A flood of concern: Effects and recovery in the St. Lucie River and Estuary following releases from Lake Okeechobee

Elizabeth Kelly

From February 17, 2024, until March 30, 2024, the US Army Corps of Engineers released water from Lake Okeechobee to the St. Lucie River and Estuary and the Caloosahatchee River. In this study, the effects of these flows into the St. Lucie River and Estuary are analyzed through flow data collected from local water control structures, salinity from estuarine stations, and the resulting Fecal Indicator Bacteria (FIB) enterococci (recommended instead of E. coli per EPA standards for saline/brackish water) and microalgae/cyanobacteria levels in the River and Estuary.

The period of study was 66 days, beginning on February 14th, before the first release, continuing through the time period during which the releases occurred in the St. Lucie River and Estuary, until April 19th, to measure the recovery period. Our observations revealed that when the flow increased, salinity decreased and counts of enterococci and cyanobacteria (some expressing toxins) increased. Whether salinity, enterococci, or cyanobacteria were analyzed in this study, the parameters responded fairly quickly (approximately one day) to the changing ecosystem as the Lake flowed through the river and estuary; after all three releases, it took approximately two weeks to one month for these parameters to return to the levels at which they were in early February.

Introduction

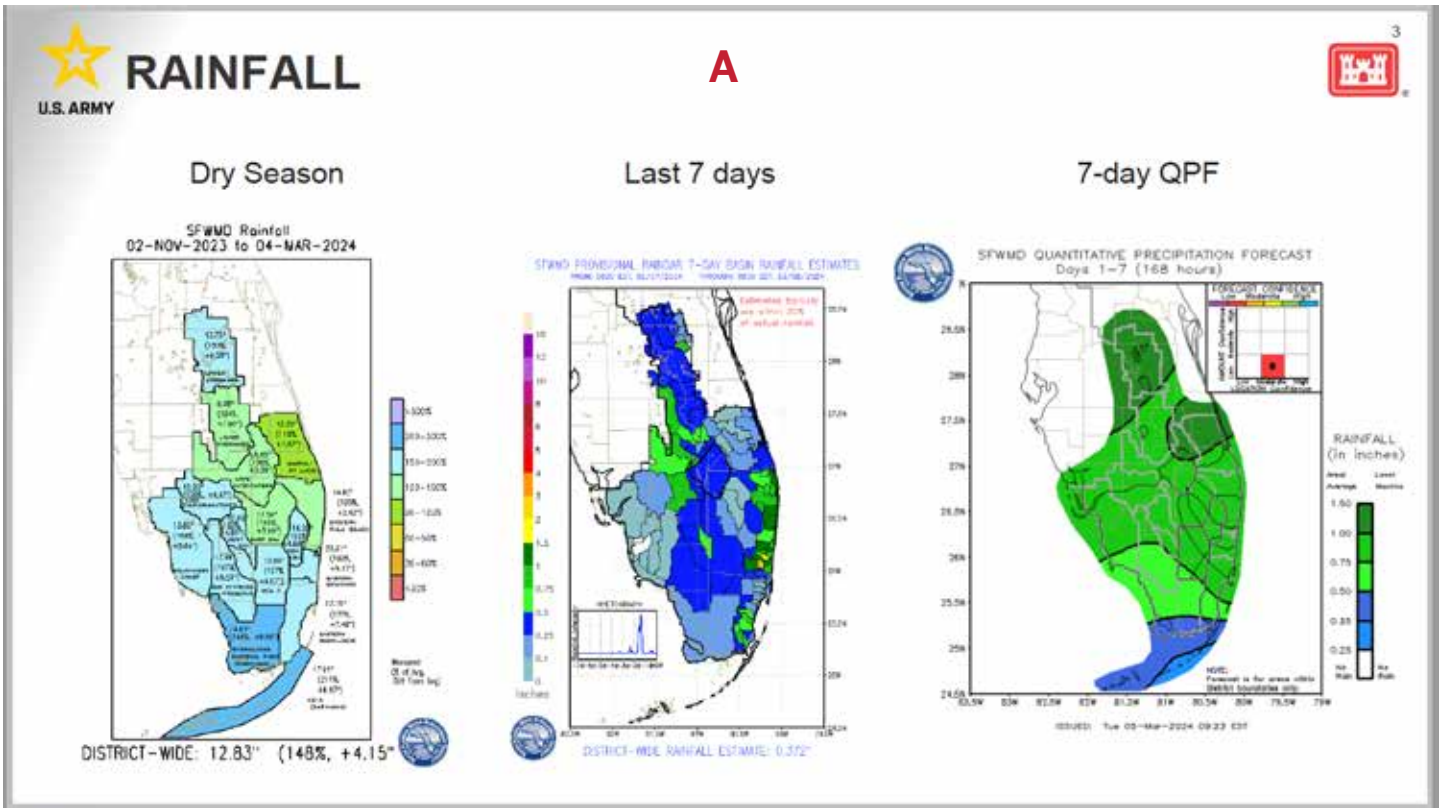
Lake Okeechobee is a large, shallow eutrophic lake located in subtropical south-central Florida. It is designated a Class I water (potable water supply). It is a large multipurpose lake providing drinking water for urban areas, irrigation water for agricultural lands, recharge for aquifers, freshwater for the Everglades, habitat for fish and waterfowl, flood control, navigation, and many recreational opportunities. High phosphorus loadings resulting from man-induced hydrologic and land-use modifications over the past 60 years have degraded the water quality of the lake (FDEP TMDL). One of the man-induced hydrologic modifications was a connection, known as the C-44 Canal, created from the lake to the St. Lucie River and Estuary. This connection was designed to allow the lake to drain during high-water conditions such as hurricanes or other major rainfall events.

The connection is managed by the US Army Corps of Engineers (USACE) through a series of gates, one that manages flow out of the lake and into the C-44, and a second one that allows flow out of the C-44 and into the south fork of the St. Lucie River. While hydrologic flow is carefully managed near the lake and into the C-44, the resulting nutrients, enterococci, and cyanobacteria (along with other microbes and chemical compounds), and their effects on water quality in the St. Lucie River and Estuary are not well understood.

During the fall of 2022, Hurricanes Ian and Nicole made landfall on the state of Florida in September and November per the National Oceanic and Atmospheric Administration's National Hurricane Center (NOAA NHC), dropping large amounts of rainfall over Lake Okeechobee and the watersheds that flow into the lake (United States Army Corps of Engineers [USACE]). During 2023, the normal wet season contributed water, followed by an unusually wet dry season resulting from El Niño conditions in late 2023 and early 2024 (USACE).

Per USACE, rainfall in the South Florida Water Management District was 143 percent of the amount normally received between November 2 and February 13. By March 4th, the amount had increased to 148 percent, and by March 25, it had further increased, to 151 percent of the normal volume (Figure 1). By February 14, 2024, the Lake elevation was 16.37 feet (South Florida Water Management District [SFWMD]). From February 17, 2024, until March 30, 2024, the US Army Corps of Engineers released water from Lake Okeechobee to the St. Lucie River and Estuary and the Caloosahatchee River. On March 26, 2024, Lake Okeechobee's elevation was 15.42 feet. As this elevation is below the intermediate guidance for the Central and Southern Florida Project 2008 Lake Okeechobee Regulation Schedule (LORS08) maintenance schedule, the releases to the St. Lucie River were discontinued on March 30th. Releases to the Caloosahatchee River continue around 2,000 CFS per day.

Neither the Caloosahatchee River nor the St. Lucie River have natural connections to Lake Okeechobee. Freshwater inputs to the St. Lucie River and Estuary only come from the watershed surrounding the North Fork and South Fork of the river. The two forks of the river meet in the estuary, which then flows out to the southern Indian River Lagoon and the coastal zone. The river is 35 miles long; the watershed encompasses about 781 square miles (SFWMD Water Supply Department). Freshwater inputs beyond what comes out of the watershed affect the natural balance of the ecosystem, bringing both natural and anthropogenic pollution with the flows, including fecal indicator bacteria (FIB) and microalgae, which includes harmful algal blooms (HABs) such as cyanobacteria. Maintaining normal



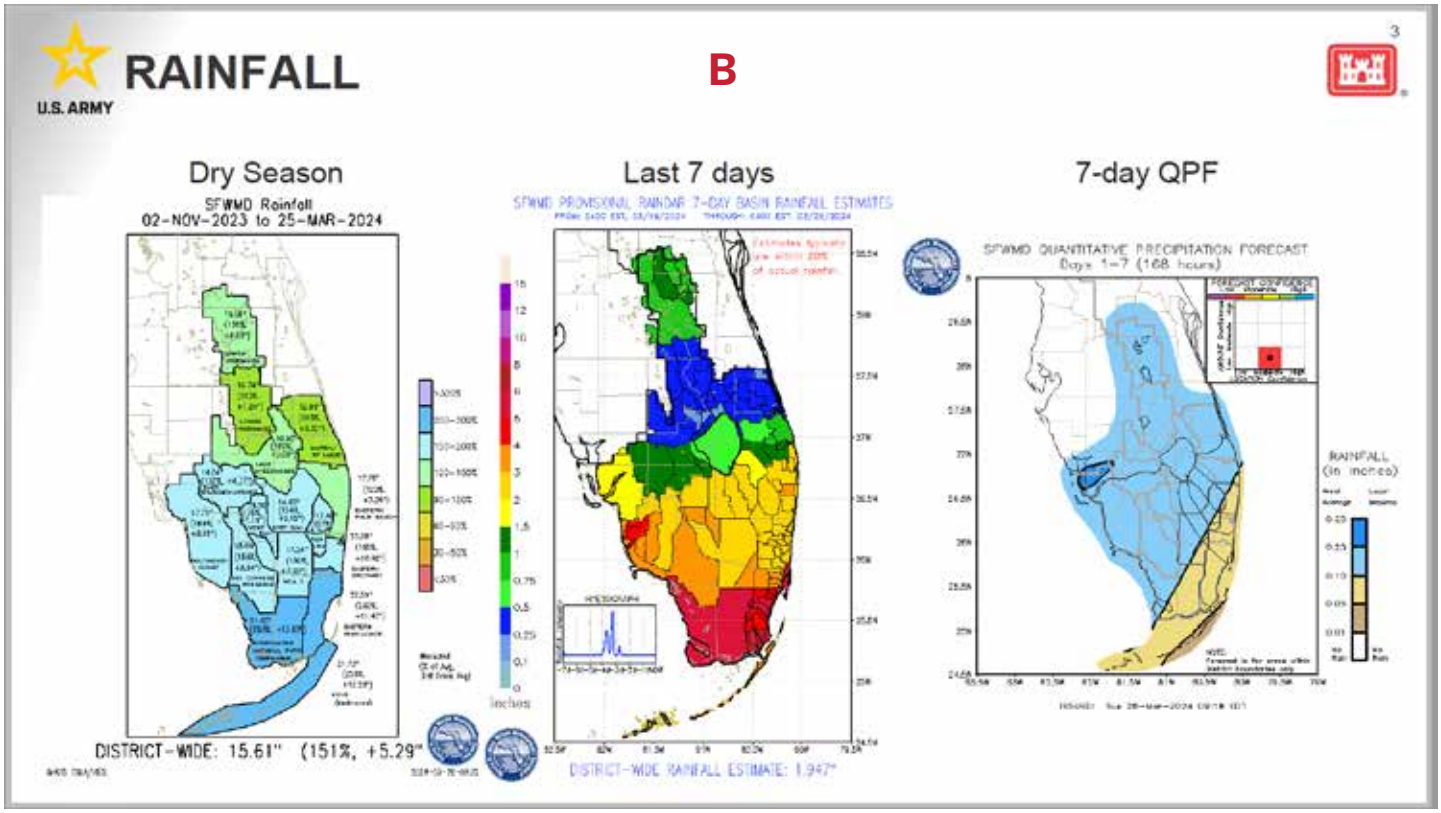
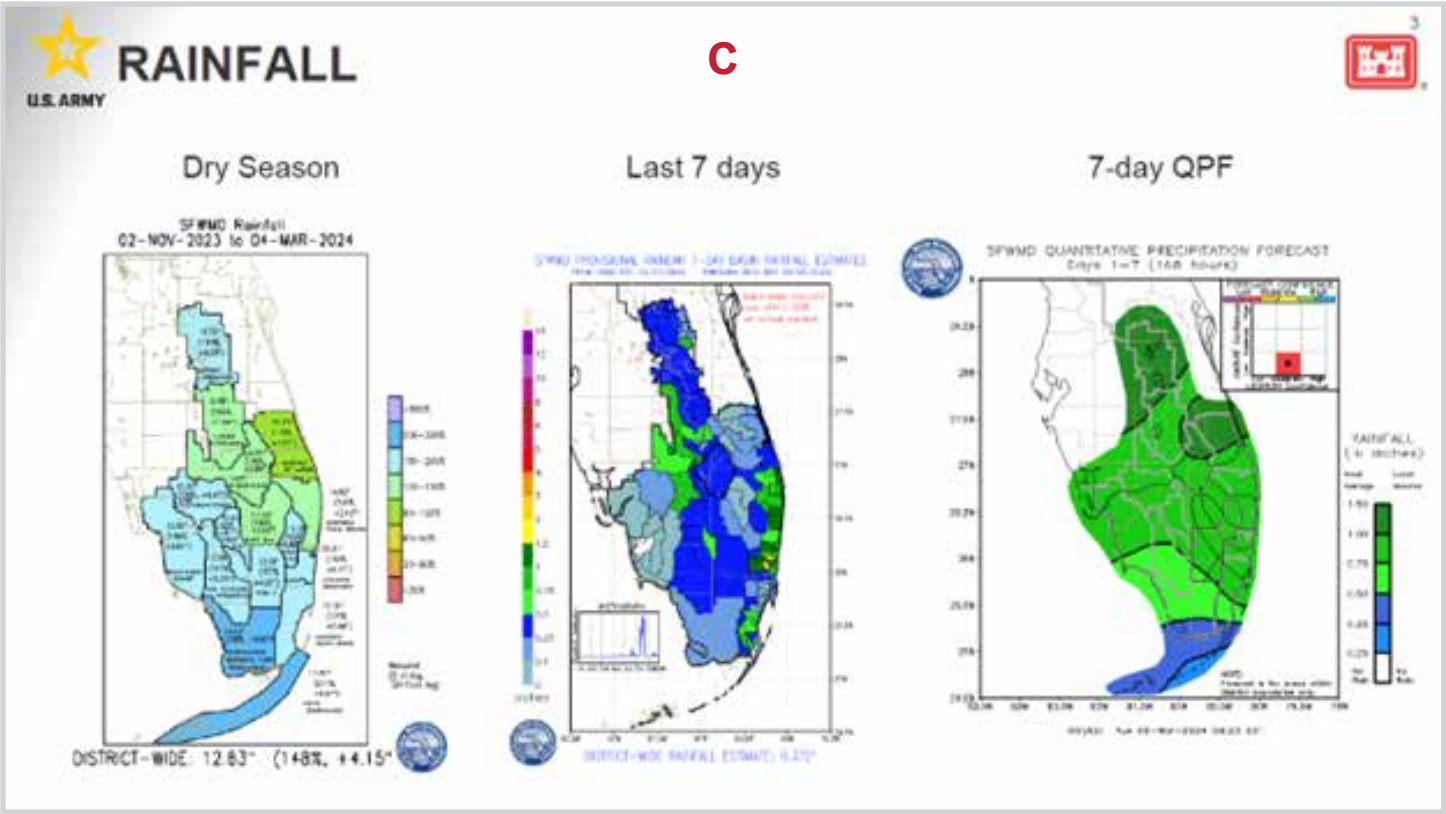


Figure 1 A and B. Rainfall over the South Florida Water Management District, November 2, 2023 - March 2024 (continued on page18).



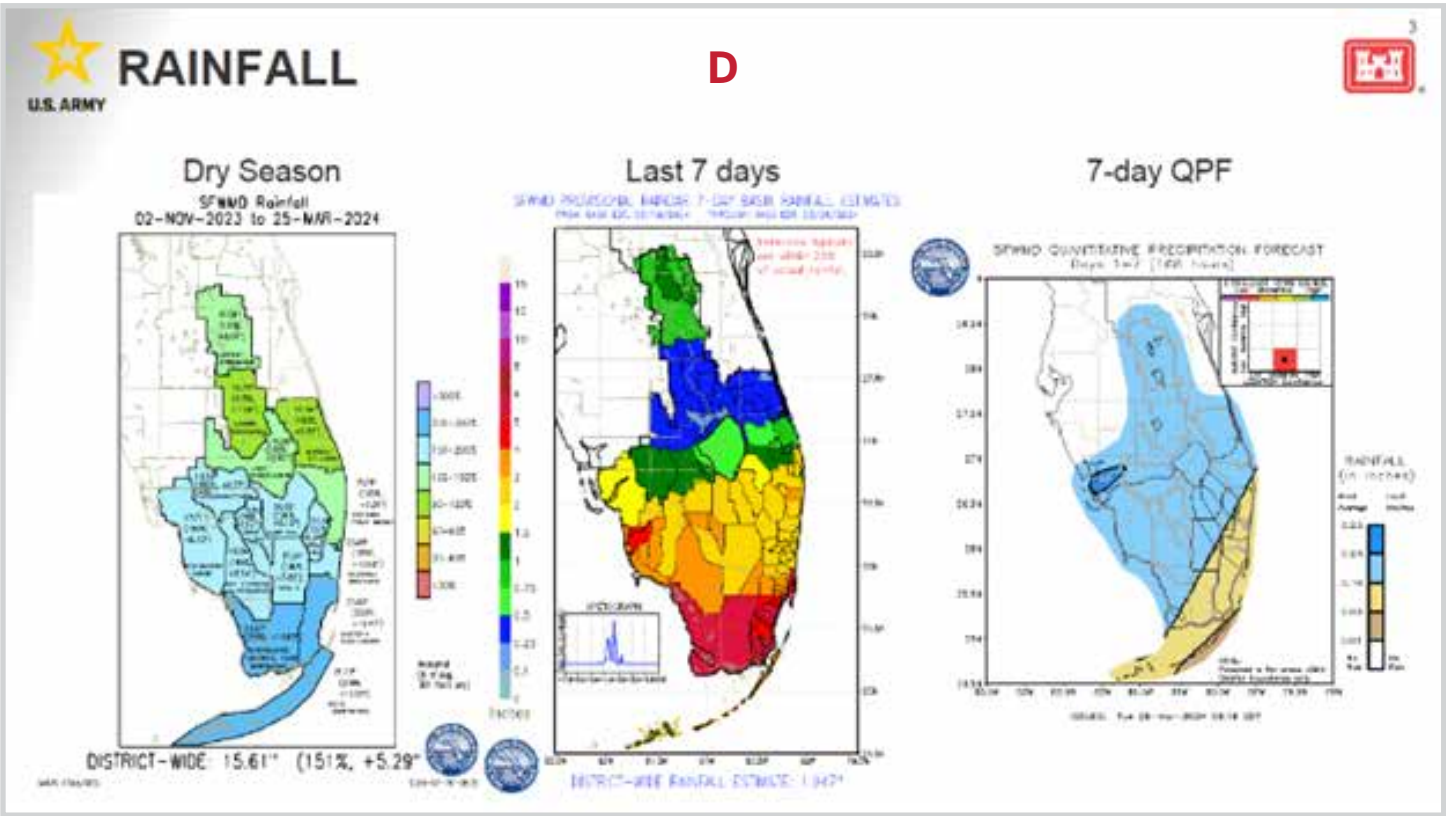


Figure 1 C and D. Rainfall over the South Florida Water Management District, November 2, 2023 - March 2024 (continued from page 17).

salinity is important to the estuary for the survival of oysters and seagrass, which are impacted by the changes in salinity along with the pollution.

This study is designed to analyze the effects of these flows into the St. Lucie River and Estuary, through flow data collected from local water control structures, salinity from estuarine stations, and the resulting FIB enterococci (recommended instead of E. coli per EPA standards for saline/brackish water) and algae/cyanobacteria levels in the River and Estuary, as collected through grab samples in the field, which are then analyzed in the laboratory. The period of study was 66 days, beginning on February 14, a few days before the first release, continuing through the time period during which the releases occurred in the St. Lucie River and Estuary (February 17, 2024, through March 30, 2024), until April 19th to measure the recovery period. The salinity data were analyzed in comparison to flow rates, as well as for the time period over which the salinity returned to post-release rates.

Methods

Methods used in this study involved the collection and review of both "historical" data (beginning in early February 2024, to provide an idea of pre-release water conditions) and "real-time" data (downloaded daily or weekly per collection/analysis schedule and the source agency). Data were collected on flow, salinity, enterococci, and cyanobacteria from the sources listed below. These data were then combined into an Excel spreadsheet to develop a database, and graphs were developed to perform evaluations. Maps were also consulted to reference sample collection locations.

Flow was evaluated in (1) the C-44/South Fork St. Lucie River [a] per the schedule provided by USACE, [b] from SFWMD's DBHYDRO data from the S-80 station on the C-44, and [c] from the USGS station 2276998 before the S-80. Flow was evaluated (2) from the watershed through [a] the C-23 Canal at S-97_S, through the [b] C-24 Canal at S-49_S, and at [c]) Ten Mile Creek through the Gordy Road structure (GORDY_S). These data are provided daily, most at 15-minute intervals. For these sites, a daily average was created for use in this analysis.

Salinity was measured through the USGS 0227710 Station (STL_RIVER) at Roosevelt Bridge and at the St. Lucie Estuary at USGS 02277110 Station (STL_A1A). These are measured via sonde. These data are provided daily.

Enterococci data comes from the Martin County Department of Health (DOH). Samples are collected once per week at each site. If the site exceeds the threshold, a follow-up sample is collected as soon as possible after the initial collection and analysis, until the samples collected no longer demonstrate exceedance. Exceedance of enterococci is determined to be bacterial counts greater than 70 MPN (EPA). Most Probable Number (MPN) indicates that analysis was performed in the laboratory using a statistical method to estimate the numbers of bacteria via a series of dilutions. The diluted samples are then incubated for 24 hours at 41+/-5 degrees Celsius with a nutrient substrate targeted for enterococci. The nutrient substrate includes a fluorescent indicator that fluoresces blue when metabolized by enterococci. The numbers of blue squares are then counted, recorded, and reported to the public and to the state DOH Environmental Health office. See Appendix C for the full dataset from the period of study.

Cyanobacteria data on algae samples were collected from the Florida Department of Environmental Protection Blue-Green Algae Dashboard (FDEP). Samples are collected at the location of any sighting of possible algae reported to FDEP. Sample collection is not regular; FDEP responds to reports of possible cyanobacteria made by the public through their Algae Bloom Monitoring and Response website (https://www.surveygizmo.com/s3/3444948/Algal-Bloom-Reporting-Form).

Algae are first speciated via microscope to determine the type of algae present. The sample is then analyzed to determine whether the toxins microcystin (from *Microcystis aeruginosa*) or CYN (*Cylindrospermopsin raceborskii*) are being expressed. Florida's current guidelines for toxin levels are to report to the public if any toxins are detected. Once the samples are collected and the dominant species is determined to be Microcystin, a caution is issued by the DOH at that location. If the microcystin is found, through laboratory analysis, to be expressing the microcystin toxin, a health alert is issued, and signage is placed at the area to avoid swimming or other contact with the water.

Results

Flow from all stations generally followed the schedule set by USACE. There were three release periods (February 17-March, March 2-March 15, and March 29). These release periods appear as peaks on the flow graph (Figure 2). Flow in the first release period as scheduled by USACE started at 3,200 cubic feet per second (CFS), peaked at 3,600 CFS, and then tapered to 1,300 CFS, followed by four days of 0 CFS for recovery of the estuary. The second release period started at 2,000 CFS, increasing to 3,500 CFS during the middle. It then tapered off to 1,000 CFS, ending in 0 CFS for the last three days of the schedule. The third release period started with three days of 0 CFS, building to 3,500 CFS, and ending on March 29 with 2,000 CFS. Flows remained at 0 CFS from March 30 onward; they are to remain there in the future unless a major rainfall event occurs.

Flow data per the USACE schedule and the flow out of the C-44 at the S-80 should be the same, but in comparison, the actual flow out of the S-80 does not match the schedule. This created some differences that were reflected in the graph (Figure 2). The combined watershed data also generally followed the USACE schedule, but the results were higher than what was scheduled during the first two releases. The combined watershed and the C-44 S-80 were both lower than the schedule at the peak and tapered off at the same rate to 0 CFS. The combined watershed has had releases of 74.53 CFS since March 31st due to the constant flow from Ten Mile Creek at Gordy Road.

Flow and Salinity. In comparing the flow to the salinity, increase in flow, both on the USACE schedule and the flow through

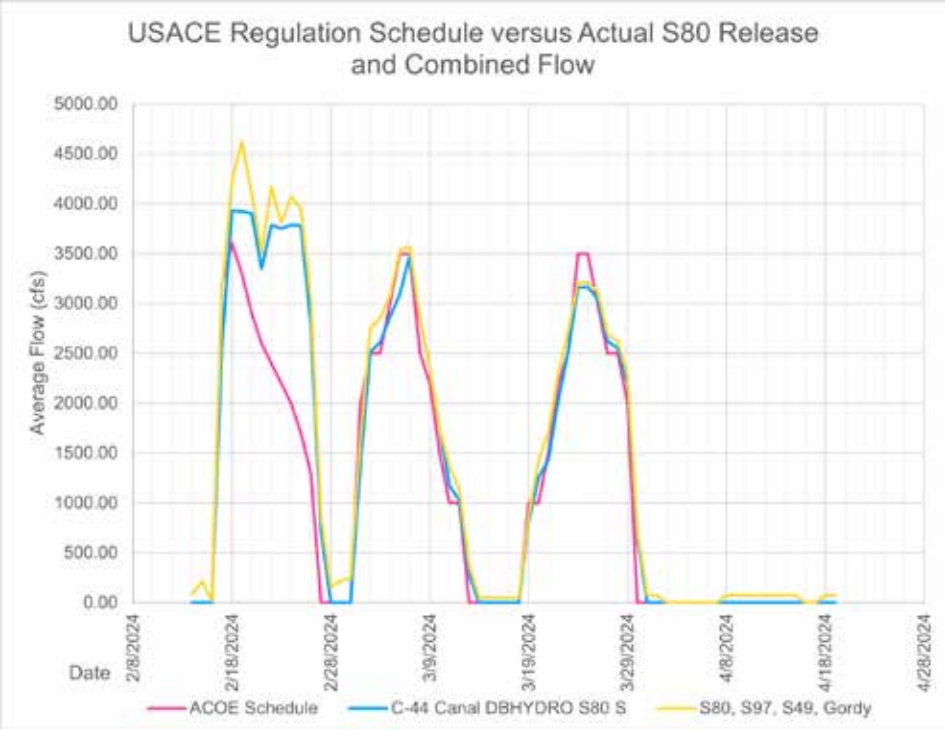


Figure 2. Flow via USACE Schedule, C-44 at S-80 per SWWMD, and combined flow from the watershed (S-80, S-97, and Gordy Road).

the S-80 structure, correlated with a decrease in salinity. Salinity ranged from 5.6 Practical Salinity Units (PSU) to 22 PSU (average of 13.37 PSU) at the Roosevelt Bridge (STL_RIVER) and 8.8 PSU to 30 PSU (average of 18.38 PSU) at the Estuary (STL_A1A). The indirect relationship can be seen in Figure 3; as the flow increases, reaching its highest levels, the salinity decreases, reaching its lowest levels. The rest periods between releases are also reflected as the salinity rebounded.

As can be seen in Figure 4, salinity levels dropped to stressful and harmful levels for oysters and seagrass. For the estuary near Roosevelt Bridge, the "stressful" level was reached for seagrass and oysters, and the "harmful" level for oysters was reached during the lowest salinity levels. In the St. Lucie Estuary near A1A (Figure 5), the "stressful" level was reached for both seagrass and oysters.

Flow and Enterococci. The flows also corresponded with increases in exceedances of enterococci (more than 70 MPN/CFU) and increases in reports of cyanobacteria confirmed by laboratory analysis. At the Roosevelt Bridge site (1 on Figure 6), results of laboratory analysis revealed that enterococci levels were 10 MPN for both February 5 and February 12 (Figure 7). On February 19, enterococci levels were 99 MPN; on February 21, enterococci levels remained high at 150 MPN. Levels dropped to 10 MPN on February 26, March 4, and March 11, but returned to 64 MPN ("moderate" water quality, which does not warrant a resample) on March 18. After lower levels on March 21st and March 25, there was an increase to 53 MPN (again, moderate water quality) on April 1. Enterococci levels returned to 10 MPN on April 8 and April 15. At Leighton Park, (3 on Figure 6), enterococci levels were 53 MPN and 20 MPN for February 5th and February 12, respectively (Figure 7). On February 19, enterococci levels were 150 MPN; on February 21, enterococci levels remained high at 178 MPN. Levels dropped to a "moderate" 64 MPN on February 26 and March 4. On March 11, levels rose to 53 MPN.

On March 18, enterococci levels were 238 MPN. After lower levels on March 21 (42 MPN), the counts rose to 64 MPN for March 25 and April 1. Enterococci levels returned to 10 MPN on April 8 and April 15.

Flow and Cyanobacteria. Cyanobacteria were reported, analyzed, and confirmed at multiple sites throughout Martin County during the period of study (Figure 8). The first confirmed location was on the north side of the estuary on February 29; while

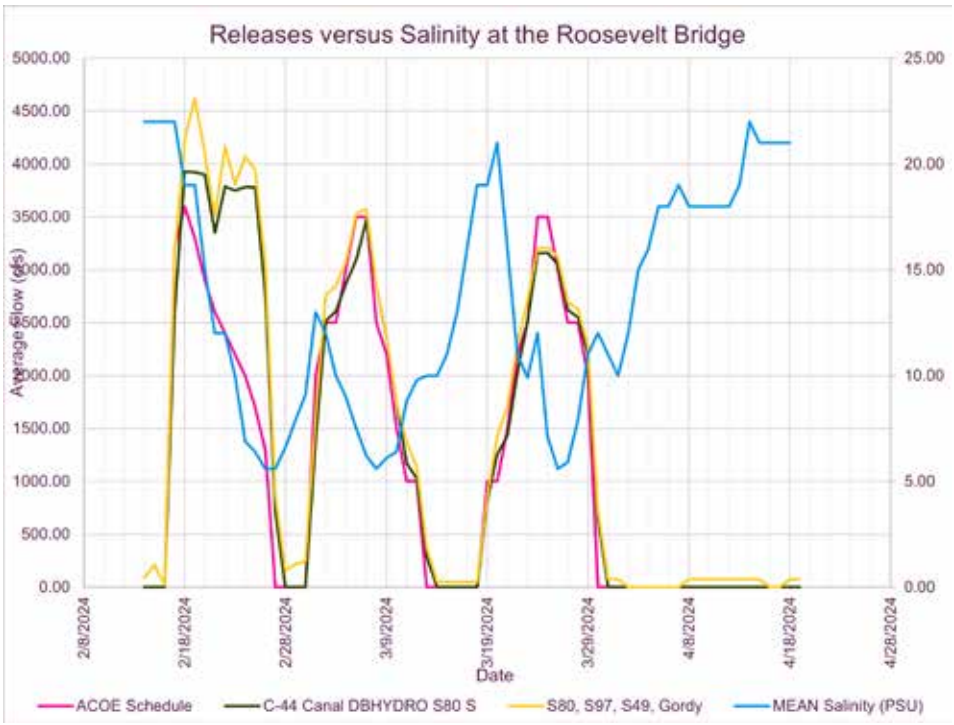


Figure 3, Flow from USACE Schedule, C-44 at S-80 per SWWMD, and combined flow from the watershed (S-80, S-97, and Gordy Road) versus mean salinity at Roosevelt Bridge.

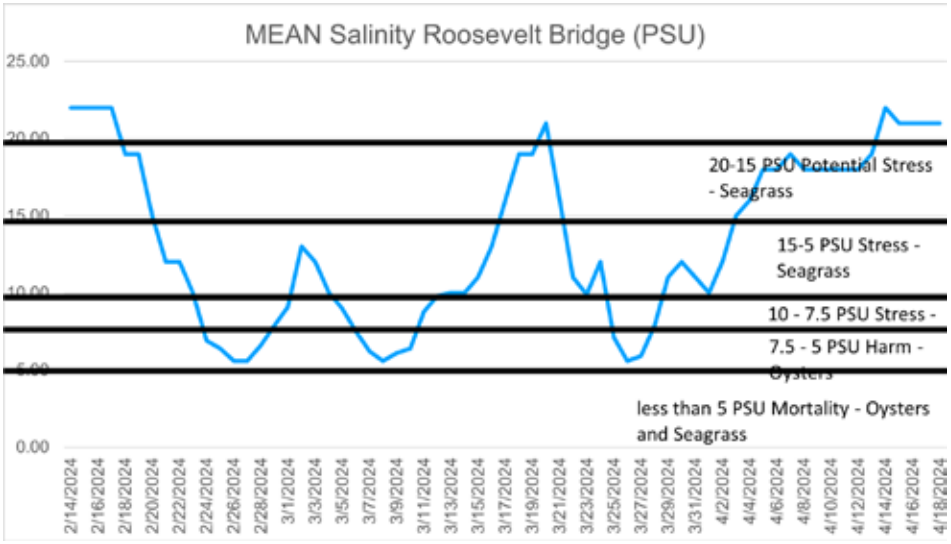


Figure 4, Mean Salinity at Roosevelt Bridge 2/14/2024 – 4/18/2024. Information on seagrass and oyster stress courtesy of Florida Oceanographic Society, personal communication *2024.*

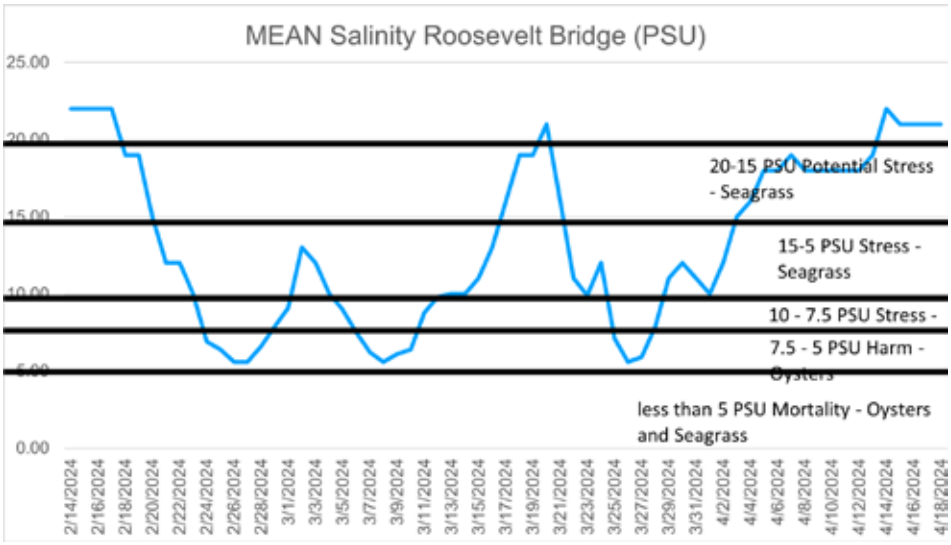


Figure 5. Mean Salinity at the St. Lucie Estuary at A1A 2/14/2024 - 4/18/2024. Information on seagrass and oyster stress courtesy of Florida Oceanographic Society, personal communication *2024.*

Microcystis aeruginosa was the dominant taxon, the toxin microcystin was not being expressed. On March 25- 28, five additional sites were found to have *Microcystis aeruginosa* as the dominant taxon, with four of them expressing microcystin. Two were below detectable limits, and two were above the EPA standard of 8 µg (11 µg and 17 µg). Between April 2 and April 9, three more sites had the presence of *Microcystis aeruginosa* confirmed as the dominant taxon, with no microcystin detected. On April 16, five more sites were reported, but only one (located at the S308 lock) had *Microcystis aeruginosa* as the dominant taxon. In total, nine sites had confirmed microcystin (Figure 9). The others were mixed species. All blue sites in Figure 8 had *M. aeruginosa* as the dominant taxon at least once during the study period.

Discussion

In comparing any of the variables against the flow data, a pattern begins to emerge. At the beginning of the dataset, the variables are at a baseline for this study. While it is necessary to keep in mind that large amounts of unseasonable rainfall and a very high lake were the reasons that flows from the lake to the St. Lucie River and Estuary and the Caloosahatchee River were necessary, it is also important to note that releases had not been made to the St. Lucie River except in small increments to equalize the head in the C-44 canal and the Lake (SFWMD).

As the ecosystem received only small amounts of lake water (which likely remained in the C-44 as it did not pass through the locks at S-80) since January of 2023 in response to Hurricane Ian, a baseline had been established. As we have no way of knowing what the conditions would have been in the river and estuary before the connection to the lake was established, we can utilize the conditions that existed before the S308 and S-80 were opened on February 17, 2024.

The variables (salinity, enterococci, and cyanobacteria) demonstrate their changes fairly quickly after the releases. Salinity near the Roosevelt Bridge began to drop about a day after releases began and fell from 22 PSU to 5.6 PSU in about 10 days. Salinity remained around that level, where seagrass is stressed and oysters are harmed, until the flows decreased. A break between February 27 and March 1 allowed for the salinity to increase to 13 PSU. A decrease back to 5.6 PSU was followed by a longer break, which allowed for an increase to 21 PSU on March 20. The final releases began on March 19 and concluded on March 29. In turn, the salinity levels fell back to 5.6 PSU on March 26 and returned to 22 PSU on April 14.

During these salinity fluctuations, the enterococci levels were also responding. Enterococci counts were measured at 10 MPN at Roosevelt Bridge on February 5 and 12t. On February 19th, bacterial counts had increased to 99 MPN and 150 MPN on February 21. During the break from flows, the levels return to 10 MPN on February 26 and March 11. On March 18, following the second round of releases, the levels are a moderate 64 MPN. They decreased to near 0 MPN on March 21st before rising to 20 MPN on March 25 during the third round of releases, and 53 on April 4. With no additional releases, enterococci levels at the Roosevelt Bridge have remained at 10

Figure 6. Sample collection locations on the St. Lucie River for enterococci by Martin County Department of Health. Roosevelt Bridge is station 1 and Leighton Park is station 3.

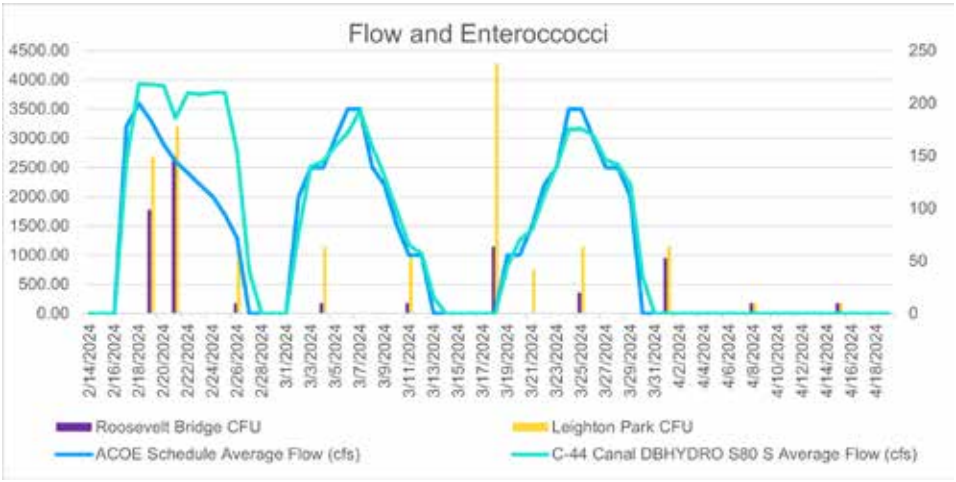


Figure 7. Flow data and resulting enterococci during the period of study.

MPN through collections on April 8th and April 15. Leighton Park followed a pattern similar to that of Roosevelt Bridge but reached its peak exceedance during the second round of releases (178 MPN on February 21 and 238 on March 18.) The third round of releases brought a moderate 64 MPN for March 25th and April 1. It has also remained at 10 MPN since April 8 at the time of this writing (4/25/24).

Reports of cyanobacteria also increased during the period of study. During 2024, it had been fairly inactive for cyanobacteria in January and early February, as would be expected under normal dry season conditions, despite the excessive rainfall that occurred to the El Niño event. There was a report of cyanobacteria at the S-308 (Port Mayaca) lock that separates Lake Okeechobee from the C-44, but there had been no occurrences in the C-44 or the St. Lucie River and Estuary. On February 26 and February 29, the first reports of possible cyanobacteria in the South Fork (near Leighton Park) and in the North Fork (by Roosevelt Bridge) were investigated. While both were found to have no dominant species and no toxins, over the next month (2/29/2024 – 3/28/2024), confirmed cyanobacteria were found in the C-44 near the S-80 and in the South Fork. Cyanobacteria persisted at these sites until April 9.

Per USACE, the releases to the St. Lucie River and Estuary resulted in 86 percent of the Total Daily Inflow to the watershed being contributed from Lake Okeechobee between January 16 and March 28th, 2004 (Figure 10). Whether analyzing salinity, enterococci, or cyanobacteria, the variables responded fairly quickly to the changing ecosystem as the lake flowed through the river and estuary; it took these variables a while to return to the levels at which they were in early February.

Conclusions

During the period of study, the St. Lucie River and Estuary ecosystem changed in response to the flows out of Lake Okeechobee. Salinity decreased, stressing oysters and seagrass; and both enterococci and cyanobacteria increased, causing a risk to human health as well as to environmental health. While the entire ecosystem from the North and South Fork,

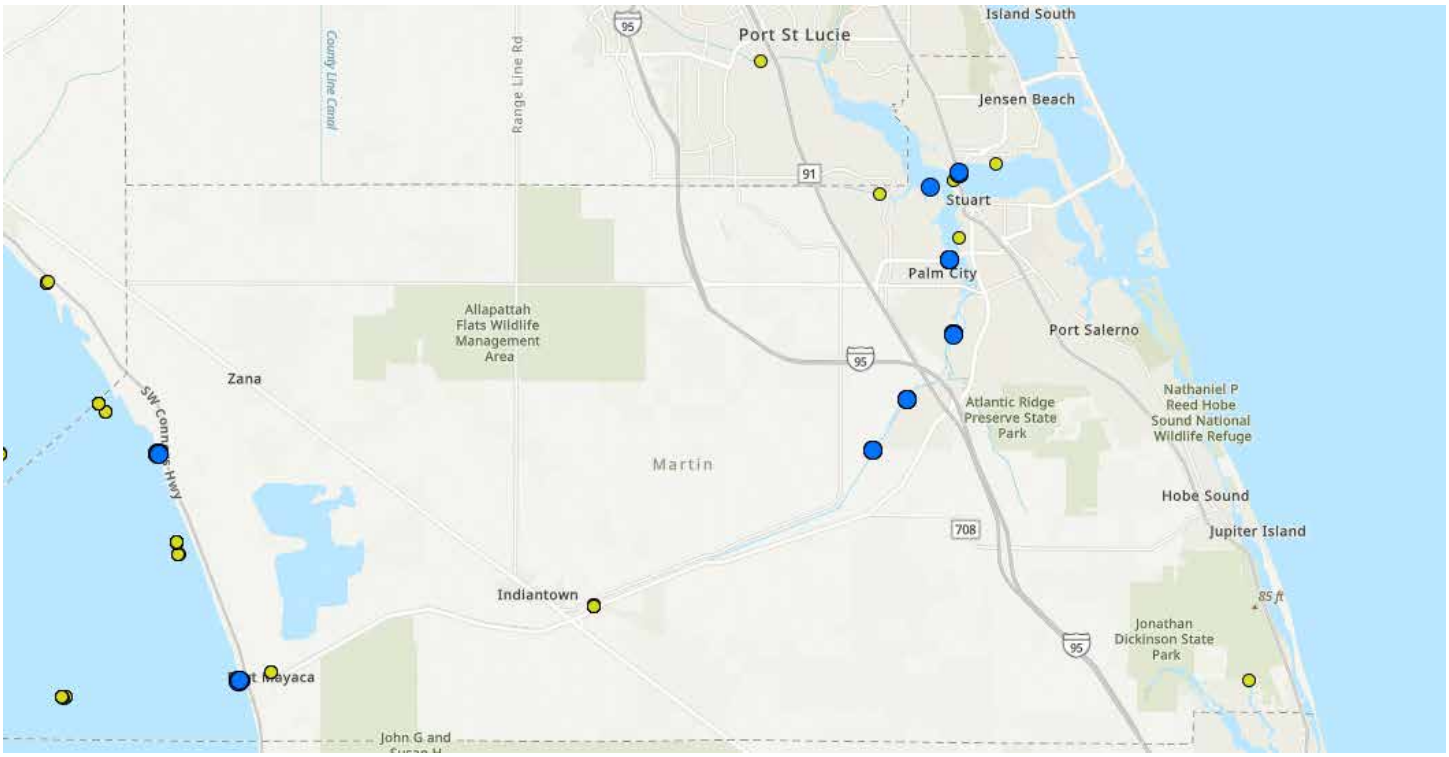


Figure 8. Location of laboratory confirmed cyanobacteria per FDEP (blue circles). Lake Okeechobee is on the left and the St. Lucie River and Estuary are on the upper right. The yellow circles indicate locations at which samples were collected, but cyanobacteria were not detected. As FDEP returns to sites to resample following the detection of cyanobacteria, the yellow circle may be the last in a series of samples, indicating that cyanobacteria had been detected in the past, but is no longer at this location.

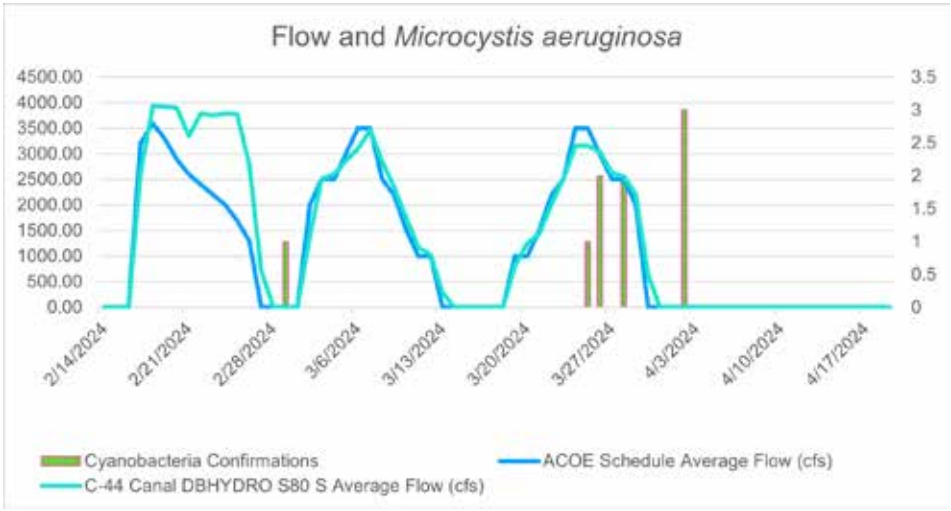


Figure 9. Flow data per USACE and SFWMD and confirmed cyanobacteria (microcystis aeruginosa) in the C-44 and the St. Lucie River and Estuary during the period of study.

all the way through the estuary to the Indian River Lagoon and the coastal zone demonstrated effects, the South Fork and the mid-estuary (near Roosevelt Bridge to Rio) demonstrated the strongest effects: the lowest salinities and the highest enterococci and cyanobacteria levels. This is likely due to the close location of these areas to the S-80, making these areas the first to receive the flow and to receive it full-force, sometimes at 3,500 CFS per day. Such a large volume of water, entering a small watershed at 1,000 – 3,500 CFS per day, can change the microbiome, nutrient balance, and other physical-chemical characteristics of the watershed. While the period of study is short, the data provided will be used to guide future work in characterizing the St. Lucie River and Estuary watershed, and in planning for resilience strategies for the ecosystems. We will continue to build upon these data through the upcoming wet season and beyond, investigating the connections among the microbiome, the nutrient balance, and the physical-chemical characteristics of the ecosystems in the watershed, and the resulting water quality.

References cited

DBHYDRO – South Florida Water Management District DBHYDRO Environmental Database. 2024. https://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu

DOH – Martin County Department of Health. 2024. https://martin.floridahealth.gov/programs-and-services/environmental-health/beach-and-river-sampling/results/index.html

FDEP TMDL – Total Maximum Daily Load for Total Phosphorus, Lake Okeechobee, Florida 2001. https://floridadep.gov/sites/default/files/Lake_O_TMDL_Final.pdf

FDEP – Florida Department of Environmental Protection Algal Bloom Dashboard. 2024. https://floridadep.gov/AlgalBloom

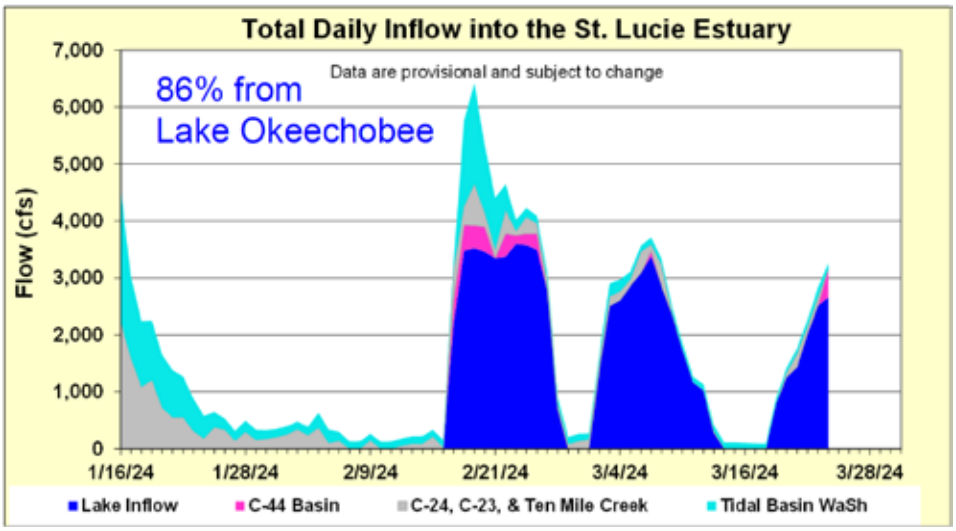


Figure 10. US Army Corps of Engineers Total Daily Inflow estimate to the St. Lucie Estuary, 1/16/24 - 3/8/24.

FOS – Florida Oceanographic Society, *personal communication*, February 2024.

LORS 08 – Central and Southern Florida Project 2008 Lake Okeechobee Regulation Schedule, 2008.

NOAA NHC – Bucci, L., L. Alaka, A. Hagen, S. Delgado and J. Beven. 2023 National Hurricane Center Tropical Cyclone Report Hurricane Ian April 2023. Retrieved April 24, 2024. https://www.nhc.noaa.gov/data/tcr/AL092022_Ian.pdf

NOAA NHC – Beven, J. and L. Alaka. National Hurricane Center Tropical Cyclone Report Hurricane Nicole March 2023. Retrieved April 24, 2024. https://www.nhc.noaa.gov/data/tcr/AL172022_Nicole.pdf

SFWMD – South Florida Water Management District. 2024. Lake Okeechobee and Water Conservation Area Daily Status. https://w3.saj.usace.army.mil/h2o/reports/StatusDaily.htm

SFWMD – Water Supply Department – Technical Documentation to Support Development of Minimum Flows for the St. Lucie River and Estuary May 2002. Retrieved April 24, 2024.

USACE – US Army Corps of Engineers, Periodic Scientists' Call meetings and presentations. February 2024-April 2024.

Elizabeth Kelly, Ph.D., PWS, is an environmental scientist at the Martin County Department of Public Works, Environmental Resource Division. She specializes in microbial ecology, soils, and hydrology. Her research focuses on water quality in freshwater, coastal, and estuarine environments, specifically involving the study of fecal indicator bacteria (FIB), cyanobacteria (blue-green algae), and nutrients.