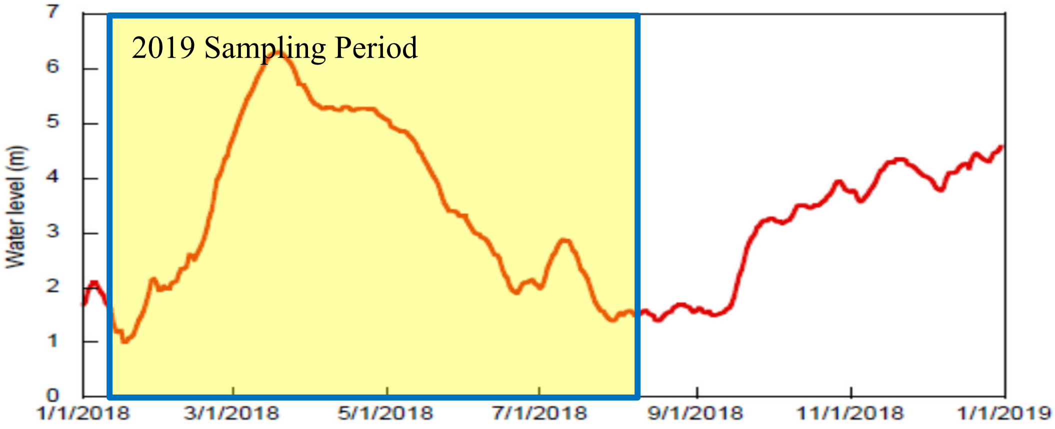

*Figure 41. Atchafalaya River water levels at Butte La Rose 2019.*

Data was apparently collected from Early January through December but the only data forthcoming from the state covered the period from Mid-January 2019 to the first week of August 2019. Nevertheless, the data are beneficial to this discussion.

Figure 42 reveals locations of the TNC monitoring stations while Figure 43 displays the mean daily water levels at the TNC monitoring stations.

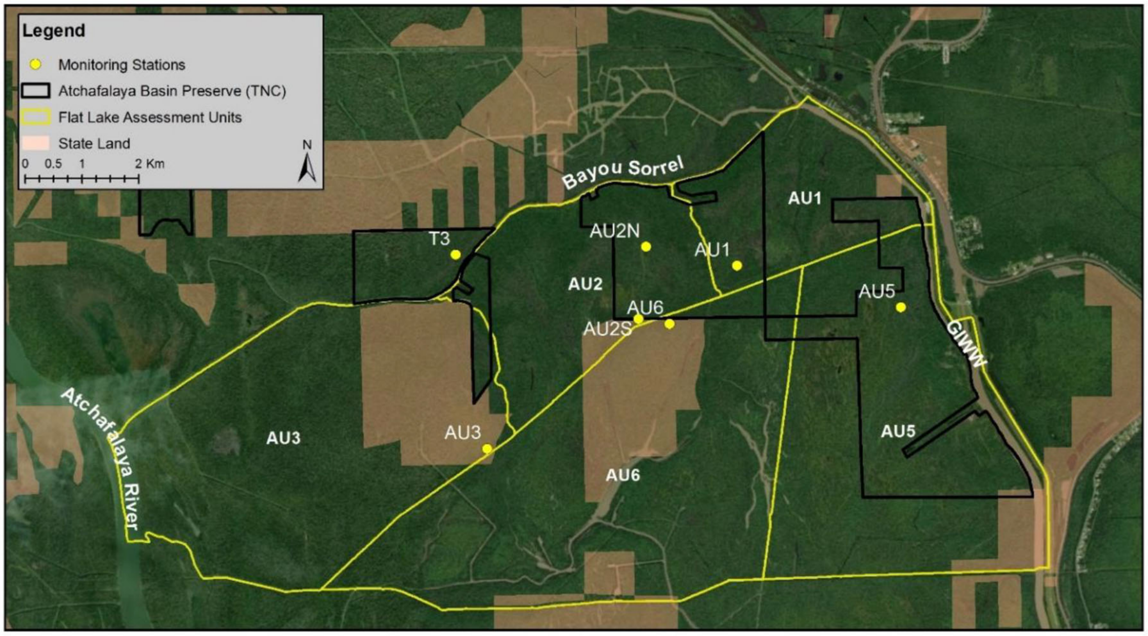

*Figure 42. The TNC 2019 monitoring sites.*

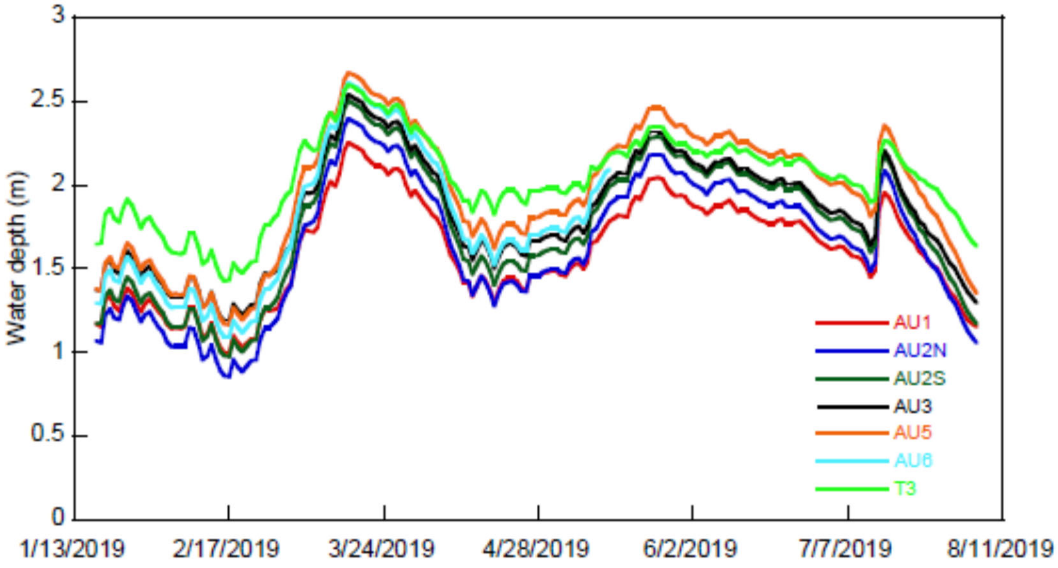

*Figure 43. Mean Daily water levels at TNC monitoring stations 2019.*

What is obvious from Figure 43 is that the monitoring sites were being well flushed with flood water the depth, including instrument offset above ground, ranging from about 1.15 m to a high of about 2.65 m. Figure 44 displays the mean daily DO concentrations in mg/l for the swamp stations that TNC has monitored and are comparable to their previous data (TNC 2017, 2018). What is glaringly obvious it that the DO concentration drops throughout the study period and in many ways mirrors that of the Atchafalaya River at its Morgan City outlet for 2019 (See Figure 16, page 26). Many sites start at about 10 mg/l and fall to a low of less than 2.0 mg/l by early August 2019. Considering seasonal temperature differences as measured by TNC at their sites (winter 10 C; summer 27 C, Figure 45), the seasonality in the drop of Oxygen levels can be explained but not the much lower dissolved Oxygen levels as compared to the source Mississippi waters. If all things are equal, then the Oxygen levels should exactly follow the trend and values of Oxygen in the Mississippi River (Figures 13, pg. 22).

During the summer warmth the Oxygen levels should be about 8 mg/l, not the less than 2.0 mg/l as displayed in Figure 44. Why this huge difference in Oxygen levels in the flow in these swamp and levee locations sampled by TNC? Why are the Oxygen levels at the end of the data collection period, namely early August, Mid summer, less than 2.0 mg/l? Something is 'sucking' the oxygen out of the water. In the shallow waters of the Basin swamps and lakes photosynthesis is taking place so one would expect, as explained in the introduction, that Oxygen levels would be helped by Photosynthesis. But nevertheless the Oxygen levels in this major flood drop way below what can be explained by the temperature rising as the sampling period progressed.

The only explanation is the very high nutrient levels, three times what characterized river floods prior to 1973, is the cause. The DO levels in Atchafalaya, as evidenced where the waters leave the Basin at its southern end, are at times half that of the basically saturated DO Missisppi flow inputs to the Basin. The drop in DO levels cannot be explained by seasonal temperature differences. Instead this is classical eutrophication. Microorganisms and such are having a huge feast due to the heavy nutrient loads of the Mississippi River precipitating marked lowering of DO as they consume the DO.

The TNC 2019 data very strongly show the impact of nutrient loading and consequential eutrophication and hypoxia even when there is a long duration flood and the swamp is being well flushed. Again, and again, these 2019 data strongly support that flushing of swampland channels and channel cuts is not the solution to eutrophication. Rather it adds and abets the eutrophication problems.

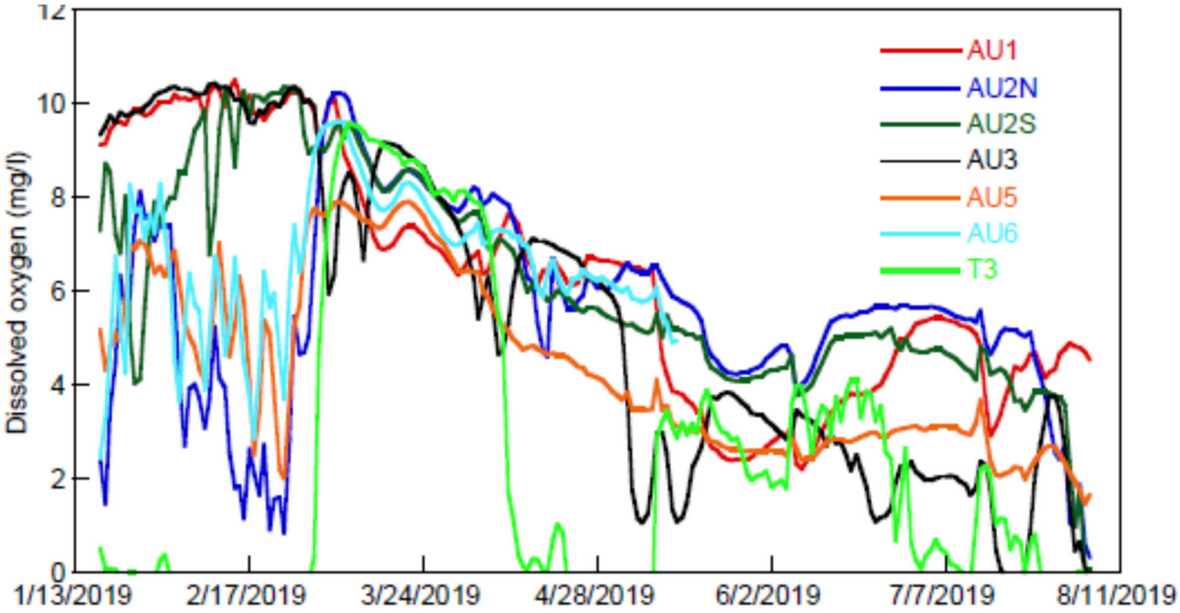

*Figure 44. Mean daily dissolved oxygen concentrations at the TNC monitoring stations. For locations see Figure 34.*

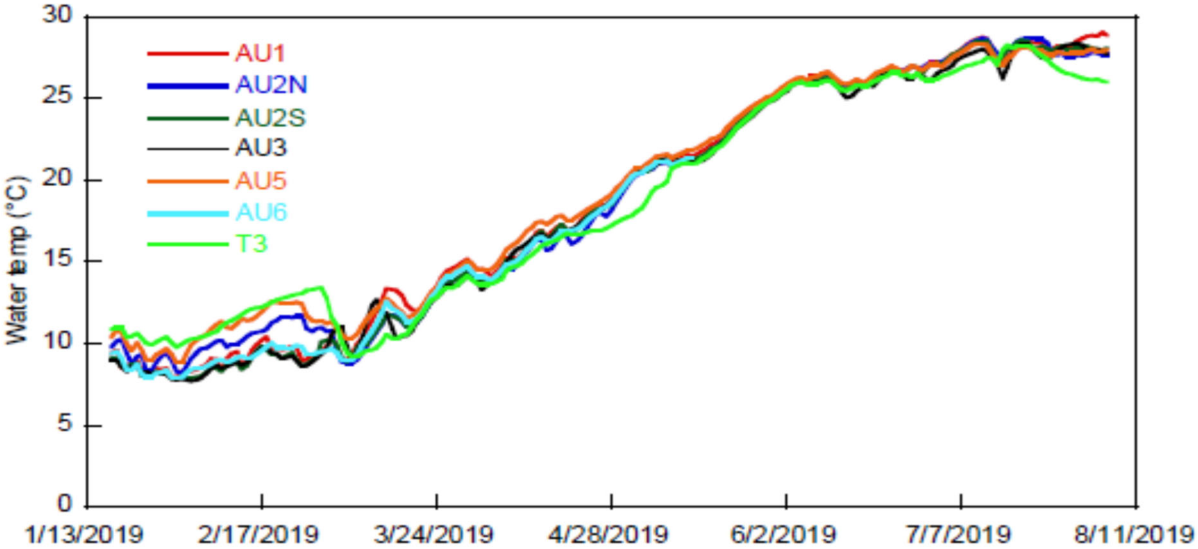

*Figure 45. Mean daily temperatures at the TNC monitoring sites Jan to August 2019.*

## CONCLUSIONS

1. The Big Picture data presented for the Mississippi and Atchafalaya Rivers in Chapter 1 strongly demonstrates that as the Mississippi derived waters flow through the Atchafalaya Basin there appears to be a pattern of modification in traversing the Basin. When there are high levels of turbidity in the water with a rising flood, and temperatures are lower, turbidity rises as flood water crosses the Basin (to be discussed in more detail by van Heerden 2020). At the same time the N levels fall as do the Dissolved Oxygen concentrations. This therefore suggests that in the shallows of the swamps, biological activity substantially increases resulting in a lowering of N levels as they are consumed by microorganisms and an attendant drop in Dissolved Oxygen. Increased biological activity thus results in an increase in turbidity as measured where the Basin waters exit seawards of Morgan City. Most importantly, Oxygen falls from January to July every year from 2016 through 2019. This has major ramifications for the management of the Basin. The source of eutrophication is the nutrient rich Mississippi waters entering each flood at Old River, and as the flood progresses eutrophication accelerates resulting in increased turbidity and lowering of Oxygen levels and to hypoxia. Remember nutrient input as revealed in Figure 1, is 3 times what it was before the widespread of industrial fertilizer in the Mississippi catchment.
2. Kong's data collected within a Basin swamp for flood peaks in 2016 and 2017 reveal that as the flood peak starts DO levels are high and as the flood progresses they fall down to hypoxic conditions, except when a low turbidity rainfall induced flood peak crossed her study area in 2017. This data is very strong evidence that Eutrophication and eventual Hypoxia is the result of the very high nutrient loads entering the swamps and the rapid reduction in DO follows as microorganisms feast and suck up the DO.
3. The TNC data for 2017, 2018, and 2019 mirror the results found in the Big Picture study as well as the review of Kong's Thesis.
4. While the only nutrient studied in this thesis was Nitrogen; as streamflow was decreasing in the 2011 flood in the Lower Mississippi River - Atchafalaya River sub basin, Welch etal (2014) pointed out that orthophosphate composed an increasing percentage of the total phosphorous concentration, probably because of return of waters low in oxygen concentration from stillwater areas such as inundated lands, backwater streams, and floodways. Poorly oxygenated waters promote the release of sediment-bound phosphorous into the more readily available dissolved form. So, the data collected by the Welch etal (2014) suggest that a low oxygen concentration promotes the release of phosphorous.
5. The solutions to management of the Atchafalaya Basin (including the floodway and outside sections) are not projects such as those proposed by supporters of the EGL project. Rather one needs to look outside of the box, dispel the "folklore" solutions of the past and truly follow the science. Additionally, managers need to look at reinstating some of the natural hydrology that characterized the area in the past such as removing oil canal spoil banks and engineering some kind of controllable connections between the

Floodway Basin and the Verret and Fausse Point sub basins. Just two of a number of suggestions.

This study has not covered the problems with increased sedimentation in the Basin Floodway and man's role in enhancing this devastation consequence of sediment mis management. Van Heerden 2020, in a sister thesis to this manuscript, addresses these management issues.

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