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Historical Water Quality of a Tampa Bay Estuary: A Literature Review and Case Study of Clam Bayou in Pinellas County, Florida

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By

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Abstract

Estuaries are important ecosystems that provide many valuable services to coastal communities and society at large. Clam Bayou is an estuary located in Pinellas County, Florida, which is a popular area for recreational activities such as kayaking. However, Clam Bayou has a history of water quality decline by factors such as sewage discharge, stormwater runoff, industrial pollution, among many others. This literature review is aimed at examining the past research done on Clam Bayou regarding water quality and offering future ideas for research. Research revealed that studies concerning Clam Bayou are limited, but have a strong concentration on sewage discharge and stormwater runoff as drivers for water quality decline. There is strong evidence that relates the effects of urbanization and stormwater runoff to the decrease of water quality in Tampa Bay, such as how the population increased by 148% and 158% in Hillsborough county and Pinellas County respectively, from 1960 to 2001 (Xian, Crane, & Su, 2007). It was also found that impervious surfaces have significantly increased, reaching almost 80% coverage in some areas of Tampa Bay (Xian, Crane, & Su, 2007). Clam Bayou's water quality, according to the literature, seems to be worsening with time. When compared to 2008, in 2016, Clam Bayou has had warmer water temperatures (range of 29.68 to 32.03°C) and a much lower salinity (range of 24.35 to 31.19 psu). High amounts of aromatic hydrocarbons were also found in the sediments such as DDT, which is a substance that is banned for being carcinogenic (Karlen et. al, 2016). The literature also shows that there there have been a few projects that have improved the water quality of Clam Bayou, such as planting mangroves and oyster reefs as well as creating new storm water drains (Newborn, 2019). Although

understudied, it is crucial that estuaries such as Clam Bayou are continually researched and restored for the betterment of our natural world.

Introduction

I. Intent of Report

This study is a literature review of Clam Bayou, an impaired estuary in Tampa Bay. This review involves looking at the research that has already been done involving Clam Bayou, in hopes of discovering trends for the water quality decline and to suggest ideas for future research. There has been past research covering fecal coliform contamination (Rojas, 2012) and an assessment of the Benthic Macrofaunal Community and Sediment Quality Conditions (Karlen et al, 2016) of Clam Bayou in the past. This report aims to present this past research regarding water quality in a concise manner. This information could prove beneficial to those who wish to improve the water quality of Clam Bayou or Tampa Bay in the future, which is vital for future remediation efforts. This report also has the potential to assist with public health and safety by being informative about the contaminants of the water, as well as promoting the overall health of the ecosystem,

II. The Water Quality Issue in Tampa Bay

Tampa Bay is a large estuary network located in Florida that is considered a productive natural system that comprises an area around 1000 square kilometers. Within this vast expanse of water, there are many different smaller estuaries that make it up, such as Clam Bayou. Due to its proximity to the large cities of Gulfport and St. Petersburg, there is constant runoff into the Bay. This runoff has the ability to affect the quality of the water by contaminating it, thereby harming the ecosystems that are thriving within them. Water quality refers to the physical, biological, and chemical characteristics of water that are used to measure the condition of the water relative to ecosystem health or for activities such as swimming. Tampa Bay has battled with the problem of water pollution since the 1970s in many different forms. Some of the main components such as oil and E. coli bacteria are constantly being added to the Bay, thereby worsening the already declining condition of the water. In society's natural quest for the extraction of natural resources comes reckless conservation practices and greedy corporations (Johansson and Lewis, 1992). Oftentimes, the benefits of taking these resources in the form of monetary compensation are the greatest concern as opposed to preserving the natural habitat that it came from.

In the 1970s, Tampa Bay was extremely polluted to the point where the Bay experienced continuous blue-green algae blooms that lasted for long periods of time (Johansson and Lewis, 1992). Blue-green algae and other types of phytoplankton grow faster in areas where the amount of nutrients is the most abundant. In cases such as Clam Bayou where there are many different sources that are contributing to these nutrients such as sewage dumping, land runoff, and human usage -- there is a heightened chance for algae blooms to occur. When these blooms do happen, a process called eutrophication occurs whereby the available oxygen in the water column is depleted by the decomposition of organic matter, including the large amounts of decaying phytoplankton. Often, this process leads to suffocation of the life below due to there not being enough oxygen. Excess nutrients that are not needed in the water such as nitrates and phosphates may lead to additional environmental problems such as habitat loss and an extreme decline in water quality. One of the most detrimental effects other than environmental decline is the possibility of it harming human health. This can come through exposure from recreation or drinking the water, both of which are plausible as Clam Bayou is known for its recreational activities such as kayaking and fishing.

One of the leading causes of water pollution in the Tampa Bay area are the growing effects of urbanization. In Pinellas and Hillsborough county, the population has increased by 148% and 158% respectively from 1960 to 2001 (Xian, Crane, & Su, 2007). With urbanization comes a growing population and an increase in anthropogenic impervious surfaces which has reached a maximum of 80% coverage in some areas. This then leads to a higher rate of surface runoff which increases the chance of local flooding that contains pollutants such as nitrates, phosphates, heavy metals, oil, etc. (Xian, Crane, & Su, 2007). Normally, the sources of these pollutants originate from points of surface runoff from places like farms or local industries. A major contributor to water pollution are the corporate polluters that are in violation of the Clean Water Act due to the lack of state-level enforcement. Two of the major polluters -- TECO and Coca-Cola, -- among others, who continue to illegally discharge waste into Tampa Bay without reporting, are a big part of the issue (Bradshaw, 2018). Without stricter regulations on water pollution, the issue with water quality decline will continue to be a problem. Clam Bayou is just one of the significant examples where the quality of water changes with the amount of pollution coming in.

This study looks at a specific estuary in Tampa Bay, Clam Bayou, to examine this history of water quality decline. The literature used in this review starts in the

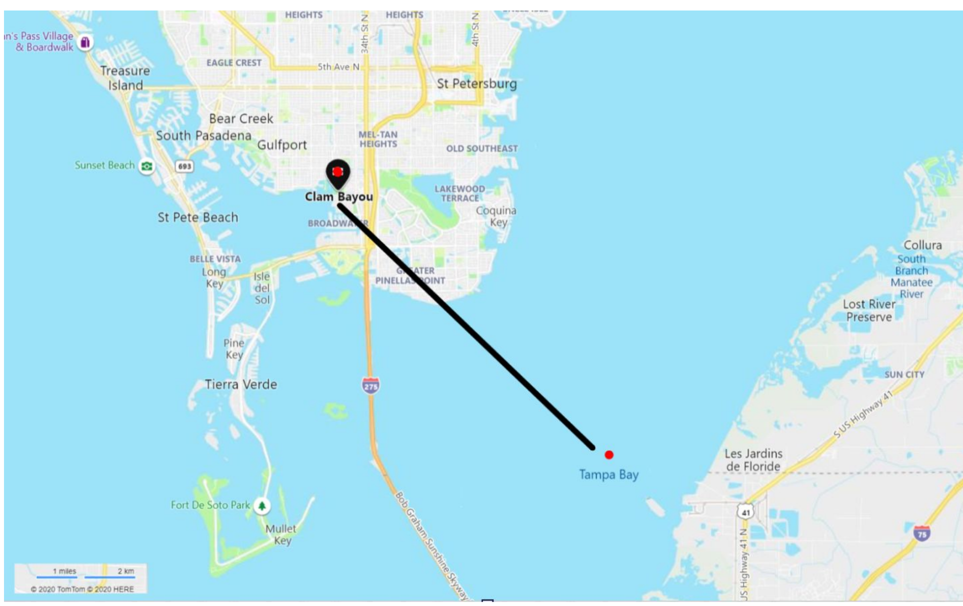
1960's and continues through 2019. Sifting through the past and current research concerning Tampa Bay and Clam Bayou reveals historical trends and ideas that may be used for future research.

III. Site of Interest: Clam Bayou in Pinellas County, Florida

The site of this report, Clam Bayou (27.741 latitude, -82.691 longitude), is located in Pinellas County, Florida. This 170 acre large estuary neighbors Boca Ciega Bay, which is part of the lower part of Tampa Bay. Since the 1920s, the quality of this area has declined because of the effects of urbanization. Much of the natural area has been lost due to development, with many of the original coastal areas being turned into urban canals due to dredging practices (Rojas, 2012). It is also located in an area called the Gulf Coastal Lowlands physiographic region, where soils are poorly drained since the water table is near the surface. This makes for the water of Clam Bayou to be insufficiently filtered, which leads to a decline in water quality (Rojas, 2012). The site is connected to the two aquifers in Pinellas County (the surficial Aquifer and the Floridan aquifer). The surficial aquifer consists of undifferentiated sands, silt, and clay all of varying thickness. This aquifer is also used for irrigation purposes along with domestic use. In Pinellas county, the Floridan Aquifer is the principal water source for industrial use, mining, public supply, irrigation, and brackish water desalination (Rojas, 2012).

Another major component of the Clam Bayou makeup is its karst topography, which is terrain that is made up of soluble rocks such as limestone and is characterized by sinkholes and caves (Kacaroglu, 1999). Watersheds that are located on top of karst layers are labeled as vulnerable to contamination. This is due to the karst features infiltrating the water table, which creates contact with the above land pollution to the underground water. Karst aquifers, like the one found under Clam Bayou, are vulnerable to pollution and from activities due to their hydraulic and hydrologic characteristics (Kacaroglu, 1999). A direct connection between the surface water and the groundwater is established, which creates the possibility for problems such as saltwater intrusion, which is when saltwater mixes with freshwater sources. There could also be harmful contaminants that come with the surface water, which would then be transferred to the groundwater -- polluting it. Such pollutants could be chemicals or pesticides that were applied to or spilled on the land, or fertilizer carried in surface runoff (Rojas, 2012).

Figure 1: Map of Clam Bayou and Tampa Bay



- Figure 1 shows the position of Clam Bayou in reference to Tampa Bay. Clam Bayou also borders Boca Ciega Bay, which is part of Lower Tampa Bay.

Past and Present Water Quality of Clam Bayou

I. Point vs. Nonpoint Sources

Knowing the difference between point sources versus nonpoint sources of water pollution is critical for finding the source of contaminants in places like Clam Bayou. It is important to understand the individual sources of pollutants to the impaired waterbody. Point sources involve pollution that comes from an easily identified confined space that causes a discharge of effluents over a wide area. Some examples of point sources are oil refineries, industrial waste discharge lines, etc. The discharge is typically to surface waters via a discernible conveyance, such as a pipe (Rojas, 2012). Some traditional point sources are domestic and industrial wastewater treatment facilities.

On the other hand, “nonpoint” sources involve indirect discharge into water. This type of source involves the rainfall-driven diffuse sources of pollution that are rooted in anthropogenic actions, such as runoff from farms, urban areas, and mining. Nonpoint source pollution picks up natural and human-made pollutants as runoff and then deposits them to the nearby water bodies.

II. Sewage Discharge Pollution

In Clam Bayou, there has been evidence of sewage water discharge from the city of St.Petersburg and Gulfport. When there is consistent prolonged rainfall in these cities, it floods the outdated septic system and leads to sewage water in the streets. There have been multiple incidents in the past where the City of St. Petersburg dumped thousands of gallons of untreated sewage into Clam Bayou. In 2016, St. Petersburg Mayor Krisemen said that this would not happen again when confronted by the concerned community (Deeson, 2016). After these events in the same year, the Clam Bayou area became swamped with contaminants, including E.coli bacteria. E. coli is a type of bacteria that originates in the intestines of humans.It is often used as an indicator of fecal pollution, more so than other fecal coliforms (Odonko & Ampofo, 2013). In some cases, E. coli has the potential to cause intestinal infections from exposure. The symptoms of this infection include diarrhea, abdominal pain, and fever. In the worst cases, severe dehydration and kidney failure may occur (Odonko & Ampofo, 2013). These symptoms may happen if people are exposed to the contaminated water through activities such as swimming or drinking. E.coli also increases the presence of algae in ecosystems, which has a significant impact on the water clarity of the Bayou. Although E.coli is the most commonly used indicator of fecal coliforms, it is a natural component of water ecosystems and most of these bacteria are harmless to humans ("Bacteria and E.coli in water", n.d.).

The presence of E-coli in Clam Bayou after these events caused the area to become closed and roped off. According to Tampa Bay 8 News, one of the main reasons for the influx of sewage discharge was the elimination of one of the water treatment plants after the city decided to go from four to three in an effort to save money. Because of this, less sewage was being treated and therefore the city had no other choice but to dump it into the Bayou (Deeson, 2016). The sewage system in St.

Petersburg is outdated and has leaky pipes which put sewage water into the streets when the below-ground system is flooded after persistent rain events. The biggest concern with the E.coli bacteria being present in the water are the harmful effects that it has on both the environment and human health.

IV. Sediments and Water Clarity

Higher sedimentation rates can affect the clarity of the water which has a direct correlation to the health of the benthic community of Clam Bayou. More sedimentation leads to higher turbidity in the water column, which decreases the amount of dissolved oxygen in the water. With an insufficient amount of oxygen in the water, the ecosystem is unable to sustain life. The state criterion for dissolved oxygen is a minimum of 5 mg/L to maintain healthy conditions for aquatic life as anything below that may result in environmental decline through loss of biodiversity (Florida Department of Environmental Protection, 2008). Levels above 5 mg/L (approaching 10 mg/L) is the prime dissolved oxygen concentration for a water body in terms of productivity and supporting aquatic life.

Past research has been conducted concerning the sediment makeup of Clam Bayou in 2008 and 2016. Clam Bayou had been labeled as a “special site” due to it having a restoration project underway in an attempt to improve the water quality under the Southwest Florida Water Management District/ Surface Water Improvement Program (Karlen et al, 2016). Findings from the 2008 sampling found high levels of sediment contaminants, involving pesticides and aromatic hydrocarbons. For example, in 2008, there was 371.36 (μg/kg) of Phenanthrene, an aromatic hydrocarbon, found in the sediment of Clam Bayou (Karlen et al, 2016). Aromatic hydrocarbons are frequently carcinogenic and are considered dangerous from large amounts of exposure. Due to these findings such as this, the Florida Department of Environmental Protection mandated another sampling to document any temporal changes in the sediment contaminant levels. In 2016, there were notably higher water temperatures and lower salinities relative to 2008. In 2016, bottom water temperatures ranged from 29.68 to 32.03°C and were significantly higher than in 2008 (Karlen et. al, 2016). As for salinity, in 2016, it ranged from 24.35 to 31.19 psu, which were significantly lower than in 2008 ($p<.001$) (Karlen et. al, 2016). They also found higher silt and clay sediment which was associated with the decline in benthic community composition in Clam Bayou. In 2016, there were significantly high rates of pesticides with DDT, an aromatic hydrocarbon that is now banned, within the sediment (Karlen et al, 2016).

V. Graphical Display of Three Common Water Quality Parameters

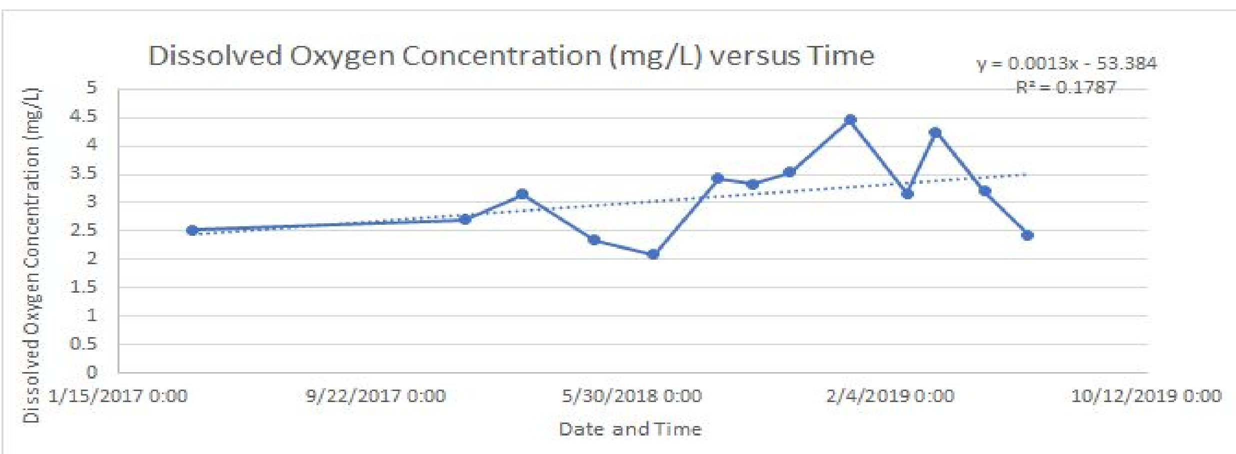
The following graphs display three common parameters used to indicate water quality: dissolved oxygen, chlorophyll-a, and fecal coliforms. This data was gathered from the Pinnellas Wateratlas online database. These measurements are taken and recorded by data-monitoring stations located in Clam Bayou maintained by the City of St. Petersburg. For this particular data set, the measurements were taken at the Clam Bayou East Drain staton, shown in Figure 5. The data for these graphs ranges from 2017-2019. The station records measurements constantly and then reports them to the satellite, which is then displayed in realtime on the website. Figure 2 shows the dissolved oxygen concentrations with respect to time, with an R value of 0.1787 and a p value of 1.83 e-9. Figure 3 depicts the chlorophyll-a concentrations with respect to time, with an R value of 0.0662 and a p value of 0.001178. Figure 4 shows the fecal coliform concentrations with respect to time, with an R value of 0.0344 and a p value 0.046684.

Table A: **Surface Water Threshold Values for Graphed Water Quality Parameters** found in Criteria for Surface Water Quality Classifications, Rules 62-302 and 62-303, Florida Administrative Code (F.A.C.)

Parameter	**Threshold/ Criterion**	**Designated Use**
Fecal Coliform (cfu/100ml)	< 400 colonies (cfu/100ml)	Recreation
Dissolved Oxygen Con. (mg/L)	> 5.0 (mg/L)	Aquatic Life
Chlorophyll-a (ug/L)	≤ 20 (µg/L)	Aquatic Life

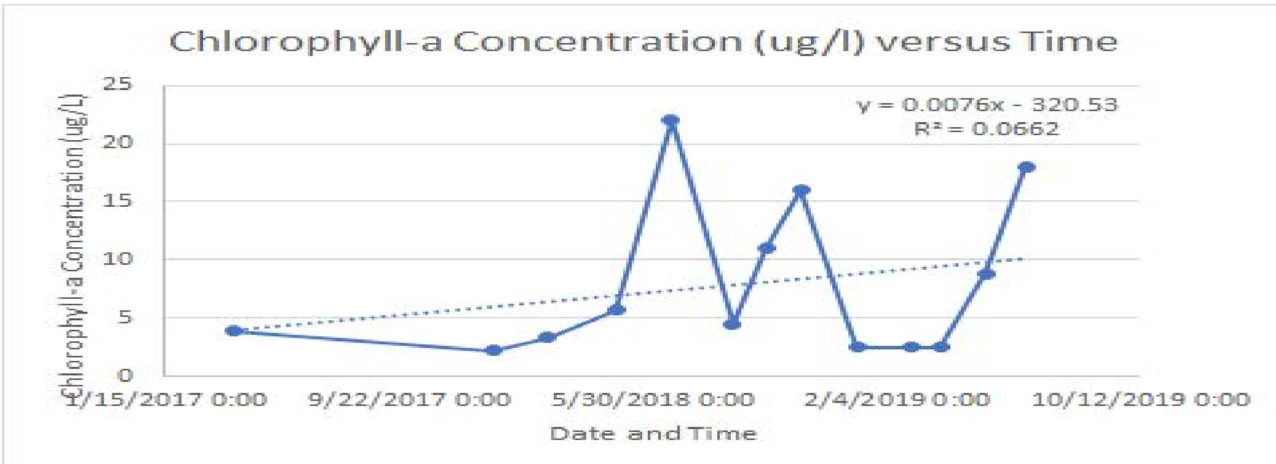
* mg/L – milligrams per liter; µg/L – micrograms per liter; cfu - colony-forming unit

Figure 2:



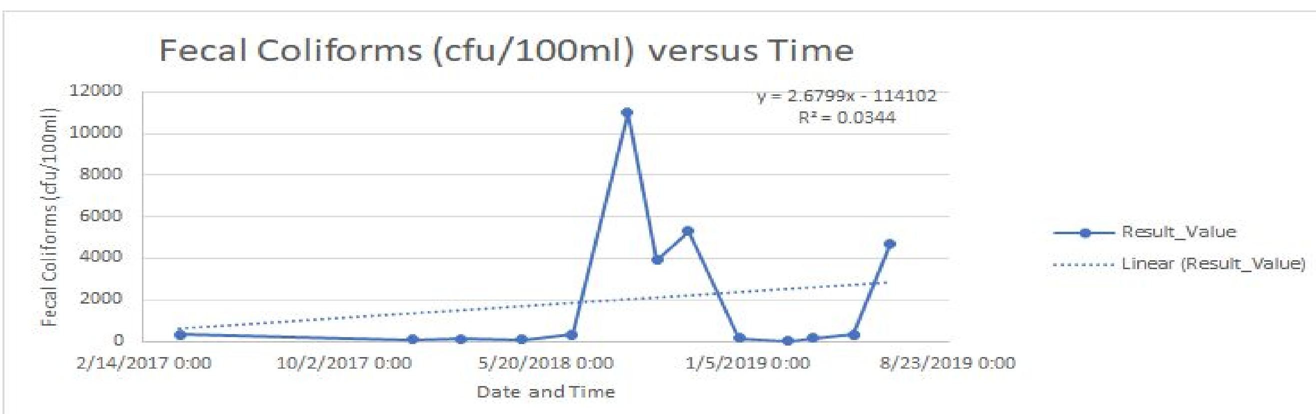
- Figure 2 represents time series data ranging from 1995 to 2019 in terms of dissolved oxygen concentration in mg/L at the Clam Bayou drain. Data was gathered from the Pinellas Wateratlas from the Clam Bayou East Drain Station. This data has an R value of 0.1787 and a p value of 1.83 e-9.

Figure 3:



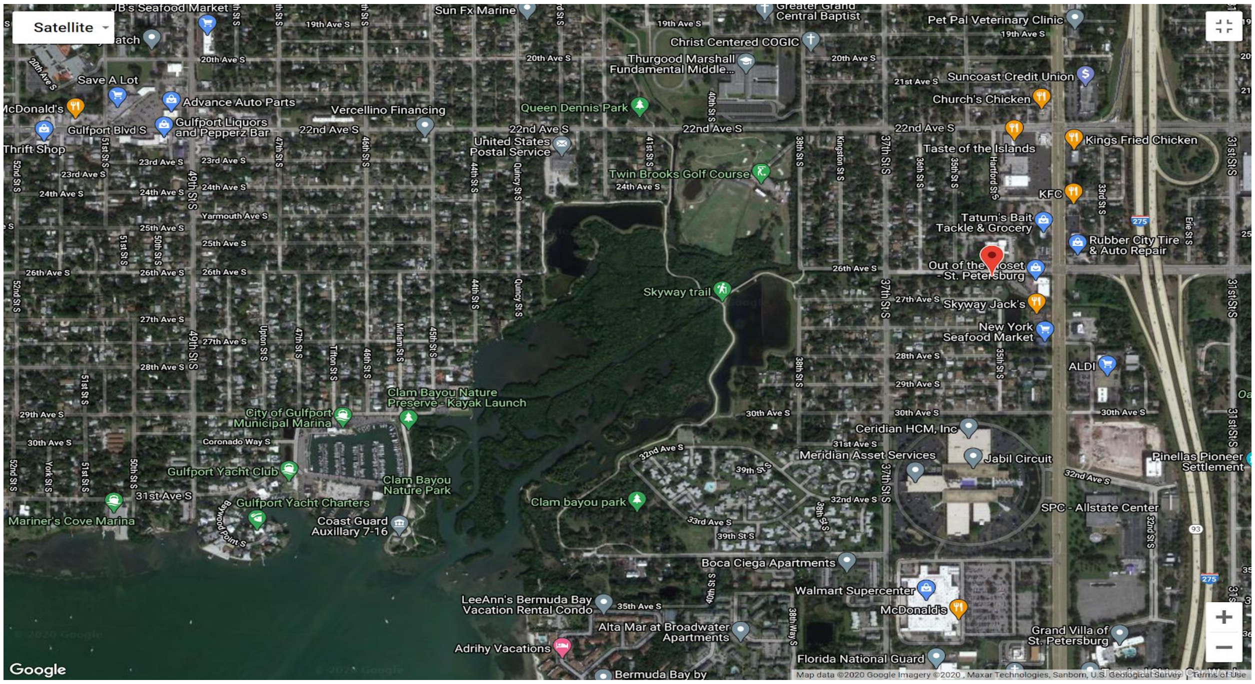
-Figure 3 illustrates the chlorophyll-a concentrations in Clam Bayou ranging from 2017-2019. Data was sourced from Pinellas Wateratlas from Clam Bayou East Drain station. This data has an R value of 0.0662 and a p value of 0.001178.

Figure 4:



-Figure 4 illustrates the fecal coliform concentrations ranging from 2017-2019. The data for this graph was sourced from the Pinellas Wateratlas from Clam Bayou East Drain station. This data has an R value of 0.0344 and a p value 0.046684.

Figure 5: Map of Clam Bayou East Drainage Station (CB-01)

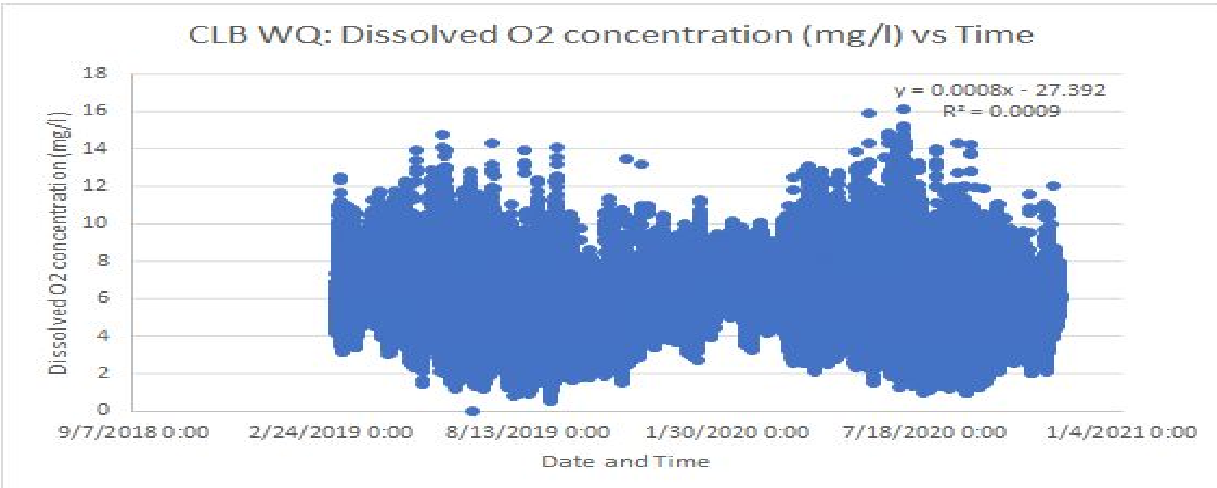


- Figure 5 displays the point where the Clam Bayou East Drainage Station is located: coordinates (27.745 latitude, -82.680 longitude). This is the location where the data was collected for Figures 2-4, gathered from the Pinellas WaterAtlas.

VI. Comparison of Dissolved Oxygen versus Temperature

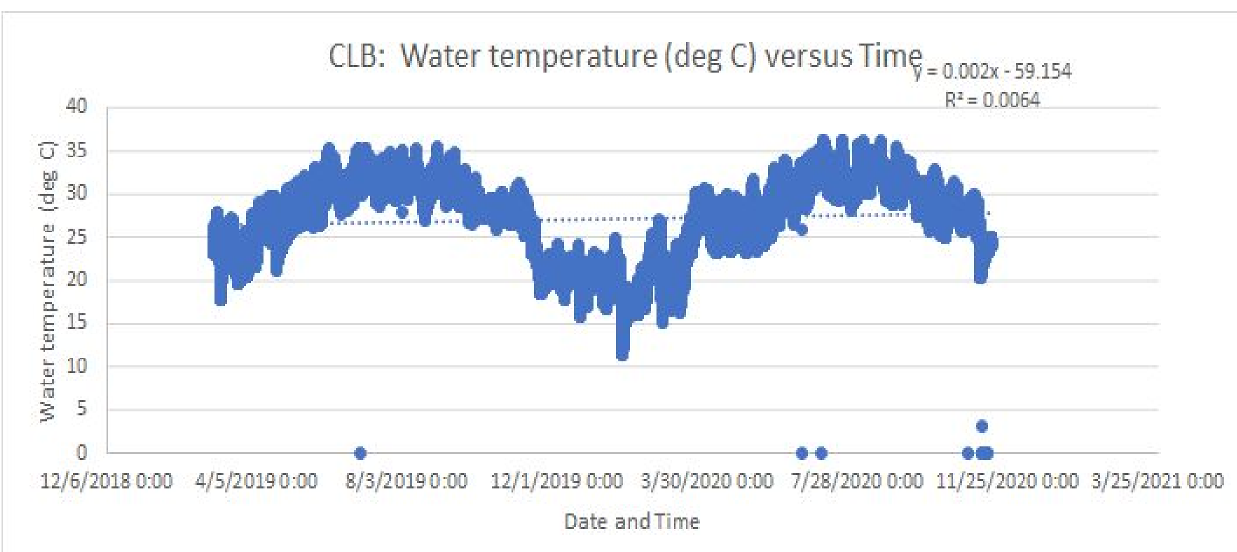
The following graphs were created by downloading data from the USF Coastal Ocean Monitoring and Prediction System (COMPS) from their Clam Bayou monitoring stations. COMPS provides real-time data using both offshore buoys and coastal tidal stations for an array of relevant parameters concerning coastal waters and water quality. Measurements are taken in 6 to 12 minute intervals at the top of every hour, internally stored, and transmitted hourly to a NOAA satellite. Figure 6, showing the DO concentrations over time has an R value 0.0009 of and a p-value of 4.7e-11. Figure 7, showing the water temperature with respect to time has an R value of 0.0064 and a p value of 0.000568.

Figure 6:



- Figure 6 shows the correlation between dissolved oxygen concentrations in Clam Bayou versus time, with the dates ranging from January 1, 2019 to December 1, 2020.

Figure 7:



-Figure 7 displays the water temperature of Clam Bayou in degrees Celsius versus time, with the dates ranging from January 1, 2019 to December 1, 2020.

Methodology

I. Literature Review Process

This review concentrates on the historical and present water quality of Clam Bayou and is largely based on internet searches, scanning through bibliographies of relevant studies, and utilizing keyword searches that include water quality, restoration projects, and Clam Bayou data on websites such as Google Scholar and JSTOR. Published articles were screened for citations that may have been related to the paper. The time period of the literature varies, but mostly encompasses data from the 1960's to 2019. The total number of studies reviewed was twenty. This review presents this information by introducing the current literature then discussing the solutions that are now underway concerning Clam Bayou as well as suggestions for future research. Graphs were utilized to display some of the information found in the literature by downloading data from online databases including COMPS and the Pinellas Wateratlas. Although not many studies have been conducted concerning Clam Bayou, other studies such as that of the Tampa Bay watershed were discussed to help explain some of the mentioned ideas.

Discussion

I. Evaluation of Graphs

Figure 2, displaying the dissolved oxygen concentrations versus time seems to be highly variable. The last six months of the graph show a sharp decrease in dissolved oxygen concentrations. Most of the values are also sustained under 4 mg/L, which is under the predetermined threshold of 5 mg/L. This is possibly indicative of worsening water quality. This data has an R value of 0.0344 and a p value 0.046684. The R value is not close to 1, so the data seems to be not well correlated. The p value is less than 0.05, so the data is statistically significant. Figure 3 depicts chlorophyll-a concentrations with respect to time with an R value of 0.0662 and a p value of 0.001178. The R value being not close to 1 means that this data is not well correlated, but it is considered statistically significant since the p value is less than 0.05. The graph of Figure 3 is only based on a few measurements, but has a steady increase in the most recent measurements taken. The values are high relative to the pre-established thresholds of <20 (μg/L). This could be possibly indicative of higher productivity or an influx in nutrients, which can be linked to an eventual decrease in water quality. Figure 4 shows the relationship between fecal coliforms to time in Clam Bayou. This dataset has an R value of 0.0344 and a p value 0.046684. This meaning, the data is not well correlated but it is statistically significant. The data in Figure 4 has a similar trend to that of Figure 3, which could potentially mean that the increase in chlorophyll-a was related to an increase in fecal coliforms. The data also was variable, but the most elevated levels were in 2018 and 2019. When compared to the predetermined threshold value of < 400 cfu/100ml, the values in the graph are extremely high, indicating that there is a large amount of fecal coliform in Clam Bayou.

The second set of graphs using data taken from the USF COMPS website displays the correlation between dissolved oxygen and temperature in Clam Bayou.

Figure 6, showing the DO concentrations over time has an R value 0.0009 of and a p-value of 4.7e-11. The R value is not close to 1, so this data is not well correlated. The p value is extremely small and less than 0.05, so the data is statistically significant. Figure 7, showing water temperature with respect to time has an R value of 0.0064 and a p value of 0.000568. Since the R value is not close to 1, it is not well correlated but the p value, less than 0.05, indicates that this data is statistically significant. These two graphs were created to have the exact same timeline which was January 1 2019 to December 1, 2020. The lowest portions of the dissolved oxygen in Figure 6 are inversely related to the high points of water temperature displayed in Figure 7. This indicates the possibility of when the water temperature increases in Clam Bayou, the DO concentration decreases. This is indicative of eutrophication and a decline in water quality to a point where the aquatic biota get stressed. If hypoxia, or a severe depletion of oxygen in a water body occurs, the aquatic species may be unable to reproduce and the number of organisms would be expected to decline overall. These two graphs show the correlation between DO and water temperature in Clam Bayou and how water quality can damage the biodiversity of an ecosystem.

II. Current Solutions for Water Pollution in the Tampa Bay Area

The quality of Tampa Bay has been worse in the past as according to the literature and has improved some as a result of the plethora of restoration projects that have been implemented over the most recent decades. In recent years, the Tampa Bay area has attempted to implement new policies to help improve water quality. Much of the focus has been on reducing the pollution originating from point sources as opposed to nonpoint sources. Among these point sources -- mainly sewage outfalls and powerplants-- policies mainly focus on limiting the type and amount of pollution that is allowed to be discharged. Tampa has imposed a summertime fertilizers ban for residents with lawns in an attempt to cut down on nitrogen and phosphorus laden runoff, which is one of the main reasons for algal blooms (Newborn, 2019). Moreover, there has been evidence of the creation of oyster beds which help enhance the habitats and filter water at the same time. The establishment of habitat restoration projects has also occurred in hopes of helping the biological environment and cleaning the water. Some of these projects include the restoration of mangroves, salt marshes, and exotic vegetation control (Newborn, 2019). Essentially, the solutions that are currently underway within the Bay area to fix this problem are a mix of infrastructure improvement projects, policy-driven management actions, and site-specific controls of industrial and municipal point sources (Beck, Sherwood, & Henkel, 2019). Although some of these projects have proved to be more useful than others, the water quality of Tampa Bay has improved when compared to its rough history.

I. Current Solutions for Improving Water Quality in Clam Bayou

Since Clam Bayou has been significantly impaired in terms of water quality in the past, there have been a few instances to improve the water quality. For example, the Clam Bayou Restoration Project that began in 1995 and ended around 2012. This project was headed by the City of Gulfport and the Florida Department of Environmental Protection to restore a total of 20 acres in cooperation with the City of St. Petersburg. (“Final Clam Bayou Restoration Phase Under Way”, 2010). The largest project, completed in 2012, aimed to treat storm runoff sites to improve Clam Bayou’s ecosystems. In this project, around twenty acres of stormwater ponds were constructed to help reduce the impacts of runoff. The stormwater ponds that were implemented filter and remove pollutants from the runoff before it reaches Clam Bayou. There was also a natural restoration part of the project that involved restoring around 24 acres of estuarine and coastal habitats. Trash was removed and more native species were planted (“Final Clam Bayou Restoration Phase Under Way”, 2010).

Research by Milbrandt et. al (2015) suggests that a multiple habitat restoration strategy is what is needed to restore Clam Bayou. One of the major components of this restoration was the reestablishment of the red mangrove fringe which involved mature propagules being planted in 15 different areas in Clam Bayou (Milbrandt et. al, 2015). By doing so, mangroves have the potential to filter the water, thus improving the water quality of the area. There has also been the construction of oyster reefs at five different sites in Clam Bayou in hopes of introducing more filter feeders in the area (Milbrandt et. al, 2015). Oyster beds have the ability to increase water quality through sustainable oyster recruitment as the oysters filter nutrients and pollutants from the water (La Peyre et. al, 2014).

III. Evaluation of Current Solutions and Research

Based upon the current research that has been conducted at Clam Bayou and the restoration projects underway, it is clear that scientists are concerned about the health of this estuary. The Clam Bayou Restoration Project, headed by the City of Gulfport, lasted until 2012. Since then, events such as changes in temperature, sea level rise, and algal blooms have been occuring, so an update on this project is most definitely needed.

This project focused on stormwater runoff and the construction of stormwater ponds, as well as the restoration of native habitats in the area such as mangrove fringes and oyster reefs. Although these projects do help in preventing excess runoff into the estuary, projects such as these need to be followed up on so that the performance is still effective in improving the water quality of the area. According to the Tampa Bay Water Atlas, it was ruled by the Florida Department of Environmental Protection's (FDEP) implementation of the Impaired Waters Rule (IWR) that Clam Bayou's water quality is considered "imparied." The results of this project are contested, but there is a general ruling that it has improved the water quality of Clam Bayou to some degree. For example, in Ma'alaea Harbor in Hawaii, single oysters filter up to 50 gallons of water a day and are used to improve the surrounding water quality by trapping large volumes of sediment and pollutants in their system (Kayian, 2020).

The most promising current solutions include the restoration and reestablishment in the local habitat, including red mangroves and oyster reefs. By reintroducing these species, not only is there enrichment in biodiversity, there were significant improvements in water filtration rates (Milbrandt et. al, 2015). Not only that, these restoration projects bring in other ecosystem services such as providing habitats for other organisms, water filtration, and shoreline stabilization (Milbrandt et. al, 2015).

IV. Suggestion for Future Research

As noted in Rojas (2012), there is a common occurrence wherein old sewers meet their capacity as a result of reduced capacity, blockages, or deterioration of materials. These sanitary sewer overflows are increased during periods of heavy rainfall, meaning that during storms, Clam Bayou and all other nearby bodies of water are subject to extreme contamination (Rojas, 2012). When these prolonged storm events occur, raw sewage and other harmful pollutants runoff into the estuaries, which can have extremely detrimental effects on both ecosystem health and water quality. Future research for the City of St. Petersburg and the City of Gulfport should focus on this issue and determine how significant the influx of fecal matter in the estuary affects water quality decline. There is most likely a high possibility for an increase in algal blooms, eutrophication, and a decrease in biodiversity. By focusing research on this issue, scientists would have a better understanding of the level of contaminants in Clam Bayou and where to focus their energy in hopes of improving water quality.

As climate change worsens, so will the factors that face Clam Bayou: storms are becoming stronger and more frequent, temperatures are getting warmer, sea level is rising, and the amount of pollution in the atmosphere and on land is continuing to increase. Therefore, it is important for researchers such as Rojas (2012), Karlen (2017), COMPS, and the Pinellas Wateratlas to continue sampling and determining the health of Clam Bayou in response to these changes. If not, these changes will occur at too fast of a rate and will be nearly impossible to correct. The research in this review indicates that the quality of Clam Bayou has been generally improving with the few projects that were carried out, but the quality is still nowhere near where it should be. The best thing that researchers could focus their time on is trying to find the main drivers for water quality decline and coming up with strategic efforts to combat said issues.

Conclusion

Clam Bayou has a clear history of water quality decline as well as multiple efforts to improve it. Though its status of water quality is still “impaired”, the few projects that have been done have succeeded to a certain extent in improving water quality. The best performance seems to come from multifaceted restoration projects that aim to reestablish native species such as red mangroves and oysters that have the ability to filter water and thus improve water quality. A combination of environmental policy, discharge limits, and habitat restoration serves the best solution for Clam Bayou. Sewage discharge pollution and stormwater runoff seem to be the leading concerns with water quality in the literature and therefore should be the priorities for scientists to continually research. Since Clam Bayou is used for a wide variety of reasons, it is imperative that the research it kept up with it. This literature review suggests that research is extremely limited concerning Clam Bayou, so it is crucial for research to continue for the future of this key estuary.

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