Analysis Report

by

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ABSTRACT:

The purpose of this report is to:

1. Document the discharge flow rates, suspended solid loading, and nutrient loading into the St. Lucie Estuary resulting from water releases from Lake Okeechobee by the US Army Corps of Engineers

2. Document the impacts of these Lake Okeechobee water releases on the St. Lucie Estuary water quality parameters (salinity, water clarity, nitrogen, and phosphorous).

REFERENCED REPORTS

1.) “St. Lucie River Estuary, Volunteer Water Quality Monitoring Network Manual,” Florida Oceanographic Society, Revised by Robert L.P. Voisinet, Oct 2005.

2.) “Some Thoughts on Low Level Discharges into the St. Lucie Estuary,” Florida Oceanographic Society Memo, Bob Voisinet, May 30, 2006

3.) “Restoration Plan for the Northwest Fork of the Loxahatchee River,” South Florida Water Management Report, April 12, 2006.

4.) “New Grading for the St. Lucie Estuary”, Florida Oceanographic Society Memo, BobVoisinet, Aug 11, 2006.

5.) “Discharges and Nutrient Loading into the St. Lucie Estuary,” Florida Oceanographic Society Memo, Bob Voisinet, Nov 2, 2007.

6.) “Impacts to the St. Lucie Estuary from Lake Okeechobee Discharges 2003-2005,” Florida Oceanographic Society Memo, Nov 24, 2007, Bob Voisinet

7.) “Mucking Up the St. Lucie,” Florida Master Naturalist Program Final Report, Robert L.P. Voisinet, Dec 14, 2007

8.) “Characterization, Sources, Beneficial Re-Uses, and Removal of Marine Muck Sediments in the St. Lucie Estuary,” SFWMD Contract C-10281-A1, prepared by St. Lucie River Initiative, Inc., Stuart, FL, June 2004

SUMMARY

The St. Lucie Estuary water quality has been analyzed in relation to discharges into the Estuary from Lake Okeechobee and from the surrounding St. Lucie watershed. Data has been obtained from the South Florida Water Management District which records both its own data collection as well as data from the US Army Corps of Engineers and USGS. This data is available for download from the web and includes flow rates through the major canal structures and water quality data at regularly sampled stations throughout the estuary. Additional water quality data from the Florida Oceanographic Society's Volunteer Water Quality Monitoring Network has been analyzed and used to supplement the data from SFWMD. Computations of flow rates and loading have been conducted to show the magnitude of the water releases and their effects on water quality parameters in the estuary.

Based on the calculations, analysis, and trending of the government's data, it appears that Lake Okeechobee discharges had a significant impact on the St. Lucie Estuary in terms of:

a.) Releasing large quantities of water to the Estuary over extended periods of time

b.) Causing prolonged periods of extremely low salinity in the Estuary (changing the water environment from brackish to fresh)

c.) Reducing clarity of the water to extremely low levels for prolonged periods of time (limiting visibility for marine and bird life and hindering sunlight penetration to marine seagrasses)

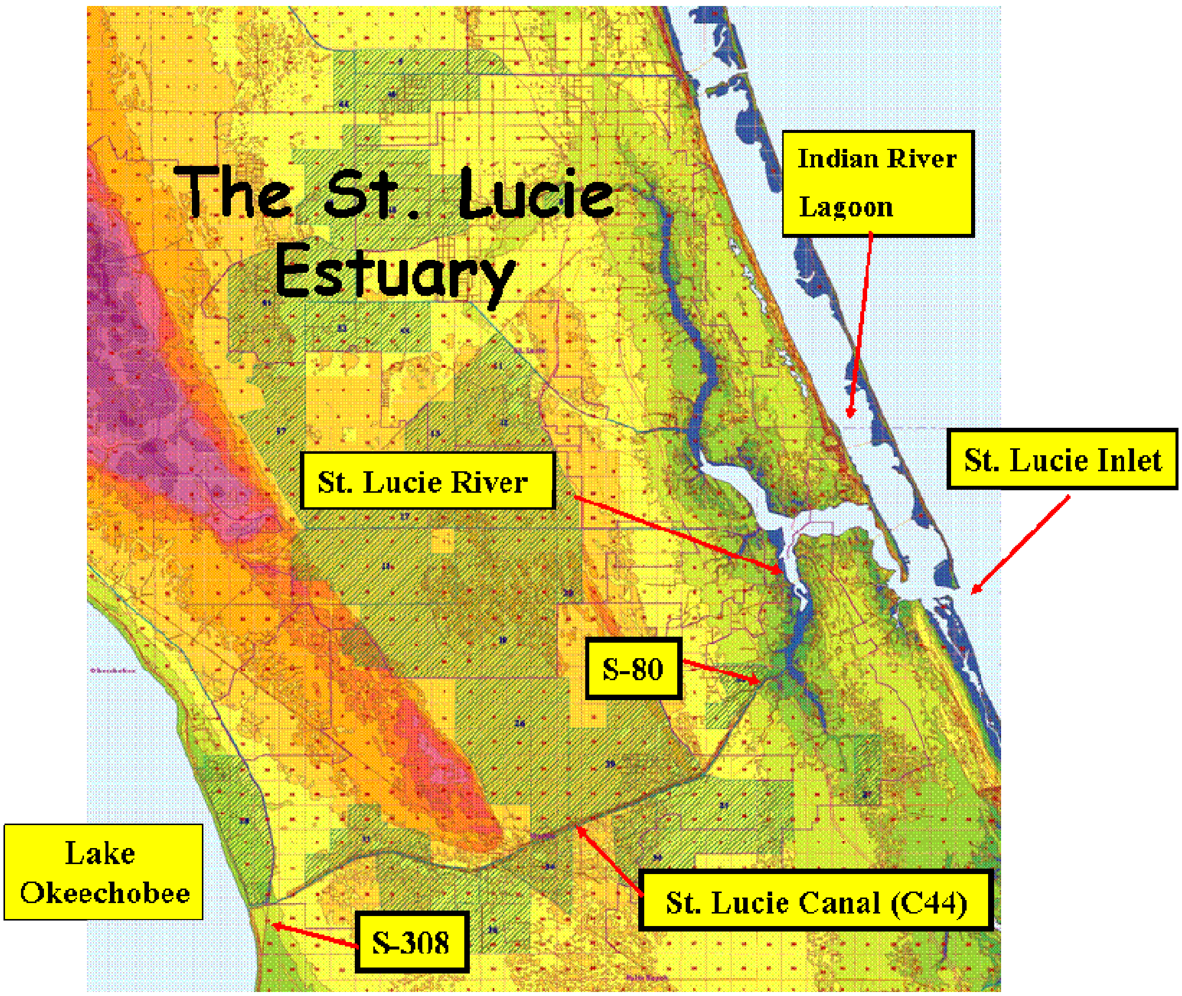
d.) Transferring large amounts of total suspended solids into the Estuary (resulting in large deposition of muck into the Estuary)

e.) And transferring large quantities of nitrogen and phosphorous nutrients into the Estuary (resulting in elevated concentrations which could be linked to the development of algae blooms).

ANALYSIS

<u>Background</u>

The first chart shows the St. Lucie Estuary, Lake Okeechobee, and the St. Lucie Canal (C44) which connects the two. Two control structures, S308 and S80, are indicated at the western and eastern ends of the canal. These are controlled by the US Army Corps of Engineers and can be opened allowing water to flow between the respective bodies of water.   Because of elevation difference, the flow is generally from Lake Okeechobee to the St. Lucie Estuary.



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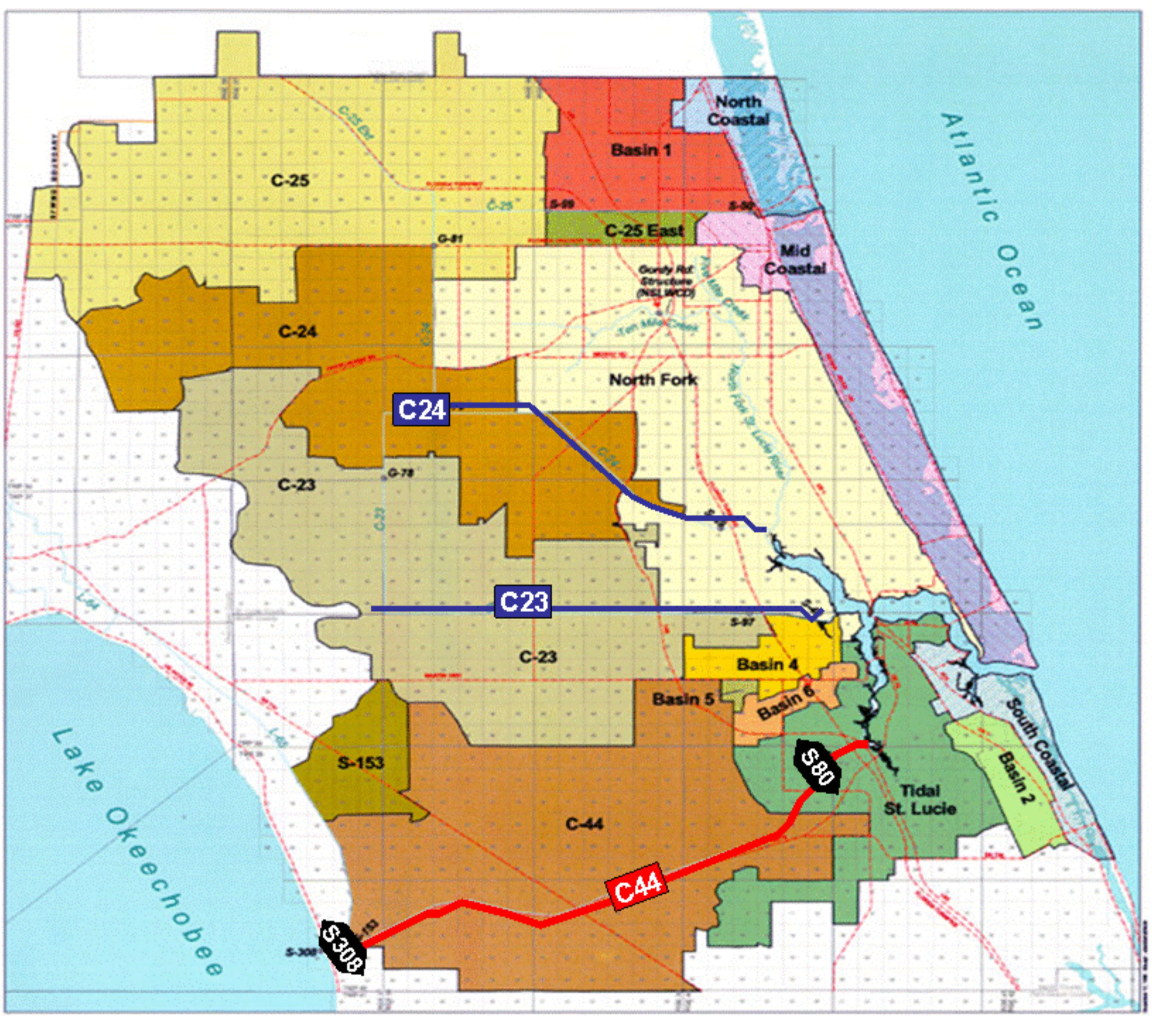
In particular, during the period 2003 to 2005, Lake Okeechobee water levels were sufficiently high that the Corps discharged large amounts of water through S308 and S80 resulting in massive discharges to the St. Lucie Estuary. This water eventually flowed through the Estuary into the Indian River Lagoon and out the St. Lucie Inlet to ocean.

In the discussions that follow, comments will be made relative to the St. Lucie Canal (C44) as well as two other canals (C23 & C24) flowing into the St. Lucie Estuary. C23 and C24 canals drain areas of the St. Lucie watershed as depicted by the color patterns on the map with C23 draining the gray area and C24 draining the orange-brown area. These areas are referred to as the C23 watershed and C24 watershed with each watershed draining into the respective canals and then into the St. Lucie Estuary.

The light-brown area surrounding the C44 canal drains into C44. This area is referred to as the C44 watershed. While C23, C24, and C44 canals move water from the respective watersheds to the St. Lucie Estuary, C44 is also the flowway that connects Lake Okeechobee to the St. Lucie Estuary. The US Army Corps of Engineers releases water into C44 from Lake Okeechobee by opening gates S308 at the western-most end of the C44 Canal at Port Mayaca. At the eastern end of C44, the flow is controlled by a locks/spillway structure S80 (also known as the St. Lucie Locks). Water releases from S80 flow into the St. Lucie. While some of the water coming through S80 comes from the C44 watershed, most of the flow historically has come from Corps of Engineers Lake Okeechobee discharges that come through S308.



Water Discharges and Loading

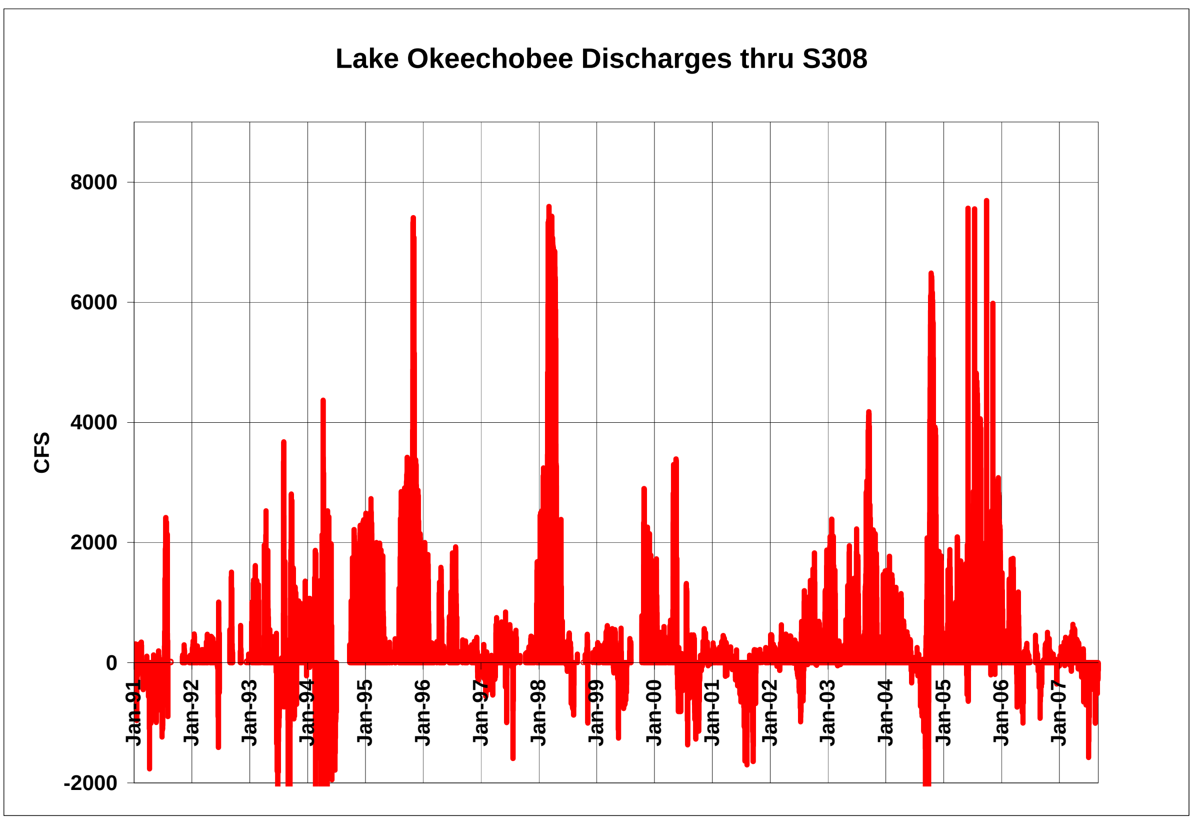
The attached tables and charts are a compilation of water quality data analyzed for the St. Lucie Estuary over a 16-year period, from approximately 1991 through 2006. These dates correlate with the most complete and reliable data available from the South Florida Water Management District's (SFWMD's) DBHYDRO data base available on the web at http://glades.sfwmd.gov/. Data were downloaded by the author on Sep 22, 2007.

The water discharges into the St. Lucie were determined by measurements taken by the US Army Corps of Engineers and South Florida Water Management District at the following locations:

Flow Data

- S308 – Flow data at S308 spillway on St. Lucie Canal at L. Okeechobee
- S80 – Flow data at S80, St. Lucie Locks and Spillway
- S48 – Flow data at S48 structure on C23 Canal
- S97 – Flow data at S97 structure on C23 Canal
  (alternate when S48 data was not available)
- S49 – Flow data at S49 Structure on C24 Canal

For example, here is a plot of the daily flow rate data for S308.

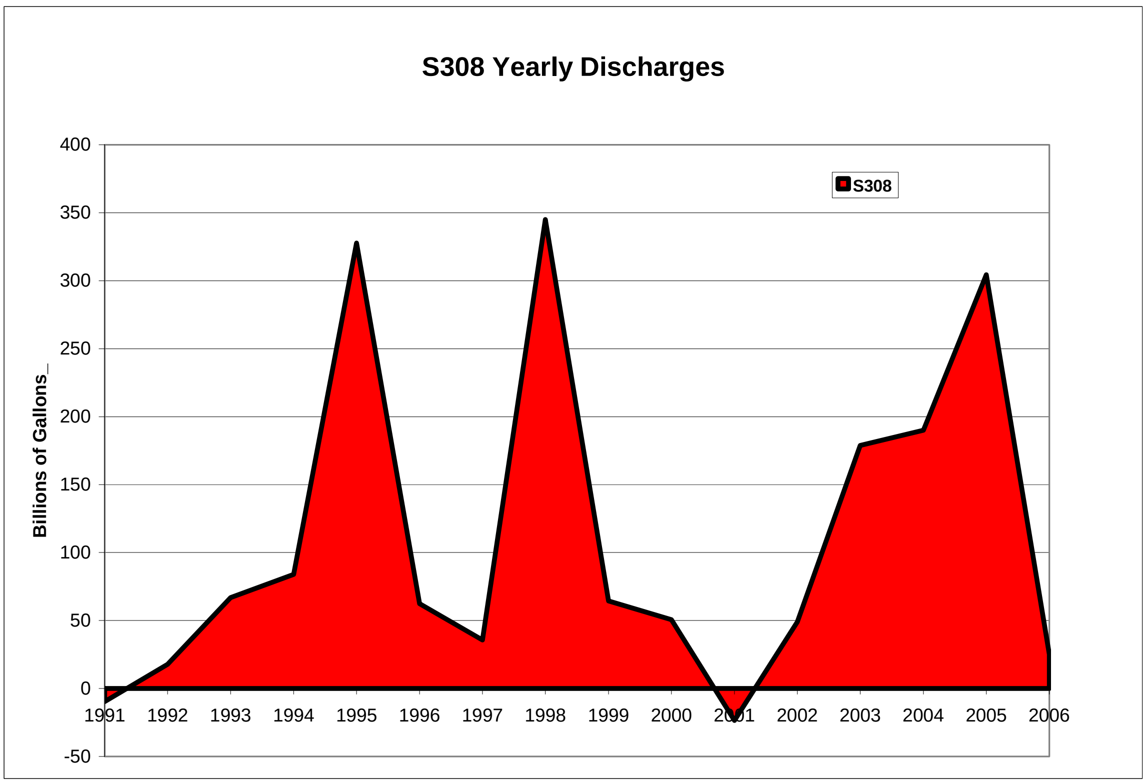


Flow rate data is given in Cubic Feet per Sec (CFS) on a daily average basis in DBHYDRO. From the previous chart, one can observe the periods of time when the discharges from Lake Okeechobee were minimal as in 2001 and when the discharges were large as in 1995, 1998, and 2003-2005. During these peak discharge years, we see flow rates of up to 7500 CFS.

Note that some of the discharge rates through S308 are negative. This indicates that the flow was in reverse, in this case flowing from the C44 canal back into Lake Okeechobee. This occurs in drought years when the lake is very low. In this case the flow is from the C44 watershed, into C44, and into Lake Okeechobee.

The concern is with the high flow periods when billions of gallons of water flow into the C44 Canal and on through to the St. Lucie Estuary. In addition, we will be concentrating on the period of record from 2000 to 2006 and the impacts due to the high discharges in the 2003 to 2005 timeframe.

In order to get daily water loading into the Estuary, the daily average rates had to be multiplied by the 24 hours timeframe. This daily loading was then summed to get monthly and yearly loading values. To do this, the daily loads were averaged on a monthly basis by the author. Days when no data was available were not included in the monthly daily average calculation. Once a monthly daily average was computed, its value was multiplied by the number of days in that month to come up with a monthly total discharge in gallons. A yearly discharge total was computed by summing up the monthly totals. The yearly discharge loading for S308 is shown below.



The following table shows the yearly discharge loads in Billions of Gallons for the canals and structures of interest. S308 and S80 values are for flows through the Corps control structures on C44. C23 WS and C24 WS values represent flows from the C23 and C24 watersheds down the respective canals. The C44 WS value represents the C44 watershed flow into the C44 Canal and is calculated by taking the difference between the flow into the C44 canal through S308 and the flow out of the C44 canal through S80. It will be assumed that this difference is attributable to flows into the canal from the C44 watershed alone.

Detailed tabular data is available from Refs. 5, 6, and 7, including monthly discharge loads. The yearly summaries are presented in the following table.

Yearly Billions of Gals					
Date	S308	S80*	C44 WS	C23 WS	C24 WS
1991	-9.639	51.967	61.606	55.888	66.579
1992	17.775	90.905	73.130	69.122	52.275
1993	66.890	76.542	9.652	58.079	63.991
1994	83.960	171.214	87.255	91.413	92.536
1995	327.789	415.819	88.030	85.764	82.202
1996	62.549	95.829	33.280	31.271	34.383
1997	35.76	32.23	-3.53	34.08	51.08
1998	345.07	406.23	61.16	45.09	60.67
1999	64.39	113.50	49.11	57.02	67.37
2000	50.68	55.92	5.24	13.08	16.38
2001	-23.42	14.86	38.28	43.65	64.34
2002	49.06	61.41	12.35	38.56	50.04
2003	178.84	235.68	56.84	48.00	51.90
2004	190.01	226.34	33.61	67.38	71.47
2005	304.44	398.55	94.12	103.11	91.24
2006	25.09	38.02	12.93	20.37	16.29

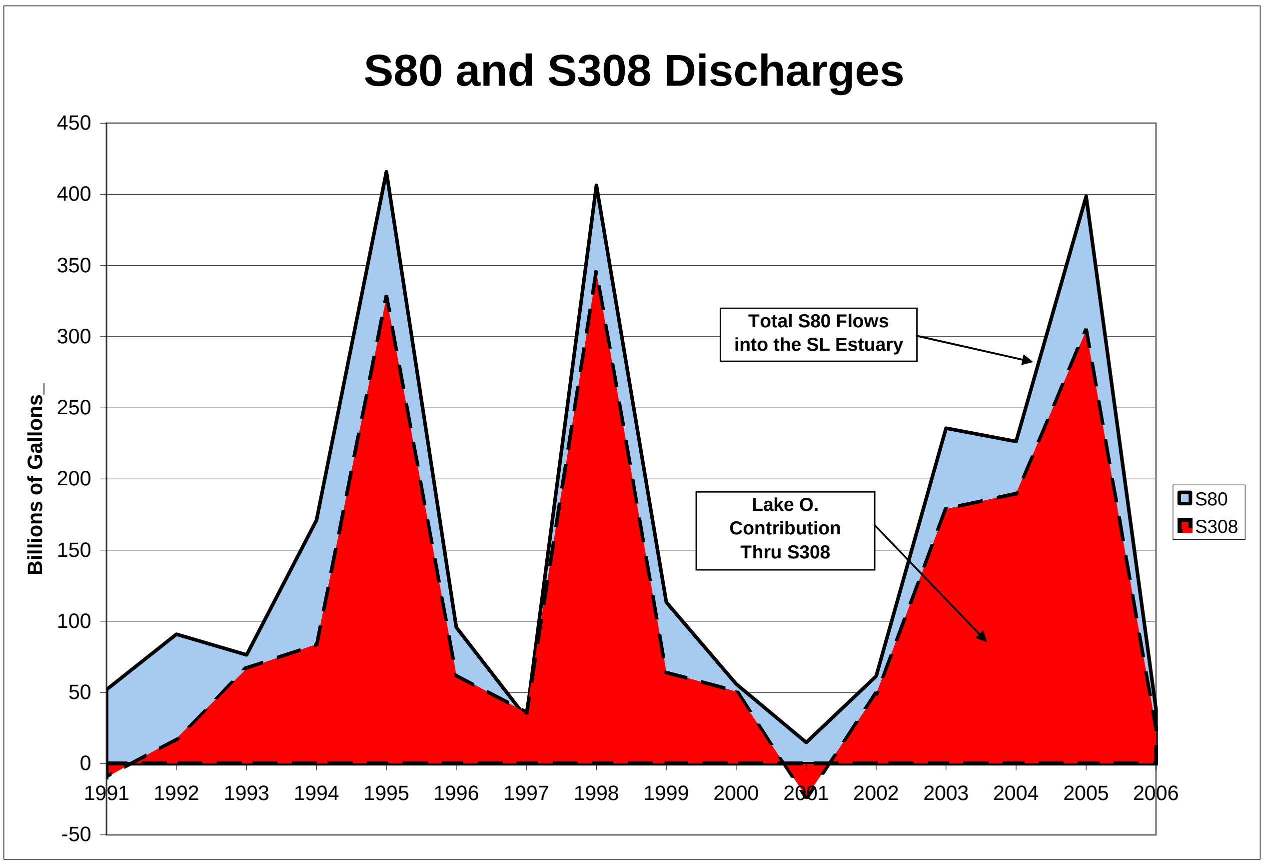
* Includes water flowing from S308

Note that in 1991 and 2001, the discharges through S308 are negative. This indicates that the flow was in reverse, in this case flowing from the C44 canal back into Lake Okeechobee. This occurs in drought years when the lake is very low as described earlier. Because of the elevation difference, the water cannot flow from the St. Lucie Estuary into the C44 Canal at S80.

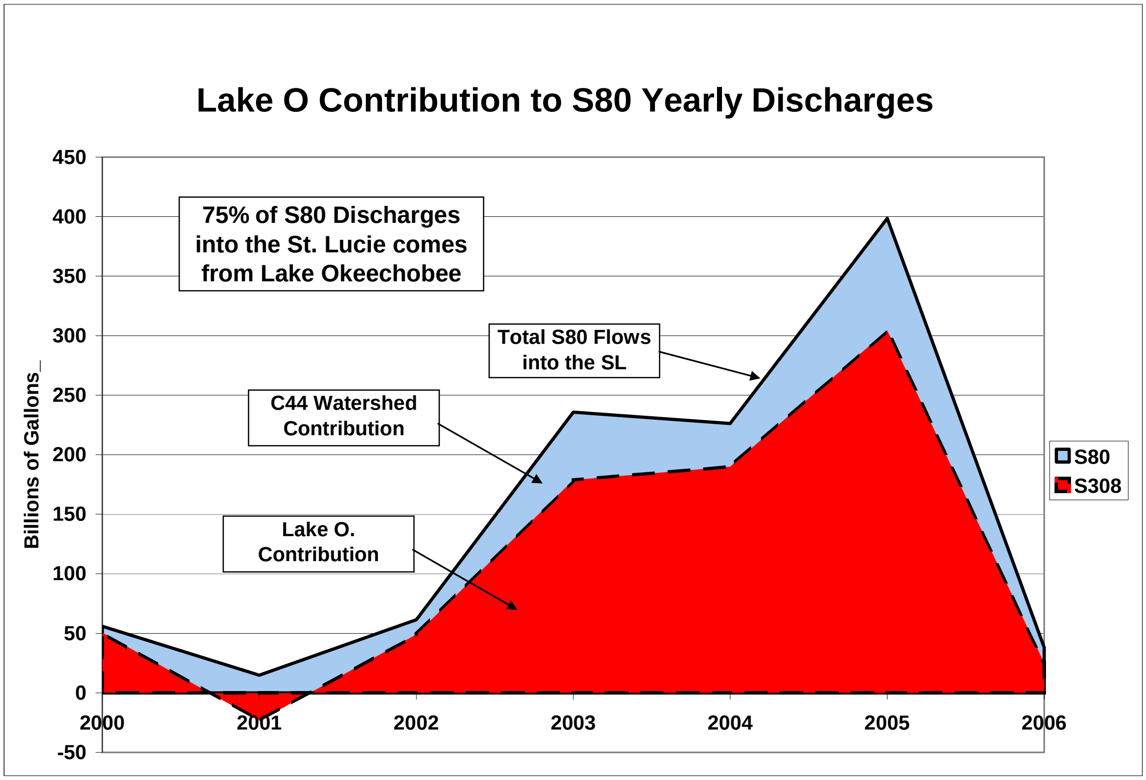
To get total flows to the St. Lucie Estuary from major canals, one would sum the columns for S80, C23, and C24. (S308 water from Lake Okeechobee flows into the C44 canal and eventually flows through S80 into the S.L. Estuary. As such, S80 flow values include the water discharged from Lake Okeechobee. through S308.)

Flow Data Trending

Since tabular data is often difficult to interpret; much of the data will be presented in graphical form. For example, the following chart shows the yearly discharges through two of the flow structures, S80 and S308, on the C44 Canal. This plot shows 16 years of discharge data for the C44 Canal. The solid black line depicts the total flow amounts coming out of the C44 Canal in Stuart at the St. Lucie Locks (S80). The dashed line shows the Lake Okeechobee discharge amounts entering the C44 Canal at Port Mayaca at structure S308. The difference between the two (the blue area) is the result of some water flowing into the C44 canal from smaller feeder canals coming from the watershed around the C44 Canal. Looking at this chart, we can see the high Lake Okeechobee discharge years of 1995, 1998, and especially 2003 thru 2005. We can also notice that the C44 watershed contribution (the area in blue) is much smaller than the Lake Okeechobee contribution (the area in red).



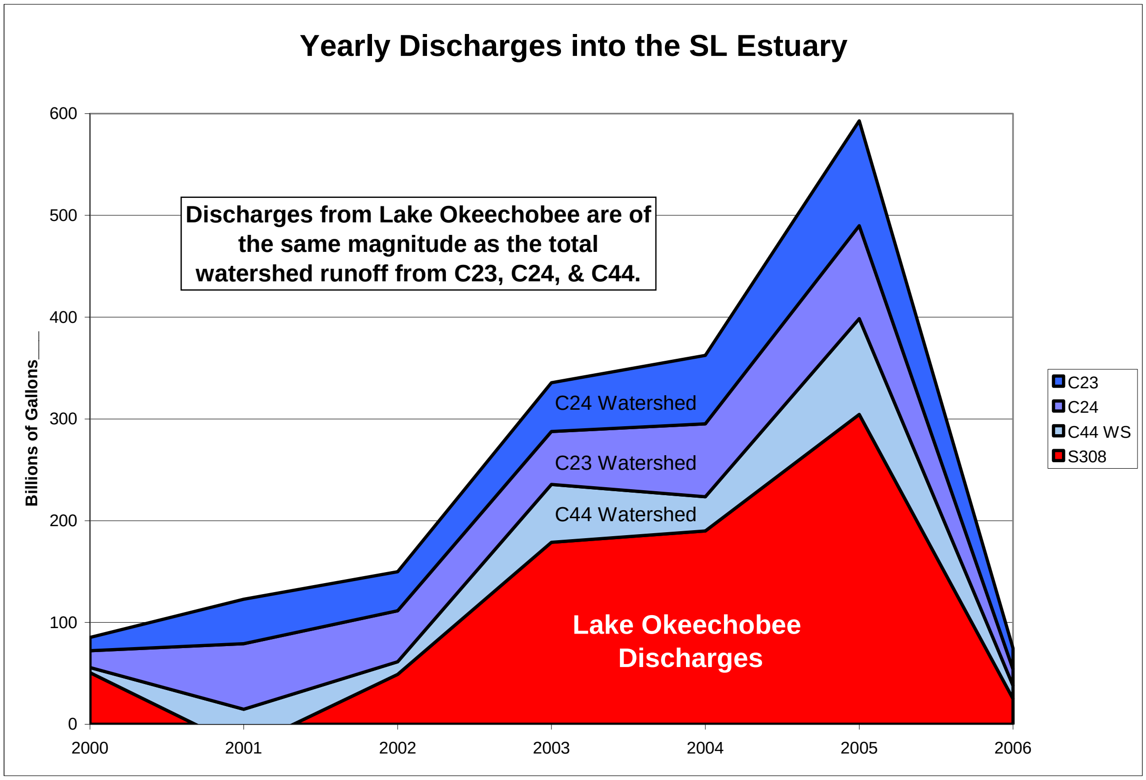
If we analyze the data for the period of record for this lawsuit (2000 to 2006), we see that 75% of the water entering the St. Lucie Estuary from the St. Lucie Locks (S80) comes from Lake Okeechobee (through S308).



As in the first previous plot, the area in light blue is the difference between the flow into the C44 canal through S308 and the flow out of the C44 canal through S80. This light blue area is the C44 watershed flow resulting from flows into the C44 canal from its surrounding watershed.

In summary, the prime contributor to discharges through the St. Lucie Locks (S80) into the St. Lucie Estuary is from Lake Okeechobee. It is because of this high ratio that we can pretty much equate C44 discharges with Lake Okeechobee discharges. Water flows into the C44 Canal from Lake Okeechobee through C308. Water flows out of the C44 Canal and into the St. Lucie Estuary through S80. The difference between the inflow and outflow is due to smaller canals feeding C44 from the surrounding watershed. These flows do not compare in magnitude to the massive discharges emanating from Lake Okeechobee during heavy discharge years.

If we now add the flows into the St. Lucie Estuary from the C23 and C24 canals, we will be able to see the relative magnitudes of all the major canal flows into the St. Lucie Estuary. This is shown in the next graph.

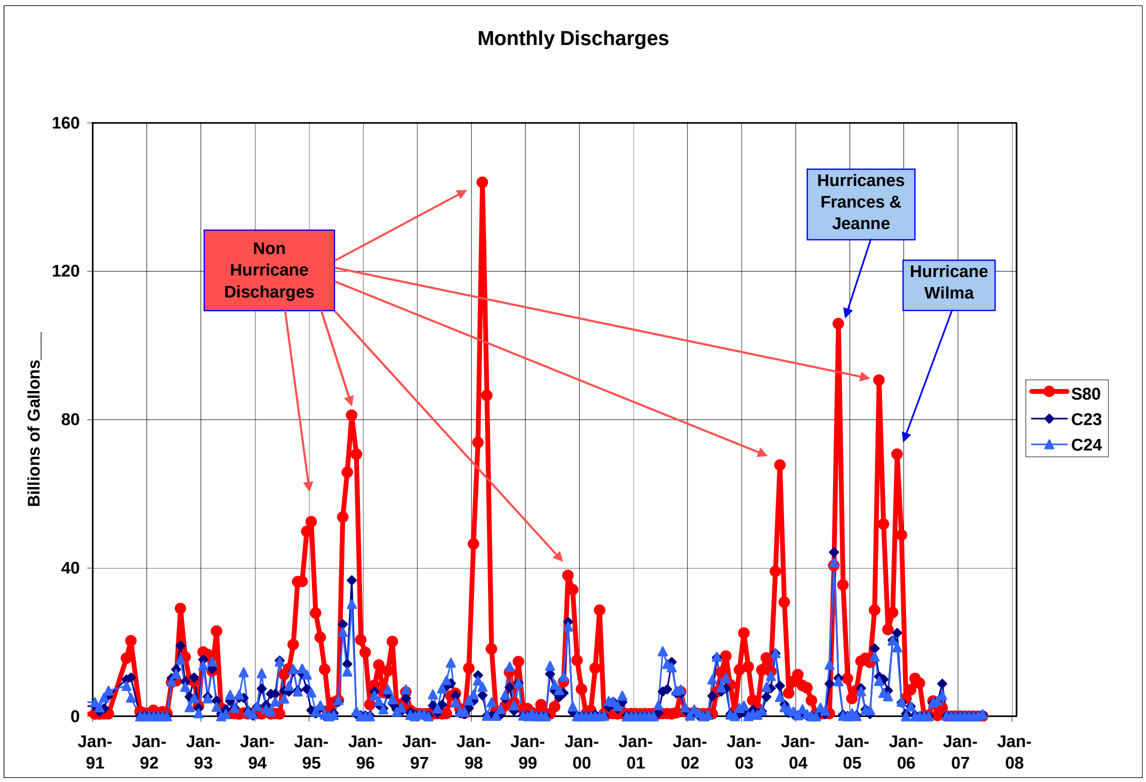


The discharges from Lake Okeechobee are shown in red. The flows from the watershed are shown in blue. The graph shows the discharges from Lake Okeechobee to be of the same magnitude as the total watershed runoff from the C23, 24, and 44 watersheds combined. In particular, in 2005, Lake Okeechobee discharges amounted to 304 billion gallons while the corresponding watershed flows (C23, C24, & C44 WS flows combined) amounted to only 288 billion gallons. So, in 2005, Lake Okeechobee discharges more than doubled (105% increase) the flow that would have come from the watershed alone.

The St. Lucie Estuary sees flows from three major canals, C44, C23, and C24. C23 and C24 provide drainage from the local western watershed areas and are primarily rain driven. Most of the water flow is during the rainy season and is usually of shorter duration. These discharges are considered to be “nature driven.” On the other hand, C44 discharges are primarily dictated by the Corps of Engineers to control the level of Lake Okeechobee. These discharges are often large, can last for long periods of time, and can occur at times which may be “unnatural” to the yearly marine cycle in the estuary. Fish and oyster spawning periods could be affected, specifically when these discharges are made at the wrong times of the year.

Hurricanes

Hurricanes are often blamed for the destruction of the estuary. In most cases hurricanes result in periods of heavy rain and these rains result in flows to the estuary. But many of the large discharges from the Corps of Engineers through C44 are in non-hurricane years or between hurricanes. In most cases the Corps is trying to deal with too much water in Lake O resulting from flows from north of the Lake, or in anticipation of high levels in Lake O from potential future rain events. See the chart below and note the high discharges in 1998 and 2003 (and even in 2005 between hurricanes). In the 2000 to 2006 timeframe, heavy Lake O releases occurred in 2003 when there were no hurricanes and in 2005 heavy Lake O releases occurred prior to Hurricane Wilma.



As such, heavy discharges to the Estuary cannot be blamed on hurricanes alone.

Water Quality Grading for the St. Lucie Estuary

One way of evaluating the impact of Lake Okeechobee water discharges on the St. Lucie Estuary is by establishing a water quality grading system as described in Reference 4. The Florida Oceanographic Society derived a procedure for grading the water quality in the St. Lucie Estuary by comparing weekly measurements taken by trained volunteers and comparing them against standards. In the procedure described, the St. Lucie Estuary is broken down into a series of zones and the water quality is assessed according to guidelines for each of those zones as described in Ref. 4. The testing procedures are standard and are documented in Ref. 1. The primary measurements of water quality include salinity, water and air temperature, clarity (using a Secchi disk), and dissolved oxygen. Using the algorithms outlined in Ref 4, a grading of each of the sections of the river is computed and an overall Estuary grade is computed. Results are compiled weekly and posted on the Florida Oceanographic Society's website. An example of a weekly report is given below:

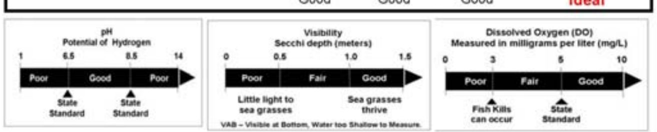
St. Lucie River Estuary
Water Quality Outlook

This information is provided by the Florida Oceanographic Society with support of the Marine Resources Council. It is collected by the Citizen Volunteer Water Quality Monitoring Network. For complete data go to our website at:
http://www.floridaoceanographic.org/water.htm

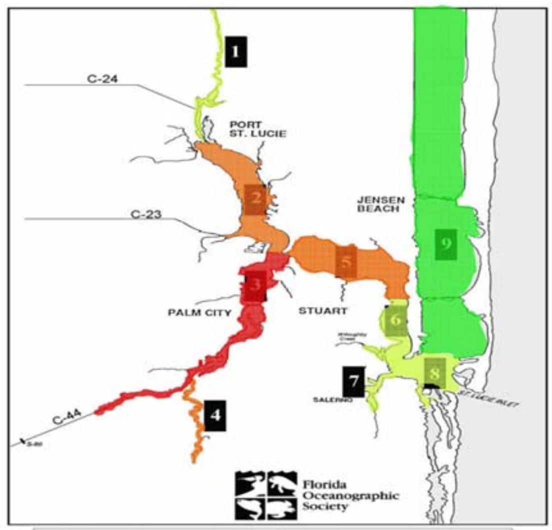
Posted: 03/22/06

Overall Grade:	77.6%	C+	SATISFACTORY

Zone/ Location	Water Temp. Deg. F	pH	Visibility (Secchi) Meters	Salinity ppt	Dissolved Oxygen mg/L	Location Score	Grade
1. Winding North Fork	79	7.8	0.60 Fair	4.0 Good	8.1 Good	87%	B Good
2. North Fork	76	8.1	0.90 Fair	9.5 Poor	7.4 Good	66%	D Poor
3. South Fork	75	8.5	0.25 Poor	1.0 Poor	10.3 Good	56%	F Destructive
4. Winding South Fork	73	7.8	0.60 Fair	0.0 Poor	6.0 Good	66%	D Poor
5. Wide Middle River	72	8.0	0.80 Fair	14.0 Poor	6.9 Good	66%	D Poor
6. Narrow Middle River	76	8.5	0.80 Fair	26.0 Good	7.7 Good	87%	B Good
7. Manatee Pocket	77	8.1	0.88 Fair	29.4 Good	6.3 Good	87%	B Good
8. Inlet Area	73	8.4	0.88 Fair	34.5 Good	6.2 Good	87%	B Good
9. IRL	70	8.1	1.30 Good	36.0 Good	6.4 Good	97%	A Ideal



Comment: The data above may indicate areas of concern in the St. Lucie Estuary. Citizens should call the Florida Department of Environmental Protection (DEP) at 871-7662 or the South Florida Water Management District (SFWMD) 223-2600 to ask about the quality of a specific area and report observations of pollution.

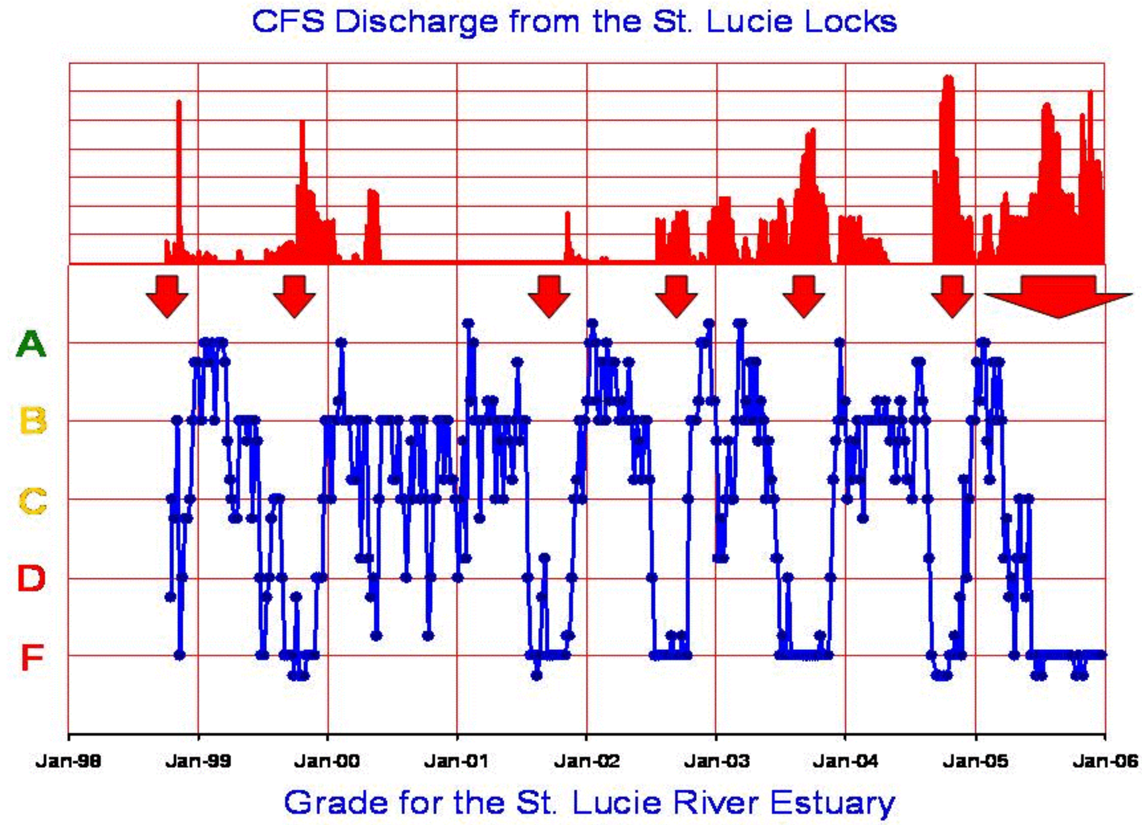


Grading				
A	B	C	D	F
90-100	80-89	70-79	60-69	0-59
IDEAL	GOOD	SATISFACTORY	POOR	DESTRUCTIVE

Salinity (Parts per Thousand)

Zones	Description	Good	Fair	Poor
1 & 4	Winding North & South Forks	2 to 8	1 to 2 or 8 to 15	< 1 or > 15
2 & 3	Inner St. Lucie Estuary (North & South Fork)	15 to 25	10 to 15 or > 25	< 10
5	Wide Middle St. Lucie River	> 20	15 to 20	< 15
6	Narrow Middle St. Lucie River	> 25	20 to 25	< 20
7	Manatee Pocket	> 27.5	20 to 27.5	< 20
8 & 9	Inlet and Indian River Lagoon (to Jensen Beach Causeway)	>30	25 to 30	< 25

If the Estuary Grade is plotted over time with an overlay of the discharge rates from Lake Okeechobee, we get a plot as shown below.



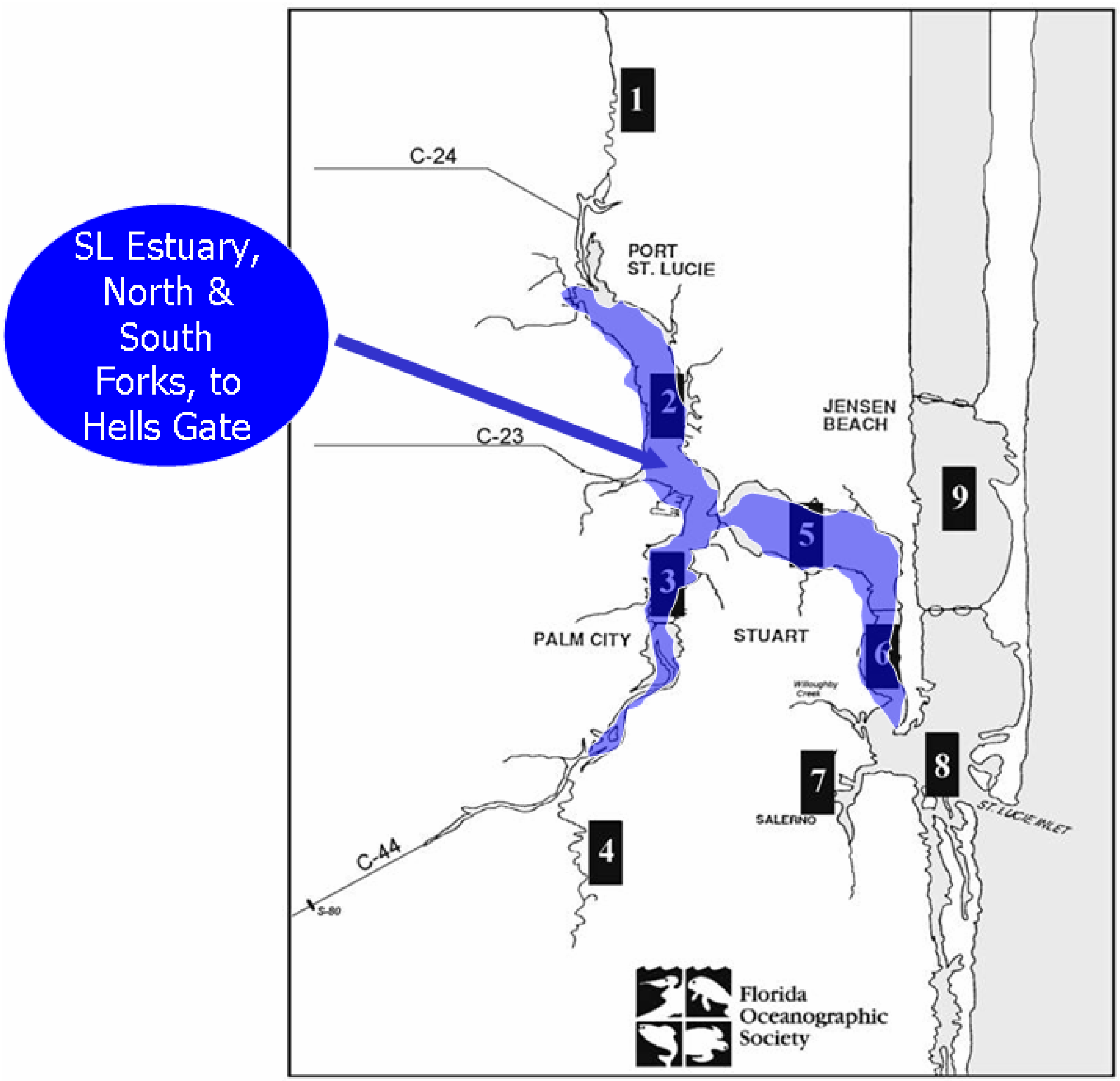
From this chart we observe a correlation (follow the arrows) between the Lake Okeechobee discharges into the Estuary and the overall grade for the St. Lucie Estuary. When the discharges are low, the Estuary grade is high, an A, B, or C. When the discharges are high, the grade drops to values of D and F. In particular, in the 2003 and 2005 timeframes, the Estuary grade was at an F level for extended periods of time. An F grade in this case is described as “Destructive” to the estuarine environment.

The water quality grade is primarily dependent on two water quality parameters, namely, the water salinity and the water clarity. These will be discussed next.

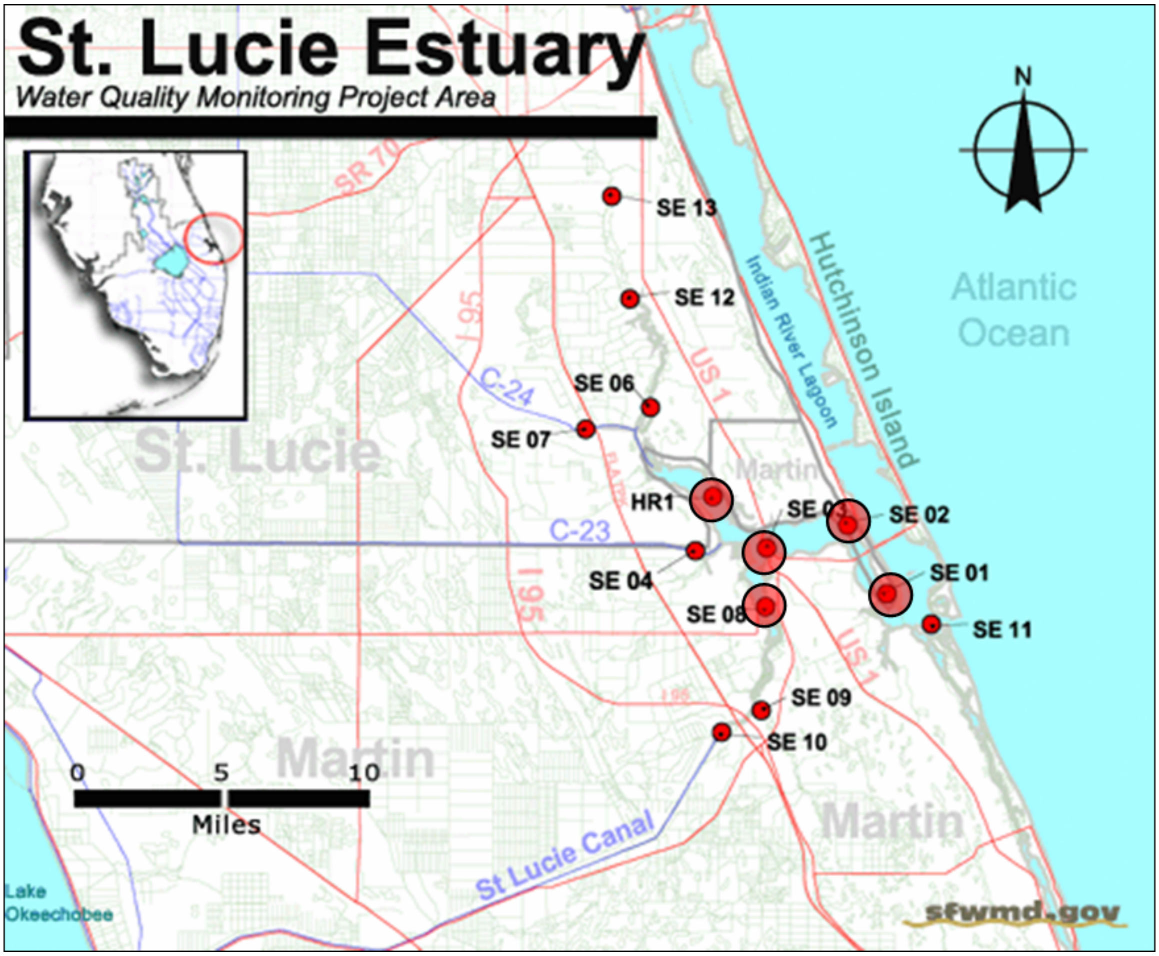
Water Quality Data Sets

An extensive data base exists on water quality conditions in the St. Lucie Estuary. Monthly measurements from the South Florida Water Management District are available from DBHYDRO, their data base repository on the web. In addition, data is available on a weekly basis from Florida Oceanographic Society's Citizen's Volunteer Water Quality Testing Network as posted on their website.

Data will be plotted from both sources for the St. Lucie Estuary, which we will define by the area shown below, highlighted in blue. The blue region encompasses the north and south forks, the wide middle, and the narrow middle sections of the St. Lucie Estuary to a point known as Hells Gate. The FOS data that will be presented comes from measurements in FOS Zones 2, 3, 5, and 6.



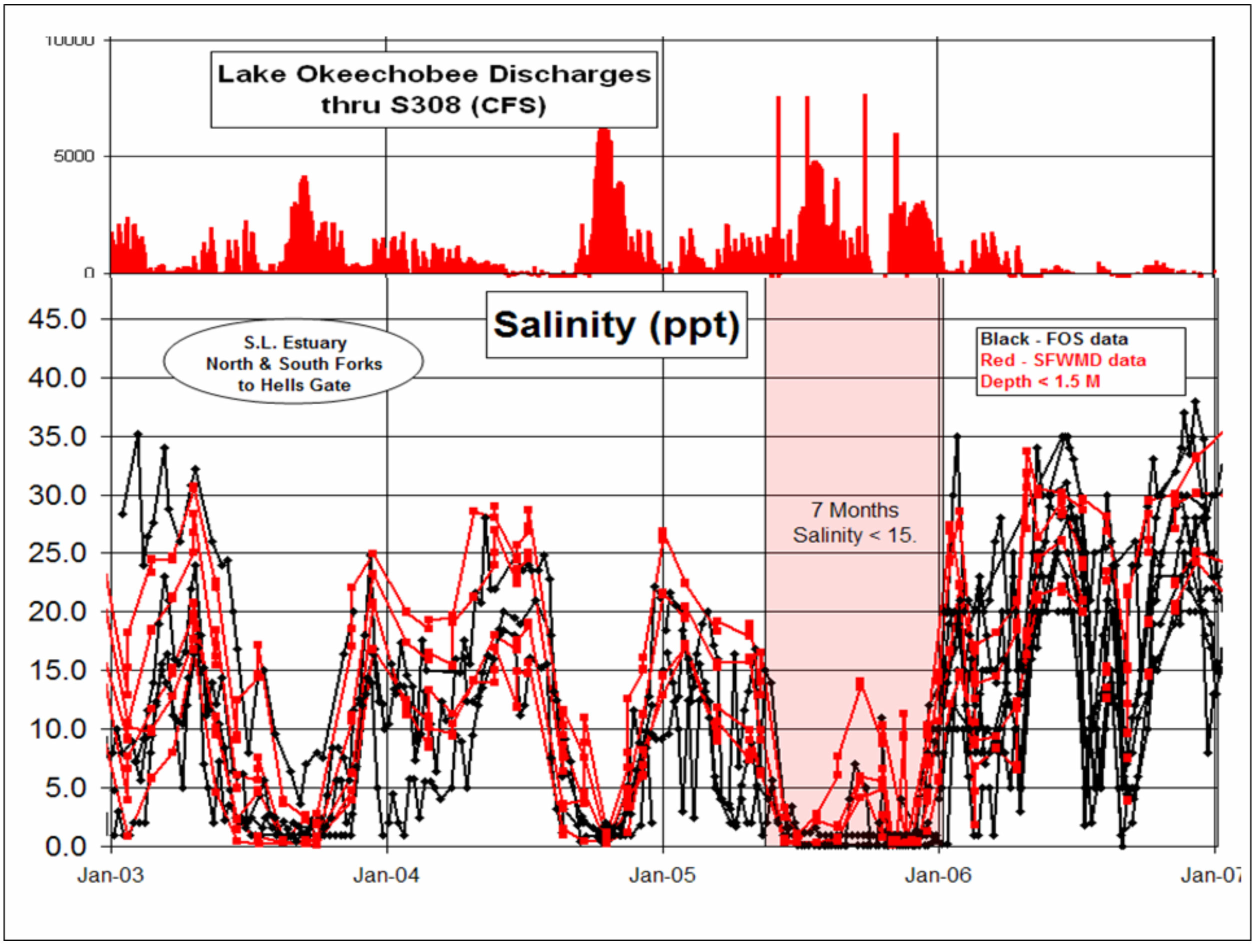
The data from the SFWMD is illustrated on the next figure. We will be plotting data for the same corresponding areas as describe above. SFWMD data is from the following measurement locations: HR1, SE8, SE1, SE2, and SE3 (large circles). These locations correspond to the same area described above in blue highlighting.



In the graphs that follow, we will be plotting data from both data sources with FOS data plotted in black and SFWMD plotted in red.

Salinity

We will begin by plotting the salinity in the St. Lucie Estuary. The following plot shows all the salinity measurements from the sources described above. Data in red is from the SFWMD, data in black is from FOS volunteers.



This graph very pointedly illustrates the relationship between discharges from Lake Okeechobee and the salinity in the St. Lucie. When the discharges increase, the salinity in the Estuary drops, when the discharges decrease, the salinity increases. The higher the discharges, the lower the salinities. Under non-discharge conditions the salinity in the estuary is expected to be between 15 and 30, with values being somewhat dependent on where the measurement station is located (how close it is to the inlet and the tidal salt water).

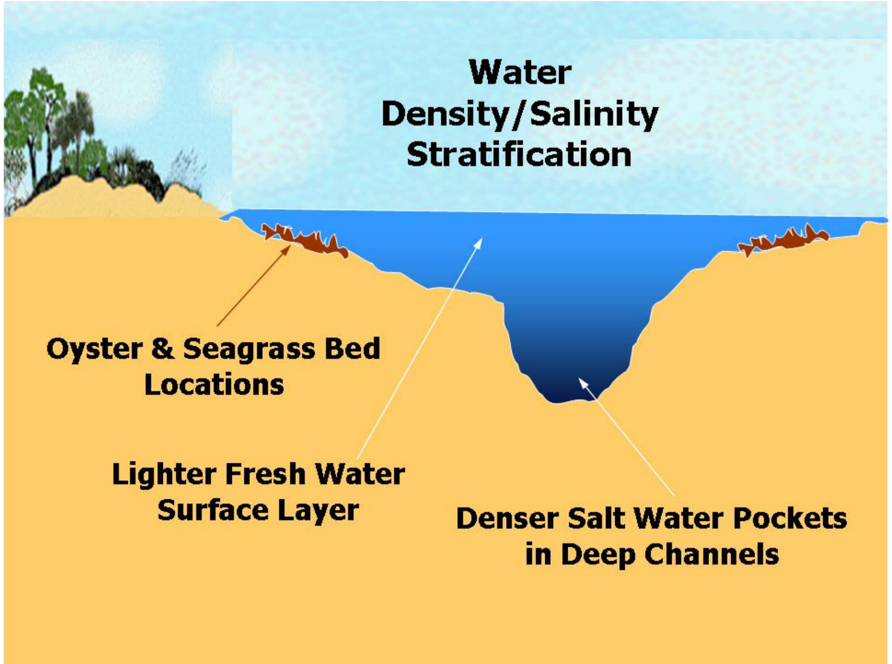
The problem with the discharge events from Lake Okeechobee, especially in the 2003-2005 timeframe is that the discharges were large and they occurred for extended periods of time. Of particular note is the period in 2005 when the heavy discharges from Lake Okeechobee dropped the salinity in the Estuary to below 15 ppt for a 7-month timeframe.

In a SFWMD publication relating to the "Restoration Plan for the Northwest Fork of the Loxahatchee River", dated April 12, 2006, guidelines for both oyster and seagrass health are presented. In that document, salinity ranges are presented for when oysters are in their best environment, when they are stressed, and when they die. For oysters, it is dependent on the stage of their development – Eggs, Larvae, Spat & Juveniles, or Adults. And, not only is salinity a factor, but the duration of the exposure must also be taken into account. It is mentioned that oysters can take fresh water flushing, that is, they will close up and almost go into hibernation when exposed to low salinities for short periods of time (days). But they can only stay in that state for a limited time. In 2005, when the Estuary had the 7 months of low salinity due to Lake Okeechobee discharges, it is highly probable that oyster mortality prevailed.

There are also guidelines for seagrasses in the SFWMD report. According to the SFWMD publication, seagrass mortality depends on what variety of grass we are talking about –Shoal, Manatee, Turtle, or Johnson's seagrass. And, there are not only salinity criteria, but also length of exposure criteria, similar to oysters. And, although not mentioned, we know that the water clarity affects seagrasses. If the sunlight can't get to the plants, then they aren't going to survive, no matter what salinity they are exposed to. When the Lake Okeechobee discharges come, the water clarity decreases along with the decreased salinity. To the best of my knowledge, the SFWMD report does not take into account the water clarity level in its mortality prediction model for seagrasses because that report dealt with the Loxahatchee River which is not directly affected by the high discharges and high turbidity from Lake Okeechobee. But based on the low salinity values and high turbidity during the extended 7-month period, it is highly probable that seagrass mortality prevailed.

Under rainy conditions, there is natural rain water runoff into the Estuary. This is a natural event, occurring for a relatively short period of time. The Estuary generally adapts as it should being a mixing region between the salty ocean waters and the fresh streams feeding the Estuary. The salinity generally drops some but recovers back to normal brackish conditions shortly after the rain event is over. These short term effects can cause some stress to the marine environment. But it is the extended periods when Lake Okeechobee discharges occur that we see conditions which are more than stressing, these periods can lead to high mortalities of species like oysters and seagrasses. The long duration releases do not give the marine environment a chance to recover. The salinity remains too low for too long. This may have been the case in 2005 during the 7-month period of low water salinity.

One point of clarification needs to be made relative to the salinity presented in the previous graph. The salinities which are plotted are for depths less than 1.5 meters. It is common for the salinity in a body of water to be layered or stratified as shown in the next figure.

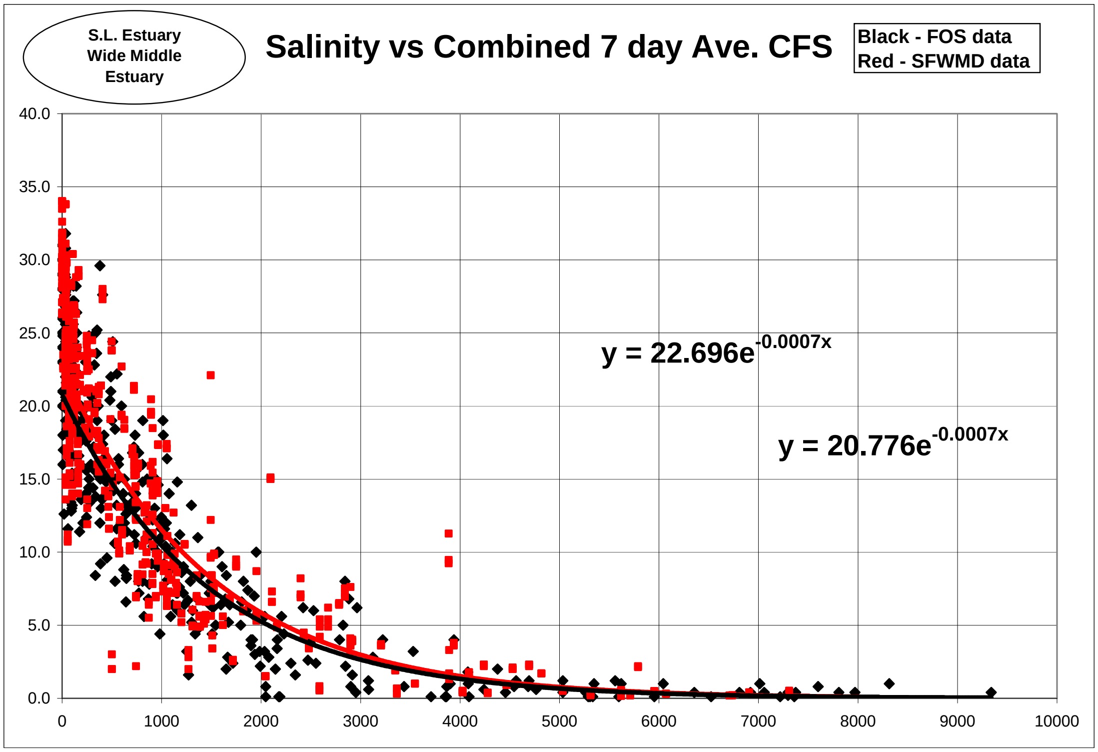


When fresh water flows into salty water, the fresh water will generally flow over the salty water because it is less dense. This effect is sometimes referred to as a "salinity wedge". During times of discharge it is not uncommon to find fresh water flowing into the Estuary over pockets of salty water at the bottom of deeper sections of the river, in holes and in deeper channels. SFWMD measures its water quality data at various depths, usually at locations in the middle of the river. FOS volunteers measure data from shore, taking samples from the surface water. It is the opinion of the author that near-surface measurements are more representative for salinity because it is this near-surface water that makes its way to the shorelines where oyster bars and seagrass beds exist. And even though there may be saltier water in the depths of the river, in the channels, that water is of no assistance to oysters and seagrasses that cannot migrate to those locations.

Another problem with the Lake Okeechobee discharges which is not immediately obvious is that the discharges often occur at the wrong times of the year. Generally, the life cycles of oyster, fish, and other marine life in the estuary follow a seasonal pattern, often aligned with the rainy and dry seasons of the year. For example, oysters spawn in the spring. Fish spawn with the moon and tides in the spring. Unfortunately, the Corps of Engineers has had heavy discharges at "unnatural" times of the year, often in the spring, prior to the start of the rainy season.

It is important to remember that even clean fresh water discharges are a pollutant to the Estuary because of the effect on salinity. Looking at the magnitude of the fresh water inputs to the Estuary, we see yearly discharges of nearly 600 billion gallons, with half of that coming from Lake Okeechobee. During these heavy discharge years, the salinity in the Estuary is changed dramatically with the St. Lucie Estuary becoming a near fresh water body. The marine environment is changed to a fresh water environment and the marine life is affected.

The salinity correlation with discharge rate has been studied in Ref. 2. An example of the salinity correlation is shown below.



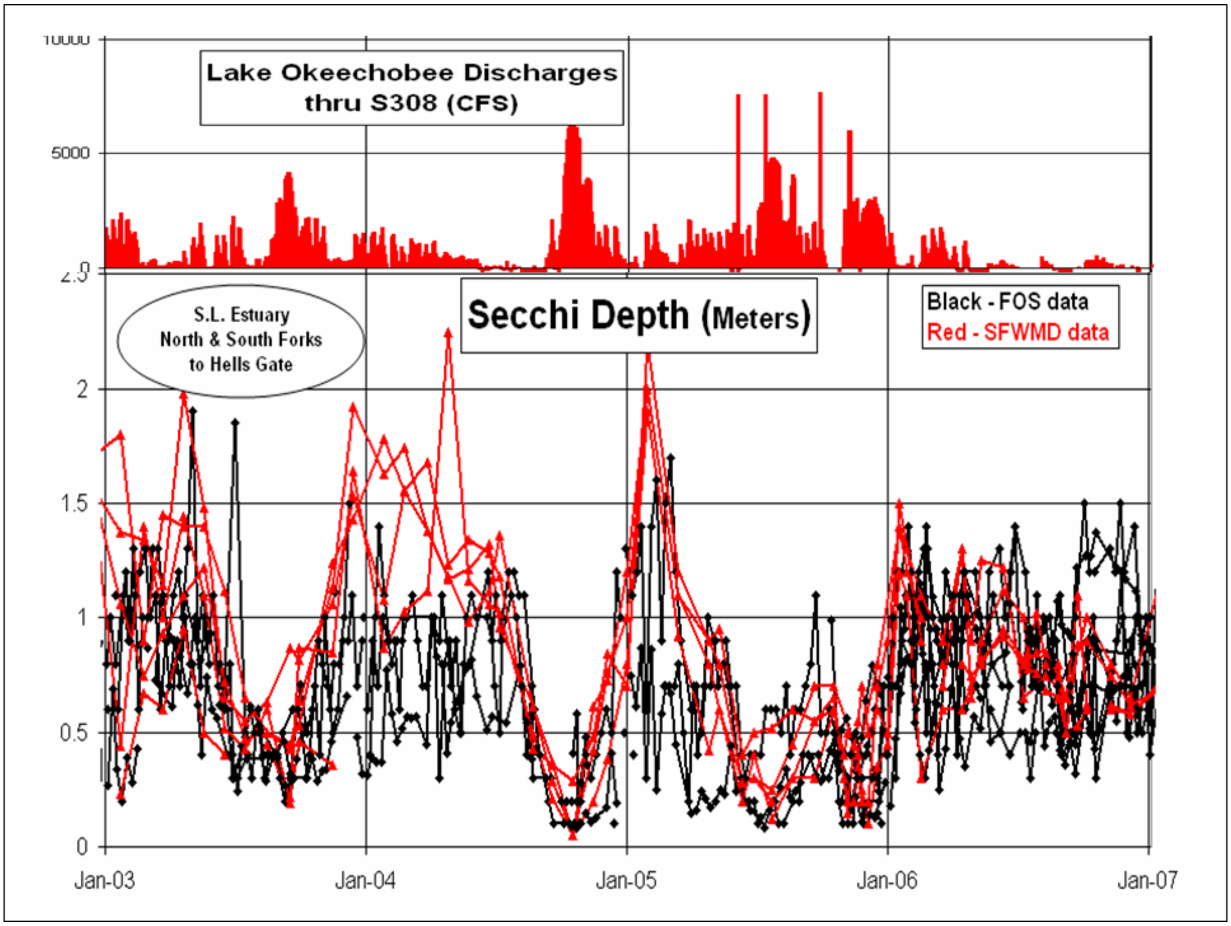
This plot shows data for one zone in the Estuary, Zone 5. It shows that if the salinity measured at any one time is plotted against the average flow rate into the estuary over the past 7 days, then the data shows a trending as describe earlier, namely, when the discharge rate (in CFS) increases, the salinity drops. The plot also shows the comparison of data sets between the SFWMD and the FOS volunteers. The data agree very nicely and the curve fits of the respective data sets almost overlap each other.

The graph shows that if the discharge rate is zero, the salinity in Zone 5 of the Estuary is expected to be around 20 or 22 ppt. However, if the discharge rate increases to values of 2000 CFS, then the salinity will drop to values around 5 ppt. As can be seen, some of the flow rates into the Estuary have reached values above 7000 CFS resulting in salinities below 1 ppt. With fresh water having a salinity of 0 ppt and ocean water having a salinity of 35 ppt, the impact of discharges is to transform a salty or brackish estuary into a fresh water lake.

Water Clarity

The second water quality parameter to be plotted is the Secchi depth. The Secchi depth is a measurement of the water clarity (visibility in the water.) A Secchi disk is a black and white patterned disk which is lowered into the water. The disk is lowered to the point where the pattern cannot be discerned by the observer, and it is the depth at which the pattern cannot be recognized that is defined to be the Secchi depth. This measurement is important because it represents how far one can see into the water, how far a fish can see under water, how far a bird can see into the water from above, and how far the sunlight can penetrate into the water to illuminate seagrasses.

Normally, we would consider Secchi depths of 1 meter or more to be ideal. The Secchi depths for the period in question are shown below.



The Secchi depth graph shows similar trends with Lake Okeechobee discharges as were seen with salinity. When the discharges occur, the Secchi depth drops (water becomes less clear) and when the discharges stop, the water clarity improves. At times of very high discharge, the Secchi depths are as low as 0.1 meters. That is approximately 3 inches! During those times the water is chocolate brown and one can barely see his own hand in the water. When the visibility is only 3 inches, it blocks out almost all sunlight to the submerged plants, the seagrasses in the Estuary. Without sunlight, they cannot survive. And indeed, large expanses of seagrass beds were impacted by the extended Lake Okeechobee discharges in the 2003-2005 timeframe.

I would think it would be hard for a fish to forage for food when the visibility is so poor, not to mention the clogging of gills from the silt in the water. Even the seabirds are impacted. I personally have noted the lack of bird life when the discharges are occurring. Osprey, gulls, pelicans seem to leave the area. It is no wonder, since they gain their food from diving down into the water and catching fish. If they can't see the fish, then they can't very well catch them. I have waded in the chocolate brown water at times when I could not see my feet in the water and the water was only a foot deep.

Even after the discharges have subsided, we see continued turbidity in the water. In 2006 for example, the water clarity remained relatively low (generally between 0.5 and 1.0 meters) over most of the estuary. This is the result of the clay-like silt that was brought into the estuary from the discharges. This silt settles to the bottom of the Estuary but is stirred up by boat traffic or wind and wave action. So, even after the discharges are over, the impacts continue.

In summary, the discharges from Lake Okeechobee are truly unnatural in the sense of the quantity of water discharged, the quality of water, the clarity of water, and the duration and timing of the discharges.

Silt and Nutrient Loading Calculations

The next step in evaluating the water quality was to obtain nutrient loading for the three major canals discharging into the Estuary. Much of this data was computed in Refs. 5, 6, and 7. Multiplying the total flows by the nutrient concentrations gives us the total nutrient loading. Three nutrients were evaluated from data in DBHYDRO. These included:

Total Suspended Solids (T.Susp) (mg/L)
Total Nitrogen (TKN) (mg/L)
Total Phosphorous (TPO4) (mg/L)

Concentration data for these parameters was generally available on a monthly basis in the SFWMD database. In some cases more than one sample was available in a month. In these cases, the concentration values were averaged to get a monthly average. In some months values were missing. In these months values were interpolated between the previous and next month's data.

The following measurement stations were used to determine the nutrient concentrations for the respective canals:

SE10 – Downstream of St. Lucie Locks (S80)
SE04 – Downstream of S48 on C23 Canal
SE07 – Downstream of S49 on C24 Canal
S308C – Downstream of S308 on C44 Canal

By multiplying the concentrations in mg/L by the number of discharge gallons and making a few conversions, the loading was computed in metric tons (1000 Kg). Detailed data listings including monthly flow rates and concentration levels are given in Refs. 5, 6, and 7.

The yearly nutrient loading totals for the three major canals which discharge into the St. Lucie Estuary are shown below:

C44 Yearly Nutrient Loading (Metric Tons)			
Date	T.Susp	TKN	TPO4
1991	673.5	199.2	34.0
1992	1,468.3	410.5	80.8
1993	2,917.9	292.1	47.6
1994	7,827.6	696.8	101.5
1995	72,712.1	2,251.1	308.4
1996	3,286.9	443.2	51.3
1997	716.4	133.0	26.5
1998	71,470.3	2,404.1	348.4
1999	6,078.8	351.1	117.9
2000	6,253.0	277.0	48.7
2001	263.3	54.0	15.5
2002	-34.1	229.9	48.1
2003	22,928.4	1,077.3	268.7
2004	58,792.5	1,443.1	327.6
2005	67,640.7	2,134.2	434.9
2006	2,734.3	169.6	30.9

C23 Yearly Nutrient Loading (Metric Tons)			
Date	T.Susp	TKN	TPO4
1991	1,809.2	289.9	54.8
1992	2,455.2	348.0	119.2
1993	2,726.6	181.4	60.7
1994	2,049.5	396.6	104.0
1995	2,394.9	434.6	144.9
1996	1,195.1	163.8	28.1
1997	626.6	170.1	35.1
1998	2,068.5	277.2	70.8
1999	8,717.2	326.3	122.7
2000	169.0	57.8	14.0
2001	1,450.0	224.3	74.3
2002	566.9	196.9	57.8
2003	1,044.1	249.9	80.9
2004	1,370.1	430.6	211.0
2005	5,011.0	536.7	150.1
2006	582.1	108.8	19.8

C24 Yearly Nutrient Loading (Metric Tons)			
Date	T.Susp	TKN	TPO4
1991	1,510.5	323.4	67.8
1992	898.3	258.0	61.5
1993	1,305.1	308.8	55.4
1994	1,393.5	382.2	68.0
1995	1,913.8	382.1	96.2
1996	731.3	174.6	26.0
1997	1,362.1	287.4	65.6
1998	1,359.4	368.5	65.8
1999	3,512.8	339.9	101.0
2000	139.0	71.6	18.7
2001	374.6	310.9	95.5
2002	323.3	238.9	60.9
2003	58.1	240.0	60.0
2004	709.9	437.5	167.8
2005	1,526.9	438.4	122.1
2006	360.7	79.2	16.9

These yearly totals show amazing quantities (hundreds and thousands of Metric Tons) of sediment and nutrient loading into the St. Lucie Estuary.   Most of the nutrient loading coming through S80 is the result of Lake Okeechobee loading from S308. For this reason, S308 loading is presented below:

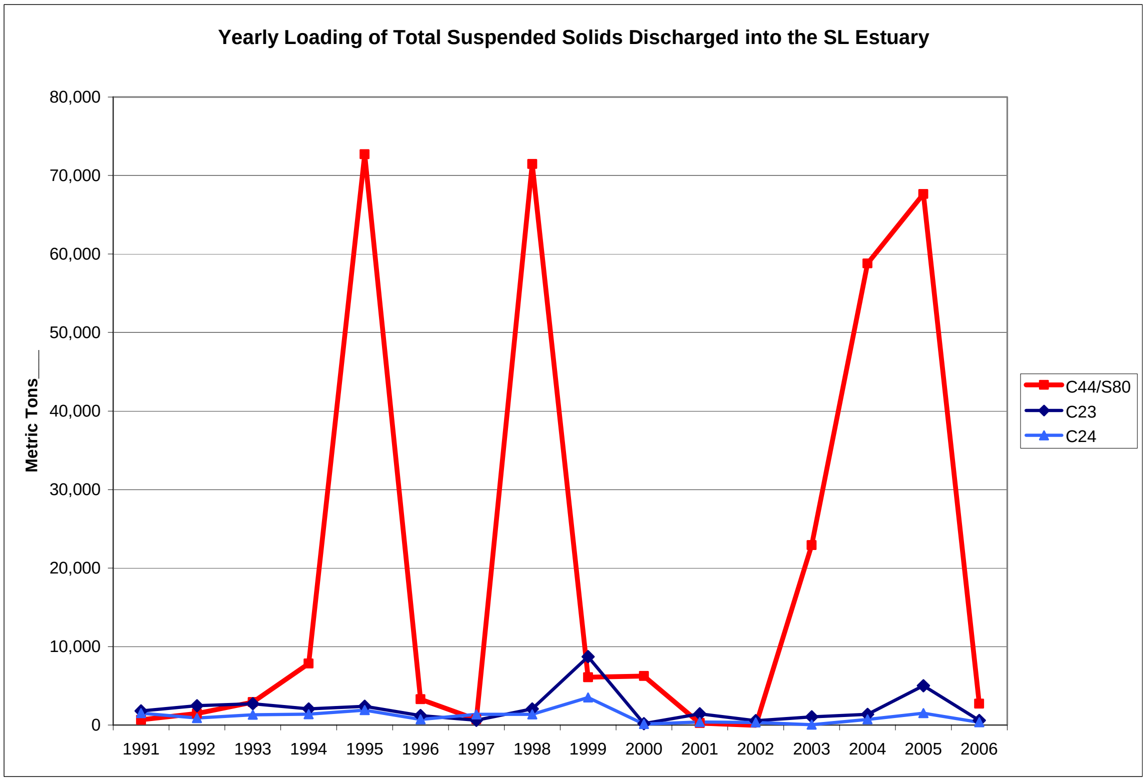
S308 Yearly Loading				
Date	**Discharges**	**T.Susp**	**TKN**	**TPO4**
	Billions of Gals	**Metric Tons**	**Metric Tons**	**Metric Tons**
1991	-10	-913	-13	-57
1992	18	2,141	90	8
1993	67	14,550	440	0
1994	84	8,348	517	41
1995	328	31,693	1,558	413
1996	63	5,955	303	31
1997	36	4,209	231	16
1998	345	119,944	2,333	307
1999	64	22,412	389	48
2000	51	12,543	347	38
2001	-23	6,765	-109	-23
2002	49	5,998	269	21
2003	179	25,676	929	108
2004	190	54,942	1,048	167
2005	304	83,551	1,822	291
2006	25	6,696	140	24

Total Suspended Solids Loading

The next contributor to pollution to be analyzed is the total suspended solids which are brought into the Estuary with the discharges. These suspended solids drop out of suspension primarily when the flow slows down in the south fork and middle estuary of the St. Lucie where the river widens. The suspended solids are nominally very small claylike particles that are in a colloidal suspension when they come into the Estuary from the fresh water canals. When this fresh water hits the brackish water, the colloidal suspension breaks down, the particles coagulate, and then they fall to the bottom of the Estuary. The silt buildup in the Estuary is nominally 2 to 6 feet thick. The muck or "ooze" is stirred by wave and boat action and is continually being re-suspended into the river waters, blocking out sunlight, and coating habitat and organisms like oysters and seagrasses with silt and debris.

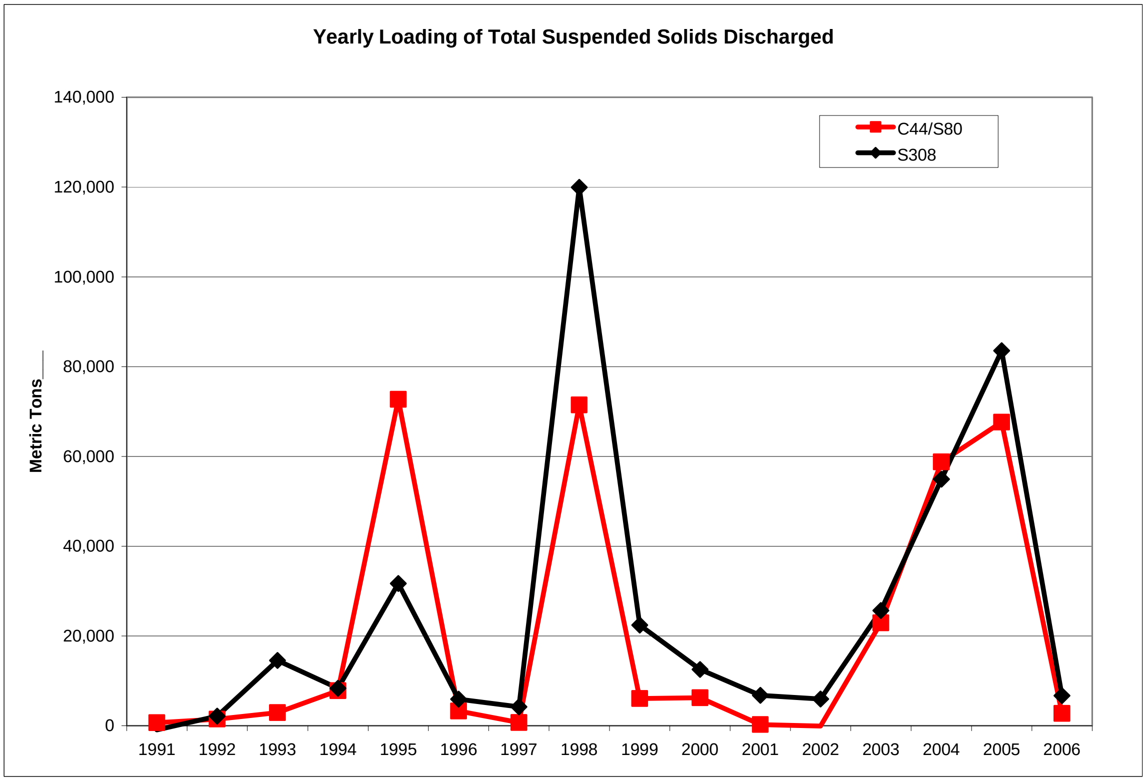
The jet-black muck at the bottom of the St. Lucie Estuary has the consistency of mayonnaise. It is very slippery and tends to form a gel-like blob similar to chocolate pudding. It is sticky and very difficult to clean up. And it has a foul odor.

The following graph shows the contributions to the silting of the Estuary from the three primary canals discharging into the Estuary.



The magnitude in tonnage is almost unbelievable for C44 discharges. Looking at 1998 and 2005, we see values of 70,000 metric tons of solids being deposited just from the C44 canal in one year. The other canals do not carry much sediment with them as seen by the low values of loading. Again, C44 is the biggest source of suspended solids loading to the Estuary. Approximately 86% of the total major canal derived solids are from C44.

If we compare the total suspended solid loading coming through S80 with the loading coming from S308, we see an almost one-to-one correlation.



This graph shows that the amount of silt coming into the C44 Canal from S308 is almost equal to the amount of silt leaving C44 at S80 and discharging into the St. Lucie Estuary. This also makes the point that Lake Okeechobee discharges are the primary contributor to the silting of the St. Lucie River. The high silt loading coming from Lake Okeechobee just flows on through to the St. Lucie Estuary.

Ref. 8 provided considerable information about the muck in the St. Lucie and its negative impact on the estuarine environment.

Specific points made in the report include the following:

- The rapid increase in sedimentation of muck sediments …. is mainly attributed to the construction of drainage canals that occurred in the last 100 years. These canals not only drained all the fine materials from wetland (swamps) to the St. Lucie Estuary but also transported organic and clay materials from agricultural fields to the water bodies.

- Large areas of muck sediments in the wide North and South Forks and the Middle Estuary exceed 15 feet in depth.

- Muck sediments are a problem within the St. Lucie Estuary for many reasons. They form a loose, flocculent cloud several feet think in some areas of the Estuary. During calm conditions, and especially during the summer months, this cloud can consume oxygen in the lower regions of the water column to the point that few aerobic organisms (a living thing with an oxygen-based metabolism) can survive.

- This cloud of flocculent sediments can consolidate during calm conditions or re-suspend when wind, wave or boating shear forces reach it. Re-suspension of muck sediments significantly increases turbidity and color in the waters, which restrict the growth of seagrasses.

- Muck sediments, when more consolidated under the uppermost flocculent layer, tend to become anaerobic due to high biochemical oxygen demand of the organic fractions, and tend to be very soft substrate. Even very deep sediments, when containing organic matter, continue to produce gas, reducing bulk density and subjecting the sediment column to hydrogen sulfide gas, among others. These chemical and physical properties preclude colonization by most desirable benthic organisms, resulting in large areas of the bottom of the Estuary being <u>a biological desert.</u>

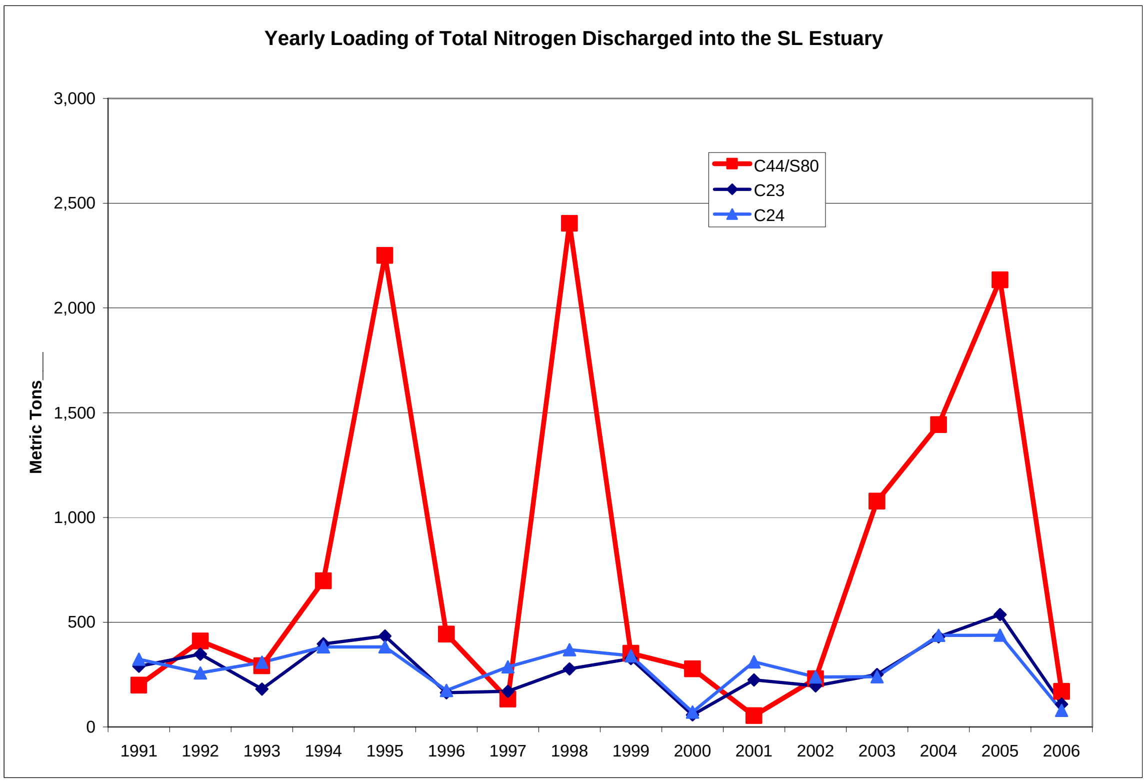
- The settling and consolidation tests indicate the material settles and consolidates at extremely low rates. … this sediment would be classified at the bottom of the least useful category of soils for any construction or structural purpose.

- 91% of this material was classified as silt and clay. Salt content was 24 parts per thousand. Repeated daily rinsing with distilled freshwater did not rapidly leach the salt out, suggesting it is tightly bound in a clay matrix.

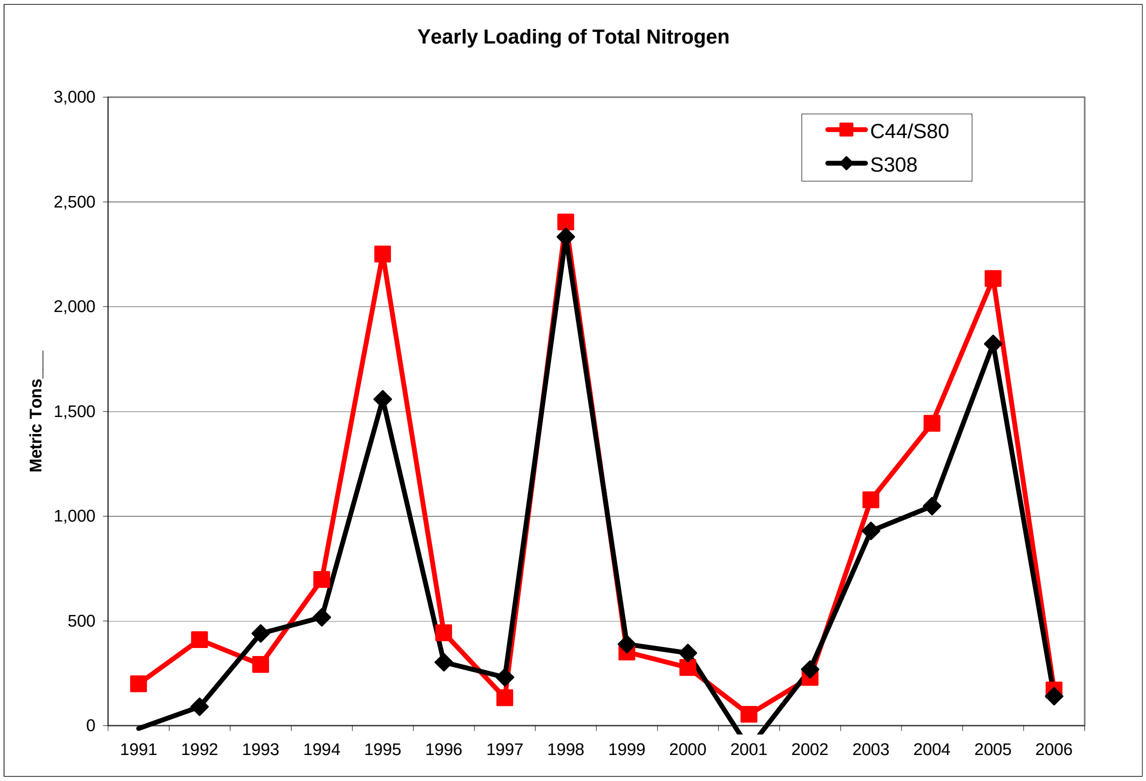
- Muck sediments are an important source of nutrient loading to the Estuary. … Aquatic plants are typically sensitive to lower amounts of nutrients than terrestrial plants, so it is reasonable to assume the muck sediments can supply more than adequate nutrients for algae growth when suspended. Also, benthic flux of nutrients is higher in summer than in winter. These may be important factors in algae blooms reported in the North fork of the St. Lucie.

Nitrogen and Phosphorous Loading

Nitrogen and Phosphorous are common nutrients which are also attributed to algae growth and algae blooms, some varieties of which can become toxic to human health. Again, hundreds and thousands of tons of these nutrients are discharged into the Estuary on a yearly basis and particularly when heavy flows come from Lake Okeechobee. Following the plotting routine presented in the silting section, we can show the yearly loading of nitrogen and phosphorous from the three major canals. Similarly, we can show how the C44 discharges through S80 are influenced by the inputs coming from Lake Okeechobee through S308. These are shown on the following graphs.



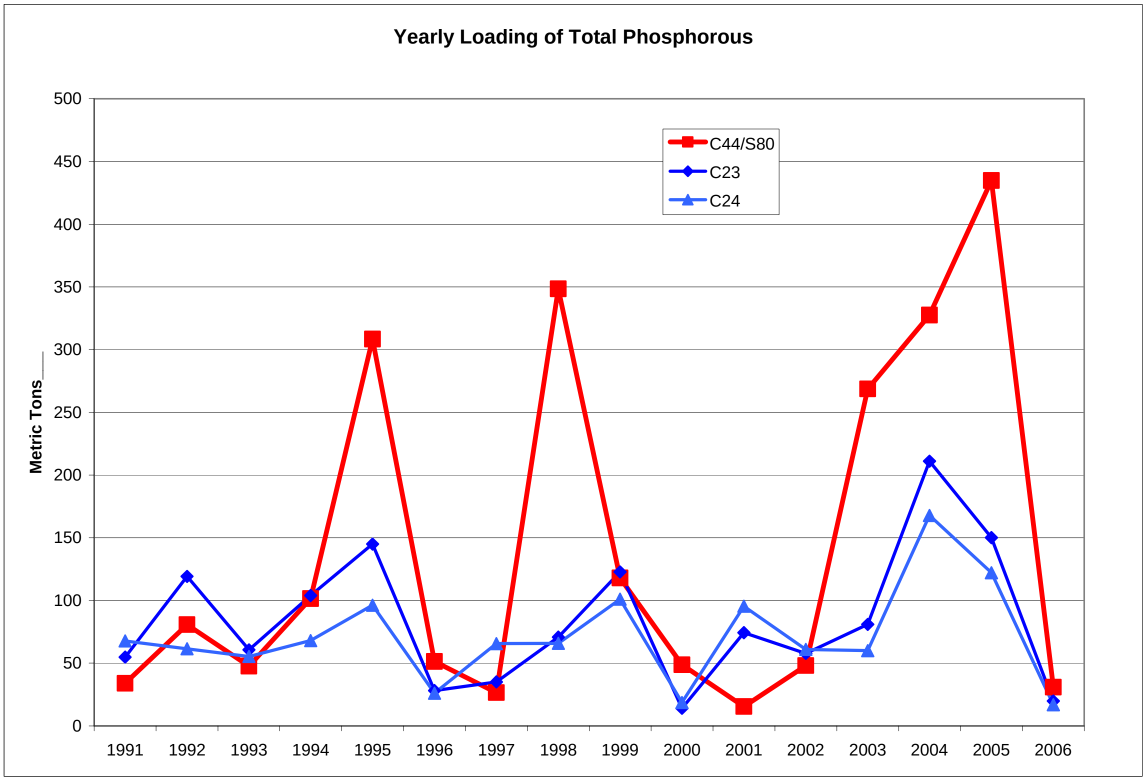
As was the case with the total suspended solids, nitrogen loading is primarily dominated by the C44 Canal discharges. The other canals (C23 and C24) show levels below 500 metric tons whereas the C44 discharges reach loads above 2000 metric tons.

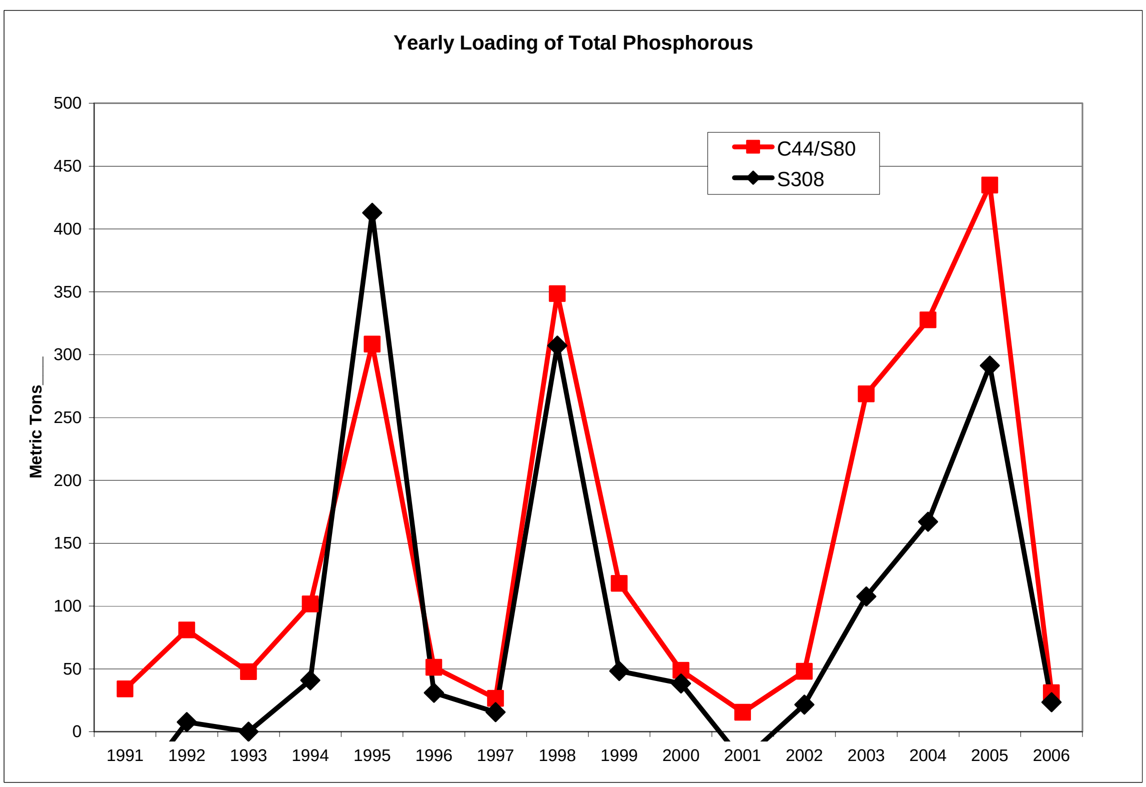


And by plotting the S308 and S80 nitrogen loading levels, we again see that the nitrogen coming into the C44 Canal from Lake Okeechobee just flows down through the canal, passes through S80, and on into the St. Lucie Estuary.

As such, Lake Okeechobee is seen to be the major contributor of nitrogen loading into the St. Lucie Estuary.

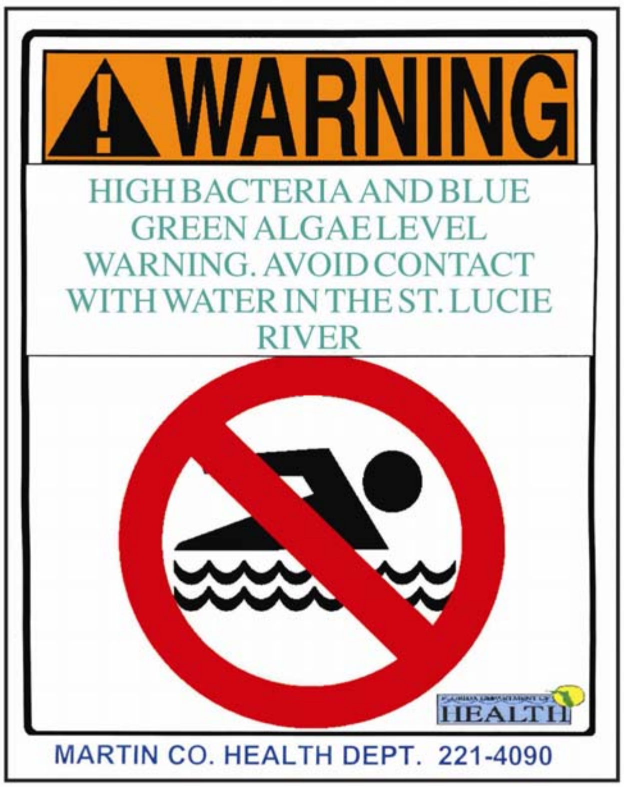
The following two graphs show the same trends with phosphorous loading with Lake Okeechobee again being the major contributor of phosphorous loading into the St. Lucie.


Yearly Loading of Total Phosphorous
Metric Tons
C44/S80
C23
C24
0
50
100
150
200
250
300
350
400
450
500
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006


Yearly Loading of Total Phosphorous
Metric Tons
C44/S80
S308
0
50
100
150
200
250
300
350
400
450
500
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

The previous graphs again show that hundreds and thousands of tons of these nutrients were discharged into the estuary and particularly when heavy flows came from Lake Okeechobee. In 2005 for example, 1800 Metric Tons of Nitrogen and 290 Metric Tons of Phosphorous were discharged from Lake Okeechobee. In comparison, the latest goal for Maximum Yearly Phosphorous Loading into the whole of Lake Okeechobee has been proposed at 105 Metric Tons. Discharges to our Estuary have been almost three times that value! The C44 Canal remains the greatest nutrient loading contributor among the three major canals discharging into the St. Lucie Estuary. And the data shows that the high nitrogen and phosphorous loading coming into the Estuary from C44 through S80 actually is merely a flow-thru of nutrients from Lake Okeechobee.

The problem with Nitrogen and Phosphorous is that they enhance algae growth and in extreme cases cause algae blooms. The St. Lucie estuary was hit with a massive toxic blue-green algae bloom in 2005 that closed the river to recreational use. The Martin County Health Department posted signs warning citizens to avoid contact with the water in the St. Lucie River. This brought great attention to the Estuary's problems and concern over nutrient loading.



CONCLUSIONS

Based on the calculations and illustrations presented in this report, it has been shown that Lake Okeechobee discharges into the St. Lucie Estuary by the US Army Corps of Engineers have caused considerable negative impact on the St. Lucie Estuary.

The following observations were made:

a.) Large quantities of water were released to the Estuary over the 2000-2006 timeframe by the US Corps of Engineers. Water coming through the C44 Canal contributed most of the discharge water to the Estuary of which 75% of S80 discharges came directly from Lake Okeechobee through S308. In 2005, Lake Okeechobee discharges more than doubled the amount of water (105% increase) that would have come into the Estuary from St. Lucie watershed alone.

b.) The high discharges of water from Lake Okeechobee by the Corps of Engineers significantly changed the character of the St. Lucie by changing it from a brackish Estuary to a near fresh body of water. It caused prolonged periods of extremely low salinity. In 2005, because of the high Lake Okeechobee releases, the Estuary salinity was below 15 ppt for more than 7 months, and for much of that time it was well below 10 ppt. A direct correlation between discharge rate and salinity shows a trend of higher discharge rates causing lower salinities in the Estuary. Very low salinities for prolonged times are expected to have had a very negative impact on oysters and seagrasses in the St. Lucie Estuary in the 2003-2005 timeframe.

c.) The discharge water coming from Lake Okeechobee carries with it considerable silt that is eventually deposited in the Estuary. The suspended solids carried by the water are very small and tend to stay in suspension for long times. The water clarity during high discharges was seen to reach Secchi depths of only 0.1 meters (3 inches of visibility) during high discharge periods. This is expected to have had negative impacts on fish and other wildlife such as birds and marine mammals. Also, because of the blocking of sunlight by the dirty water, seagrasses are expected to have been negatively impacted because they got very limited sunlight exposure during those times.

d.) In 2005, the silt loading from Lake Okeechobee was shown to reach levels of between 70,000 and 80,000 metric tons of total suspended solids. C44 Canal was shown to be the biggest contributor to the silting of the St. Lucie Estuary and the flow of sediments through S80 were shown to come from Lake Okeechobee. In 2005 alone, the amount of silt coming from C44 was 10 times that coming from the C23 and C24 canals combined. The silt that has been deposited in the Estuary continues to grow in depth with measured sediment thicknesses reported to be 2 to 6 feet deep throughout the Estuary and up to 15 feet deep in some areas. This silting was shown in Ref. 8 to have negative effects on the estuarine environment.

e.) In a manner similar to the silt loading, large quantities of nitrogen and phosphorous nutrients were shown to be carried into the Estuary by the discharges from Lake Okeechobee. When the US Army Corps of Engineers opens the gates to the S308 and S80 structures, they allow hundreds and thousands of tons of nitrogen and phosphorous to flow into the St. Lucie Estuary. In 2005, nitrogen loading from Lake Okeechobee through C44 was almost twice the loading from the rest of the watershed (C23 and C24 canals combined). In 2005, phosphorous loading amounts doubled because of Lake Okeechobee discharges. Nitrogen and phosphorous have been shown to enhance algae growth and have been targeted by the Department of Environmental Protection for reduction in the waters of the state and nation.