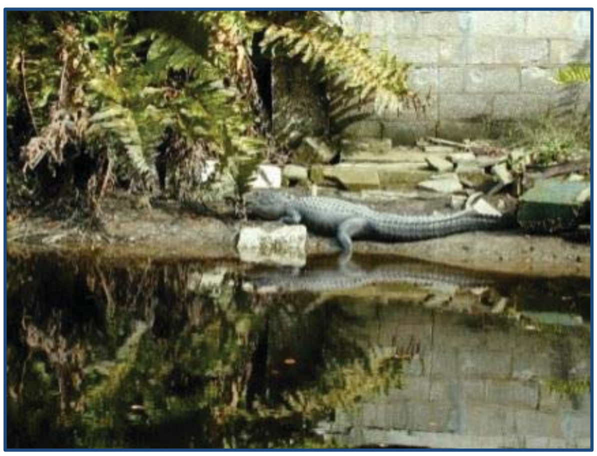
# A Hydrobiological Assessment of the Phased Implementation of Minimum Flows for the Lower Hillsborough River



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Southwest Florida
Water Management District

# A Hydrobiological Assessment of the Phased Implementation of Minimum Flows for the Lower Hillsborough River

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**April 24, 2015**

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## List of Acronyms, Abbreviations and Terms

| | |
|---|---|
| °C | degrees Celsius |
| cfs | cubic feet per second |
| City | City of Tampa |
| CPUE | catch-per-unit-effort |
| District | Southwest Florida Water Management District |
| DO | dissolved oxygen |
| EPCHC | Environmental Protection Commission of Hillsborough County |
| F.A.C. | Florida Administrative Code |
| FDEP | Florida Department of Environmental Protection |
| F.S. | Florida Statutes |
| FFWCC | Florida Fish and Wildlife Conservation Commission |
| FWRI | Florida Fish and Wildlife Research Institute |
| HBMP | Hydrobiological Monitoring Program |
| L or l | liter(s) |
| LAMFE | Laterally Averaged Model for Estuaries |
| m | meter(s) |
| MFLs | Minimum Flows and Levels |
| mgd | million gallons per day |
| NOx | nitrite + nitrate nitrogen |
| pcu | platinum-cobalt units |
| ppt | parts per thousand |
| PSU | practical salinity units |
| SWFWMD | Southwest Florida Water Management District |
| TBC | Tampa Bypass Canal |
| TBW | Tampa Bay Water |
| µg | microgram(s) |
| TN | total nitrogen |
| TP | total phosphorus |
| USF | University of South Florida |
| USGS | United States Geological Survey |

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# Executive Summary

The recovery strategy that was adopted with the minimum flow rule for the Lower Hillsborough River in 2007 requires that in 2013, and for each five-year period through 2023, the Southwest Florida Water Management District shall evaluate the hydrology, dissolved oxygen, salinity, temperature, pH and biologic results achieved from implementation of the recovery strategy for the previous five years, including the duration, frequency, and impacts of the adjusted minimum flows. This first five-year report addresses that objective by examining changes in the hydrobiological characteristics of the lower river in response to the minimum flows that were implemented between 2002 and 2013. These results are compared to data collected in the river prior to the implementation of minimum flows so that any changes in the river's hydrobiological characteristics due to minimum flows can be assessed. The report also discusses the status of either the current or projected use of four water sources that are identified in the recovery strategy to provide minimum flows to the Lower Hillsborough River.

The implementation of minimum flows for the Lower Hillsborough River, below the Hillsborough River Dam, began in the spring of 2002. Until 2008, minimum flows were comprised solely of diversions from Sulphur Springs, usually at a rate of 10 cfs. Beginning in 2008, diversions from Sulphur Springs were accompanied by freshwater releases from the Hillsborough River Reservoir / Tampa Bypass Canal (TBC) system. Beginning in the spring of 2012, total minimum flow rates from 18 to 27 cfs were achieved because modifications to the pumping facilities at Sulphur Springs allowed for the diversion of greater quantities of springflow to the base of the dam. The minimum flow rates achieved after the spring of 2012 met the minimum flows for the lower river on many days.

Modifications to the pumping facilities at Sulphur Springs in 2012 resulted in increased spring water salinity when water levels in the spring pool were lowered to induce springflow. The salinity of water from Sulphur Springs averaged 2.7 psu after the spring pool was lowered in 2012, compared to a mean value of 1.6 psu in previous years when water levels in the spring pool were maintained near normal operating levels. As a result, there were slight increases in mean and median salinity values at the salinity recorder closest to the dam after the spring of 2012. However, the variability of salinity was reduced, as greater minimum flow rates helped prevent the periodic occurrence of high salinity values in that area of the river.

A principal goal of the minimum flow rule for the Lower Hillsborough River is to extend a zone of oligohaline water (i.e., water with salinity < 5 psu) from the base of the Hillsborough River dam toward Sulphur Springs. The results of this study demonstrate the benefit of increased minimum flows for achieving that goal. Based on data from continuous recorders upstream of Sulphur Springs, it appears that minimum flow rates in the range of 23 to 26 cfs produce significantly lower and less variable salinity conditions compared to a minimum flow rate of 20 cfs. However, beginning about two kilometers below the dam, the benefits of increased minimum flows are primarily restricted to shallow waters, as pronounced vertical stratification occurs in river between Hannah's Whirl and Sulphur Springs. The data are scarce for rates of flow between 20 and 30 cfs, but the available information indicates that minimum flow rates in the range of 23 to 26 cfs are effective at producing salinity values < 5 psu in waters shallower than 1 to 2 meters in this reach of the river. However, at two meters depth and greater the salinity response to minimum flows is much weaker.

Measurements of dissolved oxygen (DO) concentrations indicate that minimum flows in the range of 22 to 25 cfs are effective at preventing hypoxic conditions (< 2.5 mg/l DO) upstream of Hannah's Whirl. From Hannah's Whirl to Sulphur Springs, improvements in DO concentrations are largely restricted to shallow depths, i.e., less than 1 to 2 meters. The persistence of hypoxia at deeper depths during higher rates of flow is likely related to the vertical salinity stratification that occurs in that part of the river.

The implementation of minimum flows using diversions from Sulphur Springs results in a moderation of water temperatures in the river immediately below the dam, with warmer temperatures in the winter and slightly cooler temperatures in the spring. There should be no negative effects, and possibly some positive ecological effects associated with temperature moderation in this reach of the river for cold-sensitive species such as snook. The implementation of minimum flows appeared to have only slight effects on pH in the river below the dam, which is not expected to have any negative effects on the biological communities in the lower river.

Color values near the dam have also been moderated following minimum flow implementation. The releases of reservoir water for minimum flows after 2008 increased color in the river near the dam; however, the color values are well within those expected for a healthy tidal river in the region.

Based on data collected at two long-term stations in the river monitored by the Environmental Protection Commission of Hillsborough County (EPCHC), the implementation of minimum flows has coincided with a marked reduction in total nitrogen concentrations above Sligh Avenue, with lowest values corresponding to minimum flow releases from reservoir combined with diversions from Sulphur Springs. Total nitrogen data collected by the District and Tampa Bay Water support these findings. A similar but less distinct reduction was observed for nitrate + nitrite nitrogen (NOx) concentrations, particularly at the higher minimum flow rates, due in part to releases of water from the reservoir which has lower NOx concentrations. The implementation of minimum flows also appears to have resulted in a reduction of both total and ortho-phosphorus concentrations in the river below the dam.

Additionally, the implementation of minimum flows has resulted in a marked reduction of chlorophyll *a* concentrations. The combined data from all agencies supported this finding and indicate lower and more stable chlorophyll *a* concentrations above Sulphur Springs, particularly at the higher minimum flow rates. It is presumed that the implementation of minimum flows may result in lower chlorophyll *a* concentrations through improving flushing near the dam.

Biological communities that were assessed in the lower river included the plankton catch of invertebrates and the early life stages of fishes, larger invertebrates and fish captured by seines, and benthic macroinvertebrates collected from the river bottom. The abundance and taxonomic richness of the plankton community was not adversely affected by implementation of minimum flows; however, diversity declined, likely as a result of decreased salinities. Changes in several planktonic indicator taxa were also observed in the river below the dam as minimum flows increased. These changes included reduced occurrence and abundance of species associated with mesohaline or polyhaline conditions that presumably moved downstream in response to minimum flow releases.

There were also changes in the nekton community that accompanied the implementation of minimum flows. The total abundance of individuals collected by seines decreased with increasing minimum flows; however upstream movement and crowding of certain estuarine taxa near the dam during low flow periods could partially explain this trend. Changes in the taxonomic richness and diversity were less clear. High richness and diversity values occurred during the middle minimum flow period, when diversions of spring water alone were introduced at the base of the dam. As minimum flows were implemented, there were significant increases in the number of freshwater fish in the segments above Sulphur Spring, indicating that minimum flows have resulted in improved conditions for this component of the fish community in the dry season. Similarly, a number of benthic macroinvertebrate species that are characteristic of freshwater and low salinity waters increased with the implementation of minimum flows, particularly with the release of reservoir water that accompanied the diversion of water from Sulphur Springs after 2008.

In general, the findings of the study supported the validity of the minimum flows that were adopted for the Lower Hillsborough River in 2007. Those minimum flows, without the adjustment (flow decrease) that is required for low upstream flows at Zephyrhills, can range between 20 and 27 cfs depending on how the freshwater equivalent component of the adopted minimum flows is applied. The minimum flows for the lower river are expressed as seasonal freshwater equivalent flows of 20 and 24 cfs to account for use of water from Sulphur Springs, which is slightly brackish, as a source for the minimum flows. The “freshwater equivalent” term means water that has a salinity concentration of 0.0 ppt for modeling purposes. Based on application of the District’s two-dimensional mechanistic salinity model of the Lower Hillsborough River, the mixture of water used for minimum flows should result in volumes of water with salinity <5 psu upstream of Sulphur Springs that are equivalent to seasonally releasing either 20 or 24 cfs of fresh water at the base of the dam. The findings of this study indicate that minimum flows in the range of 23 to 26 cfs produce more consistent and beneficial results than a minimum flow rate of 20 cfs or less. In that regard, the adjustment for low flows at the Zephyrhills gage, which resulted in minimum flow rates as low as 15 cfs during the course of the study, represents a reduction in the effectiveness of the minimum flows. However, the flow adjustment criteria were developed because it was deemed unreasonable to expect higher freshwater equivalent flow rates during extreme drought conditions that are not related to water withdrawals. In addition, the biological effects of the low flow adjustment depend on the duration of its implementation.

The results of this study indicate that increased diversions from Sulphur Springs benefit the lower river by allowing for greater minimum flow rates. However, the diversion of greater quantities of water from Sulphur Springs to the base of the dam has contributed to the growth of filamentous algae in the spring run. The District is currently investigating relationships between flows, current velocities and growth of filamentous algae in the spring run. If the reduction of the algal mats in the spring run becomes a criterion for management, consideration could be given to manually removing the algae if it allows for more spring water to be used for minimum flow diversions to the base of the dam.

In conjunction with this minimum flows evaluation, the District is assessing output from additional hydrodynamic salinity modeling runs of the Lower Hillsborough River, using the same two-dimensional model that provided much of the technical basis for the minimum flows that were adopted in 2007. This updated modeling effort includes simulation of changes in the volume of water less than 5 psu salinity associated with the minimum flows that were implemented between 2002 and 2013. These modeling results can then be compared to the findings of this minimum flows evaluation to further assess the effectiveness of the minimum flows implemented to date. Also, the updated modeling effort will include simulations of increased diversions of higher salinity water from Sulphur Springs to the base of the dam. Such modeling results may aid the identification of total rates of minimum flows needed to address the freshwater equivalent consideration based on various combinations of diverted quantities from Sulphur Springs and freshwater releases from the reservoir.

This study recommends continuation of the existing salinity and water quality monitoring programs for the lower river, with the possible addition of two additional water quality sites between the dam and Sulphur Springs. It is also recommended there be increased monitoring of dissolved oxygen (DO) concentrations, particularly between Hannah's Whirl and Sulphur Springs. Continuous (e.g., hourly) DO recorders should be deployed at two locations in this reach of the river, including one that is currently operated by the EPCHC. Because of the role that salinity stratification plays in the occurrence of low DO concentrations in this part of the river, preliminary analyses should be conducted to examine the feasibility of mixing devices to vertically circulate the water column and improve aeration between Hannah's Whirl and Sulphur Springs.

Recommendations are also made for two sampling events for benthic macroinvertebrates and fish sampled by seine, with an option of a third sampling event pending the findings of the first two. Sampling for both communities should be conducted after the prolonged implementation of minimum flows in the dry season, with a higher density of samples spatially distributed between Sulphur Springs and the dam.

The Lower Hillsborough River recovery strategy identifies four water sources that are to be used to provide minimum flows to the Lower Hillsborough River: Sulphur Springs, Blue Sink, Morris Bridge Sink and the Hillsborough River Reservoir / TBC system. Use of these sources has and will require implementation of projects involving installation and construction of pumps and piping for conveying water from each source to the base of the dam. Modified weir and pumping facilities at Sulphur Springs were completed in 2012 and have allowed higher diversion rates (up to 20.6 cfs) from the spring source to the base of the dam. A water use application has been issued to the City of Tampa to use Blue Sink for minimum flow diversions to the base of the dam at a maximum daily rate of 2 million gallons per day (mgd), equivalent to 3.1 cfs. The District has completed an evaluation of projected minimum flow withdrawals from Morris Bridge Sink and will be submitting a water use permit application to the Florida Department of Environmental Protection to withdraw up to 3.9 mgd from that sink to provide minimum flows to the Lower Hillsborough River. Temporary pumping facilities have been in operation on the TBC since 2008, providing up 11 cfs of minimum flow water from the canal to the reservoir, from where 75% of this water is released to the lower river for minimum flows. The District and the City of Tampa will be entering into a cooperative agreement to construct permanent pumping facilities on the middle pool of the TBC and at the reservoir spillway to provide minimum flows. The water transmission pipeline identified in the recovery strategy that was to run between the middle pool of the TBC to the City of Tampa water treatment plant with a spur to the dam from minimum flow releases was subject to independent peer review. The review concluded that the water savings from the pipeline would be very small, thus the pipeline will not be constructed.

# 1 Purpose of the Minimum Flows Evaluation

## 1.1 Introduction

The purpose of this report is to evaluate the hydrobiological effects of minimum flows that have been adopted and gradually implemented for the Lower Hillsborough River. The Southwest Florida Water Management District (SWFWMD or District) approved minimum flow rules for the Lower Hillsborough River in 1999 and adopted rules for the system into its Water Levels and Rates of Flow Rules in 2000. These original minimum flow rules specified that 10 cubic feet per second (cfs) of flow be supplied to the base of the Hillsborough River Dam and allowed diversions from Sulphur Springs to be used for that purpose. Diversions of water from Sulphur Springs to meet minimum flows began in the spring of 2002.

The minimum flow rules adopted in 2000 specified that minimum flows for the lower river be reevaluated within a five-year time frame. Accordingly, a new minimum flow study of the Lower Hillsborough River was performed (SWFWMD 2006) and revised minimum flow rules were adopted for the lower river in 2007. The current minimum flow rule (adopted in 2007) requires minimum flows of 20 or 24 cfs at the base of the dam depending on the month of the year. The current minimum flow rules for the Lower Hillsborough River reads as follows in the District's 40D-8 Water Levels and Rates of Flow Rules within the Florida Administrative Code (F.A.C.):

***40D-8.041 Minimum Flows.***

*(1) Minimum Flows for the Lower Hillsborough River.*

*(a) For the purposes of Minimum Flows, the Lower Hillsborough River is defined as the River downstream of Fletcher Avenue. A tributary of the Lower Hillsborough River is Sulphur Springs, an artesian spring which enters the River via a short spring run at a point 2.2 miles downstream of the City's dam.*

*(b) The Minimum Flows for the Lower Hillsborough River are based on extending a salinity range less than 5 ppt from the Hillsborough River Dam toward Sulphur Springs. The Minimum Flows for the Lower Hillsborough River are 20 cubic feet per second ("cfs") freshwater equivalent from July 1 through March 31 and 24 cfs fresh water equivalent from April 1 through June 30 at the base of the dam as adjusted based on a proportionate amount that flow at the United States Geological Survey Gauge No. 0203000 near Zephyrhills, Florida ("Gauge") is below 58 cfs. The adjustment is that for each one cfs that Hillsborough River flow at the Gauge is below 58 cfs, when 20 cfs freshwater equivalent is otherwise required, the Minimum Flow is adjusted by reducing it by 0.35 cfs; when 24 cfs freshwater equivalent is otherwise required, the Minimum Flow is adjusted by reducing it by 0.40 cfs. For purposes of this paragraph 40D-8.041(1)(b), F.A.C., freshwater equivalent means water that has a salinity concentration of 0.0 ppt for modeling purposes.*

The minimum flows for the lower river are expressed as freshwater equivalents to account for use of water from Sulphur Springs, which is slightly brackish, as a source for helping meet minimum flows. The freshwater equivalent term means that based on application of the District's two-dimensional mechanistic salinity model of the Lower Hillsborough River, the mixture of water that is used for minimum flows should result in volumes of water with salinity <5 psu upstream of Sulphur Springs that are equivalent to seasonally releasing either 20 or 24 cfs of fresh water at the base of the dam. The 20 cfs value is applied to the months July through March and the 24 cfs value is applied to the months April through June. Within both periods, the minimum flows may be periodically reduced based on the occurrence of low flows in the river as indicated by flows at the upstream Hillsborough River near Zephyrhills gage. This low flow adjustment was developed because it was deemed unreasonable to expect freshwater equivalent flow rates during extreme drought conditions not related to water withdrawals.

## 1.2 The minimum flows recovery strategy for the Lower Hillsborough River and the phased implementation of minimum flows

Because the lower river was not meeting minimum flows adopted in 2007, a recovery strategy to meet the minimum flows was adopted along with the revised minimum flow rule. The text of the recovery strategy taken from Chapter 40D-80 of the District's rules is included as Appendix 1A to this report. Four water sources that can be used to provide minimum flows to the Lower Hillsborough River are identified in the strategy: Sulphur Springs, Blue Sink, Morris Bridge Sink and the Tampa Bypass Canal (TBC). Use of these sources has required or will require feasibility assessments and projects involving installation or construction of pumps and piping necessary for conveying water from each source to the base of the Hillsborough River Dam. Key components of these projects involving changes to the weirs and pumping facilities at Sulphur Springs to increase diversion of spring water to the base of the dam were completed in the spring of 2012. Facilities to pump water from Blue Sink and Morris Bridge Sink for release to the base of the dam have not yet been constructed. Diversions of water for the TBC to the Hillsborough River Reservoir and release of that water as minimum flows to the Lower Hillsborough River have been implemented since 2008.

Use of source water from the Sulphur Springs and the TBC has provided an informative data base on which to examine changes in the physical, chemical, and biological characteristics of the lower river over an eleven-year period during which minimum flows have gradually increased. As will be described in the following chapter, the minimum flows for the lower river have been met on many days since the spring of 2012.

The recovery strategy specifies that the District shall evaluate the results achieved from implementation of the minimum flows. Paragraph 9(h) of the recovery strategy states:

*In 2013, and for each five-year period through 2023, the District shall evaluate the hydrology, dissolved oxygen, salinity, temperature, pH and biologic results achieved from implementation of the recovery strategy for the prior five years, including the duration, frequency and impacts of the adjusted minimum flow as described in paragraph 40D-8.041(1)(b), F.A.C. As part of the evaluation, the District* *will assess the recording systems used to monitor these parameters. The District shall also monitor and evaluate the effect the Recovery Strategy is having on water levels in the Hillsborough River above the City's dam to at least Fletcher Avenue. The District will evaluate all projects described in this Recovery Strategy relative to their potential to cause unacceptable adverse impacts prior to their implementation.*

This report addresses these objectives except for those stated in the last sentence of this paragraph. Evaluations of the projects described in the recover stratgegy relative to their potential to cause unaccepatble adverse impacts prior to their implementation have been or are being assesed as part of other efforts which are described in corresponding documents (City of Tampa 2013, SWFWMD 2013, SWFWMD 2015 in prep).

## 1.3 Emphasis of this report

In this report, physicochemical and biological data from the Lower Hillsborough River are analyzed to investigate any changes in river's ecological characteristics that have occurred over the period of minimum flow implementation. Additionally, the reponse of these same variables are examined in relation to the different minimum flow rates that have been implemented to date. The entire period of minimum flow implementation is examined in this first five-year report. Data are also included for the period prior to minimum flow implementation so that the changes in ecological characteristics of the lower river can be compared to conditions prior to the implementation of minimum flows. This long-term data base provides valuable information regarding changes in the ecological charateristics of the lower river that have resulted from the gradual increase in minimum flow rates implemented to date.

The content of the remaining chapters of this report is as follows. Chapter 2 provides a hydroloical characterization of theHillsborough River / Tampa Bypass Canal system, including how often minimum flows have been in effect and the minimum flow rates that have been implemented since 2002. Chapter 3 describes the analytical methods utilized in the report. Chapters 4 through 8 describe changes over time and relationships with flow for the following variables; salinity, dissolved oxygen, water temperature, pH, water chemistry (color, nutrients) and chlorophyll *a*. The response of three biological communites in the river; fish and invertebrate plankton; free swimming fishes and invertebrates, and bentic macroinvertebrates are examained in Chapters 9 through 11. The status of the water sources identified to provide minimum flows to the Lower Hillsborough River is described in Chapter 12. A synthesis of the reports findings and and assessment of the recording sytems and other data collection programs to monitor the effects of the minimum flows are presented in Chapter 13. The report concludes with the Literature Cited. Appendices for this report are provided in a separate document.

## 2 Hydrologic Characteristics of the Hillsborough River / Tampa Bypass Canal System in Relation to Minimum Flows for the Lower River

### 2.1 Watershed overview

The Hillsborough River watershed, which covers approximately 675 square miles ($mi^2$) in Hillsborough and Pasco counties, comprises the largest river drainage basin that flows to Tampa Bay. The river originates in the Green Swamp and flows approximately 55 miles in a generally southwesterly direction through the cities of Temple Terrace and Tampa to the mouth of the river in downtown Tampa (Figure 2-1). The river discharges into Hillsborough Bay, which is the most northeastern lobe of Tampa Bay.

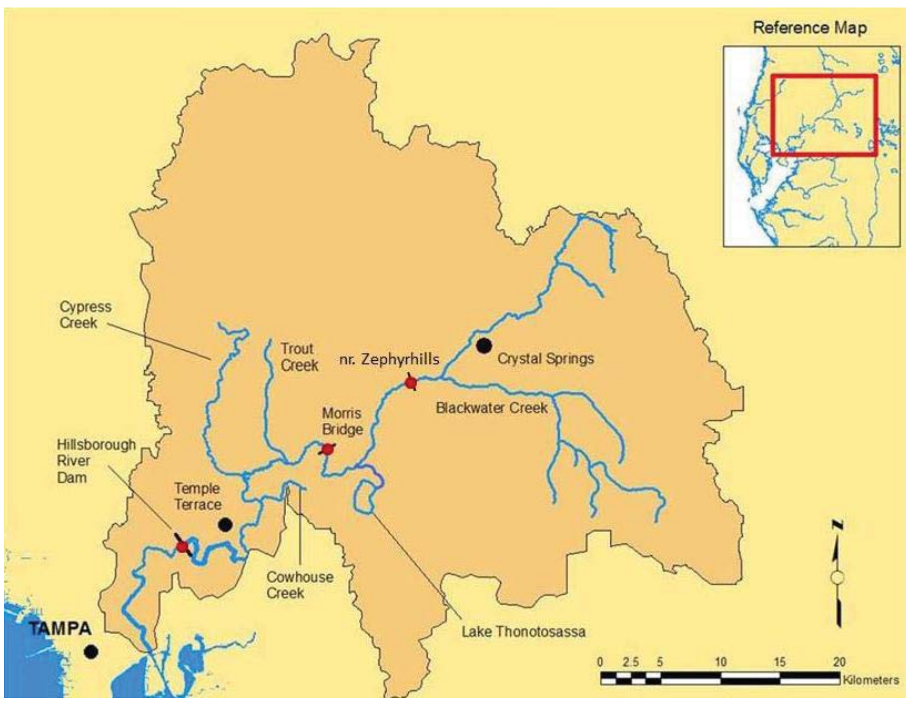


**Figure 2-1. Hillsborough River watershed showing location of Crystal Springs and USGS gages near Zephyrhills, Morris Bridge, and at the Hillsborough River Dam (modified from SWFWMD 2006).**

The river has been impounded near the site of the present Hillsborough River dam, about 10 miles upstream of the river mouth in the City of Tampa, for over one hundred years. The current dam was constructed in 1944, though the gates at the dam have undergone periodic modifications. The reservoir created by the dam has been used for public water supply by the City of Tampa Water Department since the 1920s, utilizing a water treatment plant located on the south bank of the reservoir. Backwater effects of the reservoir extend over 15 miles upstream of the dam through the City of Temple Terrace to near Interstate 75. The reach of the river from the dam to Fletcher Avenue is referred to as the Middle

Hillsborough River. The reach of the river below the Hillsborough Dam is referred to as the Lower Hillsborough River, which is the principal subject of this minimum flows evaluation.

The U.S. Geological Survey (USGS) monitors water levels and discharge over the dam at the Hillsborough River near Tampa gage site. Water levels are also monitored at the USGS Hillsborough River at Fowler Avenue near Temple Terrace site  about 9.8 miles upstream from the dam. There are two principal streamflow gages on the main channel of the river upstream of the dam. The USGS gage Hillsborough River near Zephyrhills is located approximately 40 miles upstream of the mouth of the river in Hillsborough River State Park. The average flow for this gage based on daily records dating back to 1939 is 235 cfs. The other gage, Hillsborough River at Morris Bridge, is approximately 29 miles upstream of the river mouth. The average flow at this gage since 1972 is 250 cfs.

Major tributaries to the river upstream of the Hillsborough River dam are Crystal Springs, Blackwater Creek, Trout Creek and Cypress Creek. During the dry season, the majority of baseflow in the river comes from Crystal Springs, a second order spring near the headwater region of the river in Pasco County (Figure 2-1). The average flow for Crystal Springs for the years 2002 to 2013 was 45 cfs. Blackwater Creek, which is the largest tributary to the river, flows to the river between the Zephyrhills and Morris Bridge gages. Downstream of Morris Bridge, the two main tributaries to the river are Cypress Creek and Trout Creek. The USGS operates streamflow gages on both of these tributaries. The combined drainage area covered by these two gages plus the gage on the river at Morris Bridge Gage totals 558 square miles, or approximately 86% percent of the drainage area to the Hillsborough River above the dam.

## 2.2 Construction of the Tampa Bypass Canal

A significant modification of the Hillsborough River watershed was the construction of the Tampa Bypass Canal, which was completed in 1981 to divert flood waters from the river around the cities of Tampa and Temple Terrace. A map of the Lower and Middle Hillsborough River and the TBC is shown in Figure 2-2. The uppermost reaches of the TBC intersect the river upstream of Fletcher Avenue (not shown in Figure 2-2). Structure S-155 is located there on the river channel, and during times of very high flow, this structure is closed and flow from the river is routed through the TBC to McKay Bay, a sub-unit of Hillsborough Bay. The TBC is also connected to the Hillsborough River Reservoir via the Harney Canal, which is a lateral canal that extends from the TBC to the reservoir about six miles upstream of the dam. Flows in the river can be diverted from the reservoir to the TBC via the Harney Canal through Structure S-161. The diversion of moderately high flows through the Harney Canal is fairly frequent, occurring during the wet season of most years. In contrast, the diversion of flood flows from the river via the closing of Structure S-155 is infrequent, and has only been implemented four times during floods associated with hurricanes or tropical storms during 1985, 1988 and 2004 and during very high flows during the El Niño winter of 1997-1998.

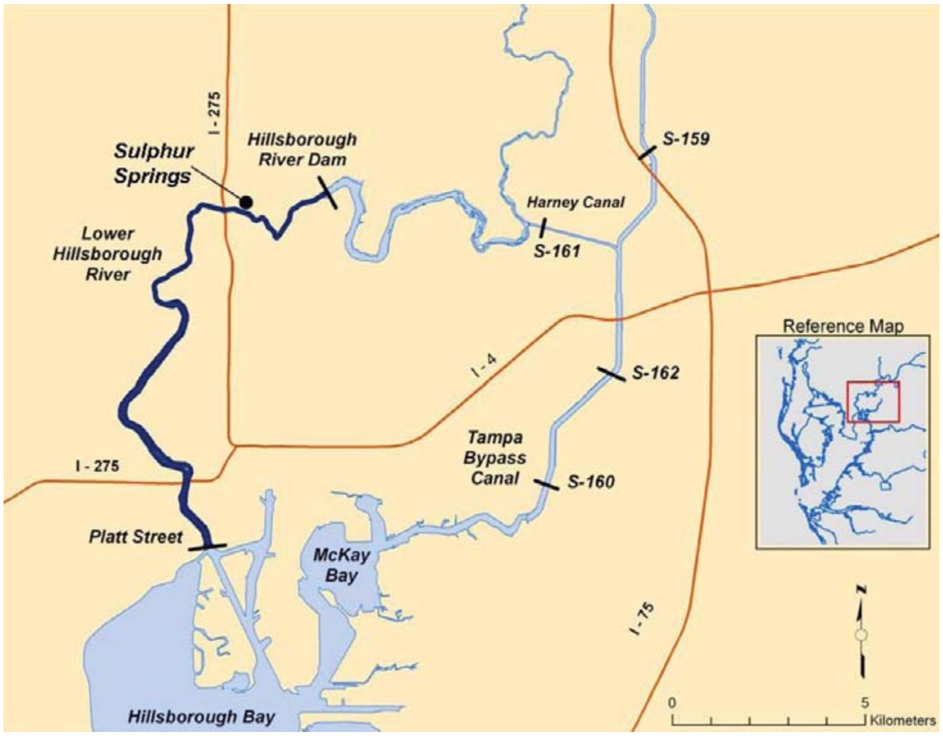


**Figure 2-2. Map of the Lower Hillsborough River and the Tampa Bypass Canal including the Harney Canal. Uppermost portion of the Tampa Bypass Canal not shown.**

An important factor concerning the TBC is that excavation of the canal resulted in cutting into the confining bed that separates the Upper Florida Aquifer from the overlying surficial aquifer, and in several places, breached the Upper Floridan aquifer (Geraghty and Miller, Inc. 1982. Knutilla and Corral 1984). This resulted in groundwater discharge to the canal between structures S-159 and S-160, which lowered the potentiometric surface of the Upper Floridan aquifer near the canal and eliminated flow from two springs in the Harney Flats area. As a result of this development, Structure S-162 on the TBC was constructed to maintain higher surface water levels in the middle pool of the canal to partially reduce the groundwater discharge to the canal (Motz, 1975). Knutilla and Coral (1984) analyzed data from the late 1970s to the early 1980s and estimated that average groundwater discharge to the canal was approximately 31 cfs (equivalent to 20 million gallons per day). However, groundwater discharge to the canal varies with hydrologic conditions and was less in several very dry years that occurred after that study period.

## 2.3 Water supply use from the Hillsborough River Reservoir, the Tampa Bypass Canal, and Sulphur Springs

Withdrawals from the Hillsborough River Reservoir by the City of Tampa Water Department are regulated under water use permit issued by the District that was most recently renewed in 2004. This permit allows an annual average withdrawal quantity that cannot exceed a rate of 82 million gallons per day (mgd) and a maximum day withdrawal rate of 120 mgd. The 2004 permit renewal increased the maximum day quantity from 104 to 120 mgd to allow for the increased of Aquifer Storage Recovery facilities by the City to store water in the Upper Florida aquifer in the wet season for subsequent withdrawal and use in the dry season. An important modification of the City of Tampa's water use from the reservoir also occurred in the 1980s, when augmentation of reservoir with water pumped from the TBC first began. Because the construction of the TBC greatly increased groundwater discharge to the canal, it was concluded that pumpage from the TBC could be used to augment the water supplies available from the reservoir. Pumpage from the TBC to the reservoir began in 1985 by utilizing by a temporary pumping facility that pumped water from the Harney Canal around Structure S-161 into the reservoir. This temporary pump was replaced by the current pumping facility at Structure S-161 in 1992.

Withdrawals from the canal are regulated under a water use permit from the District that allows an average annual pumpage rate that cannot exceed a rate of 20 mgd (31 cfs) and a peak monthly quantity of 40 mgd (62 cfs). Although this water use permit is held by TBW, the City of Tampa Water Department determines the timing and rate of the daily pumping rates from the canal to the reservoir. Withdrawals from the TBC to augment the reservoir can occur when water levels in the reservoir fall below the elevation of the crest of the dam spillway (22.5 feet). However, withdrawals from the Harney Canal must not cause water levels in the middle pool of the canal to fall below regulatory levels that are based on maintaining acceptable head differences between the middle pool and the reservoir.

In 1999, a water use permit was issued to TBW to also withdraw water from the TBC for potable water supply. Withdrawals from either the middle or lower pool of the TBC are diverted to a water treatment plant near the eastern shore of the lower pool that was constructed in 2002. The permit for TBW is structured so water can be obtained directly from the TBC, or during times of relatively high flow, water can be diverted from the Hillsborough River Reservoir through the Harney Canal to the TBC where TBW can withdraw the diverted river flows. Under this scenario, diversions from the reservoir to the TBC for potable supply can occur when flows at the Hillsborough River dam are above 100 cfs. A graduated diversion schedule is then employed, where 0% up to40% of flow from the river can be diverted based on the rate of flow at the dam. The current permitted quantities for total withdrawals by TBW from the river and the TBC are an average annual rate of 85 mgd (132 cfs) and maximum day rate of 258 mgd (399 cfs). Withdrawals from the combined river/canal system by TBW for the years 2002 to 2013 have averaged 33.3 mgd (52 cfs), with the highest average yearly withdrawal rate of 60.4 mgd (93 cfs) occurring in 2005.

A hydrograph of monthly potable supply withdrawals from the Hillsborough River Reservoir by the City of Tampa for the period 1955 to 2012 is shown in Figure 2-3. These withdrawals include any water pumped from the TBC to the reservoir for potable supply. Water supply withdrawals by the City have increased over time, from monthly values ranging primarily between 20 to 30 mgd in the 1950s to monthly pumpage rates frequently over 70 mgd in recent years, with lower pumpage rates occurring during drought years such as 2000, 2001, and 2009. Based on calendar years, the highest average pumpage rate from the reservoir was 79.4 mgd in the year 2005. Monthly values of augmentation of the reservoir from the TBC for the period 1985-2012 are shown in Figure 2-4. Average monthly pumpage rates of over 35 mgd have occurred on three occasions. The highest yearly average pumpage rate from the TBC for reservoir augmentation (23.2 mgd) occurred during the year 2000.

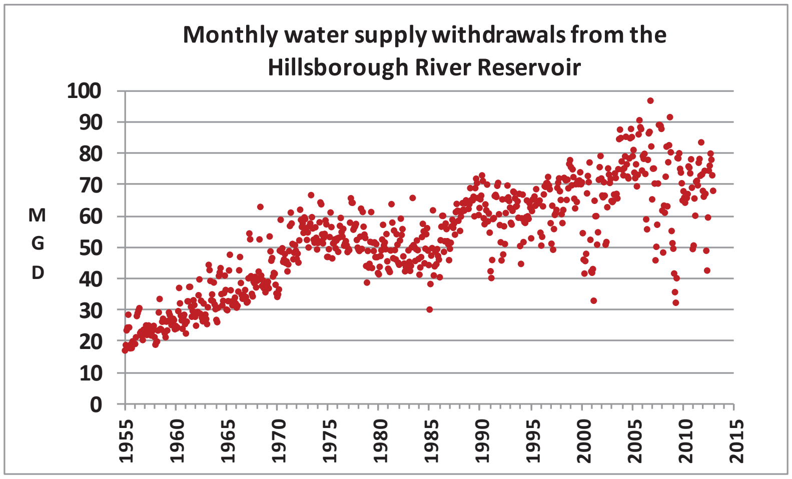


**Figure 2-3. Mean monthly water supply withdrawals from the Hillsborough River Reservoir by the City of Tampa for the period 1955 to 2012.**

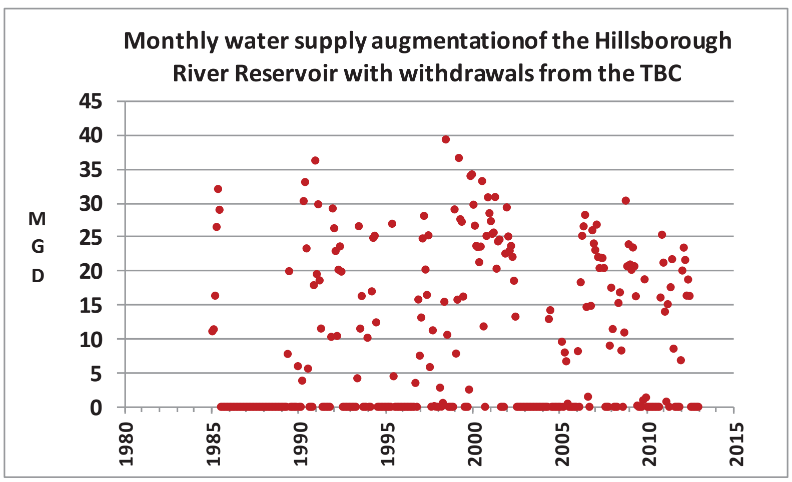


**Figure 2-4. Montly mean values for augmentation of water supplies in the Hillsborough River Reservoir with withdrawals of water from the middle pool of the Tampa Bypass Canal.**

The City of Tampa is also permitted to augment water supplies in the reservoir with diversions from Sulphur Springs, which discharges to the channel of the Lower Hillsborough River about 2.2 miles downstream of the Hillsborough River dam. A pipe to transmit flow from Sulphur Springs to the reservoir has been in place since the mid-1960s. As part of their permit for reservoir withdrawals, the City can withdraw an annual average of 10 mgd from the spring and a maximum daily quantity of 20 mgd, which frequently equals the total flow of the spring in the dry season. However, as will be discussed further in this report, the discharge from Sulphur Springs is highly mineralized and exceeds Class I potable water quality standards for certain constituents (SWFWMD 2004). Therefore, the City of

Tampa has diverted water from Sulphur Springs for potable supply only during times of water shortage, relying on blending of the spring water with water in the reservoir to not exceed potable water supply standards in their withdrawals from the reservoir.

A hydrograph of monthly pumpage rates from Sulphur Springs to the reservoir is shown in Figure 2-5 for period 1985 – 2012. The highest pumpage rates occurred during the droughts of 1985 and 2000 to 2001. Withdrawals from Sulphur Springs are also included in the total pumpage from the reservoir (Figure 2-3), which shows the net withdrawals from the reservoir by the City after augmentation from the TBC and Sulphur Springs.

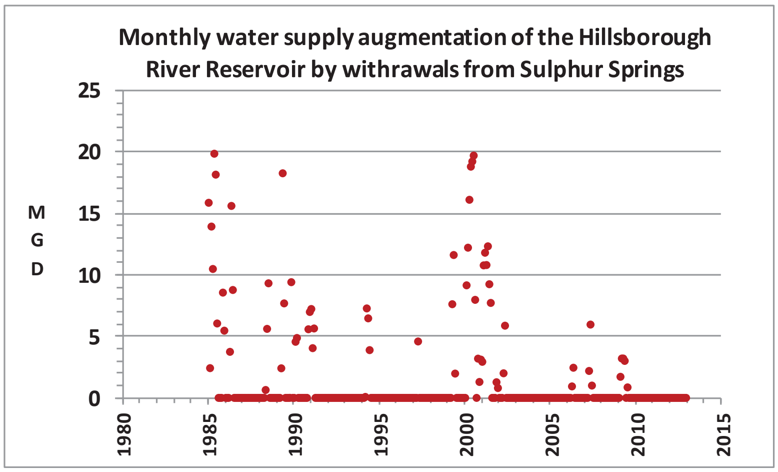


**Figure 2-5. Monthly mean values for augmentation of water supplies in the Hillsborough River Reservoir with withdrawals from Sulphur Springs.**

Another factor that has contributed to reduced pumpage from the spring in recent years has been the adoption of minimum flows for Sulphur Springs and the Lower Hillsborough River. As discussed in more detail in Section 2.5.1, flows from Sulphur Springs are now diverted to the base of the Hillsborough River dam to help meet the minimum flows for the lower river. Also, in 2004 the District adopted minimum flows for Sulphur Springs which must be maintained to prevent the incursion of brackish water from the Hillsborough River into the spring run (citation). As a result of the establishment of minimum flows for both the lower river and the spring run, the use of Sulphur Springs to augment water supplies in the reservoir by the City of Tampa has been greatly reduced.

## 2.4 Flow to the Lower Hillsborough River

The United States Geological Survey (USGS) has recorded daily records for flows from the Hillsborough River Reservoir to the lower river at the Hillsborough River Dam since 1939 (gage #02304500, Hillsborough River near Tampa). A hydrograph of average monthly flows at the dam for the years 1939 to 2012 is shown in Figure 2-6. Flows to the lower river have significantly declined over this period, with increased water use from the reservoir being the primary causative factor. Changes in rainfall have also played a role, and construction of the TBC increased groundwater loss from the reservoir to the TBC, but pumpage from the TBC to the reservoir has more than made up for that loss term and has acted to result in a net gain of inflow to the reservoir.

Water levels in the reservoir have not shown a similar decline (Figure 2-7), due largely to changes in how water levels, withdrawals, and discharges from the reservoir have been managed over the years. It is assumed that in the 1940s through the 1960s, there was less concern about water supply demands exceeding the water storage in the reservoir and water levels were maintained well below the elevation of the dam spillway even in wet season months. Beginning in the 1970s, water levels in the reservoir were generally maintained at higher levels to preserve water storage in the reservoir. Since 1985, augmentation of water supplies by pumpage from the TBC has also helped maintain water levels in the reservoir. However, water levels fell to low levels (<18 feet) during various months in dry years such as 1977, 1981, 1985, 2000 through 2002 and 2006 through 2008.

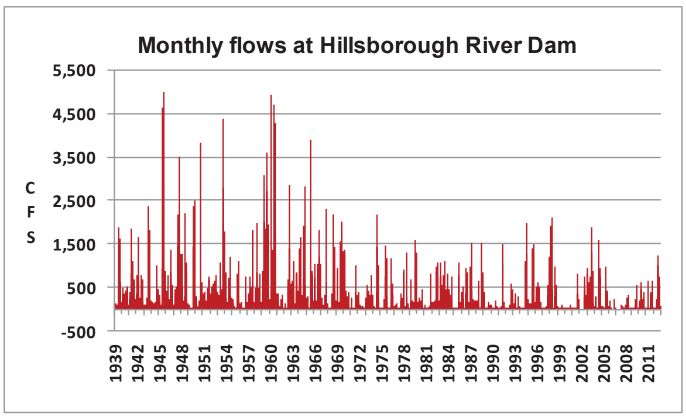


**Figure 2-6. Average monthly flows at the Hillsborough River Dam for the years 1939 to 2012.**

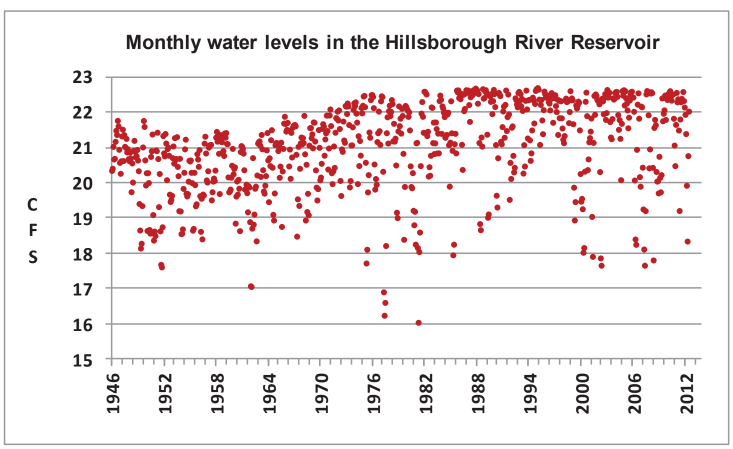


**Figure 2-7. Average monthly water levels in the Hillsborough River Reservoir at the dam for the years 1946 to 2012.**

As a result of decreased flows at the dam, the number of no flows days to the Lower Hillsborough River has increased over time. The number of days per year when flow at the dam spillway were less than 3 cfs is plotted in Figure 2-8. The value of 3 cfs was used to identify no flow days because during some earlier years, the USGS reported flow rates of less than three cfs to estimate seepage from the reservoir rather than surface water discharges from the dam. Few low flow days occurred in 1945 and in the mid to late 1960s. However, the frequent occurrence of no flow days began in the 1970s, with the number of no flow days averaging 153 days per year for the period 1971 through 1979.

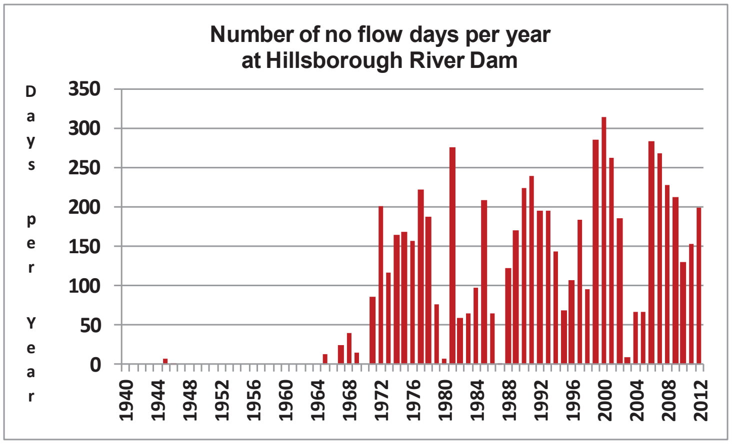


**Figure 2-8. Number of days per year with flows < 3 cfs at the Hillsborough River Dam.**

The number of no flow days per year have averaged 156 days since 1971, and averaged 171 days for the 20-year period from 1993 to 2012. Variations in climatic conditions have contributed to the number of no flow days, as the 1970s were generally dry and high numbers of no flow days occurred in very dry years (1981, 1999 through 2001 and 2006 through 2009). The highest number of no flow days (313) occurred in the year 2000 which was during a severe drought in west-central Florida.

It is important to note that the Lower Hillsborough River also receives ungaged flow from 25 square miles of urbanized area downstream of the Hillsborough River dam. Using hourly rainfall data with runoff coefficients and delineated boundaries for ten drainage basins in the ungaged area, the District estimated ungaged flow to the lower river (SWFWMD 2006). Updating these values for the period 2000 to 2012 indicated that the estimated ungaged flow to the lower river averaged 34 cfs, whereas the gaged flow at the dam averaged 194 cfs. However, this ungaged flow is primarily stormwater runoff that occurs during or soon after rainfall events and essentially has zero or very little baseflow. A flow duration curve of flows at the dam and ungaged flow for the period 2000 to 2012 is shown in Figure 2-9. Ungaged flow was less than 1 cfs for 62% of the time, less than 10 cfs for 72% of the time, and less than 50 cfs for 84% if the time. Ungaged flow is most frequent in the wet season when flows from the dam are also most common.

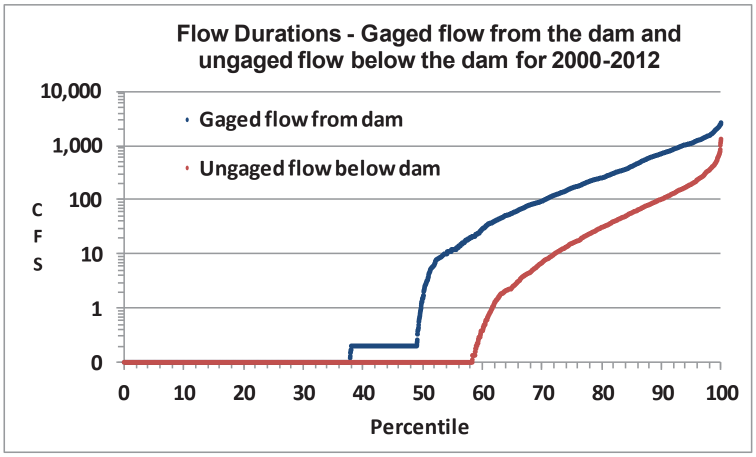


**Figure 2-9. Percentile distributions of gaged flows at the dam and estimated ungaged flows to the lower river below the dam for the years 2000 to 2012.**

## 2.5 Minimum flow rates for the Lower Hillsborough River since 2002

As described in Chapter 1, the minimum flows for the Lower Hillsborough River are 20 cfs for the months July through March and 24 cfs for the months April through June. However, when flows at the Hillsborough River near Zephyrhills gage are less than 58 cfs, these minimum flow rates are reduced by coefficients specific to each time period. These final minimum flow rates are referred to as adjusted minimum flows in the adopted rule and recovery strategy.

Daily minimum flow rates that would have been required for the years 2002 to 2013 are discussed below. It is important to note that a single minimum flow rate of 10 cfs was in effect between 2002 and 2007, with the current minimum flows first put into effect in 2008. .

Figure 2-10 shows the minimum flows that would have been in effect for the period January 1, 2002 through June 8, 2013. This ending period was when high flow resumed at the dam during the summer of 2013. During this period, minimum flow rates would have been in effect for 55% of the days. These results are not corrected for adding any water for the freshwater equivalent, which depending on how it is calculated, could increase the number of minimum flow days by a small amount (e.g., 55.8 % of the days if 3 cfs is added to the minimum flows).

The values in Figure 2-10 do not plot solely at rates of 20 and 24 cfs due to adjustment for low flows at the Zephyrhills gage. This adjustment was applied to 19% of the days that minimum flows were required. The lowest adjusted minimum flows were near 15 cfs, which occurred in the month of March in 2007 and 2009. The blue bars in Figure 2-10 show the limited number of days when low flows over the dam spillway at rates less than 20 to 24 cfs would have contributed to the meeting the minimum flows for the lower river. Flows over the dam spillway are generally either well over the minimum flow rates or zero. As such, low flows over the dam spillway would have contributed to the minimum flows on only 1.6% of the days that minimum flows were required. In the following discussion, these flows over the dam spillway, which are reported by the USGS, are differentiated from minimum flow releases from the reservoir that are discussed in Section 2.5.2.

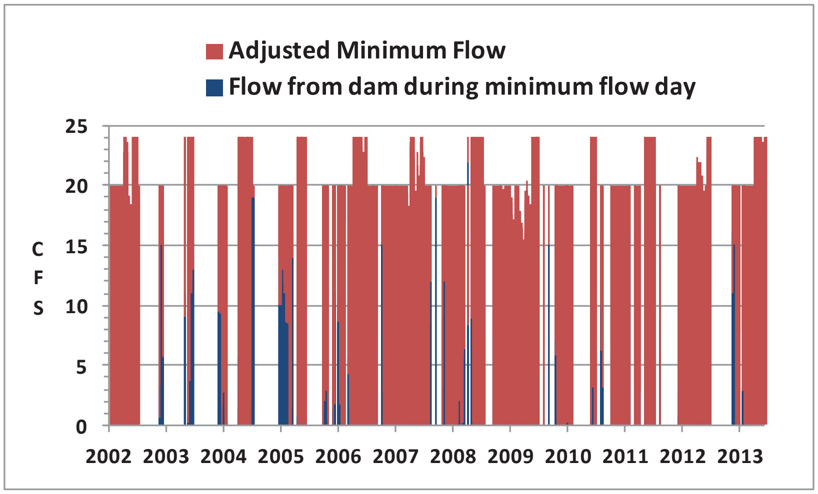


**Figure 2-10. Adjusted minimum flow rates and amount that low flows at the dam spillway that contributed to minimum flows for the peirod January 1, 2002 through June 8, 2013.**

There is substantial variation between years for the number of days that minimum flows would have been in effect. Minimum flow implementation typically begin at the end of the wet season, usually in September or October, and extends until the resumption of high flows at the dam, usually in June or July. However, specific dates when minimum flows end and resume differ considerably among years. Also, during some years, episodic flows at the dam, often during January through March, can temporarily alleviate the need for minimum flows in the dry season.

Table 2-1 lists the beginning and ending dates for when minimum flows would have begun and ended for the fall to spring seasons ending in the years 2002 through 2013. The total number of days and the percentage of days that minimum flows would have been in effect within each period are also listed. The longest minimum flow period of 303 days occurred from early October 2006 to early August 2007, when high flows in the river began late in the summer of 2007. The fewest number of days that minimum flows would have been required (38 days) were between November 2002 and June 2003, when there was flow over the dam for most of the dry season. There was one other period (October 2009 through June 2010) when minimum flows were required less than 50% of the days in the dry season. These results indicate how frequently minimum flows can be required in the dry season and how important they are to maintaining the hydrobiological characteristics of the river immediately below the dam.

**Table 2-1. Beginning and ending dates for minimum flows periods spanning the dry seasons of years between the fall of 2001 and the spring of 2012. The number of days that minimum flows would have been required and the percentage of minimum flow days within each period are also listed.**

| Beginning Date | Ending Date | Number of minimum flow days | Percent of days within period |
|---|---|---|---|
| October 28, 2001 | July 3, 2002 | 249 | 100% |
| November 12, 2002 | June 17, 2003 | 38 | 17% |
| November 26, 2003 | July 1, 2004 | 131 | 60% |
| December 13, 2004 | June 3, 2005 | 125 | 72% |
| September 18, 2005 | August 31, 2006 | 277 | 80% |
| October 4, 2006 | August 2, 2007 | 303 | 100% |
| October 19, 2007 | July 16, 2008 | 207 | 76% |
| September 8, 2008 | June 26, 2009 | 283 | 97% |
| October 11, 2009 | June 24, 2010 | 123 | 48% |
| September 29, 2010 | July 8, 2011 | 225 | 80% |
| November 28, 2011 | June 23, 2012 | 205 | 98% |
| November 13, 2012 | June 8, 2013 | 185 | 89% |

### 2.5.1 Minimum flow diversions from Sulphur Springs

As described in Chapter 1, minimum flows for the Lower Hillsborough River have been adopted twice, with the first minimum flow rule adopted in 1999 and the current minimum flow rule adopted in 2007. The initial minimum flow rule required that a flow rate of 10 cfs must be provided to the base of the dam and diversions from Sulphur Springs could be used for that purpose. Accordingly, a junction was put in the pipeline that extends from Sulphur Springs to the reservoir so that spring water could be released to the river below the dam. A flume was constructed to deliver this water from the pipeline junction to the dam (2-11). Data collected at the bottom of the flume has found that the springwater is well oxygenated before it flows into the river.

**Figure 2-11. The flume that delivers diversions from Sulphur Springs to the near the base of the Hillsborough River Dam.**

The routing of water from Sulphur Springs to the base of the dam began on March 20, 2002. Temporary modifications to the pumping facility at Sulphur Springs were made to implement these flows. The single-rate pump which ran at a rate of 20 mgd (31 cfs) was not replaced, but a return pipe was installed to the spring pool so that water not needed for minimum flows was returned to the spring pool for discharge to the spring run.

As described in Chapter 1, the minimum flow rule that was adopted in 2007 required that minimum flow rates of 20 or 24 cfs be delivered to the dam depending on the month, with 20 cfs during the months July through March and 24 cfs during the months April through June. As also previously described, these rates were expressed as freshwater equivalents, which means the volume of water less than 5 psu that is achieved between the dam and Sulphur Springs should be equivalent to releasing either 20 or 24 cfs at the dam spillway with all of the flow from Sulphur Springs discharging at the normal spring outfall. A modeling simulation presented in the 2006 minimum flow report indicated that if 18 cfs of Sulphur Springs water was used to meet the minimum flows, a total of 23 cfs flow with five cfs of fresh water would be needed to meet the 20 cfs minimum flow for the dam. Additional modeling simulations were conducted to evaluate the amount of freshwater required for various rates of springflow diversion (Janicki Environmental, 2010). As described in Section 13.2.1, the freshwater equivalent conversions for various rates of springflow and reservoir releases will be reassessed as part of updated hydrodynamic modeling of salinity distributions in the Lower Hillsborough River.

To also address the increased minimum flows that were required in the 2007 rule, the temporary pumping facility at Sulphur Springs was replaced with a new facility that was completed in the spring of 2012. The purpose of the new facility was to allow for improved reliability, accuracy, and flexibility in the management of flows from Sulphur Springs and the diversion of greater flows to the base of the dam. The new system allows for the simultaneous management of water levels in the pool along with the rates of pumpage from the spring to either the dam or the spring run. As described in more detail in the minimum flows report for Sulphur Springs (SWFWMD 2004), lowering the water levels in the spring pool increases flow from the Sulphur Springs by reducing the hydrostatic pressure over the spring vent.

Another modification at Sulphur Springs was replacing the weir in that in the spring run that is located about 300 feet downstream for the spring pool. The weir contains a rectangular opening approximately ten feet wide, though which water from the spring run discharges to the Hillsborough River. The weir was modified so that the bottom elevation of this opening can be adjusted to better prevent the incursion of brackish water the Hillsborough River into the spring run, or alternately, lowered to allow manatee access into the spring run during cold periods. When the thermal requirements of manatees are not an issue, the weir allows for greater diversions of spring water to be used for minimum flows at the dam as less water is needed to prevent the incursion of brackish water into the spring run. However, when water temperatures in the lower river near the spring run fall below 20 degrees Celsius ($^{o}$C), 18 cfs of spring water must be released through the weir to provide for a thermal refuge for manatees in the river near the spring outfall. This temperature threshold differs from the threshold included in the minimum flow rule for Sulphur Springs and was developed as part of the permitting process for modifications to the lower weir (City or Tampa 2010, Pickard et al. 2014, Pickard 2015).

### 2.5.2 Minimum flow releases from the Hillsborough Reservoir / TBC system

To address the requirements of the 2007 minimum flow rule, releases of fresh water from the reservoir were first implemented on December 31, 2007, which for brevity is rounded to the beginning of 2008 for discussion in this report. These releases have been implemented by the District using a pumping facility on the north bank of the reservoir at the dam to divert water through a pipe over the dam to the lower river.

As specified in the adopted recovery strategy for the Lower Hillsborough River, minimum flow releases from the reservoir are to be replenished by pumpage from the TBC. Using a temporary pumping facility on the north bank of the Harney Canal, the District began pumping up to 11 cfs from the middle pool of the TBC around Structure S-161 to the reservoir in 2008. Based on concerns expressed by the City of Tampa regarding loss terms from the reservoir, twenty-five percent of the minimum flow water pumped from the Harney Canal was considered lost from the reservoir system, so 75% of the minimum flow water pumped from the Harney Canal pool is released from the reservoir to the lower river. Therefore, a maximum pumpage rate of 11 cfs from the Harney Canal results in a release of 8.3 cfs to the lower river.

The recovery strategy also specifies that minimum flow water pumped from the Harney Canal, which is part of the middle pool of the TBC, is to be replenished by water pumped from the lower pool to the middle pool. In 2007, the District installed a pump at Structure S-162 for this purpose (see Figure 2-2) and in 2008 began pumping up to 11 cfs around Structure S-162 to the middle pool for this purpose. The twenty-five percent loss tem is not applied to pumpage from the TBC lower pool the middle pool.

The recovery strategy, which is included as Appendix 1A to this report, specifies that the District will continue to operate the pumping facility on the lower pool. However, the City of Tampa will ultimately be responsible for permanent pumping facilities on the Harney Canal and at the Hillsborough River dam. A cooperative funding agreement between the City and the District will co-fund the construction of these two pumping facilities, for which completion is expected in 2017. In the meantime, the District will continue to operate the temporary pumping facilities at these two locations, plus retain operation of the pump on the lower pool.

### 2.5.3 Total minimum flow releases to the Lower Hillsborough River

As a result of the changes in pumping and diversion facilities at the dam, the Harney Canal and Sulphur Springs, there has been a gradual increase in the total quantity of minimum flow water that has been diverted to the base of the dam. The increase in the amount of water from Sulphur Springs that has been diverted to the base of the dam since the spring of 2012 is shown in 2-12. In 2013, diversions of spring water at rates of 18 cfs or slightly greater (maximum 20.6 cfs) were common. Figure 2-13 shows freshwater releases to the lower river which began in 2008. Releases of 8.3 cfs are most common, although on some days, less water has been released because that was all that was needed to meet minimum flows.

The flows from these two sources are summed and shown as the total minimum flow delivered to the base of the dam in Figure 2-14. Since 2008, i.e., when reservoir releases began, the total minimum flows have exceeded 20 cfs on various days, particularly since the spring of 2012 when increased diversions of water from Sulphur Springs became possible. One notable exception to this pattern is during a 52-day period in the late spring of 2012 when the total minimum flows declined from values primarily in the 24 to 26 cfs range to values primarily in the 14 to 17 cfs range. This period of relatively low minimum flows occurred because the recovery strategy specifies that when water levels in the TBC lower pool decline to an elevation of 6.0 feet NGVD 1929, diversions of minimum flow water from the TBC ceases until water levels in the lower rebound to 9.0 feet and remain above that elevation for twenty days. Water levels in the lower pool declined to 6.0 feet on April 13, 2012 and rebounded to 9.0 feet on May 14, 2012.

The pumpage of minimum flow water from the TBC to the lower river was suspended during that time and resumed on June 5th. During this time, minimum flows to the river were comprised solely of diversions of water from Sulphur Springs. As discussed in Section 4.1.1 (page 4-4), this period provided an opportunity to examine the effects of diversions solely from Sulphur Springs compared to including freshwater releases from the reservoir in the total minimum flow.

The implementation of reservoir releases and the ability to divert increasing amounts of water from Sulphur Springs resulted in a general increase in total minimum flow rates since minimum flows were first implemented in 2002. This was the case starting in March 2012, when the modified pumping facilities at Sulphur Springs were completed, thereby allowing greater amounts of spring water to be diverted to the dam. With the exception of the 52-day period described above when freshwater releases to the lower river were suspended, there were 237 days between March 1, 2012 and May 31, 2013 when minimum flows were required. The combined minimum flows implemented during this period met the minimum flow requirements of the river for 76% of those days, assuming no adjustment for the freshwater equivalent. If the freshwater equivalent was applied by adding 3 cfs to the required minimum flows, the minimum flows that were implemented would have met the minimum flows on 34% of the days. If the freshwater equivalent is not applied to the months April through June, when the minimum flow rate increases to 24 cfs, the total minimum flows would have met the minimum flow requirements on 57% of the days.

The implementation of minimum flows, particularly the diversions of water from Sulphur Springs, has required a series of changes in pumps, piping and metering to implement the minimum flows. Minimum flows were implemented as quickly as possible so that their benefits in the river could be realized, even if accurate metering of flows was not initially possible. For parts of the period represented in Figures 2-12 to 2-14, the values listed for diversions from Sulphur Springs are estimates, as there were times when it was difficult to get accurate metering of spring diversions.

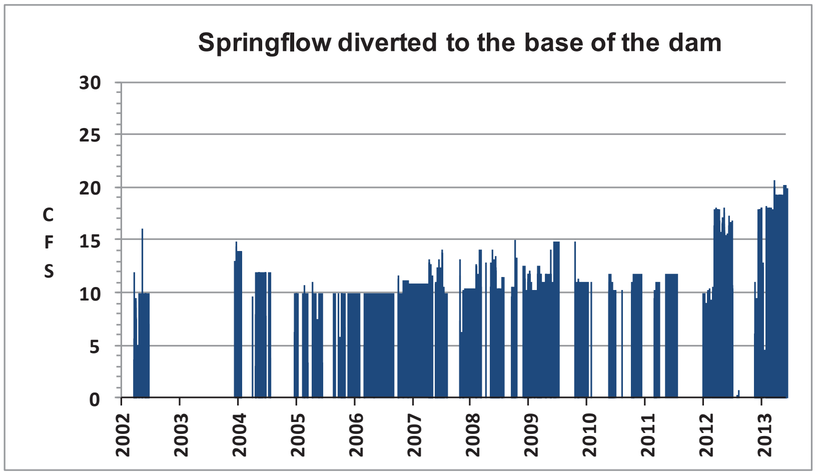


**Figure 2-12. Daily quantities of water diverted from Sulphur Springs to the base of the dam for minimum flows.**

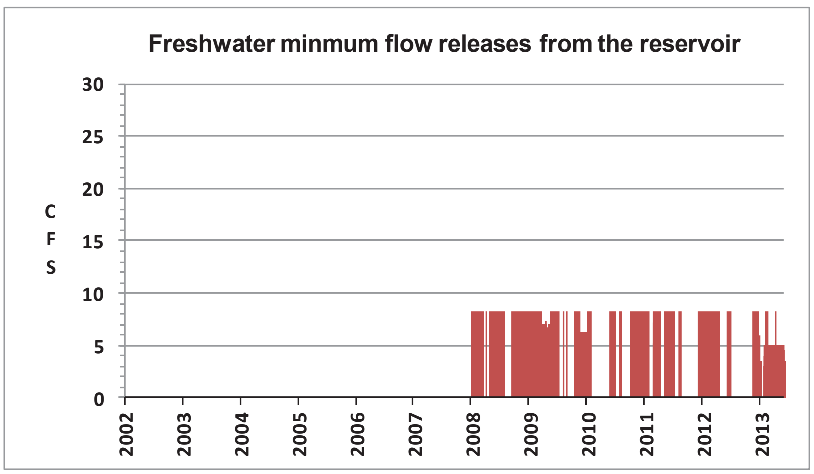


**Figure 2-13. Daily quantities of water released from the reservoir for minimum flows.**

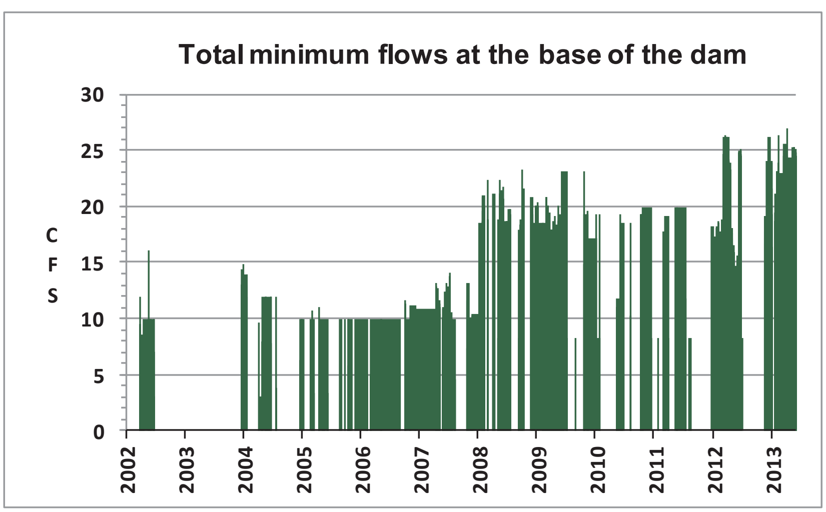


**Figure 2-14. Daily values for total minimum flows delivered to the base of the dam.**

For the preparation of this report, City of Tampa staff submitted estimated diversion rates from Sulphur Springs, acknowledging that there could be errors in some of the reported values. District staff reviewed the records of estimated diversions and compared them to water levels and rates of flow from the spring reported by the USGS. In some cases, the estimated spring diversions were set to missing if there appeared to be some inconsistency with water level records in the spring pool. There were 2,059 days between the initiation of minimum flows on March 20, 2002 and May 31, 2013 for which the City of Tampa records showed diversions of spring water to the dam. Upon review of these records, District staff changed 142 to missing, equivalent to 6.9 %, of all the estimated springflow records. Values for total minimum flows were also set to missing if there was a missing springflow value. It was concluded that for the analyses presented in this report, it was preferable to exclude data for which the minimum flow values were suspect. The data plotted in Figures 2.12 to 2.14 represent these edited values and are the minimum flow rates that are examined in the following sections of this report.

## 2.6 Water quality of the minimum flows sources

The water quality of diversions from Sulphur Springs and releases from the reservoir differ considerably. Of particular importance is the mineralization and salinity of water in Sulphur Springs. As mentioned in Section 2.5.1, modification of the pumping facilities at Sulphur Springs allowed the lowering of water levels in the spring pool to induce greater flow from the spring vent. Figure 2-15 shows average daily water levels in the spring pool for the period May 1999 through May 2013. The normal operating water levels in the Sulphur Springs pool are just above 7 feet NGVD29 when there are no diversions from the spring. The low water levels records (<3 feet) in the years 1999 through 2002 occurred when water from the spring pool was diverted into the Hillsborough River Reservoir for water supply during water shortage conditions. The low water levels in 2011 occurred when there was construction at the spring pool associated with modifying the pumping facilities at Sulphur Springs.

The lowering of water levels in the range of 3 to 5 feet beginning in 2012 corresponds to completion of the pumping facilities at the spring and the diversion of greater quantities of water to the base of the dam for minimum flows (Figure 2-12). Diversions of minimum flow water between 2002 and the spring of 2012, typically at a rate of 10 cfs using a temporary pumping facility, usually did not appreciably lower water levels in the spring pool.

As discussed in more detail in the minimum flows report for Sulphur Springs (SWFWMD 2004), lowering the water levels in the spring pool acts to increase the salinity of the spring discharge. Mean daily salinity values in Sulphur Springs pool for the period May 1999 through May 2013 are shown in Figure 2-16. Increases in salinity are apparent in the years 2000 to 2002 when water supply withdrawals lowered the water levels in the spring pool. Salinity also increased in 2011 when the pool was lowered for construction work, and then remained high during 2012, including the period after March 2012 when the spring pool was lowered to induce flow from the spring. When minimum flows were implemented from March 2002 through February 2012 and water levels were maintained near normal operating levels, the salinity of the spring discharge averaged 1.6 psu. However, after February 2012 when water levels in the pool were lowered to induce discharge for minimum flows, the salinity of the spring discharge averaged 2.7 psu.

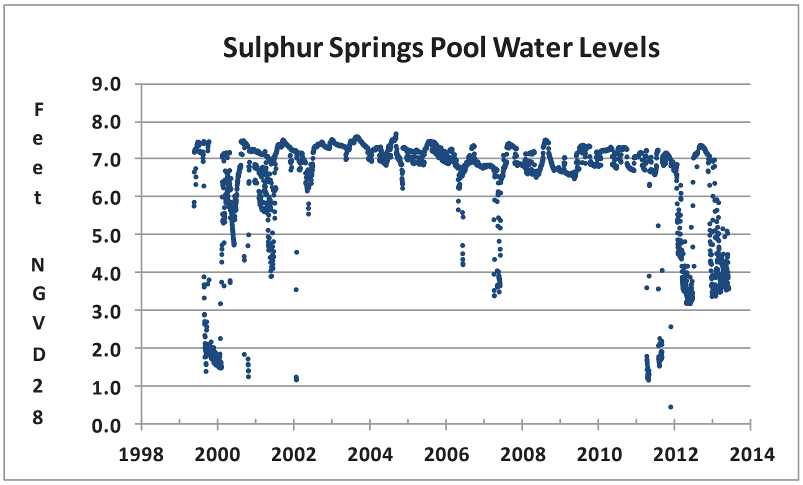


**Figure 2-15. Water levels in the Sulpur Springs Pool for May 1999 thorugh May 2013.**

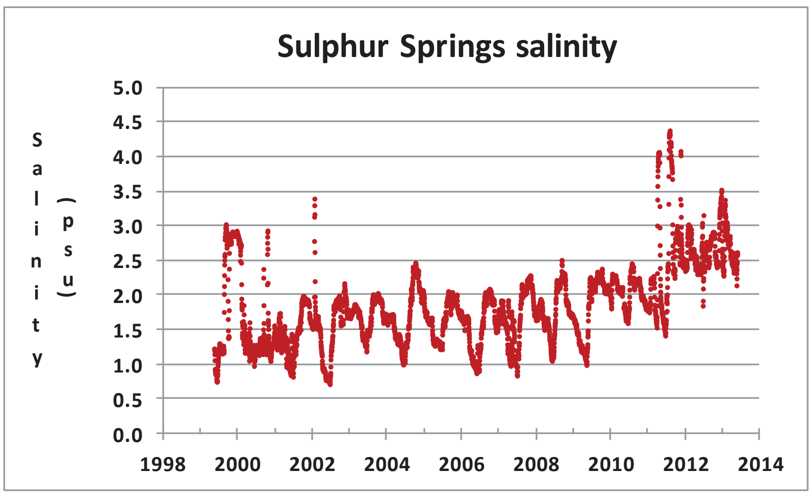


**Figure 2-16. Average daily salinity values in the Sulphur Springs Pool for May 1999 through May 2013.**

In contrast to Sulphur Springs, releases of water from the reservoir provide fresh water to the lower river with salinity values less than 0.3 psu. Also, because they represent fundamentally different types of water bodies, there are differences in other water quality parameters between Sulphur Springs and the reservoir that can have effects in the lower river. Summary statistics for various water quality parameters in Sulphur Springs Pool are listed in Table 2-2 for data recorded by the City of Tampa Water Department. These data were collected between March 2002 and February 2012 on days when minimum flows were in effect, prior to the modifications of the pumping facilities at the spring pool.

**Table 2-2. Summary statistics for selected water quality parameters measured in the Sulphur Springs Pool by the City of Tampa between March 2002 and February 2012 on days when minimum flows for the Lower Hillsborough River were in effect.**

| Parameter | Units | N | Mean | St. Dev. |
|---|---|---|---|---|
| Water Temperature | $^{o}C$ | 45 | 24.3 | 1.1 |
| pH | pH units | 45 | 7.4 | 0.2 |
| Specific Conductance | µmhos/cm | 58 | 3567 | 879 |
| Salinity | psu | 45 | 1.5 | 0.5 |
| Chloride | mg/l | 46 | 855 | 253 |
| Sulphate | mg/l | 45 | 254 | 59 |
| Color | PCU | 8 | 14 | 4 |
| Nitrate N | mg/l N | 46 | 0.21 | 0.30 |
| Nitrite N | mg/l N | 44 | 0.03 | 0.04 |
| Ammonium N | mg/l N | 46 | 0.11 | 0.04 |
| Total Nitrogen | mg/l | 43 | 0.77 | 0.24 |
| Ortho Phosphorus | mg/l P | 45 | 0.08 | 0.08 |
| Total Phosphorus | mg/l P | 42 | 0.18 | 0.12 |

Table 2-3 presents the same statistics for days when minimum flows were in effect starting in March 2012, after modifications of the pumping facility at the spring and the water levels in the spring were maintained at lower levels. Although there are just five observations, this represents the most recent data for the spring pool and corresponds to how the spring is managed under the current minimum flow management plan.

**Table 2-3. Summary statistics for selected water quality parameters measured in the Sulphur Springs Pool by the City of Tampa. Data limited to minimum flow periods between March 2012 and May 2013 on days when minimum flows for the Lower Hillsborough River were in effect.**

| Parameter | Units | N | Mean | St. Dev. |
|---|---|---|---|---|
| Water Temperature | $^{o}C$ | 5 | 24.1 | 0.9 |
| pH | pH units | 5 | 7.1 | 0.1 |
| Specific Conductance | µmhos/cm | 5 | 5230 | 564 |
| Salinity | psu | 5 | 2.6 | 0.3 |
| Chloride | mg/l | 5 | 1427 | 143 |
| Sulfate | mg/l | 5 | 394 | 30 |
| Color | PCU | 0 | NA | NA |
| Nitrate N | mg/l N | 4 | 0.11 | 0.17 |
| Nitrite N | mg/l N | 5 | 0.01 | 0.01 |
| Ammonium N | mg/l N | 5 | 0.10 | 0.00 |
| Total N | mg/l | 5 | 0.19 | 0.16 |
| Ortho Phosphorus | mg/l P | 5 | 0.07 | 0.02 |
| Total Phosphorus | mg/l P | 5 | 0.12 | 0.02 |

The low variance for water temperature indicates water temperature of the spring, which averaged 24.1 and 24.3 $^{o}C$ over the two time periods, is relatively consistent. Salinity in these water quality grab samples were higher in the latter period, with a mean of 2.6 psu compared to 1.5 psu for the earlier period, which is similar to the continuous recorder data presented in Figure 2-16. Mean chloride and sulfate concentrations are high, reflecting the brackish character of Sulphur Springs, but are somewhat elevated in the latter period due to the increased mineralization of the spring when the water levels are lowered. Mean nitrate concentrations were 0.21 mg/l for the early period and 0.11 mg/l for the latter period, but the data in the latter period are too sparse to statistically evaluate whether nitrate concentrations in the spring discharge have truly declined. Total nitrogen values were also much higher in the early period, but again there is not enough data to determine if there has truly been a reduction in total nitrogen values in the spring discharge.

For comparison to the data collected by the City of Tampa, statistics for water quality parameters measured from the spring pool by the District on four dates between May and August 2013 are presented in Table 2-4. Both the City and District data show that dissolved organic color values in the spring pool are generally low, which is typical of spring discharge. Mean chloride and sulfate values for the District data are also high, confirming the findings of the City data. The mean nitrate + nitrite (NOx) value for the District data was 0.22 mg/l, compared to a mean of 0.11 for the City data during minimum flow period after March 2012. Mean values for both ortho-phosphorus and total phosphorus values were similar for the District and City data. Chlorophyll *a* data were not collected as part of the City data collection program, but the mean value for the District data was very low (1.4 µg/l), which also is characteristic of spring discharge.

**Table 2-4. Summary statistics for selected water quality parameters measured in the Sulphur Springs Pool by the Southwest Florida Water Management District between May and August, 2013.**

| Parameter | Units | N | Mean | St. Dev. |
|---|---|---|---|---|
| Specific Conductance | µmhos/cm | 3 | 4724 | 491 |
| Chloride | mg/l | 4 | 1285 | 184 |
| Sulfate | mg/l | 4 | 346 | 47 |
| Color | pcu | 4 | 11 | 7 |
| Nitrate + Nitrite N | mg/l N | 4 | 0.22 | 0.21 |
| Ammonia N | mg/l N | 4 | 0.04 | 0.02 |
| Ortho Phosphorus | mg/l P | 4 | 0.09 | 0.01 |
| Total Phosphorus | mg/l P | 4 | 0.11 | 0.01 |
| Chlorophyll *a* | µg/l | 4 | 1.4 | 0.8 |

Water quality in the Hillsborough River reservoir is monitored by the City of Tampa as part of water use permit for reservoir withdrawals. Because water quality in the reservoir can exhibit large variations between the wet and dry seasons, summary statistics are presented in Table 2-5 for periods when minimum flows were in effect for the years 2002 through 2012. These results are indicative of the variable quality of water that is released to the lower river as part of minimum flows in the dry season.

Water quality in the reservoir is fundamentally different than in Sulphur Springs, reflecting the quality of fresh river water flowing into it. The reservoir water typically exhibits much lower specific conductance values and concentrations of chloride and sulfate as compared to Sulphur Springs. Although the mean water temperature for the reservoir is similar to that for the spring, the standard deviation is greater indicating greater seasonal temperature variation in the reservoir. Color is also higher in the reservoir (mean = 50 pcu), reflecting the higher dissolved organic color in the Hillsborough River. Nitrate nitrogen concentrations are lower in the reservoir compared to the spring, due presumably in part due to greater phytoplankton update in the reservoir compared to the spring in addition to generally lower concentrations in the inflowing river water. However, ammonium concentrations in the reservoir are relatively high (0.11 mg/l) compared to the Sulphur Springs. Ortho phosphorus and total phosphorus concentrations in the reservoir are generally similar to concentrations in the spring. There are no chlorophyll *a* data collected in the reservoir by the City, so it is not possible to determine how algal populations in the reservoir might affect the quality of freshwater releases from the reservoir to the lower river.

**Table 2-5. Summary statistics for selected water quality parameters measured in the Hillsborough River Reservoir by the City of Tampa during minimum flow periods between 2012 and 2013.**

| Parameter | Units | N | Mean | Std. |
|---|---|---|---|---|
| Water temperature | degrees C | 50 | 23.9 | 4.9 |
| pH | pH units | 50 | 7.9 | 0.4 |
| Specfic conductance | µsiemens/cm | 51 | 422 | 86 |
| Salinity | psu | 50 | 0.1 | 0.2 |
| Chloride | mg/l | 43 | 27 | 11 |
| Sulfate | mg/l | 43 | 50 | 18 |
| Color | pcu | 51 | 50 | 35 |
| Nitrate N | mg/l N | 47 | 0.05 | 0.06 |
| Nitrite N | mg/l N | 48 | 0.01 | 0.01 |
| Ammonium N | mg/l N | 41 | 0.11 | 0.05 |
| Total Nitrogen | mg/l N | 49 | 0.61 | 0.48 |
| Ortho Phosphorus | mg/l P | 48 | 0.07 | 0.06 |
| Total Phosphorus | mg/l P | 48 | 0.15 | 0.1 |

## 2.7 Streamflow conditions during the minimum flow study

The Lower Hillsborough River is a tidal ecosystem that is affected by inflows to the lower river that have occurred over preceding periods of time. In the following chapters, the water quality and biological characteristics of the lower river are examined over a recent eleven-year period during which minimum flows have been implemented. Changes in the river's hydrobiological characteristics, particularly in reaches near the dam, have resulted from the gradual increase in minimum flows over that time. However, changes in the river water quality and biological characteristics have been strongly influenced by seasonal and inter-annual changes in flow to the Lower River and conditions in Hillsborough Bay. Accordingly, the following section presents a brief characterization of flows to the lower river during the months when minimum flows were typically in effect.

Average flows at the dam spillway, not including any minimum flow releases, are shown in Figure 2-17 for the months October through May, when minimum flows for the lower river are typically in effect. Although the preceding summer flows also affect the lower river for some time into the fall, it was assumed flows for the eight months from October through May would be most informative for examining streamflow conditions that affected the river during periods of minimum flow implementation. The years listed on the horizontal axis in Figure 2-17 correspond to the May that ended each 8 month period. Monthly flows that occurred during each of these 8 month periods are shown in Figure 2-18, with no data shown for the months July through September.

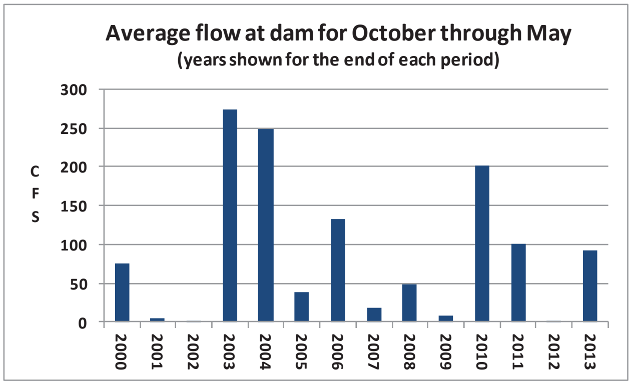


**Figure 2-17. Average flows at the Hillsborough River Dam for eight-month periods extending from October through May for October 1999 through May 2013. Minimum flows are not inlcuded.**

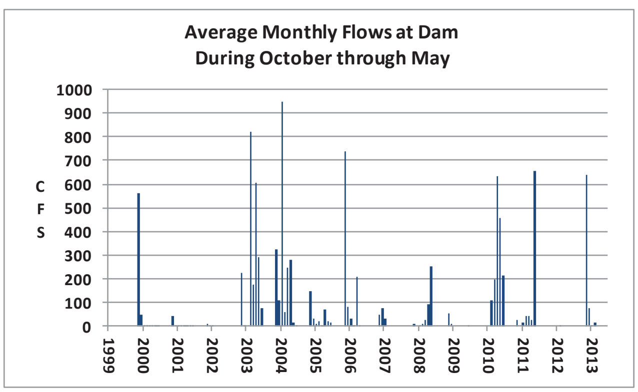


**Figure 2-18. Average monthly flows at the dam calcuated for the months October through May for the period October 1999 through May 2013. Minimum flows are not included.**

The very dry conditions in 2000, 2001 and 2002 are apparent. With the exception of October 1999 and monthly flows of 41 and 46 cfs in November 1999 and October 2000, there was no flow at the dam during the October to May periods that ended in 2000, 2001, and 2002 (Figure 2-18). Minimum flow diversions of water from Sulphur Springs started in late March 2002. Therefore, in interpreting the changes in the river that have resulted from implementation of the minimum flows, it is important to note that much of the pre-minimum flow data collected in the river for this study occurred during extreme low flow conditions from 2000 through 2002. An exception to this are data from two-long term water quality stations in the lower river operated by the Environmental Protection Commission of

Hillsborough County (EPCHC).  Data from those stations are examined in following chapters to aide understanding of conditions in the river in earlier years prior to the implementation of minimum flows.

Wet periods occurred in 2003 and 2004, and minimum flows were not necessary during much of the dry seasons of those years (Figure 2-14). Very dry periods also occurred during 2007, 2009 and 2012. The dry periods in 2009 and 2012 occurred when there were minimum flow diversions from both Sulphur Springs and releases of fresh water from the reservoir, resulting in an informative data base to examine the effects of combined minimum flow releases during very dry conditions.

## 2.8 Salinity in Hillsborough Bay during the study period

Salinity and water quality in Hillsborough Bay also exert a strong influence on the Lower Hillsborough River, particularly during times of low streamflow. The effects of the bay are strongest near the river mouth, but do extend upstream with the effects of minimum flow releases being increasingly more important in the reaches closest to the dam. To aid the interpretation of results presented in the following chapters, a time series plot of monthly mid-depth salinity values at EPCHC water quality station 44 is presented in Figure 2-19. This station is located in Hillsborough Bay approximately 1.4 miles east of the mouth of the river between Bayshore Boulevard and Davis Islands.

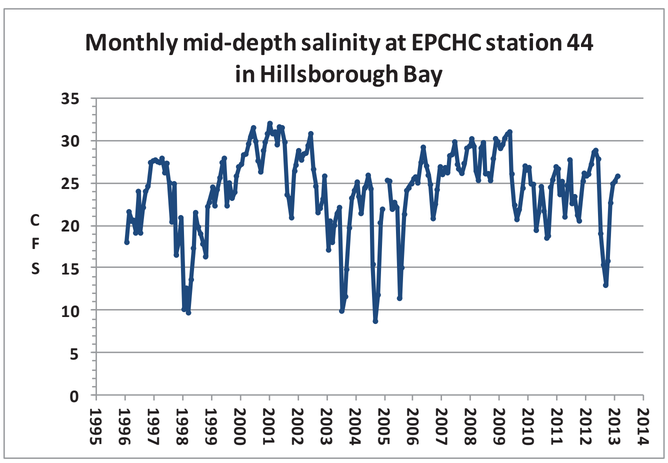


**Figure 2-19. Monthly mid-depth salinity values at EPCHC station 44 in Hillsborouh Bay for the period January 1996 through Feburary 2013.**

The highest salinity conditions at this station occurred in 2000 and 2001 prior to the implementation of minimum flows. High salinity values were also common between 2006 and 2009, which were dry years. Salinity dropped in the summer of 2009, and generally fluctuated between 18 and 24 psu for the remainder of the study. The highest salinity conditions after 2009 occurred during the spring of 2012, which was followed by a drop in salinity due to high flows during the summer of that year. The data available from EPCHC at the time of the preparation of this report ended in February 2013, but a salinity recorder at the mouth of the river indicated that salinity in the spring of 2013 was not as high as in 2012. In sum, over the period of minimum flow implementation, including the years since 2008 when combined minimum flows have been achieved, there has been large variation in flow conditions at the river dam and salinity in Hillsborough Bay. Data collected during this period comprises an informative data base for examining effects of minimum flows on the salinity, water quality, and biological characteristics of the lower river over a wide range of climatic and hydrologic conditions.

# 3 Methods

## 3.1 Geographic range of study

The purpose of the minimum flows implementation is to extend a zone of water less than 5 psu salinity from the City of Tampa Dam at river kilometer 16.2 toward Sulphur Springs, which flows into the Hillsborough River between kilometers 12.7 and 12.8, or approximately 3.5 kilometers (2.2 miles) below the dam (Figure 3-1). Although the emphasis of the study was the reach of the river upstream of Sulphur Springs, data were also analyzed to just above the Sligh Avenue Bridge (kilometer 10.6) to examine how the reach of the river immediately below might respond to minimum flows.

The data were divided into river segments for graphical and statistical analyses. When a large volume of data was available, such as for vertical profile measurements of salinity and dissolved oxygen, the data were divided into the following river segments:

- kilometers 10.6 to < 11.6 (alternatively kilometers 10.6 to 11.6)
- kilometers 11.6 to < 12.6 (alternatively kilometers 11.6 to 12.6)
- kilometers 12.6 to < 13.4 (alternatively kilometers 12.6 to 13.4)
- kilometers 13.4 to <14.1 (alternatively kilometers 13.4 to 14.1)
- kilometers 14.1 to <14.5 (alternatively kilometers 14.1 to 14.5)
- kilometers 14.5 to <15.2 (alternatively kilometers 14.5 to 15.2)
- kilometers 15.2 to 16.2 (alternatively kilometers 15.2 to 16.2)

There were less data available for the laboratory water quality (color, nutrients, and chlorophyll *a*) and the biological study components. The river segments were combined in order to allow for sufficient sample density per segment. The following segments were used:

- kilometers 10.6 to < 12.6 (alternatively kilometers 10.6 to 12.6)
- kilometers 12.6 to <14.5 (alternatively kilometers 12.6 to 14.5)
- kilometers 14.5 to <16.2 (alternatively kilometers 14.5 to 16.2)

## 3.2 Data sources

Water quality data were comprised of *in-situ* water column profile measurements (salinity, temperature, pH, dissolved oxygen), laboratory data (chlorophyll, color, and nutrients), and continuous recorder data (temperature and specific conductance). *In-situ* water column profile data and laboratory data for the Lower Hillsborough River were obtained from TBW through their Hydrobiological Monitoring Program (HBMP), which is required as part of the conditions of a water use permit issued to TBW for diverting high flows from the Hillsborough River Reservoir to the TBC for subsequent withdrawal and use for public supply purposes, from the Environmental Protection Commission of Hillsborough County (EPCHC) through their long term water quality monitoring program, and from the District through their long term water quality monitoring program.

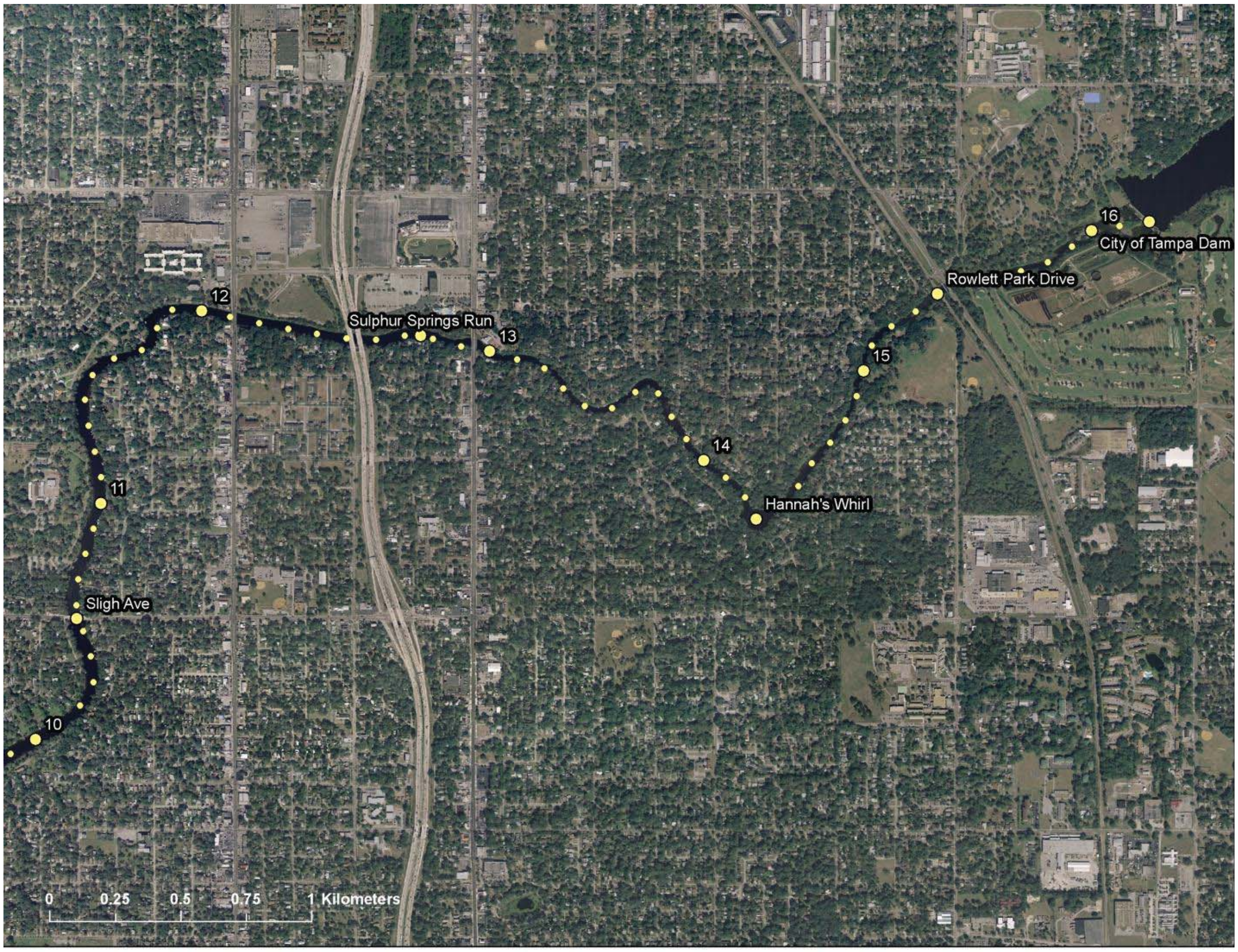


**Figure 3-1. River kilometers and selected points on the Hillsborough River from Sligh Avenue to the City of Tampa Dam.**

Laboratory water quality data for Sulphur Springs and the Hillsborough River Reservoir were obtained from the City of Tampa Water Department as contained in files submitted to the Southwest Florida Water Management District as part of the City's water use permit for withdrawals from the reservoir. Laboratory water quality data were also obtained from the District's long term water quality monitoring program.

Continuous recorder data were available from the TBW HBMP (at Sligh Avenue), the EPCHC (at kilometer 13.6) and the USGS (at Rowlett Park Drive, Hannah's Whirl, Hillsborough River at Sulphur Springs, Platt Street and the Sulphur Springs Pool). Specific conductance data collected at these recorders were mathematically converted to salinity using formulae from YSI, Inc., Yellow Springs, OH.

Biological data were available from TBW through their HBMP. Hydrologic data were provided by the United States Geologic Survey, the District (minimum flow releases to the reservoir) and the City of Tampa Water Department (diversions of water from Sulphur Springs to the base of the Hillsborough River dam).

## 3.3 Methods of analysis

### 3.3.1 General water quality data analysis

All data analysis and graphic generation were performed using SAS version 9.3 or 9.4 (SAS Institute, Inc., Cary, NC) software. The Univariate Procedure was used to test the normality of the distribution of the various datasets and to produce the tables of summary statistics for the various water quality and biological constituents. The data were almost exclusively non-normally distributed, therefore the Wilcoxon rank sum test, which is a non-parametric test for differences between two populations of data. Unless as specified otherwise, the p-value for the two-tailed test was used to determine whether differences were statistically significant. The GContour Procedure was used to generate multidimensional contour plots for the various water quality constituents. The SGPlot Procedure was used to produce the various scatter, line, and box plots for this report.

The data used in the graphics and analyses were a subset of the complete dataset to focus specifically on times when minimum flows were the predominant source of flow to the lower river. To accomplish this objective, the data were subset for dates where the flow over the spillway at the City of Tampa Dam was less than 1 cfs.

Prior to calculating summary statistics for continuous recorder data, the data were summarized as daily averages, and the daily average values were used to generate summary statistics. Time series, scatter and box and whisker plots were produced for all of the water quality data components (separate plots for continuous recorder and *in situ* data). These plots use symbols to distinguish the different minimum flow periods described in Section 2.5.3, so that inferences can be made about the impact of changes in minimum flows to these constituents. In order to quantitatively assess the changes among the minimum flow periods the Wilcoxon rank sum test was applied to the data for each segment, comparing data from the different periods.

### 3.3.2 Relationships with minimum flows

The relationship between water quality constituents and the rate of minimum flow was graphically assessed by producing two dimensional contour plots for different flow conditions, plots of constituent concentrations versus flow, and graphics depicting conditions at the continuous recorder sites throughout specific short term events during which the rate minimum flows flow changed. In addition, differences in salinity at the continuous recorder were tested using the one-tailed Wilcoxon rank sum test on average daily salinity values in flow classes that grouped the data into flow ranges of 3 cfs.

## 3.4 Biological data analysis

Treatment of the biological data for individual taxa consisted of calculating an average catch for each selected taxon in each segment for each month, and using this monthly average as the value for analysis. For calculation of total abundance, the total catch per sample was calculated for each segment and month; this value was used for graphics and analysis.

# 4 Salinity

## 4.1 Daily data from continuous recorders

Data from six continuous specific conductance / salinity recorders in the Lower Hillsborough River were analyzed for this minimum flows evaluation (salinity was calculated from specific conductance measurements at each site). The locations of the recorders from upriver to downriver were at Rowlett Park Drive, Hannah's Whirl, kilometer 13.6, Sulphur Springs, Sligh Avenue, and Platt Street (recorders upstream from Sligh Avenue shown in Figure 4-1). The operating agency, the river kilometer locations upstream from the dam, and the periods of data assessed for each recorder are listed in Table 4-1.

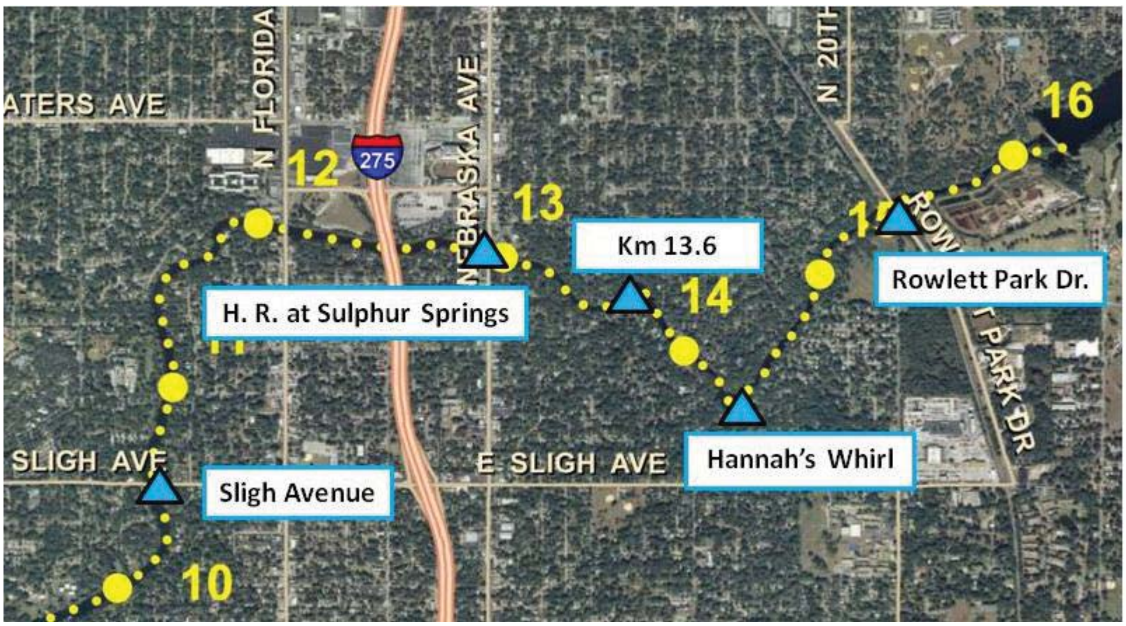


**Figure 4-1. Locations of salinity recorders in the Lower Hillsborough River above Sligh Avenue with kilometers in tenth kilometer increments shown in yellow.**

**Table 4-1. Recorder name, agency, river kilometer, and beginning and ending date for data at six continuous salinity recorders in the Lower Hillsborough River analyzed for this study.**

| Location | Agency | Kilometer | Begin Date | End Date |
|---|---|---|---|---|
| Rowlett Park Drive | USGS | 15.4 | 23-Dec-96 | 11-Jun-13 |
| Hannah's Whirl | USGS | 14.4 | 15-Jun-01 | 30-Sep-05 |
| Kilometer 13.6 | EPCHC | 13.6 | 14-May-02 | 8-Mar-13 |
| At Sulphur Springs | USGS | 12.9 | 1-May-99 | 11-Jun-13 |
| Sligh Avenue | TBW | 10.5 | 01-Oct-02 | 11-Jul-13 |
| Platt Street | USGS | 0.1 | 16-Feb-01 | 11-Jun-13 |

All of the recorders are currently in operation except for the site at Hannah's Whirl, which was discontinued on September 30, 2005. The station at Platt Street, which is located near the mouth of the Hillsborough River, is discussed to provide perspective on changes in boundary condition salinity for the Lower Hillsborough River which exhibits considerable seasonal and inter-annual variability in response to changes in climatic conditions, streamflow, and salinity in Hillsborough Bay.

The emphasis of the minimum flow evaluation is the reach of the river above Sulphur Springs for this is where the adopted rule specifies that an oligohaline zone (< 5 psu salinity) is to be established. The location of Sulphur Springs is shown in Figure 4-2 on a bar graph of the cumulative volume of the lower river by river kilometer. The location of the four salinity recorders upstream of Sulphur Springs is shown on a graph of the river volume upstream of kilometer 12 in Figure 4-3.

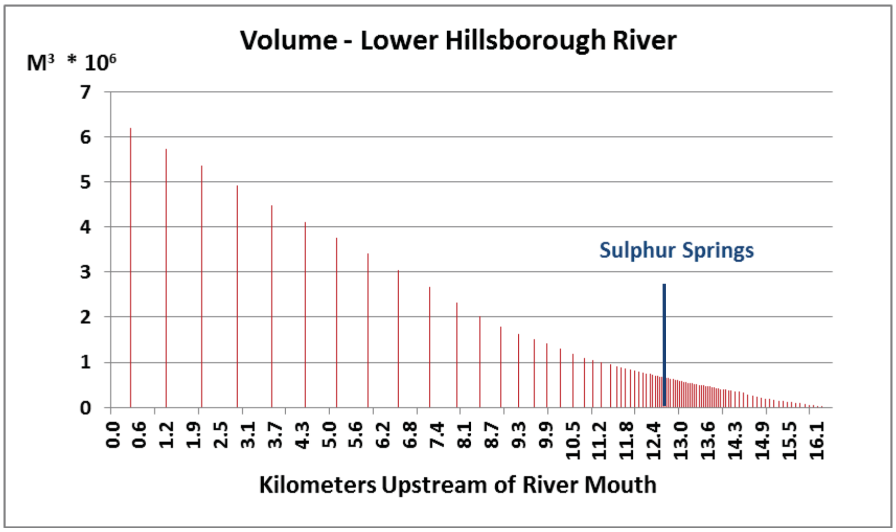


**Figure 4-2. Cumulative volume of the Lower Hillsborough River versus kilometer including the location of mouth of Sulhpur Springs Run at kilometer 12.75.**

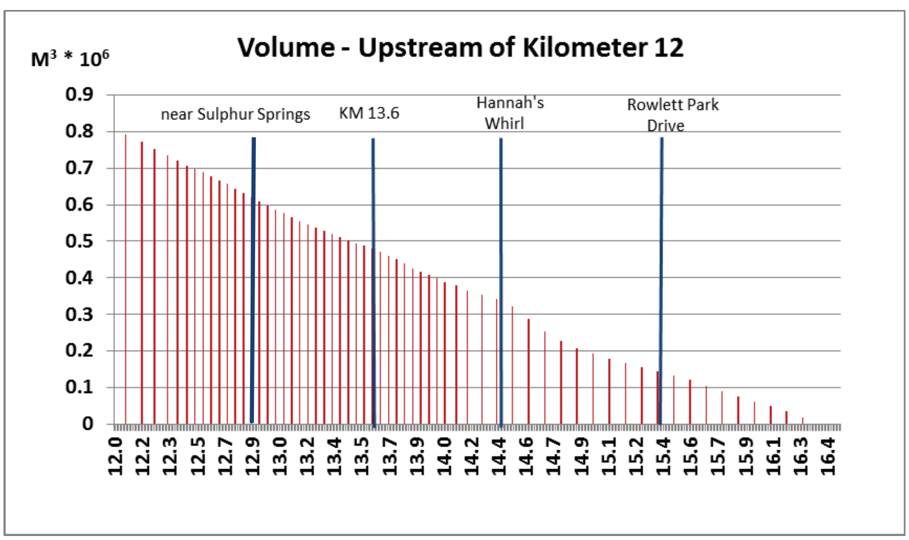


**Figure 4-3. Cumulatve volume of the Lower Hillsborough River upstream of kilometer 12 showing the location of four continuous salinity recorders in the river upstream of Sulphur Springs.**

The total volume of the lower river upstream of the river mouth is approximately 6.19 million cubic meters ($6.19 * 10^6$ $m^3$). The volume of the river upstream of Sulphur Springs is $0.63 * 10^6$ $m^3$, which represents about 10.2 % of the volume of the entire lower river. The nearby Hillsborough River near Sulphur Springs recorder presents about 9.5% of the volume of the lower river, and about 93% of the target area for the establishment of oligohaline waters above the mouth of Sulphur Springs Run. The EPCHC recorder at kilometer 13.6 represents 7.6% of the volume of the lower river, equal to about 74% of the minimum low target area above Sulphur Springs. The recorder at the upstream end of Hannah's Whirl represents 4.7% percent of the volume of the lower river, equal to about 46% of minimum flow target area, while the recorder at Rowlett Park Drive represents 1.9% percent of the volume of the lower river, equal to about 19% of minimum flow target area above Sulphur Springs. These relative volume values are useful for assessing the effectiveness of the minimum flows when reviewing the results from the different continuous salinity recorders presented on the following pages.

Specific conductance was measured either every 15 minutes or hourly at each of the recorders. Specific conductance sensors were deployed in both top and bottom waters, with mid-depth sensors also deployed at the Hillsborough River at Sulphur Springs and Platt Street stations. As described in the Methods (Chapter 3), specific conductance values were mathematically converted to salinity as practical salinity units (psu). Daily average, minimum, and maximum salinity values were then calculated for the period of study at each recorder.

The data from the continuous recorders provide an informative record on which to assess changes in salinity in the river at these locations during the periods of minimum flow implementation. Time series graphics, box and whisker plots, statistical summaries and tests for significant differences in salinity at the recorders during the various minimum flow periods are examined. During high flows at Hillsborough River dam, recorders in the upper part of the study area are flushed with fresh water. Because the focus of this study is the effectiveness of the minimum flows in the dry season, the average daily salinity values discussed below are for periods when flows at the dam spillway, other than minimum flow releases, were less than 1 cfs. Although minimum flows can be in effect when flows at the dam spillway are between 1 and 24 cfs, days when flows at the spillway are in that range are rare. Therefore, it was concluded that utilizing data when flows were less than 1 cfs provided a consistent approach to examine the effect of the minimum flows which have gradually increased over time.

### 4.1.1 Rowlett Park Drive

A time series plot of average daily surface salinity at the Rowlett Park recorder during the different minimum flow periods is shown in Figure 4-4, with corresponding plots of average daily bottom salinity values included in Appendix 2A. Box and whisker plots of average daily salinity values for both surface and bottom waters for these same minimum flow periods are shown in Figure 4-5.

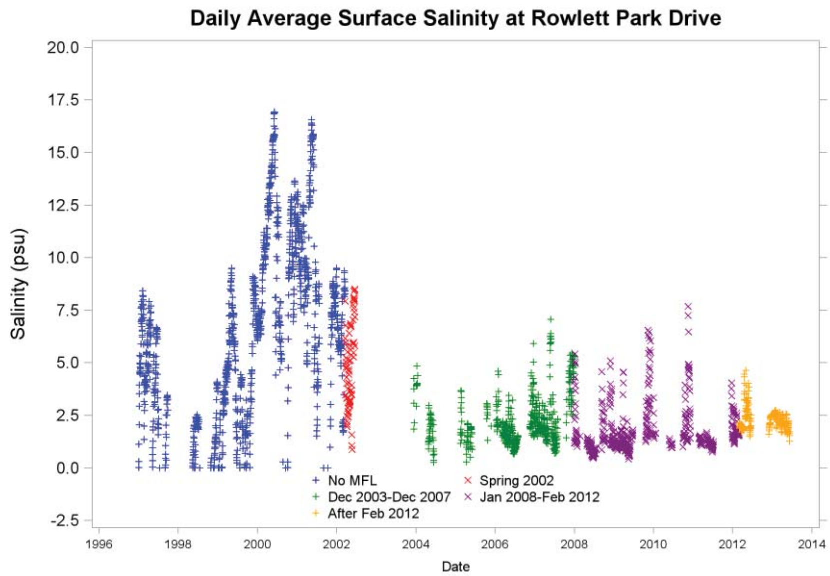


**Figure 4-4. Time series of average daily surface salinity values at the Rowlett Park Drive continuous recorder with the minimum flow periods highlighted by different symbols.**

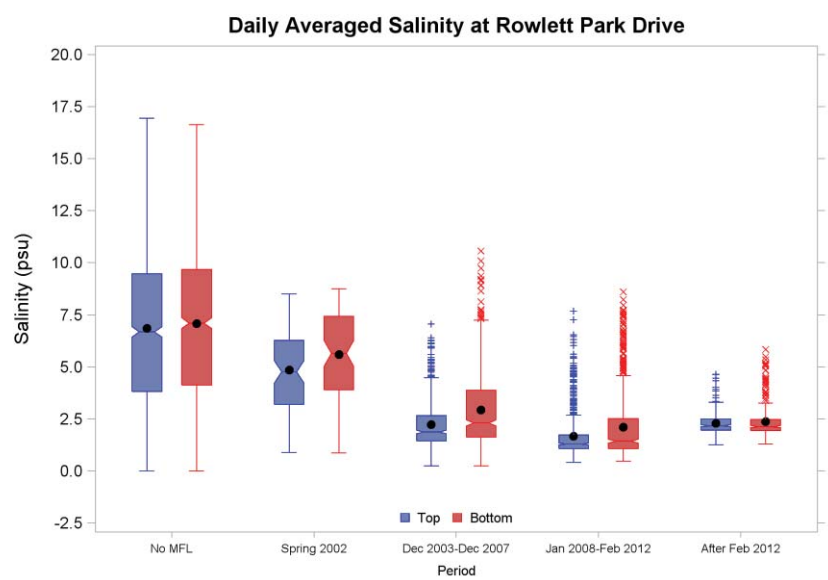


**Figure 4-5. Box and whisker plots of daily average salinity at the Rowlett Park Drive continuous recorder during the minimum flow periods.**

Salinity at Rowlett Park Drive decreased markedly at both the top and bottom sensor as minimum flows were increased during minimum flow periods. Results of the Wilcoxon rank sum test for difference show that all periods are significantly different from each other (see summary table of statistical tests in Appendix 2B). The relative differences in the minimum flow periods are apparent in Figure 4-4 and Figure 4-5 and indicate that the minimum flow discharges were effective in substantially reducing the salinity at Rowlett Park Drive. Since 2008, when both Sulphur Springs and reservoir releases were primarily used to maintain the minimum flow, both top and bottom salinity values at Rowlett Park Drive were typically well below 5 psu.

Summary statistics of average daily salinity for surface and bottom waters within the minimum flow periods are presented in Table 4-2. During the final minimum flow period (after Feb. 2012), when increased diversions of Sulphur Springs were used, there was less variation in salinity and maximum and 90$^{th}$ percentile salinity values were lower than during the preceding period. However, the mean, median and percentile values below the 90$^{th}$ percentile were slightly greater due to the diversions of greater quantities of water from Sulphur Springs, which had a mean salinity of 2.7 during the final minimum flow period. This increase in central tendency salinity values after February 2012 at Rowlett Park is also apparent in the time series plot (Figure 4-4). As discussed in Section 2.6, the lowering of water levels in Sulphur Springs pool to increase flow from the spring also increases the salinity in the spring discharge. The results from Rowlett Park Drive are illustrative of the effect of higher minimum flow rates preventing higher maximum salinity values at that location. It should be emphasized that the number of records and the climatic conditions during the final two minimum flow periods differed, which likely influenced these results. However, the pattern that was observed appears to be valid.

**Table 4-2. Summary statistics for salinity at the Rowlett Park Drive continuous recorder.**

| Sensor Level | Period | Mean | Maximum | 90th Percentile | 75th Percentile | Median | 25th Percentile | 10th Percentile | Minimum | Number of days with samples |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottom | No MFL | 7.1 | 16.6 | 12.4 | 9.7 | 7.1 | 4.1 | 1.9 | 0 | 1239 |
| Bottom | Spring 2002 | 5.6 | 8.7 | 8.2 | 7.4 | 5.6 | 3.9 | 3.1 | 0.9 | 88 |
| Bottom | Dec 2003-Dec 2007 | 2.9 | 10.6 | 5.7 | 3.9 | 2.3 | 1.6 | 1.1 | 0.2 | 642 |
| Bottom | Jan 2008-Feb 2012 | 2.1 | 8.6 | 4.6 | 2.5 | 1.4 | 1.1 | 0.9 | 0.5 | 612 |
| Bottom | Mar 2012 - Jun 2013 | 2.1 | 3.2 | 2.5 | 2.3 | 2.1 | 1.9 | 1.8 | 1.5 | 218 |
| Top | No MFL | 6.8 | 16.9 | 12.4 | 9.5 | 6.7 | 3.8 | 1.7 | 0 | 1239 |
| Top | Spring 2002 | 4.9 | 8.5 | 7.9 | 6.3 | 4.8 | 3.2 | 2.5 | 0.9 | 88 |
| Top | Dec 2003-Dec 2007 | 2.2 | 7.1 | 4 | 2.7 | 1.9 | 1.4 | 1.1 | 0.3 | 642 |
| Top | Jan 2008-Feb 2012 | 1.7 | 7.7 | 3.2 | 1.7 | 1.3 | 1.1 | 0.9 | 0.4 | 612 |
| Top | Mar 2012 - Jun 2013 | 2.1 | 2.7 | 2.5 | 2.3 | 2.1 | 1.9 | 1.8 | 1.5 | 218 |

An example of how combined reservoir releases and spring discharge kept the salinity at Rowlett Park Drive fairly stable is presented in Figure 4-6. Initially, the combined minimum flow from Sulphur Springs and reservoir releases which totaled about 26 cfs, maintained a steady salinity at around 2 psu. When releases from the reservoir ceased due to low water levels in the Tampa Bypass Canal (beginning April 14$^{th}$; see page 2-14), salinity fluctuated between about 2 and 5 psu until May 28$^{th}$. This decline is likely due to ungaged storm runoff below the dam. Implementation of reservoir releases on June 4$^{th}$ maintained salinity again near 2 psu, with salinity decreasing to zero in late June when higher flows resumed at the dam. The discontinuation of reservoir releases in 2012 also influenced the greater salinity variation observed in 2012 compared to 2013, as shown by the time series plot in Figure 4-4.

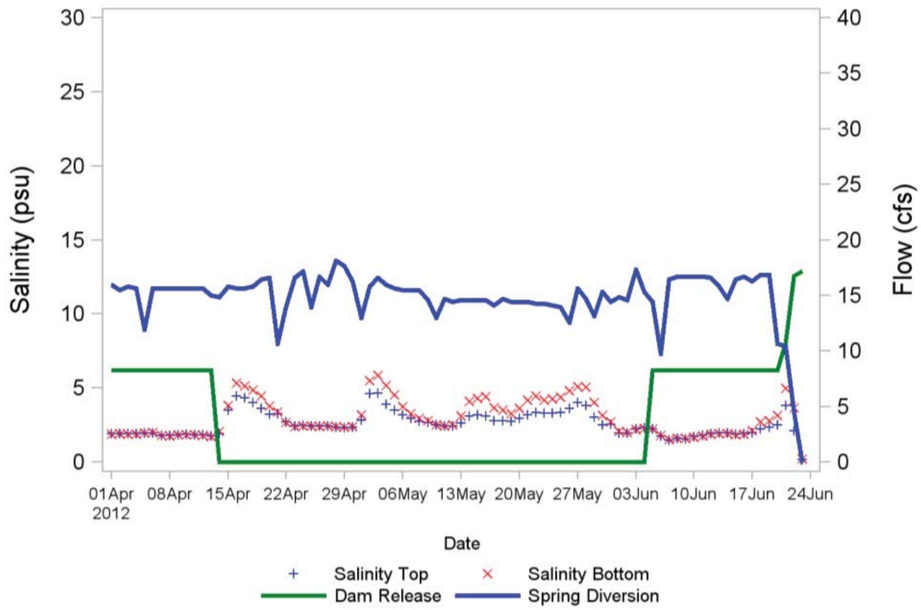


**Figure 4-6. Daily average salinity and flows by source at Rowlett Park Drive, April 1 to June 23, 2012.**

### 4.1.2 Hannah's Whirl

The recorder at Hannah's Whirl was located on a dock on the east bank of the river at the upstream end of the deep bend that is called Hannah's Whirl. The period of record at Hannah's Whirl is shorter than for the other continuous recorders, ending in September 2005. Compared to conditions when minimum flows were not implemented, average salinity at Hannah's Whirl decreased markedly at both the top and bottom sensors during the minimum flow period beginning in December 2003, when minimum flows were limited to diversions from Sulphur Springs (Figure 4-7 and Figure 4-8). As shown by Table 4-3, salinity values less than 5 psu were common during this period (90$^{th}$ percentile surface value of 4.7 psu, 75$^{th}$ percentile bottom value of 5.8 psu). Salinity during this period was also lower than during the minimum flow period in 2002, when spring diversions were briefly employed during a very dry spring. The Dec. 2003 – Sep. 2005 period, for which the most recent data are available for Hannah's Whirl, was relatively wet, and salinity at the site was reduced (Figure 4-7 and Figure 4-8). However, it is reasonable to conclude that higher minimum flow rates, which include both spring diversions and reservoir releases, would be successful in terms of establishing oligohaline habitat at Hannah's Whirl a majority of the time. This conclusion is supported by vertical profile salinity data collected from the area of Hannah's Whirl for a series of dates that extend to 2013 that are discussed in Section 4.3.

**Table 4-3. Summary statistics for salinity at the Hannah's Whirl continuous recorder.**

| Sensor Level | Period | Mean | Maximum | 90th Percentile | 75th Percentile | Median | 25th Percentile | 10th Percentile | Minimum | Number of days with samples |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottom | No MFL | 8.7 | 15.7 | 12.3 | 10.5 | 8.5 | 7.2 | 5.9 | 0 | 1239 |
| Bottom | Spring 2002 | 9.3 | 16.6 | 14 | 11.7 | 9.2 | 6.4 | 4.9 | 3.9 | 88 |
| Bottom | Dec 2003-Sep 2005 | 4.1 | 10.6 | 6.8 | 5.8 | 3.9 | 2.3 | 1.2 | 0.5 | 642 |
| Top | No MFL | 7.5 | 12.5 | 10 | 9.2 | 7.7 | 6.3 | 4.1 | 0 | 1239 |
| Top | Spring 2002 | 6.4 | 10.5 | 9 | 7.5 | 6.5 | 4.9 | 4.1 | 2.3 | 88 |
| Top | Dec 2003-Sep 2005 | 2.9 | 6 | 4.7 | 3.7 | 3 | 1.9 | 1 | 0.5 | 642 |

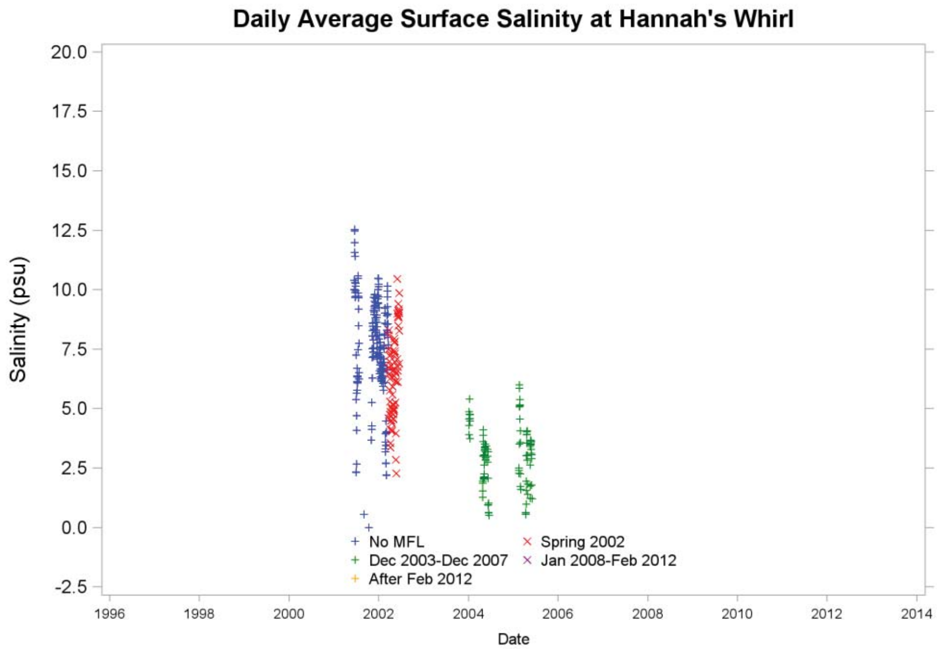


**Figure 4-7. Time series of average daily surface salinity values at the Hannah's Whirl continuous recorder with the minimum flow periods highlighted by different symbols.**

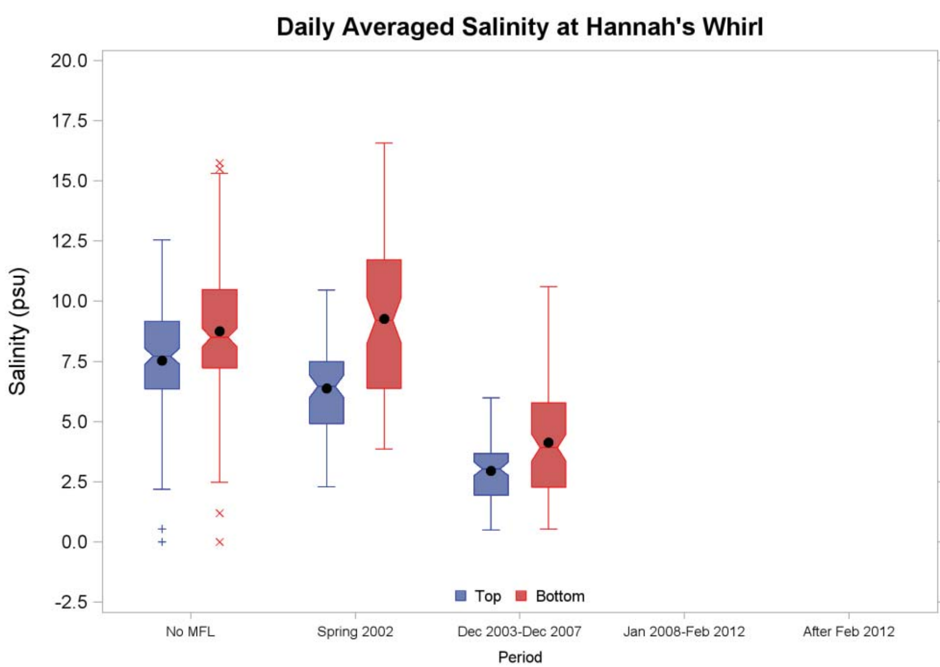


**Figure 4-8. Box and whisker plots of daily average salinity at the Hannah's Whirl continuous recorder during the minimum flow periods.**

### 4.1.3 Kilometer 13.6

The recorder near Kilometer 13.6, which is operated by the EPCHC, is the only continuous recorder located between Hannah's Whirl and Sulphur Springs. Data collection at this site began in May 2002; therefore data are not available prior to the implementation of the minimum flows. Average salinity at Kilometer 13.6 was lower in all periods after Spring 2002 than it was during Spring 2002 (Table 4-4 and Figure 4-9 and Figure 4-10). However, the very dry conditions during the brief implementation of minimum flows during 2002 influenced these results. Based on mean salinity values, oligohaline (< 5 psu) conditions in top water were achieved during the final two minimum flow periods, which included diversions from Sulphur Springs and minimum flow releases from the reservoir. Based on mean and median values, oligohaline conditions were not achieved in bottom waters during any of the minimum flow periods, with mean values of 6.7 and 5.5 psu occurring during the final two minimum flow periods after 2008. However, a median value of 5.0 psu was observed in the final minimum flow period.

**Table 4-4. Summary statistics for salinity at the kilometer 13.6 continuous recorder.**

| Sensor Level | Period | Mean | Maximum | 90th Percentile | 75th Percentile | Median | 25th Percentile | 10th Percentile | Minimum | Number of days with samples |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottom | Spring 2002 | 10.9 | 14.9 | 13.4 | 12.5 | 11.6 | 9.3 | 7.1 | 5.8 | 88 |
| Bottom | Dec 2003-Dec 2007 | 7 | 16.7 | 11.1 | 9.1 | 6.9 | 5 | 3 | 0.5 | 642 |
| Bottom | Jan 2008-Feb 2012 | 6.7 | 16.8 | 10.9 | 8.4 | 6.4 | 4.7 | 3.2 | 0.7 | 612 |
| Bottom | Mar 2012 - Jun 2013 | 5.5 | 12.6 | 9.9 | 6.6 | 5.0 | 3.8 | 2.8 | 2.3 | 122 |
| Top | Spring 2002 | 7.2 | 11.8 | 10.6 | 9.5 | 7.6 | 5.5 | 3.7 | 0 | 88 |
| Top | Dec 2003-Dec 2007 | 5 | 11.6 | 7.1 | 6.1 | 4.9 | 3.8 | 2.6 | 0.5 | 642 |
| Top | Jan 2008-Feb 2012 | 4.4 | 10.6 | 6.4 | 5.3 | 4.3 | 3.4 | 2.7 | 0 | 612 |
| Top | Mar 2012 - Jun 2013 | 4.4 | 7.5 | 6.6 | 5.5 | 4.0 | 3.4 | 2.7 | 0 | 89 |

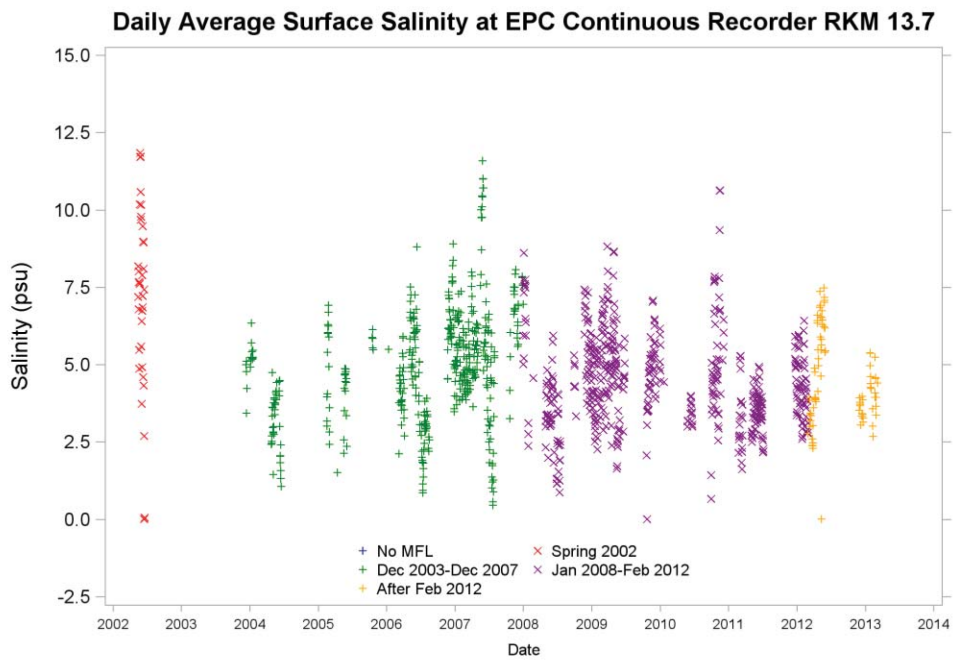


**Figure 4-9. Time series of average daily surface salinity values at the kilometer 13.6 continuous recorder with the minimum flow periods highlighted by different symbols.**

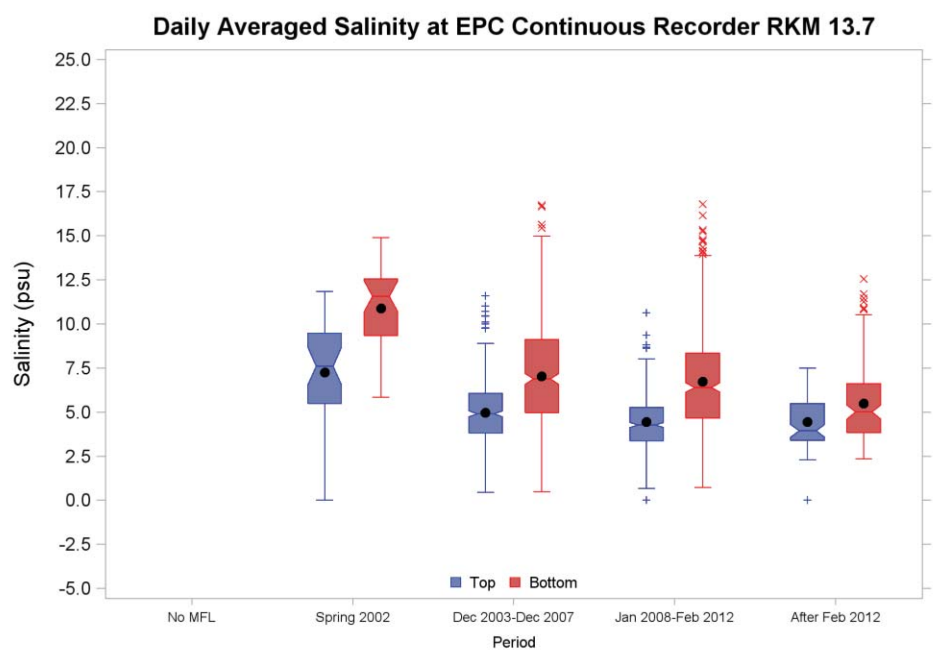


**Figure 4-10. Box and whisker plots of daily average salinity at the kilometer 13.6 continuous recorder during the minimum flow periods.**

A time series of salinity at kilometer 13.6 during the period of discontinuation of reservoir releases in the spring of 2012 is shown in Figure 4-11. Similar to Rowlett Park Drive, relatively stable salinity values were observed in early April when both springflow diversions and reservoir releases were in effect. More variable salinity values occurred after April 14th when reservoir releases were discontinued. Unfortunately, there was a period of missing data at this recorder during the period when reservoir releases resumed in early June 2012, limiting the interpretation of Figure 4-11.

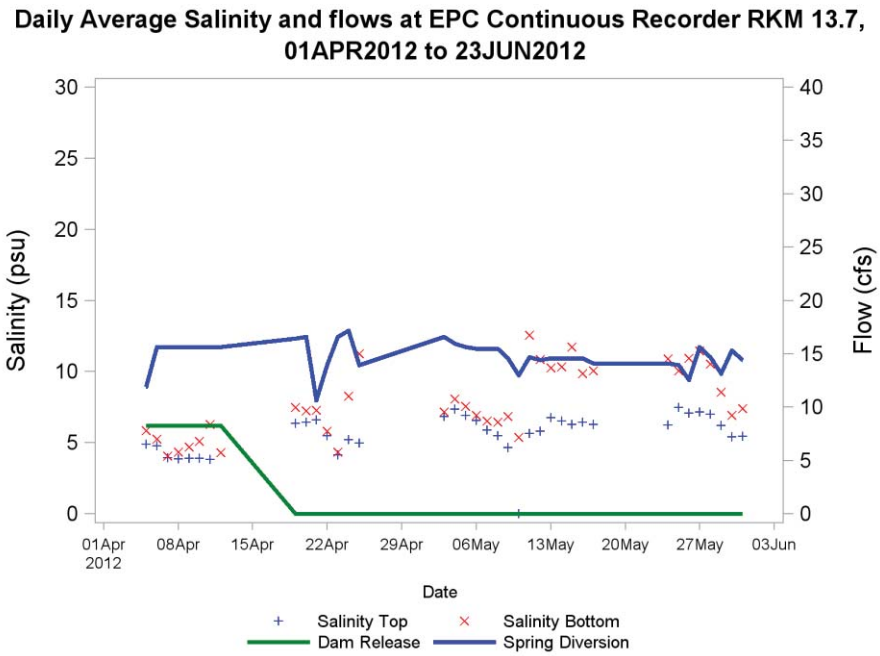


**Figure 4-11. Daily average salinity and flows by source at kilometer 13.6, April 1, 2012 to June 23, 2012.**

### 4.1.4 Hillsborough River at Sulphur Springs

The USGS recorder Hillsborough River at Sulphur Springs is located on the east bank of the river, about 150 meters upstream and on the opposite bank of where Sulphur Springs enters the Lower Hillsborough River. Given its location, salinity at this site is strongly influenced both by flows from the dam and from the nearby spring outfall. The only mean salinity value that was less than 5 psu at this site was the top value in the final minimum flow period beginning in March 2012 (Table 4-5). As with the other recorders upstream, the lowest and most stable salinity values were observed in the spring of 2013 (Figure 4-12), when there was an uninterrupted release of reservoir water matched with increased flows from Sulphur Springs diverted to the base of the dam. However, climatic and hydrologic conditions also influenced these results, as the dry season of 2013 was not as pronounced as during some other years, including 2012. There are large differences in surface and bottom salinity values (Table 4-5 and Figure 4-13), as there is usually a high degree of vertical stratification at this location until it becomes flushed with fresh water at high flows.

**Table 4-5. Summary statistics for salinity at the Hillsborough River at Sulphur Springs continuous recorder.**

| Site | Sensor Level | Period | Mean | Maximum | 90th Percentile | 75th Percentile | Median | 25th Percentile | 10th Percentile | Minimum | Number of days with samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hillsborough River at SS | Bottom | No MFL | 15.9 | 24.3 | 20.6 | 18.7 | 16.4 | 13.6 | 10.3 | 0.2 | 1239 |
| Hillsborough River at SS | Bottom | Spring 2002 | 15.6 | 22 | 19.9 | 18.4 | 16.2 | 13.3 | 9 | 8.1 | 88 |
| Hillsborough River at SS | Bottom | Dec 2003-Dec 2007 | 13.2 | 20.9 | 18.1 | 16.4 | 13.9 | 10.8 | 6.9 | 0.7 | 642 |
| Hillsborough River at SS | Bottom | Jan 2008-Feb 2012 | 14.2 | 24.1 | 19.1 | 17.1 | 14.6 | 11.6 | 8.5 | 2.7 | 612 |
| Hillsborough River at SS | Bottom | Mar 2012 - Jun 2013 | 10.1 | 17.8 | 15.9 | 14 | 9.8 | 6.7 | 4.3 | 1.8 | 218 |
| Hillsborough River at SS | Top | No MFL | 10.5 | 20.2 | 16.2 | 13.2 | 10.2 | 7.6 | 5.6 | 0.1 | 1239 |
| Hillsborough River at SS | Top | Spring 2002 | 9.2 | 14.1 | 12.9 | 11.2 | 8.5 | 7.1 | 6.3 | 4.9 | 88 |
| Hillsborough River at SS | Top | Dec 2003-Dec 2007 | 6.7 | 15.3 | 10.3 | 8.3 | 6.6 | 4.9 | 3.2 | 0.4 | 642 |
| Hillsborough River at SS | Top | Jan 2008-Feb 2012 | 7 | 16.4 | 10 | 8.3 | 6.7 | 5.4 | 4 | 1.5 | 612 |
| Hillsborough River at SS | Top | Mar 2012 - Jun 2013 | 4.9 | 10.9 | 7.9 | 6 | 4.6 | 3.6 | 2.9 | 0.8 | 218 |

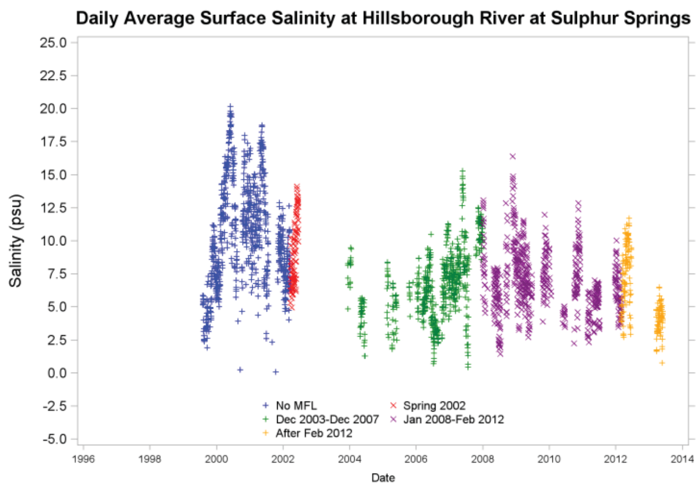


**Figure 4-12. Time series of average daily surface salinity values at the Hillsborough River at Sulphur Springs continuous recorder with the minimum flow periods highlighted by different symbols.**

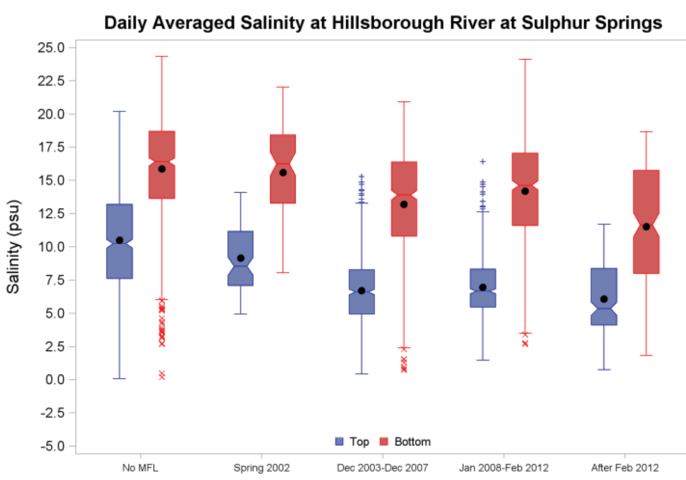


**Figure 4-13. Box and whisker plots of daily average surface and bottom salinity at the Hillsborough River at Sulphur Springs continuous recorder during the minimum flow periods.**

### 4.1.5 Sligh Avenue

The recorder at Sligh Avenue is operated as part of the TBW HBMP. Data collection at this recorder began in October 2002, so there are no data prior to the implementation of minimum flows. The Sligh Avenue is recorder is located at kilometer 10.5, which is about 2.2 kilometers downstream of Sulphur Springs and well below the area where the minimum flows are intended to maintain an oligohaline zone. However, data from Sligh Avenue were assessed in this study to examine how the river downstream of Sulphur Springs might be affected by minimum flows and the re-routing of flows from Sulphur Springs.

Similar to the recorder in the river at Sulphur Springs, there are large differences in salinity between surface and bottom waters at Sligh Avenue (Figure 4-15). The changes in salinity at Sligh Avenue over minimum flows periods are less than at the upstream gages. However, after February 2012 when minimum flows were at their highest rates, both surface and bottom salinity were significantly lower compared to the previous period (Appendix 2B). During the final minimum flow period, surface salinity averaged 7.2 psu during while bottom salinity averaged 15 .0 psu (Table 4-6). As with other sites, higher salinity values were observed in the spring of 2012 compared to the spring of 2013 (Figure 4-14). The discontinuation of reservoir releases during the spring of 2012 likely influenced these results, but differences in hydrologic conditions between the two years were also likely a factor.

Because the Sligh Avenue site is downstream of Sulphur Springs, minimum flows that were implemented prior to January 2008 represent no net gain in upstream flow at the site. Prior to 2008, minimum flows to the river involved solely rerouting water from Sulphur Springs to the base of the dam. Net gains in flow were only achieved at Sligh Avenue when reservoir releases began in 2008. In that regard, it is interesting to note that salinity values were very similar between the 2003 to 2007 and 2008 to February 2012 periods (Table 4-6). These similarities could indicate that the releases from the reservoir for minimum flows had little effect on salinity at Sligh Avenue. However, variations in climatic conditions and overall salinity in the river also likely played a major role in these relationships. Salinity values were somewhat lower after March 2012, when the highest minimum flow rates were implemented.

**Table 4-6. Summary statistics for salinity at the Sligh Avenue continuous recorder.**

| Sensor Level | Period | Mean | Maximum | 90th Percentile | 75th Percentile | Median | 25th Percentile | 10th Percentile | Minimum | Number of days with samples |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottom | Dec 2003-Dec 2007 | 17.4 | 24.4 | 21.4 | 20 | 17.8 | 15.5 | 12.9 | 2.9 | 587 |
| Bottom | Jan 2008-Feb 2012 | 17.9 | 26.4 | 22.1 | 20.2 | 17.9 | 15.5 | 13.5 | 7.7 | 577 |
| Bottom | Mar 2012 - Jun 2013 | 15 | 21.7 | 18.7 | 17.6 | 15.2 | 12.8 | 11.4 | 1.6 | 201 |
| Top | Dec 2003-Dec 2007 | 8.4 | 16.9 | 11.4 | 9.7 | 8.4 | 6.9 | 4.8 | 1.8 | 504 |
| Top | Jan 2008-Feb 2012 | 8.5 | 14 | 11.2 | 10 | 8.4 | 7.2 | 5.9 | 2.3 | 584 |
| Top | Mar 2012 - Jun 2013 | 7.2 | 11.7 | 9.1 | 8.4 | 7.5 | 6.2 | 5 | 1.2 | 218 |

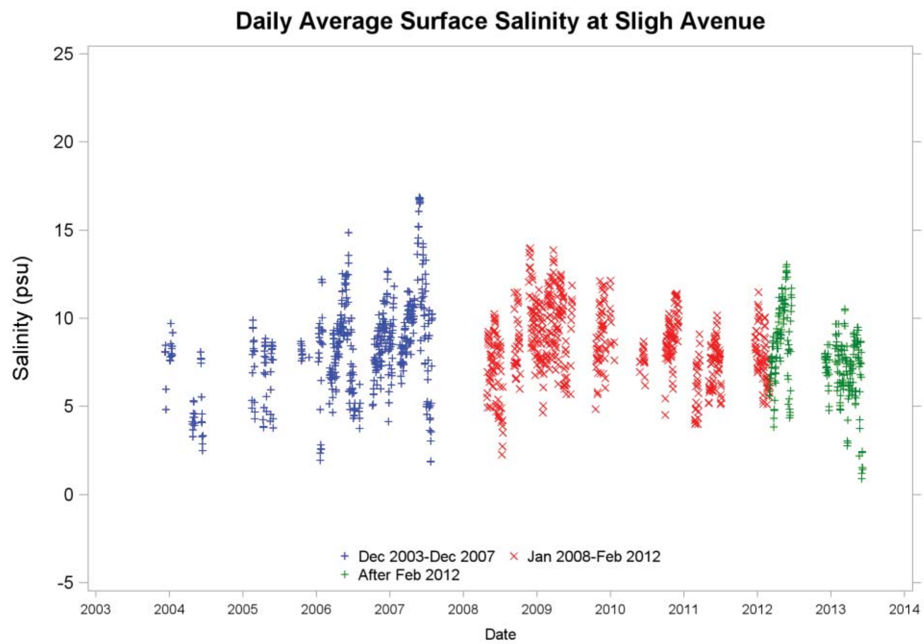


**Figure 4-14. Time series of average daily surface salinity values at the Sligh Avenue continuous recorder with the minimum flow periods highlighted by different symbols.**

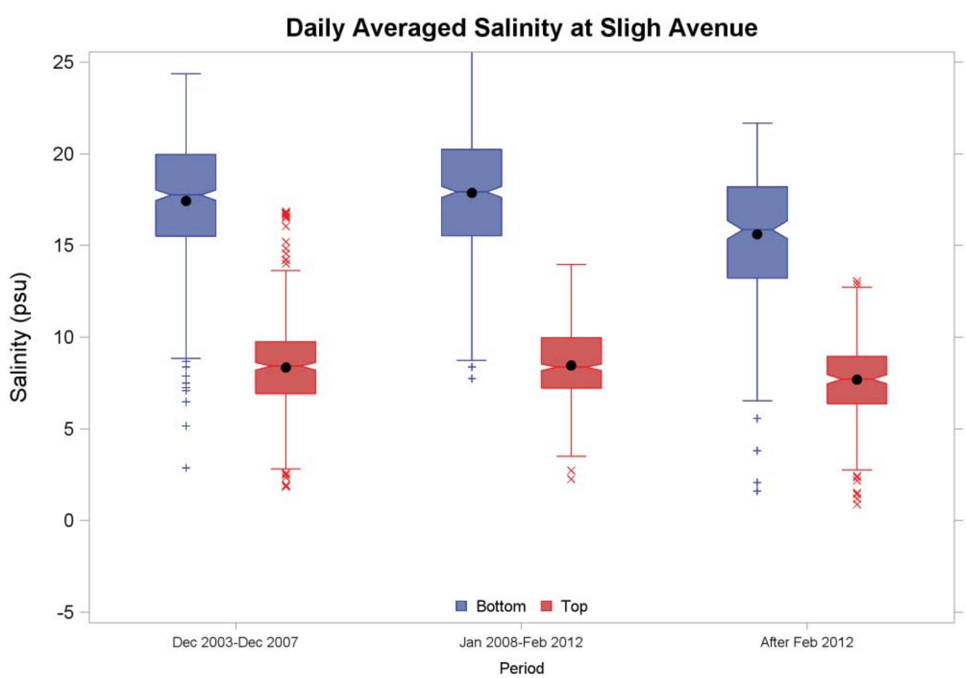


**Figure 4-15. Box and whisker plots of daily average surface and bottom salinity waters at the Sligh Avenue continuous recorder during the minimum flow periods.**

### 4.1.6 Platt Street

The recorder at Platt Street is located at the mouth of the Hillsborough River. Salinity at Platt Street can be influenced by freshwater flow from the dam, particularly during high flows. However, during times of very low flow, salinity at this site is primarily influenced by salinity in Hillsborough Bay. Therefore, the time series plot of daily surface salinity in Figure 4-16, which is restricted to periods when there was less than 1 cfs flow from the dam spillway, shows temporal variations that influenced more by salinity in Hillsborough Bay than the relatively small minimum flows at the dam. Also, as with the recorder at Sligh Avenue, minimum flows implemented before 2008 did not involve any net gain of flow above Platt Street because it involved only the re-routing of water from Sulphur Springs.

It that regard, it is interesting to note that mean and median salinity values during the January 2008 – February 2012 period, when there were freshwater minimum flow releases, were slightly higher than during the period December 2003 – December 2007, when the minimum flows were comprised only of diversions from Sulphur Springs (Table 4-7 and Figure 4-17). These similarities again reflect the strong influence of climatic conditions and salinity in the bay on the Platt Street recorder and the limited effect of low freshwater flow rates from the dam (e.g., < 10 cfs) at this location. The high salinity values in 2009 reflect the very dry conditions during the winter and spring of that year. Salinity did decline somewhat during the period after February 2012, with climatic conditions again likely being a major factor, but it should be noted that freshwater releases from the dam were uninterrupted during periods when minimum flows were required from March 2013 through May 2013, which may have played some role in preventing very high surface salinity values at Platt Street.

As mentioned on page 4-2, data are presented for Platt Street to give an indication of the salinity boundary conditions in the river during the period of minimum flow implementation. At locations further upstream (Rowlett Park Drive, Kilometer 13.6), the effects of low flows at the dam are more pronounced due to the smaller volume of the river, closer proximity to the dam, and different estuarine mixing characteristics compared to more downstream reaches of the river.

**Table 4-7. Summary statistics for salinity at the Platt Street continuous recorder.**

| Site | Sensor Level | Period | Mean | Maximum | 90th Percentile | 75th Percentile | Median | 25th Percentile | 10th Percentile | Minimum | Number of days with samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Platt | Bottom | No MFL | 29.6 | 32.5 | 31.8 | 31.2 | 29.7 | 28.3 | 26.9 | 23.4 | 1239 |
| Platt | Bottom | Spring 2002 | 28.9 | 31.2 | 30.5 | 29.9 | 29.2 | 28.2 | 26.8 | 24.3 | 88 |
| Platt | Bottom | Dec 2003-Dec 2007 | 26 | 30.2 | 29.1 | 27.5 | 25.7 | 24.3 | 23.6 | 21.7 | 642 |
| Platt | Bottom | Jan 2008-Feb 2012 | 27.8 | 32.4 | 30.6 | 29.8 | 27.4 | 26 | 25.1 | 24 | 612 |
| Platt | Bottom | Mar 2012 - Jun 2013 | 25.8 | 28.8 | 27.2 | 26.5 | 25.6 | 25 | 24.3 | 23 | 218 |
| Platt | Top | No MFL | 27.2 | 31.8 | 30.5 | 29.5 | 26.9 | 25.1 | 24.2 | 16.9 | 1239 |
| Platt | Top | Spring 2002 | 26.7 | 28.4 | 27.9 | 27.6 | 26.8 | 26 | 25.3 | 23.2 | 88 |
| Platt | Top | Dec 2003-Dec 2007 | 24 | 28.8 | 27.4 | 25.8 | 23.9 | 22.4 | 21.1 | 18 | 642 |
| Platt | Top | Jan 2008-Feb 2012 | 25.2 | 30.5 | 28.5 | 27.1 | 24.8 | 23.5 | 22.5 | 19 | 612 |
| Platt | Top | Mar 2012 - Jun 2013 | 24.1 | 27.5 | 25.8 | 25.1 | 24.2 | 23.3 | 22.6 | 17 | 218 |

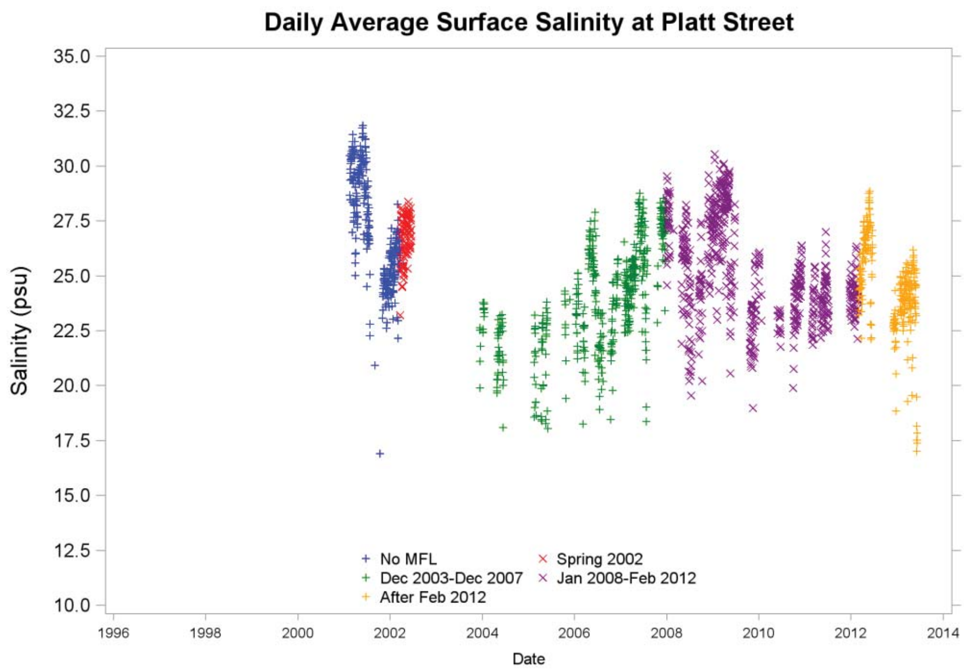


**Figure 4-16. Time series of average daily surface salinity values at the Platt Street continuous recorder with the minimum flow periods highlighted by different symbols.**

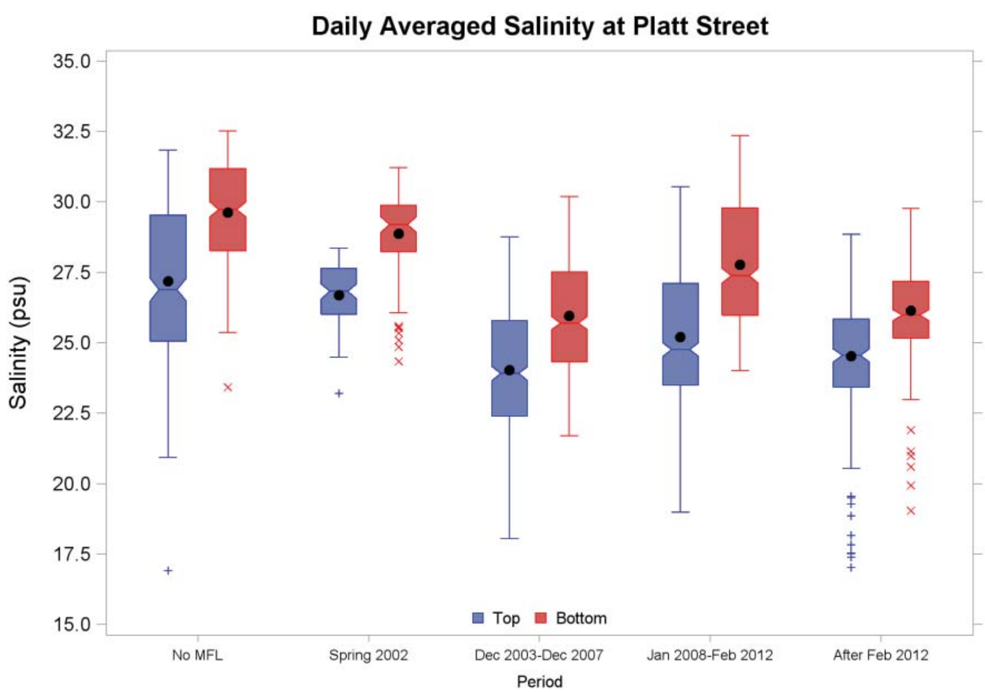


**Figure 4-17. Box and whisker plots of daily average surface and bottom salinity at the Platt Street continuous recorder during the minimum flow periods.**

## 4.2 Salinity at continuous recorders in response to minimum flow rates at the dam

Daily average salinity values at the continuous recorders were also examined as a function of the minimum flow rates that have been implemented at the dam. While the effects of climatic conditions still continue to influence salinity in the lower river, this approach more directly addresses the response of salinity at the locations of the continuous recorders to the rate of minimum flow. Plots of average daily salinity for surface and bottom waters at the continuous recorders versus flow are presented this section. Statistics were generated for top and bottom salinity in various flow classes, but no regressions or other predictive relationships were fitted to the data.

As with the time series analysis, the graphics are presented proceeding from upstream to downstream and symbols are again used to denote the minimum flow period in which each observation occurred. The total flows in the graphics are limited to flow values less than 40 cfs to better illustrate the effects of low flows on the river. Same-day flows, or the mean daily flow that occurred on the day of each salinity observation, are used in the graphics.

Each graphed flow value represents the total flows at base of the dam, which include diversions from Sulphur Springs, minimum flow releases from the reservoir, and flows over the dam spillway that occurred independent of the minimum flows. Some of the higher flow values in the graphics represent days when there were adequate flows over the spillway and minimum flows were not in effect; these are plotted as total freshwater flows greater than 8.3 cfs. In the day-to-day management of minimum flows, staff from the District and the City check the real-time flows at the dam and calculate the needed minimum flows for each day. These daily determinations of daily minimum flow are based on provisional real-time data reported on the USGS web site. Flows would sometimes change over the course of the day after the minimum flow was determined. Also, the final published values for flow at the dam (which are utilized in these graphics) would sometime differ from provisional real-time values.

### 4.2.1 Rowlett Park Drive

There was a very similar response in surface and bottom salinity at Rowlett Park, as this is a shallow site where there is generally not a large difference between surface and bottom salinity values (Figure 4-18 and Figure 4-19). Salinity values less than 5 cfs were consistent at flows of 21 cfs and greater. The stability of salinity during the period after February 2012 is again apparent, when surface and bottom salinities averaged near 2.5 psu. Greater flows at the dam (> 28 cfs) resulted in salinity typically less than 1. 5 psu, with salinity values approaching fresh water (< 0.5 psu) at flows greater than about 37 cfs.

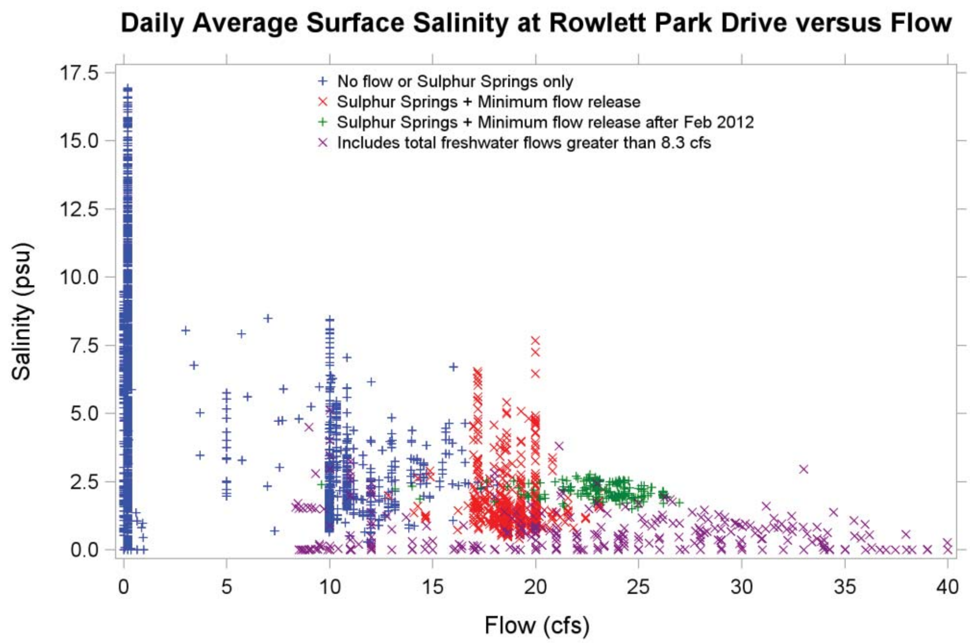


**Figure 4-18. Average daily surface salinity at the Rowlett Park continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

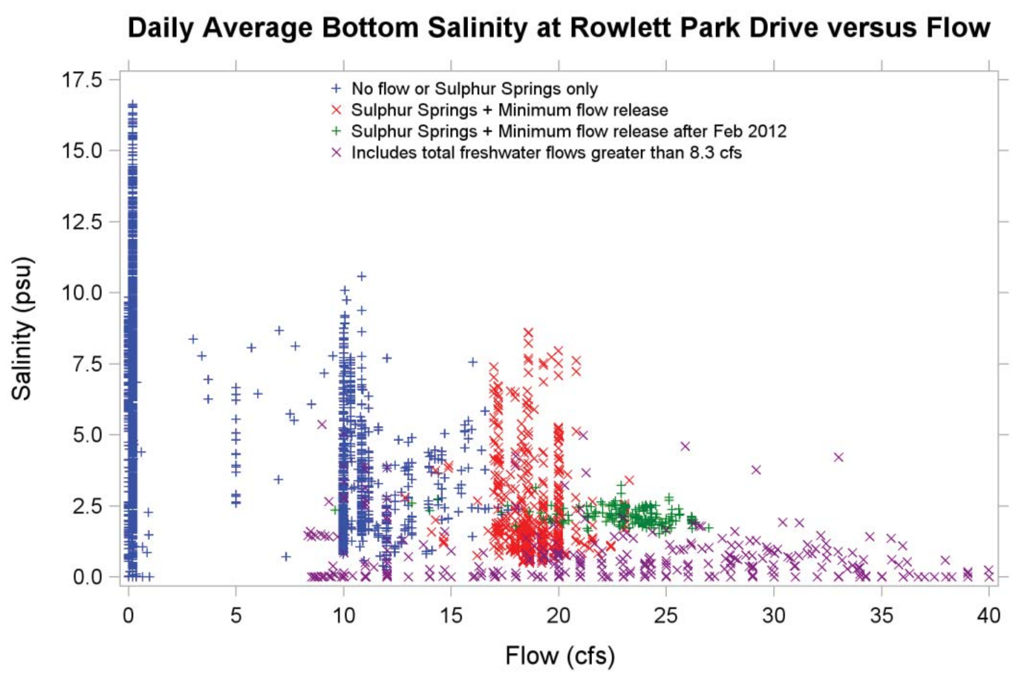


**Figure 4-19. Average daily surface salinity at the Rowlett Park continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

In order to examine salinity values within different flow ranges of flows, statistics were generated from the average daily salinity values at the Rowlett recorder for flow classes that covered a rage of three cfs, such as 20 to 22 cfs, 21 to 23 cfs, etc. The lowest flow class that was examined was 17 to 19 cfs and the highest flow class was 25 to 27 cfs. There were a few observations outside of these flow ranges, which are inclusive of the adopted minimum flow rates for the lower river that not are not adjusted by low flows at the Zephyrhills gage.

For discussion purposes, each flow class is described by the mid-point value within each class, for example 18 cfs describes the 17 to 19 cfs flow class while 26 cfs describes the 25 to 27 cfs flow class. Summary statistics for average daily salinity values for the different flow classes are listed in Tables 4-8 and 4-9 for the surface and bottom recorders at Rowlett Park. To characterize salinity in the absence of periodic flows over the dam spillway, these statistics were generated when same-day flows over the dam spillway were less than 1 cfs. These values do not include data from one of the flow categories shown in Figure 4-18 and Figure 4-19 (days with total freshwater flows greater than 8.3 cfs). However, not including those values makes the statistics more representative of the salinity values that were obtained when the minimum flows were in effect without any periodic flows over the dam spillway.

The number of observations within each flow class varied considerably. The most observations (N ranging from 134 to 202) were in three flow classes that covered between 19 and 21 cfs, as these correspond to the minimum flow rates that were in effect most often during the 11 years that minimum flows were gradually implemented. The higher flow classes correspond to when there were greater diversions from Sulphur Springs, which primarily occurred in the final minimum flow period after February 2012, thus there are fewer observations (N ranging from 22 to 64). Also listed in Tables 4-8 and 4-9 are the avereage flow quantities from both Sulphur Springs and the freshwater minimum flow releases that occurred in each flow class. There was not a clear trend in the quantity of freshwater releases from the reservoir among the flow classes. Instead, the higher flow classes correspond to greater diversions from Sulphur Springs to the base of the dam. As described in Section 2.6, these higher spring diversion rates were accompanied by slightly elevated salinity in the spring due to the lowering of the spring pool to induce spring discharge.

Mean salinity values of 2.0 to 2.2 in the surface water at the Rowlett Park recorder occurred at flow classes that covered between 24 to 26 cfs, due to the greater use of higher salinity water from Sulphur Springs. Lower mean salinity values occurred at minimum flow rates that covered between 19 and 23 cfs when less spring water was used. However, similar to the patterns shown in Figures 4-18 and 4-19, the variability of salinty was reduced at the higher minimum flow rates, as evidenced by lower values for the standard deviations and coefficients of variation (the standard deviaton divided by the mean). The maximum daily salinity values were also lower at the higher minimum flow rates, with maximum values consistently below 3 psu at flow classes from 23 to 26 cfs. A similar but not as clear a pattern was found for bottom waters (Table 4-9).

**Table 4-8. Summary statistics for average top surface salinity values at the Rowlett Park continuous recorder for nine 3-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions for used minimum flows during each flow class.**

| Rowlett Top | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Salinity (psu) | | | | | | Mean Flows (cfs) | |
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | | Reservoir_Release | Spring_Flume |
| 18 (17 to 19) | 70 | 2.7 | 1.6 | 0.60 | 0.7 | 6.5 | | 6.6 | 10.5 |
| 19 (18 to 20) | 134 | 1.5 | 0.7 | 0.47 | 0.5 | 4.6 | | 7.9 | 10.2 |
| 20 (19 to 21) | 202 | 1.5 | 0.9 | 0.62 | 0.4 | 5.4 | | 8.2 | 10.7 |
| 21 (20 to 22) | 169 | 1.7 | 1.2 | 0.69 | 0.7 | 7.7 | | 8.1 | 11.8 |
| 22 (21 to 23) | 22 | 1.8 | 0.8 | 0.42 | 0.8 | 3.4 | | 7.0 | 14.0 |
| 23 (22 to 24) | 34 | 1.8 | 0.6 | 0.31 | 0.8 | 2.7 | | 6.6 | 15.4 |
| 24 (23 to 25) | 56 | 2.2 | 0.4 | 0.16 | 1.3 | 2.7 | | 5.9 | 17.1 |
| 25 (24 to 26) | 64 | 2.1 | 0.3 | 0.12 | 1.6 | 2.6 | | 6.1 | 17.9 |
| 26 (25 to 27) | 60 | 2.0 | 0.2 | 0.09 | 1.5 | 2.4 | | 7.6 | 18.0 |

**Table 4-9. Summary statistics for average bottom surface salinity values at the Rowlett Park continuous recorder for nine 3-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions used for minimum flows during flow each flow class.**

| Rowlett Bottom | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Salinity (psu) | | | | | | Mean Flows (cfs) | |
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | | Reservoir_Release | Spring_Flume |
| 18 (17 to 19) | 70 | 3.5 | 1.9 | 0.54 | 0.7 | 7.4 | | 6.6 | 10.5 |
| 19 (18 to 20) | 134 | 1.9 | 1.2 | 0.66 | 0.5 | 6.5 | | 7.9 | 10.2 |
| 20 (19 to 21) | 202 | 2.0 | 1.8 | 0.89 | 0.5 | 8.6 | | 8.2 | 10.7 |
| 21 (20 to 22) | 169 | 1.9 | 1.4 | 0.74 | 0.7 | 8.0 | | 8.1 | 11.8 |
| 22 (21 to 23) | 22 | 2.4 | 1.9 | 0.77 | 0.8 | 7.6 | | 7.0 | 14.0 |
| 23 (22 to 24) | 34 | 1.8 | 0.6 | 0.32 | 0.8 | 2.7 | | 6.6 | 15.4 |
| 24 (23 to 25) | 56 | 2.2 | 0.4 | 0.17 | 1.4 | 3.4 | | 5.9 | 17.1 |
| 25 (24 to 26) | 64 | 2.1 | 0.3 | 0.12 | 1.6 | 2.5 | | 6.1 | 17.9 |
| 26 (25 to 27) | 60 | 2.0 | 0.2 | 0.11 | 1.5 | 2.8 | | 7.6 | 18.0 |

Significant differences in salinity values between the flow classes were examined for the Rowlett Park recorder using the one-tailed Wilcoxon rank sum test. Results of these tests are listed in Table 4-10 along with results for two other continuous recorders (Kilometer 13.6 and Hillsborough River at Sulphur Springs) with data sufficient for analysis that are in the target area for the establishment of oligohaline waters above Sulphur Springs. The tabular results are color coded so that blue shading indicates the salinity for the flow class in the row corresponding to a cell was significantly greater than the salinity for the flow class in the column corresponding to that cell. Yellow shading indicates the salinity for the flow class in the row corresponding to a cell was significantly less than the salinity for the flow class in the column corresponding to that cell.

For both the top and bottom recorders at Rowlett Park, the pattern of significantly greater salinity at the higher flow classes is shown, likely due to the diversion of greater amounts of flow from Sulphur Springs. However, salinity at 26 cfs was less than at the flow classes of 24 and 25 cfs, which may have been due to a somewhat average higher reservoir release that corresponded to the 26 cfs flow class. Another exception to this pattern was that salinity in the 18 cfs flow class was greater than all other flow classes for bottom waters and greater than flow classes from 19 to 23 cfs for surface waters. This exception is likely attributable to the relatively low e average rate of reservoir release for the 18 cfs flow class (Table 4-8 and Table 4-9).

**Table 4-10. Probability values (p) for Type 1 error for one-tailed Wilcoxon rank sum tests for differences in salinity between flow classes for the Rowlett Park, kilometer 13.6 and Hillsborough River at Sulphur Springs continuous recorders. Blue shading indicates the salinty for the flow class in the corresponding row was signficantly ($p < 0.05$) greater than salinity for the flow class in the corresponding column, while yellow shading incates the salinity for the flow class in the correspoding row was signficantly less than salinity in the flow class for the corresponding column.**

**Rowlett Park Drive - Top**

| Flow class (cfs) | 18 (17 - 19) | 19 (18 - 20) | 20 (19 - 21) | 21 (20 - 22) | 22 (21 - 23) | 23 (22 - 24) | 24 (23 - 25) | 25 (24 - 26) |
|---|---|---|---|---|---|---|---|---|
| 19 (18 - 20) | <.0001 | | | | | | | |
| 20 (19 - 21) | <.0001 | .045 | | | | | | |
| 21 (20 - 22) | <.0001 | .147 | .0006 | | | | | |
| 22 (21 - 23) | .012 | .028 | .004 | .068 | | | | |
| 23 (22 - 24) | .020 | .0002 | <.0001 | .002 | .404 | | | |
| 24 (23 - 25) | .468 | <.0001 | <.0001 | <.0001 | .006 | .002 | | |
| 25 (24 - 26) | .321 | <.0001 | <.0001 | <.0001 | .014 | .027 | .157 | |
| 26 (25 - 27) | .460 | <.0001 | <.0001 | <.0001 | .072 | .331 | .0003 | .001 |

**Rowlett Park Drive - Bottom**

| Flow class (cfs) | 18 (17 - 19) | 19 (18 - 20) | 20 (19 - 21) | 21 (20 - 22) | 22 (21 - 23) | 23 (22 - 24) | 24 (23 - 25) | 25 (24 - 26) |
|---|---|---|---|---|---|---|---|---|
| 19 (18 - 20) | <.0001 | | | | | | | |
| 20 (19 - 21) | <.0001 | .056 | | | | | | |
| 21 (20 - 22) | <.0001 | .303 | .110 | | | | | |
| 22 (21 - 23) | .007 | .041 | .013 | .041 | | | | |
| 23 (22 - 24) | <.0001 | .081 | .110 | .048 | .317 | | | |
| 24 (23 - 25) | .004 | <.0001 | <.0001 | <.0001 | .032 | .001 | | |
| 25 (24 - 26) | .003 | <.0001 | <.0001 | <.0001 | .162 | .095 | .004 | |
| 26 (25 - 27) | .001 | <.0001 | <.0001 | <.0001 | .415 | .451 | <.0001 | .009 |

**Kilometer 13.6 - Top**

| Flow class (cfs) | 18 (17 - 19) | 19 (18 - 20) | 20 (19 - 21) | 21 (20 - 22) | 22 (21 - 23) | 23 (22 - 24) | 24 (23 - 25) | 25 (24 - 26) |
|---|---|---|---|---|---|---|---|---|
| 19 (18 - 20) | <.0001 | | | | | | | |
| 20 (19 - 21) | .0002 | .368 | | | | | | |
| 21 (20 - 22) | <.0001 | .366 | .498 | | | | | |
| 22 (21 - 23) | .304 | .028 | .035 | .066 | | | | |
| 23 (22 - 24) | <.0001 | .151 | .248 | .248 | .092 | | | |
| 24 (23 - 25) | <.0001 | .286 | .213 | .131 | .123 | .084 | | |
| 25 (24 - 26) | <.0001 | .011 | .038 | .049 | .030 | .287 | .0005 | |
| 26 (25 - 27) | <.0001 | <.0001 | <.0001 | .0001 | .0009 | .011 | <.0001 | .007 |

**Kilometer 13.6 - Bottom**

| Flow class (cfs) | 18 (17 - 19) | 19 (18 - 20) | 20 (19 - 21) | 21 (20 - 22) | 22 (21 - 23) | 23 (22 - 24) | 24 (23 - 25) | 25 (24 - 26) |
|---|---|---|---|---|---|---|---|---|
| 19 (18 - 20) | <.0001 | | | | | | | |
| 20 (19 - 21) | .006 | .039 | | | | | | |
| 21 (20 - 22) | <.0001 | .169 | .002 | | | | | |
| 22 (21 - 23) | .166 | .496 | .405 | .284 | | | | |
| 23 (22 - 24) | .004 | .485 | .157 | .266 | .500 | | | |
| 24 (23 - 25) | <.0001 | .041 | .002 | .221 | .148 | .049 | | |
| 25 (24 - 26) | <.0001 | .0001 | <.0001 | .002 | .118 | .001 | .097 | |
| 26 (25 - 27) | <.0001 | .0005 | <.0001 | .006 | .088 | .004 | .076 | .500 |

**Hillsborough River at Sulphur Springs - Top**

| Flow class (cfs) | 18 (17 - 19) | 19 (18 - 20) | 20 (19 - 21) | 21 (20 - 22) | 22 (21 - 23) | 23 (22 - 24) | 24 (23 - 25) | 25 (24 - 26) |
|---|---|---|---|---|---|---|---|---|
| 19 (18 - 20) | <.0001 | | | | | | | |
| 20 (19 - 21) | .0002 | .035 | | | | | | |
| 21 (20 - 22) | .0002 | .065 | .453 | | | | | |
| 22 (21 - 23) | .468 | .113 | .173 | .168 | | | | |
| 23 (22 - 24) | <.0001 | .041 | .014 | .011 | .029 | | | |
| 24 (23 - 25) | <.0001 | .026 | .004 | .003 | .043 | .445 | | |
| 25 (24 - 26) | <.0001 | <.0001 | <.0001 | <.0001 | .0001 | .0004 | .004 | |
| 26 (25 - 27) | <.0001 | .002 | .0004 | .0002 | .005 | .249 | .167 | .037 |

**Hillsborough River at Sulphur Springs - Bottom**

| Flow class (cfs) | 18 (17 - 19) | 19 (18 - 20) | 20 (19 - 21) | 21 (20 - 22) | 22 (21 - 23) | 23 (22 - 24) | 24 (23 - 25) | 25 (24 - 26) |
|---|---|---|---|---|---|---|---|---|
| 19 (18 - 20) | 0.006 | | | | | | | |
| 20 (19 - 21) | .446 | .013 | | | | | | |
| 21 (20 - 22) | .002 | .296 | .002 | | | | | |
| 22 (21 - 23) | .097 | .013 | .088 | .009 | | | | |
| 23 (22 - 24) | .0007 | .071 | .009 | .102 | .006 | | | |
| 24 (23 - 25) | .017 | .274 | .028 | .413 | .014 | .122 | | |
| 25 (24 - 26) | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | .004 | .0002 | |
| 26 (25 - 27) | <.0001 | .0008 | <.0001 | .004 | .0006 | .244 | .038 | .046 |

### 4.2.2 Hannah's Whirl

The data for Hannah's Whirl only include days when there was either no minimum flow, minimum flows provided only by Sulphur Springs diversions, or flows over the reservoir spillway that were not released for minimum flows. Minimum flows of solely springwater in the range of 10 to 13 cfs had wide variation in salinity, with surface salinity values in this flow range averaging 3.6 psu, and bottom salinity values averaging 5.6 psu. Flows over the reservoir spillway above 13 cfs frequently produced freshwater conditions at this site, although higher salinity values near 2.5 psu were observed at some higher flow rates (Figure 4-20). Bottom salinity showed a similar response, but at somewhat higher salinity values (Figure 4-21). Statistics were not generated for this recorder due to the limited range of minimum flows that were achieved.

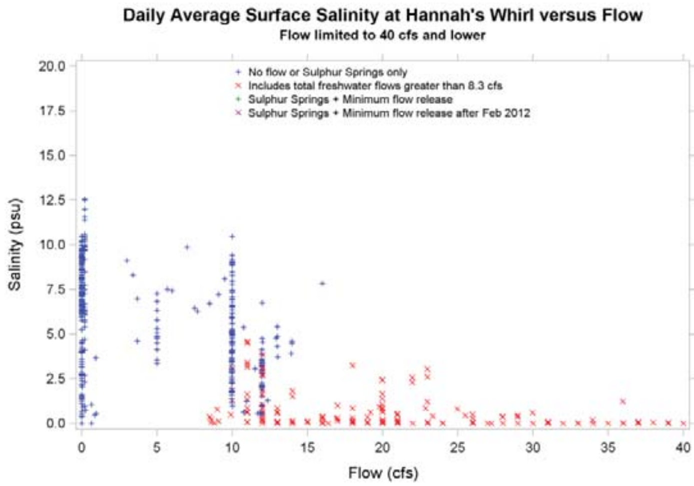


**Figure 4-20. Average daily surface salinity at the Hannah's whirl continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

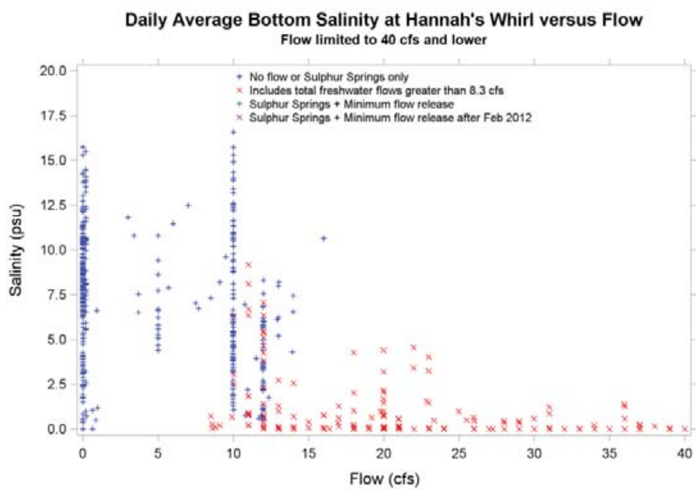


**Figure 4-21. Average daily bottom salinity at the Hannah's Whirl continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

### 4.2.3 Kilometer 13.6

The response of salinity at the EPCHC recorder at kilometer 13.6 also shows an apparent breakpoint in the relationship with flow, with surface salinity values of less than 5 psu nearly consistent at flows above 21 cfs and consistent at flows of 24 cfs and above except for a value near 5 psu on one day (Figure 4-22). Bottom salinity values showed breakpoints in the same flow ranges, but at higher salinity values (Figure 4-23). However, there was more scatter at higher flows, as the bottom waters do no respond as readily to changes in same-day flows at the dam compared to surface values.

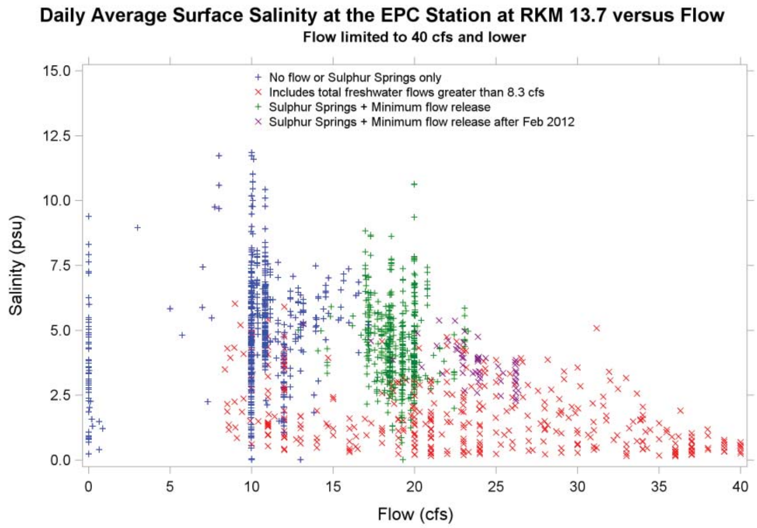


**Figure 4-22. Average daily surface salinity at the kilometer 13.6 continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

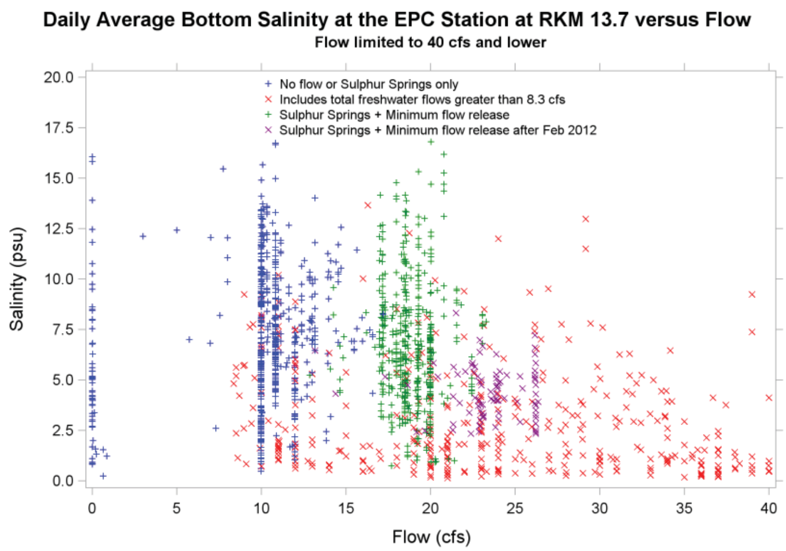


**Figure 4-23. Average daily surface salinity at the kilometer 13.6 continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

Summary statitics for salinity in the surface and bottom waters at the recorder at kilometer 13.6 are listed in Tables 4-11 and 4-12 for the same flow classes identified for the Rowlett Park recorder site. Maximum salinity values and the variation of saliny were again reduced at the higher flow classes, with maximum salinity values of less than 10 psu restricted to flow classes of above 22 cfs for top waters and above 23 for bottom waters. Salinity in surface waters was signficanly less for the 25 and 26 cfs flow classes compared to all lesser flow classes with one exception (refer to Table 4-10). In bottom waters there was not a tendency for salinty to be significantly less until the flow classes reached 24 to 26 cfs. Mean salinity values less than 5 psu were only achieved in bottom waters at a flow classes of 25 and 26 cfs.

**Table 4-11. Summary statistics for average top surface salinity values at the kilometer 13.6 continuous recorder for nine 3-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions used for minimum flows during each flow class.**

| Kilometer 13.6 Top | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Salinity (psu) | | | | | | Mean Flows (cfs) | |
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | | Reservoir_Release | Spring_Flume |
| 18 (17 to 19) | 70 | 5.5 | 1.4 | 0.25 | 2.2 | 8.8 | | 6.2 | 10.9 |
| 19 (18 to 20) | 101 | 4.2 | 1.1 | 0.25 | 1.8 | 6.4 | | 7.9 | 10.3 |
| 20 (19 to 21) | 169 | 4.2 | 1.5 | 0.37 | 0.0 | 8.6 | | 8.2 | 10.7 |
| 21 (20 to 22) | 146 | 4.3 | 1.7 | 0.38 | 1.3 | 10.6 | | 8.2 | 11.7 |
| 22 (21 to 23) | 15 | 5.2 | 1.8 | 0.35 | 2.8 | 7.4 | | 8.1 | 12.8 |
| 23 (22 to 24) | 14 | 3.9 | 1.0 | 0.25 | 2.0 | 5.4 | | 7.4 | 14.6 |
| 24 (23 to 25) | 22 | 4.3 | 0.8 | 0.18 | 2.7 | 5.9 | | 6.7 | 16.3 |
| 25 (24 to 26) | 16 | 3.6 | 0.5 | 0.14 | 2.6 | 4.8 | | 7.4 | 16.5 |
| 26 (25 to 27) | 22 | 3.2 | 0.5 | 0.17 | 2.3 | 3.9 | | 8.3 | 17.8 |

**Table 4-12. Summary statistics for average bottom salinity values at the kilometer 13.6 continuous recorder for nine three-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions used for minimum flows during each flow class.**

| Kilometer 13.6 Bottom | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Salinity (psu) | | | | | | Mean Flows (cfs) | |
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | | Reservoir_Release | Spring_Flume |
| 18 (17 to 19) | 68 | 7.9 | 2.5 | 0.32 | 3.2 | 14.2 | | 6.2 | 10.9 |
| 19 (18 to 20) | 103 | 6.3 | 2.7 | 0.43 | 0.7 | 14.8 | | 7.8 | 10.3 |
| 20 (19 to 21) | 163 | 6.9 | 3.1 | 0.45 | 1.0 | 15.3 | | 8.2 | 10.7 |
| 21 (20 to 22) | 123 | 5.9 | 2.9 | 0.49 | 0.9 | 16.8 | | 8.2 | 11.7 |
| 22 (21 to 23) | 18 | 7.5 | 5.2 | 0.70 | 1.0 | 16.2 | | 7.6 | 13.4 |
| 23 (22 to 24) | 23 | 6.1 | 2.1 | 0.34 | 2.3 | 9.5 | | 7.2 | 14.8 |
| 24 (23 to 25) | 34 | 5.3 | 1.9 | 0.36 | 2.4 | 8.2 | | 6.1 | 16.9 |
| 25 (24 to 26) | 22 | 4.4 | 0.8 | 0.18 | 2.7 | 6.3 | | 7.1 | 16.8 |
| 26 (25 to 27) | 27 | 4.5 | 1.4 | 0.32 | 2.3 | 7.2 | | 8.3 | 17.8 |

Similar to the Rowlett Park site, there was a clear trend in lower maximum values and reduced variability in salinity at the higher flow classes for both surface and bottom waters at the kilometer 13.6 recorder. Maximum values less than 5 psu were limted to flow classes of 25 and 26 cfs in surface waters, while an apparent breakpoint in bottom waters occurred at a flow class of 23 cfs, with maximum salinity values of 9.5 psu or less above that flow rate and maximum values of 14.2 psu or greater at flows classes less than 23 cfs.

Because of its location, the recorder at kilometer 13.6 is very useful for evaluating the effectiveness of the minimum flows in the reach of the river below Hannah's Whirl. As described in page 4-3, this recorder presents about 74% of the volume of the minimum flow target area between the dam and Sulphur Springs. At this location, the increased use of Sulphur Springs does not seem to cause a rise in salinity as it did at Rowlett Park, possibly due to the mixing of spring and river water between the dam and kilometer 13.6. The results indicate that greater volumes of low salinity water reach the recorder at kilometer 13.6 at the higher flow classes.

Caution, however, is urged in interpreting the results of salinity versus flow at this recorder and all other locations in the river. Because the minimum flows have been implemented gradually over time, the number of observations differ greatly between flow classes with relatively low number of observations for flow classes of 22 cfs and above. Also, there are the potentially confounding influences of tides and climate in the data. As previously discussed, the higher minimum flows rates that were achieved were limited to the last 15 months of the study period (starting in March 2012). Differences in rainfall, ungaged runoff, periodic flow over dam, and salinity in Hillsborough Bay during the final minimum flow period influence these results compared to other periods. Furthermore, data from March through the mid-June in 2012 during the final minimum flow period were collected during very dry conditions (see Table 2-1 and Figures 2-17 and 2-18). Thus, the results from the spring of 2012 are useful for evaluating the effectiveness of the higher minimum flow rates during dry conditions.

### 4.2.4 Hillsborough River at Sulphur Springs

Plots of average daily salinity versus flow for the surface, mid-depth and bottom depths at the Hillsborough River at Sulphur Springs recorder are shown in Figures 4-24, 4-25 and 4-26. The elevations of these sensors are at -0.5, -1.1, and -2.0 meters deep relative to NGVD 1929. The response of salinity varies with depth, being most responsive to flow in the surface waters. As with other recorders located upriver, there is an apparent break in the relationship around 21 to 22 cfs, with the flows after February 2012 in the range of 23 to 26 cfs resulting in surface salinity typically in the range of 2.5 to 9 psu. Total flows above 27 cfs typically resulted in slightly lower salinity values, though there is considerable scatter in the relationship. At flows in the range of 8 to 20 cfs, there is not a strong relationship between surface salinity and flow at this site. In this range, the switch from diversions solely from Sulphur Springs to the addition of releases from the reservoir does not appear to make any difference in salinity. However, differences in climatic conditions between these two periods may have influenced the results.

Higher salinity values and a much more subdued response to flow were observed for mid and bottom depths. There appears to be little relationship with flow in the range of 8 to 20 cfs. In addition, the response to flow at flows greater than 22 cfs is much weaker than in the surface waters, but again it is likely that climatic factors influence the results. The mid-depth sensor is only 2 feet below the surface sensor at this recorder and the differences between the surface and mid-depth values reflect a high degree of salinity stratification that is frequently observed at this site. Though the mid-depth and bottom sensors differ by 3 feet in depth, the salinity values and response to flow are fairly similar, indicating that the most pronounced stratification in the water column occurs at relatively shallow depths.

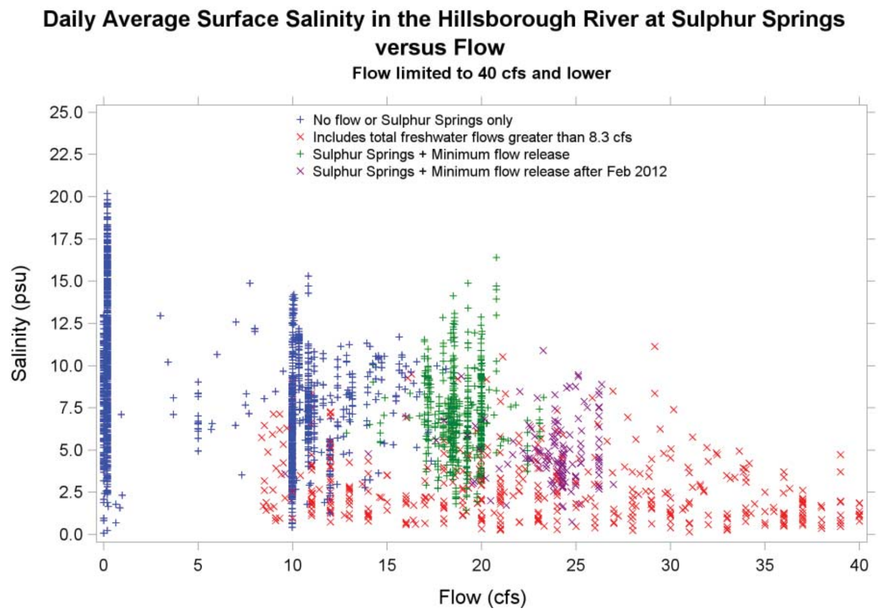


**Figure 4-24. Average daily surface salinity at the Hillsborough River at Sulphur Springs continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

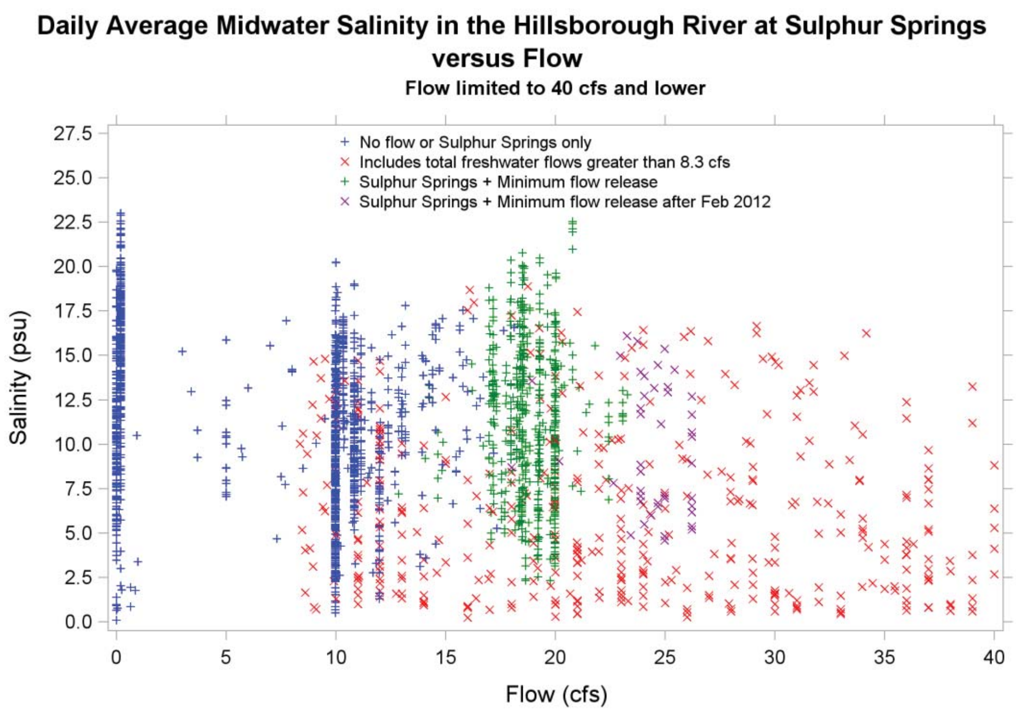


**Figure 4-25. Average daily mid-depth salinity at the Hillsborough River at Sulphur Springs continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

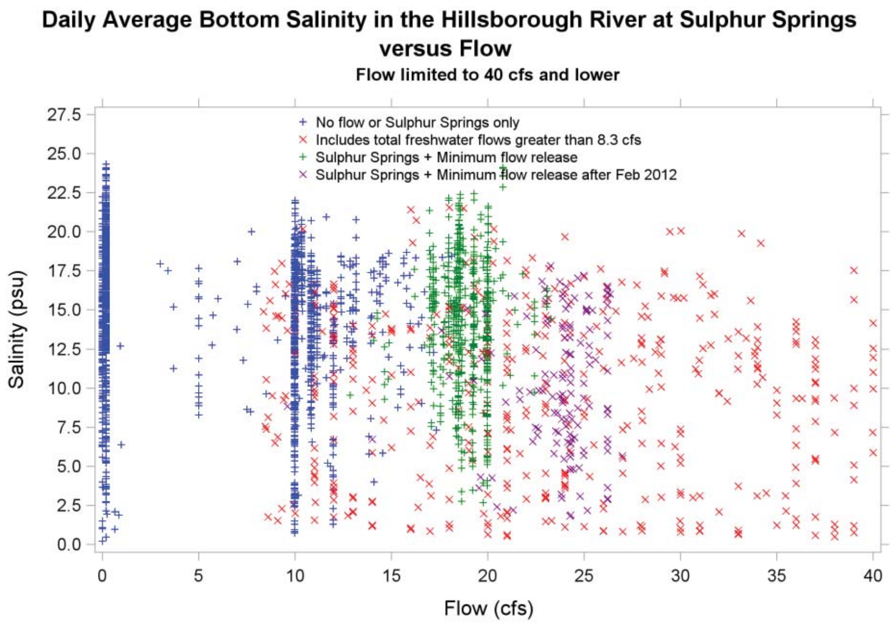


**Figure 4-26. Average daily bottom salinity at the Hillsborough River at Sulphur Springs continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

Summary statistics for salinity values in nine flow classes for surface and bottom waters at the Hillsborough River at Sulphur Springs recorder are listed in Tables 4-13 and 4-14. There was a general trend of decreasing mean surface salinity with mean values of 5.7 psu or less at flow classes of 23 cfs and greater. Salinity in the flow classes of 23 and greater was significantly less than in the lower flow classes (refer to Table 4-10), indicating a break in the data at that flow rate. The lowest mean salinity of 4.4 psu occurred at a flow class of 25 cfs, although a mean of 5.4 psu was found at the next higher flow class. Salinity in the 26 cfs flow class was significantly greater than at 25 cfs. Also, the 22 cfs flow class for bottom water had the highest mean value, and significantly greater salinity than two lower flow classes (refer to Table 4-10), illustrating that caution should be used in interpreting these results due to the relatively low numbers of observations and the influence of other confounding factors.

**Table 4-13. Summary statistics for average top surface salinity values at the Hilsborough River at Sulpur Springs continuous recorder for nine 3-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions used for minimum flows during each flow class.**

| Hillsbororough River at Sulphur Springs Top | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Salinity (psu) | | | | | Mean Flows (cfs) | |
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | Reservoir_Release | Spring_Flume |
| 18 (17 to 19) | 75 | 7.9 | 2.0 | 0.25 | 2.9 | 11.6 | 6.1 | 11.0 |
| 19 (18 to 20) | 134 | 6.5 | 2.0 | 0.31 | 2.7 | 12.9 | 7.8 | 10.4 |
| 20 (19 to 21) | 200 | 6.9 | 2.6 | 0.38 | 1.5 | 14.9 | 8.2 | 10.6 |
| 21 (20 to 22) | 166 | 6.8 | 2.3 | 0.34 | 1.9 | 12.9 | 8.1 | 11.8 |
| 22 (21 to 23) | 17 | 8.5 | 4.5 | 0.53 | 1.7 | 16.4 | 7.7 | 13.2 |
| 23 (22 to 24) | 16 | 5.6 | 1.4 | 0.25 | 3.8 | 8.5 | 7.0 | 15.2 |
| 24 (23 to 25) | 27 | 5.7 | 1.6 | 0.28 | 3.9 | 10.9 | 6.8 | 16.3 |
| 25 (24 to 26) | 50 | 4.4 | 1.5 | 0.33 | 1.6 | 8.3 | 6.0 | 18.1 |
| 26 (25 to 27) | 44 | 5.4 | 2.3 | 0.43 | 0.8 | 9.5 | 7.7 | 17.9 |

Due to vertical stratification at this site, mean salinity values in bottom waters were considerably higher for all flow classes. There was a general trend for lower mean values at the higher flow classes, with mean bottom salinity values less than 11 psu for flow classes of 25 and 26 cfs, which were significantly less than for the lower flow classes (Table 4-10).

**Table 4-14. Summary statistics for average bottom surface salinity values at the Hilsborough River at Sulpur Springs continuous recorder for nine 3-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions used for minimum flows during each flow class.**

| Hillsborerough River at Sulphur Springs Bottom | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Salinity (psu) | | | | | Mean Flows (cfs) | |
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | Reservoir_Release | Spring_Flume |
| 18 (17 to 19) | 75 | 14.9 | 2.9 | 0.20 | 7.3 | 21.3 | 6.1 | 11.0 |
| 19 (18 to 20) | 136 | 13.7 | 3.6 | 0.27 | 6.4 | 22.1 | 7.8 | 10.4 |
| 20 (19 to 21) | 200 | 14.6 | 4.5 | 0.31 | 2.8 | 22.4 | 8.2 | 10.6 |
| 21 (20 to 22) | 166 | 13.2 | 4.4 | 0.33 | 2.4 | 21.6 | 8.1 | 11.8 |
| 22 (21 to 23) | 17 | 16.4 | 6.2 | 0.38 | 2.2 | 24.1 | 7.7 | 13.2 |
| 23 (22 to 24) | 16 | 12.2 | 3.1 | 0.26 | 6.6 | 17.3 | 7.0 | 15.2 |
| 24 (23 to 25) | 25 | 13.0 | 3.6 | 0.28 | 5.8 | 17.8 | 6.7 | 16.4 |
| 25 (24 to 26) | 50 | 9.3 | 4.0 | 0.43 | 1.8 | 16.8 | 6.0 | 18.1 |
| 26 (25 to 27) | 44 | 10.9 | 4.7 | 0.43 | 2.2 | 17.2 | 7.7 | 17.9 |

### 4.2.5 Sligh Avenue

Similar to the recorder in the river at Sulphur Springs, salinity in the surface waters at Sligh Avenue are much more responsive to the rate of flow than the bottom waters (Figure 4-27 and Figure 4-28). Surface salinity values in the flow range of 22 to 27 cfs averaged 6.6 cfs, while bottom salinity values in this flow range averaged 15.0 psu, reflecting the high degree of vertical salinity stratification in this part of the river. Surface salinity values were typically less than 5 psu at flows above 27 cfs, but bottom salinity values were generally above 10 psu in this flow range. An interesting pattern was observed in bottom waters in which the diversions from Sulphur Springs that were matched with releases from the reservoir tended to be as high as or higher than the preceding period when only diversions from Sulphur Springs were employed. However, salinity was lower in the period after February 2012 when the highest minimum flow rates were in effect.

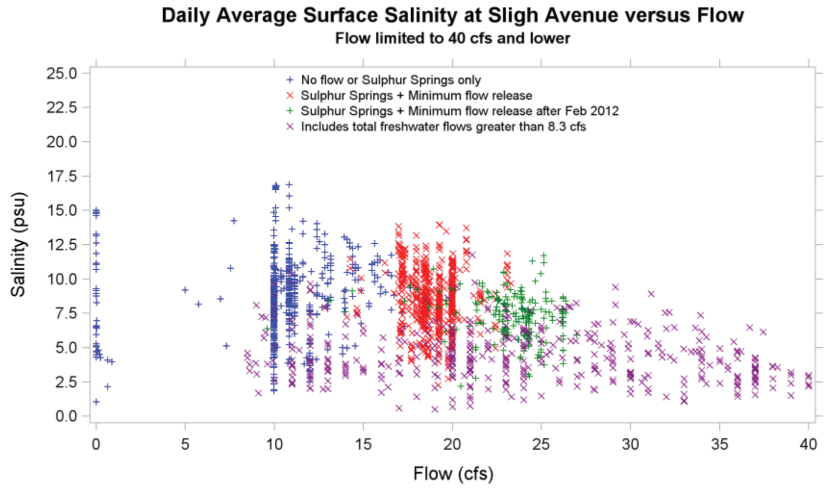


**Figure 4-27. Average daily surface salinity at the Sligh Avenue continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

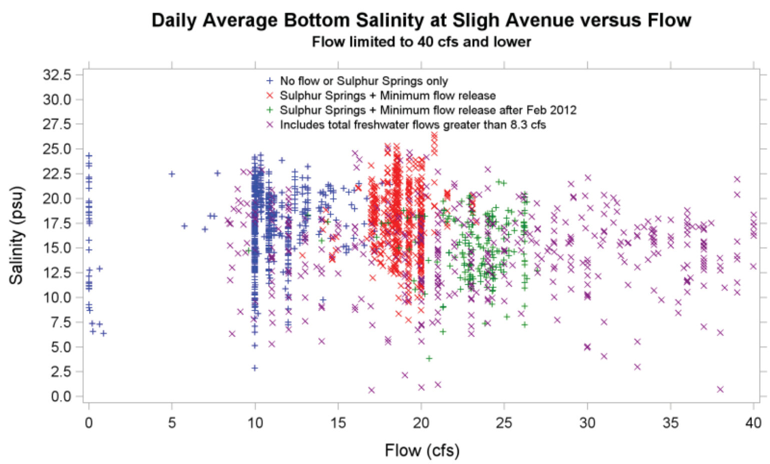


**Figure 4-28. Average daily bottom salinity at the Sligh Avenue continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

Summary statistics for salinity values in three-cfs flow classes for surface and bottom waters at the Sligh Avenue recorder are listed in Tables 4-15 and 4-16. There was not strong a tendency in reduced salinty with increased minimum flows, although mean values in both surface and bottom waters were slightly less than mean values at the lower flow classes. What is clear are the much higher values in bottom waters for all flow classses, reflecting the vertical salinity stratification in at this location. Mean salinty values were generally about twice the values in surface waters for all flow classes. The results of statistical tests for differeces in salinty among flow classes are not presented for the Sligh Avenue and Platt Street recorders as these sites are outside the priority target area for the establishment of oligohaline conditions.

**Table 4-15. Summary statistics for average top surface salinity values at the Sligh Avenue continuous recorder for nine 3-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions used for minimum flows during each flow class.**

| | | Salinity (psu) | | | | | Mean Flows (cfs) | |
|---|---|---|---|---|---|---|---|---|
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | Reservoir_Release | Spring_Flume |
| 17 to 19 | 76 | 9.6 | 2.2 | 0.23 | 4.2 | 13.8 | 6.1 | 11.0 |
| 18 to 20 | 136 | 8.3 | 1.8 | 0.21 | 4.0 | 13.2 | 7.8 | 10.4 |
| 19 to 21 | 178 | 8.1 | 2.0 | 0.25 | 2.3 | 14.0 | 8.2 | 10.7 |
| 20 to 22 | 168 | 8.3 | 2.0 | 0.24 | 2.2 | 13.5 | 8.1 | 11.8 |
| 21 to 23 | 20 | 8.8 | 3.1 | 0.36 | 2.8 | 13.7 | 6.9 | 14.2 |
| 22 to 24 | 34 | 8.0 | 1.3 | 0.16 | 5.0 | 9.7 | 6.6 | 15.4 |
| 23 to 25 | 55 | 7.9 | 1.6 | 0.21 | 4.8 | 11.9 | 5.8 | 17.2 |
| 24 to 26 | 64 | 6.9 | 1.4 | 0.21 | 2.9 | 9.4 | 6.1 | 17.9 |
| 25 to 27 | 60 | 7.2 | 1.8 | 0.25 | 3.7 | 11.7 | 7.6 | 18.0 |

**Table 4-16. Summary statistics for average bottom salinity values at the Sligh Avenue continuous recorder for nine three-cfs flow classes on days when flows from the dam spillway were less than 1 cfs. Also listed are mean values for reservoir releases and spring diversions used for minimum flows during each flow class.**

| | | Salinity (psu) | | | | | Mean Flows (cfs) | |
|---|---|---|---|---|---|---|---|---|
| Flow Class (cfs) | N | Mean | Std | Coef. Var. | Min | Max | Reservoir_Release | Spring_Flume |
| 17 to 19 | 75 | 18.3 | 2.1 | 0.11 | 12.0 | 23.3 | 6.1 | 11.0 |
| 18 to 20 | 128 | 17.6 | 3.1 | 0.18 | 12.4 | 25.3 | 7.8 | 10.4 |
| 19 to 21 | 194 | 18.3 | 3.7 | 0.20 | 7.7 | 25.3 | 8.2 | 10.7 |
| 20 to 22 | 161 | 16.7 | 3.4 | 0.20 | 3.8 | 23.9 | 8.1 | 11.8 |
| 21 to 23 | 18 | 18.7 | 6.0 | 0.32 | 6.5 | 26.4 | 6.7 | 14.3 |
| 22 to 24 | 26 | 16.8 | 2.7 | 0.16 | 10.9 | 20.6 | 6.1 | 15.8 |
| 23 to 25 | 54 | 15.8 | 3.0 | 0.19 | 10.9 | 20.4 | 5.8 | 17.2 |
| 24 to 26 | 53 | 14.4 | 2.8 | 0.19 | 7.4 | 18.7 | 5.7 | 18.4 |
| 25 to 27 | 57 | 15.8 | 3.1 | 0.20 | 7.3 | 21.7 | 7.6 | 18.1 |

### 4.2.6 Platt Street

As with the time series plots, the graphic of salinity versus flow at Platt Street shows a difference from the other sites, in that salinity values recorded during the period between Jan 2008 to February 2012 were frequently as high or higher than salinity during the previous period when only diversions from Sulphur Springs were implemented and the total minimum flow rate was lower (Figure 4-29 and Figure 4-30). Again, the effects of climatic conditions and changes in bay salinity during the study period may have influenced these results.

There does, however, appear to be a general relationship with flow, with one exception, surface salinity values above 25 psu did not occur at total flows greater than 27 cfs. Similarly, bottom salinity values were generally lower at total flow rates above 27 cfs. Total flow values greater than 24 to 27 cfs occurred when there was some flow at the dam spillway in addition to minimum flow releases. However, it should be noted that when there are flows at the spillway the reservoir is full, there has generally been some appreciable rainfall in the watershed, and stormwater runoff below the dam likely plays more of a factor on salinity in the river than during prolonged periods of no flow at the dam spillway.

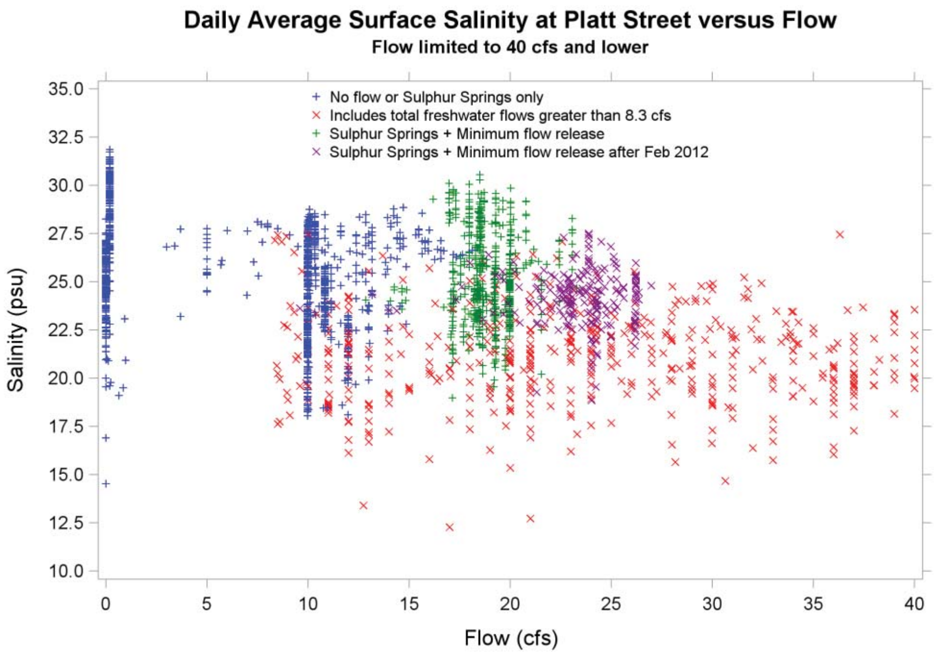


**Figure 4-29. Average daily surface salinity at the Platt Street continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

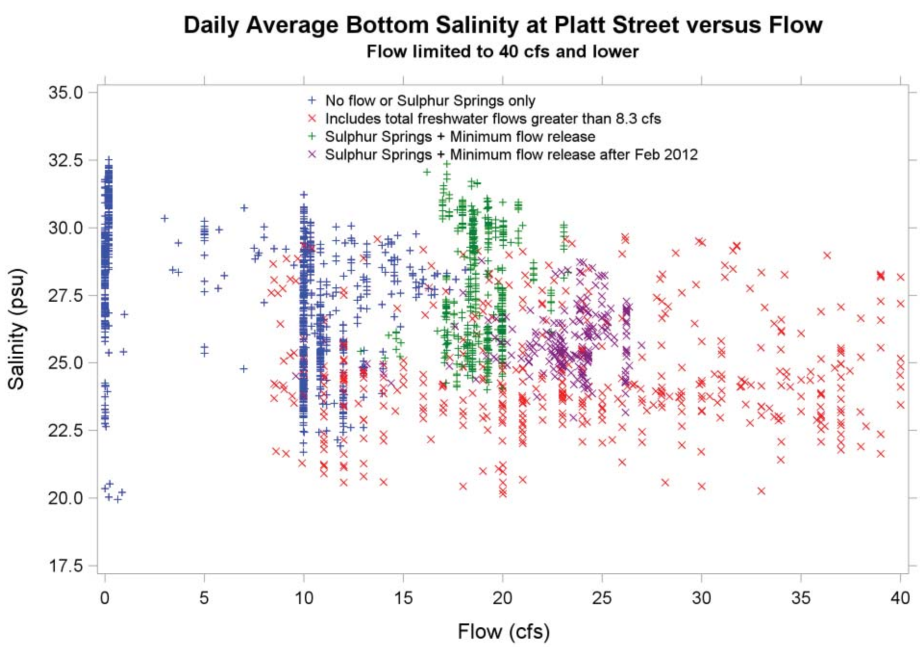


**Figure 4-30. Average daily bottom salinity at the Platt Street continuous recorder versus same-day total flow at the base of the Hillsborough River Dam.**

Summary statistics for salinity values in 3-cfs flow classes for surface and bottom waters at Platt St. are listed in Tables 4-17**.** There is no apparent relationship between the minimum flow rates and mean surface salinity at this site at flow less than 27 cfs, as climatic conditions and the salinity of Hillsborough Bay exert strong effects on salinity at this site.

**Table 4-17. Summary statistics for average bottom salinity values at the Platt St. continuous recorder for nin 3 cfs flow classes that cover three cfs on days when flows from the dam spillway were less than 1 cfs. . Also listed are mean values for reservoir releases and spring diversions used for minimum flows during each flow class.**

| | | Salinity (psu) | | | | | Mean Flows (cfs) | |
|---|---|---|---|---|---|---|---|---|
| **Flow Class (cfs)** | **N** | **Mean** | **Std** | **Coef. Var.** | **Min** | **Max** | **Reservoir_Release** | **Spring_Flume** |
| **17 to 19** | 70 | 25.4 | 2.8 | 0.11 | 19.0 | 30.1 | 6.0 | 11.1 |
| **18 to 20** | 135 | 25.1 | 2.2 | 0.09 | 21.4 | 30.1 | 7.8 | 10.4 |
| **19 to 21** | 200 | 25.5 | 2.4 | 0.10 | 19.5 | 30.5 | 8.2 | 10.7 |
| **20 to 22** | 169 | 24.7 | 1.8 | 0.07 | 20.4 | 29.8 | 8.1 | 11.8 |
| **21 to 23** | 22 | 25.8 | 2.4 | 0.09 | 19.3 | 29.2 | 7.0 | 14.0 |
| **22 to 24** | 34 | 24.6 | 1.5 | 0.06 | 20.2 | 27.1 | 6.6 | 15.4 |
| **23 to 25** | 56 | 24.7 | 1.4 | 0.06 | 22.5 | 28.3 | 5.9 | 17.1 |
| **24 to 26** | 64 | 24.0 | 1.8 | 0.08 | 18.9 | 27.5 | 6.1 | 17.9 |
| **25 to 27** | 60 | 24.2 | 1.3 | 0.05 | 21.7 | 27.1 | 7.6 | 18.0 |

## 4.3 Vertical profile salinity data

Vertical profile measurements of salinity and other *in situ* parameters (dissolved oxygen, pH, and water temperature) have been made in the study area by three agencies; the Southwest Florida Water Management District, the EPCHC, and TBW. After reviewing the periods of record and the sampling designs of data collection programs by these three agencies, it was concluded that the vertical profile data available from the District and TBW would be analyzed for this minimum flows assessment. Data available from these sampling programs are informative because they include vertical profiles of *in situ* water quality parameters at a wide range of locations distributed across the study area.

Data collected by the District were from 17 fixed location stations located between kilometers 10.4 and 16.0. On each sampling date, surface, bottom and 1 meter increment vertical salinity profiles were obtained at each station by boat. A total of 61 sampling trips were conducted from March 2002 through May 2013. The profile data for TBW were collected as part of the HBMP required as a condition of their water use permit issued for diversion of water from the Hillsborough River during high flows for potable supply. Vertical profile measurements collected by boat for the HBMP were distributed using a probabilistic design in which six longitudinal strata (i.e., segments) on the Lower Hillsborough River were randomly sampled during each sampling trip. Vertical profile data were also included from the benthic invertebrate sampling program and the ichthyoplankton program that are conducted as part the HBMP. Details of all components the HBMP sampling program can be found in reports submitted by TBW to the District (TBW, 1999, 2006, 2010). Vertical profile data from the HBMP program above kilometer 10.6 were analyzed for this project. Data from the HBMP that were available for analysis in this study were collected on 520 separate dates during the period from April 12, 2000 to September 12, 2012, with an average of 3.8 profiles taken on each date.

Vertical profile data from the District and the HBMP were combined into one data base with date and the river kilometer of collection as unique, identifying variables. Based on data from the continuous recorders and previous assessment of the lower river, it was known that the relationships of the minimum flows with salinity and dissolved oxygen vary considerably depending on the distance from the dam. In order to best evaluate the effectiveness of the minimum flows, the vertical profile data were analyzed in seven river segments that extended from just above Sligh Avenue (kilometer 10.6) to the dam (Figure 4-31). The two segments downstream of kilometer 12.6 were included to evaluate how river segments immediately below Sulphur Springs respond to the minimum flows and provide information concerning how the resulting physical-chemical characteristics there might influence the ecology of the river above Sulphur Springs.

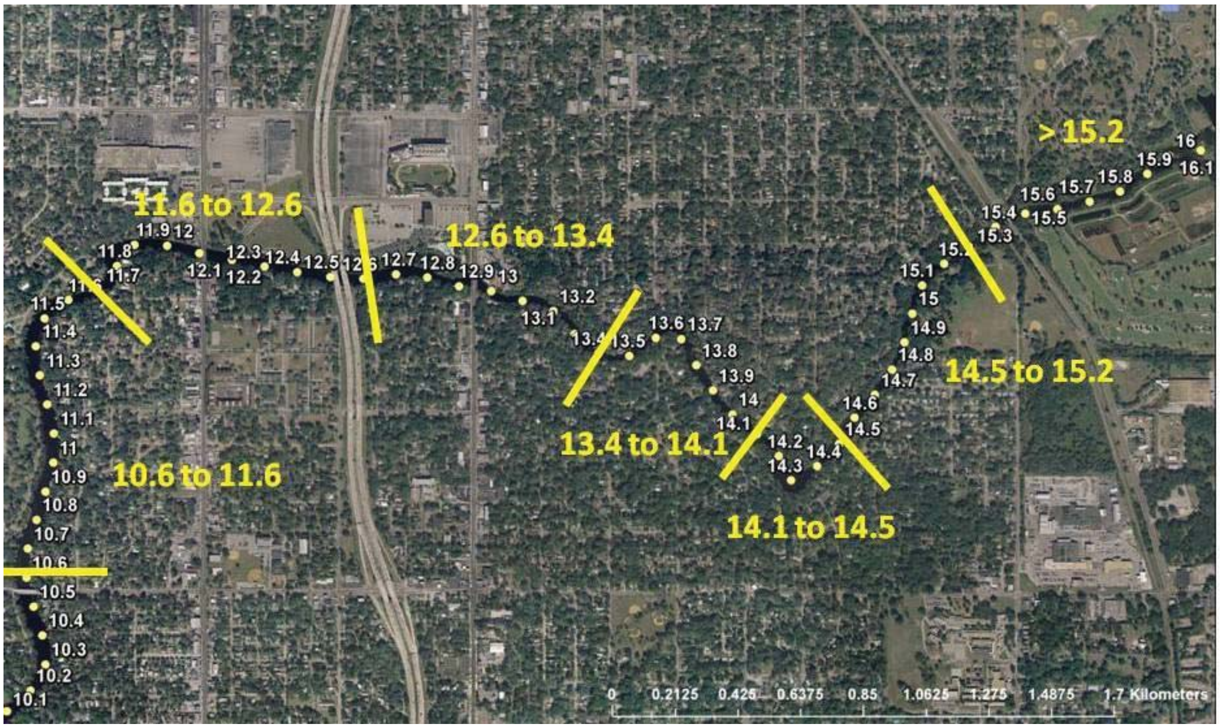


**Figure 4-31. Map of the lower river above kilometer 10 showing the seven segments by which vertical profile salinity data were analyzed.**

The next upstream segment, which extended from kilometer 12.6 to 13.4, began about 150 meters downstream of the Sulphur Springs confluence to capture data from the area near the spring outfall. This 0.8 km long segment extended 0.65 km upstream of the Sulphur Springs to also capture conditions in the river upstream of the spring outfall. A segment of near equal length extended from kilometer 13.4 to kilometer 14.1 near Hannah's Whirl. A short segment was centered on Hannah's Whirl, as this is a large deep spot in the river which appears to be a transitional site in the salinity characteristics of the river during times of minimum flow. Two segments extended from just above Hannah's Whirl to the dam. The uppermost segment above kilometer 15.2 to kilometer 16.2 was slightly longer than the segment immediately below (kilometer 14.5 to 15.2), but the upper 0.3 kilometers of the most upstream segment often could not be sampled due to shallow water depths and limits to navigation.

The number of vertical profiles that were measured in each segment by the District and TBW are listed in Table 4-18. Although this segmentation scheme limited the number of samples that could be assessed within each segment, it was concluded such a spatial approach was needed to evaluate the effectiveness of the minimum flows in segments of the river that are located progressively farther away from the dam.

**Table 4-18. Number of vertical profile samples collected in seven segments of the Lower Hillsborough River by the (TBW) HBMP and by the Southwest Florida Water Management District (SWFWMD).**

| By Agency & total number | Segments (kilometers) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10.6 to 11.6 | 11.6 to 12.6 | 12.6 to 13.4 | 13.4 to 14.1 | 14.1 to 14.5 | 14.5 o 15.2 | 15.2 to 16.2 |
| **TBW** | 122 | 122 | 182 | 121 | 61 | 182 | 126 |
| **SWFWMD** | 644 | 293 | 477 | 161 | 92 | 155 | 143 |
| **Total** | 766 | 415 | 659 | 282 | 153 | 337 | 269 |

Because it was known that salinity profiles in the study are often vertically stratified, salinity data were also assessed for different depth intervals. The first grouping was for data shallower than one meter, which usually included a single near-surface value for each profile. The second depth interval was for 1 to < 2 meters to capture the one meter readings and anything measured between one and two meters. The third depth interval was for two meters (rounded to one decimal place) as both monitoring programs typically took a two-meter reading if the water was deep enough. The fourth depth interval was for all reading deeper than 2 meters.

Salinity data for the segments and depth intervals were assessed for the same minimum flow periods and flow conditions that were assessed for the continuous recorders. Tables of summary statistics for salinity in each segment and depth interval for the different minimum flow periods are presented in Table 4-19 and Table 4-20. Table 4-19 lists the number of observations, means, and standard deviations within each group while Table 4-20 lists the median values. The Wilcoxon rank sum test was conducted to test for significant differences between groups, with the results listed in Appendix 2C. However, the low number of observations limited the power of the test for some groups, and the test was not conducted on groups that had less than 10 observations.

**Table 4-19. Means, standard deviations, and number of observations for vertical profile salinity measurements in four depth intervals in seven river segments for the minimum flow periods. Note the most upsteam river segment should be labeled as "River Kilometers 15.2 to 16.2".**

**River Kilometers 10.6 to < 11.6**

| Depth | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|---|
| 0 to < 1 m | 9.9, (4.7,127) | 7.2, (2.7,187) | 6.7, (2,151) | 5.9, (1.3,28) | 3.6, (1.1,21) |
| 1 to < 2m | 14, (5,116) | 11.7, (4.3,164) | 12.1, (4,130) | 9.8, (3.4,21) | 6.8, (3.8,15) |
| 2 m | 18.1, (4.7,55) | 16.5, (4,94) | 17.6, (3.5,67) | 14.8, (3.7,12) | 12.4, (5.5,10) |
| >2 m | 18.9, (4.7,78) | 17.5, (3.6,131) | 18.7, (2.8,112) | 16.6, (2.5,19) | 13.4, (4.1,15) |

**River Kilometers 11.6 to < 12.6**

| Depth | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|---|
| 0 to < 1 m | 9.5, (4.3,69) | 6.4, (2.5,144) | 5.6, (1.9,96) | 5.2, (1.1,15) | 3.4, (1.6,6) |
| 1 to < 2m | 15.1, (4.2,57) | 11.7, (4.7,118) | 11, (4.5,77) | 10.7, (3,12) | 7.6, (4.2,7) |
| 2 m | 18.5, (2.9,16) | 14.7, (4.1,46) | 16.1, (3.9,35) | 15.9, (2.2,6) | 14.1, (4,5) |
| >2 m | 18.7, (2.3,39) | 15.3, (3.7,86) | 18.1, (2.5,50) | 16.6, (2,9) | 14.2, (3.7,7) |

**River Kilometers 12.6 to < 13.4**

| Depth | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|---|
| 0 to < 1 m | 8.9, (4.5,87) | 6.1, (2.5,167) | 5.1, (1.6,130) | 4.2, (1,18) | 2.2, (0.9,20) |
| 1 to < 2m | 12.2, (4.7,83) | 9.6, (4,164) | 9.7, (3.9,148) | 7.4, (3.2,25) | 4.3, (2.8,18) |
| 2 m | 15.8, (4.9,42) | 13.1, (4.1,56) | 14.9, (3.9,51) | 10.4, (4.2,10) | 8.8, (5.9,11) |
| >2 m | 17.3, (4.4,51) | 14.5, (3.9,75) | 16.2, (3.4,50) | 13, (3.9,12) | 8.2, (5.1,13) |

**River Kilometers 13.4 to <14.1**

| Depth | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|---|
| 0 to < 1 m | 9.9, (3.5,45) | 5.3, (2,93) | 4.3, (1.6,88) | 3.3, (0.7,13) | 2, (1.1,10) |
| 1 to < 2m | 13, (3.8,33) | 8.4, (4.4,82) | 7.9, (4.1,76) | 5.1, (3.2,13) | 2.6, (2.1,12) |
| 2 m | 16.3, (2.9,5) | 9.8, (3.8,38) | 12.7, (3.3,32) | 6.5, (3,8) | 5.6, (4.4,7) |
| >2 m | 16.3, (2.3,18) | 11.6, (4.3,93) | 14.8, (2.8,76) | 8.8, (4.1,14) | 7.7, (3.4,15) |

**River Kilometers 14.1 to < 14.5**

| Depth | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|---|
| 0 to < 1 m | 9.3, (3.7,38) | 4.1, (1.9,39) | 2.8, (0.9,57) | 2.6, (0.2,11) | 1.8, (0.7,6) |
| 1 to < 2m | 10.5, (3.1,23) | 6.6, (3.8,34) | 5, (2.3,46) | 3.3, (1,7) | 3.3, (2.6,6) |
| 2 m | 11, (4.2,4) | 7.2, (2.7,12) | 10.3, (3.7,14) | 4.2, (1.6,3) | 2, (1.3,3) |
| >2 m | 10.7, (3.8,14) | 9.9, (3.4,32) | 11.3, (3.7,43) | 5.8, (2.1,9) | 2.6, (1.9,5) |

**River Kilometers 14.5 to < 15.2**

| Depth | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|---|
| 0 to < 1 m | 11, (3.3,36) | 3.6, (2,104) | 2.2, (0.8,66) | 2.4, (0.2,18) | 1.2, (0.4,9) |
| 1 to < 2m | 9.8, (3.1,20) | 4.5, (2.1,103) | 3.8, (2,67) | 2.6, (0.5,13) | 1.2, (0.5,13) |
| 2 m | 9.1, (.,1) | 4.1, (2.2,17) | 4.2, (1.2,7) | | 2.4, (0.3,2) |
| >2 m | 13.3, (.,1) | 4.2, (1.7,7) | 7.6, (1.7,2) | | |

**River Kilometers 15.2 to 16.1**

| Depth | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|---|
| 0 to < 1 m | 7.5, (4.5,88) | 2.1, (1.3,115) | 1.4, (0.6,82) | 2.3, (0.3,33) | 1.3, (0.4,9) |
| 1 to < 2m | 8.8, (4.4,64) | 3, (1.9,81) | 1.7, (1.1,61) | 2.3, (0.2,10) | 1.3, (0.4,8) |
| 2 m | 8.8, (4.1,6) | 3.9, (2.3,16) | 2.5, (1.8,15) | 2.3, (0.1,2) | 1.3, (0.4,3) |
| >2 m | 7.7, (4.4,25) | 3.1, (1.9,37) | 2.1, (1.7,20) | 2.3, (0.2,7) | 1.3, (0.4,3) |

**Table 4-20. Medians and number of observations for vertical profile salinity measurements in four depth intervals in seven river segments for the minimum flow periods. Note the most upsteam river segment should be labeled as "River Kilometers 15.2 to 16.2".**

| River Kilometers 10.6 to < 11.6 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 8.3, (127) | 7, (187) | 6.8, (151) | 6, (28) | 3.4, (21) |
| **1 to < 2m** | 14.8, (116) | 12.1, (164) | 12.2, (130) | 9.7, (21) | 5.7, (15) |
| **2 m** | 19.4, (55) | 16.9, (94) | 18.4, (67) | 17, (12) | 13.8, (10) |
| **>2 m** | 19.7, (78) | 18.4, (131) | 19.1, (112) | 17.8, (19) | 12.4, (15) |

| River Kilometers 11.6 to < 12.6 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 8.8, (69) | 6.2, (144) | 5.5, (96) | 5.3, (15) | 2.6, (6) |
| **1 to < 2m** | 15.3, (57) | 11.2, (118) | 10.8, (77) | 10.2, (12) | 6.6, (7) |
| **2 m** | 19.2, (16) | 15.8, (46) | 16.5, (35) | 16.2, (6) | 15.4, (5) |
| **>2 m** | 19.2, (39) | 16.2, (86) | 17.9, (50) | 16.6, (9) | 15.7, (7) |

| River Kilometers 12.6 to < 13.4 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 7.9, (87) | 5.9, (167) | 5.1, (130) | 4.2, (18) | 1.9, (20) |
| **1 to < 2m** | 12.3, (83) | 9, (164) | 9.6, (148) | 7, (25) | 3.2, (18) |
| **2 m** | 16.9, (42) | 14.1, (56) | 15.5, (51) | 10.9, (10) | 8.8, (11) |
| **>2 m** | 17.9, (51) | 15.9, (75) | 16.4, (50) | 14.3, (12) | 8.3, (13) |

| River Kilometers 13.4 to <14.1 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 9.6, (45) | 5.3, (93) | 4, (88) | 3.2, (13) | 1.5, (10) |
| **1 to < 2m** | 13.9, (33) | 7.7, (82) | 6.8, (76) | 4.5, (13) | 1.9, (12) |
| **2 m** | 17.3, (5) | 9.6, (38) | 12.8, (32) | 6.2, (8) | 4.9, (7) |
| **>2 m** | 16, (18) | 13, (93) | 15.1, (76) | 9.4, (14) | 7.7, (15) |

| River Kilometers 14.1 to < 14.5 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 9.3, (38) | 3.8, (39) | 2.8, (57) | 2.6, (11) | 2.1, (6) |
| **1 to < 2m** | 9.7, (23) | 6.6, (34) | 4.7, (46) | 3, (7) | 2.9, (6) |
| **2 m** | 10.2, (4) | 7.6, (12) | 10.9, (14) | 3.9, (3) | 2.1, (3) |
| **>2 m** | 10.1, (14) | 9.8, (32) | 12, (43) | 6.1, (9) | 2.4, (5) |

| River Kilometers 14.5 to < 15.2 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 12.1, (36) | 3.1, (104) | 2, (66) | 2.4, (18) | 1, (9) |
| **1 to < 2m** | 9.2, (20) | 4.2, (103) | 3.5, (67) | 2.5, (13) | 1, (13) |
| **2 m** | 9.1, (1) | 4.2, (17) | 3.9, (7) | | 2.4, (2) |
| **>2 m** | 13.3, (1) | 4.6, (7) | 7.6, (2) | | |

| River Kilometers 15.2 to 16.1 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 7.5, (88) | 1.9, (115) | 1.3, (82) | 2.3, (33) | 1.2, (9) |
| **1 to < 2m** | 8.3, (64) | 2.5, (81) | 1.3, (61) | 2.3, (10) | 1.2, (8) |
| **2 m** | 8.1, (6) | 3, (16) | 1.6, (15) | 2.3, (2) | 1.1, (3) |
| **>2 m** | 6.7, (25) | 2.9, (37) | 1.6, (20) | 2.2, (7) | 1.3, (3) |

Although data from the entire study period are referenced briefly below, the following discussion centers upon the final minimum flow period after February 2012 because the minimum flows that were implemented at that time were the closest to the adopted minimum flows for the lower river. For the segment above km 15.2, which is roughly above Rowlett Park Drive, mean and median salinity values above 5 psu occurred throughout the water column prior to minimum flows, but oligohaline conditions (< 5 psu) were established during all subsequent minimum flow periods. Although the number of observations were insufficient for statistical analysis, salinity during the final minimum flow period was lower than during the previous 2008 – Feb 2012 period, with mean and median salinity values ranging between 1.1 and 1.3 psu at all depths after February 2012.

Declines in salinity with the progressive increase in minimum flows were also observed in the segment between kilometers 14.5 and 15.2. Data are very limited from depths of 2 meters and below in this shallow segment. However, salinity in waters above 2 meters depth were lower in the segment during the final minimum flow period, with mean and median values ranging from 1.0 to 1.2 psu, compared to a range of 2.4 to 2.6 psu during the previous minimum flow period. Again, although the low number observations prohibited tests for significance, lower salinity values were observed with increasing minimum flows in the segment from kilometer 14.1 to 14.5 with mean and median salinity values ranging from 1.8 to 3.3 psu for all depths during the final minimum flow period. This is the segment of the river, however, where frequent salinity stratification begins to appear, especially during the period of low minimum flow rates prior to 2008. During the period from January 2008 through February 2012, the mean and median salinity values in waters below 2 meters were more than twice the surface values, but were near oligohaline conditions. Prior to 2008, there was more pronounced salinity stratification at this site, except during the period of no minimum flow when there was no flow in this segment other than occasional stormwater runoff. The most pronounced stratification appears to occur in the period from December 2003 to December 2007, when the minimum flows were limited to diversions of water from Sulphur Springs. Based on mean and median values, the largest gradient in vertical salinity profiles tended to occur between 1 and 2 meters depth.

Downstream of kilometer 14.1, vertical stratification becomes more apparent during all the minimum flow periods. Based on mean and median values, low salinity conditions (1.5 to 2.6 psu) were achieved in the segment from kilometers 13.4 to 14.1 at depths above 2 meters during the final minimum flow period, but values near or above the oligohaline limit (4.9 to 7.7 psu ) were found at 2 meters depth and below. More pronounced salinity stratification and much higher salinity values at deeper depths were found in the periods prior to 2008.

Salinity stratification becomes more pronounced during all minimum flow periods in the segment from 12.6 to 13.4, which is the segment that includes Sulphur Springs. Oligohaline conditions were observed in waters above 2 meters depth only during the final minimum flow period, with a relatively large vertical gradient apparent at 2 meters depth and below, where mean and median salinity values ranged between 8.2 and 8.8 psu. As with the segment immediately upstream, more pronounced salinity stratification and much higher salinity values at deeper depths were found in the periods prior to 2008. There is some influence of data from very near Sulphur Springs or just below Sulphur Springs affecting these values, but the pattern that is reported in Table 4-19 and Table 4-20 were also apparent in data collected between kilometer 13.0 and kilometer 13.4. As shown by data from the USGS recorder at kilometer 12.9 (Hillsborough River at Sulphur Springs), the section of the river near Sulphur Springs is frequently highly stratified, with this effect increasing with proximity to Sulphur Springs. This largely occurs because the discharge from the lower salinity water from the spring flows over a relatively shallow sill and layers over the more brackish water in the river in this area during periods of low flow.

Vertical stratification was pronounced in the segments of the river extending downstream from Sulphur Springs, with oligohaline waters only achieved in surface waters. There was some reduction in deep salinity values with progressive increases in minimum flows, but these declines were fairly small, and salinity in the deeper waters remained fairly relatively high as these deeper waters are relatively isolated from the surface waters. It is again emphasized that this section of the river was not the management target for the minimum flow establishment, but is included to provide information on the overall hydrobiological characteristics of the upper reaches of the lower river.

Because data were collected at 17 fixed location stations that were distributed over the study area on each sampling date, the sampling program conducted by the SWFWMD is very useful for examining salinity gradients in the study area over a range of minimum flows. Two dimensional graphics of salinity gradients collected in the study area are presented in Appendix 2D, utilizing data collected downstream to kilometer 10.4. Two-dimensional plots were constructed for 47 sampling dates that had total flows below the dam between 5 and 40 cfs, with plots arranged in an order of increasing total flow. The amount of spring diversion and total freshwater flow from the reservoir is identified for each graphic, with the freshwater flow component including both releases for minimum flows and any flow at the dam spillway.

Three example plots for Appendix 2D are presented in Figures 4-32 to 4-34, corresponding to total flow rates of 10, 16 and 24 cfs. Vertical reference lines are shown at kilometers 12.65 and 16.2 to denote the approximate location of Sulphur Springs and the dam, so all contours between these lines are in the principal target area for minimum flows. It is reiterated that these graphics are shown only as examples of salinity gradients and not as clear evidence of the effectiveness of various minimum flow rates, because other factors such as climate, ungaged runoff below the dam, and tides at the time of sampling can have major effects on salinity gradients. Also, the program that draws the contours is affected by the different maximum sample depths at the stations, so the contours are approximate estimates that are subject to graphical software limitations.

The data from the SWFWMD sampling transects that were used to construct graphics are listed in Table 4-21. This table is intended to generally portray the salinity characteristics of the study area, so in order to improve the visual clarity of the tables, salinity values were rounded to one integer with values at or below 5 psu shown in black and values above 5 psu shown in red. Also, it was impractical to construct tables that showed all the different bottom depths that were recorded, so values that are underlined are bottom values that were rounded to the nearest 0.5 meters depth. The area shown in yellow is the priority area for the establishment of an oligohaline zone between the dam and Sulphur Springs.

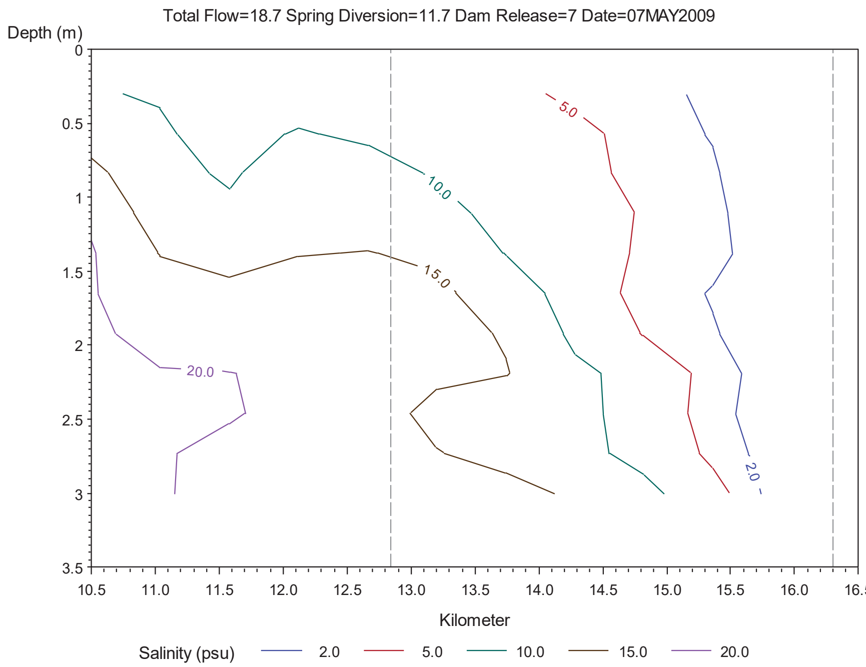


**Figure 4-32. Two-dimensional salinity plot for the river segment above kilometer 10.5 for May 7, 2009, which had a total flow of 18.7 cfs below the dam.**

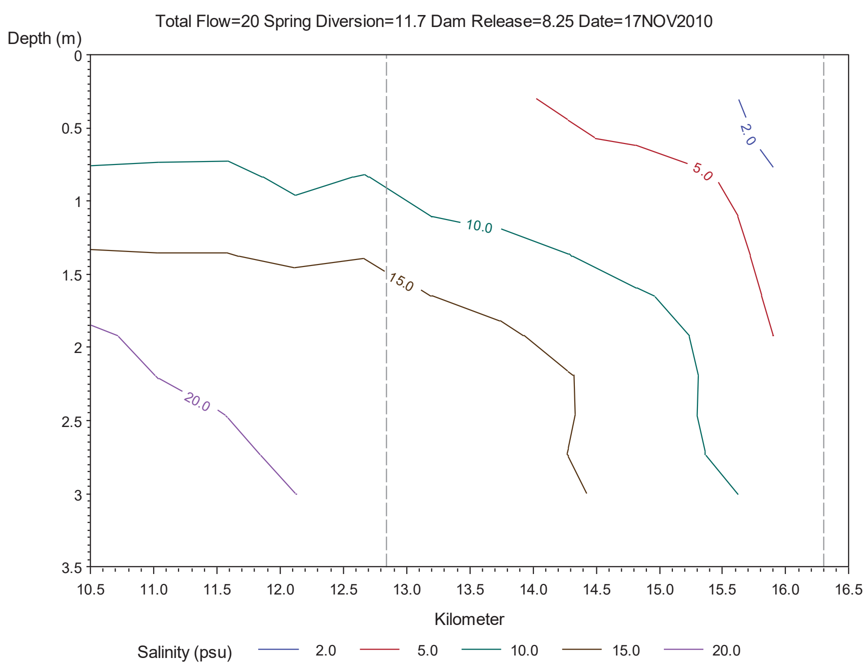


**Figure 4-33. Two-dimensional salinity plot for the river segment above kilometer 10.5 for the November 17, 2010, which had a total flow of 20 cfs below the dam.**

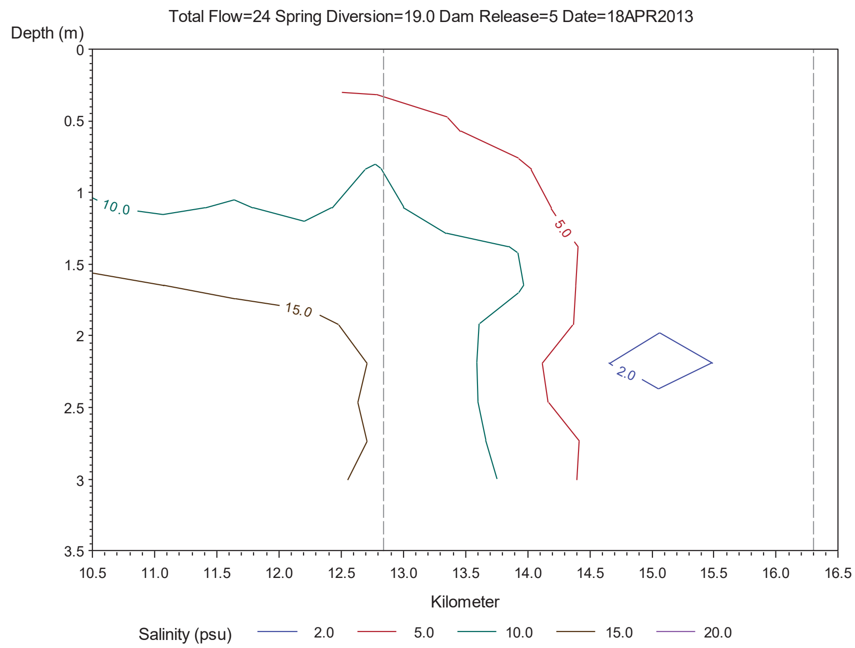


**Figure 4-34. Two dimensional salinity plot for the river segment above kilometer 10.5 for April 18, 2013, which had a total flow of 20 cfs below the dam.**

**Table 4-21. Salinity values in four depths measured at fixed stations between kilometers 10.4 and 16.0 by SWFWMD on three dates between May 2009 and April 2013.**

| A | May 7, 2009 | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total flow = 18.7 cfs, Spring diversion = 11.7 cfs, Reservoir release = 7 cfs | | | | | | | | | | | | | | | | |
| | Salinity (psu) | | | | | | | | | | | | | | | | |
| | Kilometers | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 10 | 10 | 9 | 8 | 8 | 7 | 7 | 7 | 6 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | |
| 1 meters | 18 | 12 | 10 | 12 | 12 | 13 | 11 | 12 | 8 | 8 | 7 | 4 | 3 | 3 | 1 | | |
| 2 meters | 20 | 20 | 19 | 19 | 18 | 17 | 17 | 16 | 16 | 11 | 10 | 5 | 4 | | 1 | | |
| 3 meters | 20 | 20 | | 19 | 19 | | 18 | | 18 | 14 | 13 | | | | 2 | | |
| B | November 17, 2010 | | | | | | | | | | | | | | | | |
| | Total flow = 20 cfs, Spring diversion = 11.7 cfs, Reservoir release = 8.3 cfs | | | | | | | | | | | | | | | | |
| | Salinity (psu) | | | | | | | | | | | | | | | | |
| | Kilometers | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 7 | 7 | 7 | 7 | 5 | 6 | 6 | 6 | 5 | 5 | 5 | 4 | 3 | 2 | 3 | 2 | |
| 1 meters | 12 | 12 | 12 | 10 | 11 | 13 | 9 | 11 | 8 | 8 | 6 | 6 | 7 | 6 | 6 | 2 | |
| 2 meters | 21 | 20 | 20 | 19 | 19 | 18 | 18 | 15 | 16 | 14 | 14 | 10 | 10 | | 8 | | |
| 3 meters | 21 | 21 | | | 19 | | 18 | | 17 | 16 | 15 | | | | | | |
| C | April 18, 2013 | | | | | | | | | | | | | | | | |
| | Total flow = 24 cfs, Spring diversion = 19.0 cfs, Reservoir release = 5 cfs | | | | | | | | | | | | | | | | |
| | Salinity (psu) | | | | | | | | | | | | | | | | |
| | Kilometers | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 7 | 7 | 6 | 6 | 5 | 5 | 5 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |
| 1 meters | 10 | 9 | 10 | 8 | 11 | 11 | 8 | 7 | 8 | 4 | 3 | 3 | 2 | 2 | 2 | | |
| 2 meters | 18 | 17 | 17 | 16 | 16 | 14 | 13 | 12 | 10 | 5 | 4 | | 2 | | 2 | | |
| 3 meters | 19 | | 17 | 17 | | | 13 | | 11 | 6 | | | | | 2 | | |

The two-dimensional graphics and corresponding tables show the pronounced vertical stratification that occurs in the lower part of the priority area, especially below Hannah's Whirl and increasing toward Sulphur Springs. Salinity values of 10 psu at 2 meters depth extended to kilometers 14.3 and 14.8 on two of the dates shown, but were located at kilometer 13.6 on April 13, 2013 when the total flow was 24 cfs. Waters less than 5 psu were limited to the surface and on one-meter readings on all dates, with surface water less than 5 psu reaching Sulphur Springs only on April 13, 2013. Water less than 5 psu at one meter depth did not reach Sulphur Springs in any on any of the three dates illustrated. However, it is reiterated these dates are shown only as examples. Probably the best indicator of near surface salinity in the river near Sulphur Springs is the USGS continuous recorder that is located about 150 meters upstream of the spring, which was discussed on page 4-25.

To examine the relationships of salinity in the river segments with flow, salinity values from the combined vertical profile data set are plotted versus same-day total flow at the dam in Figures 4-35 through 4-41. Data are plotted for the same depth intervals and river segments listed in Tables 4-19 and 4-20. This data set includes values prior to the implementation of minimum flows, so flow values of 0 cfs are included in the graphics. A reference line is included at 5 psu to denote the establishment of oligohaline conditions for each depth interval. Data that included periodic flows over the dam spillway are included in these graphics. Statistical tests were not performed for differences in salinity in different flow classes due to the much lower number of observations compared to the continuous recorder data.

For the segment above kilometer 15.2, oligohaline conditions were established at all depth intervals at flows above 10 cfs (Figure 4-35). The USGS recorder at Rowlett Park Drive is located near the downstream limit of this segment.

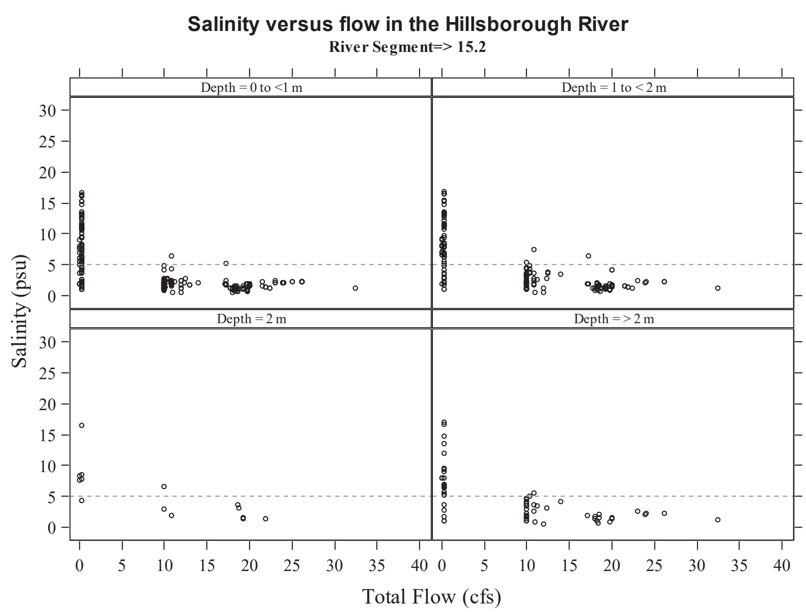


**Figure 4-35. Salinity values for four depth intervals versus total flow at the dam for the river segment between kilometers 15.2 and 16.2.**

The data are much more limited for the segment between kilometers 14.5 to 15.2, particularly at deeper depths (Figure 4-36). However, in waters above 1 meter depth, oligohaline conditions are established at flows greater than 15 cfs. The data are more mixed at the 1 to < 2 m depth interval, with total flows of 17 to 20 cfs producing primarily oligohaline conditions but with five values slightly over 5 psu.

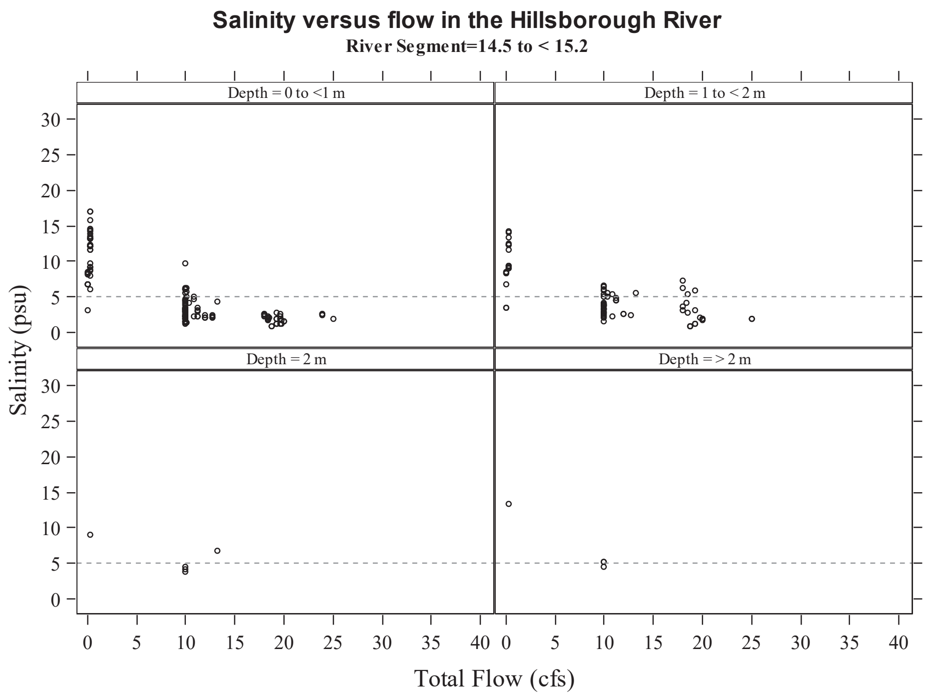


**Figure 4-36. Salinity values for four depth intervals versus total flow at the dam for the river segment between kilometers 14.5 and 15.2.**

The data for kilometers 14.1 to 14.5, which is centered on Hannah's Whirl, also indicates that flows above 15 cfs produced oligohaline conditions in surface waters (Figure 4-37). There appears to be a breakpoint around 19 to 20 cfs for the 1 to < 2 meter depth with flows of that rate and greater producing oligohaline conditions. The data are limited at deeper depths, but it appears that water above 5 psu persists at > 2 meters depth at flows up to 20 to 22 cfs, with some reduction in salinity at flows above 23 cfs.

For the segment from kilometers 13.4 to 14.1, flow rates near 20 cfs largely, but not consistently, produce oligohaline conditions in surface waters. There is considerable variation in salinity at the flow range at the 1 to <2 m depth, with several values over 10 to 15 psu recorded (Figure 4-38). There may be some break in the salinity relationship at 21 to 25 cfs, but the data are much too limited to draw any conclusions. The data are also limited at 2 meters and below, but it appears that high salinity values persist at flow rates in the range of 20 to 25 cfs. The continuous salinity recorder at kilometer 13.6 provides valuable information on the response of salinity to flow in approximately the middle of this zone.

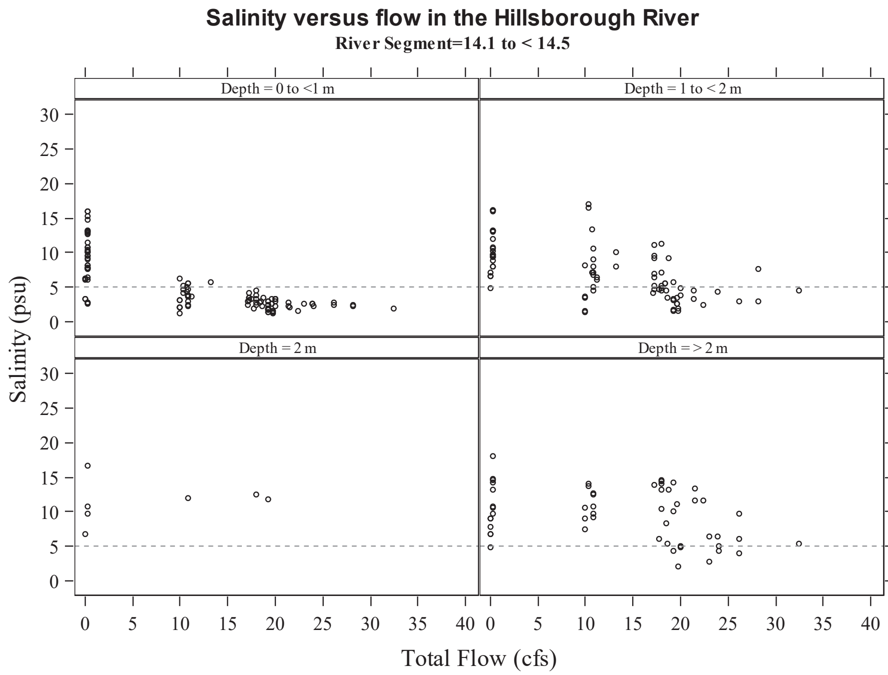


**Figure 4-37. Salinity values for four depth intervals versus total flow at the dam for the river segment between kilometers 14.1 and 14.5.**

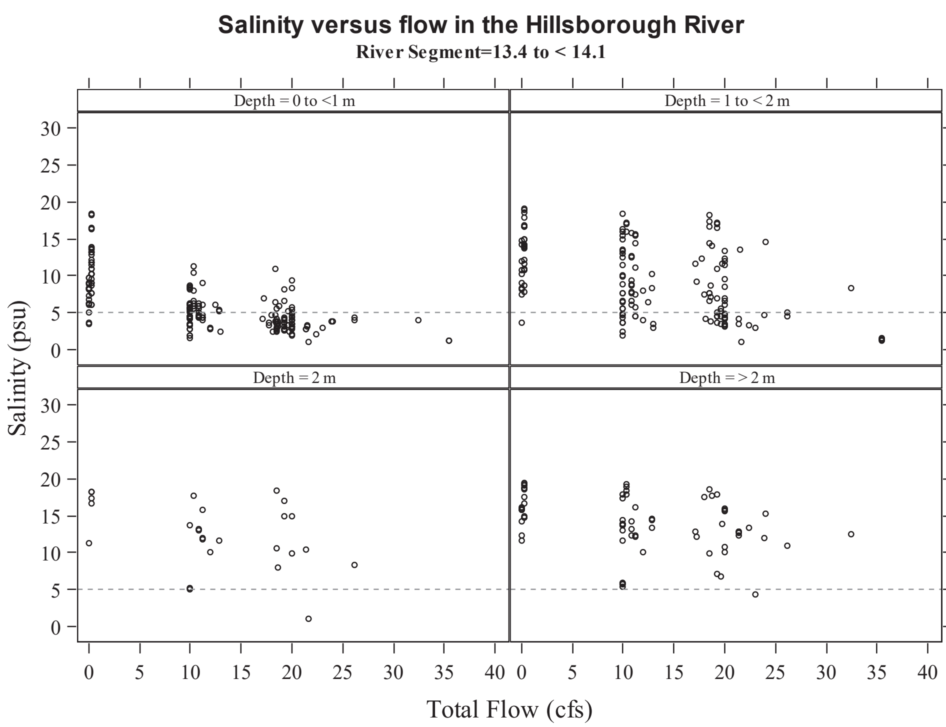


**Figure 4-38. Salinity values for four depth intervals versus total flow at the dam for the river segment between kilometers 13.4 and 14.1.**

The segment from kilometers 12.6 to 13.4 is important for it represents the most downstream segment in the target area for the establishment of oligohaline conditions. It is reiterated, however, that the adopted minimum flow rule for the lower river calls for the establishment of a zone of water less than 5 psu toward, but not necessarily to, Sulphur Springs. The results for the segment are informative for examining how various rates of flow are in establishing oligohaline conditions in the area just upstream of Sulphur Springs.

There appears to be a breakpoint around 20 cfs for the establishment of oligohaline conditions in surface waters (Figure 4-39). The data are limited, but relatively high salinity values (10 to 18 psu) persist at flows near 20 cfs at depths of 1 to < 2 meters. Based on very few observations, flows in the range of 25 cfs may result in somewhat lower salinity at these depths, but high salinity values persist at flows above 20 to 25 cfs at depths of 2 meters and greater. The USGS recorder Hillsborough River at Sulphur Springs is located near the downstream end of this segment. As discussed with regard to data from that recorder and the statistical summaries for the vertical profile measurements (Tables 4-18 and 4-19), during low flows this segment of the river is characterized by a high degree of salinity stratification and the relationship of salinity to flow is most responsive in shallower waters. Much greater amounts of flow are needed to reduce salinity in deeper waters to oligohaline conditions.

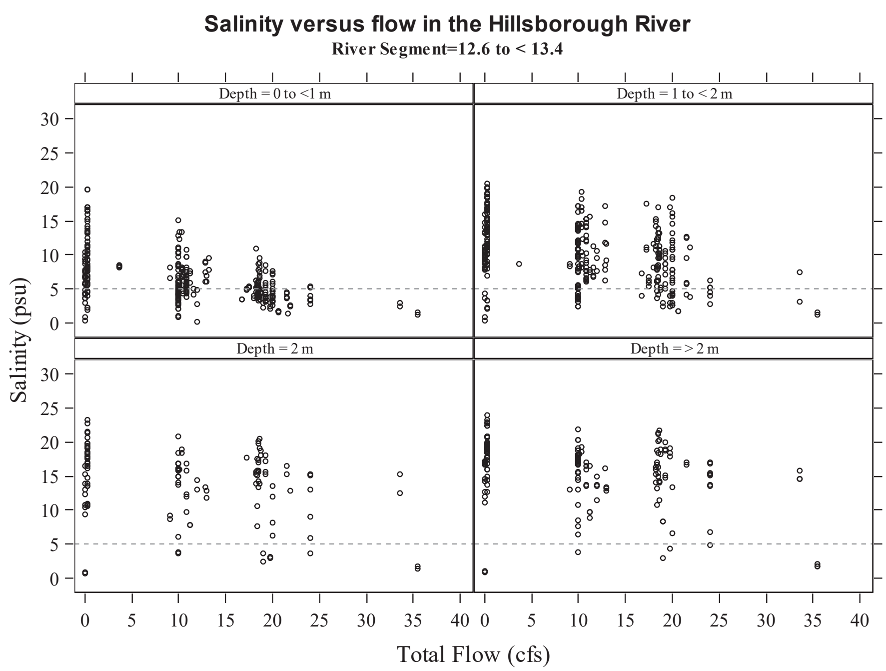


**Figure 4-39. Salinity values for four depth intervals versus total flow at the dam for the river segment between kilometers 12.6 and 13.4.**

Graphics of salinity at the four depth intervals are shown for the two segments extending downstream from Sulphur Springs, which is outside the priority area for the establishment of oligohaline conditions. This information is useful, however, for evaluating any potential benefits that minimum flows may have for these segments of the river and how salinity characteristics of that section of the river might influence the upstream priority area. For the segment from kilometer 11.6 to 12.6, salinity values near or less than 5 psu were only common at flows of approximately 18 cfs and greater (Figure 4-40). Salinity values at the deeper depths were considerably higher, though there were no observations with flows above 24 cfs. Salinity values were also well above 5 psu in the deeper layers in the segment from kilometer 10.6 to 11.6, with the exception of one two observations with flows of 35 cfs. Surface salinities less than 5 psu were most common at flows above 20 cfs at this station, with an apparent break at that rate of flow (Figure 4-41).

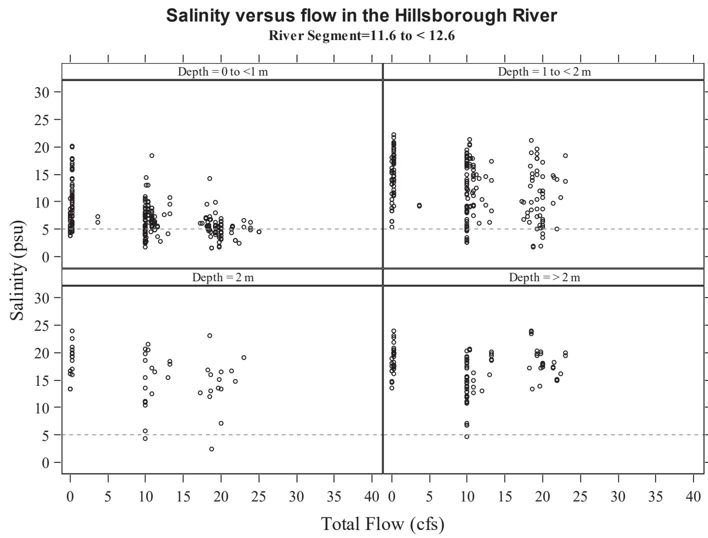


**Figure 4-40. Salinity values for four depth intervals versus total flow at the dam for the river segment between kilometers 11.6 and 12.6.**

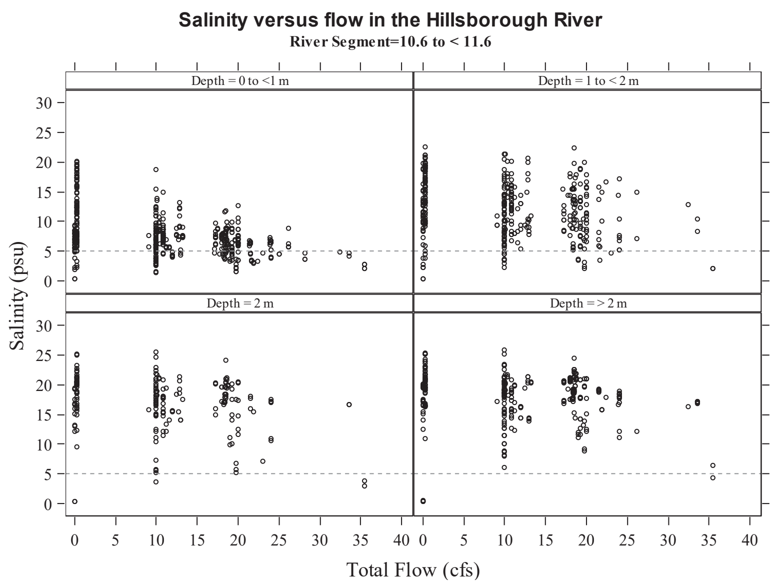


**Figure 4-41. Salinity values for four depth intervals versus total flow at the dam for the river segment between kilometers 10.6 and 11.6.**

## 4.4 Discussion

Changes in salinity were examined over an eleven-year period from the spring 2002 to the spring 2013 during which minimum flows to the Lower Hillsborough River were gradually increased as projects to provide the minimum flows were completed. These data were compared to data collected prior to the implementation of minimum flows to examine changes in the salinity characteristics of the lower river.

There were three general categories of minimum flow releases that were implemented sequentially over time: (1) minimum flows comprised solely of diversions from Sulphur Springs from 2002 through 2007; (2) minimum flow comprised of diversions from Sulphur Springs and releases from the Hillsborough River Reservoir from 2008 through the spring of 2013; and (3) a subset of category 2, starting in March 2012, in which releases from the reservoir where accompanied by increased diversions from Sulphur Springs. During this final minimum flow period, total minimum flows as high as 27 cfs were periodically achieved. However, the increased diversions from Sulphur Springs resulted in increased salinity of the spring water that was routed to the dam. The average salinity of spring water diverted to the dam prior to March 2012 was 1.6 psu, but increased to an average of 2.7 psu after March 2012 when the spring pool was lowered to induce greater spring discharge.

The minimum flow rule for the Lower Hillsborough River calls for the extension of a zone of water less than 5 psu salinity from the dam toward Sulphur Springs. A specific area or volume of oligohaline water (< 5 psu) is not specified in the rule. The minimum flow report on which the rule was based analyzed output from a two-dimensional hydrodynamic model of the lower river to assess incremental gains in the volume of oligohaline water as a function rate of minimum flow. Based on those results, the minimum flows that were adopted for the river were 20 cfs for the months July through March and 24 cfs for the months April through June. However, these minimum flows are expressed as freshwater equivalents, which means that the actual quantity of water to be delivered can be greater than these amounts if water from Sulphur Springs is used to provide part of the minimum flows. Generally, expressing the minimum flows as freshwater equivalents increases minimum flows by about 3 cfs, but this conversion is being re-examined with additional modeling of the lower river.

The minimum flows can also be reduced during times of low flow when flow at the Hillsborough River near Zephyrhills gage are below a rate of 58 cfs. During the eleven-year study period, the adjustment for low flows was applied on 19% of the days with the lowest minimum flow rate of 15 cfs (uncorrected for freshwater equivalent), which occurred briefly in the month of March in 2009 and 2012. In sum, the minimum flows that were required for the lower Hillsborough for River for the eleven-year study period ranged between 15 and 27 cfs, depending on how the freshwater equivalent requirement was included in flow assessment. The ability to meet these minimum flows increased over time as projects to provide the minimum flows were completed. During the final minimum flow period, the required minimum flows were met a majority of the time not accounting for the freshwater equivalent.

This minimum flows evaluation report provides an opportunity to examine how salinity data collected in the river over a range of minimum flow rates compare to the goals of the adopted minimum flows that were based on hydrodynamic modeling. Of particular utility are data from four continuous salinity recorders that were operated in target area for the establishment of oligohaline water between the dam and Sulphur Springs. Salinity at each recorder was examined for changes over time and as a function of the rate of minimum flow. Because of the difficultly in managing and measuring the minimum flow that have been implemented, minimum flow rates were examined in ranges of flow spanning 3 cfs (e.g. 20 to 22 cfs), with the mid-point of each 3 cfs range (e.g., 21 cfs for 20 to 22 cfs) used to represent the minimum flow rate.

Minimum flow rates of 19 cfs and greater were effective at achieving low salinity water at the Rowlett Park Drive recorder, located 0.9 kilometers downstream of the dam. Average salinity values of 1.5 to 1.8 psu were achieved at total minimum flow rates of 19 to 23 cfs. Greater minimum flow rates (24 to 26 cfs) resulted in mean salinity values of 2.0 to 2.2 psu, as these minimum flow rates included greater diversions from Sulphur Springs when salinity in the spring pool was slightly elevated. However, the higher minimum flow rates (23 to 26 cfs) resulted in much less salinity variation at Rowlett Park, as maximum values near 3 psu were recorded in top and bottom waters in the final minimum period, compared to maximum values that ranged from 3.4 to 7.7 psu in surface waters and 6.5 to 8.6 psu in bottom waters at minimum flow rates from 19 to 22 cfs. In general, the increased use of Sulphur Springs to achieve higher minimum flow rates results in slightly higher mean salinity at Rowlett Park, but a more stable salinity environment with less incursions of higher salinity water at that location.

A continuous recorder was also operated at the upstream end of Hannah's Whirl, which is a deep spot in the river that represents a transitional point in the salinity characteristics of the river between the dam and Sulphur Springs. Data collection at the Hannah's Whirl recorder ended in September of 2005, thus the only minimum flows that were implemented while the recorder was operational were diversions from Sulphur Springs (usually at a rate of 10 cfs). Data from this recorder between 2002 and 2005 showed improvement in the salinity characteristics at this location as compared to the no minimum flows condition, as surface salinity averaged 2.9 psu between December 2003 and September 2005 and bottom salinity averaged 4.1 during this same period.

A recorder is operated at by the EPCHC at kilometer 13.6. This recorder lies between Hannah's Whirl and Sulphur Springs and represents about 74% of the water volume in the target area for the establishment of oligohaline water between the dam and Sulphur Springs. Mean salinity values less than 5 psu were achieved in surface waters at a minimum flow rate of 23 cfs and greater and in bottom waters at minimum flow rates of 25 cfs and greater. Salinities achieved with minimum flow rates of 24 to 26 cfs tended to be significantly less than for lower flow rates. As with the Rowlett Park recorder, the variation of salinity at this recorder was markedly reduced at higher minimum flow rates (23 cfs and greater).

The recorder at the Hillsborough River near Sulphur Springs is located about 150 meters upstream of Sulphur Springs, which places it close to the downstream limit of the target area for the establishment of oligohaline water. Data from this recorder demonstrate the high degree of vertical salinity stratification in this part of the river, with much of the gradient occurring between surface and mid-depths. There appeared to be a breakpoint in salinity at this recorder at a flow rate of 23 cfs, as mean salinity values in surface waters were limited to flows at or greater than that flow rate. Bottom salinity also decreased with increasing minimum flows, but the lowest mean value (9.3 psu at flow rate of 25 cfs) was well above 5 psu, reflecting the high degree of vertical stratification at this site. Salinity at minimum flow rates of 23 cfs were significantly less in surface waters compared to lower minimum flow rates, while salinity at 25 cfs was significantly less than in bottom waters at lower minimum rates. Maximum salinity values in surface and bottom waters showed a marked reduction at flows of 23 cfs and greater compared to lower flow rates.

Collectively, the data from these four recorders indicate that significant improvements in salinity in the priority area for the establishment of oligohaline water can be achieved at minimum flow rates between 23 and 25 cfs. The average salinity values that result from these flow rates are below 5 psu at the recorder at kilometer 13.6 and near 5 psu in surface waters at recorder in the river near Sulphur Springs. Salinity variation is also reduced at these minimum flow rates as were the maximum salinity values that were observed.

Data were also assessed from two recorders downstream of the target area for establishing oligohaline waters, one located at Sligh Avenue at kilometer 10.6 and one near the mouth of the river at Platt Street. Data from these recorders show much less response to minimum flows, but are informative for documenting the salinity characteristics of the river at those locations. Because these recorders are located downstream of the target area for establishing oligohaline conditions, comparisons of empirical data with the goals of the adopted minimum flows do not include these two recorders.

Salinity data from vertical profile measurements covering a wide range of locations in the lower river were also assessed. Although the number of observations for these data were less than for the continuous recorders, the data demonstrate the generally high degree of vertical salinity stratification that occurs between Hannah's Whirl and Sulphur Springs and generally supported the relationships with flow observed at the continuous recorders.

The results for salinity presented in this report are considered preliminary because the reported minimum flow rates for diversions from Sulphur Springs contained some potential errors. The City of Tampa expeditiously implemented diversions from Sulphur Springs following adoption of the initial minimum flow rules for the lower river; however, accurate metering of these diversions was initially difficult given the changing infrastructure and pumping conditions during the early phases of project implementation. Now that the final pumping facilities at Sulphur Springs are in place, more accurate metering of diversions from Sulphur Springs is possible.

The results presented in this report should also be considered preliminary because they were influenced by climatic conditions during the period of study and the higher minimum flow rates were only achieved in the last 15 months of the study, beginning in March 2012. There were fewer observations for the higher minimum flow rates compared to the minimum flows rates that were in effect for longer periods of time. Continued data collection as higher minimum flow rates are implemented should address this limitation in the data.

Despite the preliminary nature of the results, the data presented in this report are the best available information at this time and can be used to guide management decisions. It appears that minimum flow rates in the range of 23 to 26 cfs result in significantly lower salinity in the minimum flows oligohaline target area as compared to lower minimum flow rates, particularly the 20 cfs minimum flow rate adopted for nine months of the year, if it is not adjusted for the freshwater equivalent. Minimum flows in the range of 23 to 26 cfs appear sufficient to create oligohaline conditions in surface and bottom waters at kilometer 13.6. Further downstream, these minimum flow rates create oligohaline water in the upper water column, but higher salinity persists in deeper waters. Available data also show that minimum flow rates above 23 cfs result in less salinity variation in the river, with reduced maximum values compared to lower minimum flow rates.

Given these findings, the adopted minimum flows for the Lower Hillsborough River appear to reasonably support the goal of extending an oligohaline zone of water from the Hillsborough River Dam toward Sulphur Springs. The results indicate increased flows in the range of 23 to 26 cfs associated with adjustment of the 20 cfs minimum flow requirements based on the freshwater equivalent, enhance the minimum flow oligohaline salinity zone goal. A second conclusion of this report is that reduction of the minimum flow rates due to low flows at the Zephyrhills gage as allowed by the adopted rule results in a reduction in the effectiveness of the minimum flows for creating oligohaline conditions below the dam.

It is recommended that the results of this study be supplemented with additional hydrodynamic modeling of the Lower Hillsborough River using the District's LAMFE model. This new modeling effort could be used to evaluate changes in the volume of oligohaline water associated the minimum flows that have been implemented to date. The modeling effort would also allow for the evaluation of effects associated with use of differing quantities of water (i.e., flow rates) from the reservoir and Sulphur Springs and increased salinity of the spring water that may result from lowering the spring pool to increase spring discharge. New modeling simulations may also be used to evaluate minimum flow scenarios under consistent climatic and hydrologic conditions for rainfall, ungaged runoff, and salinity in Hillsborough Bay.

# 5 Dissolved Oxygen

## 5.1 Overview of applicable dissolved oxygen criteria

The relationship of low flows on dissolved oxygen (DO) concentrations in the Lower Hillsborough River was an important factor that was evaluated for adoption of the minimum flows in 2007 (SWFWMD 2006). Since that minimum flows report was completed, much more DO data have become available for the Lower Hillsborough River. Accordingly, relationships of the minimum flows that have been implemented to date with DO concentrations in the lower river were assessed for this study.

Dissolved oxygen is critical for aquatic life and prolonged low DO concentrations can adversely impact the biological diversity and productivity of aquatic systems. The complete or near complete absence of DO (≈0 mg/l) is referred to as anoxia, while the occurrence of low DO concentrations (below 2 to 3 mg/l) is referred to as hypoxia (Ecological Society of America 2006, USGS 2006). Based on marked changes in the species richness of fishes caught in trawls in the Lower Hillsborough River (FFWCC and USF 2006), the District used a DO concentration of 2.5 mg/l to identify the threshold for hypoxia in this minimum flows assessment.

Because DO concentrations are affected by water temperature and salinity, DO concentrations in water bodies are often also expressed as percent saturation, or the percentage that a DO concentration is relative a DO concentration at 100% saturation for a given water temperature and salinity. In unpolluted well-mixed water bodies, percent saturation values can be at or near 100%. In cases where there are high levels of photosynthesis, including nutrient enriched water bodies, percent saturation values can exceed 100% during daylight hours. It is low percent saturation values, however, that are of primary concern for health of aquatic life. In water bodies with high nutrient or organic loadings or where mixing is limited, low percent saturation values can occur and result in impacts to the aquatic biota.

Until 2009, the Florida Department of Environmental Protection (FDEP) based state DO standards on concentration values that ranged from 4.0 to 5.0 mg/l based on whether a water body was fresh or marine and whether the DO value was an instantaneous reading or a daily average value. However, because DO concentrations can periodically be below these concentrations in some Florida waters that are relatively natural and unpolluted, the FDEP revised the State DO standards to be based on percent saturation values. These percent saturation criteria, which are described in Chapter 62-302.533 of the Florida Administrative Code, are specific to various classes of fresh and marine waters based on their designated use, with special criteria for certain regions of the state (see text: FDEP DO criteria in Appendix 3A)

The Lower Hillsborough River is a Class III water, meaning it is to be managed for the propagation of fish and wildlife. The FDEP classifies the reach of the lower river between the dam and Nebraska Avenue (at Kilometer 12.9) as a freshwater zone, with an estuarine designation downstream from Nebraska Avenue to the river mouth. The entire Lower Hillsborough River is tidally affected, but during high flows from the dam the upper reaches of the river can be flushed with fresh water. However, during times of low flow, brackish waters extend throughout the reach of the river above Nebraska Avenue and a mixture of tidal freshwater and estuarine fauna exist in this reach of the river (Catalano et. al 2005, FFWCC and USF 2006, SWFWMD 2006, TBW 2010). Since the assessment of effectiveness of minimum flows pertains to the drier periods of year, the District concluded that for this study, the DO criteria specific to marine waters should apply to the priority target area upstream of Sulphur Springs with regard to the effectiveness of the minimum flows.

The FDEP criteria for Class III Marine water involve several thresholds depending on whether DO saturation readings are based on average values calculated over 1, 7, or 30 days. The criterion for daily average values is that the daily average percent DO saturation shall not be below 42 percent saturation in more than 10 percent of the values. However, the FDEP criteria also state that if it is determined that the natural background DO saturation in the water body (including values that are naturally low due to vertical stratification) is less than the applicable criteria, the applicable criteria shall be 0.1 mg/l below the DO concentration associated with the natural background DO saturation level.

There are a large number of sites where instantaneous DO measurements have been taken in the Lower Hillsborough River, with most of these during mid-day hours when DO measurements would be expected to be near their highest values. As part of this study, it was not practical to calculate natural background DO levels in the sections of the river that are highly stratified. Instead, the District chose to use the 42 percent saturation value as a reference threshold to assess the effects of the minimum flows on DO percent saturation values in the river. It is emphasized this was not done in a regulatory compliance manner, but instead was used as a general reference point to assess the occurrence of low DO percent saturation values in the lower river in relation to minimum flows. This threshold was used along with the 2.5 mg/l DO concentration value that was previously described to evaluate the effects of minimum flows on overall DO conditions in the Lower Hillsborough River.

## 5.2 Dissolved oxygen data available for analysis

Data for DO concentrations in the river were available from the EPCHC, the SWFWMD, and TBW's HBMP. The data for DO discussed in the following chapter are from two sources, the long-term water quality stations monitored by the EPCHC and the combined vertical profile data base comprised of measurements made by SWFWMD and as part of the TBW HBMP. These data sources are described in the previous chapter of this report, as DO data were collected concurrently with field measurements of salinity. There were no reliable continuous recorder data of long duration for DO available for assessment at the time of the preparation of this minimum flows assessment.

Although minimum flows can be in effect when flows at the dam are between 1 and 24 cfs, days when flows over the dam spillway are in this range are infrequent. Therefore, it was concluded that utilizing data when flows at the spillway were less than 1 cfs provided a consistent approach to examine the effect of the minimum flows that have been implemented. The discussion of DO concentration and percent saturation values presented in the following sections of this report utilize data for days when same-day flows over the dam spillway were less than 1 cfs, unless specified as otherwise.

## 5.3 EPCHC fixed-location stations

The EPCHC has fixed-location water quality monitoring stations at Rowlett Park Drive and at Sligh Avenue where *in situ* water column profile monitoring for DO is conducted on a monthly basis. Sampling at the Rowlett Park Drive (Station 105) station began in 1997, while sampling at Sligh Avenue (Station 152) began in 1999. Water column profiles at these stations consisted of measurements at the surface, mid-water column depth, and near the river bottom. Data from all depths are combined for the following analyses and discussion.

### 5.3.1 EPCHC station at Rowlett Park Drive

Summary statistics (n, mean, standard deviation) for DO concentration and percent saturation values at the EPCHC Rowlett Park station are listed for five minimum flow periods in Table 5-1, ranging from the early period of no minimum flows to the most recent period of increased diversions of water from Sulphur Springs matched with freshwater releases from the reservoir. The results of Wilcoxon Rank Sum test for differences in these periods are listed in Appendix 3B, with the spring 2002 period combined with the 2003 to 2007 period. Apart from the 2002 period, which had only six observations, mean values for both DO concentration and percent saturation gradually increased through time at Rowlett Park. Both DO concentrations and percent saturation values were significantly greater during the final minimum flow period (Appendix 3B).

**Table 5-1. Mean, standard deviation and number of observations for DO concentration and percent saturation values for all depths at EPCHC station 105 at Rowlett Park Drive.**

| EPCHC Station 105 (Rowlett Park Drive) | | | | | | |
|---|---|---|---|---|---|---|
| | Units | No MFL | Spring 2002 | Dec. 03 - Dec. 07 | Jan. 08 - Feb 2012 | After Feb. 2012 |
| DO concentration | mg/l | 3.9, (1.7,126) | 3.3, (1.5,6) | 4.8, (1.7,66) | 5, (1.2,55) | 5.6, (0.4,18) |
| DO Percent saturation | Percent | 47,(0.2,126) | 41,(0.19,6) | 58, (0.2,66) | 60,(0.13,55) | 68,(0.04,18) |

Time series plots of DO concentration and percent saturation at the Rowlett Park station are shown in Figure 5-1 and 5-3. Since 2009, both DO concentration and percent saturation have remained above the applicable thresholds (2.5 mg/l and 42% saturation). These results also show the generally higher and more stable DO during the final minimum flow period. Is should be noted, however, that the Rowlett Park station is 0.8 kilometers downstream of the dam and represents only about 19% of the volume of the minimum flow target area above Sulphur Springs.

DO concentration and percent saturation values are plotted versus flow in Figures 5-2 and 5-4, with symbols denoting the minimum flow period and days when there were adequate flows over the spillway and minimum flows were not in effect; these latter values are plotted as “Dam flow between 8.4 and 40 cfs” or “Any Period, FW Flows> 8.3 cfs.” The number of observations are very limited, but indicate that minimum flows in the range of 20 to 25 cfs are effective for maintaining suitable DO concentrations at Rowlett Park Drive.

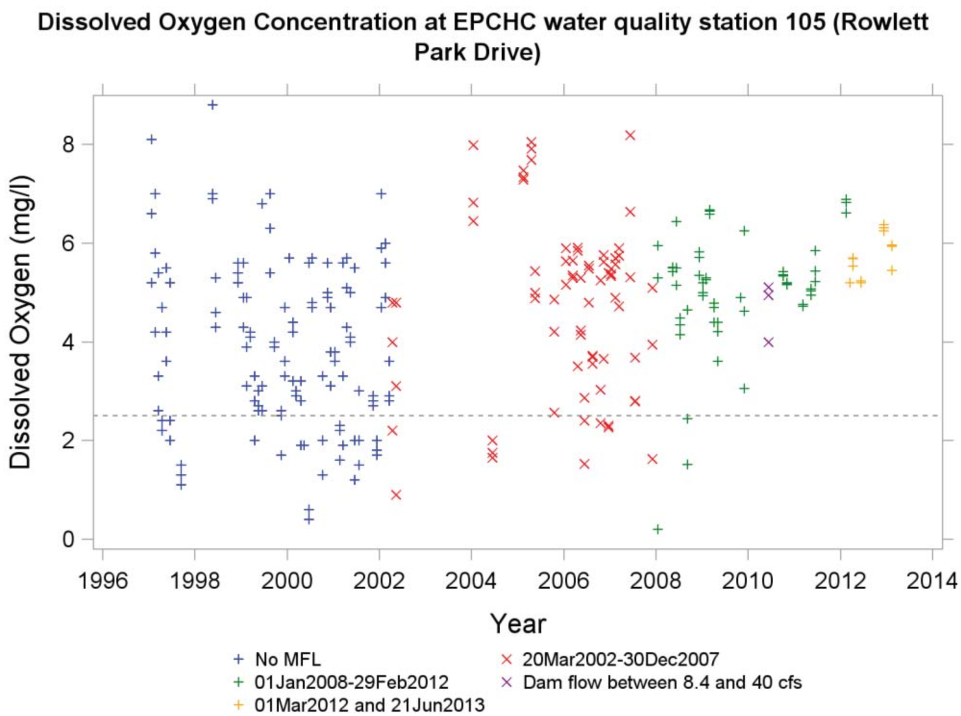


**Figure 5-1. Time series of dissolved oxygen concentrations for all depths at the Rowlett Park Drive station.**

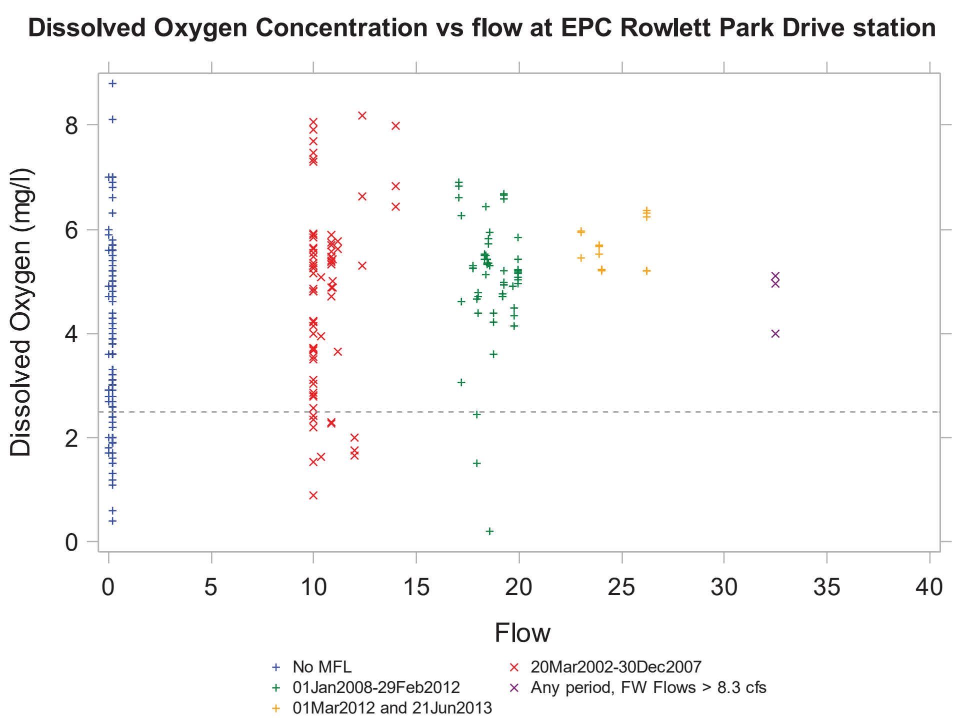


**Figure 5-2. Dissolved oxygen concentrations for all depths versus flow at the Rowlett Park Drive station.**

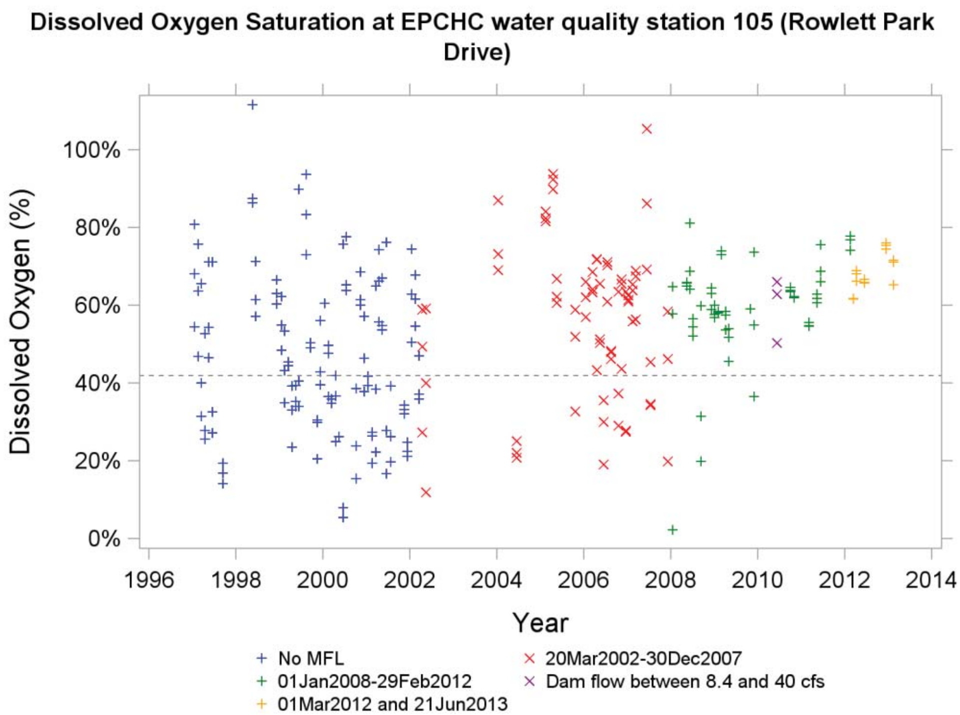


**Figure 5-3. Time series of dissolved oxygen percent saturation values for all depths at the Rowlett Park Drive station.**

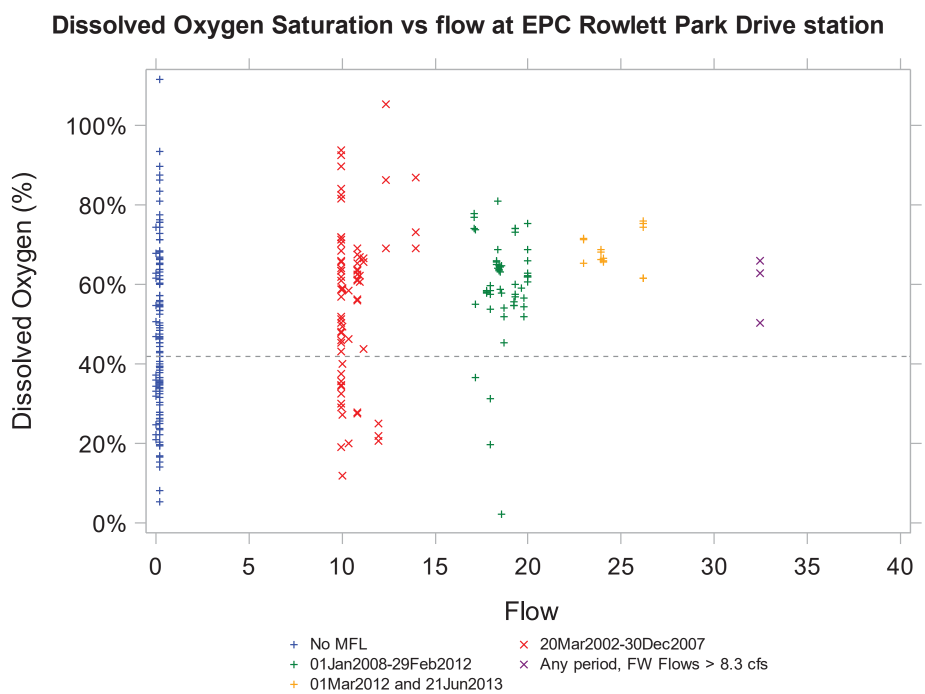


**Figure 5-4. Dissolved oxygen percent saturation values for all depths versus flow at the Rowlett Park Drive station.**

## 5.3.2 EPCHC station at Sligh Avenue

Compared to Rowlett Park, DO concentration and percent saturation values are lower at the Sligh Avenue station for all minimum flow periods (Table 5-2). Graphically, there was no apparent improvement in DO values versus time (Figures 5-5 and 5-7; plotted similarly to the graphics presented for the Rowlett Park Station) and there were no significant differences between minimum flow periods (Appendix 3B). During all periods, there were substantial numbers of DO concentration and percent saturation values below the applicable thresholds. Although the data are limited, there is similarly very little apparent relationship with flow, with some indication that DO values may be depressed at higher flow rates (Figures 5-6 and 5-8).

It is reiterated that the Sligh Avenue station is approximately 2.2 kilometers downstream of the minimum flow target area that begins at Sulphur Springs. Additional data from the reach of the river immediately above Sligh Avenue that are included in vertical profile data base are presented in the next section.

**Table 5-2. Mean, standard deviation and number of observations for DO concentration and percent saturation values for all depths at EPCHC station 152 at Sligh Avenue.**

| EPCHC Station 152 (Sligh Ave.) | | | | | | |
|---|---|---|---|---|---|---|
| | Units | No MFL | Spring 2002 | Dec. 03 - Dec. 07 | Jan. 08 - Feb 2012 | After Feb. 2012 |
| DO concentration | mg/l | 2.4, (1.9,78) | 1, (1.1,6) | 2.1, (1.9,66) | 2.4, (2,60) | 2.7, (2,18) |
| DO Percent saturation | Percent | 31, (0.24,78) | 13, (0.14,6) | 26, (0.23,66) | 30, (0.24,60) | 35, (0.26,18) |

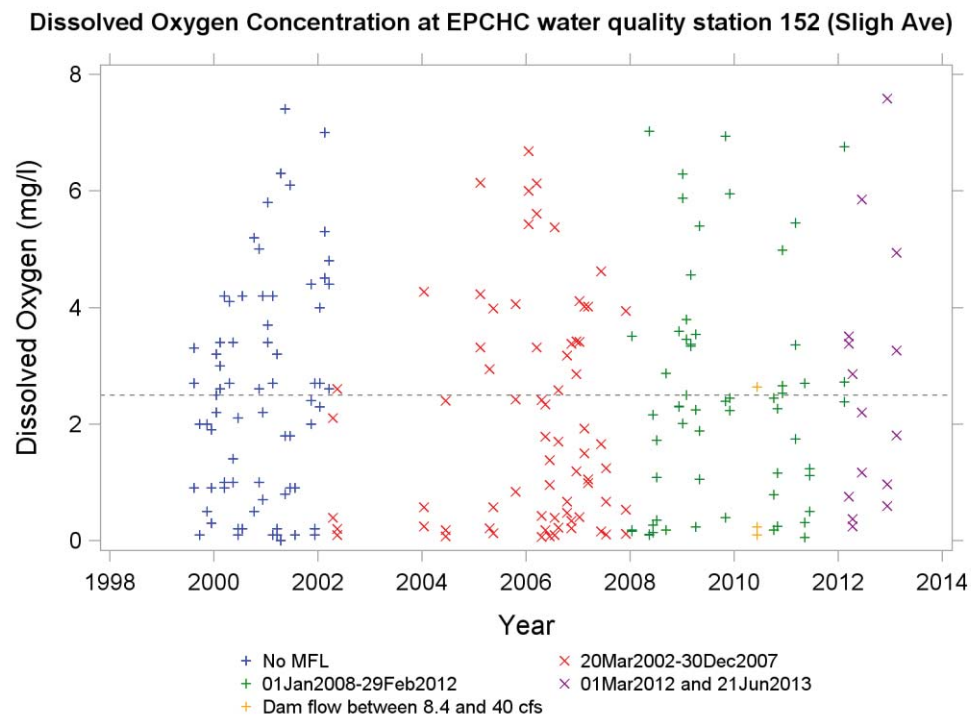


**Figure 5-5. Time series of dissolved oxygen concentrations for all depths at the Sligh Avenue station.**

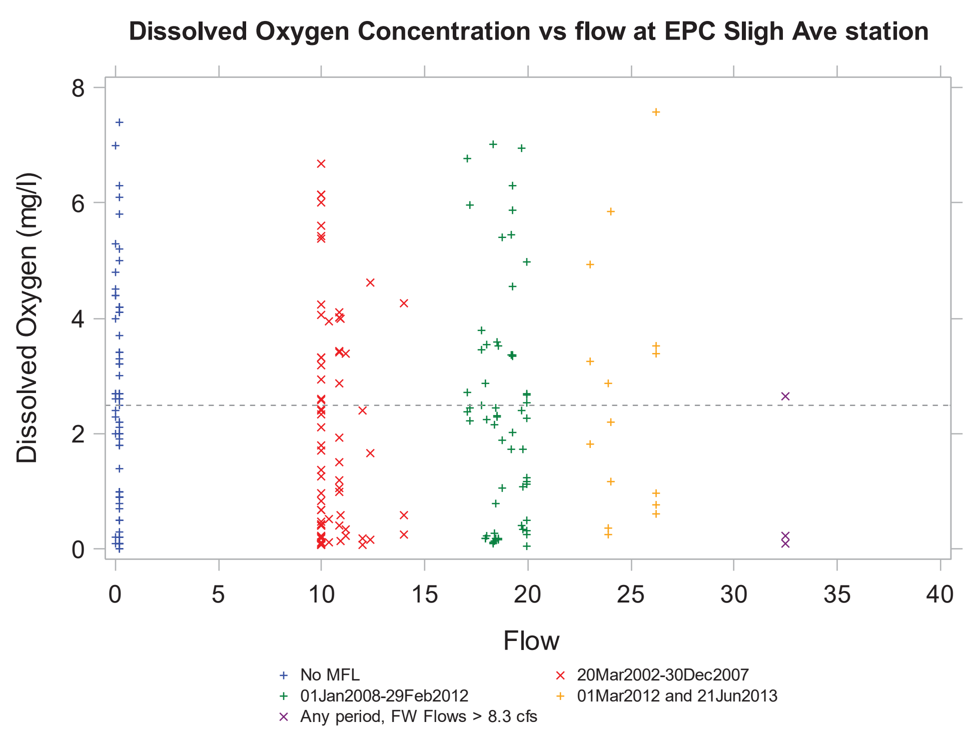


**Figure 5-6. Dissolved oxygen concentrations for all depths versus flow at the Sligh Avenue station.**

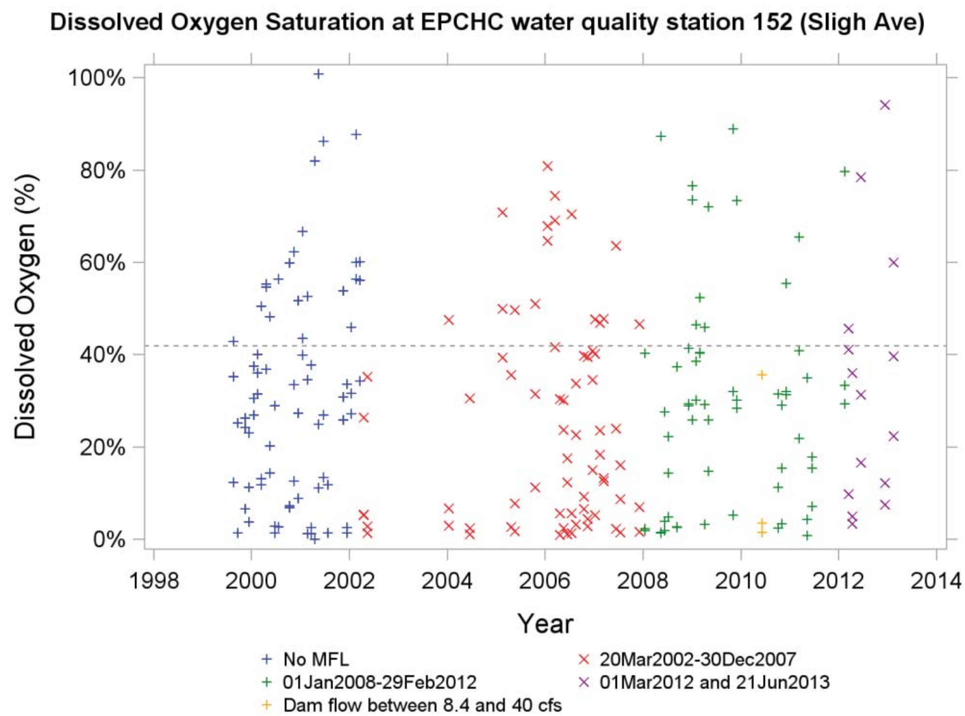


**Figure 5-7. Time series of dissolved oxygen percent saturation values for all depths at the Sligh Avenue station.**

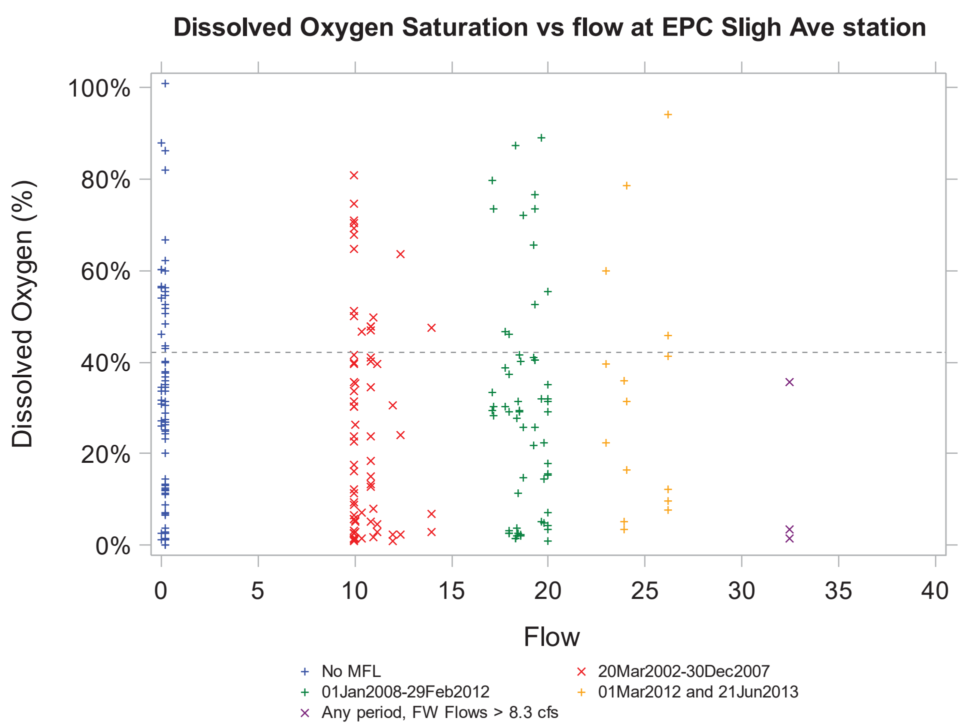


**Figure 5-8. Dissolved oxygen percent saturation versus values versus flow at the Sligh Avenue station.**

## 5.4 Dissolved oxygen data from vertical profiles

Vertical profile measurements of DO and other *in situ* parameters (salinity, pH, water temperature) have been made in the study area by three agencies; SWFWMD, EPCHC, and TBW. The data available from these sampling programs are informative because they measured DO at a wide range of locations distributed across the study area.

Vertical profile data from the District and the TBW HBMP were combined into one database with date, river kilometer, and depth of collection as the unique identifying variables. The vertical profile data were analyzed by segment in the reach of the river between Sligh Avenue and the dam. The same seven segments were determined between kilometer 10.6 and the dam for salinity were also used for the analyses of DO (see Figure 4-31). The data were also divided into the same depth intervals used for salinity in order to examine how DO varies with depth. The data were similarly examined in five different time periods that extended from the period before minimum flows to the most recent period when minimum flows were at their highest rates.

Summary statistics for DO concentrations in each river segment and depth interval during the different minimum flow periods are provided in Table 5-3. The data are limited to periods when flows at the Hillsborough River Dam were less than 1 cfs except for any minimum flow releases. In most segments, DO concentrations decreased markedly with depth and were generally low at depths of 2 meters and greater. Results of the Wilcoxon rank sum tests for each river segment and depth interval are provided in Appendix 3C, with the brief minimum flow period during 2002 grouped with the data from 2003 through 2007 for statistical analysis.

Summary statistics for DO percent saturation values in each river segment and depth interval during the different minimum flow periods are provided in Table 5-4 for the same low flow conditions. Percent saturation values similarly declined with depth were generally low at depths of 2 meters and greater. Results of the Wilcoxon rank sum tests for each river segment and depth interval are provided in Appendix 3D, with the brief minimum flow period during 2002 grouped with the data from 2003 through 2007 for statistical analysis.

**Table 5-3. Means, standard deviations, and number of observations for vertical profile dissolved oxygen concentrations (mg/L) in four depth intervals in seven river segments for the minimum flow periods.**

| River Kilometers 10.6 to < 11.6 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 4.9, (1.7,125) | 4.4, (2,39) | 5.1, (2.1,149) | 4.6, (2.2,153) | 3.9, (1.5,37) |
| **1 to < 2m** | 3.3, (2,116) | 3.2, (1.9,34) | 3.4, (2.3,131) | 2.8, (1.9,132) | 3, (1.4,32) |
| **2 m** | 2.3, (1.7,55) | 1.4, (1.1,23) | 2.2, (1.9,71) | 1.7, (1.6,69) | 1.8, (1.1,15) |
| **>2 m** | 1.7, (1.7,78) | 0.5, (0.5,32) | 1.5, (1.6,100) | 1.3, (1.5,115) | 1.1, (1.3,27) |

| River Kilometers 11.6 to < 12.6 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 4.7, (2.1,69) | 4.1, (1.5,29) | 4.7, (1.8,116) | 4.3, (2.2,94) | 4.6, (1.6,17) |
| **1 to < 2m** | 2.5, (1.8,57) | 2.2, (1.5,28) | 2.4, (1.8,91) | 2.3, (1.7,75) | 2.9, (1.2,14) |
| **2 m** | 1.5, (1.3,16) | 0.9, (1.2,17) | 1.8, (1.7,29) | 1.3, (1.5,35) | 1.1, (0.5,8) |
| **>2 m** | 1.2, (1.2,39) | 0.2, (0.4,23) | 1.1, (1.5,64) | 1, (1.2,48) | 1, (0.4,13) |

| River Kilometers 12.6 to < 13.4 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 4.4, (2.1,87) | 3.4, (1.6,52) | 4.9, (2.1,116) | 4.8, (2.1,133) | 4.8, (1.3,24) |
| **1 to < 2m** | 3.1, (1.6,83) | 1.9, (1.3,50) | 3.3, (2,114) | 2.8, (1.8,152) | 3.1, (1.5,33) |
| **2 m** | 2.5, (1.6,42) | 1.3, (0.9,22) | 2.6, (1.8,34) | 1.6, (1.6,54) | 1.8, (1.3,14) |
| **>2 m** | 1.8, (1.5,51) | 0.6, (0.6,28) | 1.5, (1.5,49) | 0.9, (1.1,56) | 0.9, (1,18) |

| River Kilometers 13.4 to <14.1 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 4.5, (2.6,45) | 2.9, (1.3,22) | 4.3, (1.8,72) | 4.8, (2.3,90) | 5, (1.6,16) |
| **1 to < 2m** | 2.4, (1.9,33) | 1.9, (1.1,22) | 2.5, (1.7,61) | 2.5, (1.9,78) | 3.9, (2.1,16) |
| **2 m** | 1.2, (0.9,5) | 1.1, (1,17) | 1.7, (1.1,21) | 1.2, (1.2,34) | 2.9, (2.3,10) |
| **>2 m** | 0.8, (1.1,18) | 0.4, (0.7,42) | 1.4, (1.2,52) | 0.8, (0.9,82) | 2.1, (2,19) |

| River Kilometers 14.1 to < 14.5 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 3.7, (2.2,38) | 2.9, (0.6,10) | 5.4, (2.2,30) | 5.2, (1.6,58) | 5.5, (2.2,13) |
| **1 to < 2m** | 3.3, (2.6,23) | 2.1, (0.9,10) | 3.2, (2.4,25) | 3.1, (2,47) | 5.2, (2.4,8) |
| **2 m** | 3, (2.8,4) | 1.2, (1.1,9) | 1.2, (0.7,3) | 1.6, (1.5,15) | 3.9, (2.7,4) |
| **>2 m** | 3, (2.4,14) | 0.5, (0.8,19) | 1.1, (1.2,14) | 0.9, (1.2,44) | 1.7, (1.5,13) |

| River Kilometers 14.5 to < 15.2 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 4, (3.5,36) | 3.5, (0.7,35) | 6, (2,69) | 6.4, (2.2,67) | 6.2, (1.1,23) |
| **1 to < 2m** | 2, (1.2,20) | 2.6, (0.8,45) | 5.5, (2.5,58) | 5.5, (2.7,68) | 5.2, (1.9,20) |
| **2 m** | 1.6, (.,1) | 1.6, (0.7,8) | 2.5, (1.8,9) | 2.8, (1.7,9) | 2.7, (.,1) |
| **>2 m** | 3.7, (.,1) | 0.8, (0.9,2) | 1.3, (1.7,5) | 0.7, (0.5,2) | |

| River Kilometers 15.2 to 16.2 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 5.2, (2.7,88) | 5.8, (1.7,26) | 7, (2.4,91) | 6.9, (2.3,84) | 8.2, (2.6,38) |
| **1 to < 2m** | 3.9, (2.4,64) | 4, (1.1,24) | 5.8, (2,58) | 5.9, (1.9,62) | 6, (0.8,14) |
| **2 m** | 3, (1,6) | 3, (1,10) | 5.4, (1.4,6) | 4.9, (1.9,15) | 5.1, (1.5,5) |
| **>2 m** | 3.1, (1.6,25) | 2.6, (0.9,10) | 4.6, (1.8,27) | 5.3, (1.5,21) | 5.7, (0.7,8) |

**Table 5-4. Means, standard deviations, and number of observations for vertical profile dissolved oxygen saturation values in four depth intervals in seven river segments for the minimum flow periods.**

| River Kilometers 10.6 to < 11.6 | | | | | |
|---|---|---|---|---|---|
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 60.7, (24.3,125) | 57.7, (26.4,39) | 63.6, (26,149) | 55.6, (27.2,153) | 50.9, (21,37) |
| **1 to < 2m** | 41.4, (26.2,116) | 42.2, (25.6,34) | 43.5, (28.8,131) | 35.6, (23.6,132) | 40.3, (19.1,32) |
| **2 m** | 27.6, (20.8,55) | 19, (15,23) | 27.9, (23.5,71) | 22.5, (20.5,69) | 25.3, (16.5,15) |
| **>2 m** | 20.2, (19.5,78) | 6.6, (6.9,32) | 19, (19.9,100) | 17.3, (19.4,115) | 15.6, (18.7,27) |
| **River Kilometers 11.6 to < 12.6** | | | | | |
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 60.6, (28.2,69) | 52.3, (19.2,29) | 58.6, (22.3,116) | 52.6, (26.9,94) | 60.8, (21.8,17) |
| **1 to < 2m** | 31.9, (23.3,57) | 29.4, (18.9,28) | 29.9, (22.3,91) | 28.8, (20.3,75) | 40.7, (16.4,14) |
| **2 m** | 20.2, (17.5,16) | 11.7, (16.4,17) | 21.4, (19.7,29) | 17.3, (18.9,35) | 16.1, (6.8,8) |
| **>2 m** | 15.8, (16.4,39) | 3.3, (5,23) | 14.7, (18.9,64) | 13.3, (15.5,48) | 14.5, (6.1,13) |
| **River Kilometers 12.6 to < 13.4** | | | | | |
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 53.6, (26.7,87) | 43.3, (21.1,52) | 58.6, (26.7,116) | 57.8, (25.8,133) | 64.1, (18.5,24) |
| **1 to < 2m** | 38.5, (20.6,83) | 24.9, (17.4,50) | 40.9, (23.6,114) | 33.9, (21.7,152) | 42.2, (19,33) |
| **2 m** | 28.7, (18.2,42) | 17.1, (11.9,22) | 32.2, (22.6,34) | 20.2, (19.8,54) | 23.4, (15.6,14) |
| **>2 m** | 20.5, (16.9,51) | 8.3, (8.4,28) | 18.9, (19,49) | 12.5, (14.2,56) | 11.2, (12.4,18) |
| **River Kilometers 13.4 to <14.1** | | | | | |
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 53.9, (29.9,45) | 36.9, (17.3,22) | 52.8, (21.8,72) | 55.5, (25.9,90) | 65.6, (20.2,16) |
| **1 to < 2m** | 29.6, (21.5,33) | 24.5, (14.6,22) | 31.2, (20.6,61) | 29.8, (20.6,78) | 51, (25.5,16) |
| **2 m** | 15.4, (11.5,5) | 14.2, (12.5,17) | 20.8, (13.4,21) | 15, (13.7,34) | 38.2, (27.5,10) |
| **>2 m** | 10.1, (13.7,18) | 5.4, (9.3,42) | 17.9, (14.5,52) | 11, (12.1,82) | 27.8, (24,19) |
| **River Kilometers 14.1 to < 14.5** | | | | | |
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 47, (26.8,38) | 37.3, (8.2,10) | 63.8, (23.5,30) | 61, (17.4,58) | 69.4, (26.8,13) |
| **1 to < 2m** | 41.3, (32.3,23) | 26.2, (10.8,10) | 38.6, (27.7,25) | 37.8, (22.6,47) | 67.6, (30,8) |
| **2 m** | 37.1, (31.4,4) | 15.2, (13.7,9) | 15.7, (9.2,3) | 18.3, (16.1,15) | 53.8, (36.4,4) |
| **>2 m** | 37.4, (29.2,14) | 6.7, (9.6,19) | 13.2, (14.7,14) | 11.1, (13.4,44) | 21.7, (18.5,13) |
| **River Kilometers 14.5 to < 15.2** | | | | | |
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 49.6, (41.8,36) | 43.7, (8.3,35) | 71.6, (23.3,69) | 74, (22.7,67) | 82.2, (14.7,23) |
| **1 to < 2m** | 25.2, (14.6,20) | 33.2, (9.9,45) | 66.7, (28.4,58) | 64.6, (30.1,68) | 69.4, (25.2,20) |
| **2 m** | 20.8, (.,1) | 20.4, (8.9,8) | 31.7, (20.6,9) | 35.1, (20.9,9) | 34.8, (.,1) |
| **>2 m** | 47, (.,1) | 10.4, (11.6,2) | 16, (20.4,5) | 8.6, (6.2,2) | |
| **River Kilometers 15.2 to 16.2** | | | | | |
| **Depth** | **No MFL** | **Spring 2002** | **Dec 2003 - Dec 2007** | **Jan 2008 - Feb. 2012** | **After Feb. 2012** |
| **0 to < 1 m** | 63.5, (32.4,88) | 72.4, (21.1,26) | 82.2, (34.5,91) | 75.8, (33.5,84) | 107.8, (41.3,38) |
| **1 to < 2m** | 48.1, (28.1,64) | 49.8, (12.8,24) | 67.6, (28,58) | 67.2, (25.2,62) | 76.3, (12.7,14) |
| **2 m** | 36.7, (10.4,6) | 38.1, (11.7,10) | 65.7, (14.9,6) | 57.1, (21.8,15) | 66.5, (20.8,5) |
| **>2 m** | 39, (20.6,25) | 31.9, (11.9,10) | 52.5, (25,27) | 56.4, (24.4,21) | 72.8, (11.6,8) |

Results for each river segment are discussed in detail in the following report sub-sections. Box and whisker plots and plots of DO concentrations and percent saturation versus flow for the differing minimum flow periods and for all periods combined when flows exceeded 8.4 cfs are presented. These graphics include data for days when flows at the dam spillway were greater than 1 cfs, in contrast to the statistics in Tables 5-3 and 5-4 and statistical results presented in Appendices 3C and 3D that do not include days when flows at the dam spillway were more than 1 cfs.

### 5.4.1 Kilometers 15.2 to 16.2

Figure 5-9 shows box plots of DO concentrations for different depth intervals and minimum flow periods in this segment that extends from just below Rowlett Park upstream to the dam. For all of the depth intervals, DO concentrations were lowest in the period prior to minimum flow implementation and increased after minimum flows began. DO concentrations were generally above the 2.5 mg/l threshold after minimum flow implementation began regardless of depth (Figure 5-10). At depths above 2 meters where there were more observations, the Wilcoxon rank sum test indicated significant increases between the successive minimum flow periods, although the final minimum flow period could not be tested due to the lower number of observations (Appendix 3C).

Figure 5-11 shows box and whisker plots of DO percent saturation for different depth intervals and minimum flow periods. In the two most recent periods (since 2008) and during higher freshwater flows, the DEP minimum criterion of 42% saturation is almost always met at all depths (Figures 5-11 and 5-12). Results of the Wilcoxon rank sum tests for DO percent saturation are presented in Appendix 3D. Similar to the results for DO concentration, the results of the Wilcoxon rank sum test indicate that at depths above 2 meters where there are more observations, there were significant increases in DO saturation after 2008, although the final minimum flow period after the spring of 2012 could not be tested due to a low number of observations.

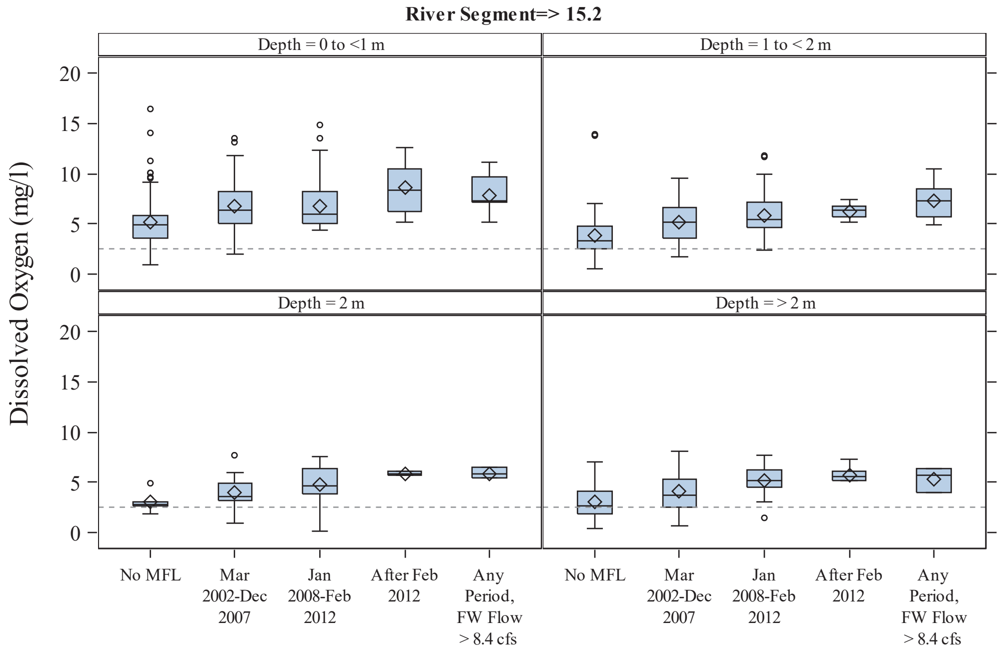


**Figure 5-9. Box and whisker plots of dissolved oxygen concentrationfor the river segment between kilometers 15.2 and 16.2.**

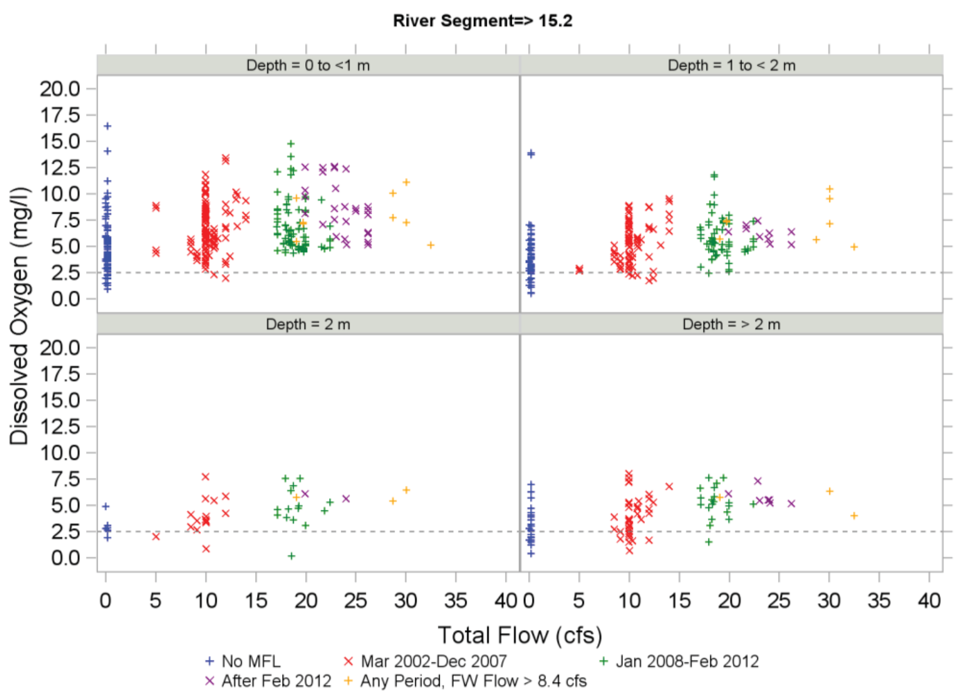


**Figure 5-10. Dissolved oxygen concentration versus flow in the river segment between kilometers 15.2 and 16.2.**

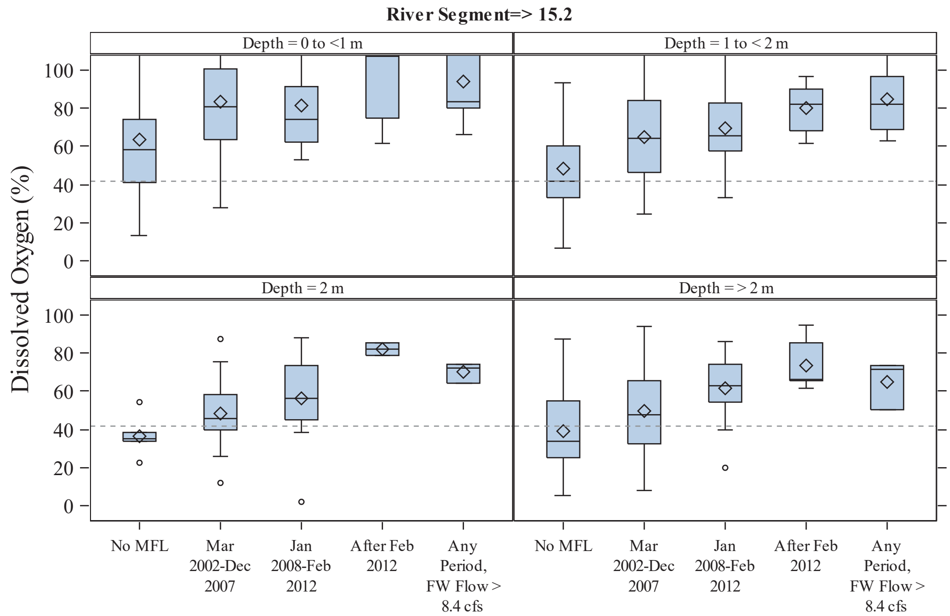


**Figure 5-11. Box and whikser plots of dissolved oxygen saturation in the river segment between kilometers 15.2 and 16.2.**

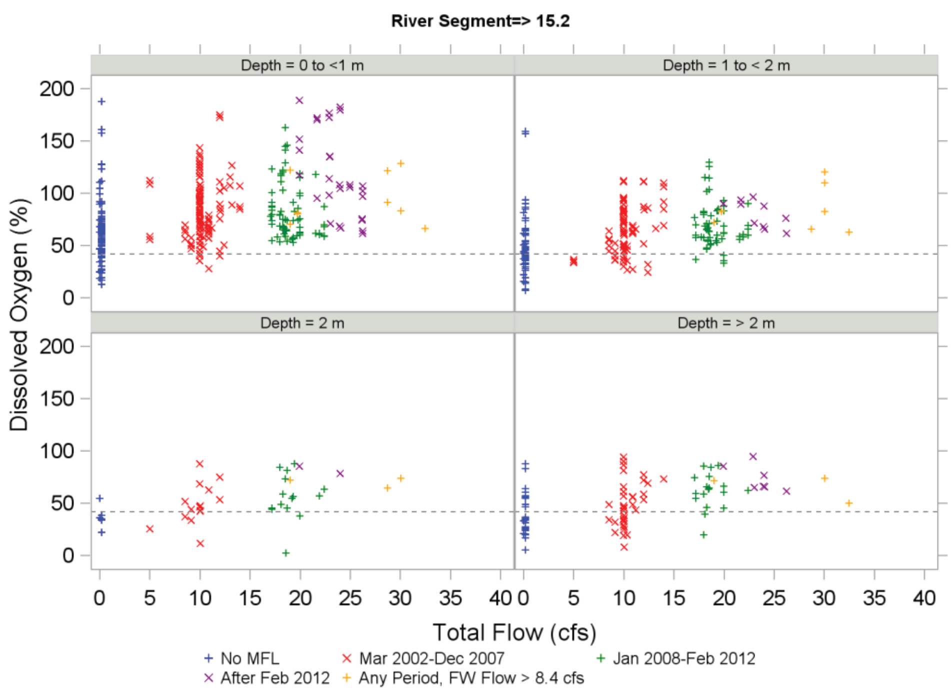


**Figure 5-12. Dissolved oxygen saturation versus flow in the river segment between kilometers 15.2 and 16.2.**

### 5.4.2 Kilometers 14.5 to 15.2

This river segment extends from just above Hannah's Whirl upstream to near Rowlett Park. Depths in this river segment are shallower than in other segments. At shallow depths (≤ 2 meters), DO concentrations were typically near or above the 2.5 mg/l threshold after minimum flow implementation and generally increased over time (Figure 5-13). However, there were some concentrations below 2.5 mg/l at these shallower depths until minimum flow rates reached 20 cfs (Figure 5-14). DO concentrations between 1 and 2 meters depth were significantly greater during the final minimum flow period (Appendix 3C). Although the data are very limited, DO concentrations were lower at deeper depths (2 meters and below) with little apparent relationship with flow.

Figure 5-15 shows box and whisker plots of DO percent saturation values for different depth intervals and minimum flow periods. For depths above 2 meters there has been a general increase in DO percent saturation values over time. Similar to DO concentrations, percent saturation values between 1 and 2 meters depth were significantly greater during the final minimum flow period (Appendix 3D). Because DO concentration and percent saturation are closely related, plots of DO saturation versus flow show similar patterns as described above, with values above 2 meters depth above the 42% threshold at flows greater than 20 cfs (Figure 5-16).

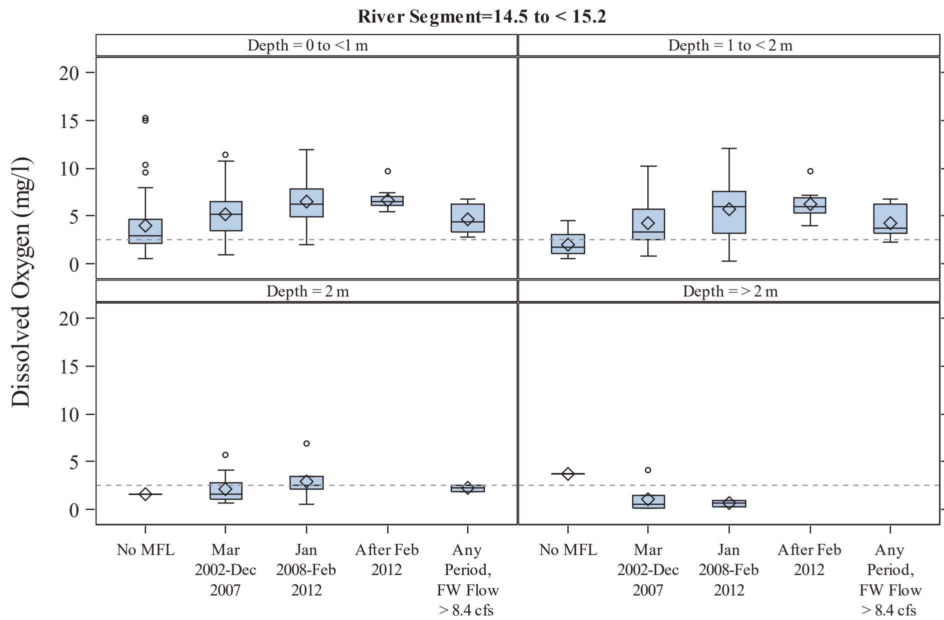


**Figure 5-13. Box and whisker plots of dissolved oxygen concentration in the river segment between kilometers 14.5 and 15.2.**

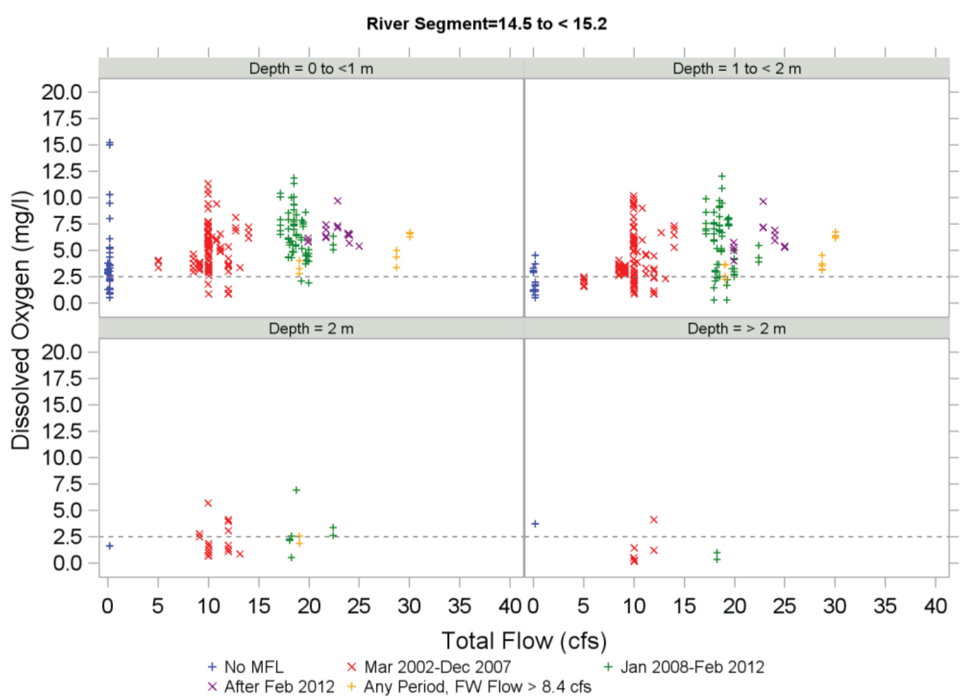


**Figure 5-14. Dissolved oxygen concentration versus flow in the river segment between kilometers 14.5 and 15.2.**

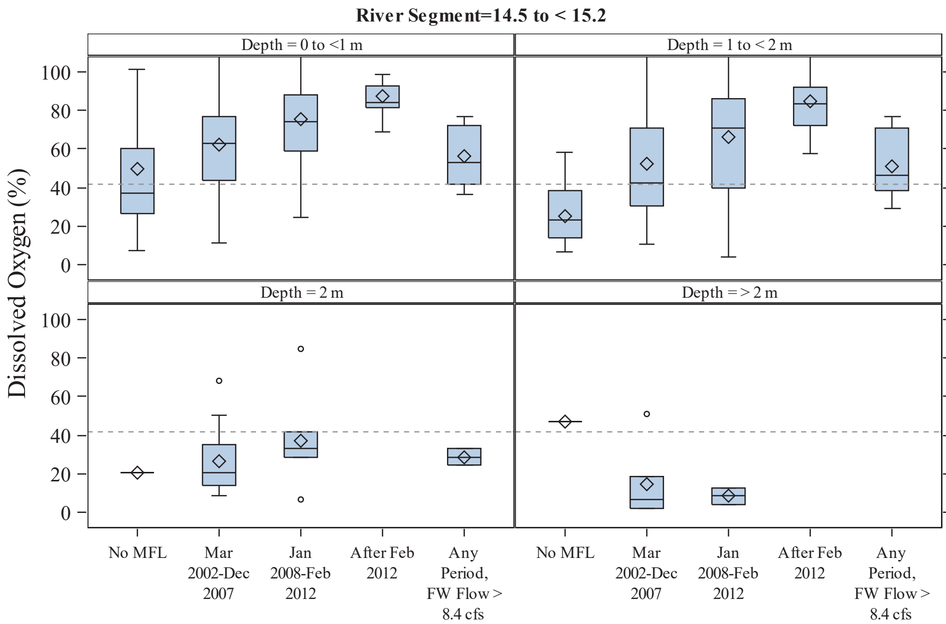


**Figure 5-15. Box and whisker plots of dissolved oxygen saturation in the river segment between kilometers 14.5 and 15.2.**

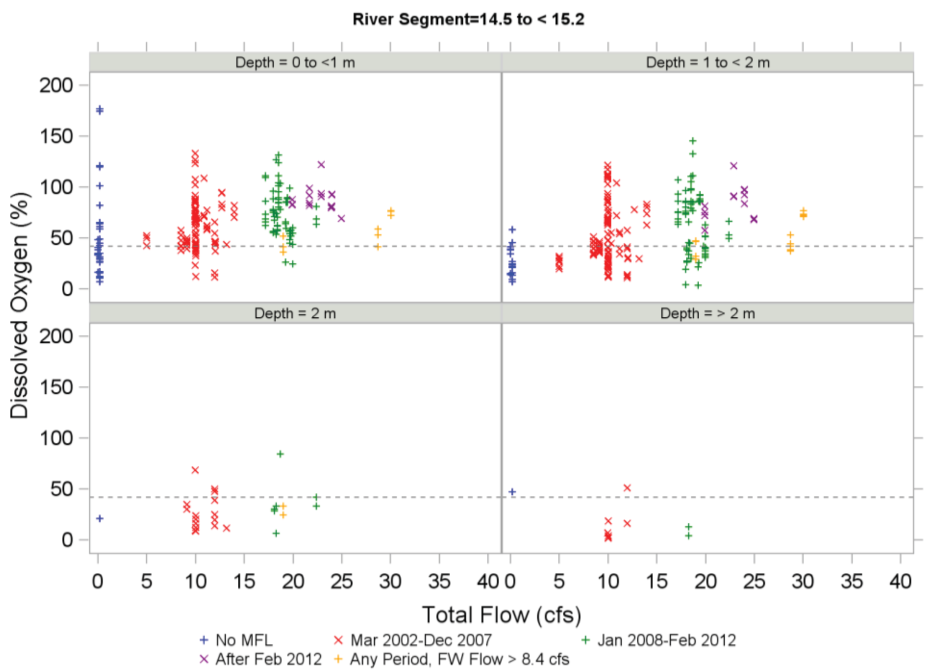


**Figure 5-16. Dissolved oxygen saturation versus flow in the river segment between kilometers 14.5 and 15.2.**

### 5.4.3 Kilometers 14.1 to 14.5

This segment covers Hannah's Whirl, which is a large deep bend in the river that represents a transition point in the vertical salinity and dissolved oxygen characteristics of the river. Figure 5-17 shows box plots of DO concentrations for different depth intervals and minimum flow periods. Low numbers of observations prevented statistical tests for many depths among the different flow periods, but there are some apparent patterns in the data. Although the data are very limited at depths of 2 meters and shallower, the results indicate that DO concentrations are improved at minimum flow rates greater than about 23 to 25 cfs (Figure 5-18). DO saturation data exhibit a similar pattern. Although the data were too limited to allow statistical comparison, the results indicated that at depths of 2 meters and shallower DO percent saturation was greater during the final minimum flow period (Figures 5-19 and 5-20).

At a depth of 2 meters, DO concentrations and percent saturation tended to decline during the first two minimum flow periods relative to no minimum flows, but rebounded during the final minimum flow period (Figures 5-17 and 5-19). This may have been due to the creation of a well-mixed layer of water to 2 meters depth as a result of the implementation of higher minimum flow rates in the later period. Hypoxia was common during all minimum flow periods at depths greater than 2 meters.

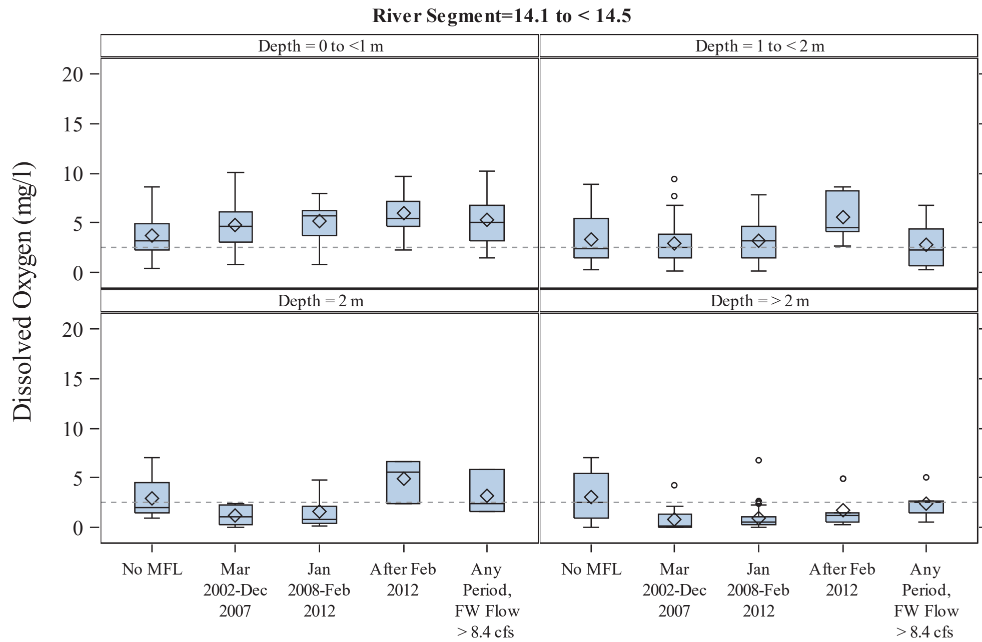


**Figure 5-17. Box and whisker plots of dissolved oxygen concentration in the river segment between kilometers 14.1 and 14.5.**

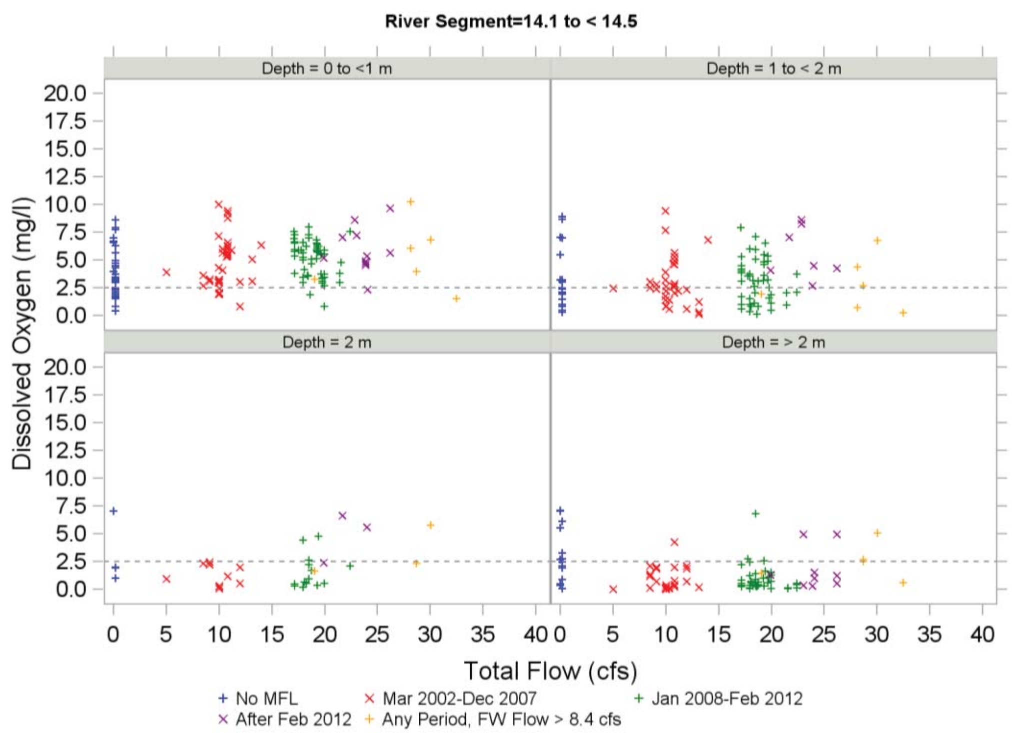


**Figure 5-18. Dissolved oxygen concentration versus flow in the river segment between kilometers 14.1 and 14.5.**

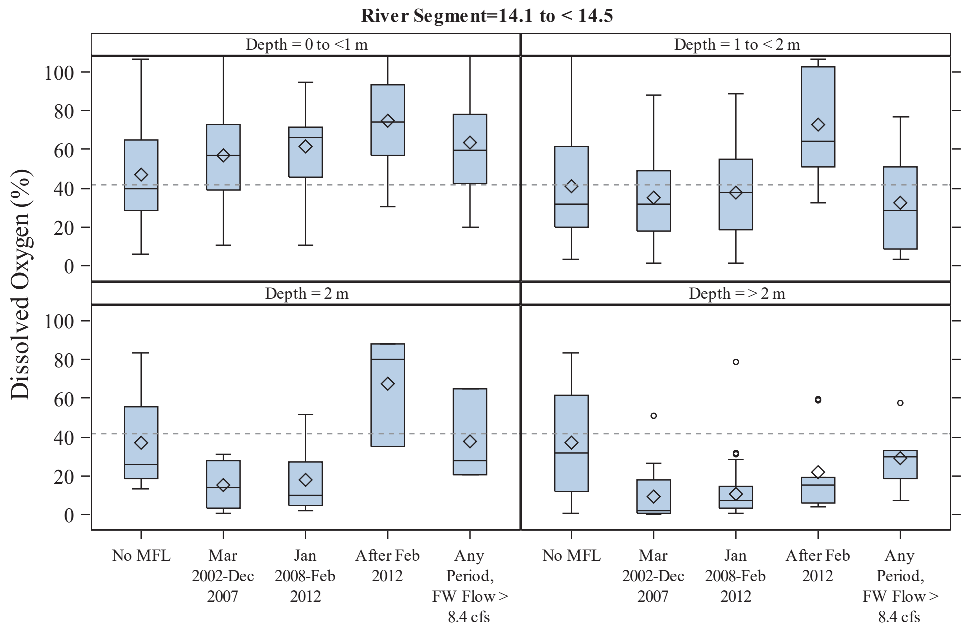


**Figure 5-19. Box and whikser plots of dissolved oxygen saturation in the river segment between kilometers 14.1 and 14.5.**

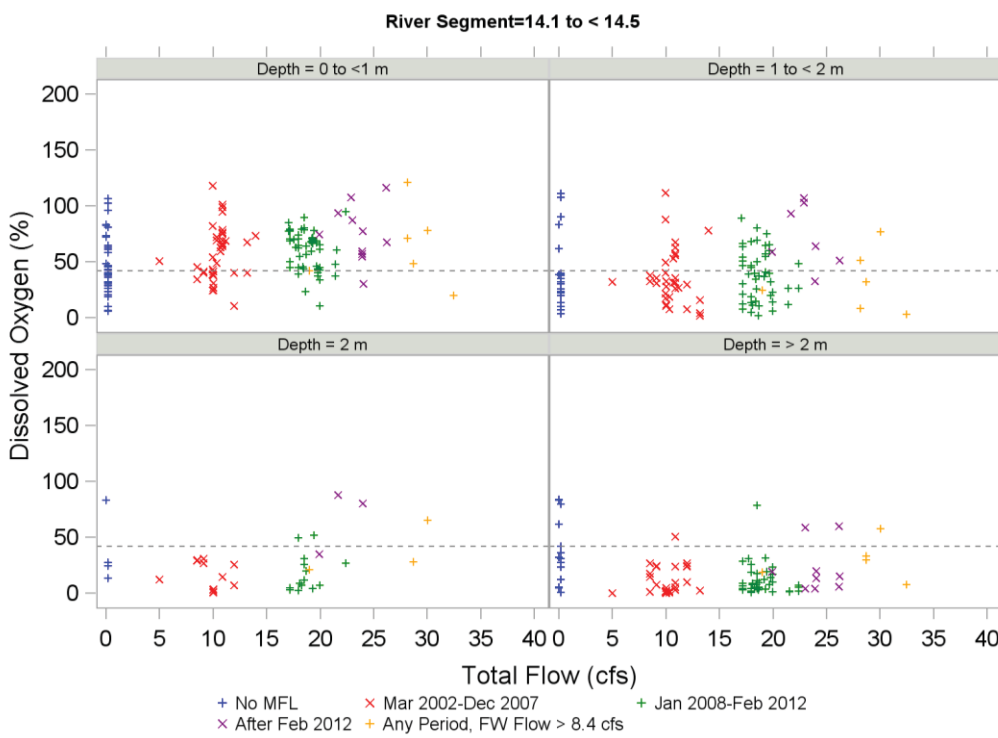


**Figure 5-20. Dissolved oxygen saturation versus flow in the river segment between kilometers 14.1 and 14.5.**

### 5.4.4 Kilometers 13.4 to 14.1

Figure 5-21 shows box plots of DO concentrations for different depth intervals and minimum flow periods for this segment that extends 0.7 kilometers downstream from Hannah's Whirl. Mean DO concentrations at depths of 1 to < 2 meters were above the 2.5 mg/l threshold only during the final minimum flow period (Table 5-3 and Figure 5-21). The data are limited, but indicate that DO in surface waters are improved a flows greater than 20 cfs (Figure 5-22) and were significantly greater during the final minimum flow period compared to the previous period (Appendix 3C). Based only on 10 observations, the mean value at 2 meters depth in the final minimum flow period (2.9 mg/l) was the only mean value that did not indicate hypoxic conditions (Table 5-3 and Figure 5-21). There appeared to be some improvement in values at depths greater than 2 meters, with DO concentrations during the final minimum flow period significantly greater than during previous periods (Appendix 3C).

The results for DO saturation showed similar relationships, with the mean saturation values during the final minimum flow period above the 42% threshold for depths between one and two meters, with mean values below the threshold for the previous minimum flow periods (Figure 5-23). Although data are limited, the results indicate that at depths of 2 meters and greater, there was some improvement in DO saturation at flows in the 22 to 25 cfs range (Figure 5-24).

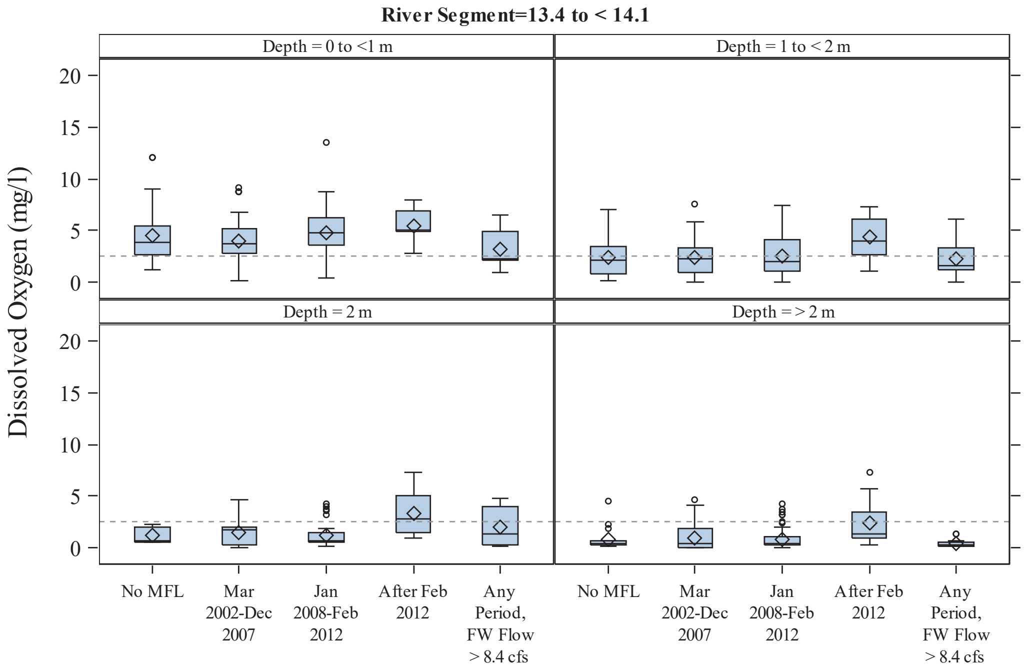


**Figure 5-21. Box and whisker plots of issolved oxygen concentration in the river segment between kilometers 13.4 and 14.1.**

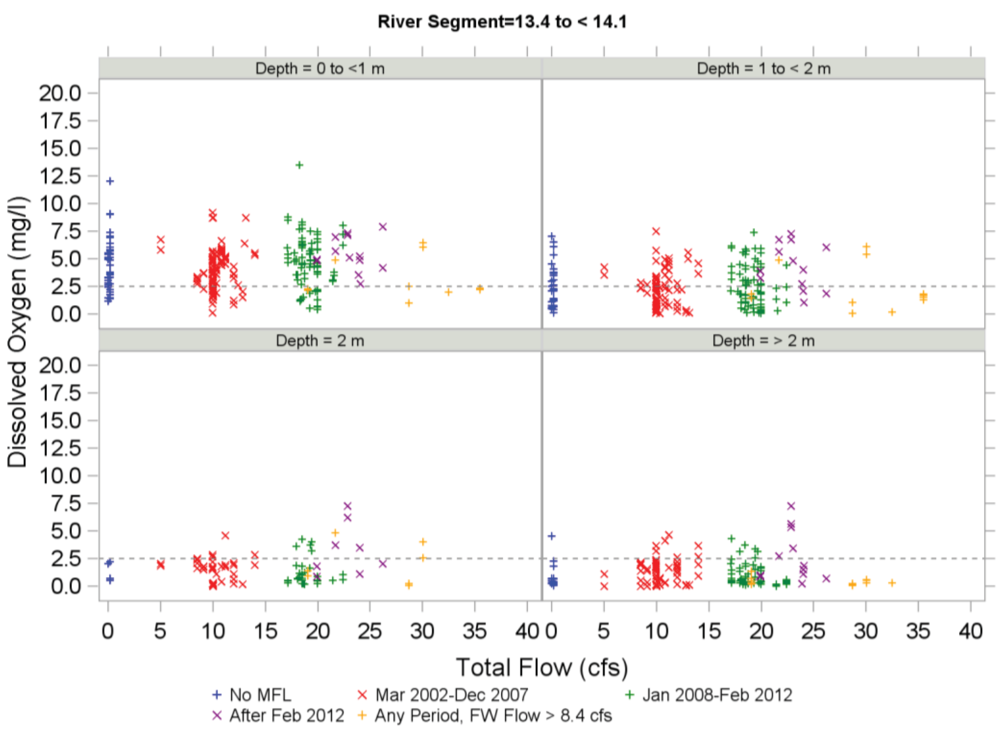


**Figure 5-22. Dissolved oxygen concentration versus flow in the river segment between kilometers 13.4 and 14.1.**

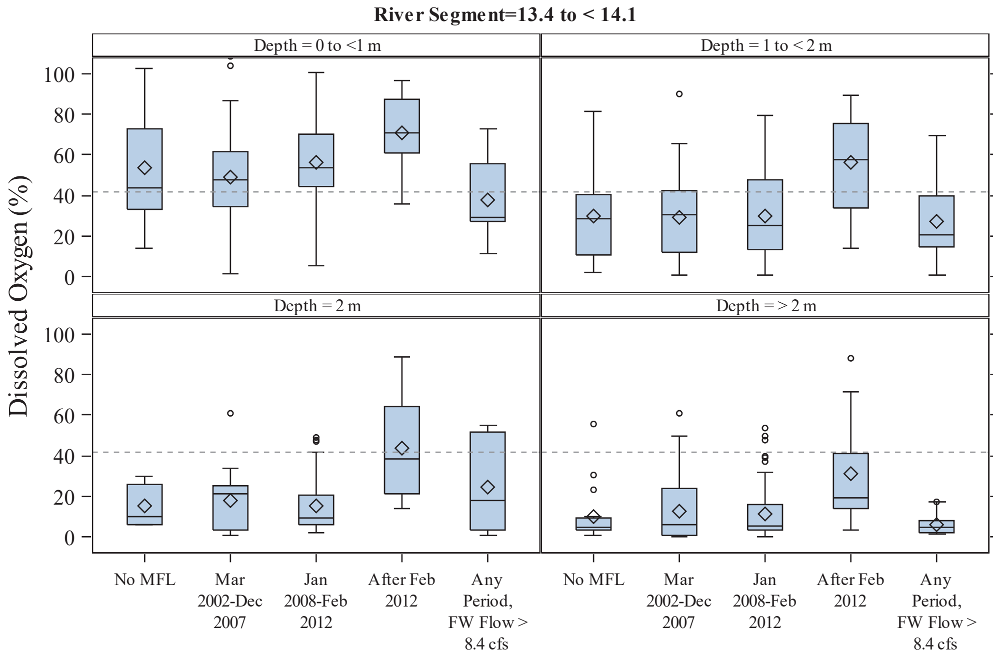


**Figure 5-23. Box and whisker plots of dissolved oxygen saturation in the river segment between kilometers 13.4 and 14.1.**


**Figure 5-24. Dissolved oxygen saturation versus flow in the river segment between kilometers 13.4 and 14.1.**

### 5.4.5 Kilometers 12.6 to 13.4

This segment begins about 0.15 kilometers below Sulphur Springs and extends 0.65 kilometers above the spring outfall. As described in Section 4.3, this section of the river is characterized by pronounced vertical salinity stratification which exerts a strong effect on dissolved oxygen concentrations in deeper waters. Figure 5-25 shows box and whisker plots of DO concentration for different depth intervals and minimum flow periods. There appeared to be some improvement in DO concentrations in surface waters as minimum flows were gradually increased, the results of Wilcoxon rank sum test were mixed, possibly due to differences in the number of observations among the minimum flow periods. DO concentrations were frequently below 2.5 mg/l at depths of 2 meters and greater during all periods. Percent saturation values at depths of 2 meters and greater were typically well below the 42% threshold during all minimum flow periods (Figure 5-27). Relationships with flow indicate there was some improvement in DO concentration values at depths shallower than 2 meters at flow greater than about 22 to 25 cfs, but there was no apparent improvement with flow at deeper depths (Figure 5-26). Similar patterns were observed for plots of percent saturation values with flow (Figure 5-28).

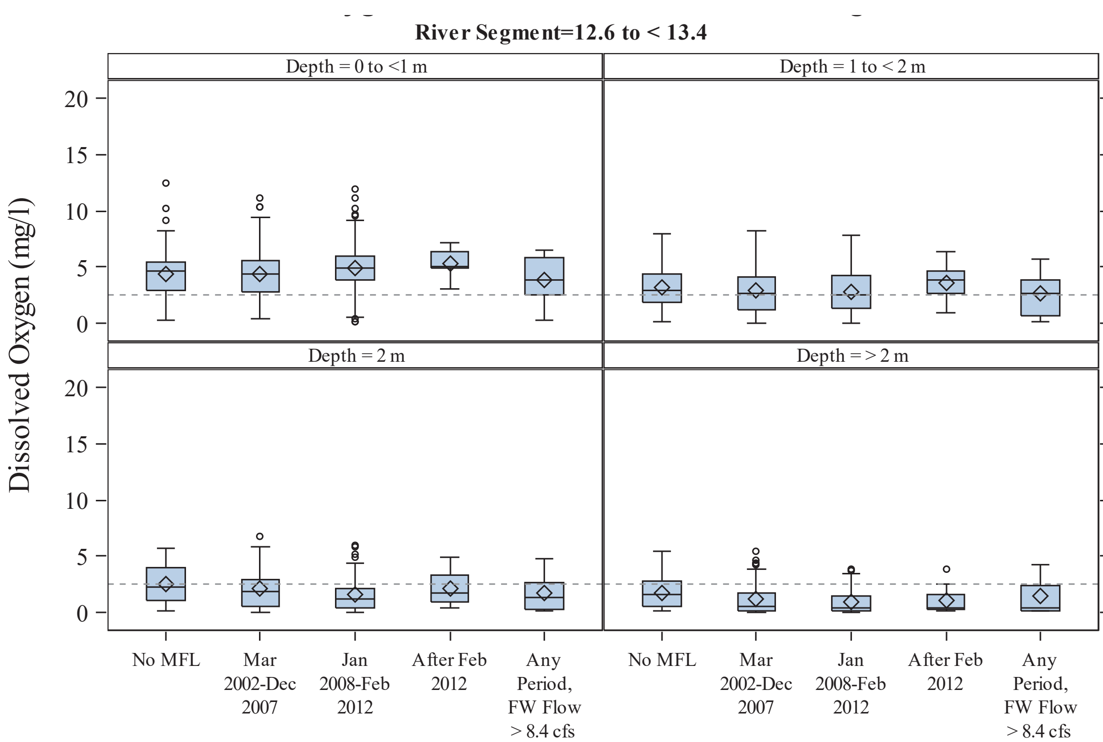


**Figure 5-25. Box and whisker plots of dissolved oxygen concentration in the river segment between kilometers 12.6 and 13.4.**

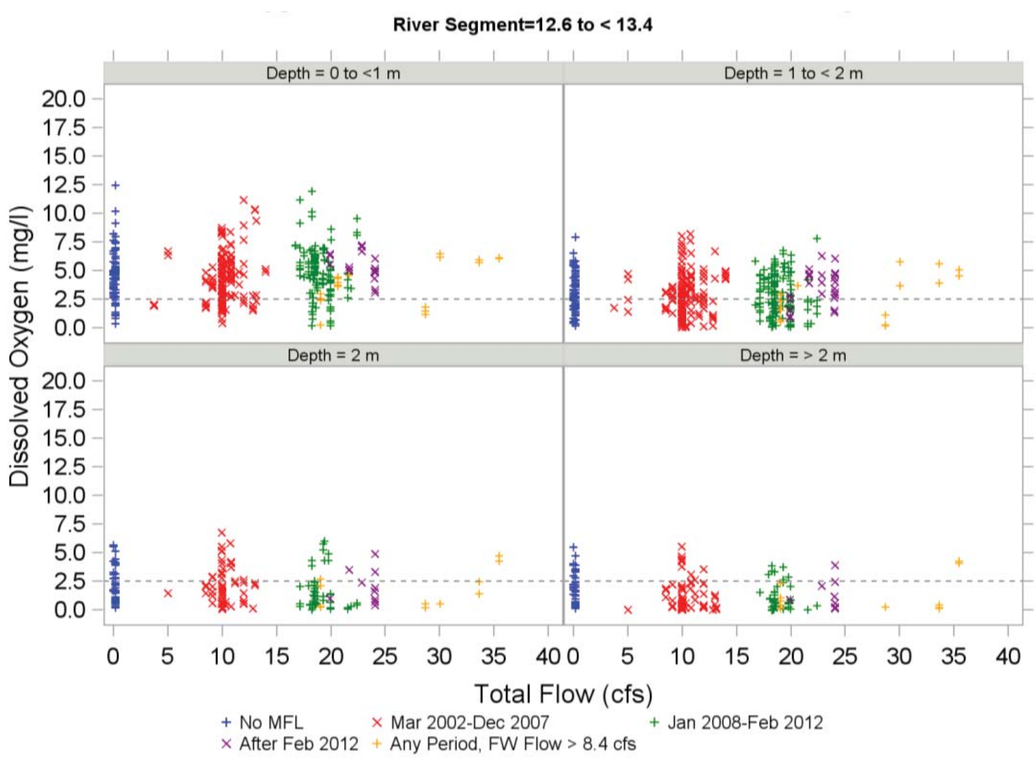


**Figure 5-26. Dissolved oxygen concentration versus flow in the river segment between kilometers 12.6 and 13.4.**

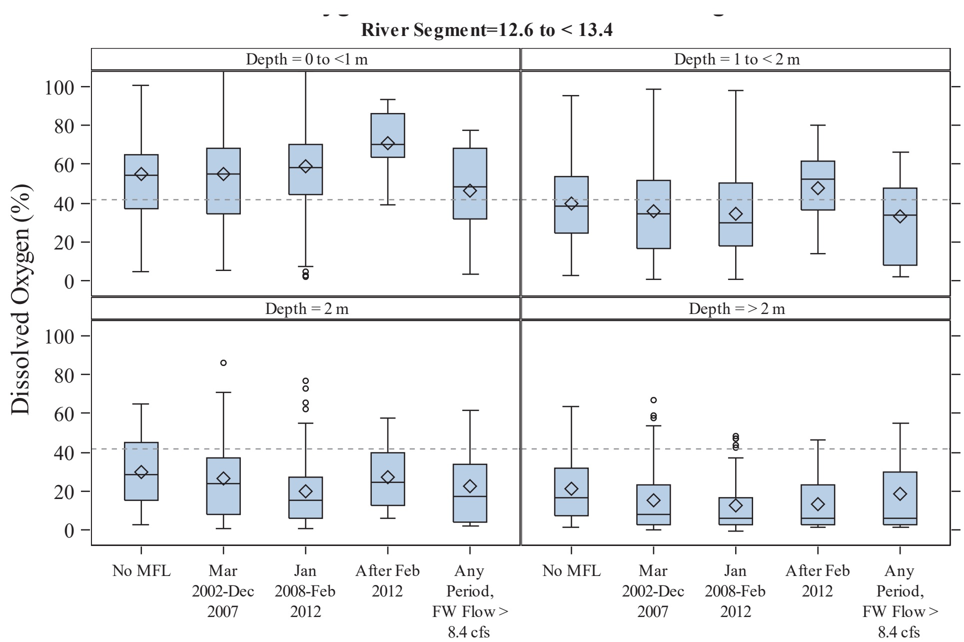


**Figure 5-27. Box and whisker plots of dissolved oxygen saturation in the river segment between kilometers 12.6 and 13.4.**

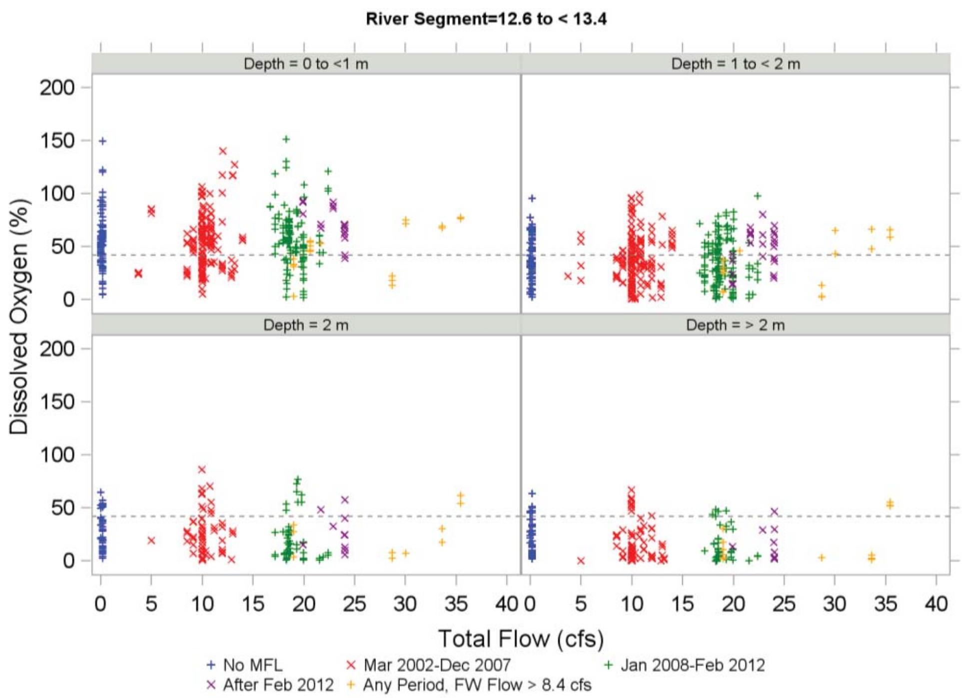


**Figure 5-28. Dissolved oxygen saturation versus flow in the river segment between kilometers 12.6 and 13.4.**

### 5.4.6 Kilometers 11.6 to 12.6

This segment between kilometers 11.6 and 12.6 is immediately downstream of the minimum flow target area, but is ecologically an important zone of the river. DO concentrations in this segment below Sulphur Springs were typically among the lowest found in the study area. With the exception of surface values during the final minimum flow period, mean values for all depth intervals and minimum flows periods were lowest for his segment compared to all others (Table 5-3). Other than the surface layer, plots of DO concentration with flow show very little relationship with the minimum flow rate, with possibly a reduction in DO concentration at deeper depths at higher flow rates (Figure 5-30). DO saturation values showed similar patterns.

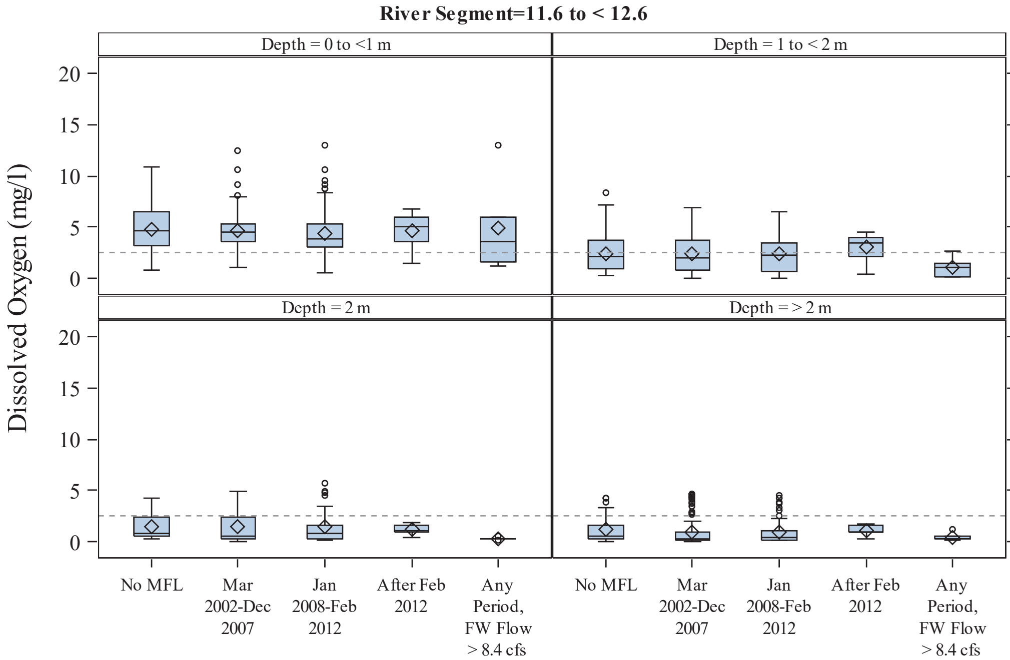


**Figure 5-29. Box and whisker plots of dissolved oxygen concentration in the river segment between kilometers 11.6 and 12.6.**

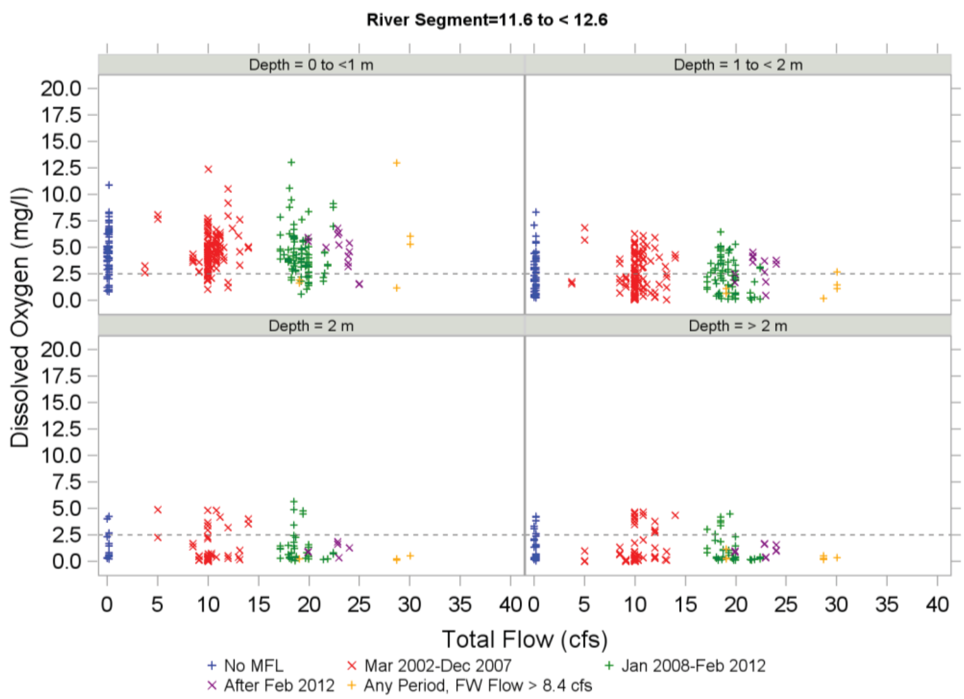


**Figure 5-30. Dissolved oxygen concentration versus flow in the river segment between kilometers 11.6 and 12.6.**

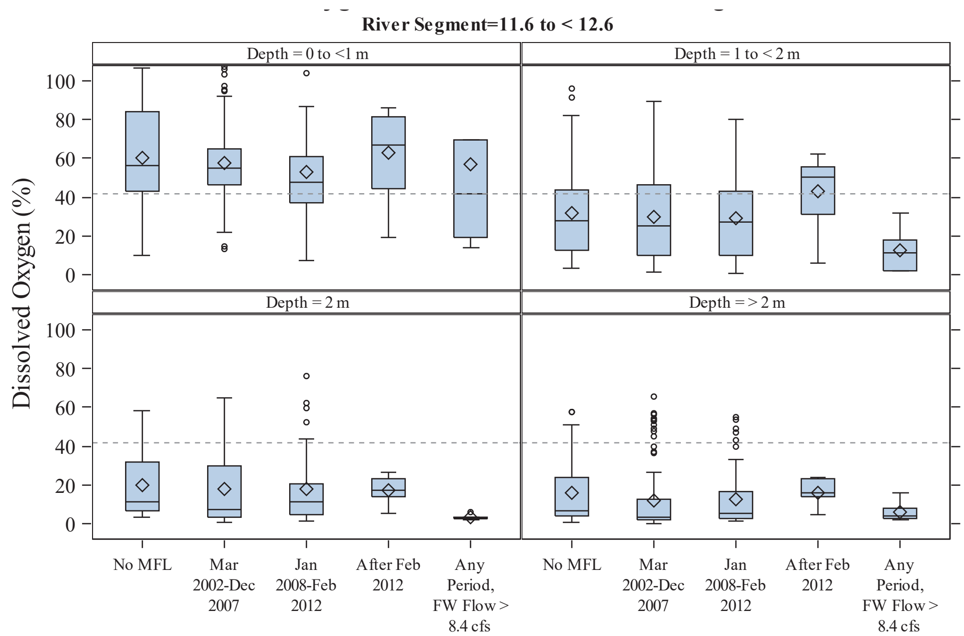


**Figure 5-31. Box and whisker plots of dissolved oxygen saturation in the river segment between kilometers 11.6 and 12.6.**

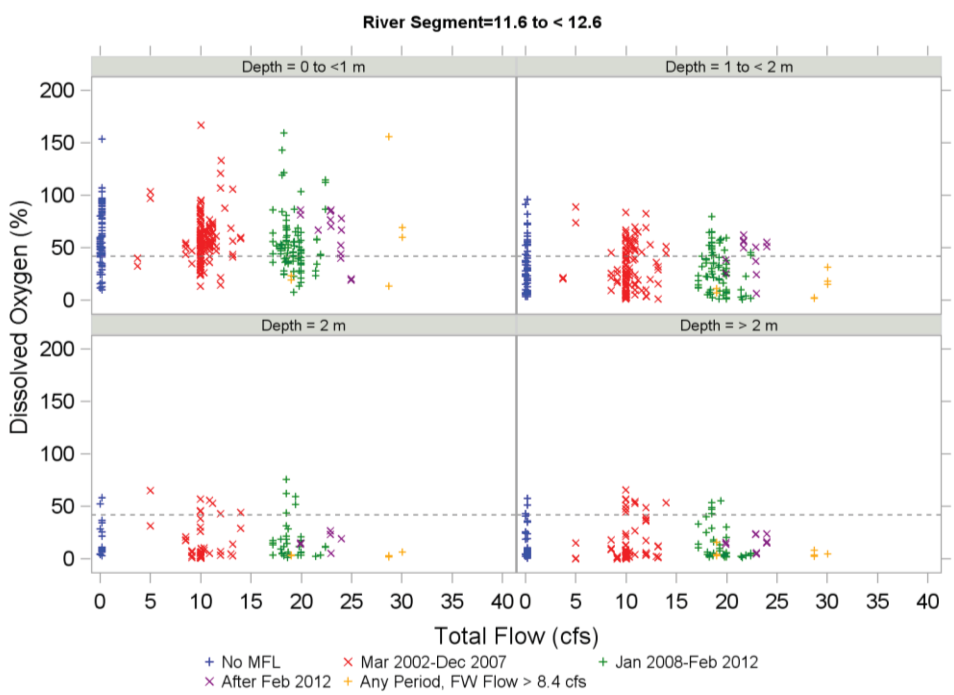


**Figure 5-32. Dissolved oxygen saturation versus flow in the river segment between kilometers 11.6 and 12.6.**

### 5.4.7 Kilometers 10.6 to <11.6

Dissolved oxygen concentrations in this segment just above Sligh Avenue generally show some improvement from the adjacent upstream segment. Figure 5-33 shows DO concentrations for different depth intervals and minimum flow periods. Similar to the segment immediately upstream, mean and median DO concentrations were near the 2.5 mg/l threshold during all minimum flow periods at the 1 to < 2 meters depth, but below the threshold at deeper depths. There appeared to be little relationship between DO concentration and flow, with the possible exception of a trend toward lower values at flow rates above 25 cfs (Figure 5-34). DO saturation values showed a similar pattern, and were frequently below the 42% threshold at depths of 2 meters and greater during all minimum flow periods.

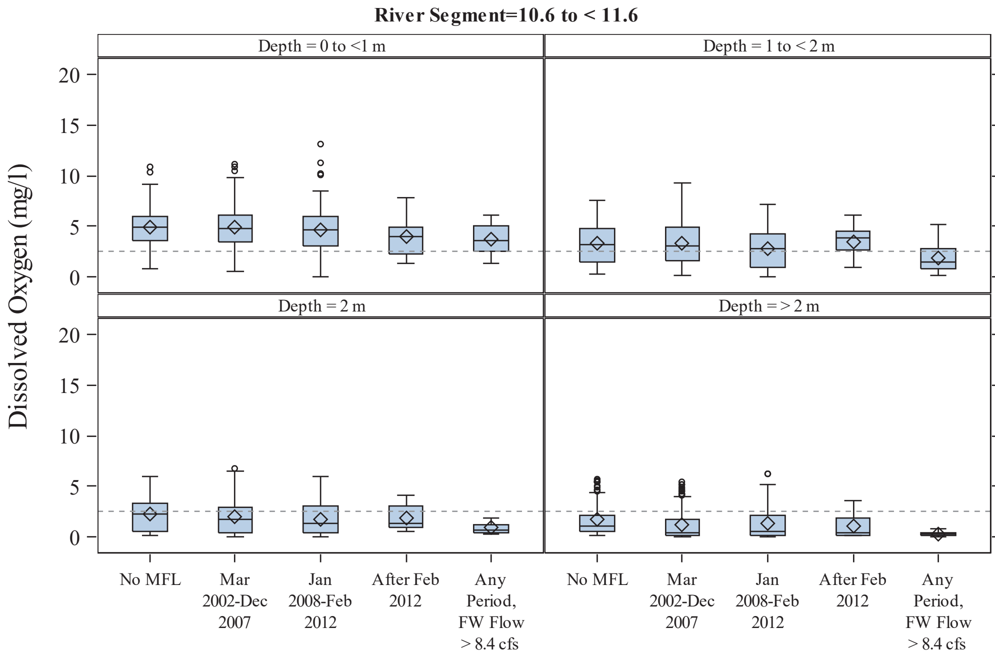


**Figure 5-33. Box and whisker plots of dissolved oxygen concentrations in the river segment between kilometers 10.6 and 11.6.**

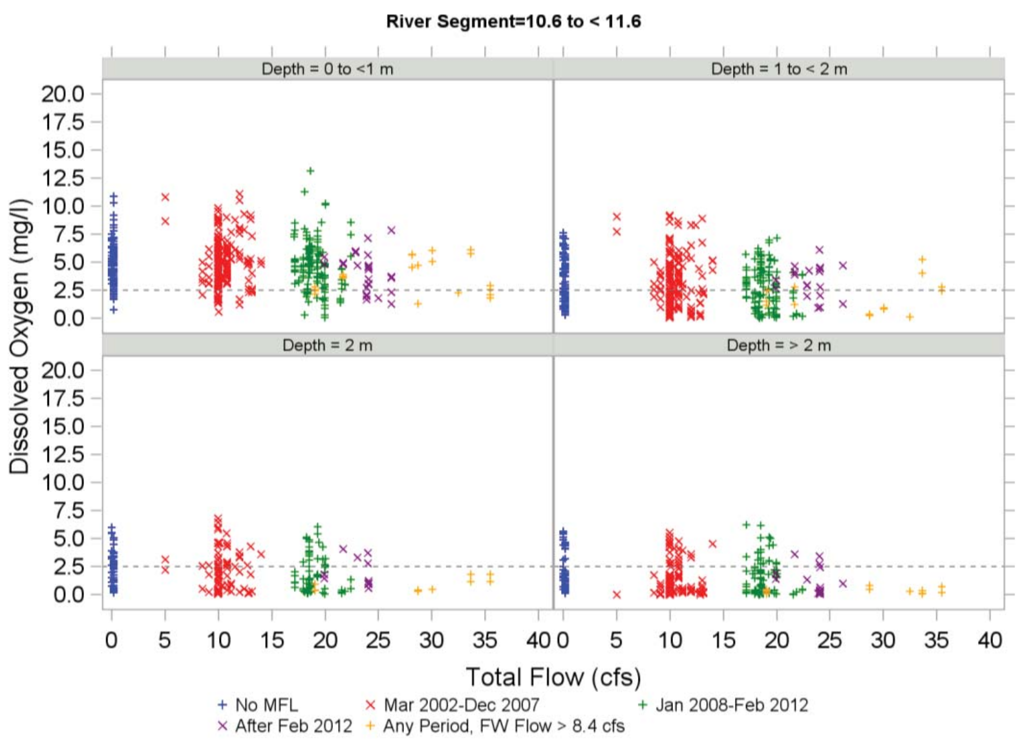


**Figure 5-34. Dissolved oxygen concentration versus flow in the river segment between kilometers 10.6 and 11.6.**

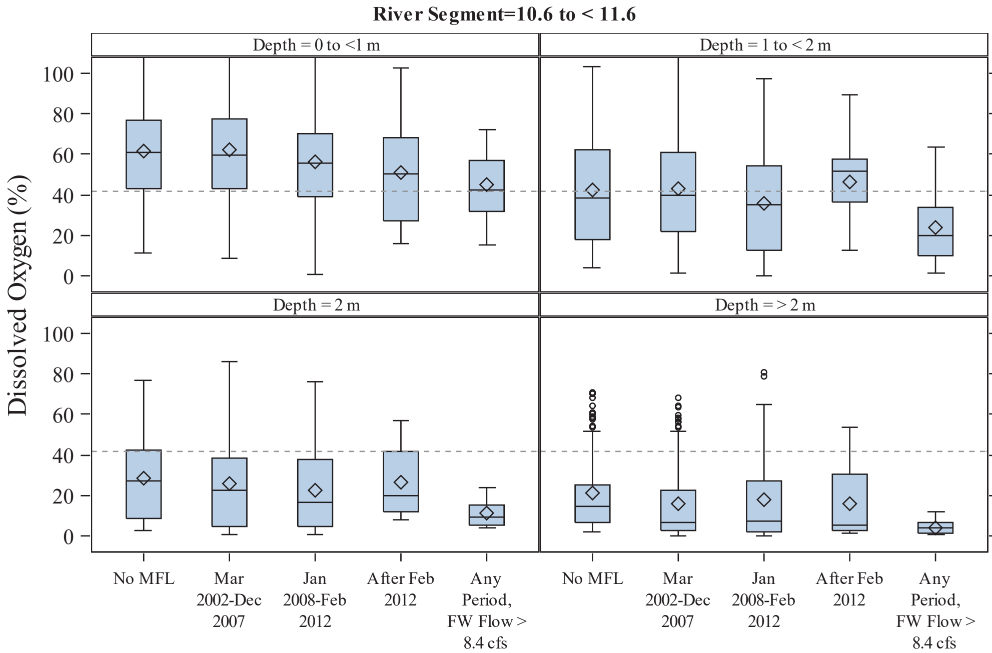


**Figure 5-35. Box and whikser plots of dissolved oxygen saturation in the river segment between kilometers 10.6 and 11.6.**

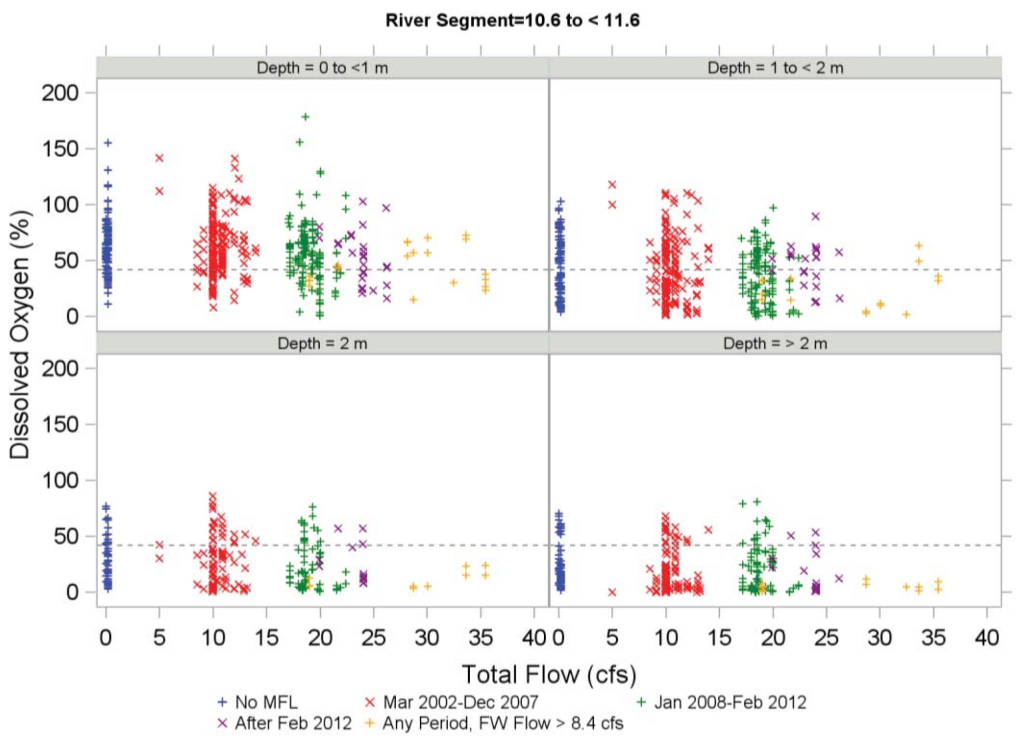


**Figure 5-36. Dissolved oxygen saturation versus flow in the river segment between kilometers 10.6 and 11.6.**

## 5.5 Relationships of dissolved oxygen concentrations with salinity stratification

Dissolved oxygen is a very dynamic component of water quality as DO concentrations can be affected by temperature, salinity, mixing, exchange with the atmosphere and biological activity (e.g., primary production and respiration). The water column of the Lower Hillsborough River often becomes vertically stratified with limited mixing between the surface and deeper waters, which typically leads to low DO concentrations in deeper waters due a lack of DO exchange with the atmosphere.

Table 5-5 through 5-7 graphically illustrate salinity, DO concentration and DO percent saturation on three dates when minimum flows were in effect. These data arefrom the SWFWMD sampling program in which vertical profile measurements were taken at the same fixed location stations each sampling trip. The three dates are the same as those in Table 4-16 which showed results solely for salinity distributions. The same graphical conventions as used with the minimum flow target area above Sulphur Springs is shaded in yellow. Salinity values shown in black are 5 psu or less, which is the oligohaline salinity threshold for the minimum flow target area. Salinity values greater than 5 psu are shown in red. Dissolved oxygen concentrations greater than 2.5 mg/l threshold are shown in black, while DO concentrations less than 2.5 mg/l are shown in red. DO percent saturation values greater than the 42% threshold are shown in black, while DO thresholds below 42% saturation are shown in red.

While these tables only represent three days, consistent patterns occur throughout the data. Salinity increases with depth and distance downstream and DO concentrations are relatively high in the deeper waters upstream until salinity stratification occurs. On May 7, 2009, when the total minimum flow was 18.7 cfs, DO concentrations above 2.5 mg/l occurred above Hannah's whirl, but concentrations below 2.5 mg/l occurred at 2 meters depth in Hannah's Whirl (kilometer 14.3) to near Sulphur Springs (kilometer 12.8), with DO concentrations below 2.5 mg/l at one meter depth at kilometers 12.8 and 13.0 (Table 5-5). DO percent saturation values below 42% occurred at one meter depth and deeper beginning at Hannah's Whirl and extending to Sulphur Springs.

Similar, but slightly saltier and more hypoxic conditions occurred on November 17, 2010, when the total minimum flow was 20 cfs (Table 5-6). Salinity values less than 5 psu occurred at one meter depth and greater from near Rowlett Park (kilometer 15.4) to near Sulphur Springs. DO was above 2.5 mg/l at stations above Hannah's Whirl, but DO concentrations less than 2.5 mg/l occurred at one meter depth and greater from Hannah's Whirl to Sulphur Springs. Percent saturation values were less than 42% at one meter depth and greater downstream of kilometer 15.1 and less than 42% in surface waters downstream of kilometer 13.6

There was some improvement in salinity and DO on April 18, 2013, when the total minimum flow was 24 cfs (Table 5-7). Salinity values less than 5 psu extended to one meter deep down to kilometer 13.9, but higher salinity waters were found at one meter depth further downstream. With the exception of one station, DO concentrations above 2.5 mg/l at one meter depth occurred to near Sulphur Springs, with values above that threshold occurring at two meters depth down to kilometer 13.9. DO saturation values showed a similar pattern.

**Table 5-5. Salinity and dissolved oxygen concentrations and % saturation by kilometer on May 7, 2009.**

| May 7, 2009 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total flow = 18.7 cfs, Spring diversion = 11.7 cfs, Reservoir release = 7 cfs | | | | | | | | | | | | | | | | | |
| | Salinity (psu) | | | | | | | | | | | | | | | | |
| | Kilometers | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 10 | 10 | 9 | 8 | 8 | 7 | 7 | 7 | 6 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | |
| 1 meters | 18 | 12 | 10 | 12 | 12 | 13 | 11 | 12 | 8 | 8 | 7 | 4 | 3 | 3 | 1 | | |
| 2 meters | 20 | 20 | 19 | 19 | 18 | 17 | 17 | 16 | 16 | 11 | 10 | 5 | 4 | | 1 | | |
| 3 meters | 20 | 20 | | 19 | 19 | | 18 | | 18 | 14 | 13 | | | | 2 | | |
| | Dissolved Oxygen (mg/l) | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 6.1 | 6.5 | 4.9 | 4.3 | 4.0 | 4.0 | 3.5 | 3.3 | 3.7 | 4.6 | 4.6 | 6.4 | 6.5 | 8.4 | 6.2 | 12.2 | |
| 1 meters | 2.7 | 4.2 | 3.6 | 3.4 | 1.9 | 2.0 | 1.7 | 1.4 | 3.0 | 2.8 | 3.1 | 6.7 | 6.3 | 10.9 | 6.6 | | |
| 2 meters | 0.9 | 0.6 | 0.8 | 0.3 | 0.5 | 2.9 | 0.5 | 1.4 | 0.2 | 1.3 | 1.7 | 9.5 | 6.9 | | 6.9 | | |
| 3 meters | 1.5 | 0.6 | | 0.4 | 1.0 | | | | 0.2 | 0.2 | 0.3 | | | | 7.1 | | |
| | Dissolved Oxygen Percent Saturation (%) | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 77 | 82 | 62 | 53 | 50 | 47 | 44 | 38 | 43 | 53 | 57 | 78 | 78 | 104 | 74 | 146 | |
| 1 meters | 37 | 55 | 46 | 43 | 22 | 22 | 20 | 16 | 37 | 32 | 37 | 85 | 77 | 132 | 78 | | |
| 2 meters | 13 | 9 | 11 | 5 | 6 | 39 | 8 | 17 | 2 | 16 | 20 | 111 | 85 | | 81 | | |
| 3 meters | 24 | 8 | | 6 | 16 | | | | 3 | 3 | 5 | | | | 84 | | |

**Table 5-6. Salinity and dissolved oxygen concentration and % saturation by kilometer on Nov. 17, 2010.**

| November 17, 2010 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total flow = 20 cfs, Spring diversion = 11.7 cfs, Reservoir release = 8.3 cfs | | | | | | | | | | | | | | | | | |
| | Salinity (psu) | | | | | | | | | | | | | | | | |
| | Kilometers | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 7 | 7 | 7 | 7 | 5 | 6 | 6 | 6 | 5 | 5 | 5 | 4 | 3 | 2 | 3 | 2 | |
| 1 meters | 12 | 12 | 12 | 10 | 11 | 13 | 9 | 11 | 8 | 8 | 6 | 6 | 7 | 6 | 6 | 2 | |
| 2 meters | 21 | 20 | 20 | 19 | 19 | 18 | 18 | 15 | 16 | 14 | 14 | 10 | 10 | | 8 | | |
| 3 meters | 21 | 21 | | | 19 | | 18 | | 17 | 16 | 15 | | | | | | |
| | Dissolved Oxygen (mg/l) | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 4.3 | 3.9 | 3.6 | 3.4 | 3.1 | 3.3 | 3.3 | 2.7 | 4.2 | 3.8 | 3.7 | 4.7 | 4.0 | 5.1 | 5.2 | 9.7 | |
| 1 meters | 4.1 | 3.6 | 2.8 | 2.4 | 2.2 | 1.4 | 1.0 | 1.7 | 2.0 | 1.9 | 1.9 | 3.2 | 2.7 | 4.2 | 3.4 | 9.5 | |
| 2 meters | 2.2 | 2.4 | 2.0 | 1.6 | 1.4 | 1.3 | 0.6 | 2.7 | 0.5 | 0.9 | 0.5 | 3.0 | 3.3 | | 3.1 | | |
| 3 meters | 2.1 | 2.7 | | | 1.5 | | 0.8 | | 0.4 | 1.7 | 0.7 | | | | | | |
| | Dissolved Oxygen Percent Saturation (%) | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 53 | 47 | 44 | 41 | 38 | 40 | 39 | 30 | 51 | 47 | 45 | 55 | 44 | 60 | 60 | 119 | |
| 1 meters | 51 | 45 | 34 | 30 | 27 | 18 | 23 | 21 | 24 | 22 | 23 | 39 | 33 | 52 | 41 | 115 | |
| 2 meters | 28 | 31 | 26 | 21 | 18 | 17 | 8 | 39 | 6 | 11 | 7 | 37 | 41 | | 38 | | |
| 3 meters | 27 | 39 | | | 20 | 30 | 11 | | 5 | 22 | 10 | | | | | | |

**Table 5-7. Salinity and dissolved oxygen concentration and % saturation by kilometer on April 18, 2013.**

| April 18, 2013 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total flow = 24 cfs, Spring diversion = 19.0 cfs, Rservoir release = 5 cfs | | | | | | | | | | | | | | | | | |
| | Salinity (psu) | | | | | | | | | | | | | | | | |
| | Kilometers | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 7 | 7 | 6 | 6 | 5 | 5 | 5 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |
| 1 meters | 10 | 9 | 10 | 8 | 11 | 11 | 8 | 7 | 8 | 4 | 3 | 3 | 2 | 2 | 2 | | |
| 2 meters | 18 | 17 | 17 | 16 | 16 | 14 | 13 | 12 | 10 | 5 | 4 | | 2 | | 2 | | |
| 3 meters | 19 | | 17 | 17 | | | 13 | | 11 | 6 | | | | | 2 | | |
| | Dissolved Oxygen (mg/l) | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 8.4 | 7.2 | 5.7 | 4.6 | 5.4 | 4.9 | 4.9 | 4.3 | 5.2 | 4.9 | 5.4 | 6.5 | 6.5 | 5.7 | 7.4 | 12.4 | 12.4 |
| 1 meters | 6.0 | 6.1 | 4.2 | 3.8 | 3.4 | 2.6 | 4.4 | 3.4 | 2.1 | 4.0 | 4.5 | 6.5 | 6.9 | 6.0 | 6.3 | | |
| 2 meters | 3.4 | 3.7 | 2.8 | 1.3 | 1.6 | 1.5 | 1.6 | 1.3 | 1.1 | 3.5 | 5.6 | | 6.9 | | 5.6 | | |
| 3 meters | 3.3 | | 2.7 | 1.1 | | | 1.1 | | 1.1 | 1.5 | | | | | 5.5 | | |
| | Dissolved Oxygen Percent Saturation (%) | | | | | | | | | | | | | | | | |
| | 10.4 | 10.8 | 11.3 | 11.8 | 12.3 | 12.8 | 13 | 13.3 | 13.6 | 13.9 | 14.3 | 14.5 | 14.8 | 15.1 | 15.4 | 15.7 | 16 |
| 0.3 meters | 122 | 103 | 82 | 67 | 78 | 70 | 71 | 62 | 75 | 70 | 77 | 93 | 93 | 81 | 105 | 179 | 183 |
| 1 meters | 89 | 90 | 62 | 55 | 51 | 39 | 64 | 50 | 31 | 58 | 64 | 92 | 97 | 84 | 88 | | |
| 2 meters | 53 | 57 | 43 | 19 | 24 | 23 | 24 | 20 | 16 | 50 | 80 | | 98 | | 79 | | |
| 3 meters | 51 | | 42 | 16 | | | 17 | | 17 | 22 | | | | | 77 | | |

The data from these three dates are presented only as examples of the spatial distributions of salinity and dissolved oxygen in the river and not as conclusive evidence of the effectiveness of various minimum flow rates. Factors such as tide stage and climatic conditions at the time of sampling, preceding flow rates at the dam, and ungaged runoff can strongly influence salinity and dissolved oxygen concentrations. However, the relationship between vertical salinity stratification and hypoxia is clear. Greater minimum flow rates push the area of better mixed, low salinity water further downstream, but the salt wedge will continue to persist somewhere above Sulphur Springs until flows at the dam spillway are above the flow rates covered by the adopted minimum flows.

The relationship between water column stratification and dissolved oxygen are displayed in Figures 5-37 to 5-40, in which DO concentrations and percent saturation values from different depths are plotted versus the salinity stratification at each depth (salinity at sample depth minus surface salinity value). The data are combined for two reaches of the lower river: from Sligh Avenue to just below Sulphur Springs (kilometer 10.6 to 12.6), and from just below Sulphur Springs to near the dam (kilometer 12.6 to 16.2).

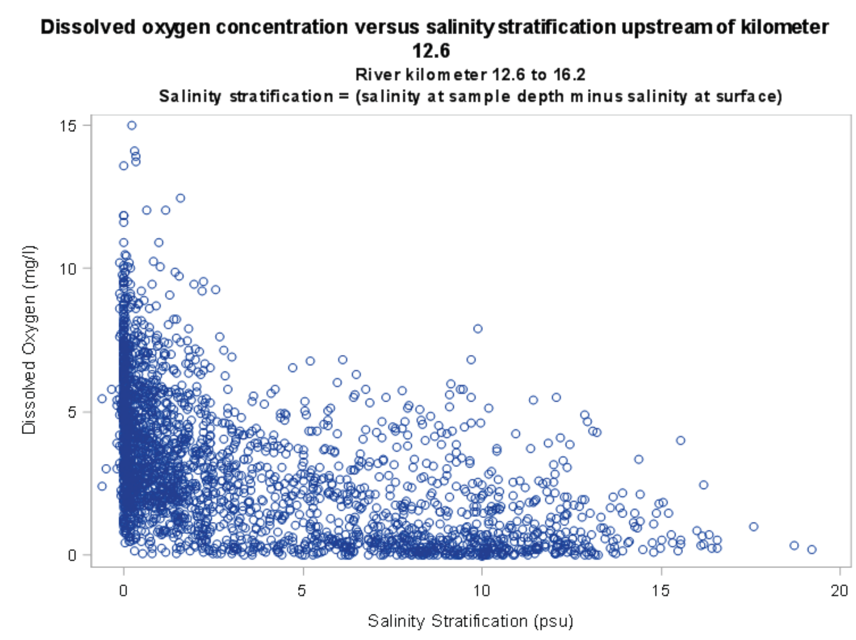


**Figure 5-37. Dissolved oxygen concentration versus salinity stratification in the river segment between kilometers 12.6 and 16.2.**

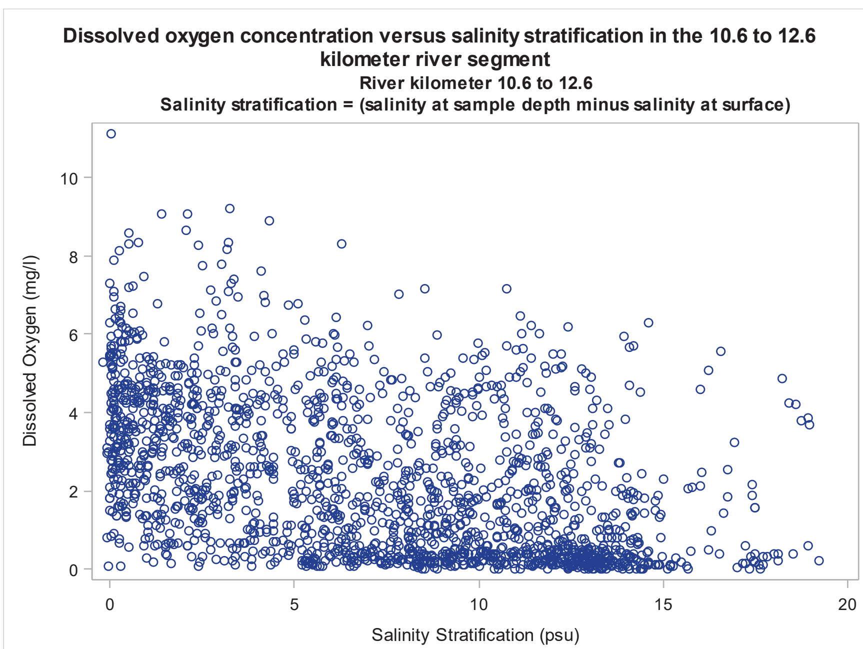


**Figure 5-38. Dissolved oxygen concentration versus salinity stratification in the river segment between kilometers 10.6 and 12.6.**

In both reaches of the river there is a distinct inverse relationship between DO concentrations and percent saturation with salinity stratification. Salinity stratification is generally lower in the upstream segment, with many stratification values in the range of 0 to 2 psu (Figure 5-37). In this reach, which is the priority area for minimum flow establishment, DO concentrations less than 2.5 mg/l represent a high proportion of the values when stratification exceeds about 2 to 3 psu. The reach downstream of Sulphur Springs, which is characterized by higher salinity, has a greater proportion of stratification values in the 5 to 15 psu range, where very low DO concentrations (<1 mg/l) are common (Figure 5-38). Plots of DO saturation versus percent stratification show similar patterns as DO concentration. In the reach above Sulphur Springs, saturation values less than 42% are very common at stratification values greater than about 2 to 3 psu (Figure 5-39). In the downstream reach, between kilometers 10.6 and 12.6, saturation values less than 42% were more evenly distributed across the range of observed stratification values (Figure 5-40).

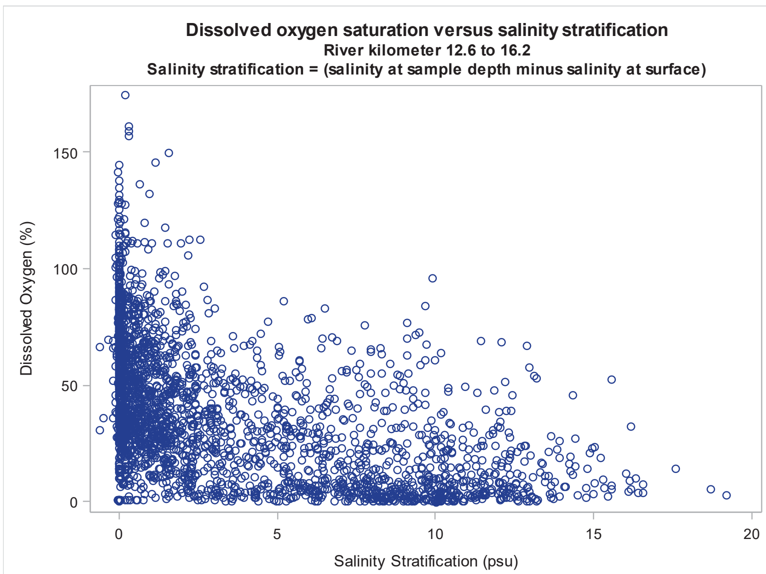


**Figure 5-39. Dissolved oxygen percent saturation versus salinity stratification in the river segment between kilometers 12.6 and 16.2.**

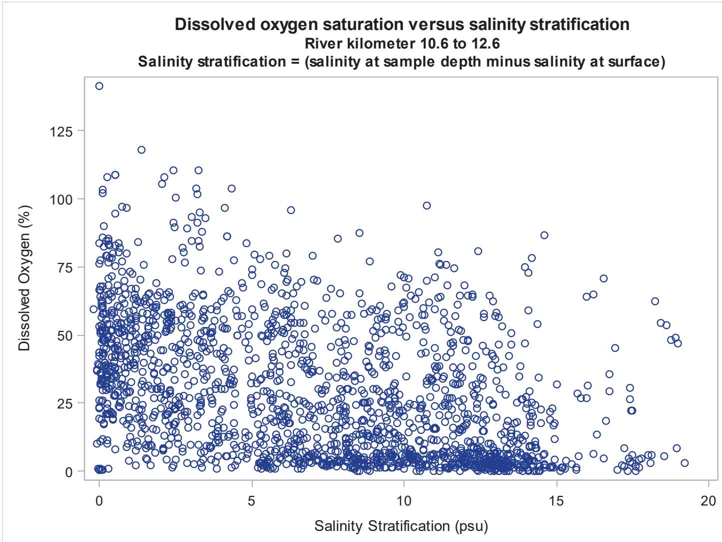


**Figure 5-40. Dissolved oxygen percent saturation versus salinity stratification in the kilometers 10.6 to 12.6 segment.**

## 5.6 Discussion

The implementation of minimum flows has resulted in some improvements in DO concentrations in the lower river, with the most apparent improvements in the reach of the river upstream from Hannah's Whirl. Minimum flows also appear to have resulted in some improvements in DO concentrations in shallow water depths (< 2 meters) between the Hannah's Whirl and Sulphur Springs; however, these findings are preliminary because the number of observations that were collected at the higher minimum flow rates are limited. The data do clearly show that low DO concentrations persist at deeper depths downstream of Hannah's Whirl at the minimum flow rates that have been implemented to date.

The occurrence of low DO is closely associated with the salinity characteristics of the river between the dam and Sulphur Springs. Greater minimum flows tend to move the zone of low salinity water and greater vertical mixing further downstream. Even in areas where vertical stratification persists in the water column, higher minimum flow rates tend to move the zone of vertical stratification slightly deeper in the water column, thus allowing better aeration to slightly deeper depths. This is shown by evidence of DO concentrations improving in the water depths between 1 and 2 meters depth downstream of Hannah's Whirl at the higher minimum flow rates.

Given these findings, it is appropriate at this time to base any conclusions regarding the effectiveness of the minimum flow rates that have been applied to date primarily on changes in salinity distributions. By improving salinity distributions below the dam, the apparent breakpoints observed for salinity appear to benefit DO concentrations as well.

However, it may be concluded that increased data collection is needed for DO and associated *in situ* parameters (salinity, temperature) on the reach between the dam and Sulphur Springs, particularly below Hannah's Whirl. Unlike salinity, for which there were four continuous recorders between the dam and Sulphur Springs, the data for DO were restricted to instantaneous grab samples collected one time each day during periodic sampling trips. The data for DO would be greatly enhanced if continuous (e.g., hourly) data were also recorded for DO at two locations in the river between Hannah's Whirl and Sulphur Springs. Although the EPCHC collected continuous DO measurements at kilometer 13.6, these data appeared to have some possible errors which were not resolved at the time of the writing of this report, and those data were not analyzed.

The technology for DO probes that can be left in the field for extended periods of time has improved in recent years. Optical DO sensors with self-cleaning mechanisms are now available that can be used to collect accurate DO data on an hourly or more frequent basis. Although periodic maintenance is still necessary, many of these optical DO sensors are less prone to fouling than earlier membrane sensors. The District and City staff should interact with the EPCHC to get reliable DO data for top and bottom waters at the continuous recorder at kilometer 13.6, which is located at a key location in the river. The City and or the District should also install and operate a second continuous DO sensor just upstream of Nebraska Avenue to document DO concentrations closer to Sulphur Springs. Collection of continuous DO data at these sites would provide valuable information on how DO at those locations respond to minimum flows.

Improved data collection for DO should also include the continuation of vertical profile measurements at a large number of sampling locations in order to characterize horizontal and vertical profiles of the salinity and DO gradients in the river. The fixed location sampling by the District at the 17 stations between kilometers 10.6 and 16.0 will continue on a regular monthly basis when minimum flows are in effect. However, the measurements of *in situ* DO data as part of the TBW HBMP program has ended. To increase the amount of DO data available for the lower river, it would be valuable if another entity could also collect vertical profile measurements in the river in this study area when minimum flows are in effect. The EPCHC conducts periodic vertical profile sampling in the river, and the District should coordinate with the EPCHC to determine how sampling by that agency could be better coordinated with the minimum flows program.

# 6 Water Temperature

Water temperatures in the Hillsborough River are primarily a function of regional climate, with the expected seasonality and inter-annual variability. Temperatures in the Hillsborough River are also affected by discharge from Sulphur Springs, which typically remains near 24 to 25 $^{o}$C year-round. When this spring water is rerouted to the Tampa Dam during low flows, the potential exists for water temperatures to be moderated between the Tampa Dam and Sulphur Springs. In this river segment, water temperature may be slightly increased during cold periods and decreased during warm periods.

The most informative data representing changes in water temperature within the river are continuous recorder data, which are the focus of this section. Because the fresh or low salinity waters that are used to provide the minimum flows tend to flow over more saline water in the lower river, water temperatures in surface waters are expected to be more sensitive to the minimum flow implementation than bottom waters. Time series plots of daily surface water temperatures at the continuous recorders are shown below using symbols denoting the different minimum flow periods discussed in previous chapters. Box plots for both surface and bottom temperatures are also shown for these same minimum flow periods. As before, the data presented are for periods when there was less than 1 cfs of flow at the Hillsborough dam spillway, other than minimum flow releases from the reservoir.

## 6.1 Water temperature at continuous recorders

### 6.1.1 Rowlett Park Drive

The range of daily average surface temperature values at the Rowlett Park Drive continuous recorder was moderated in the period following the implementation of minimum flows (Figure 6-1). The range of temperatures in the period after February 2012 is reduced more than in the prior period during which minimum flow implementation occurred (Figure 6-2). This may, in part, be associated with less extreme regional temperatures, as this period was also more moderate than the others at the Platt Street recorder near the mouth of the river. In general, however, the data indicate that minimum flows that utilize diversions from Sulphur Springs result in a moderation of temperature extremes, particularly low temperatures, at the Rowlett Park Drive station.

### 6.1.2 Hillsborough River at kilometer 13.6

There are no data available at the kilometer 13.6 continuous recorder for the period prior to the minimum flow implementation. The patterns in surface and bottom temperatures (Figure 6-3 and Figure 6-4) are similar to the patterns observed at the Rowlett Park Drive recorder. Compared to no minimum flows, it is likely that any temperature effects at kilometer 13.6 resulting from minimum flow implementation would be slightly less than the observed effects at Rowlett Park Drive. Therefore, there is no reason to suspect that any changes in water temperature at kilometer 13.6 would have negative ecological impacts due to implementation of minimum flows.

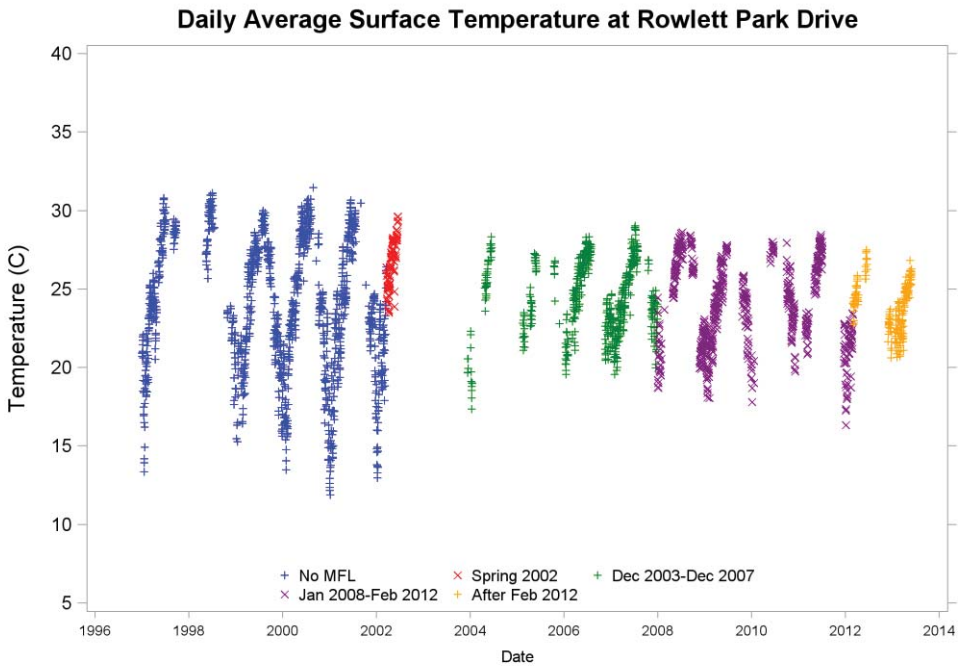


**Figure 6-1. Daily average surface temperature at the Rowlett Park Drive continuous recorder.**

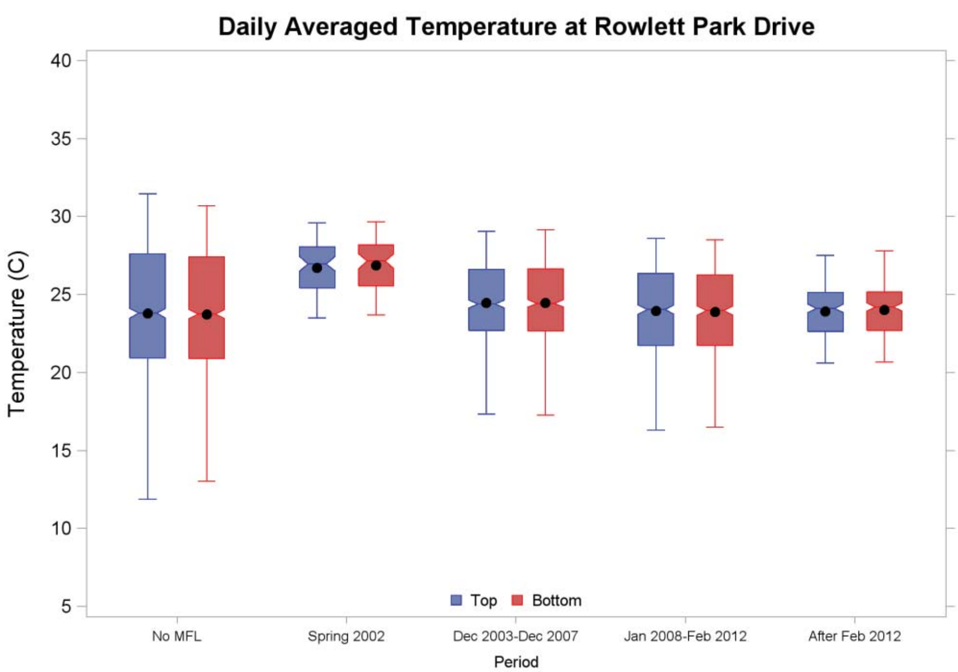


**Figure 6-2. Box and whisker plots of daily average surface and bottom temperatures at the Rowlett Park Drive continuous recorder.**

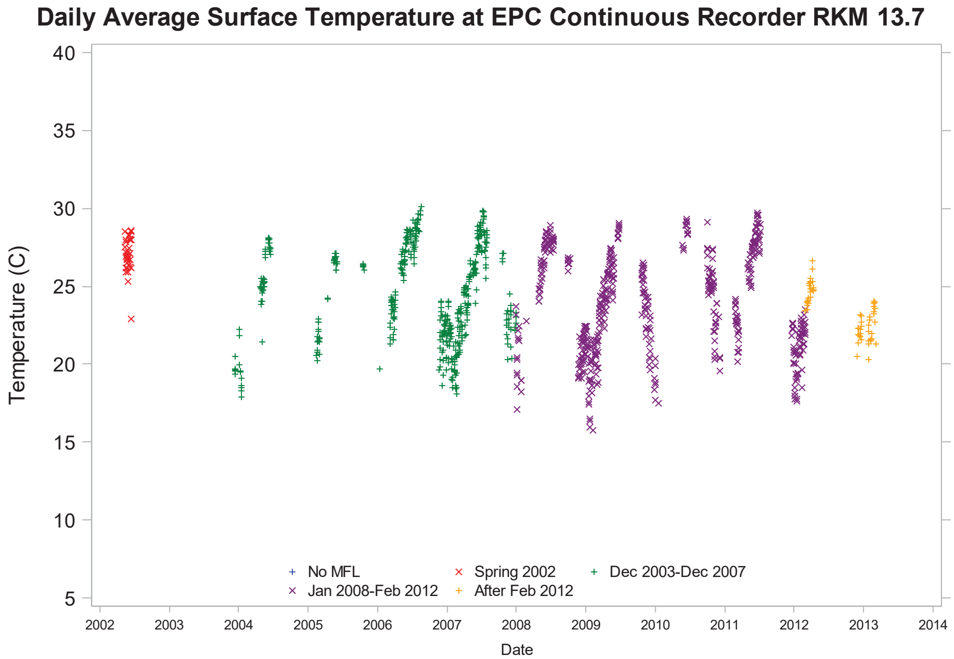


**Figure 6-3. Daily average surface temperature in the Hillsborough River at the kilometer 13.6 continuous recorder.**

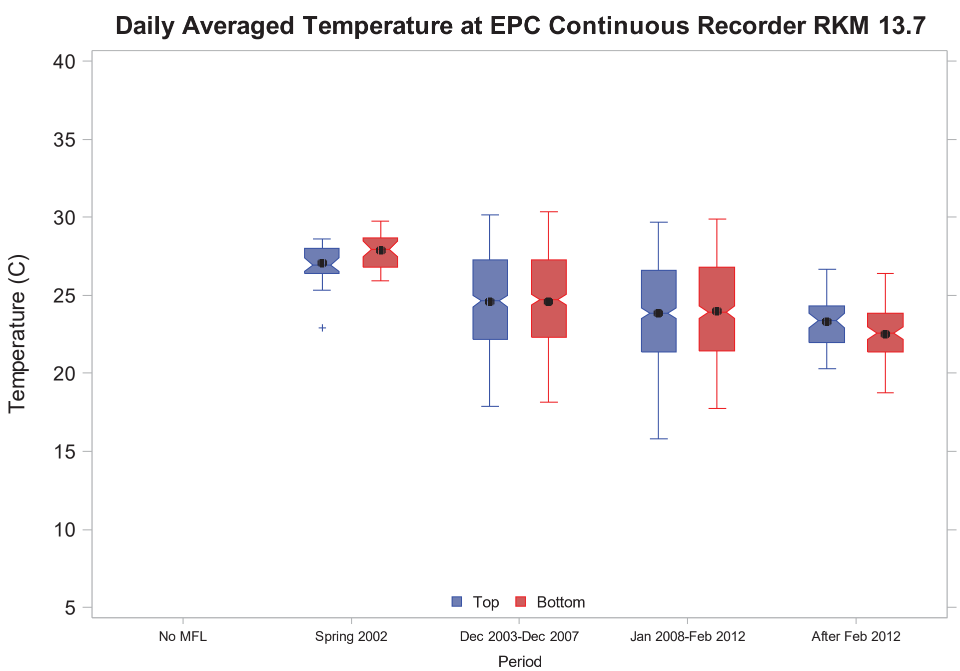


**Figure 6-4. Box and whisker plots of daily average surface and bottom temperatures in the Hillsborough River at the kilometer 13.6 continuous recorder.**

### 6.1.3 Hillsborough River at Sulphur Springs

The range of daily average temperature for the surface continuous recorders in the Hillsborough River at Sulphur Springs (Figure 6-5) is similar before and after implementation of the minimum flow. The temperature range in the most recent period is reduced relative to the other periods (Figure 6-6), as was observed for the other continuous recorders. There does not appear to be a change in temperatures in the Hillsborough River at Sulphur Springs after minimum flow implementation, other than the changes which may be due to regional climate (Figure 6-6). This is expected, as the total discharge from Sulphur Springs is unchanged at this point in the river, regardless of minimum flow implementation.

### 6.1.4 Sligh Avenue

There are no data available at the Sligh Avenue continuous recorder station from the period prior to the minimum flow implementation. The pattern in surface temperatures (Figure 6-7) is similar to the pattern observed at other continuous recorder stations. This station is more than two kilometers downstream from the Hillsborough River at Sulphur Springs station. As there were no observed changes in temperature, it is unlikely that minimum flow implementation had any impact on water temperatures at Sligh Avenue. The decreased temperature range observed at the other stations was present at the Sligh Avenue station as well (Figure 6-8).

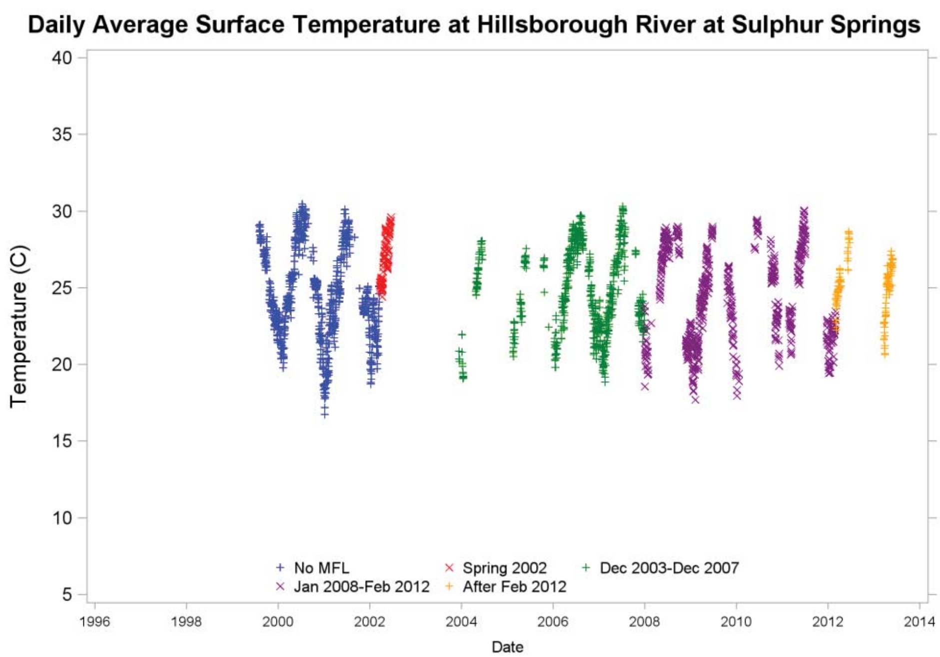


**Figure 6-5. Daily average surface temperature in the Hillsborough River at the Sulphur Springs continuous recorder.**

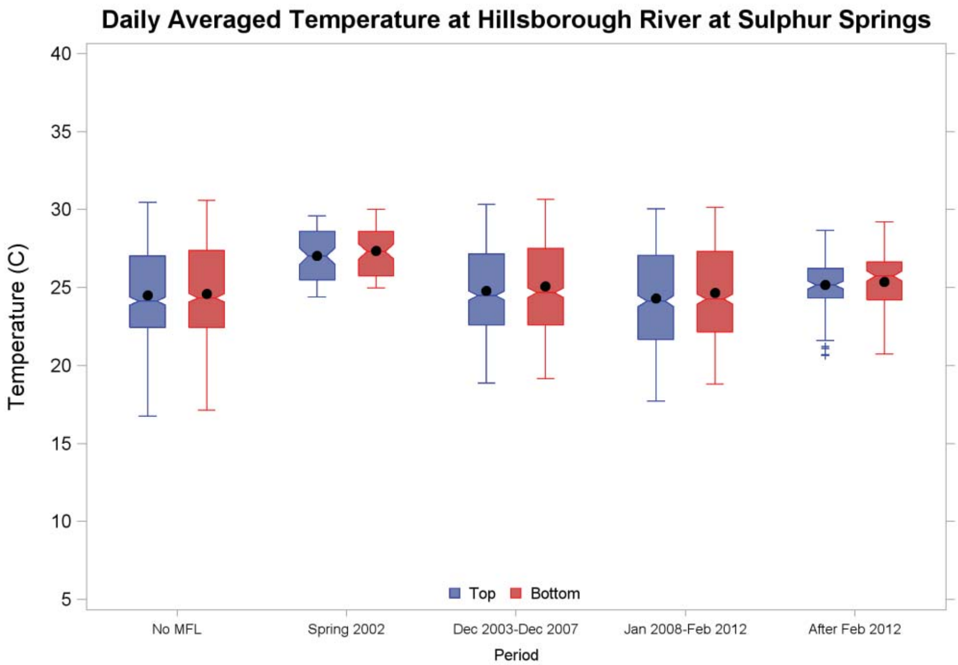


**Figure 6-6. Box and whisker plots of daily average surface and bottom temperature in the Hillsborough River at the Sulphur Springs continuous recorder.**

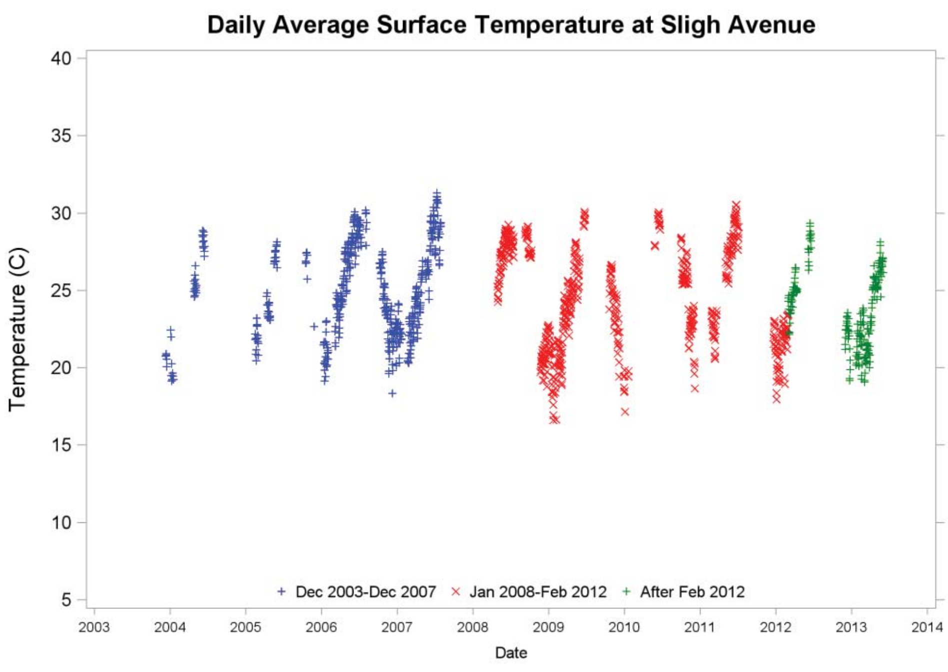


**Figure 6-7. Daily average surface temperature at the Sligh Avenue continuous recorder.**

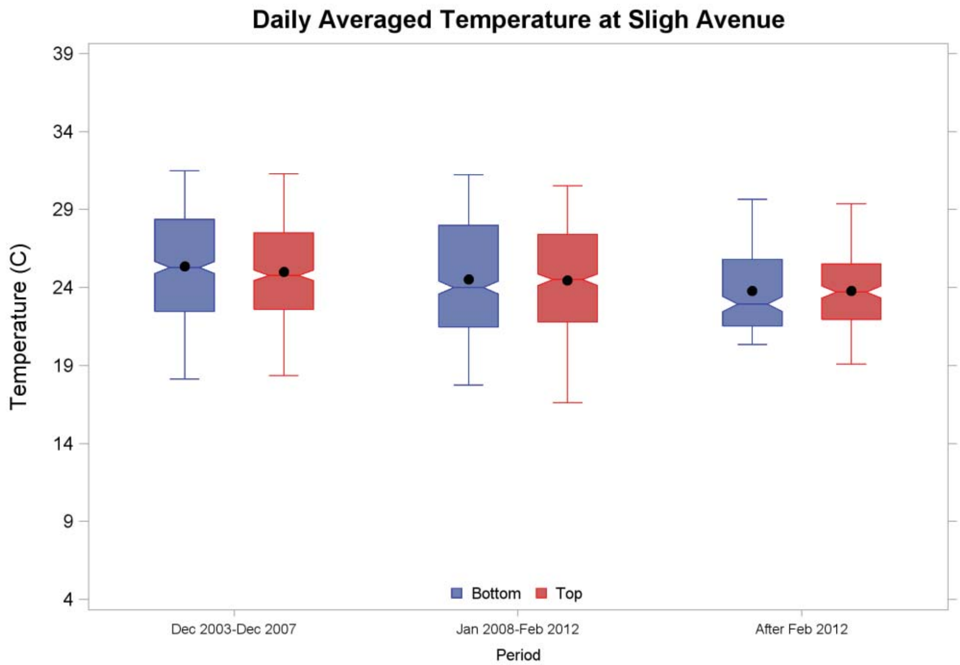


**Figure 6-8. Box and whisker plots of daily average temperature at the Sligh Avenue continuous recorder.**

### 6.1.5 Platt Street

The continuous recorder station at Platt Street is located near the mouth of the river and is strongly affected by water temperatures in Hillsborough Bay during low flows. This station is a viewed as a control for the upstream stations, rather than a station at which water temperature effects are expected to change due the implementation of minimum flows. The range of daily average water temperature at surface continuous recorders at Platt Street (Figure 6-9) is similar before and after implementation of the minimum flows. The temperature range in the most recent period is reduced relative to the other periods (Figure 6-10), as was observed at upstream stations and was possibly due to less variable climatic conditions. There was not a change in temperatures at Platt Street after minimum flow implementation, other than the changes that could be associated with regional climate. This was expected, as the station is highly influenced by bay temperature during low flows, and the volume of discharge from Sulphur Springs is unchanged below the Hillsborough River at Sulphur Springs recorder, regardless of minimum flow implementation.

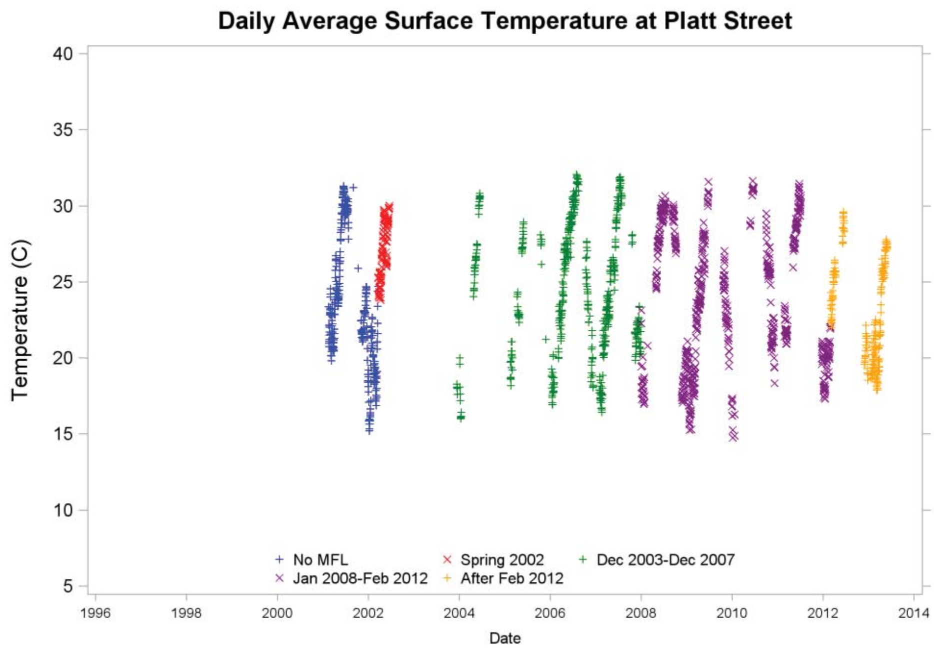


**Figure 6-9. Daily average surface temperature at the Platt Street continuous recorder.**

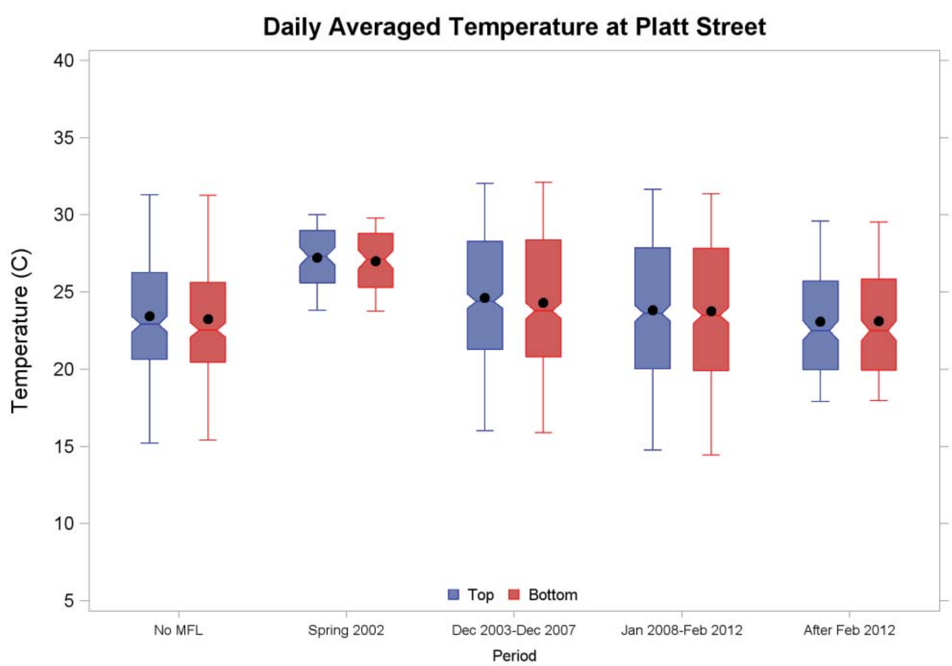


**Figure 6-10. Box and whisker plots of daily average surface and bottom temperatures at the Platt Street continuous recorder.**

# 7 pH

The available data for pH assessed for this study were comprised of combined vertical profile data bases assembled from the TBW HBMP and the SWFWMD fixed station sampling described in Section 4.3. These data were then separated by river segment, and data for all depths were combined for analysis.

During times of minimum flow implementation, pH in the river below the dam could potentially be affected by the pH of the water sources used to provide the flows, whether it is diversions from Sulphur Springs or freshwater releases from the reservoir. The pH characteristics of those two minimum flow sources were described in Chapter 2. The pH of water from Sulphur Springs averaged 7.4 prior to modification of the pumping facilities at Sulphur Springs. Based on only five observations, pH in the spring pool averaged 7.1 after the pumping facilities were modified in the spring of 2012. The pH in the reservoir during times that minimum flows were implemented averaged 7.9.The pH in the river below the dam is strongly affected by the water chemistry and physicochemical and biological processes that occur in the tidal river. The results presented below from the combined vertical profile data base indicate that the implementation of minimum flows should cause no appreciable changes or pose any ecological problems with regard to pH in the river below the dam.

## 7.1 pH from vertical profiles

Summary statistics for pH values in seven river segments between kilometers 10.6 and the dam are listed in Table 7-1 for four minimum flow periods, including the period of no minimum flow before March 2002. The period from March 2002 to December 2007 involved diversions of Sulphur Springs only, while the periods starting in January 2008 involved the diversion of water from Sulphur Springs and releases from the reservoir. The period after February 2012 involved increased diversions from Sulphur Springs plus freshwater releases from the reservoir. The statistics in Table 7-1 were calculated for days when flows at the Hillsborough River spillway, other than minimum flow releases, were less than one cfs. The pH values from all depths in the vertical profiles were combined for analysis. The results of Wilcoxon rank sum tests for difference in pH among minimum flow periods within each river segment are listed in Appendix 4A. Plots of pH versus flow in the river segments are included in Appendix 4B.

**Table 7-1. Means , standard deviatons, and number of observations for pH in 7 river segments for four minimum flow periods for the Lower Hillsborough River upstream of kilometer 10.6.**

| Kilometer | No MFL | March 2002 - Dec 2007 | Jan 2008 - Feb. 2012 | After Feb. 2012 |
|---|---|---|---|---|
| 10.6 to < 11.6 | 7.3, (0.2,367) | 7.3, (0.6,579) | 7.3, (0.2,409) | 7.4, (0.3,65) |
| 11.6 to < 12.6 | 7.3, (0.3,181) | 7.3, (0.7,397) | 7.2, (0.2,244) | 7.2, (0.2,42) |
| 12.6 to < 13.4 | 7.2, (0.2,256) | 7.3, (0.6,465) | 7.3, (0.2,368) | 7.4, (0.3,65) |
| 13.4 to < 14.1 | 7.2, (0.3,101) | 7.2, (0.5,309) | 7.3, (0.3,218) | 7.3, (0.2,33) |
| 14.1 to < 14.5 | 7.2, (0.2,79) | 7.2, (0.6,120) | 7.3, (0.2,118) | 7.4, (0.2,15) |
| 14.5 to < 15.2 | 7.3, (0.4,58) | 7.3, (0.2,231) | 7.4, (0.2,133) | 7.5, (0.1,31) |
| > 15.2 | 7.5, (0.3,57) | 7.4, (0.7,180) | 7.4, (0.2,110) | 7.6, (0.2,37) |

Mean pH values in all river segments and time periods were slightly above neutral, with mean values ranging from 7.2 to 7.6. Standard deviation values were 0.7 or less, indicating that pH values in these river segments are relatively stable during times of minimum flow. Box plots of pH in the river segments for the different minimum flow periods are shown the following sections to illustrate typical variations in pH during the different minimum flow periods.

### 7.1.1 Kilometer 15.2 to 16.2

The distribution of pH values across the different time periods were very similar in the kilometers 15.2 to 16.2 river segment (Figure 7-1). The pH was not significantly greater in the most recent period (after February 2012) relative to the pre-minimum flow period, but was greater than during the period from January 2008 –February 2012. Mean pH values across the different periods ranged from 7.4 to 7.6 (Table 7-1), with no indication of ecologically meaningful differences between periods.

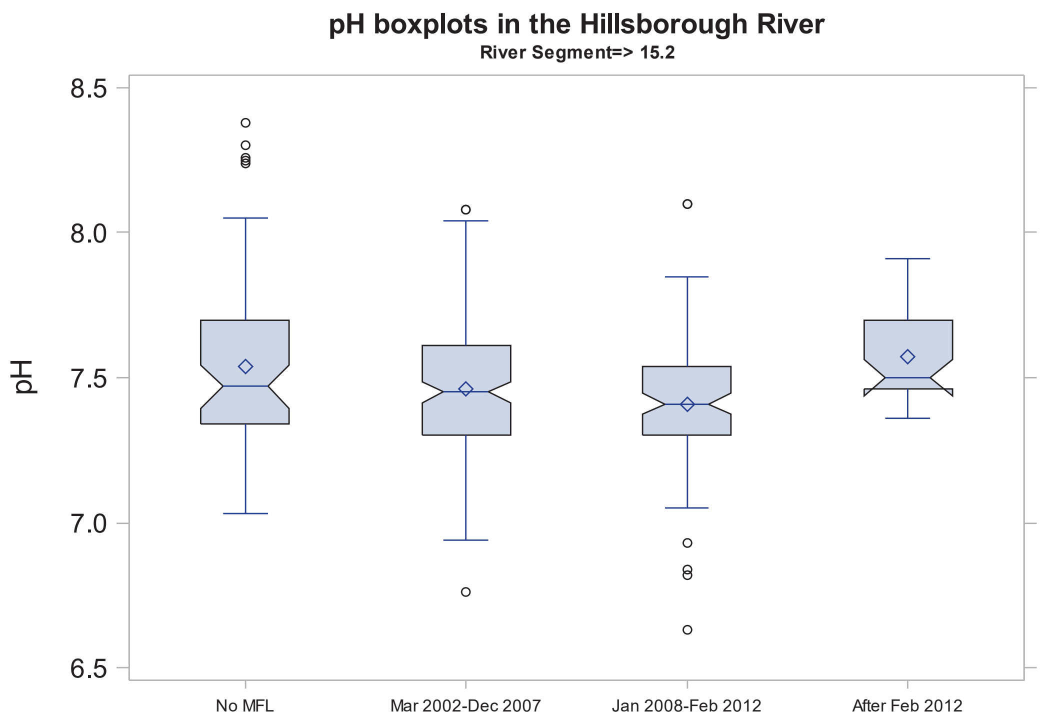


**Figure 7-1. Box and whisker plots of pH in the river segment between kilometers 15.2 and 16.2.**

### 7.1.2 Kilometers 14.5 to 15.2

The distribution of pH values across the different time periods tended to increase after the implementation of the minimum flows (Figure 7-2). This may be due to the influence of more buffered Sulphur Springs water on the river stretch upstream of the Sulphur Springs run. Mean pH values across the different periods and depth combinations ranged from 7.2 to 7.5, with no indication of ecologically meaningful differences between periods. It is notable that there were periodic pH observations above 8 during the period prior to minimum flow implementation. This may have been due to high photosynthesis rates during this period, when high chlorophyll concentrations were periodically recorded in the upper reaches of the lower river (see section 8.6).

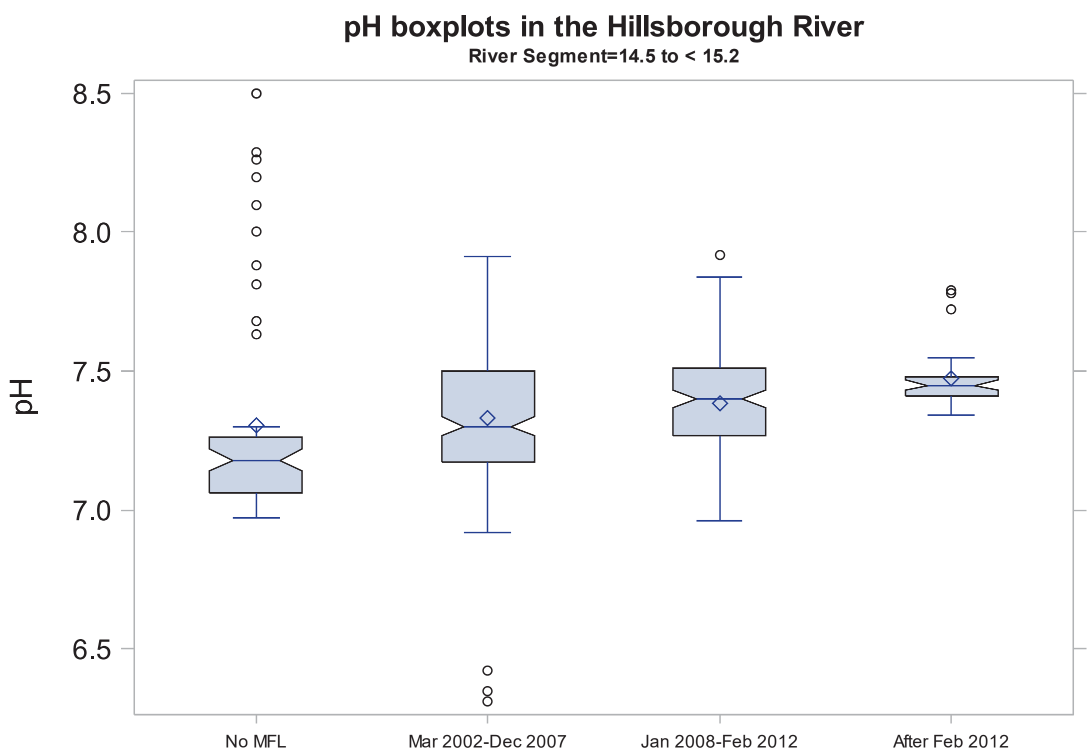


**Figure 7-2. Box and whisker plots of pH in the river segment between kilometers 14.5 and 15.2.**

### 7.1.3 Kilometers 14.1 to 14.5

The distribution of pH values across the different time periods were similar in the kilometers 14.1 to 14.5 river segment (Figure 7-3) with a slight increase in pH in the period after February 2012. There are relatively few samples available for this period, which included increased diversions of Sulphur Springs water to the base of the dam, as well as minimum flow releases from the Hillsborough River Reservoir. Mean pH values across the different periods ranged from 7.2 to 7.4, with no indication of ecologically meaningful differences between periods.

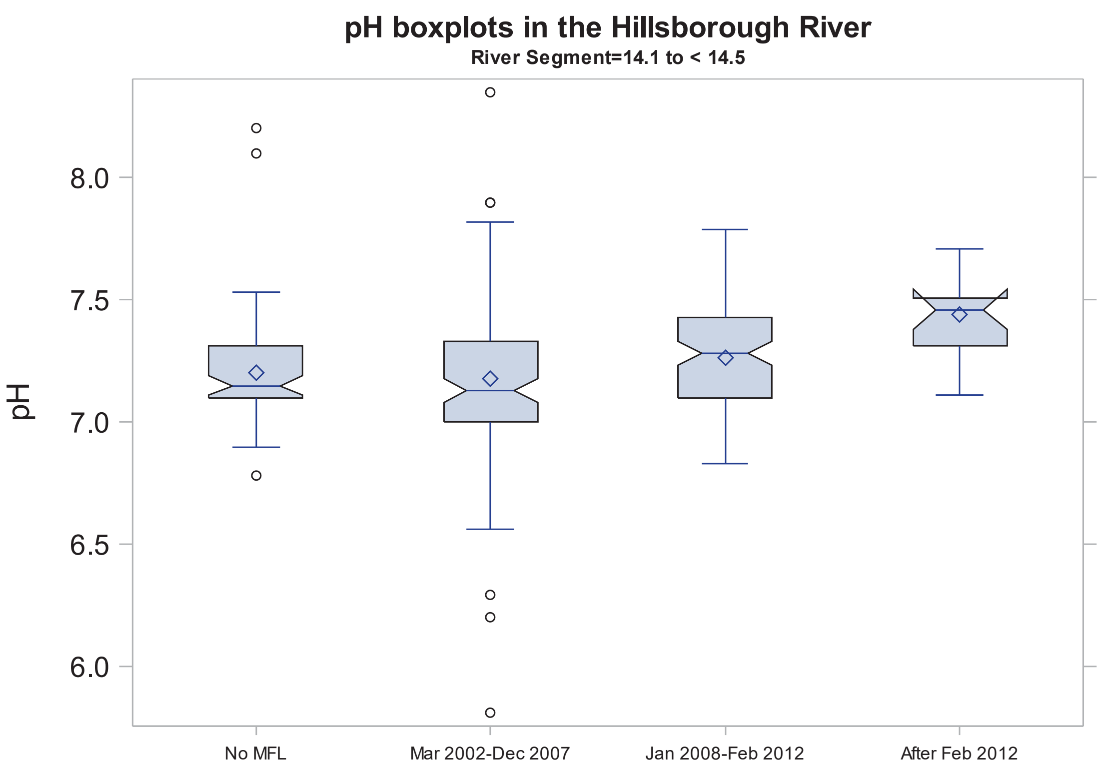


**Figure 7-3. Box and whisker plots of pH in the river segment between kilometers 14.1 and 14.5.**

### 7.1.4 Kilometers 13.4 to 14.1

The distribution of pH values across the different time periods were similar in the kilometers 13.4 to 14.1 river segment (Figure 7-4) with a slight increase in pH in the period after February 2012. There are relatively few samples available for this period, which included increased diversions of Sulphur Springs water to the base of the dam, as well as minimum flow releases from the Hillsborough River Reservoir. Mean pH values across the different periods ranged from 7.2 to 7.3, with no apparent differences between periods.

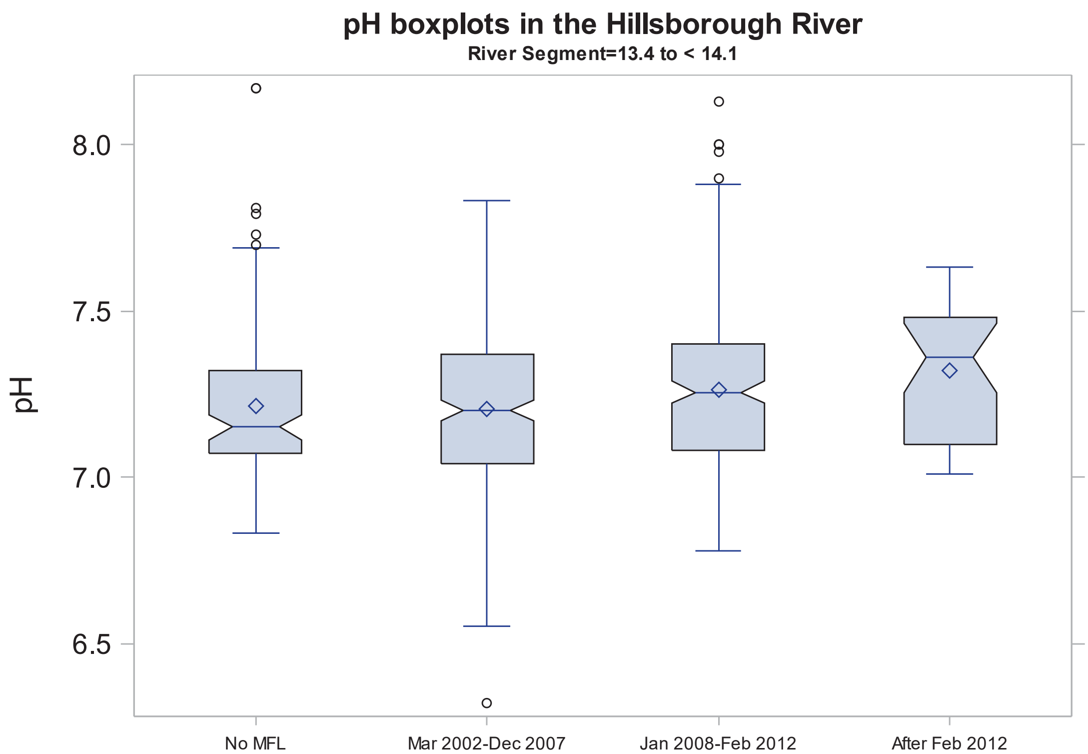


**Figure 7-4. Box and whisker plots of pH in the river segment between kilometers 13.4 and 14.1.**

### 7.1.5 Kilometers 12.6 to 13.4

The distribution of pH values across the different time periods were similar in the kilometers 12.6 to 13.4 river segment (Figure 7-5) with a slight increase in pH in the period after February 2012. Mean pH values across the different periods ranged from 7.2 to 7.4, with no apparent ecologically meaningful differences between periods.

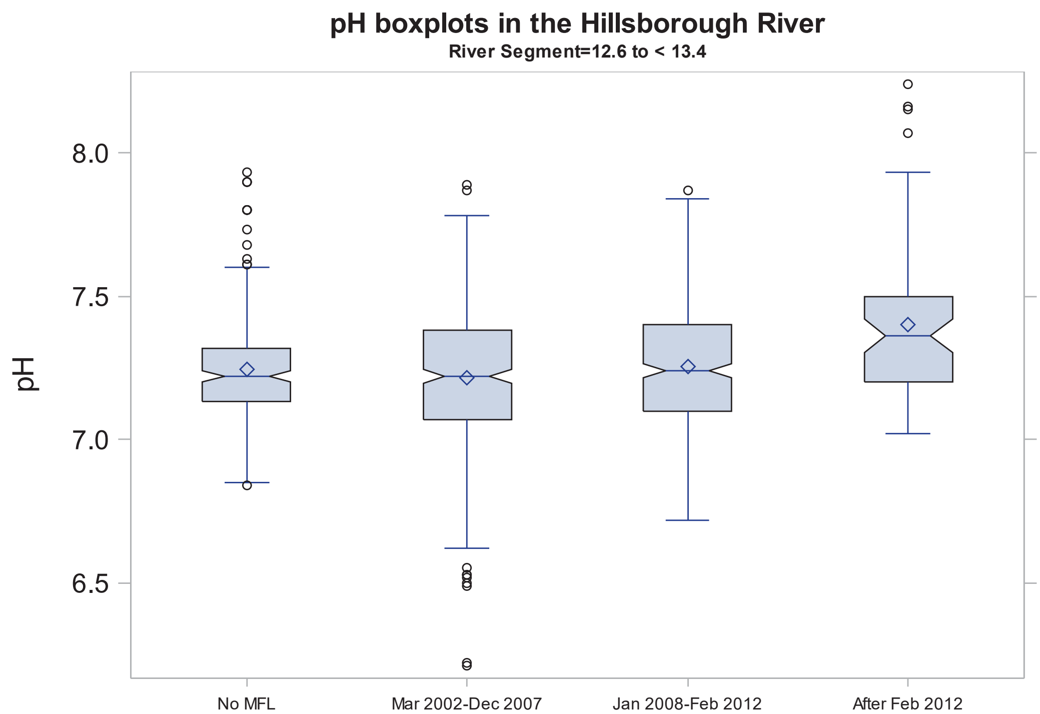


**Figure 7-5. Box and whisker plots of pH in the river segment between kilometers 12.6 and 13.4.**

### 7.1.6 Kilometers 11.6 to 12.6

The distribution of pH values across the different time periods were similar in the kilometers 11.6 to 12.6 river segment (Figure 7-6) with no apparent changes after the MFL implementation. Mean pH across the different periods ranged from 7.2 to 7.3, with no indication of any differences between periods. The implementation of minimum flows appeared to have had no measurable effect on pH in this river segment which extends below Sulphur Springs.

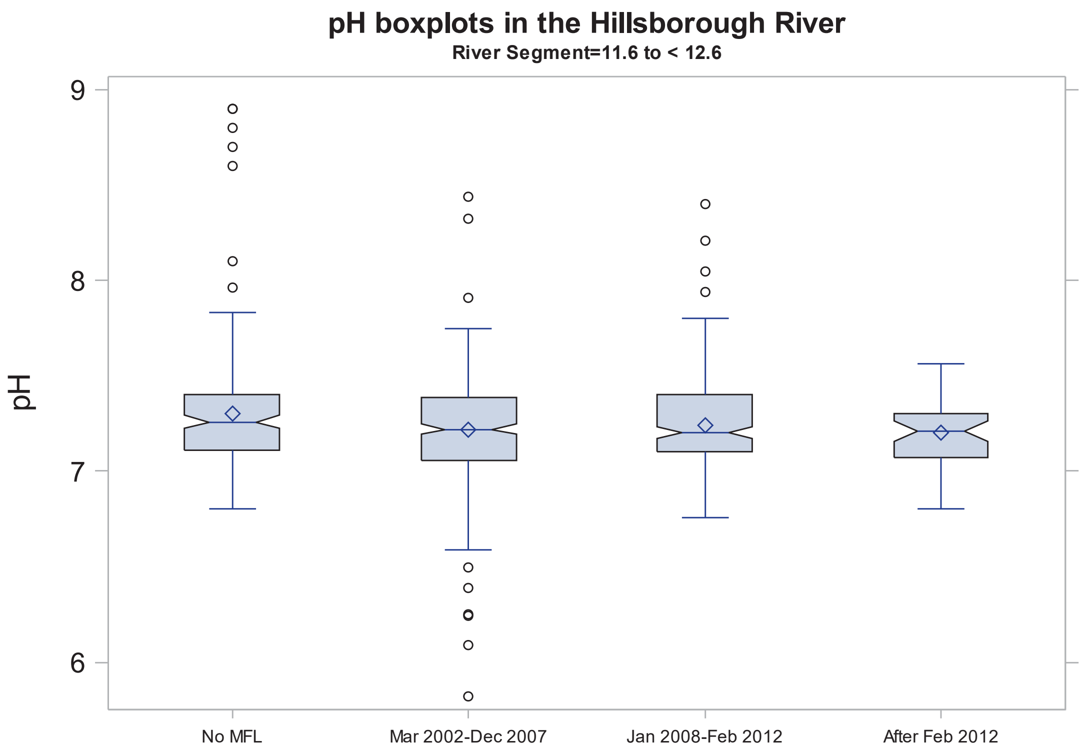


**Figure 7-6. Box and whisker plots of pH in the river segment between kilometers 11.6 and 12.6.**

### 7.1.7 Kilometers 10.6 to 11.6

The distribution of pH values across the different time periods in kilometers 10.6 to 11.6 were similar with apparent changes after minimum flow implementation (Figure 7-7). Mean pH across the different periods ranged from 7.2 to 7.3, with no indication of any differences between periods. The minimum flow implementation has had no discernable effect on pH in this river segment of the river.

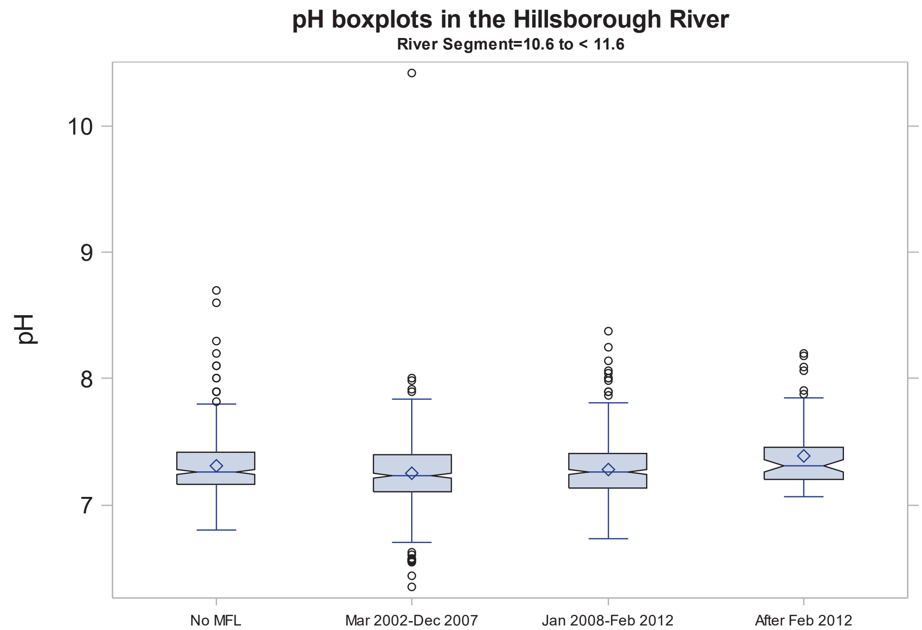


**Figure 7-7. Box and whisker plots of pH in the river segment between kilometers 10.6 and 11.6.**

## 7.2 Discussion

The results presented above indicate that in the some segments of the lower river there were significant increases in pH over time as increasing amounts of water from Sulphur Springs were matched with releases from the reservoir. However, these increases were small and should not result in any adverse biological effects. In some segments the implementation of minimum flows resulted in less variability in pH, with a reduction in the periodic occurrence of high (>8) pH values. Waters in the river below the dam can include tidal freshwaters, oligohaline, and mesohaline habitats depending on the rate of flow. The FDEP has issued criteria for pH in Class III surface waters. These specify that pH should not be altered more than 1 unit above or below natural background levels, provided pH remains above 6 and below 8.5 in fresh waters and above 6.5 and below 8.5 in marine waters (FAC 62-302). The results presented in this study indicate that any changes that do occur as a result of minimum flows will comply with the FDEP criteria for Class III surface waters for either freshwater for marine ecosystems.

# 8 Water Chemistry

Water chemistry data as described in this section are those constituents that are collected in the field and delivered to the laboratory for analysis. These constituents include color, nutrients (nitrogen and phosphorus species), and chlorophyll *a*. Data associated with these constituents were collected by the SWFWMD, EPCHC, and TBW through their respective monitoring programs. These data are less numerous than the vertical profile data, so this reduced amount of data required some changes to the selection of time periods and river segments for analysis. In order to have sufficient data for robust analyses, three river segments were used:

1. Below Sulphur Springs (kilometer 10.6 to 12.6)
2. Sulphur Springs to just above Hannah's Whirl (kilometer 12.6 to 14.5)
3. Hannah's Whirl to the dam (kilometer 14.5 to 16.2)

The three time periods selected were:

1. No minimum flow (prior to March 2002)
2. Diversions from Sulphur Springs only (March 2002 to December 2007)
3. Diversions from Sulphur Springs and releases from the reservoir (January 2008 to June 2013)

The EPCHC and SWFWMD sampling programs both use a fixed station design, while the TBW program, which ended in 2012, used a probabilistic, stratified random design. Table 8-1 provides the number of sampled dates for each of the data sources, partitioned by time period and river segment with the data limited to periods when there was no flow at the dam other than minimum flow releases. It is important to note that the number of sample dates is not equivalent to the number of samples for all constituents. There are two EPCHC fixed stations in the analyzed portion of the river (station 105 Rowlett Park Drive and station 152 at Sligh Avenue). Sampling at the EPCHC Rowlett Park Drive station began in January 1974, while sampling at the Sligh Avenue station began in September 1999. The EPCHC monitoring provided the majority of the data in the pre-minimum flow period.

**Table 8-1. Number of water chemistry samples during three minimum flow periods.**

| Source | Kilometer | No Minimum Flow | March 202 – Dec. 2007 Sulphur Springs Only | Jan 2008 - June 2013 Sulphur Springs and Reservoir |
|---|---|---|---|---|
| EPCHC | 10.6 to 12.6 | 31 | 70 | 66 |
| | 12.6 to 14.5 | 0 | 0 | 0 |
| | 14.5 to 16.2 | 337 | 70 | 66 |
| TBW | 10.6 to 12.6 | 19 | 57 | 47 |
| | 12.6 to 14.5 | 17 | 40 | 32 |
| | 14.5 to 16.2 | 8 | 31 | 28 |
| SWFWMD | 10.6 to 12.6 | 0 | 26 | 30 |
| | 12.6 to 14.5 | 0 | 13 | 15 |
| | 14.5 to 16.2 | 0 | 13 | 14 |

The use of a stratified random sampling design in the TBW HBMP resulted in the locations of samples to change every month within each specific segment of the river (identified as strata). TBW began collecting water chemistry samples in the lower river in April 2000. Initially nutrient data were not collected, but in January 2004 collection of nutrient data was initiated. Collection of water chemistry data by the TBW HBMP ended in September, 2012.

The SWFWMD monitoring program has fixed stations at kilometers 10.8, 12.3, 13.6, and 15.4. The SWFWMD data analyzed for this report were collected on thirty dates from April 2002 to May 2013. The SWFWMD monitoring program during that period was not conducted on a regular monthly basis, as were the EPCHC and TBW programs. The data set resulting from combining these data sources provides substantial information on the sampled water chemistry analytes in the Hillsborough River. The following sections will review the data for color, nitrate + nitrite nitrogen, total nitrogen, orthophosphate, total phosphorus, and chlorophyll *a*.

## 8.1 Color

Color is also called colored (or chromophoric) dissolved organic material and is present naturally in surface waters as a product of the degradation of organic material, with much of the color originating from surface runoff in the watershed. The groundwater that discharges from Sulphur Springs has very low color levels (see Section 2.6). The routing of water from Sulphur Springs to the base of the dam during minimum flows is expected to reduce color (by simple dilution) in the segments immediately below the dam relative to normal flow conditions. For results discussed in this report, color is expressed in platinum-cobalt units.

### 8.1.1 Color at EPCHC fixed-location stations

Average color at the EPCHC Rowlett Park Drive station decreased from 29.6 to 15.6 pcu after implementation of Sulphur Springs diversions, and then increased to 19.6 pcu after initiation of minimum flow releases from the reservoir (Table 8-2). Time series and box plots of color at the Rowlett Park Drive station (Figure 8-1 and Figure 8-2) reflected the same pattern as the means. Results of the Wilcoxon rank sum tests indicate that color was significantly higher in the pre-minimum flow period than after implementation (Table 3 in Appendix 5A).

**Table 8-2. Mean, standard deviation, and number of observations for color at the EPCHC fixed stations.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| Sligh Avenue | 16.5, (5.8,26) | 14.6, (3.8,24) | 16.2, (10.9,13) |
| Rowlett Park Drive | 29.6, (20.8,143) | 15.6, (15.7,24) | 19.6, (20.2,13) |

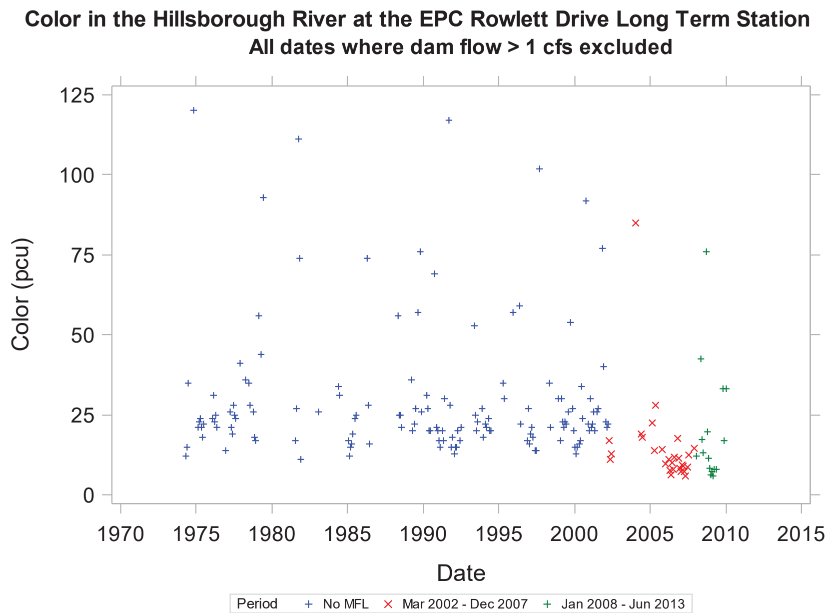


**Figure 8-1. Color at the Rowlett Park Drive station.**

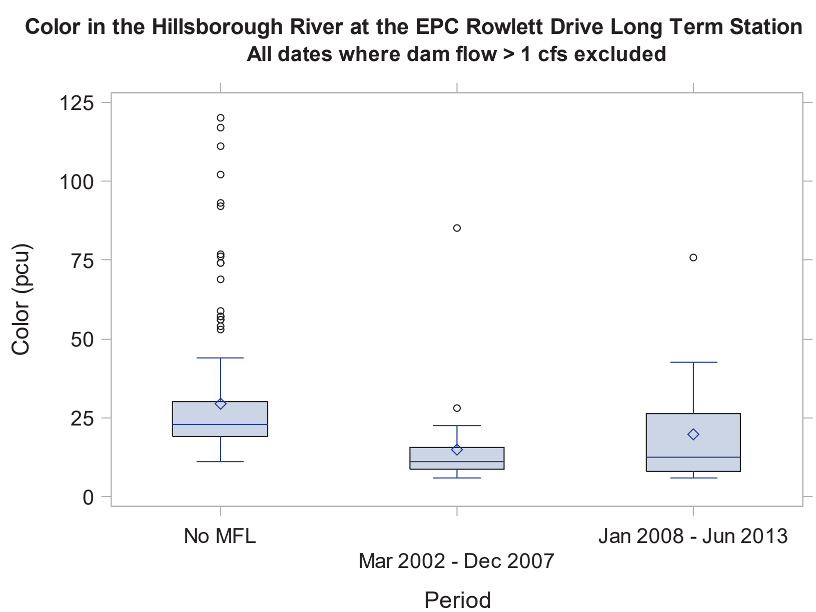


**Figure 8-2 Box and whisker plots of Color at the Rowlett Park Drive station.**

Average color at the EPCHC Sligh Avenue station decreased from 16.5 to 14.6 pcu after implementation of Sulphur Springs diversions, and then increased to 16.2 pcu after initiation of minimum flow releases from the reservoir (Table 8-2). Time series and box plots of color at Sligh Avenue (Figure 8-3 and Figure 8-4) do not show a strong pattern, although the two highest values were recorded in the final minimum flow period when water was being released from the reservoir. Since Sligh Avenue is located downstream of Sulphur Springs, much smaller changes, if any, should be expected between the period of no minimum flows and the following minimum flow period that was comprised solely of diversions from  Sulphur Springs. Results of the Wilcoxon rank sum statistical tests indicate there were no significant differences in color between periods at the Sligh Avenue fixed station (Table 6 in Appendix 5A).

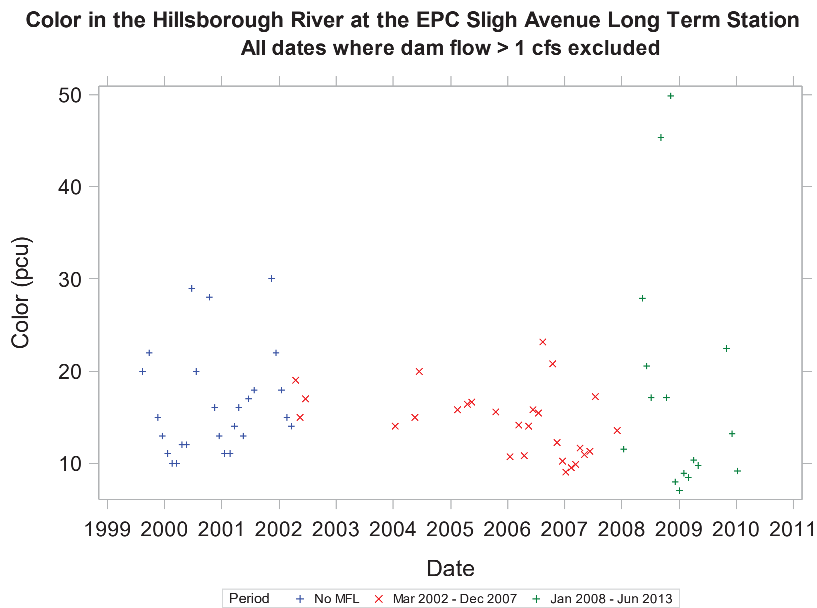


**Figure 8-3. Color at the Sligh Avenue station.**

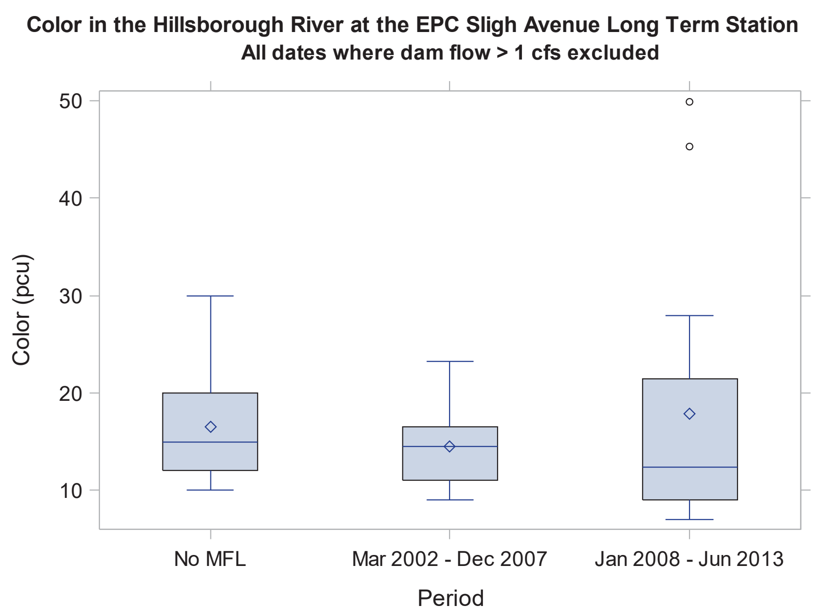


**Figure 8-4. Box and whikser plots of color at the Sligh Avenue station.**

### 8.1.2 Combined color data

The pattern observed in the combined color data (data from all sources) is the same throughout the sampled area as the pattern observed at the EPCHC fixed stations. Color was highest in the pre-minimum flow period, lowest when minimum flows were solely from diversions of water from Sulphur Springs, and intermediate when both Sulphur Springs and reservoir releases were used for minimum flows (Figure 8-5). There was relatively little data for the Sulphur Springs to Hannah's Whirl river segment (kilometer 12.6 to 14.5), which may be the reason for the unusually high distribution and mean color values in this river segment during the pre-MFL period (Table 8-3).

**Table 8-3. Mean, standard deviation, and number of observations for color in the combined data.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location (km)** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| 10.6 to < 12.6 | 23.6, (19.4,33) | 14.7, (4.8,30) | 21.2, (15.1,37) |
| 12.6 to < 14.5 | 48.6, (24.7,7) | 13.3, (5.8,3) | 25.3, (19.6,12) |
| > 14.5 | 30.1, (21.1,145) | 15.1, (14.9,27) | 21.7, (18.7,24) |

These observations are further corroborated by plots of color versus flow in the three river segments (Figures 8-6 to 8-8). Flows were often around at or very near zero during the pre-minimum flow period, yet color was higher in the segments above Sulphur Springs than in the other flow conditions because any periodic flows were exclusively from the reservoir. Under the initial minimum flow implementation, Sulphur Springs water with very low color was introduced, causing a substantial decrease in color. This was followed by the period of mixed Sulphur Springs and reservoir water, which yielded slightly higher flows and intermediate color levels. In these cases the source water is the factor driving color as much as the total flow.

Results of the Wilcoxon rank sum test indicate that for the Sligh Avenue to Sulphur Springs segment (kilometer 10.6 to 12.6) color was significantly higher in the pre-minimum flow period relative to the Sulphur Springs only period, but not significantly different than the period with augmentation from both Sulphur Springs and the reservoir (Table 5 in Appendix 5A). This may have been due to effect of periodic flows from the dam. In the Hannah's Whirl to the dam segment, color was significantly higher in the pre-minimum flow period than in both subsequent periods, which reflects the diversion of low color water from Sulphur Springs to the base of the dam.

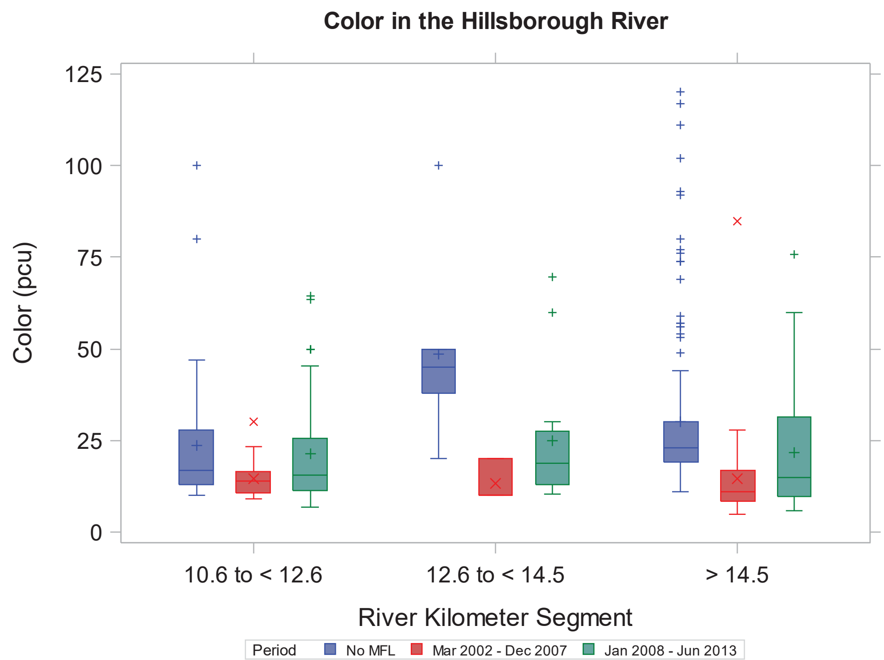


**Figure 8-5. Box and whisker plots of color from the combined water chemistry data base for three river segments during three minimum flow periods.**

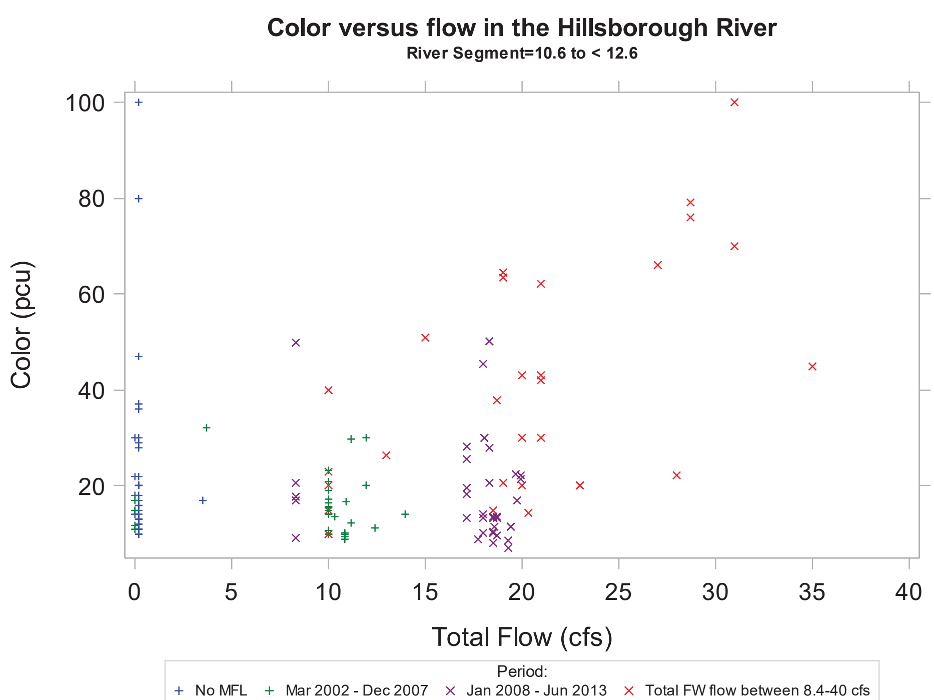


**Figure 8-6. Color versus flow in the river segment between kilometers 10.6 and 12.6.**

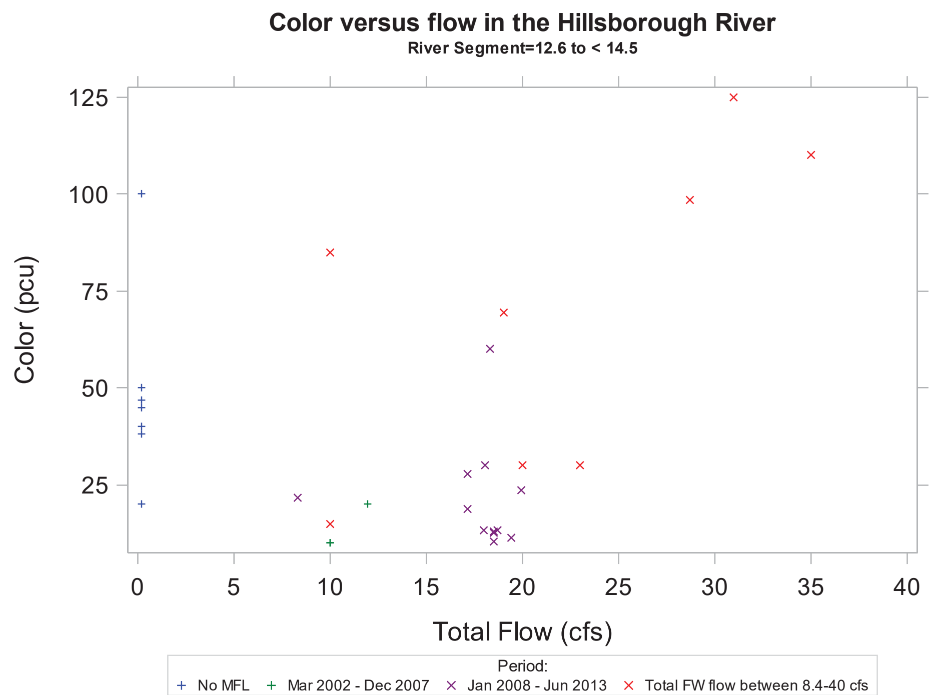


**Figure 8-7. Color versus flow in the river segment between kilometers 12.6 and14.5.**

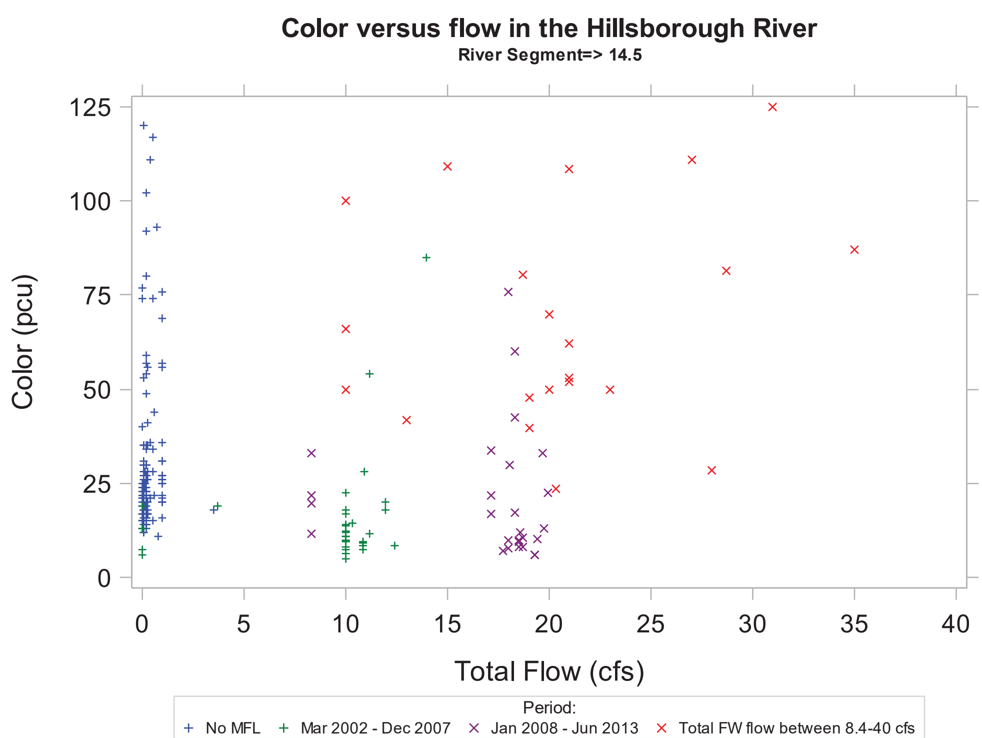


**Figure 8-8. Color versus flow in the river segment between kilometers 14.5 and16.2.**

## 8.2 Total nitrogen

Total nitrogen (TN) is the sum of total Kjeldahl nitrogen plus nitrate and nitrite nitrogen. This represents the total concentration of nitrogen in the sample regardless of chemical form or availability. Nitrogen is a critical nutrient for plant growth and is often implicated as a causal factor for algal blooms in enriched estuarine systems. For results discussed in this report, TN concentrations are reported as milligrams per liter nitrogen.

### 8.2.1 Total nitrogen at EPCHC fixed-location stations

Average TN at the EPCHC Rowlett Park Drive station decreased from 1.22 to 0.72 mg/l after implementation of Sulphur Springs diversions, and then decreased further to 0.55 mg/l after initiation of minimum flow releases from the reservoir (Table 8-4). Results of the Wilcoxon test indicate that TN was significantly lower in the periods after minimum flow implementation than in the pre-minimum flow period (Appendix 5B). Figure 8-9 and Figure 8-10 show the declining trend in TN at the Rowlett Park Drive station.

**Table 8-4. Mean, standard deviation, and number of observations for total nitrogen at the EPCHC fixed stations.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| Sligh Avenue | 1.00, (0.37,26) | 0.72, (.17, 26) | 0.55, (0.22, 35) |
| Rowlett Park Drive | 1.22, (0.43, 111) | 0.60, (0.30, 26) | 0.48, (0.23, 32) |

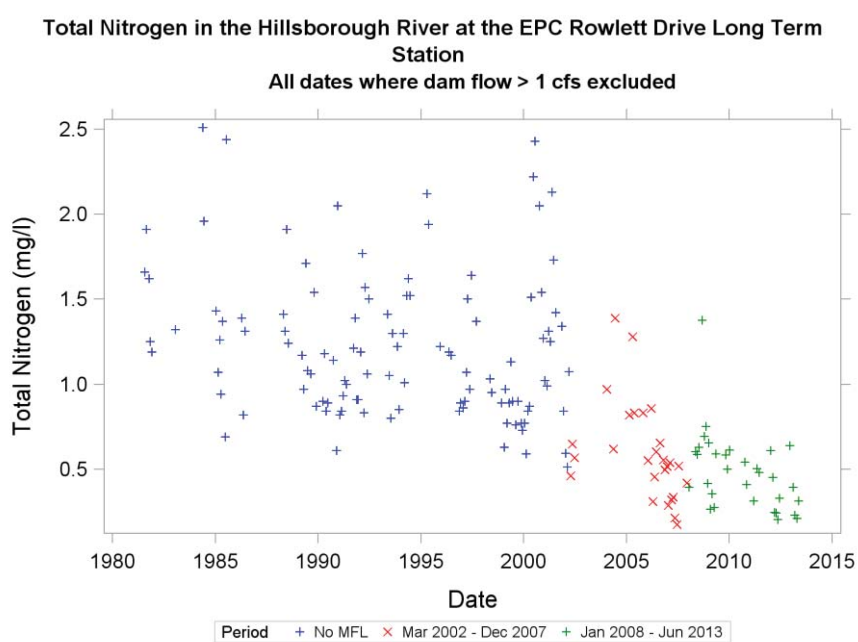


**Figure 8-9. Total nitrogen at the Rowlett Park Drive station.**

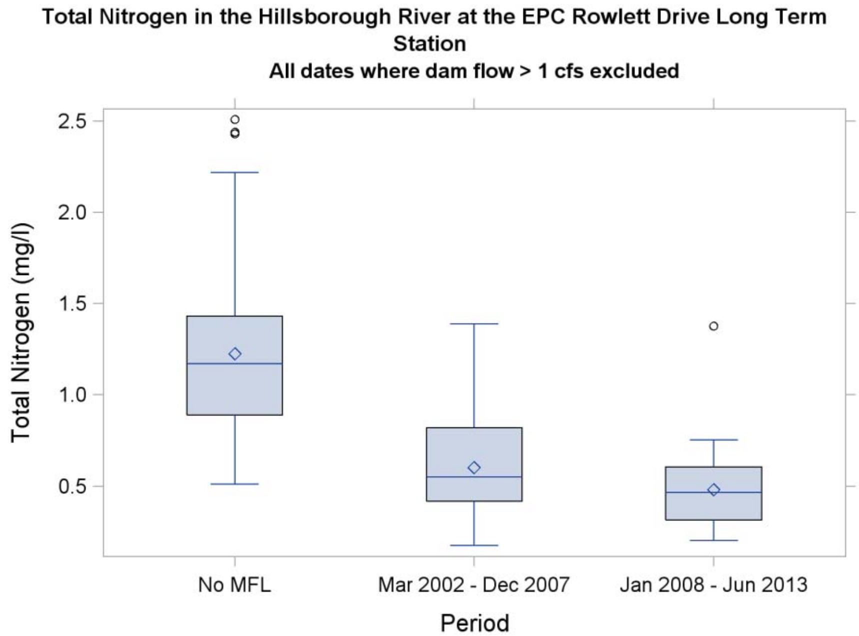


**Figure 8-10. Box and whisker plots of total nitrogen at the Rowlett Park Drive station.**

The pattern of TN concentrations observed at Rowlett Park Drive was also observed at the EPCHC Sligh Avenue fixed station (Figure 8-11 and Figure 8-12). Average TN decreased from 1.0 mg/l in the pre-minimum period to 0.72 mg/l in the Sulphur Springs only period, to 0.55 mg/l in the most recent period when reservoir releases were included in the minimum flows. Results of the Wilcoxon rank sum test indicate significantly lower TN at Sligh Avenue in each subsequent period. The reduction in TN coincides closely with minimum flows implementation. As was the case with Rowlett Park Drive, this analysis does not definitively attribute any causality for the TN reductions. However, it is clear that the minimum flow implementation did not cause TN levels to increase, and have may have played a role in significant TN reductions.

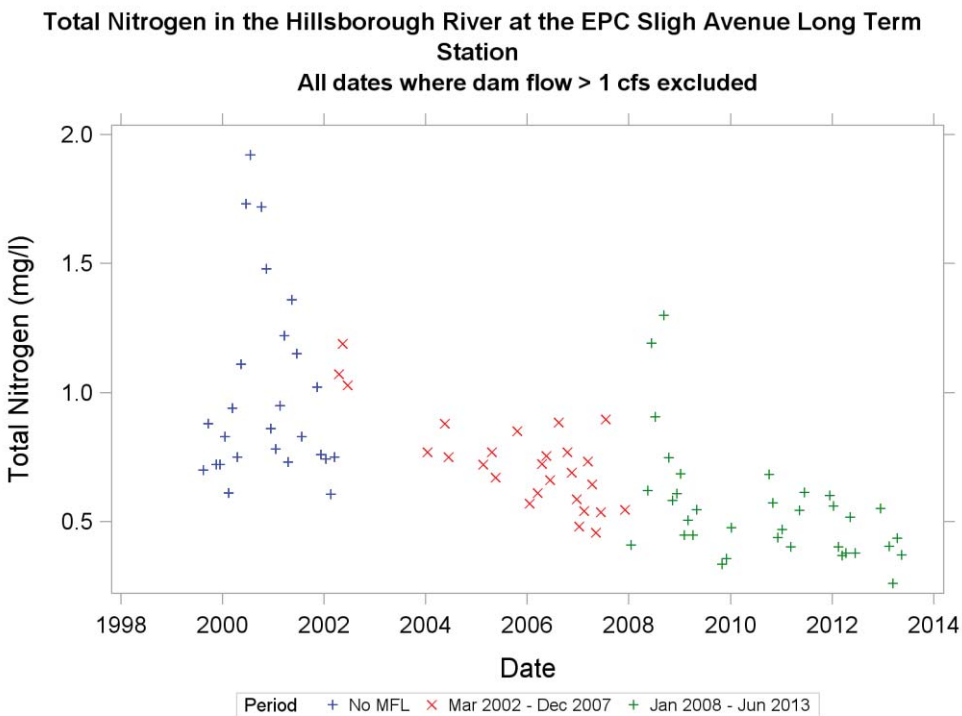


**Figure 8-11. Total nitrogen at the Sligh Avenue station.**

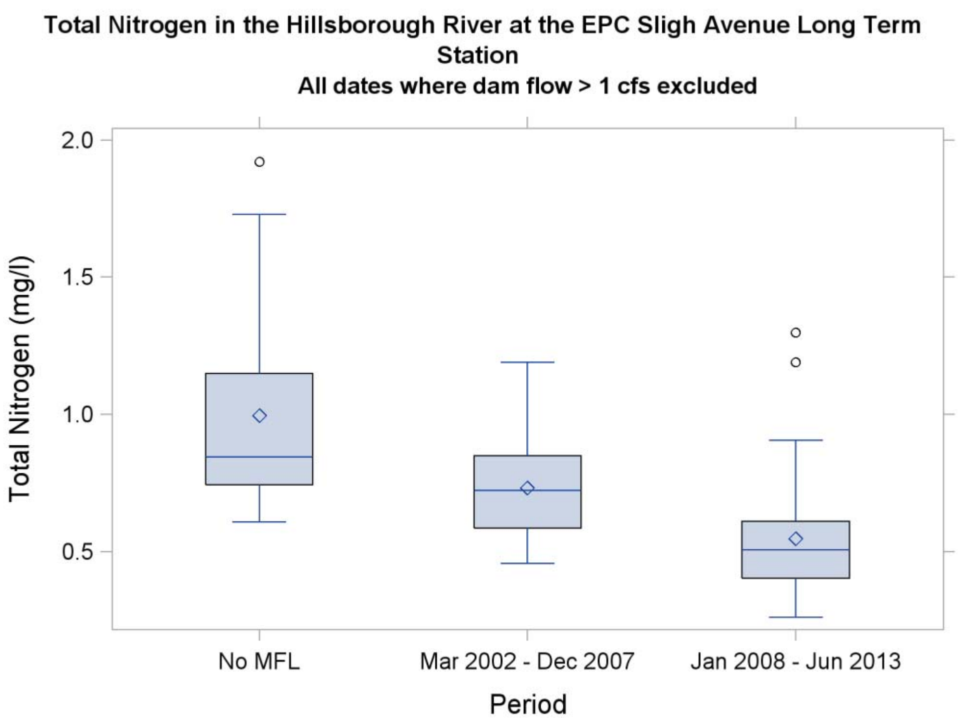


**Figure 8-12. Box and whisker plots of total nitrogen at the Sligh Avenue station.**

### 8.2.2 Combined total nitrogen data

The pattern observed in the combined TN data (data from all sources) was the same throughout the sampled area as the pattern observed at the EPCHC fixed location stations. TN was highest in the pre-minimum period, lower when flow augmentation was exclusively from Sulphur Springs, and lowest when both Sulphur Springs and reservoir water were used (Figure 8-13). There is relatively little data in the Sulphur Springs to Hannah's Whirl river segment (Table 8-5), including no available data during the pre-minimum flow period. Results from the other two segments indicate that minimum flow implementation has not increased TN concentrations, and may have helped to reduce TN concentrations. In the segments with available data, TN was significantly lower after minimum flow implementation than pre-minimum flow (Appendix 5B).

These observations are further corroborated by plots of TN versus flow in the three river segments, which suggest a negative correlation between flow and TN concentration (Figures 8-14 to 8-16). The mean concentrations of TN in Sulphur Springs and the reservoir are both lower than the mean TN concentration for the pre-minimum flow period (see Section 2.6). The introduction of these waters during low flow periods has likely led to some of the observed decreases in TN concentration.

**Table 8-5. Mean, standard deviation, and number of observations for total nitrogen in the combined data.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location (km)** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| 10.6 to < 12.6 | 1, (0.4,26) | 0.7, (0.2,43) | 0.6, (0.3,62) |
| 12.6 to < 14.5 | | 0.6, (0.2,15) | 0.6, (0.2,21) |
| > 14.5 | 1.2, (0.4,111) | 0.6, (0.3,34) | 0.5, (0.3,46) |

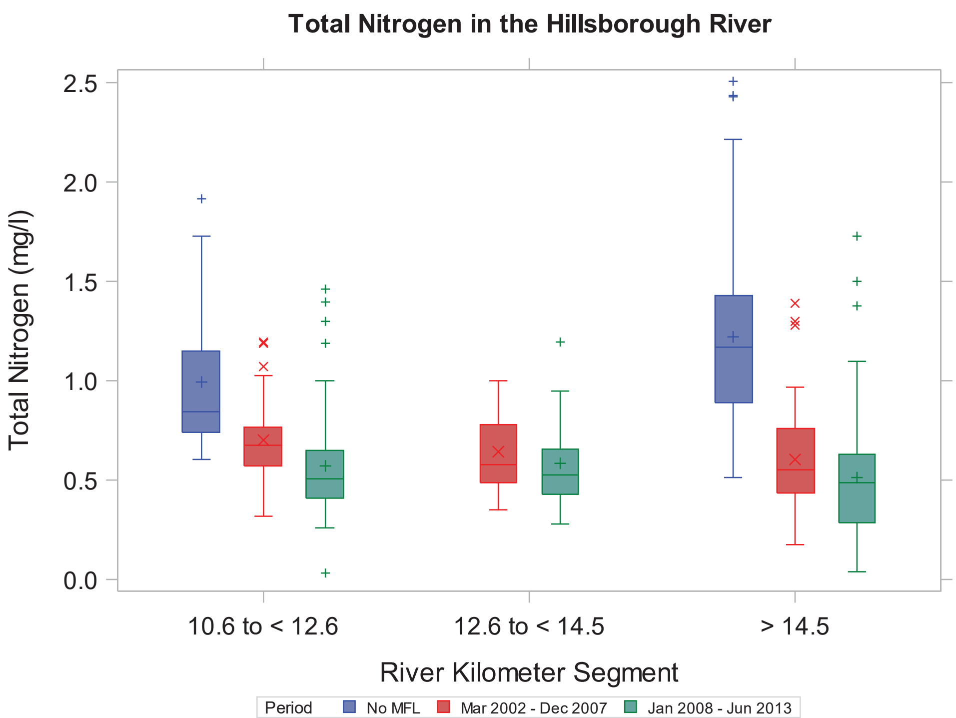


**Figure 8-13. Box and whisker plots of total nitrogen from the combined water chemistry data base for three river segments during three minimum flow periods.**

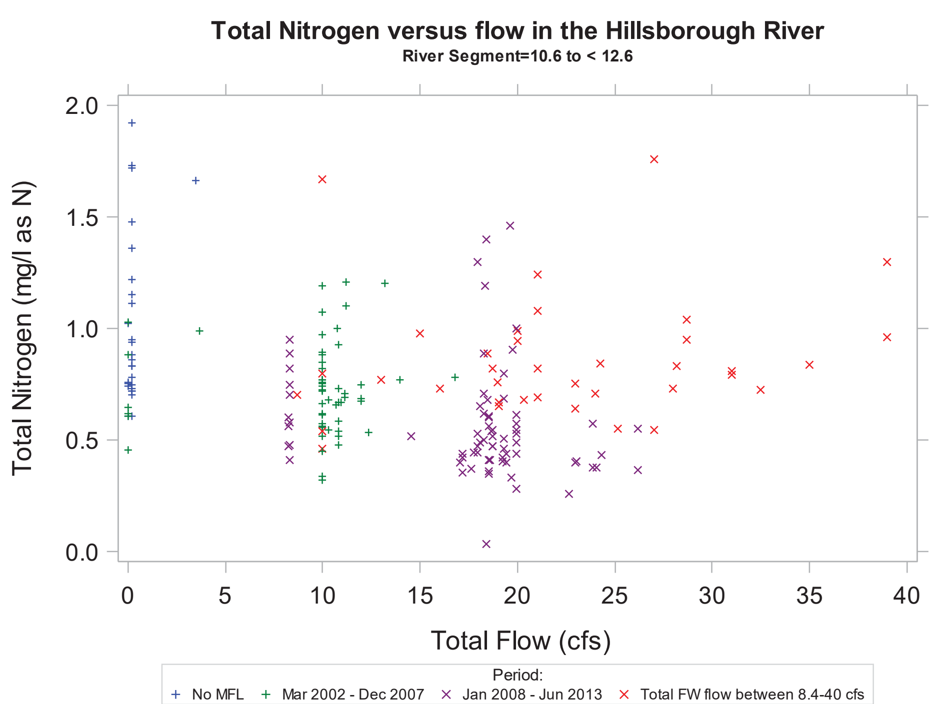


**Figure 8-14. Total nitrogen versus flow in the river segment between kilometers 10.6 and 12.6.**

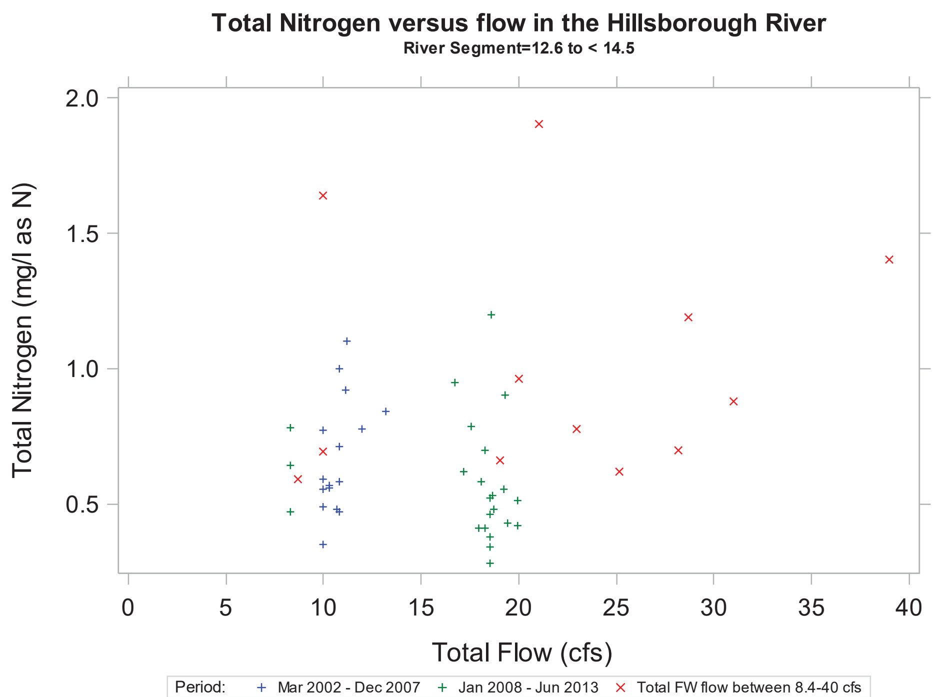


**Figure 8-15. Total nitrogen versus flow in the river segment between kilometers 12.6 and 14.5.**

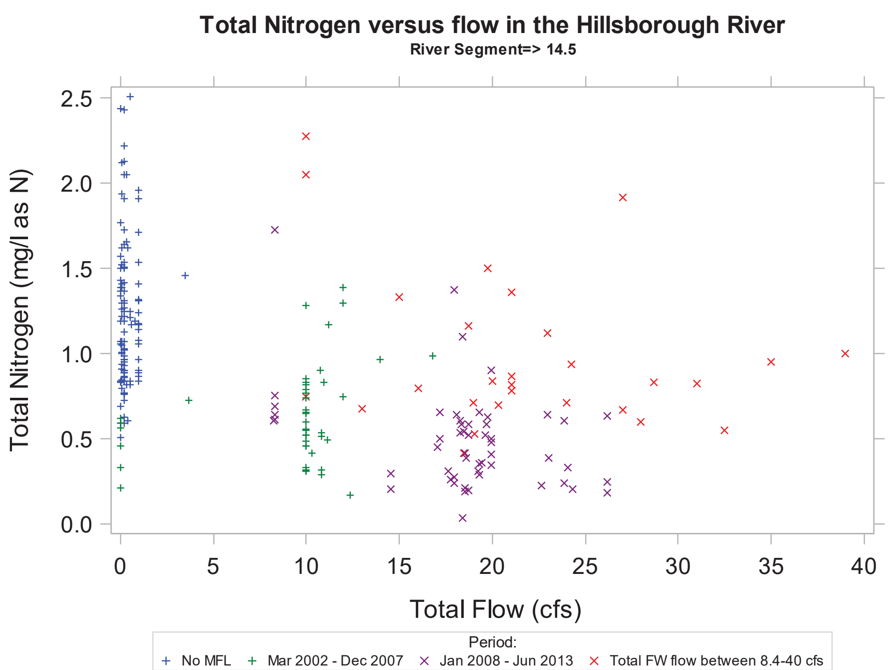


**Figure 8-16. Total nitrogen versus flow in the river segment between kilometers 14.5 and 16.2.**

## 8.3 Nitrate + nitrite nitrogen

Nitrate ($NO_3$) + Nitrite ($NO_2$), together can be referred to as NOx, are the primary components of inorganic nitrogen (with ammonia) which are readily available for phytoplankton uptake. Nitrate, which is more oxidized than $NO_2$, usually comprises nearly all of the NOx in natural surface waters. NOx concentrations in the river below the dam are influenced by NOx concentrations in the minimum flow source water. NOx can move readily through ground water and some Florida springs have become enriched in NOx (Copeland et al. 2009). Sulphur Springs has enriched $NO_3$concentrations, averaging between 0.11 and 0.24 mg/l between different time periods and laboratories (see Section 2.6). Data from the reservoir indicate that NOx levels are substantially lower (mean = 0.06 mg/l), possibly due to lower concentrations in the river above the dam and/or algal uptake of NOx in the reservoir. NOx concentrations below the dam are also affected by the chemistry of the tidal waters in the Lower Hillsborough River and physicochemical and biological processes that occur there. For results discussed in this report, NOx concentrations are reported as milligrams per liter nitrogen.

### 8.3.1 Nitrate + nitrite nitrogen at EPCHC fixed-location stations

Mean NOx concentrations at the EPCHC Rowlett Park Drive station were 0.14 and 0.15 mg/l before and after implementation of Sulphur Springs diversions, and then decreased to 0.11 mg/l after initiation of minimum flow releases from the reservoir (Table 8-6). Results of the Wilcoxon test indicate that NOx was not significantly different after minimum flow implementation than in the pre-minimum flow period. However, a pattern was observed that with one exception, NOx values beginning in 2010 were consistently below 2.0 mg/l (Figure 8-17), with less variability compared to the earlier periods (Figure 8-18).

Average NOx at the EPCHC Sligh Avenue station increased from 0.09 to 0.16 mg/l after implementation of Sulphur Springs diversions, and then decreased to 0.10 mg/l after initiation of augmentation from the reservoir (Table 8-6). Results of the Wilcoxon test indicate that NOx was significantly higher in the initial minimum flow period, when only spring diversions were used, than in both the pre-minimum flow period and the second minimum flow period when minimum flow releases from the reservoir were also used. Figure 8-19 and 8-20 confirm the pattern observed in the summary statistics. This pattern is difficult to interpret, as Sligh Avenue is downstream of Sulphur Springs and the volume of Sulphur Springs water passing the Sligh Avenue station was not affected by the initial minimum flow implementation. It may be that NOx was higher at this location during the March 2002-December 2007 period for reasons not related to minimum flows.

**Table 8-6. Mean, standard deviation, and number of observations for nitrate + nitrite at the EPCHC fixed stations.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| Sligh Avenue | 0.09, (0.08, 26) | 0.16, (0.09, 27) | 0.10, (0.08,35) |
| Rowlett Park Drive | 0.14, (0.11, 105) | 0.15, (0.10, 27) | 0.11, (0.08, 32) |

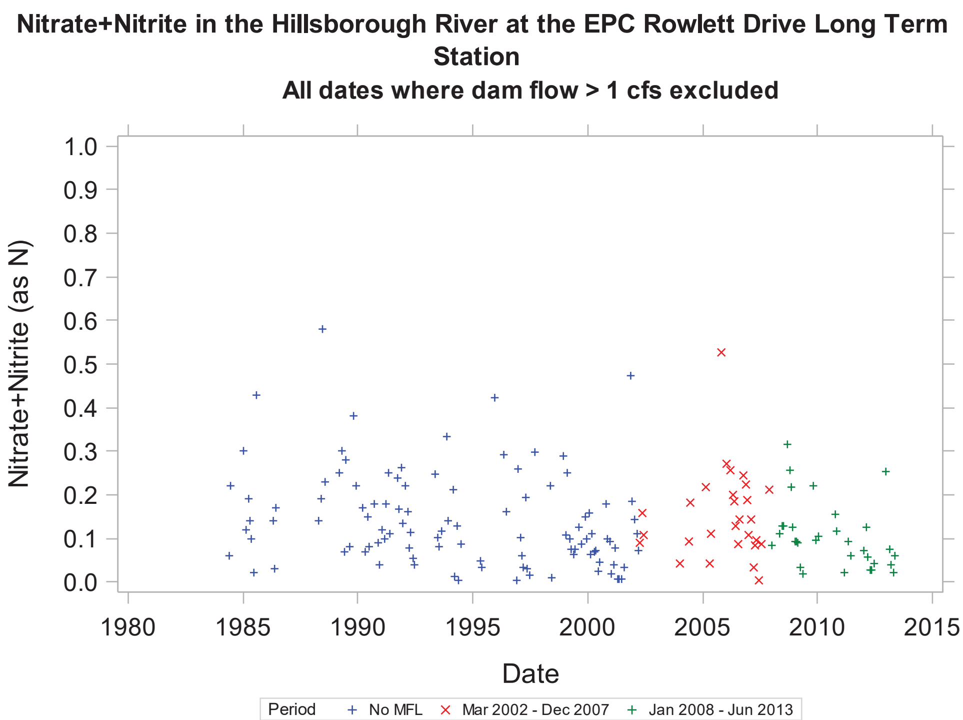


**Figure 8-17. Nitrate + nitrite at the Rowlett Park Drive station.**

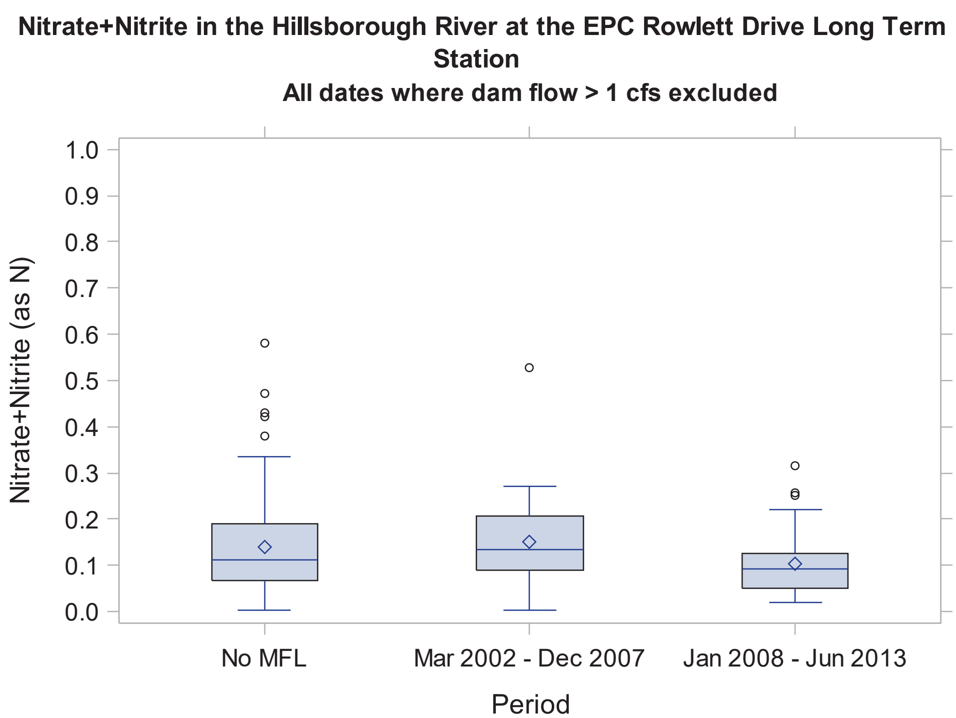


**Figure 8-18. Box and whisker plots of nitrate + nitrite at the Rowlett Park Drive station.**

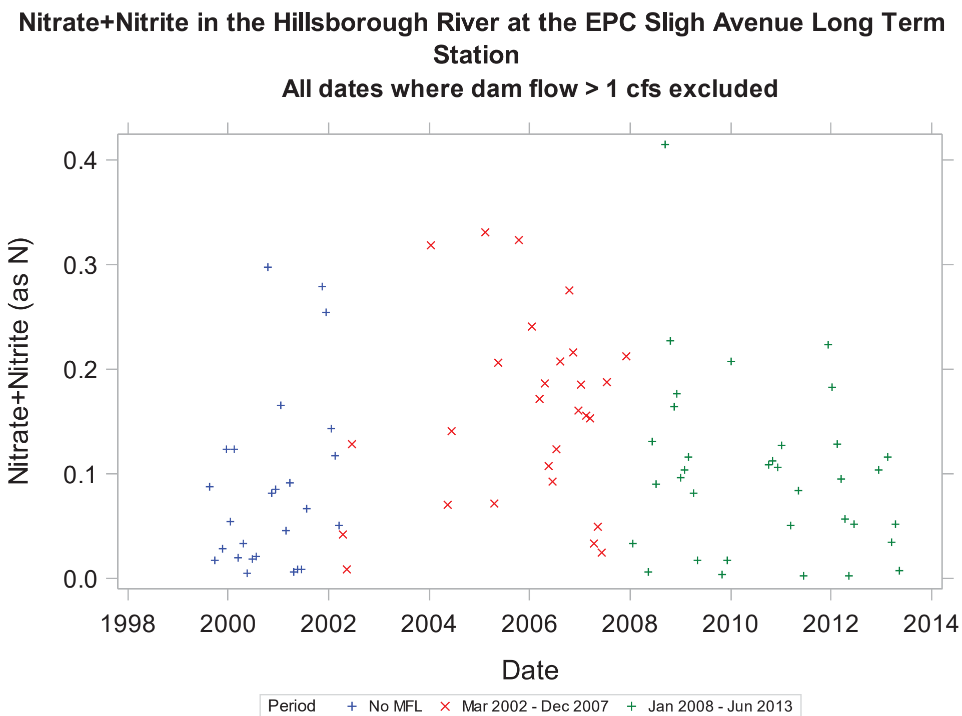


Figure 8-19. Nitrate + nitrite at the Sligh Avenue station.

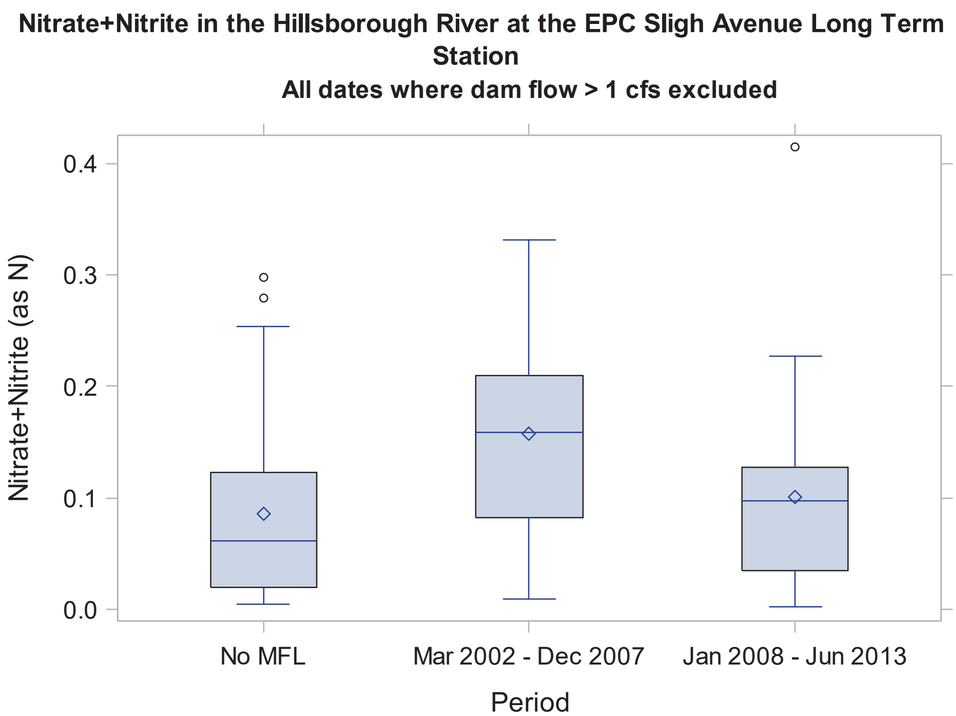


Figure 8-20. Box and whisker plots of nitrate + nitrite at the Sligh Avenue station.

### 8.3.2 Combined nitrate + nitrite data

The pattern observed in the combined NOx data (data from all sources) is the same throughout the sampled area as the pattern observed at the EPCHC fixed stations. NOx was slightly higher in the initial minimum flow implementation period (Sulphur Springs only), and lower in the pre-minimum flow and most recent minimum flow periods (Figure 8-21). There are relatively little data for the Sulphur Springs to Hannah's Whirl River segment, including no available data during the pre-minimum flow period (Table 8-7). Results of the Wilcoxon tests indicate that in the river segment from Hannah's Whirl to the Tampa Dam (kilometer > 14.5), NOx was not significantly higher in the initial period than in the pre-minimum flow, but was significantly lower in the most recent period than in the pre-minimum flow period (Appendix 5C). In the Sligh Avenue to Sulphur Springs segment (kilometer 10.6 to < 12.6), NOx was significantly higher in the initial minimum flow implementation period, but was not significantly different in the most recent period relative to before minimum flows.

Plots of NOx versus flow in the three river segments (Figures 8-22 to 8-24) support the observations made from analysis of the summary statistics and boxplot graphics. The use of Sulphur Springs waters alone to meet the minimum flow requirements may have the capacity to raise NOx levels in the stretch of the river upstream of Sulphur Springs; however, the addition of releases from the reservoir seems to mitigate this issue with lower NOx concentrations tending to occur at the higher minimum flow rates.

**Table 8-7. Mean, standard deviation and number of observations for nitrate + nitrite in the combined data.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location (km)** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| 10.6 to < 12.6 | 0.1, (0.1,26) | 0.2, (0.1,45) | 0.1, (0.2,66) |
| 12.6 to < 14.5 | | 0.2, (0.1,15) | 0.1, (0.1,26) |
| > 14.5 | 0.1, (0.1,105) | 0.2, (0.1,35) | 0.1, (0.1,47) |

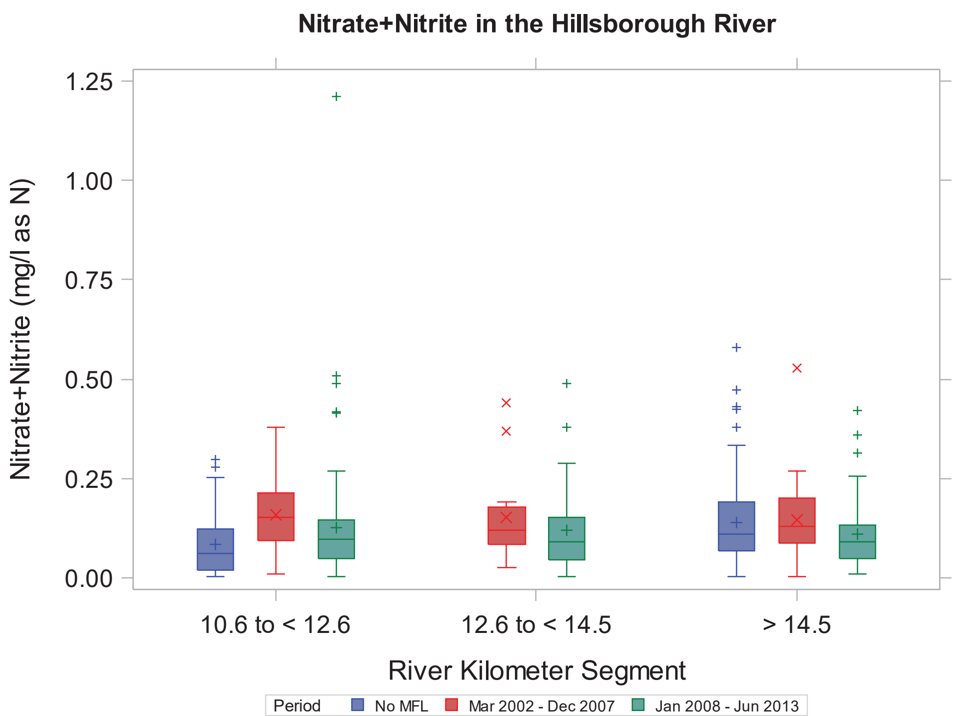


**Figure 8-21. Box and whisker plots of nitrate + nitrite the combined water chemistry data base for three river segments during three minimum flow periods.**

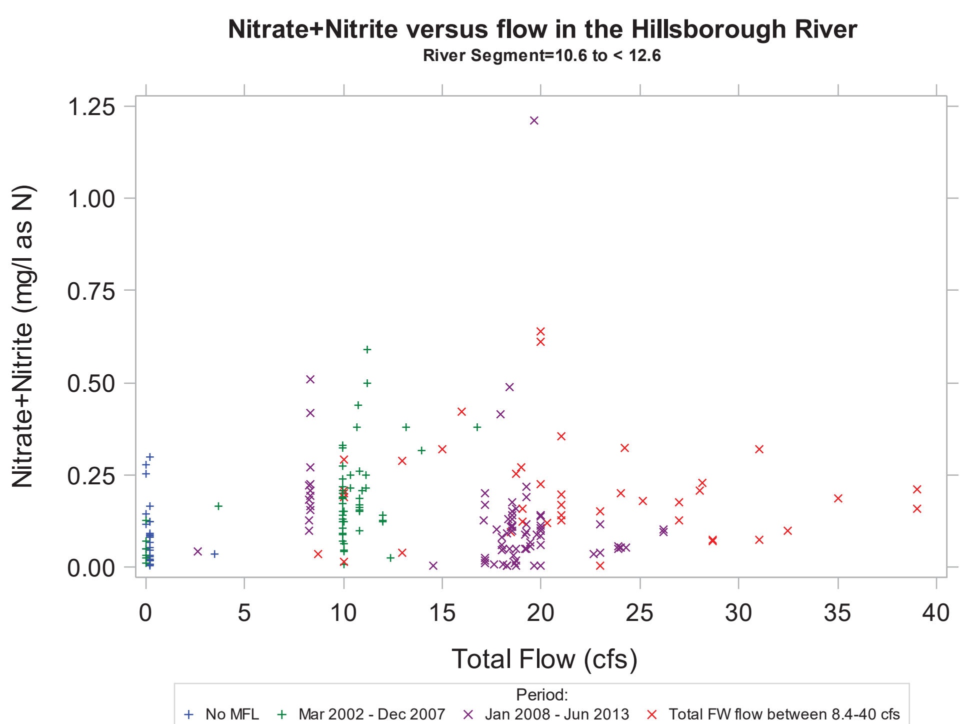


**Figure 8-22. Nitrate + nitrite versus flow in the river segment between kilometers 10.6 and12.6.**

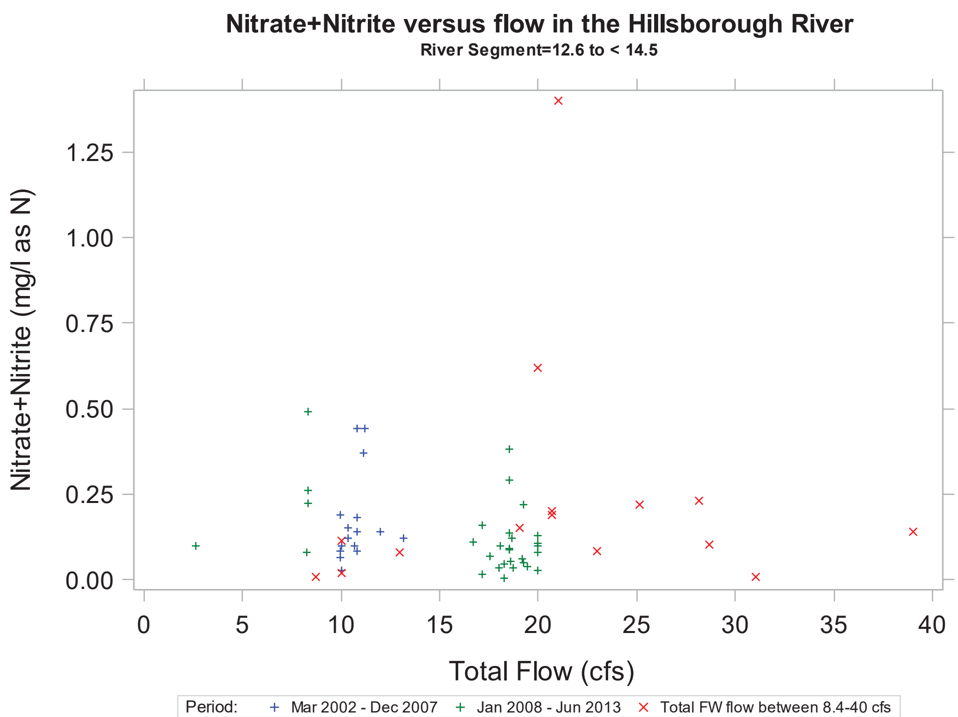


**Figure 8-23. NOx versus flow in the river segment between kilometers 12.6 and14.5.**

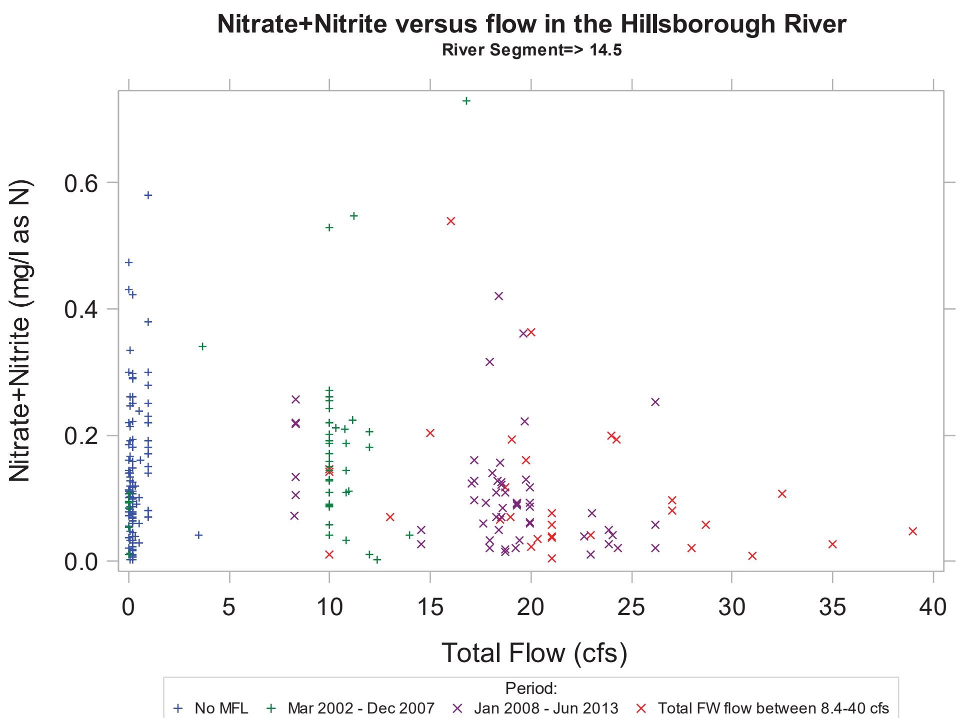


**Figure 8-24. Nitrate + nitrite versus flow in the river segment between kilometers 14.5 and 16.2.**

## 8.4 Total phosphorus

Total phosphorus (TP) represents the total concentration of phosphorus in a water sample regardless of chemical form or availability. Phosphorus is a critical nutrient for plant growth, and can be a causal factor for algal blooms in nutrient enriched systems. There are naturally phosphorus rich geologic formations in the Tampa Bay region, in addition to possible anthropogenic sources such as point source discharges and urban or agricultural runoff. For a description of TP levels in the Lower Hillsborough River source waters see Section 2.6. For results discussed in this report, TP concentrations are reported as milligrams per liter phosphorus.

### 8.4.1 Total phosphorus at EPCHC fixed-location stations

The pattern observed for total phosphorus concentration at the EPCHC Rowlett Park Drive station is similar to the pattern for total nitrogen (Section 8.2). Total phosphorus at the Rowlett Park station averaged 0.46 mg/l in the pre-minimum flow period, decreasing to 0.14 mg/l in the initial minimum implementation period, and to 0.12 mg/l in the most recent period (Table 8-8). The reduction in TP coincides very well with the initial implementation of minimum flows (Figure 8-25) and the values remained substantially lower throughout the minimum flow implementation (Figure 8-26). Total phosphorus was significantly lower after minimum implementation than in the pre-minimum flow period (Appendix 5D).

Total phosphorus concentration at the Sligh Avenue station also decreased in the periods following minimum flow implementation, from an average of 0.21mg/l in the pre-minimum flow period to 0.18 and 0.16 mg/l in the two subsequent periods. The decrease in TP at Sligh Avenue (Figure 8-27 and Figure 8-28) is less pronounced than the decrease at Rowlett Park Drive, and TP was significantly lower only during the period beginning January 2008 (Appendix 5D).

**Table 8-8. Mean, standard deviation, and number of observations for total phosphorus at the EPCHC fixed stations.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| Sligh Avenue | 0.21, (0.06, 26) | 0.18, (0.05, 28, ) | 0.16, (0.05, 35) |
| Rowlett Park Drive | 0.46, (2.00, 143) | 0.14, (0.05, 28) | 0.12, (0.05, 32) |

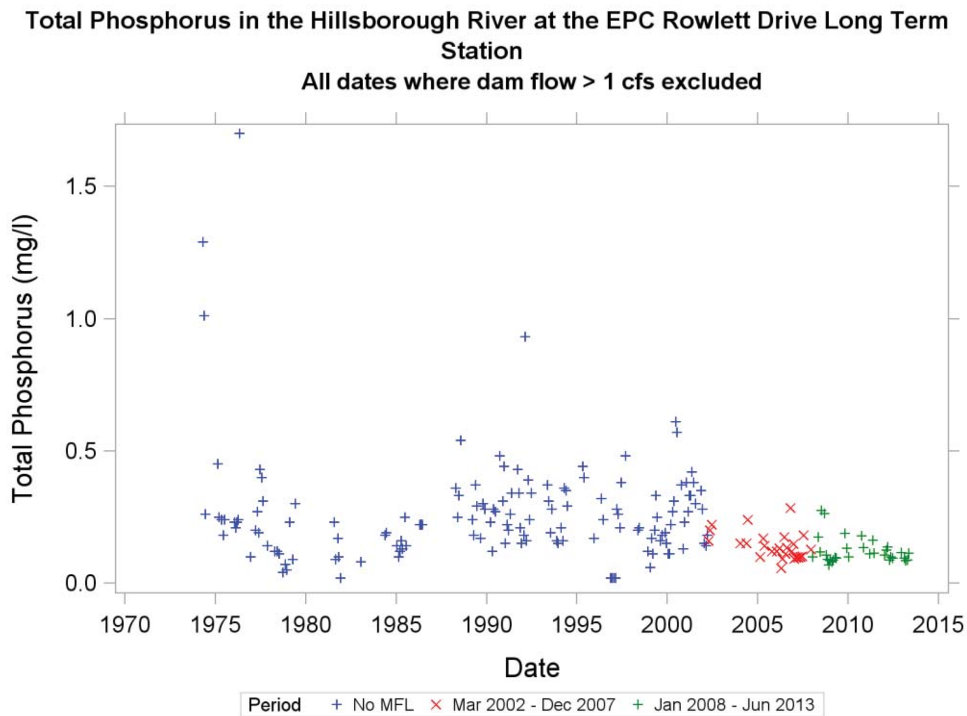


**Figure 8-25. Total phosphorus at the Rowlett Park Drive station.**

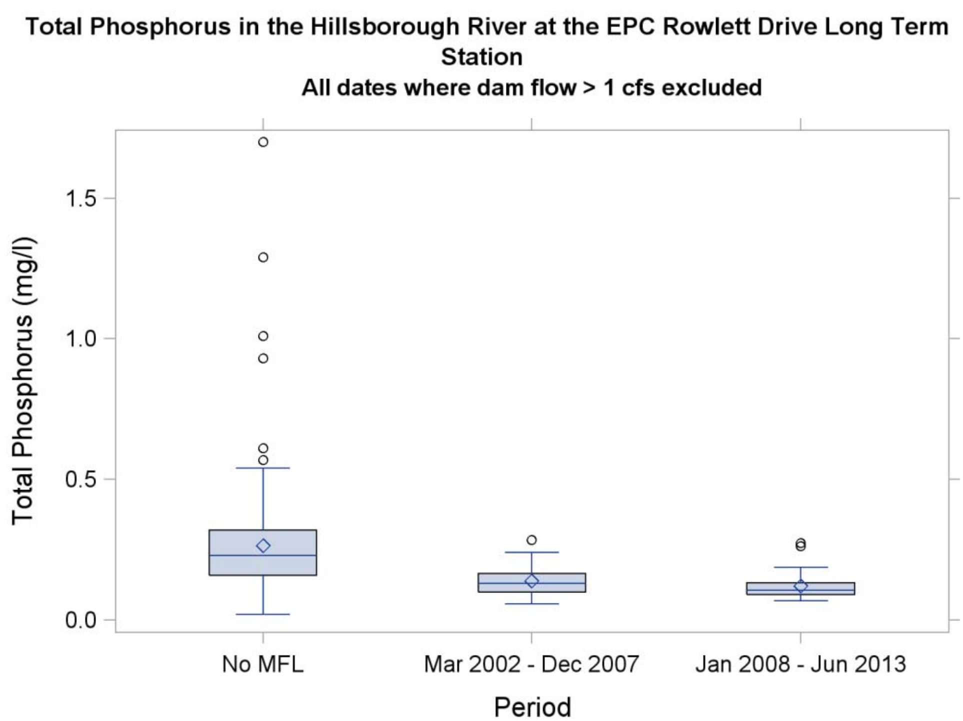


**Figure 8-26. Box and whisker plots of total phosphorus at the Rowlett Park Drive station.**

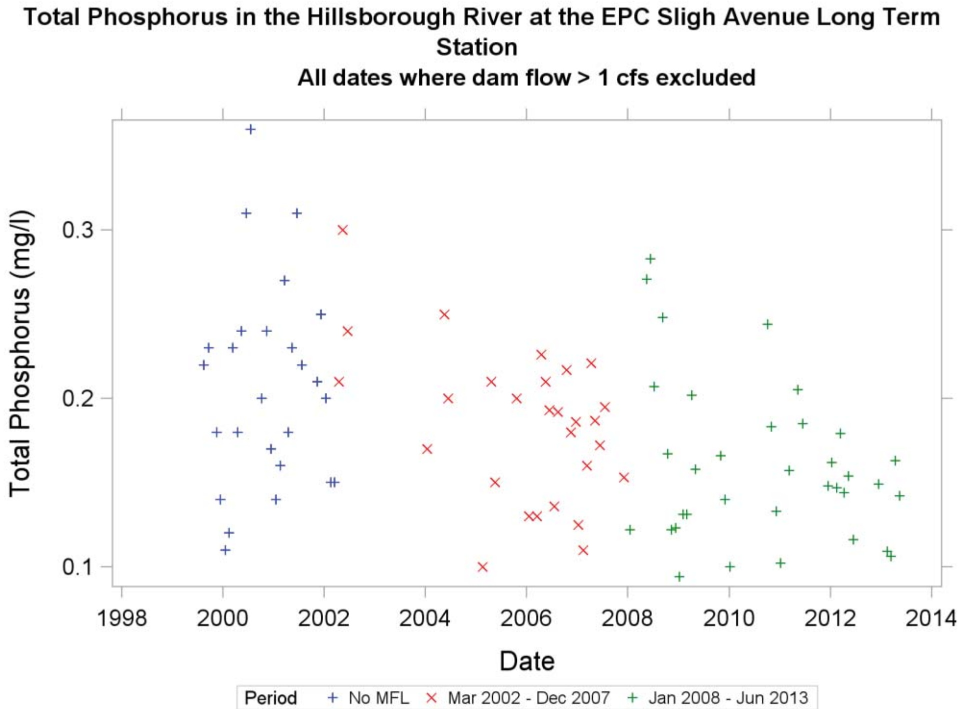


**Figure 8-27. Total phosphorus at the Sligh Avenue station.**

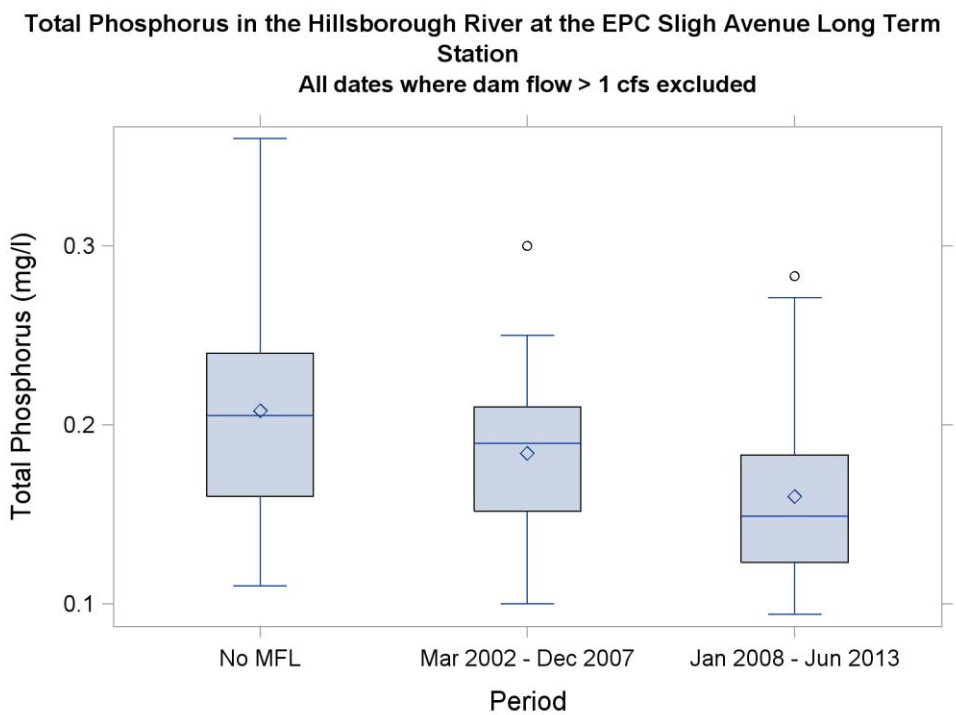


**Figure 8-28. Box and whisker plots of total phoshros at the Sligh Avenue station.**

### 8.4.2 Combined total phosphorus Data

The pattern observed in the combined TP data (data from all sources) in the study area was similar to pattern observed at the EPCHC fixed stations, with large decreases in TP in the upstream segment, and less pronounced decreases downstream (Figure 8-29). Data are sparse for the river segment between Hannah's Whirl and Sulphur Springs (Table 8-9), with no available data for the pre-minimum flow period. Results of the Wilcoxon tests indicate that TP concentrations in the river segments from Hannah's Whirl to the Tampa Dam and from Sligh Avenue to Sulphur Springs TP were significantly lower in both periods following minimum flows implementation (Appendix 5D).

Plots of TP versus flow in the three river segments (Figures 8-30 to 8-32) support the observations made from analysis of the summary statistics and boxplot graphics. The reduction in TP concentrations with the implementation of minimum flows appears particularly strong in the Hannah's Whirl to Tampa Dam river segment (Figure 8-32). There were no data from the pre-minimum flow period in the Sulphur Springs to Hannah's Whirl segment (8-31).

**Table 8-9. Mean, standard deviation, and number of observations for total phosphorus in the combined data.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location (km)** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| 10.6 to < 12.6 | 0.2, (0.1,26) | 0.2, (0,45) | 0.2, (0.1,65) |
| 12.6 to < 14.5 | | 0.2, (0,15) | 0.2, (0.1,25) |
| > 14.5 | 0.5, (2,143) | 0.1, (0,35) | 0.1, (0.1,47) |

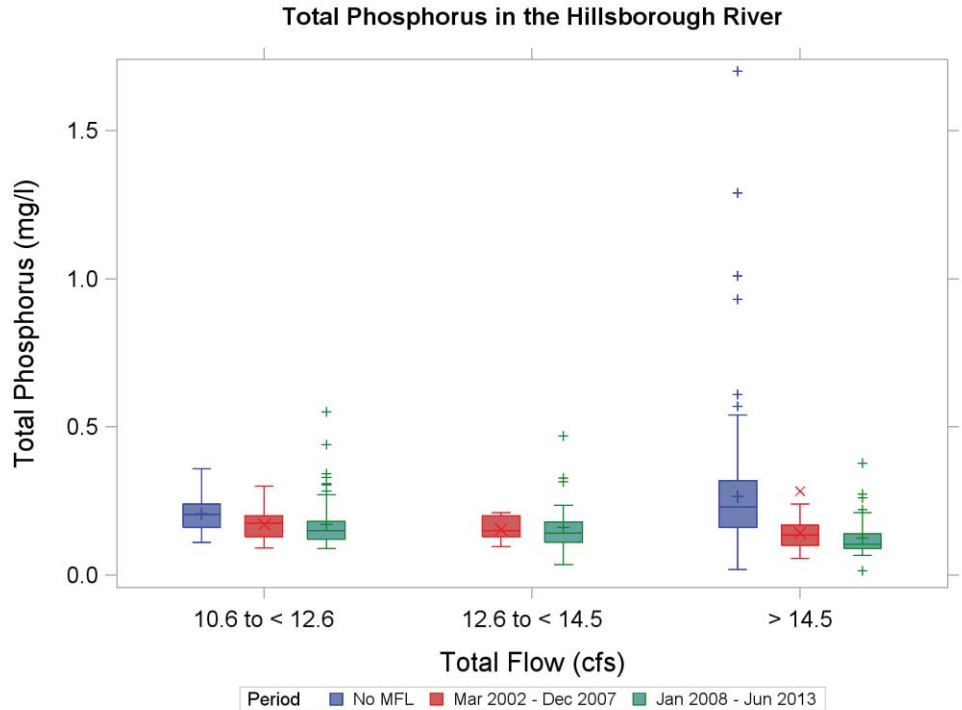


**Figure 8-29. Box and whisker plots of total phosphorus from the combined water chemistry data base for three river segments during three minimum flow periods.**

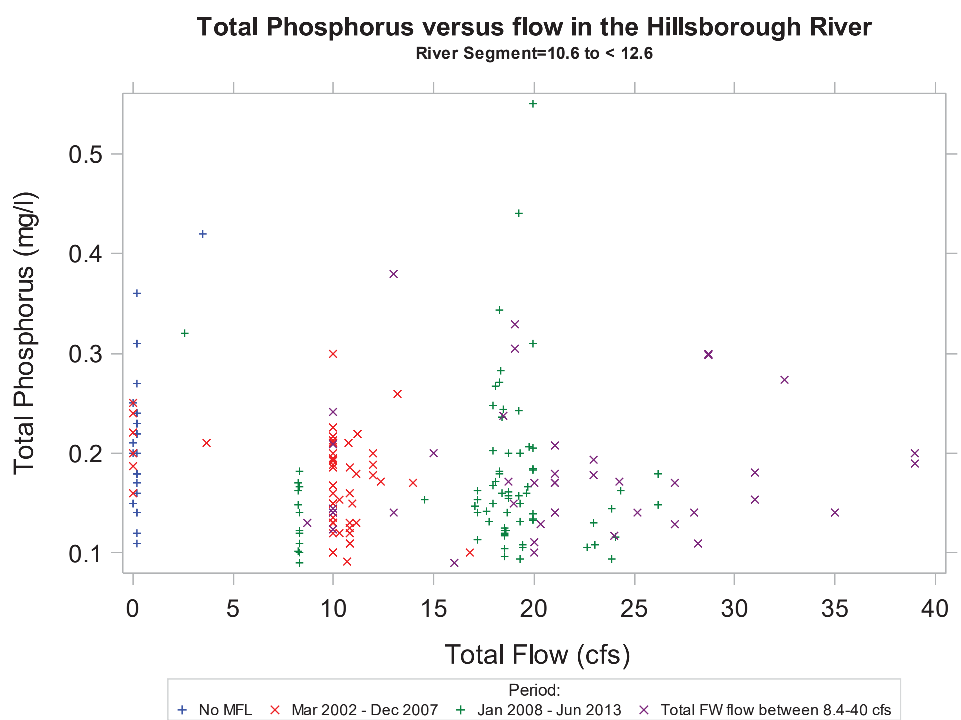


**Figure 8-30 Total phosphorus versus flow in the river segment between kilometers 10.6 and 12.6.**

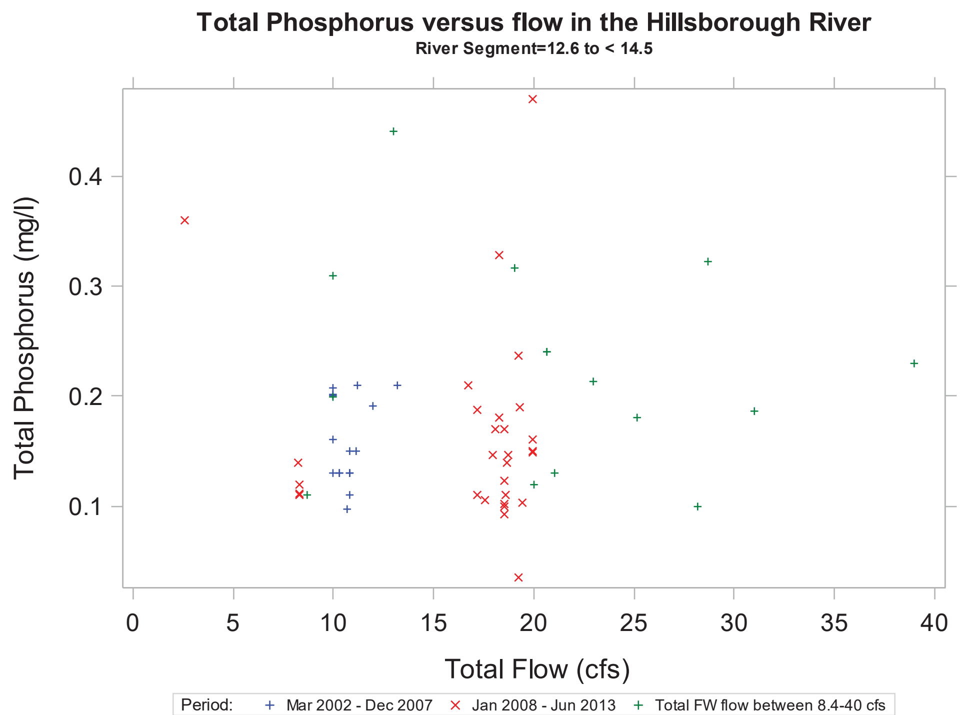


**Figure 8-31. Total phosphorus versus flow in the river segment between kilometers 12.6 and 14.5.**

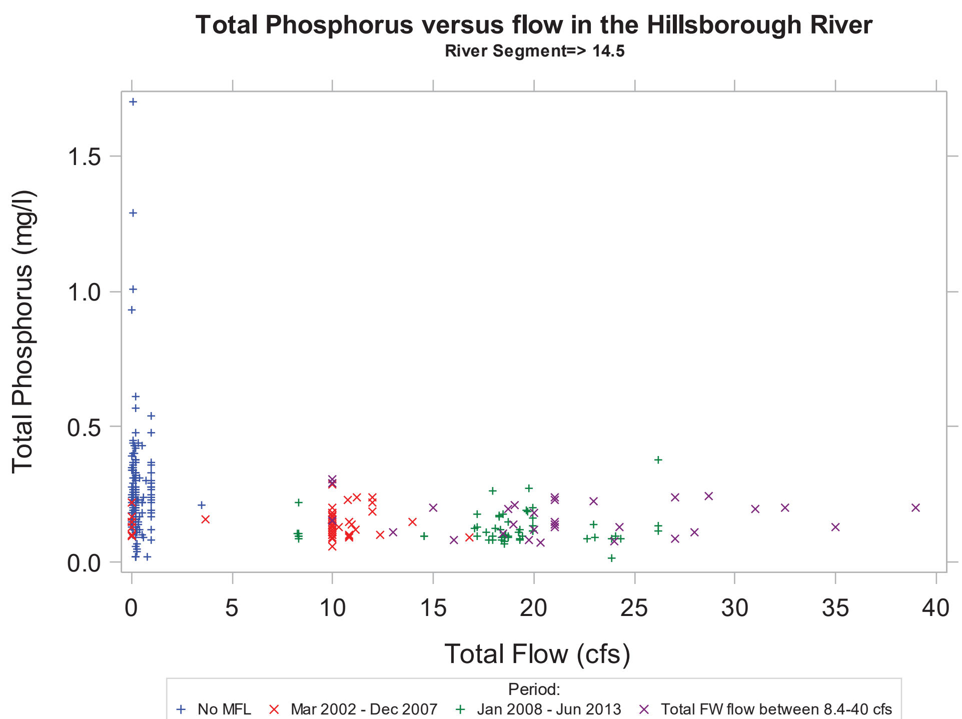


**Figure 8-32. Total phosphorus versus flow in the river segment between kilometers 14.5 and 16.2.**

## 8.5 Orthophosphate

Orthophosphate is a dissolved form of phosphorus which is readily available for uptake by phytoplankton, and is often referred to as orthophosphous. Phosphorus in orthophosphate is usually bound with oxygen as phosphate ($PO_4$), with the concentrations reported as milligrams per liter phosphorus. See Section 2.6 for a description of orthophosphate levels in the Lower Hillsborough River minimum flows source waters.

### 8.5.1 Orthophosphate at the EPCHC fixed-location stations

The pattern observed for orthophosphate concentration at Rowlett Park Drive is very similar to the pattern for TP. Orthophosphate at the EPCHC Rowlett Park Drive station averaged 0.19 mg/l in the pre-minimum flow period, decreasing to 0.10 mg/l in the periods after MFL implementation (Table 8-10). The reduction in $PO_4$ coincides very well with the initial implementation of minimum flows (Figure 8-33) and the values remained substantially lower throughout the minimum flow implementation (Figure 8-34). Orthophosphate was significantly lower after minimum flow implementation than in the pre-minimum flow period (Appendix 5E).

Orthophosphate was also lower at the Sligh Avenue station in the periods following minimum flow implementation. The decreases in $PO_4$ at Sligh Avenue were less dramatic (Figure 8-35 and Figure 8-36) compared to the decreases at Rowlett Park Drive. In the pre-minimum flow period $PO_4$ averaged 0.14mg/l, decreasing to 0.12 mg/l in the initial minimum flow implementation period and 0.11 mg/l in the most recent period. $PO_4$was significantly lower in the most recent period when compared to the pre-minimum flow period (Appendix 5E).

**Table 8-10. Mean, standard deviation, and number of observations for orthophosphate at the EPCHC fixed stations.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location (km)** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| Sligh Avenue | 0.14, (.05, 26) | 0.12, (0.03, 28) | 0.11, (0.03, 35) |
| Rowlett Park Drive | 0.19, (0.14, 81) | 0.10, (0.03, 28) | 0.10, (0.04, 32) |

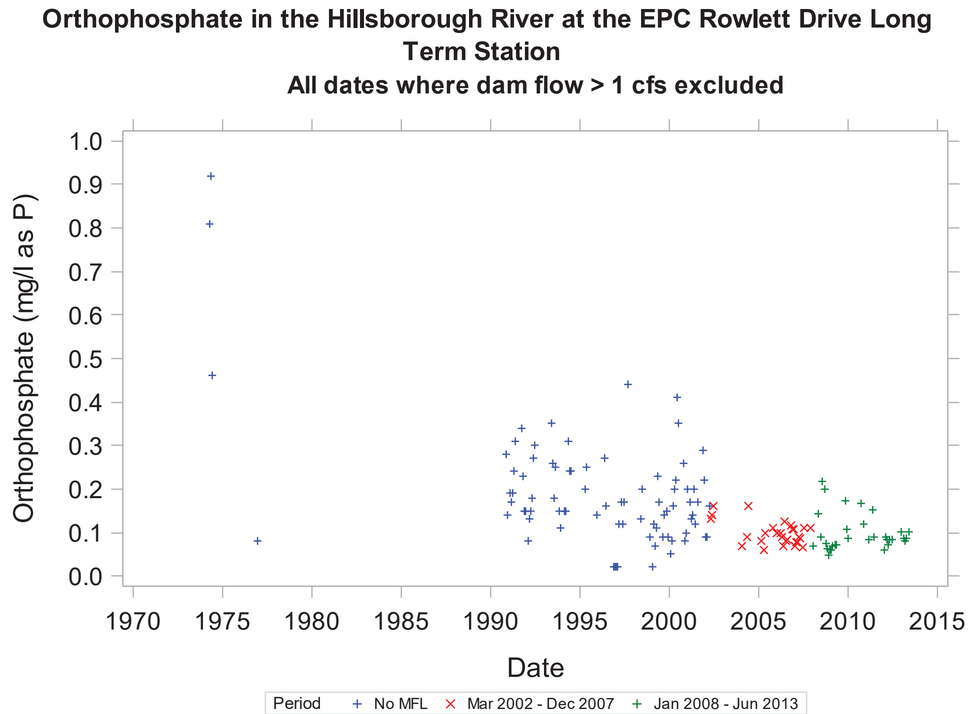


**Figure 8-33. Orthophosphate at the Rowlett Park Drive station.**

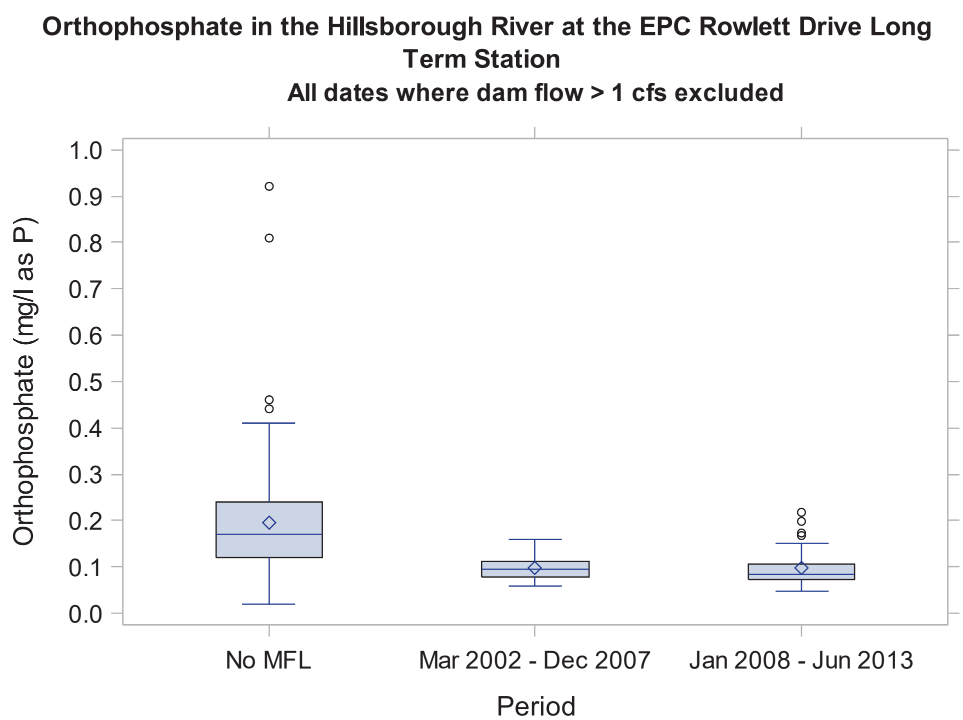


**Figure 8-34. Box and whisker plots of orthophosphate at the Rowlett Park Drive station.**

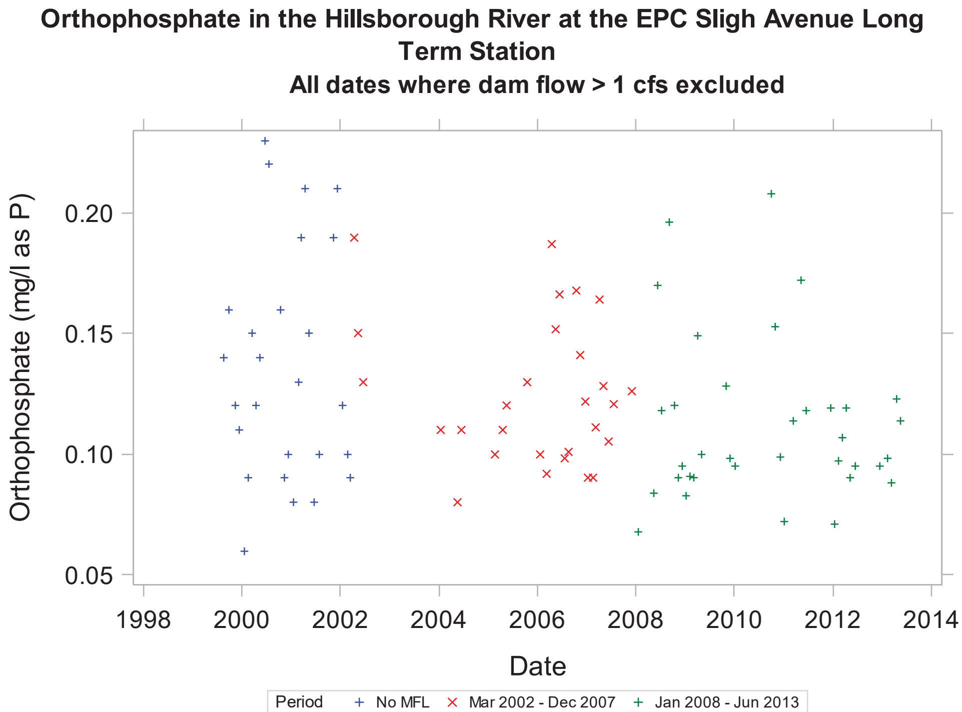


**Figure 8-35. Orthophosphate at the Sligh Avenue station.**

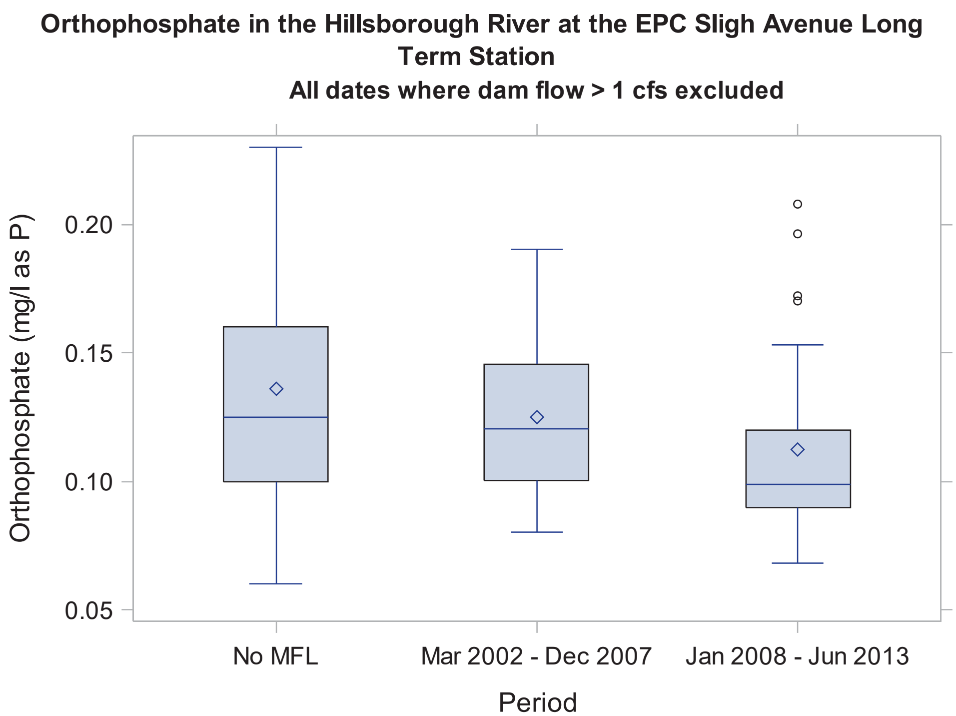


**Figure 8-36. Box and whisker plots of orthophosphate at the Sligh Avenue station.**

### 8.5.2 Combined orthophosphate data

The pattern observed in the combined $PO_4$ data is the same throughout the sampled area as the pattern observed at the EPCHC fixed stations, with large decreases in $PO_4$ in the upstream segment, and less pronounced decreases downstream. There is relatively little data for the Sulphur Springs to Hannah's Whirl river segment (Table 8-11), including no available data during the pre-minimum flow period (Table 8-11). Results of the Wilcoxon tests indicate that in the river segment from Hannah's Whirl to the Tampa Dam, $PO_4$ was significantly lower in both periods following minimum flow implementation (Appendix 5E). In the river segment from Sligh Avenue to Sulphur Spring $PO_4$ was not significantly different among any of the periods.

Plots of $PO_4$ versus flow in the three river segments (Figures 8-38 to 8-40) indicate very little relation between flow and $PO_4$ in the downstream segments, but a reduction in high $PO_4$ values after minimum flow implementation in the uppermost segment. These graphics support the observations made from analysis of the summary statistics and boxplots.

**Table 8-11. Mean, standard deviation and number of observations for orthophosphate in the combined data.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location (km)** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| 10.6 to < 12.6 | 0.1, (0,26) | 0.1, (0,45) | 0.1, (0,66) |
| 12.6 to < 14.5 | ND | 0.1, (0,15) | 0.1, (0,26) |
| > 14.5 | 0.2, (0.1,81) | 0.1, (0,35) | 0.1, (0,47) |

ND = no data available

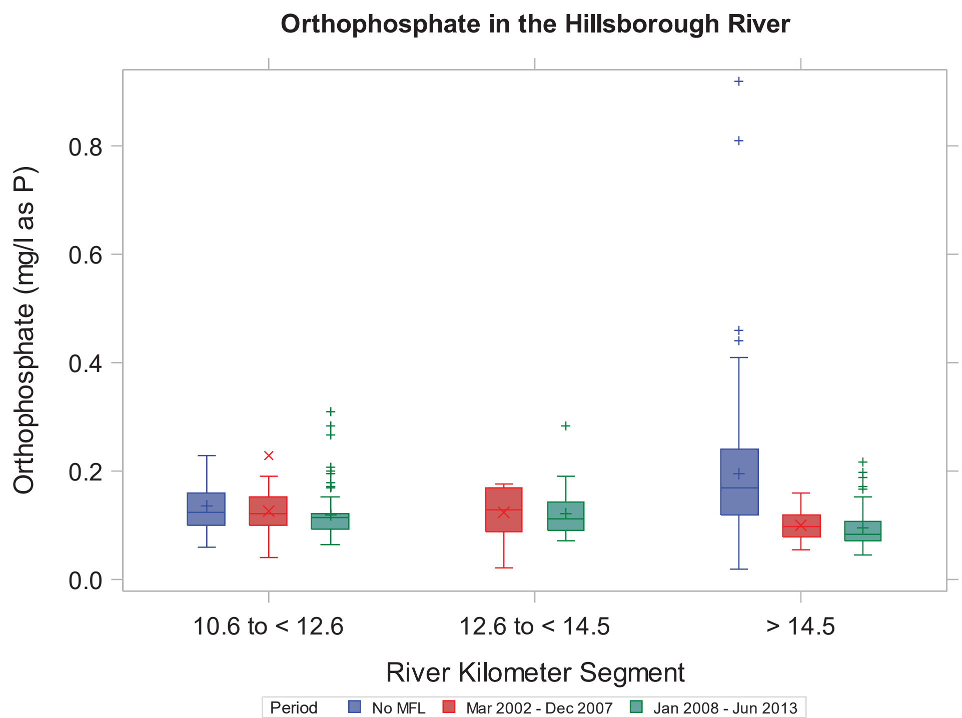


**Figure 8-37. Box and whisker plots of orthophosphate from the combined water chemistry data base for three river segments during three minimum flow periods.**

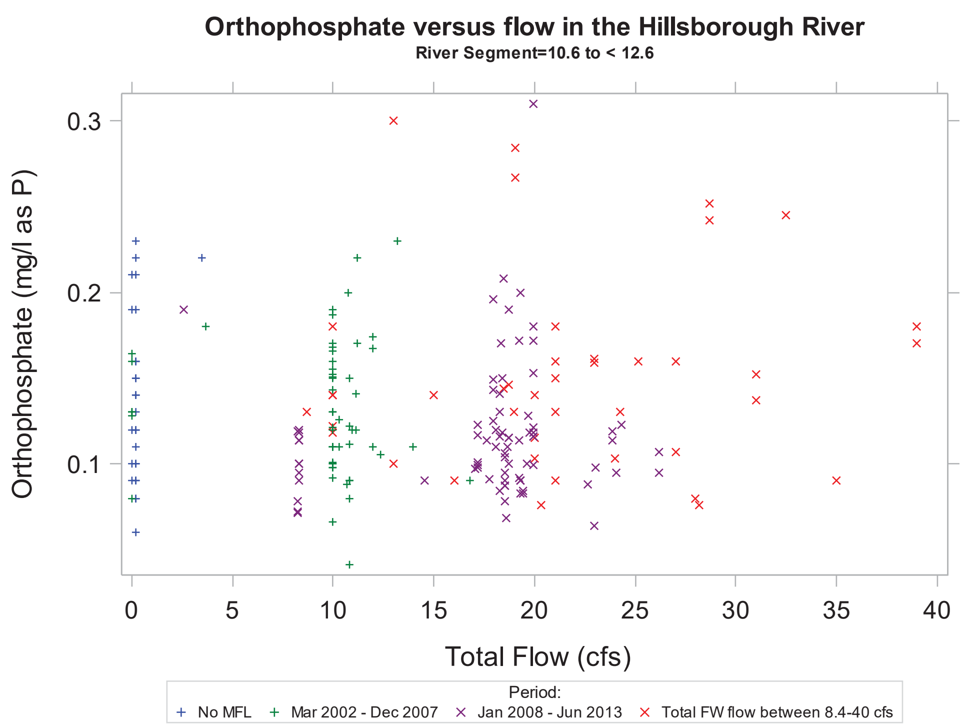


**Figure 8-38. Orthophosphate versus flow in the river segment between kilometers 10.6 and12.6.**

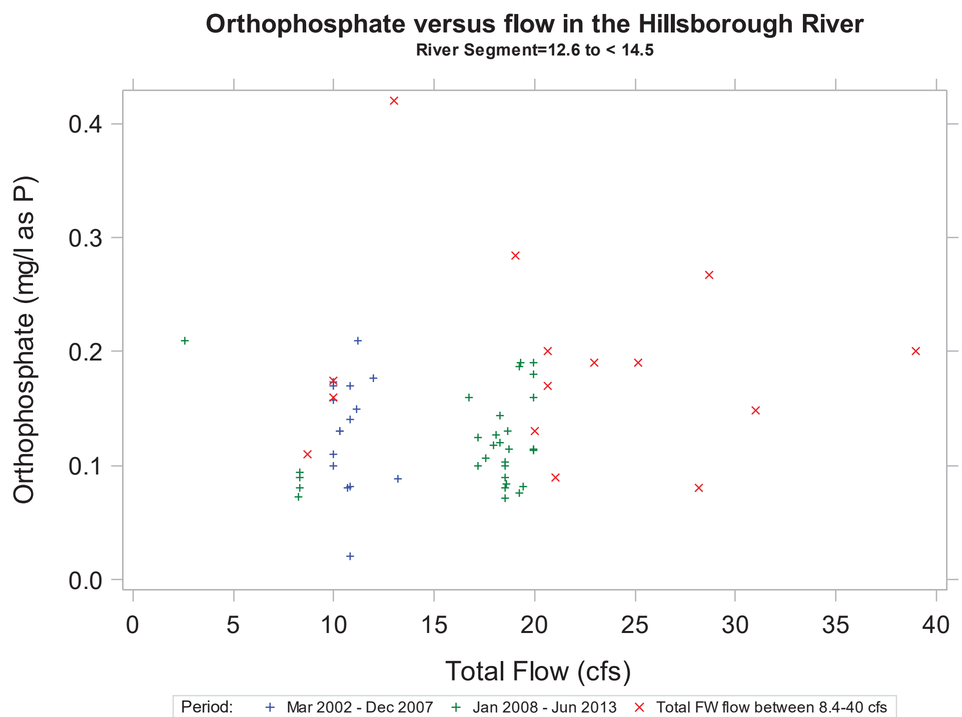


**Figure 8-39. Orthophosphate versus flow in the river segment between kilometers 12.6 and 14.5.**

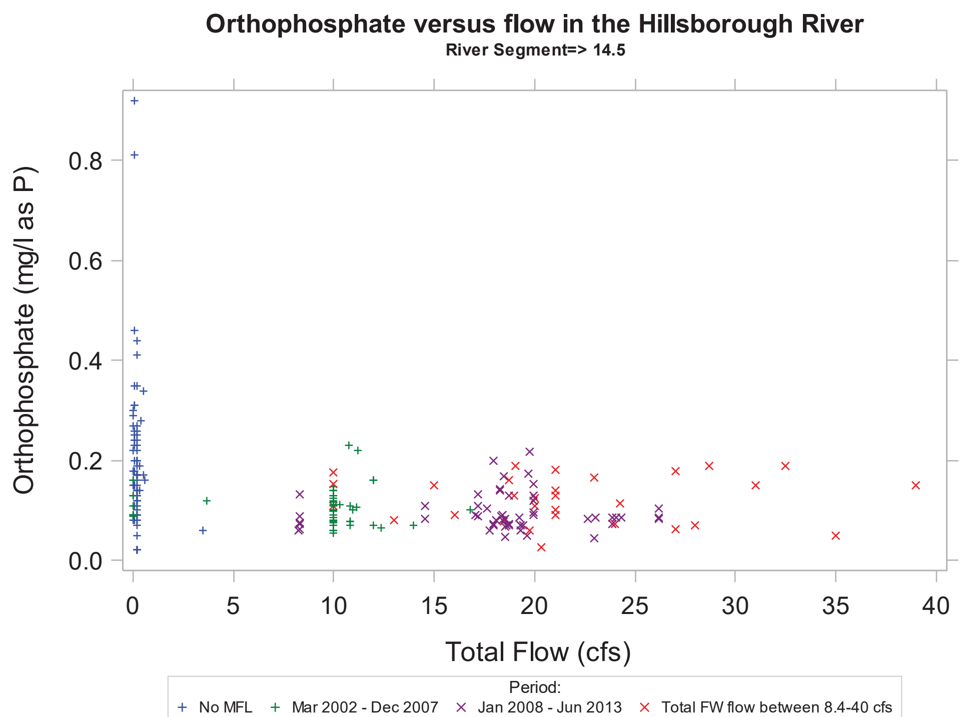


**Figure 8-40. Orthophosphate versus flow in the river segment between kilometers 14.5 and 16.2.**

## 8.6 Chlorophyll *a*

Chlorophyll *a*, which is the principal photosynthetic pigment in most groups of phytoplankton, represents a proxy for the biomass of phytoplankton present in water. \However, chlorophyll *a* concentrations only approximate phytoplankton biomass because phytoplankton taxa have different photosynthetic pigment composition and within taxa the chlorophyll *a* content can vary depending on physicochemical conditions (e.g., light, nutrients) and the physiological condition of the algae. However, chlorophyll *a* is a useful and widely applied indicator for the trophic state of water bodies, because chlorophyll *a* concentrations generally show a positive relationship with phytoplankton abundance and are often elevated in nutrient enriched water bodies. For results discussed in this report, chlorophyll *a* concentrations are reported as micrograms (µg) per liter.

### 8.6.1 Chlorophyll *a* at the EPCHC fixed-location stations

The mean chlorophyll *a* concentration at the EPCHC Rowlett Park Drive station was 25.5 µg/l in the period prior to minimum flows, progressively decreasing to 17.5 and 5.4 µg/l in the periods following minimum flow implementation (Table 8-12). However, the distribution of chlorophyll *a* values is highly skewed and variable. A time series plot of the data (Figure 8-41) indicates data variability was much less in the final minimum flow period when Sulphur Springs diversions were accompanied by reservoir releases. The boxplot of chlorophyll *a* at Rowlett Park Drive also indicates that chlorophyll *a* concentrations decreased substantially in the final minimum flow period (Figure 8-42). Wilcoxon rank sum test results indicate that chlorophyll *a* concentrations were significantly lower in both periods following minimum flow implementation, with concentrations in the final minimum flow period significantly lower than the period when only diversions from Sulphur Springs were employed (Appendix 5F).

A plot of chlorophyll *a* concentration versus flow confirms this pattern, with high concentrations common at zero flows, occasional high concentrations in the 10 to 15 cfs flow range, and higher minimum flow rates (> 22 cfs) resulting in concentrations less than 20 µg/l (Figure 8-43). One exception to this pattern was a single chlorophyll *a* value near 75 µg/l when there were total flows of about 27 cfs (Figure 8-43 includes flows over the dam spillway).

**Table 8-12. Mean, standard deviation, and number of observations for chlorophyll *a* at the EPCHC fixed stations.**

| | Time - Flow Condition | | |
|---|---|---|---|
| River Location (km) | No MFL | Mar. 02 - Dec. 07 | Jan. 08 - Jun. 13 |
| Sligh Avenue | 29.3, (21.9, 26) | 24.1, (77.4, 44) | 31.2, (55.1, 56) |
| Rowlett Park Drive | 25.5, (33.7, 143) | 17.5, (29.9, 44) | 5.4, (6.6, 56) |

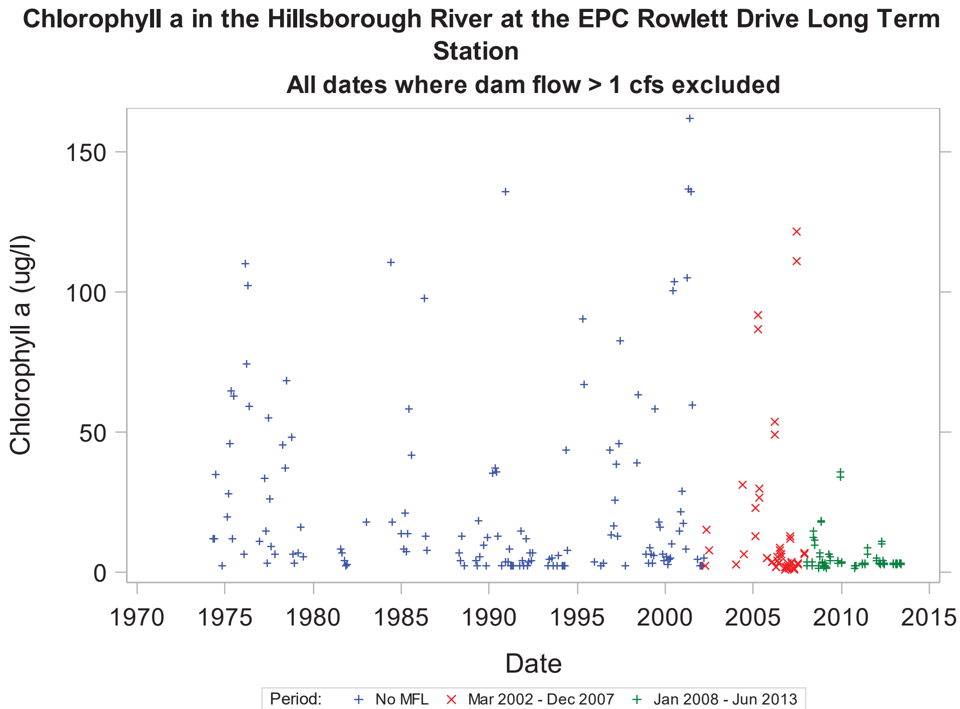


**Figure 8-41. Chlorophyll *a* at the Rowlett Park Drive station.**

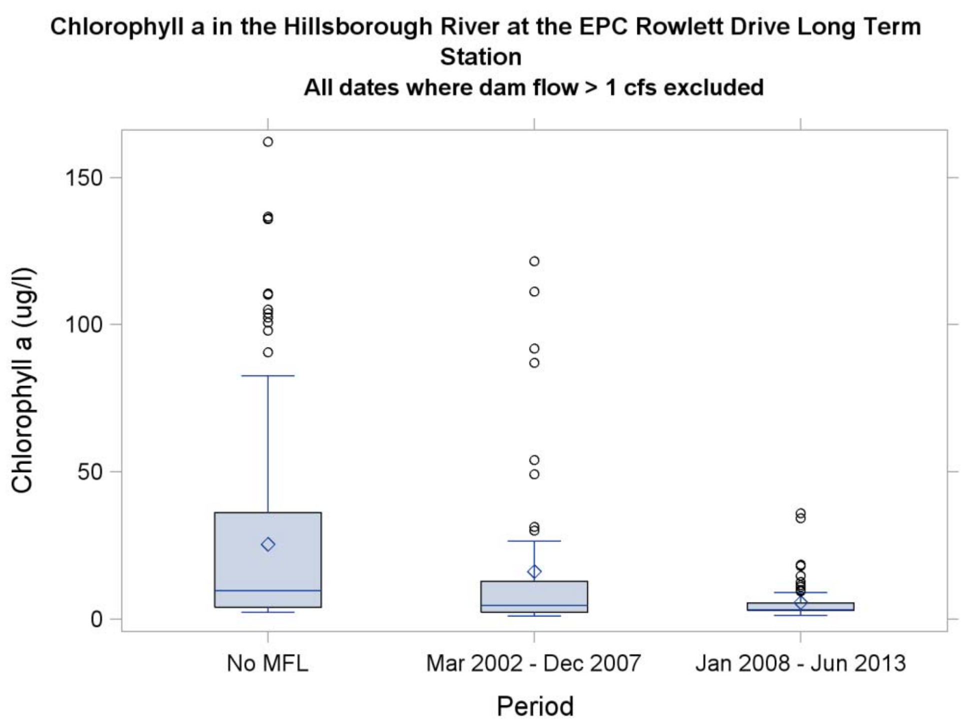


**Figure 8-42. Box and whisker plots of chlorophyll *a* at the Rowlett Park Drive station.**

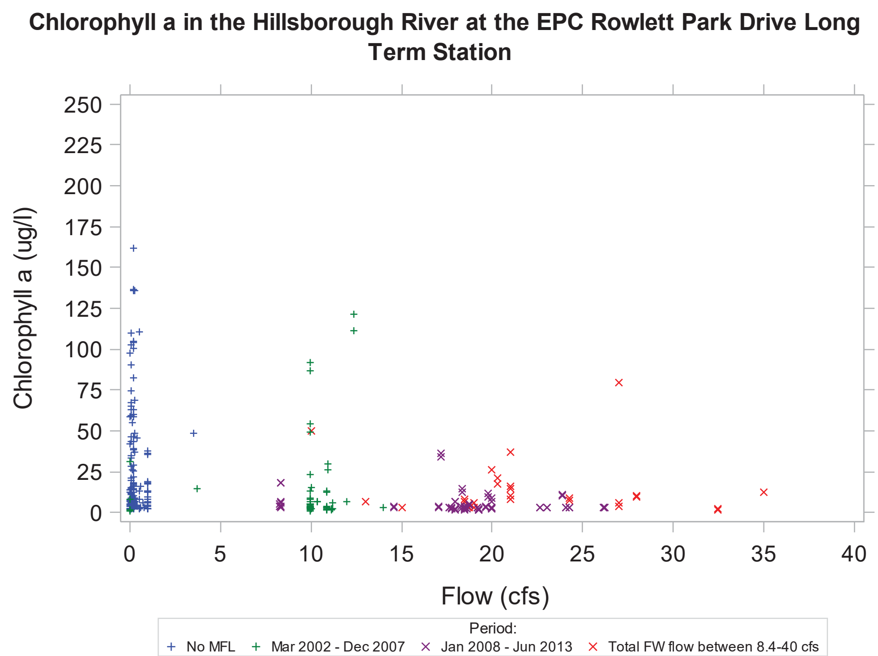


**Figure 8-43. Chlorophyll *a* concentrations at the Rowlett Park Drive station versus flow.**

Mean chlorophyll *a* values changed much less at the EPCHC Sligh Avenue station, ranging from 24.1 µg/l in the first minimum flow period to 31.2 µg/l in the final minimum flow period (Table 8-12). Chlorophyll *a* distributions were also heavily skewed at the Sligh Avenue, indicating that there were differences in the data between periods that are not reflected in the mean values. The time series plots indicate that chlorophyll *a* tended to be lowest during the period when only flows from Sulphur Springs were used for minimum flows (Figure 8-44). Concentrations over 50 µg/l occurred eight times in the final minimum flow period when diversions from Sulphur Springs were matched with releases from the reservoir. However, median chlorophyll *a* values were highest in the period prior to the implementation of minimum flows (Figure 8-45). A plot of chlorophyll *a* at Sligh Avenue versus flow indicates that the highest concentrations occurred near flow rates of 18 to 19 cfs (Figure 8-46).

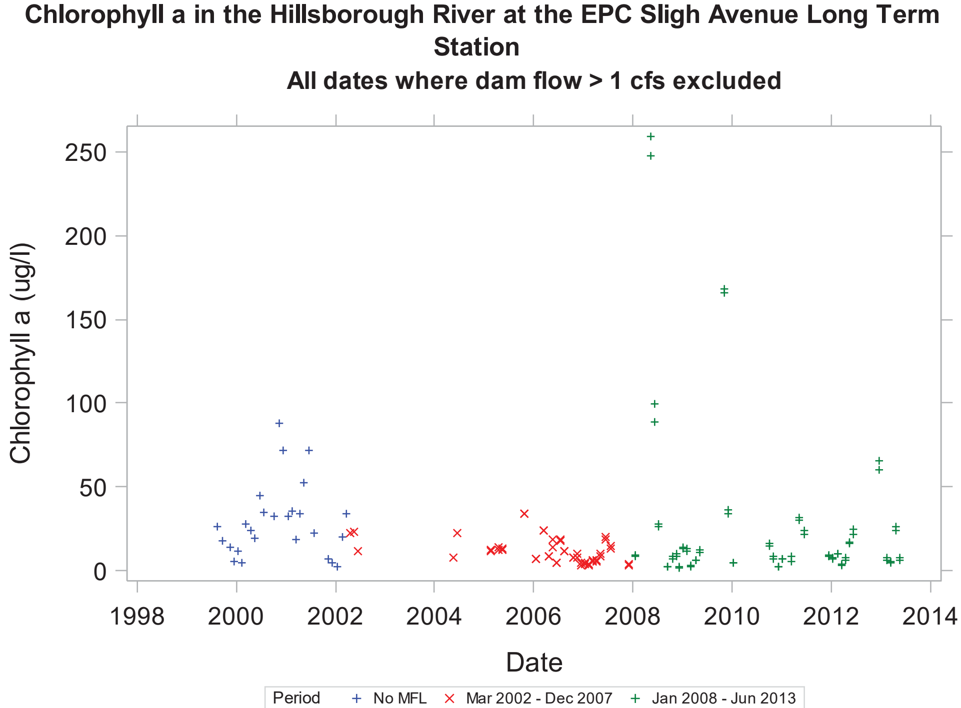


**Figure 8-44. Chlorophyll *a* at the Sligh Avenue station.**

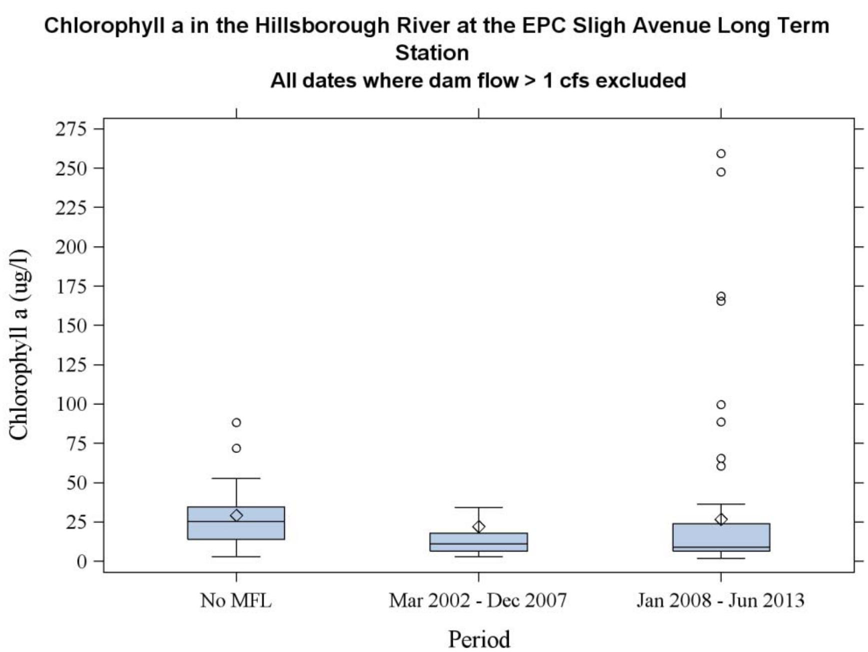


**Figure 8-45. Box and whisker plots of chlorophyll *a* at the Sligh Avenue station.**

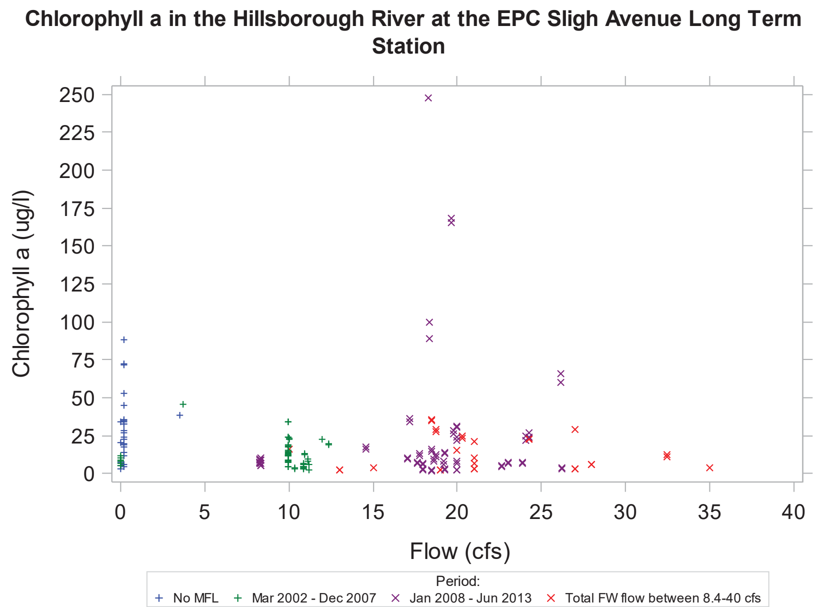


**Figure 8-46. Chlorophyll *a* concentrations at the Sligh Avenue station versus flow.**

## 8.6.2 Combined chlorophyll *a* data

The patterns observed in the chlorophyll data combined water quality data base were generally similar to the pattern observed at the EPCHC fixed stations. Mean concentrations in the segment above Hannah's Whirl (> kilometer 14.5) showed a consistent reduction with implementation of greater minimum flows through time (Table 8-13). The number of observations was more limited for the segment between Sulphur Springs and Hannah's Whirl (kilometers 12 .6 to 14.5), but chlorophyll *a* concentrations were significantly less during both minimum flow periods compared to the period prior the minimum flows (Appendix 5F). However, in this segment the lowest concentrations were during the period when minimum flows were comprised only of diversions from Sulphur Springs.

**Table 8-13. Mean, standard deviation and number of observations for chlorophyll *a* in the combined data.**

| | Time - Flow Condition | | |
|---|---|---|---|
| **River Location (km)** | **No MFL** | **Mar. 02 - Dec. 07** | **Jan. 08 - Jun. 13** |
| 10.6 to < 12.6 | 33.7, (50.3,41) | 21.2, (64.7,64) | 26.6, (58.6,94) |
| 12.6 to < 14.5 | 30.5, (51.5,14) | 7.5, (8.4,17) | 16, (25.4,26) |
| > 14.5 | 32.2, (42.8,48) | 19.1, (35,56) | 5.6, (6.6,74) |

Mean concentrations showed less apparent trend though time in the segment below Sulphur Springs (kilometers 10.6 to 12.6). However, median values were lower following minimum flow implementation (Figure 8-47) and concentrations were significantly lower in both periods compared to the period before minimum flow implementation. Plots of chlorophyll *a* versus flow indicate that peak concentrations in all segments occurred at total flow rates less than 20 cfs, with generally less variation in chlorophyll *a* at higher flows (Figures 8-48 to 8-50).

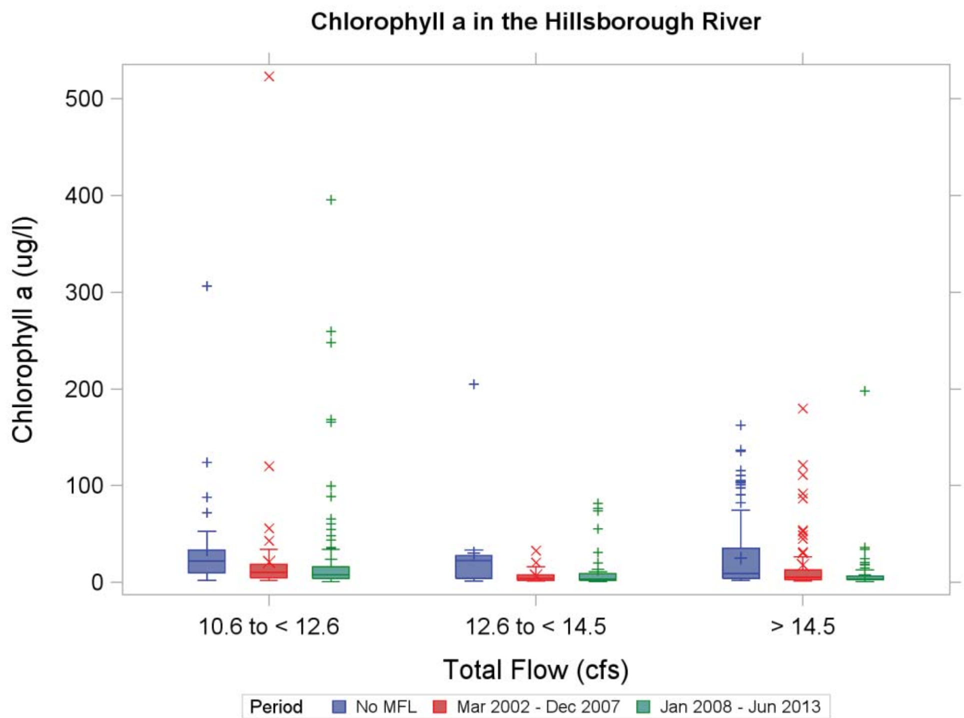


**Figure 8-47. Box and whisker plots of chlorophyll *a* from the combined water chemistry data base for three river segments during three minimum flow periods.**

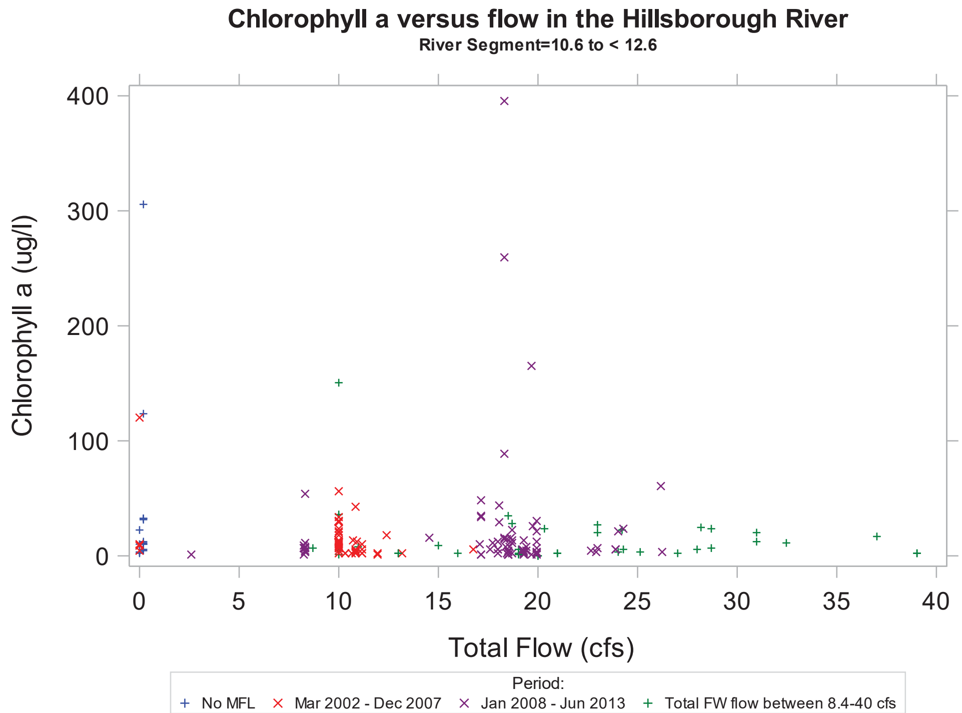


**Figure 8-48. Chlorophyll *a* versus flow in the river segment between kilometers 10.6 and12.6.**

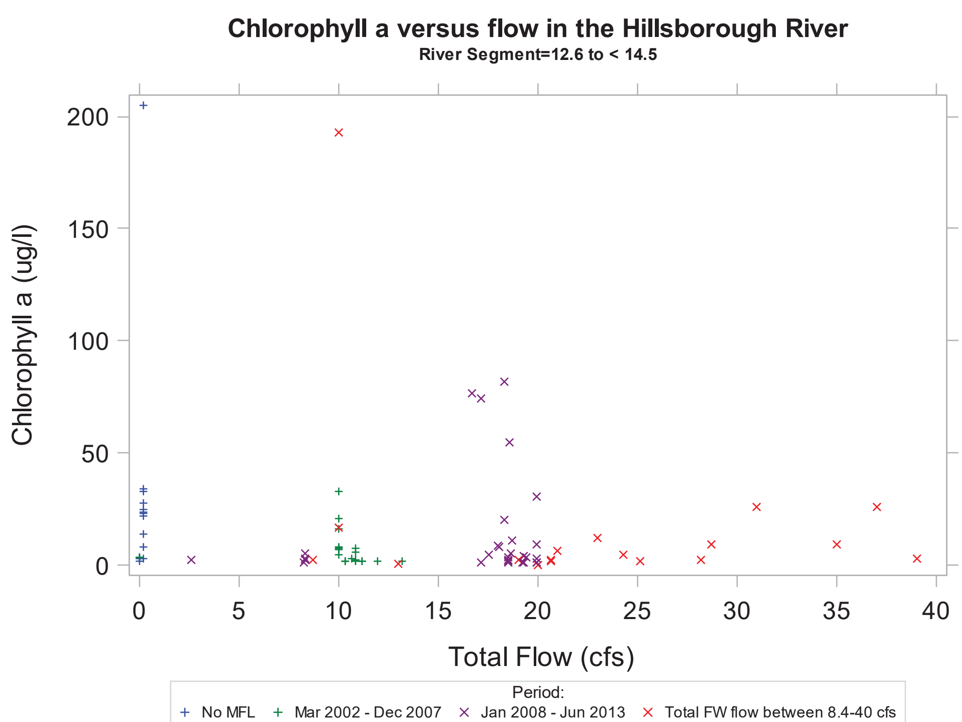


**Figure 8-49. Chlorophyll *a* versus flow in the river segment between kilometers 12.6 and 14.5.**

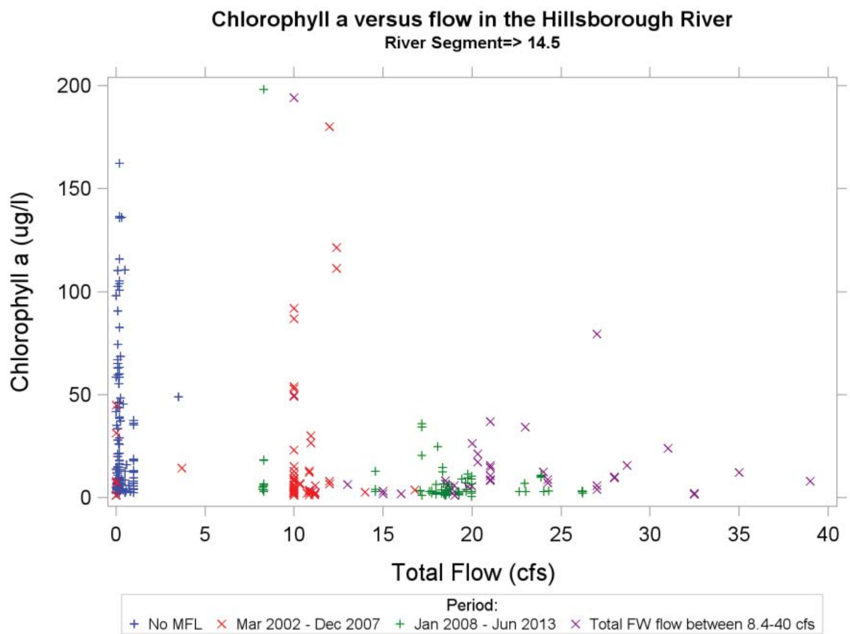


**Figure 8-50. Chlorophyll *a* versus flow in the river segment between kilometers 14.5 and 16.2.**

## 8.7 Discussion

In addition to improvements in the salinity distributions and DO characteristics of the Lower Hillsborough River, it appears the implementation of minimum flows has resulted in beneficial changes in water quality, particularly in the target area for extending oligohaline (< 5 psu salinity) conditions from the dam toward Sulphur Springs. The diversion of water from Sulphur Springs to the base of the dam acts to moderate water temperature extremes between the dam and Sulphur Springs. During strong winter cold fronts, this thermal effect should reduce the potential for mortality of cold sensitive species such as snook that occur in that reach of the river. During warm months, the diversion of spring water and the release of water from the reservoir also act to reduce the maximum water temperatures that occur in that reach of the river, which should have some slight benefit for maintaining dissolved oxygen concentrations and percent saturation values.

The protection of a thermal refuge for manatees in the winter near the Sulphur Spring outfall is also a priority for management of the lower river. Based on thermal simulations of the lower river presented in the minimum flows report for Sulphur Springs (SWFWMD 2004), a minimum of 18 cfs must discharge to the lower river at the spring outfall when water temperature in the river near the spring falls below a specific threshold. Based on input for the Florid Fish and Wildlife Conservation Commission, a threshold of 20 $^{o}$C is used as the temperature threshold to require 18 cfs at the spring outfall. This means that during some cold periods, less spring water can be diverted to the base of the dam and the moderating effect of minimum flow implementation on river water temperatures immediately below the dam will be lessened.

The implementation of minimum flows has resulted in a slight increase in pH values between the dam and Sulphur Springs. However, these increases are relatively small and are not expected to adversely affect the river. The implementation of minimum flows has also resulted in some changes in water color in the lower river. The lowest mean color values above Sulphur Springs occurred between 2002 and 2007 when the minimum flows were comprised solely of water diverted from Sulphur Springs. The initiation of minimum flow releases from the reservoir resulted in some slight increases in water color, but mean concentrations were still below those recorded in the period before minimum flow implementation. Like other water quality constituents, the effects minimum flows on color were much less in the reach of the river below Sulphur Springs.

Some of the most striking findings of the study were reductions in nitrogen and phosphorus species below the dam after the implementation of minimum flows. At both the Rowlett Park and Sligh Avenue water quality stations sampled by the EPCHC, pronounced declines in TN were observed as minimum flows were gradually increased. The findings for NOx nitrogen were not as dramatic, but the lowest concentrations and reduced variability were observed above Sulphur Springs when minimum flows were comprised of diversions from Sulphur Springs and releases of up 8.3 cfs from the reservoir. TP and orthophosphate ($PO_4$) concentrations also declined with the implementation of minimum flows.

The response of chlorophyll *a* differed somewhat in the reaches above and below Sulphur Springs. Above Sulphur Springs, the implementation of minimum flow resulted in dramatic reductions in chlorophyll *a* concentrations, with greatly reduced variability in the final minimum flow period when the highest minimum flow rates were implemented. Of particular benefit was the near elimination of the very high chlorophyll concentrations (> 50 µg/l) indicative of large phytoplankton blooms that occurred in the river above Sulphur Springs prior to implementation of the minimum flows. Downstream from Sulphur Springs, the changes in chlorophyll *a* concentrations were not as pronounced. Although the data were limited, it appears the variability of chlorophyll *a* in this reach of the river was reduced at the higher minimum flow rates (> 20cfs).

In general, the data indicate that minimum flows have resulted in improvements in water quality in the reach of the river above Sulphur Springs. This may be a result of improved flushing, as prior to the implementation of minimum flows, there was likely very poor flushing and relatively long residence times in this part of the river. The variability of a number of water quality constituents in the river above Sulphur Springs was much less after the implementation of minimum flows, reflecting a change to more stable water quality conditions. The diversion of spring water to the base of the dam alone was shown to have a beneficial effect, but the release of water from the reservoir also resulted in significant improvements to water quality, in part because the reservoir releases contribute to higher minimum flow rates. Also, the reservoir water has lower inorganic nitrogen concentrations than the discharge from Sulphur Springs, which may act to reduce the potential for phytoplankton blooms in the river below the dam.

# 9 Biological Communities - Ichthyoplankton and Zooplankton

## 9.1 Overview

Extensive data for biological communities were collected in the Lower Hillsborough River during the period of minimum flow implementation, primarily as part of the HBMP conducted by TBW to support conditions included in their water use permit for diversion and withdrawal of water from the Hillsborough River Reservoir. The HBMP involved extensive data collection for fishes caught by seines and trawls (nekton), invertebrates and the early life stages of fishes captured by plankton nets, and benthic macroinvertebrates collected from the river bottom. The HBMP began in the spring of 2000, which was approximately two years before the first minimum flows were implemented with biological sampling continuing to either 2010 (benthic macroinvertebrates) or 2012 (plankton and nekton). Consistent data collection methodologies were employed during the course of the HBMP, making this an informative data bases for which to examine biological communities in the lower river during the period of minimum flow implementation.

This minimum flow assessment examined relationships between the minimum flows that have been implemented and the three biological communities sampled by the HBMP. Those results are presented in the following three chapters, with the plankton sampling effort described first below, followed by the fish sampling by seines in Chapter 10 and benthic macroinvertebrates in Chapter 11.

Given the typically high variability of biological data, these results are presented to generally characterize biological communities in the river segments immediately below the dam and not as definitive results to assess significant differences between the minimum flow periods. It is possible that large differences in hydrologic conditions wet and dry years (e.g., 2005 versus 2009) influenced the biological characteristics of the river during the minimum flow periods, confounding these results. Also, for species that have life cycles that extend outside the river, the status of populations in Tampa Bay that can be affected by factors such as red tides or freezes which can contribute to differences in abundance in the river between years.

Despite the many factors that can influence biological populations, the data from the HBMP over the period of minimum flow implementation provided valuable information on how the lower river is utilized by different biological communities during times of minimum flows. Changes in the species composition of these communities were observed as the minimum flows increased, providing general information on the biological effects of different ranges of minimum flows.

## 9.2 Analytical approach relative to minimum flows

Monthly biological sampling was conducted year-round for the HBMP study. However, the focus of this minimum flow evaluation was on dry periods when minimum flows were in effect. During some years (e.g., 2005, 2006), a period of moderately high flows over the dam would occur between periods of minimum flow implementation (see Sections 2.5 and 2.7). In very dry years (e.g., 2002, 2012), more prolonged minimum flows would begin in the fall and extend into the spring or early summer with either zero or very small flows at the dam spillway.

It was the goal of this minimum flow assessment to examine how biological communities in the lower river responded to conditions when minimum flows were the predominant source flow to the river between the dam and Sulphur Springs. It was assumed that periodic pulses of high flow from the dam spillway could mask the effects of the minimum flows, so the analyses of biological data were limited to collections, i.e., samples that were preceded by periods during which average flows over the dam spillway were < 5 cfs for the preceding 50 days. These collections were considered most indicative of ichthyoplankton and zooplankton responses to physical-chemical conditions in the river after fairly long periods of implementation of minimum flows.

As was done for the analyses of water quality, biological data were examined for three periods: (1) the period prior to implementation of minimum flows; (2) the period from March 2002 to December 2007 when minimum flows were limited to diversions from Sulphur Springs; and (3), after February 2012 when minimum flows were comprised of diversions from the spring and releases of fresh water from the Hillsborough River Reservoir. Biological data were examined in different segments of the lower river below the dam, but due to the more limited amount of biological data, some of the segments that were assessed for water quality were combined for biological analyses depending on the distribution of the biological sampling locations.

## 9.3 Plankton sampling for ichthyoplankton and invertebrates

Ichthyoplankton, or the early life stages of fishes that are captured with plankton nets, were monitored monthly in the Lower Hillsborough River between April 2000 and September 2012 as part of the HBMP. As part of this sampling effort, many invertebrates which spend all or part of their life cycle in the water column were also collected. This sampling program, which is referred to as the plankton sampling or plankton catch in the discussion below, was conducted by researchers from the University of South Florida College of Marine Science as part of the HBMP.

Plankton sampling was accomplished by oblique tows (gradually moving from top to bottom) tows of a 500 micron mesh plankton net with a 0.5 meter diameter mouth terminating in a one liter cod end jar. The plankton net was equipped with a calibrated flow meter to measure the volume of water sampled on each tow. The tows were conducted in the middle of the river channel for a duration of five minutes, with towing lengths extending over 400 meters and sampling volumes typically ranging from 70 to 80 cubic meters. Sampling began two hours after sunset because more organisms typically occur in the water column during nighttime hours. More complete details of the methods employed for the plankton sampling effort can be found in the study design and interpretive reports for the HBMP (TBW 2000, 2006, 2009) and a report produced for the District that analyzed results of the HBMP plankton and the seine and trawl sampling program that had been conducted in the Lower Hillsborough River until 2004 (FFWCC and USF 2006).

Plankton were sampled in six zones within the lower river for the HBMP, with two duplicate tows conducted within each zone. Two of these zones were in the area of interest for this minimum flows evaluation. One set of tows was near kilometers 11.3 to 11.7, placing it in the middle of the zone from kilometers 10.6 to 12.6 that lies downstream of Sulphur Springs. The other set of tows was between kilometers 12.8 to 13.2. The presence of shoals, logs, and the generally shallow nature of the river bottom precluded plankton sampling upstream of kilometer 13.4. However, plankton collections in the 12.6 to < 13.4 segment are listed for the segment from 12.6 to < 14.5 to be consistent with the segment that was used for the other biological sampling described in following chapters. This segment occurs in the priority target area for the establishment of oligohaline conditions flows between the dam and Sulphur Springs.

Using the hydrologic criterion of preceding 50-day flows at the dam of < 5 cfs, there were 15 months of plankton data analyzed for the period prior to minimum flows, 16 months of plankton data for the period from March 2002 to December 2007, and 19 months of plankton data for the period January 2008 to September 2012.

## 9.4 Community level analyses

Community level analyses were conducted to examine changes in total abundance, species richness, and community diversity in the plankton catch during the three minimum flow periods. Data for fishes and invertebrates in the plankton catch were combined to for general characterization of the plankton catch in river segments below the dam. Summary statistics for the abundance of total organisms in the plankton catch for the two river segments within the area of interest during the three minimum flow periods are listed in Table 9-1. These values are expressed as catch per unit effort (CPUE) in numbers per cubic meter ($m^3$). Mean CPUE values ranged from 142 to 175 per $m^3$ in the segment from kilometer 10.6 to 12.6, with the highest mean observed in the period from 2002 to 2007. Median values in this segment ranged from 24 to 88 per $m^3$, with the value during the period of no minimum flow (46 per $m^3$) appreciably lower than during the final two periods (84 and 88 per $m^3$).

**Table 9-1. Summary statistics for the combined fish and invertebrate plankton catch data in two river segments for three minimum flow periods. All values expressed at catch per unit effort (CPUE) in numbers per cubic meter.**

| River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Months Sampled | Maximum CPUE | Median CPUE | Minimum CPUE |
|---|---|---|---|---|---|---|---|
| 10.6 to < 12.6 | No MFL | 175 | 345 | 15 | 1309 | 46 | 1 |
| 10.6 to < 12.6 | Mar 02 - Dec 07 | 224 | 316 | 16 | 1206 | 84 | 1 |
| 10.6 to < 12.6 | Jan 08 - Jun 12 | 142 | 185 | 19 | 761 | 88 | 1 |
| 12.6 to < 14.5 | No MFL | 120 | 253 | 15 | 955 | 25 | 1 |
| 12.6 to < 14.5 | Mar 02 - Dec 07 | 93 | 94 | 16 | 357 | 84 | 1 |
| 12.6 to < 14.5 | Jan 08 - Jun 12 | 73 | 60 | 19 | 201 | 49 | 1 |

Mean total abundance values in the more upstream segment (kilometer 12.6 to < 14.5) were lower for each successive minimum flow period, with the means decreasing from the period of no minimum flow (120 per $m^3$) to the period when minimum flows were comprised of spring diversions and releases from the reservoir (73 per $m^3$ ). Median abundances, however, showed a different pattern, with the lowest median value (25 per $m^3$) during the period of no minimum flow and the highest value (84 per $m^3$) during the 2002-2007period when minimum flows were comprised solely of spring diversions.

Mean taxonomic richness values that represent the average number of taxa collected within each sample are listed in Table 9-2. There was no clear temporal or spatial pattern to taxonomic richness, as the mean values for the segment from kilometers 10.6 to < 12.6 ranged from 11.5 go 15.2 for the three minimum flow periods, with the lowest mean value during the middle minimum flow period from 2002 to 2007. Mean richness values were very similar for the segment from kilometer 12.6 to < 14.5, ranging from 11.6 to 12.8, with the highest value during the time of no minimum flow.

**Table 9-2. Mean taxonomic richness values for combined fish and invertebrate plankton catch in two river segments for three minimum flow periods.**

| River Kilometer | Period | Mean Richness |
|---|---|---|
| 10.6 to < 12.6 | No MFL | 14.2 |
| 10.6 to < 12.6 | Mar 02 - Dec 07 | 11.5 |
| 10.6 to < 12.6 | Jan 08 - Jun 12 | 15.2 |
| 12.6 to < 14.5 | No MFL | 12.8 |
| 12.6 to < 14.5 | Mar 02 - Dec 07 | 11.6 |
| 12.6 to < 14.5 | Jan 08 - Jun 12 | 11.1 |

Mean taxonomic diversity values are for these segments and time periods are listed in Table 9-3. Diversity is a community metric that accounts for the number of taxa present and how evenly the abundances of the different taxa are distributed within the total community. The Shannon-Weaver Diversity Index (a.k.a., Shannon Index, Shannon-Wiener Index; see Spellerberg and Fedor 2003), was determined for each monthly sample with means calculated from the monthly values. Mean diversity values were highest during the period of no minimum flows in both evaluated segments.

**Table 9-3. Mean Shannon-Weaver diversity values for for combined fish and invertebrate plankton catch in two river segments for three minimum flow periods.**

| River Kilometer | Period | Mean Diversity |
|---|---|---|
| 10.6 to < 12.6 | No MFL | 1.45 |
| 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.84 |
| 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.86 |
| 12.6 to < 14.5 | No MFL | 1.27 |
| 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.98 |
| 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.56 |

## 9.5 Abundance of major taxa including selected indicators

Mean values for all taxa that were collected that had a mean densities of at least 0.1 individuals $m^3$ in the two river segments are listed in Tables 9-4 and 9-5 for the three minimum flow periods. Unless specified otherwise, all stages (e.g., larvae, juveniles) caught by the plankton net were summed together for the total counts for a particular taxon presented in this report.

Decapod zoea or other larval forms were the most abundant taxon in each river segment for all the minimum flow periods. The jellyfish medusa, *Nemopsis sp.*, was the second most abundant taxon during the first two minimum flow periods in each river segment. The copepod *Acartia tonsa* was also abundant in the segment from kilometer 10.6 to 12.6, having peak densities in the middle minimum flow period (2002 – 2007). This taxon, which is more indicative of mesohaline environments, was much less abundant in the segment from 12.6 to < 14.5. The small mysid shrimp, *Americamysis almyra*, was also generally more abundant in the segment from 10.6 to 12.6, though it had a mean of 6.0 per $m^3$ in the segment from 12.6 to 14.5 during the period of no minimum flows. Like *Acartia tonsa*, *Americamysis* is more typical of mesohaline to polyhaline environments. Gammaridean amphipods were most abundant in the final minimum flow period in both segments.

**Table 9-4. Mean density values (numbers per m$^3$) for fish and invertebrate taxa in the plankon catch for three minimum flow periods in the segment from river kilometer 10.6 to < 12.6. Values limited to those taxa with mean densities of 0.1 per m$^3$ or greater during sampling dates when the average flow at the dam spillsay was less than 5 cfs for the preceding 50 days.**

| Ichthyoplankton - Zooplankton Catch, River Kilometer 10.6 to < 12.6 | | | | | |
|---|---|---|---|---|---|
| April 2000 - February 2002<br>No Minimum Flow (Months = 15) | | March 2002 - December 2007<br>Spring Diversions only (Months = 15) | | Jan. 2008 - June 2012, Spring Diversions<br>and Reservoir Releases (Months = 19) | |
| Description | Mean | Description | Mean | Description | Mean |
| Decapod zoeae | 90.6 | Decapod zoeae larvae | 137.5 | Decapod zoeae | 119.1 |
| Medusa, Nemopsis sp. | 68.6 | Decapod zoeae | 31.0 | Decapod zoeae larvae | 10.1 |
| Mysid, Americamysis almyra | 4.3 | Medusa, Nemopsis sp. | 20.0 | Worms, polychaete | 3.1 |
| Fish, Gobiosoma spp. | 3.5 | Copepod, Acartia tonsa | 16.9 | Copepod, Acartia tonsa | 2.5 |
| Fish, Anchoa mitchilli | 2.1 | Mysid, Americamysis almyra | 6.4 | Mysid, Americamysis almyra | 1.5 |
| Decapod mysis larvae | 1.1 | Decapod megalops larvae | 4.2 | Mysids, Americamysis spp. juveniles | 1.3 |
| Decapod megalops larvae | 1.0 | Fish, Gobiosoma spp. | 2.2 | Amphipods, gammaridean | 1.1 |
| Isopod, sp. a (Lironeca) | 0.9 | Worms, polychaete | 1.9 | Medusa, Clytia spp. | 0.9 |
| Fish, Brevoortia spp., metamorphs | 0.6 | Decapod mysis larvae | 0.9 | Fish, UID gobiids | 0.5 |
| Chaetognaths, Sagitta spp. | 0.6 | Amphipods, gammaridean | 0.5 | Fish, Anchoa mitchilli | 0.3 |
| Shrimp, Palaemonetes pugio | 0.4 | Gastropods, prosobranch | 0.5 | Decapod mysis larvae | 0.3 |
| Copepod, Acartia tonsa | 0.3 | Medusa, Clytia spp. | 0.5 | Fish, Gobiosoma spp. | 0.3 |
| Copepods, Diaptomus spp. | 0.3 | Shrimp, Palaemonetes sp. postlarvae | 0.3 | Isopod, cymothoid (Lironeca) | 0.2 |
| Fish, UID gobiids | 0.2 | Fish, Anchoa mitchilli | 0.3 | Shrimp, Palaemonetes sp. postlarvae | 0.2 |
| Gastropods, prosobranch | 0.2 | Isopod, sp. a (Lironeca) | 0.2 | polychaetes | 0.2 |
| Worms, polychaete | 0.1 | Fish, UID gobiids | 0.1 | Decapod megalops larvae | 0.1 |
| Fish, Microgobius spp. | 0.1 | Fish, Microgobius spp. | 0.1 | Fish, Microgobius spp. | 0.1 |
| Fish, Anchoa spp. | 0.0 | Mysids, unidentified juveniles | 0.1 | Anchoa mitchilli juveniles | 0.1 |
| Isopod, Probopyrus sp. (attached ) | 0.0 | Mysids, Americamysis spp. juveniles | 0.1 | Gastropods, prosobranch | 0.1 |

**Table 9-5. Mean density values (numbers per m$^3$) for fish and invertebrate taxa in the plankon catch for three minimum flow periods in the segment from river kilometer 12.6 to < 14.5. Values limited to those taxa with mean densities of 0.1 per m$^3$ or greater during sampling dates when the average flow at the dam spillsay was less than 5 cfs for the preceding 50 days.**

| Ichthyoplankton - Zooplankton Catch, River Kilometer 12.6 to < 14.5 | | | | | |
|---|---|---|---|---|---|
| April 2000 - February 2002 No Minimum Flow (Months = 15) | | March 2002 - December 2007 Spring Diversions only (Months = 15) | | Jan. 2008 - June 2012, Spring Diversions and Reservoir Releases (Months = 19) | |
| Description | Mean | Description | Mean | Description | Mean |
| Decapod zoeae | 78.9 | Decapod zoeae larvae | 52.4 | Decapod zoeae | 64.2 |
| Medusa, Nemopsis sp. | 20.1 | Decapod zoeae | 14.8 | Decapod zoea larvae | 5.5 |
| Mysid, Americamysis almyra | 6.0 | Medusa, Nemopsis sp. | 9.7 | Amphipods, gammaridean | 1.3 |
| Fish, Gobiosoma spp. | 3.9 | Medusa, Clytia spp. | 6.5 | Medusa, Clytia sp. | 0.6 |
| Decapod megalops larvae | 3.4 | Worms, polychaete | 3.2 | Worms, polychaete | 0.2 |
| Decapod mysis larvae | 2.9 | Decapod mysis larvae | 2.7 | Mysid, Americamysis almyra | 0.2 |
| Fish, Anchoa mitchilli | 1.1 | Decapod megalops larvae | 1.1 | Isopod, cymothoid (Lironeca) | 0.1 |
| Isopod, sp. a (Lironeca) | 0.7 | Copepod, Acartia tonsa | 0.7 | Fish, Anchoa mitchilli | 0.1 |
| Fish, UID gobiids | 0.7 | Mysid, Americamysis almyra | 0.7 | Fish, Gobiosoma spp. | 0.1 |
| Fish, Brevoortia spp., metamorphs | 0.4 | Gastropods, prosobranch | 0.3 | Decapod mysis larvae | 0.1 |
| Worms, polychaete | 0.4 | Fish eggs, A. mitchilli | 0.1 | Copepod, Acartia tonsa | 0.1 |
| Fish, Microgobius spp. | 0.3 | Amphipods, gammaridean | 0.1 | polychaetes | 0.1 |
| Chaetognaths, Sagitta spp. | 0.3 | Fish, Gobiosoma spp. | 0.0 | Pseudodiaptomus coronatus | 0.1 |
| Shrimp, Palaemonetes sp. postlarvae | 0.2 | Fish, UID gobiids | 0.0 | Mysids, Americamysis spp. juv. | 0.0 |
| Shrimp, Palaemonetes pugio | 0.2 | Fish, Menidia spp. | 0.0 | Gastropods, prosobranch | 0.0 |
| Gastropods, prosobranch | 0.1 | Isopod, sp. a (Lironeca) | 0.0 | Decapod megalops larvae | 0.0 |
| Fish, Menidia spp. | 0.1 | Bivalves | 0.0 | Shrimp, Palaemonetes sp. postlarvae | 0.0 |
| Copepod, Acartia tonsa | 0.1 | Mysids, unidentified juveniles | 0.0 | pelecypods | 0.0 |
| Fish, Gambusia holbrooki | 0.1 | Fish, Anchoa mitchilli | 0.0 | Fish, UID gobiids | 0.0 |
| Mysids, unidentified juveniles | 0.1 | Shrimp, Palaemonetes sp. postlarvae | 0.0 | Cassidinidea ovalis | 0.0 |

Species in the fish genus *Gobiosoma spp*. were abundant in the first two minimum flow periods in the segment 10.6 to 12.6, and during the period of no minimum flow in the segment from 12.6 to 14.5. The bay anchovy *Anchoa mitchilli,* which is generally very abundant in tidal rivers*,* was relatively abundant during the period of no minimum flows, but had reduced abundances once minimum flows were implemented. The patterns observed for *Gobiosoma spp.* and *A. mitchilli* are not surprising*.* Studies of ichthyoplankton communities in many other tidal rivers in the region have shown that the spatial distribution of these and many other species are often related to the rate of freshwater inflow, with the most common response being that the population distribution move downstream as inflow increases.

The primary study area for this minimum flows assessment represents the uppermost reaches of the Lower Hillsborough River, with most of the segment above Sulphur Springs having either oligohaline or tidal freshwater conditions depending on the rate of freshwater inflow. A reduction in abundance in this zone as inflow increases is expected for some species. As inflows increase, populations of taxa that are normally found in mesohaline or polyhaline environments migrate downstream in response to increases in minimum flows. During the period of no minimum flows, which included a very severe drought during 2000-2002, unusually high salinity conditions existed in the segments assessed for this study, and communities indicative of higher salinity environments in the river shifted farther upriver than where they normally occur (FFWCC and USF 2006).

To examine changes in the spatial and temporal patterns in the distribution of several key taxa during the minimum flow periods, the District identified several fish and invertebrate taxa that were common in the upper reaches of the lower river (Table 9-6). In some cases, these were predominantly freshwater taxa that had become established below the dam (e.g., oligochaetes, Ephemeropteran larvae), while in other cases, these were estuarine species that were common in the upper reaches of the lower river (e.g., *Palaemonetes pugio*, *Clytia*, *Trinectes maculatus*).

Box and whisker plots of the abundance of these indicator taxa in the two segments below the dam are presented on the following pages. These plots were generated from the monthly catches that were preceded by 50-day average flows of < 5 cfs, which is referred to as the low flow sampling in the discussion below. Summary statistics for abundance of the indicator taxa during the low flow sampling are presented in Appendix 6A, with time series plots of these data presented in Appendix 6B. The results of Wilcoxon rank sum test for significant differences in the abundance of the indicator taxa between time periods within each segment are listed in Appendix 6C, again based on the low flow sampling. Box and whisker and time series plots for the abundance of the indicator taxa using all monthly catches during the course of the study, including wet season sampling, are included as Appendices 9D and 9E.

**Table 9-6. Invertebrate and fish indicator taxa collected by plankton net selected for analysis.**

| Taxon / life stage | Group / common name | Salinity range |
|---|---|---|
| Oligochaetes | Segmented worms | Freshwater |
| Ephemeroptera larvae | Mayflies | Freshwater |
| *Palaemonetes pugio* juveniles | Grass Shrimp | Freshwater to Marine |
| *Nemopsis* spp. | Hydromedusae | Brackish to Marine |
| *Clytia* spp. | Hydromedusae | Brackish to Marine |
| *Americamysis almyra* | Mysid shrimp | Brackish to Marine |
| *Trinectes maculatus* juveniles | Hogchoker | Freshwater to Brackish |
| *Gambusia holbrooki* juveniles | Mosquitofish | Freshwater to Brackish |
| *Brevoortia smithi* juveniles | Menhaden | Brackish to Marine |

The time series and box and whisker plots show that some of the indicator taxa were often collected in very low abundances during the low flow sampling, with occasional high values that influenced the mean values listed in Table 9-4,Table 9-5 and Appendix 6A. Many of these same taxa had greater abundances when data that had sampling dates with 50-day flows over 5 cfs were included. An emphasis of this assessment was to evaluate the abundance of the indicators during prolonged periods of minimum flow implementation. However, results that are based on all sampling conducted during the period of study are also discussed below.

### 9.5.1 Oligochaetes

Aquatic oligochaetes are segmented worms which are primarily limited to freshwater environments. Although they live primarily in the sediments, some species can migrate into the water column. Oligochaetes were a minor component of the plankton catch below the dam, but were examined to evaluate how a freshwater organism responded to different flow conditions.

Based on the low flow sampling, oligochaetes were absent from the segment from kilometer 10.6 to 12.6 during the period of no minimum flow, with only two occurrences in the final minimum flow period (Figure 9-1). When all sampling months are considered, oligochaetes were again virtually absent from the 10.6 to 12.6 segment during the period of no minimum flow, but were periodically captured during the final two minimum flow periods (Appendices 9D and 9E). In the segment from kilometer 12.6 to 14.5, oligochaetes were similarly limited to only a few occurrences during the final two minimum flow periods based on the low flow sampling. When all sampling months are considered, oligochaetes were more frequently captured, particularly in the middle minimum flow period that extended from March 2002 to December 2007, when wet years from 2003 to 2005 likely influenced their distribution.

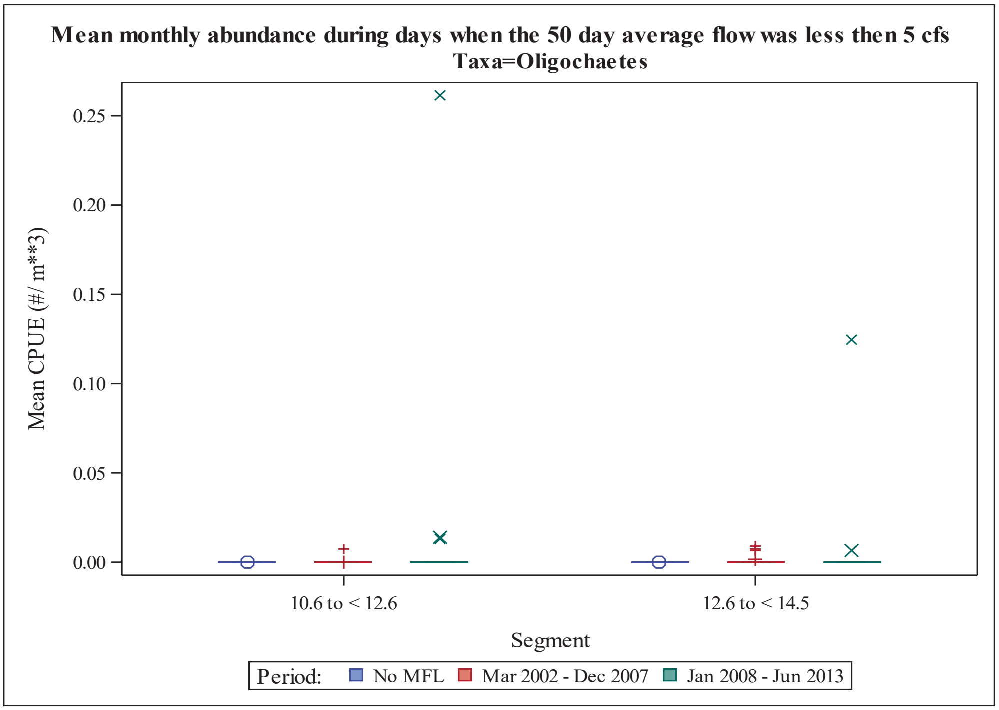


**Figure 9-1. Box and whisker plots of abundance values for oligochates in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 9.5.2 Ephemeroptera larvae

Ephemeropterans, or mayflies, are a group of freshwater aquatic insects that are members of the order Ephemeroptera. Ephemeropterans have immature larval stages that live in fresh water which eventually emerge to flying adults. Ephemeroptera larvae are also not abundant in the plankton catch in Lower Hillsborough River, but were examined to evaluate how a freshwater organism responded to different flow conditions. Ephemeroptera larvae were nearly absent from the segment from kilometer 10.6 to 12.6 during the period of no minimum flow for all sampling dates. Based on low flow conditions, they had two occurrences this segment in the final minimum flow period (Figure 9-2) and had periodic occurrences in this zone in the final two minimum flow periods when all sampling months were considered (Appendices 9D and 9E).

Ephemeropterans were generally not collected in the segment from kilometer 12.6 to 14.6 during the low flow sampling, with only two occurrences during the middle minimum flow period (Figure 9-2). However, they did have periodic occurrences during the final two minimum flow periods when sampling from all months was considered, but continued to be absent from this segment during the period of no minimum flows. It is reiterated that the period of no minimum flow assessed for this study (spring 2000 through February 2002) was unusually dry with high salinity conditions in the lower river, and the observed low abundances of ephemeropterans were, therefore, not unexpected.

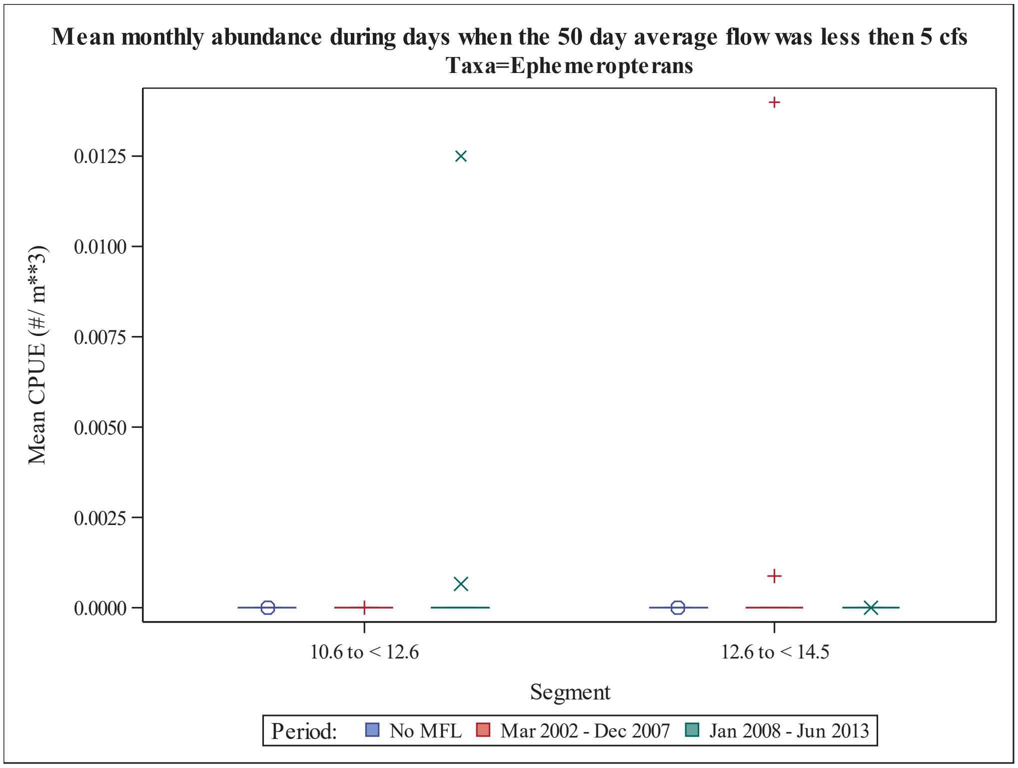


**Figure 9-2. Box and whisker plots of abundance values for mayfly (Ephemeroptera) larvae in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 9.5.3 *Palaemonetes pugio* juveniles

*Palaemonetes pugio* (*P. pugio*) is a small grass shrimp that are common in marine waters and also in mesohaline zones and polyhaline zones in the tidal rivers in west central Florida. Juvenile stages of *P. pugio* were captured by the plankton sampling in the Lower Hillsborough. The taxon primarily occurred in both river segments during the period of no minimum flow. During periods of minimum flow implementation, *P. pugio* was nearly absent from the two river segments. Results of the Wilcoxon rank sum test found that *P. pugio* was significantly more abundant in the two river segments prior to the implementation of minimum flows (Appendix 6C). *P. pugio* is an example of an estuarine species that migrated to the reaches of the river near the dam during the period of no minimum flows. Though not assessed in this report, other analyses of the Lower Hillsborough River have found that populations of *this shrimp* move downstream in the river in response to increases in freshwater flow (USF/FWRI 2006).

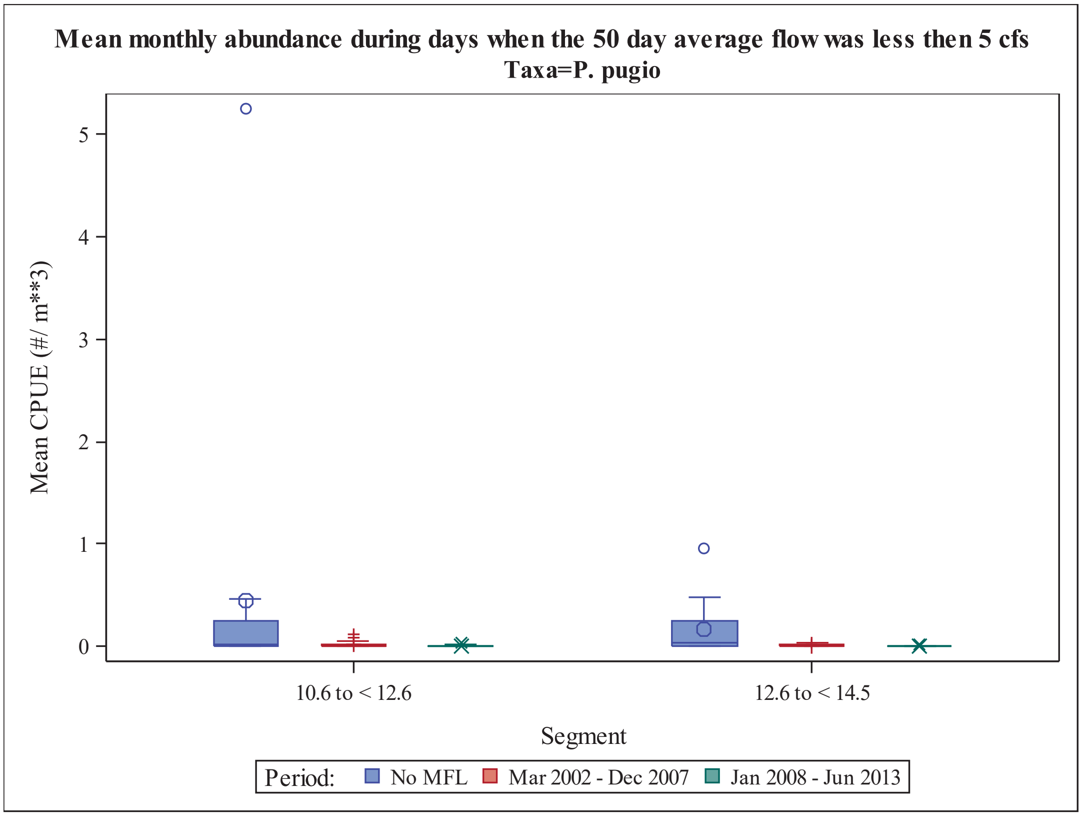


**Figure 9-3. Box and whisker plots of abundance values for *Palaemonetes pugio* juveniles in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 9.5.4 *Nemopsis* spp.

*Nemopsis spp*. are small hydroid medusa (jelly fish) which are typically marine. Because they can prey on zooplankton and the very early life states of fish, high *Nemopsis* abundance or occurrence in tidal river estuaries may not be a desirable condition. *Nemopsis* were significantly more abundant in the two river segments during the period of no minimum flow (Figure 9-4 and Appendix 6C). There were some occurrences of *Nemopsis* in the middle minimum flow period, but they were restricted to the first part of this period (2002) when the minimum flows were limited to a brief diversion of spring water and high salinity conditions persisted in the estuary (see time series plot of abundance in Appendix 6B). *Nemopsis* did not occur in the study area above kilometer 10.6 after 2002 when minimum flows were implemented (Appendix 6E).

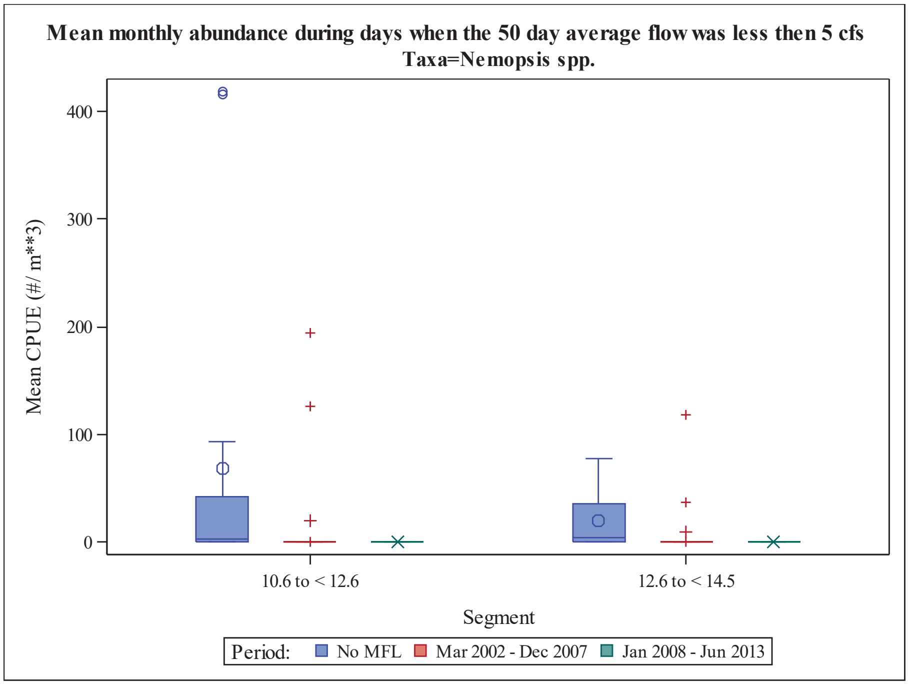


**Figure 9-4. Box and whisker plots of abundance values for *Nemopsis* spp. in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 9.5.5 *Clytia* spp.

*Clytia* spp. are also small hydroid medusa primarily of marine origin that occurred in the lower river plankton catch during the study period. However, unlike *Nemopsis*, *Clytia* was absent during the period of no minimum flow and appeared in the both segments of the lower river during the final two minimum flow periods when it was significantly more abundant (Figure 9-5 and Appendix 6C). The occurrences of *Clytia* were generally at much lower counts that the periodic occurrences of *Nemopsis*. The time series plots *Clytia* was most abundant in the segment from 10.6 to 12.6, which peak abundances between 2007 and 2009. Although minimum flows were implemented during this time, there were very dry years in 2007 and 2009 which may have contributed to periodic occurrences of *Clytia. Clytia* was absent from the two river segments during the last two years of the study, including the period after February 2012 when the highest minimum flows rates occurred (Appendix 6E).

### *9.5.6 Americamysis almyra*

*Americamysis almyra* (*A. almyra*) is a small shrimp that is an important food source for the juveniles of many estuarine fishes. It is often widely distributed in tidal rivers, but most frequently occurs in the mesohaline zones. In keeping with this distributional pattern, *A. almyra* was most abundant in the segment from kilometer 10.6 to 12.6, with its highest mean abundance in the middle minimum flow period (Figure 9-6). *A. almyra* had one high occurrence between kilometer 12.6 and 14.5 in the very dry period at the beginning of the study (spring 2000), but was at low numbers in that segment for the remaining periods. *A. almyra* is a species that is not expected to reach high abundances in the river above Sulphur Springs with the implementation of minimum flows.

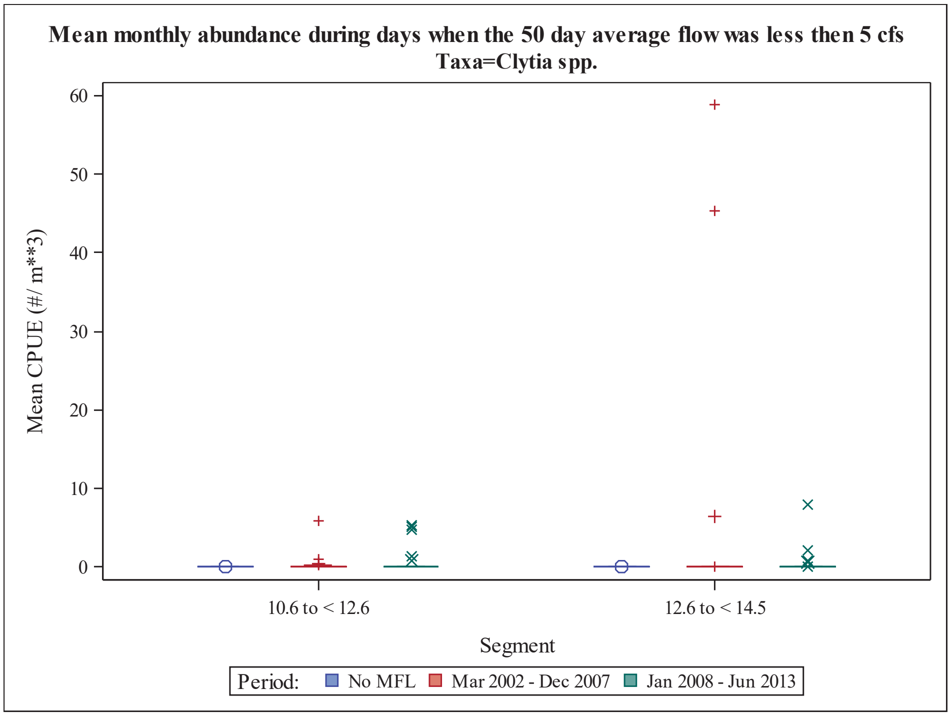


**Figure 9-5. Box and whisker plots of abundance values for *Clytia* spp. in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

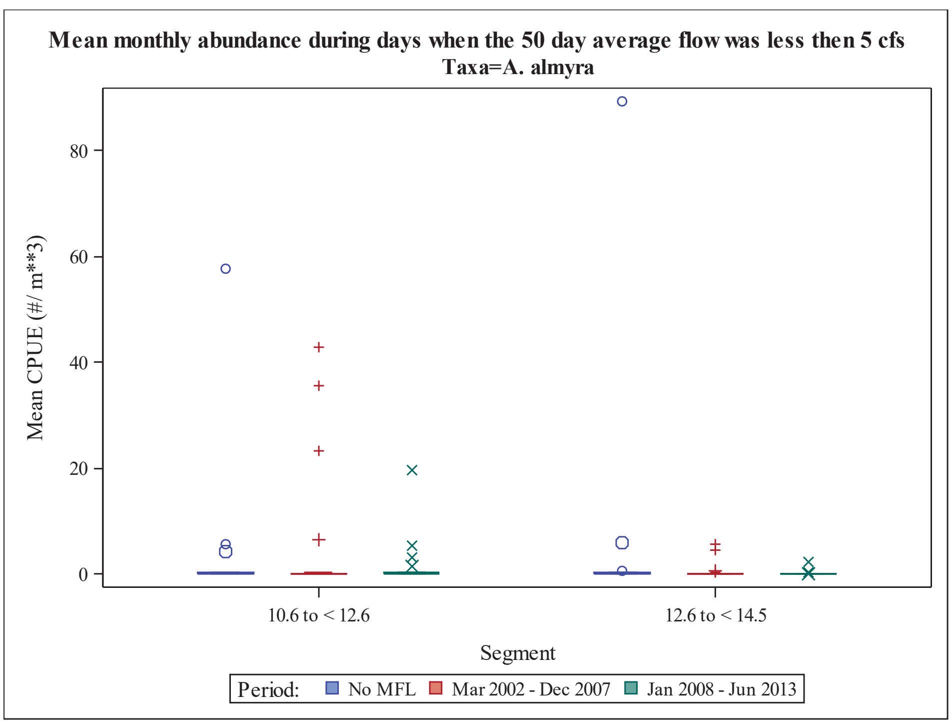


**Figure 9-6. Box and whisker plots of abundance values for *Americamysis almyra* in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 9.5.7 *Trinectes maculatus*

*Trinectes maculatus* (*T. maculatus*), commonly called hogchoker, is a small flatfish that is frequently caught in the upper reaches of tidal rivers, with distributions often centered in oligohaline or low mesohaline zones. The larvae and smaller juveniles of *T. maculatus* were captured in the plankton catch for this study, while the larger juveniles and adults were caught as part of the seine and trawl sampling. Juvenile *T. maculatus* were infrequently caught in the two segments of the Lower Hillsborough, with two occurrences between kilometer 10.6 1o 12.6 in the final minimum flow period for the low flow sampling (Figure 9-7), and four occurrences in the final minimum flow period based on all sampling dates (Appendix 6E). *T. maculatus* similarly had two occurrences between kilometer 12.6 to 14.5 in the final minimum flow period for the low flow sampling, and three in the final minimum flow period based on all sampling dates. Although juveniles of *T. maculatus* were rarely caught in the upper reaches of the river, these limited data indicate that implementation of minimum flows did not cause a shift of this species away from the segment above Sulphur Springs.

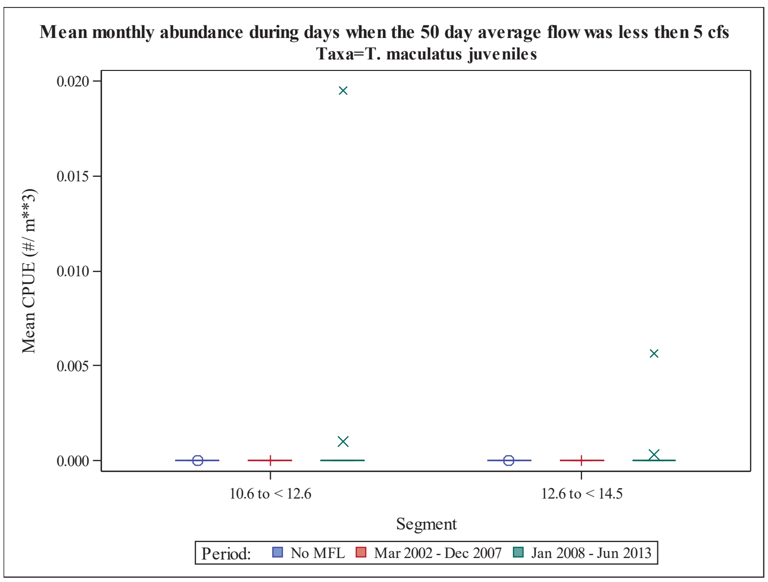


**Figure 9-7. Box and whisker plots of abundance values for hogchocker (*Trinectes maculatus)* juveniles in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 9.5.8 *Gambusia holbrooki* juveniles

*Gambusia holbrooki* (*G. holbrooki*), commonly known as eastern mosquitofish, is a small live bearing fish that is common in freshwater systems but also can have populations in tidal rivers, usually in oligohaline zones. For both low flow conditions and all sampling days, juveniles of *G. holbrooki* were most abundant in the segment from kilometer 12.6 to 14.5 (Figure 9-8). The highest density was recorded during the period of no minimum flows, but *G. holbrooki* also had occurrences during the final minimum flow period.

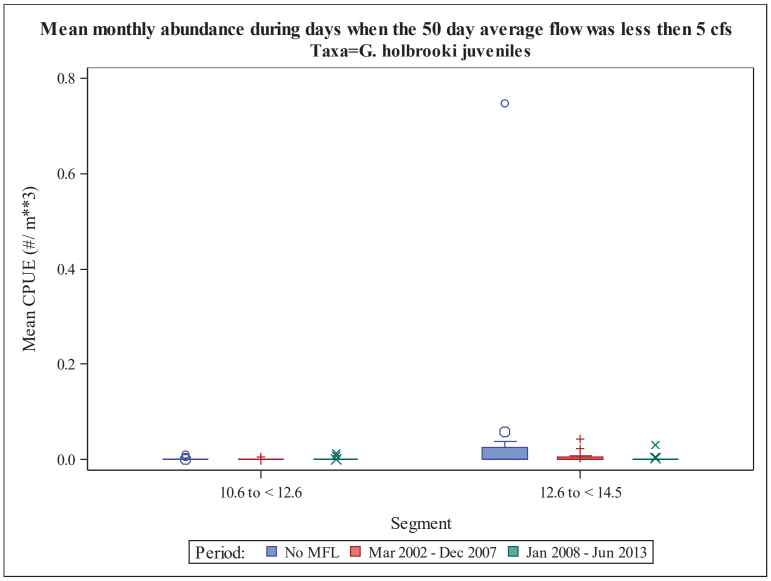


**Figure 9-8. Box and whisker plots of abundance values for eastern mosquitofish (*Gambusia holbrooki)* juveniles in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

## 9.5.9 *Brevoortia smithi* juveniles

*Brevoortia smithi* (*B smithi*), commonly known as yellowfin menhaden, is a small forage fish that is common in bays and estuaries on the Gulf Coast. Juveniles of *B. smithi* were most abundant in the segment from 10.6 to 12.6 during the period of no minimum flows (Figure 9-9 ). When data from all sampling days were considered including wet season months, *B. smithi* was less abundant in that segment. *B. smithi* is an indicator for species that occur downstream of the priority area for minimum flow establishment.

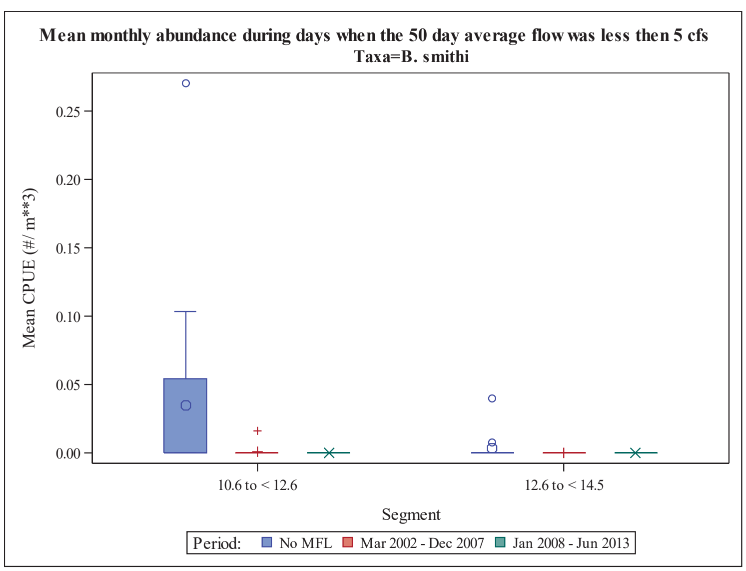


**Figure 9-9. Box and whisker plots of abundance values for yellowfin menhaden (*Brevoortia smithi)* in two river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

## 9.6 Discussion

The implementation of minimum flows appears to have resulted in changes in the species composition of the plankton catch of the river above kilometer 10.6, reflecting a change from more mesohaline to oligohaline conditions, particularly in the reach above Sulphur Springs. The emphasis of the analysis was on samples collected during periods when minimum flows were the predominant source of inflow to the river for the preceding 50 days, but data were also graphically examined for all sampling days.

Based on comparisons of mean and median values, there were no consistent temporal patterns in the total number of individuals (all taxa combined) or taxonomic richness between the two river segments that were sampled over the three minimum flow periods. There was, however, a reduction in species diversity as minimum flows increased, which is not unusual for a shift from mesohaline to oligohaline conditions. The initial sampling for the project began during very dry years in 2000, 2001, and the early part of 2002 before minimum flows were implemented. During these years, many taxa had migrated far upstream in response to the low freshwater inflow and high salinity in the lower river. Some species that are indicative of mesohaline or polyhaline environments reached peak numbers in the reach above Sulphur Springs during this period, including plankton catches of grass shrimp (*P. pugio*), yellowfin menhaden (*B. smithi*), and gobies (*Gobiosoma* spp.). The occurrence and abundance and of these species were less after minimum flows were implemented, presumably due to their migration to locations further downstream as inflows increased and salinity in the study area was reduced. Some fish taxa that are more indicative of oligohaline waters, such eastern mosquitofish (*G. holbrooki*) and hogchoker (*T. maculatus*), did not show apparent changes in their abundance as minimum flows were implemented.

Of particular importance was a change in the abundance of the jellyfish*, Nemopsis*, sp., which reached peak abundance prior to minimum flows and was significantly reduced as minimum flows were implemented, particularly during the final minimum flow period. Reduction of this jellyfish, which can prey on larval fish, is viewed as a potentially beneficial effect of the minimum flows. Another jellyfish, *Clytia* spp., reached peak abundances between 2007 and 2009 when minimum flows were in effect, but was absent from the study area in the later sampling years when the higher minimum flow rates occurred.

Two groups of freshwater invertebrates, ephemeropterans (mayflies) and oligochaetes (segmented worms) were almost absent prior to the implementation of minimum flows, but appeared after minimum flows were in effect. These results were most apparent when all sampling days were examined, which included periods of freshwater flow over the dam spillway. The occurrence of these taxa was much more limited when minimum flows were the predominant source of freshwater inflow for the previous fifty days, when salinity below the dam was characterized by more stable oligohaline conditions.

# 10 Biological Communities - Nekton Sampled by Seines

Nekton refers to free swimming aquatic organisms that can move independently of water currents, and are typically comprised of fishes and larger aquatic invertebrates (e.g., pink shrimp, blue crabs). Nekton was sampled monthly as part of HBMP conducted by TBW between May 2000 and September 2012. The HBMP nekton sampling program was conducted using a probabilistic design, which randomized the location of individual samples on a monthly basis within defined river strata (i.e., segments). The strata defined for the HBMP were not the same as the river segments defined in this minimum flows assessment, so the number of samples per month in each minimum flow segment changed depending on where the randomized samples occurred in the HBMP program.

The HBMP sampling included the use of trawls, which sampled the center of the river channel, and seines which sample the shoreline of the river. The absolute catch values were converted to catch per unit effort (CPUE) which is the number of individuals per 100 $m^2$. However, the use of trawls in the upper portion of the study area was not feasible due the uneven rocky substrate and snags. Therefore, trawl catch data were excluded from all minimum flow analyses, and the results reported in the following discussion are only for samples collected by shoreline seines.

Nekton data were analyzed for the same three minimum flow periods assessed for the plankton, which are: (1) the period prior to March 2002 when there were no minimum flows; (2) from March 2002 to December 2007 when minimum flows were comprised solely of diversions from Sulphur Springs; and (3) from January 2008 to September 2012 when minimum flows were comprised of diversions from Sulphur Springs and releases from the reservoir. Data for these three periods were analyzed within three river segments that extended from kilometers 10.6 to < 12.6, 12.6 to < 14.5, and upstream of kilometer 14.5. In order to better document nekton communities that were present after prolonged periods of minimum flow, the principal nekton analyses conducted for this assessment were for samples collected when the average 50-day flows over the dam spillway were < 5 cfs (low flow conditions). However, graphics are also provided in Appendices 10D and 10E that include catch data for all sampling dates during the study period and are discussed in the following chapter.

More complete details of the methods employed for the nekton sampling effort can be found in the study design and interpretive reports for the HBMP (TBW 2000, 2006, 2009) and a report produced for the District that analyzed results of the HBMP plankton and the seine and trawl sampling program that had been conducted in the Lower Hillsborough River until 2004 (FFWCC and USF 2006).

## 10.1 Community level analyses

Community level parameters were assessed for the nekton included total abundance, taxonomic richness, and diversity. These were calculated by aggregating all of the fish and invertebrate catch data during low flow conditions. The number of monthly seine samples collected within each river segment during low flow conditions in three major minimum flow periods are listed in Table 10-1, along with summary statistics for total nekton abundance.

Mean and median total abundance declined over time in all three river segments. These decreases in total abundance are the result of sharp declines in abundance of some baitfish taxa, including *Menidia* spp., *Brevoortia* spp., and *Anchoa* spp. These highly abundant taxa are typical of estuarine and marine systems, and typically are not as abundant in oligohaline or tidal freshwater zones. Mean values for these and other taxa collected within the river segments are discussed in the next section of this chapter.

**Table 10-1. Summary statistics for abundance of all nekton combined. All values expressed at catch per unit effort (CPUE) in numbers per square meter.**

| River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Months | Maximum CPUE | Median CPUE | Minimum CPUE |
|---|---|---|---|---|---|---|---|
| 10.6 to < 12.6 | No minimum flow | 325 | 246 | 16 | 646 | 250 | 31 |
| 10.6 to < 12.6 | Mar 02 - Dec 07 | 284 | 271 | 16 | 936 | 159 | 10 |
| 10.6 to < 12.6 | Jan 08 - Jun 12 | 76 | 99 | 20 | 358 | 31 | 7 |
| 12.6 to < 14.5 | No minimum flow | 850 | 1270 | 12 | 5268 | 464 | 30 |
| 12.6 to < 14.5 | Mar 02 - Dec 07 | 535 | 436 | 14 | 1623 | 441 | 17 |
| 12.6 to < 14.5 | Jan 08 - Jun 12 | 177 | 196 | 17 | 713 | 113 | 12 |
| > 14.5 | No minimum flow | 2934 | 8297 | 10 | 29165 | 351 | 0 |
| > 14.5 | Mar 02 - Dec 07 | 473 | 916 | 11 | 3630 | 268 | 29 |
| > 14.5 | Jan 08 - Jun 12 | 176 | 269 | 15 | 885 | 61 | 1 |

Taxonomic richness is the number of different taxa present in an individual sample. Mean richness values calculated from the monthly richness values did not exhibit a consistent pattern across the river segments and time periods (Table 10-2). Richness decreased slightly over time in the segment from kilometer 10.6 to <12.6. In the two upstream segments, richness increased from the period of no minimum flows to middle minimum flow period, before decreasing in the most recent period.

**Table 10-2. Mean richness values for the nekton sample data.**

| River Kilometer | Period | Mean Richness |
|---|---|---|
| 10.6 to < 12.6 | No MFL | 9.09 |
| 10.6 to < 12.6 | Mar 02 - Dec 07 | 8.41 |
| 10.6 to < 12.6 | Jan 08 - Jun 12 | 7.38 |
| 12.6 to < 14.5 | No MFL | 6.96 |
| 12.6 to < 14.5 | Mar 02 - Dec 07 | 8.15 |
| 12.6 to < 14.5 | Jan 08 - Jun 12 | 5.44 |
| > 14.5 | No MFL | 6.50 |
| > 14.5 | Mar 02 - Dec 07 | 8.95 |
| > 14.5 | Jan 08 - Jun 12 | 5.23 |

Diversity (in this case Shannon-Weaver Diversity) is a community metric which combines both richness and evenness (how evenly distributed the population is across the different taxa). Mean diversity values calculated from monthly diversity values did not any consistent pattern or large changes in any of the time periods or river segments, with all mean values in value from 1.10 to 1.60 (Table 10-3).

**Table 10-3. Mean diversity values for the nekton sample data.**

| River Kilometer | Period | Mean Diversity |
|---|---|---|
| 10.6 to < 12.6 | No MFL | 1.23 |
| 10.6 to < 12.6 | Mar 02 - Dec 07 | 1.14 |
| 10.6 to < 12.6 | Jan 08 - Jun 12 | 1.60 |
| 12.6 to < 14.5 | No MFL | 1.27 |
| 12.6 to < 14.5 | Mar 02 - Dec 07 | 1.31 |
| 12.6 to < 14.5 | Jan 08 - Jun 12 | 1.10 |
| > 14.5 | No MFL | 1.58 |
| > 14.5 | Mar 02 - Dec 07 | 1.76 |
| > 14.5 | Jan 08 - Jun 12 | 1.47 |

## 10.2 Abundance of major taxa including selected indicators

Mean values of all taxa that were collected which had mean CPUE values of at least 0.1 individuals per 100 $m^2$ are listed in Table 10-4, 10-5 and 10-6 for low flow conditions during the three minimum flow periods. The results are dominated by finfishes, as only a few species on nektonic invertebrates (e.g., blue crabs, grass shrimp, pink shrimp) were collected by seine in the Lower Hillsborough River and were generally in low numbers. *Menidia* spp. and *Anchoa mitchilli (A. mitchilli)* were the most abundant fish taxa in the segment from kilometer 10.6 to <12.6, with their mean abundance values progressively decreasing through time for the three minimum flow periods (Table 10-4).

In the segment from kilometer 12.6 to <14.5, *Menidia* spp. were in very high abundance during the no minimum flow (mean = 1,630), with much smaller mean values during the other two minimum flow periods, particularly during the final minimum flow period which had a mean value of 3.4 cfs (Table 10-5). *Brevoortia* spp. similarly had very high abundances in this segment during the period of no minimum flow, with dramatically lower numbers in the following minimum flow periods. Two other species (*A mitchilli* and *Lucania parva*) did not show large reductions in numbers as the minimum flows were implemented, with *Anchoa* increasing through time.

Three taxa, *G. holbrooki*, *L. parva* and *Menidia* spp. consistently had the highest mean values in the segment upstream of kilometer 14.5 for the three minimum flow periods, but their numbers were reduced during the final period beginning in 2008 (Table 10-6). Three freshwater species (*Lepomis macrochirus, Micropterus salmoides*, and *Lepomis microlophus*) appeared in the catch data during the two periods of minimum flow implementation, with their ranking among the taxa based on mean catch values being highest during the final minimum flow period. Overall, changes in mean values in Table

10-4 though Table 10-6 indicate the fish community below the dam experienced shifts in species composition and abundance in response to the implementation of minimum flows.

**Table 10-4. Mean abundance values (individuals per 100 $m^2$) for fish taxa in seine catches for three minimum flow periods in the segment from river kilometer 10.6 to < 12.6. Values limited to those data with mean abundances of 0.1 per 100 $m^2$ or greater during sampling dates when the average flow at the dam spillsay was < 5 cfs for the preceding 50 days.**

| Seine Catch, River Kilometer 10.6 to < 12.6 | | | | | | |
|---|---|---|---|---|---|---|
| April 2000 - February 2002 No Miniimum Flow (Months = 16) | | | March 2002 - December 2007 Spring Diversions only (Months = 16) | | Jan. 2008 - June 2012, Spring Diverisons and Resevoir Releases (Months= 20) | |
| **Scientific Name** | **Common Name** | **Mean** | **Scientific Name** | **Mean** | **Scientific Name** | **Mean** |
| Menidia spp. | | 420.8 | Menidia spp. | 367.6 | Anchoa mitchilli | 45.7 |
| Anchoa mitchilli | Bay anchovy | 262.3 | Anchoa mitchilli | 76.6 | Menidia spp. | 44.8 |
| Brevoortia spp. | | 37.8 | Lucania parva | 13.5 | Lucania parva | 23.6 |
| Lucania parva | Rainwater killifish | 36.0 | Cyprinodon variegatus | 13.1 | Gambusia holbrooki | 15.4 |
| Gambusia holbrooki | Eastern mosquito fish | 28.8 | Brevoortia spp. | 12.5 | Brevoortia spp. | 10.7 |
| Leiostomus xanthurus | Spot | 13.9 | Gambusia holbrooki | 10.6 | Eucinostomus spp. | 10.0 |
| Cyprinodon variegatus | Sheepshead minnow | 10.6 | Mugil cephalus | 10.1 | Mugil cephalus | 4.6 |
| Poecilia latipinna | Sailfin molly | 9.1 | Poecilia latipinna | 9.2 | Eucinostomus harengulus | 4.6 |
| Trinectes maculatus | Hogchoker | 7.0 | Microgobius gulosus | 5.5 | Cyprinodon variegatus | 4.0 |
| Fundulus grandis | Gulf killifish | 6.1 | Fundulus grandis | 3.0 | Poecilia latipinna | 2.8 |
| Microgobius gulosus | Clown goby | 3.6 | Trinectes maculatus | 3.0 | Trinectes maculatus | 2.2 |
| Mugil cephalus | Striped mullet | 2.7 | Gobiosoma bosc | 2.1 | Eugerres plumieri | 1.0 |
| Gobiosoma bosc | Naked goby | 2.6 | Tilapia spp. | 1.8 | Gobiosoma spp. | 0.9 |
| Eucinostomus spp. | | 1.6 | Leiostomus xanthurus | 1.4 | Lepomis macrochirus | 0.8 |
| Eugerres plumieri | Striped mojarra | 1.5 | Eucinostomus spp. | 1.3 | Tilapia spp. | 0.7 |
| Tilapia spp. | | 1.1 | Eucinostomus harengulus | 1.2 | Gobiosoma bosc | 0.6 |
| Elops saurus | Ladyfish | 0.9 | Elops saurus | 1.0 | Lepomis microlophus | 0.5 |
| Cynoscion arenarius | Sand seatrout | 0.7 | Anchoa hepsetus | 0.9 | Fundulus grandis | 0.5 |
| Eucinostomus harengulus | Tidewater mojarra | 0.6 | Lucania goodei | 0.4 | Fundulus seminolis | 0.5 |
| Gobiosoma spp. | | 0.5 | Floridichthys carpio | 0.2 | Oreochromis aureus | 0.4 |
| Archosargus probatocephalus | Sheepshead | 0.3 | Lepomis macrochirus | 0.1 | Elops saurus | 0.4 |
| Lagodon rhomboides | Pinfish | 0.2 | Syngnathus scovelli | 0.1 | Sarotherodon melanotheron | 0.4 |
| Oligoplites saurus | Leatherjacket | 0.2 | Micropterus salmoides | 0.1 | Leiostomus xanthurus | 0.4 |
| Sciaenops ocellatus | Red drum | 0.2 | Oligoplites saurus | 0.1 | Fundulus confluentus | 0.2 |
| Strongylura timucu | Timucu | 0.1 | Archosargus probatocephalus | 0.1 | Lagodon rhomboides | 0.2 |
| Centropomus undecimalis | Snook | 0.1 | Strongylura timucu | 0.0 | Microgobius gulosus | 0.2 |
| Syngnathus scovelli | Gulf pipefish | 0.1 | Fundulus seminolis | 0.0 | Centropomus undecimalis | 0.1 |
| Cynoscion nebulosus | Spotted seatrout | 0.1 | Centropomus undecimalis | 0.0 | Lucania goodei | 0.1 |
| Heterandria formosa | Least killifish | 0.0 | Eugerres plumieri | 0.0 | Gobiesox strumosus | 0.1 |
| Eucinostomus gula | Silver jenny | 0.0 | Lagodon rhomboides | 0.0 | Heterandria formosa | 0.1 |
| Achirus lineatus | Lined sole | 0.0 | Cynoscion nebulosus | 0.0 | Syngnathus scovelli | 0.1 |
| Lepisosteus platyrhincus | Florida gar | 0.0 | Cynoscion arenarius | 0.0 | Sciaenops ocellatus | 0.1 |
| Anchoa hepsetus | Striped anchovy | 0.0 | Sciaenops ocellatus | 0.0 | Strongylura marina | 0.1 |
| Fundulus similis | Longnose killifish | 0.0 | Gobiosoma spp. | 0.0 | Strongylura timucu | 0.1 |
| Palaemonetes spp. | Grass shrimp | 0.0 | Palaemonetes spp. | 0.0 | Micropterus salmoides | 0.1 |
| Palaemonetes paludosus | | 0.0 | Palaemonetes paludosus | 0.0 | Oreochromis/Sarotherodon spp. | 0.1 |

**Table 10-5. Mean abundance values (individuals per 100 m$^2$) for fish taxa in seine catches for three minimum flow periods in the segment from river kilometer 12.6 to < 14.5. Values limited to those data with mean abundances of 0.1 per 100 m$^2$ or greater during sampling dates when the average flow at the dam spillsay was < 5 cfs for the preceding 50 days.**

| Seine Catch, River Kilometers 12.6 to < 14.5 | | | | | | |
|---|---|---|---|---|---|---|
| April 2000 - February 2002 No Minimum Flow (Months= 12) | | | March 2002 - December 2007 Spring Diversions only (Months=14) | | Jan. 2008 - June 2012, Spring Diversions and Resevoir Releases (Months=17) | |
| Scientific Name | Common Name | Mean | Scientific Name | Mean | Scientific Name | Mean |
| Menidia spp. | | 1630.3 | Menidia spp. | 362.7 | Anchoa mitchilli | 101.7 |
| Brevoortia spp. | | 1072.7 | Gambusia holbrooki | 38.2 | Gambusia holbrooki | 41.4 |
| Gambusia holbrooki | Eastern mosquito fish | 116.8 | Anchoa mitchilli | 26.0 | Lucania parva | 17.0 |
| Poecilia latipinna | Sailfin molly | 78.1 | Tilapia spp. | 10.1 | Menidia spp. | 3.4 |
| Lucania parva | Rainwater killifish | 12.8 | Cyprinodon variegatus | 7.9 | Eucinostomus spp. | 2.2 |
| Tilapia spp. | | 7.0 | Lucania parva | 7.7 | Brevoortia spp. | 1.9 |
| Leiostomus xanthurus | Spot | 4.8 | Microgobius gulosus | 5.1 | Eugerres plumieri | 1.3 |
| Trinectes maculatus | Hogchoker | 3.0 | Trinectes maculatus | 4.3 | Cyprinodon variegatus | 1.0 |
| Anchoa mitchilli | Bay anchovy | 2.0 | Gobiosoma bosc | 2.7 | Microgobius gulosus | 1.0 |
| Microgobius gulosus | Clown goby | 1.7 | Poecilia latipinna | 1.4 | Lepomis macrochirus | 0.9 |
| Fundulus grandis | Gulf killifish | 1.0 | Elops saurus | 1.3 | Eucinostomus harengulus | 0.9 |
| Elops saurus | Ladyfish | 0.6 | Eucinostomus spp. | 0.9 | Trinectes maculatus | 0.8 |
| Gobiosoma bosc | Naked goby | 0.5 | Fundulus seminolis | 0.8 | Micropterus salmoides | 0.4 |
| Eugerres plumieri | Striped mojarra | 0.4 | Leiostomus xanthurus | 0.8 | Tilapia spp. | 0.3 |
| Fundulus confluentus | Marsh killifish | 0.3 | Eucinostomus harengulus | 0.7 | Poecilia latipinna | 0.3 |
| Cyprinodon variegatus | Sheepshead minnow | 0.3 | Gobiosoma spp. | 0.4 | Oreochromis aureus | 0.3 |
| Mugil cephalus | Striped mullet | 0.3 | Micropterus salmoides | 0.4 | Fundulus seminolis | 0.2 |
| Eucinostomus harengulus | Tidewater mojarra | 0.2 | Fundulus grandis | 0.3 | Gobiosoma bosc | 0.2 |
| Lepisosteus platyrhincus | Florida gar | 0.2 | Labidesthes sicculus | 0.3 | Sarotherodon melanotheron | 0.1 |
| Cynoscion arenarius | Sand seatrout | 0.2 | Lepomis macrochirus | 0.3 | Gobiosoma spp. | 0.1 |
| Eucinostomus spp. | | 0.1 | Fundulus confluentus | 0.2 | Heterandria formosa | 0.1 |
| Gobiosoma spp. | | 0.1 | Notropis petersoni | 0.1 | Mugil cephalus | 0.1 |
| Fundulus seminolis | Seminole killifish | 0.1 | Eugerres plumieri | 0.1 | Lucania goodei | 0.1 |
| Archosargus probatocephalus | Sheepshead | 0.1 | Amia calva | 0.0 | Strongylura timucu | 0.1 |
| Sciaenops ocellatus | Red drum | 0.1 | Syngnathus scovelli | 0.0 | Lepomis auritus | 0.1 |

**Table 10-6. Mean abundance values (individuals per 100 m$^2$) for fish taxa in seine catches for three minimum flow periods in the segment from river kilometer 12.6 to < 14.5. Values limited to those data with mean abundances of 0.1 per 100 m$^2$ or greater during sampling dates when the average flow at the dam spillsay was < 5 cfs for the preceding 50 days.**

| Seine Catch, River Kilometers > 14.5 | | | | | | |
|---|---|---|---|---|---|---|
| April 2000 - February 2002 No Minimum Flow (Months=10) | | | March 2002 - December 2007 Spring Diversions only (Months=11) | | Jan. 2008 - June 2012, Spring Diverisons and Resevoir Releases (Months=15) | |
| Scientific Name | Common Name | Mean | Scientific Name | Mean | Scientific Name | Mean |
| Gambusia holbrooki | Eastern mosquito fish | 105.2 | Menidia spp. | 121.6 | Lucania parva | 27.5 |
| Lucania parva | Rainwater killifish | 94.0 | Lucania parva | 83.1 | Menidia spp. | 24.9 |
| Menidia spp. | | 68.0 | Gambusia holbrooki | 30.2 | Gambusia holbrooki | 9.1 |
| Poecilia latipinna | Sailfin molly | 18.7 | Cyprinodon variegatus | 10.8 | Lepomis macrochirus | 4.5 |
| Brevoortia spp. | | 10.4 | Tilapia spp. | 8.5 | Fundulus seminolis | 3.4 |
| Anchoa mitchilli | Bay anchovy | 10.1 | Labidesthes sicculus | 5.9 | Trinectes maculatus | 1.9 |
| Trinectes maculatus | Hogchoker | 6.4 | Poecilia latipinna | 4.0 | Micropterus salmoides | 1.3 |
| Microgobius gulosus | Clown goby | 3.2 | Fundulus seminolis | 3.6 | Anchoa mitchilli | 0.8 |
| Gobiosoma spp. | | 3.1 | Lepomis macrochirus | 2.9 | Lepomis microlophus | 0.8 |
| Tilapia spp. | | 1.8 | Micropterus salmoides | 2.2 | Labidesthes sicculus | 0.6 |
| Gobiosoma bosc | Naked goby | 1.6 | Trinectes maculatus | 2.1 | Cyprinodon variegatus | 0.3 |
| Gobiosoma robustum | Code goby | 1.0 | Microgobius gulosus | 1.7 | Eucinostomus harengulus | 0.2 |
| Elops saurus | Ladyfish | 1.0 | Notropis petersoni | 1.5 | Lepomis punctatus | 0.1 |
| Cyprinodon variegatus | Sheepshead minnow | 0.4 | Lepomis microlophus | 1.3 | Eucinostomus spp. | 0.1 |
| Anchoa hepsetus | Striped anchovy | 0.2 | Notropis maculatus | 0.9 | Gobiosoma bosc | 0.1 |
| Fundulus grandis | Gulf killifish | 0.1 | Gobiosoma bosc | 0.6 | Poecilia latipinna | 0.1 |
| Leiostomus xanthurus | Spot | 0.1 | Eucinostomus harengulus | 0.6 | Fundulus confluentus | 0.1 |
| Fundulus confluentus | Marsh killifish | 0.0 | Leiostomus xanthurus | 0.3 | Lepomis auritus | 0.1 |
| Oligoplites saurus | Leatherjacket | 0.0 | Fundulus grandis | 0.3 | Brevoortia spp. | 0.0 |
| Palaemonetes spp. | Grass shrimp | 0.0 | Gobiosoma spp. | 0.3 | Pterygoplichthys spp. | 0.0 |
| Palaemonetes paludosus | | 0.0 | Heterandria formosa | 0.2 | Etheostoma fusiforme | 0.0 |
| Palaemonetes pugio | | 0.0 | Lepomis spp. | 0.2 | Lagodon rhomboides | 0.0 |
| Callinectes sapidus | Blue crab | 0.0 | Elops saurus | 0.2 | Gobiosoma spp. | 0.0 |
| Lepisosteus osseus | Longnose gar | 0.0 | Lucania goodei | 0.1 | Palaemonetes spp. | 0.0 |
| Lepisosteus platyrhincus | Florida gar | 0.0 | Lepomis punctatus | 0.1 | Palaemonetes paludosus | 0.0 |
| Amia calva | Bowfin | 0.0 | Anchoa mitchilli | 0.1 | Palaemonetes pugio | 0.0 |
| Notemigonus crysoleucas | Golden shiner | 0.0 | Syngnathus louisianae | 0.1 | Callinectes sapidus | 0.0 |
| Notropis maculatus | Taillight shiner | 0.0 | Lepomis marginatus | 0.1 | Lepisosteus osseus | 0.0 |
| Notropis petersoni | Coastal shiner | 0.0 | Eugerres plumieri | 0.1 | Lepisosteus platyrhincus | 0.0 |
| Pterygoplichthys spp. | Armoured catfish | 0.0 | Archosargus probatocephalus | 0.1 | Amia calva | 0.0 |

Additional analyses were performed on thirteen taxa that were selected to examine how taxa that inhabit different salinity zones in the lower river changed in response to the implementation of minimum flows. Data from the 2006 report by Florida Fish and Wildlife Conservation Commission and the University of South Florida (FFWCC/USF 2006) were reviewed, and taxa which had centers of abundance in the upper reaches of the Lower Hillsborough River were selected as indicator taxa. These taxa are listed in Table 10-7 along with their common names and broad salinity ranges

Box and whisker plots of the abundance of these indicator taxa in the three segments below the dam are presented on the following pages. These plots were generated from the monthly catches that were preceded by 50-day average flows of < 5 cfs. Summary statistics for abundance of the indicator taxa during the low flow sampling are presented in Appendix 7A, with time series plots of these data presented in Appendix 7B. The results of Wilcoxon rank sum test for significant differences in the abundance of the indicator taxa between time periods within each segment are listed in Appendix 7C, again based on the low flow sampling. Box and whisker and time series plots for the abundance of the indicator taxa using all monthly catches during the course of the study, including wet season sampling, are included as Appendices 10D and 10E.

**Table 10-7. Selected nekton indicator taxa.**

| Taxon | Common Name | Salinity Range |
|---|---|---|
| *Brevoortia* spp. | Menhaden | Brackish to marine |
| *Centropomus undecimalis* | Common Snook | Freshwater to marine |
| *Cyprinodon variegatus* | Sheepshead minnow | Freshwater to marine |
| *Fundulus seminolis* | Seminole killifish | Freshwater to brackish |
| *Gambusia holbrooki* | Eastern mosquitofish | Freshwater to brackish |
| *Labidesthes sicculus* | Brook silverside | Freshwater |
| *Lepomis macrochirus* | Bluegill | Freshwater |
| *Lepomis microlophus* | Redear sunfish | Freshwater |
| *Lucania parva* | Rainwater killifish | Freshwater to marine |
| *Micropterus salmoides* | Largemouth bass | Freshwater |
| *Palaemonetes* spp. | grass shrimp | Brackish to marine |
| *Poecilia latipinna* | Sailfin molly | Freshwater to brackish |
| *Tilapia* (genera *Oreochromis* and *Sarotherodon*) | Tilapia | Freshwater to brackish |
| *Trinectes maculatus* | Hogchoker | Freshwater to brackish |

### 10.2.1 *Brevoortia* spp.

Average catches of menhaden (*Brevoortia* spp.) were substantially lower in the periods following implementation of minimum flows (Appendix 7A). Menhaden typically form dense schools and are likely to be very abundant when caught. In the period of no minimum flows, there was one sample with extremely high abundance of menhaden (Figure 10-1) which elevated the abundance number for that entire period in the segment from kilometer 12.6 to < 14.5. Results of the Wilcoxon rank sum test (Appendix 7C) indicate that menhaden catch was significantly lower in the periods following minimum flow implementation in the 12.6 to < 14.5 segment only, otherwise there were no significant differences in menhaden catch.

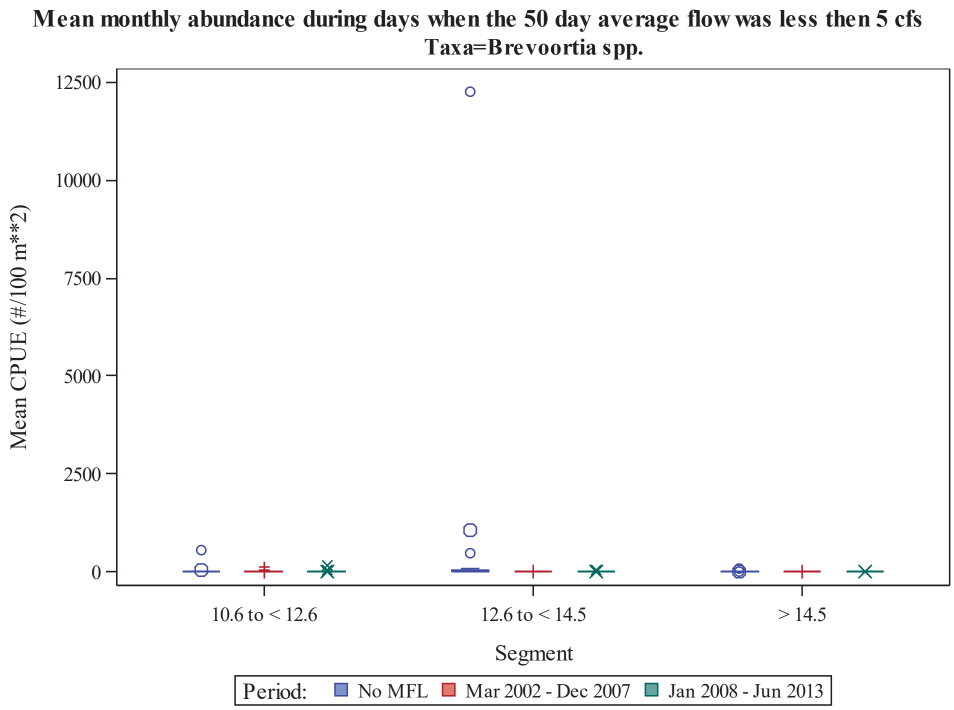


**Figure 10-1. Box and whisker plots of menhaden (*Brevoortia* spp.) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### *10.2.2 Centropomus undecimalis*

Common snook (*Centropomus unidecimalis)* is a popular sportfish which utilizes a range of salinity habitats over the course of its life cycle. Average catch of common snook was quite low regardless of the river segment or time period (Appendix 7A). There were no snook caught in the uppermost river segment, and most of those that were caught occurred in the two lowermost segments (Figure 10-2). Results of the Wilcoxon rank sum test results (Appendix 7C) indicate that there were no differences in snook catch between periods in any of the river segments.

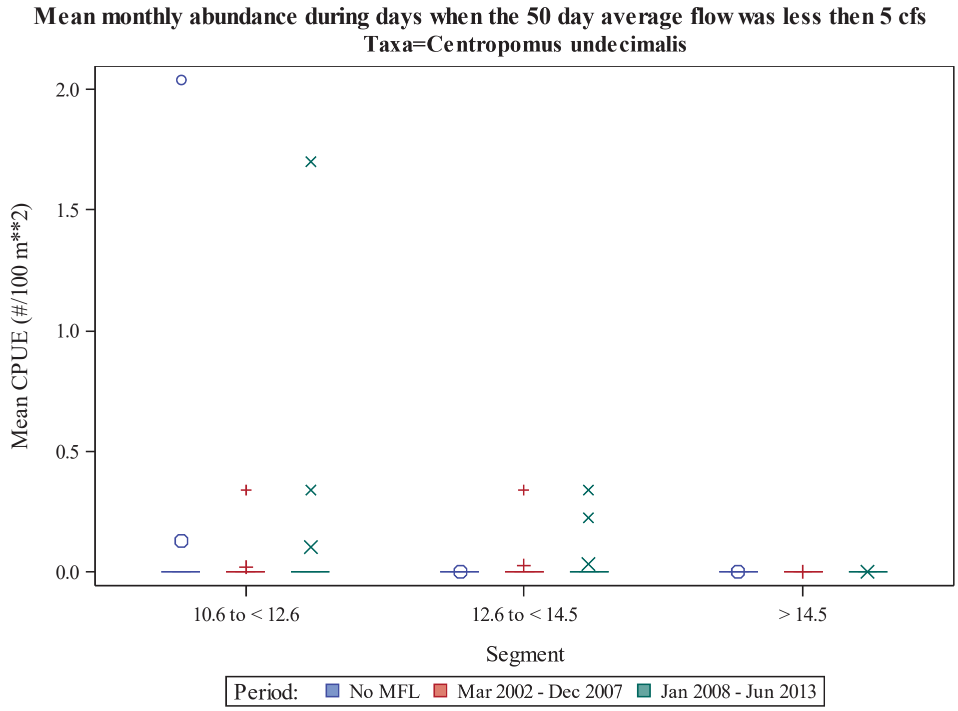


**Figure 10-2. Box and whisker plots of common snook (*Centropomus undecimalis*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### *10.2.3 Cyprinodon variegatus*

Average catch of sheepshead (*Cyprinodon variegatus*) minnow was highest during the initial minimum flow implementation period in all three river segments (Appendix 7A). Sheepshead minnow populations were generally lower in the Sulphur Springs to Hannah's Whirl (kilometers 12.6 to < 14.5) segment of the river than upstream or downstream of that segment (Figure 10-3). Results of the Wilcoxon rank sum test results indicate that sheepshead minnow populations were not significantly affected in the periods following the minimum flow implementation.

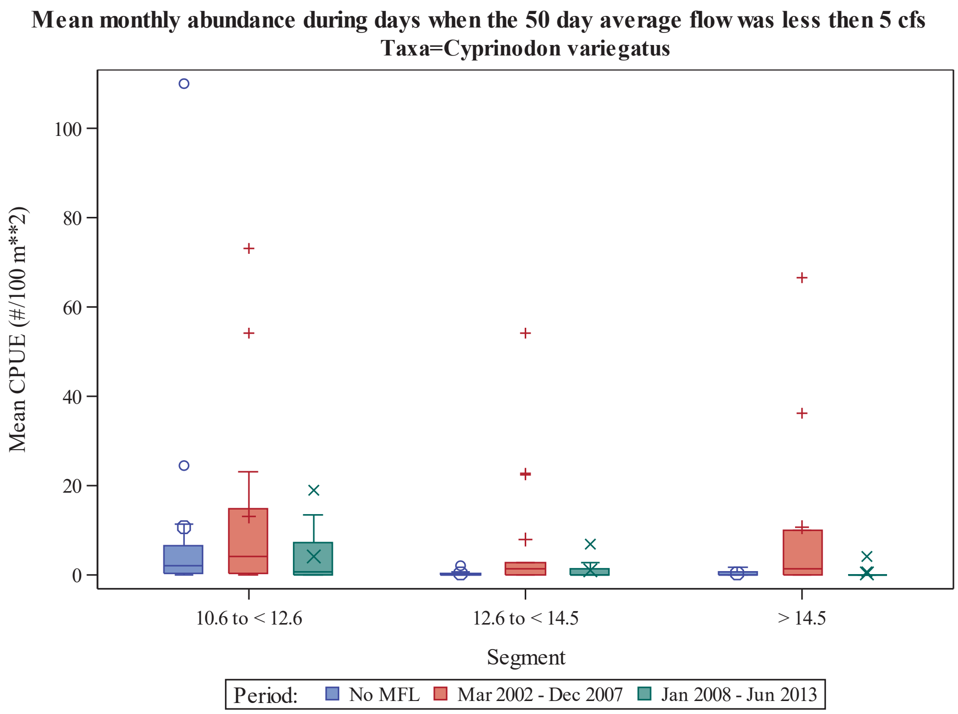


**Figure 10-3. Box and whisker plots of sheepshead minnow (*Cyprinodon veriegatus*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### *10.2.4 Fundulus seminolis*

Average catch of Seminole killifish (*Fundulus seminolis*) was highest after minimum flow implementation period in all three river segments (Appendix 7A). Seminole killifish populations increased from downstream to upstream and over time (Figure 10-4). Results of the Wilcoxon rank sum test results (Appendix 7C) indicate that Seminole killifish catch was significantly higher in the segment above kilometer 14.5 following the minimum flow implementation. Seminole killifish is a freshwater fish that went from being rarely or never caught in these river segments to being fairly common in the uppermost segment in the most recent period.

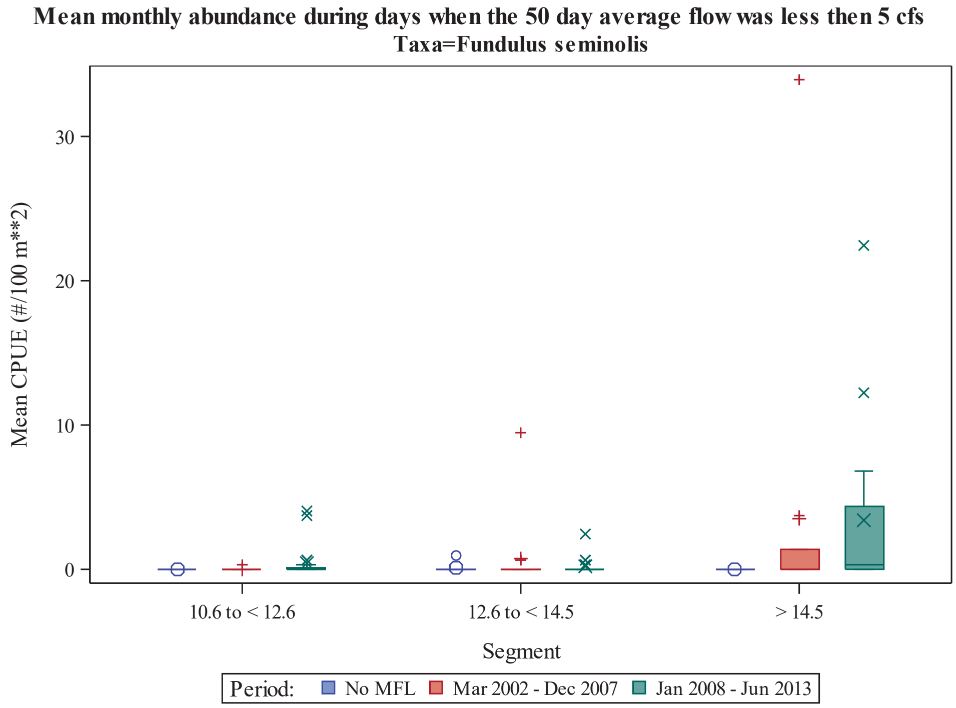


**Figure 10-4. Box and whisker plots of seminole killifish (*Fundulus seminolis*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### *10.2.5 Gambusia holbrooki*

Average catch of eastern mosquitofish (*Gambusia holbrooki*) was highest in the pre-minimum flow period in all three river segments (Appendix 7A). Eastern mosquitofish populations were highest in the two river segments upstream of Sulphur Springs, and clearly decreased in those segments in the periods following minimum flow implementation (Figure 10-5). Results of the Wilcoxon rank sum test indicate that eastern mosquitofish catch was significantly lower upstream of Sulphur Springs in the most recent period relative to the pre-minimum flow period. Eastern mosquitofish is an example of a taxon which is tolerant of a range of estuarine salinities and had a lower population density in the upper portion of the study area in the time period following minimum flow implementation.

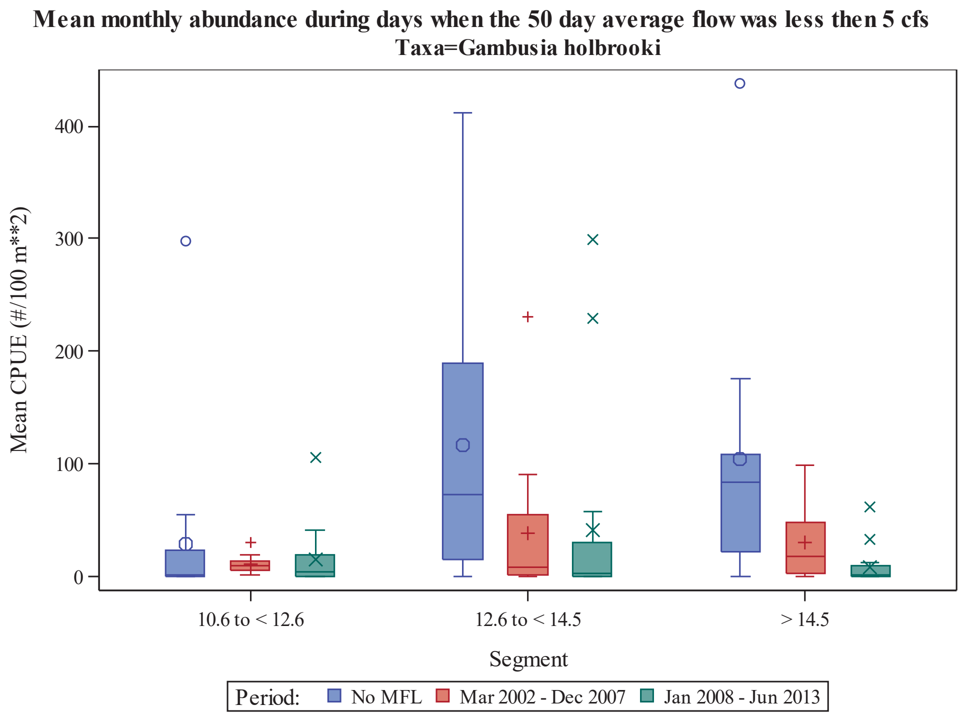


**Figure 10-5. Box and whisker plots of eastern mosquitofish (*Gambusia holbrooki*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### *10.2.6 Labidesthes sicculus*

Average catch of brook silverside (*Labidesthes sicculus*) was zero in the pre-minimum period in all three river segments (Appendix 7A). Brook silverside populations were highest in the river segment upstream of Hannah's Whirl, and clearly increased in that segment in the periods following minimum implementation (Figure 10-6). Brook silversides are a freshwater species which appears to have established a population upstream of Hannah's Whirl (> kilometer 14.5) in the periods following the minimum implementation.

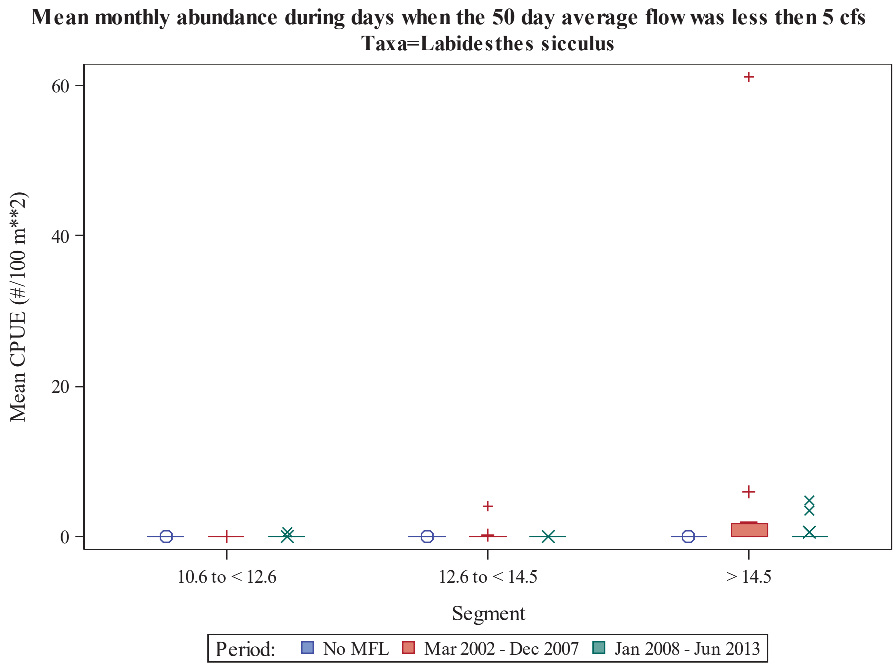


**Figure 10-6. Box and whisker plots of brook silverside (*Labidesthes sicculus*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### *10.2.7 Lepomis macrochirus*

Average catch of bluegill (*Lepomis macrochirus*) was zero in the pre-minimum flow period in all three river segments (Appendix 7A). Bluegill populations were highest in the river segment upstream of kilometer 14.5, and clearly increased in all of the study area in the periods following minimum flow implementation (Figure 10-7). Bluegill were in significantly greater numbers in the first minimum flow period compared to no minimum in the segments above Sulphur Springs, but there was no significant differences between the initial and final minimum flow period (Appendix 7C). Bluegill is a freshwater species which appears to have established a population upstream of Sulphur Springs in the periods following the minimum flow implementation.

### *10.2.8 Lepomis microlophus*

Average catch of redear sunfish (*Lepomis microlophus*) was zero in the pre-minimum flow period in all three river segments (Appendix 7A). Redear sunfish populations were highest in the river segment above kilometer 14.5, and clearly increased in this segment in the periods following minimum flow implementation (Figure 10-8. Redear sunfish were in significantly greater numbers after the implementation in the reach above Hannah's Whirl, but numbers were much less and there were no significant differences found in the segment between Sulphur Springs and Hannah's Whirl (Appendix 7C). However, there were some occurrences downstream of Sulphur Springs in the final minimum flow period when abundances were significantly greater. Redear sunfish is a freshwater species which appears to have established a population in the lower river following the minimum flow implementation.

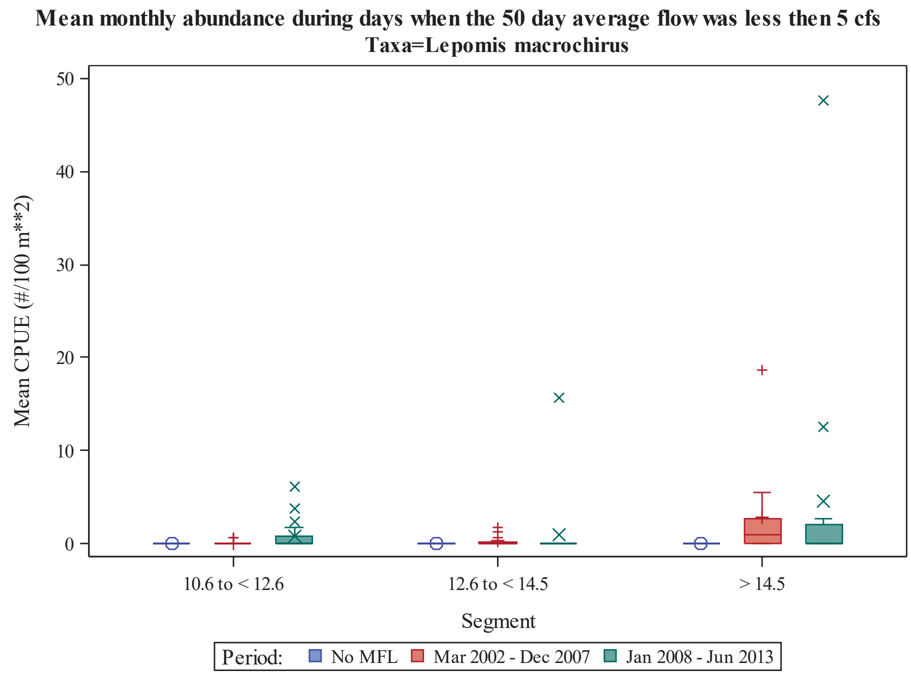


**Figure 10-7. Box and whisker plots of bluegill (*Lepomis macrochirus*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

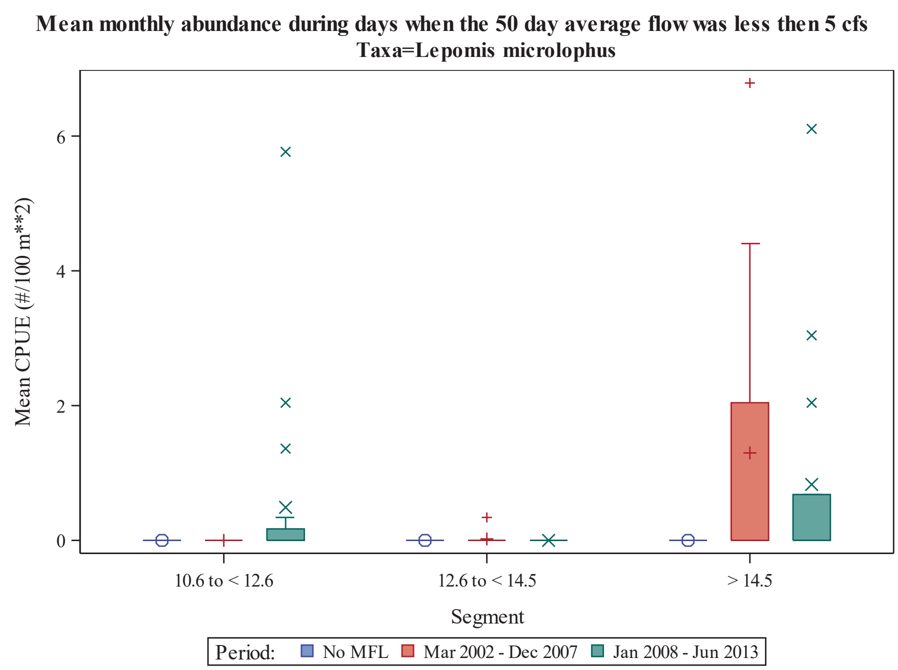


**Figure 10-8. Box and whisker plots of redear sunfish (*Lepomis microlophus*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

## *10.2.9 Lucania parva*

The average catches of rainwater killifish (*Lucania parva*) did not show a consistent pattern in the river segments (Appendix 7A). Rainwater killifish populations were highest in the river segment upstream of kilometer 14.5, and appeared to decrease following minimum flow implementation (Figure 10-9). Rainwater killifish is an example of a taxon which is tolerant of a range of estuarine salinities and had a lower population density in the upper portion of the study area in the time period following minimum flow implementation, but did not show apparent changes further downstream.

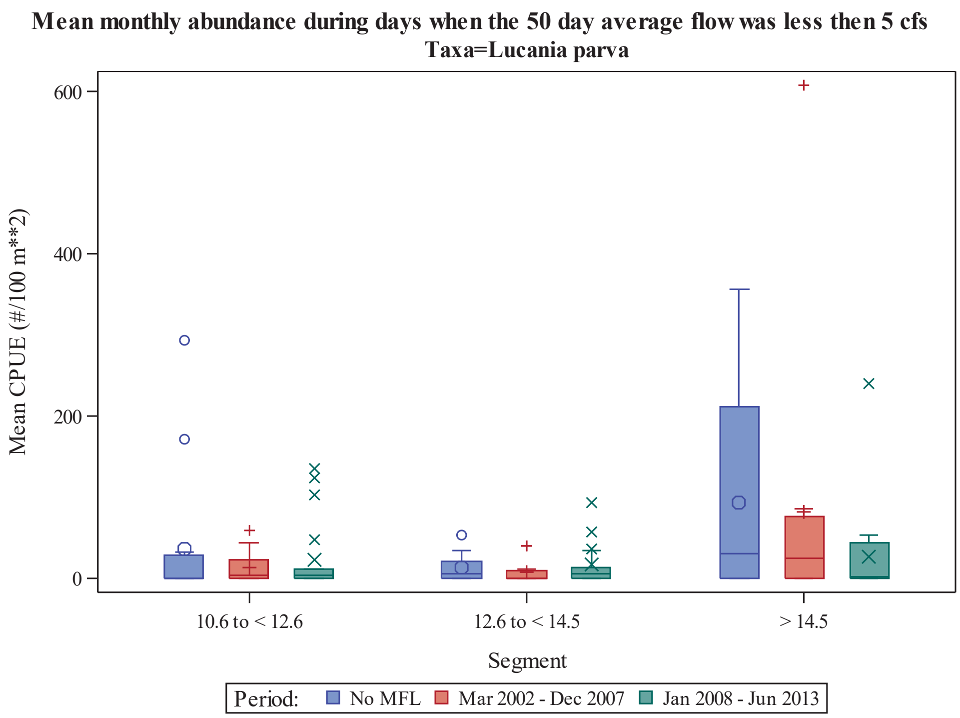


**Figure 10-9. Box and whisker plots of rainwater killifish (*Lucania parva*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

## *10.2.10 Micropterus salmoides*

Catches of largemouth bass (*Micropterus salmoides*) were zero in the pre-minimum flow period in all three river segments (Appendix 7A). Largemouth bass populations were highest in the river segment upstream of kilometer 14.5, and increased in all of the study area in the periods following minimum flow implementation with particularly high catch levels in the initial implementation period (Figure 10-10). Largemouth bass are a freshwater species which appear to have established a population upstream of Sulphur Springs in the periods following the minimum flow implementation. Results of the Wilcoxon rank sum test indicate that largemouth bass populations significantly increased in the segment upstream of kilometer 14.5 after the implementation of minimum flows (Appendix 7C).

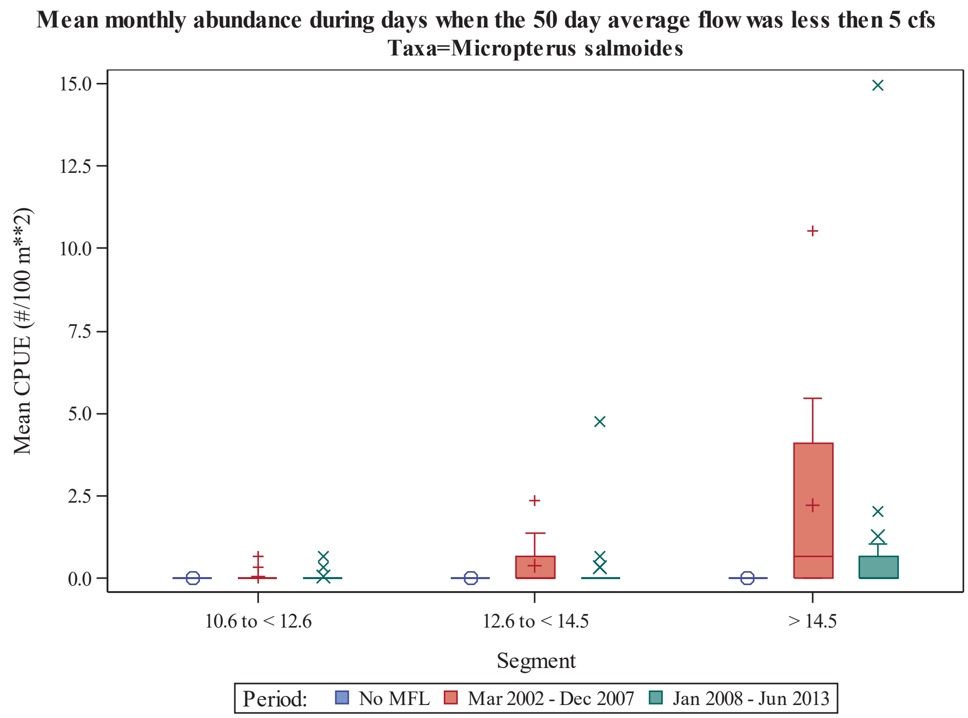


**Figure 10-10. Box and whisker plots of largemouth bass (*Micropterus salmoides*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 10.2.11 *Palaemonetes* spp.

Average catch of grass shrimp (*Palaemonetes* spp.) was highest in the pre-minimum period in all three river segments (Appendix 7A). Grass shrimp populations were quite low in the periods following minimum flow implementation (Figure 10-11). Grass shrimp are an important food source for fishes in the estuarine ecosystems. Grass shrimp is an example of a taxon which is tolerant of a range of estuarine salinities and has clearly had a lower population density in the upper portion of the study area in the time period following minimum flow implementation.

### *10.2.12 Poecilia latipinna*

Average catch of sailfin molly (*Poecilia latipinna*) was highest in the pre-minimum flow period in all three river segments (Appendix 7A). Sailfin molly populations were quite low in the periods following minimum flow implementation (Figure 10-12). Sailfin molly is an example of a taxon which is tolerant of a range of estuarine salinities and has clearly had a lower population density in the upper portion of the study area in the time period following minimum flow implementation.

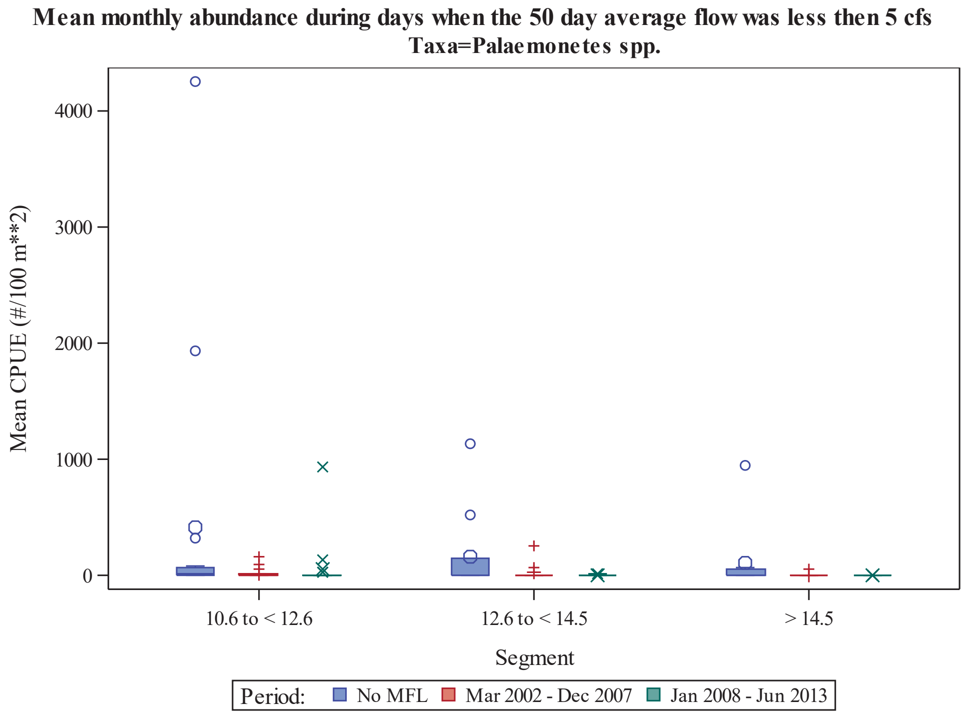


**Figure 10-11. Box and whisker plots of grass shrimp (*Palaemonetes* spp.) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

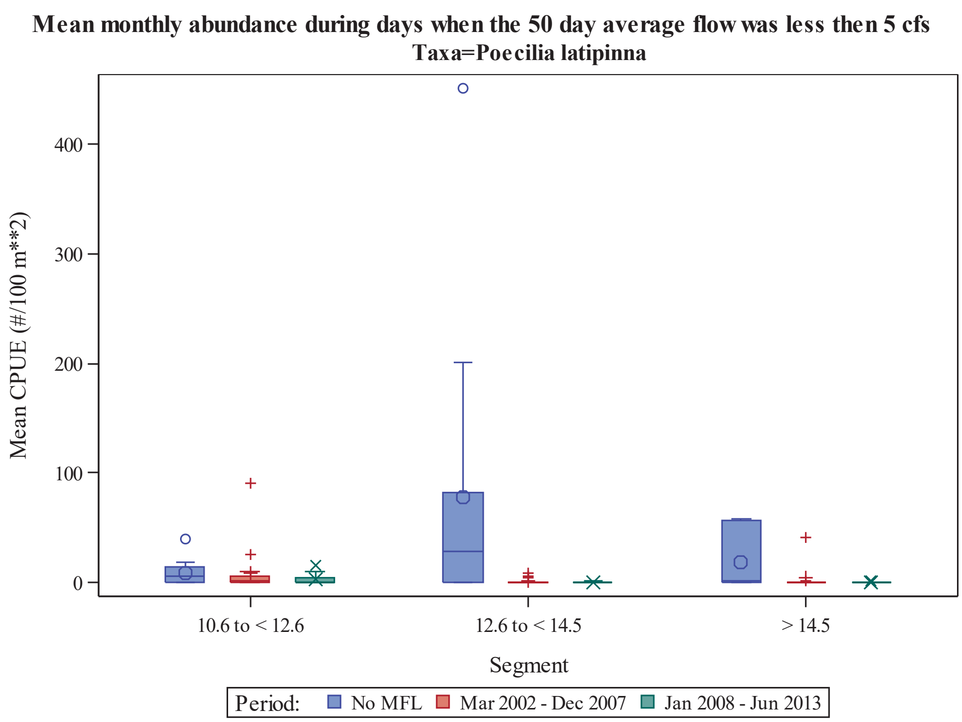


**Figure 10-12. Box and whisker plots of sailfin molly (*Poecilia latipinna*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### 10.2.13 Tilapia

The data for tilapia in this analysis are comprised of all catch in the genera *Oreochromis* and *Sarotherodon*. There were no Tilapia caught during the first two time periods, with catches only occurring in the final minimum flow period in the two most downstream segments (Appendix 7A and Figure 10-13). Tilapia is a non-native taxon which can occur in both freshwater and brackish systems. The data are limited, but there may be some evidence that they did better in the segments near the dam during the final period of higher minimum flows. Tilapia are commonly observed in Sulphur Springs Run (SWFWMD 2004) and the increased diversions of spring water to the base of the dam during the final minimum flow period may act to increase its abundance above Sulphur Springs.

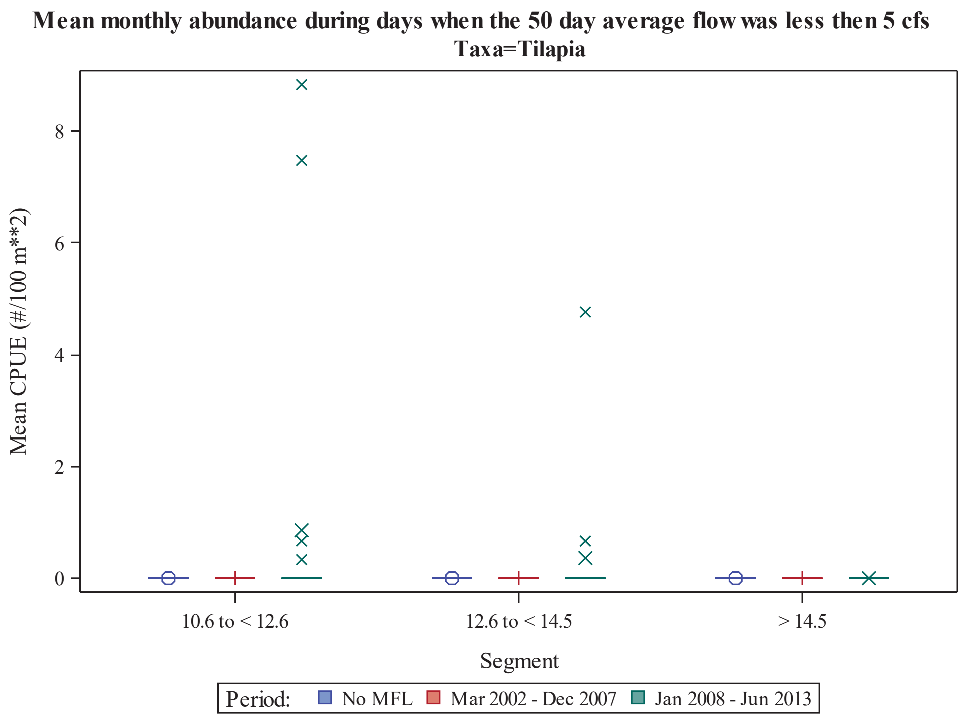


**Figure 10-13. Box and whisker plots of *Tilapia* spp. catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

### *10.2.14 Trinectes maculatus*

The average catch of hogchokers (*Trinectes maculatus*) did not display a consistent pattern across river segments and time periods (Appendix 7A), as they were frequently caught in all river segments during all periods (Figure 10-14). Results of the Wilcoxon rank sum test (Appendix 7D) indicate that there were no significant differences in hogchoker catch between periods. *T. maculatus* is a species very characteristics of oligohaline areas was maintained its abundance in the segments below the dam under a range of inflow conditions.

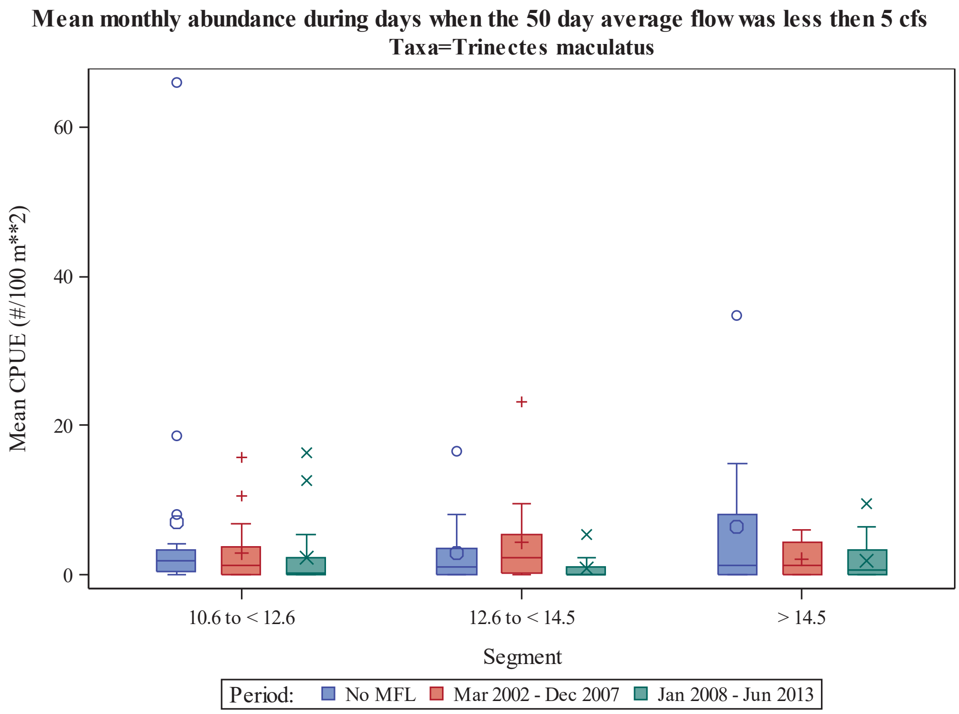


**Figure 10-14. Box and whisker plots of hogchoker (*Trinectes maculatus*) catch in three river segments during three minimum flow periods for sampling dates with 50-day average flows of less than 5 cfs.**

## 10.3 Discussion

There were apparent shifts in the total abundance of all taxa and species composition of the nekton community as minimum flows were implemented and increased over time. As described for the plankton, the nekton sampling began in 2000 and captured conditions in very dry periods in 2000, 2001, and the early part of 2002 when salinity conditions in the river was near recorded maxima. A previous study of the Lower Hillsborough River demonstrated that the distribution of many taxa in the lower river shift in response to changes in freshwater inflow (FFWCC/USF 2006). During the dry periods before minimum flow implementation, taxa that are most commonly caught in mesohaline and polyhaline areas had migrated upriver in response to the low freshwater inflow and high salinity conditions. High total abundance numbers in the period before minimum flows implementation reflected periodic high catches of estuarine taxa such as *Menidia* spp., bay anchovy (*A. mitchilli)*, and menhaden (*Brevoortia* spp.). Total abundance values decreased in all river segments upstream of kilometer 10.6 after the implementation of minimum flows, presumably due to estuarine species migrating downstream in response increases in freshwater inflow and reductions in salinity in the upper reaches of the lower river.

Species richness and diversity, however, did not follow this pattern and the highest mean values for both parameters occurred during the initial minimum flow period in the two segments above Sulphur Springs. Also, the abundances of a number of indicator taxa significantly changed over the period of study. Estuarine taxa such as *Brevoortia* spp., *L. parva*, and *P. latipinna* were significantly less abundant in the upper river segments after the implementation of minimum flows.

A number of freshwater species including bluegill, redear sunfish, brook silversides, Seminole killifish, and largemouth bass had significantly greater abundance in the upper river reaches after minimum flows were implemented. Some other taxa, which frequently inhabit oligohaline waters such as snook, sheepshead minnow, and hogchoker did not show pronounced changes in abundance as minimum flows were implemented. In sum, the data from the nekton sampling indicate that the goal of establishing oligohaline conditions below the dam is having a significant effect on the fish fauna above Sulphur Springs, including the occurrence of some freshwater species that are tolerant of low salinity.

As discussed further in Section 13.5, it is recommended that additional sampling and analysis be conducted for nekton sampled by seines, emphasizing a distribution of samples in the reach of the river above Sulphur Springs. These sampling efforts should be conducted in two separate years after the prolonged implementation of minimum flows, with the possibility of a third year of sampling pending the findings of the first two sampling efforts.

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# 11 Biological Communities - Benthic Macroinvertebrates

## 11.1 Introduction

Data for benthic macroinvertebrates (benthos) examined for this minimum flows evaluation were collected as part of the TBW HBMP implemented by TBW to support conditions included in their water use permit for diversion and withdrawal of water from the Hillsborough River Reservoir. Benthos samples were collected by deployment of Young-modified Van-Veen grab sampler, which samples sediments from an area of 0.04 square meters on the bottom of the river. Additional details on field sampling and laboratory protocols employed by the HBMP are in design and monitoring reports published by TBW (1999, 2006, 2010).

The HBMP sampling program is a probabilistic design that randomizes the location of benthos sampling stations on a monthly basis within defined river strata (segments). The strata defined for the HBMP were not the same as the river segments defined in this minimum flows assessment, so the number of samples per month in each minimum flow segment changed depending on where the randomized samples occurred in the HBMP program. The segments that were used for the assessing benthos in this minimum flows evaluation were the same as those used for the nekton, with segments extending from kilometers 10.6 to < 12.6, 12.6 to < 14.5, and upstream of 14.5

Due to a change in the laboratories doing the species identifications, benthos data that were identified with consistent taxonomic resolution in low salinity zones began in August 2005. Benthos sampling in the Lower Hillsborough River ended after September 2010, resulting in a range of five years of data available for analysis. While samples were collected during all months, only the samples from January to March and July to September were processed, identified, and counted by the laboratory utilized by the HBMP. This protocol was established because TBW can only divert water away from the Lower Hillsborough River via the Harney Canal for public supply when flows at the dam spillway are over 100 cfs. Because the processing and identification of benthic macroinvertebrate samples is time consuming and expensive, data were processed only for the January to March and July to September time periods for they represent the months when TBW is most likely to divert water away from the lower river. As a result of this limited seasonal approach, there were fewer samples processed for benthic macroinvertebrates than for the other biological communities that had year-round sampling and data processing.

Given this protocol and the 2005 -2010 period with consistent taxonomic resolution, there were two periods for which benthos data were available for this minimum flows evaluation: (1) a period from August 2005 through September 2007 when minimum flows were comprised solely of diversions from Sulphur Springs; and (2); a period from January 2008 through September 2010 when diversions from Sulphur Springs were accompanied by freshwater releases from the reservoir. There were no comparable benthos data for the period prior to the implementation of minimum flows.

As with the analysis of other biological communities, a goal of this minimum flows evaluation was to examine benthos communities after prolonged periods of minimum flows. Therefore, statistics were generated for benthos collections that were limited to periods when 50-day average flows at the dam were < 5 cfs. It was assumed that including sampling dates that were preceded by substantial flows at the dam spillway would mask relationships that benthic macroinvertebrate communities have with the prolonged implementation of minimum flows.

The numbers of months from which benthos samples that were analyzed during each of the two minimum flow periods in the three river segments are listed in Table 11-1. The range of months and years listed for each segment-period combination correspond to sampling dates that had preceding 50-day average flows at the dam spillway less than five cfs. Within a given period, the number of monthly benthos samples differed between segments because the HBMP sampling design did not correspond to an even distribution of samples across the segments used for this minimum flows assessment. The number of samples available for analyses ranged from two monthly samples in the segment above kilometer 14.5 during the first minimum flow period to six monthly samples in the segment from kilometer 12.6 to 14.5 in the first minimum flow period. Despite the sparseness of the available data set, the benthos communities exhibited spatial and temporal patterns that may be related to the implementation of minimum flows.

## 11.2 Community level analyses

Community level parameters were assessed for the benthos included total abundance, taxonomic richness, and diversity (Table 11-1). Mean and median abundance values decreased from the first to the second minimum flow periods in the two river segments above kilometer 12.6. Although it was based on only two months of sampling, high mean (23,925 per $m^2$) minimum (16,625 per $m^2$) abundance values in the uppermost river segment occurred during 2007 when minimum flows were comprised only of diversions from Sulphur Springs. In contrast, mean and median values in the segment from kilometer 10.6 to 12.6 increased after 2008. However, 3, these mean abundance values are based on low numbers of samples that collectively comprise very small sampling areas. Therefore, although informative, the results in Table 11-1 should not be interpreted to suggest changes in the actual abundance of macroinvertebrates distributed over these river segments.

**Table 11-1. Summary statistics for abundance of all benthic invertebrate taxa combined for sampling dates with preceding 50-day average flow rates < 5 cfs. All values expressed as numbers per square meter.**

| River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum |
|---|---|---|---|---|---|---|---|
| 10.6 to < 12.6 | July 2006 – March 2007 | 4,747 | 5,594 | 4 | 12,713 | 2,775 | 725 |
| 10.6 to < 12.6 | Jan. 2008 – March 2009 | 8,105 | 7,865 | 5 | 18,800 | 7,125 | 150 |
| 12.6 to < 14.5 | July 2006 – July 2007 | 11,798 | 9,441 | 6 | 28,575 | 10,806 | 2,325 |
| 12.6 to < 14.5 | Jan. 2008 - March 2009 | 5,678 | 3,873 | 4 | 10,350 | 5,550 | 1,263 |
| > 14.5 | March 2007 – July 2007 | 23,925 | 10,324 | 2 | 31,225 | 23,925 | 16,625 |
| > 14.5 | July 2008 – March 2009 | 8,196 | 5,214 | 3 | 11,238 | 11,175 | 2,175 |

Taxonomic richness is the number of different taxa present in an individual sample. Mean richness values increased in all three river segments over time, with the highest value of 18.8 recorded in the segment nearest the dam in the final minimum flow period (Table 11-2). Diversity (in this case Shannon-Weaver Diversity) is a community metric which combines both richness and evenness (how evenly distributed the population is across the different taxa). Mean diversity values decreased in the segment from kilometer 10.6 to 12.6, did not change between kilometers 12.6 to 14.5, and increased upstream of kilometer 14.5 (Table 11-3). Collectively, these results indicate that taxonomic richness and diversity tended to be highest in the most upstream segment above Hannah's Whirl and tended to increase as minimum flows were increased over time.

**Table 11-2. Mean taxonomic richness values in the benthic invertebrate data for sampling dates with preceding 50-day average flow rates < 5 cfs.**

| River Kilometer | Period | Mean Richness |
|---|---|---|
| 10.6 to < 12.6 | July 2006 – March 2007 | 5.4 |
| 10.6 to < 12.6 | Jan. 2008 – March 2009 | 7.3 |
| 12.6 to < 14.5 | July 2006 – July 2007 | 9.3 |
| 12.6 to < 14.5 | Jan. 2008 - March 2009 | 11.9 |
| > 14.5 | March 2007 – July 2007 | 13.0 |
| > 14.5 | July 2008 – March 2009 | 18.8 |

**Table 11-3. Average diversity in the benthic invertebrate data for sampling dates with preceding 50-day average flow rates < 5 cfs**

| River Kilometer | Period | Mean Diversity |
|---|---|---|
| 10.6 to < 12.6 | July 2006 – March 2007 | 1.2 |
| 10.6 to < 12.6 | Jan. 2008 – March 2009 | 0.8 |
| 12.6 to < 14.5 | July 2006 – July 2007 | 1.5 |
| 12.6 to < 14.5 | Jan. 2008 - March 2009 | 1.5 |
| > 14.5 | March 2007 – July 2007 | 1.7 |
| > 14.5 | July 2008 – March 2009 | 2.9 |

## 11.3 Macroinvertebrate abundance and species composition in the study area

Because of the smaller number of samples compared to other biological data, the analyses of spatial and temporal patterns in the species composition of the benthic macroinvertebrate community were limited to comparisons of mean abundance values for the various taxa collected over the five year study period. As previously discussed for community based parameters, these mean values were calculated from benthos collections that were preceded by 50-day flow rates of less than five cfs.

Mean abundance values for all taxa collected at low flows during each of the two minimum flow periods in each of the three river segment are listed in Appendix 8A. These means were calculated from the monthly mean values collected within each river segment. The taxa are ranked in order by their overall mean abundance values, which were calculated as the simple average of the six mean abundance values corresponding to the two minimum flow periods for the three river segments. This approach was taken to develop a more spatially-balanced estimate of the overall mean, because the number of monthly samples differed between the time periods and river segments.

In order to better characterize spatial and temporal patterns in the species composition of the benthos community, the mean values for the taxa in each segment and time period are also presented in Tables 11-4 and 11-5. Although they differ in the number of rare taxa that are listed, the mean values for commonly occurring taxa in the study area are the same in the two tables. The tables differ in how the taxa are ranked to facilitate the comparison of spatial and temporal changes in the species composition among the three river segments. The taxa in Table 11-4 are ranked by the average of the mean values for the two minimum flow periods in the most downstream segment between kilometers 10.6 and 12.6. This segment lies downstream of Sulphur Springs, which represents a more mesohaline macroinvertebrate community. The data in Table 11-4 are limited to only those taxa that were collected in that segment in at least one of the minimum flow periods.

The taxa in Table 11-5 are ranked by the average of the mean values for the two minimum flow periods in the segment above Hannah's Whirl (upstream of kilometer 14.5). This is the segment closes to the dam and represents the lower salinity conditions in the lower river. The data in Table 11-5 are limited to only those that were collected in that segment in at least one of the minimum flow periods.

Although the term mean abundance is used in the following discussion, the data are not sufficiently robust to suggest changes in the actual abundance of any taxon over an entire river segment. The area that is sampled by the benthos sampler is very small, and during most months, there was only one grab sample collected in each river segment. The results are indicative of abundance and species composition of benthos at the specific sites that were sampled. Although these findings are informative and indicate relationships of the benthos community with salinity and the source and rate of minimum flows, they should not be interpreted to suggest changes in the actual abundance of any taxon over the length of any of the river segments over time.

### 11.3.1 Macroinvertebrate community downstream of Sulphur Springs

The dominant taxa in the segment downstream Sulphur Springs (10.6 to 12.6) were the polychaetes of *Streblospio* spp*.* and *Stenoninereis martini* (Table 11-4), which are common polychaetes in mesohaline waters. Both of these taxa were in greatly reduced numbers in the segment above Hannah's Whirl (> kilometer 14.5), particularly in the final minimum flow period when the minimum flow rates were the highest. However, *Stenoninereis martini* had high abundance values in the middle segment between Sulphur Springs and Hannah's Whirl throughout the study (kilometer 12.6 to 14.5). The next highest ranked taxa in the most downstream segment were the red-rimmed melania snail (*Melanoides tuberculatus*) and tubicoid oligochaetes in the family *Naididae.* These are principally freshwater organisms that are tolerant of low salinity, and their abundances were much higher in the upstream segments, particularly the segment above Hannah's Whirl. In those two segments the mean abundances were highest in the period when minimum flows were comprised solely of water diverted from Sulphur Springs.

This was especially the case for *Melanoides tuberculatus,* which reached high abundance values in the middle segment during the first minimum flow period. The next ranked, i.e., most abundant taxon in the downstream segment was another polychaete (*Polydora* spp.). This taxon was restricted to that segment, although the *Polydora cornuta* sp. complex, which was ranked number 10, was most abundant in the middle river segment between Sulphur Springs and Hannah's Whirl.

Three taxa that were ranked 7 through 9 in the downstream segment; *Grandidierrella bonnieroides* (amphipod) *Laeonereis culveri* (polychaete), and *Mytilopsis leucophaeta* (mussel) were more abundant in the two upstream segments. These are commonly occurring taxa in tidal river estuaries that can reach high numbers in oligohaline and mesohaline waters (Janicki Environmental 2007). Three other estuarine taxa were ranked between 11 and 14; *Amphibalanus* spp. (barnacle), *Ficopomatus* spp. and *Limnodriloidinea* spp. (worms) were primarily restricted to the downstream segment. Snails in the family *Hydrobiidae,* which were ranked number 12 in the downstream segment, were much more abundant in the upstream segments. This family contains a mix of freshwater and brackish snails and it appears taxa collected in the Hillsborough River were those that prefer either fresh or low salinity water.

The remaining taxa in the downstream segment included several other taxa that were more abundant in the upstream segments, including: *Cassidinidea ovalis* (isopod), *Chironomus* spp., and *Dicrotendipes* spp. (midges), and *Rhithropanopeus harrisii* (mudcrab). Several other taxa that were collected in fairly low numbers; e.g., *Cerapus* sp. C. (amphipod*), Glottidia pyramidata* (brachiopod) and *Onuphidae* (polychaete) were collected only in the downstream segment during the five-year sampling period.

The benthos community in the downstream segment appeared to be dominated by three polychaetes, with lesser numbers of several species that were more abundant in the two segments upstream of Sulphur Springs. This contributed to lower mean richness and diversity values for the downstream segment compared to the segments upstream (Tables 11-2 and 11-3). As described in Chapter 5, the section of the river between kilometer 10.6 and 12.6 experiences frequent hypoxia, which likely affects the benthic macroinvertebrate community in this part of the river. However, based on assessment of relationships of dissolved oxygen and flow presented in Sections 5.4.6 and 5.4.7, it does not appear that the implementation of minimum flows would have had a negative impact on the benthic macroinvertebrate community downstream of Sulphur Springs.

**Table 11-4. Mean abundance values for benthic macroinvertebrate taxa in three river segments during two minimum flow periods on sampling dates when preceding 50-day flows were < 5 cfs. Taxa are ranked by the mean abundance in the segment from kilometer 10.6 to 12.6. Values are limited to those taxa which had mean values greater than zero in that segment for at least one minimumflow period. All values expressed as individuals per m$^2$.**

| | | Kilometer 10.6 to < 12.6 | | Kilometer 12.6 to < 14.5 | | Kilometer ≥ 14.5 | |
|---|---|---|---|---|---|---|---|
| Rank | Taxon | July 2006 - March 2007 | Jan 2008 - March 2009 | July 2006 - July 2007 | Jan 2008 - March 2009 | March 2007 - July 2007 | July 2008 - March 2009 |
| 1 | Streblospio gynobranchiata | 0 | 5,035 | 0 | 119 | 0 | 88 |
| 2 | Stenoninereis martini | 1,358 | 2,125 | 3,492 | 2,691 | 863 | 50 |
| 3 | Streblospio spp. | 1,385 | 0 | 96 | 0 | 13 | 0 |
| 4 | Melanoides tuberculatus | 348 | 98 | 3,744 | 134 | 11,350 | 1,104 |
| 5 | Tubificoid Naididae spp. | 388 | 0 | 481 | 56 | 1,788 | 1,021 |
| 6 | Polydora spp. | 0 | 215 | 0 | 0 | 0 | 0 |
| 7 | Grandidierella bonnieroides | 5 | 208 | 56 | 153 | 313 | 150 |
| 8 | Laeonereis culveri | 85 | 123 | 335 | 650 | 738 | 8 |
| 9 | Mytilopsis leucophaeata | 75 | 73 | 204 | 1,084 | 25 | 550 |
| 10 | Polydora cornuta sp. complex | 8 | 95 | 71 | 281 | 0 | 25 |
| 11 | Amphibalanus spp. | 0 | 35 | 0 | 0 | 0 | 0 |
| 12 | Hydrobiidae spp. | 28 | 0 | 2,833 | 28 | 7,975 | 1,921 |
| 13 | Ficopomatus spp. | 0 | 15 | 6 | 0 | 0 | 0 |
| 14 | Limnodriloidinae spp. | 0 | 15 | 0 | 0 | 0 | 0 |
| 15 | Panopeidae spp. | 0 | 10 | 2 | 100 | 0 | 0 |
| 16 | Edotia triloba | 0 | 10 | 0 | 6 | 0 | 0 |
| 17 | Cassidinidea ovalis | 0 | 5 | 15 | 25 | 25 | 717 |
| 18 | Chironomus spp. | 0 | 5 | 98 | 41 | 50 | 208 |
| 19 | Dicrotendipes spp. | 0 | 5 | 15 | 69 | 13 | 254 |
| 20 | Rhithropanopeus harrisii | 0 | 5 | 23 | 59 | 13 | 0 |
| 21 | Cyclaspis varians | 5 | 0 | 6 | 0 | 0 | 0 |
| 22 | Melita nitida complex | 0 | 5 | 0 | 6 | 0 | 0 |
| 23 | Polypedilum scalaenum group | 5 | 0 | 6 | 0 | 0 | 0 |
| 24 | Carazziella hobsonae | 5 | 0 | 0 | 0 | 0 | 0 |
| 25 | Cerapus sp. C | 0 | 5 | 0 | 0 | 0 | 0 |
| 26 | Dubiraphia spp. | 0 | 5 | 0 | 0 | 0 | 0 |
| 27 | Gammarus spp. | 0 | 5 | 0 | 0 | 0 | 0 |
| 28 | Glottidia pyramidata | 5 | 0 | 0 | 0 | 0 | 0 |
| 29 | Leitoscoloplos foliosus | 0 | 5 | 0 | 0 | 0 | 0 |
| 30 | Onuphidae spp. | 0 | 5 | 0 | 0 | 0 | 0 |
| 31 | Polymesoda caroliniana | 3 | 0 | 0 | 0 | 0 | 0 |

## 11.3.2 Macroinvertebrate community upstream of Sulphur Springs

Mean abundance values for 59 macroinvertebrate taxa that were collected in the river in the most upstream segment above Hannah's Whirl (> kilometer 14.5) are listed in Table 11-5, ranked by their overall mean value in that segment for the two minimum flow periods. Also listed are the mean abundances for these same taxa in the other two river segments during the two minimum flows periods. For species that are listed in both Table 11-4 and 11-5, the mean values are the same but are reordered in Table 11-5 for discussion purposes.

Snails comprised the most abundant taxa in the two river segments above Sulphur Springs. The red-rimmed melania *(Melanoides tuberculatus)* had the highest density of any organism recorded during the study (11,340 per m$^2$) during the first minimum flow period in the segment above Hannah's Whirl. This freshwater snail is native to Africa and southern Asia and was first recorded in Florida in 1969 and has become widespread (Thompson 1984). Snails of the family *Hydrobiidae* comprised the second most abundant group upstream of Hannah's Whirl, where they also had their highest mean abundance values. As previously mentioned, this is a large group of snails that include both freshwater and brackish water species. It is not possible from the identifications to determine which species were collected, but based on their distribution it appears these were species of *Hydrobiidae* that prefer either fresh water or low salinity conditions.

Freshwater oligochaetes of the family *Naididae* were the third most abundant taxonomic group upstream of Hannah's Whirl, where they were much more abundant than in the more downstream segments. The next ranked species, *Stenoninereis martini* and *Laeonereis culveri*, are estuarine polychaetes which had greater abundance above Hannah's Whirl in the first minimum flow period. These species were in much lower abundances after 2008, when reservoir releases began and salinity was generally lower in this reach of the river. An opposite pattern was observed for the isopod *Cassidinidea ovalis*, which is common in both oligohaline and tidal freshwaters and increased from the first to the second minimum flow period. Two mollusks, the Asian clam (*Corbicula fluminea)* and the mussel *Mytilopsis leucophaeta,* also had higher mean abundance values in the final minimum flow period. *M. luecophaeta* is common in low salinity waters, but *C. fluminea* is a freshwater species that has become established below the dam. The freshwater oligochaete, *Limnodrilus hoffmeisteri*, was most abundant in the segment above Hannah's Whirl, but showed a modest drop in mean abundance from the first to the second minimum flow period. Mean abundance values for the widespread estuarine amphipod *Grandidierella bonneiroides* were similar to values for the downstream segments.

Of the taxa ranked 10 and lower above Hannah's Whirl, there were several that showed low abundances in the first minimum flow period, but were absent after 2008 when the highest minimum flow rates were implemented. These included three common estuarine species *Gammarus mucronatus* (amphipod), *Streblospio* pp. (polychaete) *and Rhithropanopeus harrissi* (mudcrab) and two freshwater species *Libellula* spp. (dragonflies) and Ephemeroptera spp. (mayflies). In contrast, there were also a number of estuarine species that were absent in the first minimum flow period but appeared in low numbers in the final minimum flow period including *Anopsilana jonesi* (isopod), *Boccardiella ligerica* (polychaete), *Streblospio gynobranchiata* (polychaete), *Aoridae* spp. (amphipod) and *Amphibalanus venustus* (barnacle).

The most striking characteristic of Table 11-5 is the large number of freshwater taxa that were collected only during the final minimum flow period when the minimum flows were the highest. These included several species of midges, including *Chironomus* spp*., Dicrotendipes* spp., *Ablabesmyia rhamphe* group, and *Asheum beckae* plus other taxa from other invertebrate groups such as *Naidinae* spp. (oligochaete), *Euhridinea* spp. (leech), and *Oectis* spp. (caddisfly). It is the largely the presence of these freshwater taxa that cause the number of taxa collected in the upstream river segment (59) to be greater than the number that were collected in the segment below Sulphur Springs (31). These largely freshwater taxa contributed to high taxonomic richness and diversity values found in the segment above Hannah's Whirl during the final minimum flow period (refer to Tables 11-2 and 11-3).

**Table 11-5. Mean abundances values for benthic macroinvertebrate taxa in three river segments during two minimum flow periods on sampling dates when preceding 50-day flows were < 5 cfs. Taxa are ranked by the mean abundance in the segment upstream from kilometer 14.5. Values are limited to those taxa which had mean values grater than zero in that segment for at least one minimumflow period. All values expressed as individuals per m$^2$.**

| | | Kilometer 10.6 to < 12.6 | | Kilometer 12.6 to < 14.5 | | Kilometer ≥ 14.5 | |
|---|---|---|---|---|---|---|---|
| Rank | Taxon | July 2006 - March 2007 | Jan 2008 - March 2009 | July 2006 - July 2007 | Jan 2008 - March 2009 | March 2007 - July 2007 | July 2008 - March 2009 |
| 1 | Melanoides tuberculatus | 348 | 98 | 3,744 | 134 | 11,350 | 1,104 |
| 2 | Hydrobiidae spp. | 28 | 0 | 2,833 | 28 | 7,975 | 1,921 |
| 3 | Tubificoid Naididae spp. | 388 | 0 | 481 | 56 | 1,788 | 1,021 |
| 4 | Stenoninereis martini | 1,358 | 2,125 | 3,492 | 2,691 | 863 | 50 |
| 5 | Laeonereis culveri | 85 | 123 | 335 | 650 | 738 | 8 |
| 6 | Cassidinidea ovalis | 0 | 5 | 15 | 25 | 25 | 717 |
| 7 | Limnodrilus hoffmeisteri | 0 | 0 | 169 | 6 | 575 | 163 |
| 8 | Mytilopsis leucophaeata | 75 | 73 | 204 | 1,084 | 25 | 550 |
| 9 | Corbicula fluminea | 0 | 0 | 44 | 0 | 63 | 433 |
| 10 | Grandidierella bonnieroides | 5 | 208 | 56 | 153 | 313 | 150 |
| 11 | Pyrgophorus platyrachis | 0 | 0 | 6 | 0 | 0 | 463 |
| 12 | Dicrotendipes spp. | 0 | 5 | 15 | 69 | 13 | 254 |
| 13 | Chironomus spp. | 0 | 5 | 98 | 41 | 50 | 208 |
| 14 | Anopsilana jonesi | 0 | 0 | 0 | 6 | 0 | 233 |
| 15 | Boccardiella ligerica | 0 | 0 | 0 | 0 | 0 | 179 |
| 16 | Streblospio gynobranchiata | 0 | 5,035 | 0 | 119 | 0 | 88 |
| 17 | Hyalella spp. | 0 | 0 | 0 | 0 | 0 | 71 |
| 18 | Libellula spp. | 0 | 0 | 0 | 0 | 50 | 0 |
| 19 | Spionidae spp. | 0 | 0 | 0 | 0 | 0 | 50 |
| 20 | Sphaeroma terebrans | 0 | 0 | 17 | 0 | 0 | 46 |
| 21 | Tarebia granifera | 0 | 0 | 0 | 63 | 0 | 42 |
| 22 | Ablabesmyia rhamphe group | 0 | 0 | 0 | 0 | 0 | 42 |
| 23 | Asheum beckae | 0 | 0 | 0 | 0 | 0 | 38 |
| 24 | Gammarus mucronatus | 0 | 0 | 0 | 0 | 38 | 0 |
| 25 | Amphibalanus venustus | 0 | 0 | 0 | 0 | 0 | 33 |
| 26 | Stenochironomus spp. | 0 | 0 | 0 | 0 | 0 | 33 |
| 27 | Polydora cornuta sp. complex | 8 | 95 | 71 | 281 | 0 | 25 |
| 28 | Dero pectinata | 0 | 0 | 0 | 0 | 0 | 25 |
| 29 | Ephemeroptera spp. | 0 | 0 | 0 | 0 | 25 | 0 |
| 30 | Paranais litoralis | 0 | 0 | 0 | 0 | 0 | 25 |
| 31 | Procladius (Holotanypus) spp. | 0 | 0 | 0 | 0 | 13 | 8 |
| 32 | Ceratopogonidae spp. | 0 | 0 | 0 | 0 | 0 | 21 |
| 33 | Polypedilum halterale group | 0 | 0 | 2 | 0 | 0 | 17 |
| 34 | Uromunna reynoldsi | 0 | 0 | 0 | 0 | 0 | 17 |
| 35 | Streblospio spp. | 1,385 | 0 | 96 | 0 | 13 | 0 |
| 36 | Rhithropanopeus harrisii | 0 | 5 | 23 | 59 | 13 | 0 |
| 37 | Euhirudinea spp. | 0 | 0 | 0 | 6 | 0 | 13 |
| 38 | Gastropoda spp. | 0 | 0 | 0 | 3 | 0 | 13 |
| 39 | Oecetis spp. | 0 | 0 | 0 | 0 | 0 | 13 |
| 40 | Chironomidae spp. | 0 | 0 | 0 | 6 | 0 | 8 |
| 41 | Arhynchobdellida spp. | 0 | 0 | 0 | 0 | 0 | 8 |
| 42 | Bratislavia unidentata | 0 | 0 | 0 | 0 | 0 | 8 |
| 43 | Chironominae spp. | 0 | 0 | 0 | 0 | 0 | 8 |
| 44 | Cladotanytarsus sp. F | 0 | 0 | 0 | 0 | 0 | 8 |
| 45 | Cryptotendipes spp. | 0 | 0 | 0 | 0 | 0 | 8 |
| 46 | Parachironomus carinatus | 0 | 0 | 0 | 0 | 0 | 8 |
| 47 | Pristina spp. | 0 | 0 | 0 | 0 | 0 | 8 |
| 48 | Procladius spp. | 0 | 0 | 0 | 0 | 0 | 8 |
| 49 | Tanytarsus sp. G | 0 | 0 | 0 | 0 | 0 | 8 |
| 50 | Nemertea spp. | 0 | 0 | 2 | 6 | 0 | 4 |
| 51 | Eudendrium spp. | 0 | 0 | 0 | 3 | 0 | 4 |
| 52 | Aoridae spp. | 0 | 0 | 0 | 0 | 0 | 4 |
| 53 | Apedilum spp. | 0 | 0 | 0 | 0 | 0 | 4 |
| 54 | Chaoborus punctipennis | 0 | 0 | 0 | 0 | 0 | 4 |
| 55 | Enallagma spp. | 0 | 0 | 0 | 0 | 0 | 4 |
| 56 | Hydrozoa spp. | 0 | 0 | 0 | 0 | 0 | 4 |
| 57 | Melinna maculata | 0 | 0 | 0 | 0 | 0 | 4 |
| 58 | Naidinae spp. | 0 | 0 | 0 | 0 | 0 | 4 |
| 59 | Polycladida spp. | 0 | 0 | 0 | 0 | 0 | 4 |

## 11.4 Discussion

Benthic macroinvertebrates are a critical link the food webs in tidal river ecosystems as they process organic matter and comprise a principal food source for a the juveniles of most fishes and also many wading birds. Although the benthic macroinvertebrate data collected in the Lower Hillsborough River are not sufficient to characterize changes in the actual abundance of key taxa in the river segments over time, the data clearly indicate there are strong spatial gradients in the benthic macroinvertebrate community with a more mesohaline fauna downstream of Sulphur Springs transitioning to a more oligohaline fauna with some tidal freshwater characteristics above the spring. In particular, during the final minimum flow period when the highest minimum flow rates were implemented, the data indicate that the segment above Hannah's Whirl had relatively high taxonomic richness and diversity due in part to the presence of freshwater taxa that were present below the dam.

It is reiterated these findings pertain to periods when minimum flows had been the predominant source of flow below the dam for the preceding 50 days. During the wet times of the year, fresh water can extend downstream of Sulphur Springs for months at a time. The minimum flows are intended to enhance ecological stability by creating an oligohaline zone below the dam during the dry season, when, in the absence of minimum flow releases, mesohaline waters often occur below the dam. Although the minimum flows established for the Lower Hillsborough River are based on to extending an oligohaline zone (< 5 psu salinity) toward Sulphur Springs, lower salinity water (< 2 psu) occurs in the reaches closest to the dam. As described in Chapter 4, the lowering of water levels in Sulphur Springs makes more spring water available for diversion to the base of the dam but increases the salinity of the spring discharge. If slightly higher salinity water from the spring can acceptably be introduced above Hannah's Whirl, the increased use of Sulphur Springs allows for greater minimum flows that push a zone of low salinity water further downstream from the dam.

At this time, it is concluded that a suitable macroinvertebrate community that is comprised of a mixture of freshwater and estuarine taxa, the latter of which are species common in oligohaline waters, was established in the river reaches below the dam at salinity values that occurred after 2008. However, the stability of the salinity regime should also be considered, with the goals of having reduced variability and the infrequent occurrence of high salinity values. The findings for salinity presented in Chapter 4, indicate that the higher minimum flow rates that began in March 20012 (23 to 26 cfs) appear effective in that regard. As described in Chapter 4, the continuous salinity recorders at Rowlett Park and at kilometer 13.6 are very informative for assessing salinity in the river above and below Hannah's Whirl and these recorders should be continued.

The effects of minimum flows on DO concentrations in the river can also have important implications for the benthic macroinvertebrate community. Statistical relationships of benthic macroinvertebrates with DO concentrations and percent saturation values at the time of benthos sampling were not examined as part of this study. However, based on general knowledge of ecological relationships, the effects of different minimum flow rates on preventing or minimizing the occurrence of hypoxic conditions should be a strong factor or evaluating the potential effects of minimum flows on the benthic macroinvertebrate community.

As discussed further in Section 13.5, it is recommended that additional sampling and analysis be conducted for benthic macroinvertebrates, emphasizing a distribution of samples in the reach of the river above Sulphur Springs. These sampling efforts should be conducted during two separate years after the prolonged implementation of minimum flows, with consideration given to a third year of sampling pending the findings of the first two sampling efforts.

# 12 Status of the Water Sources Identified to Provide Minimum Flows

This chapter summarizes status of the four water sources that are identified in the adopted Recovery Strategy for the Lower Hillsborough River to be used to provide minimum flows to the Lower Hillsborough River. These four sources are Sulphur Springs, Blue Sink, Morris Bridge Sink, and the Tampa Bypass Canal. The water quantities, including those that are currently implemented and those that are projected, are briefly summarized along with their priority for use. A complete description of the details regarding the projected quantities, priority, flows, and water level conditions related to the use of these four water sources is provided in the adopted Recovery Strategy for the Lower Hillsborough River provided as Appendix 1A to this report.

The recovery strategy specifies that the District evaluate all identified projects relative to their potential to cause unacceptable adverse impacts prior to their implementation. The status of the projects that are identified in the recovery strategy are discussed briefly below. For projects that are currently in the evaluation, design, or permitting phases, reference is made to other documents that can be consulted for additional details. In the case of Sulphur Springs, for which the pumping facilities have been completed, information presented in previous sections of this report is referenced.

The recovery strategy also specifies that the District shall also monitor and evaluate the effect the recovery strategy is having on water levels in the Hillsborough River above the City's dam to at least Fletcher Avenue. Because the use of the Tampa Bypass Canal to provide minimum flows has an effect on water levels in the Hillsborough River Reservoir, the effect of the recovery strategy on water levels in the river above the dam is also discussed in this chapter.

## 12.1 Sulphur Springs

As described in Section 2.5.1, the current pumping facility at Sulphur Springs was completed in 2012. This facility utilizes a dual pump system with separate pumps to divert water from the spring pool to the base of the Hillsborough River dam or to Sulphur Springs Run. This new system also allows for the management of water levels in Sulphur Springs Pool over a wider range of elevations than before. As described Section 2.6, maintaining lower water levels in the spring pool increases spring discharge but results in an increase in the salinity of the water discharging from the spring.

To get the minimum flows underway, the City of Tampa implemented the diversions of spring water to the base of the dam as quickly as possible by changing the pumps and piping system at Sulphur Springs to increase the minimum flows. However, the accurate metering of spring diversions was difficult at times due to the changes in the facilities used to deliver the flows. It is emphasized that some of the spring diversion rates presented in this report contain some potential error associated with these metering issues, but were the best available data at the time.

One issue the increased diversion of spring water to the base of the dam has been the occurrence of large mats of filamentous algae in the spring run. Large mats of filamentous algae were first observed prior to the implementation of minimum flows in 2000 and 2001 when large quantities of flow from Sulphur Springs were diverted to the reservoir for water supply during the drought in those years. The minimum flows report for Sulphur Springs reported on this occurrence, and suggested that reduced current velocities in the spring run may have contributed to the algae growth (SWFWMD 2004). That report further suggested it was not known what rates of flow are necessary to prevent excessive expansions of filamentous algae in the spring run, but it was assumed that greater flow rates would reduce the potential for excessive growths of algae.

Based on visual observations by District staff, large mats filamentous algae have historically not been present in Sulphur Springs Run under normal flow conditions and were not present in the wet years of 2003 through 2005 when there were only infrequent diversions of spring water to the dam. A study of fish populations in Sulphur Springs in 2003 by researchers from the University of Florida found the coverage of filamentous algae was less than six percent at their sampling stations (SWFWMD 2004).

In recent years, however, large growths of filamentous algae in the spring run have appeared as minimum flows have been implemented. Quantitative data are not available prior to June 2013, but visual observations by District staff indicated that the algae became more widespread after the diversion of higher rates of spring flow to the base of the dam began in the spring of 2012. The collection of quantitative data on areal coverage, biomass, and species composition of the filamentous algae in the spring run began June 5, 2013. Eight sampling trips have been made to sample algae since that time with the most recent sample on July 15, 2014. A photograph of filamentous algae just upstream of the footbridge on Sulphur Springs run taken run on May 14, 2014 is shown in Figure 12-1.

**Figure 12-1. Photograph of filmentous algae just upstream of the food bridge in Sulphur Springs Run on May 14, 2014.**

The filamentous algae that has been observed have primarily been green algae (Chlorophyta) of the genera *Chatetomorpha* spp. and *Cladophora* spp. and a yellow-green alga (Xanophyta) of the genus *Vaucheria* spp. Small quantities of the macroalga *Chara* spp. and the vascular submersed aquatic plants *Najas* spp. and *Hydrilla verticillata* have also been observed in the spring run since sampling began. The analyses of these data is still preliminary, but the data collected to date show the peak biomass of algae were observed on the sampling dates of June 5, 2013 and July 15, 2014 (Figure 12-2). There may be a seasonal component to the filamentous algae growth, but changes in discharge from the spring pool and current velocities in the spring run are also likely factors affecting the abundance of the filamentous algae.

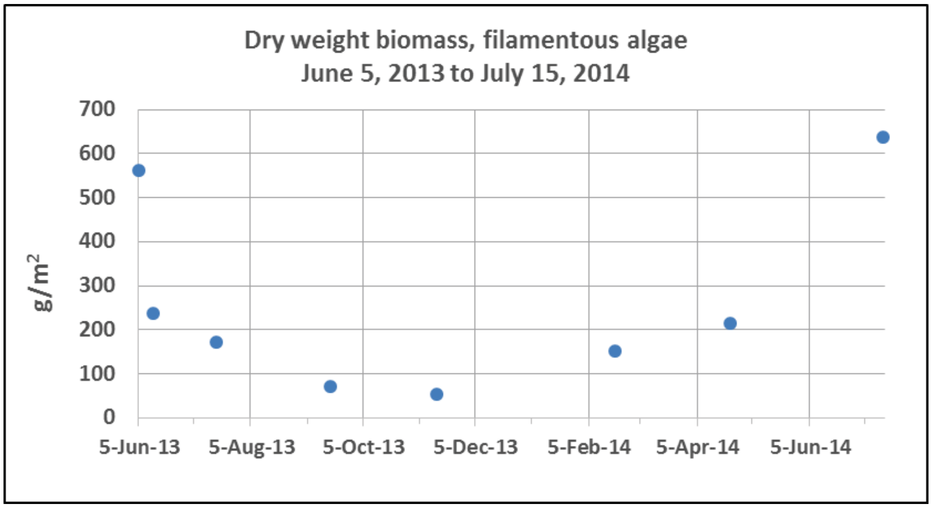


**Figure 12-2. Dry weight biomass of filamentous algae in Sulphur Springs run on eight sampling events between June 5, 2013 and July 15, 2014.**

These results are shown only as an example of data that are being collected as part of ongoing investigations of the relationships of the rate of flow to the spring run and the abundance of filamentous algae. Field measurements of current velocity are being made as part of every sampling trip. Also, the USGS is installing an acoustic Doppler current profile device in the spring run so that measurements of net cross sectional velocity can be obtained every 15 minutes. Continuous measurements of current velocity will be particularly important due the strong effects of tides in the spring run. The monitoring of, flows, water levels and current velocities in the spring run as various rates of minimum flows are implemented should provide useful information regarding factors affecting the abundance of filamentous algae in Sulphur Springs Run.

If the abundance of filamentous algae becomes a criterion for management of Sulphur Springs, this could affect the amount of spring water that can be diverted for minimum flows to the Lower Hillsborough River. The new facilities at Sulphur Springs allow for the management of spring flow much more effectively than in previous years. The dual pump system at Sulphur Springs Pool now allow for effective management of flows to the spring run in small increments (≈ 1 cfs). Also, the modified weir near the mouth of the spring run allows for some manipulation of water levels in the spring run.

The manual harvesting of filamentous algae from the spring run could also be considered as a management option. If manual harvesting is feasible, it may allow for more water to be diverted to the base of the dam while keeping algal levels in the spring run at acceptable levels. It is therefore recommended that manual harvesting be considered in continued investigations of factors affecting filamentous algal abundance in Sulphur Springs Run.

## 12.2 Blue Sink

Blue Sink is a natural sinkhole in the City of Tampa that lies in an urbanized area of North Tampa. Descriptions of the hydrologic setting of Blue Sink can be found in reports by the District (2009) and MWH (2009) that are discussed below. Blue Sink receives flow from Curiosity Creek, which drains a 3.5 square mile basin. Ewanowski Spring, a small spring on residential property, is connected to Curiosity Creek approximately 50 meters upstream from Blue Sink. Water from Curiosity Creek and Ewanowski Spring that discharge into Blue Sink historically flowed toward Sulphur Springs via natural underground conduits within the Upper Florida Aquifer. However, sometime during the 1970s, the connection between Blue Sink and Sulphur Springs began to deteriorate due to trash and debris accumulation and sediment deposition. By the 1980s, the connection between Blue Sink and Sulphur Springs was blocked. As a result, water levels in Blue Sink and Curiosity Creek began to rise and flooding incidents in the area began to increase. In order to remove excess storm water from Curiosity Creek, the City of Tampa constructed a large retention pond just south of Blue Sink and a permanent lift station to pump water out of this system and convey it to the Hillsborough River via the storm drainage network to a location downstream of Sulphur Springs.

The concept of using Blue Sink to provide minimum flows is to return water from the Blue Sink / Curiosity Creek system to the Lower Hillsborough River where it may have the greatest ecological benefit. To examine options for accomplishing this goal, the City of Tampa sponsored a feasibility study of how Blue Sink could be used to provide minimum flows to the lower river (MWH 2009). Options that were investigated included: diverting water from Blue Sink via a pump and pipeline to Jasmine or Orchid Sink and relying on underground karst from those sinks to Sulphur Springs from where it could be diverted from the spring pool to the base of the dam; and construction of a pump and pipe system to the Sulphur Springs pump station or the base of the City of Tampa Dam.

The alternative that was selected for was the construction of a pump station at Blue Sink and a pipeline that extends from the sink to the transmission pipeline that extends from Sulphur Springs to the City of Tampa dam. A number of factors were considered in the alternatives analysis (e.g., costs, permitting, water quality), but a critical factor for the selection of this alternative is that it would provide for high levels of efficiency and reliability for transporting the water pumped from Blue Sink to the base of the dam. In other words, as opposed to using groundwater flow paths, this alterative would best ensure that most or all of the water diverted from Blue Sink for minimum flows would make it to the base of the

Hillsborough River Dam. Full details of all the considerations that went into the alternatives that were considered are contained in the Blue Sink feasibility study performed for the City by MWH (2009).

The recovery strategy does not specify the quantity of water that can be diverted from Blue Sink to provide minimum flows to the Lower Hillsborough River. However, in the spring of 2008 and 2009 the District conducted pumping tests to evaluate the potential yield of Blue Sink. The pumping test conducted in 2008 was compromised by a mechanical failure that interrupted pumpage from the sink for 36 hours, with levels in Blue Sink quickly recovering to pre-pumping levels. A second pumping test was conducted from March 2 to April 1, 2009, when a pumpage rate of 2 mgd (3.1 cfs) was sustained for 30 days. Water levels in Blue Sink, Ewanowski Spring, and number of wells and lakes in the area were monitored during the pumping test. Drawdowns in the Upper Florida aquifer and lakes in the area were calculated based on the results of the pumping test. Based on these findings, the District concluded that Blue Sink could likely provide up to 2 mgd (3.1 cfs) to assist meeting the minimum flows of the Lower Hillsborough River in the typical spring dry season. A full description of the methods and findings of the District pumping tests are provided in SWFWMD (2009).

Based largely on the District's findings, the City of Tampa submitted a water use application to the District on July 10, 2013 to use Blue Sink at a rate of 2 mgd (City of Tampa 2013). Analyses provided with the City's permit application indicated that Blue Sink would be needed for minimum flows a maximum of 287 days during the driest recent calendar year (2006), which agreed well with the District's analyses. To be conservative, the City simulated the withdrawal of 2 mgd of water continuously over a 318-day period to evaluate worst case conditions. Another simulation was run assuming a 2 mgd pumpage rate for the entire year. The effects of these withdrawals were simulated in a numerical groundwater flow model (DWRM2) and drawdowns in the surficial and Upper Floridan aquifers were predicted. The City's analyses concluded that water level impacts were relatively small (City of Tampa 2013).

The District reviewed the City's findings as part of the water use permit review process and concluded the requested quantities (2 mgd) met the District's conditions for issuance. Accordingly, the District issued a water use permit to the City of Tampa in December 2013 for the use of Blue Sink that authorizes a peak monthly withdrawal rate of 2.0 mgd and an annual average withdrawal rate of 1.74 mgd (SWFWD 2013). The District and the City also have a cooperative funding project to construct the Blue Sink pump station and pipeline. The design of these facilities is complete, and it is expected that construction will begin in 2015 with construction complete in 2016. Water use from the sink will be metered and water levels will be monitored either by the District or the City of Tampa in Blue Sink, Ewanowski Spring, and a number of lakes and monitor wells in the area.

## 12.3 Tampa Bypass Canal

The recovery strategy establishes how diversions from the lower and middle pools of the Tampa Bypass Canal (TBC) are to be used to provide minimum flow water to the Lower Hillsborough River. In the priority ranking of the four water sources, the TBC is to be used to provide minimum flows to the lower river after Sulphur Springs and Blue Sink have been utilized. How the lower and middle pools of the TBC are to be used to provide minimum flows is very specific, depending on water levels in the TBC and the rate of flow from the middle pool to the lower pool. For details on how those conditions are applied, readers should consult the Recovery Strategy for the Lower Hillsborough River which is included as Appendix 1A to this report. A general description of how the TBC is used to provide minimum flows to the lower river is provided below.

Minimum flows to the Lower Hillsborough River that originate from the Tampa Bypass Canal are implemented by pumping water from the middle pool of the TBC over Structure S-161 on the Harney Canal into the Hillsborough River Reservoir. Under certain water level conditions in the TBC, minimum flow pumpage from the middle pool may be replaced by pumpage from the TBC lower pool. Once within the reservoir, water diverted from the TBC is released to the lower river using pumping facilities located at the Hillsborough River Dam. Due to concerns expressed by the City of Tampa about the loss of water pumped from the TBC into the reservoir, only seventy-five percent of the water pumped from the TBC into the reservoir is released to the lower river for minimum flows.

The pumping facilities on the middle pool of the TBC and at the Hillsborough River Dam are ultimately to be owned and operated by the City of Tampa. However, to get the minimum flows implemented as soon as possible, the District constructed temporary pumping facilities on the middle and lower pools of the TBC and at the Hillsborough River Dam in 2007. These temporary pumps have been in operation since December 31, 2007, providing minimum flow water to the Hillsborough River.

The District and the City of Tampa are entering into a cooperative funding agreement to construct permanent pumping facilities on the middle pool of the TBC and at the Hillsborough River Dam which will be owned and operated by the City of Tampa. The facility at the dam will be a regulated and metered siphon system that takes advantage of the head difference in water levels between the reservoir and the lower river. The design capacity of both the pump on the middle pools of the TBC and the siphon at the Hillsborough River Dam will be 17 cfs. The recovery strategy specifies that the pumping facility used to move water from the lower pool to the middle pool of the TBC will remain in ownership and be operated by the District.

### 12.3.1 Minimum flow use from the TBC since 2008

For simplicity in discussion and the labeling of figures and tables, the diversions of minimum flow water from the TBC to the lower river that began on December 31, 2007 are described as starting on January 1, 2008 in this report. As described in Section 2.5, these diversions from the TBC have supplemented diversions of spring water to the base of the dam, which began in 2002 and increased over time. As previously discussed, the diversions of water from the TBC are to be used after diversions from Blue Sink. Because the Blue Sink diversion facility has not yet been completed, the minimum flows that have been provided to the lower river since 2008 have come solely from Sulphur Springs and the TBC.

A hydrograph of minimum flow pumpage from the middle pool of the TBC to the reservoir is shown in Figure 12-3 for the period January 1, 2008 to June 20, 2013. The recovery strategy states that diversions from the middle pool for minimum flows shall not exceed a rate of 7.1 mgd, which is equivalent to 11 cfs. Figure 12-3 shows that minimum flow pumpage from the middle pool to the reservoir at rate of 11 cfs has been frequent since 2008. However, pumpage rates in 2013 were less, because 11 cfs was not needed to meet the minimum flows during this relatively wet period.

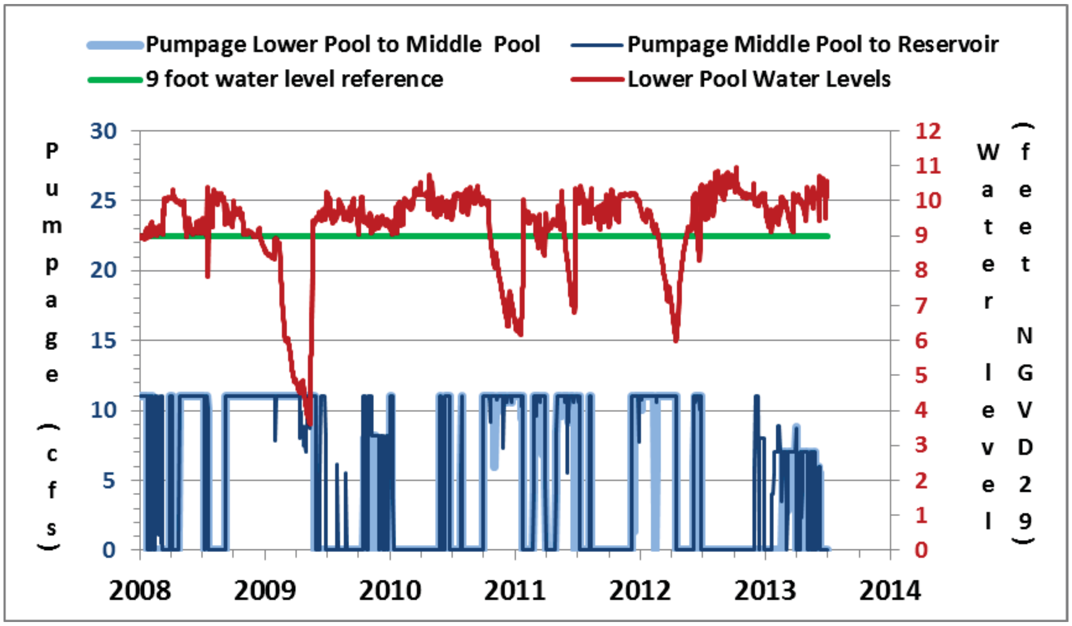


**Figure 12-3. Minimum flow pumpage rates from the lower pool to the middle pool of the TBC, from the middle pool of the TBC to the Hillsborouh River resevoir, water levels in the lower pool of the TBC, and a reference line at 9.0 feet for water levels in the lower pool of the TBC.**

Although not shown in Figure 12-3, minimum flow releases from the reservoir occurred on all dates that there was minimum flow pumpage from the middle pool. However, 75% of the pumpage rate from the middle pool is released to the lower river due to concerns expressed by the City of Tampa about loss terms for water pumped from the TBC to the reservoir. Accordingly, the 11 cfs pumpage rates from the middle pool of the TBC were matched by releases of 8.3 cfs to the lower river at the Hillsborough River Dam.

Figure 12-3 also shows minimum flow pumpage from the lower pool to the middle pool. This pumpage is also capped at a rate of 11 cfs, and is intended to replace the minimum flow pumpage from the middle pool to the reservoir. However, if water levels in the middle pool are over 12.0 feet NGVD29 and there is at least 11 cfs flow over Structure S-162, then pumpage from the lower pool is not required. Water levels in the middle pool and flows over Structure S-162 are not shown in Figure 12-3, but the frequent pumpage from the lower pool occurred because these conditions were not in effect and pumpage from the lower pool was required. An exception to this was in December 2012, when due to high water levels and flows from the middle pool, pumpage from the lower pool was not needed to replace minimum flow pumpage from the middle pool.

An important condition for use of the lower pool for minimum flows pertains to water levels in the lower pool. When water levels in the lower pool are below 8.7 feet, withdrawals from the lower pool are considered to be from water storage. The recovery strategy stipulates that if water levels in the lower pool fall below an elevation of 6.0 feet, withdrawals from the lower pool are to cease and not resume until water levels in the lower pool rebound to 9.0 feet and remain above that elevation for 20 days in order to allow replenishment of the lower pool. It is District procedure that during such periods of lower pool replenishment minimum flow pumpage from the middle pool to the reservoir ceases as well.

Water levels in the lower pool and a 9 foot reference level are shown in Figure 12-3. Water levels fell below 9.0 feet during four sustained intervals in between 2008 and June 2013. The lowest water levels occurred in the spring of 2009 when water levels in the lower pool fell to an elevation of 3.6 feet. The District requested and was issued a variance from the US Army Corps of Engineers to pump the lower pool at elevations below 6.0 feet and minimum flow pumpage continued during this period. Unusually heavy rains in May 2009 caused water levels in the lower pool to rebound to above 9.0 feet.

Water levels dropped to 6.0 feet again in the spring of 2012, when the protocol regarding pumpage from the lower pool described in the recovery strategy was followed. When water levels reached 6.0 feet on April 13, 2012, minimum flow pumpage from the lower pool ceased and did not resume until June 5, 2012, which was 22 days after water levels in the lower pool had rebounded to 9.0 feet. During this period, minimum flow pumpage from the middle pool to the reservoir also ceased, as did minimum flow releases from the reservoir to the lower river. This period of no reservoir release provided an opportunity to examine changes in salinity in the lower river as freshwater releases were turned on and off, and is discussed in Sections 4.1.1 and 4.1.3 of this report.

## 12.4 Morris Bridge Sink

The recovery strategy specifies that contingent upon approval of any required permit, Morris Bridge Sink shall be used to provide up minimum flow water up to a rate of 3.9 mgd (6 cfs). Morris Bridge Sink is located about 0.6 miles south of the Hillsborough River, just east of the Interstate 75 and the upper reaches of the Tampa Bypass Canal. The sink is approximately 135 feet in diameter and 200 feet deep.

Diversions from Morris Bridge Sink are to be routed via a pipeline to the upper pool of the TBC, from where it will flow via a gravity drain to the middle pool of the TBC. Once in the middle pool, an equivalent amount of water will be pumped from the Harney Canal around Structure S-161 to the Hillsborough River Reservoir. In keeping with these rates, the permanent pumping facility that will be constructed and operated by the City of Tampa at Structure S-161 will have a pumping capacity of 17 cfs to deliver the 11 cfs minimum flow water obtained from the TBC plus the 6 cfs that may come from Morris Bridge Sink.

In priority of water sources, Morris Bridge Sink is to be used for minimum flows after Sulphur Springs and Blue Sink. Then, the use of Morris Bridge Sink versus the Tampa Bypass Canal is based on water levels in the lower pool of the TBC. As described in Section 2.3, the TBC is used for potable water supply by both the City of Tampa and TBW. The recovery plan states that when TBW does not draw the lower pool down to 9.0 feet for water supply purposes and supplemental flow is needed for the Lower Hillsborough River minimum flows, the District shall divert up to 7. 1 mgd (11 cfs) from TBC lower pool to the TBC middle pool prior to diverting flow from Morris Bridge Sink to the TBC middle pool (see Appendix 1A for Recovery Strategy rule language). Basically, when water levels in the lower pool are above 9.0 feet, the lower pool will be used to replenish pumpage from the middle pool before diversions from Morris Bridge Sink are implemented. If water levels in the lower pool are below 9.0 feet, diversions from Morris Bridge Sink will be implemented first.

The pumping facility at Morris Bridge sink will be owned and operated by the District. It has been determined that a water use permit will need to be obtained to utilize the sink for minimum flow purposes. Because the District cannot issue a permit to itself, a water use permit would have to be granted to the District by the FDEP. In order to evaluate the water supply yield of Morris Bridge Sink, the District performed a 30-day pumping test with a sustained withdrawal rate of 6 cfs. The pumping test, which was conducted during extremely dry conditions in April 2009, indicated that Morris Bridge Sink could sustain a withdrawal rate of 6 cfs. The complete findings of the pumping test can be found in SWFWMD (2010).

In support of an upcoming water use permit application to the FDEP, the District has performed an analysis of the amount of water that will be needed from Morris Bridge Sink to provide minimum flows. This analysis focused on the period from 2008 to 2012 because minimum flows pumpage from the Tampa Bypass Canal had been in effect and there was corresponding water level data for the TBC lower pool (Figure 12-3). Therefore, by assuming that the Morris Bridge Sink facilities had been completed, this period allowed an assessment of how much Morris Bridge Sink would have been used to provide minimum flows in conjunction with the TBC lower pool. To be conservative, the analysis did not assume any pumpage rates from Blue Sink, as those facilities have not yet been constructed.

Also, to be conservative, the analysis focused on water years 2009 and 2011 because they represented very dry conditions when minimum flows for the Lower Hillsborough River would have been in effect for long periods of time. The analyses indicated that for the nine-months from October through June, the pumpage from Morris Bridge Sink would have been 2.8 mgd for the period ending in June 2009 and 2.6 mgd for the period ending in June 2011. If diversions from Blue Sink had been online, the average rates of pumpage from Morris Bridge Sink would have been 2.6 mgd during 2009 and 2.4 in 2011.

Using these estimated withdrawal quantity for 2009 without Blue Sink, the District has performed groundwater modeling to simulate changes in water levels in the upper Floridan and surficial aquifers near Morris Bridge Sink. Of concern are potential impacts to nearby private wells and approximately 64 acres of isolated wetlands that occur near the sink. The analyses conducted by the District indicate that the use of Morris Bridge Sink at a rate of 6 cfs (3.9 mgd) will not cause unacceptable impacts and will meet the conditions of issuance for a water use permit. The results of the District's analyses of the quantities of water needed from Morris Bridge Sink, the groundwater modeling of the projected withdrawals from the sink, and assessments of potential effects to nearby wetlands will be provided in the water use permit application submitted to the FDEP. It is expected this application will be submitted in 2015 (SWFWMD 2015, in prep).

## 12.5 Water transmission pipeline and calculation of water loss from the Hillsborough River Reservoir due to augmentation from the Tampa Bypass Canal

The recovery strategy contains a discussion of the construction of water transmission pipeline that would run from the middle pool of the TBC to the City of Tampa water treatment facility with a spur or additional pipeline running to a location just downstream of the Hillsborough River dam. The City of Tampa water treatment facility is located on the south bank of the reservoir about 4.8 miles downstream from where the Harney Canal intersects the reservoir. Water that is pumped from the Harney Canal into the reservoir to supplement of the City's potable water supplies currently flows through the reservoir to the City of Tampa's water supply intake on the reservoir. Similarly, water that is pumped from the TBC for minimum flow purposes flows through the reservoir to the dam were it is pumped around the dam for release to the lower river. Water that is pumped into the reservoir from the TBC for either potable supply or minimum flows can be referred to as reservoir augmentation.

When the recovery strategy was developed, there were concerns expressed that water pumped from the TBC into the reservoir experiences some net loss from the reservoir before it flows to either the water treatment facility or the dam. Therefore, the transmission pipeline would serve to eliminate that loss and result in a water savings, which was estimated at 1.9 mgd (2.9 cfs) for minimum flow purposes.

However, there was not consensus about the rate of any water loss that was occurring, and the District and the City agreed that the hydrologic efficiency of the proposed pipeline as opposed to having the TBC diversions flow through the reservoir be subject to peer review. A three-person review panel was formed that included faculty from the University of Florida, the University of South Florida, and a consultant from the Tampa Bay area who had considerable experience with the Hillsborough Reservoir / TBC system. The primary objective of the peer review was to determine the projected water saving that might be expected to result from the construction of a pipeline to convey augmentation water pumped from the TBC to the reservoir based on previous studies. The peer review panel developed a conceptual hydrologic model of the reservoir and a one-year water budget for the reservoir using recent data. The one-year budget relied upon estimates and assumptions taken from several previous studies.

The peer review panel published their findings in a letter report (Motz et. al, 2008). The panel concluded that previous studies that calculated water loss terms did not make the distinction between water lost to evaporation and water recirculated in the groundwater system between the reservoir and the TBC. Water that flows from reservoir back to the TBC can be returned by simply pumping the water back into the reservoir. The panel thus concluded that the only water lost to the system is from evaporation, and that any increased water loss would be the increased evaporation due to the addition of the augmented water pumped from the TBC which would slightly raise the water level and increase the surface area of the reservoir. However, the panel noted that water pumped from the TBC is also withdrawn or released from the reservoir, thus augmentation from the TBC does not raise the level of the reservoir bur rather keeps it from falling. Even ignoring the simultaneous release of the water, the panel concluded that these increased evaporation losses that would result from augmentation using the TBC are less than a few tens of thousands to a few hundred thousand gallons of water per day, and that the projected water savings that could be expected from the pipeline would be small. Based on this conclusion, the water transmission pipeline was dropped from consideration in the recovery strategy.

The findings of the review panel can also be applied to conclude that the 25% loss term that is applied to minimum flows that are delivered from the TBC to the reservoir is an overestimate. Based on the 25% loss term specified in the recovery strategy, of the 11 cfs (7.1mgd) of minimum flow water that is specified to come from the Tampa Bypass Canal, 2.7 cfs (1.8 mgd) is currently not released to the lower river. Ignoring the simultaneous release of the minimum flow water, the specified rate of water loss is much greater than the potential loss terms discussed by the peer-review panel, and it is the conclusion of this minimum flows assessment that the 25% loss term specified in the recovery strategy is an overestimate.

## 12.6 Potential impacts of the recovery strategy to water levels in the Hillsborough River Reservoir

In response to concerns about how the implementation of minimum flows for the Lower Hillsborough River might affect water levels in the river above the dam, the District completed a study of the Middle Hillsborough River in 2009 (Leeper 2009). This report designated the middle Hillsborough River as the reach between the Hillsborough River Dam and Fletcher Avenue, which is located approximately 12 river miles (19.5 kilometers) upstream of the dam running along the centerline of the reservoir. The report evaluated the middle river’s physiography, bathymetry, watershed characteristics, and water budget including withdrawals, flows at the dam and augmentation from the TBC. The report also discussed the history of the middle river, including the series of impoundments that were built near the present day Hillsborough River Dam and the construction of the Tampa Bypass Canal.

The middle river report evaluated relationships between water levels at the Hillsborough River dam and other sites in the middle river, including two USGS gages at Fletcher Avenue and Fowler Avenue, the latter of which is located about 3.6 miles upstream of the Harney Canal. The report also examined water levels at a District gage on the reservoir near the Harney Canal.

With regard to this minimum flows evaluation, the relationships between water levels at these sites is relevant only at low water levels, when there is either zero or low flow (< 24 cfs) at the Hillsborough River dam for this is when minimum flows are in effect. Water levels at the dam during periods of low rainfall fluctuate near the dam spillway elevation of 22.5 feet NGVD29, with lower water levels occurring as the dry season progresses and there are prolonged periods of no flow at the reservoir spillway. As discussed in Section 2.5, low rates of flow at the dam spillway are very infrequent, so when minimum flows are in effect, water levels in the reservoir are usually below the spillway elevation.

Using data collected during 2008, the middle river study found that there was very close agreement between water levels at the dam and Fowler Avenue when water levels at the dam were between 18.2 feet and spillway elevation of 22.5 feet. Across this range of elevations, the water surface between the dam and Fowler Avenue is relatively flat. However, when water levels at the dam drop below 18.2 feet, water levels at Fowler Avenue and points upstream tended to maintain higher water levels, due to changes in bathymetry of the bed of the river near Fowler Avenue, which was verified by a bathymetric survey of the middle river conducted in 2007 (Ping and Beck, 2008).

Using data from 2008 through 2013, this minimum flows assessment examined relationships between water levels at the Dam and Fowler Avenue. Figure 12-4 is time series plot of water levels at both locations for the period June 1, 2008 through September 30, 2013. There is very close agreement between the two sites over time except during two types of conditions. The first is when there when water levels at the dam fell to levels near 17 to 18 feet, and water levels at Fowler stabilized at higher levels, such as in 2008, 2011, and 2012.

The second is when water levels at the dam were near the spillway elevation of 22.5 feet and water levels at Fowler Avenue was considerably higher. This second category corresponds to periods of high flow in the Hillsborough River when water is released from the reservoir using the tainter gates located at the dam. During these high flow events, releases from the reservoir maintains water levels near the dam at 22.5 feet or lower, but constrictions in the reservoir cross section allow water levels at Fowler to rise as water accumulates further upstream. The regulation of high water levels in the middle river is closely managed by the District's Structure Operations Division and it not discussed further in this report, which focuses on periods of minimum flows when there is either zero or very low flow at the dam spillway.

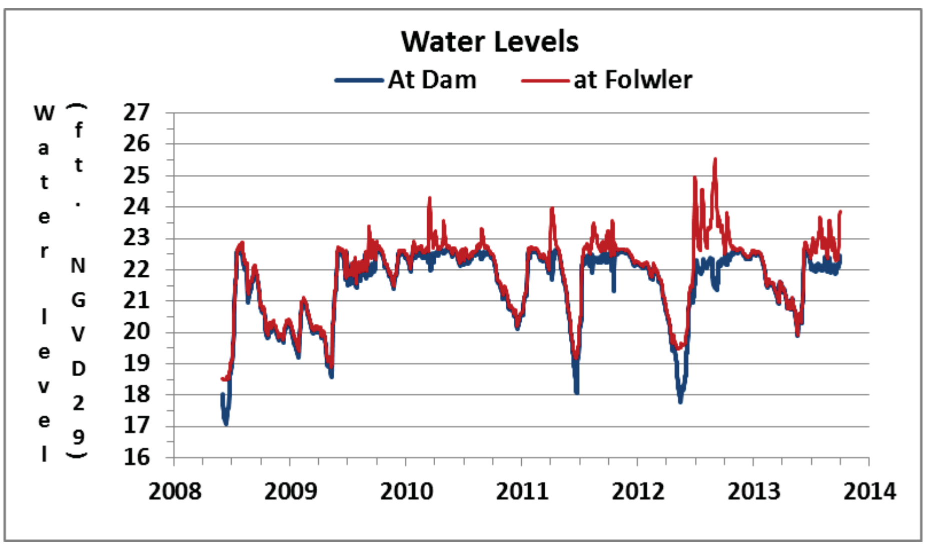


**Figure 12-4. Water levels at the USGS gages at the Hillsborough River Dam and at Fowler Avenue for the period June 1, 2008 through September 30, 2013.**

To examine the relationship of water levels in the middle river at low flows (including zero flow), water levels at the dam are plotted versus water levels at Fowler Avenue in Figure 12-5 on days when flows at the dam were < 27 cfs. As shown by the 1-to-1 correspondence line, water levels at Fowler are generally very similar to water levels at the dam during periods of low flow. However, in agreement with the time series plot in Figure 12-5, there are differences between the two gages when there are low water levels at the dam and water levels at Fowler stabilize at higher elevations. As previously discussed, this is due to changes in the elevation of the river bed near Fowler Avenue.

Results are shown for water levels at the dam and Fowler Avenue, for this is the reach of the middle river where water levels could potentially be most affected by the minimum flow water at the dam. The response of the river at points upstream, such as at Fletcher Avenue, will respond more closely to flow into the reservoir and the morphology of the river upstream of Fowler Avenue and are much less influenced by water levels at the dam.

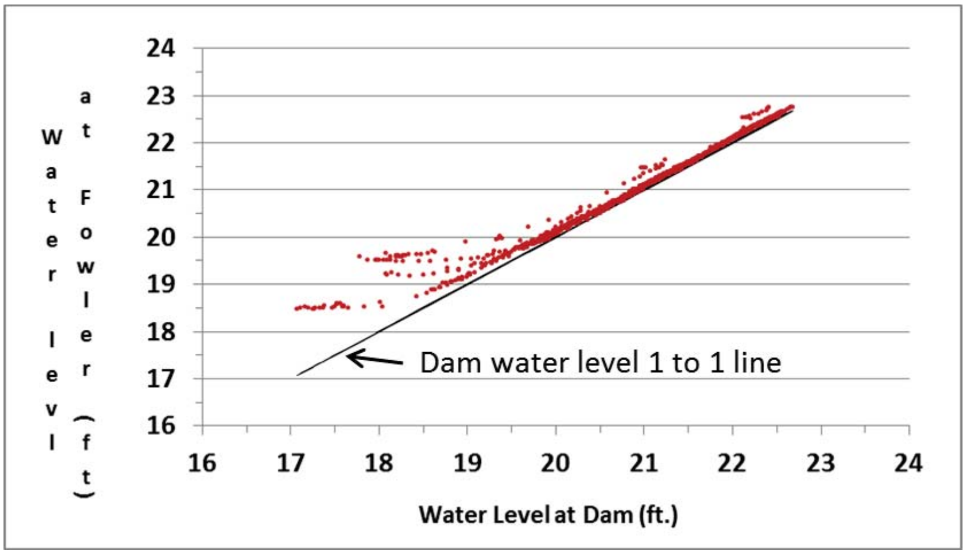


**Figure 12-5. Water levels at USGS gage at Fowler Avenue versus water levels at the USGS gage at the dam for periods with flows at the dam less than or equal to 27 cfs between June 1, 2008 and September 30, 2013. A one-to-one reference line is shown for water levels at the dam.**

The material above is presented to describe how water levels in the middle river vary both temporally and spatially during period when minimum flows for the lower river are in effect. However, with regard to the question of how does the recovery strategy affect water levels in the Middle Hillsborough River, the answer lies more directly in an examination of how the recovery strategy functions.

As described in Sections 2.5.2 and 12.3.1, any water that is released from the reservoir for minimum flows is replaced by water pumped into the reservoir from the TBC. Furthermore, due to concerns about losses of water pumped from the TBC, only 75% of the water pumped from the TBC is released at the dam for minimum flows. As previously discussed, this loss term is probably an overestimate, so the use of the TBC to replace minimum flow water released at the dam may result in a slight increase in water levels between the dam and Fowler Avenue. Such an increase would be very small, and was not examined as part of this study as the actual magnitude of any loss term should be subject to further investigation. Regardless, it can be concluded that implementation of the minimum flows recovery strategy for the Lower Hillsborough River has not resulted in a lowering of water levels in the Middle Hillsborough River and should not do so in the future given the management specifications contained adopted in the adopted recovery strategy.

# 13 Synthesis and Conclusions

## 13.1 Context and approach of the minimum flows evaluation

This final chapter presents a brief synthesis of some of the principal findings of the minimum flows evaluation for the Lower Hillsborough River. Recommendations are also presented for resource management strategies that could be pursued and topics that need further investigation.

It is important to note that the determination of minimum flows for the Lower River Hillsborough took into account that the river has been highly modified, not only by the presence of the Hillsborough River dam but also by the extensive urbanization of the lower river and the watershed below the dam. Because of these extensive alterations and the longstanding use for public water supply, the District concluded that recovery of the Lower Hillsborough River to historic hydrologic conditions was not economically or technically feasible. Instead, the District took a “bottom-up” approach in which model simulations were conducted by adding flow at the base of the dam and examining the incremental improvements in salinity and other selected parameters relative to a no flow condition.

The principal factor the District used for determining the minimum flows was increases in the volume of water less than 5 psu salinity between the dam and Sulphur Springs. Using the District’s two-dimensional hydrodynamic model of the lower river, salinity distributions were simulated for a series of gradually increasing minimum flow releases. The quantities and rates of change in the volumes of water less than 5 psu salinity were examined so that breakpoints or plateaus in these relationships could be used to determine minimum flow rates that achieve meaningful ecological benefits to the lower river while limiting impacts to potable water supplies. To use a common phrase, the determination of minimum flows took into account or identified the minimum flow rates that produce the most ecological “bang for the buck” in the Lower Hillsborough River while limiting impacts to water supplies.

In that regard, the adopted minimum flows for the lower river states “The Minimum Flows for the Lower Hillsborough River are based on extending a salinity range of less than 5 ppt from the Hillsborough River Dam toward Sulphur Springs” (see page 1-1). By specifying a salinity range that extends toward Sulphur Springs, the minimum flow rule does not establish an absolute standard that has to be met, but instead allows for the examination of incremental change to establish conditions that are beneficial to the reach of the river between the dam and Sulphur Springs.

This minimum flow evaluation provides a valuable opportunity to examine the relationship of minimum flow rates to salinity in the river based on empirical data collected in the lower river. As previously discussed, the period of study for this evaluation included incremental increases in minimum flow rates to the lower river. Near the end the study period, minimum flows rates close to or equal to the adopted minimum flows for the lower river occurred on many days. As such, this study provides an opportunity to examine changes in the salinity and ecological characteristics of the river in response to incremental increases in minimum flows and evaluate the efficacy of the minimum flows that were adopted.

Although the minimum flows were based primarily on salinity distributions, the District minimum flows report (SFWMD 2006) also examined and discussed relationships of flows at the dam with dissolved oxygen concentrations, water quality, and biological communities. Since the minimum flows report was published, considerably more data for these variables has become available. Accordingly, this minimum flows evaluation examined relationships of the minimum flow rates that have been implemented to date with a variety of water quality variables and biological characteristics in the river below the dam, in keeping with the directives for the periodic evaluations that are described in the recovery strategy for the lower river (see page 1-2).

## 13.2 Principal findings for salinity

The salinity data collected over the period of study for this minimum flows evaluation indicate that minimum flow rates in the range of 23 to 26 cfs are significantly better than a minimum flow rate of 20 cfs at reducing salinity in the river above Sulphur Springs. Lesser minimum flows (< 20 cfs) result in oligohaline waters (< 5 psu salinity) above Hannah's Whirl. Beginning in Hannah's Whirl and extending downstream, salinity in the river becomes more vertically stratified and greater minimum flow rates (23 to 26 cfs) are necessary to produce oligohaline waters down to about two meters depth. However, waters with salinity above 5 psu will continue to occur at deeper depths, with the amount of water greater than 5 psu increasing towards Sulphur Springs.

The modification of the lower weir and pumping facilities at Sulphur Springs has allowed for the diversion of greater amounts of springflow to the base of the dam. However, the lowering of the spring pool has been associated with increased salinity of the spring discharge, which averaged 2.7 psu during the final minimum flow period that started in March 2012. The blending of this higher salinity springwater with the 8.3 cfs of fresh water released from the reservoir results in slightly higher salinity at the Rowlett Park recorder, which is located about 0.8 kilometers downstream of the dam. However, the maximum salinity values at this recorder were reduced compared to lower minimum flow rates.

It is the conclusion of this report that achieving total minimum flow rates of flows in the range of 23 to 26 cfs is important to the overall salinity regime of the river above Sulphur Springs, as these rates are more effective at extending an oligohaline zone from Hannah's Whirl toward the dam. Notwithstanding the net salinity of the minimum flow water that results from using different quantities of Sulphur Springs diversions and freshwater releases from the reservoir, achieving a volume of flow corresponding to total minimum flow rates between 23 and 26 cfs should be a primary management goal.

If the slightly higher salinity that will occur near the base of the dam is acceptable, the diversion of greater amounts of water from Sulphur Springs can be of net benefit for the lower river by allowing for greater minimum flow rates. One factor that could limit the increased use of Sulphur Springs is the development of filamentous algal mats in the spring run during periods of minimum flow implementation. The District is currently conducting research on the relationships of the rate of flow and current velocities with the algae in the spring run. If filamentous algae becomes a management criterion, it could possibly reduce amount of springflow that can be diverted to the dam, thus requiring the greater use of other sources (Tampa Bypass Canal, Blue Sink, and Morris Bridge Sink) to achieve the desired minimum flow rates. However, the manual harvesting of algae in the spring run is one management option that could be investigated that could possibly allow the use of greater amounts of springflow for diversions to the base of the dam.

It is also concluded that the adjustment of the minimum flows based on low flows at the Hillsborough River near Zephyrhills gage are associated with reduction in the effectiveness of the minimum flows for creating an oligohaline zone in the river between the dam and Sulphur Springs. However, the flow adjustment criteria were developed because it was deemed unreasonable to expect higher freshwater equivalent flow rates during extreme drought conditions that are not related to water withdrawals. As described in Section 2.5, the low flow adjustment would have been applied to 19% of the days from 2012 through June 8, 2013. The ecological effects of these periodic low flow adjustments will be dependent on their duration with a given dry season. Based on the minimum flows that have been implemented to date, this study did not examine the potential effects of these low flow adjustments on the salinity or ecology of the lower river, but such analyses should be conducted as the minimum flows are more fully implemented.

### 13.2.1 Preliminary nature of the findings and recommendation for supplemental salinity modeling

Although the data conducted to date indicate strong relationships of salinity in the river above Sulphur Springs with the rate of minimum flow, these findings are considered preliminary because the reported flow rates for spring water delivered to the dam were subject to some error. As described in Section 2.5.3, the City of Tampa implemented the diversion of spring water to the base of the dam as quickly as possible by changing the pumps and piping system at Sulphur Springs to increase the minimum flows. The accurate metering of spring diversions was initially difficult at times due to the changes in the facilities used to deliver the flows. Now that the final pumping facilities at Sulphur Springs have been completed, the more accurate metering of flow from Sulphur Springs is possible, and this should be of value to future minimum flows evaluations.

A second factor that influenced the findings of this study were changing climatic and streamflow conditions over the time period of minimum flows implementation. Salinity in the river is strongly influenced by salinity in Hillsborough Bay and stormwater runoff that enters the river below the dam. Variations in climatic conditions over the period of study confounded the examination of the effects of different minimum flow rates, which gradually increased over time. However, very dry conditions did occur in the spring of 2012, which allowed for a brief period to assess the higher minimum flow rates that were implemented under fairly high salinity conditions in the lower river and Hillsborough Bay.

Because of the various factors that can affect salinity in the lower river, the District is in the process of analyzing additional model simulations of salinity distributions in the lower river produced by the District's laterally averaged mechanistic model of the lower river. This is the same model on which the minimum flows adopted in 2007 were largely based. The new modeling effort will be valuable since it can be used to evaluate salinity distributions over the same time periods and flow conditions assessed in this study.

The new modeling effort will also allow for the simulation of various minimum flow scenarios under consistent climatological conditions. Now that Sulphur Springs has been used at increasing rates for recovery of minimum flows, data are available on salinity values that can be expected in the spring discharge under various management options. In this regard, salinity distribution in the river can be examined for a series of minimum flow scenarios that include different quantities of spring diversions and reservoir releases and different salinity values for the spring discharge. These modeling analyses may provide information regarding how much water would be needed from all identified recovery flow sources, based on quantities of spring water that may be used.

### 13.2.2 Continued salinity monitoring

With regard to the salinity monitoring network, it is recommended that the three continuous recorders in operation above Sulphur Springs remain in operation (Rowlett Park, at kilometer 13.6, and near Sulphur Springs). The recorder at Rowlett Park Drive provides data on salinity near the dam that results from using different quantities of minimum flows water from the reservoir or Sulphur Springs. The recorder at kilometer 13.6 is valuable because it is near the middle of the reach between Hannah's Whirl and Sulphur Springs. This recorder is operated by the EPCHC and should be continued by another party if the EPCHC were to discontinue maintenance and data collection at the station.

There should also be continued monitoring of salinity and other *in situ* water quality parameters by boat above Sulphur Springs. Sampling designs that include a large number of spatially distributed samples on each sampling day should be emphasized to characterize the shape of the salt wedge under different minimum flow conditions. The District will continue its fixed-station sampling program of the lower river, with sampling conducted monthly during periods of minimum flow implementation.

## 13.3 Dissolved oxygen

As discussed in Section 5.6, the implementation of minimum flows has resulted in improvements in dissolved oxygen concentrations and percent saturation values in the river, but these changes have been most apparent in the reach of the river above Hannah's Whirl. Below Hannah's Whirl the data are less conclusive, but it appears that higher minimum flow rates have some benefit to DO in shallower water depths (< 2 meters). However, low DO persists at deeper depths between Hannah's Whirl and Sulphur Springs. The higher minimum flow rates (23 to 26 cfs) appear to move the zone of vertical stratification slightly deeper in the water column with benefits to DO concentrations at shallower depths. Given these tentative findings, it is appropriate to base the minimum flows primarily on salinity at this time, with the assumption that improvements in salinity distributions may benefit improvements is DO concentrations as well, at least at shallower depths.

However, the relationship of minimum flow rates with DO concentrations and percent saturation should be re-examined with continued data collection. In contrast to salinity, where data from continuous recorder were very helpful for evaluation the effectiveness of various minimum flow rates, the only reliable DO data available when this report was prepared were grab samples collected in the river during daylight hours. It is recommended that the District work with the EPCHC to upgrade their DO sensor at kilometer 13.6 to an optical based probe, which should improve the reliability of the data. The City of

Tampa or the District should also install a second continuous DO recorder just upstream of Nebraska Avenue to monitor DO concentrations near Sulphur Springs. Similar to salinity, DO should continue to be monitored by boat by the SWFWMD fixed station sampling program. However, it would be valuable if another entity could also collect vertical profile measurements in the river between Sulphur Springs and the dam.

Because the occurrence of low DO concentrations in the river above Sulphur Springs is closely related to vertical salinity stratification, consideration could be given to investigating the feasibility of installing devices to mix the water column and break the vertical stratification in that part of the river. This preliminary assessment would not involve any field equipment, bit would largely be a mathematical exercise using modeling or the physical relationships to determine if any such plan may be feasible in this tidally influenced system.

## 13.4 Water temperature and water quality

The results of this minimum flow evaluation indicate that the implementation of minimum flows has not caused any potentially detrimental changes to water temperature or pH in the river below the dam. The collection of data for these parameters at the continuous recorders or the vertical sampling profiles collected by boats described above should provide sufficient data to monitor water temperature and pH in the river between the dam and Sulphur Springs.

The results of this study also indicate that implementation of minimum flows has not resulted in any degradation of water quality, and has resulted in improvements in some water quality parameters (total nitrogen, NOx nitrogen, ortho and total phosphorus, chlorophyll *a*) in the reach of the river above Sulphur Springs, particularly above Hannah's Whirl. Water quality sampling above Sulphur Springs is currently conducted at two fixed stations in the SFWWMD sampling program and at the EPCHC station at Rowlett Park Drive. It is recommended that these monitoring programs be continued and consideration be given to adding two water chemistry stations to the District sampling program to better define water quality relationships between Hannah's Whirl and Sulphur Springs. The possible additions of some water quality stations for which sampling locations are randomized in the reach above Sulphur Springs should also be considered.

## 13.5 Biological data collection

The biological data that was assessed for this minimum flows evaluation consisted of data for benthic macroinvertebrates, nekton, ichthyoplankton and zooplankton collected as part of the HBMP conducted by TBW as part of their water use permit for diversion and withdrawal of Hillsborough River water during high flows. The monitoring of both of these communities has been discontinued, but the data that were collected over the study period indicated that the implementation of minimum flows had a significant effect on these biological communities in the reach of the river between the dam and Sulphur Springs. In general, the implementation of minimum flows has resulted in a shift from more mesohaline communities to communities that contained more taxa characteristics of oligohaline and tidal freshwater conditions.

The monitoring for the HBMP was oriented to the entire Lower Hillsborough River and was not temporally oriented to periods of no flow at the dam. However, because periods of minimum flow were so frequent during the HBMP study period, data were collected when minimum flows were in effect for prolonged periods of time. It is the recommendation of this minimum flows assessment report that some temporally and spatially focused sampling efforts for both benthic macroinvertebrates and nekton collected by seines be conducted at least twice during the period before the next minimum flows evaluation.

The purpose of these sampling efforts would confirm any changes that have occurred in the river due to the implementation of minimum flows and examine spatial gradients in biological communities in the river upstream of the Sulphur Springs. The sampling should involve more spatially intense sampling than occurred for the HBMP, with most the samples located above Sulphur Springs. However, some samples should be collected as far downstream as Sligh Avenue in order to documents communities in higher salinity zones for comparison. Each sampling event should occur after prolonged minimum flows at the dam in order to avoid the confounding factor of periodic high flows at the dam. Pending the findings of the first two sampling events, consideration could be given to conducting a third sampling event for either nekton or benthic macroinvertebrates.

It is beyond the scope of this minimum flows evaluation to propose a specific design for any renewed sampling programs, but the scope of such work could be evaluated as part of Lower Hillsborough River minimum flows project conducted by the District.

## 13.6 Summary and follow-up activities

The recovery strategy adopted with the minimum flow rule for the Lower Hillsborough River in 2007 requires that in 2013, and for each five-year period through 2023, the Southwest Florida Water Management District shall evaluate the hydrology, dissolved oxygen, salinity, temperature, pH and biologic results achieved from implementation of the recovery strategy for the previous five years, including the duration, frequency, and impacts of the adjusted minimum flow as described in paragraph 40D8.041(1)(b), F.A.C. As part of the evaluation, the District will assess the recording systems used to monitor these parameters. The District shall also monitor and evaluate the effect the Recovery Strategy is having on water levels in the Hillsborough River above the City’s dam to at least Fletcher Avenue. Finally, the District will evaluate all projects described in this Recovery Strategy relative to their potential to cause unacceptable adverse impacts prior to their implementation.

This first five-year assessment report addresses these objectives by examining changes in the hydrobiological characteristics of the lower river in response to the minimum flows that were implemented through 2013, discussion of all projects identified in the recovery strategy, and evaluation of recovery strategy implementation on water levels in the river above the dam. Evaluations of the projects described in the recovery strategy relative to their potential to cause unaccepatble adverse impacts prior to their implementation have been or are being conducted as described in other documents associated with the respective projects.

A principal goal of the minimum flow rule for the Lower Hillsborough River is to extend a zone of oligohaline water (i.e., water with salinity < 5 psu) from the base of the Hillsborough River dam toward Sulphur Springs. Results summarized in this first five-year assessment report demonstrate the benefit of increased minimum flows for achieving that goal and support the validity of the minimum flows that were adopted for the Lower Hillsborough River in 2007. This first assessment will be followed by subsequent five-year assessments through 2023, in accordance with the adopted recovery strategy.

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# Appendices

## For

# A Hydrobiological Assessment of the Phased Implementation of Minimum Flows for the Lower Hillsborough River

**By**

**The Southwest Florida Water Management District**

**And**

**Atkins North America, Inc.**

**April 24, 2015**

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# Lower Hillsborough River Minimum Flows Recovery Strategy Reprinted From:

### 40D-80.073 Comprehensive Environmental Resources Recovery Plan for theNorthern Tampa Bay Water Use Caution Area, and the Hillsborough River Strategy. Rules of the Southwest Florida Water Management District, Florida Adminstrative Code

(8) Hillsborough River Strategy.

Beginning November 25, 2007, the Minimum Flow for the Lower Hillsborough River shall be as provided in subsection 40D-8.041(1), F.A.C., to be achieved on the time schedule as set forth below. The District and the City of Tampa (City) shall measure the delivery of water to the base of the dam relative to their respective elements as described below. The City shall report this information to the District monthly on the 15th day of the following month. In addition, the City shall submit a quarterly written report of all activities and all progress towards timely completion of its elements of the recovery strategy. Such reports will be submitted to the District within 15 calendar days after each calendar year quarter.

(a) The District and the City have entered into the Joint Funding Agreement Between The Southwest Florida Water Management District and The City of Tampa For Implementation of Recovery Projects To Meet Minimum Flows of The Lower Hillsborough River, dated October 19, 2007, (the Funding Agreement), which is incorporated herein by reference. A copy of the Funding Agreement is available from the District upon request. The Funding Agreement and subsection 40D-80.073(8), F.A.C., constitute the District's recovery strategy for the Lower Hillsborough River required by Section 373.0421(2), F.S., and shall not compromise public health, safety and welfare.

(b) The schedule to achieve the Minimum Flows for the Lower Hillsborough River is as follows:

1. Sulphur Springs.

Beginning on November 25, 2007, the City shall be required to provide ten cubic feet per second (cfs) of water to the base of the City's dam each day, provided such use will not compromise public health, safety and welfare.

2. Tampa Bypass Canal Diversions.

By January 1, 2008, provided that any permit that may be required is approved, the District shall divert up to 7.1 million gallons of water on any given day from the District's Tampa Bypass Canal (TBC) to the Hillsborough River at the District's Structure 161. The District shall then deliver water from the Hillsborough River immediately above the City's dam to the base of the City's dam to help meet the minimum flow requirements of the Lower Hillsborough River. Such diversions shall not occur if public health, safety or welfare will be compromised.

a. The District shall complete a comprehensive analysis of these diversions within 90 days of the first year of operation to identify and subsequently make any mechanical or efficiency adjustments that may be necessary. The District shall use its best efforts to expedite obtaining any permit that may be needed to undertake these actions.

b. By October 1, 2013, provided that the transmission pipeline has been constructed and is operational, all of the water diverted from the TBC middle pool under this provision to help meet the minimum flow shall be provided to the Lower Hillsborough River per subparagraph 40D-80.073(8)(b)7., F.A.C.

c. These diversions shall be prioritized as follows:

(i) Priority Source One – Diversions From the TBC Middle Pool When the TBC Middle Pool is Above 12.0 feet NGVD (1929 or its 1988 equivalent), and There is Flow of at Least 11 cfs Over the District's Structure 162.

On days when the TBC middle pool is above 12.0 feet NGVD (1929 or its 1988 equivalent), as measured by the downstream gauge at the District's Structure 161, and there is flow of at least 11 cfs over the District's Structure 162, the District shall divert water from the TBC middle pool to the Hillsborough River.

A. The District shall then deliver 75 percent of any water diverted from the TBC to the Hillsborough River under this provision to the Lower Hillsborough River. Delivery of 75 percent of the water diverted from the TBC addresses concerns about potential losses due to subsurface leakage, evaporation and transpiration. This delivery shall be from the Hillsborough River just above the City's dam to the base of the City's dam, and shall supplement diversions from Sulphur Springs, Blue Sink and Morris Bridge Sink, as they are implemented, and as described in subparagraphs 40D-80.073(8)(b)1., 3., 6. and 8., F.A.C.

B. The TBC middle pool diversions will be limited to the quantity needed to achieve the minimum flow requirements of the Lower Hillsborough River set forth in subsection 40D-8.041(1), F.A.C., but will not exceed 7.1 million gallons on any given day.

C. Such diversions shall cease from the TBC middle pool if the elevation difference between the TBC middle and lower pools exceeds 7.0 feet.

D. On days when flow over the Hillsborough River Dam naturally exceeds 20 cfs during the months of July through March, or 24 cfs during the months of April through June and when diversions from the TBC middle pool are not needed to replenish the supply from Storage Projects described in paragraphs 40D-80.073(8)(c) and (d), F.A.C., diversions from the TBC middle pool shall not occur and any flows in the TBC lower pool above elevation 9.0 feet NGVD (1929 or its 1988 equivalent), shall be available for water supply.

E. Prior to October 1, 2013, and during the months of March through June, on days when some water is needed from the TBC middle pool to help meet the minimum flow for the Lower Hillsborough River, all available water from the TBC middle pool not needed to be diverted in accordance with SWFWMD Water Use Permit No. 20006675 but not exceeding 7.1 million gallons on any given day will be diverted to the Hillsborough River. Water delivered to the Hillsborough River in excess of that needed to help meet the minimum flow of the Lower Hillsborough River shall remain in the Hillsborough River above the dam. Keeping this water in the Hillsborough River above the dam will reduce the time and quantities of supplemental flow needed to help meet the minimum flow requirements.

F. During the months of July through February, on days when water is needed from the TBC middle pool to help meet the minimum flow of the Lower Hillsborough River, only that amount of water needed to help meet the minimum flow but not in excess of 7.1 million gallons on any given day shall be diverted from the TBC middle pool to the Hillsborough River, and any water in the TBC middle and lower pools above elevations 12.0 and 9.0 feet NGVD (1929 or its 1988 equivalent), respectively, shall be available for water supply.

(ii) Priority Source Two – Diversions When the TBC Middle Pool is Above 12.0 feet NGVD (1929 or its 1988 equivalent), and the Flow Over the District's Structure 162 is Less Than 11 cfs.

On days when the TBC middle pool is above 12.0 feet NGVD (1929 or its 1988 equivalent), as measured by the downstream gauge at the District's Structure 161, and the flow over the District's Structure 162 is less than 11 cfs, the District shall divert water from the TBC middle pool to the Hillsborough River.

A. The District shall then deliver 75 percent of any water diverted from the TBC middle pool to the Hillsborough River under this provision to the Lower Hillsborough River. Delivery of 75 percent of the water diverted from the TBC addresses concerns about potential losses due to subsurface leakage, evaporation and transpiration. This delivery shall be from the Hillsborough River just above the City's dam to immediately below the City's dam, and shall supplement diversions from Sulphur Springs, Blue Sink and Morris Bridge Sink, as they are implemented, and as described in subparagraphs 40D-80.073(8)(b)1., 3., 6. and 8., F.A.C.

B. The TBC middle pool diversions will be limited to the quantity needed to achieve the minimum flow requirements of the Lower Hillsborough River, but will not exceed 7.1 million gallons on any given day.

I. On days such diversions occur, the District will divert from the TBC lower pool to the TBC middle pool quantity equivalent to that diverted by the District from the TBC middle pool to the Hillsborough River.

II. Such diversions shall cease from both the TBC middle and lower pool when the stage of the TBC lower pool reaches 6.0 feet NGVD (1929 or its 1988 equivalent), as measured by the gauge at the District's Structure 160, or the elevation difference between the TBC middle and lower pools exceeds 7.0 feet.

C. Once the stage in the TBC lower pool is below 8.7 feet NGVD (1929 or its 1988 equivalent), withdrawals from this priority source to help meet the minimum flow for the lower Hillsborough River are considered withdrawals from the storage of the TBC lower pool. When the stage in the TBC lower pool is below 8.7 feet NGVD (1929 or its 1988 equivalent), the following restrictions apply:

I. At no time shall withdrawals from the lower pool to help meet the minimum flow for the lower Hillsborough River cause the stage in the lower pool to go below 6.0 feet NGVD (1929 or its 1988 equivalent), or cause the elevation difference between the TBC middle and lower pools to exceed 7.0 feet, as measured on either side of the District's Structure 162.

II. If supplemental flows are required to help meet the lower Hillsborough River minimum flow from this Priority Source, once withdrawals begin from storage they will continue until the TBC lower pool reaches an elevation of 6.0 feet NGVD (1929 or its 1988 equivalent). At such time as either of the conditions set forth in sub-sub-sub-subparagraph 40D-80.073(8)(b)2.(ii)C.I., F.A.C., above, are met, the District shall cease withdrawals from the TBC lower pool. The District shall only reinitiate withdrawals from the TBC lower pool when its elevation equals or exceeds 9.0 feet NGVD (1929 or its 1988 equivalent), for 20 consecutive days, which is defined as the TBC lower pool replenishment.

III. The total withdrawn from storage on any given day shall not exceed 7.1 million gallons on any given day.

IV. Withdrawals from storage will be limited to the quantity needed to help achieve the minimum flow requirements of the Lower Hillsborough River after utilizing the quantity diverted from all other sources, as they are implemented, and as described in paragraphs 40D-80.073(8)(b), (c) and (d), F.A.C.

(iii) Priority Source Three – Diversions When TBC Middle Pool Elevations are Between 10.0 and 12.0 Feet NGVD (1929 or its 1988 equivalent).

The District will make all reasonable efforts to obtain authorization from the United States Army Corps of Engineers to allow the withdrawals of up to 7.1 million gallons on any given day from the TBC middle pool to aid in the Lower Hillsborough River minimum flow requirements when the TBC middle pool is below 12.0 feet and above 10.0 feet NGVD (1929 or its 1988 equivalent).

A. These diversions will only occur when the stage of the TBC lower pool has reached 6.0 feet NGVD (1929 or its 1988 equivalent), or the TBC lower pool is in a state of replenishment as described in sub-sub-sub-subparagraph 40D-80.073(8)(b)2.(ii)C.II., F.A.C. These diversions will be limited to the quantity needed to help achieve the minimum flow requirements of the Lower Hillsborough River after utilizing the quantity diverted from all other sources, as they are implemented, and as described in paragraphs 40D-80.073(8)(b), (c) and (d), F.A.C., but will not exceed 7.1 million gallons on any given day.

B. These diversions shall cease if the elevation difference between the Hillsborough River and TBC middle pool exceeds 9.5 feet, if approved by the United States Army Corps of Engineers, as measured on either side of the District's Structure 161, or if the elevation difference between the TBC middle and lower pools exceeds 7.0 feet, as measured on either side of the District's Structure 162.

C. Diversions associated with this provision will not occur until the water transmission pipeline as set forth in subparagraph 40D-80.073(8)(b)7., F.A.C., is completed or by October 1, 2013, whichever is sooner. Once the stage in the TBC middle pool is below 12.0 feet NGVD (1929 or its 1988 equivalent), withdrawals to help meet the minimum flow for the Lower Hillsborough River are considered withdrawals from the storage of the TBC middle pool. When the stage is below 12.0 feet NGVD (1929 or its 1988 equivalent), the following restrictions apply:

I. At no time shall withdrawals from the TBC middle pool to help meet the minimum flow for the Lower Hillsborough River cause the stage in the middle pool to go below 10.0 feet NGVD (1929 or 1988 equivalent), or cause the elevation difference between the TBC middle pool and Hillsborough River to exceed 9.5 feet, as measured on either side of the District's Structure 161, or cause the elevation difference between the TBC middle and lower pools to exceed 7.0 feet, as measured on either side of the District's Structure 162.

II. If supplemental flows are required to help meet the Lower Hillsborough River minimum flow from this Priority Source, once withdrawals begin from storage they will continue until the TBC middle pool reaches an elevation of 10.0 feet NGVD (1929 or its 1988 equivalent). At such time as either of the conditions set forth in sub-sub-sub-subparagraph 40D-80.073(8)(b)2.c.(iii)C.I., F.A.C., above, are met, the District shall cease withdrawals from the TBC middle pool. The District shall only reinitiate withdrawals from the TBC middle pool when its elevation equals or exceeds 12.0 feet NGVD (1929 or its 1988 equivalent), for 20 consecutive days, which is defined as the TBC Pool Replenishment, and there is less than 11 cfs of flow over the District's Structure 162.

III. The total withdrawn from storage on any one day shall not exceed 7.1 million gallons.

IV. Withdrawals from storage will be limited to the quantity needed to help achieve the minimum flow requirements of the Lower Hillsborough River after utilizing the quantity diverted from all other sources, as they are implemented, and as described in paragraphs 40D-80.073(8)(b), (c) and (d), F.A.C.

3. Sulphur Springs Project.

a. By October 1, 2009, and as specified in the Funding Agreement incorporated in paragraph (8)(a) above, the City shall complete the modification of the lower weir to provide to the base of the dam all available flow from Sulphur Springs not needed to maintain the minimum flow for manatees as set forth in paragraph 40D-8.041(2)(b), F.A.C.

b. By October 1, 2010, the City shall complete the construction of the upper gates and the pump station to provide to the base of the dam all available flow from Sulphur Springs not needed to maintain the minimum flow for manatees as set forth in paragraph 40D-8.041(2)(b), F.A.C.

c. By October 1, 2012, and as specified in the Funding Agreement incorporated in paragraph (8)(a) above, the City is to provide to the base of the dam, all available flow from Sulphur Springs not needed to maintain the minimum flow for Sulphur Springs as set forth in paragraph 40D-8.041(2)(a), F.A.C.

(i) These diversions shall not exceed 11.6 million gallons on any given day.

(ii) The City is authorized to use any remaining quantities at Sulphur Springs for water supply purposes consistent with SWFWMD Water Use Permit No. 20002062.

d. Additionally, beginning on October 1, 2010, on days when the minimum flow requirements are being adjusted for the Lower Hillsborough River, as described in paragraph 40D-8.041(1)(b), F.A.C., and there is flow at Sulphur Springs in excess of the quantity needed to help meet the adjusted flow as described in paragraph 40D-8.041(1)(b), F.A.C., and the minimum flow requirements in paragraph 40D-8.041(2)(b), F.A.C., and the City is not using such flow to augment the Hillsborough River above the dam, the City shall move such quantity to the base of the City's dam up to the unadjusted quantities described in paragraph 40D-8.041(1)(b), F.A.C.

4. Blue Sink Analysis.

By October 1, 2010, and as specified in the Funding Agreement incorporated in paragraph (8)(a) above, the City in cooperation with the District shall complete a thorough cost/benefit analysis to divert all available flow from Blue Sink in north Tampa to a location to help meet the minimum flow or to the base of the City's dam.

5. Transmission Pipeline Evaluation.

By October 1, 2010, and as specified in the Funding Agreement incorporated in paragraph (8)(a) above, the City shall complete a thorough design development evaluation to construct a water transmission pipeline from the TBC middle pool to the City's David L. Tippin Water Treatment Facility, including a spur to just below the City's dam.

6. Blue Sink Project.

By October 1, 2011, and as specified in the Funding Agreement incorporated in paragraph (8)(a) above, the City will provide all available flow from Blue Sink project to help meet the minimum flow provided that all required permits are approved, and it is determined that the project is feasible. Once developed, all water from this source shall be used to the extent that flow is available to help meet the minimum flow for the Lower Hillsborough River.

7. Transmission Pipeline Project.

By October 1, 2013, and as specified in the Funding Agreement incorporated in paragraph (8)(a) above, the City shall complete the water transmission pipeline described in subparagraph 40D-80.073(8)(b)5., F.A.C., and move the water the District will move as specified in subparagraphs 40D-80.073(8)(b)2. and 8., F.A.C., to the Lower Hillsborough River directly below the dam as needed to help meet the minimum flow or to transport water in accordance with SWFWMD Water Use Permit No. 20006675.

a. This transmission line will eliminate all adjustment for losses described in subparagraphs 40D-80.073(8)(b)2. and 8., F.A.C.

b. Additionally, the City will provide an additional flow of 1.9 million gallons each day to the base of the dam from the TBC middle pool provided that water is being transported in accordance with SWFWMD Water Use Permit No. 20006675. This additional 1.9 million gallons each day is anticipated to be part of the water savings associated with this transmission pipeline.

c. Once the pipeline is completed, the 1.9 million gallons each day of additional flow provided by the City as part of the water savings associated with the pipeline will be used in preference to all other sources except Sulphur Springs and Blue Sink to help meet the minimum flow for the Lower Hillsborough River.

d. In the event that this pipeline is not substantially completed by October 1, 2013, or that the City did not provide the District with a minimum ninety (90) days notice prior to October 1, 2013, of the delay of completion of the pipeline due to circumstances beyond its control, then, the City will be responsible for delivering the flows the District was previously obligated to divert from the TBC middle pool to the Hillsborough River and then to immediately below the City's dam under subparagraphs 40D-80.073(8)(b)2. and 8., F.A.C.; except that the District shall continue to be responsible to pump water from the TBC lower pool to the middle pool as described in sub-subparagraph 40D-80.073(8)(b)2.b., F.A.C., and from Morris Bridge Sink to the TBC middle pool as described in subparagraph 40D-80.073(8)(b)8., F.A.C.

e. The City shall also provide the 1.9 million gallons each day if needed to help meet the flow described in this provision, from some other permitable source and is obligated to do so pursuant to sub-subparagraph (8)(b)2.d. above.

8. Morris Bridge Sink Project (see sub-paragraph ii below).

a. By October 1, 2012, or earlier, and upon completion of the project, provided that any permit that may be required is approved, the District shall divert up to 3.9 million gallons of water on any given day from the Morris Bridge Sink to the TBC middle pool.

(i) The Morris Bridge Sink diversions will be limited to the quantity needed to achieve the minimum flow requirements of the Lower Hillsborough River, after utilizing the quantity diverted from Sulphur Springs, Blue Sink and the 1.9 million gallons of water savings each day anticipated from the transmission pipeline, as they are implemented, and as described in subparagraphs 40D-80.073(8)(b)1., 3., 6. and 7., F.A.C.

(ii) However, on days when Tampa Bay Water does not draw the TBC lower pool down to 9.0 feet NGVD (1929 or its 1988 equivalent) for water supply purposes, and supplemental flow is needed for the Lower Hillsborough River minimum flow requirements beyond water that can be delivered from Sulphur Springs, Blue Sink and the 1.9 million gallons of water savings each day anticipated from the transmission pipeline described in subparagraphs 40D-80.073(8)(b)1., 3., 6. and 7., F.A.C., the District shall divert up to 7.1 million gallons on any given day from the TBC lower pool to the TBC middle pool prior to diverting flows from the Morris Bridge Sink to the TBC middle pool.

(iii) The District shall cease to divert water from the TBC lower pool under this provision once the elevation of the TBC lower pool reaches 9.0 feet NGVD (1929 or its 1988 equivalent).

b. Prior to the completion of the pipeline described in subparagraph 40D-80.073(8)(b)7., F.A.C., the District shall transfer any water delivered to the TBC middle pool from the Morris Bridge Sink or the TBC lower pool under this provision to the Hillsborough River near the District's Structure 161.

(i) These deliveries shall be made on the same day the District delivers water from the Morris Bridge Sink or the TBC lower pool.

(ii) The District shall then deliver 75 percent of any water diverted to the Hillsborough River under this provision to the Lower Hillsborough River. This delivery shall be from the Hillsborough River just above the City's dam to immediately below the City's dam.

(iii) The deliveries of the water from the Morris Bridge Sink to the TBC middle pool then on to the Hillsborough River are in addition to any other diversions from the TBC middle pool to the Hillsborough River described in subparagraphs 40D-80.073(8)(b)2. and 8., F.A.C.

c. Once the City completes the water transmission pipeline described in subparagraphs 40D-80.073(8)(b)5. and 7., F.A.C., or as may be otherwise responsible for delivering the flows the District was previously obligated to divert pursuant to subparagraph 40D-80.073(8)(b)7., F.A.C., the City shall move any water the District delivers to the TBC middle pool from Morris Bridge Sink or the TBC lower pool under this provision to the Lower Hillsborough River directly below the dam. Such delivery by the City will occur on the same day the District delivers the water from the Morris Bridge Sink or the TBC lower pool to the TBC middle pool.

d. At no time shall withdrawals from the TBC under this provision cause:

(i) The elevation difference between the TBC middle pool and Hillsborough River to exceed 9.5 feet as measured on either side of the District's Structure 161; or

(ii) The elevation difference between the TBC middle and lower pools to exceed 7.0 feet as measured on either side of the District's Structure 162.

9. Beginning October 1, 2017, the City shall be required to meet the minimum flows at the base of the dam as set forth in subsection 40D-8.041(1), F.A.C.

(c) The City and the District shall, as specified in the Funding Agreement incorporated in paragraph (8)(a) above, cooperate in the evaluation of options for storage of water (Storage Projects) such as aquifer storage and recovery and additional source options (e.g., diversions from Morris Bridge Sink greater than those described in subparagraph 40D-80.073(8)(b)8., F.A.C.), in sufficient permitable quantities, that upon discharge to the base of the dam, together with the other sources of flow described in paragraph 40D-80.073(8)(b), F.A.C., will meet the minimum flows beginning October 1, 2017, or earlier.

(d) The City may propose for District approval additional source or storage projects that when completed may be used in lieu of all or part of one or more sources described in subparagraphs 40D-80.073(8)(b)2.-8., F.A.C.

(e) Any District sponsored project, which shall include evaluation of up to 3.9 million gallons per day of additional quantities other than those identified in subparagraph 40D-80.073(8)(b)8., F.A.C., from the Morris Bridge Sink, shall be implemented by the District no later than October 1, 2017, provided that it is deemed feasible by the District, to eliminate or reduce the need to divert water from the TBC middle and lower pool storage as described in subparagraph 40D-80.073(8)(b)2., F.A.C. Such projects shall be implemented only after receiving any required permits.

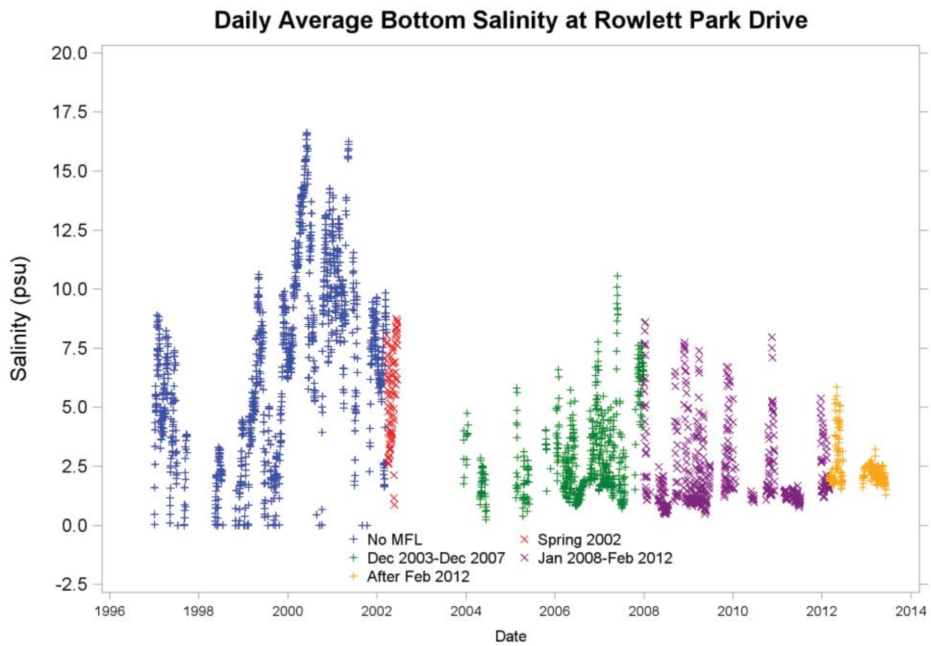
(f) Each spring, beginning in 2008, the District shall review the recovery strategy to assess the progress of implementation of the recovery strategy and report that progress to the Governing Board. This annual review and report shall include identification of the Storage Projects or other additional source options that will be operational by October 1, 2017. If and when developed, Storage Projects or other additional source options to supply supplemental flows to meet the minimum flow will be used in preference to removal of water from storage in either the middle or lower pools of the TBC as described in paragraph 40D-80.073(8)(b), F.A.C.

(g) The City and the District shall continue the existing monitoring and analysis of the water resources within the Lower Hillsborough River and the District shall provide this information to the Governing Board as part of the annual review and report described in paragraph (8)(d), above.

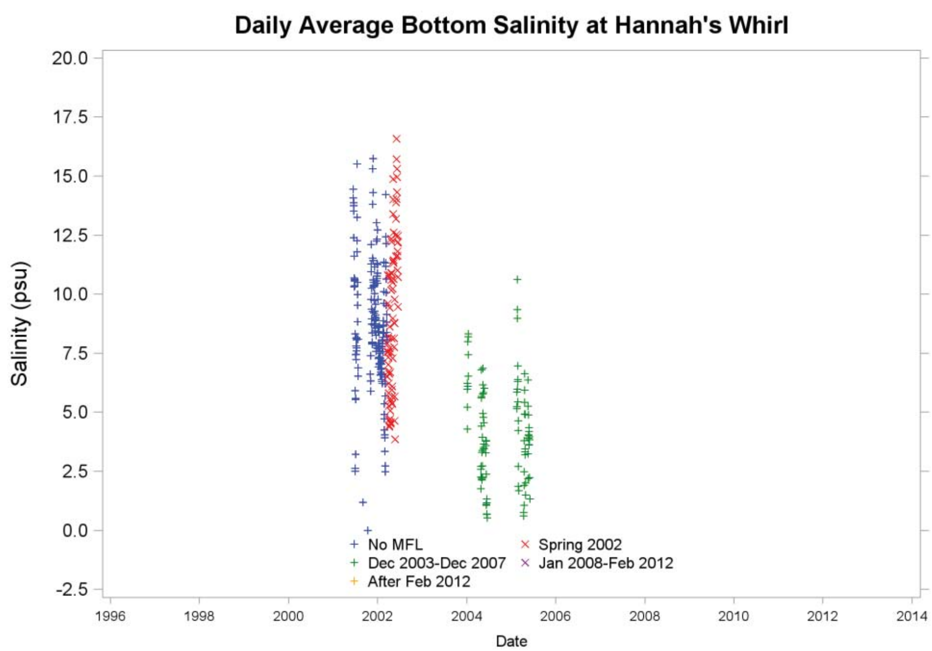
(h) In 2013, and for each five-year period through 2023, the District shall evaluate the hydrology, dissolved oxygen, salinity, temperature, pH and biologic results achieved from implementation of the recovery strategy for the prior five years, including the duration, frequency and impacts of the adjusted minimum flow as described in paragraph 40D-8.041(1)(b), F.A.C. As part of the evaluation, the District will assess the recording systems used to monitor these parameters. The District shall also monitor and evaluate the effect the Recovery Strategy is having on water levels in the Hillsborough River above the City's dam to at least Fletcher Avenue. The District will evaluate all projects described in this Recovery Strategy relative to their potential to cause unacceptable adverse impacts prior to their implementation.

(i) In conjunction with recovery of the Lower Hillsborough River and to enhance restoration of McKay Bay and Palm River estuary, the District intends to undertake a wetland restoration project adjacent to McKay Bay. The City agrees to contribute to the project by providing up to 7.1 million gallons on any given day of reclaimed water, as needed for the project. Within five years of completion of this wetland project, and for two subsequent five-year periods thereafter, the District shall review the hydrologic, dissolved oxygen, salinity, temperature, pH and biologic results achieved from the implementation of the restoration project and other similar District projects that may occur.

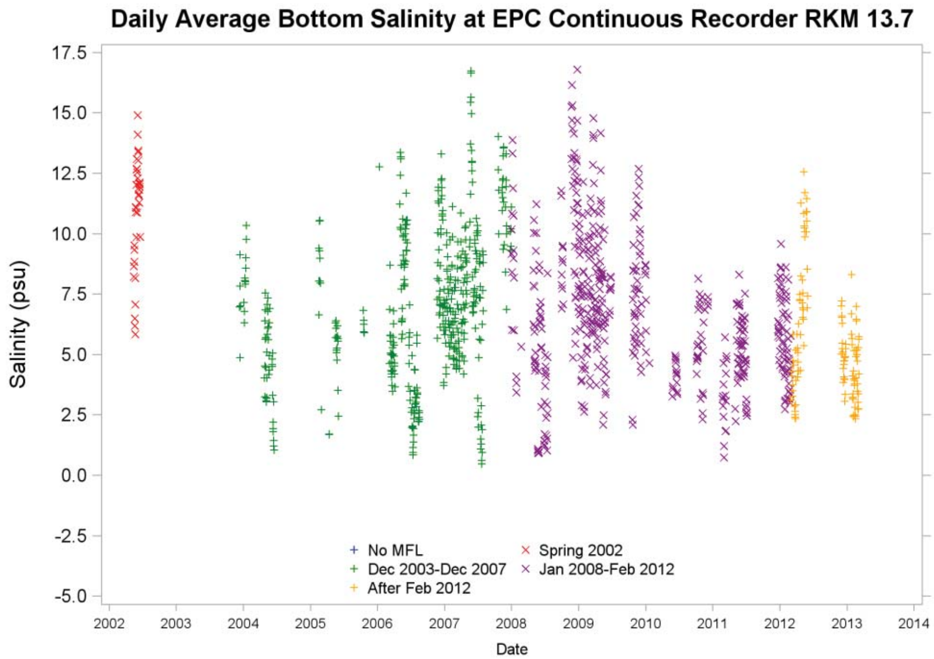
1. Daily Average Bottom Salinity at Rowlett Park Drive Continuous Recorder



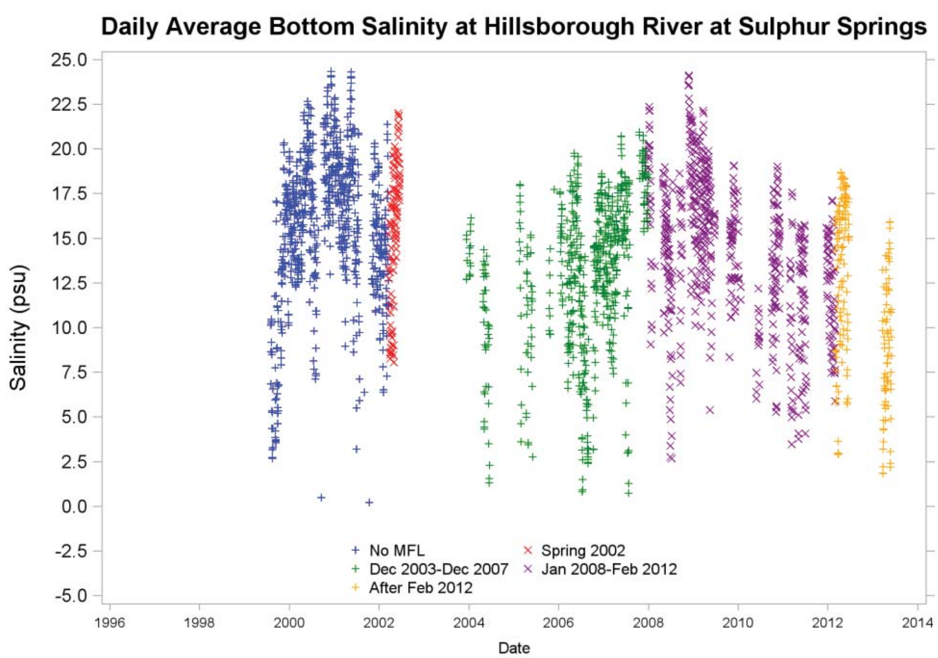

2. Daily Average Bottom Salinity at Hannah's Whirl Continuous Recorder



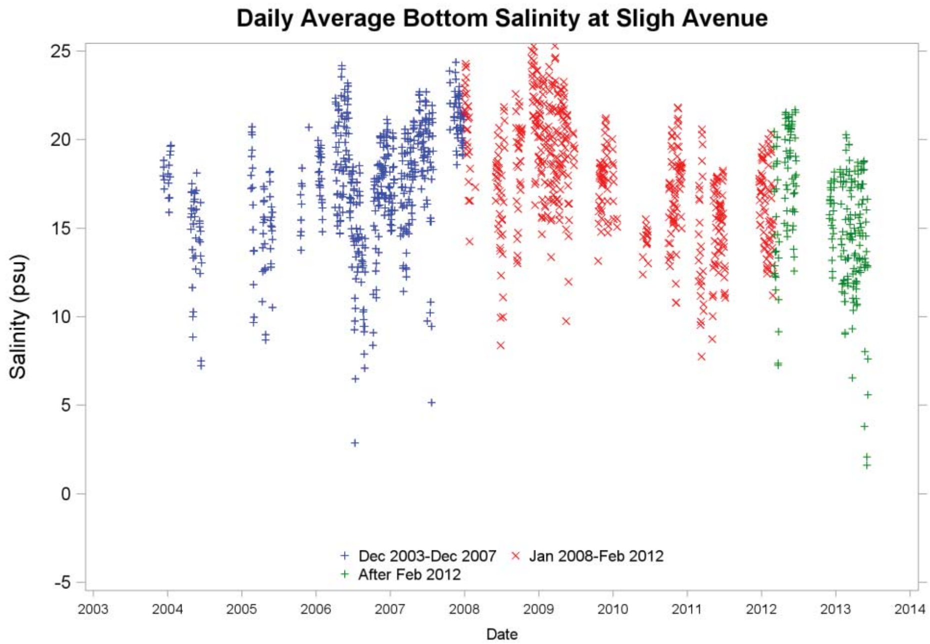
3. Daily Average Bottom Salinity at EPC Continuous Recorder RKM 13.7



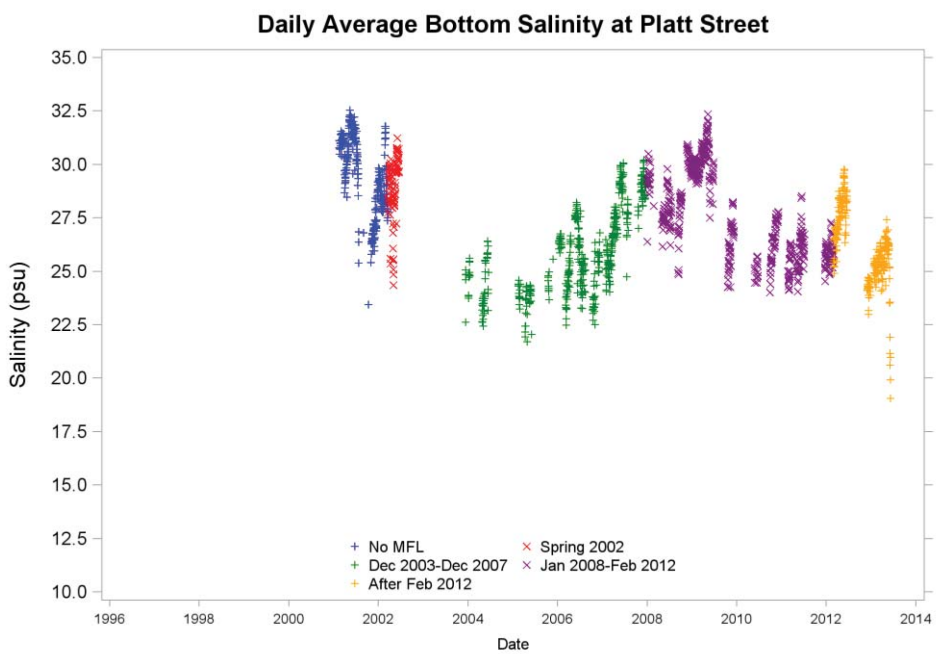

4. Daily Average Bottom Salinity at Sulphur Springs at Hillsborough River Continuous Recorder



5. Daily Average Bottom Salinity at Sligh Avenue Continuous Recorder




6. Daily Average Bottom Salinity at Platt Street Continuous Recorder



1. Wilcoxon Rank Sum Test Results for Rowlett Park Drive Bottom and Top Continuous Recorders

| Rowlett Park Drive Bottom | No MFL | Spring 2002 | Dec 2003 - Dec | Jan 2008 - Feb | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | 0.0003 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | 0.0001 | 0.0001 | 0.0001 | ---- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0109 | 0.0001 | ---- |

| Rowlett Park Drive Top | No MFL | Spring 2002 | Dec 2003 - Dec | Jan 2008 - Feb | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | 0.0001 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | 0.0001 | 0.0001 | 0.0001 | ---- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | ---- |

2. Wilcoxon Test Results for Hannah's Whirl Bottom and Top Continuous Recorders

| Hannah's Whirl Bottom | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - | After Feb |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | 0.3645 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | | | | ---- | |
| After Feb 2012 | | | | | ---- |

| Hannah's Whirl Top | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2008 - | After Feb |
|---|---|---|---|---|---|
| No MFL | | | | | |
| Spring 2002 | 0.0001 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | | | | ---- | |
| After Feb 2012 | | | | | ---- |

3. Wilcoxon Rank Sum Test Results for EPC KM 13.7 Bottom and Top Continuous Recorders

| EPC KM 13.7 Bottom | No MFL | Spring 2002 | Dec 2003 - Dec | Jan 2008 - Feb. | After Feb. |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | 0.0001 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb. | 0.0001 | 0.0001 | 0.0506 | ---- | |
| After Feb. 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | ---- |

| EPC KM 13.7 Top | No MFL | Spring 2002 | Dec 2003 - Dec | Jan 2008 - Feb. | After Feb. |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | 0.0001 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb. | 0.0001 | 0.0001 | 0.0001 | ---- | |
| After Feb. 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | ---- |

4. Wilcoxon Rank Sum Test Results for Sulphur Springs at the Hillsborough River Bottom and Top Continuous Recorders

| Sulphur Springs Bottom | No MFL | Spring 2002 | Dec 2003 – Dec | Jan 2008 - Feb | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | 0.5189 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | 0.0001 | 0.0013 | 0.0005 | ---- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | ---- |

| Sulphur Springs Top | No MFL | Spring 2002 | Dec 2003 - Dec | Jan 2008 - Feb | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | 0.0022 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | 0.0001 | 0.0001 | 0.1067 | ---- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |

5. Wilcoxon **Rank Sum** Test Results for Sligh Avenue Continuous Recorders

| Sligh Avenue Bottom | No MFL | Spring 2002 | Dec 2003 – Dec 2007 | Jan 2008 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | | ---- | | | |
| Dec 2003 - Dec 2007 | | | ---- | | |
| Jan 2008 - Feb 2012 | | | 0.1387 | ---- | |
| After Feb 2012 | | | 0.0001 | 0.0001 | ---- |

| Sligh Avenue Top | No MFL | Spring 2002 | Dec 2003 – Dec 2007 | Jan 2008 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | ---- | | | | |
| Spring 2002 | | ---- | | | |
| Dec 2003 - Dec 2007 | | | ---- | | |
| Jan 2008 - Feb 2012 | | | 0.3978 | ---- | |
| After Feb 2012 | | | 0.0001 | 0.0001 | ---- |

6. Wilcoxon Rank Sum Test Results for Platt Street Bottom and Top Continuous Recorders

| Platt Street Bottom | No MFL | Spring 2002 | Dec 2003 - Dec | Jan 2008 - Feb | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | | | | | |
| Spring 2002 | 0.0002 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | 0.0001 | 0.0001 | 0.0001 | ---- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.8294 | 0.0001 | ---- |

| Platt Street Top | No MFL | Spring 2002 | Dec 2003 - Dec | Jan 2008 - Feb | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | | | | | |
| Spring 2002 | 0.2386 | ---- | | | |
| Dec 2003 - Dec | 0.0001 | 0.0001 | ---- | | |
| Jan 2008 - Feb | 0.0001 | 0.0001 | 0.0001 | ---- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.5382 | 0.0001 | ---- |

Appendix 2C – Wilcoxon Rank Sum Test Results for Salinity Data in the Hillsborough River by Depth Interval and Kilometer Segment

1. Wilcoxon Rank Sum Salinity Test Results for Hillsborough River Kilometer Segment 16.2 to 15.2 by Increasing Depth

**Depth 0-1 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0001 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0001 | 0.0001 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0001 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.6028 | 0.0001 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.1051 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0197 | X | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

2. Wilcoxon Rank Sum Salinity Test Results for Hillsborough River Kilometer Segment 15.2 to 14.5 by Increasing Depth

**Depth 0-1 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0001 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0483 | 0.0729 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0297 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0006 | 0.0068 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | --- |

**Depth 2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | X | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | X | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

3. Wilcoxon Rank Sum Salinity Test Results for Hillsborough River Kilometer Segment 14.5 to 14.1 by Increasing Depth

**Depth 0-1 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0002 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.004 | 0.4337 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.033 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.0538 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.8113 | --- | | | |
| Dec 2003 - Dec 2007 | 0.6232 | 0.0711 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

4. Wilcoxon Rank Sum Salinity Test Results for Hillsborough River Kilometer Segment 14.1 to 13.4 by Increasing Depth

**Depth 0-1 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0001 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0001 | 0.0324 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.01 | --- |

**Depth 1-2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.2487 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0031 | 0.0042 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0051 | --- |

**Depth 2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.0031 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0392 | 0.0001 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0153 | 0.0001 | --- | |
| After Feb 2012 | 0.0001 | 0.001 | 0.0001 | 0.5268 | --- |

5. Wilcoxon Rank Sum Salinity Test Results for Hillsborough River Kilometer Segment 13.4 to 12.6 by Increasing Depth

**Depth 0-1 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0002 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0003 | 0.0164 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | --- |

**Depth 1-2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.803 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0071 | 0.0051 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.002 | --- |

**Depth 2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0005 | --- | | | |
| Dec 2003 - Dec 2007 | 0.1283 | 0.0137 | --- | | |
| Jan 2009 - Feb 2012 | 0.0015 | 0.0506 | 0.0028 | --- | |
| After Feb 2012 | 0.0011 | 0.0231 | 0.0015 | 0.5035 | --- |

**Depth >2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0335 | 0.0221 | --- | | |
| Jan 2009 - Feb 2012 | 0.0005 | 0.0583 | 0.0093 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0208 | --- |

6. Wilcoxon Rank Sum Salinity Test Results for Hillsborough River Kilometer Segment 12.6 to 11.6 by Increasing Depth

**Depth 0-1 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0115 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0589 | 0.4847 | --- | |
| After Feb 2012 | 0.0005 | X | X | X | --- |

**Depth 1-2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.3401 | --- | | |
| Jan 2009 - Feb 2012 | 0.0012 | 0.4424 | 0.6611 | --- | |
| After Feb 2012 | 0.0041 | X | X | X | --- |

**Depth 2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0012 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0254 | 0.1189 | --- | | |
| Jan 2009 - Feb 2012 | 0.0601 | X | X | --- | |
| After Feb 2012 | 0.0186 | X | X | X | --- |

**Depth >2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.2103 | 0.0001 | --- | | |
| Jan 2009 - Feb 2012 | 0.0096 | X | X | --- | |
| After Feb 2012 | 0.001 | X | X | X | --- |

7. Wilcoxon Rank Sum Salinity Test Results for Hillsborough River Kilometer Segment 11.6 to 10.6 by Increasing Depth

**Depth 0-1 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.1741 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0038 | 0.014 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | --- |

**Depth 1-2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0003 | 0.326 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0517 | 0.0083 | --- | |
| After Feb 2012 | 0.0001 | 0.0001 | 0.0001 | | --- |

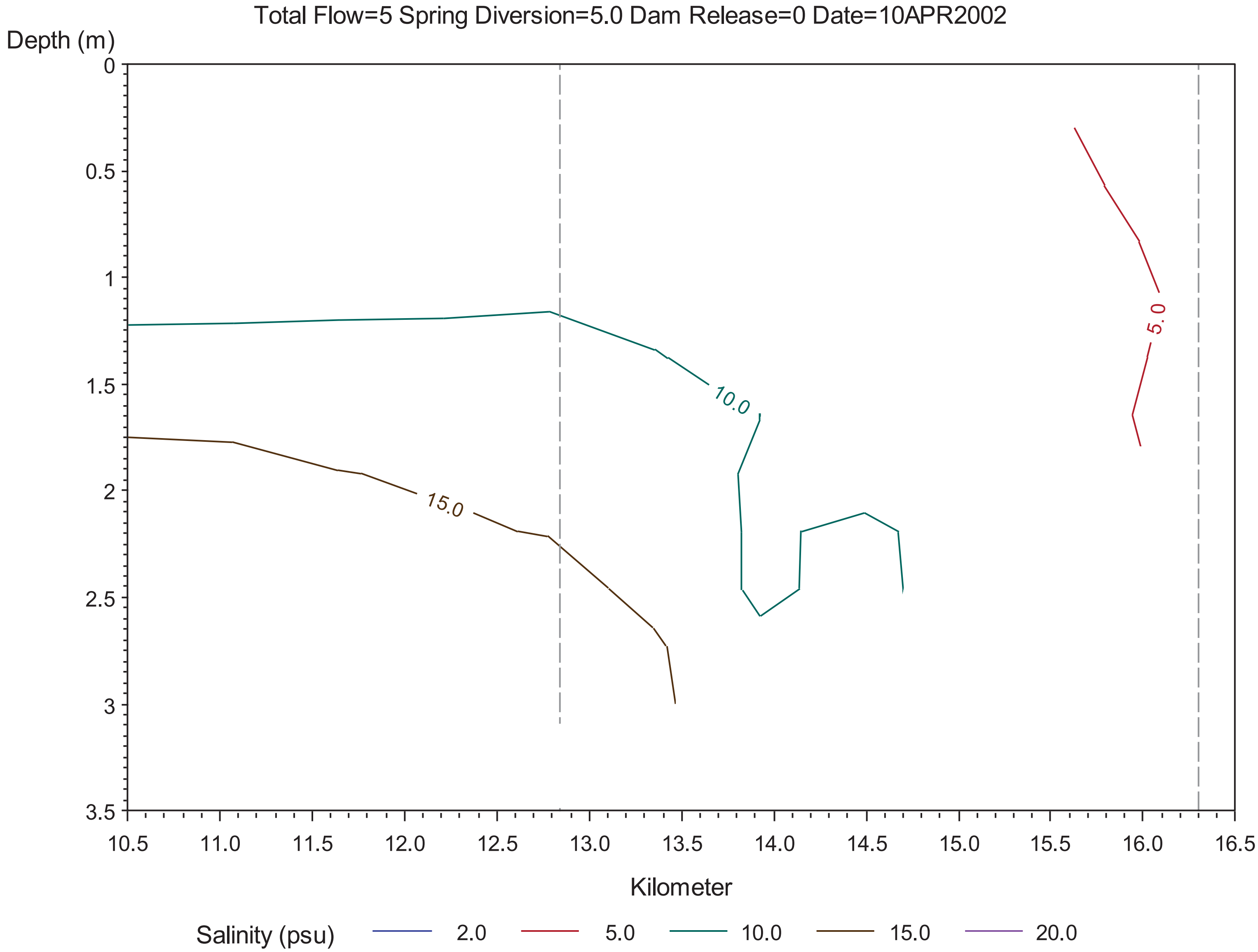
**Depth 2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0012 | --- | | | |
| Dec 2003 - Dec 2007 | 0.1034 | 0.015 | --- | | |
| Jan 2009 - Feb 2012 | 0.0035 | 0.1334 | 0.0058 | --- | |
| After Feb 2012 | 0.0007 | 0.0167 | 0.0007 | 0.0291 | --- |

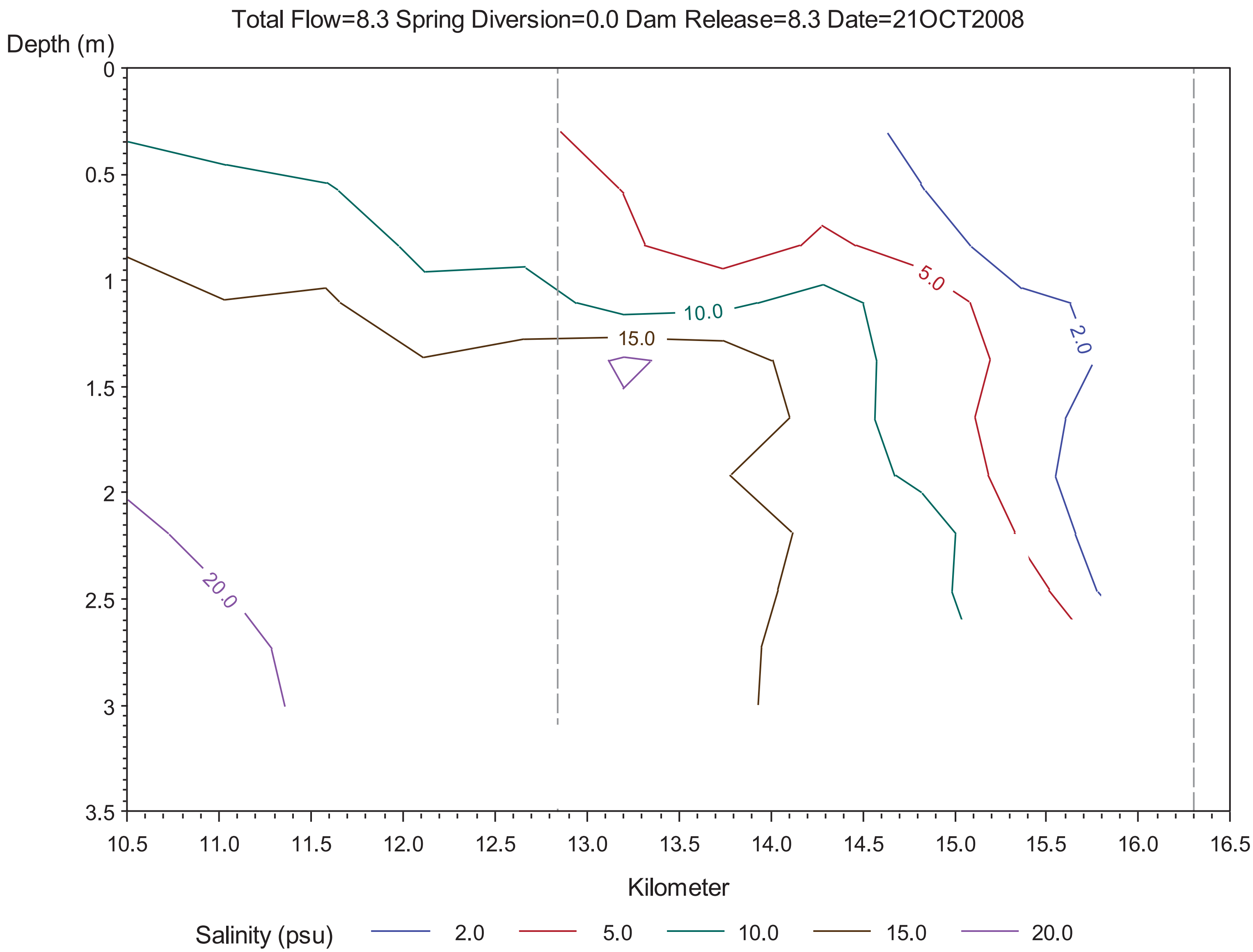
**Depth >2 m**

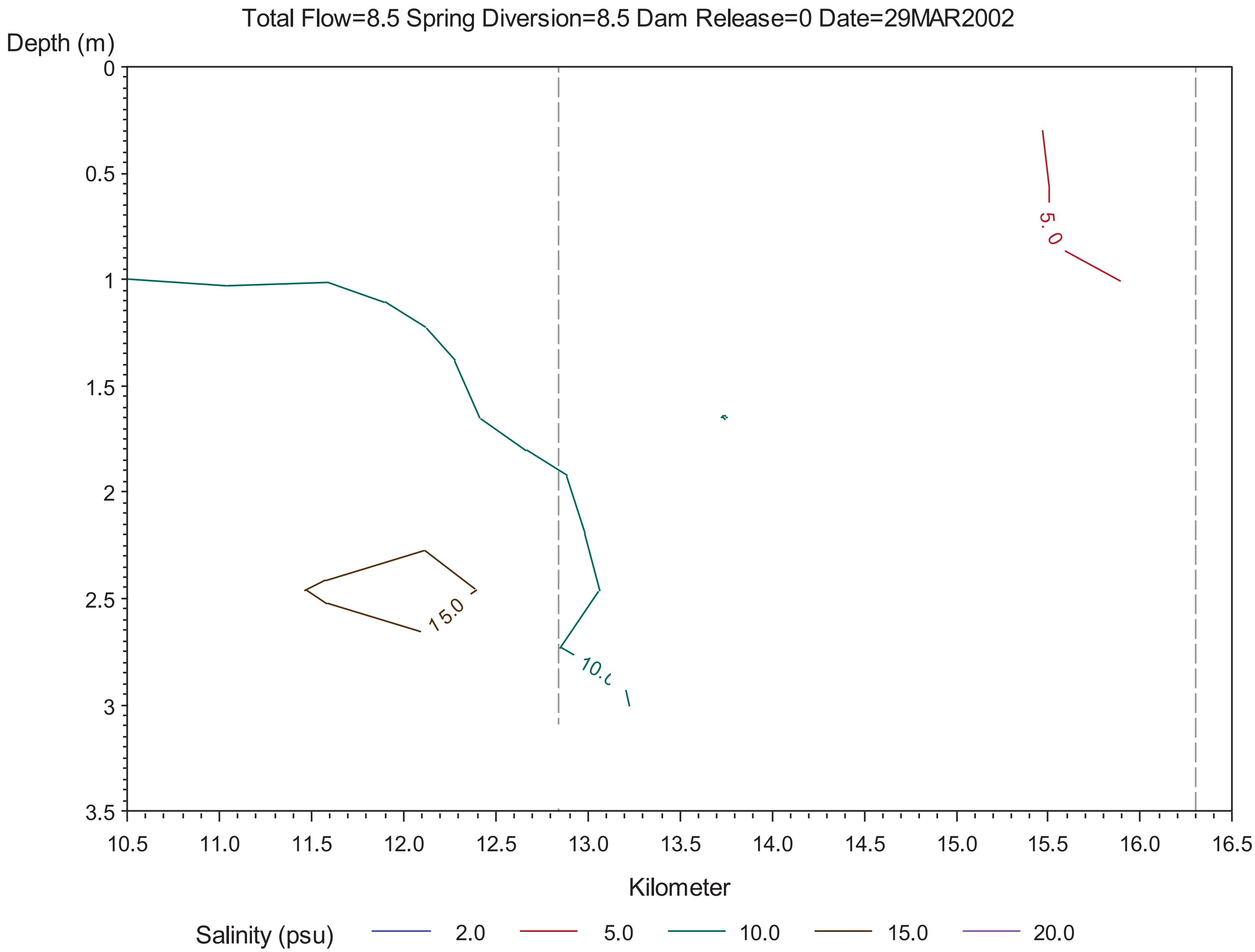
| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.1751 | 0.0029 | --- | | |
| Jan 2009 - Feb 2012 | 0.0004 | 0.0671 | 0.0009 | --- | |
| After Feb 2012 | 0.0001 | 0.0002 | 0.0001 | 0.1562 | --- |

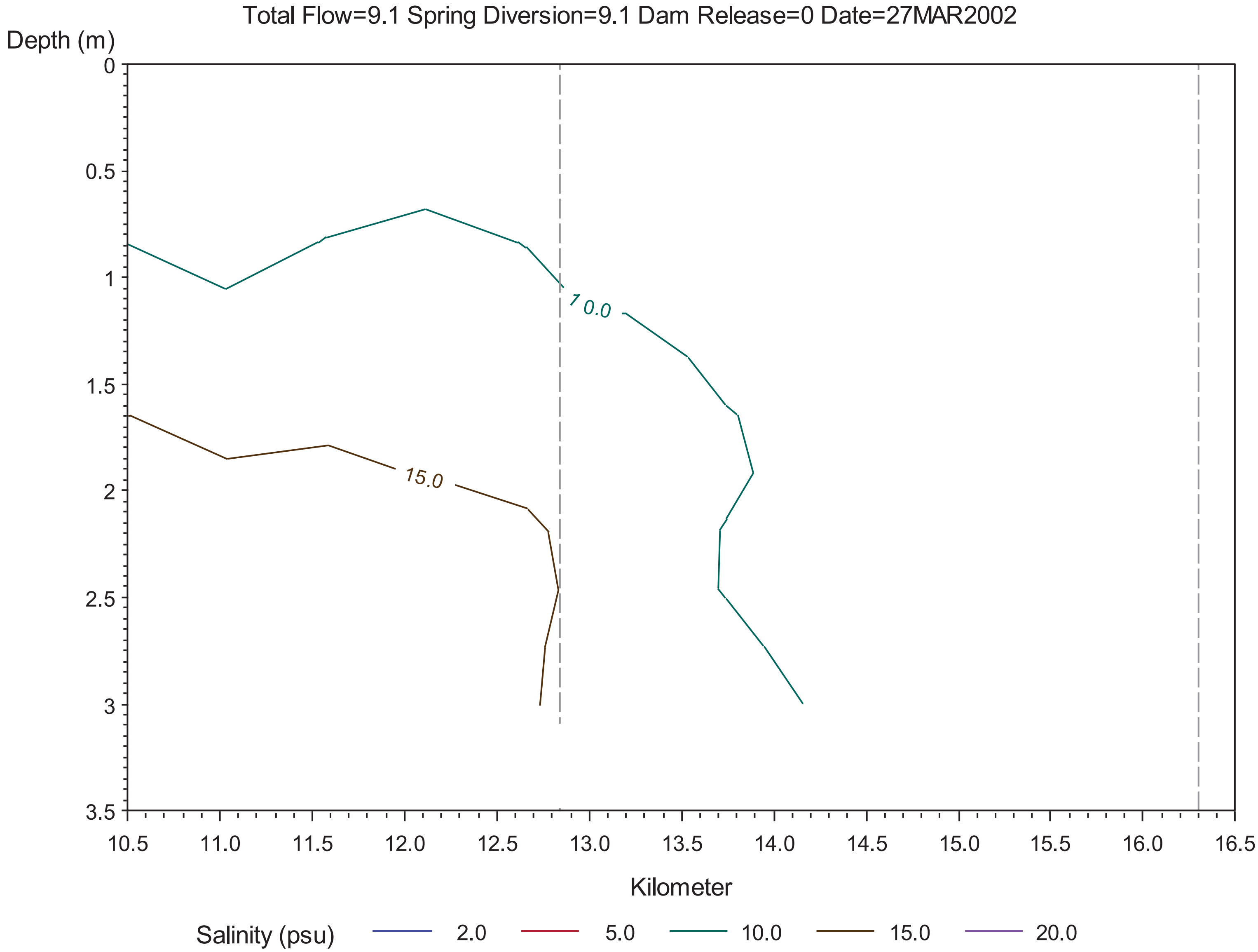
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program



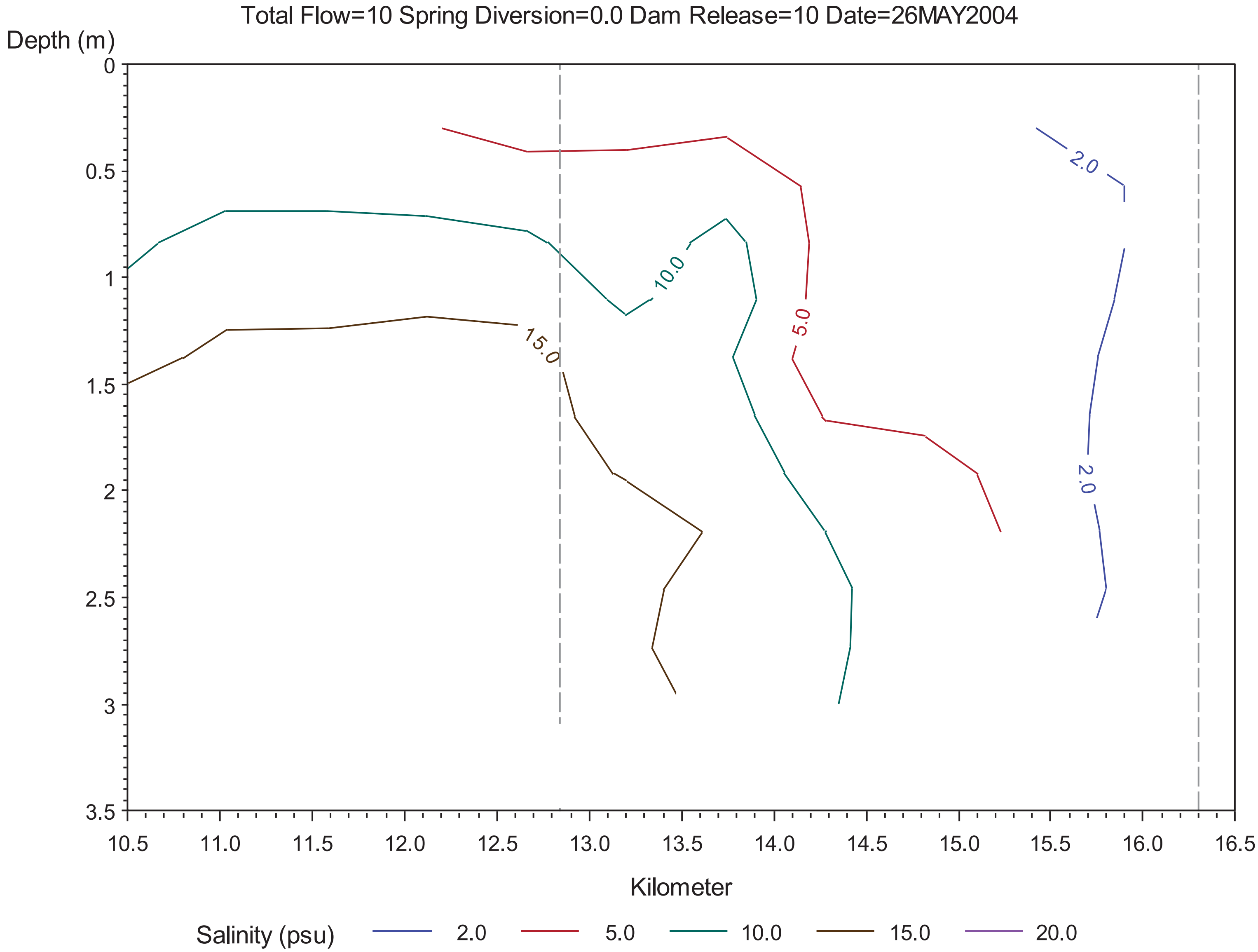
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program




Total Flow=8.5 Spring Diversion=8.5 Dam Release=0 Date=29MAR2002
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
5.0
15.0
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

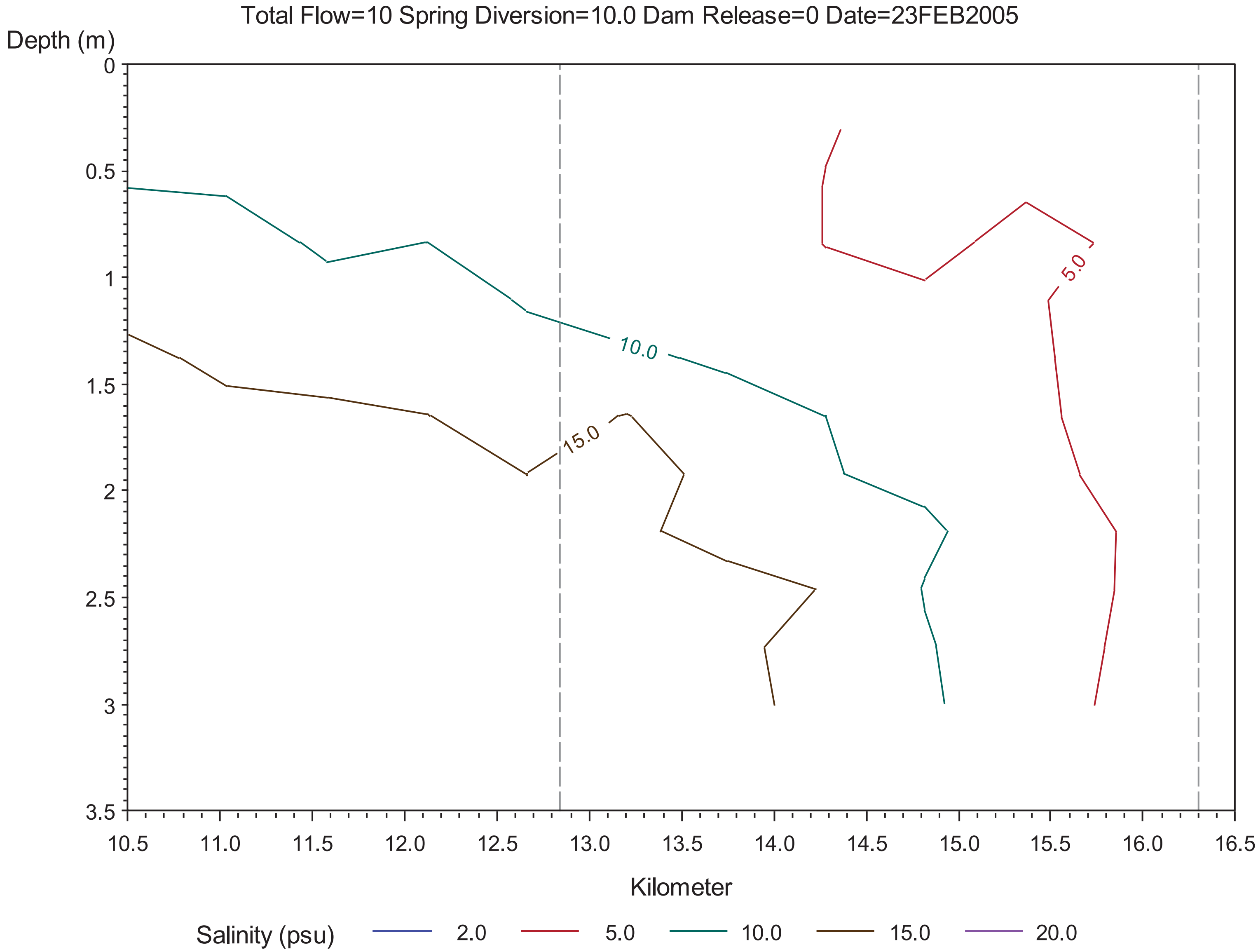

Total Flow=9.1 Spring Diversion=9.1 Dam Release=0 Date=27MAR2002
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.0
15.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

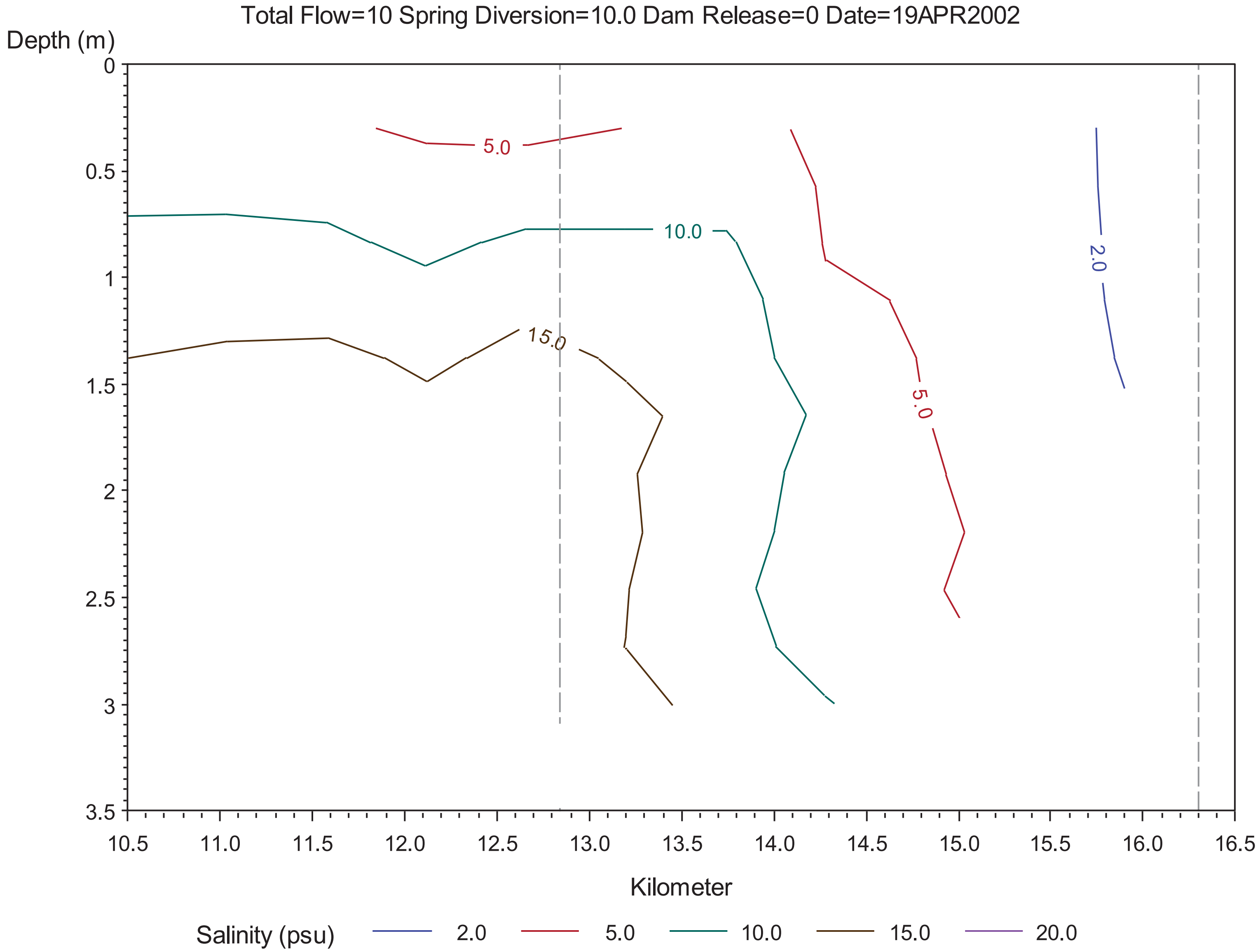
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program




Total Flow=10 Spring Diversion=10.0 Dam Release=0 Date=18FEB2005
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
10.0
15.0
20.0
5.0
2.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

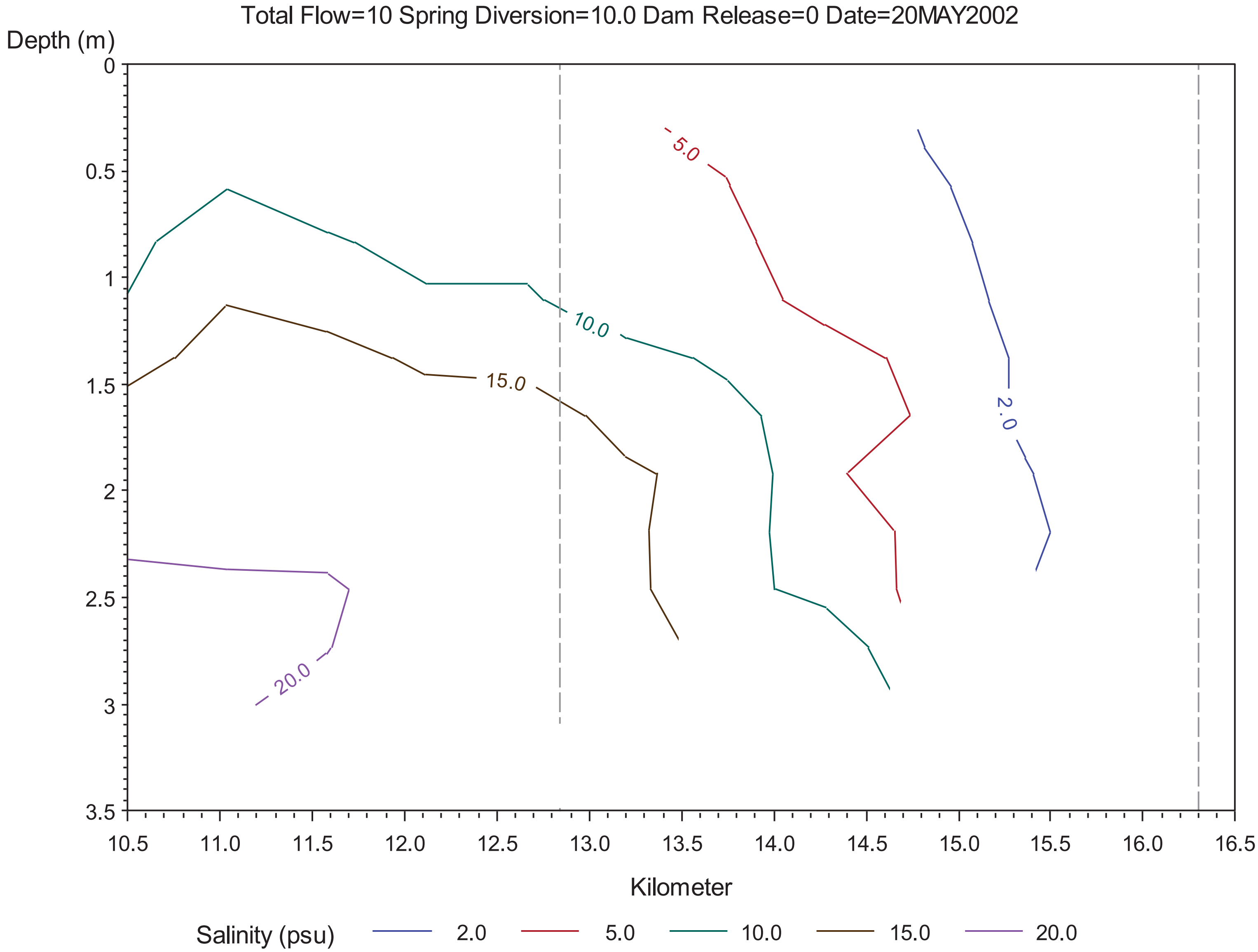
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

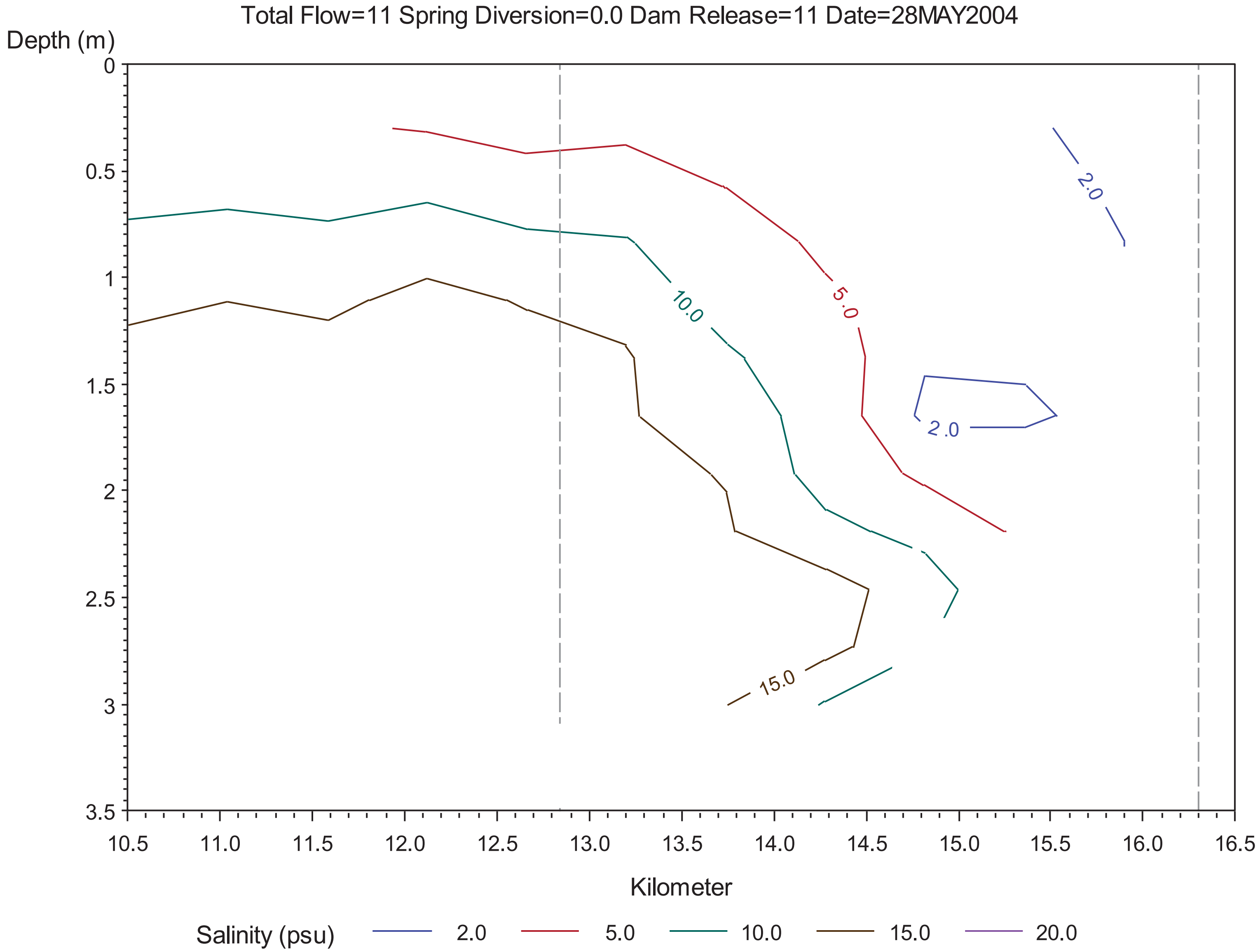




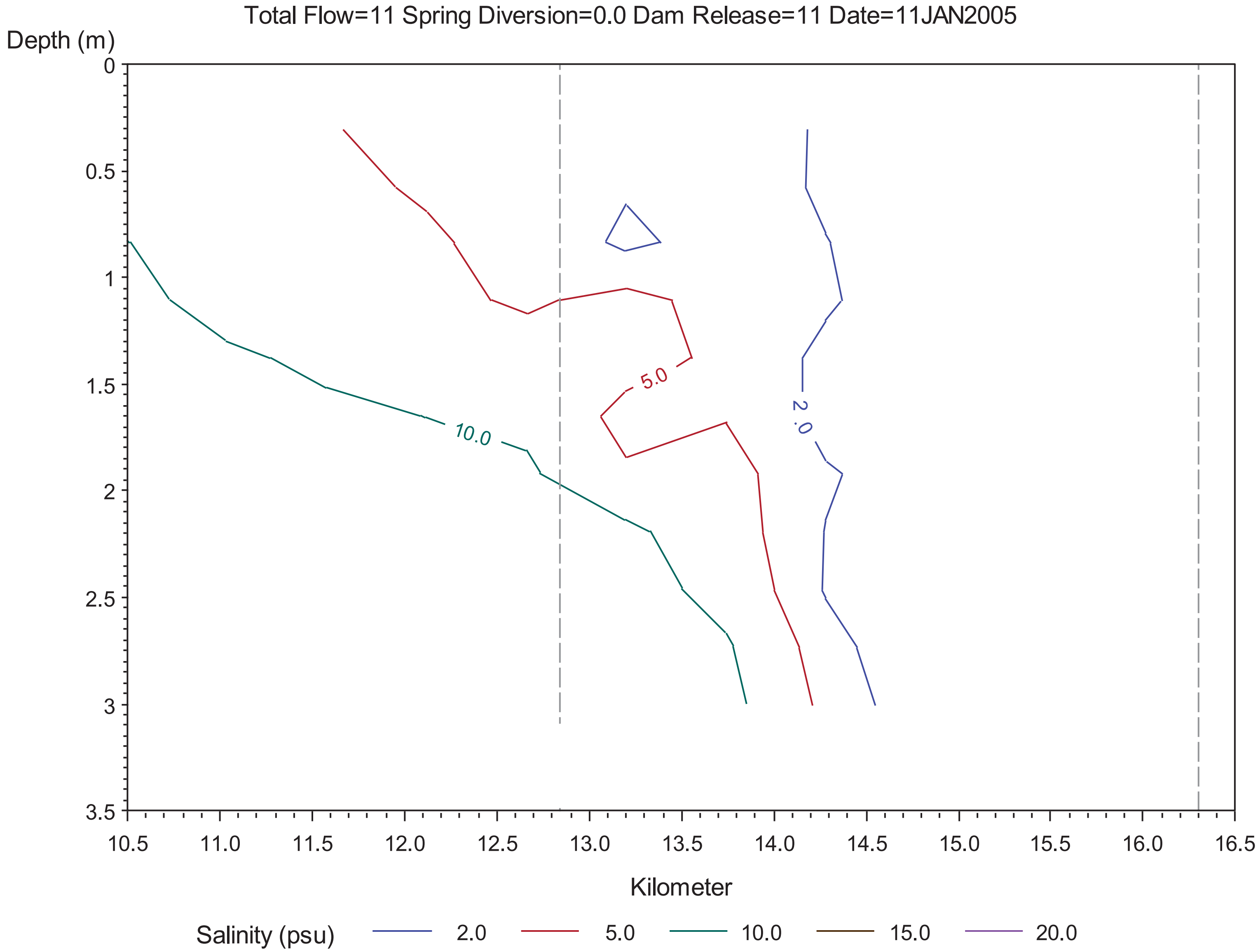
Total Flow=10 Spring Diversion=10.0 Dam Release=0 Date=19APR2002
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
5.0
10.0
15.0
5.0
2.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

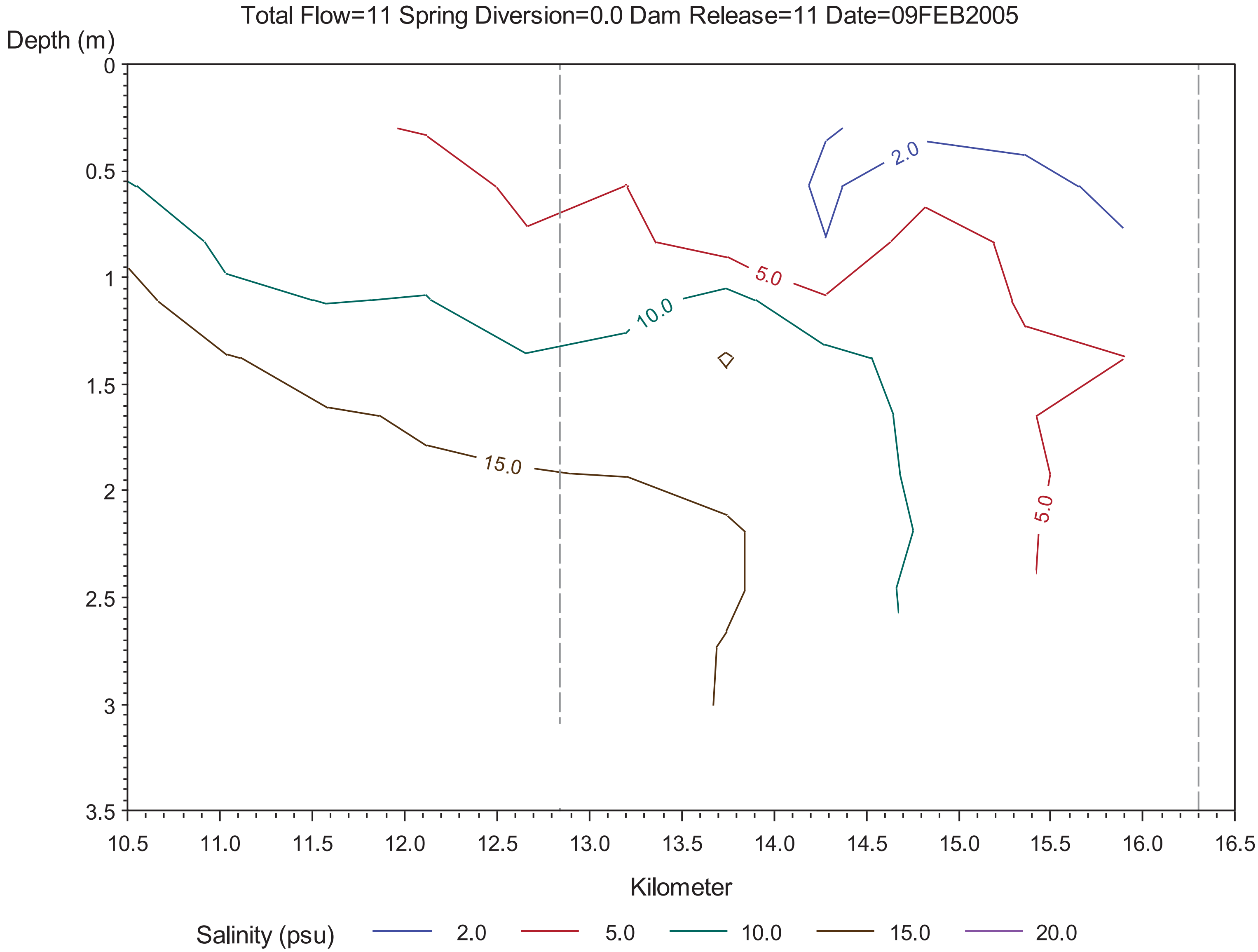
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program



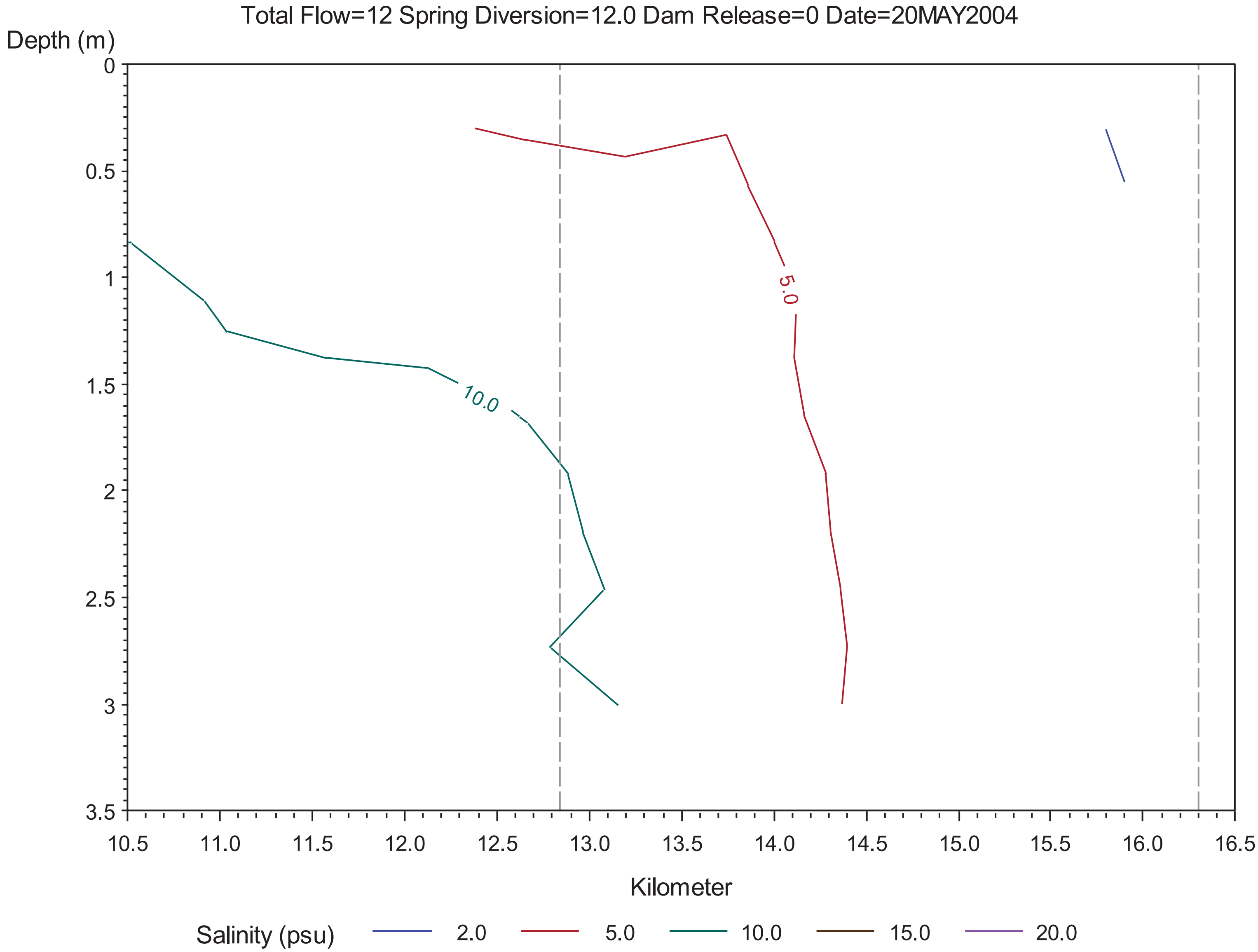


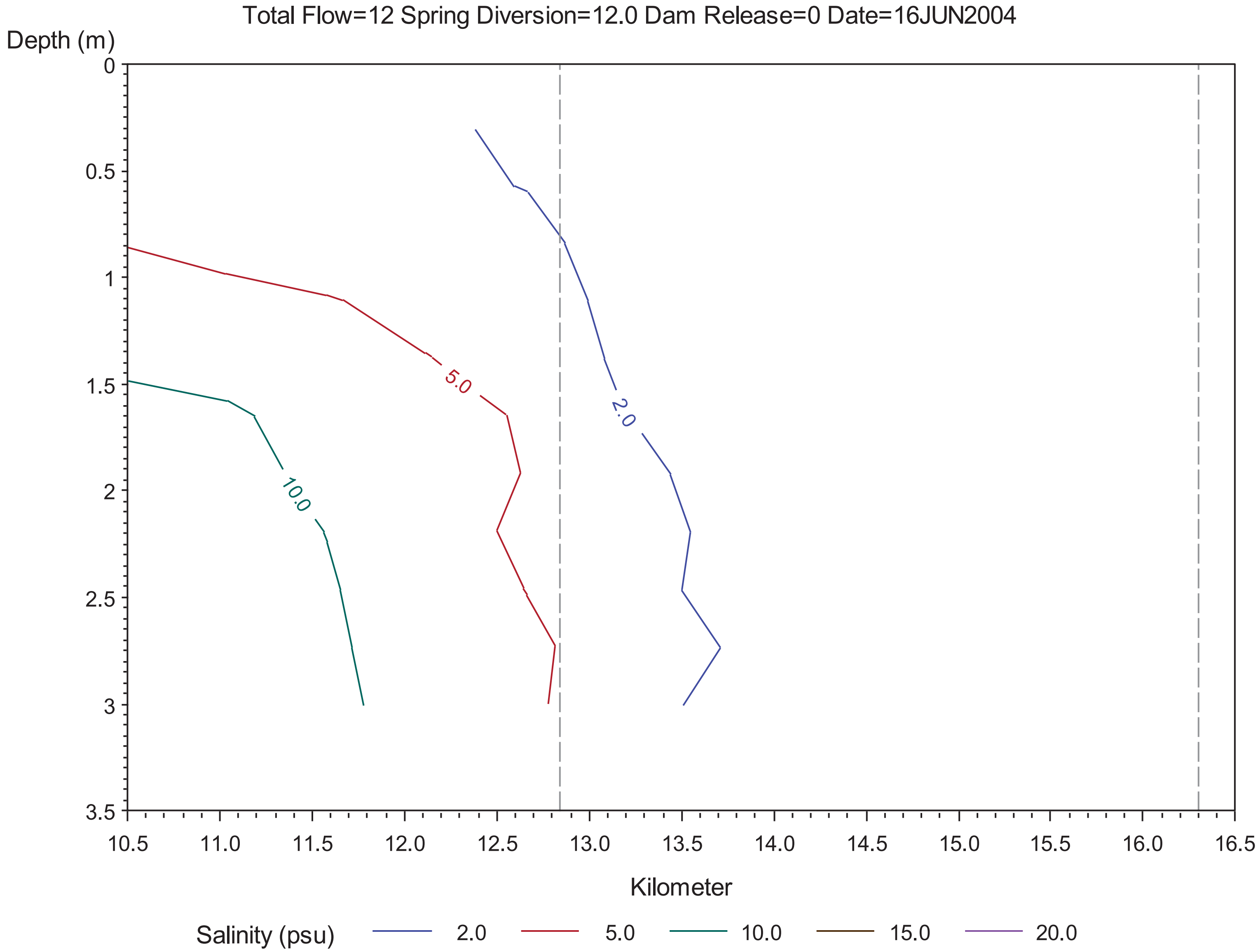
Total Flow=11 Spring Diversion=0.0 Dam Release=11 Date=28MAY2004
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
2.0
5.0
10.0
15.0
2.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0


Total Flow=11 Spring Diversion=0.0 Dam Release=11 Date=11JAN2005
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
5.0
10.0
2.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

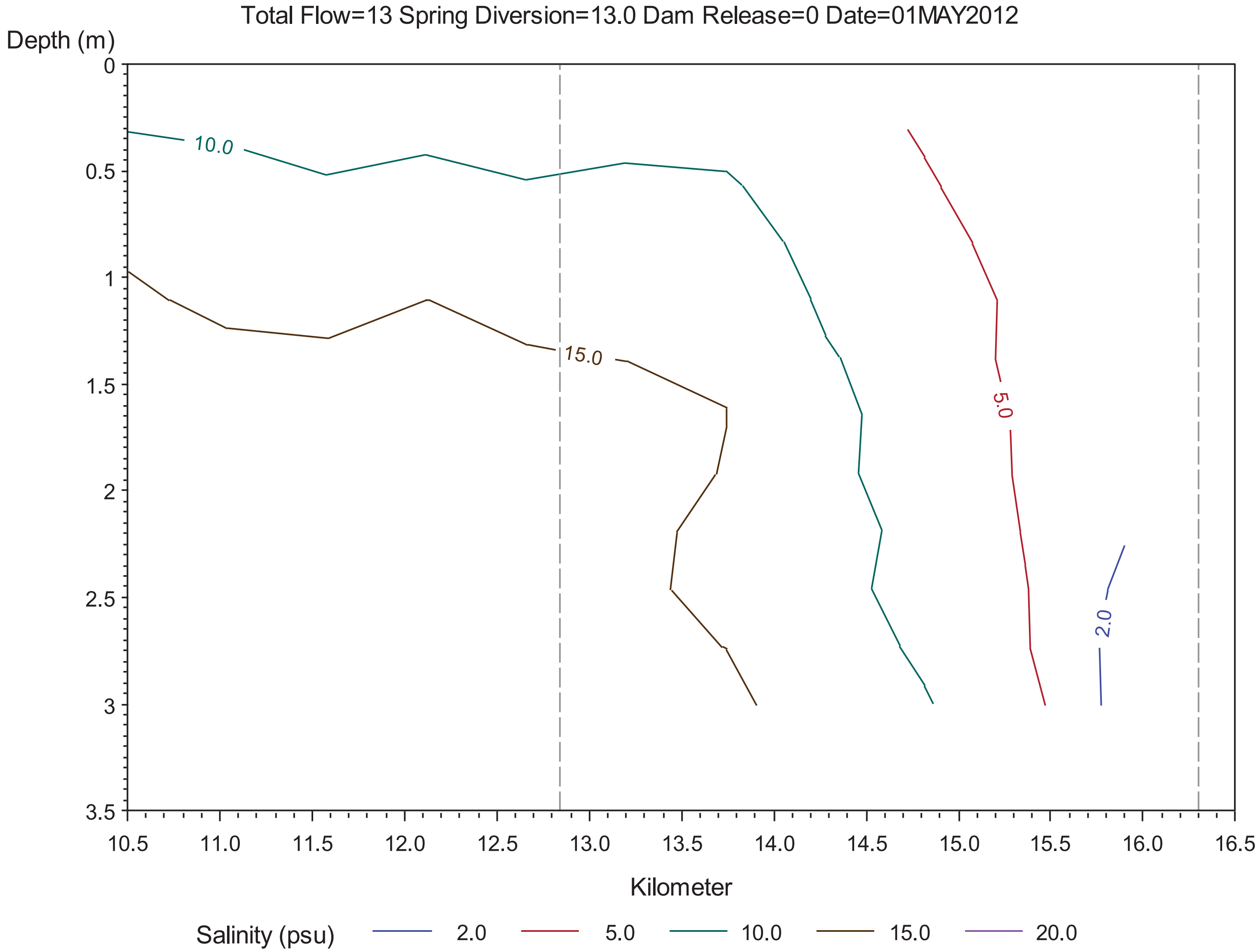

Total Flow=11 Spring Diversion=0.0 Dam Release=11 Date=09FEB2005
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
2.0
5.0
10.0
15.0
5.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

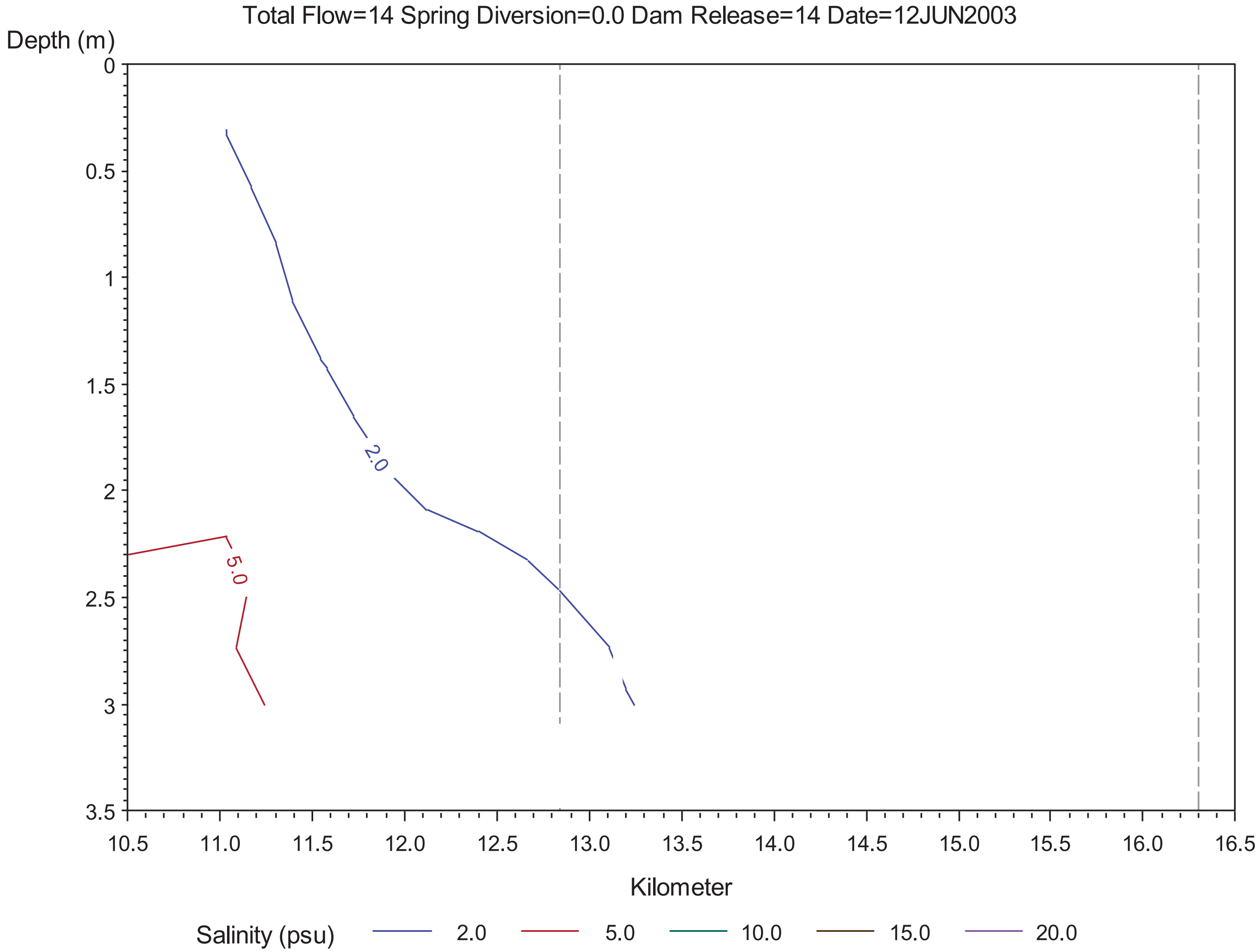
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program




Total Flow=12 Spring Diversion=12.0 Dam Release=0 Date=16JUN2004
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
5.0
2.0
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

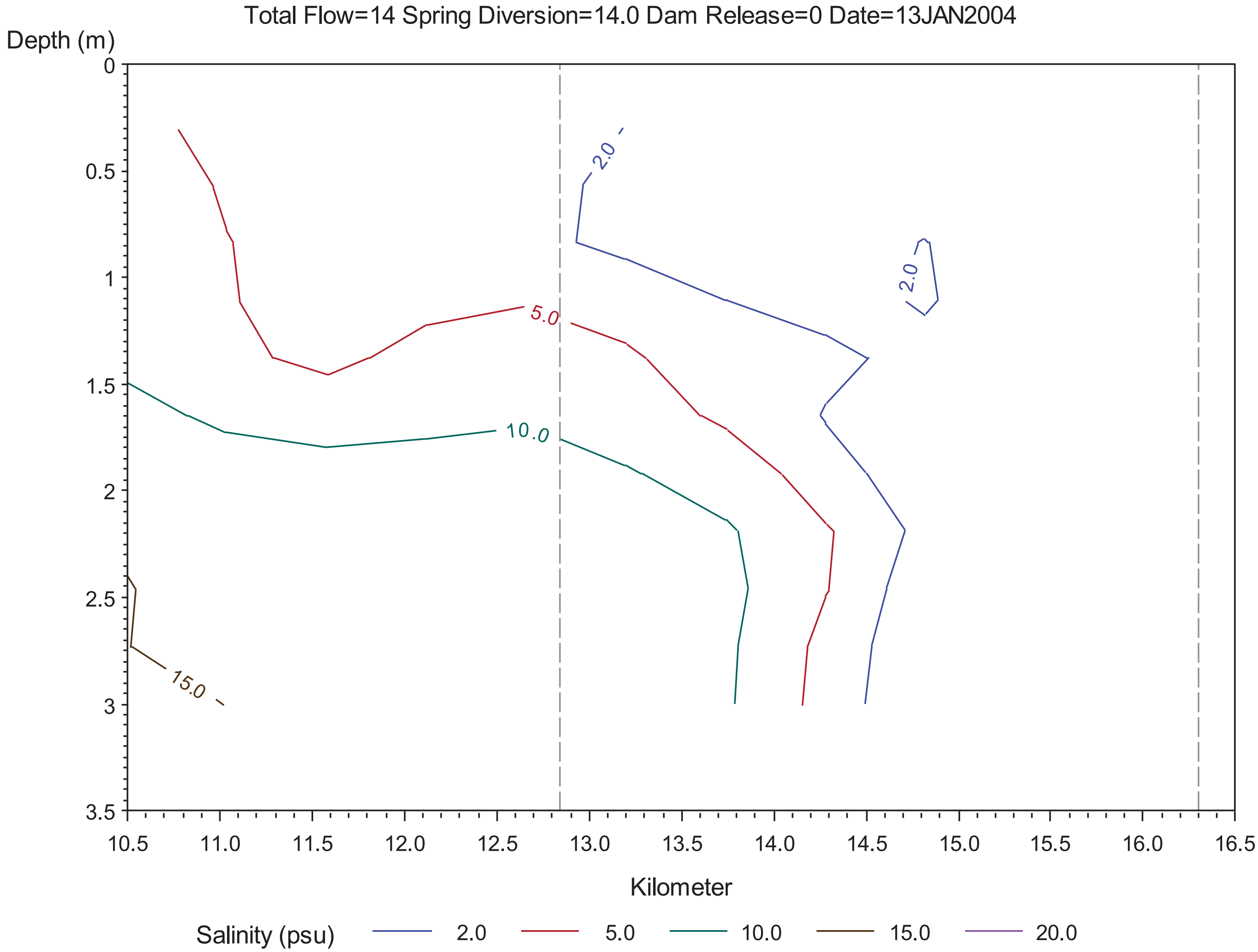
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program



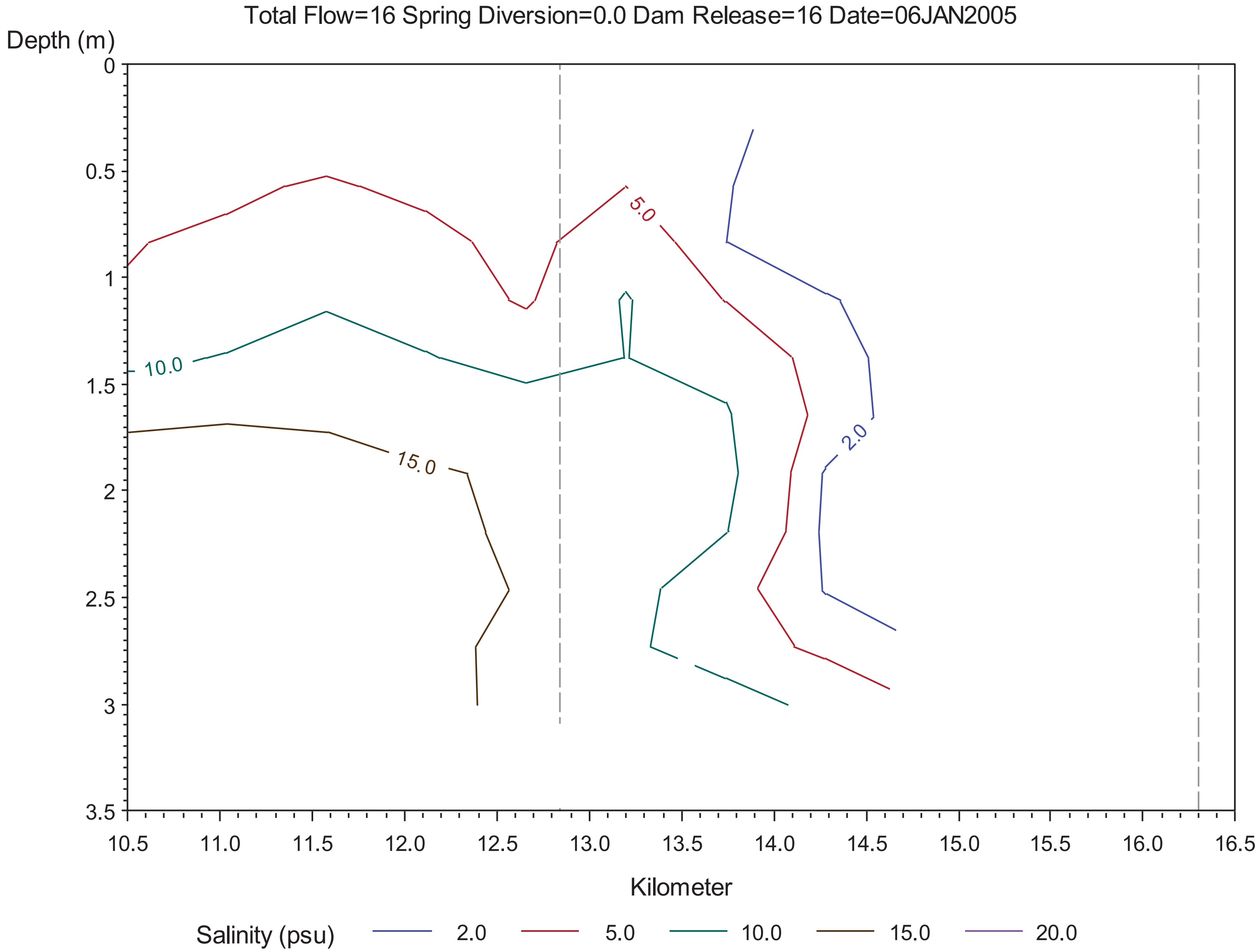


Total Flow=14 Spring Diversion=0.0 Dam Release=14 Date=12JUN2003
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
2.0
5.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

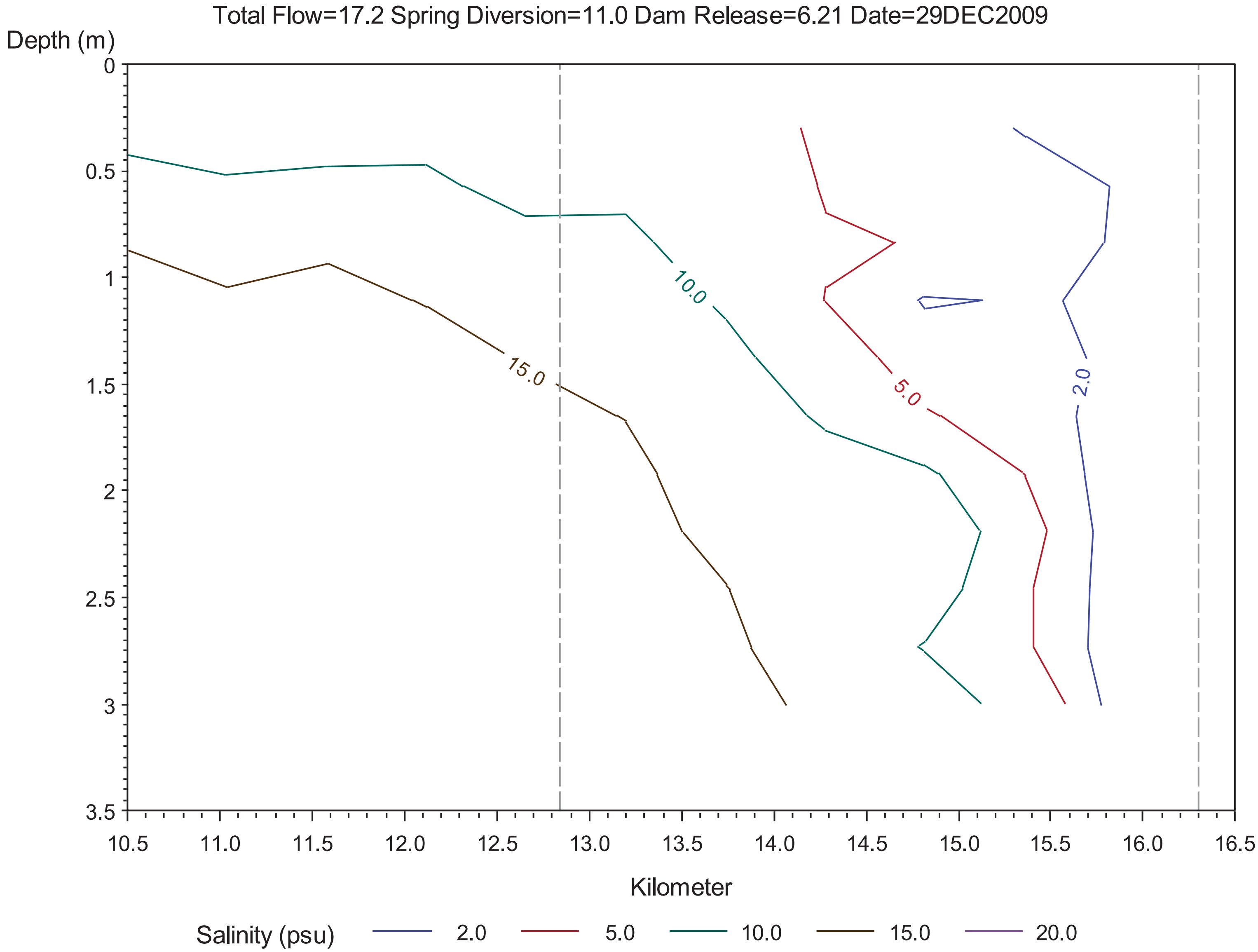
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

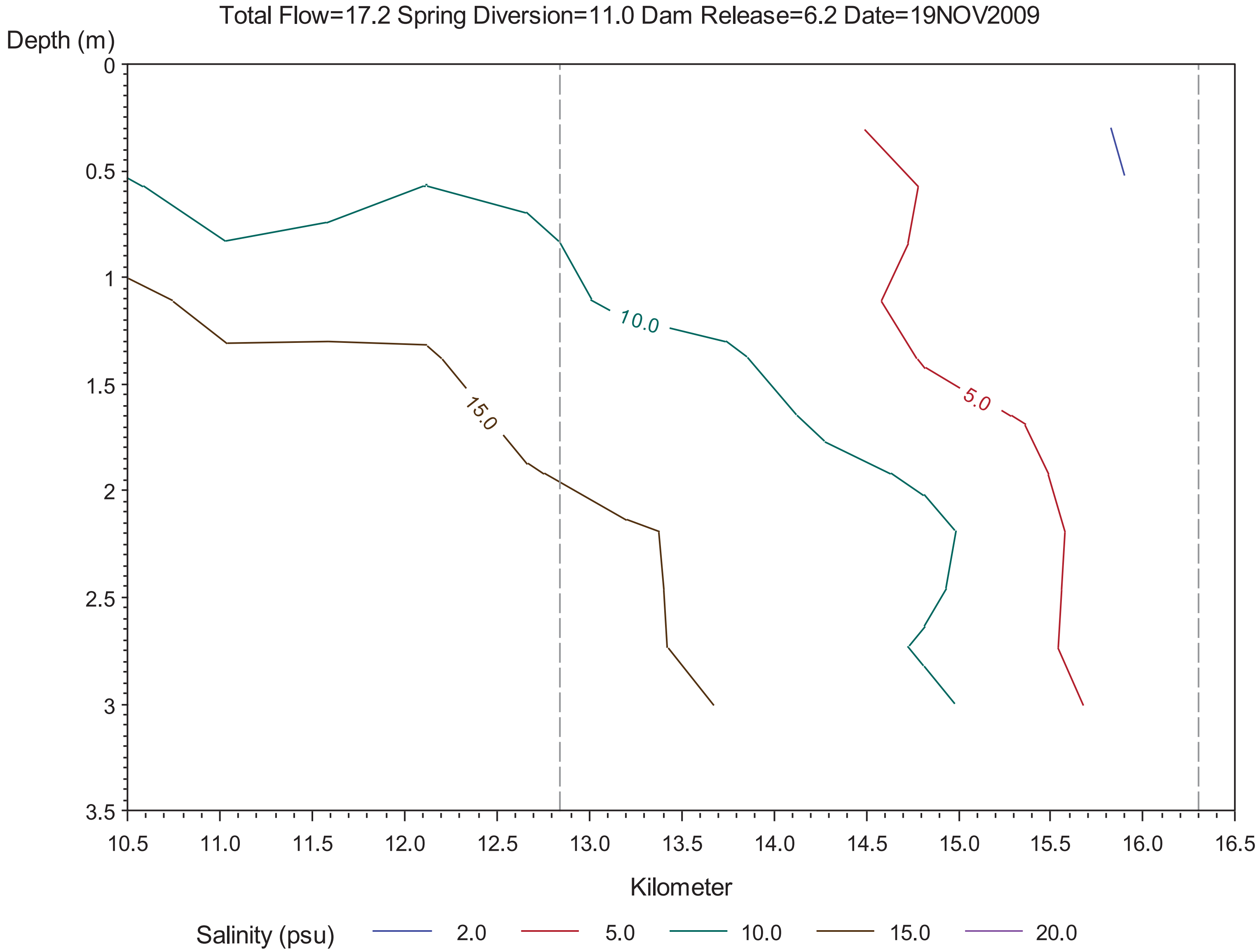


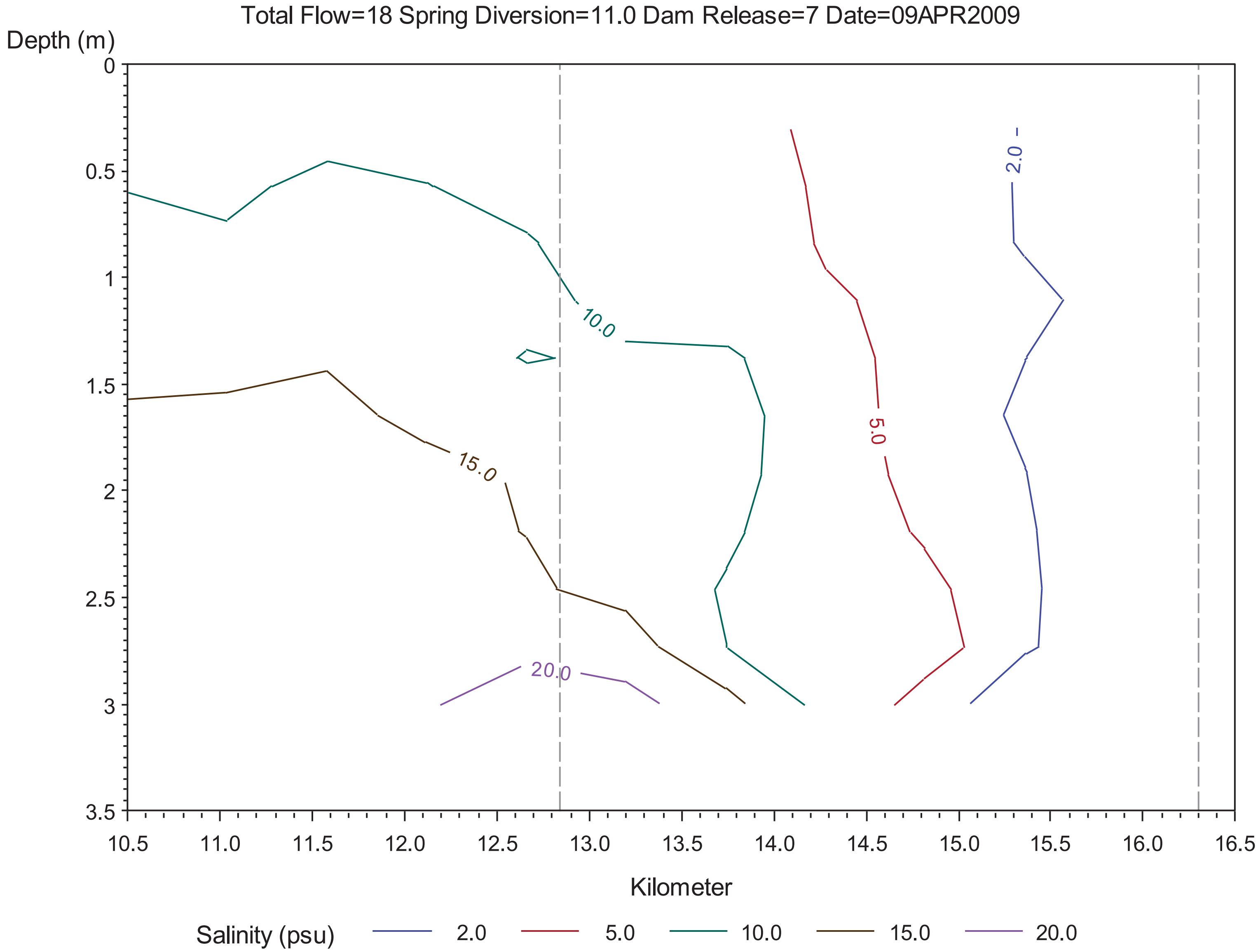
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

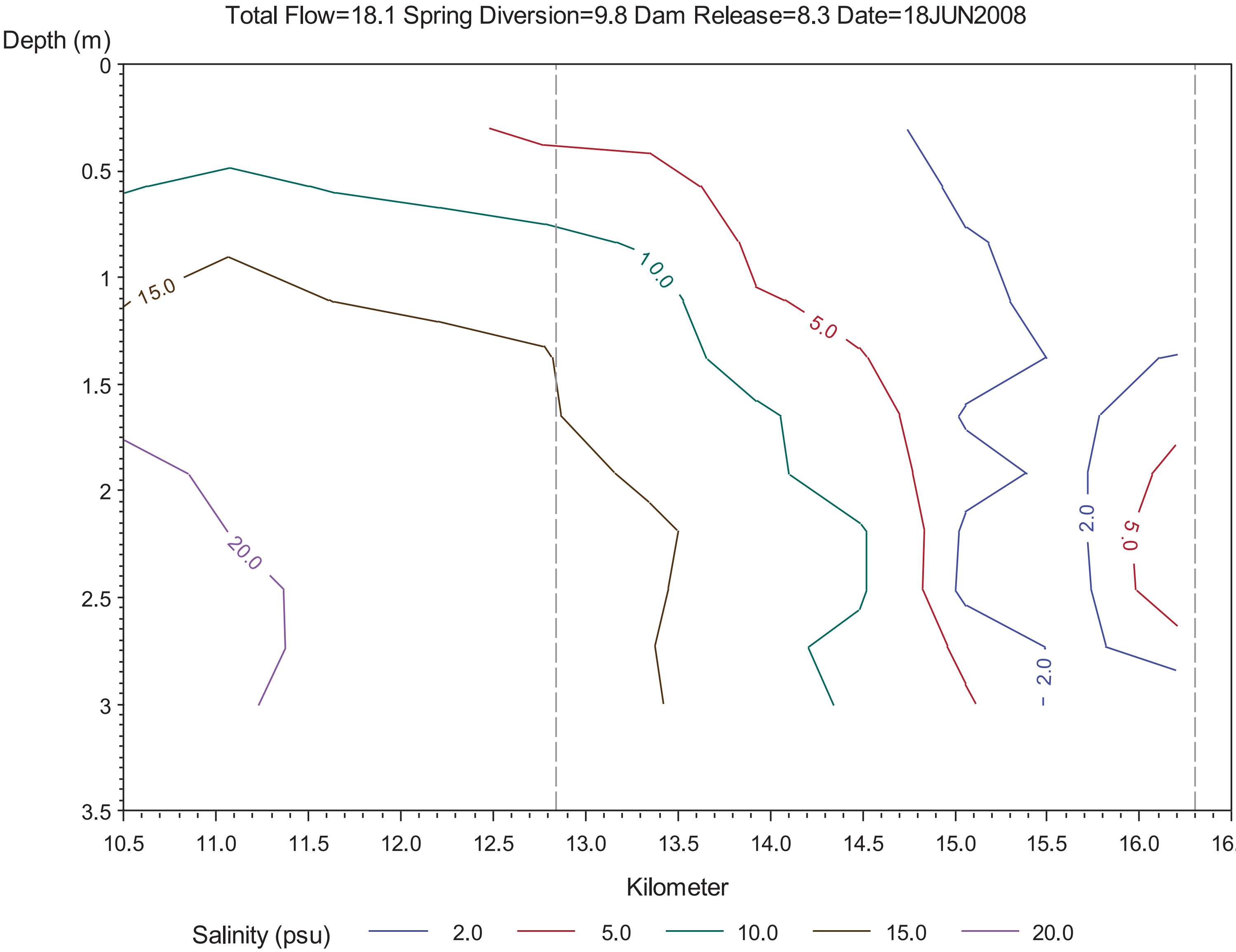


Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

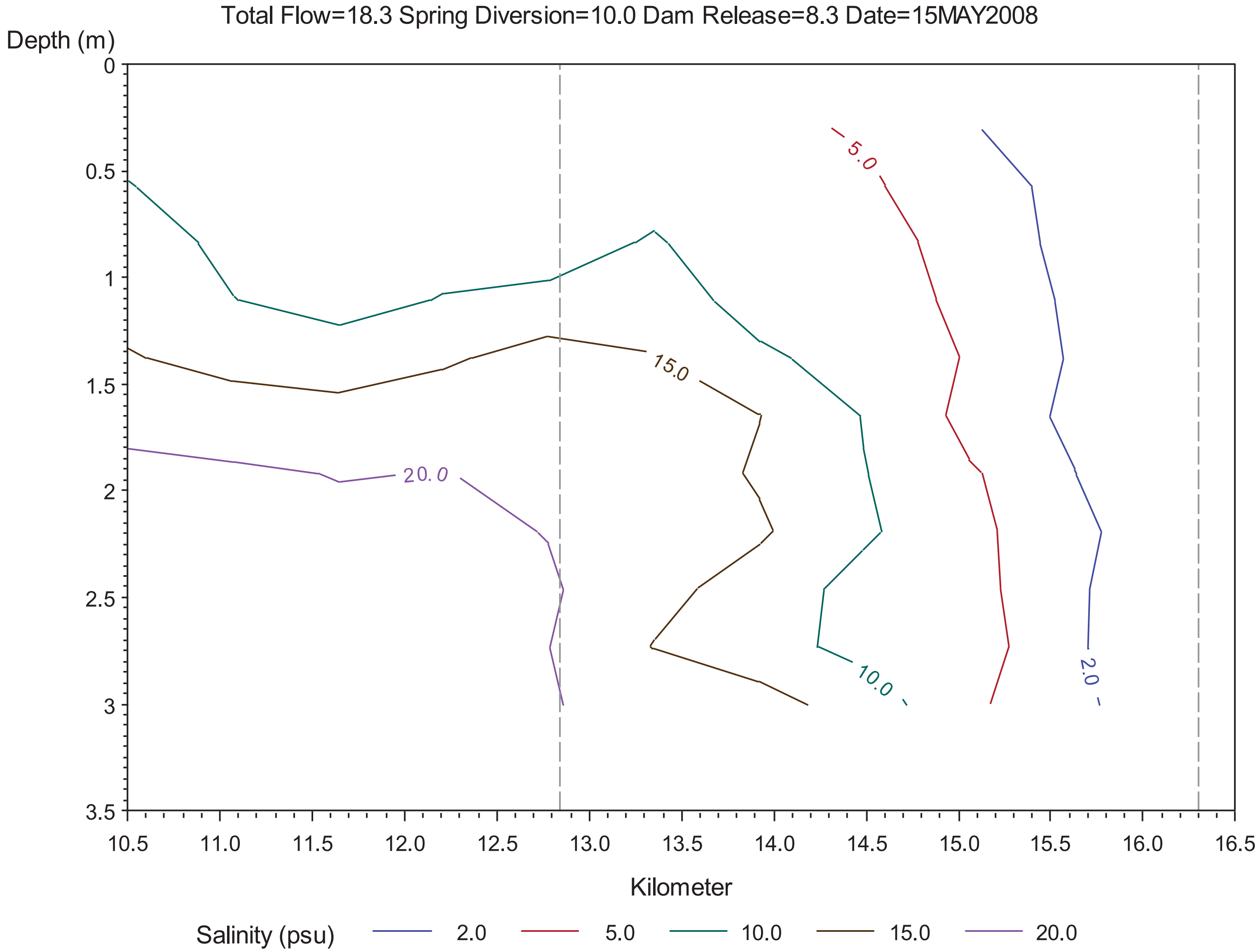


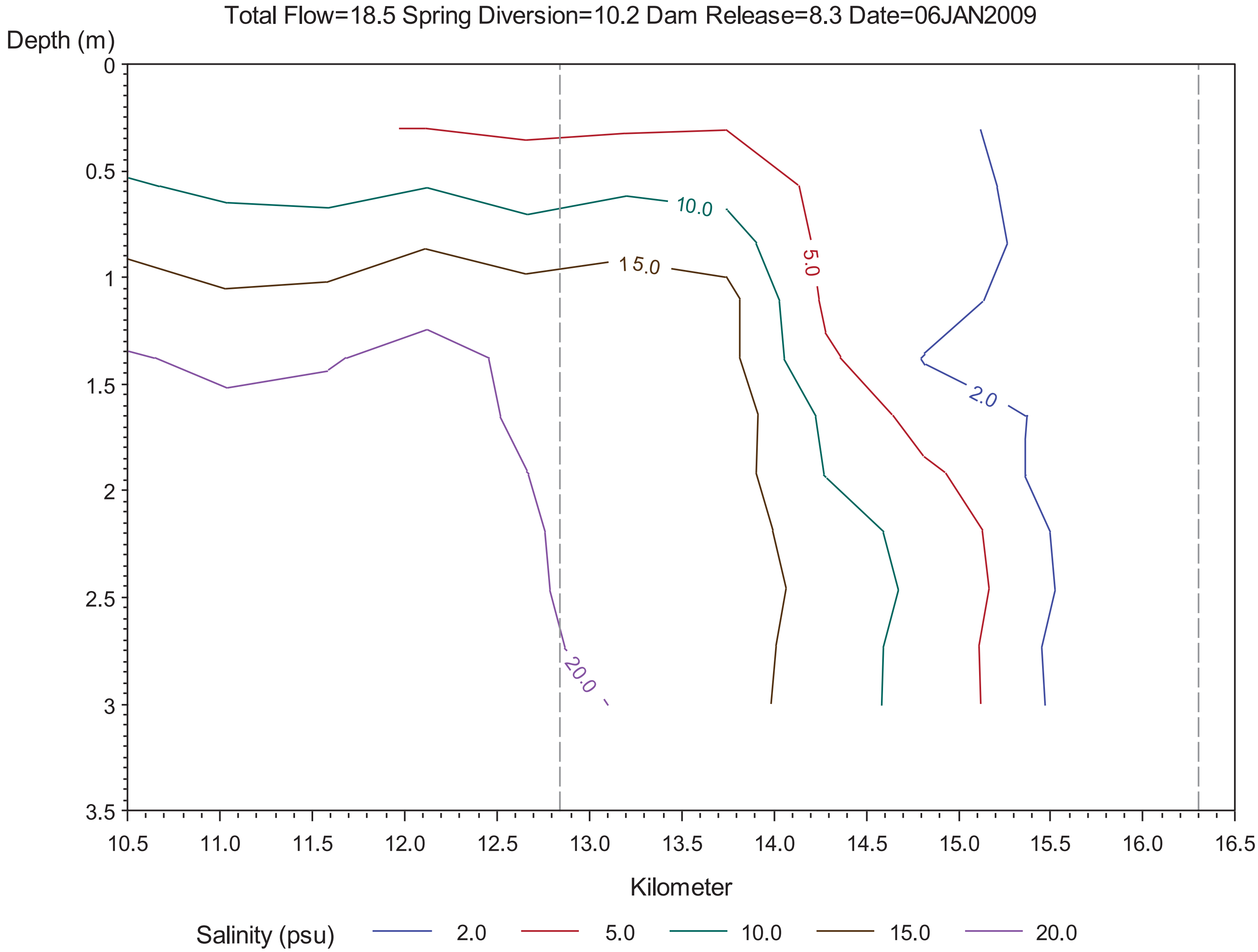

Total Flow=17.2 Spring Diversion=11.0 Dam Release=6.2 Date=19NOV2009
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.0
15.0
5.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0


Total Flow=18 Spring Diversion=11.0 Dam Release=7 Date=09APR2009
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.0
15.0
20.0
5.0
2.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

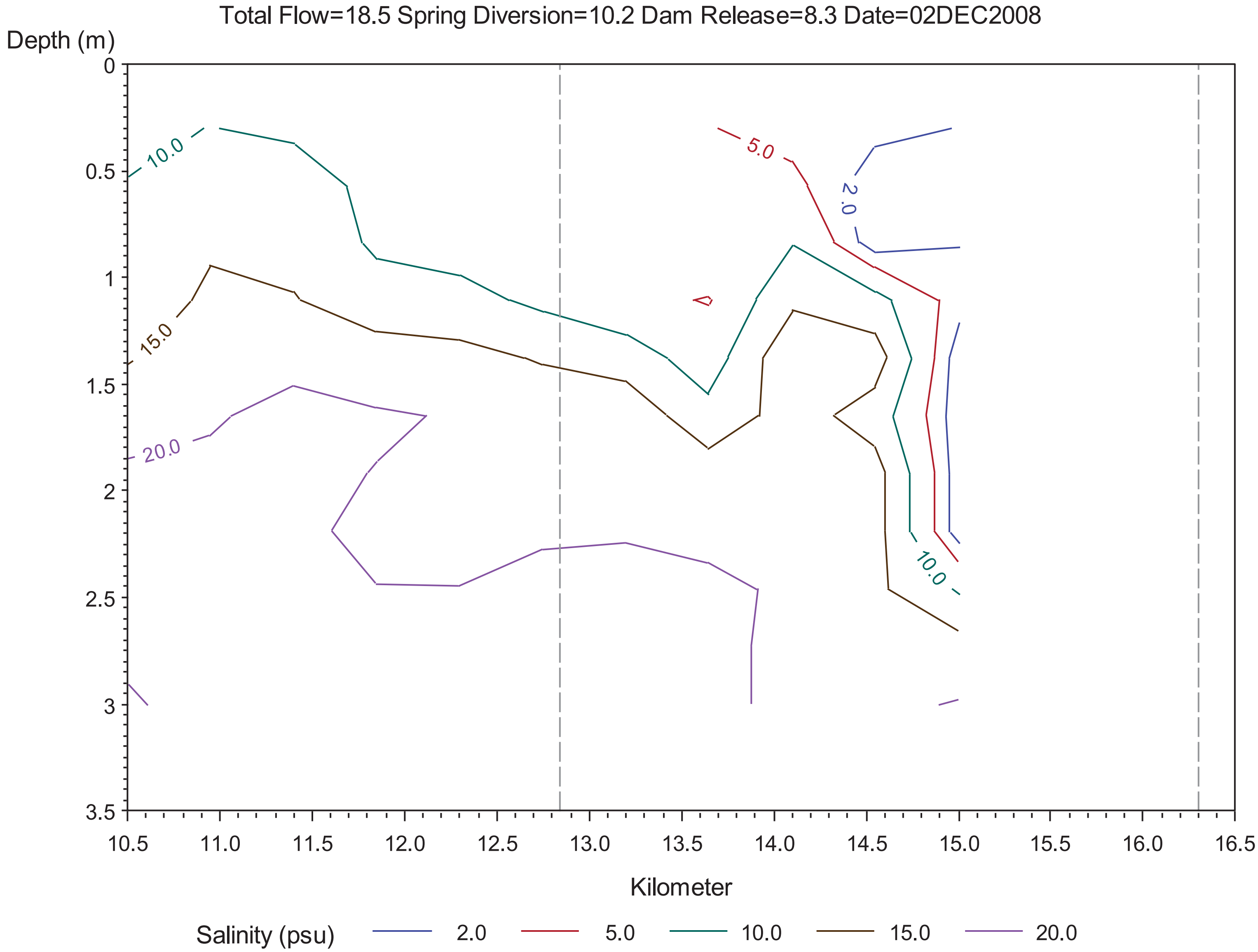

Total Flow=18.1 Spring Diversion=9.8 Dam Release=8.3 Date=18JUN2008
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
15.0
10.0
5.0
2.0
20.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

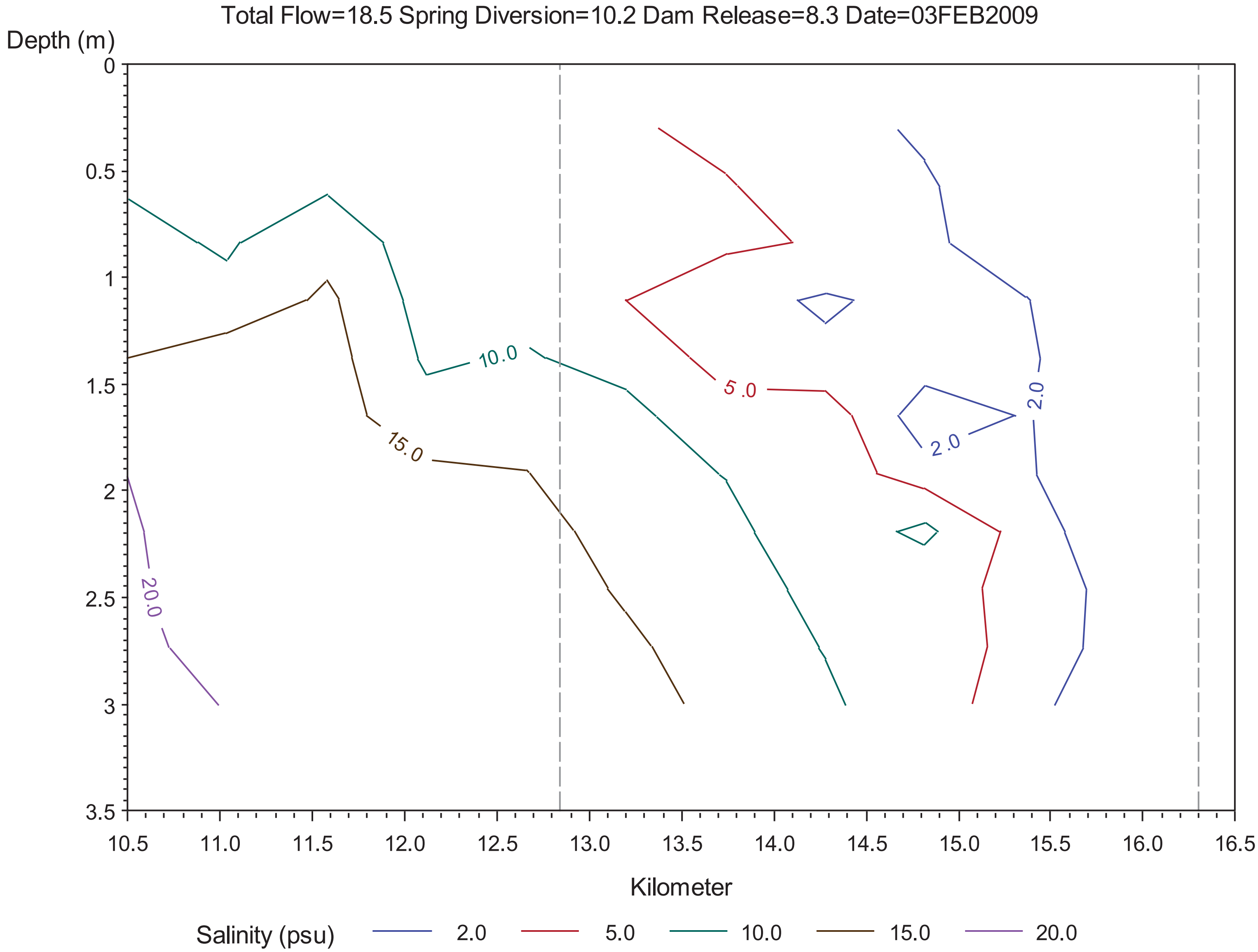


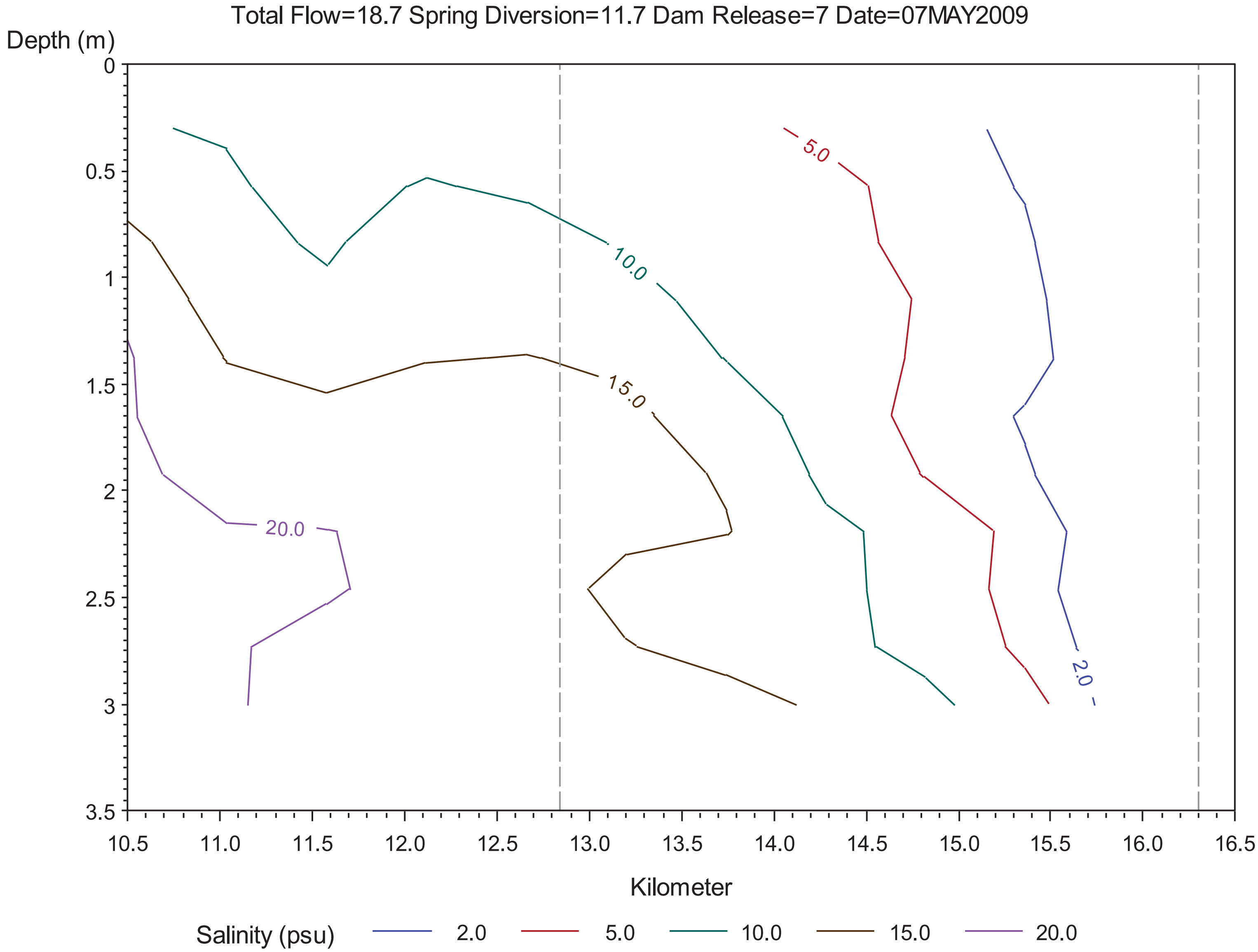

Total Flow=18.5 Spring Diversion=10.2 Dam Release=8.3 Date=06JAN2009
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
2.0
5.0
10.0
15.0
20.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

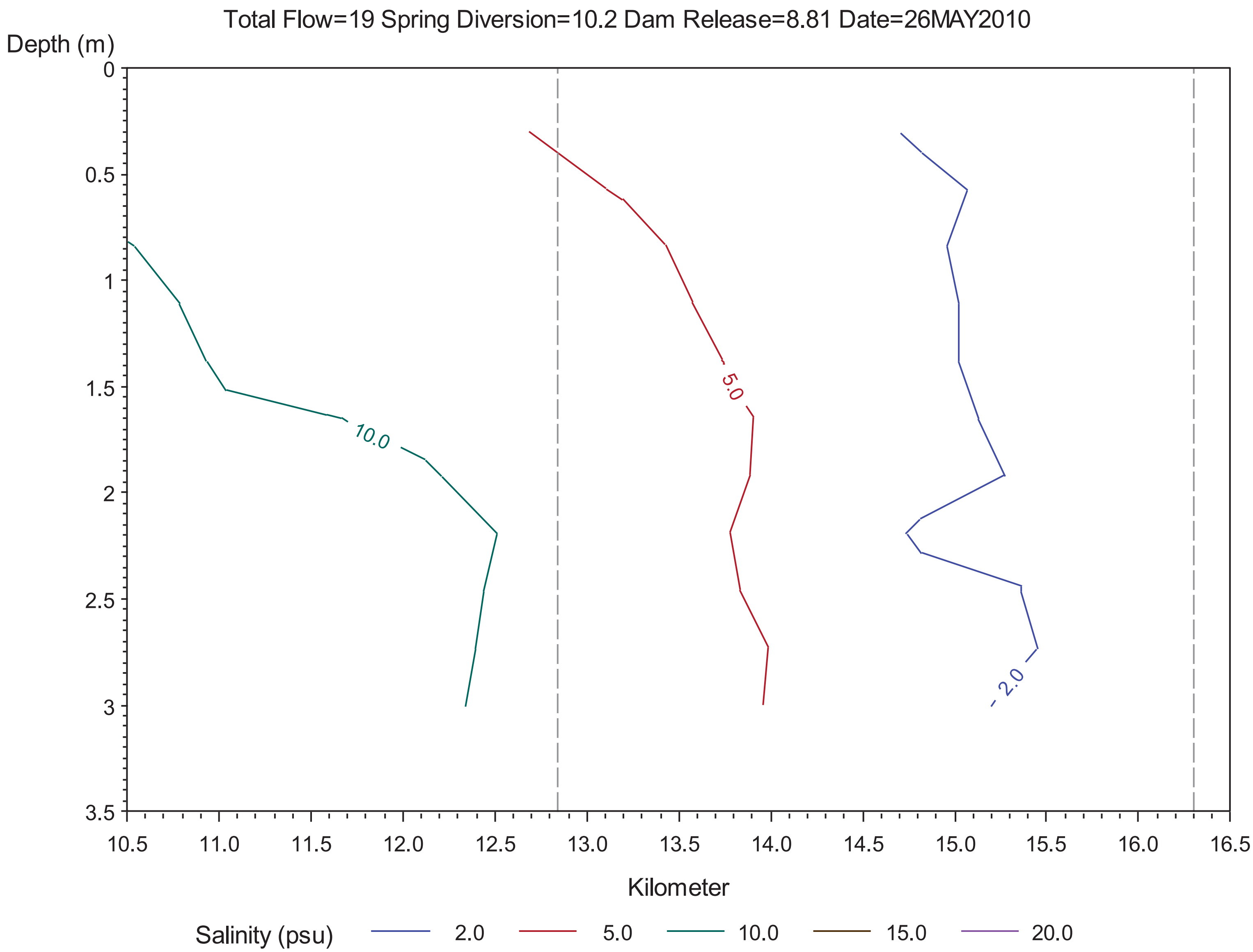


Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

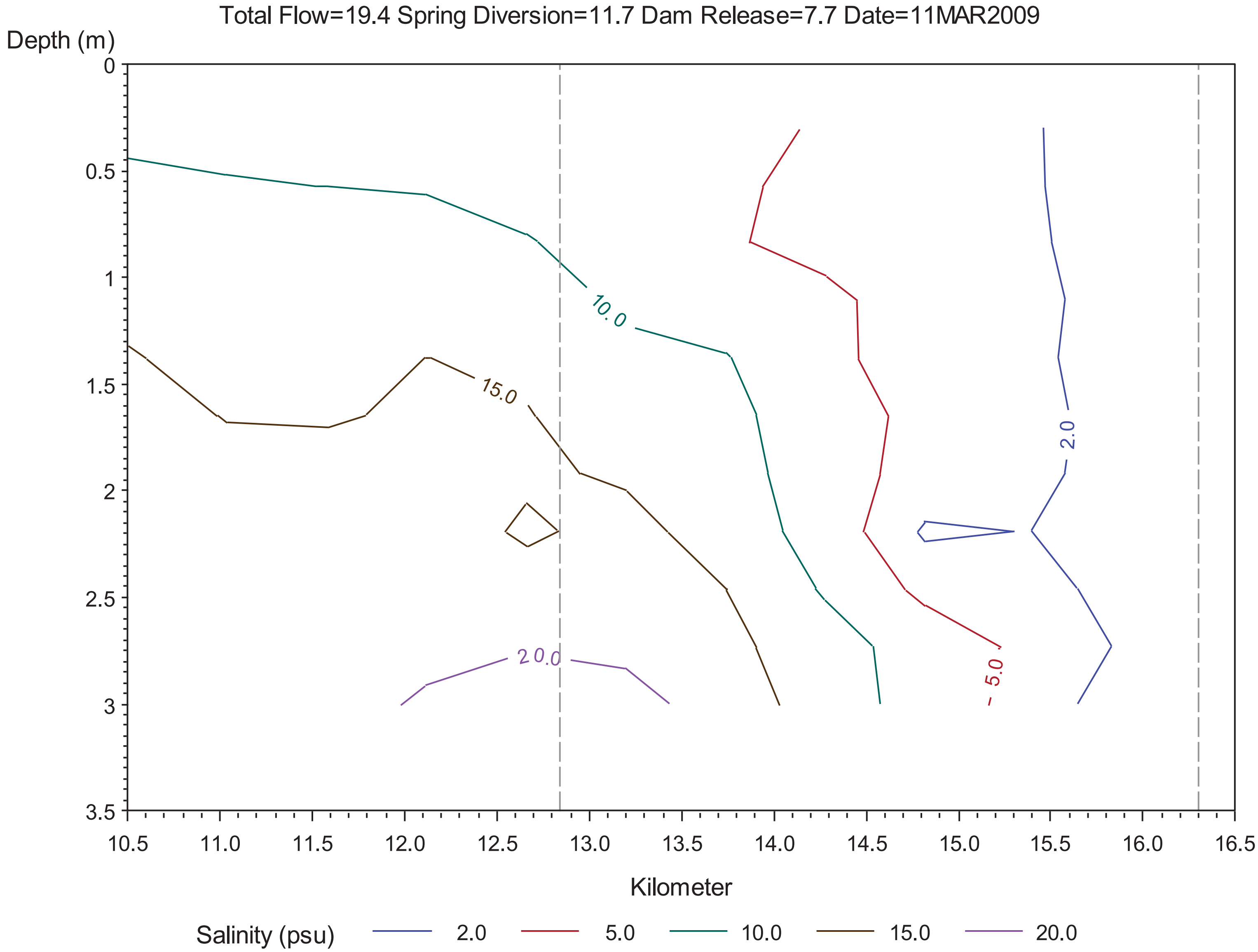


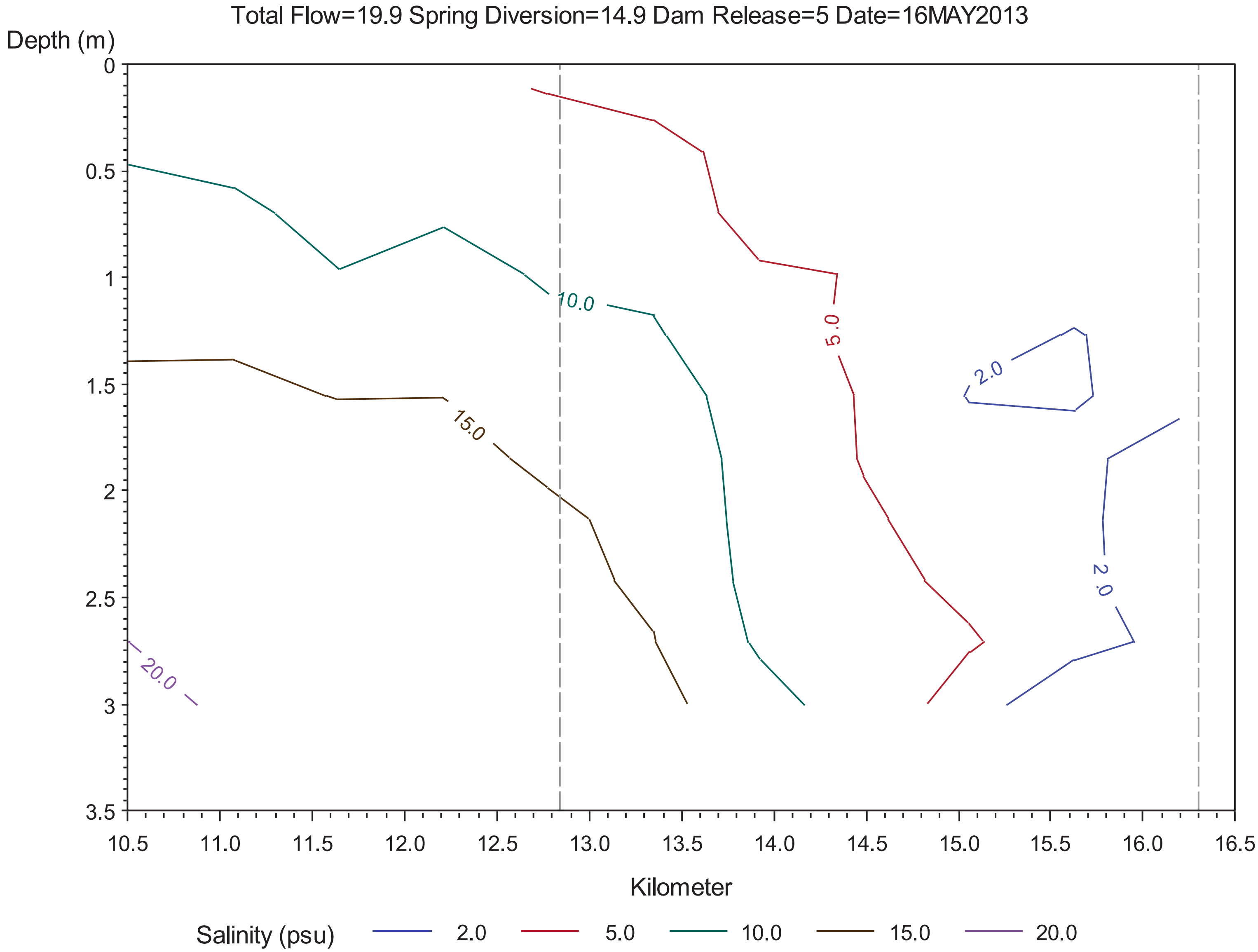

Total Flow=18.7 Spring Diversion=11.7 Dam Release=7 Date=07MAY2009
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
5.0
10.0
15.0
20.0
2.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

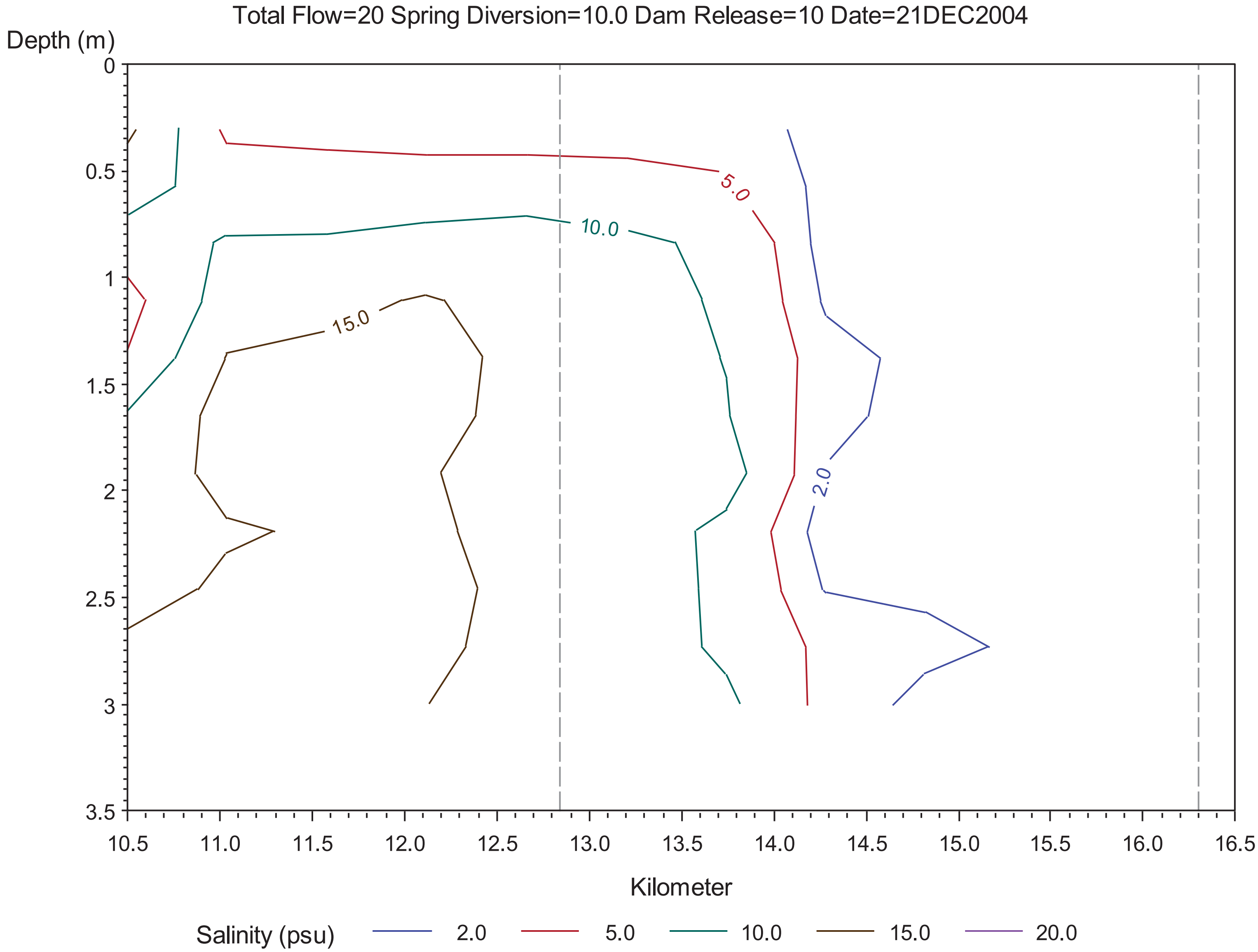
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program



Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

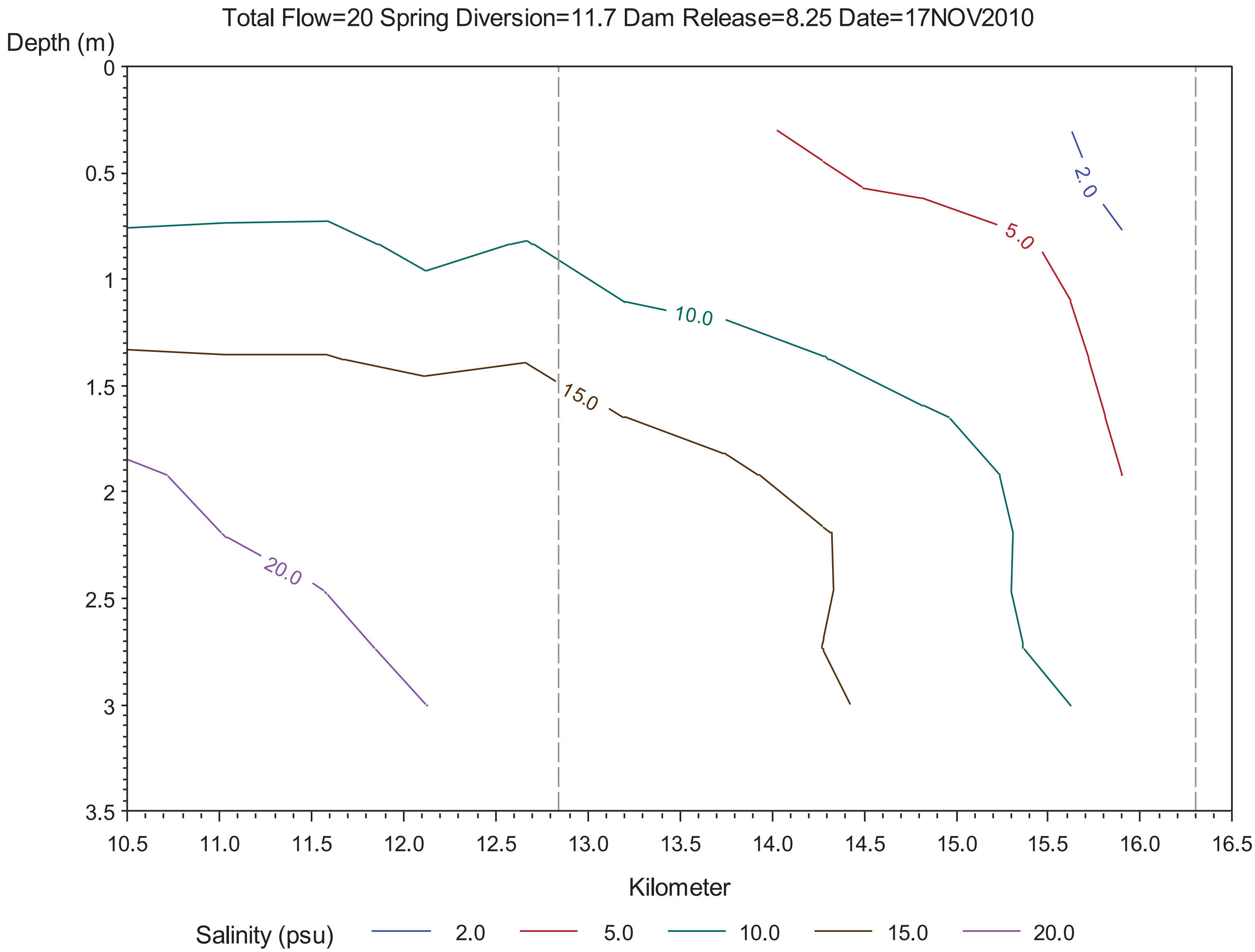



Total Flow=19.9 Spring Diversion=14.9 Dam Release=5 Date=16MAY2013
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
10.0
5.0
2.0
15.0
2.0
20.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

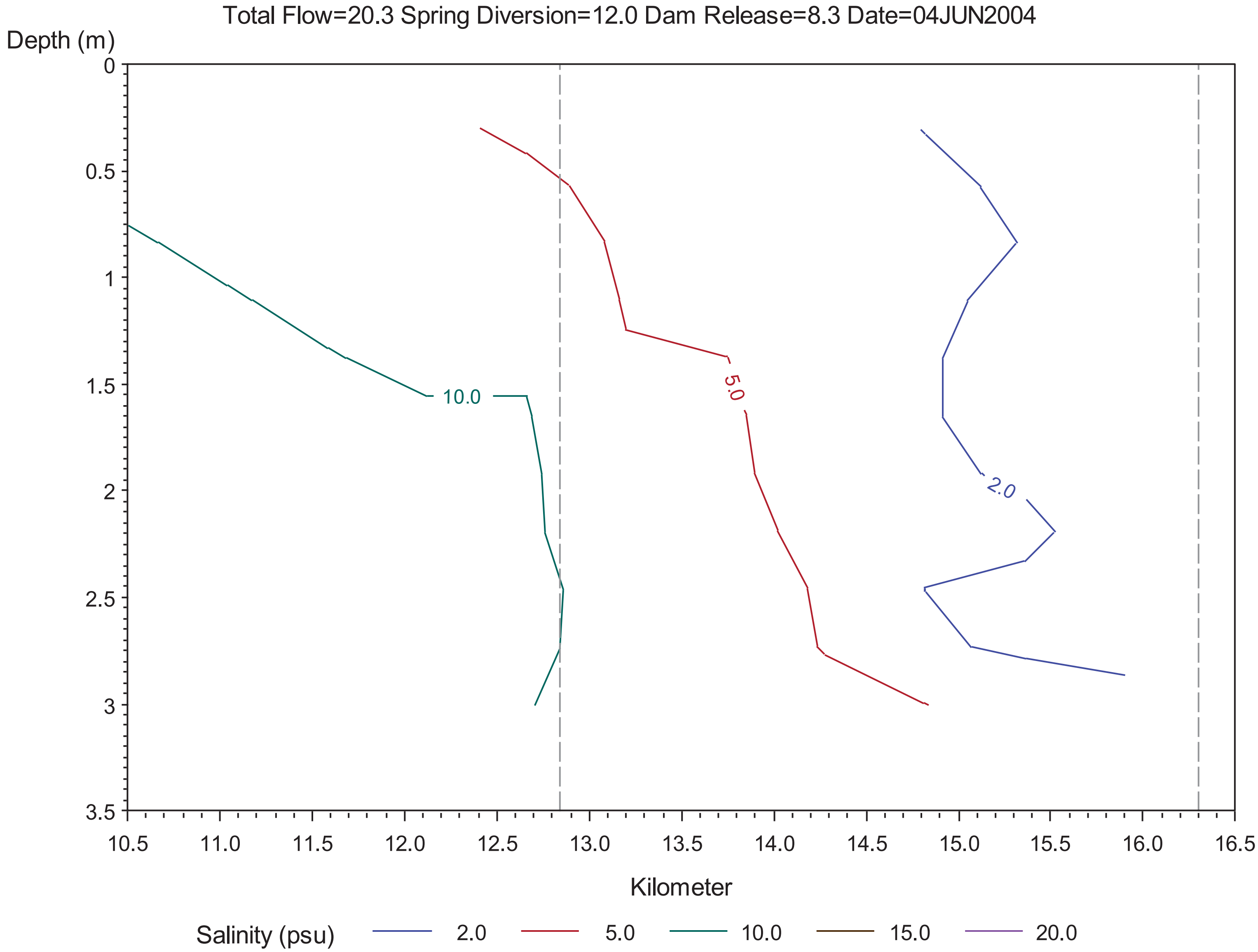


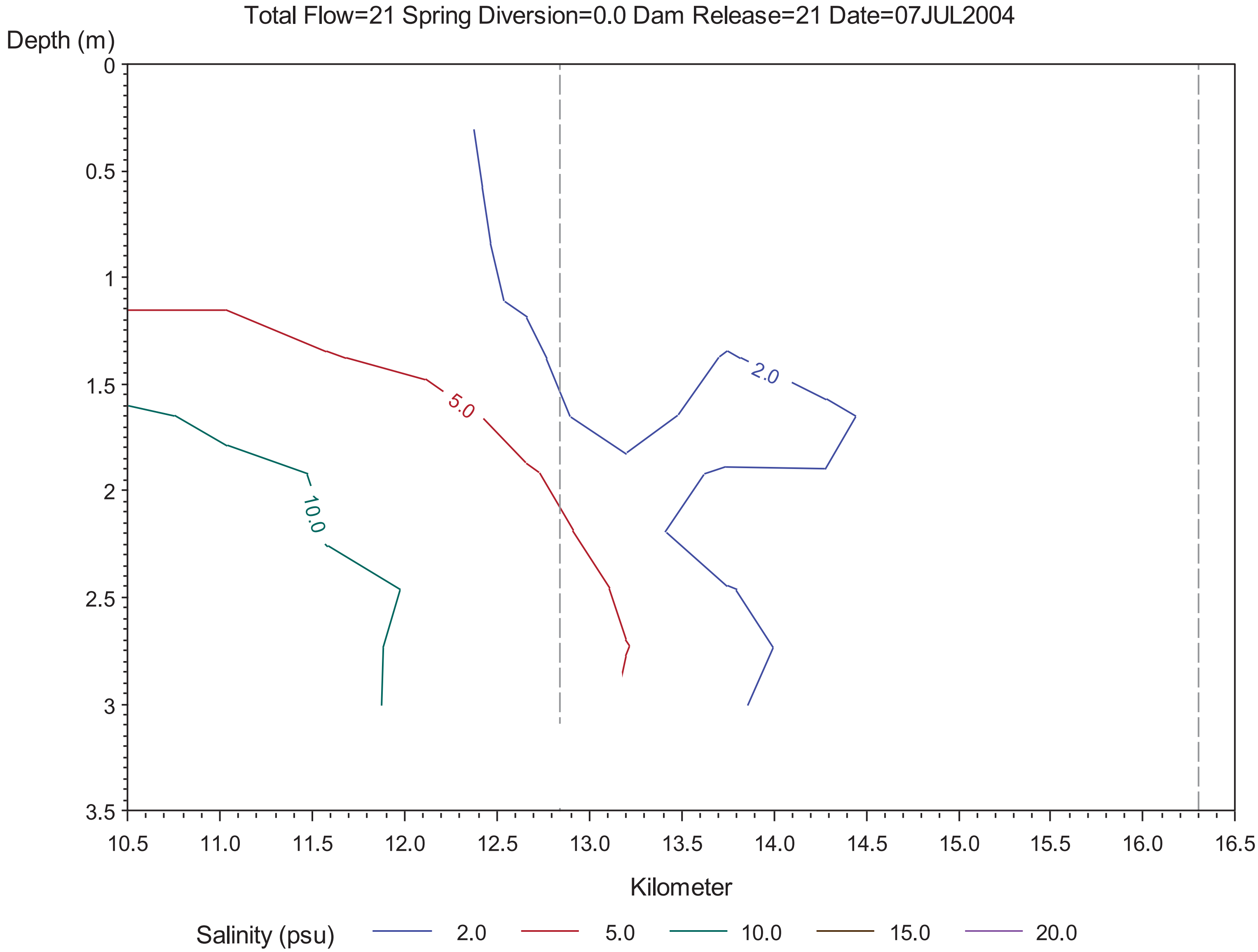
Total Flow=20 Spring Diversion=10.0 Dam Release=10 Date=21DEC2004
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
5.0
10.0
15.0
2.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

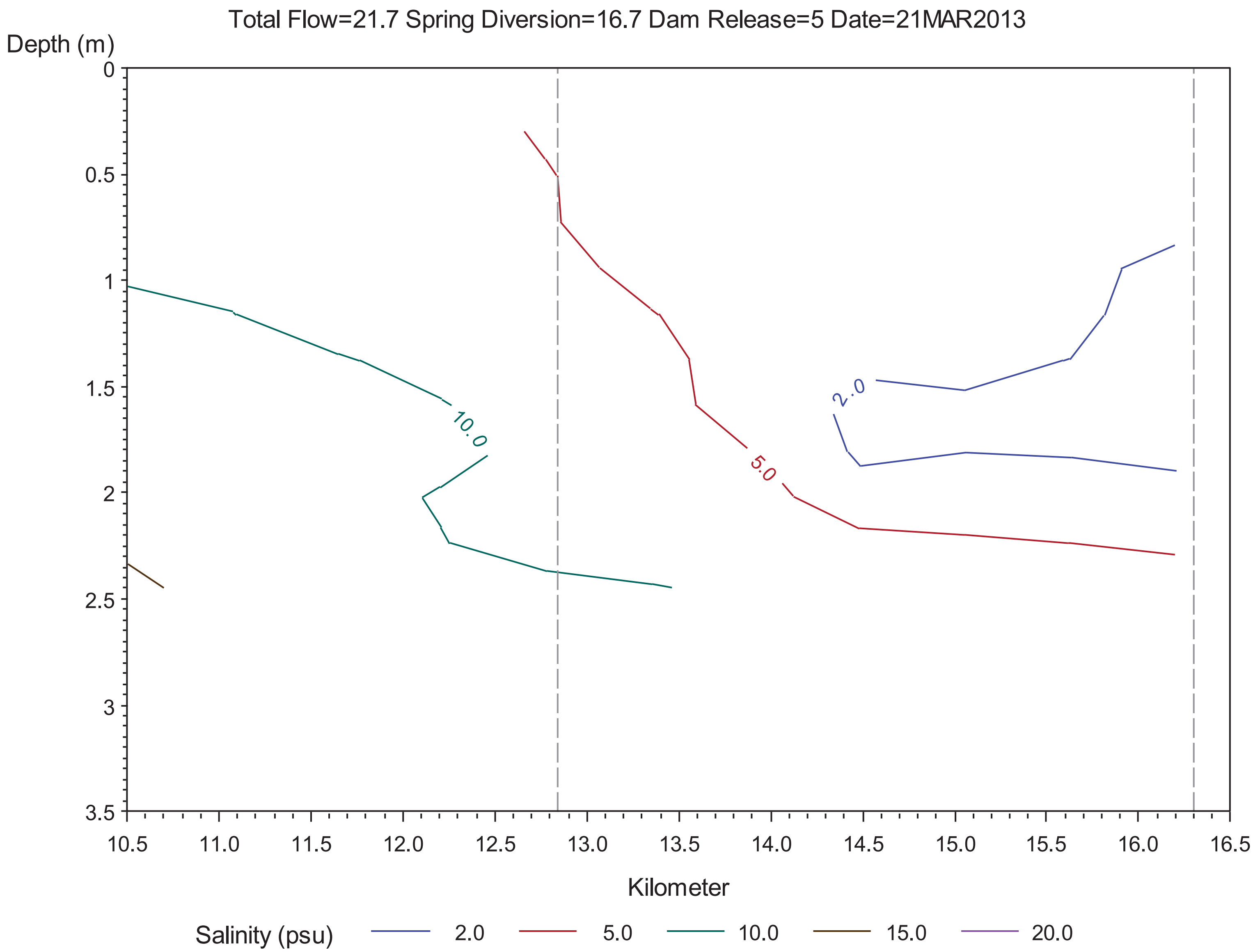


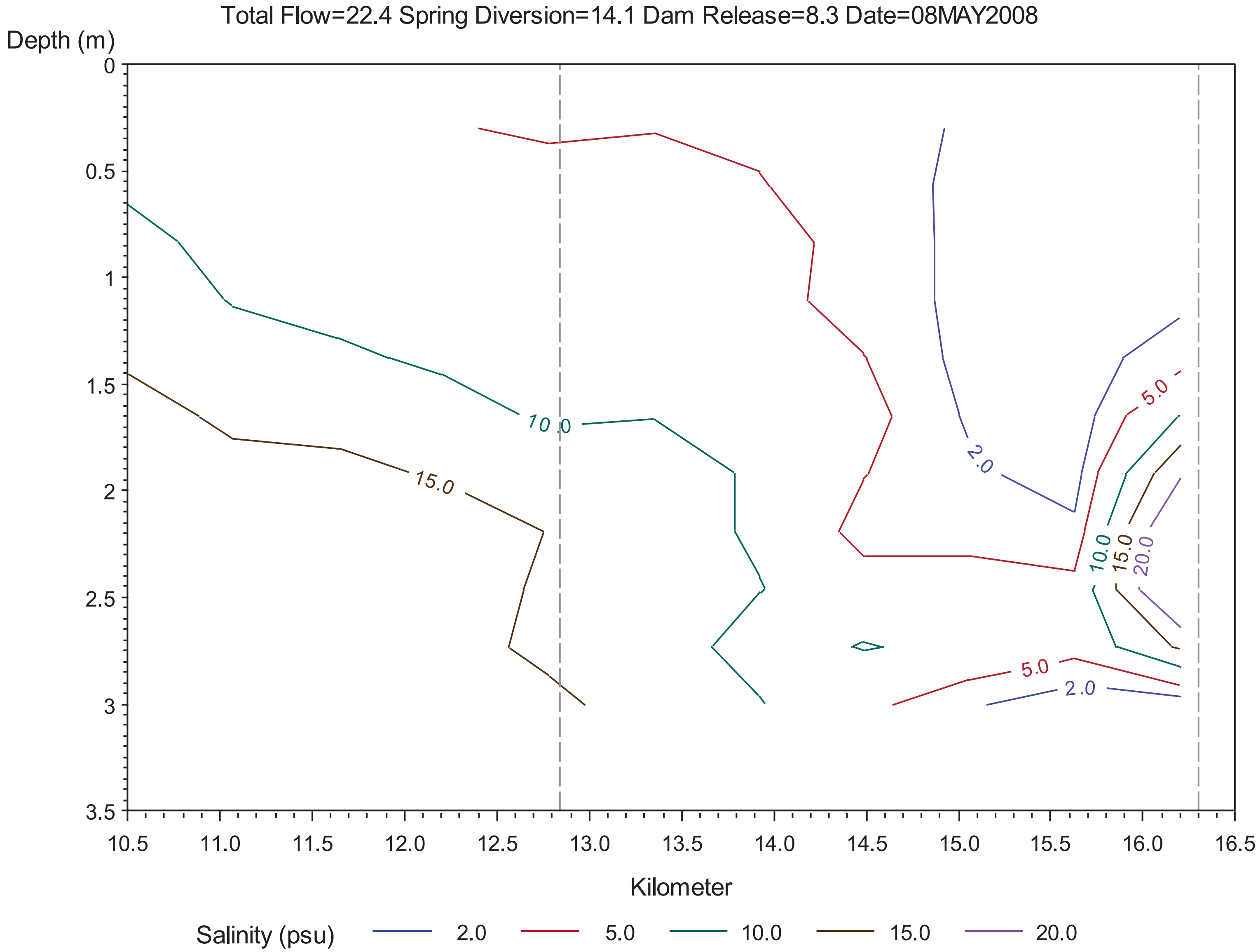
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

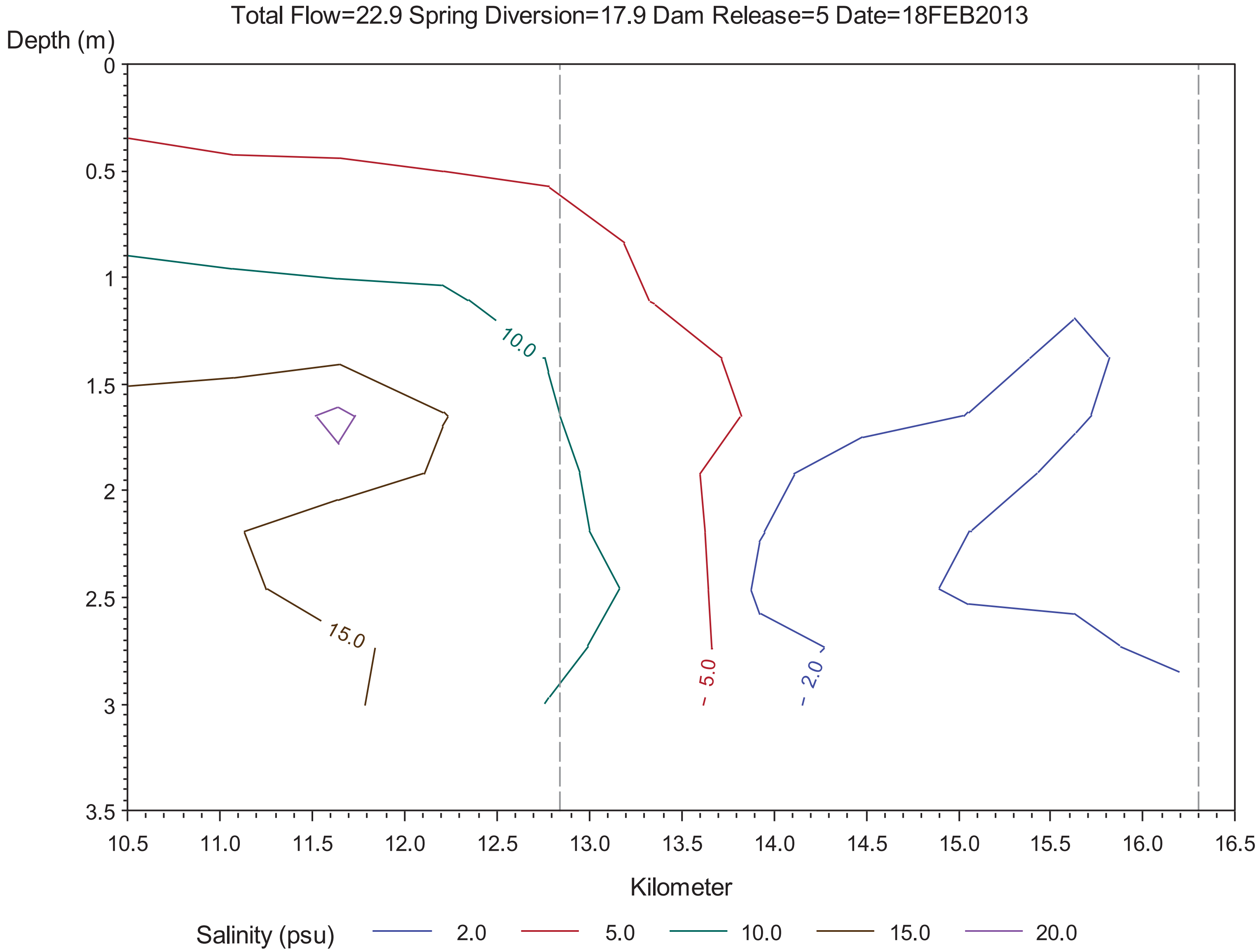


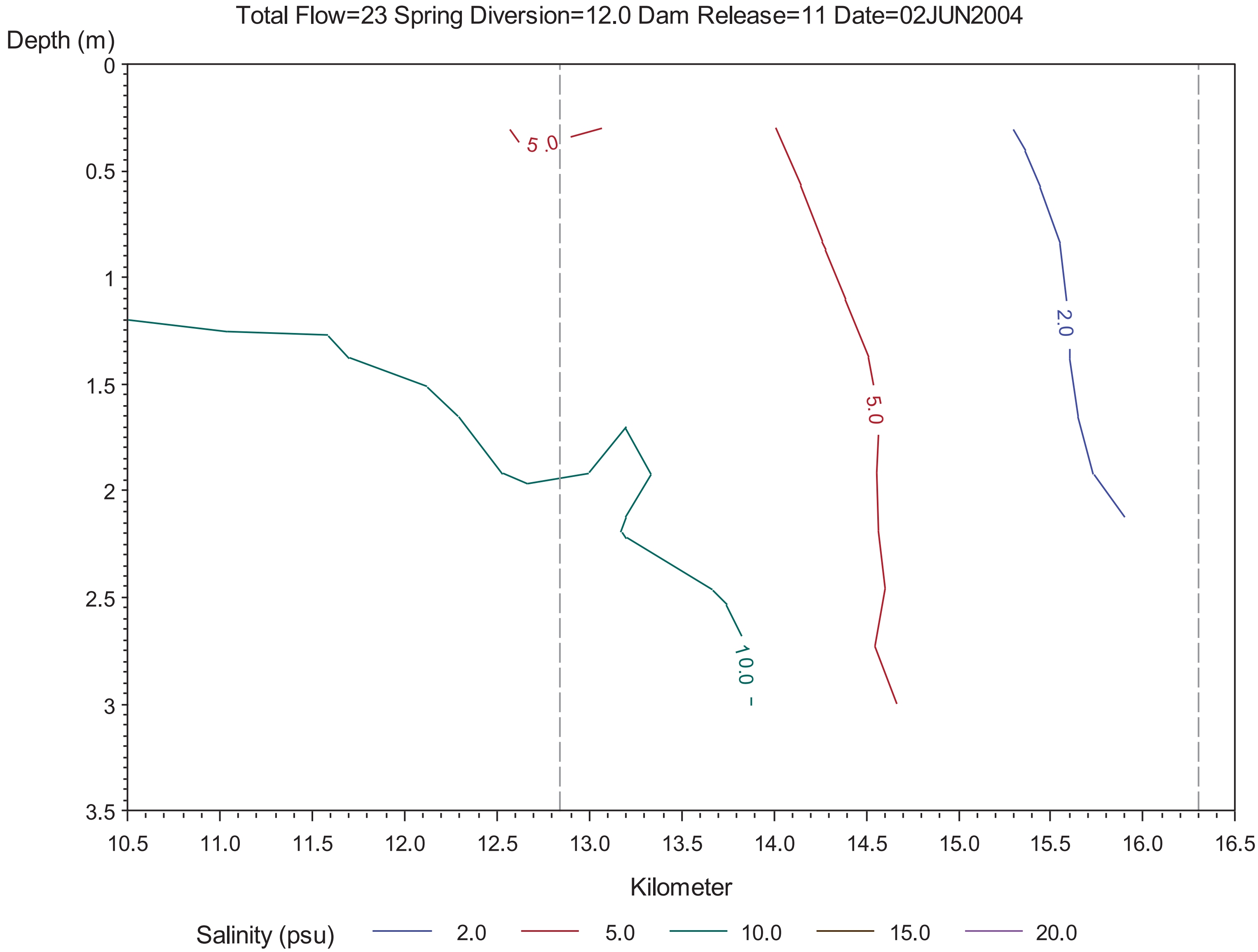

Total Flow=21 Spring Diversion=0.0 Dam Release=21 Date=07JUL2004
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
2.0
5.0
10.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

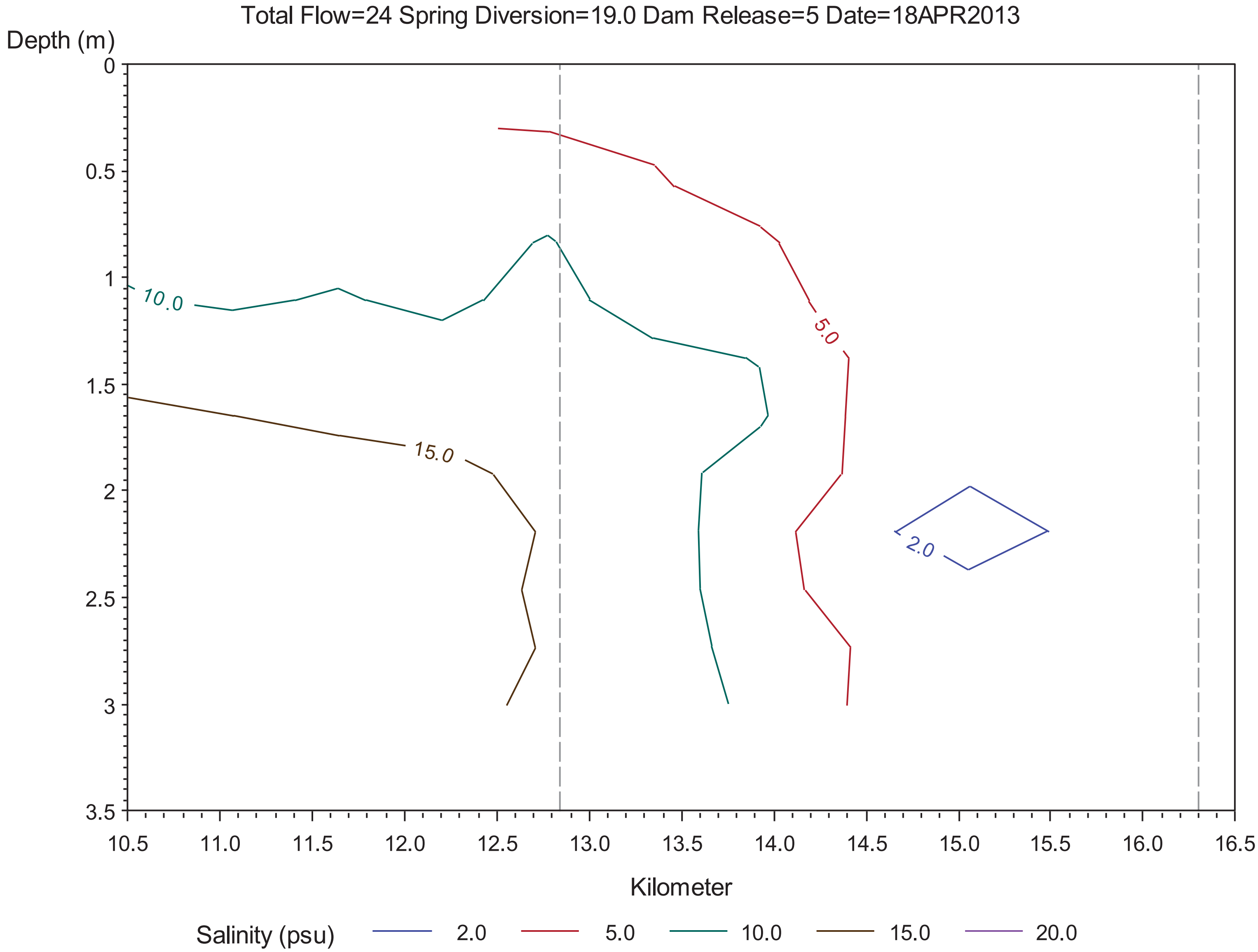
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program



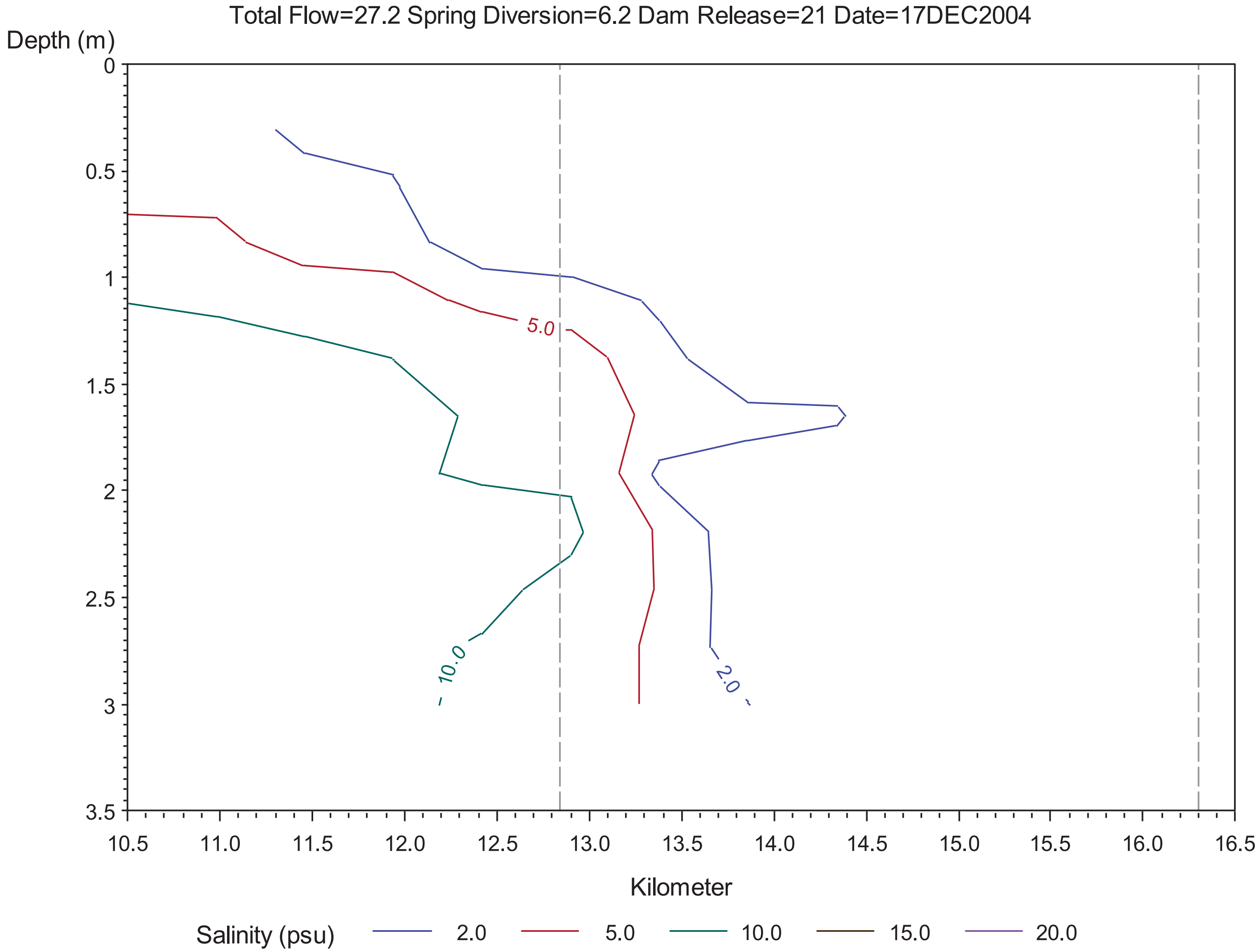

Total Flow=22.4 Spring Diversion=14.1 Dam Release=8.3 Date=08MAY2008
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
10.0
15.0
2.0
5.0
20.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0


Total Flow=22.9 Spring Diversion=17.9 Dam Release=5 Date=18FEB2013
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.0
15.0
5.0
2.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

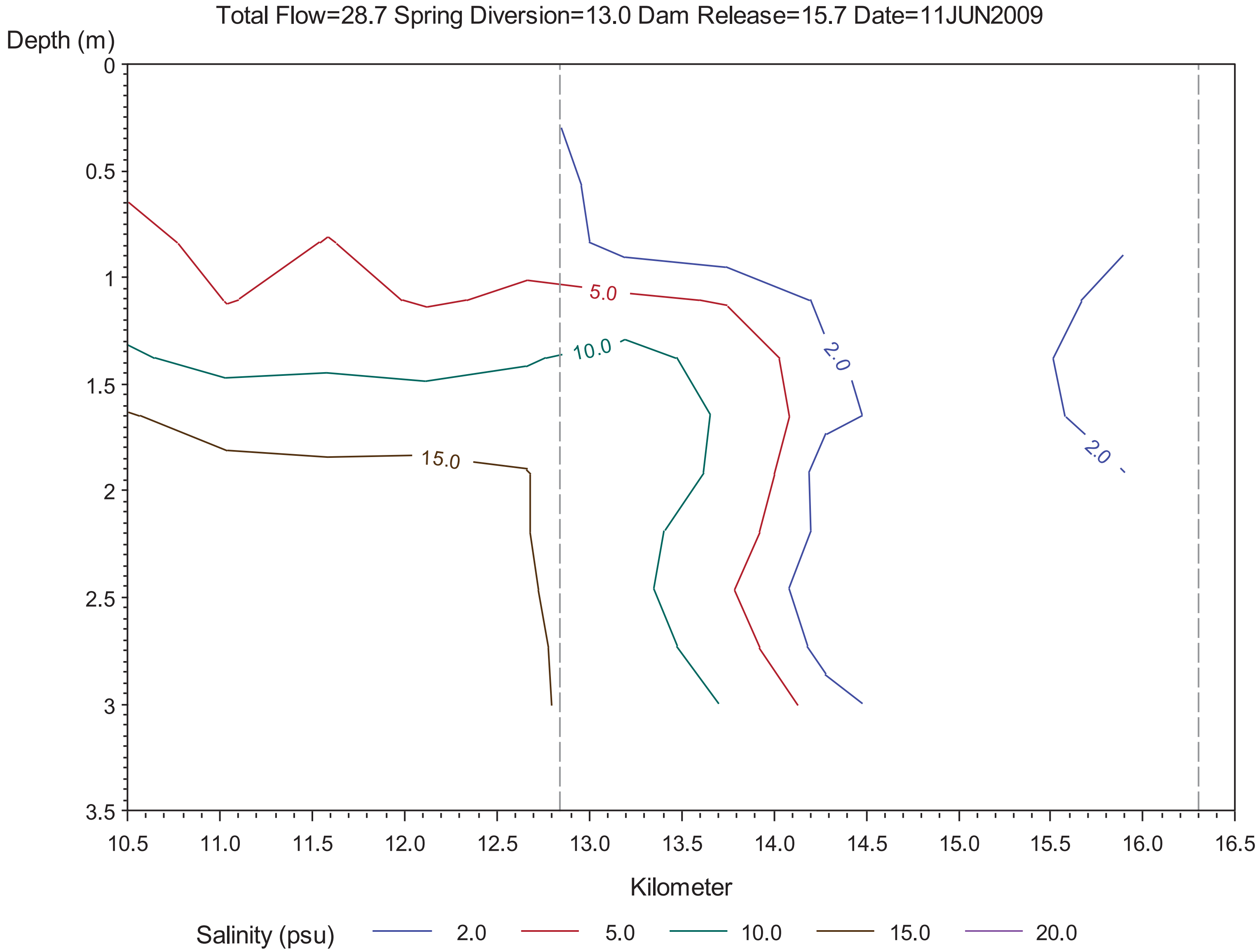

Total Flow=23 Spring Diversion=12.0 Dam Release=11 Date=02JUN2004
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
5.0
5.0
2.0
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

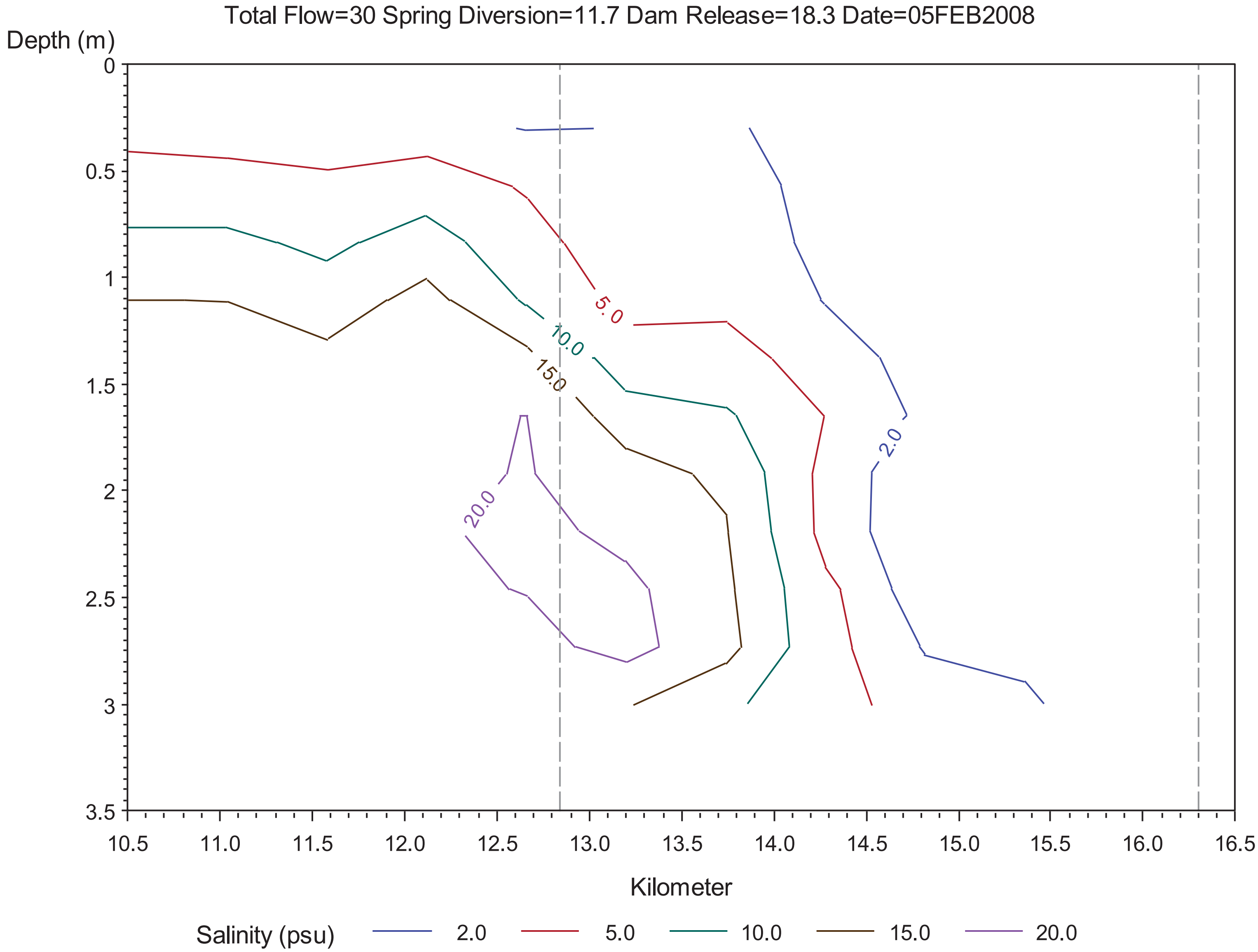

Total Flow=24 Spring Diversion=19.0 Dam Release=5 Date=18APR2013
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.0
15.0
5.0
2.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

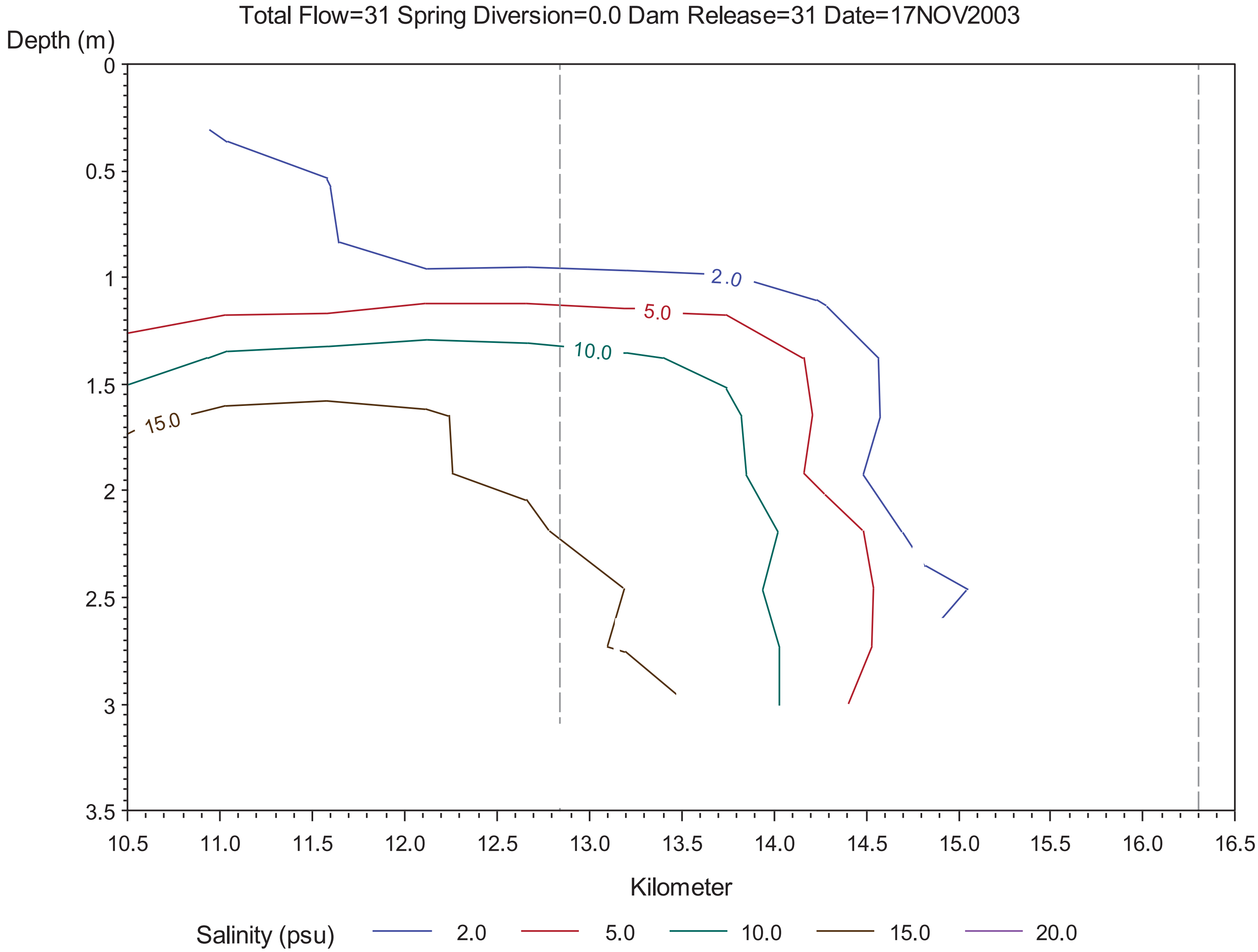
Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

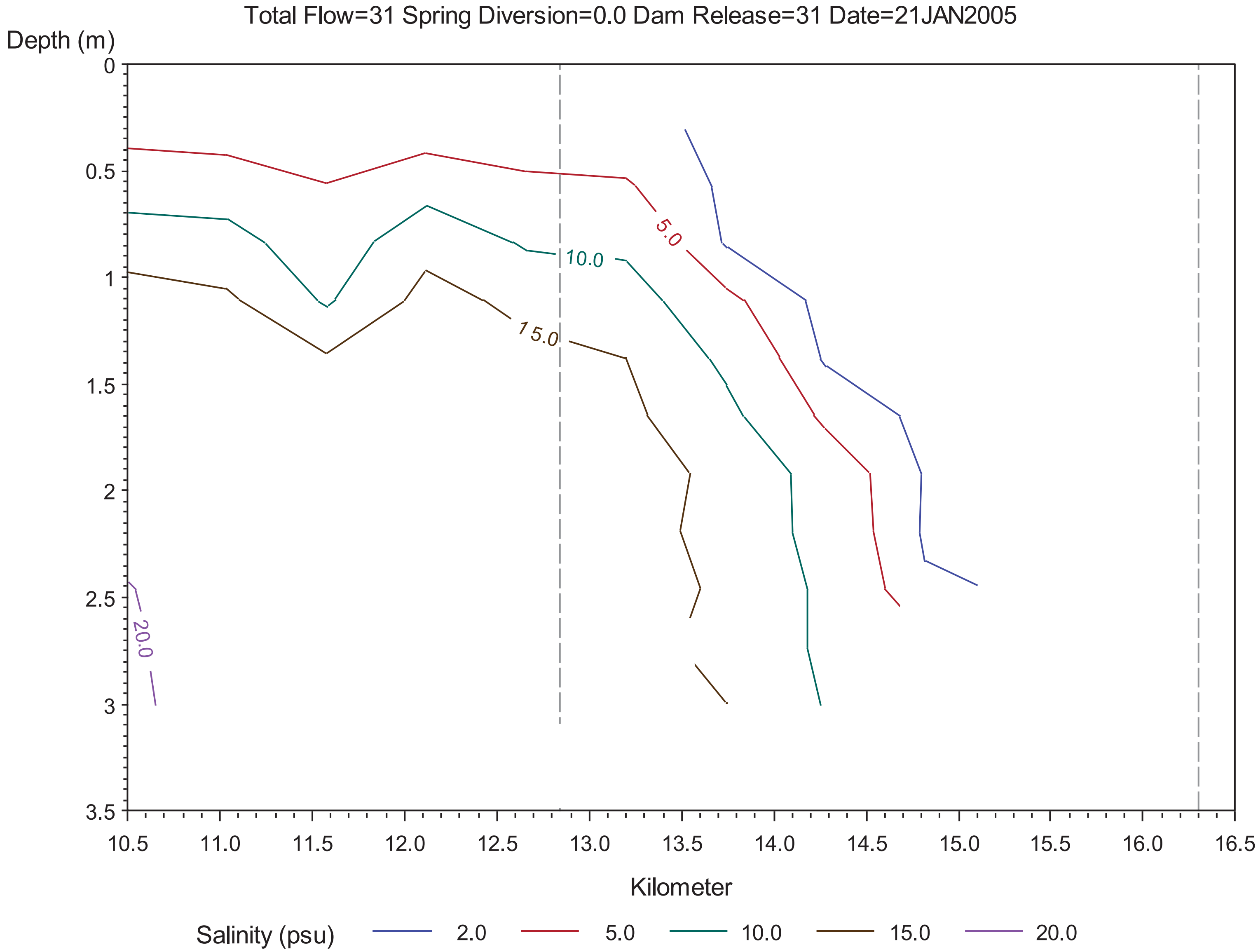


Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program

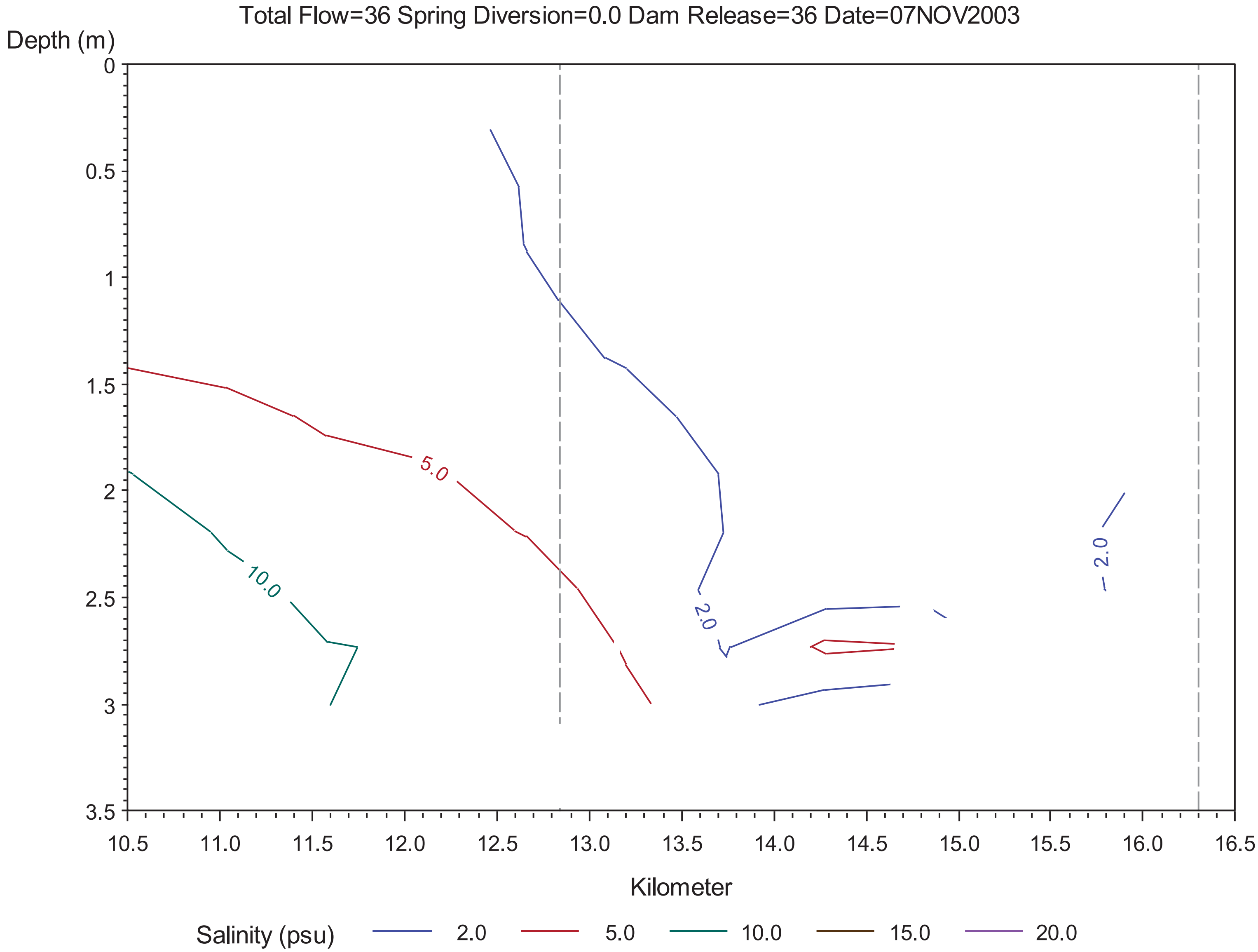


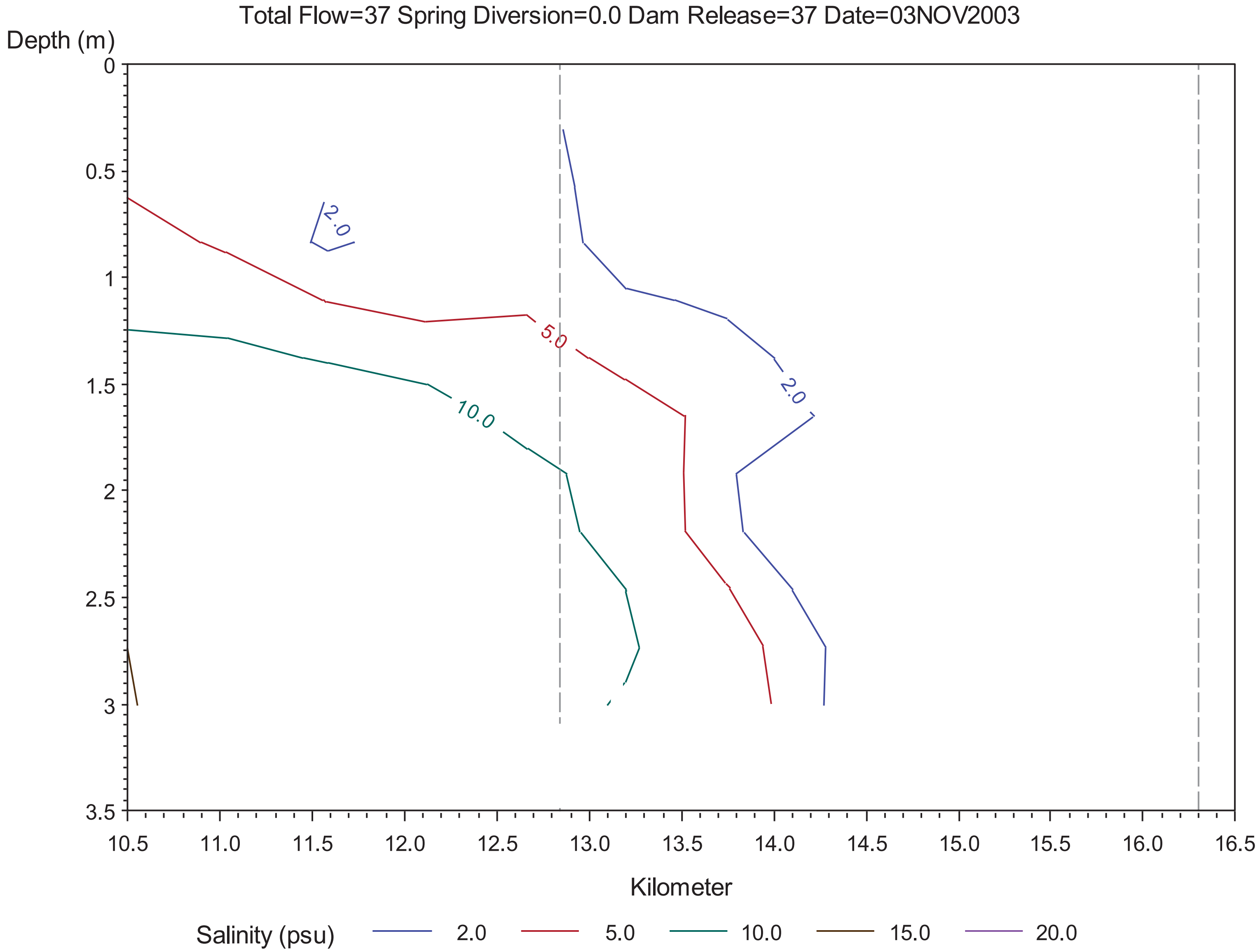

Total Flow=30 Spring Diversion=11.7 Dam Release=18.3 Date=05FEB2008
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
5.0
10.0
15.0
20.0
2.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0


Total Flow=31 Spring Diversion=0.0 Dam Release=31 Date=17NOV2003
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
2.0
5.0
10.0
15.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

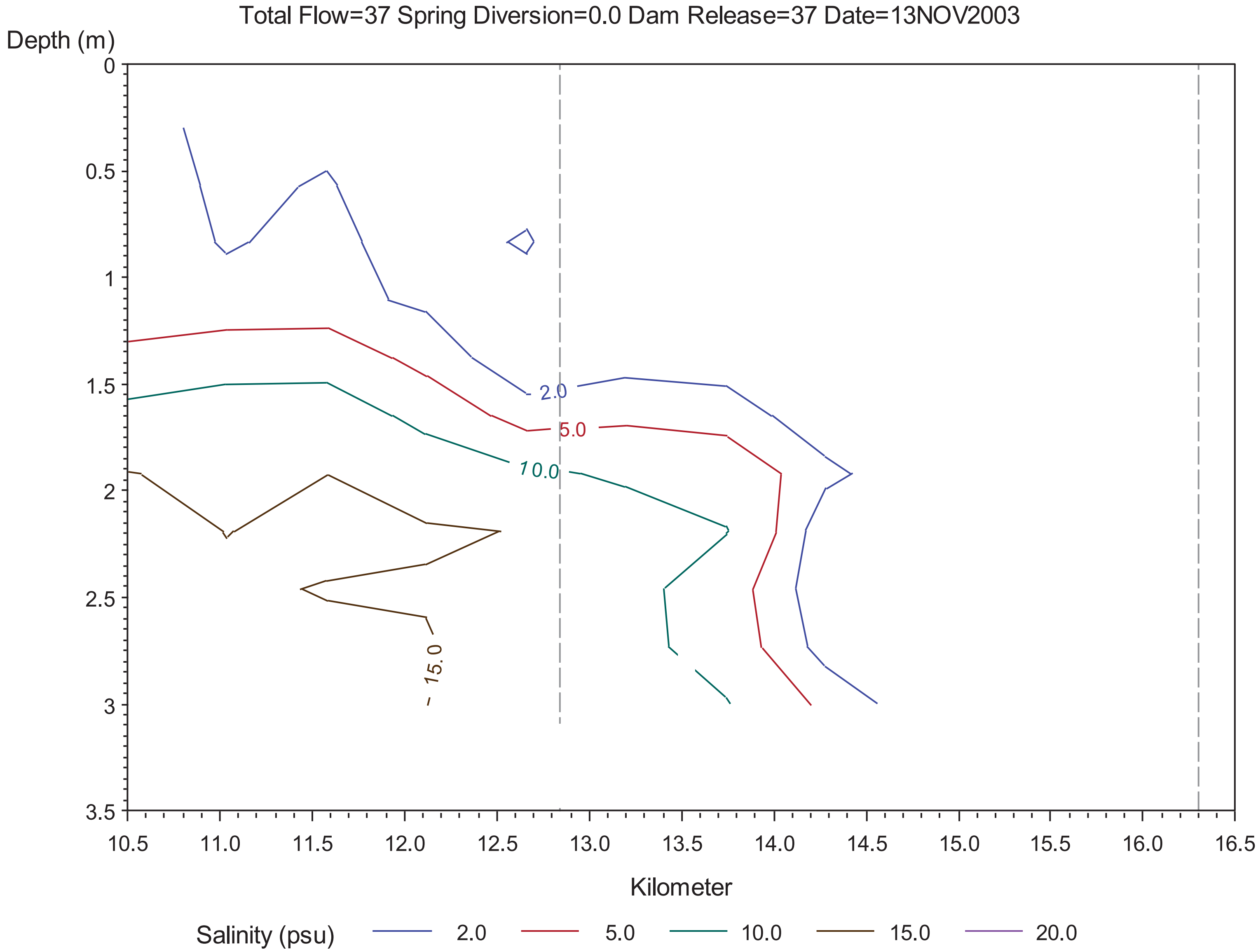

Total Flow=31 Spring Diversion=0.0 Dam Release=31 Date=21JAN2005
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
5.0
10.0
15.0
20.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program




Total Flow=37 Spring Diversion=0.0 Dam Release=37 Date=03NOV2003
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
Kilometer
2.0
5.0
10.0
2.0
Salinity (psu)
2.0
5.0
10.0
15.0
20.0

Appendix 2D – Two Dimensional Plots of Salinity in the Lower Hillsborough River From the SWFWMD Sampling Program



**62-302.533 Dissolved Oxygen Criteria for Class I, Class II, Class III, and Class III-Limited Waters.**

(1) Class I, Class III predominantly freshwaters, and Class III-Limited predominantly freshwaters.

(a) No more than 10 percent of the daily average percent dissolved oxygen (DO) saturation values shall be below the following values:

1. 67 percent in the Panhandle West bioregion,

2. 38 percent in the Peninsula and Everglades bioregions, or

3. 34 percent in the Northeast and Big Bend bioregions. A map of the bioregions is contained in *SCI 1000: Stream Condition Index Methods* (DEP-SOP-003/11 SCI 1000) (http://www.flrules.org/Gateway/reference.asp?No=Ref-02959), which is incorporated by reference in Rule 62-160.800, F.A.C.

(b) For lakes, the daily average DO level shall be calculated as the average of measurements collected in the upper two meters of the water column at the same location on the same day. For all other freshwaters, the daily average freshwater DO level shall be calculated as the average of all measurements collected in the water column at the same location and on the same day.

(c) In the portions of the Suwannee, Withlacoochee (North), and Santa Fe Rivers utilized by the Gulf Sturgeon, and in the portions of the Santa Fe and New Rivers utilized by the Oval Pigtoe Mussel, DO levels shall not be lowered below the baseline distribution such that there is 90 percent confidence that more than 50 percent of measurements are below the median of the baseline distribution or more than 10 percent of the daily average values are below the 10$^{th}$ percentile of the baseline distribution for the applicable waterbody.

(d) In the portions of the St. Johns River utilized by the Shortnose or Atlantic Sturgeon, the DO shall not be below 53 percent saturation during February and March. During other times of the year, the criteria specified in paragraph 62-302.533(1)(a), F.A.C., shall apply.

(e) The baseline distributions and maps showing the specific areas utilized by the Gulf Sturgeon and the Oval Pigtoe Mussel are provided in Appendix I of the "*Technical Support Document for the Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters*" (DEP-SAS-001/13), dated March 2013 (http://www.flrules.org/Gateway/reference.asp?No=Ref-02955), which is incorporated by reference herein. Copies of Appendix I may be obtained from the Department's internet site at http://www.dep.state.fl.us/water/wqssp/swq-docs.htm or by writing to the Florida Department of Environmental Protection, Standards and Assessment Section, 2600 Blair Stone Road, MS 6511, Tallahassee, FL 32399-2400.

(2) Class II, Class III predominantly marine waters, and Class III-Limited predominantly marine waters.

(a) Minimum DO saturation levels shall be as follows:

1. The daily average percent DO saturation shall not be below 42 percent saturation in more than 10 percent of the values;

2. The seven-day average DO percent saturation shall not be below 51 percent more than once in any twelve week period; and

3. The 30-day average DO percent saturation shall not be below 56 percent more than once per year.

(b) To calculate a seven-day average DO percent saturation, there shall be a minimum of three full days of diel data collected within the seven-day period, or a minimum of ten grab samples collected over at least three days within that seven-day period, with each sample measured at least four hours apart.

(c) To calculate a 30-day average DO percent saturation, there shall be a minimum of three full days of diel data with at least one day of data collected in three different weeks of the 30-day period, or grab samples collected from a minimum of ten different days of the 30-day period.

(d) A full day of diel data shall consist of 24 hours of measurements collected at a regular time interval of no longer than one hour.

(3) If it is determined that the natural background DO saturation in the waterbody (including values that are naturally low due to vertical stratification) is less than the applicable criteria stated above, the applicable criteria shall be 0.1 mg/l below the DO concentration associated with the natural background DO saturation level.

(4) For predominately marine waters, a decrease in magnitude of up to 10 percent from the natural background condition is allowed if it is demonstrated that sensitive resident aquatic species will not be adversely affected using the procedure described in the DEP document titled Appendix H of the "*Technical Support Document for the Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters: Determination of Acceptable Deviation from Natural Background Dissolved Oxygen Levels in Fresh and Marine Waters*" (DEP-SAS-001/13), dated March 2013 (http://www.flrules.org/Gateway/reference.asp?No=Ref-02956), which is incorporated by reference herein. Copies of Appendix H may be obtained from the Department's internet site at http://www.dep.state.fl.us/water/wqssp/swq-docs.htm or by writing to the Florida Department of Environmental Protection, Standards and Assessment Section, 2600 Blair Stone Road, MS 6511, Tallahassee, FL 32399-2400.

(5) Ambient DO levels above the minimum criteria specified in subsections 62-302.533(1) and (2), F.A.C., shall be maintained in accordance with and subject to Rules 62-302.300 and 62-4.242, F.A.C. Ambient DO levels will be considered to have declined, for purposes of this subsection if, after controlling for or removing the effects of confounding variables, such as climatic and hydrologic cycles, quality assurance issues, and changes in analytical methods, a waterbody segment is shown to have a statistically significant decreasing trend in DO percent saturation or an increasing trend in the range of daily DO fluctuations at the 95 percent confidence level using the one-sided Seasonal Kendall test for trend, as described in Helsel, D.R. and R.M. Hirsch, 2002, Statistical Methods in Water Resources, USGS, pages 338 through 340 (http://www.flrules.org/Gateway/reference.asp?No=Ref-02957), which is incorporated by reference herein, or an alternative statistically valid trend at a one-sided confidence level of 95 percent. It must be demonstrated that the data satisfy all statistical assumptions of any alternative method used, including residual distribution, variance, and shape of relationship.

*Rulemaking Authority 403.061, 403.062, 403.087, 403.504, 403.704, 403.804 FS. Law Implemented 403.021(11), 403.061, 403.087, 403.088, 403.141, 403.161, 403.182, 403.502, 403.702, 403.708 FS. History–New 8-1-13.*

Appendix 3B – Wilcoxon Rank Sum Test Results of Dissolved Oxygen Concentration and Saturation at Combined Depths by Period from the Environmental Protection Commission Continuous Recorder Stations

1. Wilcoxon Rank Sum Dissolved Oxygen Concentration Test Results for EPC Station 105 at Rowlett Park Drive

| EPC Station 105 | Period 1 | Period 2 | Period 3 | Period 4 |
|---|---|---|---|---|
| Period 1 | --- | | | |
| Period 2 | 0.002 | --- | | |
| Period 3 | 0.0001 | 0.403 | --- | |
| Period 4 | 0.0001 | 0.027 | 0.02 | --- |

2. Wilcoxon Rank Sum Dissolved Oxygen Saturation Test Results for EPC Station 105 at Rowlett Park Drive

| EPC Station 105 | Period 1 | Period 2 | Period 3 | Period 4 |
|---|---|---|---|---|
| Period 1 | --- | | | |
| Period 2 | 0.002 | --- | | |
| Period 3 | 0.001 | 0.432 | --- | |
| Period 4 | 0.001 | 0.006 | 0.002 | --- |

3. Wilcoxon Rank Sum Dissolved Oxygen Concentration Test Results for EPC Station 152 at Sligh Avenue

| EPC Station 152 | Period 1 | Period 2 | Period 3 | Period 4 |
|---|---|---|---|---|
| Period 1 | --- | | | |
| Period 2 | 0.188 | --- | | |
| Period 3 | 0.909 | 0.302 | --- | |
| Period 4 | 0.704 | 0.216 | 0.648 | --- |

4. Wilcoxon Rank Sum Dissolved Oxygen Saturation Test Results for EPC Station 152 at Sligh Avenue

| EPC Station 152 | Period 1 | Period 2 | Period 3 | Period 4 |
|---|---|---|---|---|
| Period 1 | --- | | | |
| Period 2 | 0.169 | --- | | |
| Period 3 | 0.869 | 0.32 | --- | |
| Period 4 | 0.704 | 0.191 | 0.495 | --- |

**Key: Time Period and Flow Conditions**

| | |
|---|---|
| **Period 1** | Prior to March 20, 2002 (no minimum flows) |
| **Period 2** | March 20, 2002 to December 30, 2007 (spring diversions only >= 1cfs) |
| **Period 3** | January 01, 2008 and February 20, 2012 (spring diversions plus dam releases <= 8.3 cfs, spring diversions >= 1 cfs) |
| **Period 4** | March 01, 2012 and June 21, 2013, (greater spring diversions plus dam releases <= 8.3 cfs, spring diversions >= 1 cfs) |

Appendix 3C – Wilcoxon Rank Sum Test Results for Dissolved Oxygen Concentrations in the Hillsborough River by Depth Interval and River Segments

1. Wilcoxon Rank Sum Dissolved Oxygen Concentrations Test Results for Hillsborough River Kilometer Segment 16.2 to 15.2 by Increasing Depth

**Depth 0-1 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.839 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0005 | 0.0003 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.095 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.069 | 0.215 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.093 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.052 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.014 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

2. Wilcoxon Rank Sum Dissolved Oxygen Concentrations Test Results for Hillsborough River Kilometer Segment 15.2 to 14.5 by Increasing Depth

**Depth 0-1 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0001 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0006 | 0.643 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0006 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.002 | 0.643 | --- | |
| After Feb 2012 | 0.0002 | 0.462 | 0.067 | 0.006 | --- |

**Depth 2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | X | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | X | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

3. Wilcoxon Rank Sum Dissolved Oxygen Concentrations Test Results for Hillsborough River Kilometer Segment 14.5 to 14.1 by Increasing Depth

**Depth 0-1 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.047 | --- | | | |
| Dec 2003 - Dec 2007 | 0.001 | 0.139 | --- | | |
| Jan 2009 - Feb 2012 | 0.005 | 0.173 | 0.538 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.739 | --- | | | |
| Dec 2003 - Dec 2007 | 0.779 | 0.358 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.738 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0003 | --- | | | |
| Dec 2003 - Dec 2007 | 0.001 | 0.104 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

4. Wilcoxon Rank Sum Dissolved Oxygen Concentrations Test Results for Hillsborough River Kilometer Segment 14.1 to 13.4 by Increasing Depth

**Depth 0-1 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.485 | --- | | | |
| Dec 2003 - Dec 2007 | 0.201 | 0.004 | --- | | |
| Jan 2009 - Feb 2012 | 0.092 | 0.007 | 0.137 | --- | |
| After Feb 2012 | 0.109 | 0.173 | 0.041 | 0.01 | --- |

**Depth 1-2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.842 | --- | | | |
| Dec 2003 - Dec 2007 | 0.797 | 0.799 | --- | | |
| Jan 2009 - Feb 2012 | 0.007 | 0.003 | 0.005 | --- | |
| After Feb 2012 | 0.7 | 0.509 | 0.496 | 0.016 | --- |

**Depth 2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | X | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.619 | --- | | | |
| Dec 2003 - Dec 2007 | 0.658 | 0.218 | --- | | |
| Jan 2009 - Feb 2012 | 0.001 | 0.005 | 0.0004 | --- | |
| After Feb 2012 | 0.481 | 0.754 | 0.123 | 0.0003 | --- |

5. Wilcoxon Rank Sum Dissolved Oxygen Concentrations Test Results for Hillsborough River Kilometer Segment 13.4 to 12.6 by Increasing Depth

**Depth 0-1 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.883 | --- | | | |
| Dec 2003 - Dec 2007 | 0.038 | 0.016 | --- | | |
| Jan 2009 - Feb 2012 | 0.012 | 0.01 | 0.221 | --- | |
| After Feb 2012 | 0.316 | 0.313 | 0.039 | 0.011 | --- |

**Depth 1-2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.138 | --- | | | |
| Dec 2003 - Dec 2007 | 0.108 | 0.785 | --- | | |
| Jan 2009 - Feb 2012 | 0.275 | 0.043 | 0.041 | --- | |
| After Feb 2012 | 0.299 | 0.717 | 0.761 | 0.102 | --- |

**Depth 2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.135 | --- | | | |
| Dec 2003 - Dec 2007 | 0.001 | 0.046 | --- | | |
| Jan 2009 - Feb 2012 | 0.493 | 0.83 | 0.167 | --- | |
| After Feb 2012 | 0.125 | 0.526 | 0.699 | 0.46 | --- |

**Depth >2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.005 | --- | | | |
| Dec 2003 - Dec 2007 | 0.001 | 0.458 | --- | | |
| Jan 2009 - Feb 2012 | 0.061 | 0.923 | 0.88 | --- | |
| After Feb 2012 | 0.246 | 0.832 | 0.47 | 0.807 | --- |

6. Wilcoxon Rank Sum Dissolved Oxygen Concentrations Test Results for Hillsborough River Kilometer Segment 12.6 to 11.6 by Increasing Depth

**Depth 0-1 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.639 | --- | | | |
| Dec 2003 - Dec 2007 | 0.086 | 0.043 | --- | | |
| Jan 2009 - Feb 2012 | 0.824 | 0.429 | 0.168 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.701 | --- | | | |
| Dec 2003 - Dec 2007 | 0.889 | 0.845 | --- | | |
| Jan 2009 - Feb 2012 | 0.145 | 0.116 | 0.141 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.234 | --- | | | |
| Dec 2003 - Dec 2007 | 0.5662 | 0.426 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.006 | --- | | | |
| Dec 2003 - Dec 2007 | 0.127 | 0.075 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

7. Wilcoxon Rank Sum Dissolved Oxygen Concentrations Test Results for Hillsborough River Kilometer Segment 11.6 to 10.6 by Increasing Depth

**Depth 0-1 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.993 | --- | | | |
| Dec 2003 - Dec 2007 | 0.266 | 0.216 | --- | | |
| Jan 2009 - Feb 2012 | 0.013 | 0.018 | 0.1 | --- | |
| After Feb 2012 | 0.006 | 0.008 | 0.047 | 0.832 | --- |

**Depth 1-2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.963 | --- | | | |
| Dec 2003 - Dec 2007 | 0.05 | 0.08 | --- | | |
| Jan 2009 - Feb 2012 | 0.643 | 0.633 | 0.145 | --- | |
| After Feb 2012 | 0.014 | 0.016 | 0.095 | 0.003 | --- |

**Depth 2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.1 | --- | | | |
| Dec 2003 - Dec 2007 | 0.044 | 0.524 | --- | | |
| Jan 2009 - Feb 2012 | 0.771 | 0.615 | 0.375 | --- | |
| After Feb 2012 | 0.009 | 0.153 | 0.299 | 0.044 | --- |

**Depth >2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0005 | --- | | | |
| Dec 2003 - Dec 2007 | 0.012 | 0.784 | --- | | |
| Jan 2009 - Feb 2012 | 0.043 | 0.987 | 0.923 | --- | |
| After Feb 2012 | 0.0001 | 0.017 | 0.031 | 0.044 | --- |

Appendix 3D - Wilcoxon Rank Sum Test Results for Dissolved Oxygen Percent Saturation in the Hillsborough River by Depth Interval and Kilometer Segment

1. Wilcoxon Rank Sum Dissolved Oxygen Percent Saturation Test Results for Hillsborough River Kilometer Segment 16.2 to 15.2 by Increasing Depth

**Depth 0-1 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.479 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0002 | 0.0001 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.250 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.022 | 0.030 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.138 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.055 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0007 | 0.032 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

2. Wilcoxon Rank Sum Dissolved Oxygen Percent Saturation Test Results for Hillsborough River Kilometer Segment 15.2 to 14.5 by Increasing Depth

**Depth 0-1 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.0003 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0001 | 0.010 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.002 | --- | | |
| Jan 2009 - Feb 2012 | 0.0001 | 0.0001 | 0.038 | --- | |
| After Feb 2012 | 0.0004 | 0.633 | 0.064 | 0.0005 | --- |

**Depth 2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | X | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | X | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

Appendix 3D - Wilcoxon Rank Sum Test Results for Dissolved Oxygen Percent Saturation in the Hillsborough River by Depth Interval and Kilometer Segment

3. Wilcoxon Rank Sum Dissolved Oxygen Percent Saturation Test Results for Hillsborough River Kilometer Segment 14.5 to 14.1 by Increasing Depth

**Depth 0-1 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.057 | --- | | | |
| Dec 2003 - Dec 2007 | 0.002 | 0.191 | --- | | |
| Jan 2009 - Feb 2012 | 0.006 | 0.050 | 0.121 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.668 | --- | | | |
| Dec 2003 - Dec 2007 | 0.874 | 0.386 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.719 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0003 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0007 | 0.094 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

Appendix 3D - Wilcoxon Rank Sum Test Results for Dissolved Oxygen Percent Saturation in the Hillsborough River by Depth Interval and Kilometer Segment

4. Wilcoxon Rank Sum Dissolved Oxygen Percent Saturation Test Results for Hillsborough River Kilometer Segment 14.1 to 13.4 by Increasing Depth

**Depth 0-1 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.616 | --- | | | |
| Dec 2003 - Dec 2007 | 0.343 | 0.022 | --- | | |
| Jan 2009 - Feb 2012 | 0.018 | 0.0007 | 0.025 | --- | |
| After Feb 2012 | 0.062 | 0.130 | 0.045 | 0.002 | --- |

**Depth 1-2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.924 | --- | | | |
| Dec 2003 - Dec 2007 | 0.916 | 0.979 | --- | | |
| Jan 2009 - Feb 2012 | 0.002 | 0.0009 | 0.001 | --- | |
| After Feb 2012 | 0.672 | 0.484 | 0.535 | 0.007 | --- |

**Depth 2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | X | --- | | | |
| Dec 2003 - Dec 2007 | X | 0.419 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.595 | --- | | | |
| Dec 2003 - Dec 2007 | 0.504 | 0.176 | --- | | |
| Jan 2009 - Feb 2012 | 0.001 | 0.003 | 0.0003 | --- | |
| After Feb 2012 | 0.459 | 0.738 | 0.124 | 0.0003 | --- |

5. Wilcoxon Rank Sum Dissolved Oxygen Percent Saturation Test Results for Hillsborough River Kilometer Segment 13.4 to 12.6 by Increasing Depth

**Depth 0-1 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.948 | --- | | | |
| Dec 2003 - Dec 2007 | 0.142 | 0.100 | --- | | |
| Jan 2009 - Feb 2012 | 0.0009 | 0.0008 | 0.007 | --- | |
| After Feb 2012 | 0.321 | 0.278 | 0.077 | 0.002 | --- |

**Depth 1-2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.153 | --- | | | |
| Dec 2003 - Dec 2007 | 0.046 | 0.521 | --- | | |
| Jan 2009 - Feb 2012 | 0.067 | 0.006 | 0.004 | --- | |
| After Feb 2012 | 0.255 | 0.704 | 0.928 | 0.060 | --- |

**Depth 2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.166 | --- | | | |
| Dec 2003 - Dec 2007 | 0.002 | 0.052 | --- | | |
| Jan 2009 - Feb 2012 | 0.707 | 0.701 | 0.136 | --- | |
| After Feb 2012 | 0.173 | 0.548 | 0.606 | 0.460 | --- |

**Depth >2 m**

| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.010 | --- | | | |
| Dec 2003 - Dec 2007 | 0.003 | 0.474 | --- | | |
| Jan 2009 - Feb 2012 | 0.090 | 0.947 | 0.894 | --- | |
| After Feb 2012 | 0.342 | 0.731 | 0.450 | 0.724 | --- |

6. Wilcoxon Rank Sum Dissolved Oxygen Percent Saturation Test Results for Hillsborough River Kilometer Segment 12.6 to 11.6 by Increasing Depth

**Depth 0-1 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.453 | --- | | | |
| Dec 2003 - Dec 2007 | 0.023 | 0.008 | --- | | |
| Jan 2009 - Feb 2012 | 0.726 | 0.111 | 0.035 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 1-2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.624 | --- | | | |
| Dec 2003 - Dec 2007 | 0.663 | 0.956 | --- | | |
| Jan 2009 - Feb 2012 | 0.054 | 0.028 | 0.023 | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth 2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.213 | --- | | | |
| Dec 2003 - Dec 2007 | 0.591 | 0.437 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

**Depth >2 m**

| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.004 | --- | | | |
| Dec 2003 - Dec 2007 | 0.141 | 0.060 | --- | | |
| Jan 2009 - Feb 2012 | X | X | X | --- | |
| After Feb 2012 | X | X | X | X | --- |

7. Wilcoxon Rank Sum Dissolved Oxygen Percent Saturation Test Results for Hillsborough River Kilometer Segment 11.6 to 10.6 by Increasing Depth

**Depth 0-1 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.983 | --- | | | |
| Dec 2003 - Dec 2007 | 0.056 | 0.043 | --- | | |
| Jan 2009 - Feb 2012 | 0.037 | 0.038 | 0.352 | --- | |
| After Feb 2012 | 0.002 | 0.002 | 0.041 | 0.461 | --- |

**Depth 1-2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.935 | --- | | | |
| Dec 2003 - Dec 2007 | 0.035 | 0.035 | --- | | |
| Jan 2009 - Feb 2012 | 0.404 | 0.411 | 0.046 | --- | |
| After Feb 2012 | 0.013 | 0.013 | 0.096 | 0.002 | --- |

**Depth 2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.181 | --- | | | |
| Dec 2003 - Dec 2007 | 0.636 | 0.525 | --- | | |
| Jan 2009 - Feb 2012 | 0.980 | 0.495 | 0.290 | --- | |
| After Feb 2012 | 0.008 | 0.127 | 0.250 | 0.027 | --- |

**Depth >2 m**

| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.001 | --- | | | |
| Dec 2003 - Dec 2007 | 0.025 | 0.773 | --- | | |
| Jan 2009 - Feb 2012 | 0.068 | 0.917 | 0.940 | --- | |
| After Feb 2012 | 0.000 | 0.020 | 0.031 | 0.044 | --- |

Appendix 4A – Wilcoxon Rank Sum Test Results of Continuous Recorder pH Data in the Hillsborough River by Kilometer Segments

1. Wilcoxon Rank Sum pH Test Results for Hillsborough River Kilometer Segment 16.2 to 15.2

| 16.2 – 15.2 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.003 | --- | | | |
| Dec 2003 - Dec 2007 | 0.994 | 0.001 | --- | | |
| Jan 2008 - Feb 2012 | 0.025 | 0.278 | 0.004 | --- | |
| After Feb 2012 | 0.363 | 0.0001 | 0.244 | 0.0004 | --- |

2. Wilcoxon Rank Sum pH Test Results for Hillsborough River Kilometer Segment 15.2 to 14.5

| 15.2 – 14.5 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.024 | --- | | | |
| Dec 2003 - Dec 2007 | 0.0001 | 0.001 | --- | | |
| Jan 2008 - Feb 2012 | 0.0001 | 0.0001 | 0.82 | --- | |
| After Feb 2012 | 0.0001 | 0.002 | 0.968 | 0.954 | --- |

3. Wilcoxon Rank Sum pH Test Results for Hillsborough River Kilometer Segment 14.5 to 14.1

| 14.5 – 14.1 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.255 | --- | | | |
| Dec 2003 - Dec 2007 | 0.685 | 0.783 | --- | | |
| Jan 2008 - Feb 2012 | 0.015 | 0.021 | 0.048 | --- | |
| After Feb 2012 | 0.026 | 0.042 | 0.046 | 0.192 | --- |

4. Wilcoxon Rank Sum pH Test Results for Hillsborough River Kilometer Segment 14.1 to 13.4

| 14.1 – 13.4 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.053 | --- | | | |
| Dec 2003 - Dec 2007 | 0.088 | 0.003 | --- | | |
| Jan 2008 - Feb 2012 | 0.051 | 0.001 | 0.718 | --- | |
| After Feb 2012 | 0.438 | 0.086 | 0.917 | 0.833 | --- |

5. Wilcoxon Rank Sum pH Test Results for Hillsborough River Kilometer Segment 13.4 to 12.6

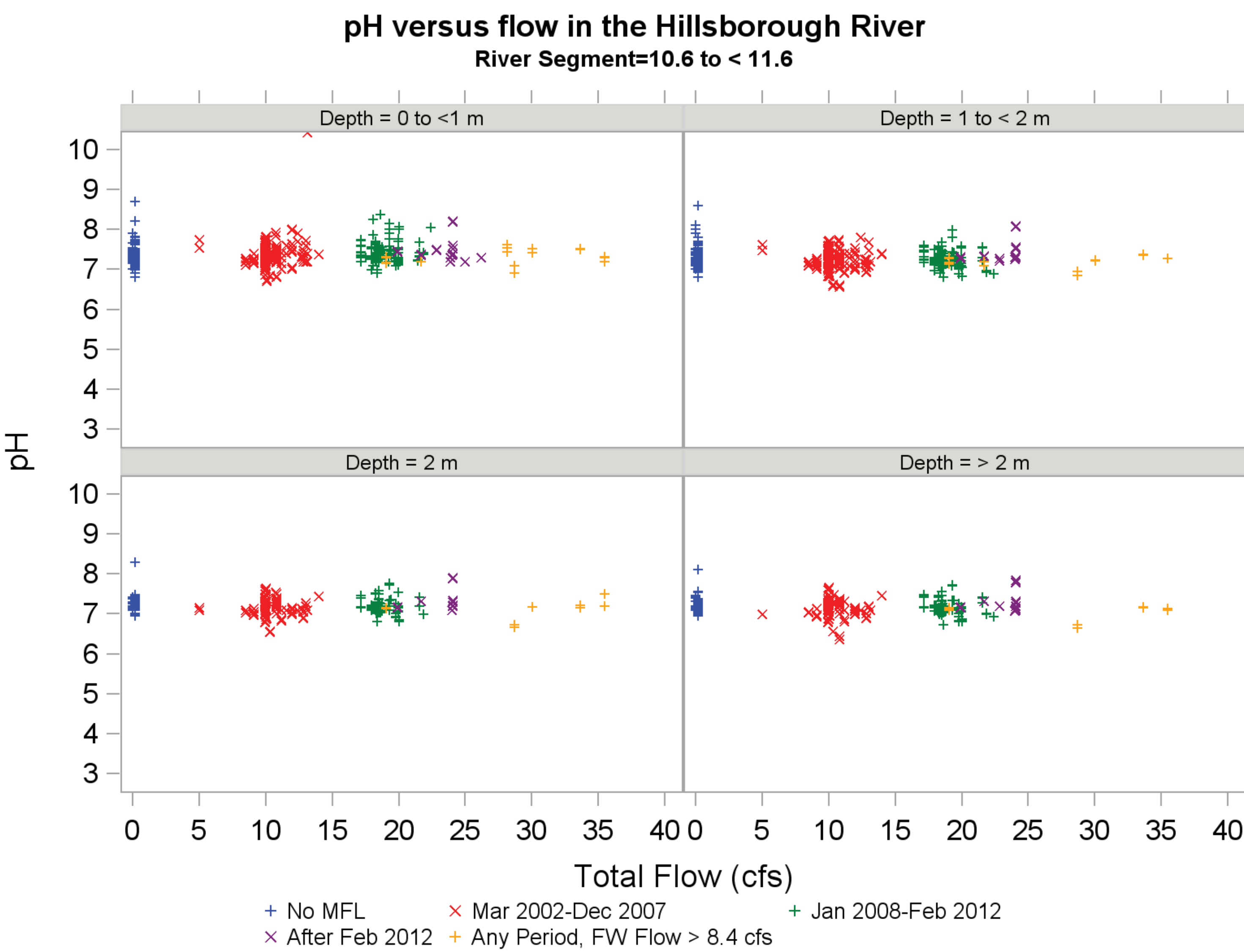
| 13.4 – 12.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.002 | --- | | | |
| Dec 2003 - Dec 2007 | 0.3 | 0.001 | --- | | |
| Jan 2008 - Feb 2012 | 0.278 | 0.0003 | 0.885 | --- | |
| After Feb 2012 | 0.009 | 0.0001 | 0.058 | 0.06 | --- |

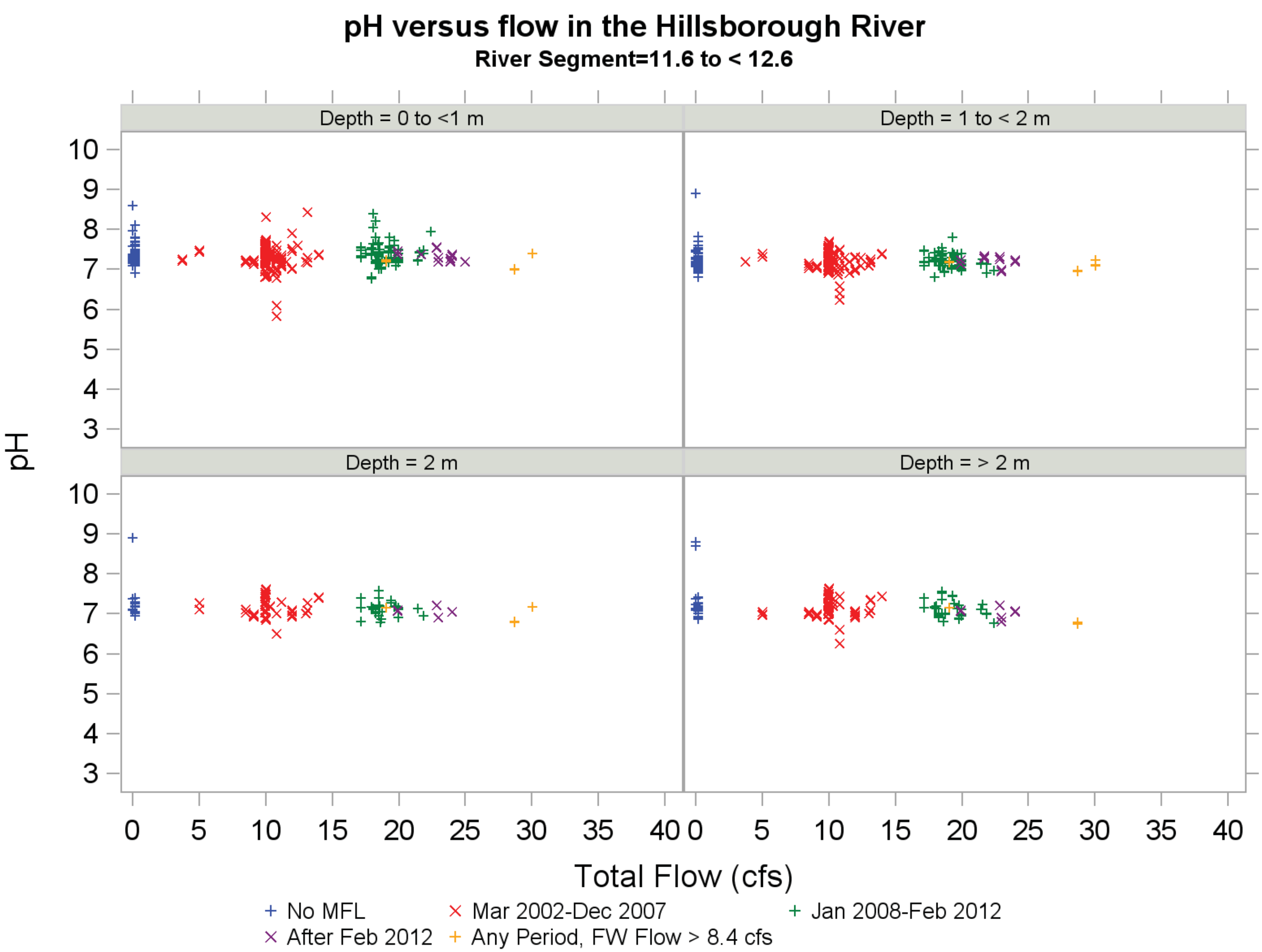
6. Wilcoxon Rank Sum pH Test Results for Hillsborough River Kilometer Segment 12.6 to 11.6

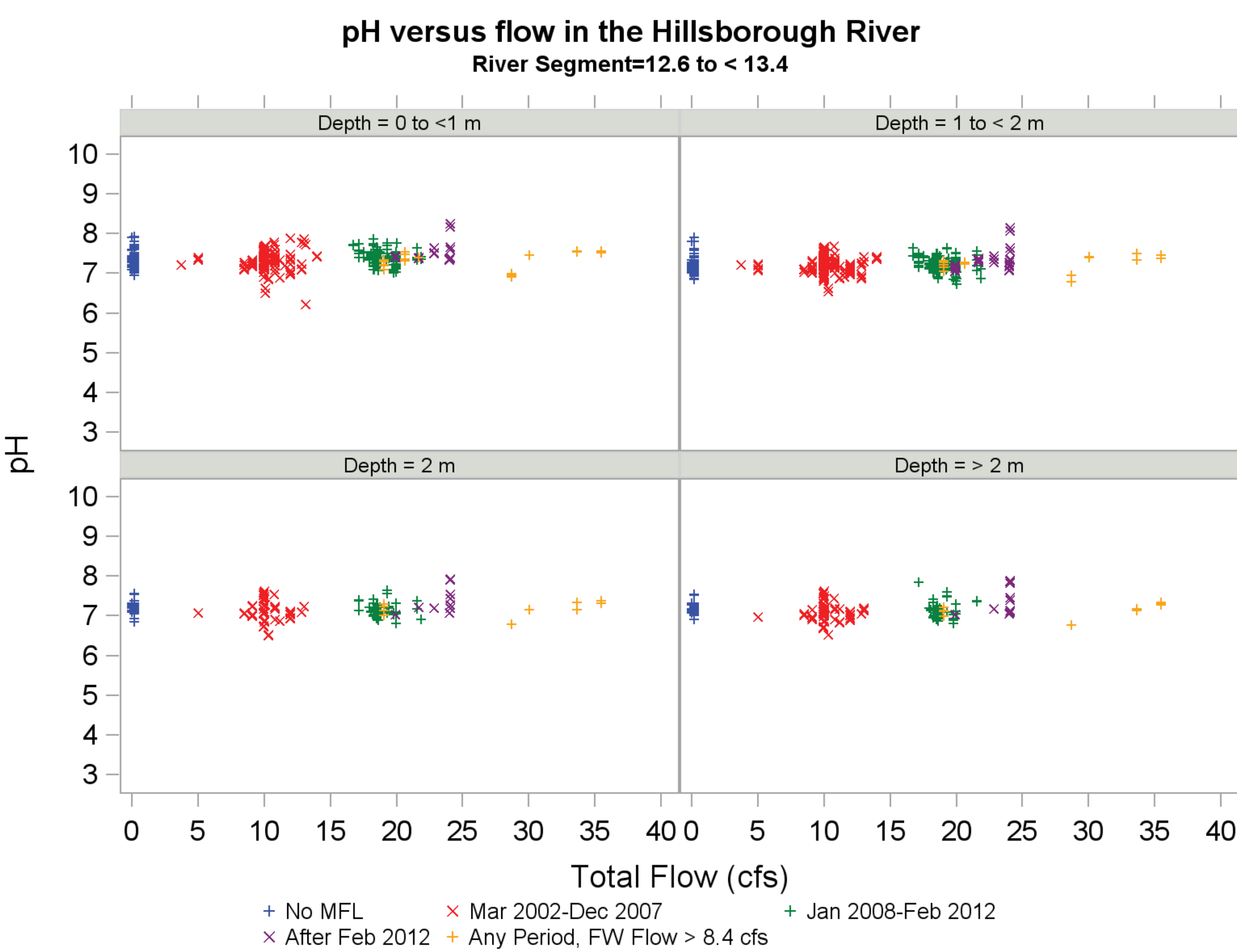
| 12.6 – 11.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.005 | --- | | | |
| Dec 2003 - Dec 2007 | 0.337 | 0.038 | --- | | |
| Jan 2008 - Feb 2012 | 0.469 | 0.021 | 0.916 | --- | |
| After Feb 2012 | 0.004 | 0.919 | 0.016 | 0.018 | --- |

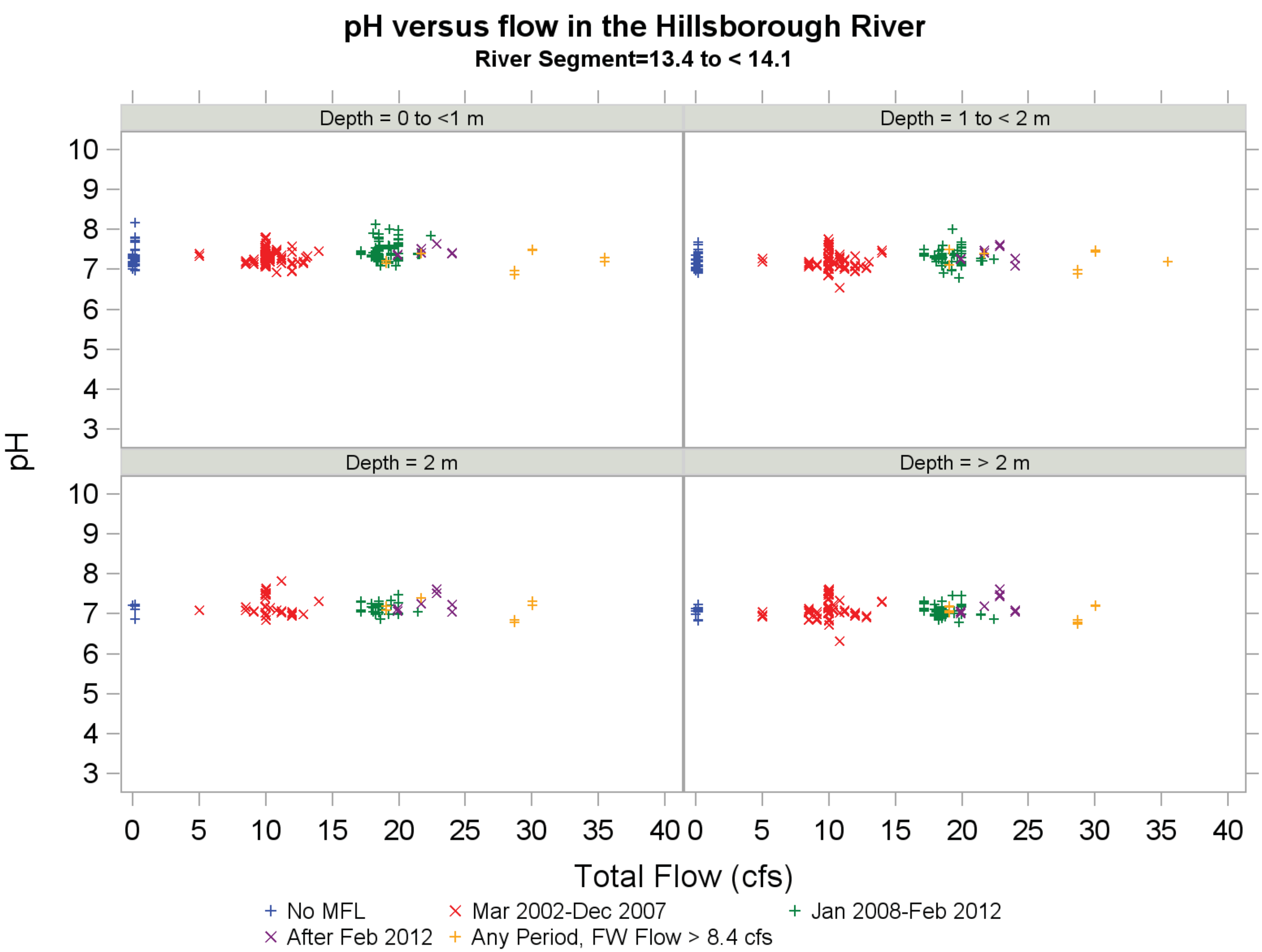
7. Wilcoxon Rank Sum pH Test Results for Hillsborough River Kilometer Segment 11.6 to 10.6

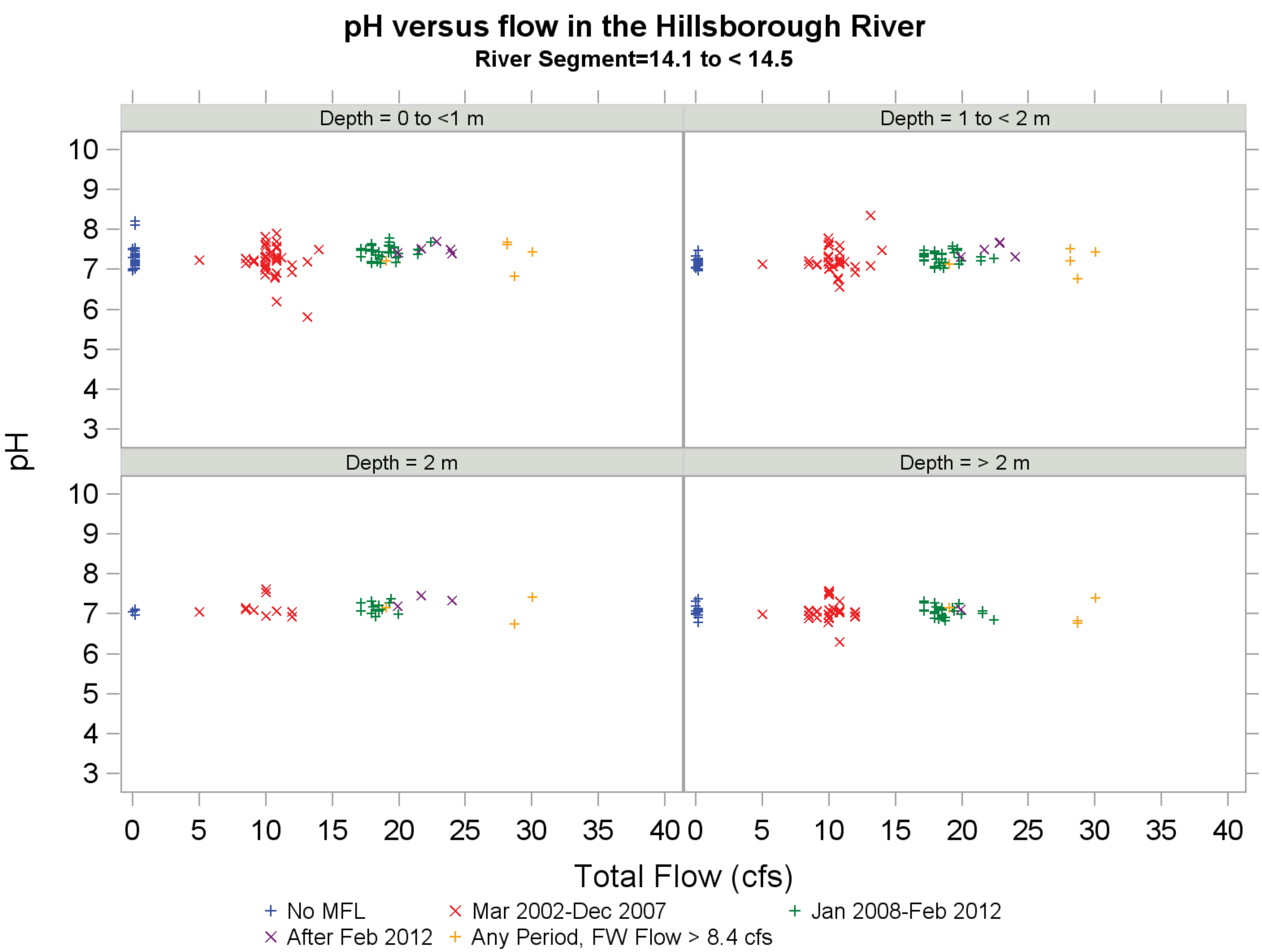
| 11.6 – 10.6 KM | No MFL | Spring 2002 | Dec 2003 - Dec 2007 | Jan 2009 - Feb 2012 | After Feb 2012 |
|---|---|---|---|---|---|
| No MFL | --- | | | | |
| Spring 2002 | 0.0003 | --- | | | |
| Dec 2003 - Dec 2007 | 0.05 | 0.041 | --- | | |
| Jan 2008 - Feb 2012 | 0.156 | 0.008 | 0.558 | --- | |
| After Feb 2012 | 0.048 | 0.0001 | 0.002 | 0.003 | --- |

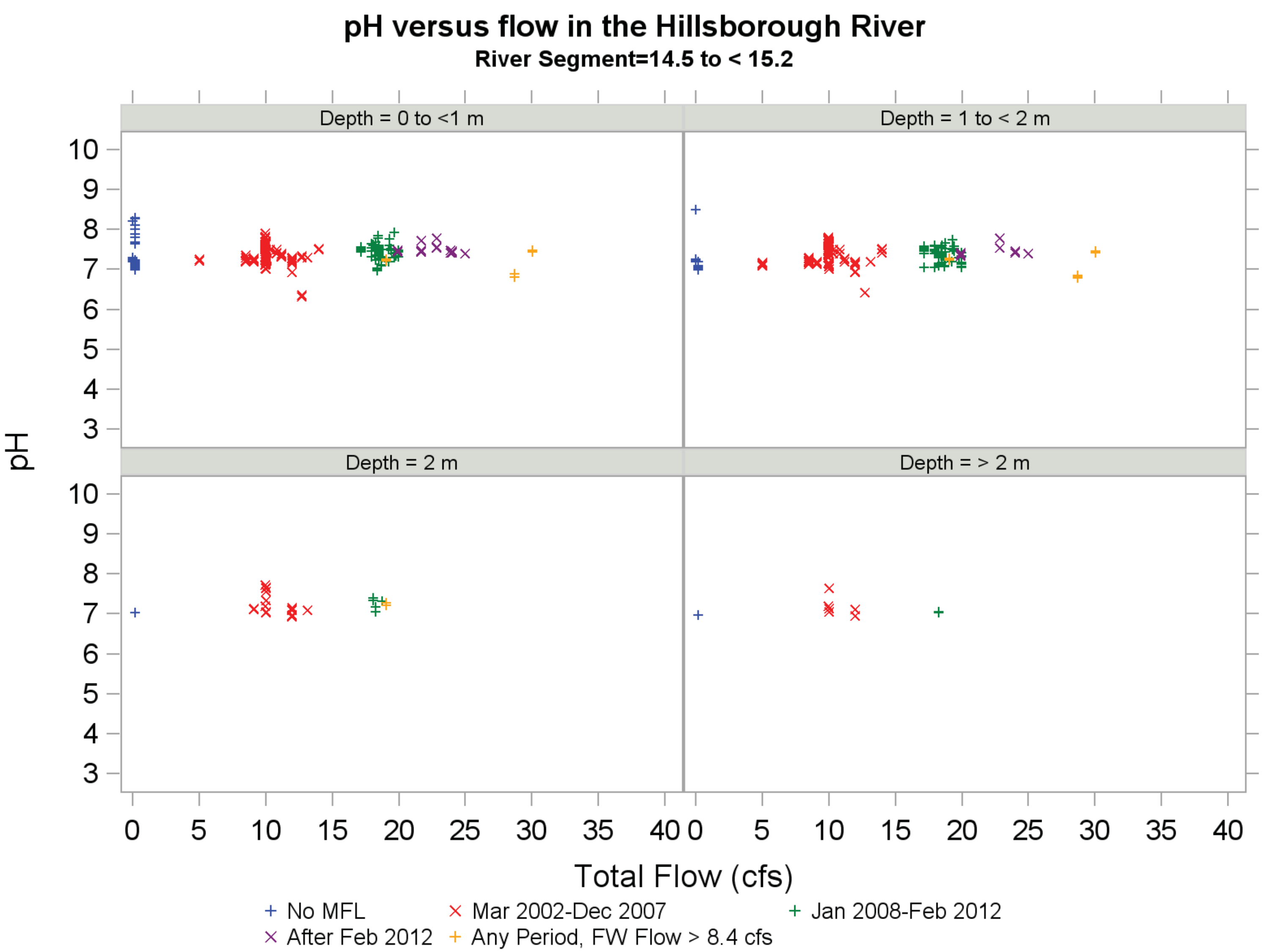

pH versus flow in the Hillsborough River
River Segment=10.6 to < 11.6
Depth = 0 to <1 m
Depth = 1 to < 2 m
Depth = 2 m
Depth = > 2 m
pH
10
9
8
7
6
5
4
3
0
5
10
15
20
25
30
35
40
Total Flow (cfs)
No MFL
Mar 2002-Dec 2007
Jan 2008-Feb 2012
After Feb 2012
Any Period, FW Flow > 8.4 cfs

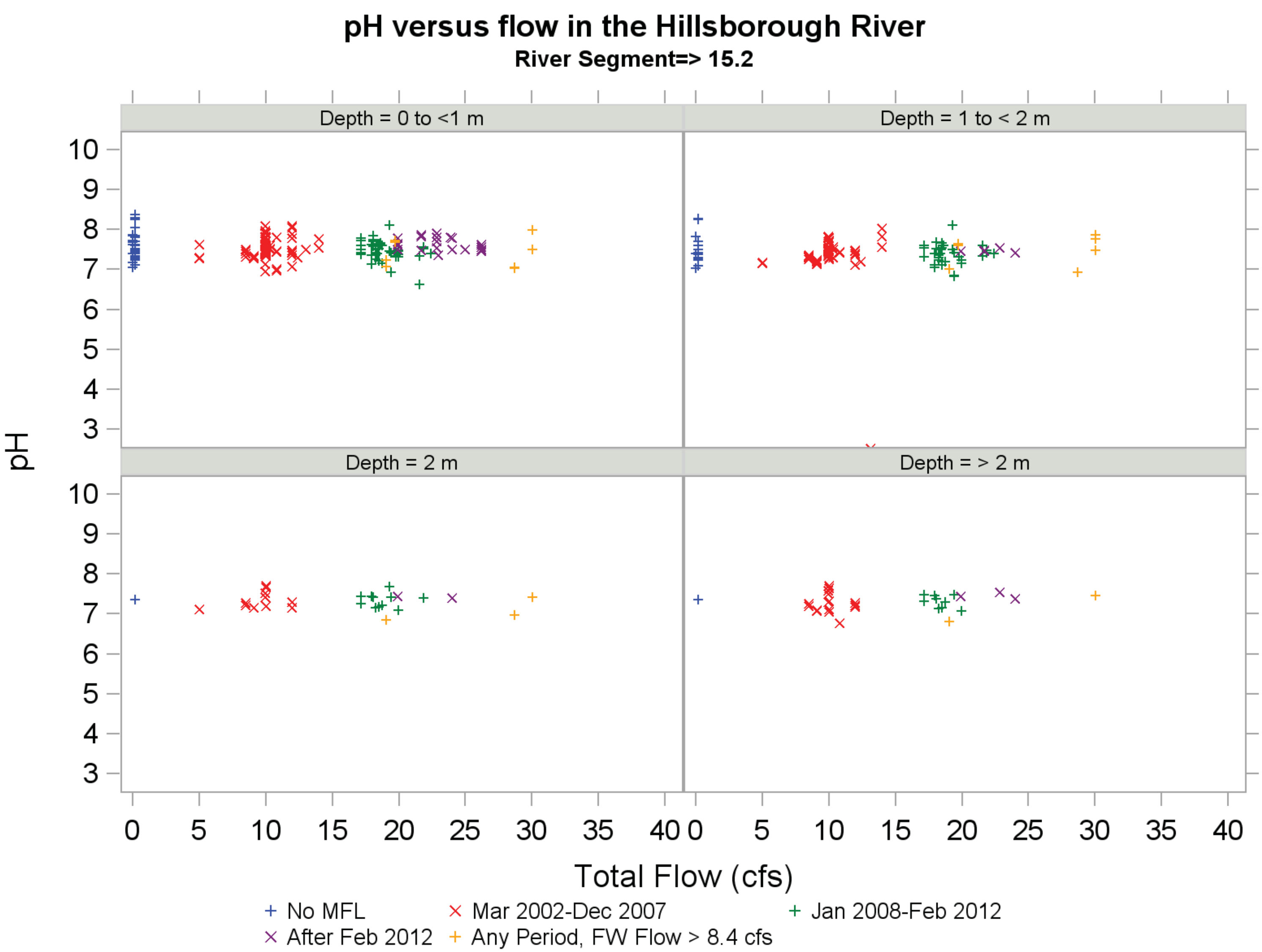

pH versus flow in the Hillsborough River
River Segment=11.6 to < 12.6
Depth = 0 to <1 m
Depth = 1 to < 2 m
Depth = 2 m
Depth = > 2 m
pH
10
9
8
7
6
5
4
3
0
5
10
15
20
25
30
35
40
Total Flow (cfs)
No MFL
Mar 2002-Dec 2007
Jan 2008-Feb 2012
After Feb 2012
Any Period, FW Flow > 8.4 cfs


pH versus flow in the Hillsborough River
River Segment=12.6 to < 13.4
Depth = 0 to <1 m
Depth = 1 to < 2 m
Depth = 2 m
Depth = > 2 m
pH
10
9
8
7
6
5
4
3
0
5
10
15
20
25
30
35
40
Total Flow (cfs)
No MFL
Mar 2002-Dec 2007
Jan 2008-Feb 2012
After Feb 2012
Any Period, FW Flow > 8.4 cfs


pH versus flow in the Hillsborough River
River Segment=13.4 to < 14.1
Depth = 0 to <1 m
Depth = 1 to < 2 m
Depth = 2 m
Depth = > 2 m
pH
10
9
8
7
6
5
4
3
0
5
10
15
20
25
30
35
40
Total Flow (cfs)
No MFL
Mar 2002-Dec 2007
Jan 2008-Feb 2012
After Feb 2012
Any Period, FW Flow > 8.4 cfs


pH versus flow in the Hillsborough River
River Segment=14.1 to < 14.5
Depth = 0 to <1 m
Depth = 1 to < 2 m
Depth = 2 m
Depth = > 2 m
pH
10
9
8
7
6
5
4
3
0
5
10
15
20
25
30
35
40
Total Flow (cfs)
No MFL
Mar 2002-Dec 2007
Jan 2008-Feb 2012
After Feb 2012
Any Period, FW Flow > 8.4 cfs


pH versus flow in the Hillsborough River
River Segment=14.5 to < 15.2
Depth = 0 to <1 m
Depth = 1 to < 2 m
Depth = 2 m
Depth = > 2 m
pH
10
9
8
7
6
5
4
3
0
5
10
15
20
25
30
35
40
Total Flow (cfs)
No MFL
Mar 2002-Dec 2007
Jan 2008-Feb 2012
After Feb 2012
Any Period, FW Flow > 8.4 cfs


pH versus flow in the Hillsborough River
River Segment=> 15.2
Depth = 0 to <1 m
Depth = 1 to < 2 m
Depth = 2 m
Depth = > 2 m
pH
10
9
8
7
6
5
4
3
0
5
10
15
20
25
30
35
40
Total Flow (cfs)
+ No MFL
× Mar 2002-Dec 2007
+ Jan 2008-Feb 2012
× After Feb 2012
+ Any Period, FW Flow > 8.4 cfs

1. Wilcoxon Rank Sum Test Results of Color Data for Hillsborough River Kilometer Segment 16.2 to 14.5

| 16.2 – 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.002 | 0.336 | --- |

2. Wilcoxon Rank Sum Test Results of Color Data for Hillsborough River Kilometer Segment 16.2 to 12.6

| 16.2 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0004 | 0.055 | --- |

3. Wilcoxon Rank Sum Test Results of Color Data for EPC Fixed Station at Rowlett Park Drive

| Rowlett Park Drive | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.001 | 0.775 | --- |

4. Wilcoxon Rank Sum Test Results of Color Data for Hillsborough River Kilometer Segment 14.5 to 12.6

| 14.5 – 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.029 | --- | |
| Jan 2008 - Jun 2013 | 0.025 | 0.129 | --- |

5. Wilcoxon Rank Sum Test Results of Color Data for Hillsborough River Kilometer Segment 12.6 to 10.6

| 12.6 – 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.015 | --- | |
| Jan 2008 - Jun 2013 | 0.41 | 0.233 | --- |

6. Wilcoxon Rank Sum Test Results of Color Data for EPC Fixed Station at Sligh Avenue

| Sligh Avenue | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.356 | --- | |
| Jan 2008 - Jun 2013 | 0.216 | 0.474 | --- |

1. Wilcoxon Rank Sum Test Results of Total Nitrogen for Hillsborough River Kilometer Segment 16.2 to 14.5

| 16.2 – 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.01 | --- |

2. Wilcoxon Rank Sum Test Results of Total Nitrogen for Hillsborough River Kilometer Segment 16.2 to 12.6

| 16.2 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.005 | --- |

3. Wilcoxon Rank Sum Test Results of Total Nitrogen for EPC Fixed Station at Rowlett Park Drive

| Rowlett Park Drive | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.107 | --- |

4. Wilcoxon Rank Sum Test Results of Total Nitrogen for Hillsborough River Kilometer Segment 14.5 to 12.6

| 14.5 – 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | | --- | |
| Jan 2008 - Jun 2013 | | 0.158 | --- |

5. Wilcoxon Rank Sum Test Results of Total Nitrogen for Hillsborough River Kilometer Segment 12.6 to 10.6

| 12.6 – 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.0001 | --- |

6. Wilcoxon Rank Sum Test Results of Total Nitrogen for EPC Fixed Station at Sligh Avenue

| Sligh Avenue | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.002 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.0001 | --- |

Appendix 5C – Wilcoxon Rank Sum Test Results of Nitrate plus Nitrite Data from the Environmental Protection Commission and Hydrobiological Monitoring Program

1. Wilcoxon Rank Sum Test Results of Nitrate plus Nitrite for Hillsborough River Kilometer Segment 16.2 to 14.5

| 16.2 – 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.179 | --- | |
| Jan 2008 - Jun 2013 | 0.04 | 0.003 | --- |

2. Wilcoxon Rank Sum Test Results of Nitrate plus Nitrite for Hillsborough River Kilometer Segment 16.2 to 12.6

| 16.2 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.187 | --- | |
| Jan 2008 - Jun 2013 | 0.017 | 0.0004 | --- |

3. Wilcoxon Rank Sum Test Results Nitrate plus Nitrite for EPC Fixed Station at Rowlett Park Drive

| Rowlett Park Drive | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.358 | --- | |
| Jan 2008 - Jun 2013 | 0.121 | 0.042 | --- |

4. Wilcoxon Rank Sum Test Results of Nitrate plus Nitrite for Hillsborough River Kilometer Segment 14.5 to 12.6

| 14.5 – 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | X | --- | |
| Jan 2008 - Jun 2013 | X | 0.179 | --- |

5. Wilcoxon Rank Sum Test Results of Nitrate plus Nitrite for Hillsborough River Kilometer Segment 12.6 to 10.6

| 12.6 – 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.44 | 0.0001 | --- |

6. Wilcoxon Rank Sum Test Results of Nitrate and Nitrite plus EPC Fixed Station at Sligh Avenue

| Sligh Avenue | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.002 | --- | |
| Jan 2008 - Jun 2013 | 0.39 | 0.009 | --- |

Appendix 5D – Wilcoxon Rank Sum Test Results of Total Phosphorus Data from the Environmental Protection Commission and Hydrobiological Monitoring Program

1. Wilcoxon Rank Sum Test Results of Total Phosphorus for Hillsborough River Kilometer Segment 16.2 to 14.5

| 16.2 – 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.035 | --- |

2. Wilcoxon Rank Sum Test Results of Total Phosphorus for Hillsborough River Kilometer Segment 16.2 to 12.6

| 16.2 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.091 | --- |

3. Wilcoxon Rank Sum Test Results of Total Phosphorus for EPC Fixed Station at Rowlett Park Drive

| Rowlett Park Drive | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.037 | --- |

4. Wilcoxon Rank Sum Test Results of Total Phosphorus for Hillsborough River Kilometer Segment 14.5 to 12.6

| 14.5 – 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | | --- | |
| Jan 2008 - Jun 2013 | | 0.823 | --- |

5. Wilcoxon Rank Sum Test Results of Total Phosphorus for Hillsborough River Kilometer Segment 12.6 to 10.6

| 12.6 – 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.007 | --- | |
| Jan 2008 - Jun 2013 | 0.007 | 0.555 | --- |

6. Wilcoxon Rank Sum Test Results of Total Phosphorus for EPC Fixed Station at Sligh Avenue

| Sligh Avenue | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.153 | --- | |
| Jan 2008 - Jun 2013 | 0.002 | 0.019 | --- |

Appendix 5E – Wilcoxon Rank Sum Test Results of Orthophosphate Data from the Environmental Protection Commission and Hydrobiological Monitoring Program

1. Wilcoxon Rank Sum Test Results of Orthophosphate for Hillsborough River Kilometer Segment 16.2 to 14.5

| 16.2 – 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.482 | --- |

2. Wilcoxon Rank Sum Test Results of Orthophosphate for Hillsborough River Kilometer Segment 16.2 to 12.6

| 16.2 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.793 | --- |

3. Wilcoxon Rank Sum Test Results of Orthophosphate for EPC Fixed Station at Rowlett Park Drive

| Rowlett Park Drive | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.0001 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.339 | --- |

4. Wilcoxon Rank Sum Test Results of Orthophosphate for Hillsborough River Kilometer Segment 14.5 to 12.6

| 14.5 – 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | | --- | |
| Jan 2008 - Jun 2013 | | 0.839 | --- |

5. Wilcoxon Rank Sum Test Results of Orthophosphate for Hillsborough River Kilometer Segment 12.6 to 10.6

| 12.6 – 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.702 | --- | |
| Jan 2008 - Jun 2013 | 0.157 | 0.143 | --- |

6. Wilcoxon Rank Sum Test Results of Orthophosphate for EPC Fixed Station at Sligh Avenue

| Sligh Avenue | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.646 | --- | |
| Jan 2008 - Jun 2013 | 0.037 | 0.036 | --- |

Appendix 5F – Wilcoxon Rank Sum Test Results of Combined Chlorophyll a Data from the Environmental Protection Commission and Hydrobiological Monitoring Program

1. Wilcoxon Rank Sum Test Results of Chlorophyll a for Hillsborough River Kilometer Segment 16.2 to 14.5

| 16.2 – 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.011 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.005 | --- |

2. Wilcoxon Rank Sum Test Results of Chlorophyll a for Hillsborough River Kilometer Segment 16.2 to 12.6

| 16.2 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.07 | --- | |
| Jan 2008 - Jun 2013 | 0.002 | 0.06 | --- |

3. Wilcoxon Rank Sum Test Results of Chlorophyll a for EPC Fixed Station at Rowlett Park Drive

| Rowlett Park Drive | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.007 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.027 | --- |

4. Wilcoxon Rank Sum Test Results of Chlorophyll a for Hillsborough River Kilometer Segment 14.5 to 12.6

| 14.5 – 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.014 | --- | |
| Jan 2008 - Jun 2013 | 0.056 | 0.941 | --- |

5. Wilcoxon Rank Sum Test Results of Chlorophyll a for Hillsborough River Kilometer Segment 12.6 to 10.6

| 12.6 – 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.001 | --- | |
| Jan 2008 - Jun 2013 | 0.001 | 0.596 | --- |

6. Wilcoxon Rank Sum Test Results of Chlorophyll a for EPC Fixed Station at Sligh Avenue

| Sligh Avenue | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.001 | --- | |
| Jan 2008 - Jun 2013 | 0.023 | 0.7 | --- |

| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| A. almyra | 10.6 to < 12.6 | No MFL | 4.285 | 14.831 | 15 | 57.65 | 0.03 | 0.00 | 60 |
| A. almyra | 10.6 to < 12.6 | Mar 02 - Dec 07 | 6.392 | 14.164 | 16 | 42.95 | 0.00 | 0.00 | 43.8 |
| A. almyra | 10.6 to < 12.6 | Jan 08 - Jun 12 | 1.556 | 4.561 | 19 | 19.53 | 0.05 | 0.00 | 68.4 |
| A. almyra | 12.6 to < 14.5 | No MFL | 6.045 | 23.054 | 15 | 89.38 | 0.00 | 0.00 | 46.7 |
| A. almyra | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.652 | 1.738 | 16 | 5.69 | 0.00 | 0.00 | 37.5 |
| A. almyra | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.164 | 0.538 | 19 | 2.36 | 0.00 | 0.00 | 47.4 |

| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| B. smithi | 10.6 to < 12.6 | No MFL | 0.035 | 0.074 | 15 | 0.27 | 0.00 | 0.00 | 33.3 |
| B. smithi | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.001 | 0.004 | 16 | 0.02 | 0.00 | 0.00 | 6.3 |
| B. smithi | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.000 | 0.000 | 19 | 0.00 | 0.00 | 0.00 | 0 |
| B. smithi | 12.6 to < 14.5 | No MFL | 0.003 | 0.010 | 15 | 0.04 | 0.00 | 0.00 | 13.3 |
| B. smithi | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.000 | 0.000 | 16 | 0.00 | 0.00 | 0.00 | 0 |
| B. smithi | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.000 | 0.000 | 19 | 0.00 | 0.00 | 0.00 | 0 |

| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Clytia spp. | 10.6 to < 12.6 | No MFL | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |
| Clytia spp. | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.465 | 1.480 | 16 | 5.93 | 0.00 | 0.00 | 31.3 |
| Clytia spp. | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.863 | 1.873 | 19 | 5.21 | 0.00 | 0.00 | 26.3 |
| Clytia spp. | 12.6 to < | No | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 14.5 | MFL | | | | | | | |
| Clytia spp. | 12.6 to < 14.5 | Mar 02 - Dec 07 | 6.516 | 17.942 | 16 | 58.84 | 0.00 | 0.00 | 37.5 |
| Clytia spp. | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.571 | 1.838 | 19 | 7.87 | 0.00 | 0.00 | 26.3 |

| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Ephemeropterans | 10.6 to < 12.6 | No MFL | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |
| Ephemeropterans | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.000 | 0.000 | 16 | 0.00 | 0.00 | 0.00 | 0 |
| Ephemeropterans | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.001 | 0.003 | 19 | 0.01 | 0.00 | 0.00 | 5.3 |
| Ephemeropterans | 12.6 to < 14.5 | No MFL | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |
| Ephemeropterans | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.001 | 0.003 | 16 | 0.01 | 0.00 | 0.00 | 6.3 |
| Ephemeropterans | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.000 | 0.000 | 19 | 0.00 | 0.00 | 0.00 | 0 |

| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| G. holbrooki juveniles | 10.6 to < 12.6 | No MFL | 0.001 | 0.003 | 15 | 0.01 | 0.00 | 0.00 | 13.3 |
| G. holbrooki juveniles | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.000 | 0.001 | 16 | 0.01 | 0.00 | 0.00 | 6.3 |
| G. holbrooki juveniles | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.001 | 0.003 | 19 | 0.01 | 0.00 | 0.00 | 15.8 |
| G. holbrooki juveniles | 12.6 to < 14.5 | No MFL | 0.057 | 0.192 | 15 | 0.75 | 0.00 | 0.00 | 40 |
| G. holbrooki juveniles | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.005 | 0.011 | 16 | 0.04 | 0.00 | 0.00 | 31.3 |
| G. holbrooki juveniles | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.002 | 0.007 | 19 | 0.03 | 0.00 | 0.00 | 10.5 |

| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Oligochaetes | 10.6 to < 12.6 | No MFL | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |
| Oligochaetes | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.000 | 0.002 | 16 | 0.01 | 0.00 | 0.00 | 6.3 |
| Oligochaetes | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.014 | 0.060 | 19 | 0.26 | 0.00 | 0.00 | 10.5 |
| Oligochaetes | 12.6 to < 14.5 | No MFL | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |
| Oligochaetes | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.001 | 0.003 | 16 | 0.01 | 0.00 | 0.00 | 18.8 |
| Oligochaetes | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.007 | 0.029 | 19 | 0.12 | 0.00 | 0.00 | 5.3 |

| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| P. pugio | 10.6 to < 12.6 | No MFL | 0.441 | 1.340 | 15 | 5.26 | 0.02 | 0.00 | 86.7 |
| P. pugio | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.021 | 0.036 | 16 | 0.13 | 0.01 | 0.00 | 56.3 |
| P. pugio | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.005 | 0.010 | 19 | 0.04 | 0.00 | 0.00 | 26.3 |
| P. pugio | 12.6 to < 14.5 | No MFL | 0.168 | 0.261 | 15 | 0.96 | 0.03 | 0.00 | 80 |
| P. pugio | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.007 | 0.012 | 16 | 0.04 | 0.00 | 0.00 | 37.5 |
| P. pugio | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.001 | 0.005 | 19 | 0.02 | 0.00 | 0.00 | 10.5 |

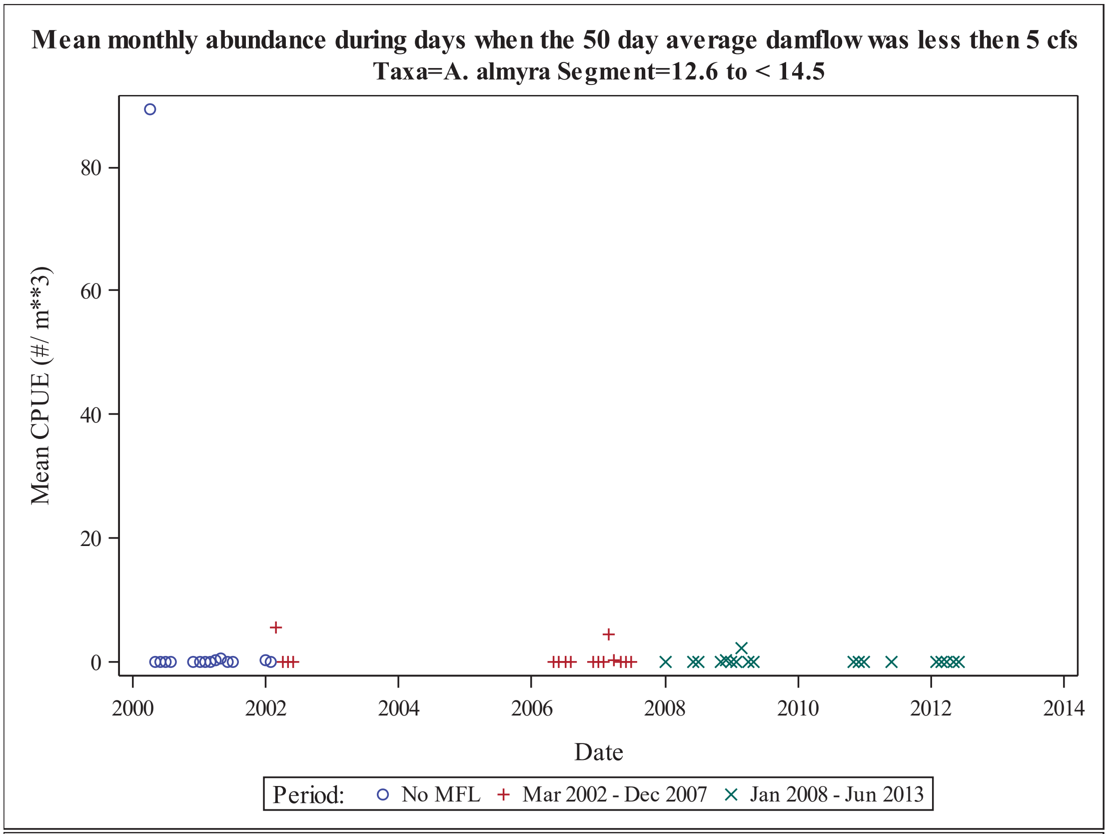
| Taxon | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| T. maculatus juveniles | 10.6 to < 12.6 | No MFL | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |
| T. maculatus juveniles | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.000 | 0.000 | 16 | 0.00 | 0.00 | 0.00 | 0 |
| T. maculatus juveniles | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.001 | 0.004 | 19 | 0.02 | 0.00 | 0.00 | 5.3 |
| T. maculatus | 12.6 to < | No | 0.000 | 0.000 | 15 | 0.00 | 0.00 | 0.00 | 0 |

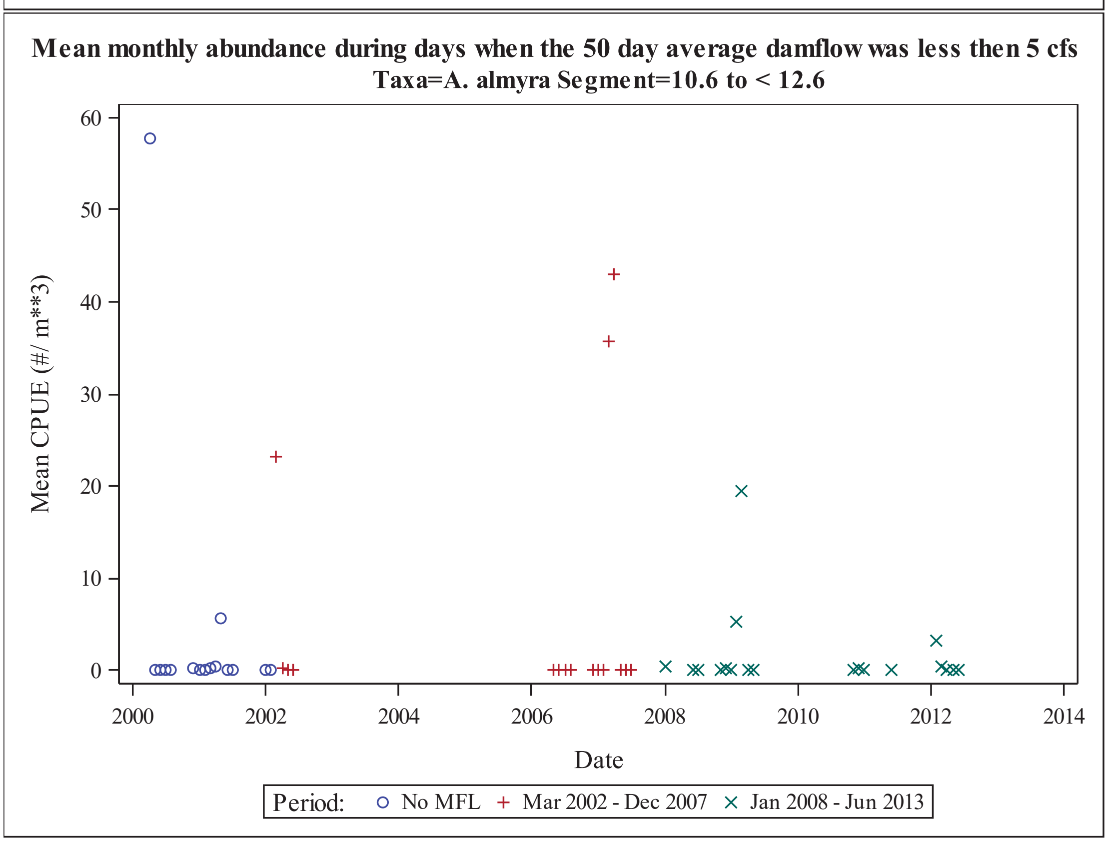
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| juveniles | 14.5 | MFL | | | | | | | |
| T. maculatus juveniles | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.000 | 0.000 | 16 | 0.00 | 0.00 | 0.00 | 0 |
| T. maculatus juveniles | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.000 | 0.001 | 19 | 0.01 | 0.00 | 0.00 | 5.3 |

| Taxa | River Kilometer | Period | Mean | Standard Deviation | Number of Months Sampled | Maximum | Median | Minimum | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Nemopsis spp. | 10.6 to < 12.6 | No MFL | 68.6 | 143.9 | 15 | 418.7 | 3.3 | 0 | 80 |
| Nemopsis spp. | 10.6 to < 12.6 | Mar 02 - Dec 07 | 20.0 | 56.1 | 16 | 193.8 | 0.0 | 0 | 25 |
| Nemopsis spp. | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.0 | 0.0 | 19 | 0.0 | 0.0 | 0 | 0 |
| Nemopsis spp. | 12.6 to < 14.5 | No MFL | 20.1 | 27.1 | 15 | 77.2 | 4.5 | 0 | 66.7 |
| Nemopsis spp. | 12.6 to < 14.5 | Mar 02 - Dec 07 | 9.7 | 30.5 | 16 | 118.9 | 0.0 | 0 | 18.8 |
| Nemopsis spp. | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.0 | 0.0 | 19 | 0.0 | 0.0 | 0 | 0 |

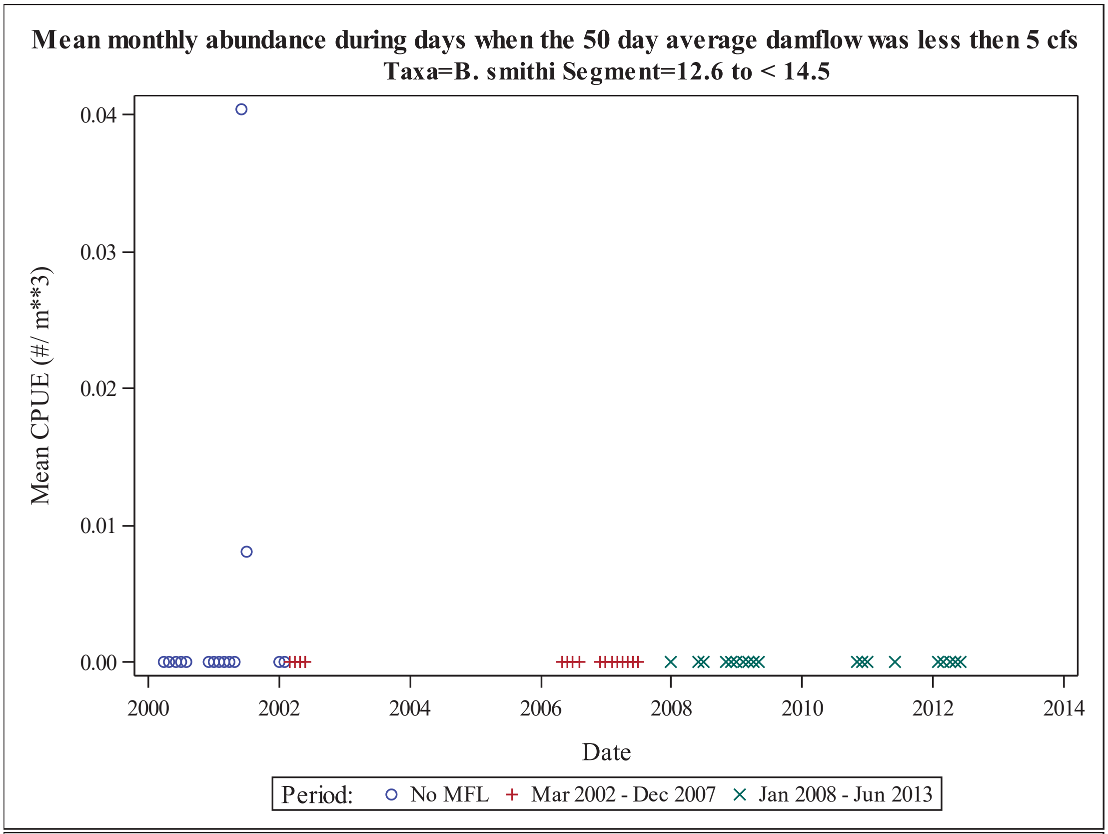
Appendix 6B - Time Series Plots of Plankton Indicators for Dates with 50-Day Flows Less than 5 cfs

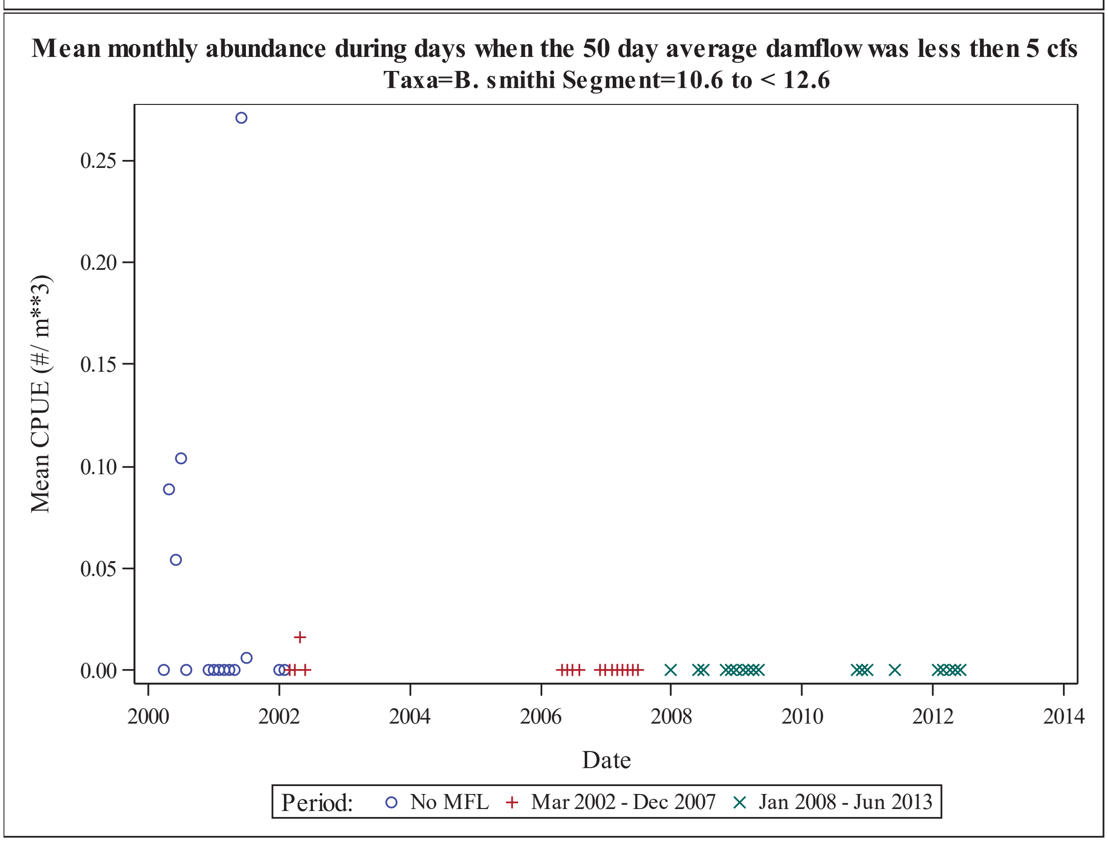
1. A. almyra



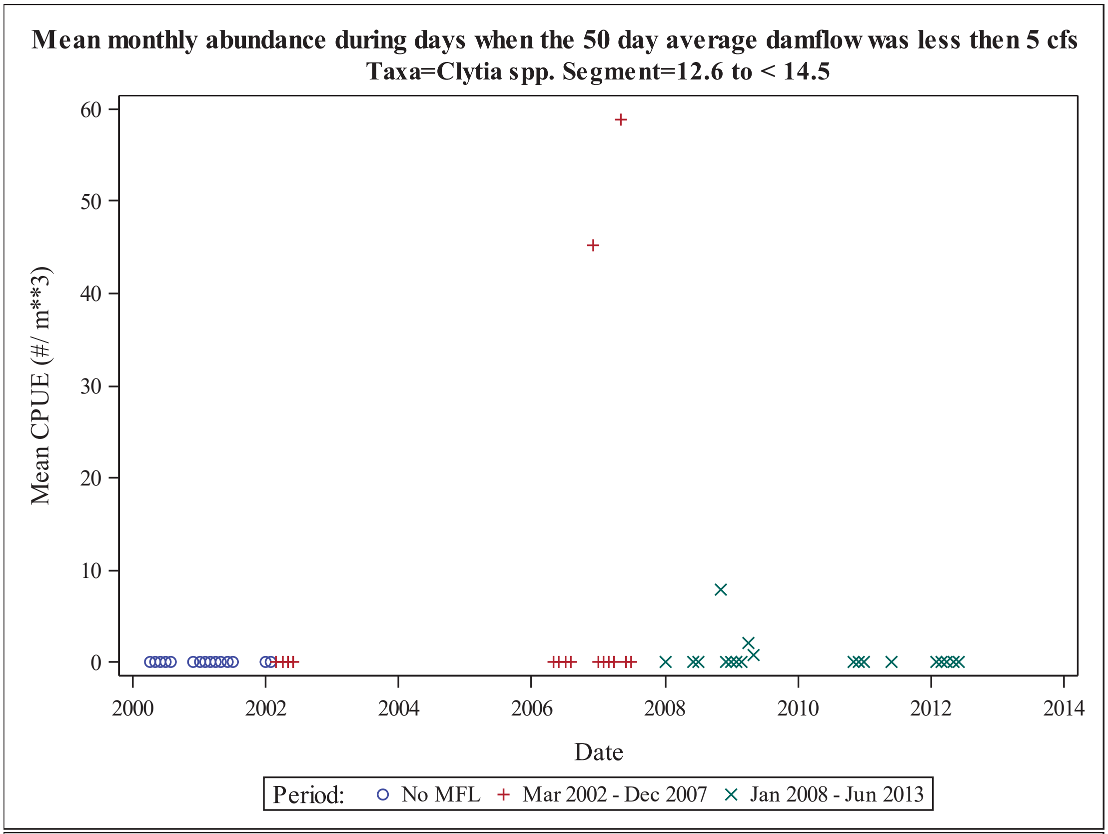



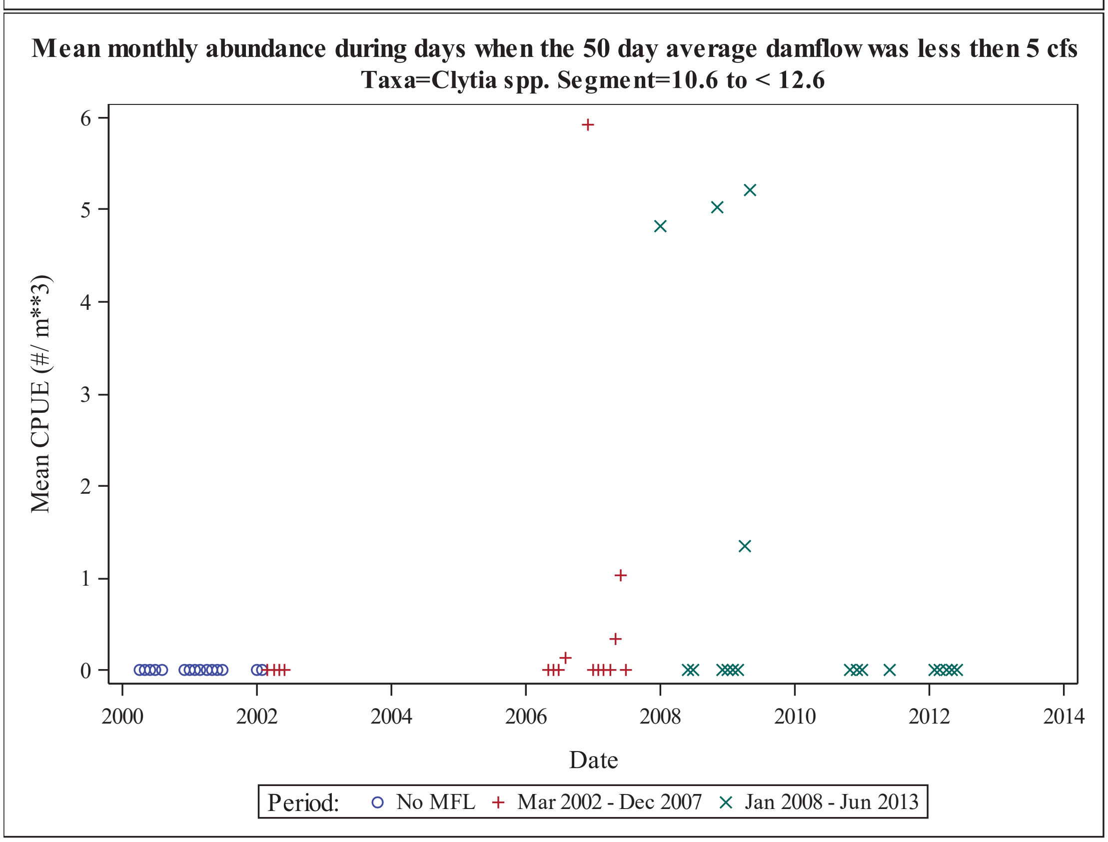
2. B. smithi


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=B. smithi Segment=12.6 to < 14.5
Mean CPUE (#/ m**3)
0.00
0.01
0.02
0.03
0.04
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

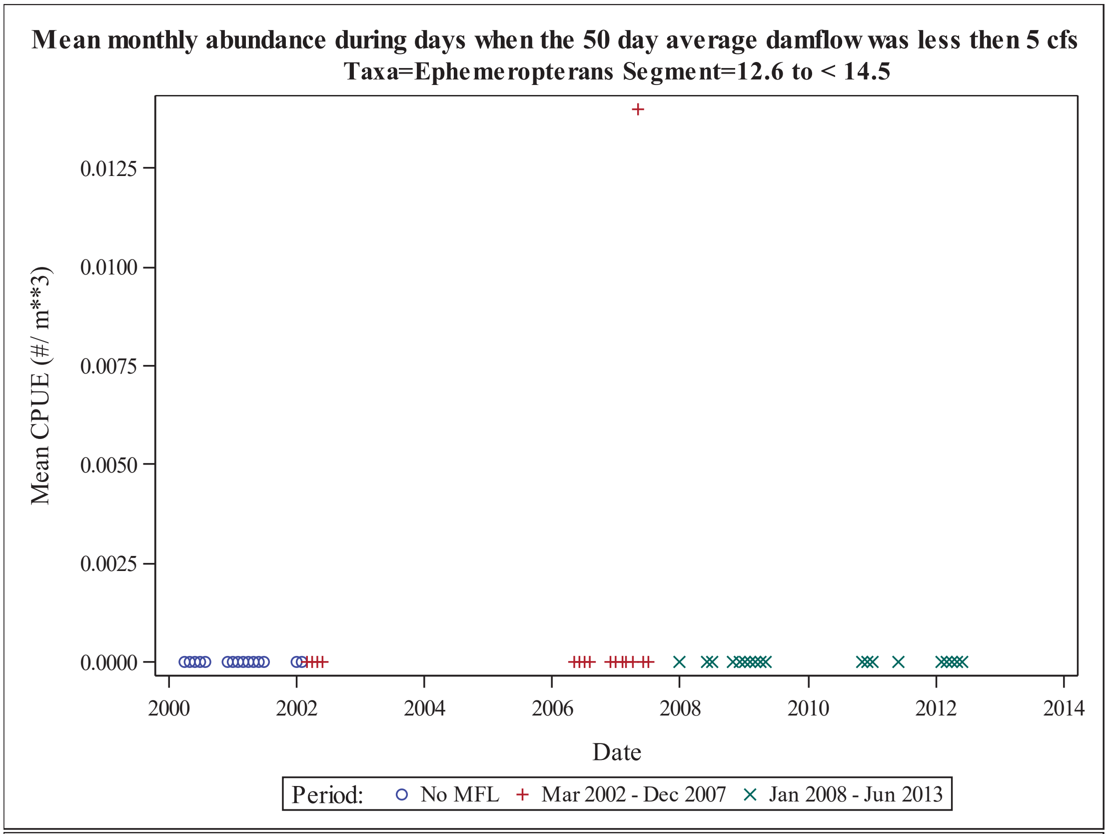

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=B. smithi Segment=10.6 to < 12.6
Mean CPUE (#/ m**3)
0.00
0.05
0.10
0.15
0.20
0.25
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

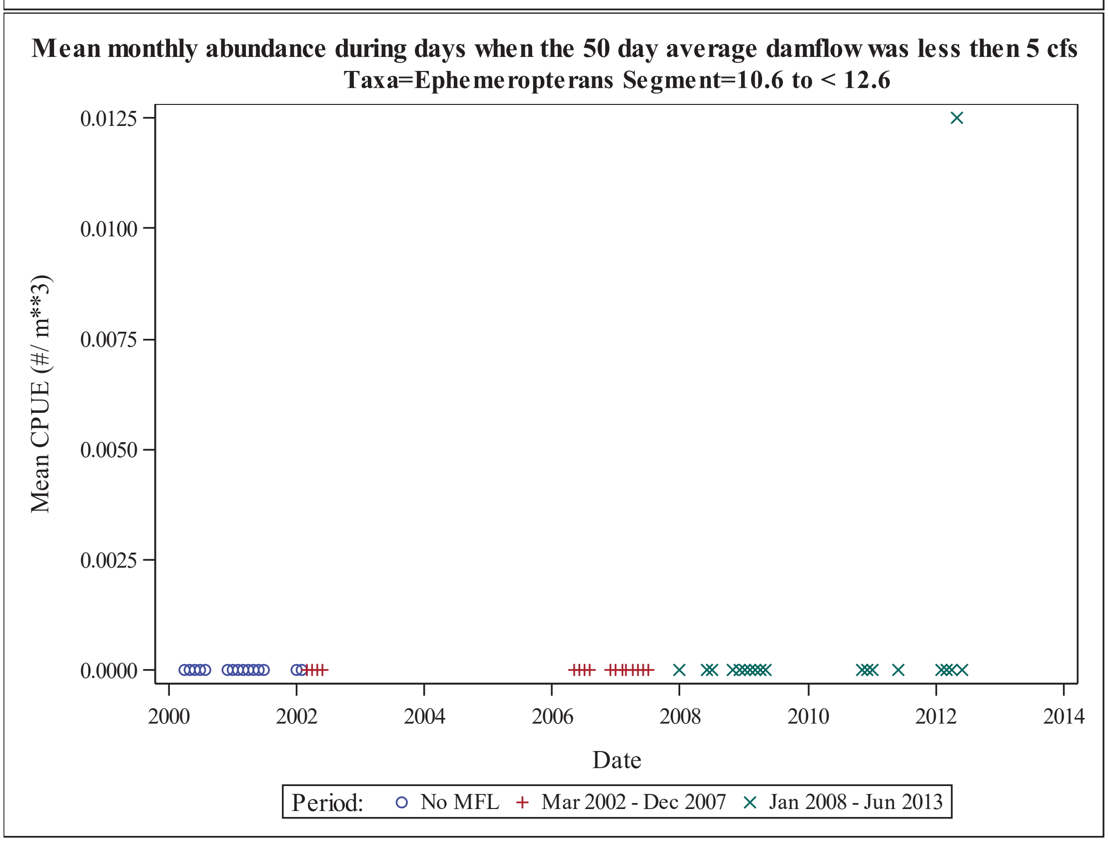
3. Clytia spp.


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Clytia spp. Segment=12.6 to < 14.5
Mean CPUE (#/ m**3)
60
50
40
30
20
10
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

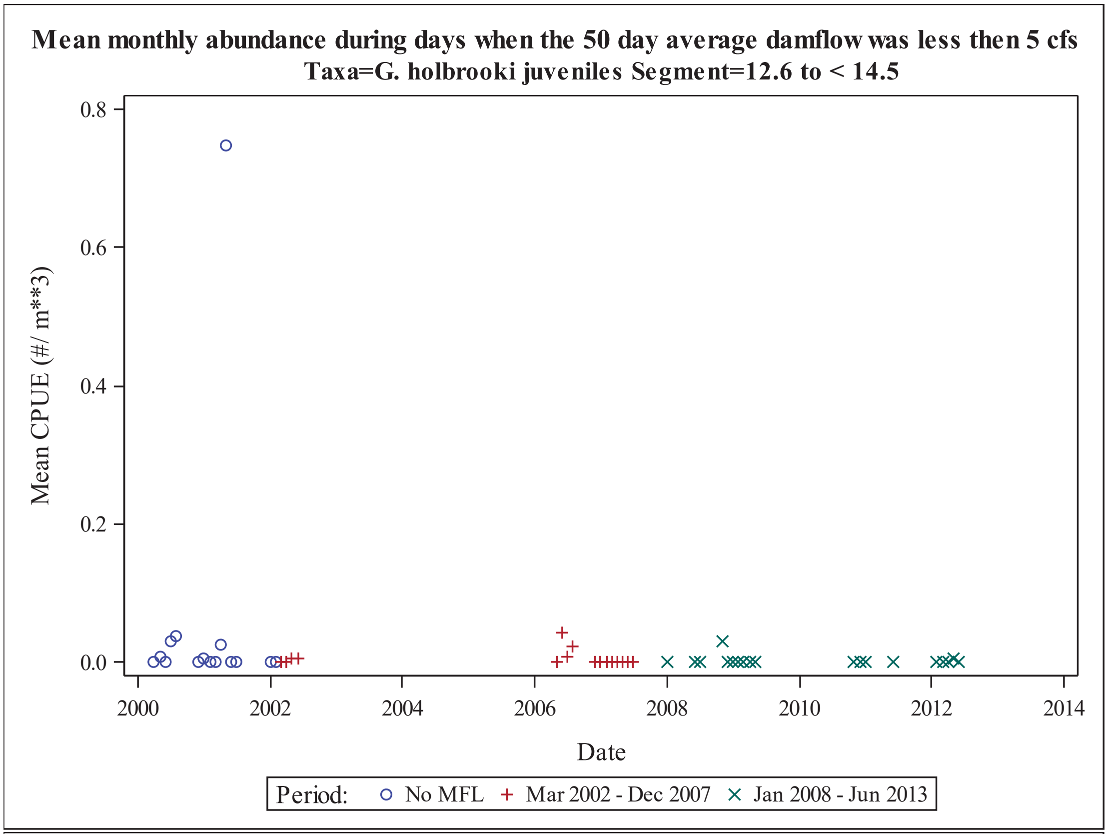

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Clytia spp. Segment=10.6 to < 12.6
Mean CPUE (#/ m**3)
6
5
4
3
2
1
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

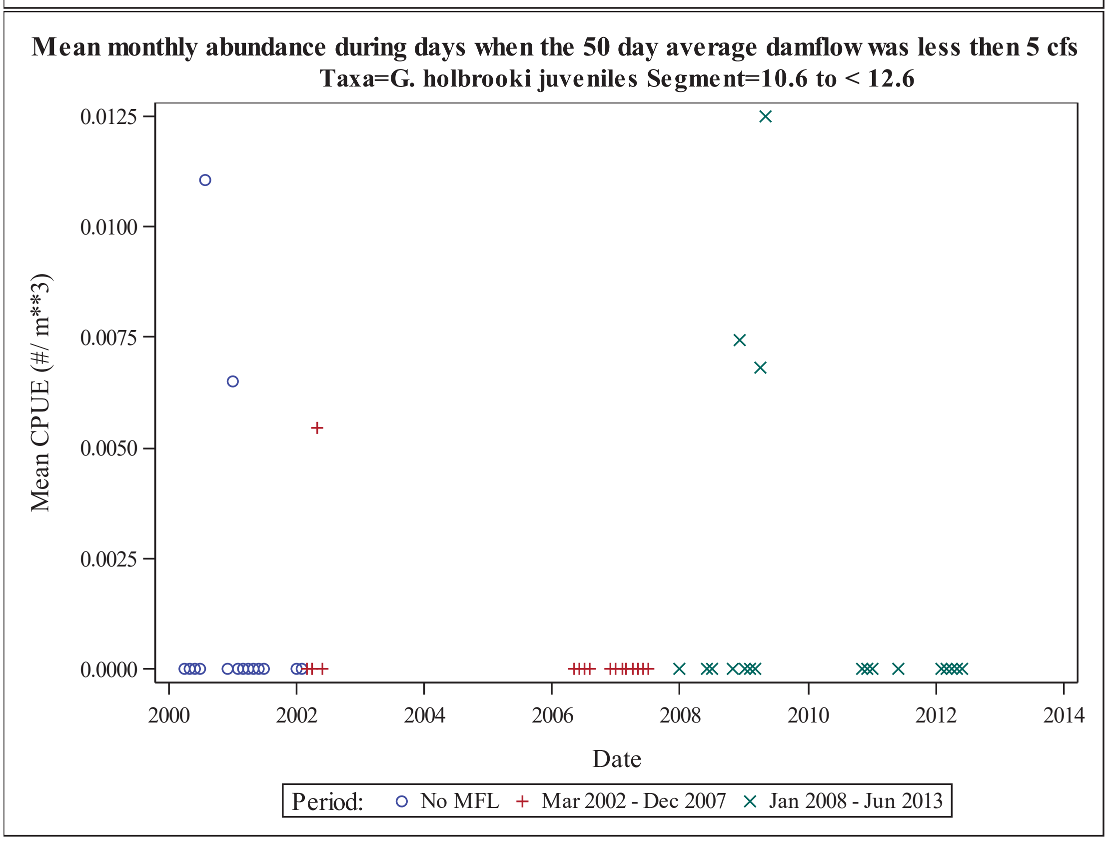
4. Ephemeropterans



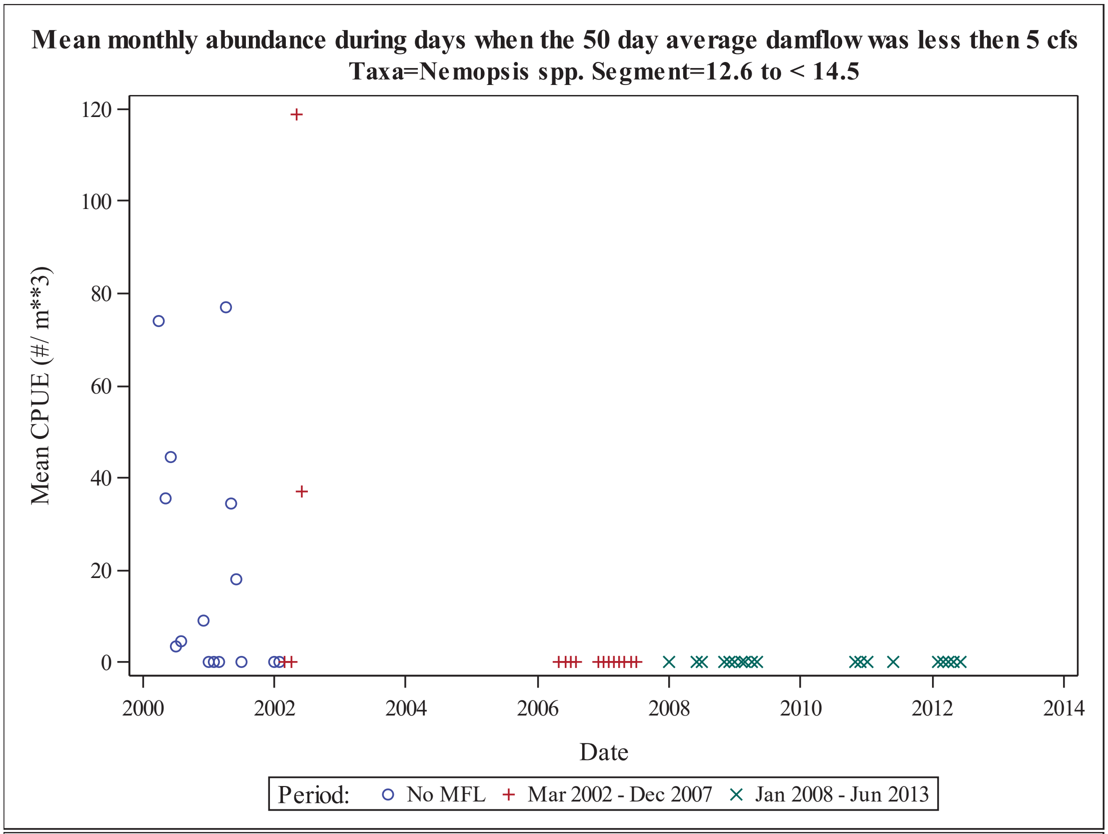



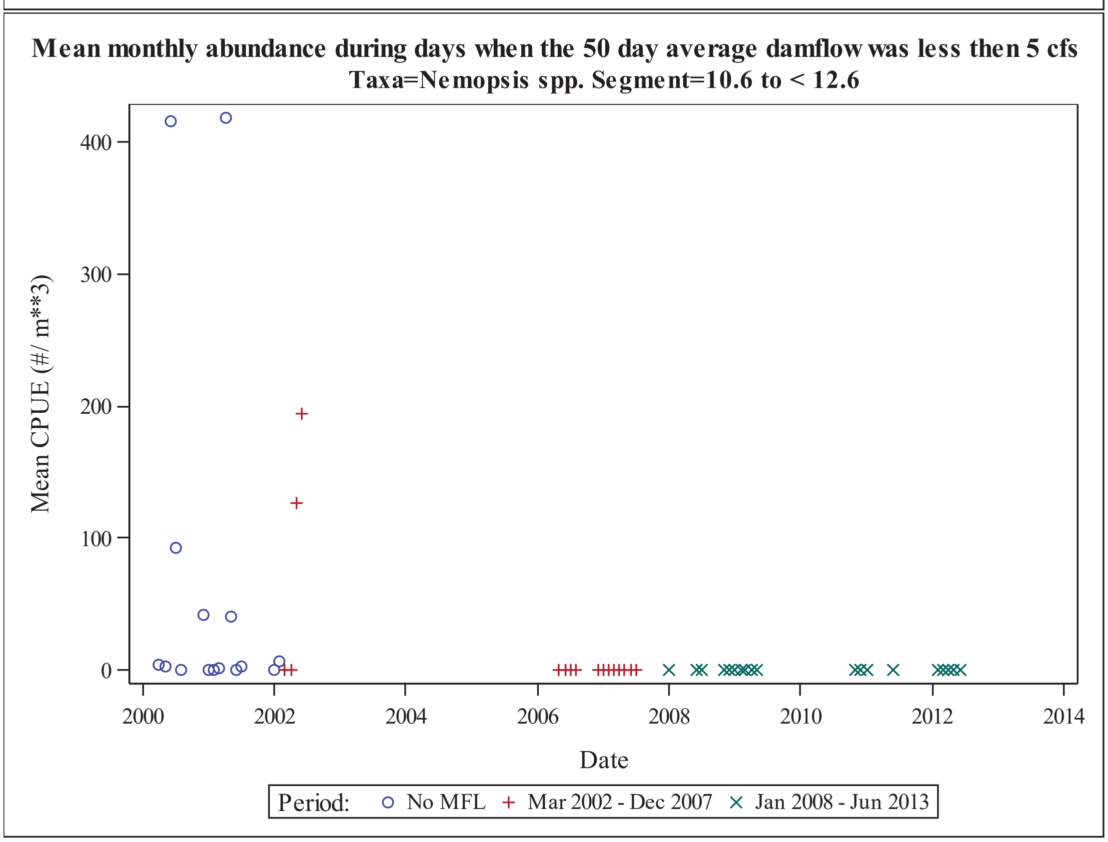
5. G. holbrooki Juveniles



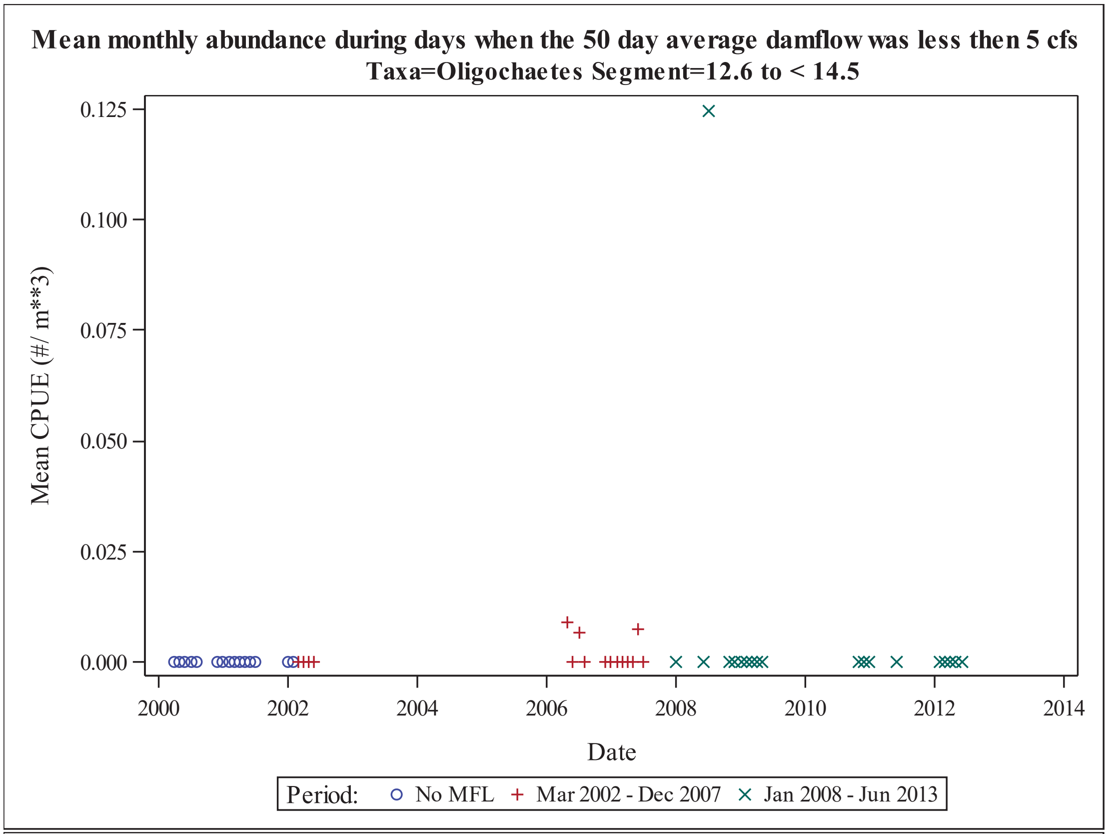



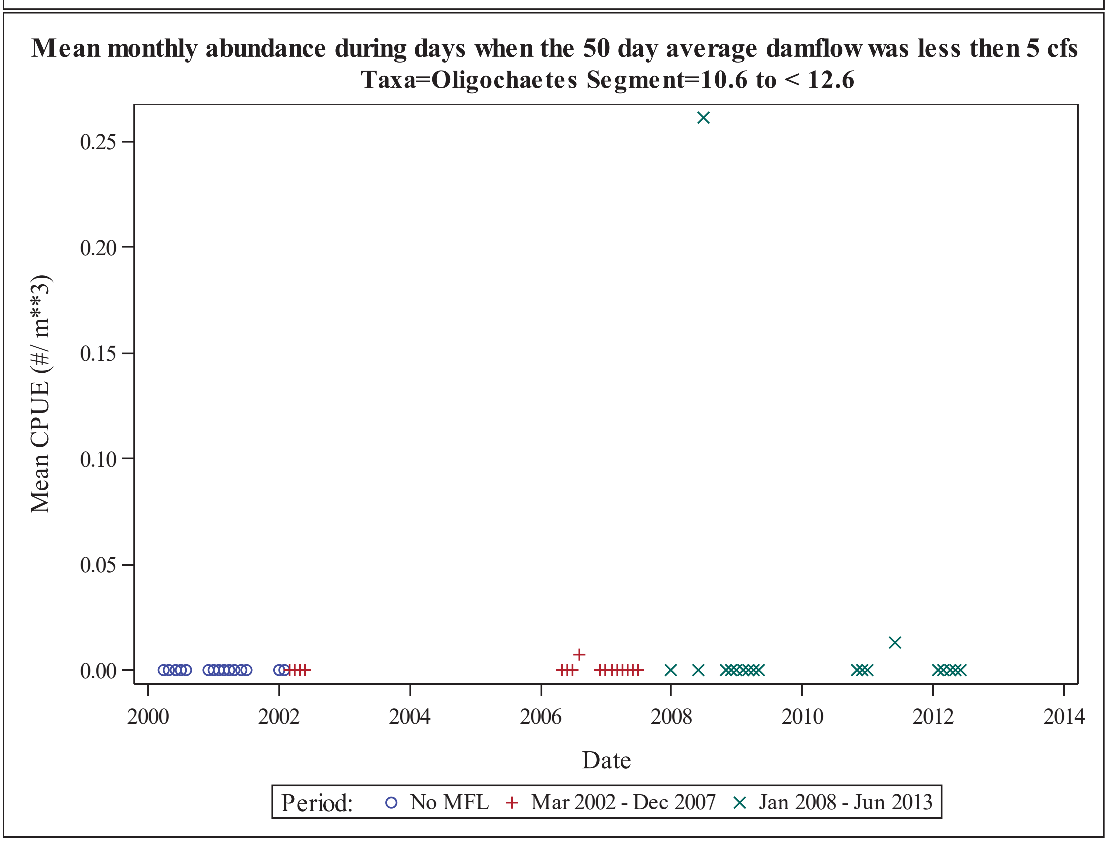
6. Nemopsis spp.



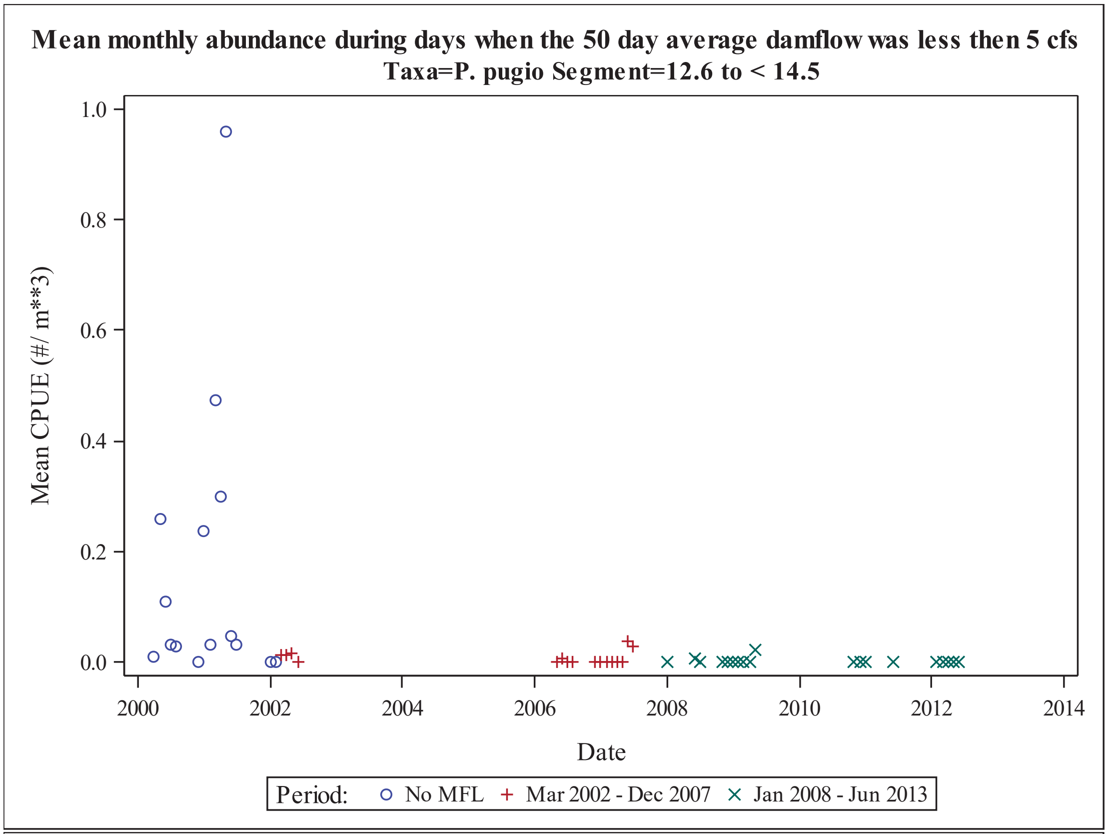



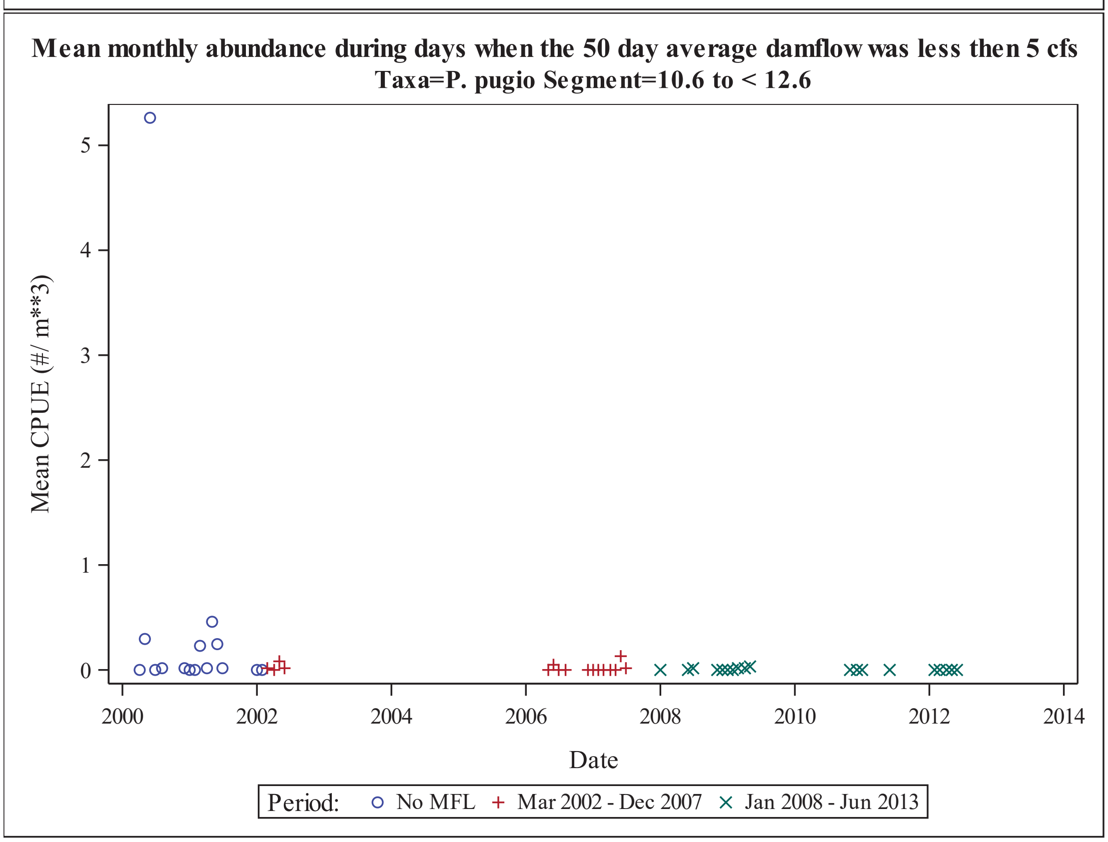
7. Oligochaetes



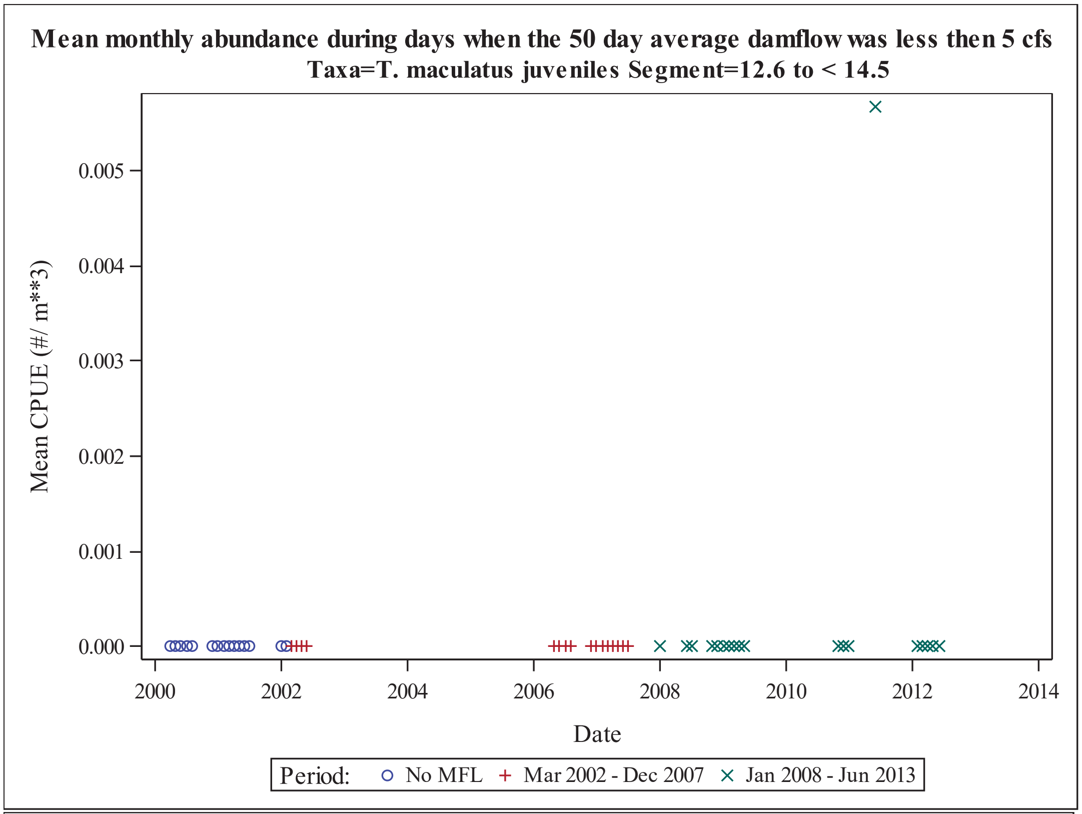



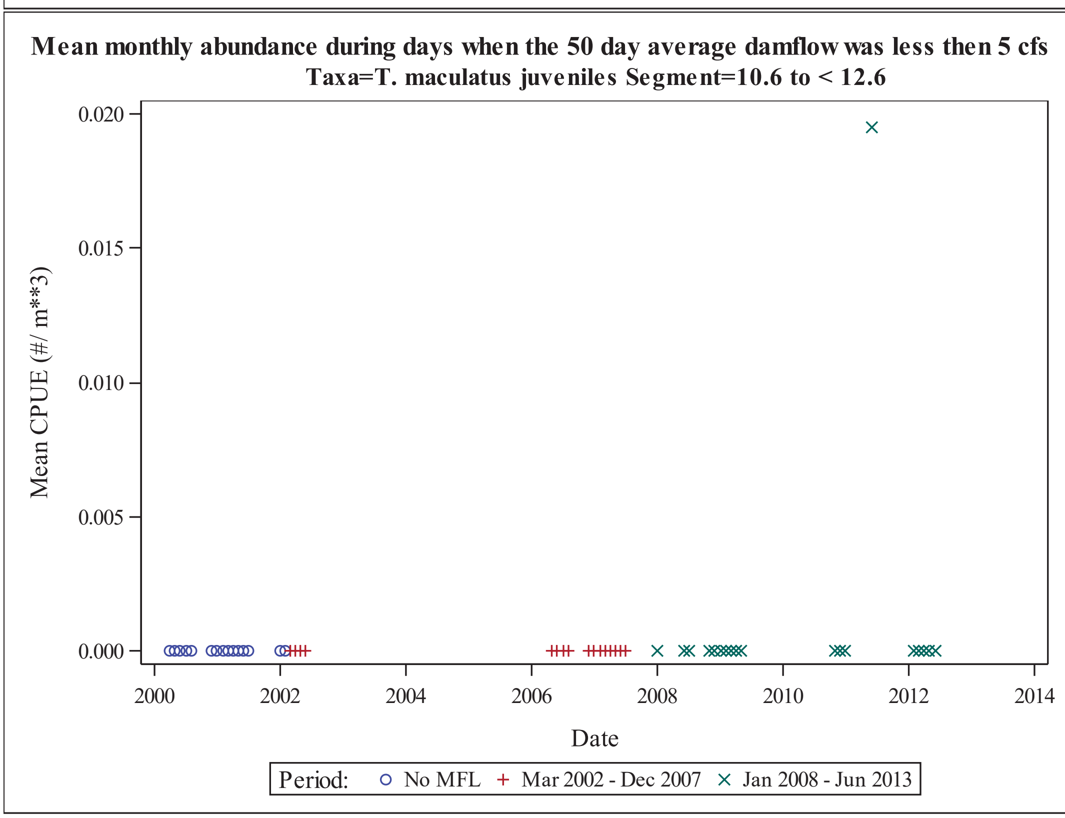
8. P. pugio


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=P. pugio Segment=12.6 to < 14.5
Mean CPUE (#/ m**3)
1.0
0.8
0.6
0.4
0.2
0.0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=P. pugio Segment=10.6 to < 12.6
Mean CPUE (#/ m**3)
5
4
3
2
1
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

9. T. maculatus Juveniles



7. Wilcoxon Rank Sum Test for A. almyra by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.644 | --- | |
| Jan 2008 - Jun 2013 | 0.822 | 0.755 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.463 | --- | |
| Jan 2008 - Jun 2013 | 0.75 | 0.248 | --- |

8. Wilcoxon Rank Sum Test for B. smithi by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.15 | --- | |
| Jan 2008 - Jun 2013 | 0.116 | 1 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.055 | --- | |
| Jan 2008 - Jun 2013 | 0.008 | 0.302 | --- |

9. Wilcoxon Rank Sum Test for Clytia spp. by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.005 | --- | |
| Jan 2008 - Jun 2013 | 0.037 | 0.507 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.022 | --- | |
| Jan 2008 - Jun 2013 | 0.037 | 0.884 | --- |

10. Wilcoxon Rank Sum Test for T. maculatus juveniles by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.407 | 0.39 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.407 | 0.39 | --- |

11. Wilcoxon Rank Sum Test for Ephemeropterans by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.366 | --- | |
| Jan 2008 - Jun 2013 | 1 | 0.302 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.407 | 0.39 | --- |

12. Wilcoxon Rank Sum Test for G. holbrooki juveniles by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.432 | --- | |
| Jan 2008 - Jun 2013 | 0.038 | 0.142 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.488 | --- | |
| Jan 2008 - Jun 2013 | 0.822 | 0.353 | --- |

## 13. Wilcoxon Rank Sum Test for P. pugio by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.002 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.056 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.069 | --- | |
| Jan 2008 - Jun 2013 | 0.0004 | 0.642 | --- |

## 14. Wilcoxon Rank Sum Test for Oligochaetes by River Kilometer Segment

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.09 | --- | |
| Jan 2008 - Jun 2013 | 0.407 | 0.268 | --- |

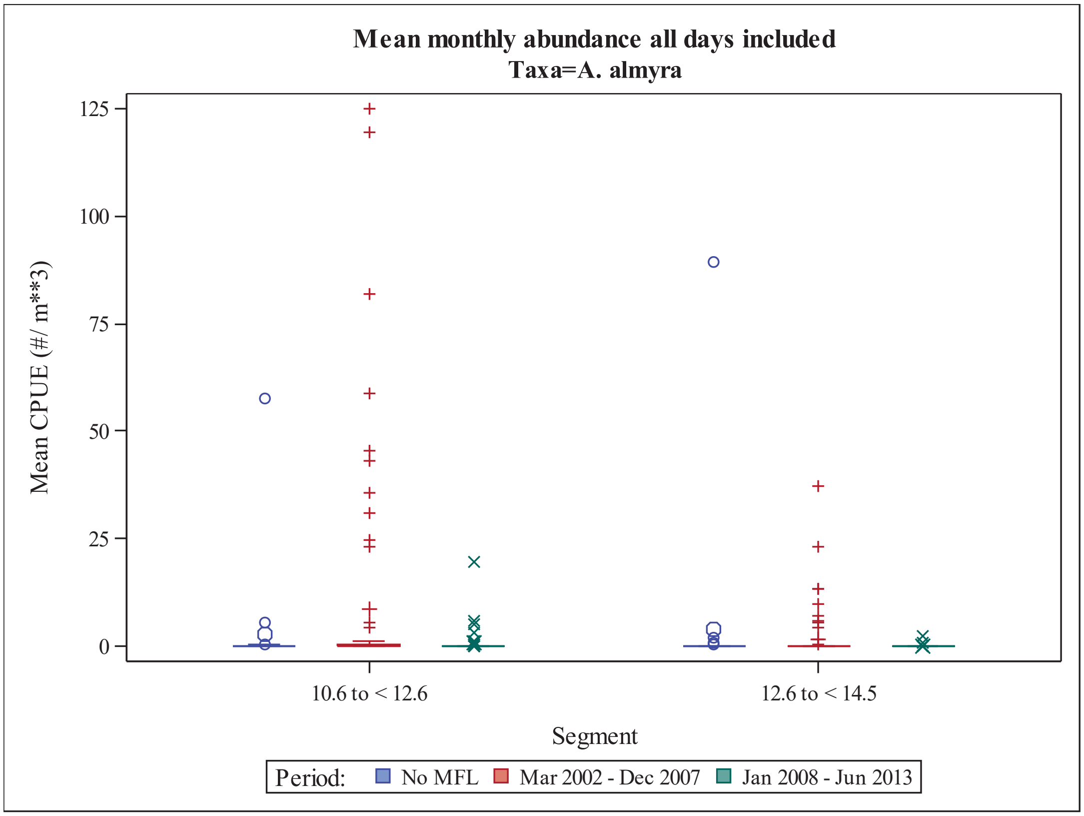
| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.366 | --- | |
| Jan 2008 - Jun 2013 | 0.218 | 0.633 | --- |

## 15. Wilcoxon Rank Sum Test for Nemopsis spp. by River Kilometer Segment

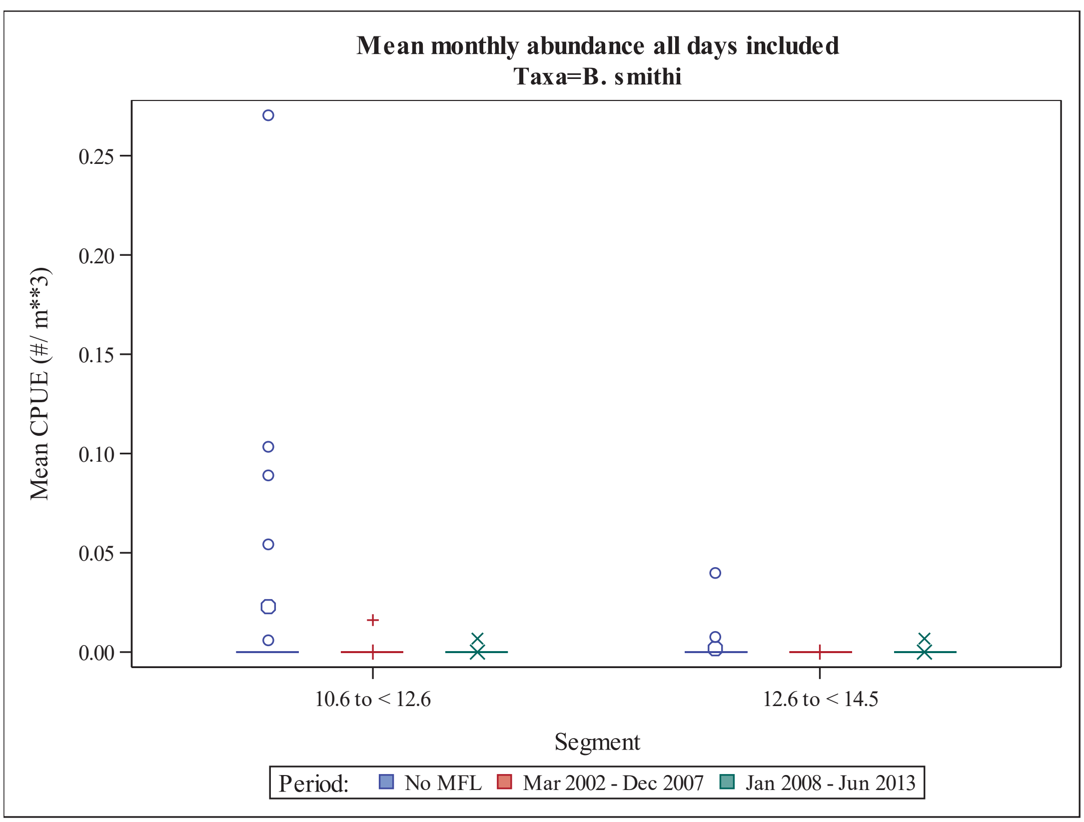
| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.015 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.056 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.005 | --- | |
| Jan 2008 - Jun 2013 | 0.0001 | 0.025 | --- |

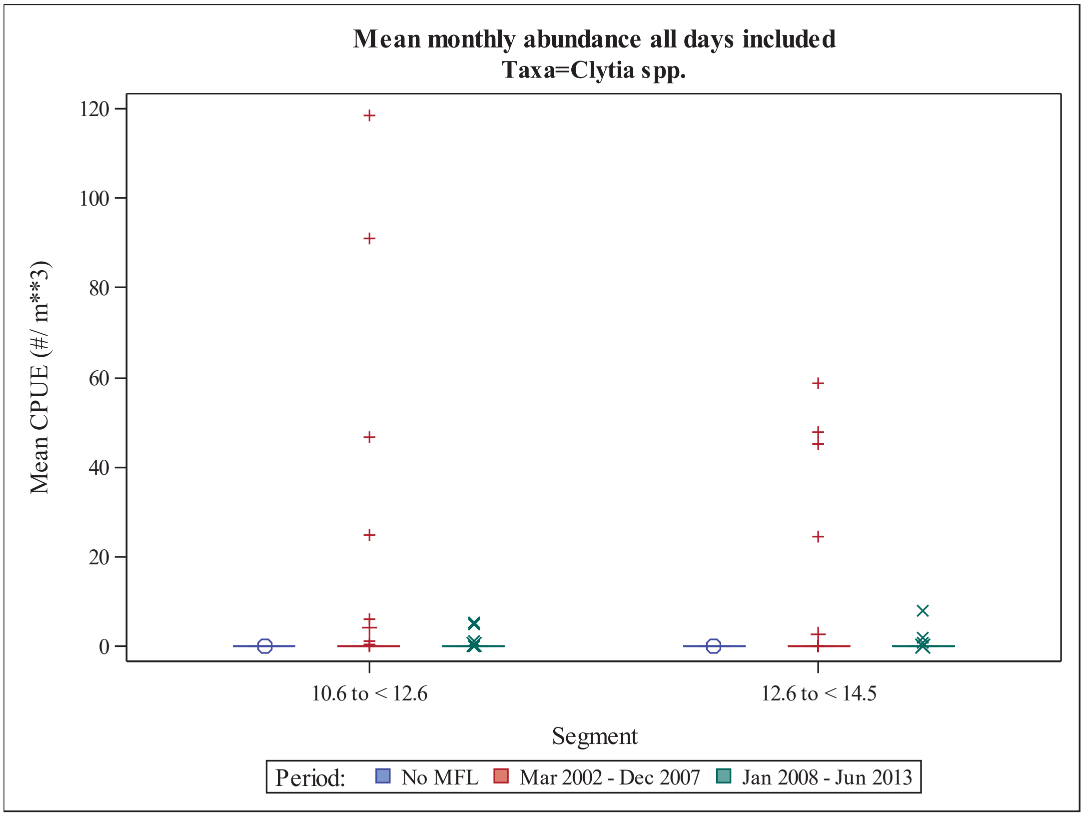
1. A. almyra



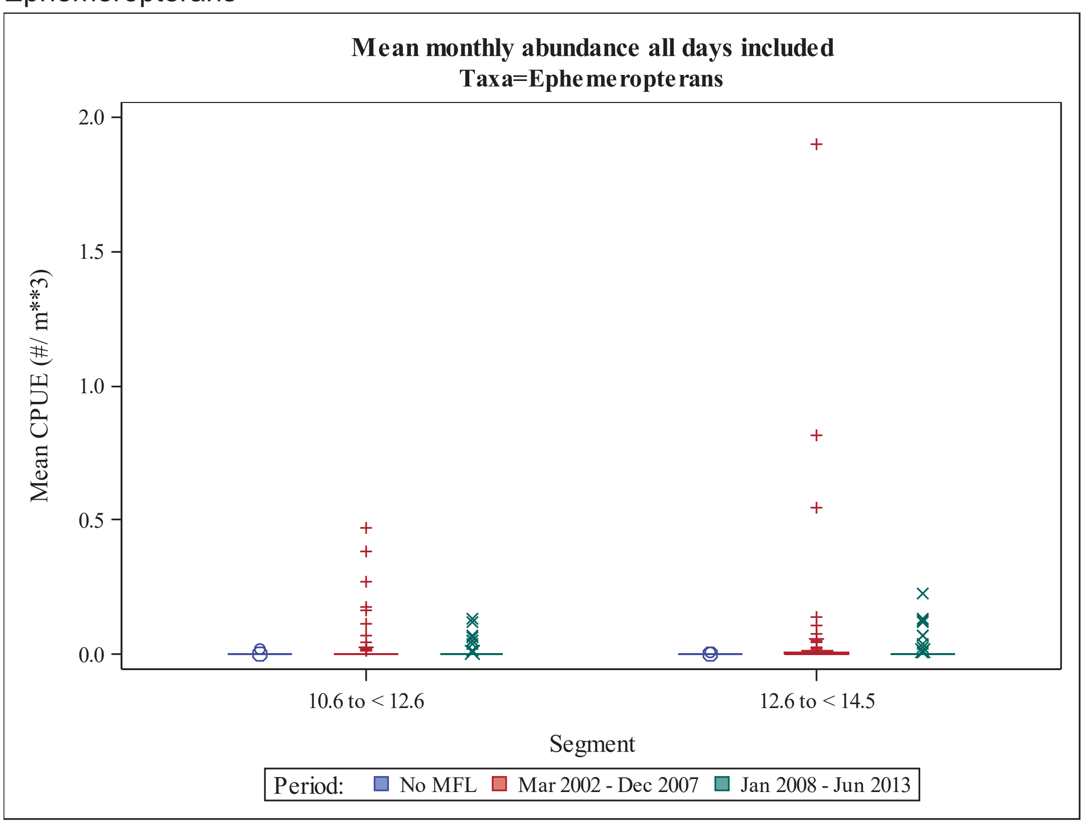

2. B. smithi



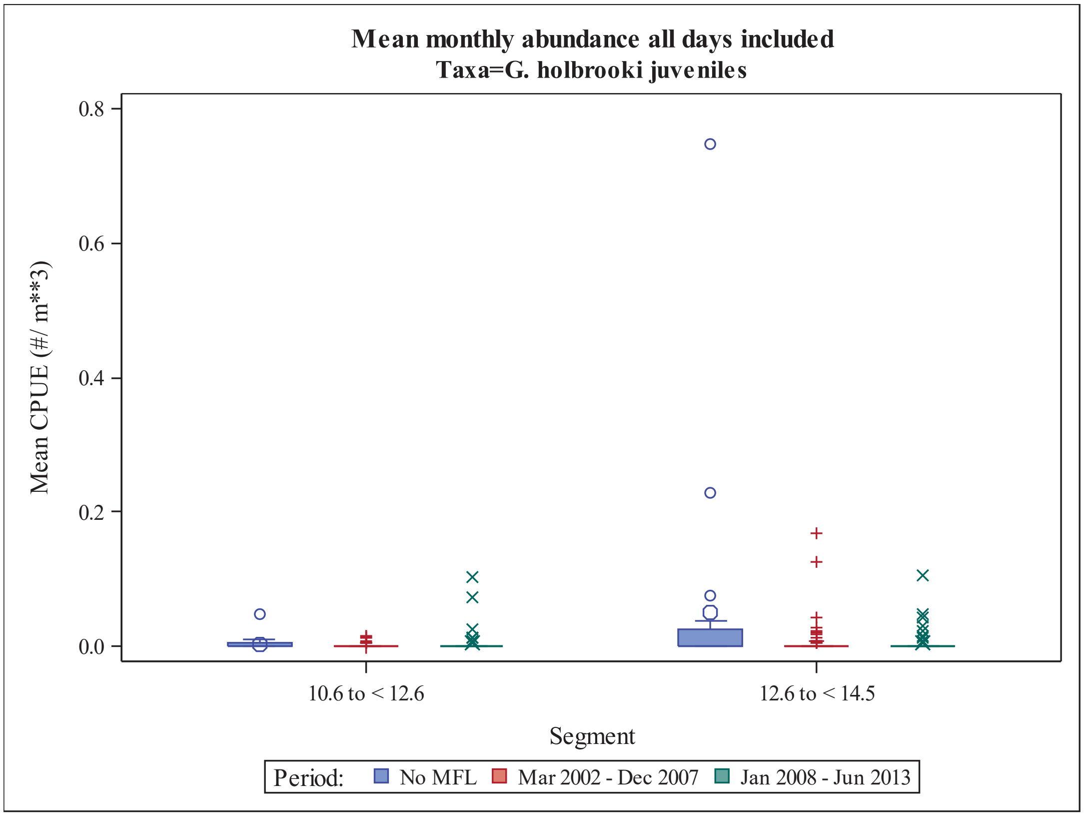
3. Clytia spp.



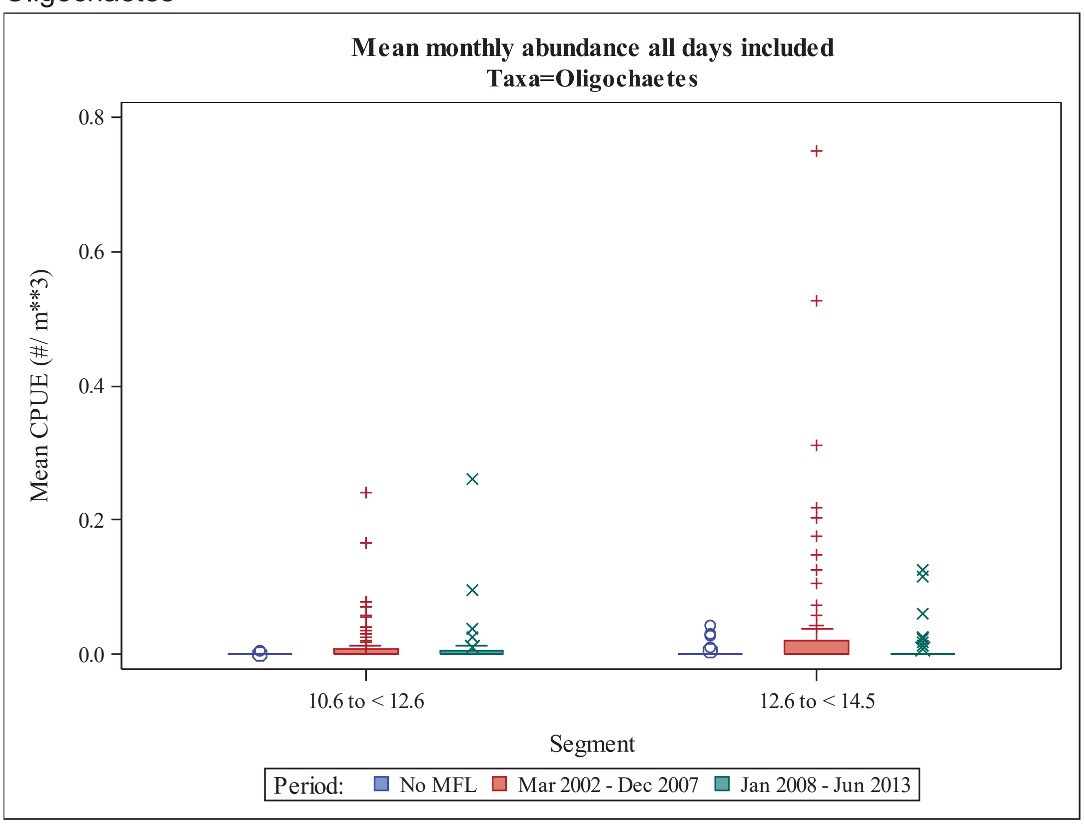

4. Ephemeropterans



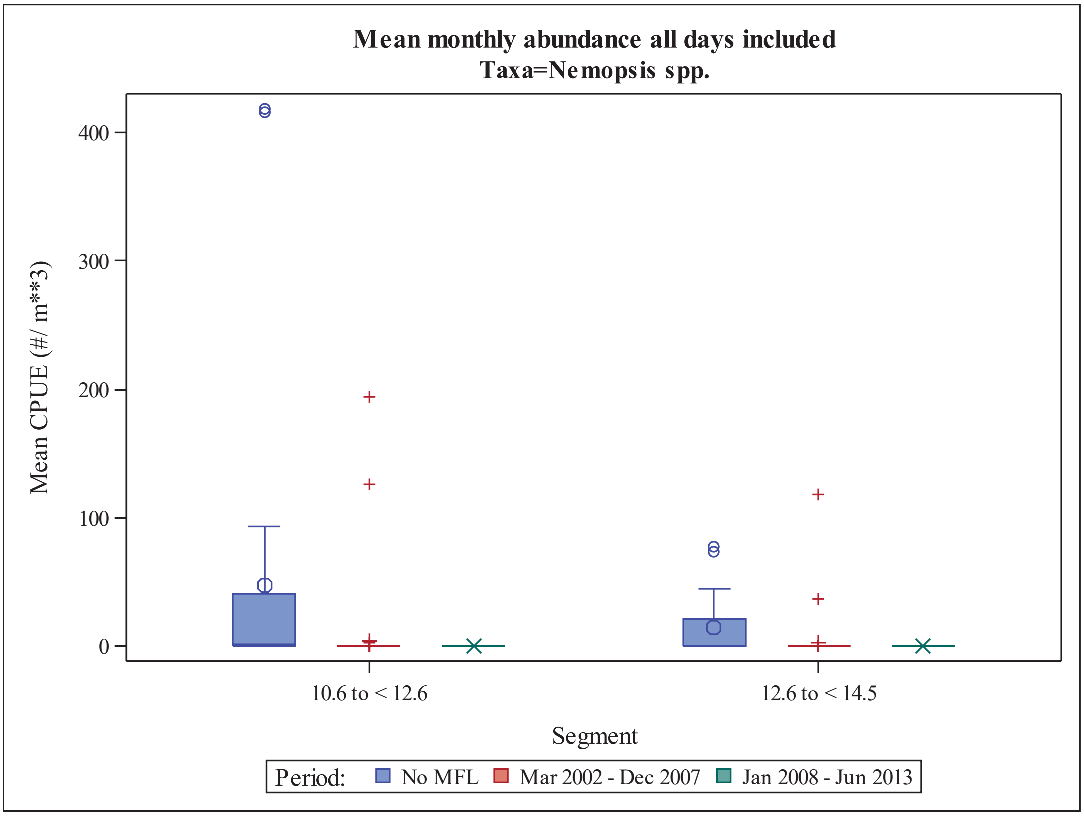
5. G. holbrooki Juveniles



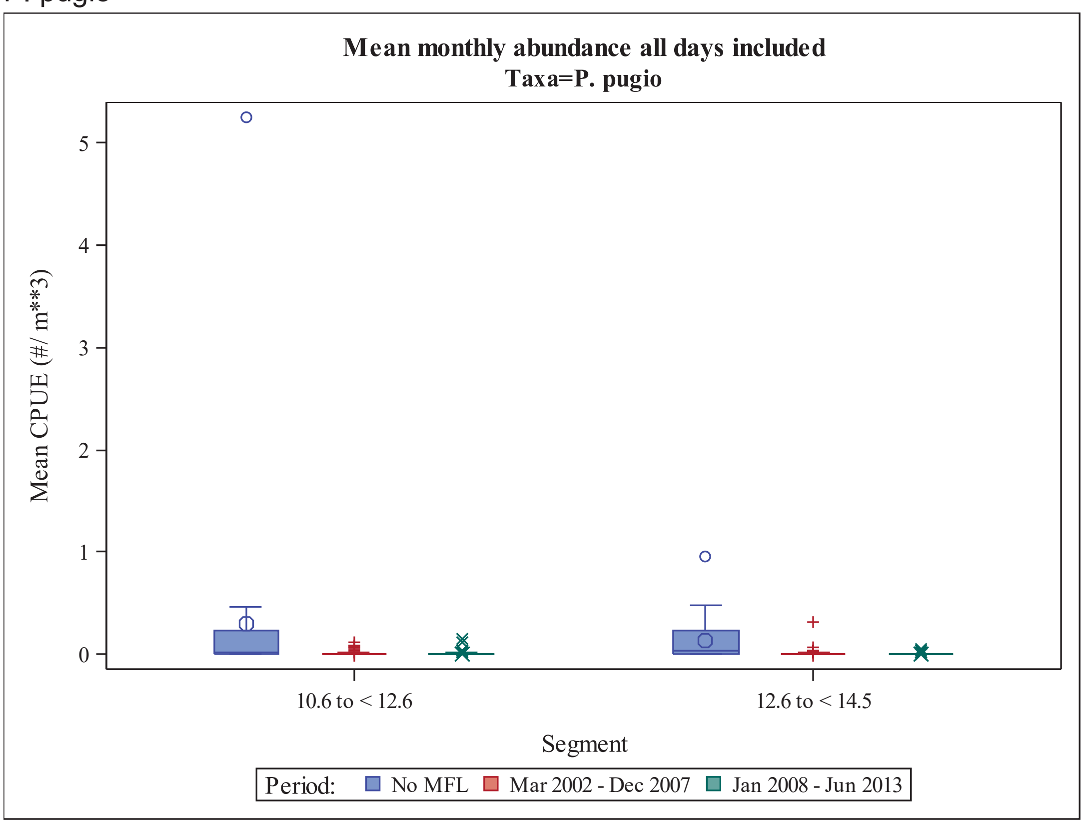

6. Oligochaetes



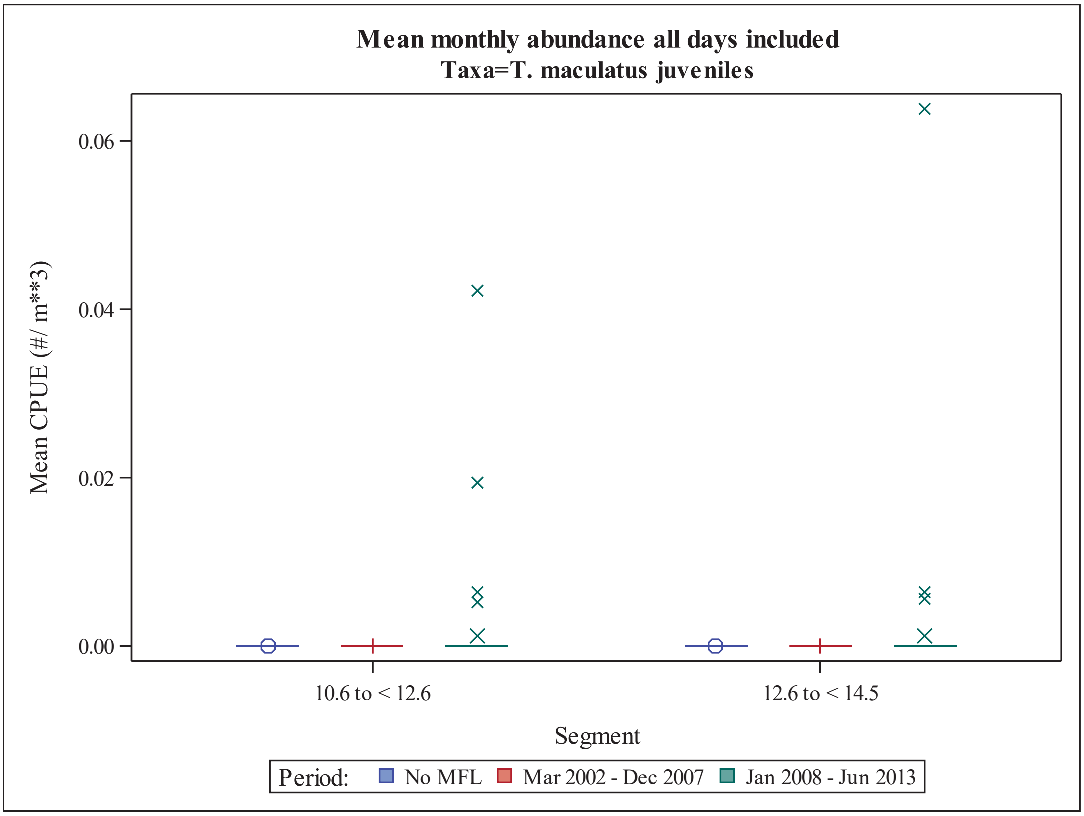
7. Nemopsis spp.



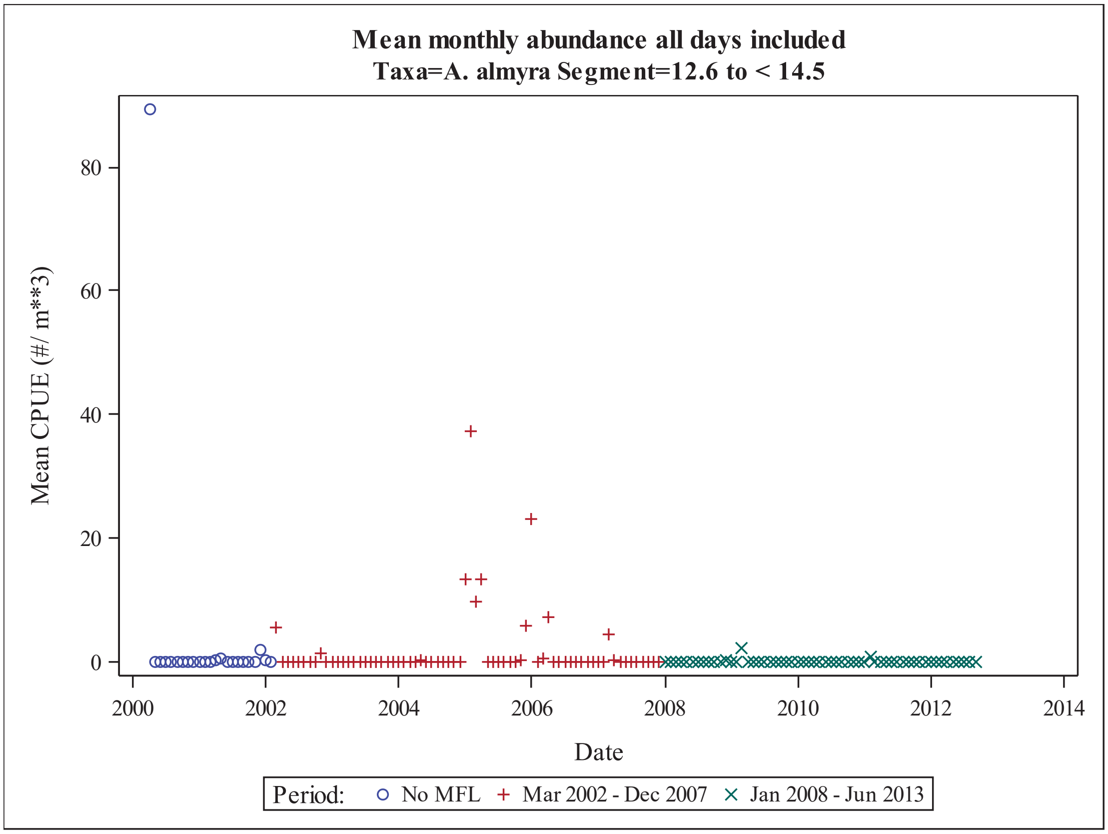

8. P. pugio



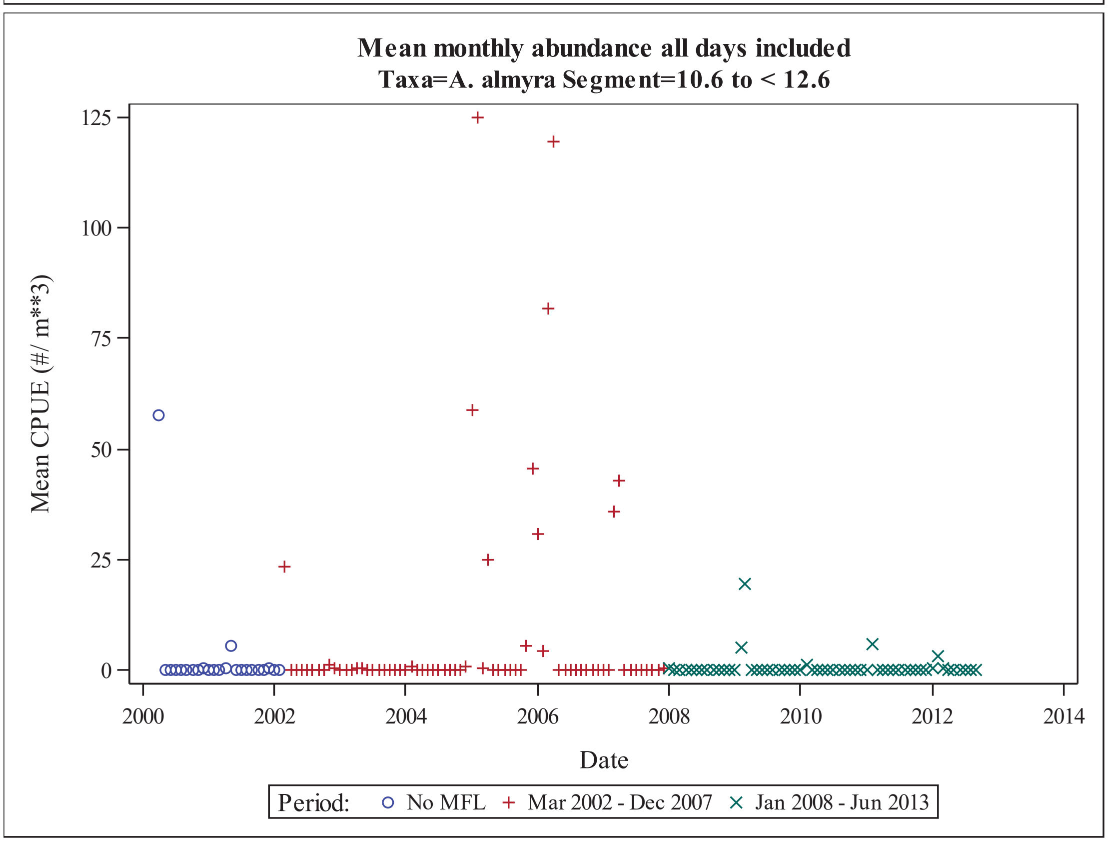
9. T. maculatus Juveniles



7. A. almyra

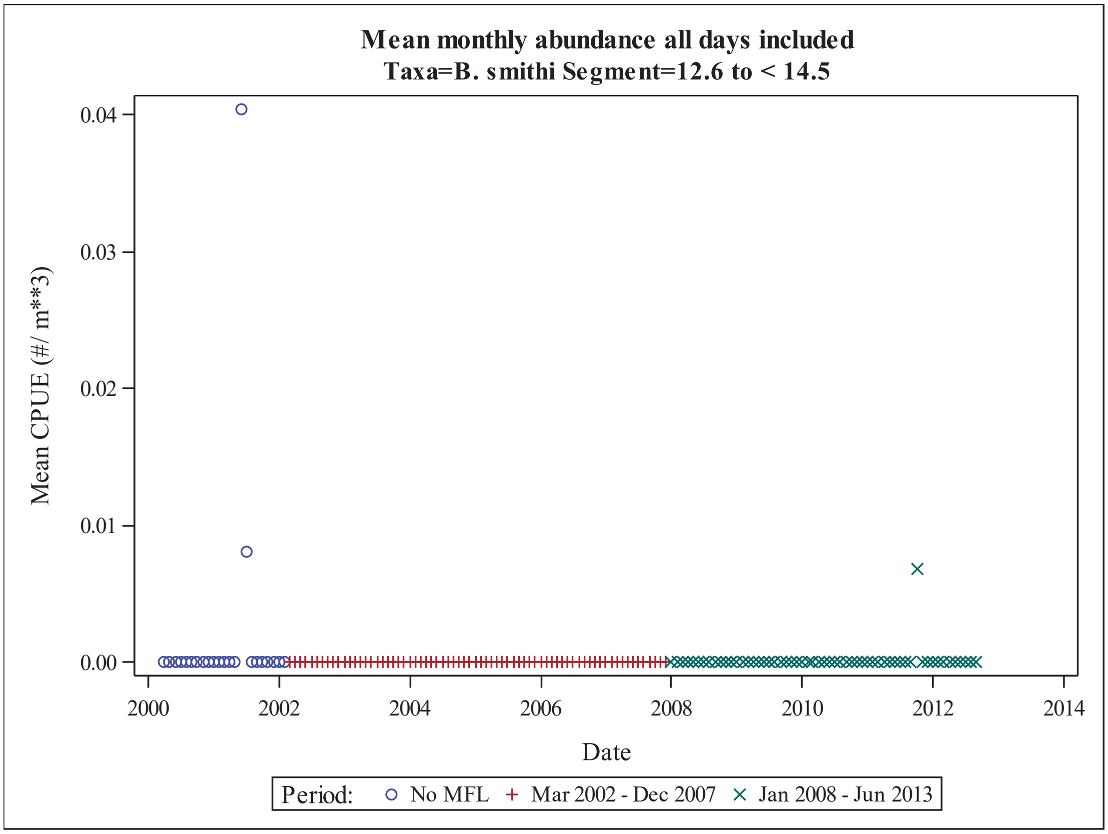


Mean monthly abundance all days included
Taxa=A. almyra Segment=12.6 to < 14.5
Mean CPUE (#/ m**3)
0
20
40
60
80
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

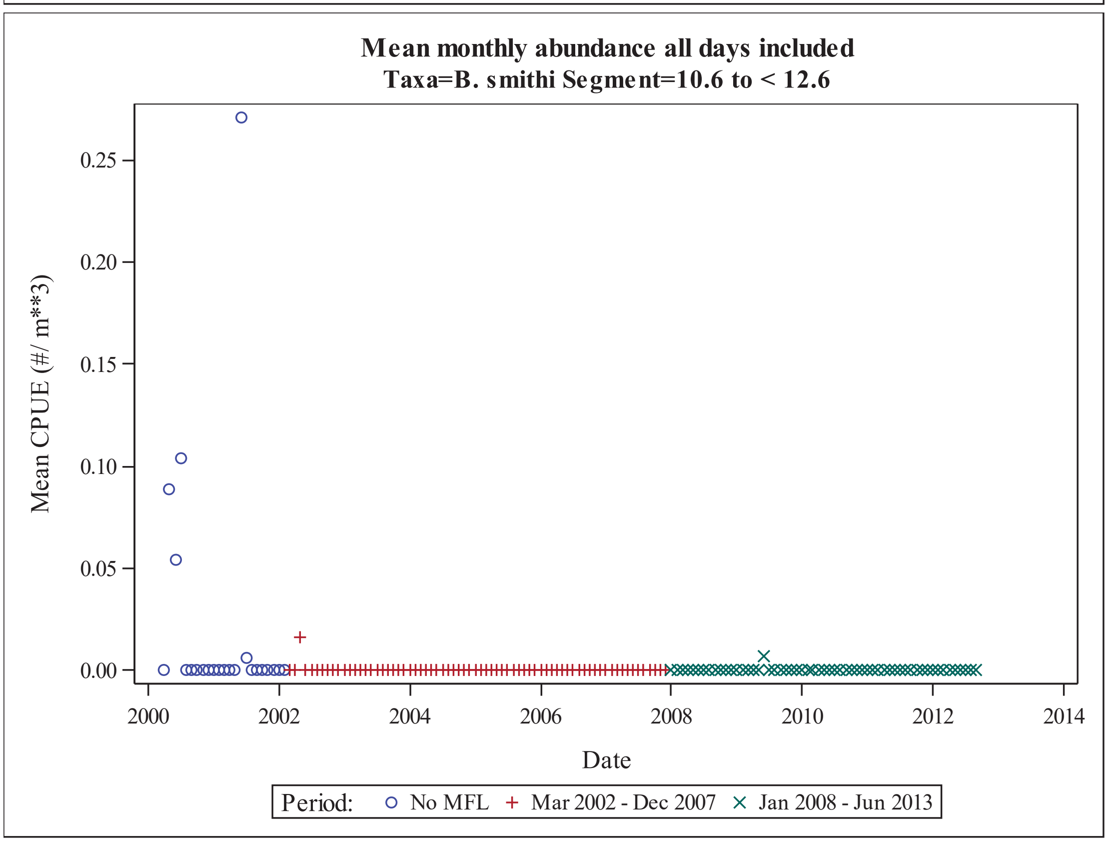



Mean monthly abundance all days included
Taxa=A. almyra Segment=10.6 to < 12.6
Mean CPUE (#/ m**3)
0
25
50
75
100
125
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

8. B. smithi

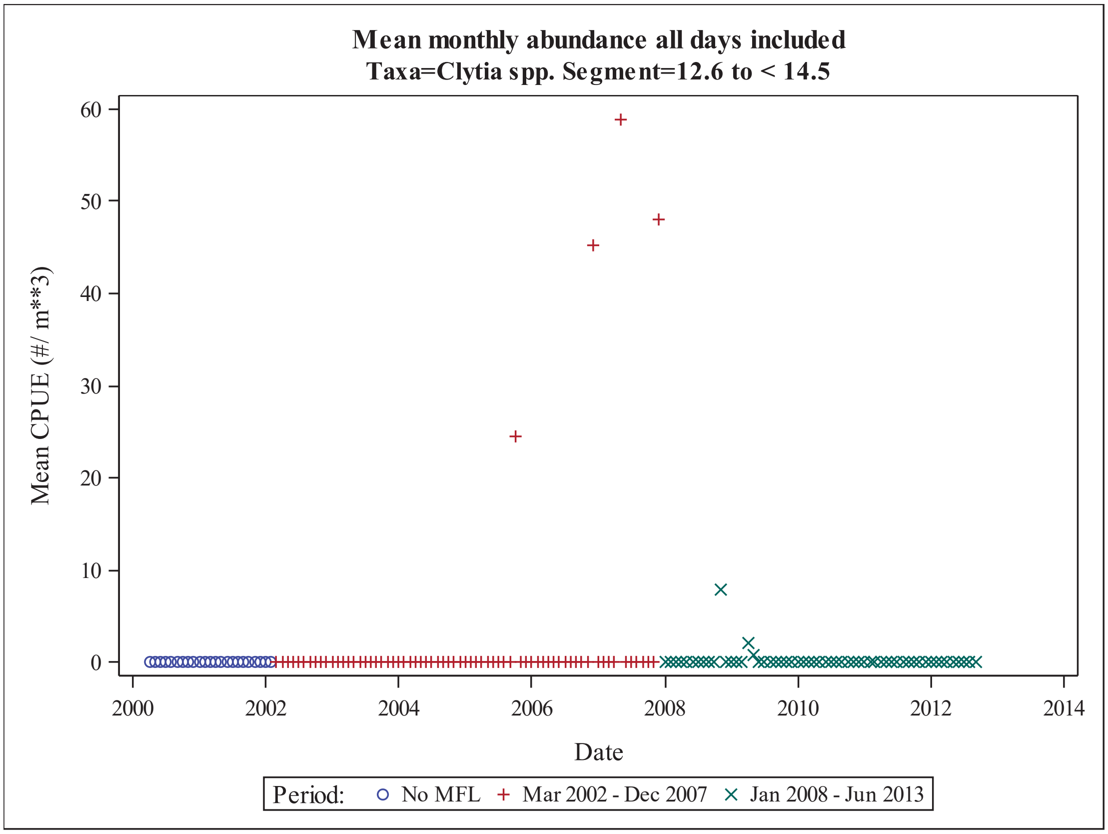


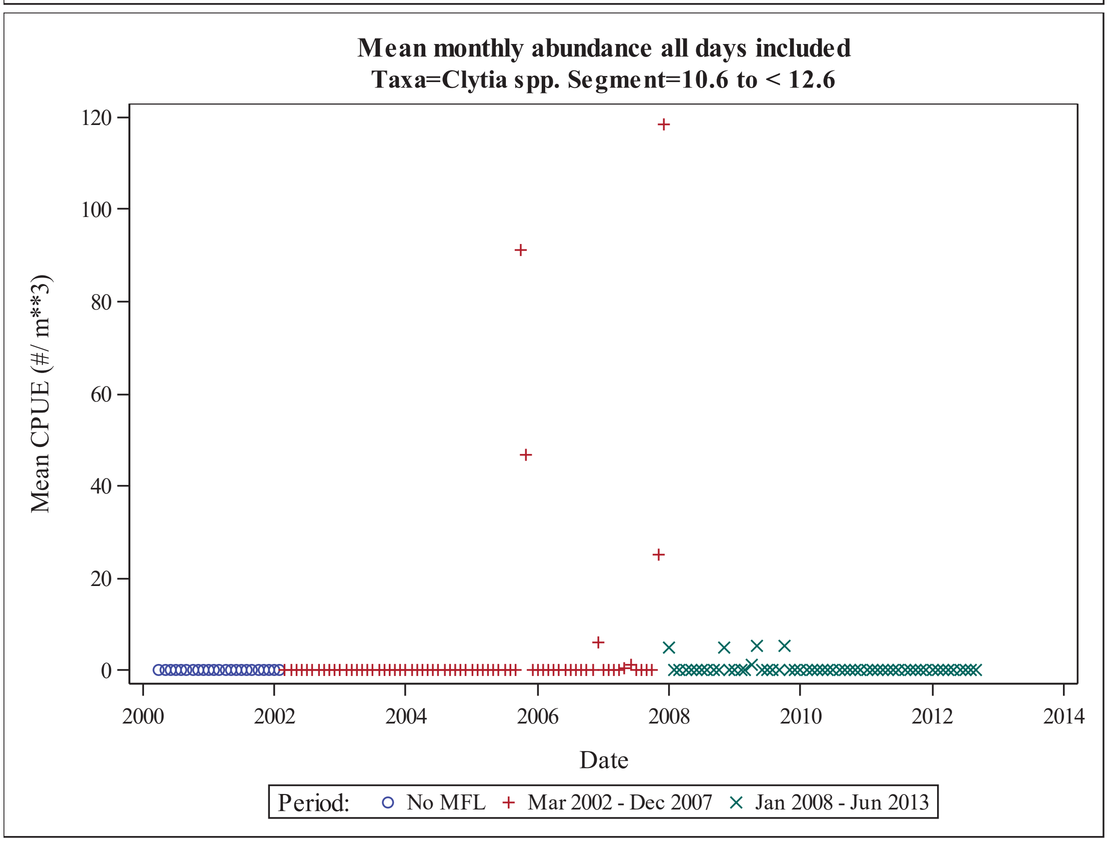
Mean monthly abundance all days included
Taxa=B. smithi Segment=12.6 to < 14.5
Mean CPUE (#/ m**3)
0.00
0.01
0.02
0.03
0.04
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

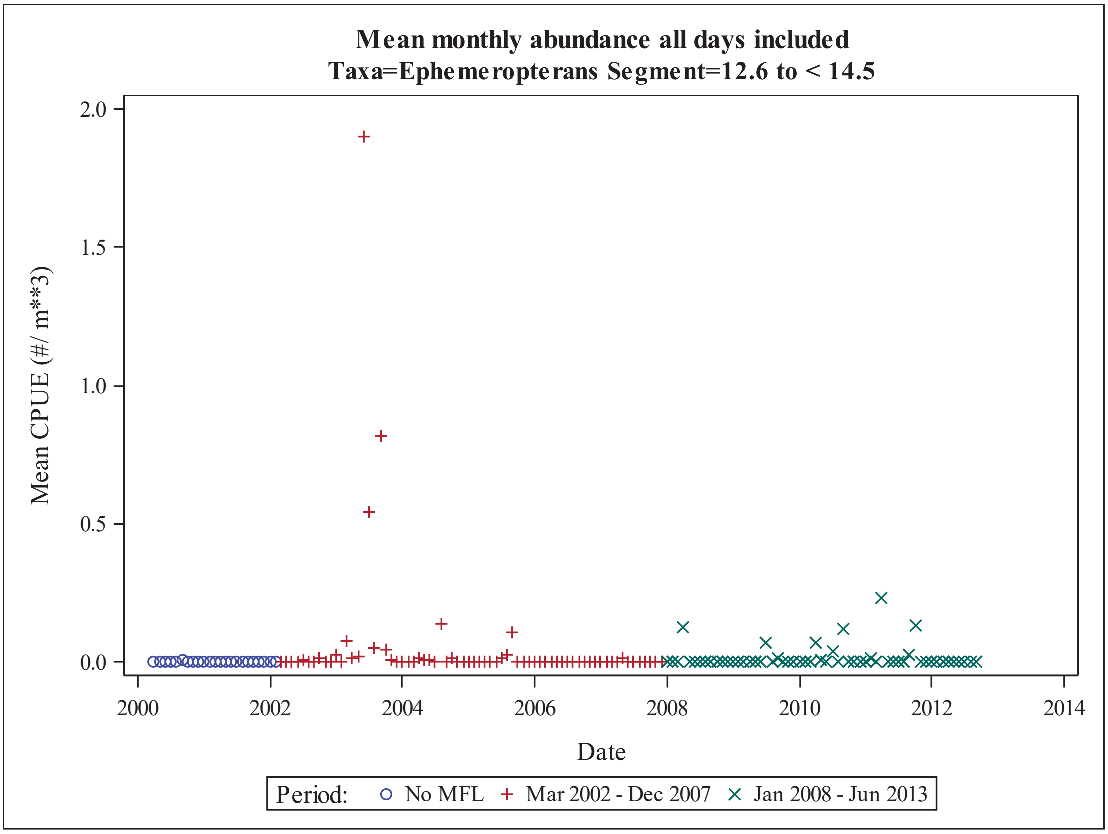
Mean monthly abundance all days included
Taxa=B. smithi Segment=10.6 to < 12.6
Mean CPUE (#/ m**3)
0.00
0.05
0.10
0.15
0.20
0.25
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

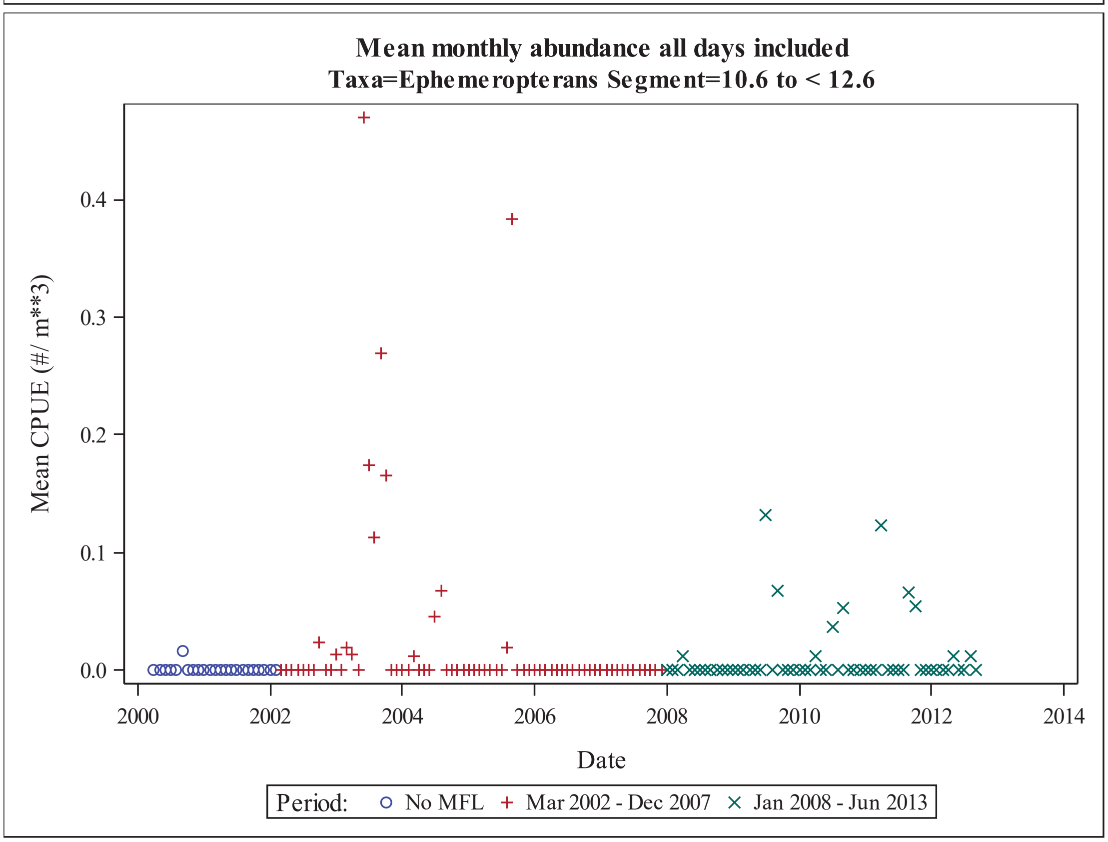
9. Clytia spp.


Mean monthly abundance all days included
Taxa=Clytia spp. Segment=12.6 to < 14.5
Mean CPUE (#/ m**3)
0
10
20
30
40
50
60
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

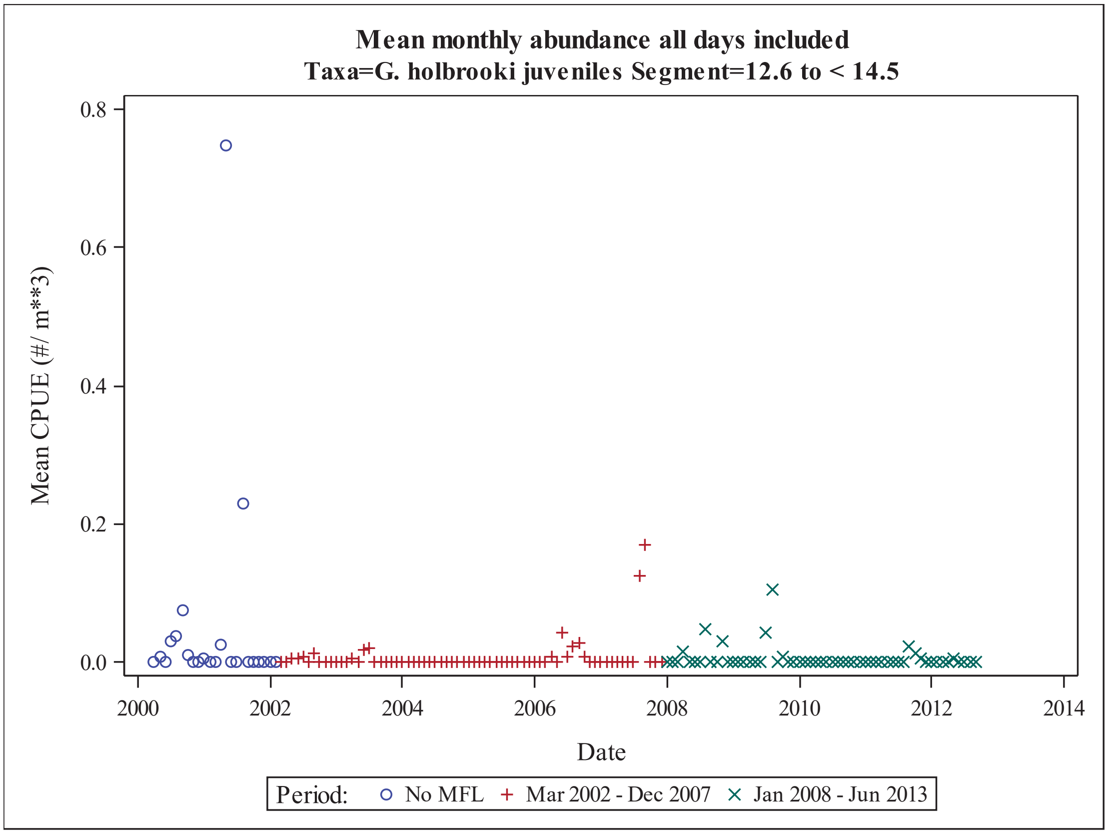

Mean monthly abundance all days included
Taxa=Clytia spp. Segment=10.6 to < 12.6
Mean CPUE (#/ m**3)
0
20
40
60
80
100
120
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

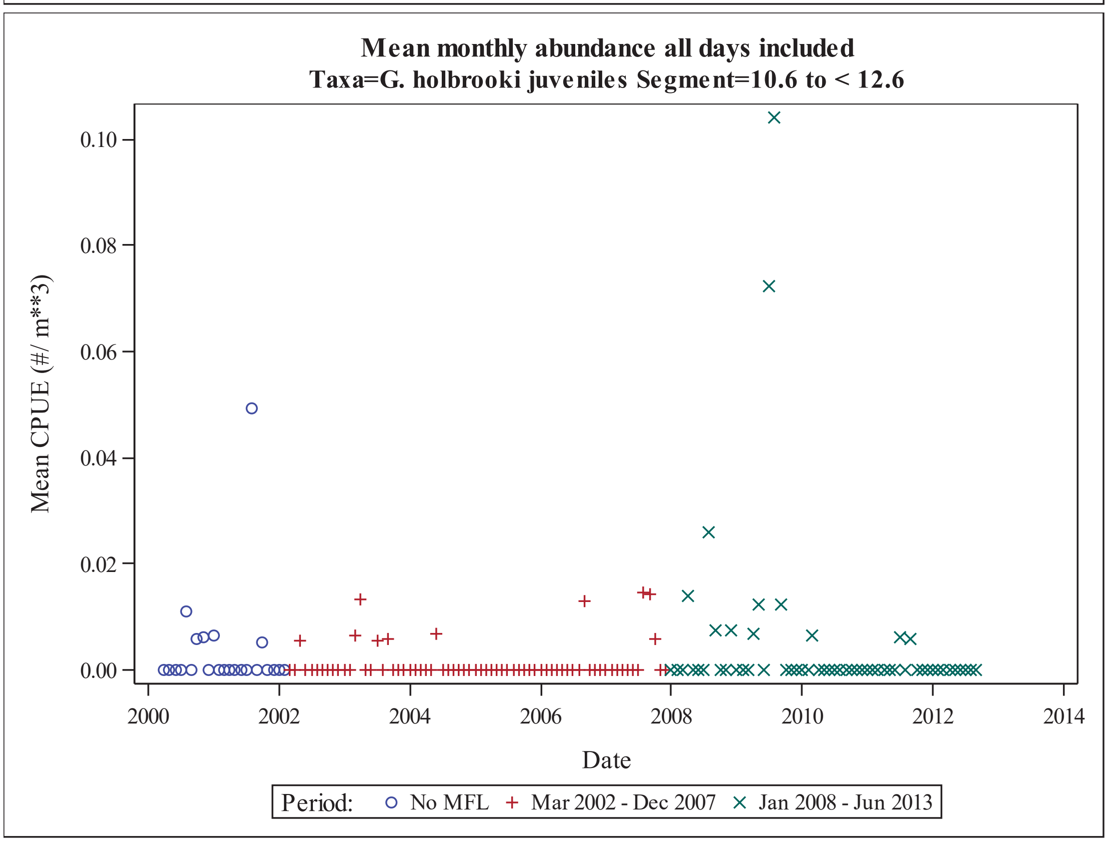
10. Ephemeropterans



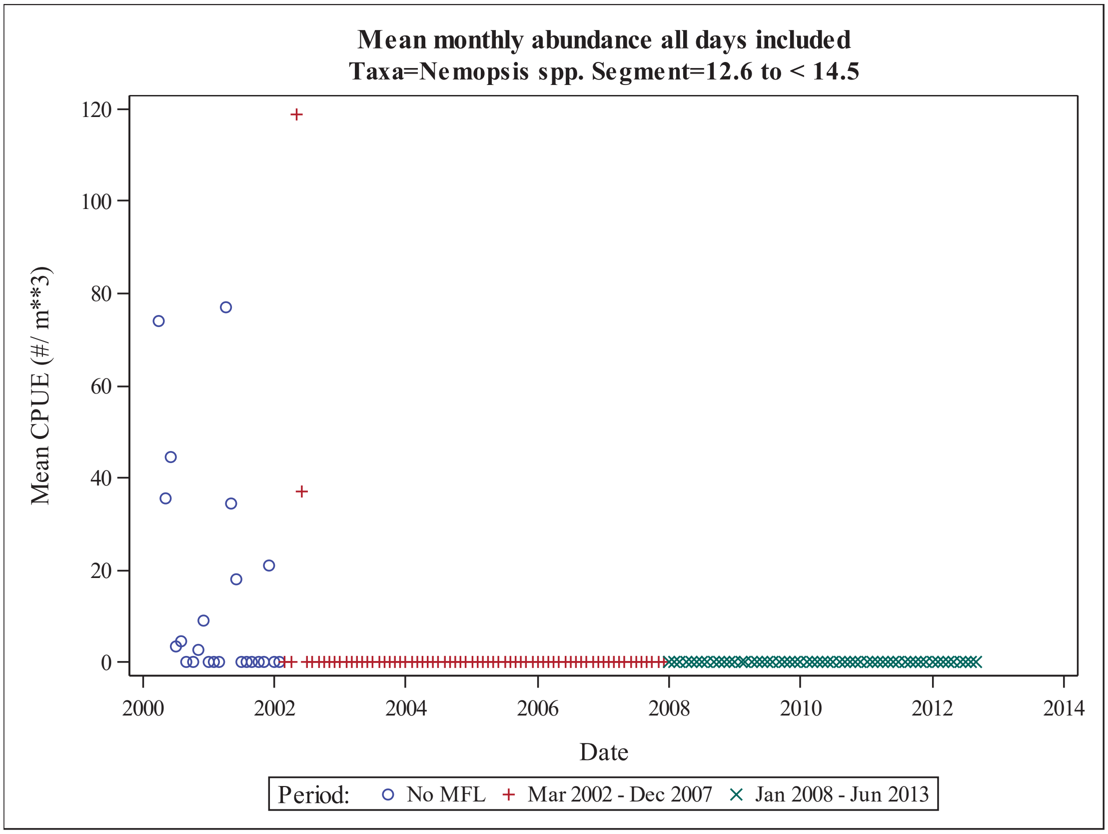



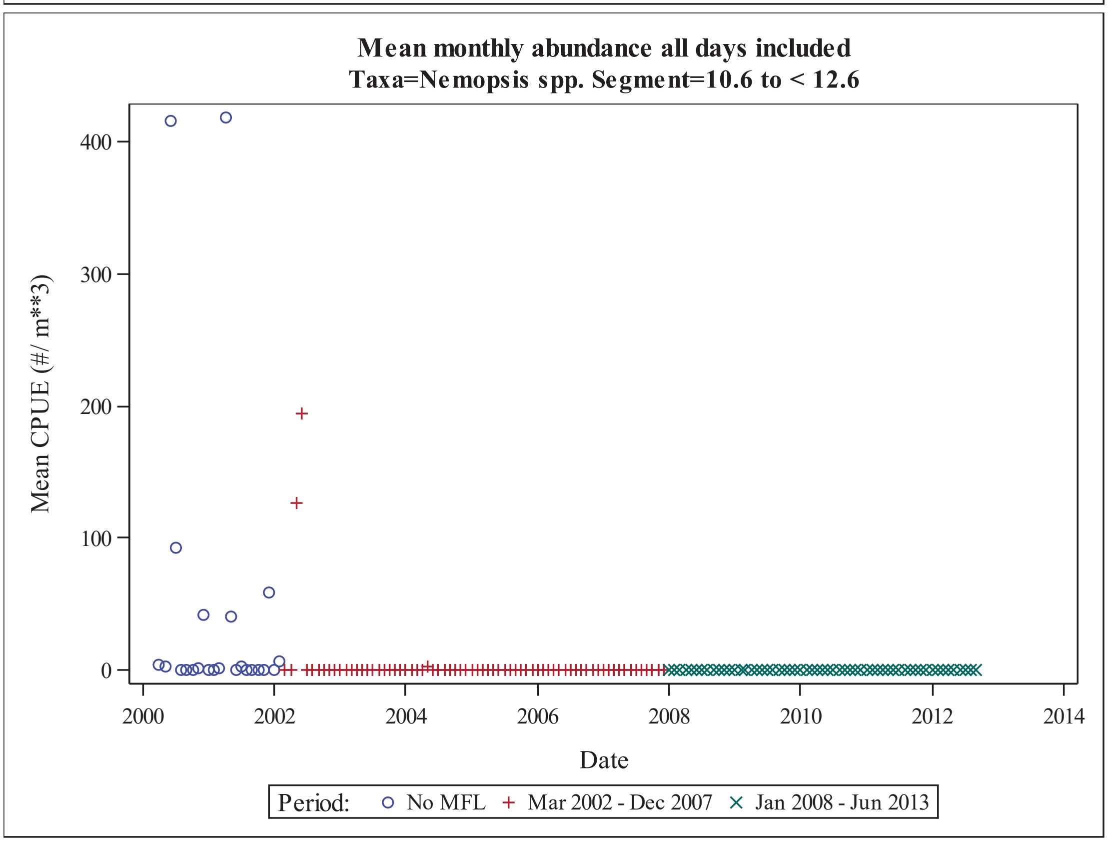
11. G. holbrooki Juveniles



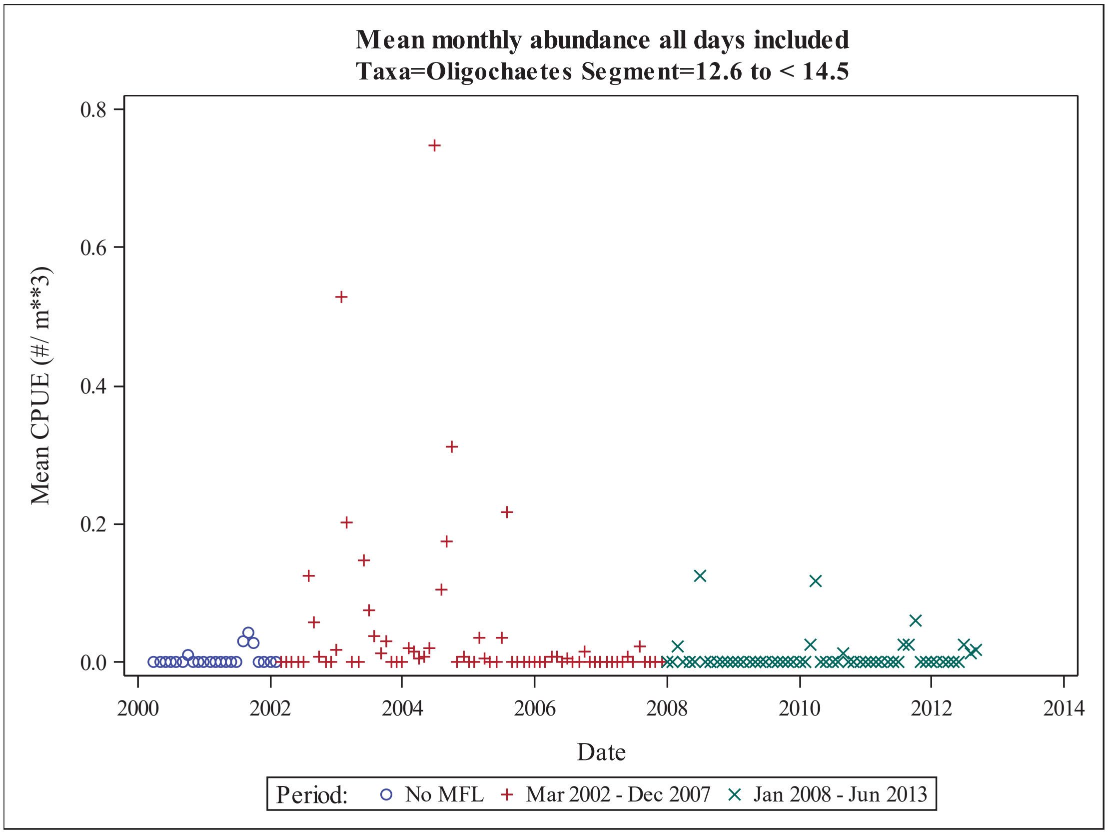



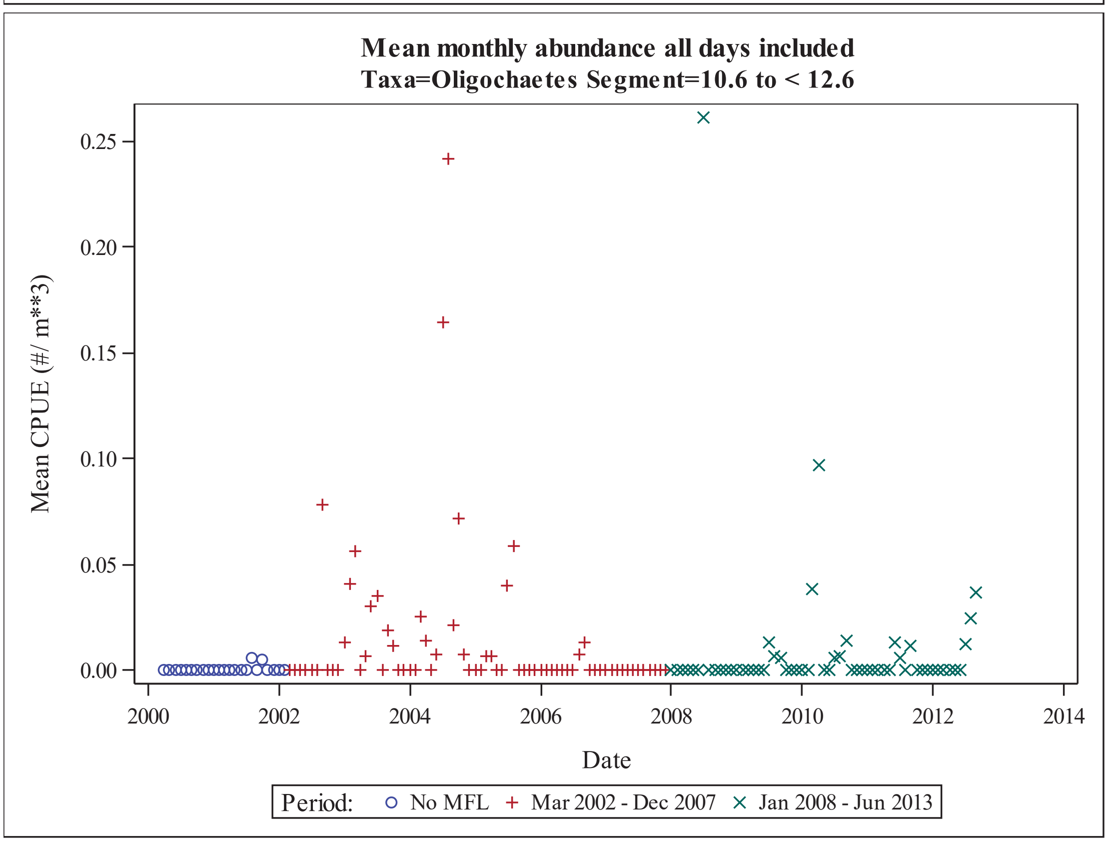
12. Nemopsis spp.



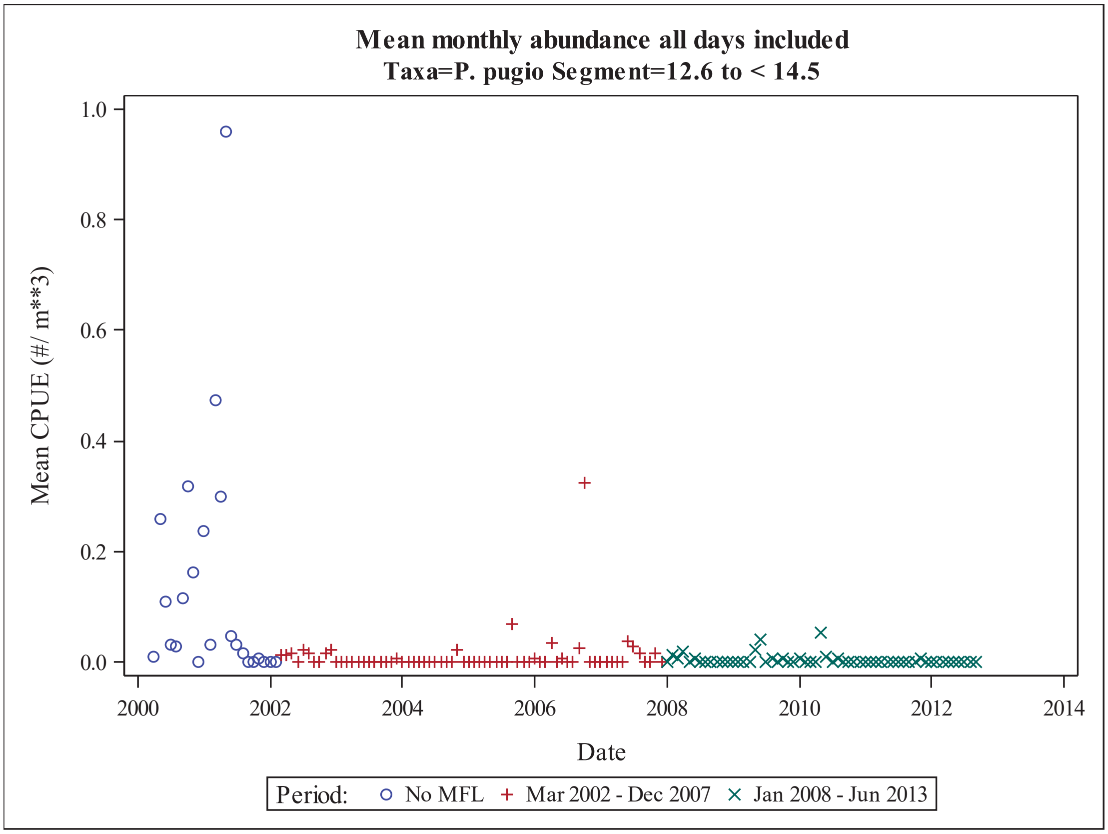



13. Oligochaetes

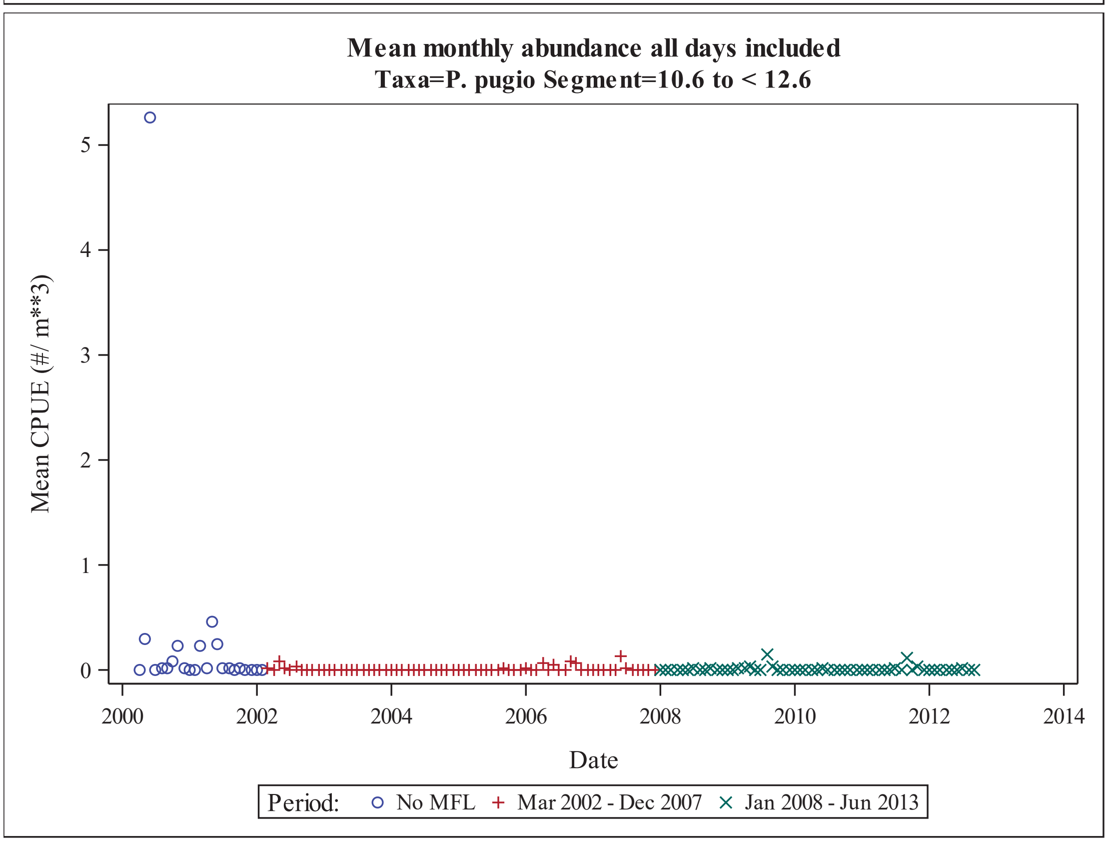


14. P. pugio

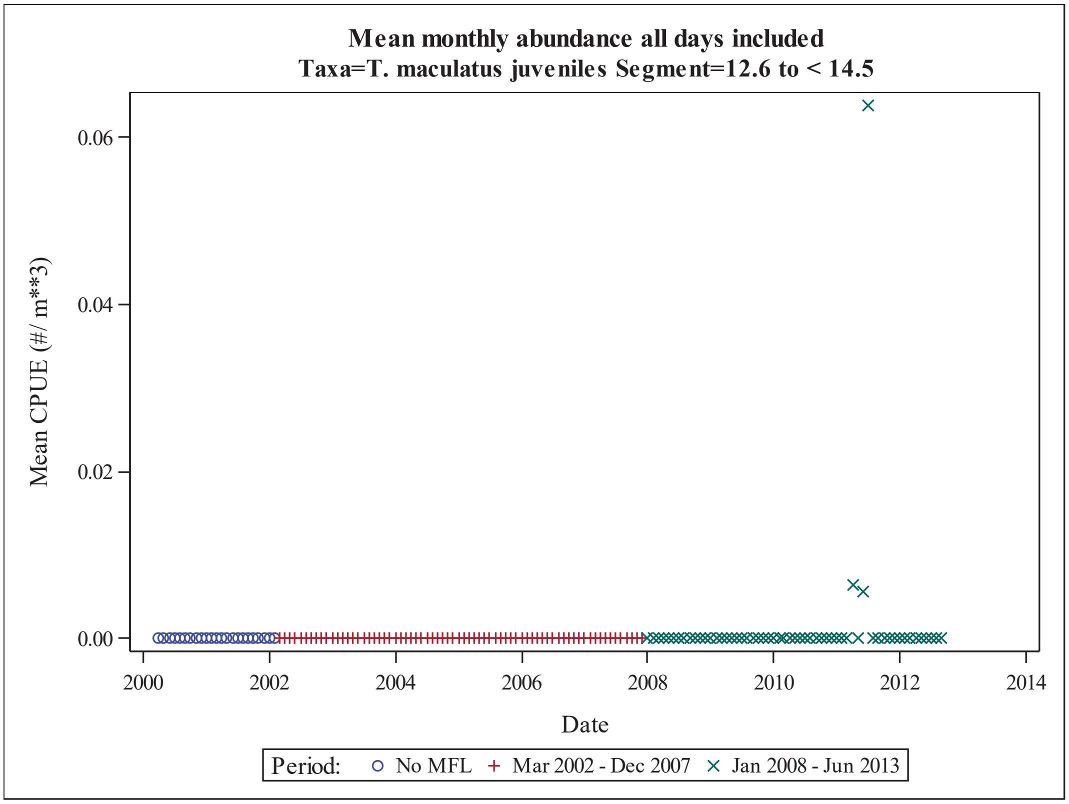


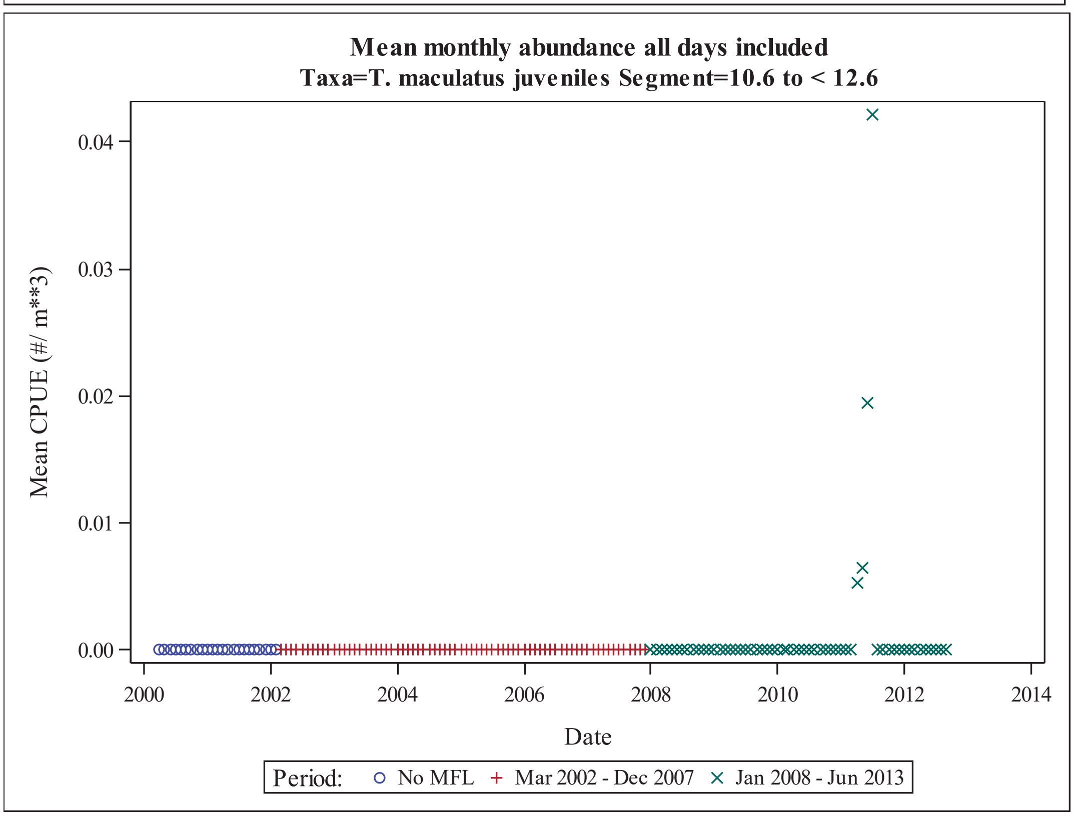
Mean monthly abundance all days included
Taxa=P. pugio Segment=12.6 to < 14.5
Mean CPUE (#/ m**3)
1.0
0.8
0.6
0.4
0.2
0.0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

Mean monthly abundance all days included
Taxa=P. pugio Segment=10.6 to < 12.6
Mean CPUE (#/ m**3)
5
4
3
2
1
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

15. T. maculatus Juveniles



| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minim um CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Brevoortia spp. | 10.6 to < 12.6 | No MFL | 37.8 | 140.9 | 16 | 566.1 | 0.0 | 0 | 37.5 |
| Brevoortia spp. | 10.6 to < 12.6 | Mar 02 - Dec 07 | 12.5 | 36.6 | 16 | 140.4 | 0.0 | 0 | 18.8 |
| Brevoortia spp. | 10.6 to < 12.6 | Jan 08 - Jun 12 | 10.7 | 38.5 | 20 | 169.7 | 0.0 | 0 | 20 |
| Brevoortia spp. | 12.6 to < 14.5 | No MFL | 1072.7 | 3529.7 | 12 | 12272.6 | 5.4 | 0 | 50 |
| Brevoortia spp. | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.0 | 0.0 | 14 | 0.0 | 0.0 | 0 | 0 |
| Brevoortia spp. | 12.6 to < 14.5 | Jan 08 - Jun 12 | 1.9 | 7.4 | 17 | 30.6 | 0.0 | 0 | 11.8 |
| Brevoortia spp. | > 14.5 | No MFL | 10.4 | 23.0 | 10 | 71.4 | 0.0 | 0 | 30 |
| Brevoortia spp. | > 14.5 | Mar 02 - Dec 07 | 0.0 | 0.0 | 11 | 0.0 | 0.0 | 0 | 0 |
| Brevoortia spp. | > 14.5 | Jan 08 - Jun 12 | 0.0 | 0.2 | 15 | 0.7 | 0.0 | 0 | 6.7 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Centropomus undecimalis | 10.6 to < 12.6 | No MFL | 0.1 | 0.5 | 16 | 2.0 | 0.0 | 0 | 6.3 |
| Centropomus undecimalis | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.0 | 0.1 | 16 | 0.3 | 0.0 | 0 | 6.3 |
| Centropomus undecimalis | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.1 | 0.4 | 20 | 1.7 | 0.0 | 0 | 10 |
| Centropomus undecimalis | 12.6 to < 14.5 | No MFL | 0.0 | 0.0 | 12 | 0.0 | 0.0 | 0 | 0 |
| Centropomus undecimalis | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.0 | 0.1 | 14 | 0.3 | 0.0 | 0 | 7.1 |
| Centropomus undecimalis | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.0 | 0.1 | 17 | 0.3 | 0.0 | 0 | 11.8 |
| Centropomus undecimalis | > 14.5 | No MFL | 0.0 | 0.0 | 10 | 0.0 | 0.0 | 0 | 0 |
| Centropomus undecimalis | > 14.5 | Mar 02 - Dec 07 | 0.0 | 0.0 | 11 | 0.0 | 0.0 | 0 | 0 |
| Centropomus undecimalis | > 14.5 | Jan 08 - Jun 12 | 0.0 | 0.0 | 15 | 0.0 | 0.0 | 0 | 0 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Cyprinodon variegatus | 10.6 to < 12.6 | No MFL | 10.64625 | 27.27857349 | 16 | 110.16 | 2.04 | 0 | 81.3 |
| Cyprinodon variegatus | 10.6 to < 12.6 | Mar 02 - Dec 07 | 13.06875 | 21.17701266 | 16 | 73.1 | 4.25 | 0 | 75 |
| Cyprinodon variegatus | 10.6 to < 12.6 | Jan 08 - Jun 12 | 4.046 | 5.806675288 | 20 | 19.04 | 0.85 | 0 | 60 |
| Cyprinodon variegatus | 12.6 to < 14.5 | No MFL | 0.311666667 | 0.588153247 | 12 | 2.04 | 0 | 0 | 41.7 |
| Cyprinodon variegatus | 12.6 to < 14.5 | Mar 02 - Dec 07 | 7.884761905 | 15.51764156 | 14 | 54.4 | 1.36 | 0 | 64.3 |
| Cyprinodon variegatus | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.98 | 1.741493612 | 17 | 6.8 | 0 | 0 | 41.2 |
| Cyprinodon variegatus | > 14.5 | No MFL | 0.442 | 0.642111101 | 10 | 1.7 | 0 | 0 | 40 |
| Cyprinodon variegatus | > 14.5 | Mar 02 - Dec 07 | 10.84909091 | 21.40836914 | 11 | 66.64 | 1.36 | 0 | 72.7 |
| Cyprinodon variegatus | > 14.5 | Jan 08 - Jun 12 | 0.34 | 1.051882666 | 15 | 4.08 | 0 | 0 | 20 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximu m CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Fundulus seminolis | 10.6 to < 12.6 | No MFL | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0 |
| Fundulus seminolis | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.0 | 0.1 | 16 | 0.3 | 0.0 | 0 | 6.3 |
| Fundulus seminolis | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.5 | 1.2 | 20 | 4.1 | 0.0 | 0 | 25 |
| Fundulus seminolis | 12.6 to < 14.5 | No MFL | 0.1 | 0.3 | 12 | 1.0 | 0.0 | 0 | 8.3 |
| Fundulus seminolis | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.8 | 2.5 | 14 | 9.5 | 0.0 | 0 | 21.4 |
| Fundulus seminolis | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.2 | 0.6 | 17 | 2.5 | 0.0 | 0 | 23.5 |
| Fundulus seminolis | > 14.5 | No MFL | 0.0 | 0.0 | 10 | 0.0 | 0.0 | 0 | 0 |
| Fundulus seminolis | > 14.5 | Mar 02 - Dec 07 | 3.6 | 10.2 | 11 | 34.0 | 0.0 | 0 | 36.4 |
| Fundulus seminolis | > 14.5 | Jan 08 - Jun 12 | 3.4 | 6.3 | 15 | 22.4 | 0.3 | 0 | 53.3 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Gambusia holbrooki | 10.6 to < 12.6 | No MFL | 28.8 | 73.7 | 16 | 297.8 | 1.0 | 0 | 62.5 |
| Gambusia holbrooki | 10.6 to < 12.6 | Mar 02 - Dec 07 | 10.6 | 7.8 | 16 | 30.6 | 9.7 | 1.02 | 100 |
| Gambusia holbrooki | 10.6 to < 12.6 | Jan 08 - Jun 12 | 15.4 | 25.4 | 20 | 105.4 | 4.3 | 0 | 65 |
| Gambusia holbrooki | 12.6 to < 14.5 | No MFL | 116.8 | 136.2 | 12 | 412.1 | 72.6 | 0 | 91.7 |
| Gambusia holbrooki | 12.6 to < 14.5 | Mar 02 - Dec 07 | 38.2 | 62.3 | 14 | 230.5 | 7.8 | 0 | 92.9 |
| Gambusia holbrooki | 12.6 to < 14.5 | Jan 08 - Jun 12 | 41.4 | 86.8 | 17 | 299.9 | 2.7 | 0 | 58.8 |
| Gambusia holbrooki | > 14.5 | No MFL | 105.2 | 128.2 | 10 | 437.9 | 84.0 | 0 | 90 |
| Gambusia holbrooki | > 14.5 | Mar 02 - Dec 07 | 30.2 | 36.4 | 11 | 98.6 | 17.7 | 0 | 81.8 |
| Gambusia holbrooki | > 14.5 | Jan 08 - Jun 12 | 9.1 | 17.1 | 15 | 62.6 | 2.0 | 0 | 60 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Labidesthes sicculus | 10.6 to < 12.6 | No MFL | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0 |
| Labidesthes sicculus | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0 |
| Labidesthes sicculus | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.0 | 0.2 | 20 | 0.7 | 0.0 | 0 | 5 |
| Labidesthes sicculus | 12.6 to < 14.5 | No MFL | 0.0 | 0.0 | 12 | 0.0 | 0.0 | 0 | 0 |
| Labidesthes sicculus | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.3 | 1.1 | 14 | 4.1 | 0.0 | 0 | 7.1 |
| Labidesthes sicculus | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.0 | 0.0 | 17 | 0.0 | 0.0 | 0 | 0 |
| Labidesthes sicculus | > 14.5 | No MFL | 0.0 | 0.0 | 10 | 0.0 | 0.0 | 0 | 0 |
| Labidesthes sicculus | > 14.5 | Mar 02 - Dec 07 | 5.9 | 18.3 | 11 | 61.2 | 0.0 | 0 | 36.4 |
| Labidesthes sicculus | > 14.5 | Jan 08 - Jun 12 | 0.6 | 1.5 | 15 | 4.8 | 0.0 | 0 | 20 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Lepomis macrochirus | 10.6 to < 12.6 | No MFL | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0 |
| Lepomis macrochirus | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.1 | 0.2 | 16 | 0.7 | 0.0 | 0 | 12.5 |
| Lepomis macrochirus | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.8 | 1.6 | 20 | 6.1 | 0.0 | 0 | 30 |
| Lepomis macrochirus | 12.6 to < 14.5 | No MFL | 0.0 | 0.0 | 12 | 0.0 | 0.0 | 0 | 0 |
| Lepomis macrochirus | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.3 | 0.6 | 14 | 1.7 | 0.0 | 0 | 28.6 |
| Lepomis macrochirus | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.9 | 3.8 | 17 | 15.6 | 0.0 | 0 | 5.9 |
| Lepomis macrochirus | > 14.5 | No MFL | 0.0 | 0.0 | 10 | 0.0 | 0.0 | 0 | 0 |
| Lepomis macrochirus | > 14.5 | Mar 02 - Dec 07 | 2.9 | 5.5 | 11 | 18.7 | 1.0 | 0 | 54.5 |
| Lepomis macrochirus | > 14.5 | Jan 08 - Jun 12 | 4.5 | 12.3 | 15 | 47.6 | 0.0 | 0 | 46.7 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Lepomis microlophus | 10.6 to < 12.6 | No MFL | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0.0 |
| Lepomis microlophus | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0.0 |
| Lepomis microlophus | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.5 | 1.4 | 20 | 5.8 | 0.0 | 0 | 25 |
| Lepomis microlophus | 12.6 to < 14.5 | No MFL | 0.0 | 0.0 | 12 | 0.0 | 0.0 | 0 | 0.0 |
| Lepomis microlophus | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.0 | 0.1 | 14 | 0.3 | 0.0 | 0 | 7.1 |
| Lepomis microlophus | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.0 | 0.0 | 17 | 0.0 | 0.0 | 0 | 0.0 |
| Lepomis microlophus | > 14.5 | No MFL | 0.0 | 0.0 | 10 | 0.0 | 0.0 | 0 | 0 |
| Lepomis microlophus | > 14.5 | Mar 02 - Dec 07 | 1.3 | 2.3 | 11 | 6.8 | 0.0 | 0 | 36.4 |
| Lepomis microlophus | > 14.5 | Jan 08 - Jun 12 | 0.8 | 1.7 | 15 | 6.1 | 0.0 | 0 | 33.3 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Lucania parva | 10.6 to < 12.6 | No MFL | 36.0 | 81.1 | 16 | 294.4 | 0.9 | 0 | 62.5 |
| Lucania parva | 10.6 to < 12.6 | Mar 02 - Dec 07 | 13.5 | 18.7 | 16 | 59.8 | 3.2 | 0 | 75 |
| Lucania parva | 10.6 to < 12.6 | Jan 08 - Jun 12 | 23.6 | 43.6 | 20 | 136.0 | 4.1 | 0 | 85 |
| Lucania parva | 12.6 to < 14.5 | No MFL | 12.8 | 17.3 | 12 | 54.4 | 5.6 | 0 | 58.3 |
| Lucania parva | 12.6 to < 14.5 | Mar 02 - Dec 07 | 7.7 | 14.5 | 14 | 40.8 | 0.9 | 0 | 64.3 |
| Lucania parva | 12.6 to < 14.5 | Jan 08 - Jun 12 | 17.0 | 25.6 | 17 | 94.2 | 5.4 | 0 | 88.2 |
| Lucania parva | > 14.5 | No MFL | 94.0 | 130.2 | 10 | 356.3 | 31.3 | 0 | 80 |
| Lucania parva | > 14.5 | Mar 02 - Dec 07 | 83.1 | 177.2 | 11 | 608.6 | 24.5 | 0 | 63.6 |
| Lucania parva | > 14.5 | Jan 08 - Jun 12 | 27.5 | 61.8 | 15 | 240.0 | 2.0 | 0 | 53.3 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximu m CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Micropterus salmoides | 10.6 to < 12.6 | No MFL | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0.0 |
| Micropterus salmoides | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.1 | 0.2 | 16 | 0.7 | 0.0 | 0 | 12.5 |
| Micropterus salmoides | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.1 | 0.2 | 20 | 0.7 | 0.0 | 0 | 10 |
| Micropterus salmoides | 12.6 to < 14.5 | No MFL | 0.0 | 0.0 | 12 | 0.0 | 0.0 | 0 | 0.0 |
| Micropterus salmoides | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.4 | 0.7 | 14 | 2.4 | 0.0 | 0 | 28.6 |
| Micropterus salmoides | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.4 | 1.1 | 17 | 4.8 | 0.0 | 0 | 23.5 |
| Micropterus salmoides | > 14.5 | No MFL | 0.0 | 0.0 | 10 | 0.0 | 0.0 | 0 | 0 |
| Micropterus salmoides | > 14.5 | Mar 02 - Dec 07 | 2.2 | 3.3 | 11 | 10.5 | 0.7 | 0 | 54.5 |
| Micropterus salmoides | > 14.5 | Jan 08 - Jun 12 | 1.3 | 3.8 | 15 | 15.0 | 0.0 | 0 | 40 |

| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Palaemonetes spp. | 10.6 to < 12.6 | No MFL | 418.9 | 1128.4 | 16 | 4250.7 | 10.0 | 0 | 81.3 |
| Palaemonetes spp. | 10.6 to < 12.6 | Mar 02 - Dec 07 | 21.7 | 46.5 | 16 | 166.9 | 0.9 | 0 | 68.8 |
| Palaemonetes spp. | 10.6 to < 12.6 | Jan 08 - Jun 12 | 57.4 | 207.2 | 20 | 928.2 | 0.9 | 0 | 65 |
| Palaemonetes spp. | 12.6 to < 14.5 | No MFL | 165.3 | 340.2 | 12 | 1134.6 | 6.1 | 0 | 58.3 |
| Palaemonetes spp. | 12.6 to < 14.5 | Mar 02 - Dec 07 | 25.7 | 69.3 | 14 | 258.1 | 2.6 | 0 | 64.3 |
| Palaemonetes spp. | 12.6 to < 14.5 | Jan 08 - Jun 12 | 3.9 | 5.3 | 17 | 19.7 | 2.0 | 0 | 70.6 |
| Palaemonetes spp. | > 14.5 | No MFL | 111.0 | 294.9 | 10 | 946.9 | 1.0 | 0 | 60 |
| Palaemonetes spp. | > 14.5 | Mar 02 - Dec 07 | 5.9 | 17.1 | 11 | 57.5 | 0.0 | 0 | 45.5 |
| Palaemonetes spp. | > 14.5 | Jan 08 - Jun 12 | 1.3 | 2.6 | 15 | 8.2 | 0.0 | 0 | 40 |

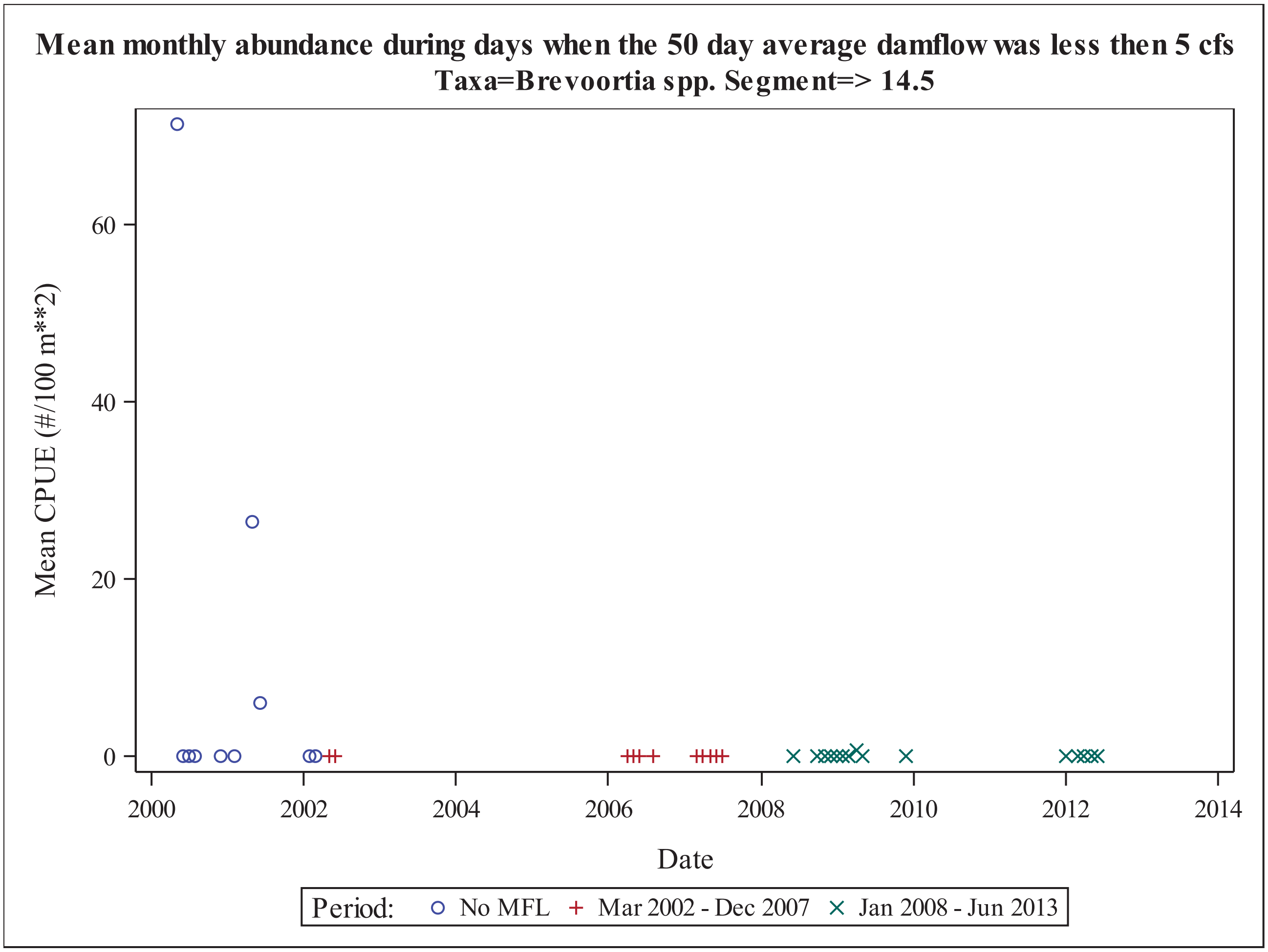
| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Poecilia latipinna | 10.6 to < 12.6 | No MFL | 9.1 | 11.0 | 16 | 40.5 | 6.0 | 0 | 75 |
| Poecilia latipinna | 10.6 to < 12.6 | Mar 02 - Dec 07 | 9.2 | 22.6 | 16 | 90.1 | 1.0 | 0 | 68.8 |
| Poecilia latipinna | 10.6 to < 12.6 | Jan 08 - Jun 12 | 2.8 | 4.6 | 20 | 16.3 | 0.3 | 0 | 55 |
| Poecilia latipinna | 12.6 to < 14.5 | No MFL | 78.1 | 132.1 | 12 | 451.5 | 28.6 | 0 | 50 |
| Poecilia latipinna | 12.6 to < 14.5 | Mar 02 - Dec 07 | 1.4 | 2.7 | 14 | 8.2 | 0.0 | 0 | 35.7 |
| Poecilia latipinna | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.3 | 0.5 | 17 | 1.4 | 0.0 | 0 | 29.4 |
| Poecilia latipinna | > 14.5 | No MFL | 18.7 | 27.0 | 10 | 58.8 | 1.7 | 0 | 60 |
| Poecilia latipinna | > 14.5 | Mar 02 - Dec 07 | 4.0 | 12.3 | 11 | 41.1 | 0.0 | 0 | 27.3 |
| Poecilia latipinna | > 14.5 | Jan 08 - Jun 12 | 0.1 | 0.4 | 15 | 1.4 | 0.0 | 0 | 13.3 |

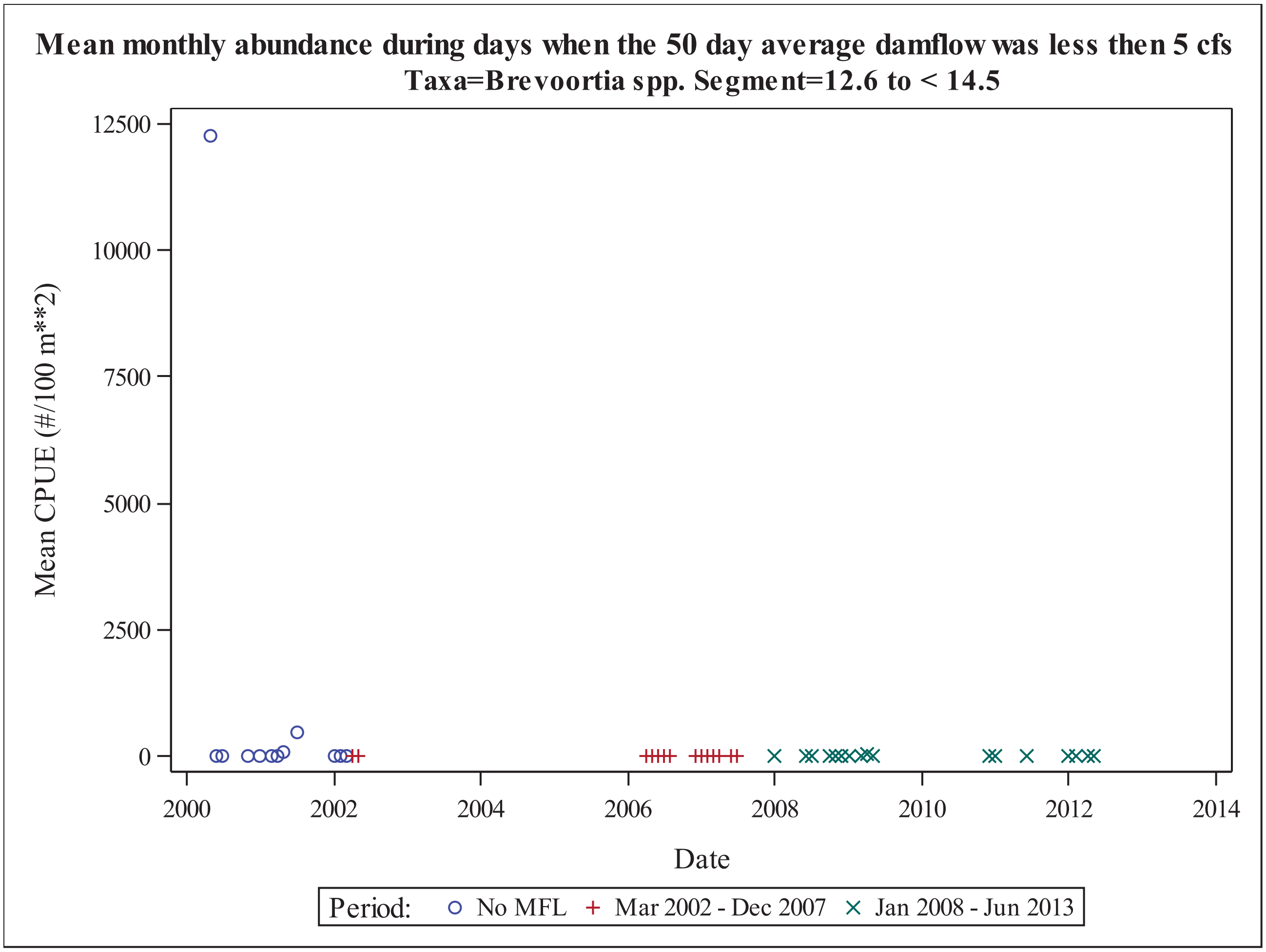
| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximum CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Tilapia | 10.6 to < 12.6 | No MFL | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0 |
| Tilapia | 10.6 to < 12.6 | Mar 02 - Dec 07 | 0.0 | 0.0 | 16 | 0.0 | 0.0 | 0 | 0 |
| Tilapia | 10.6 to < 12.6 | Jan 08 - Jun 12 | 0.9 | 2.5 | 20 | 8.8 | 0.0 | 0 | 20 |
| Tilapia | 12.6 to < 14.5 | No MFL | 0.0 | 0.0 | 12 | 0.0 | 0.0 | 0 | 0 |
| Tilapia | 12.6 to < 14.5 | Mar 02 - Dec 07 | 0.0 | 0.0 | 14 | 0.0 | 0.0 | 0 | 0 |
| Tilapia | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.4 | 1.2 | 17 | 4.8 | 0.0 | 0 | 17.6 |
| Tilapia | > 14.5 | No MFL | 0.0 | 0.0 | 10 | 0.0 | 0.0 | 0 | 0 |
| Tilapia | > 14.5 | Mar 02 - Dec 07 | 0.0 | 0.0 | 11 | 0.0 | 0.0 | 0 | 0 |
| Tilapia | > 14.5 | Jan 08 - Jun 12 | 0.0 | 0.0 | 15 | 0.0 | 0.0 | 0 | 0 |

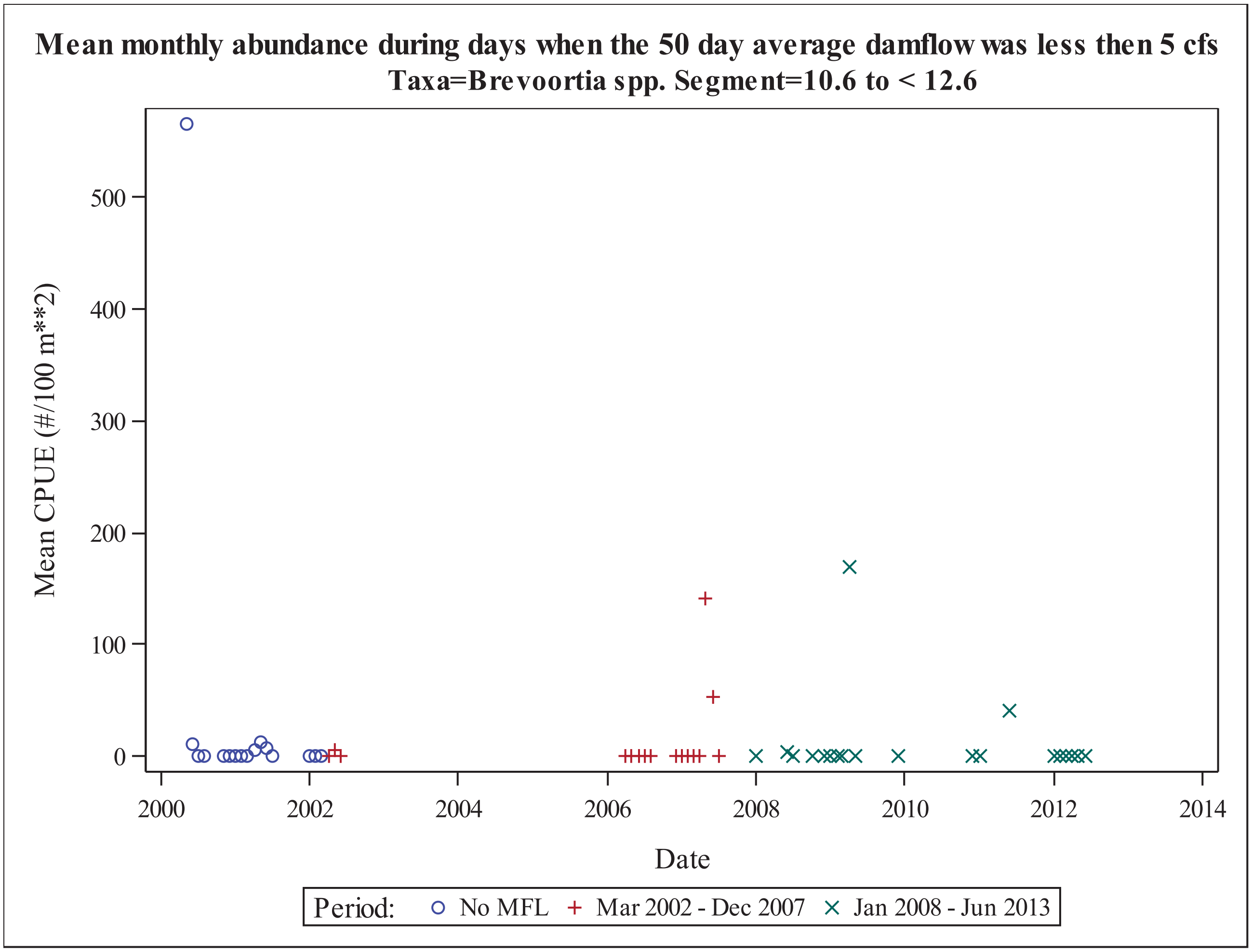
| Taxon | River Kilometer | Period | Mean CPUE | Standard Deviation | Number of Samples | Maximu m CPUE | Median CPUE | Minimum CPUE | Catch Frequency |
|---|---|---|---|---|---|---|---|---|---|
| Trinectes maculatus | 10.6 to < 12.6 | No MFL | 7.0 | 16.4 | 16 | 66.0 | 1.9 | 0 | 81.3 |
| Trinectes maculatus | 10.6 to < 12.6 | Mar 02 - Dec 07 | 3.0 | 4.5 | 16 | 15.6 | 1.2 | 0 | 68.8 |
| Trinectes maculatus | 10.6 to < 12.6 | Jan 08 - Jun 12 | 2.2 | 4.5 | 20 | 16.3 | 0.3 | 0 | 55 |
| Trinectes maculatus | 12.6 to < 14.5 | No MFL | 3.0 | 4.9 | 12 | 16.7 | 1.0 | 0 | 66.7 |
| Trinectes maculatus | 12.6 to < 14.5 | Mar 02 - Dec 07 | 4.3 | 6.2 | 14 | 23.1 | 2.4 | 0 | 78.6 |
| Trinectes maculatus | 12.6 to < 14.5 | Jan 08 - Jun 12 | 0.8 | 1.4 | 17 | 5.4 | 0.0 | 0 | 47.1 |
| Trinectes maculatus | > 14.5 | No MFL | 6.4 | 11.1 | 10 | 34.7 | 1.2 | 0 | 60 |
| Trinectes maculatus | > 14.5 | Mar 02 - Dec 07 | 2.1 | 2.3 | 11 | 6.1 | 1.4 | 0 | 63.6 |
| Trinectes maculatus | > 14.5 | Jan 08 - Jun 12 | 1.9 | 2.8 | 15 | 9.5 | 0.7 | 0 | 60 |

Appendix 7B - Time Series Plots of Nekton Indicators for Dates with 50-Day Flows Less than 5 cfs

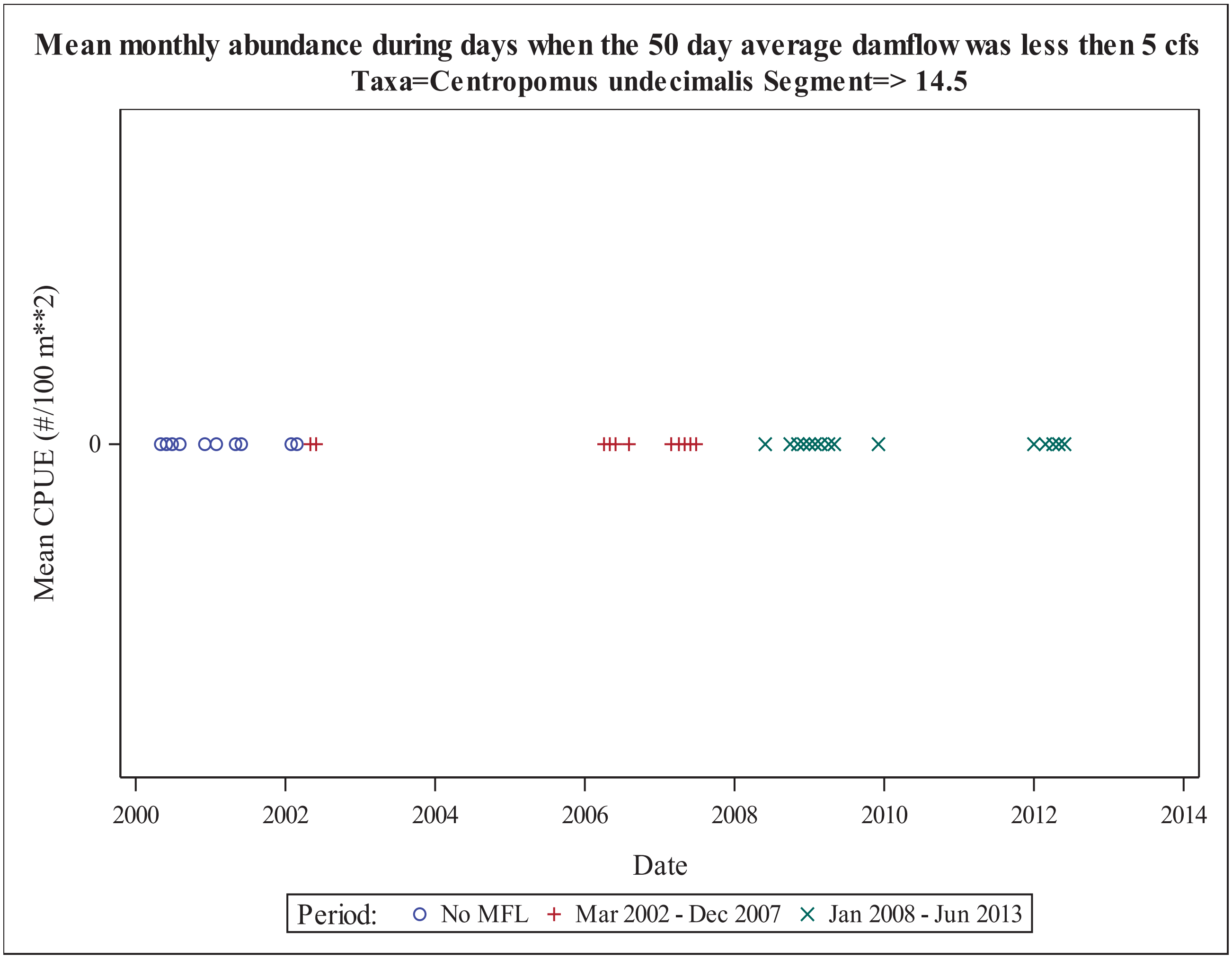
1. Brevoortia spp.

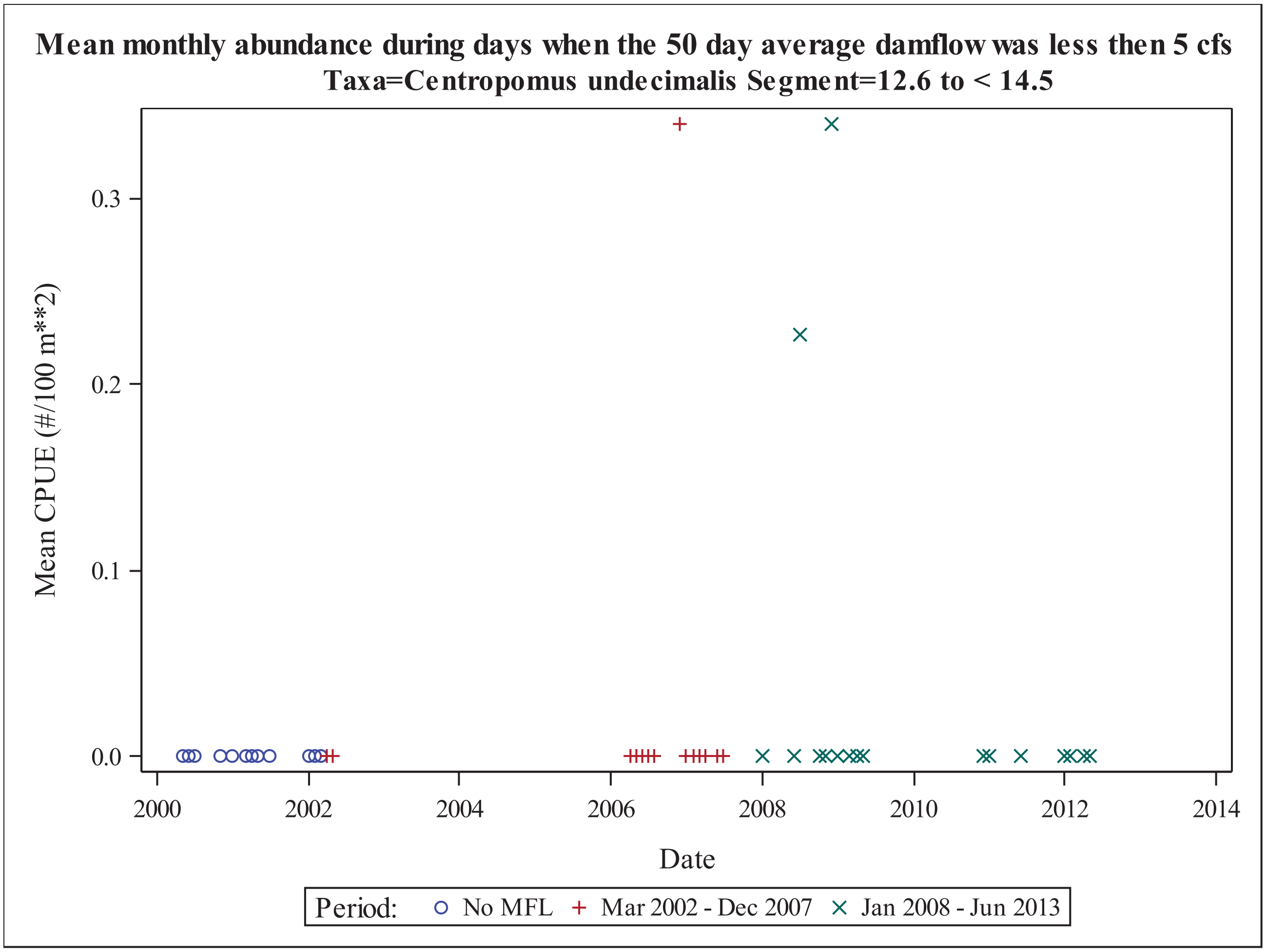


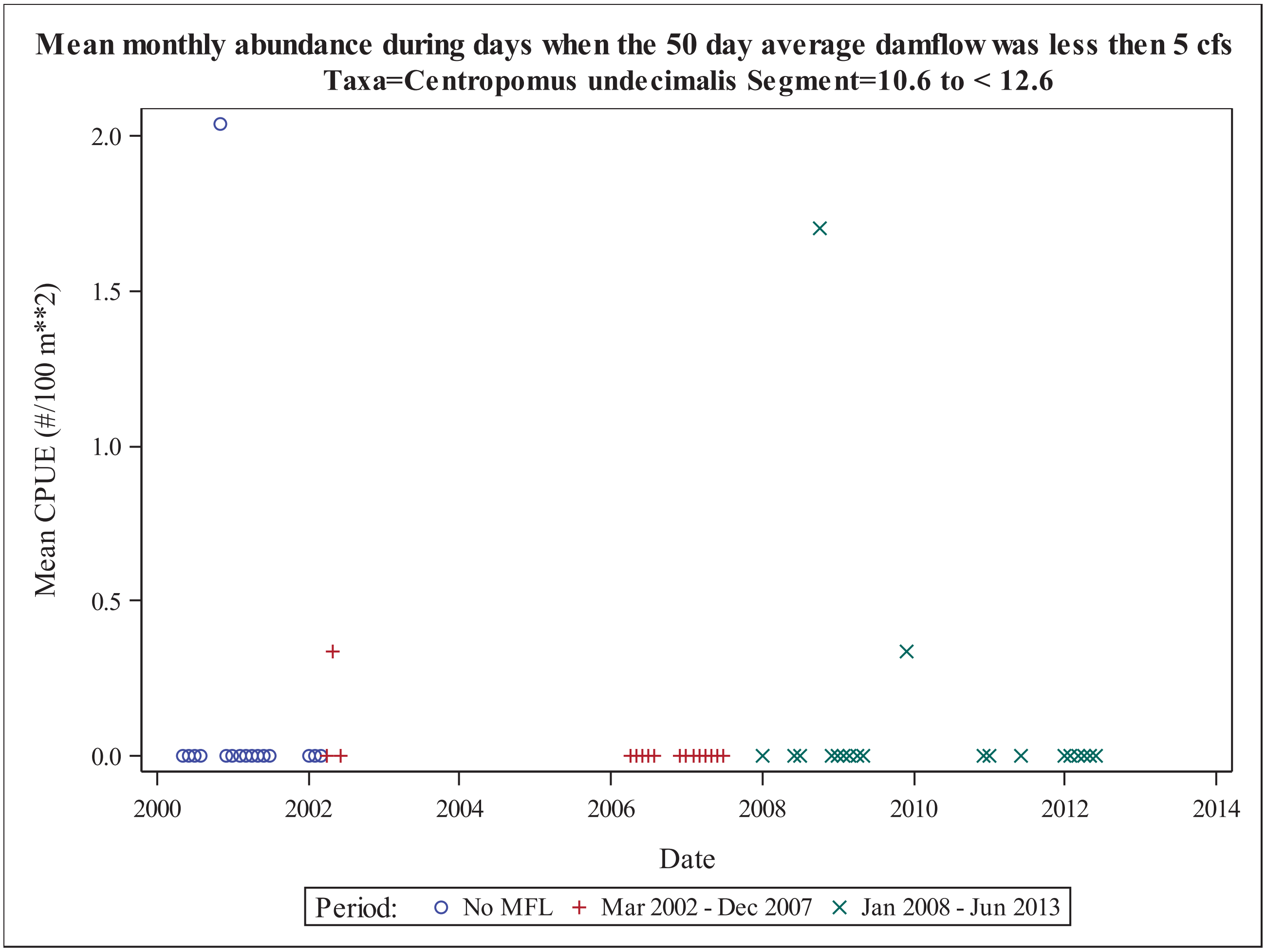

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Brevoortia spp. Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
12500
10000
7500
5000
2500
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Brevoortia spp. Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
100
200
300
400
500
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

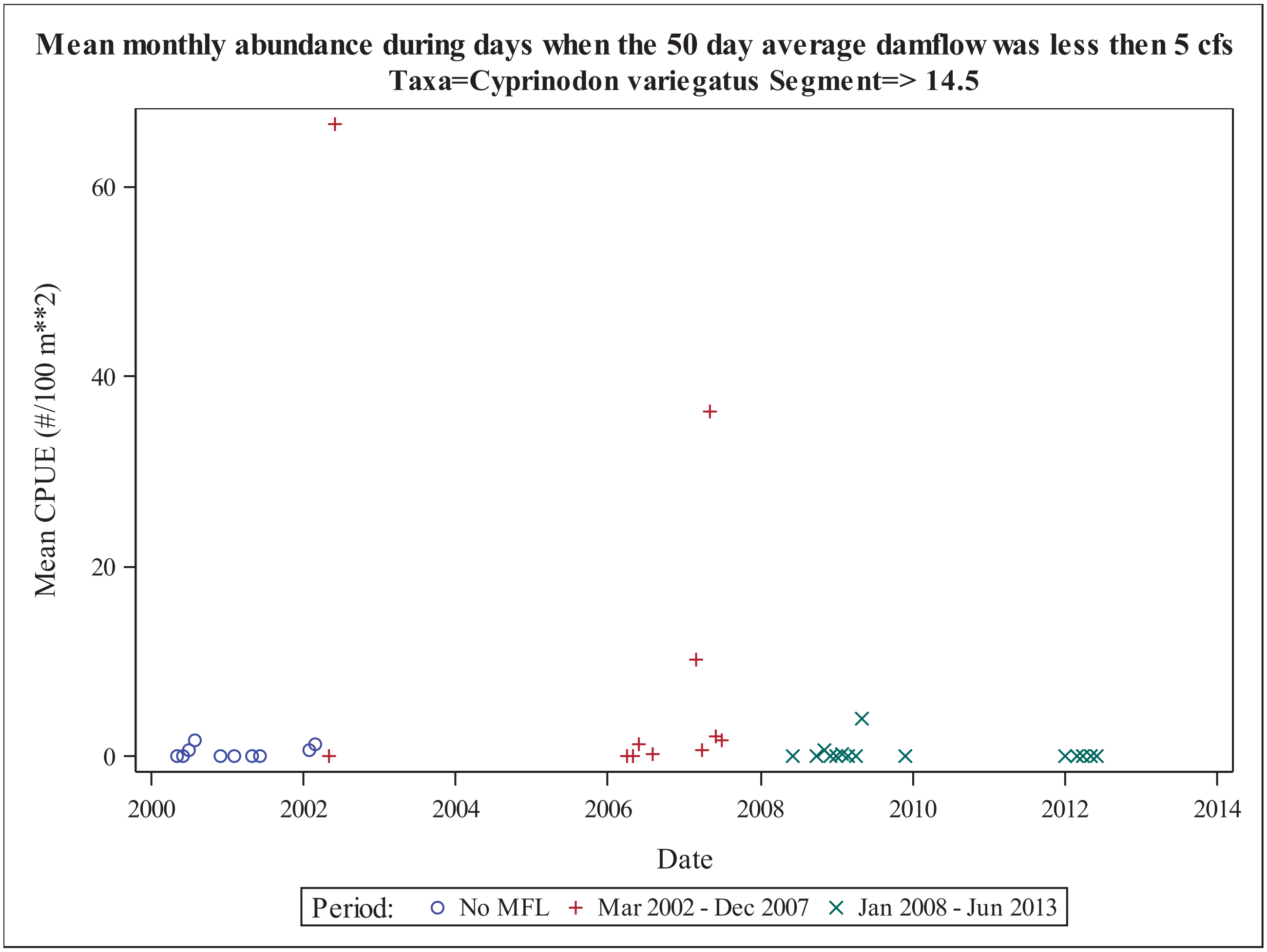
2. Centropomus undecimalis

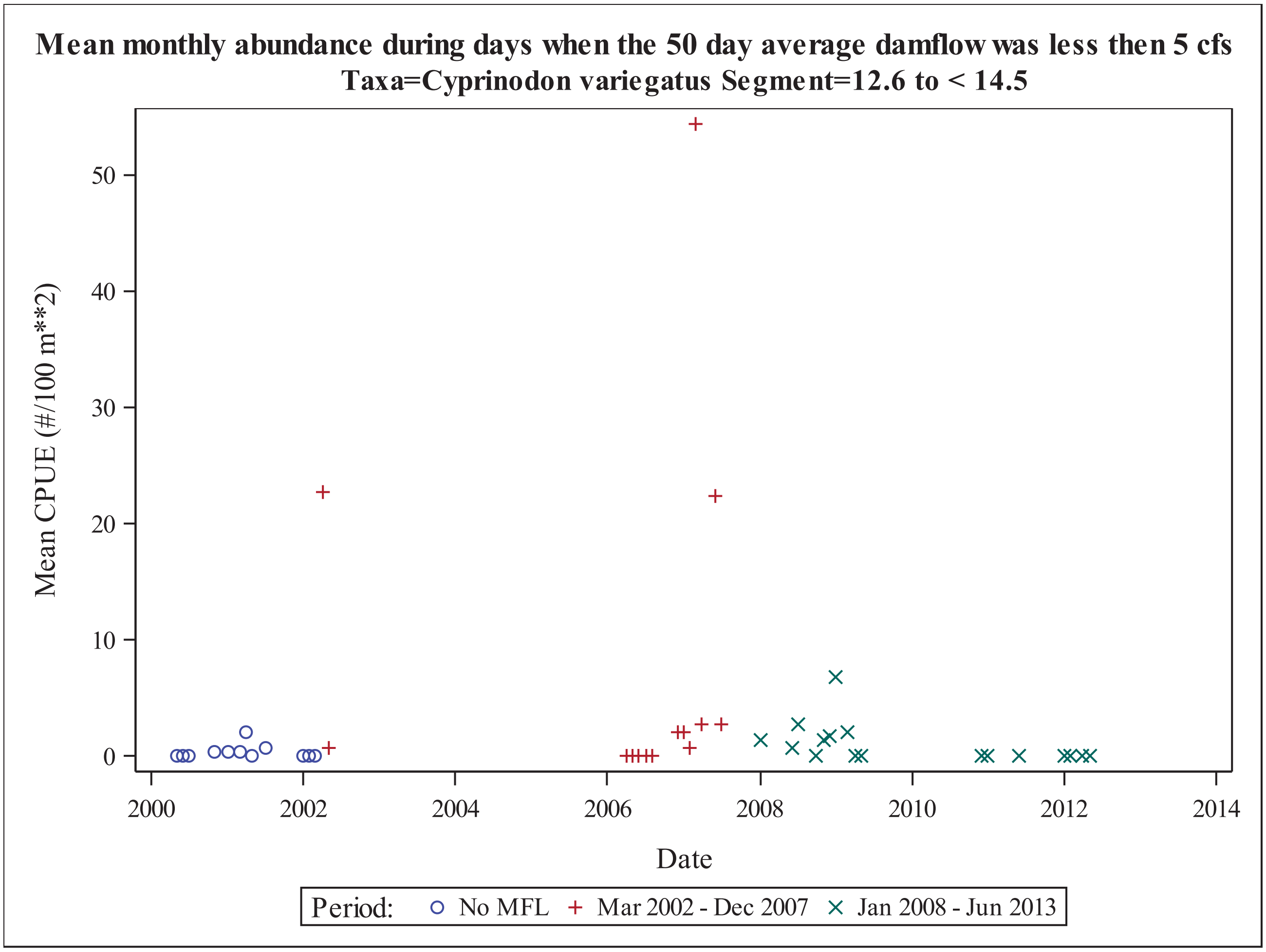


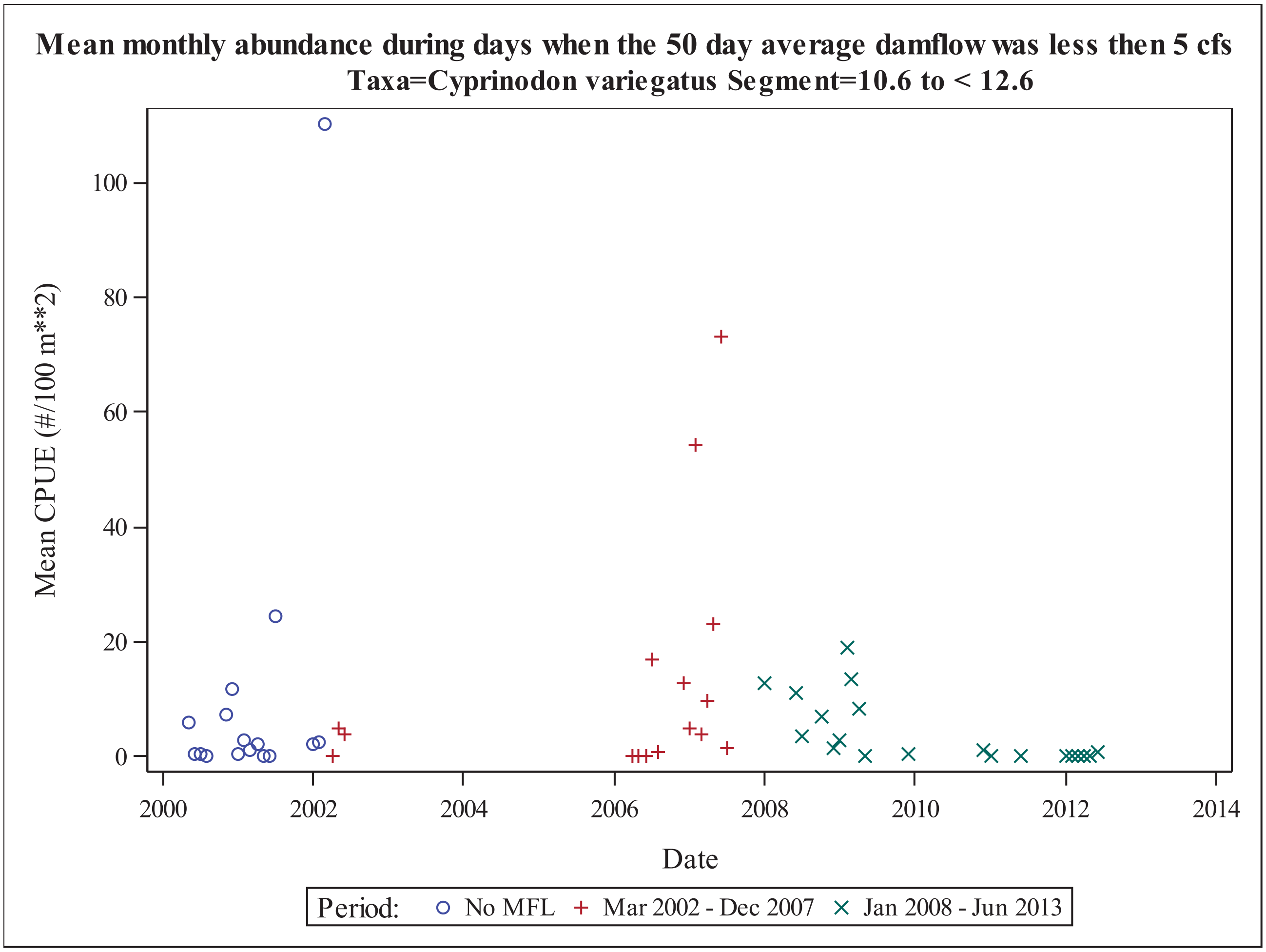

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Centropomus undecimalis Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0.0
0.1
0.2
0.3
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Centropomus undecimalis Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0.0
0.5
1.0
1.5
2.0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

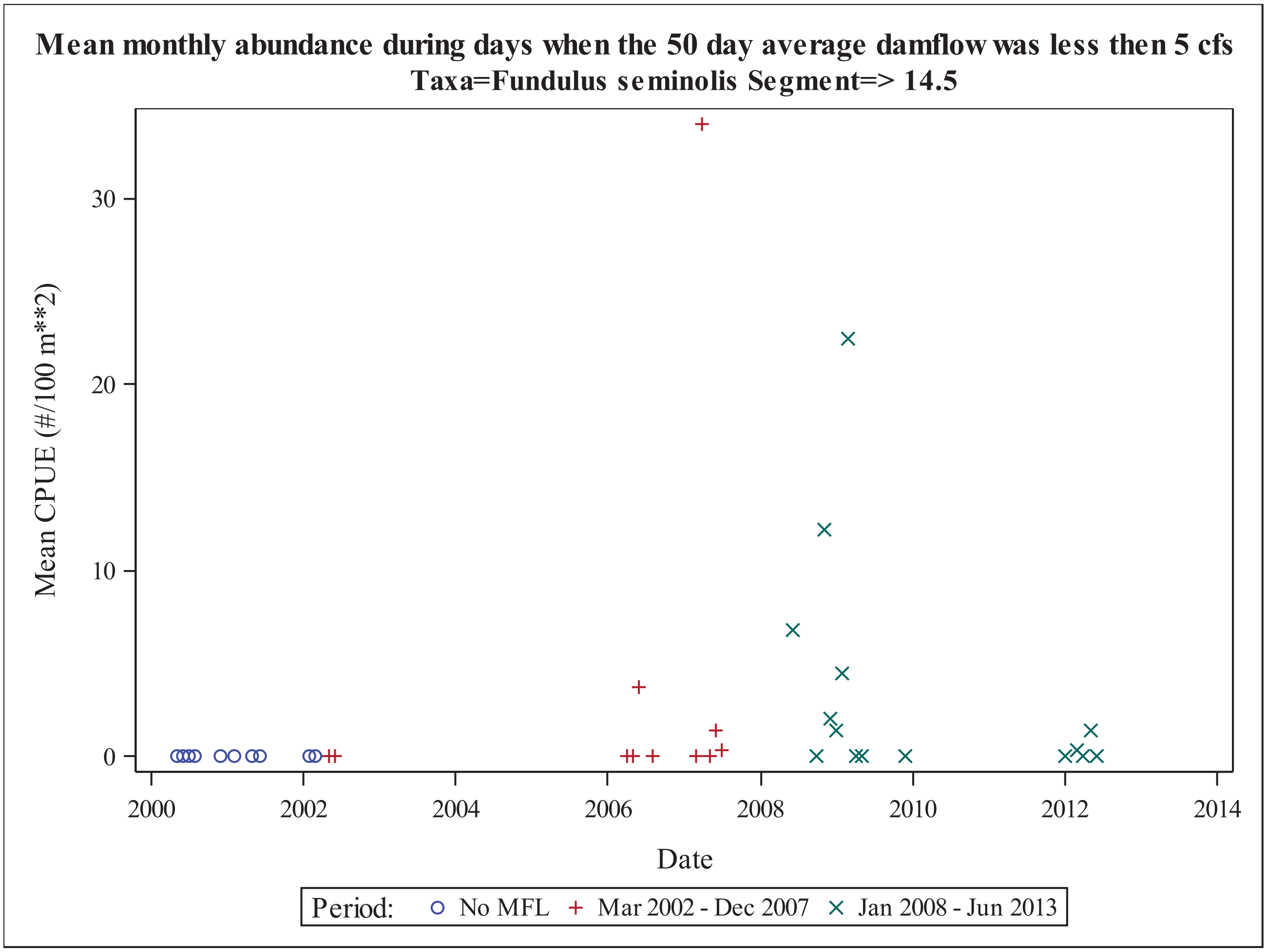
3. Cyprinodon variegatus

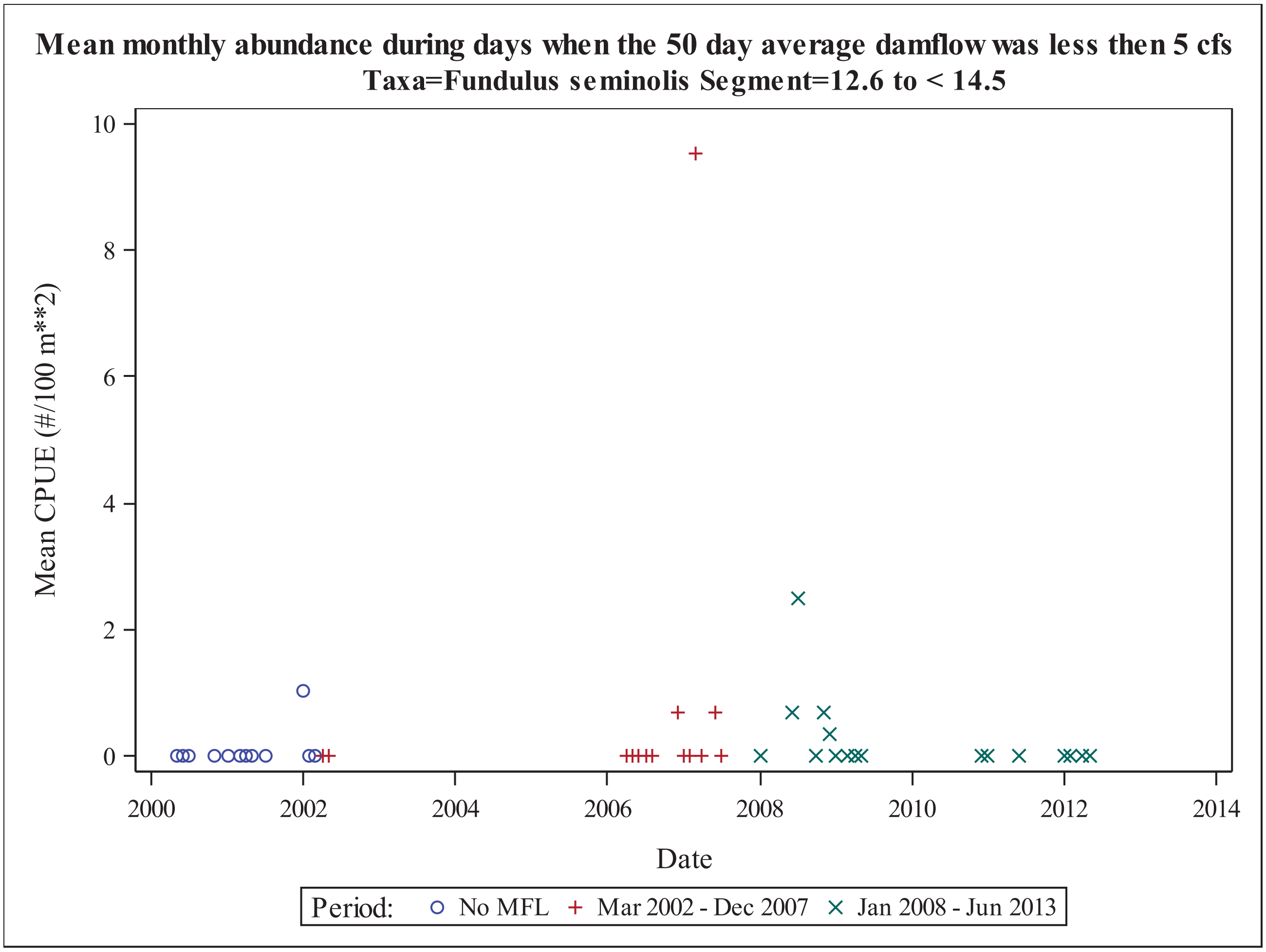



Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Cyprinodon variegatus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
10
20
30
40
50
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

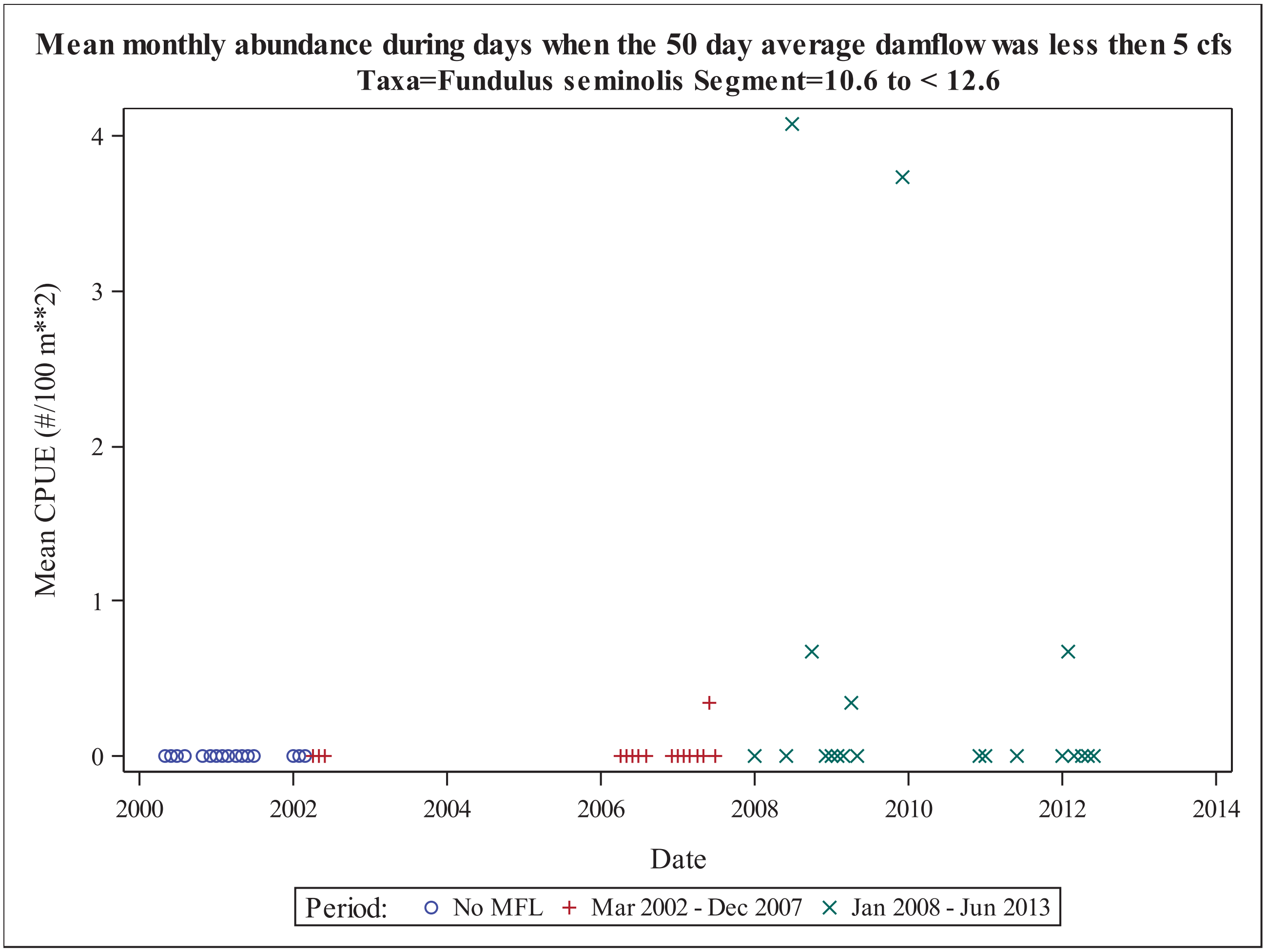

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Cyprinodon variegatus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
20
40
60
80
100
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

4. Fundulus seminolis

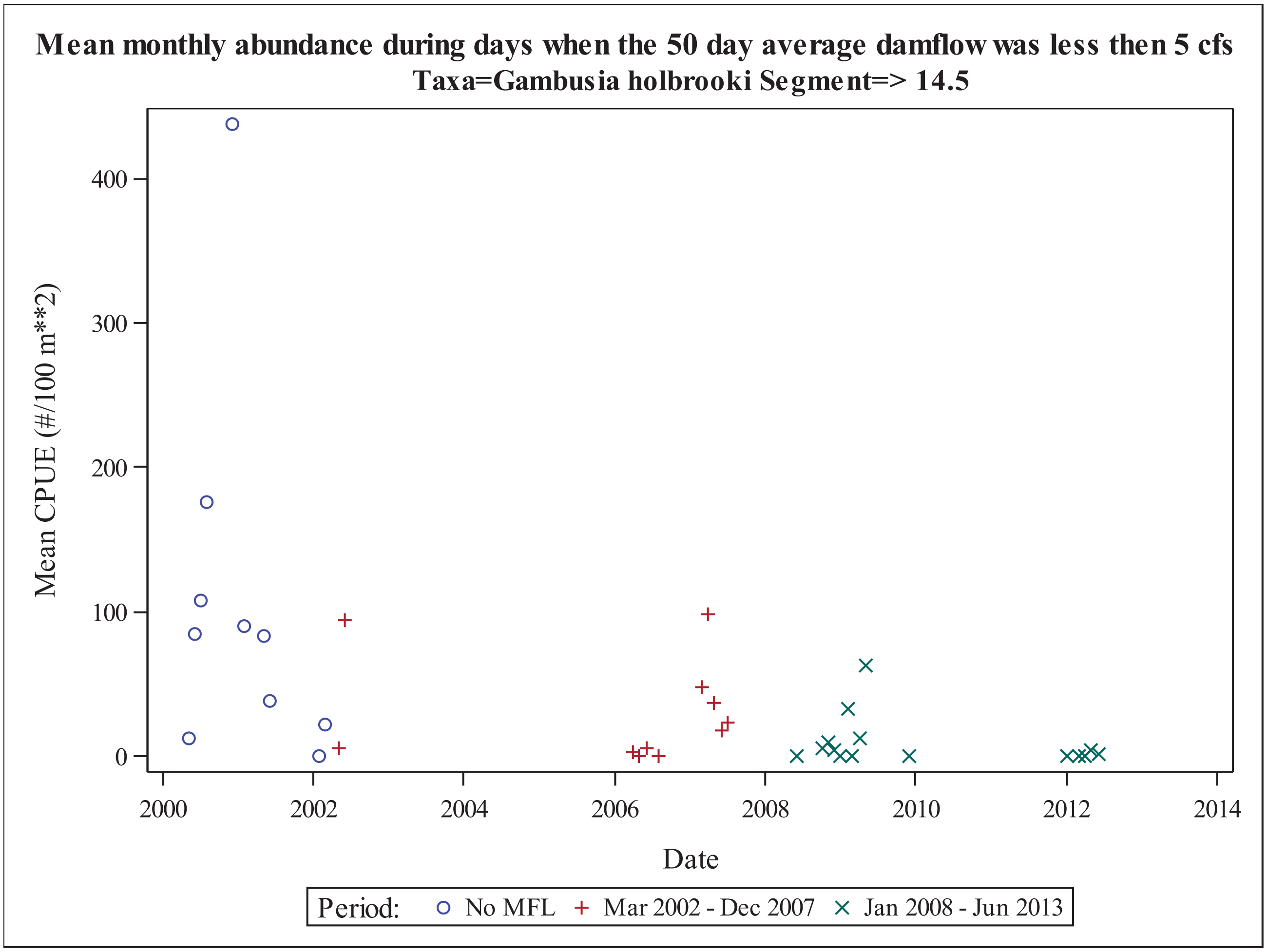


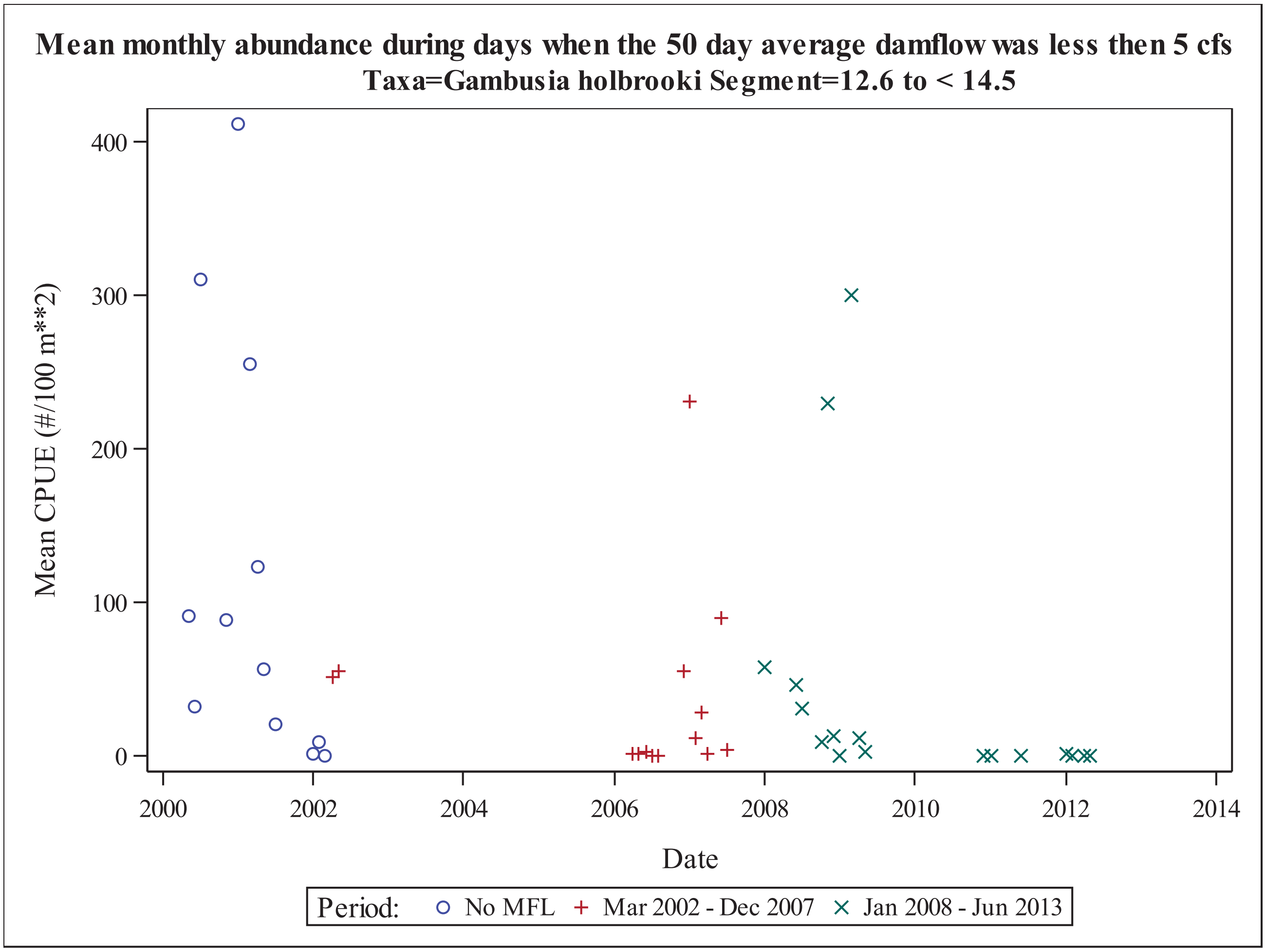


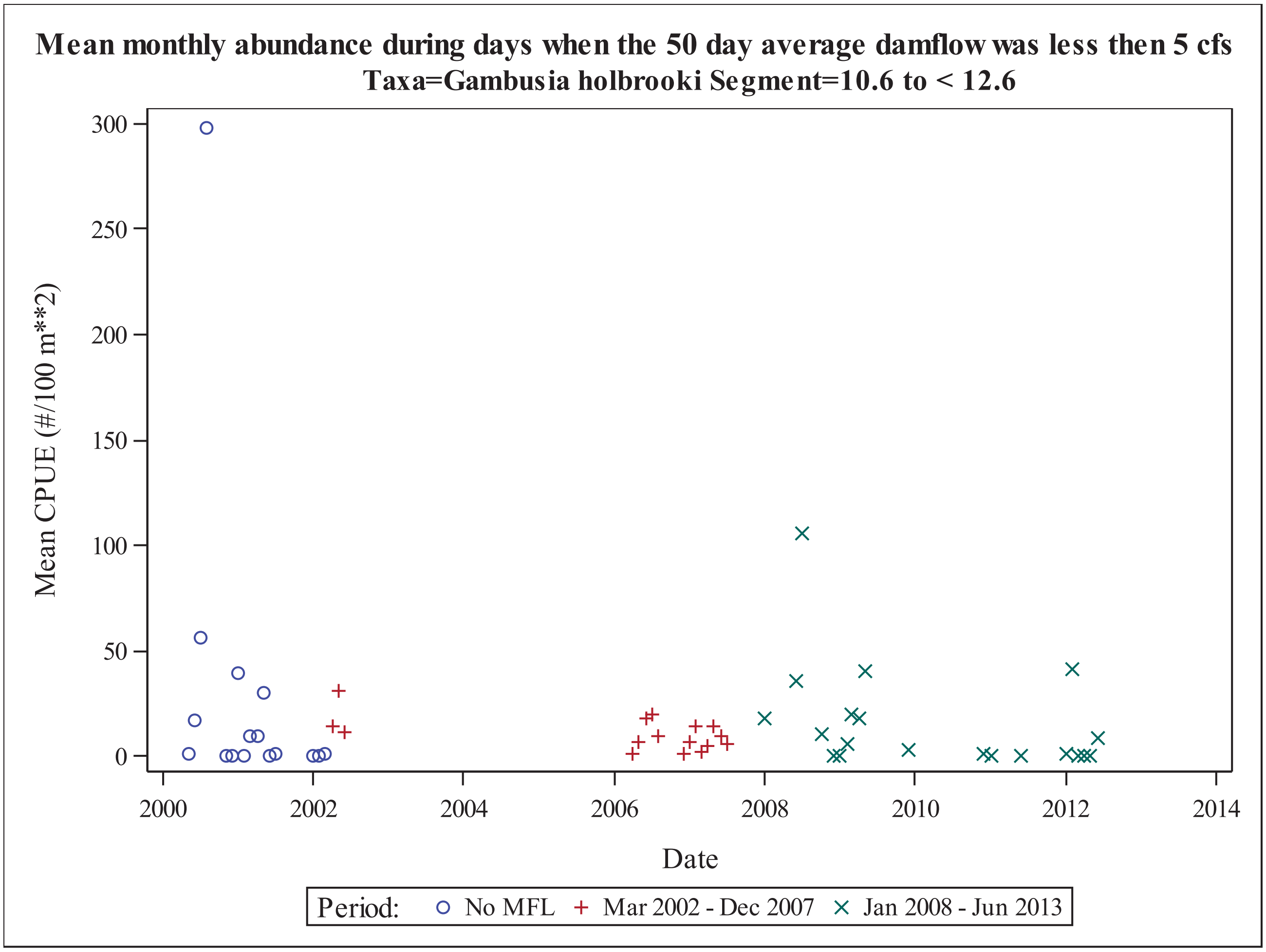
Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Fundulus seminolis Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
2
4
6
8
10
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Fundulus seminolis Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
1
2
3
4
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

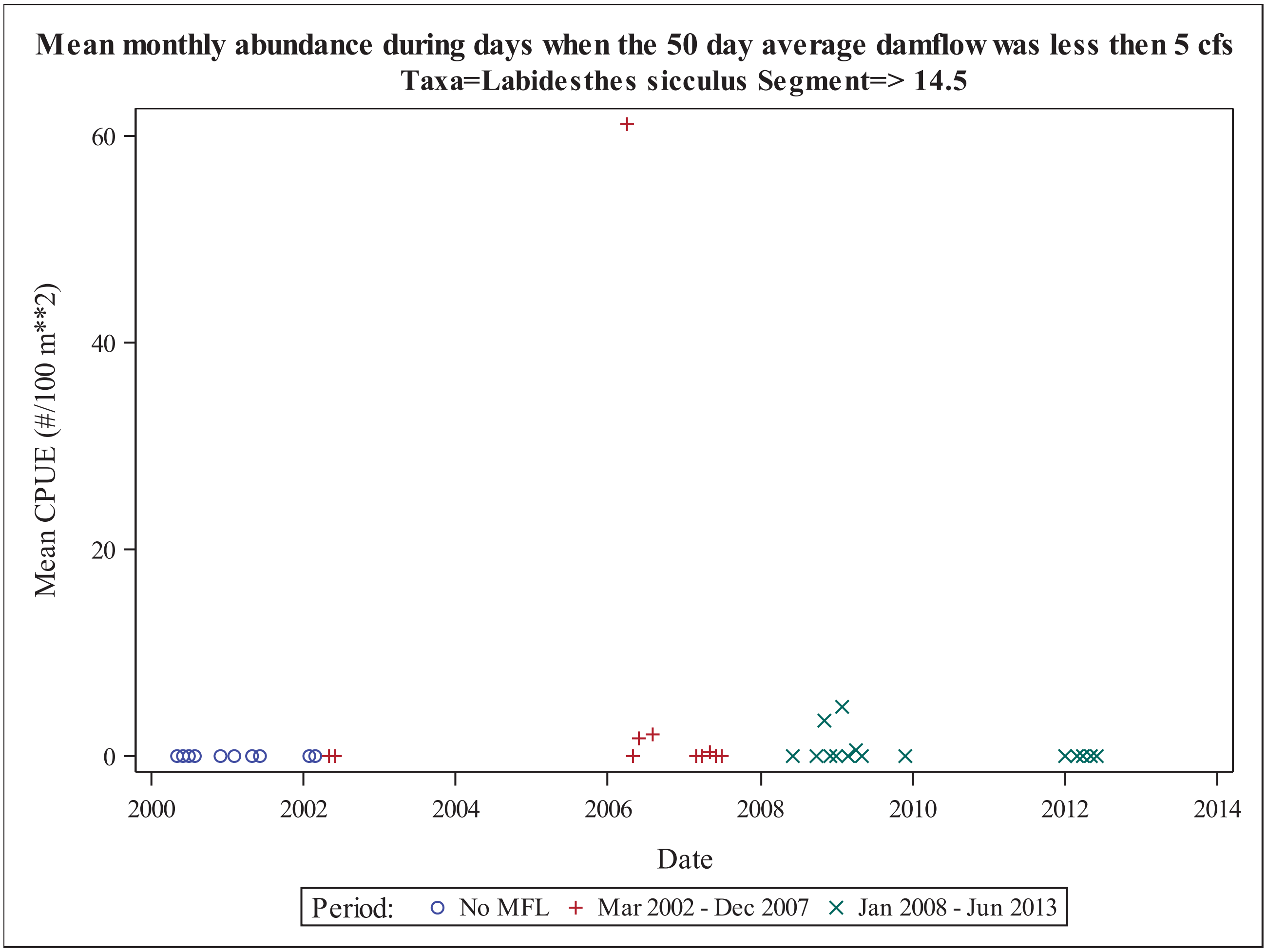
5. Gambusia holbrooki

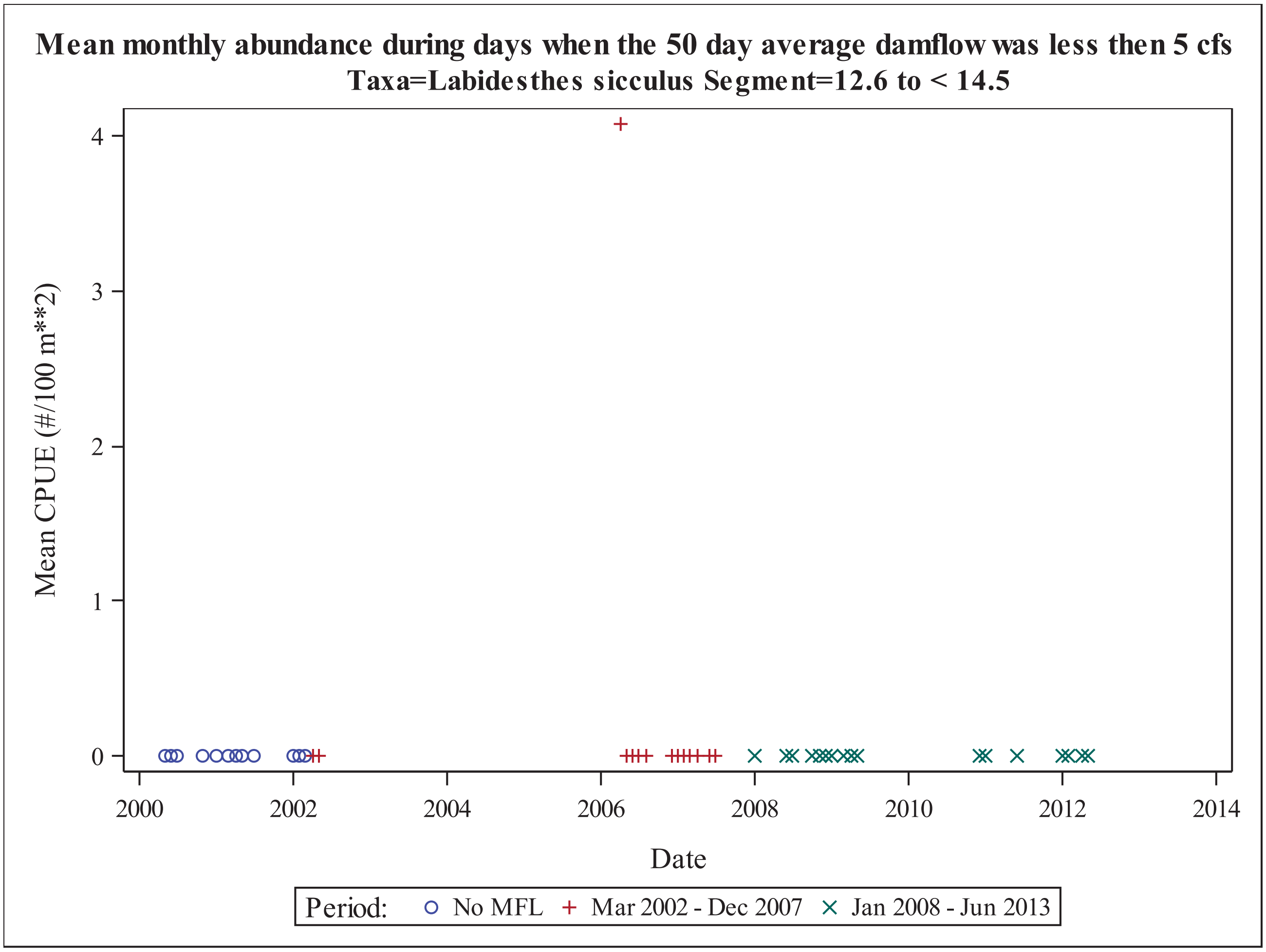


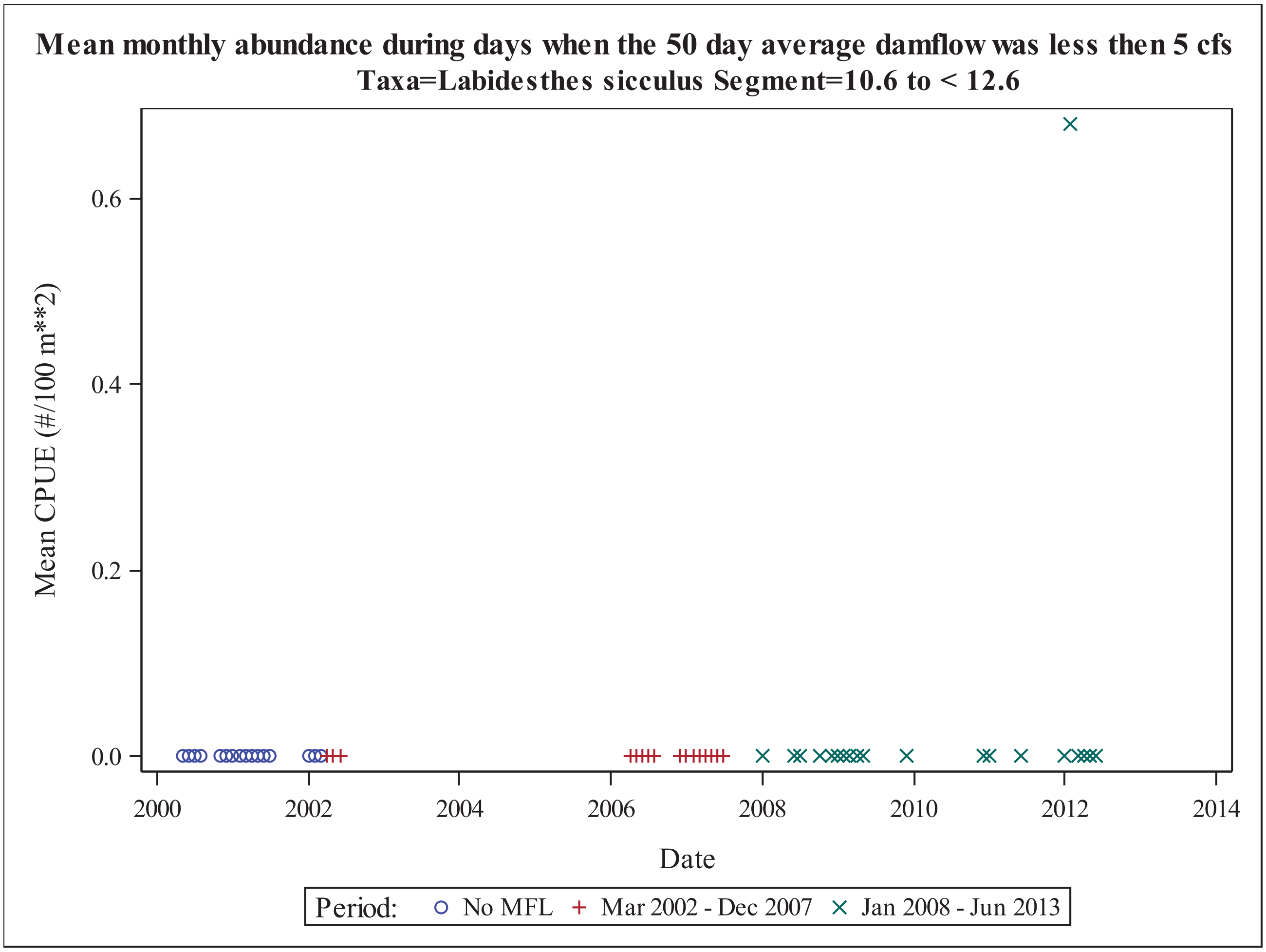

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Gambusia holbrooki Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
100
200
300
400
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Gambusia holbrooki Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
300
250
200
150
100
50
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

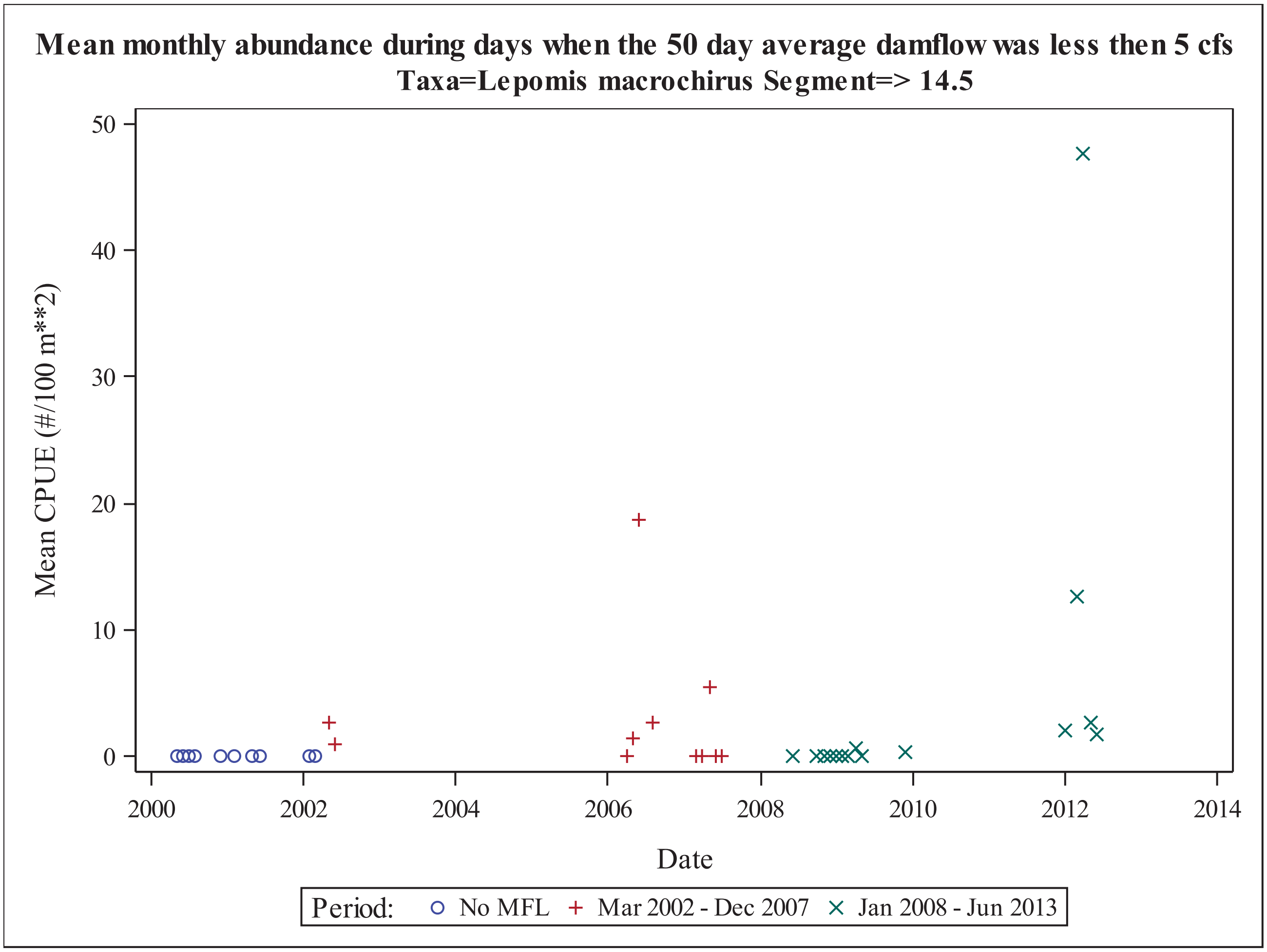
6. Labidesthes sicculus

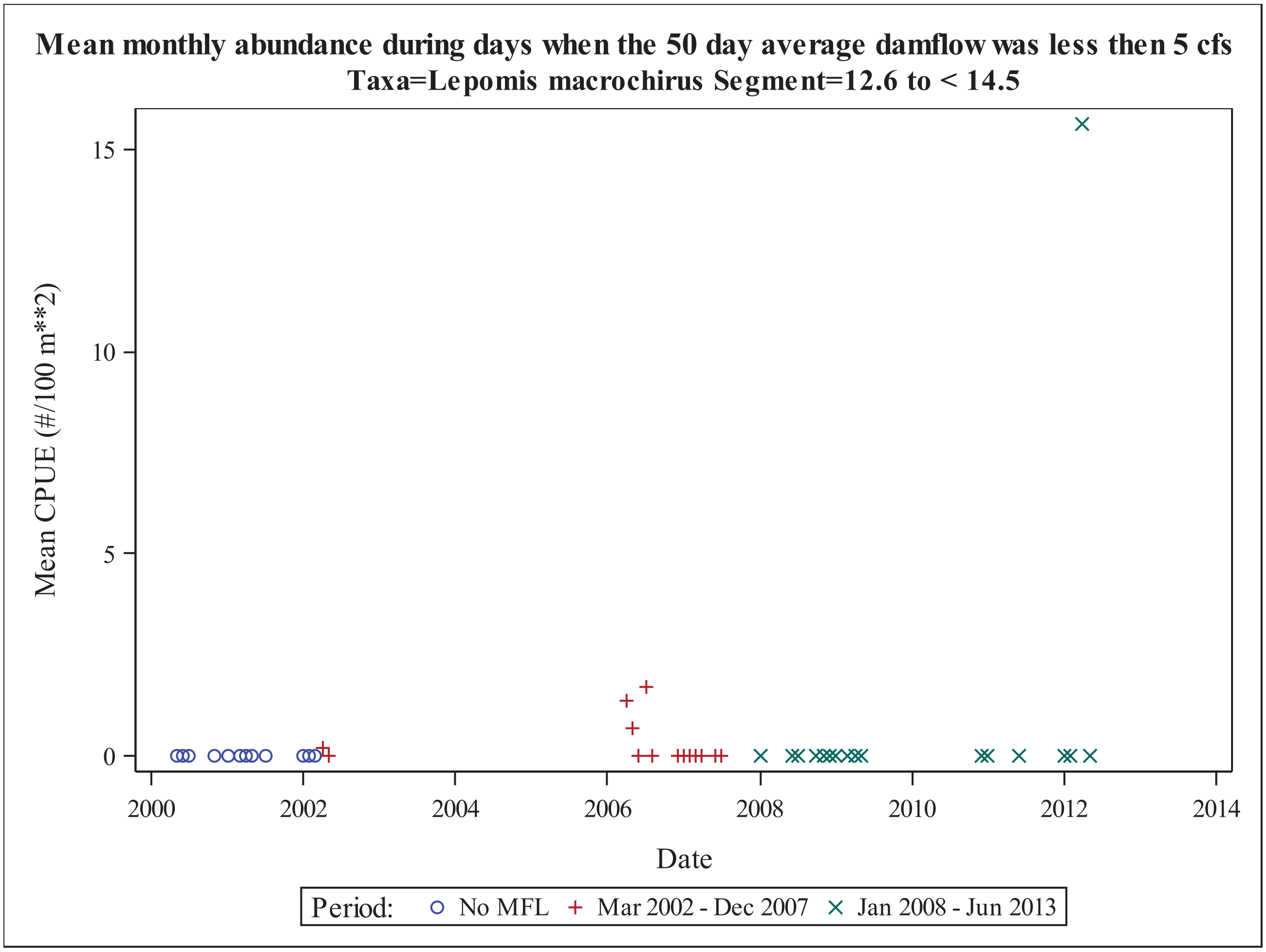


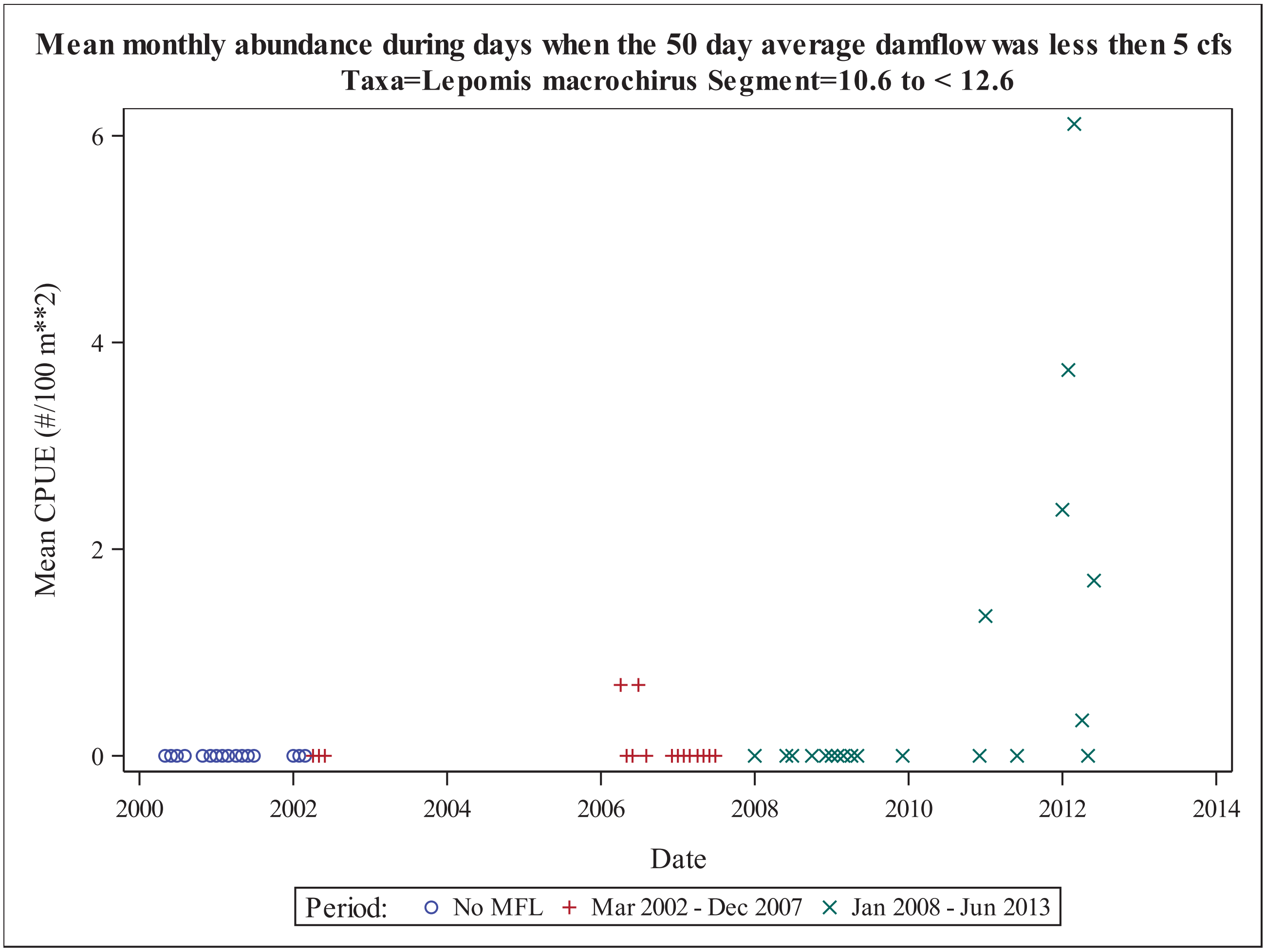

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Labidesthes sicculus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
1
2
3
4
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Labidesthes sicculus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0.0
0.2
0.4
0.6
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

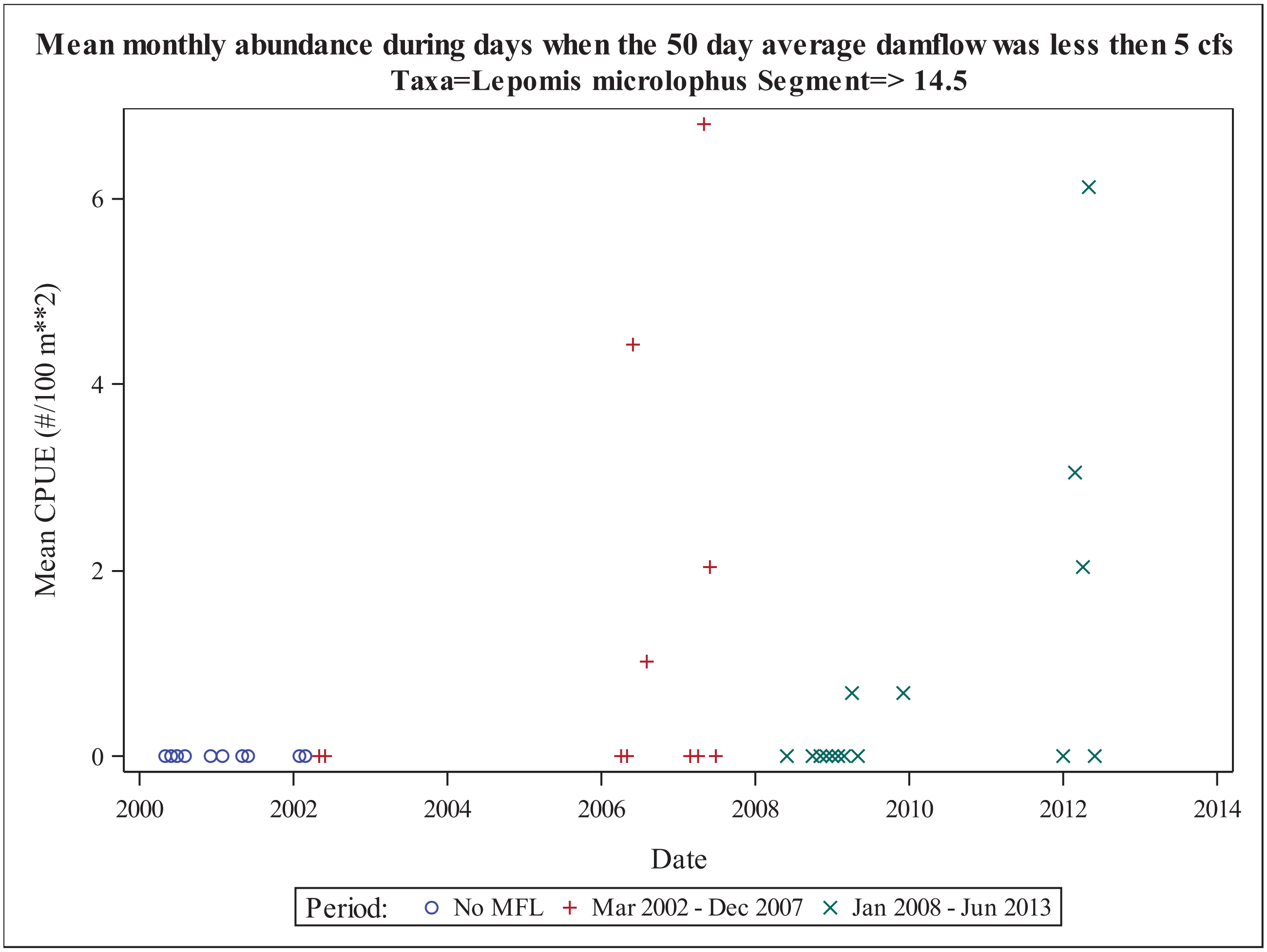
7. Lepomis macrochirus

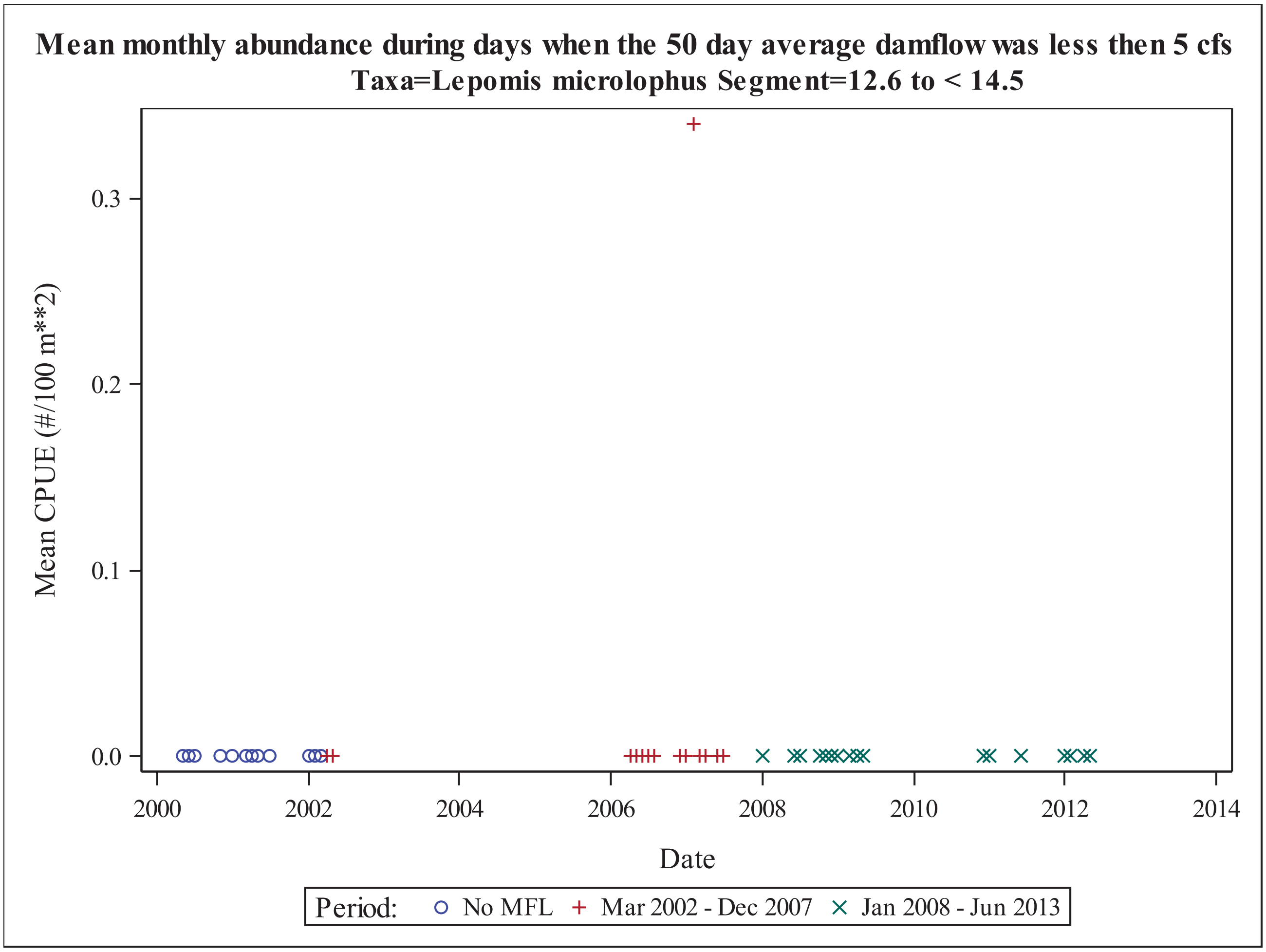


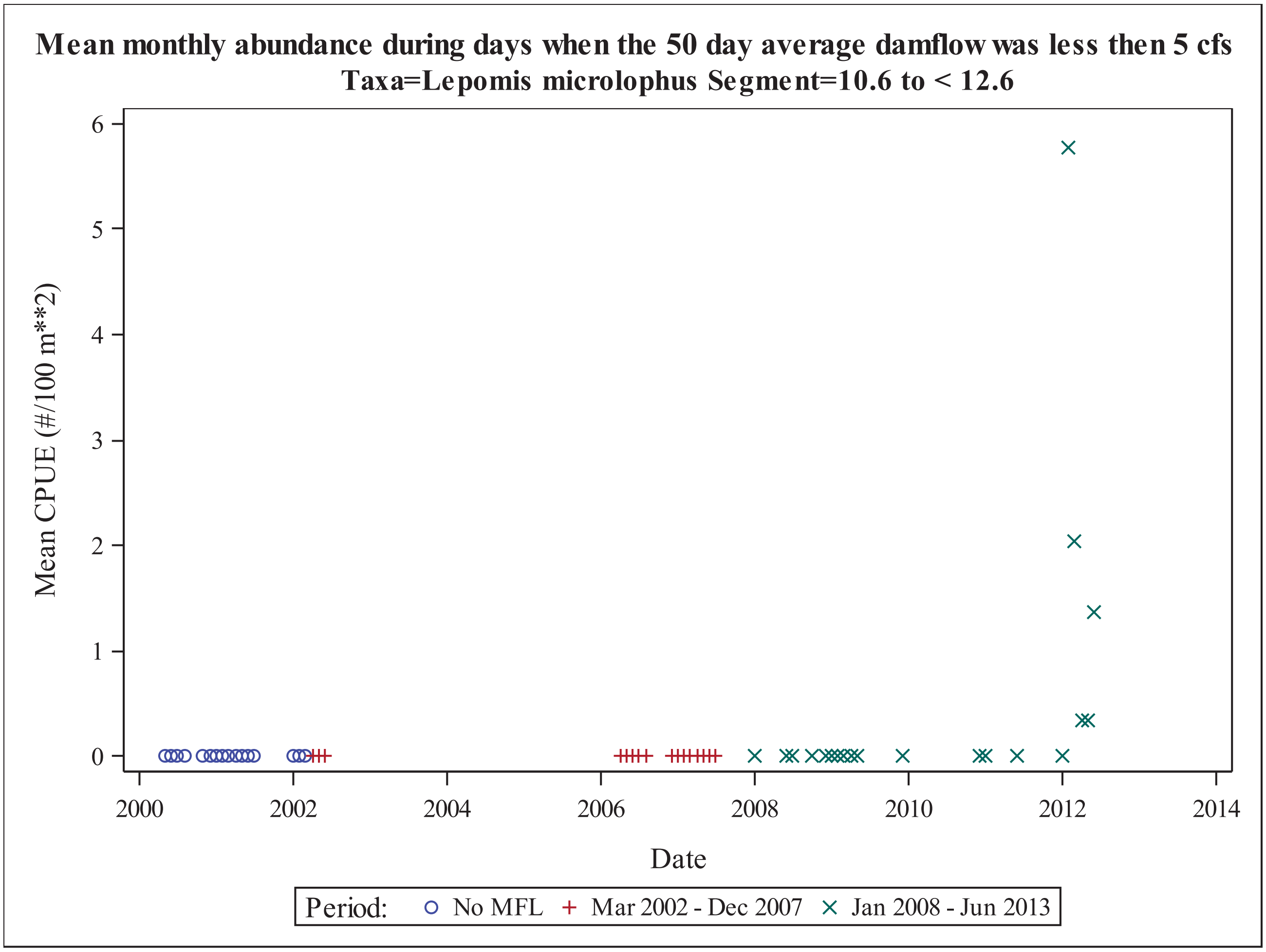

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Lepomis macrochirus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
5
10
15
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Lepomis macrochirus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
2
4
6
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

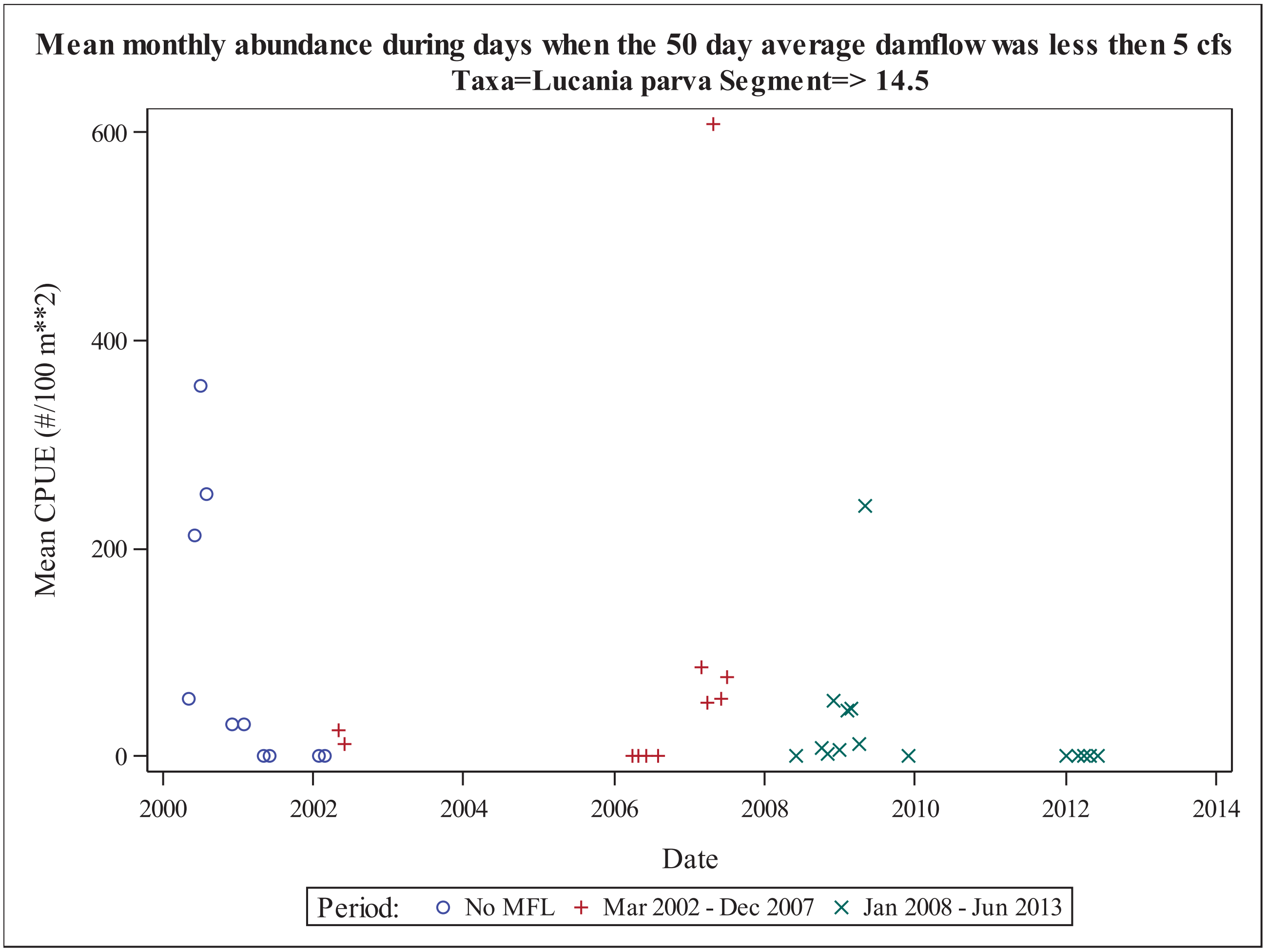
8. Lepomis microlophus

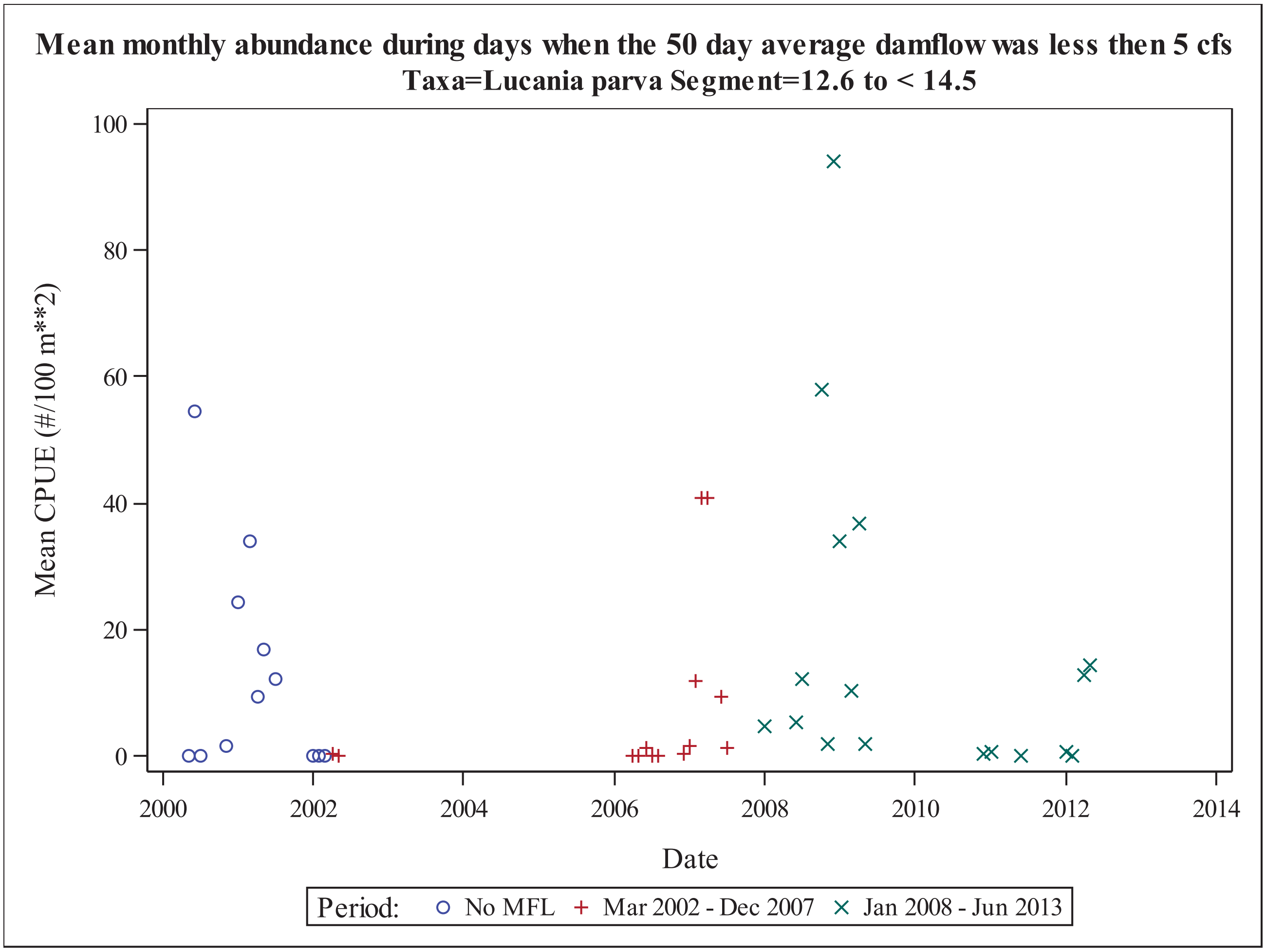


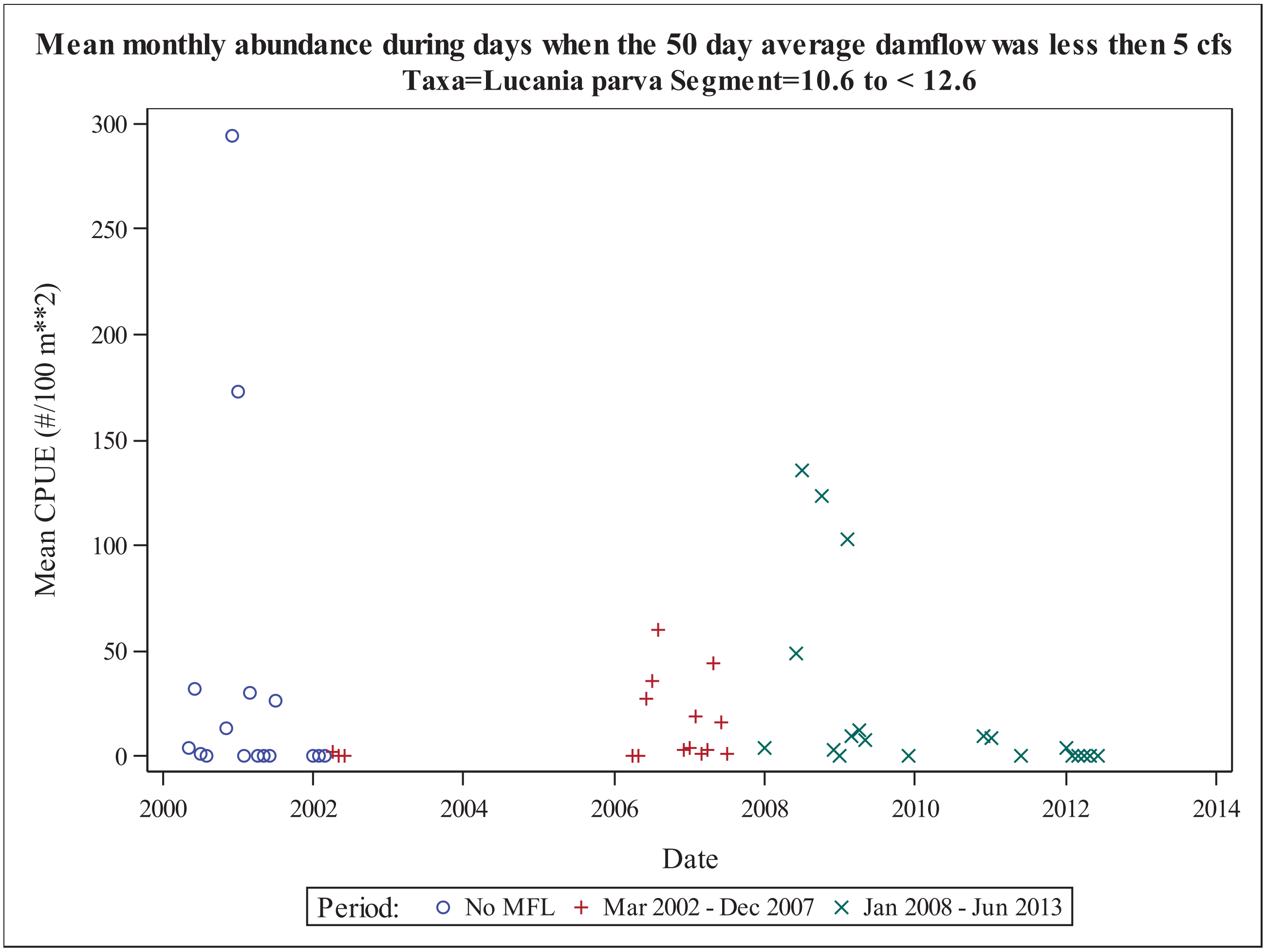

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Lepomis microlophus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0.0
0.1
0.2
0.3
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Lepomis microlophus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
1
2
3
4
5
6
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

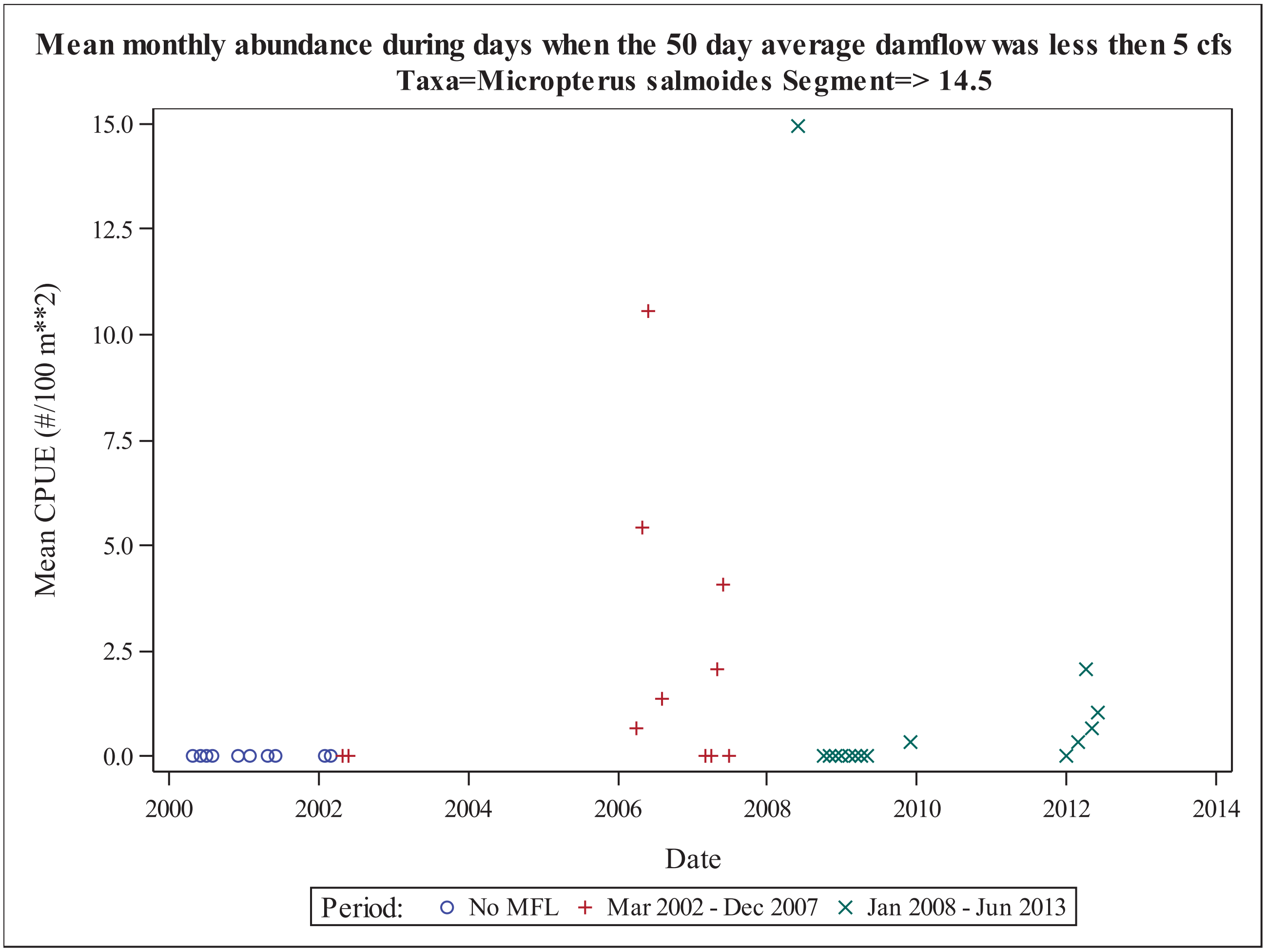
9. Lucania parva

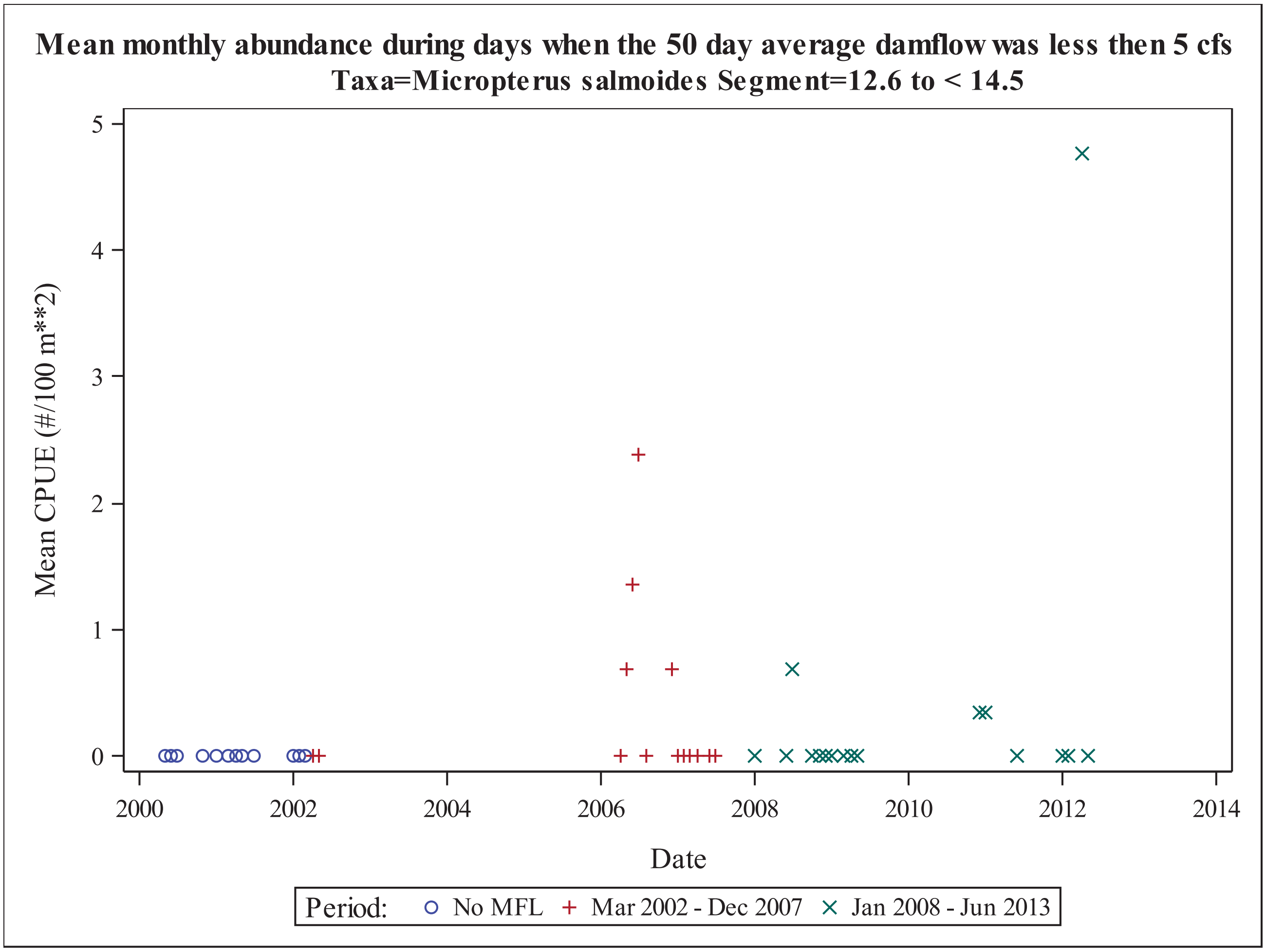


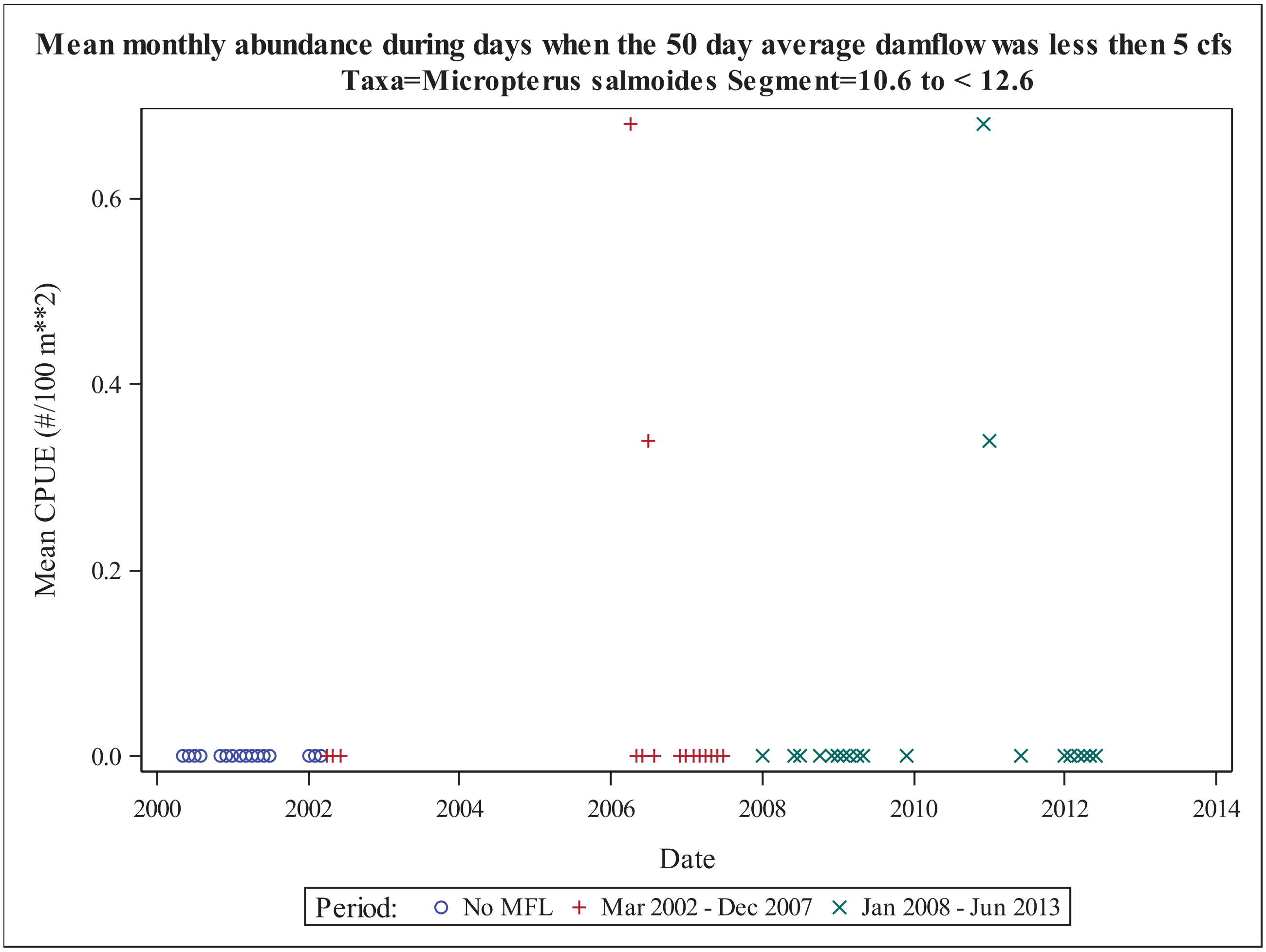

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Lucania parva Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
20
40
60
80
100
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Lucania parva Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
50
100
150
200
250
300
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

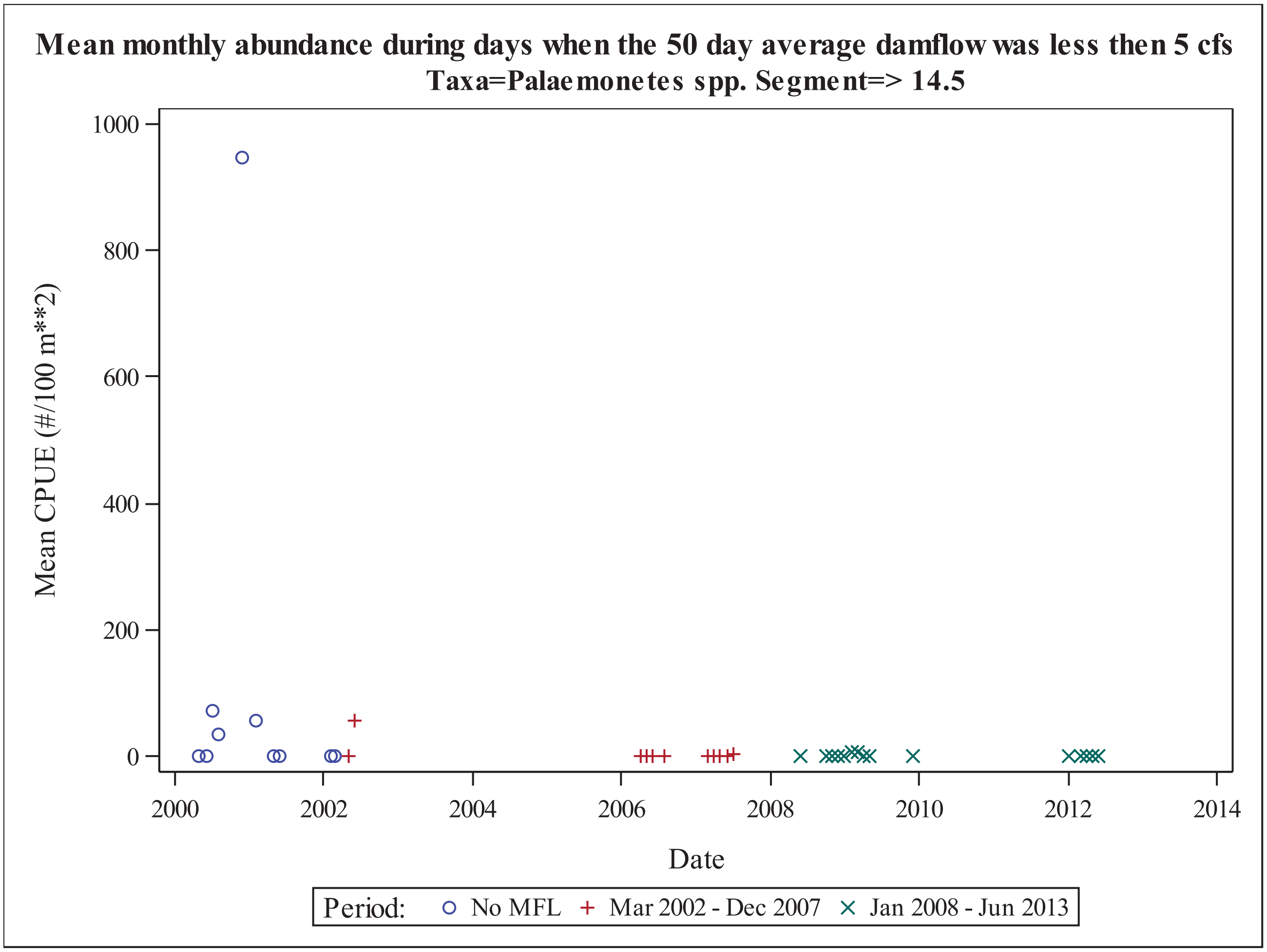
10. Micropterus salmoides

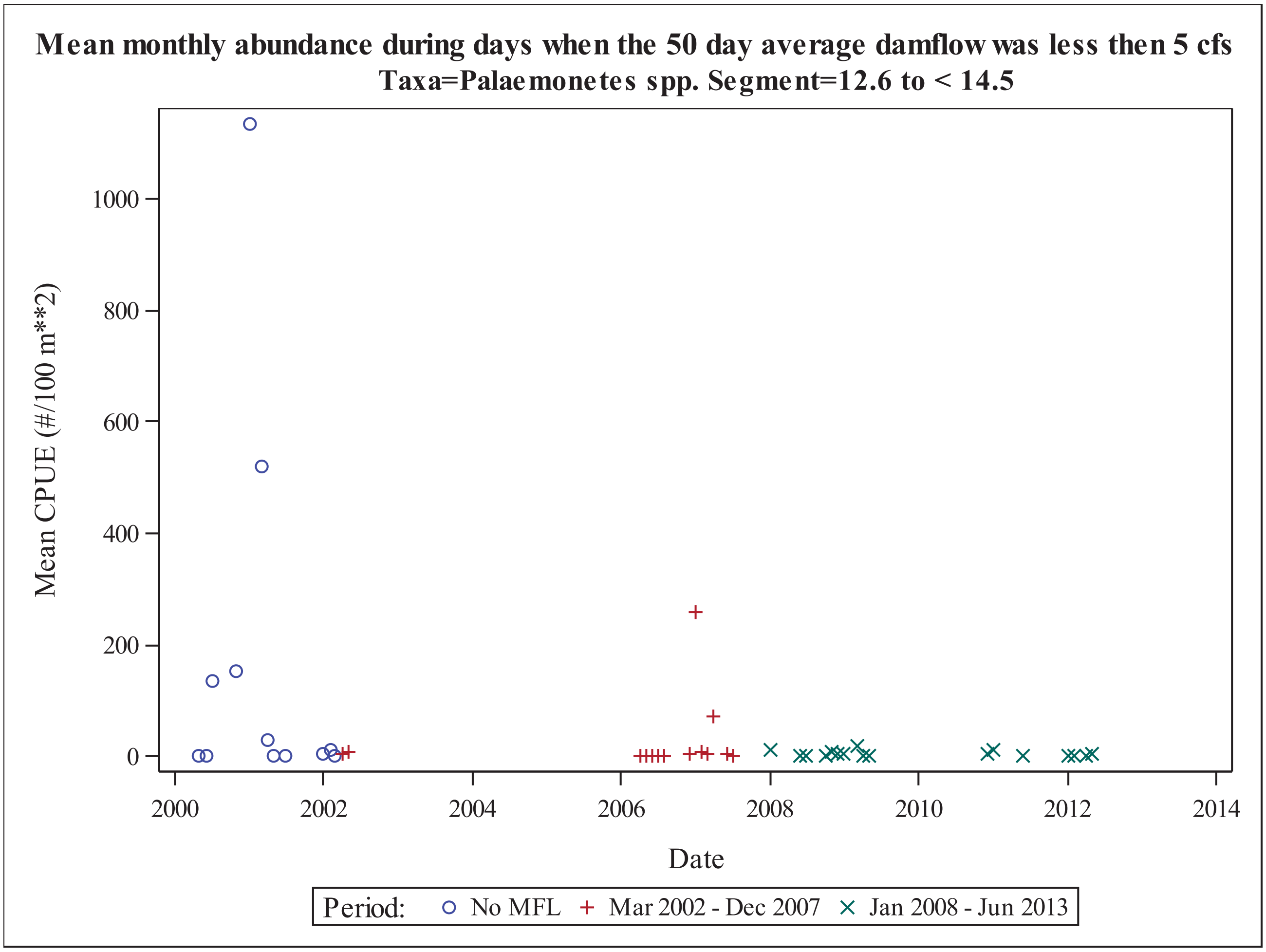



Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Micropterus salmoides Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
1
2
3
4
5
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

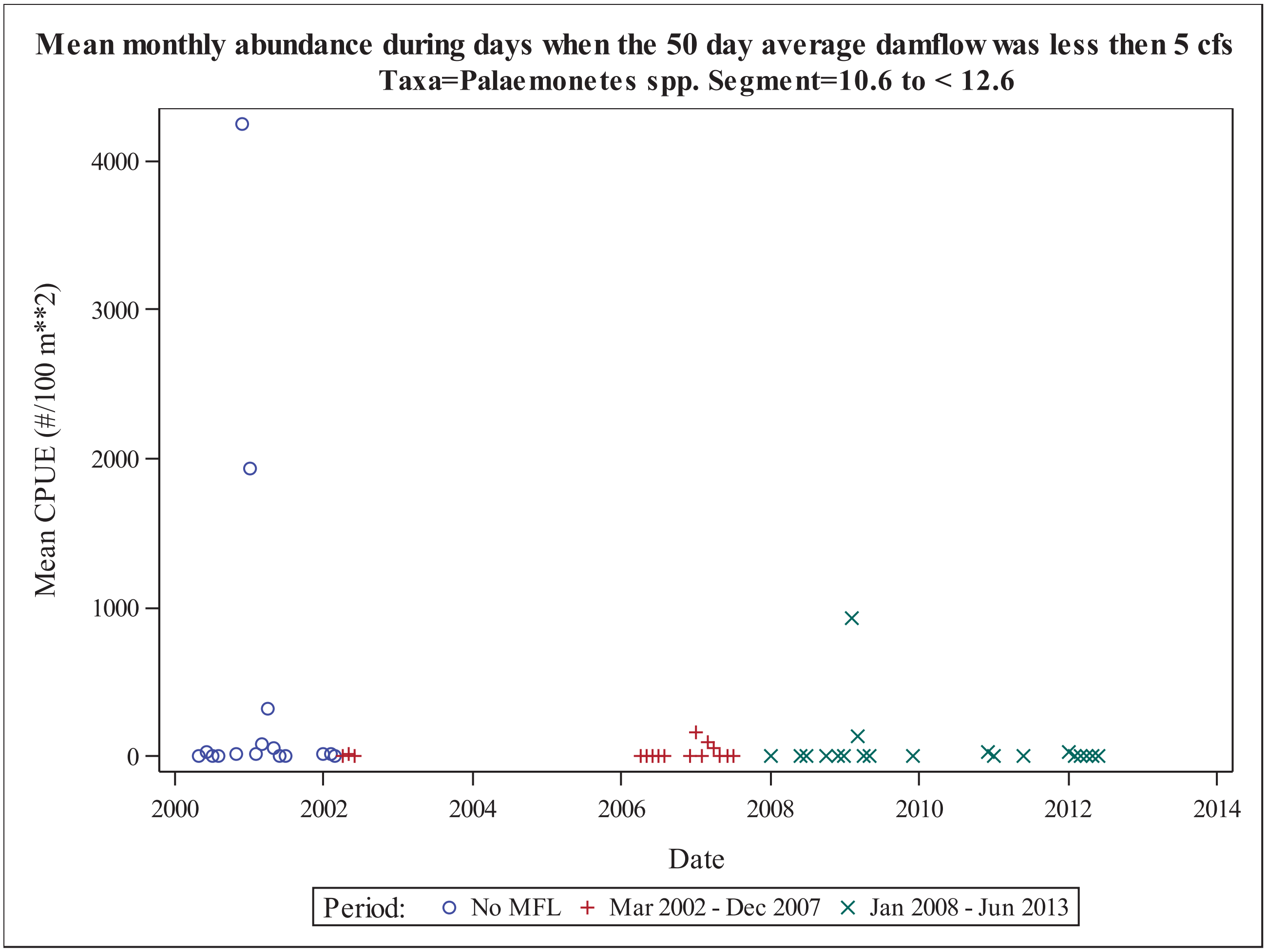

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Micropterus salmoides Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0.0
0.2
0.4
0.6
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

11. Palaemonetes spp.

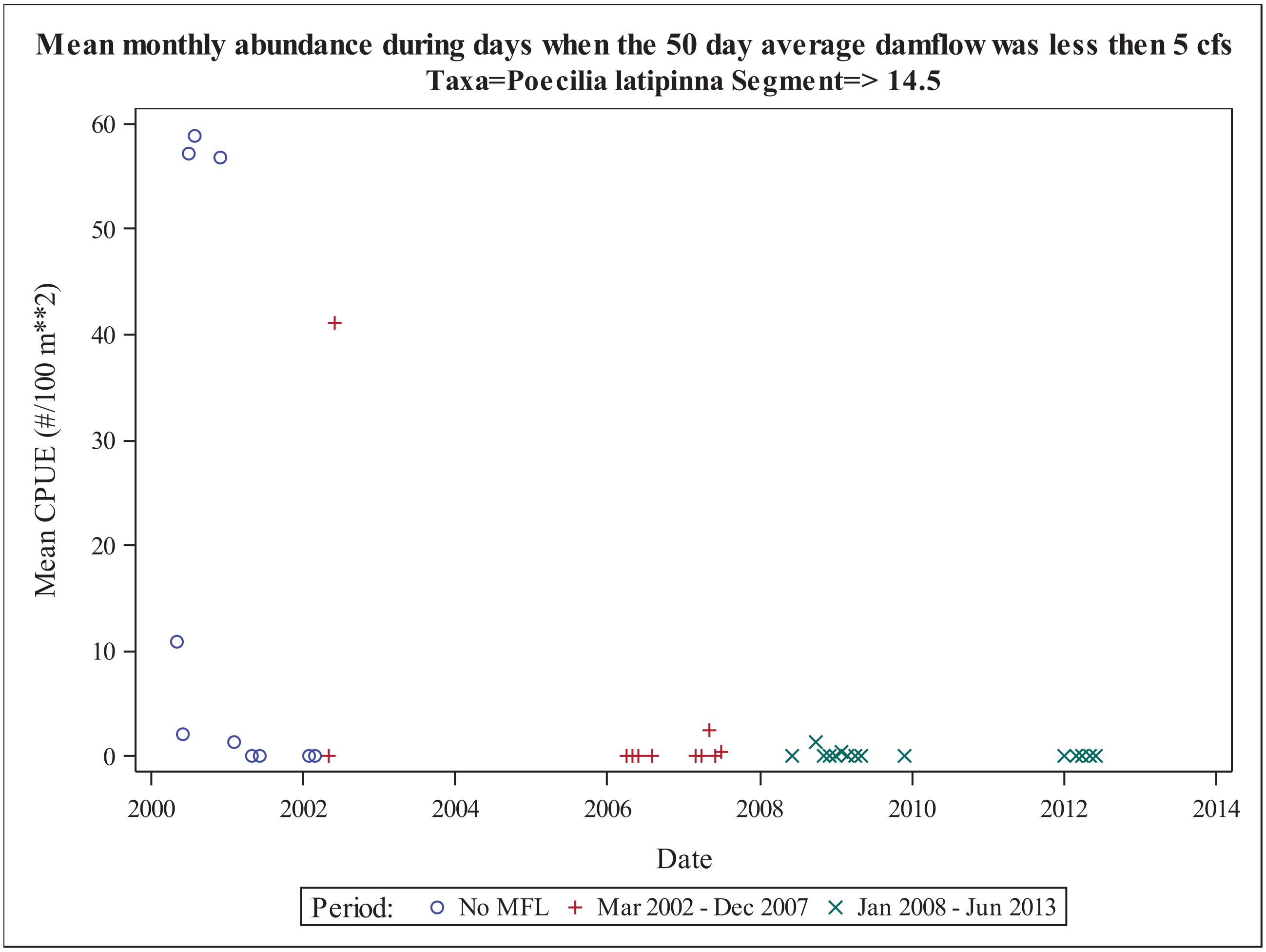


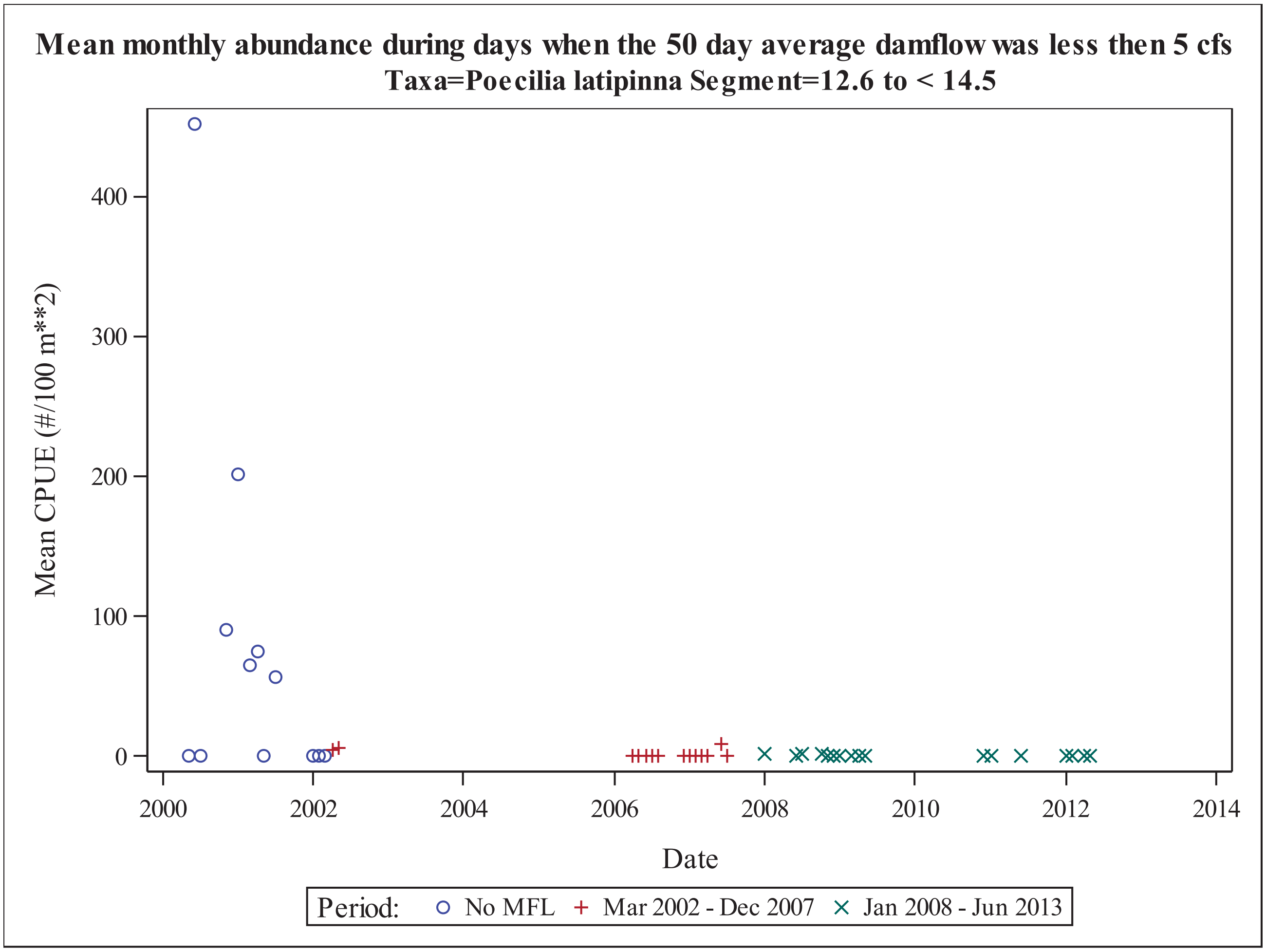


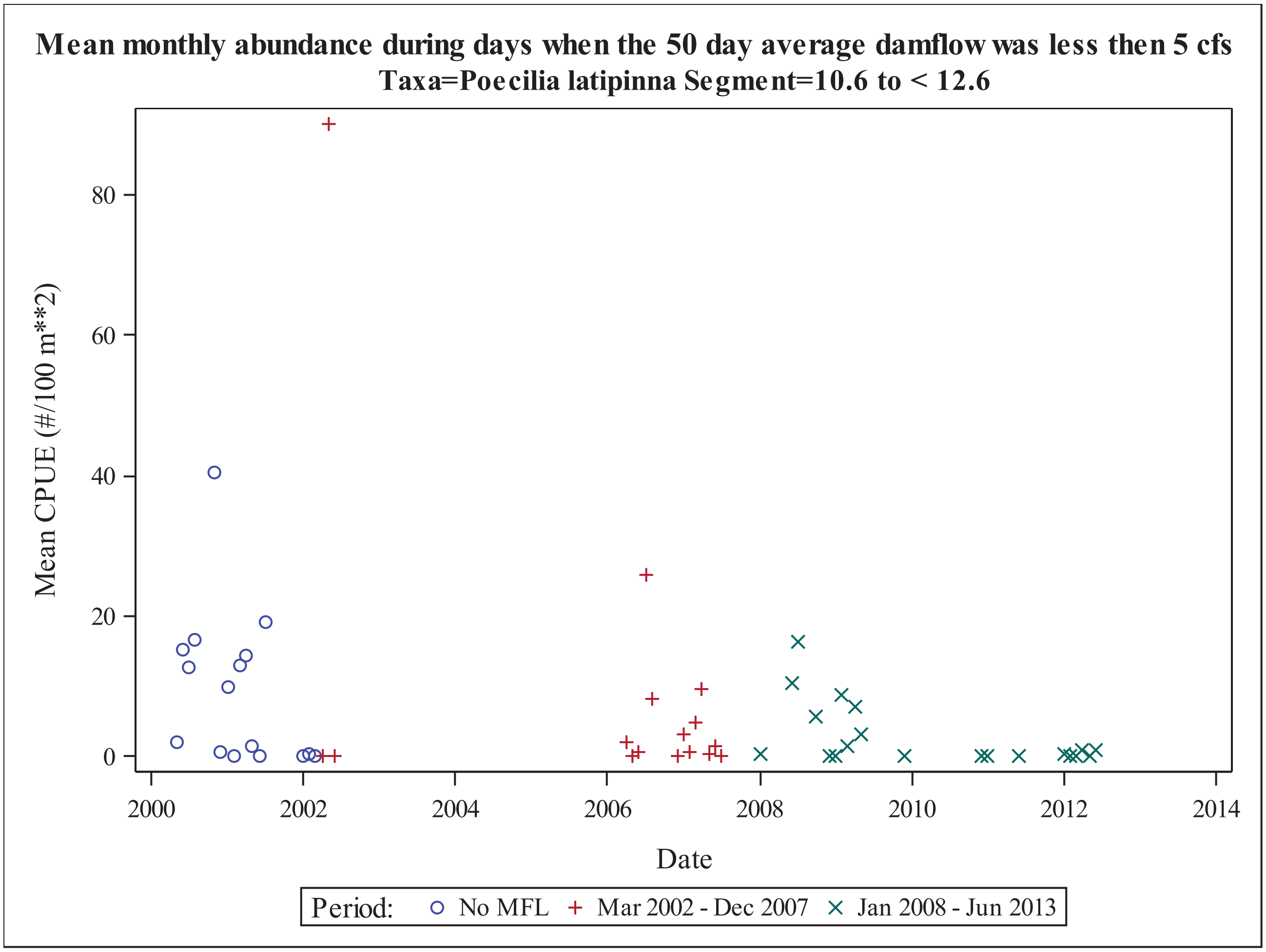
Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Palaemonetes spp. Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
200
400
600
800
1000
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Palaemonetes spp. Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
4000
3000
2000
1000
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

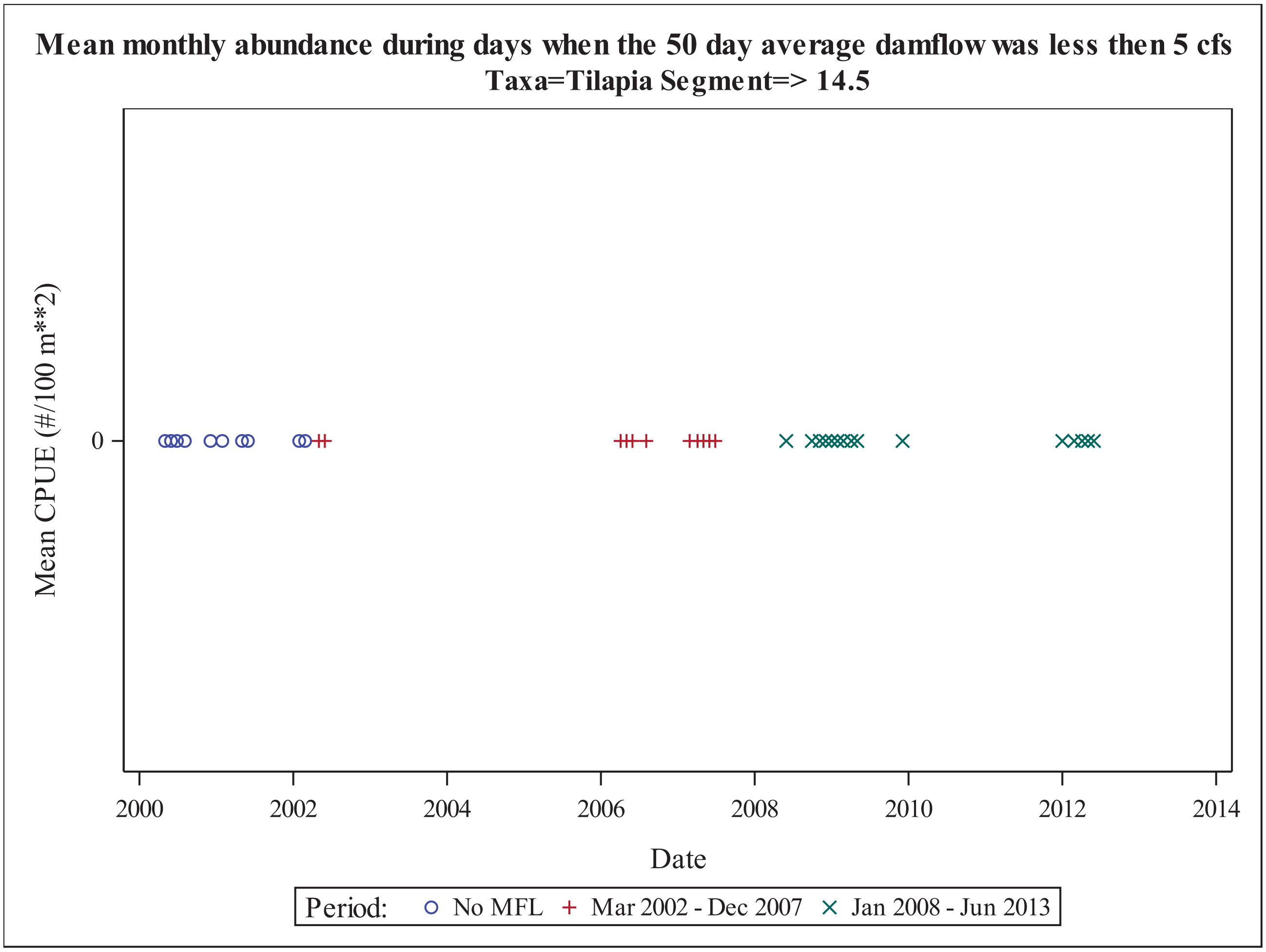
12. Poecilia latipinna

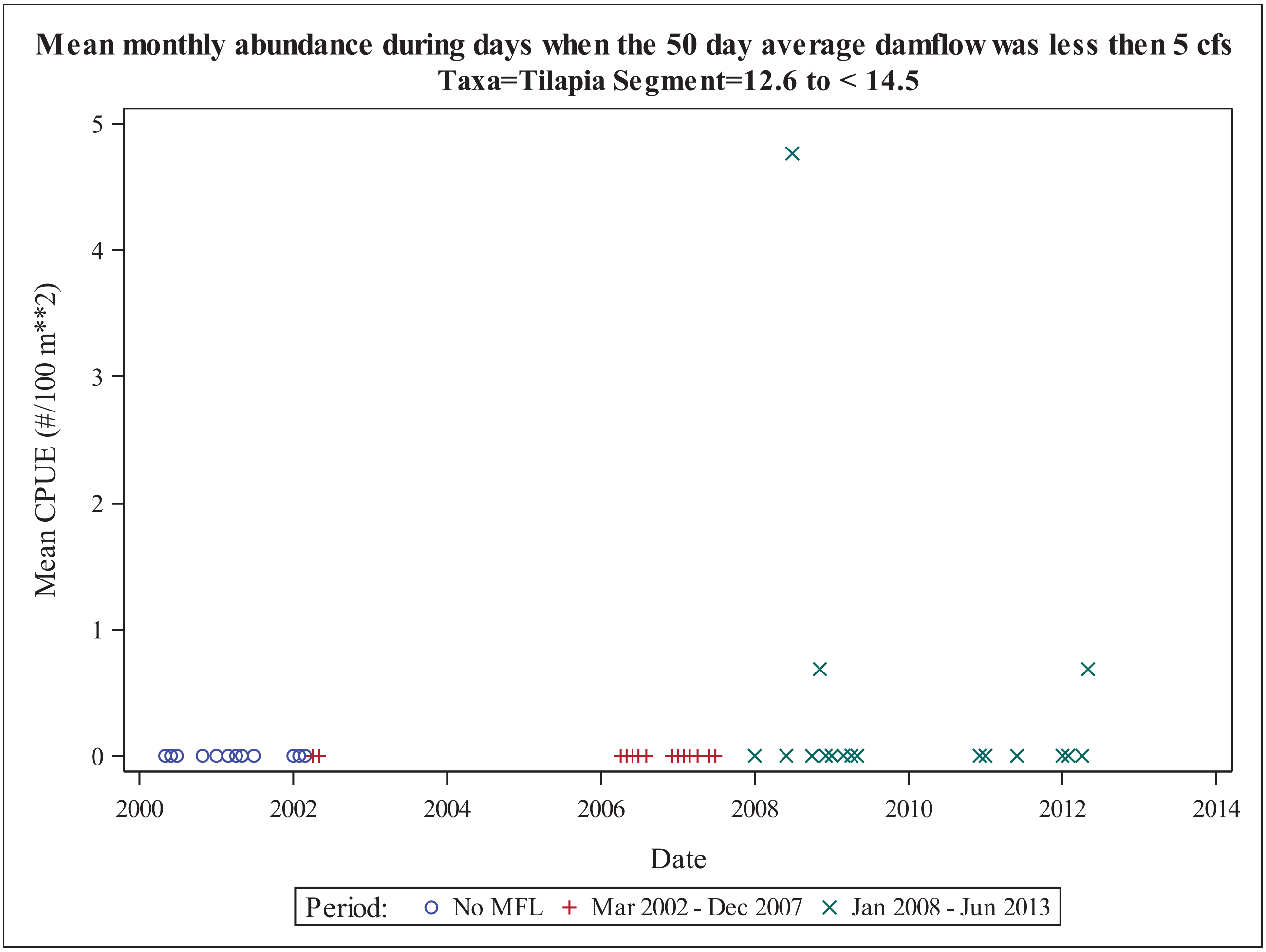


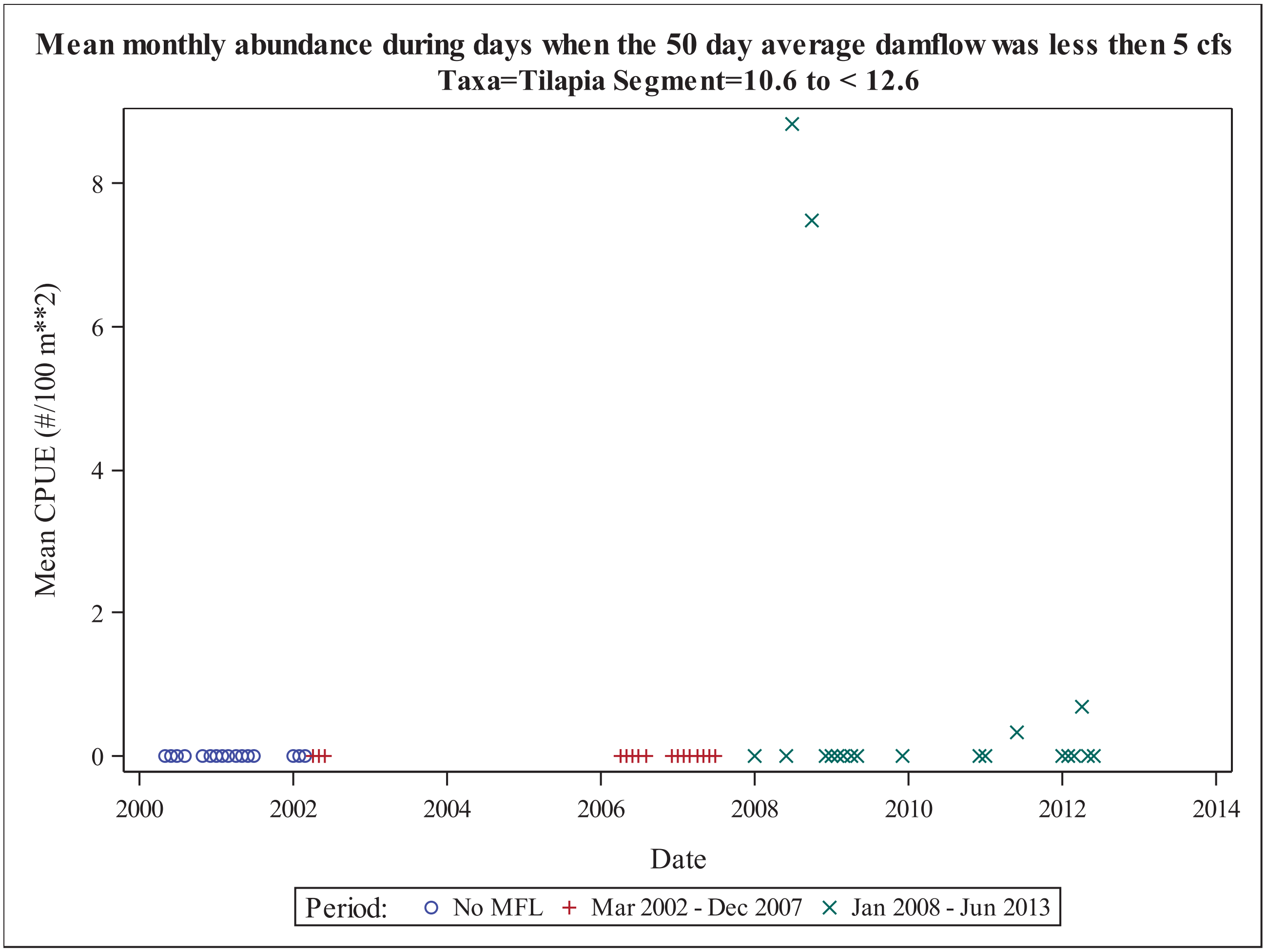

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Poecilia latipinna Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
100
200
300
400
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Poecilia latipinna Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
20
40
60
80
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

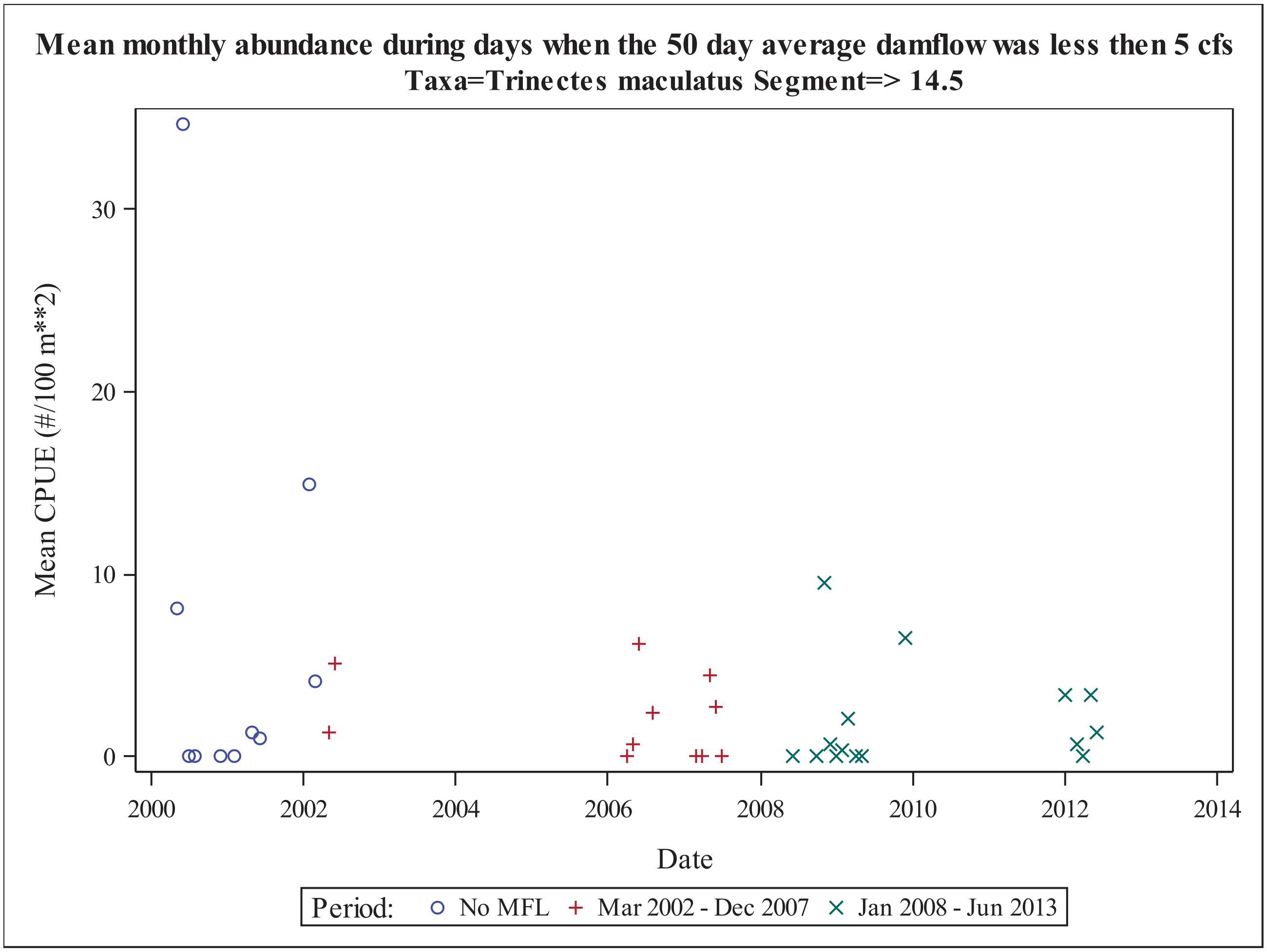
13. Tilapia

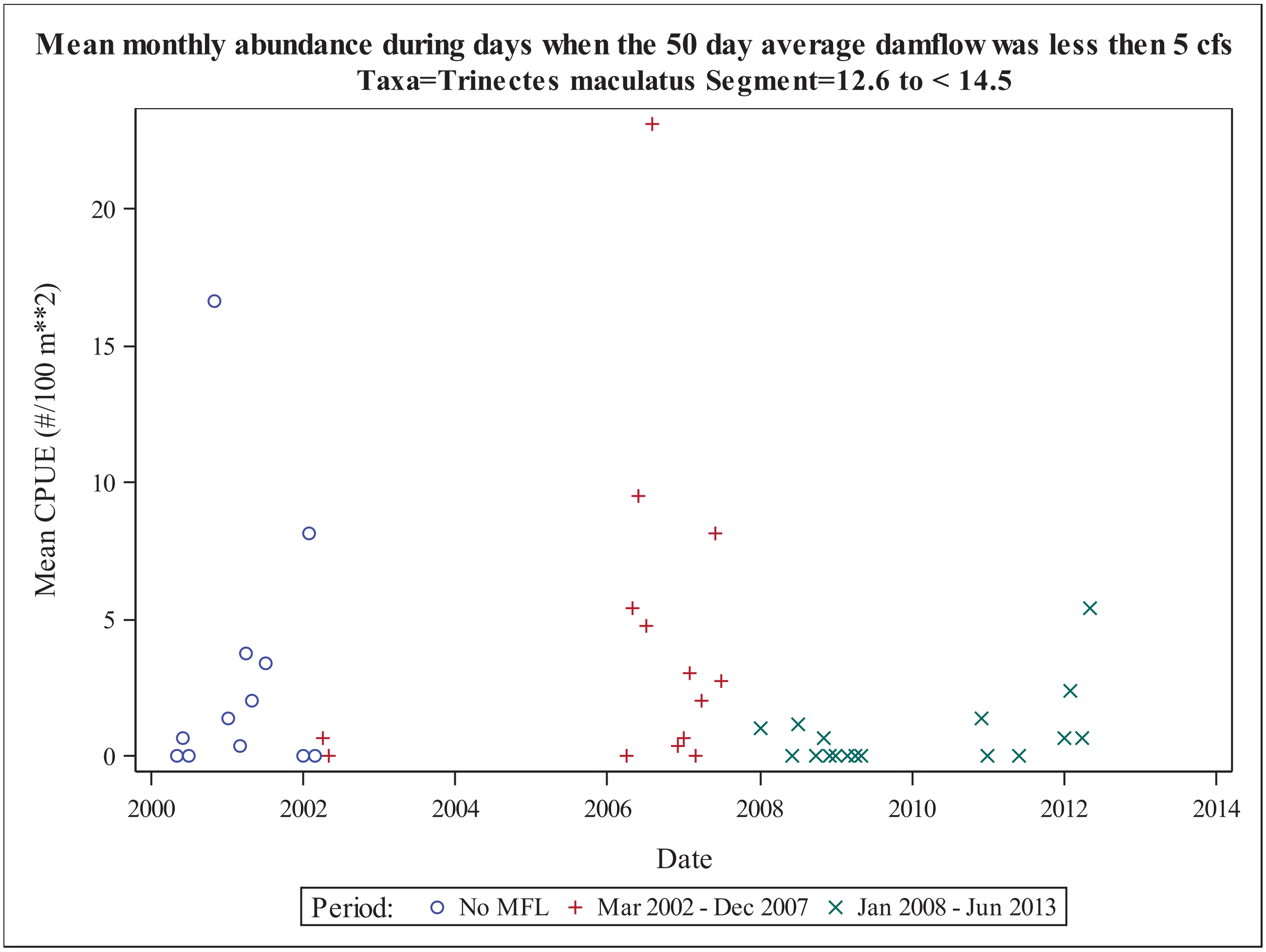

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Tilapia Segment=> 14.5
Mean CPUE (#/100 m**2)
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Tilapia Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
1
2
3
4
5
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

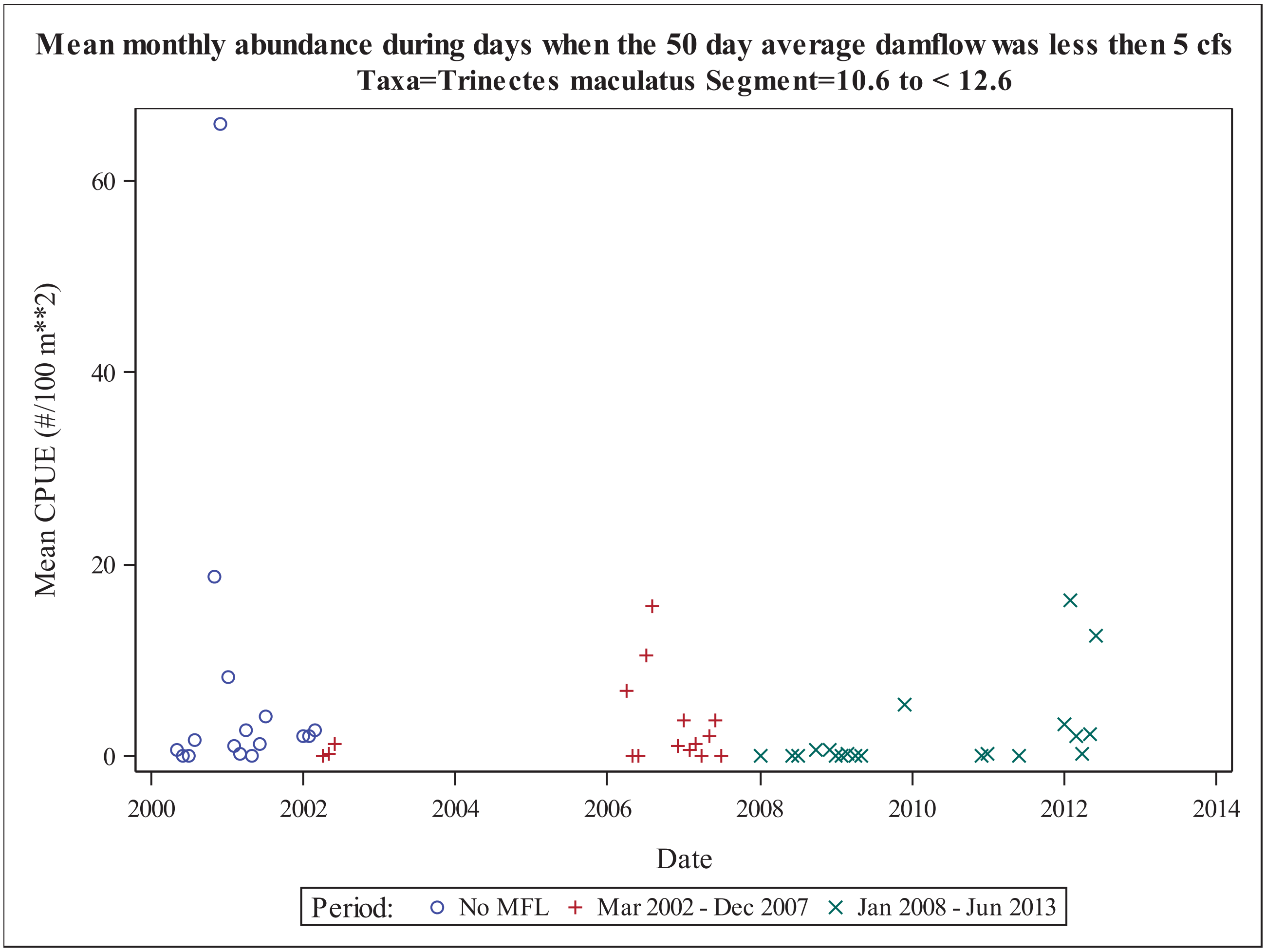

Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Tilapia Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
2
4
6
8
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

14. Trinectes maculatus




Mean monthly abundance during days when the 50 day average damflow was less then 5 cfs
Taxa=Trinectes maculatus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
5
10
15
20
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

Appendix 7B - Time Series Plots of Nekton Indicators for Dates with 50-Day Flows Less than 5 cfs



Appendix 7C - Wilcoxon Rank Sum Test for Nekton Indicators Using Data with 50-day Flows Less than 5 cfs

1. Wilcoxon Rank Sum Test for Brevoortia spp. by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.064 | --- | |
| Jan 2008 - Jun 2013 | 0.108 | 0.436 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.004 | --- | |
| Jan 2008 - Jun 2013 | 0.02 | 0.208 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.318 | --- | |
| Jan 2008 - Jun 2013 | 0.259 | 1 | --- |

2. Wilcoxon Rank Sum Test for Centropomus undecimalis by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 1 | 1 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.396 | --- | |
| Jan 2008 - Jun 2013 | 0.247 | 0.728 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.765 | 0.69 | --- |

3. Wilcoxon Rank Sum Test for Cyprinodon variegatus by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.072 | --- | |
| Jan 2008 - Jun 2013 | 0.277 | 0.006 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.045 | --- | |
| Jan 2008 - Jun 2013 | 0.569 | 0.114 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.46 | --- | |
| Jan 2008 - Jun 2013 | 0.477 | 0.149 | --- |

4. Wilcoxon Rank Sum Test for Fundulus seminolis by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.045 | --- | |
| Jan 2008 - Jun 2013 | 0.008 | 0.396 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.413 | --- | |
| Jan 2008 - Jun 2013 | 0.346 | 1 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.349 | --- | |
| Jan 2008 - Jun 2013 | 0.037 | 0.122 | --- |

5. Wilcoxon Rank Sum Test for Gambusia holbrooki by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.084 | --- | |
| Jan 2008 - Jun 2013 | 0.002 | 0.065 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.08 | --- | |
| Jan 2008 - Jun 2013 | 0.02 | 0.271 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.179 | --- | |
| Jan 2008 - Jun 2013 | 0.845 | 0.371 | --- |

6. Wilcoxon Rank Sum Test for Labidesthes sicculus by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.045 | --- | |
| Jan 2008 - Jun 2013 | 0.154 | 0.425 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.396 | --- | |
| Jan 2008 - Jun 2013 | 1 | 0.3 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.402 | 0.402 | --- |

7. Wilcoxon Rank Sum Test for Lepomis macrochirus by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.009 | --- | |
| Jan 2008 - Jun 2013 | 0.016 | 0.617 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.054 | --- | |
| Jan 2008 - Jun 2013 | 0.441 | 0.129 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.164 | --- | |
| Jan 2008 - Jun 2013 | 0.02 | 0.168 | --- |

8. Wilcoxon Rank Sum Test for Lepomis microlophus by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.045 | --- | |
| Jan 2008 - Jun 2013 | 0.052 | 0.737 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.396 | --- | |
| Jan 2008 - Jun 2013 | 1 | 0.3 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.037 | 0.037 | --- |

## 9. Wilcoxon Rank Sum Test for Lucania parva by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.695 | --- | |
| Jan 2008 - Jun 2013 | 0.147 | 0.225 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.615 | --- | |
| Jan 2008 - Jun 2013 | 0.435 | 0.079 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.632 | --- | |
| Jan 2008 - Jun 2013 | 0.573 | 0.848 | --- |

## 10. Wilcoxon Rank Sum Test for Micropterus salmoides by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.009 | --- | |
| Jan 2008 - Jun 2013 | 0.029 | 0.271 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.054 | --- | |
| Jan 2008 - Jun 2013 | 0.083 | 0.661 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.164 | --- | |
| Jan 2008 - Jun 2013 | 0.214 | 0.838 | --- |

## 11. Wilcoxon Rank Sum Test for Palaemonetes spp.by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.412 | --- | |
| Jan 2008 - Jun 2013 | 0.143 | 0.623 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.475 | --- | |
| Jan 2008 - Jun 2013 | 0.39 | 0.84 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.095 | --- | |
| Jan 2008 - Jun 2013 | 0.052 | 0.948 | --- |

## 12. Wilcoxon Rank Sum Test for Poecilia latipinna by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.093 | --- | |
| Jan 2008 - Jun 2013 | 0.007 | 0.346 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.13 | --- | |
| Jan 2008 - Jun 2013 | 0.072 | 0.582 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.34 | --- | |
| Jan 2008 - Jun 2013 | 0.05 | 0.403 | --- |

## 13. Wilcoxon Rank Sum Test for Tilapia by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 1 | 1 | --- |

| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.143 | 0.113 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 1 | --- | |
| Jan 2008 - Jun 2013 | 0.066 | 0.066 | --- |

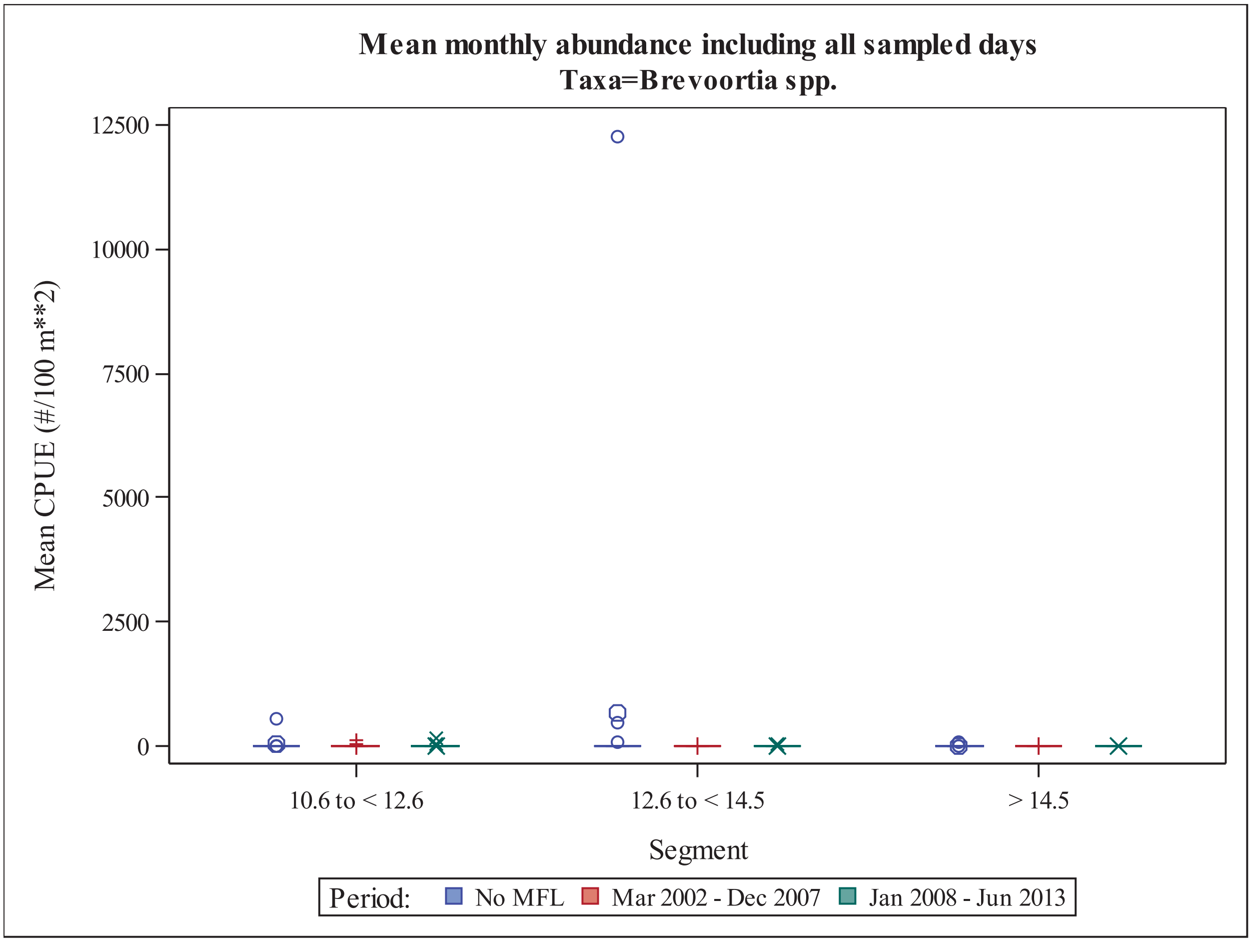
## 14. Wilcoxon Rank Sum Test for Trinectes maculatus by River Kilometer Segment

| 16.2 - 14.5 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.772 | --- | |
| Jan 2008 - Jun 2013 | 0.491 | 0.688 | --- |

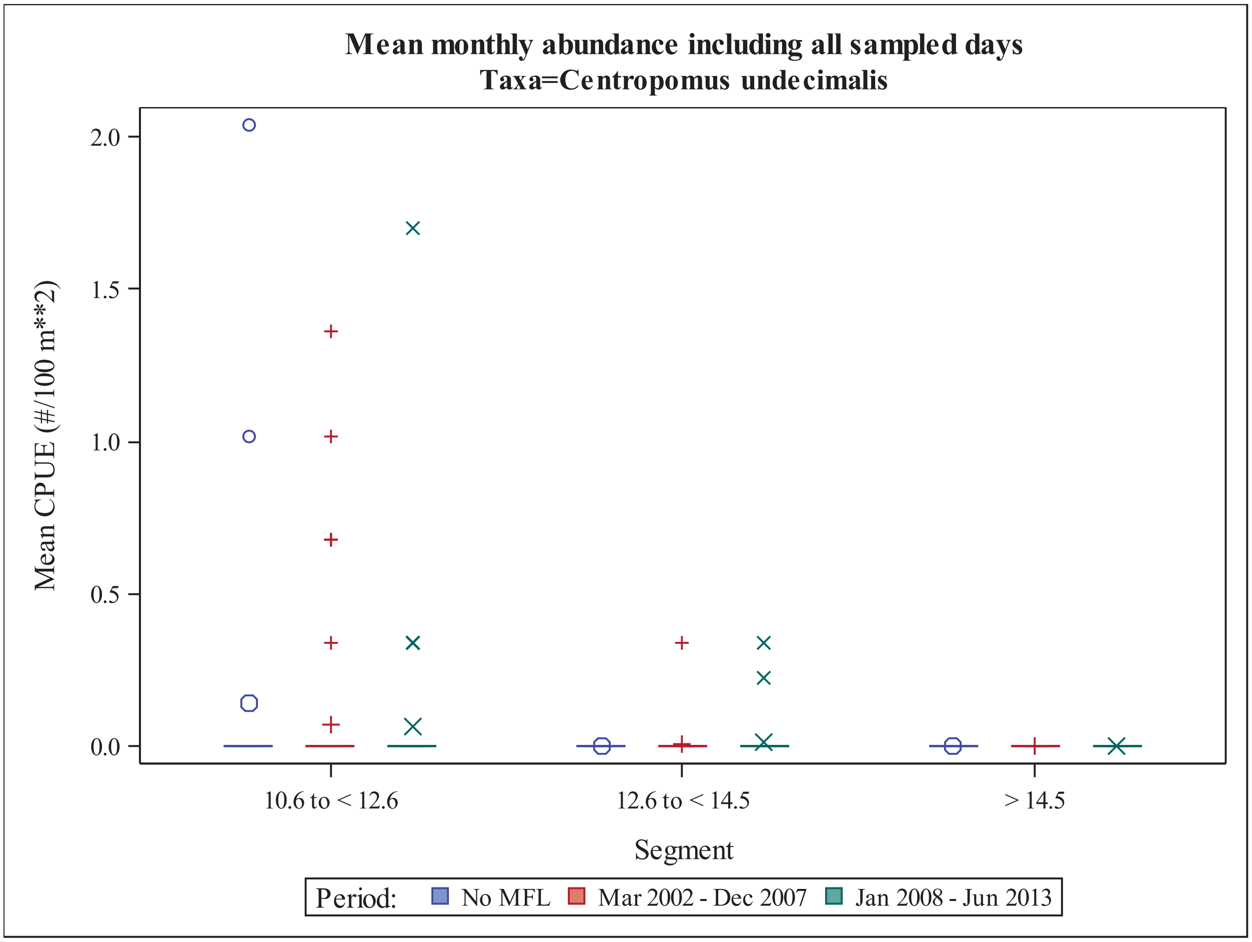
| 14.5 - 12.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.467 | --- | |
| Jan 2008 - Jun 2013 | 0.156 | 0.026 | --- |

| 12.6 - 10.6 KM | No MFL | Mar 2002 - Dec 2007 | Jan 2008 - Jun 2013 |
|---|---|---|---|
| No MFL | --- | | |
| Mar 2002 - Dec 2007 | 0.458 | --- | |
| Jan 2008 - Jun 2013 | 0.077 | 0.309 | --- |

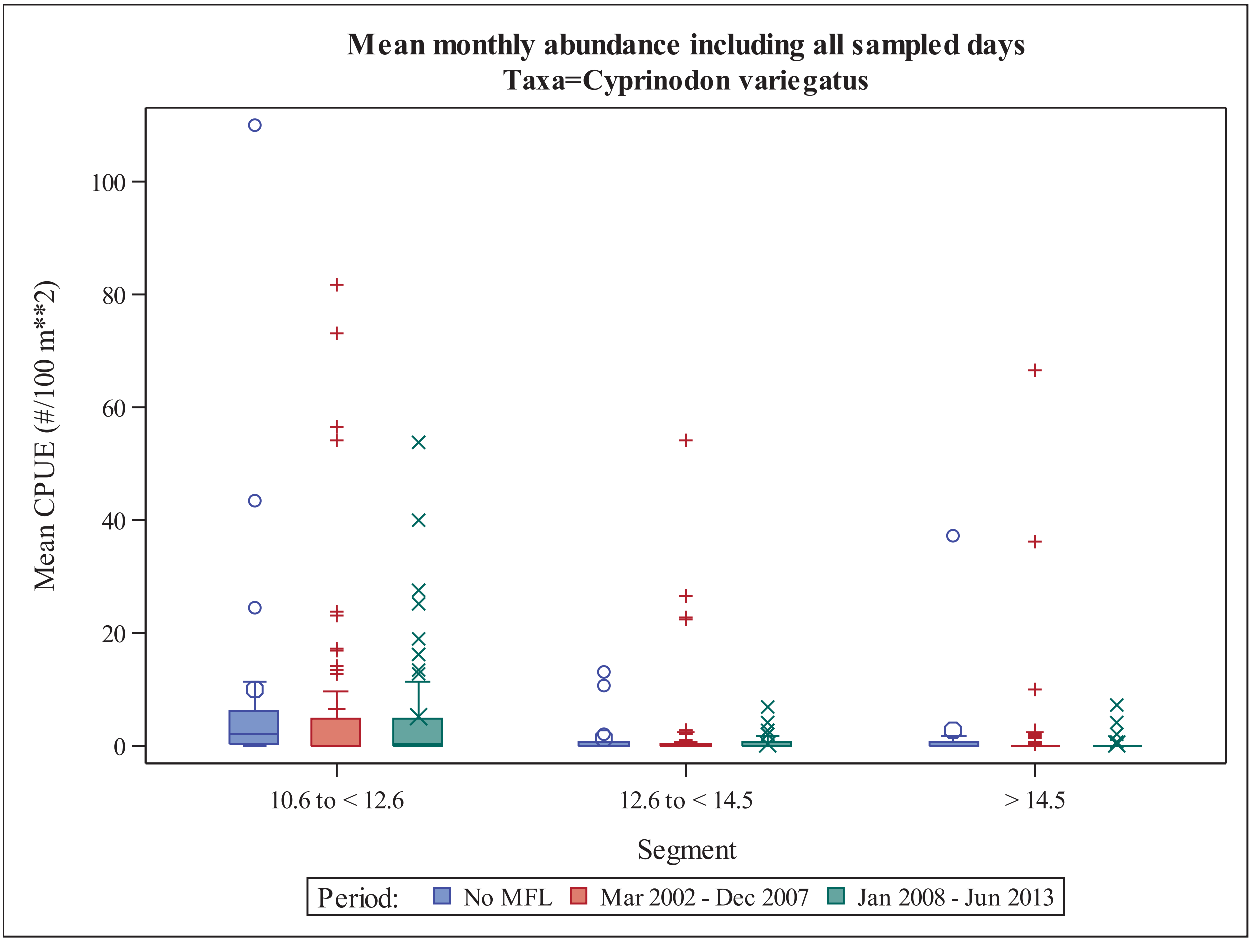
1. Mean Monthly Abundance of Brevoortia spp.



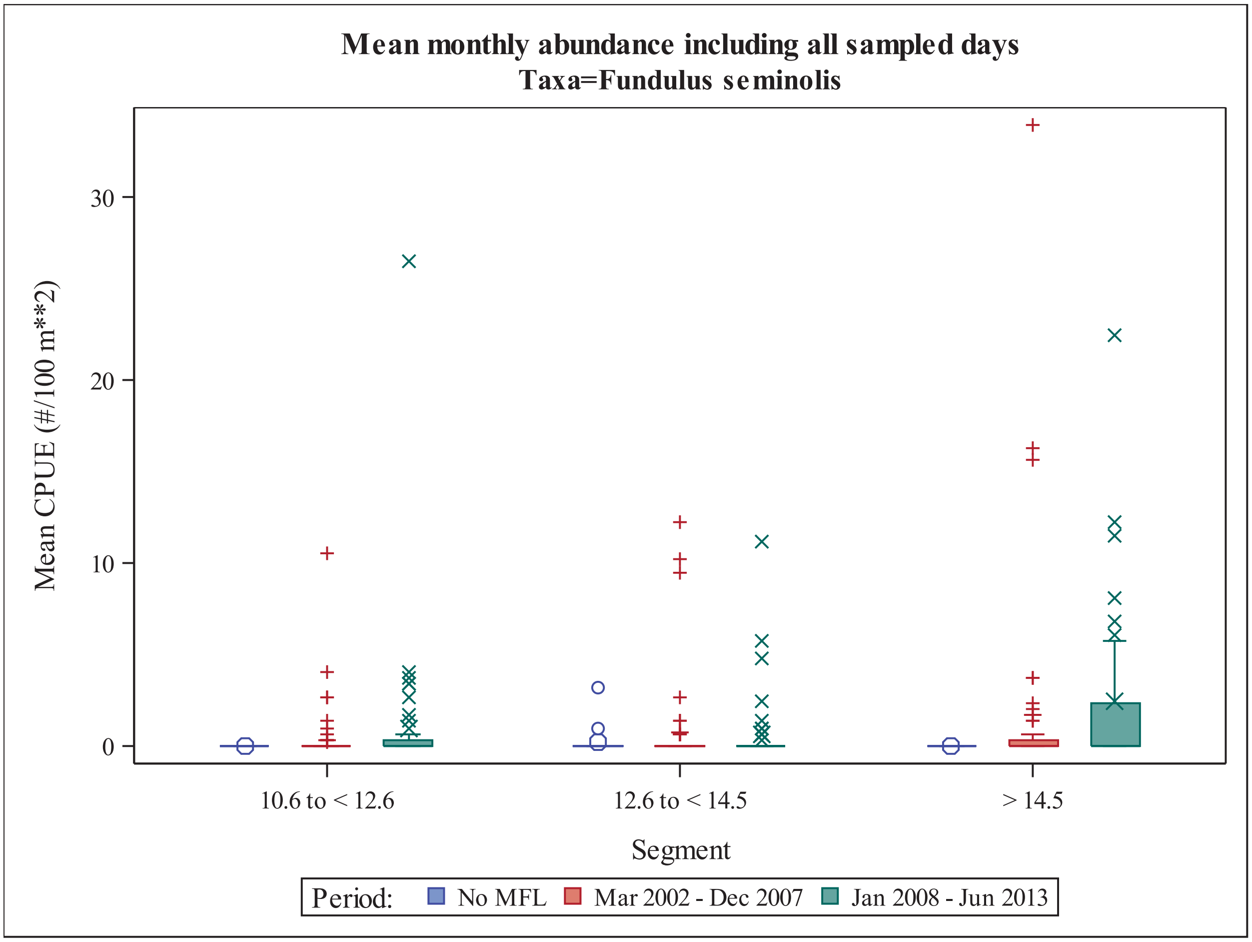
2. Mean Monthly Abundance of Centropomus undecimalis



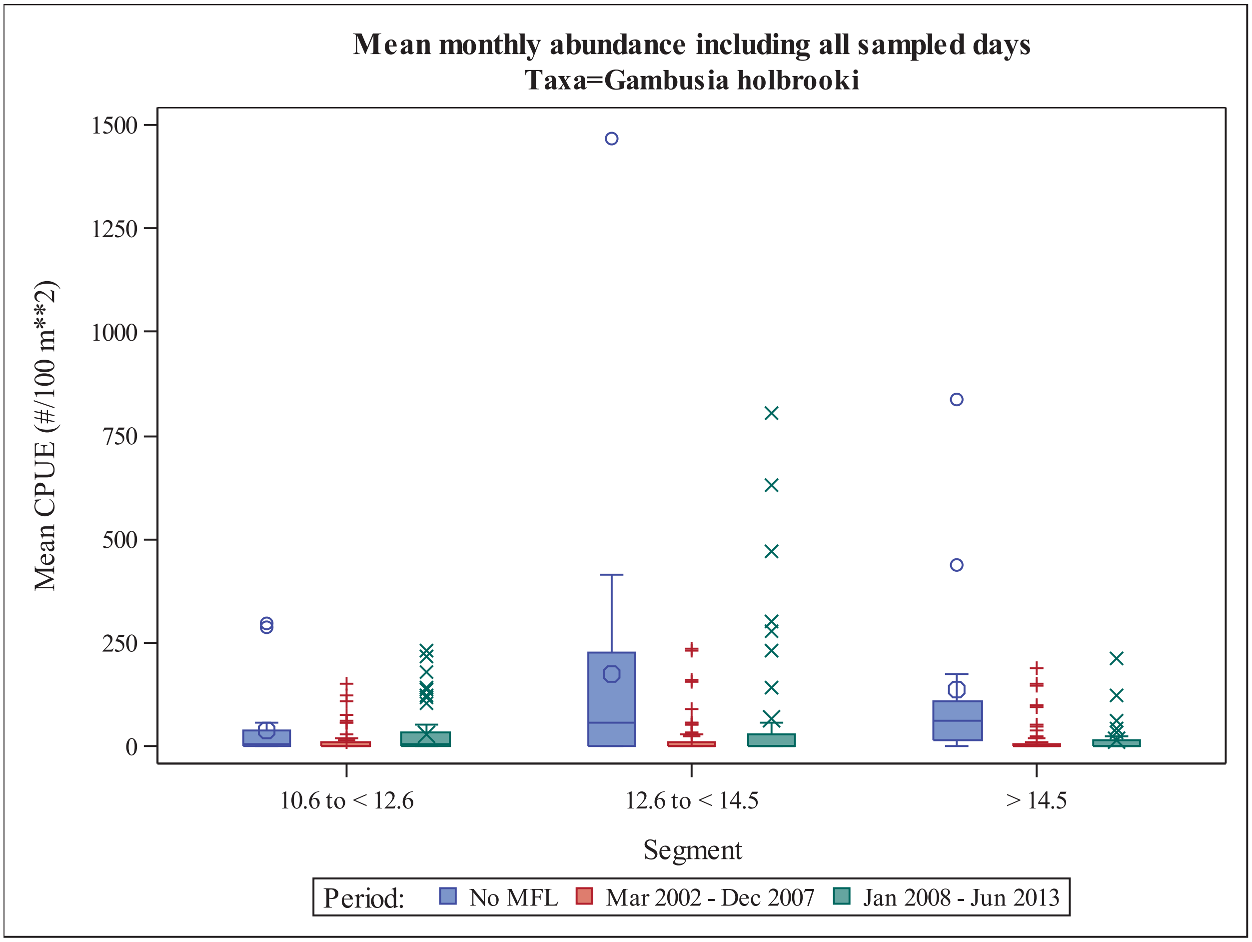
3. Mean Monthly Abundance of Cyprinodon variegatus



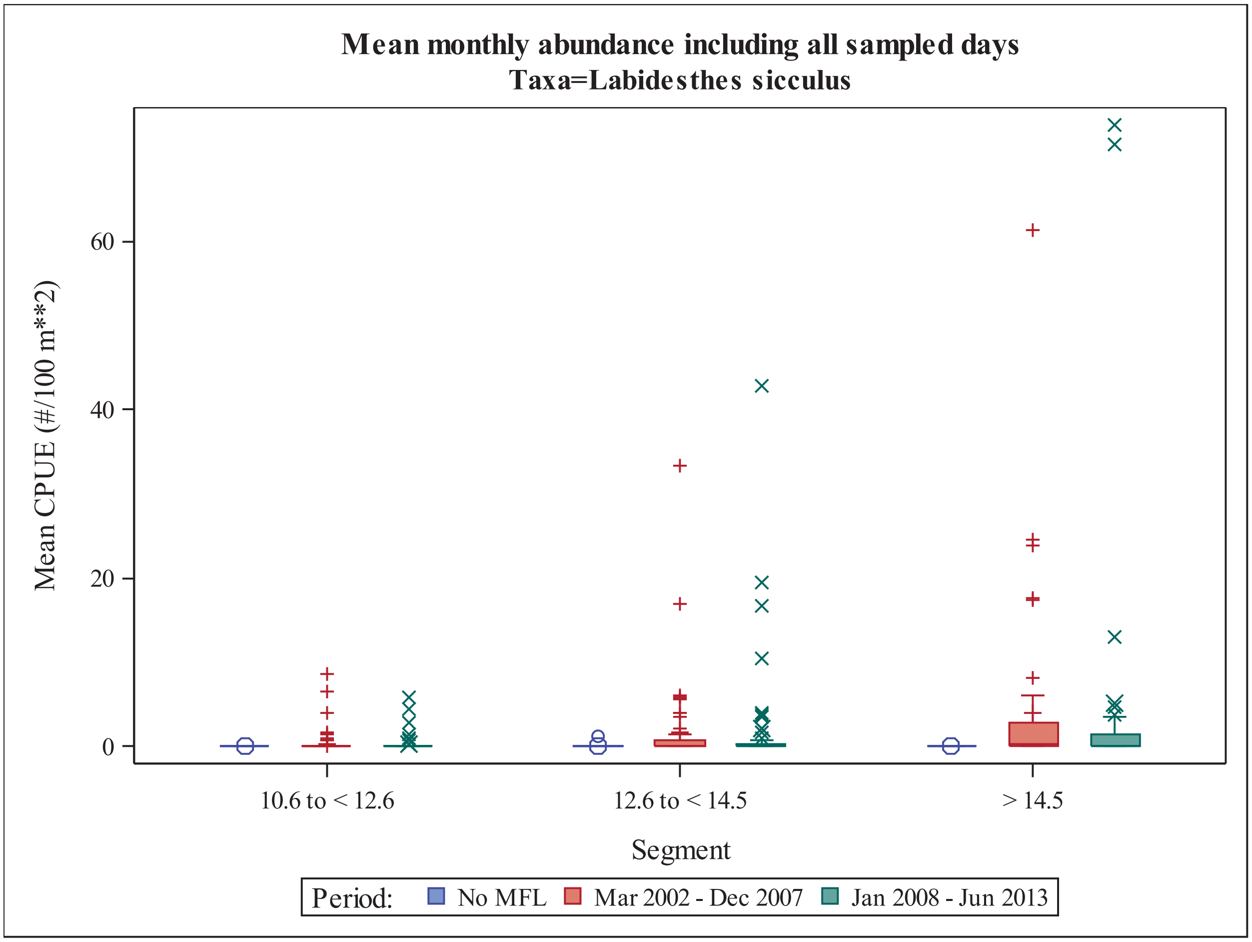
4. Mean Monthly Abundance of Fundulus seminolis



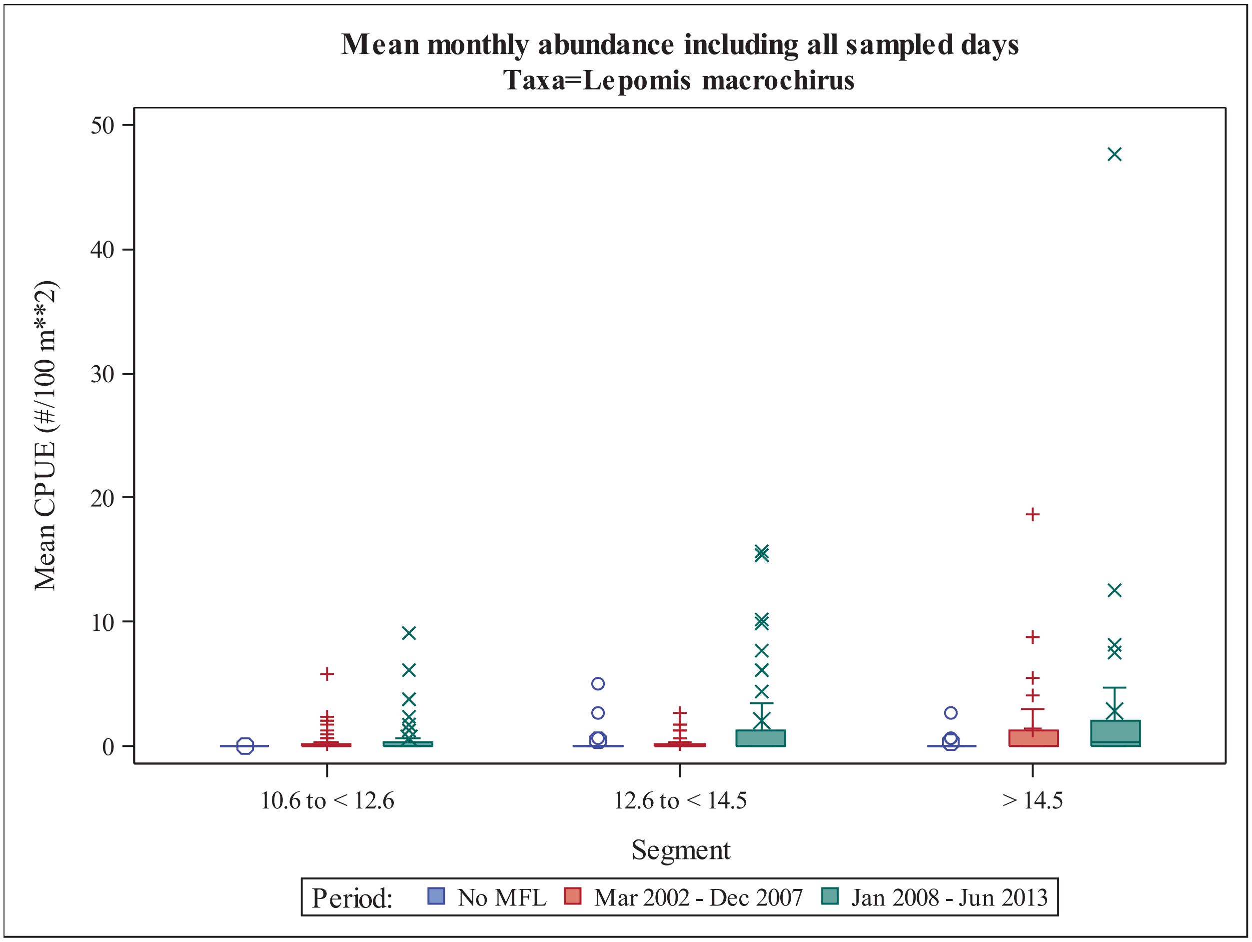
5. Mean Monthly Abundance of Gambusia holbrooki



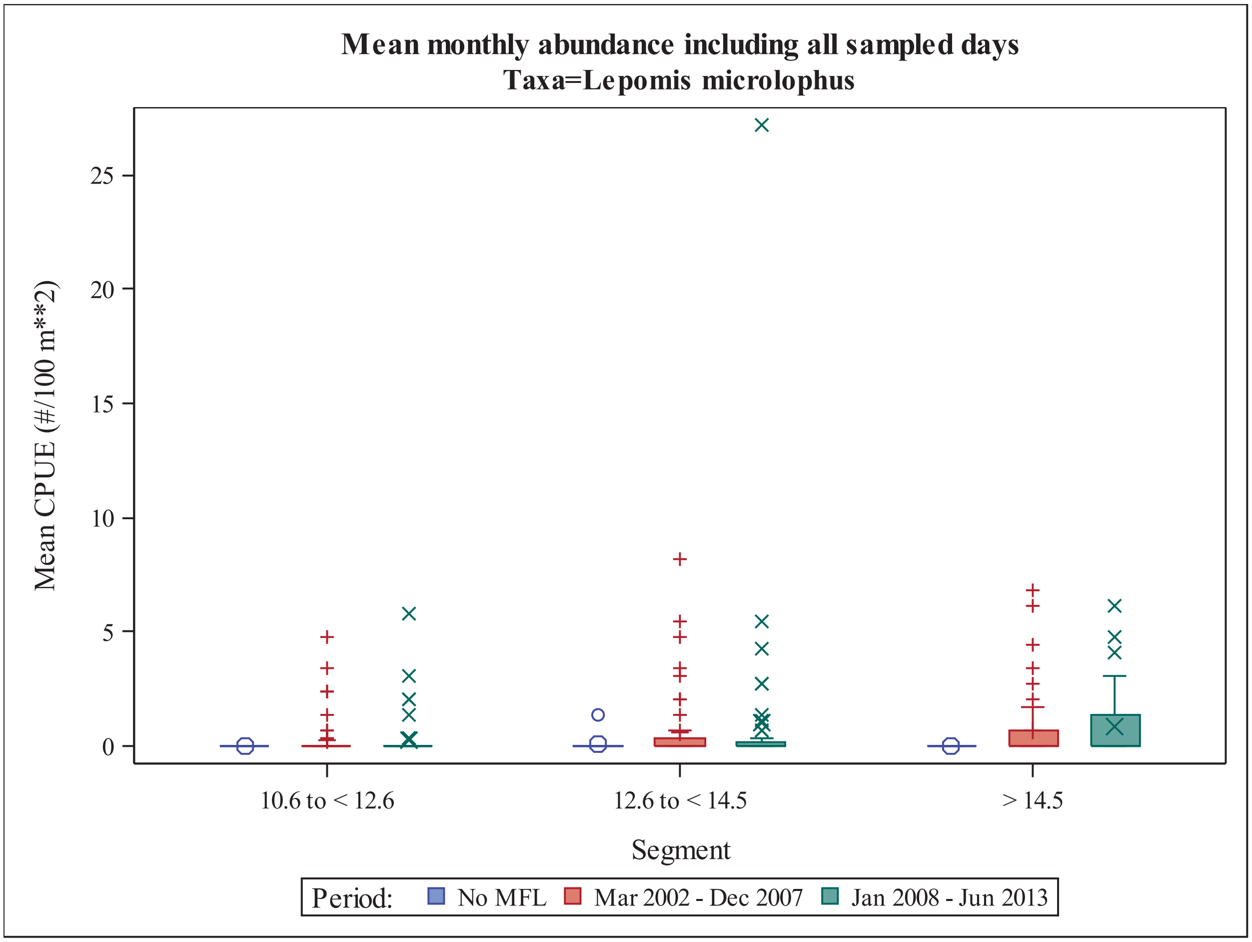
6. Mean Monthly Abundance of Labidesthes sicculus



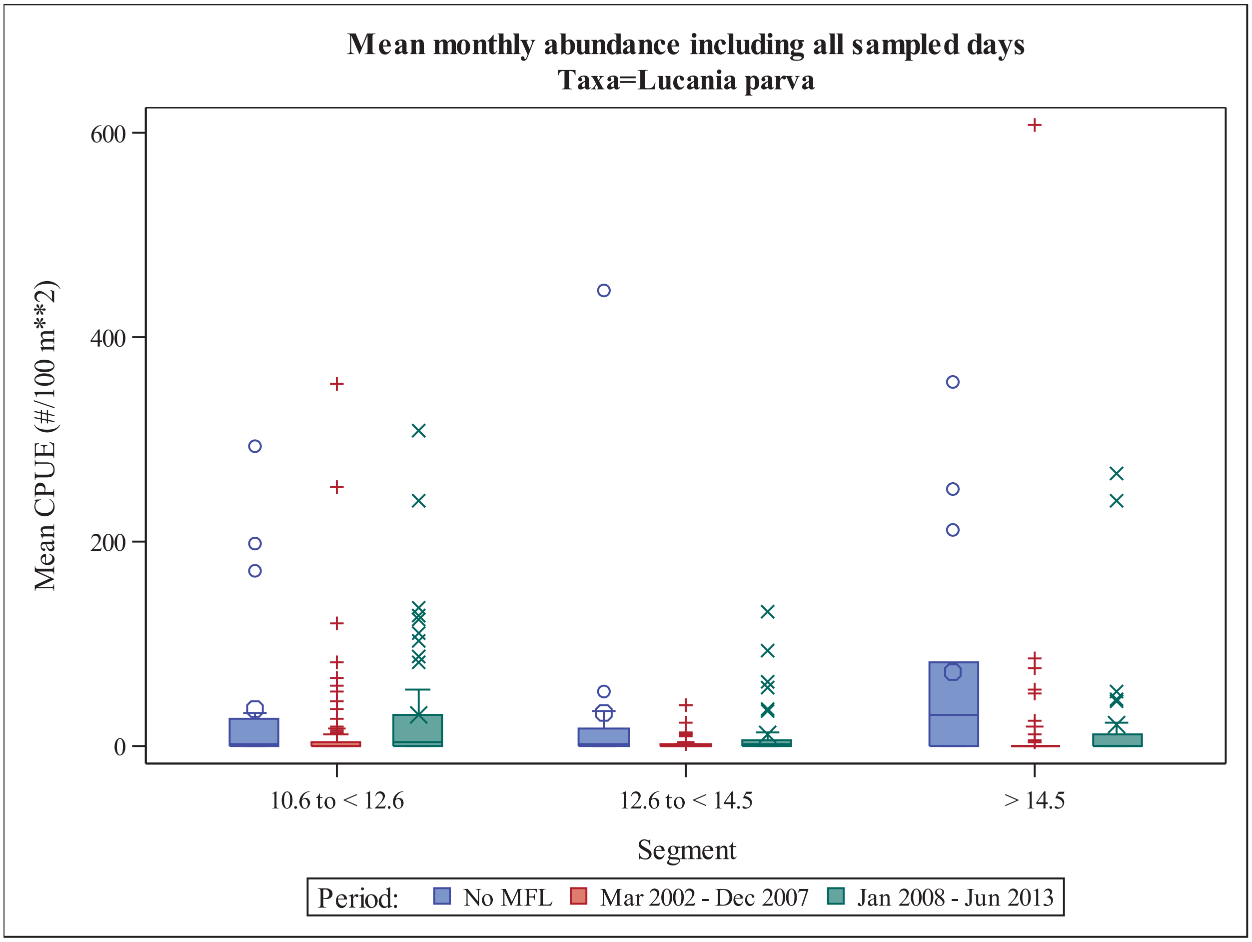
7. Mean Monthly Abundance of Lepomis macrochirus



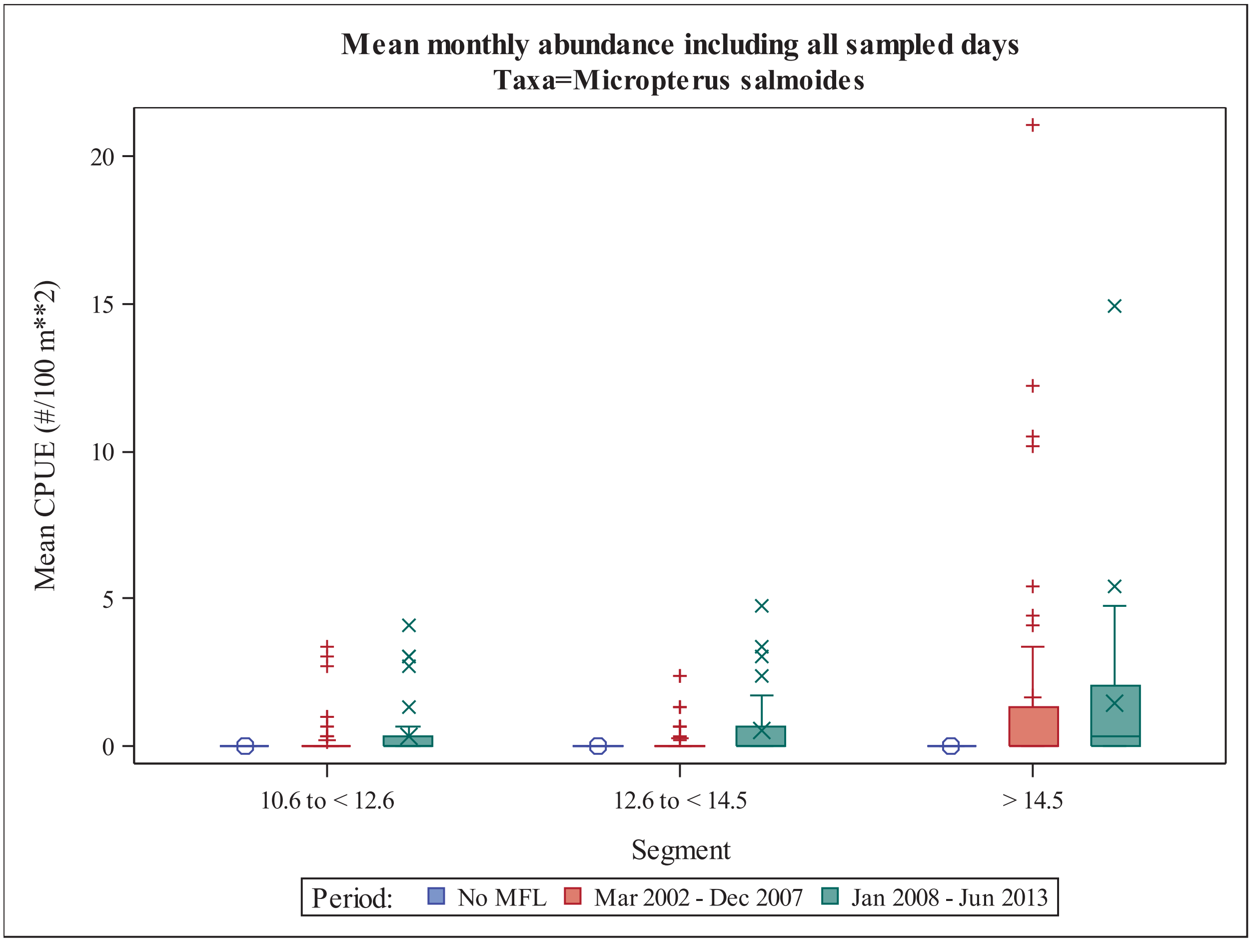
8. Mean Monthly Abundance of Lepomis microlophus



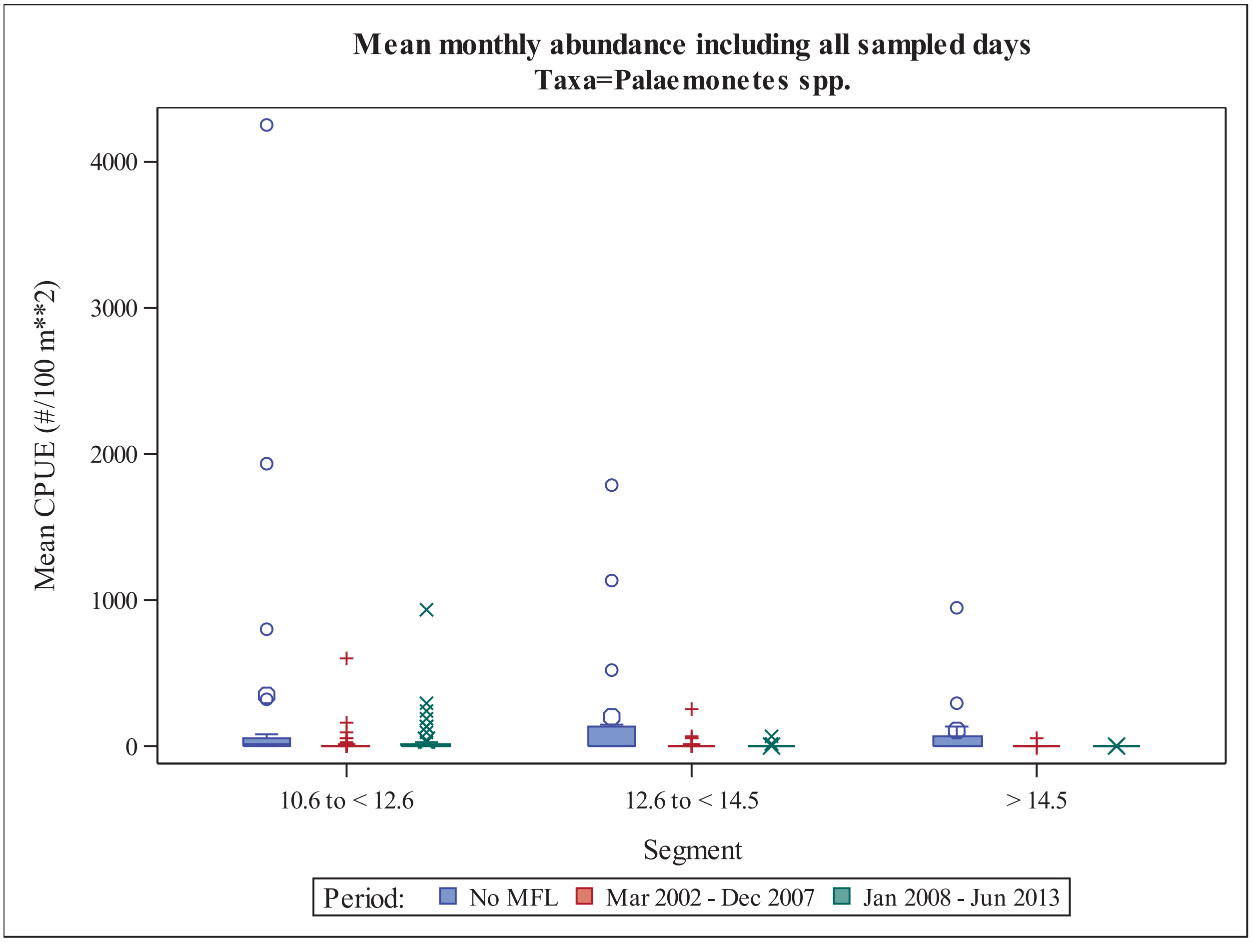
9. Mean Monthly Abundance of Lucania parva



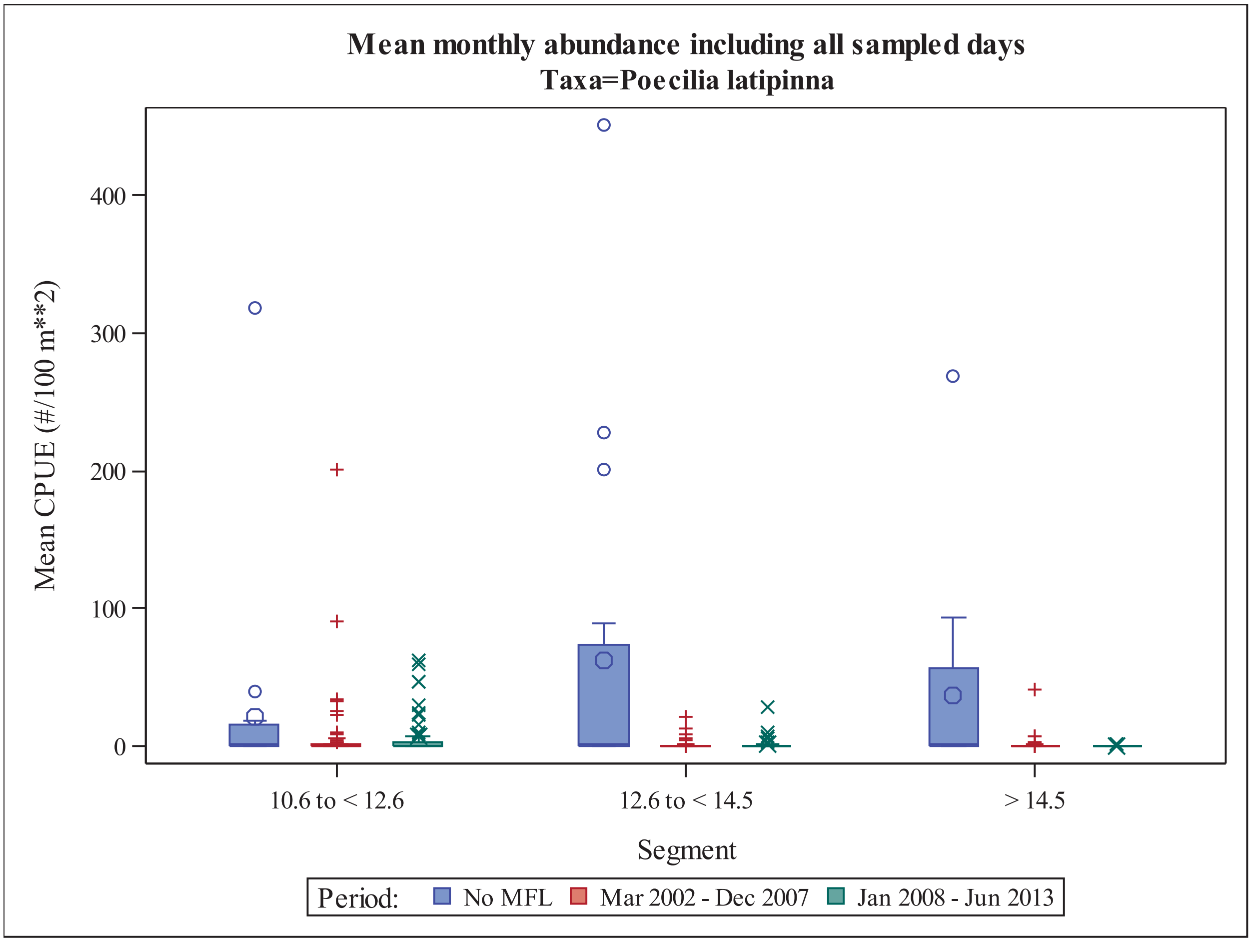
10. Mean Monthly Abundance of Micropterus salmoides



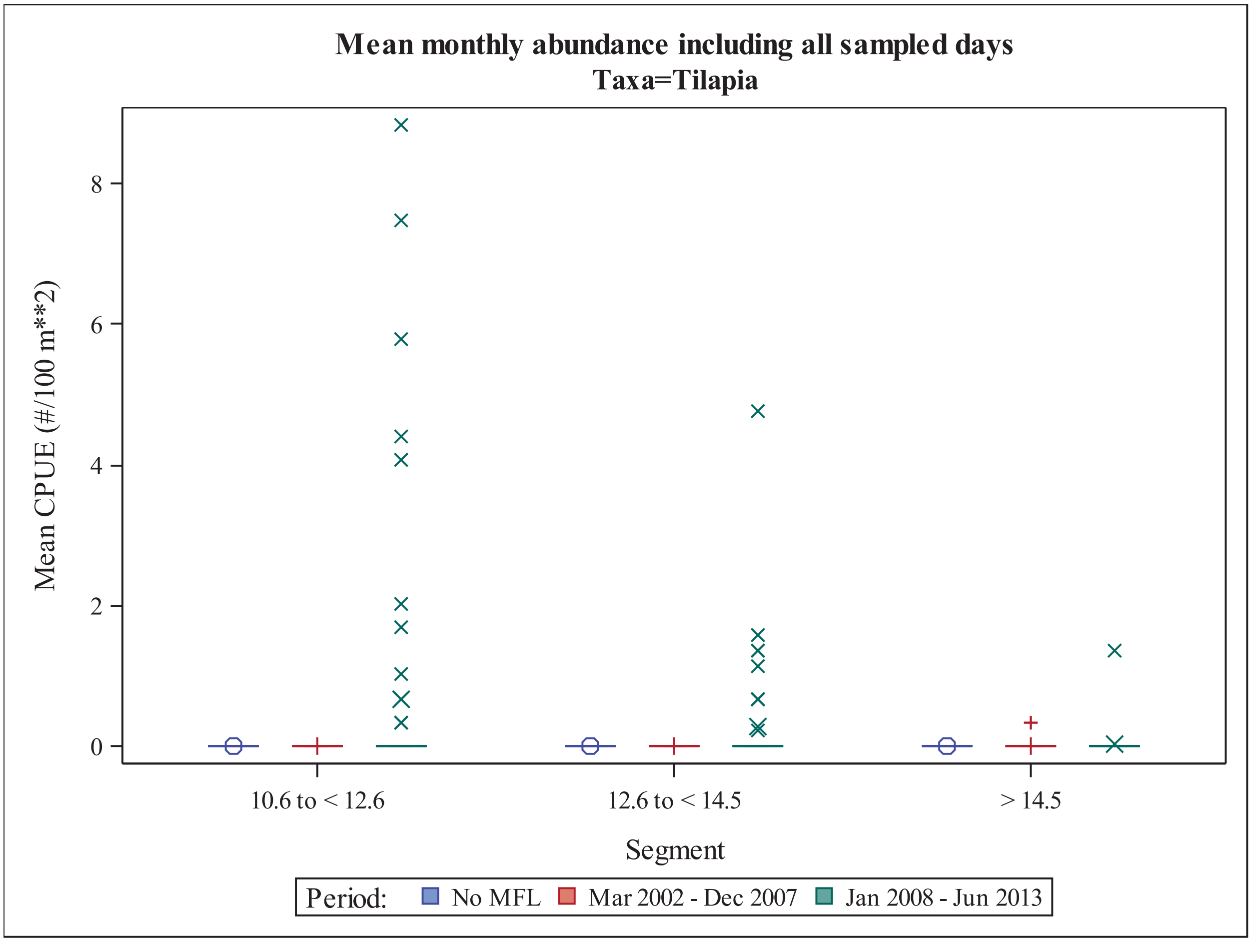
11. Mean Monthly Abundance of Palaemonetes spp



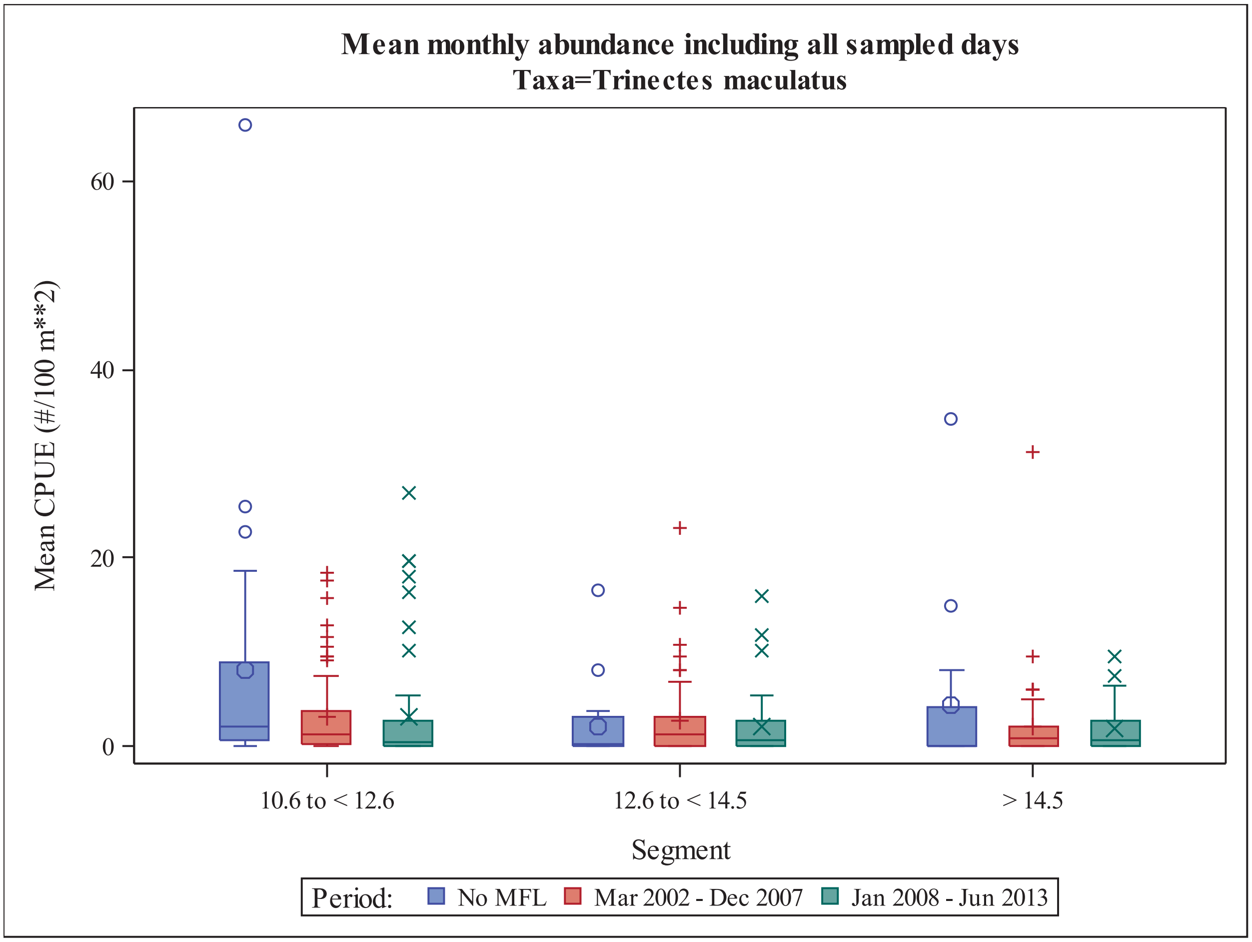
12. Mean Monthly Abundance of Poecilia latipinna



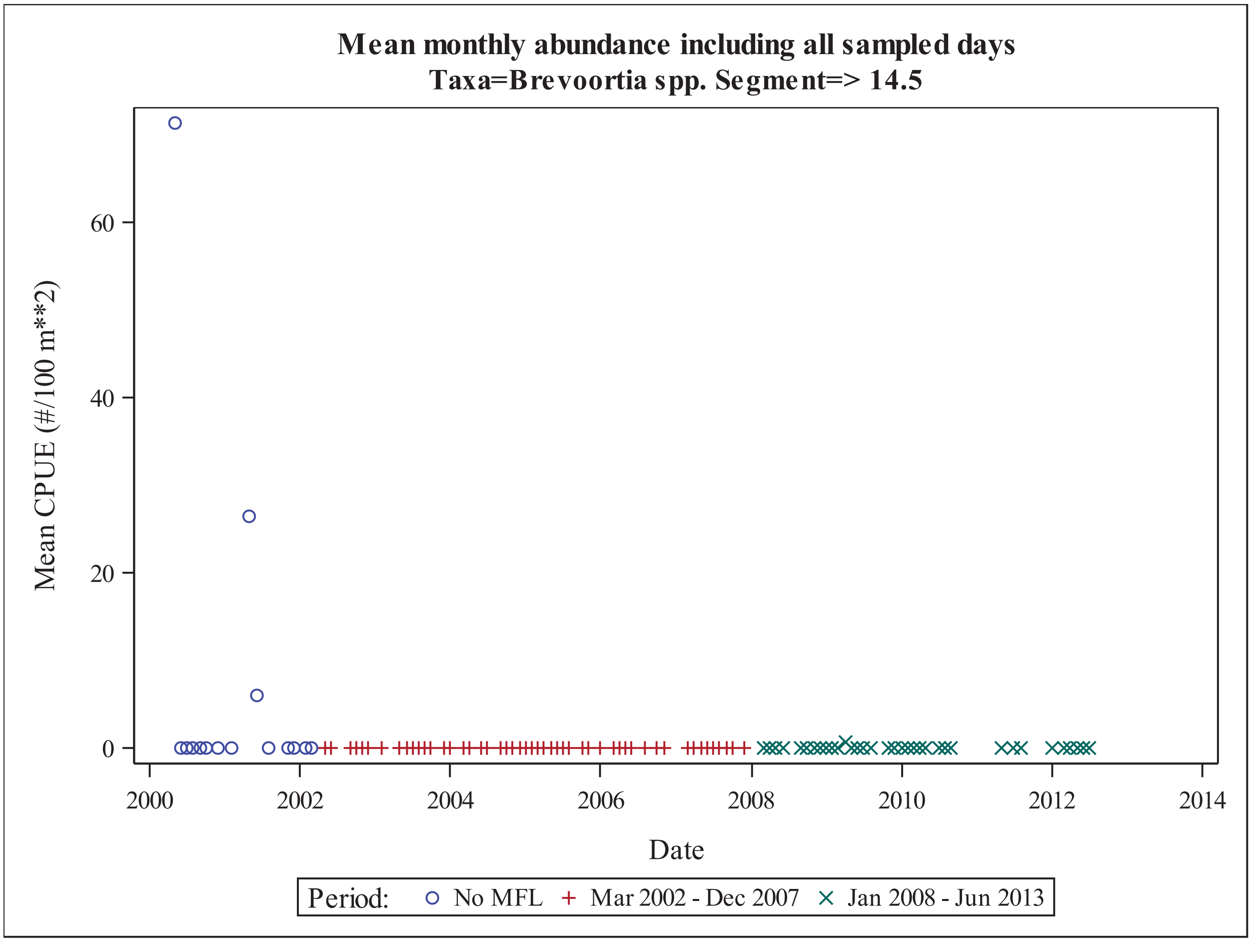
13. Mean Monthly Abundance of Tilapia

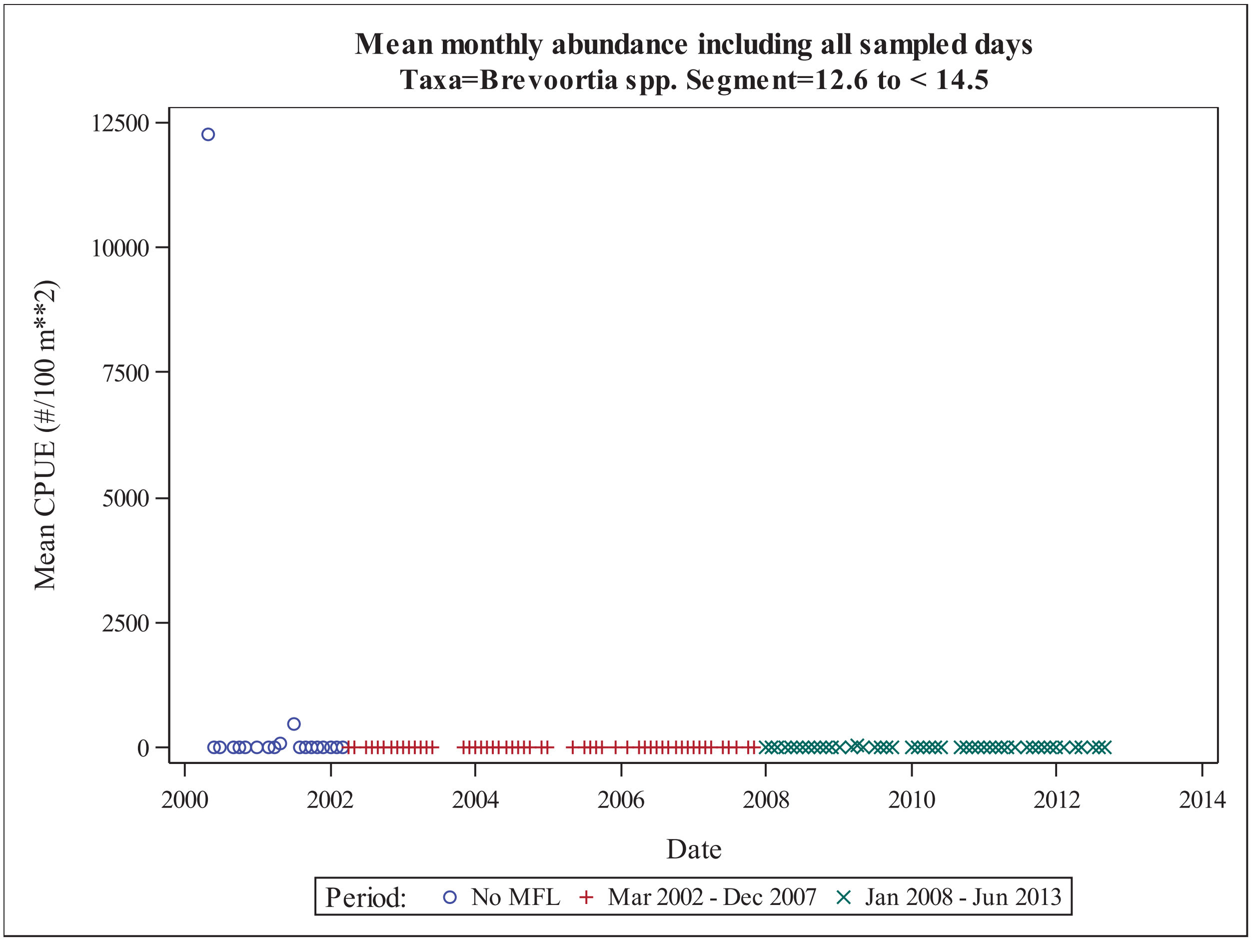


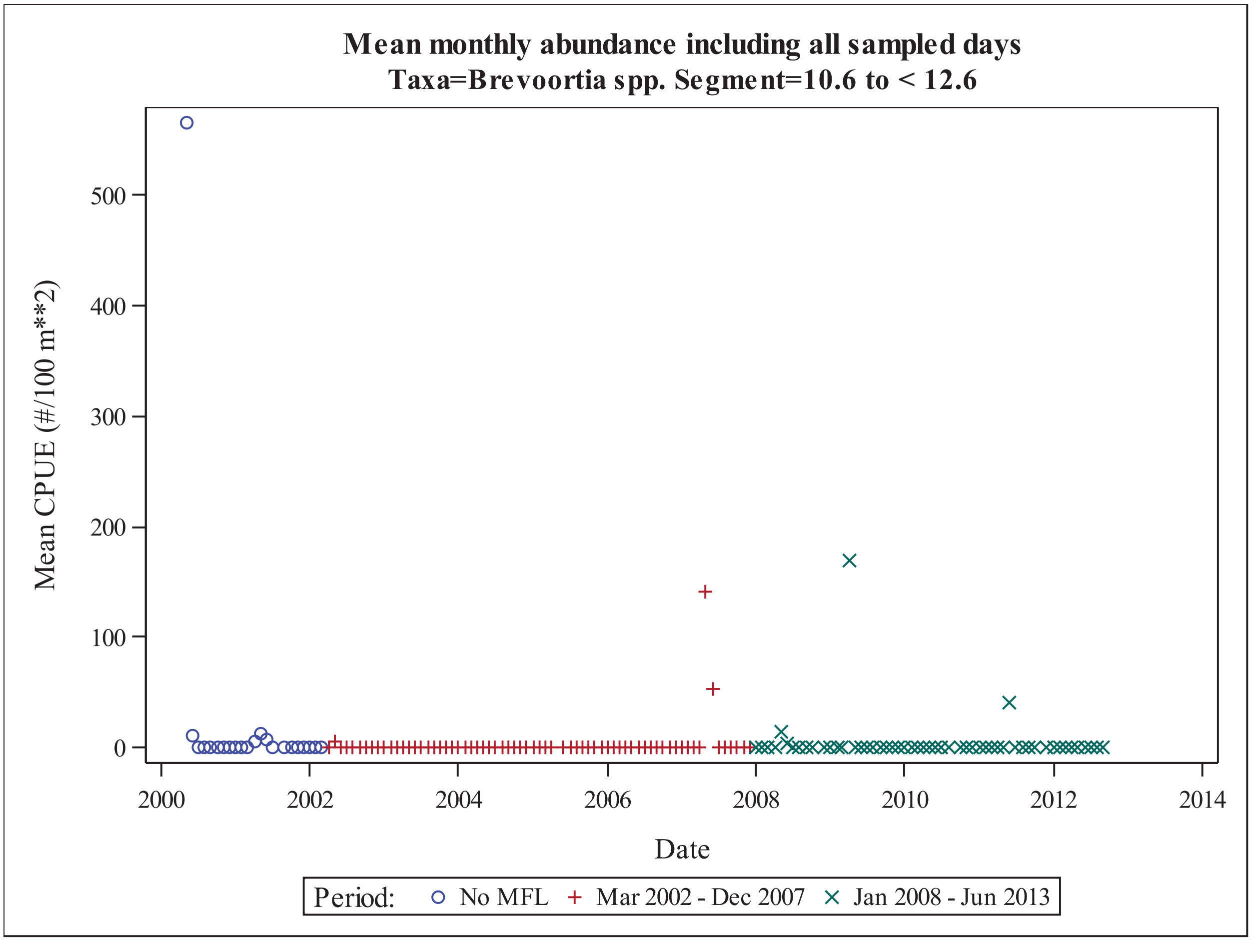
14. Mean Monthly Abundance of Trinectes maculatus



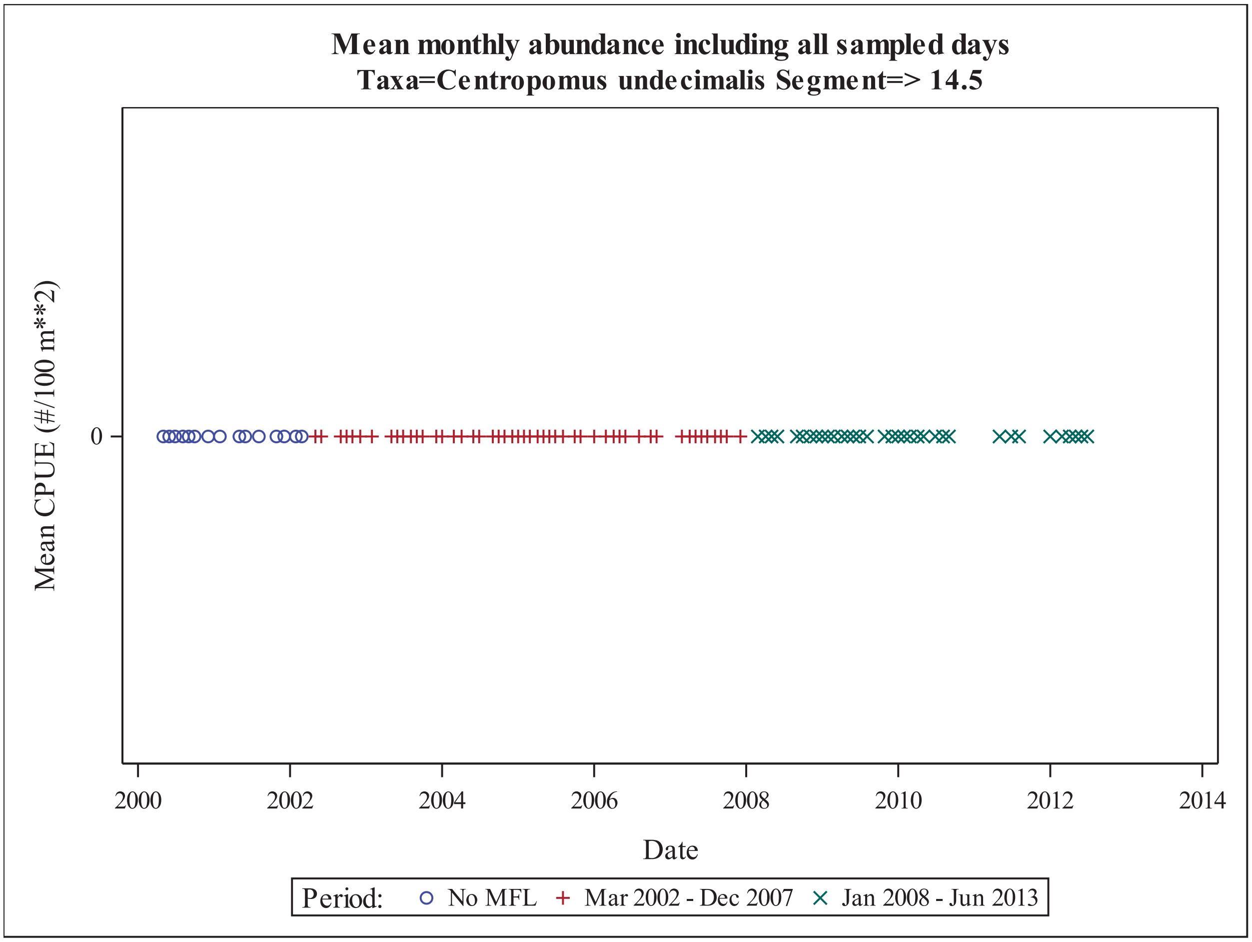
15. Brevoortia spp.

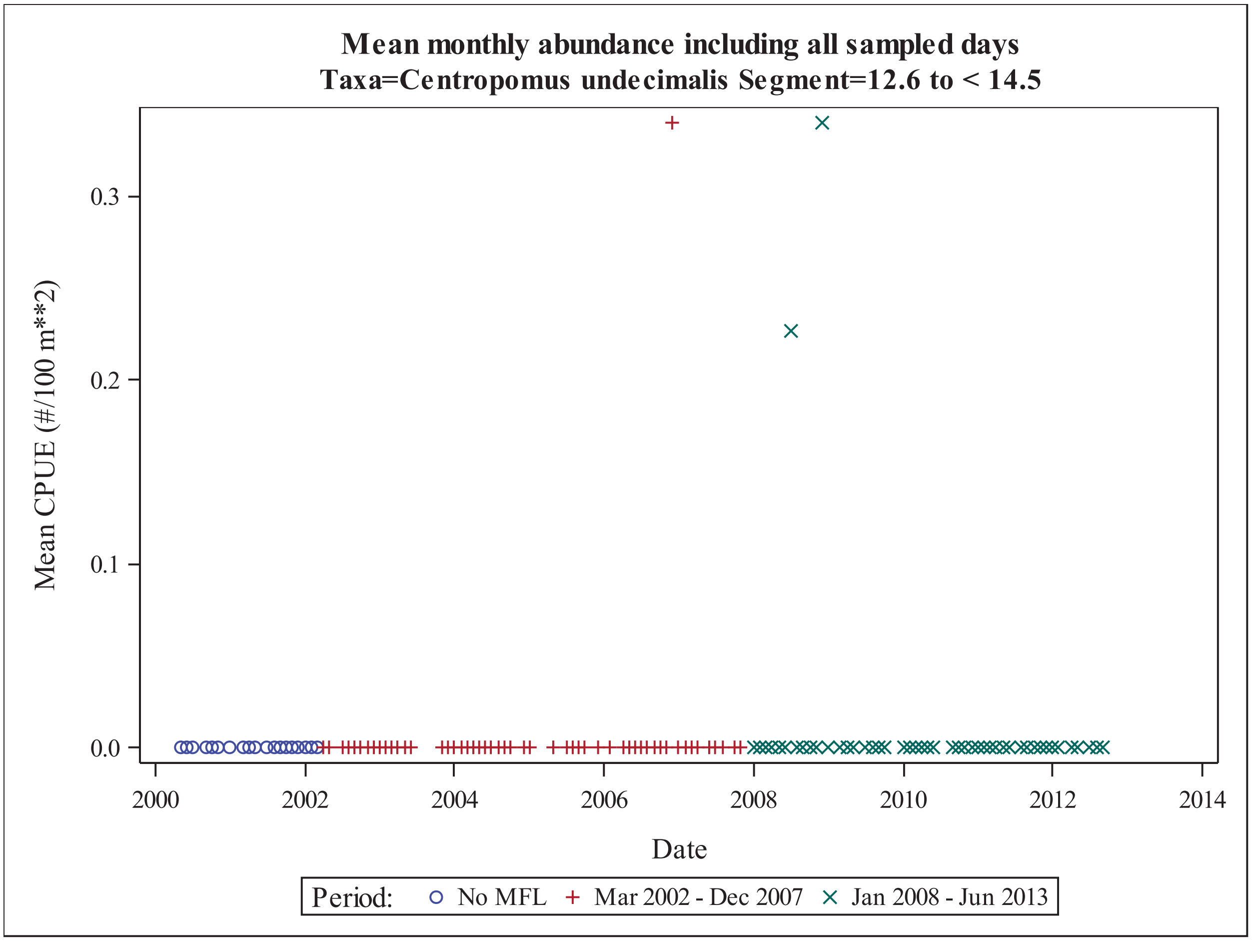


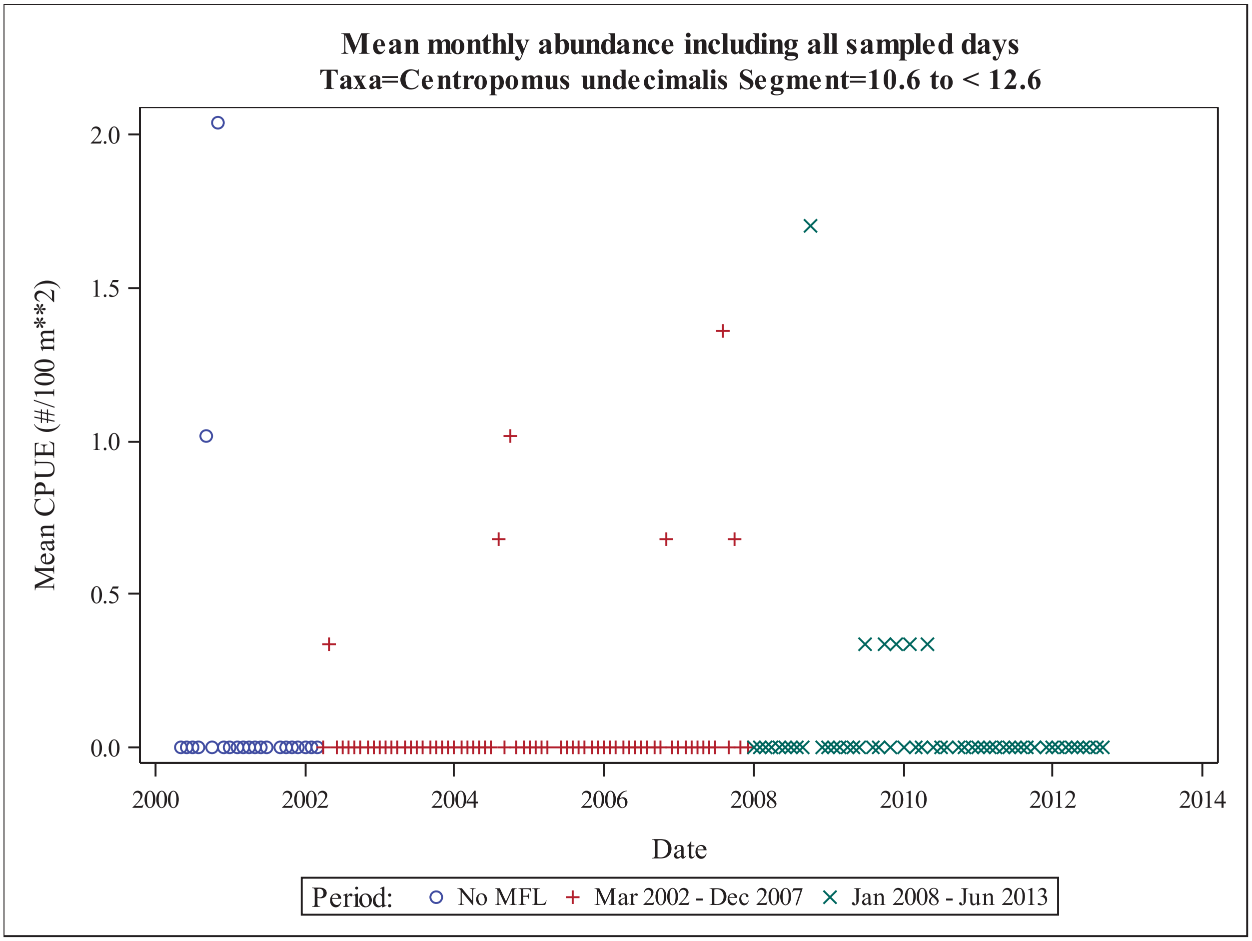

Mean monthly abundance including all sampled days
Taxa=Brevoortia spp. Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
12500
10000
7500
5000
2500
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Brevoortia spp. Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
100
200
300
400
500
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

16. Centropomus undecimalis

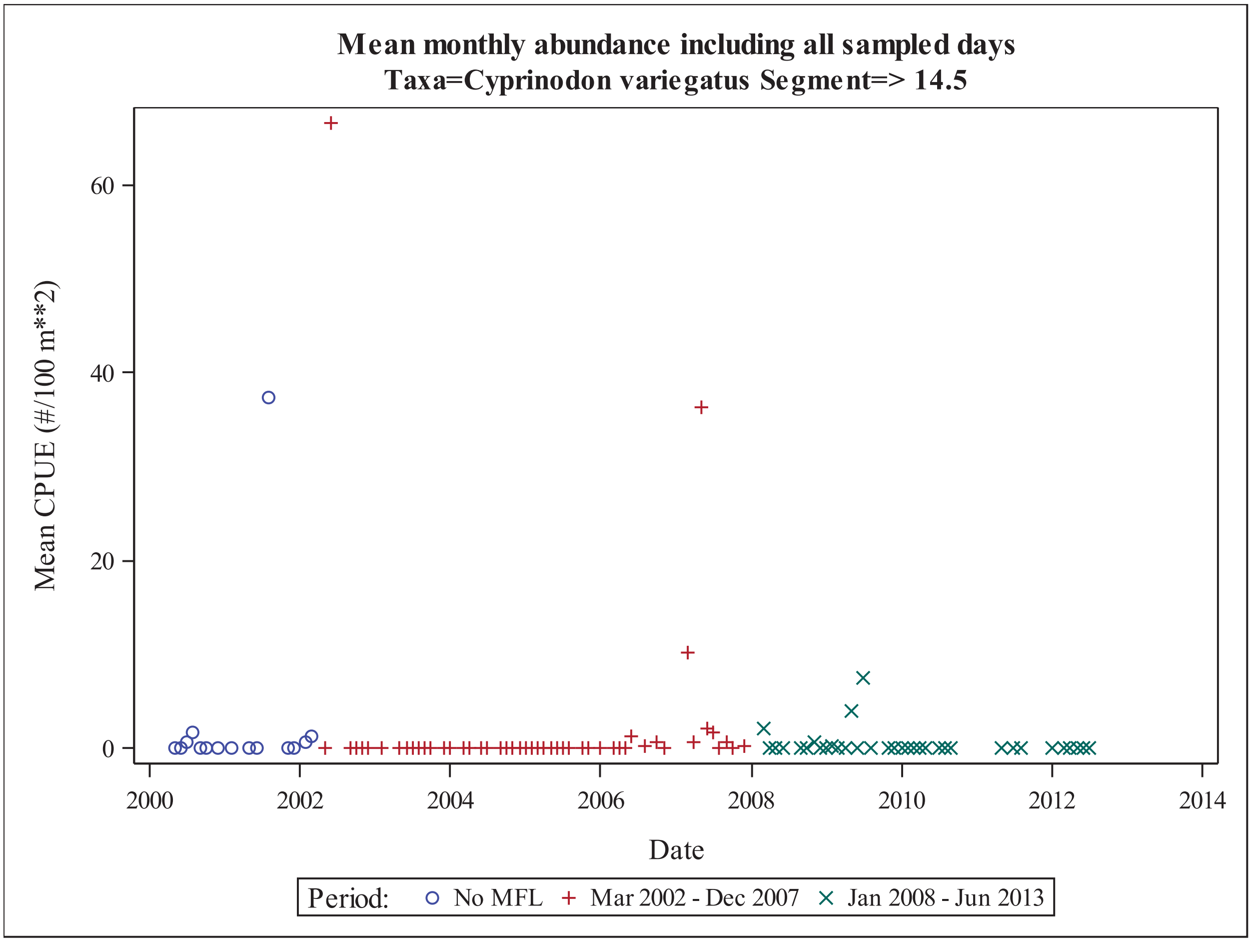


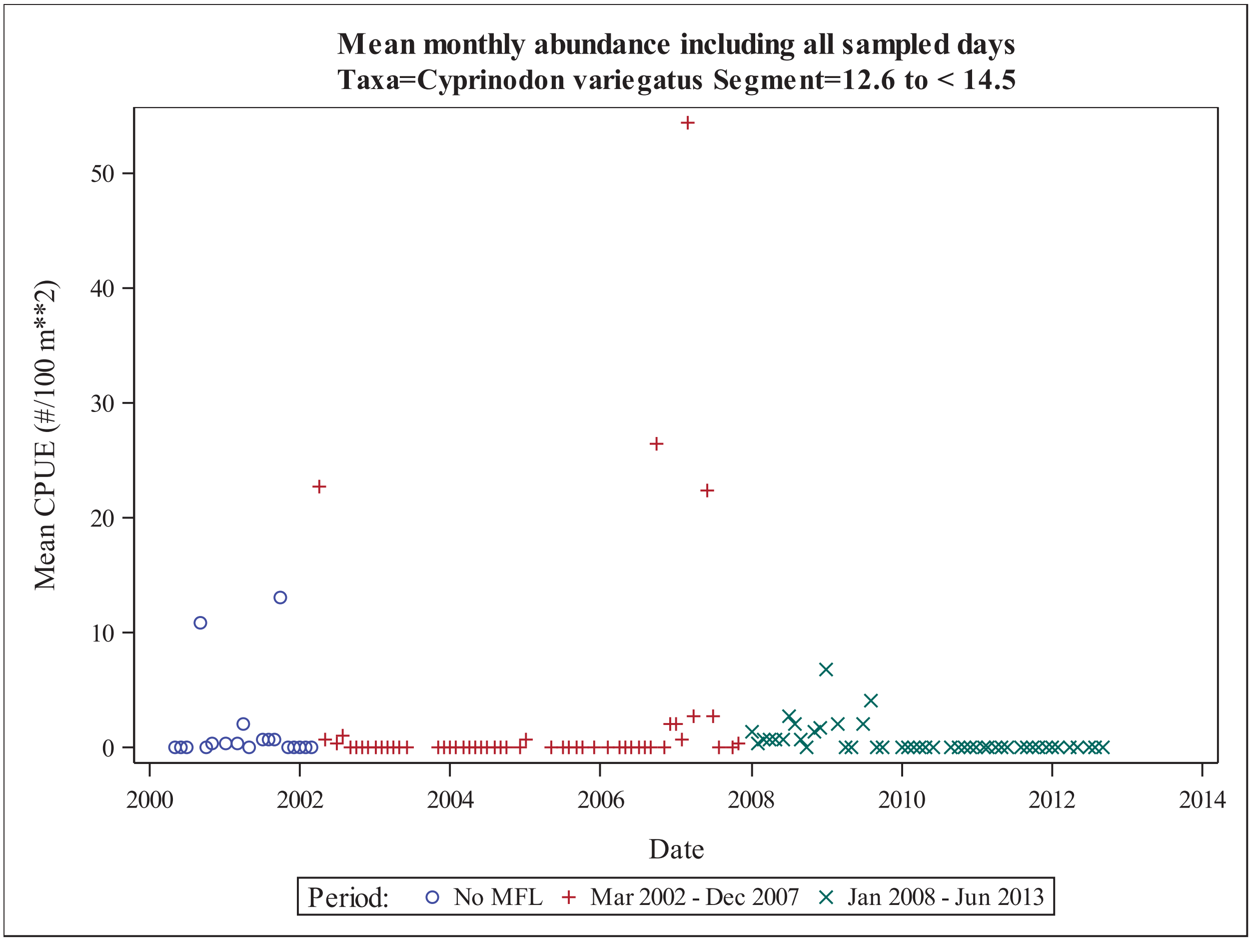

Mean monthly abundance including all sampled days
Taxa=Centropomus undecimalis Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0.0
0.1
0.2
0.3
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

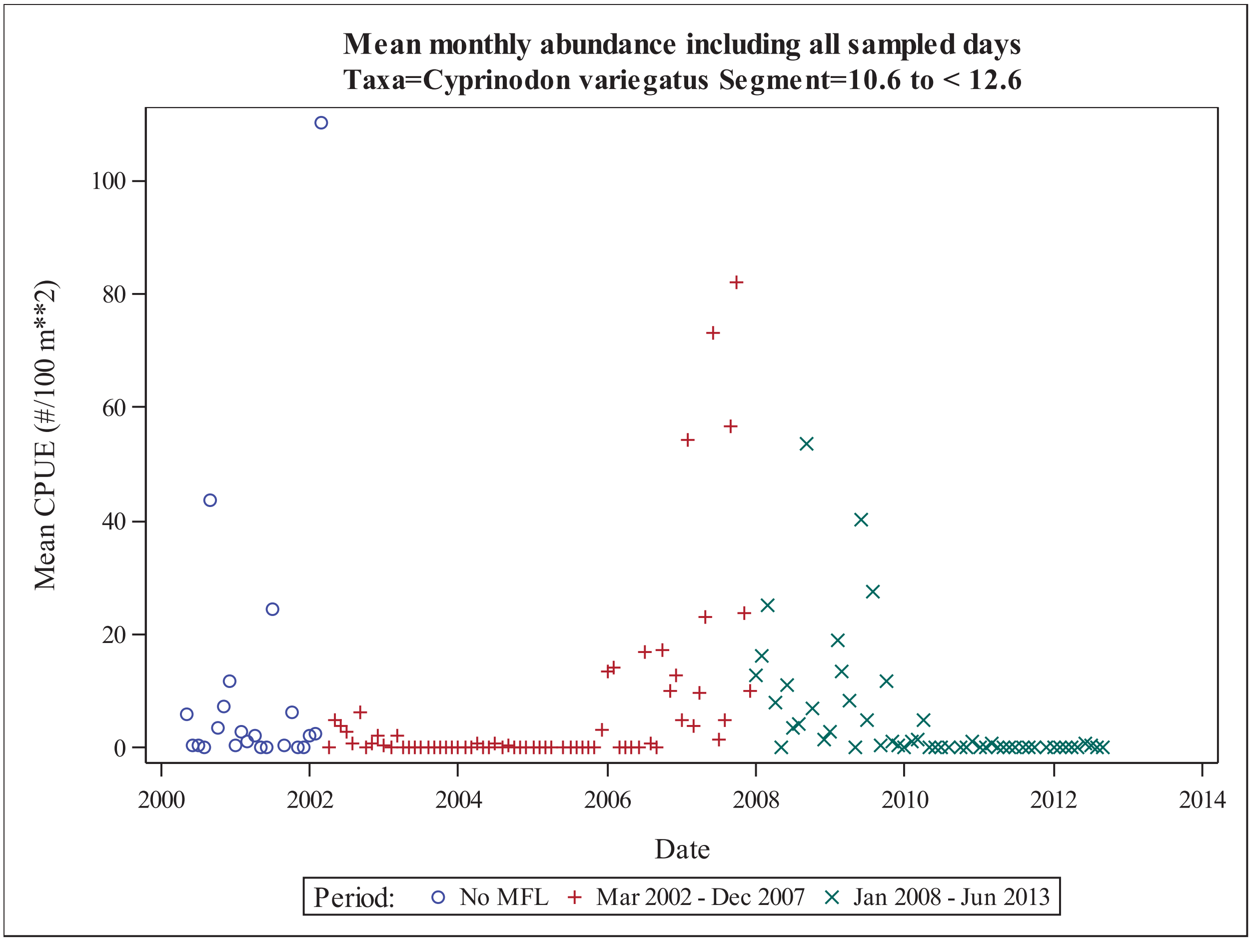


Mean monthly abundance including all sampled days
Taxa=Centropomus undecimalis Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
2.0
1.5
1.0
0.5
0.0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

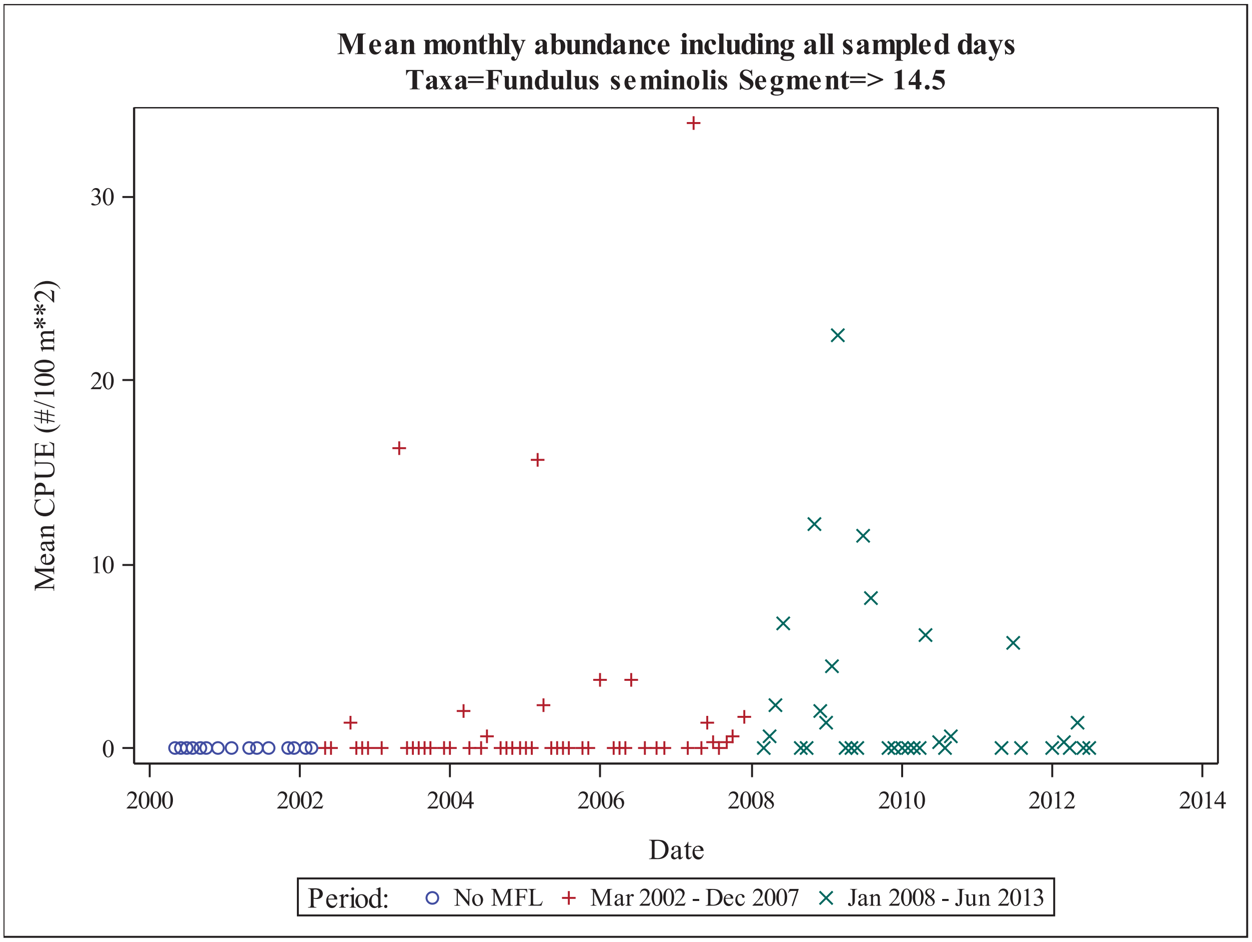
17. Cyprinodon variegatus

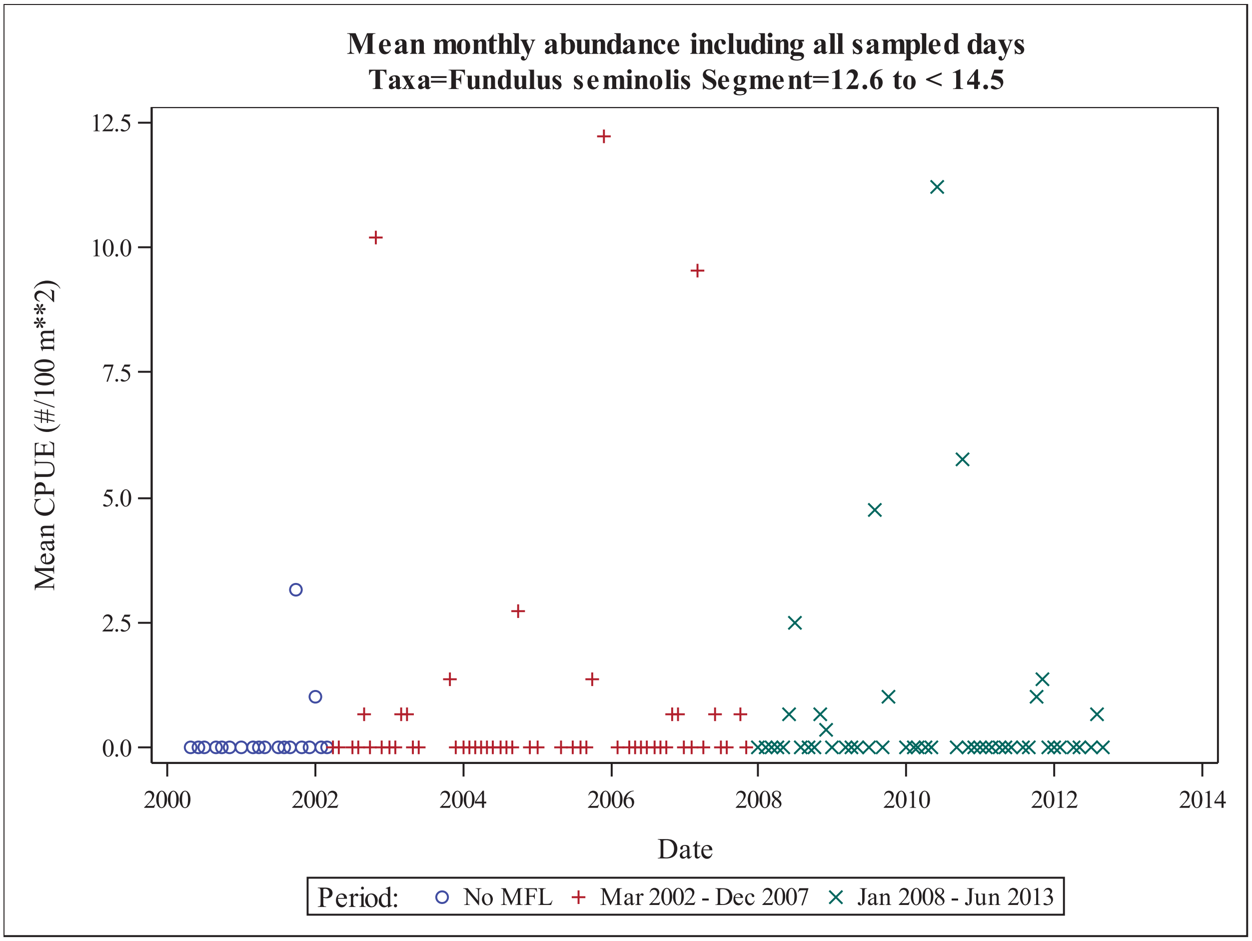


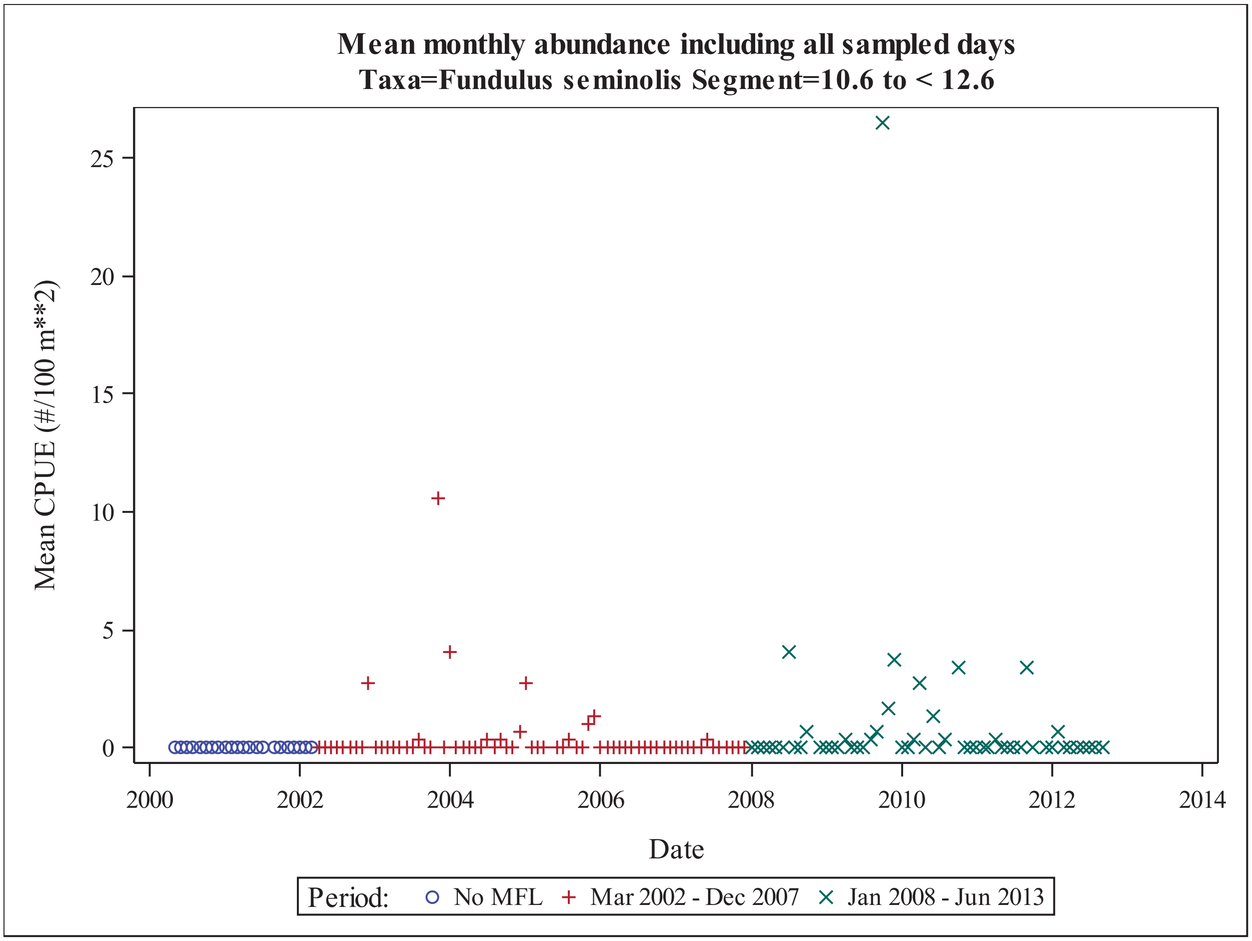

Mean monthly abundance including all sampled days
Taxa=Cyprinodon variegatus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
10
20
30
40
50
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Cyprinodon variegatus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
20
40
60
80
100
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

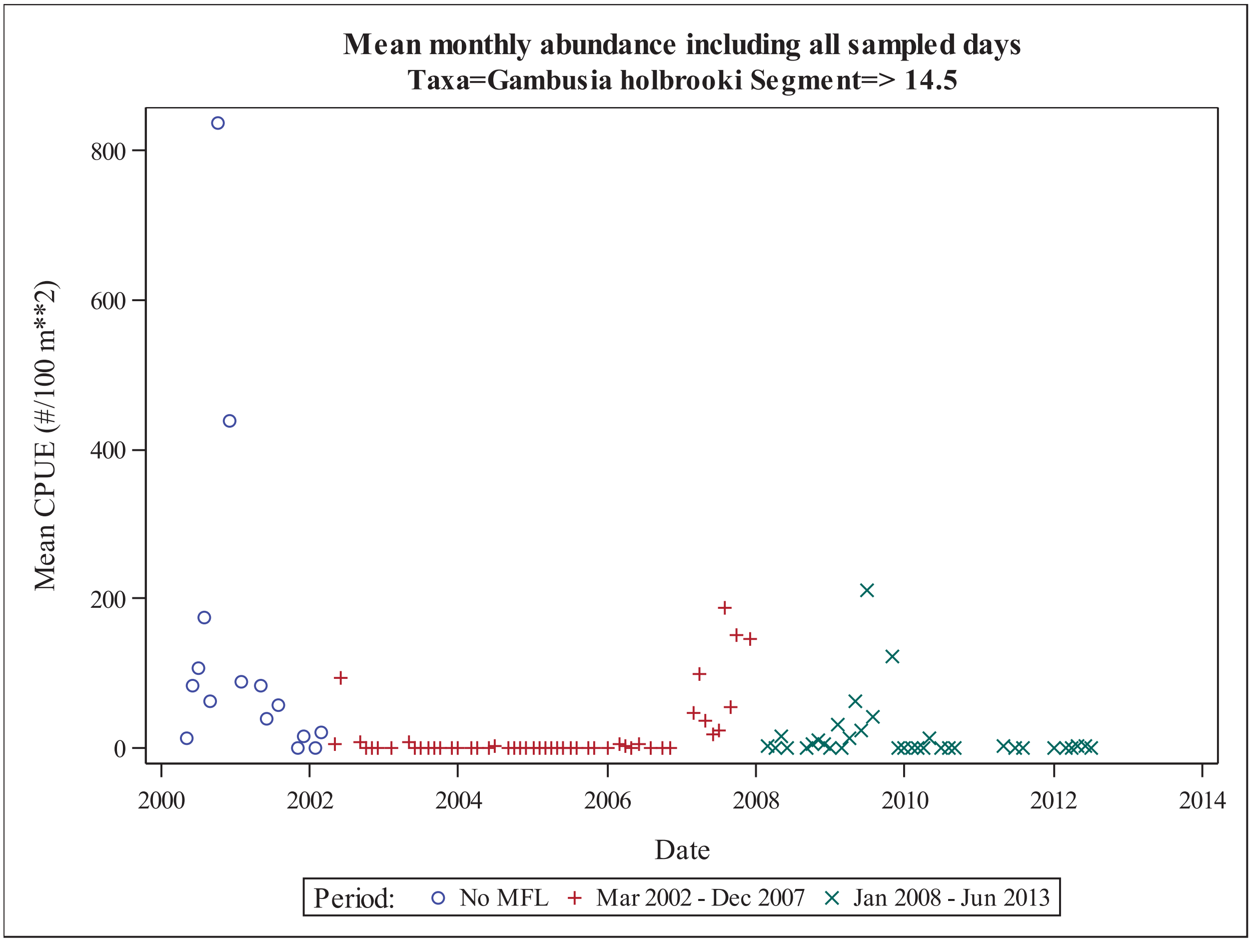
18. Fundulus seminolis

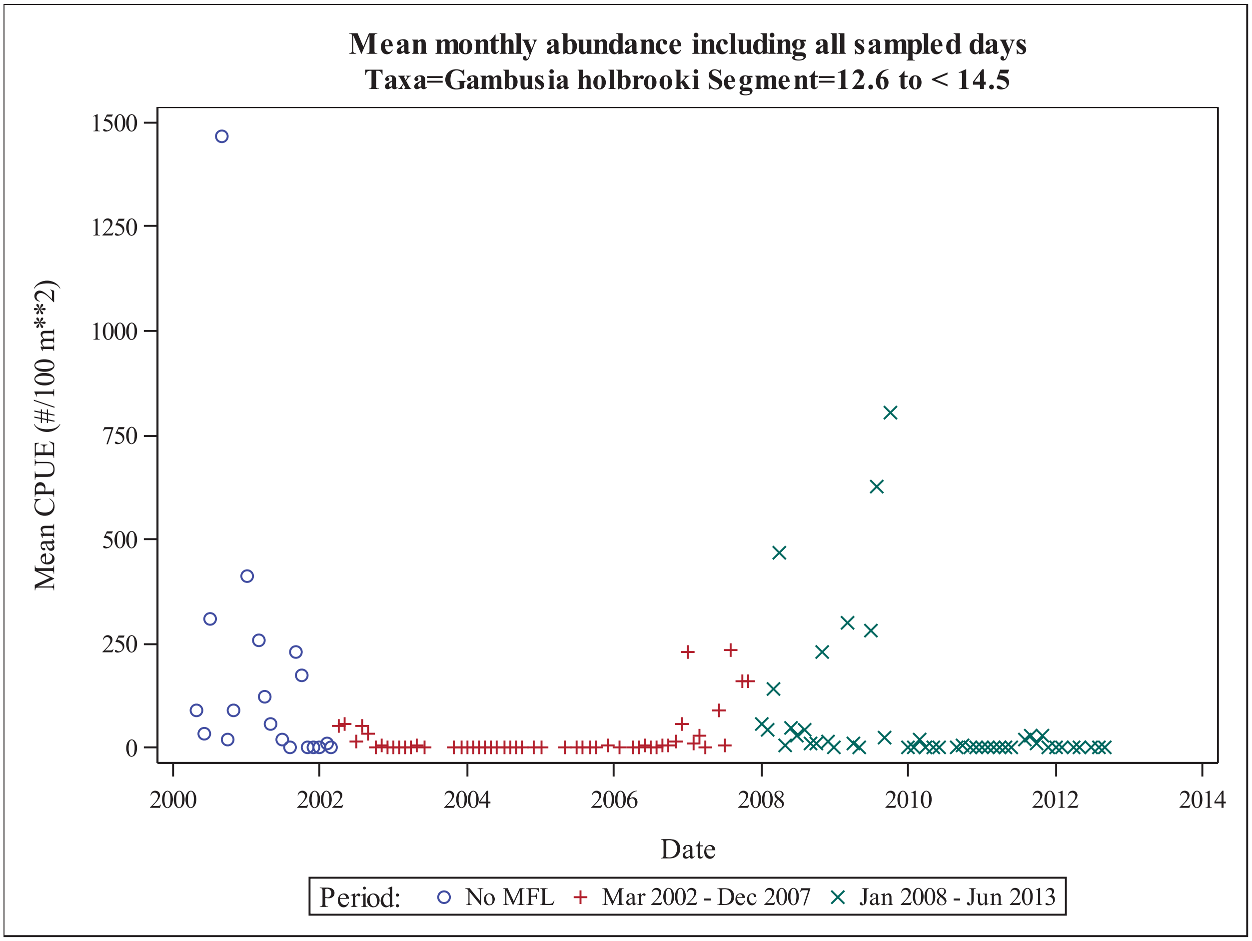


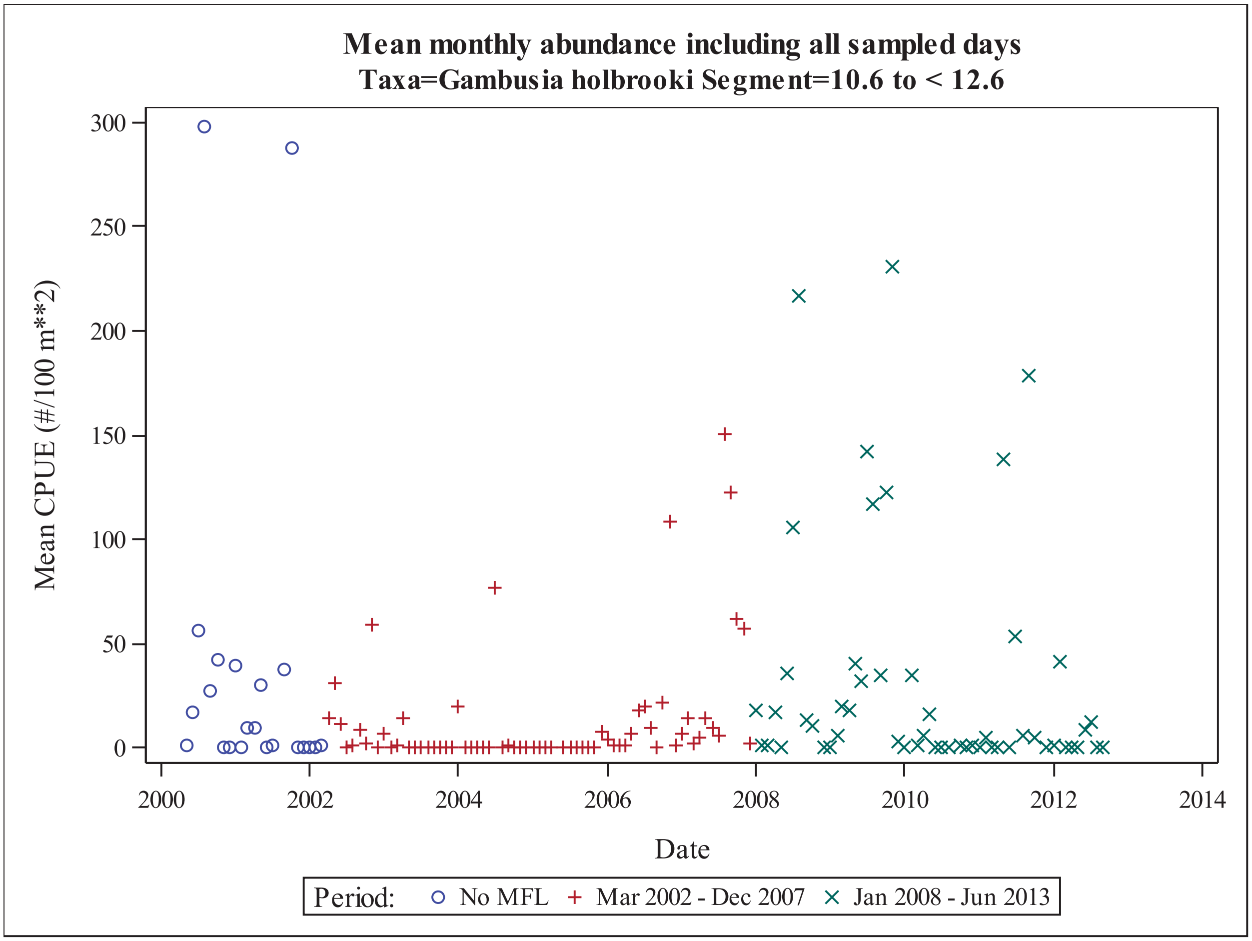

Mean monthly abundance including all sampled days
Taxa=Fundulus seminolis Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0.0
2.5
5.0
7.5
10.0
12.5
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Fundulus seminolis Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
5
10
15
20
25
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

19. Gambusia holbrooki

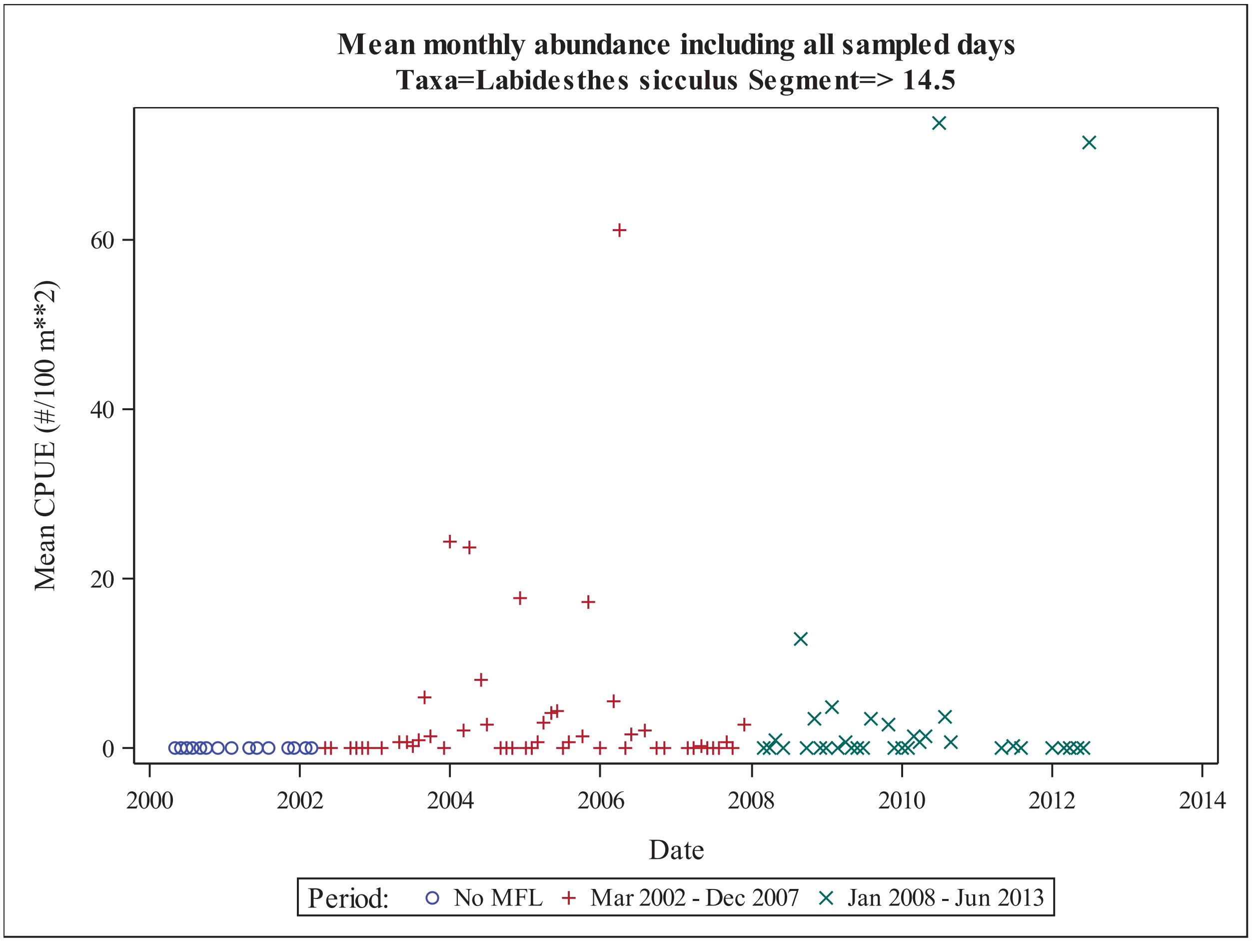


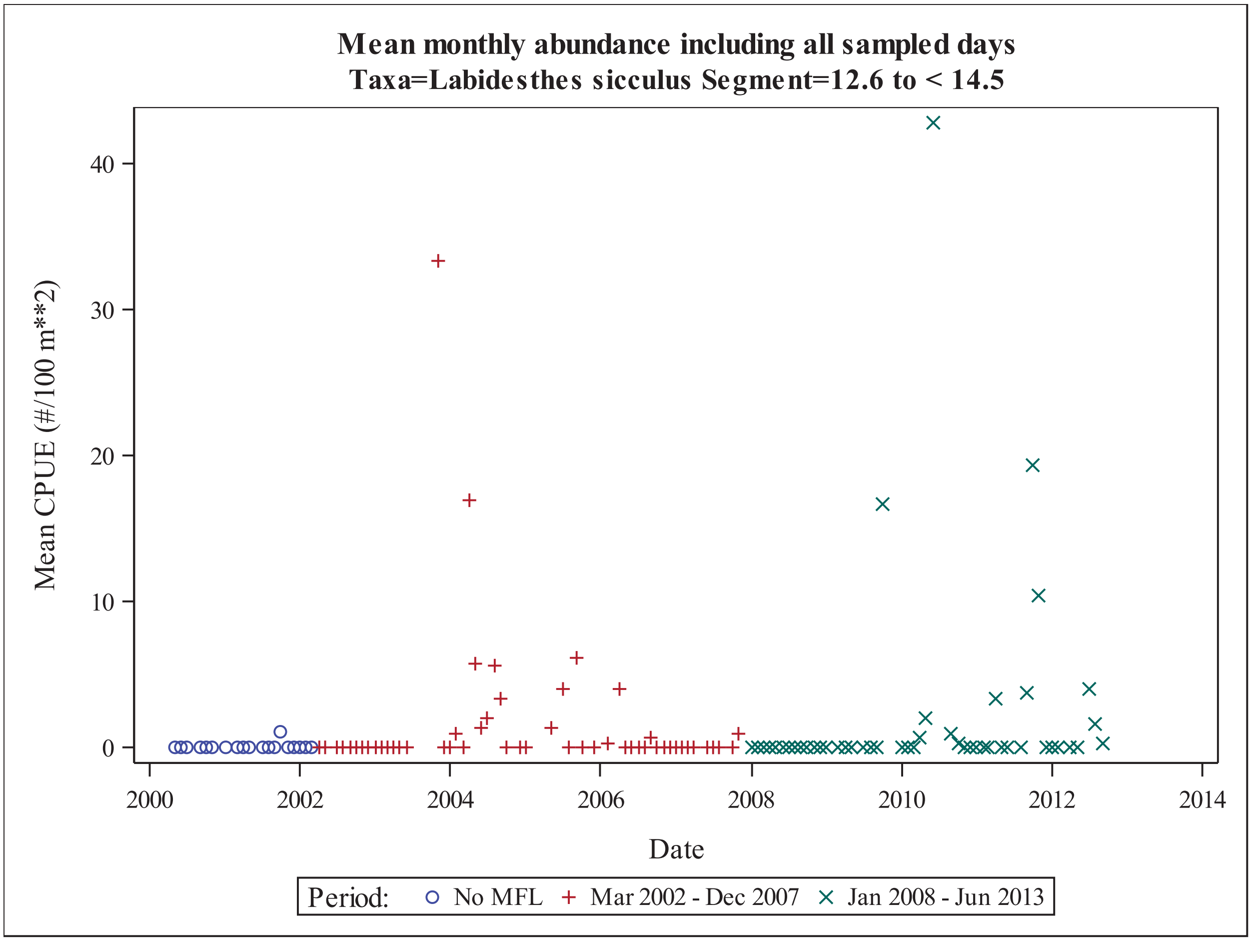

Mean monthly abundance including all sampled days
Taxa=Gambusia holbrooki Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
1500
1250
1000
750
500
250
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

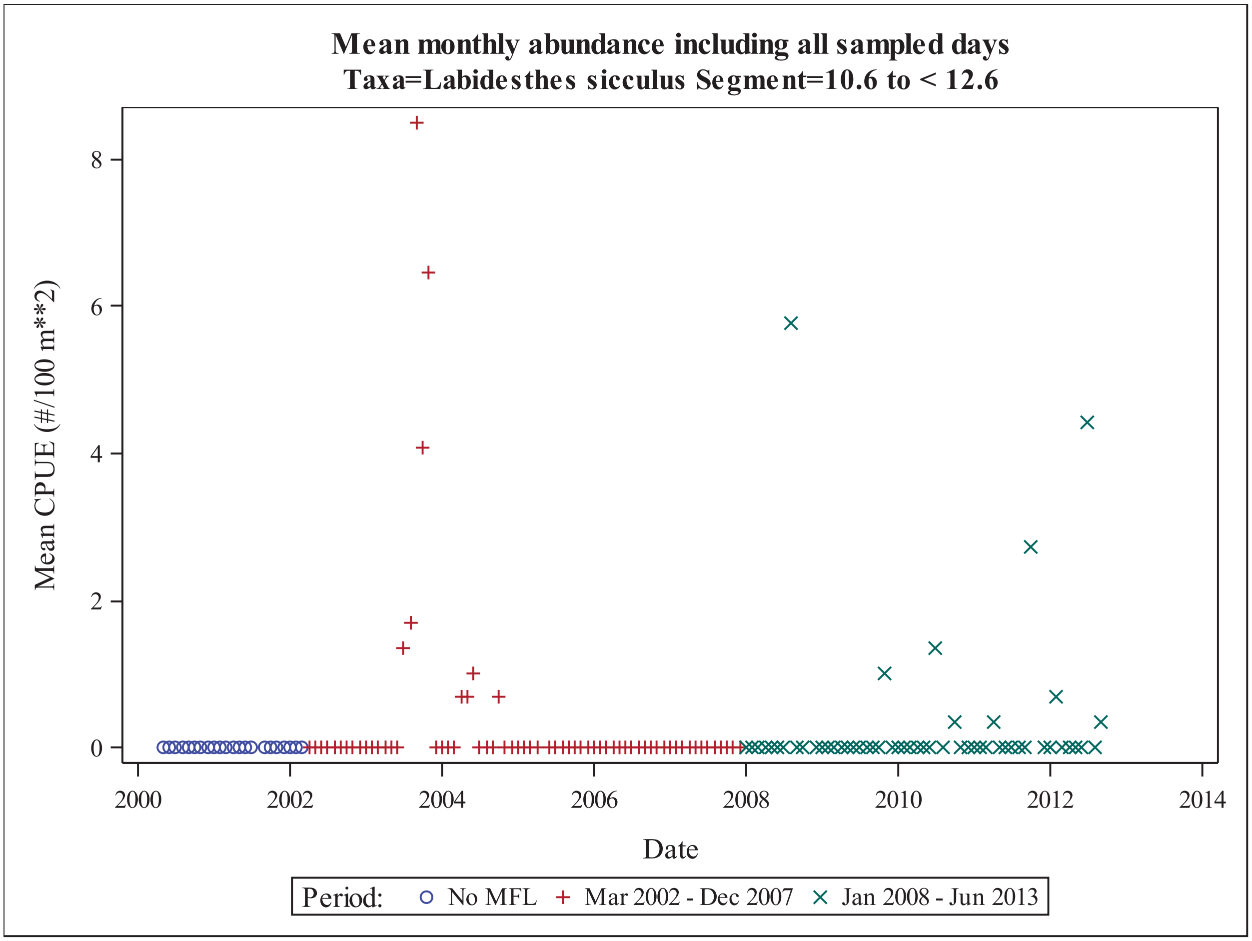


Mean monthly abundance including all sampled days
Taxa=Gambusia holbrooki Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
300
250
200
150
100
50
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

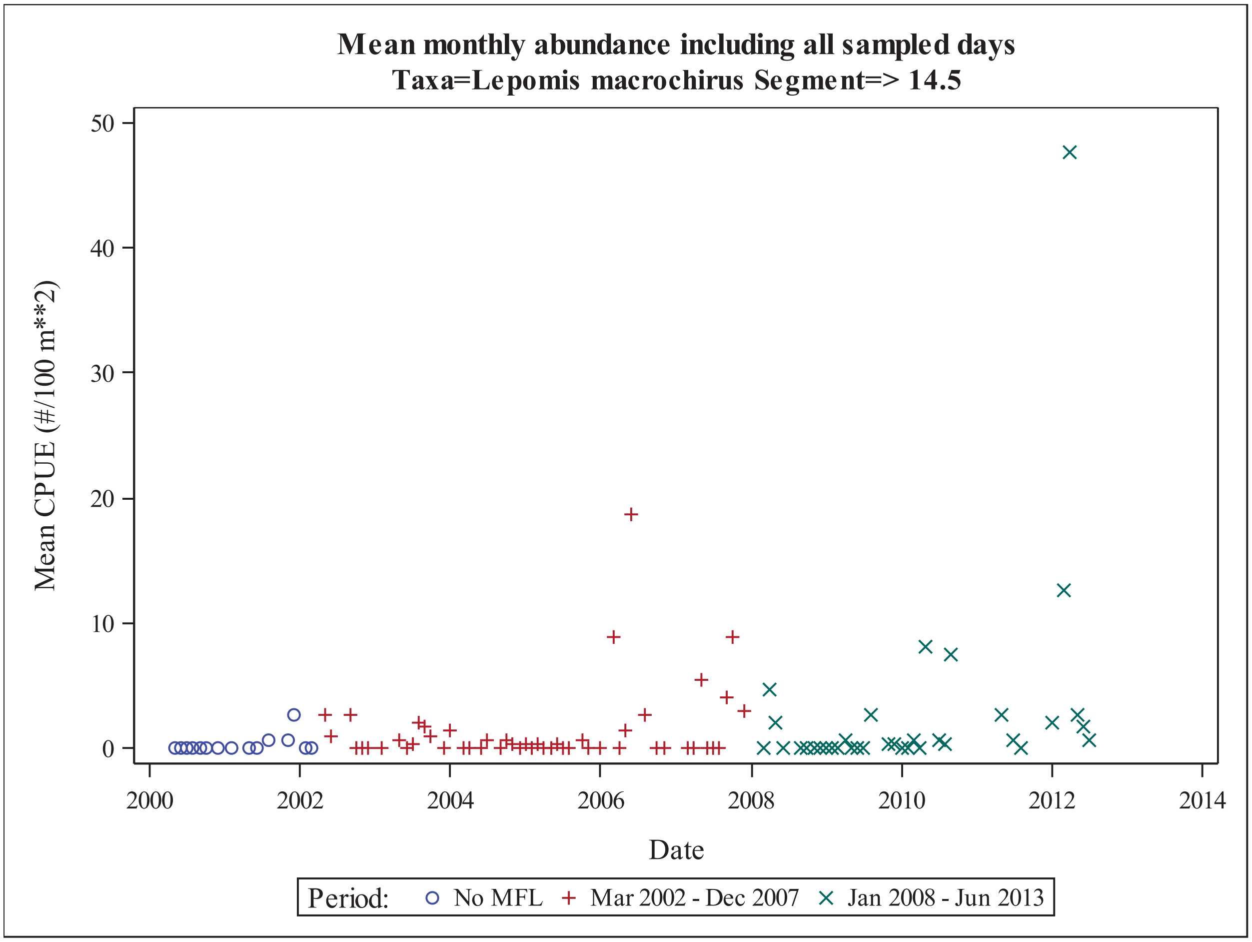
20. Labidesthes sicculus

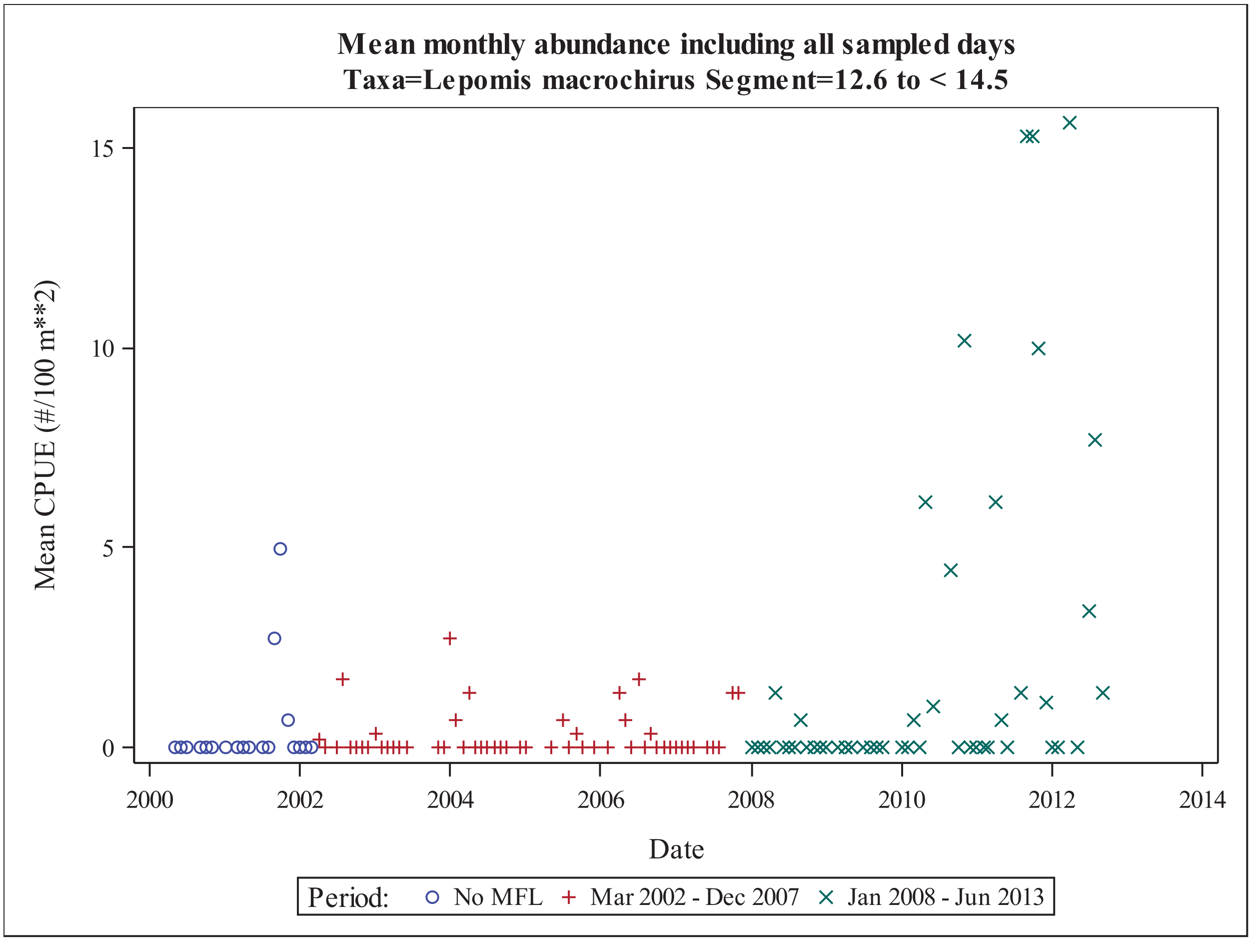


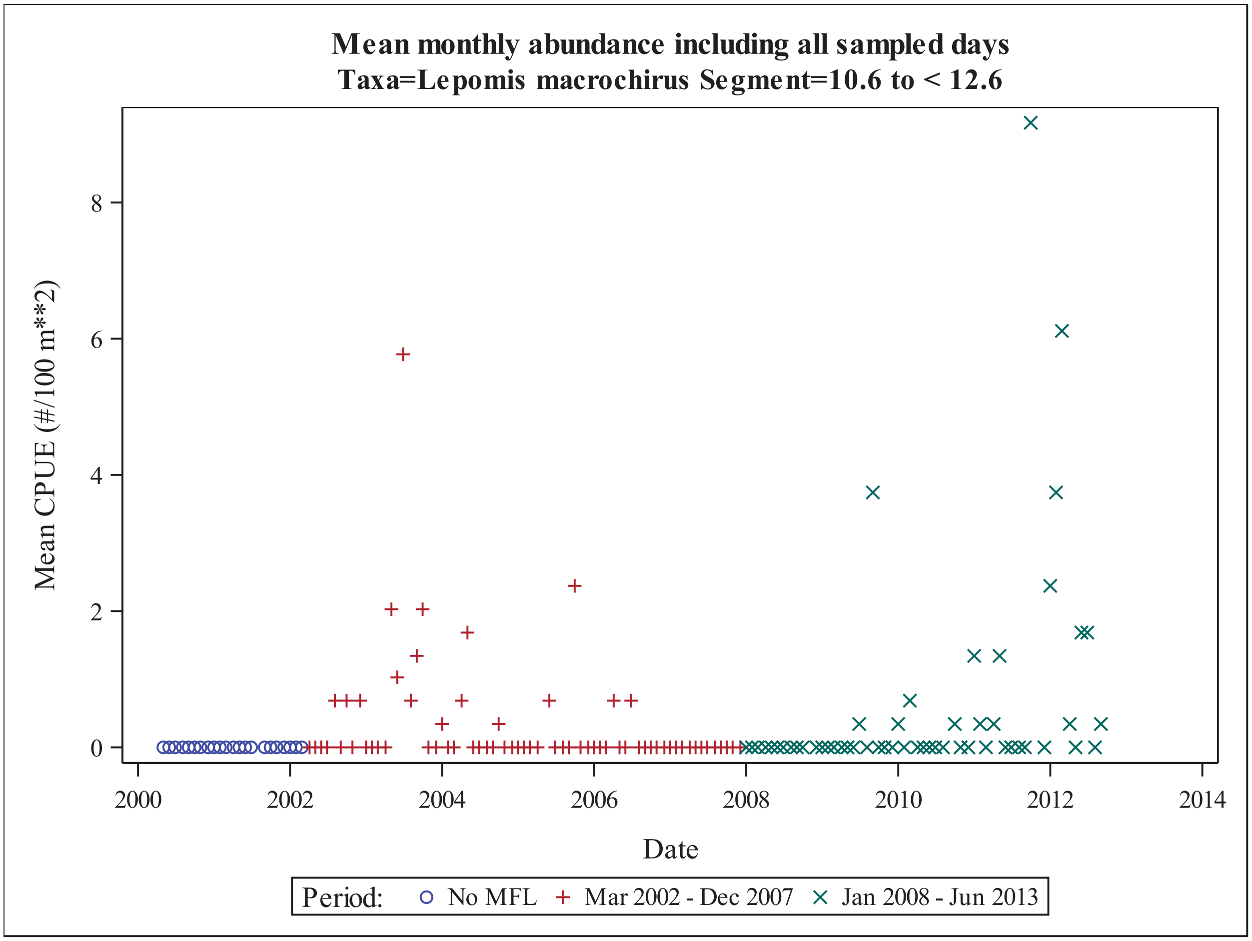

Mean monthly abundance including all sampled days
Taxa=Labidesthes sicculus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
10
20
30
40
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Labidesthes sicculus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
2
4
6
8
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

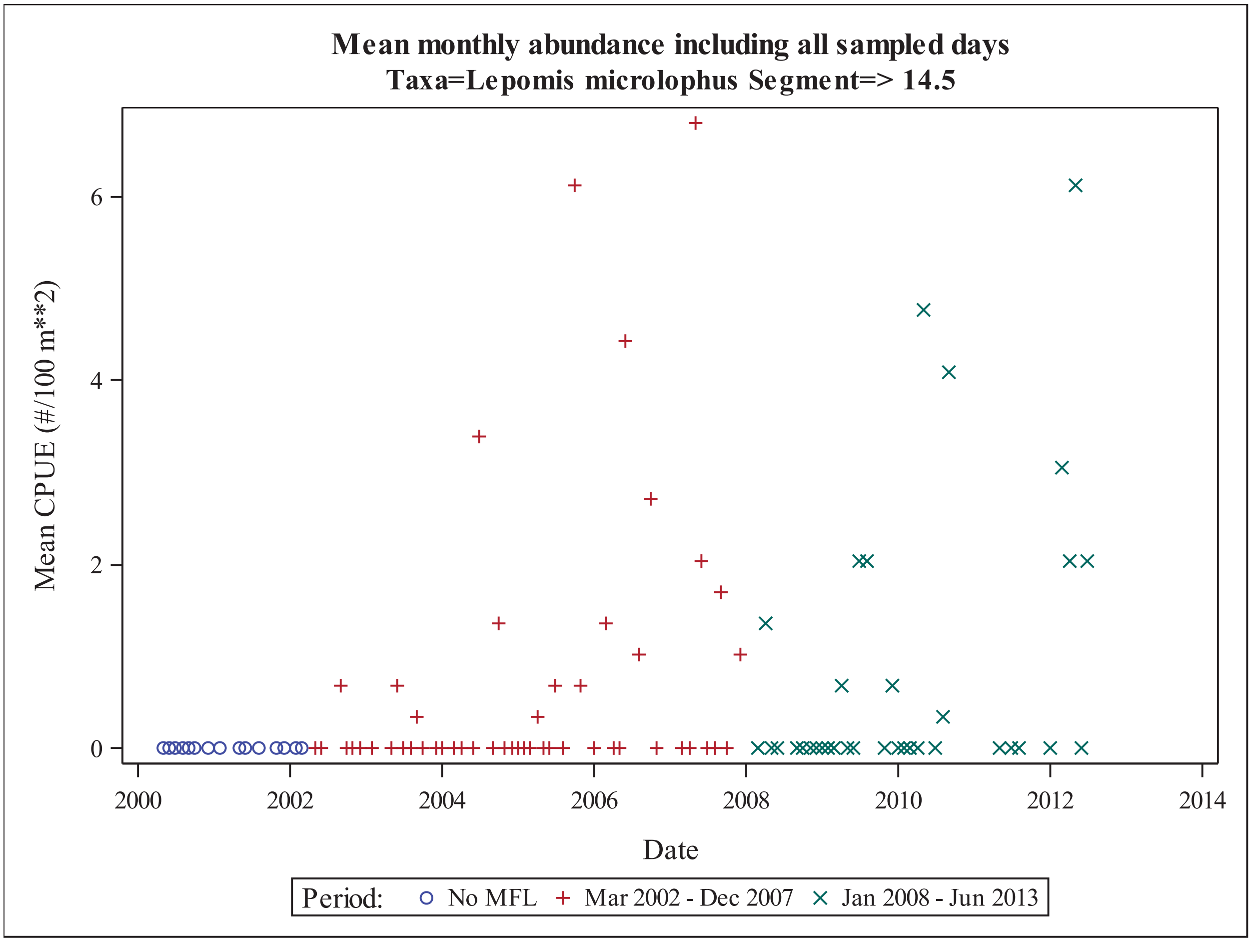
21. Lepomis macrochirus

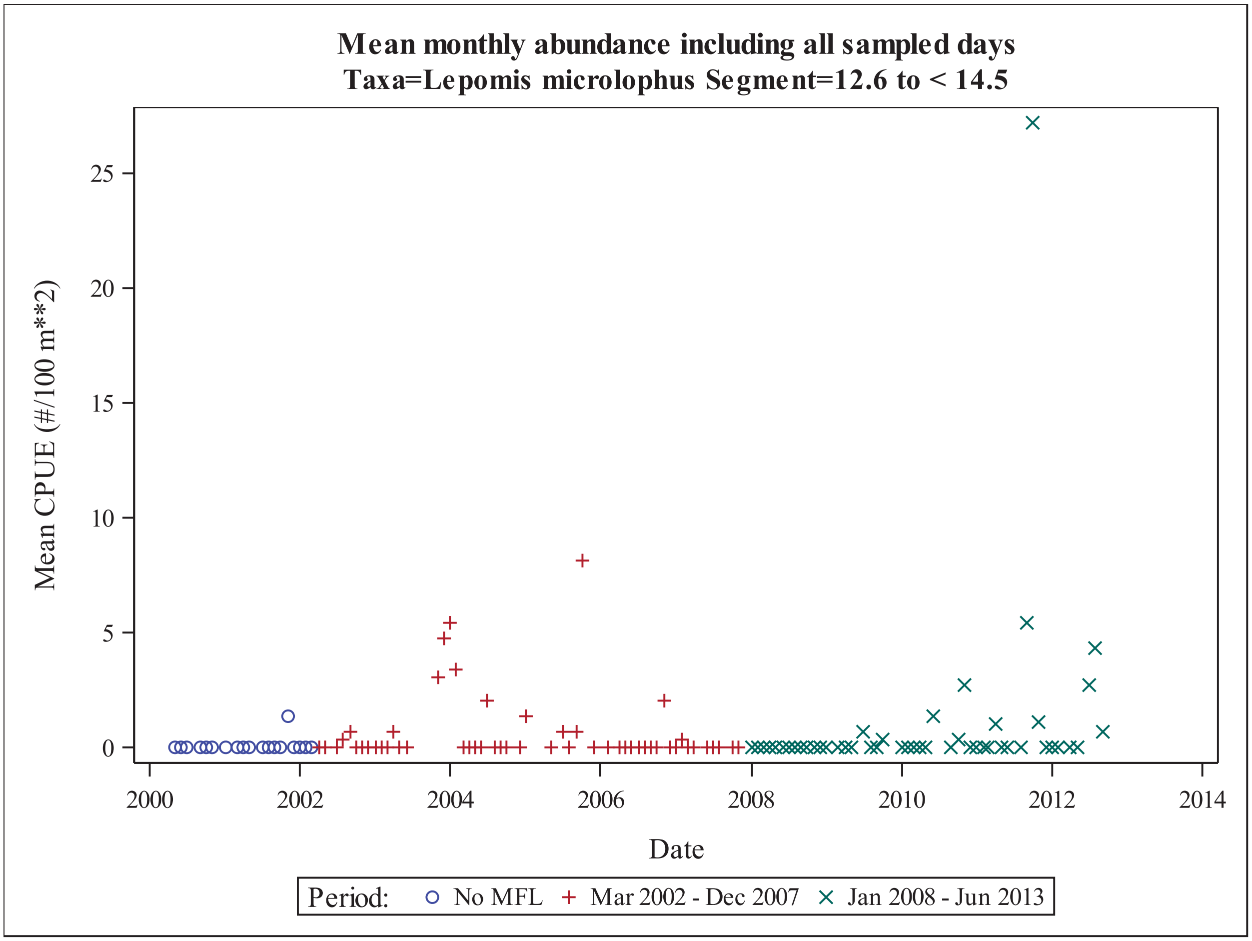


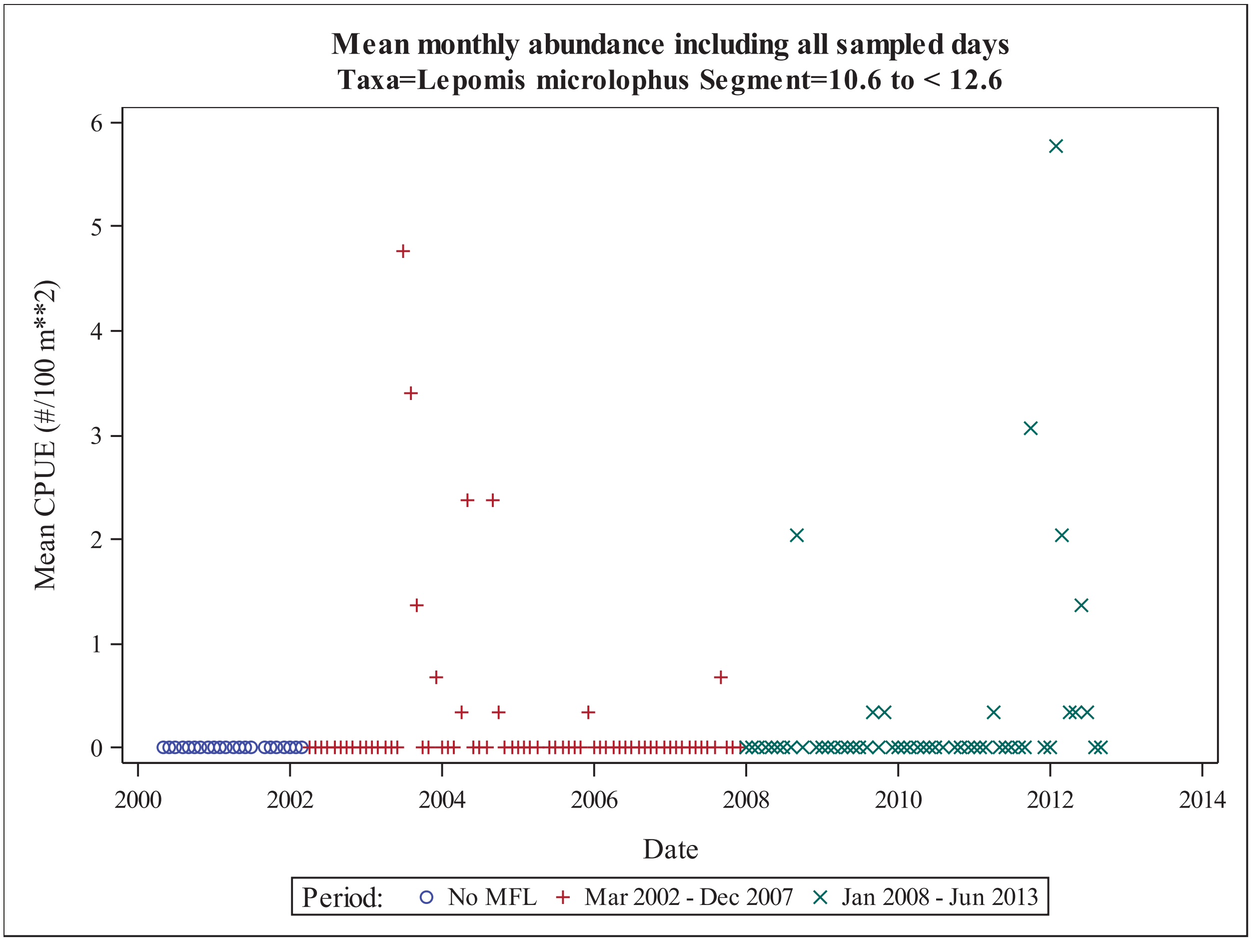

Mean monthly abundance including all sampled days
Taxa=Lepomis macrochirus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
5
10
15
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Lepomis macrochirus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
2
4
6
8
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

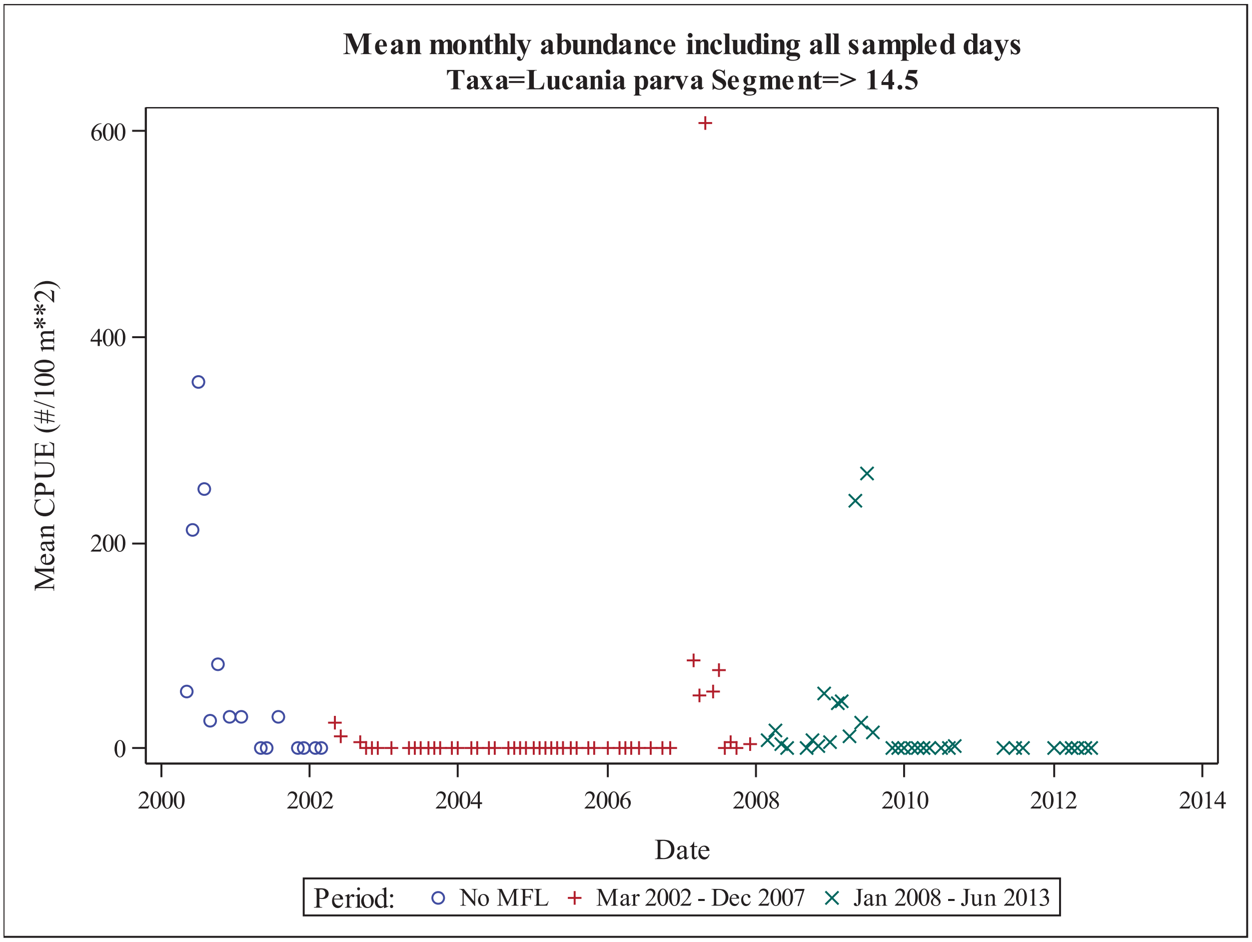
22. Lepomis microlophus

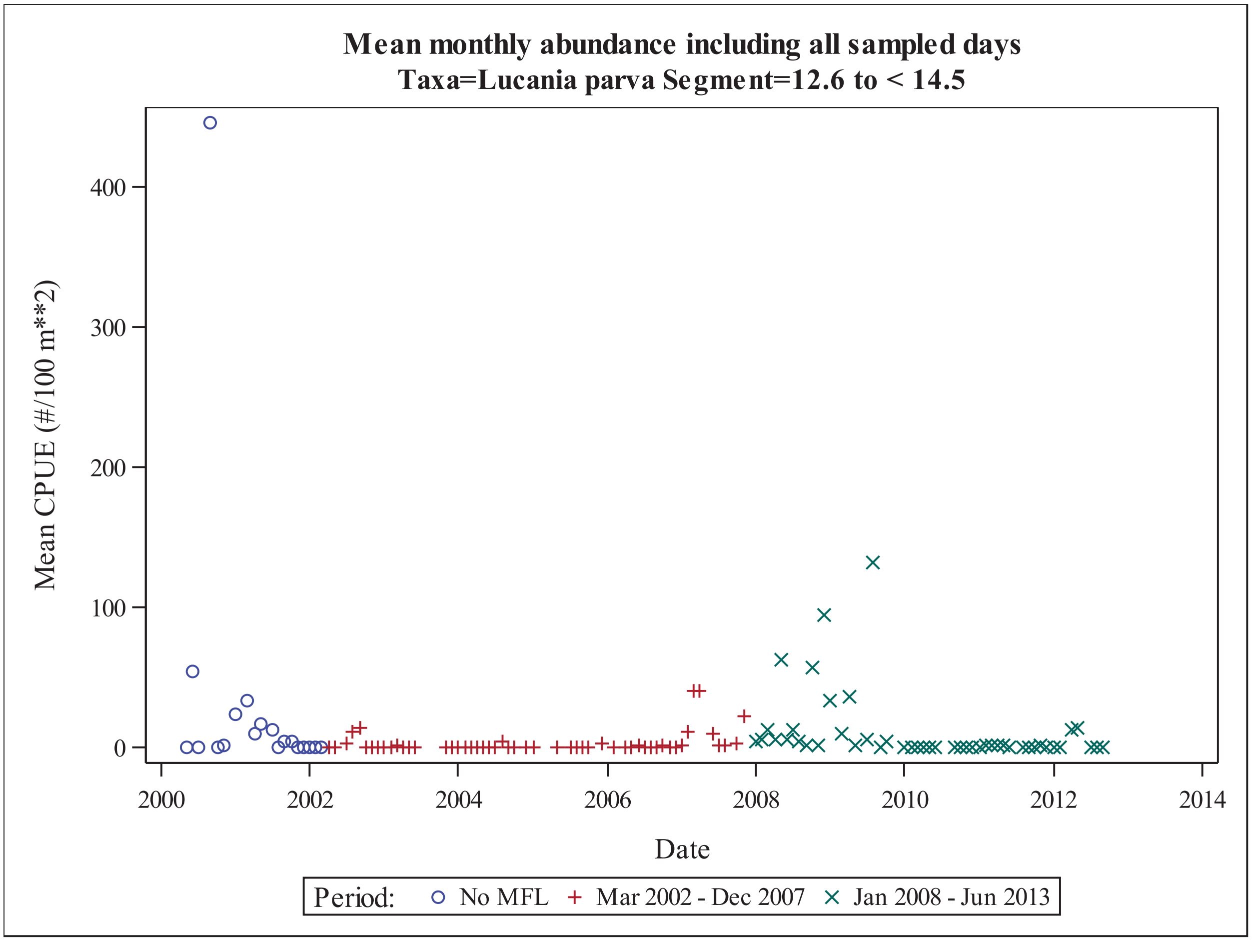


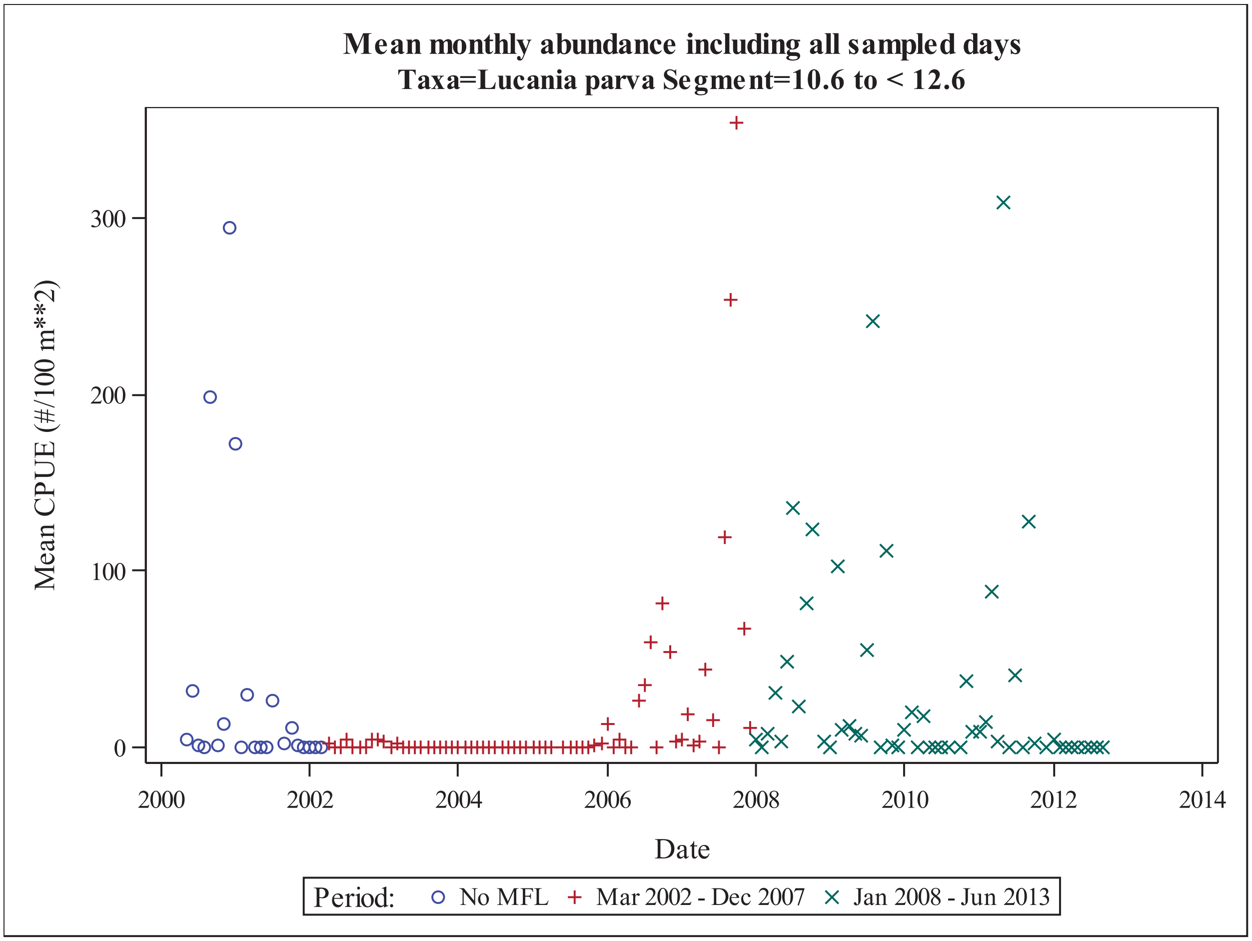

Mean monthly abundance including all sampled days
Taxa=Lepomis microlophus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
5
10
15
20
25
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Lepomis microlophus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
1
2
3
4
5
6
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

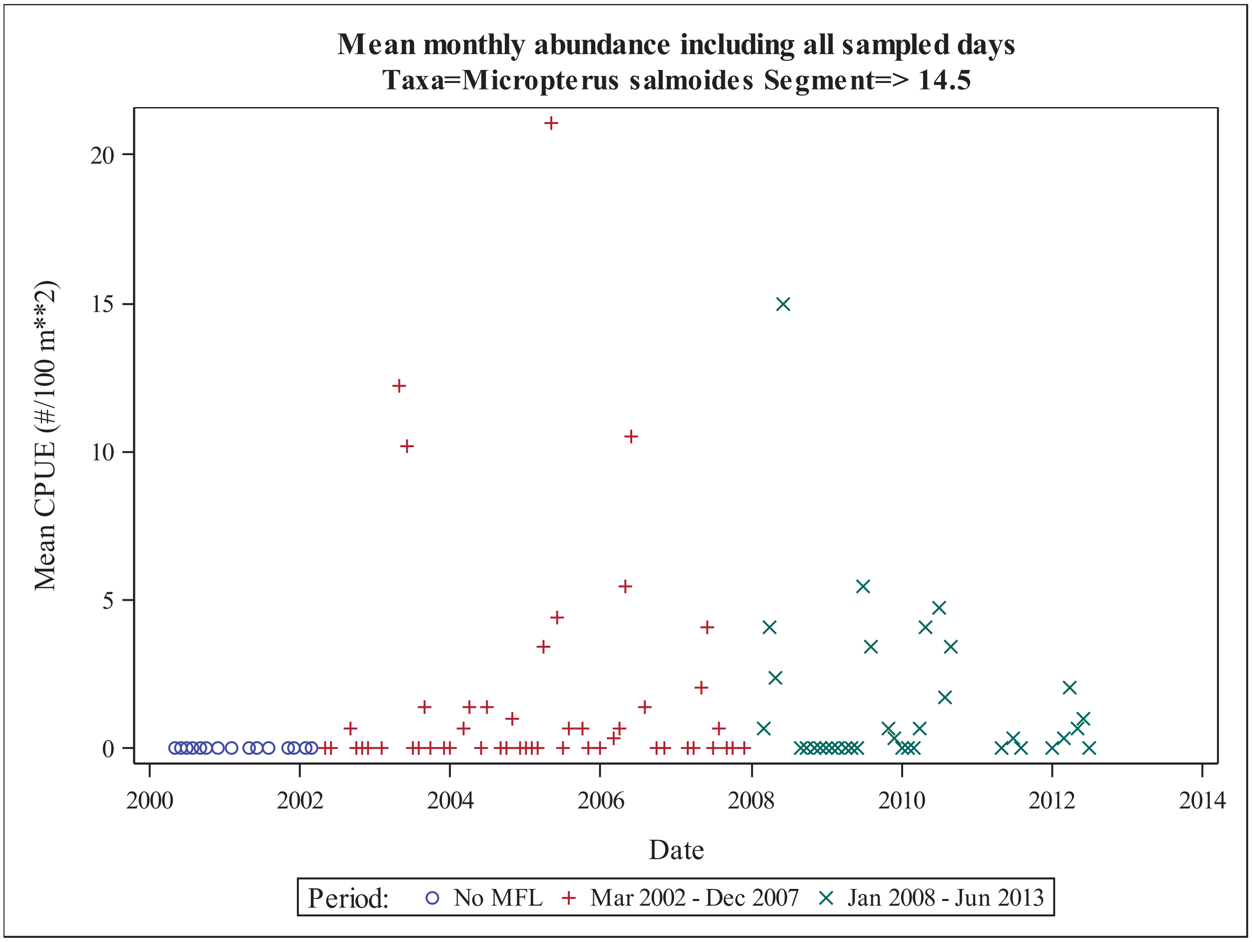
23. Lucania parva

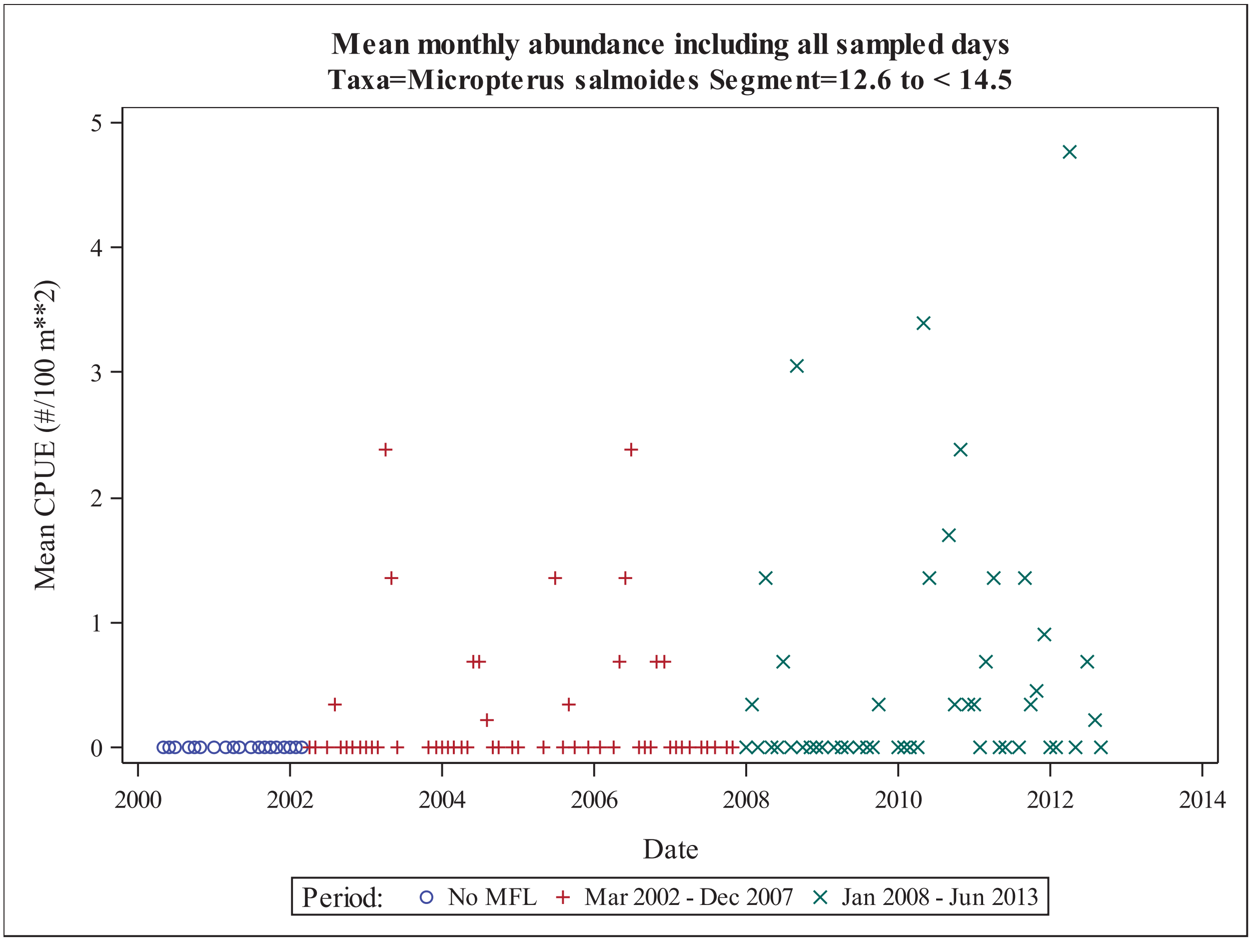


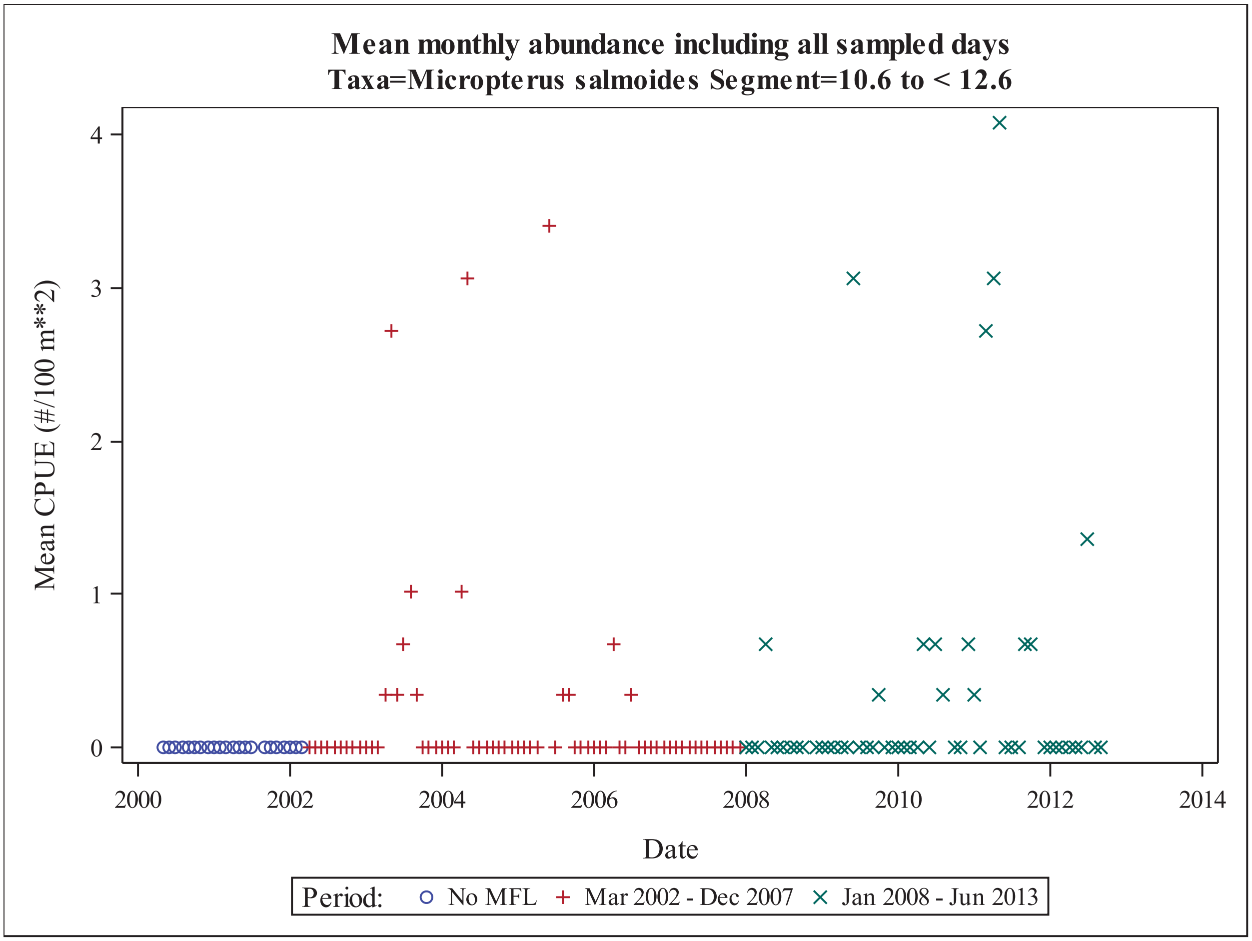

Mean monthly abundance including all sampled days
Taxa=Lucania parva Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
100
200
300
400
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Lucania parva Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
100
200
300
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

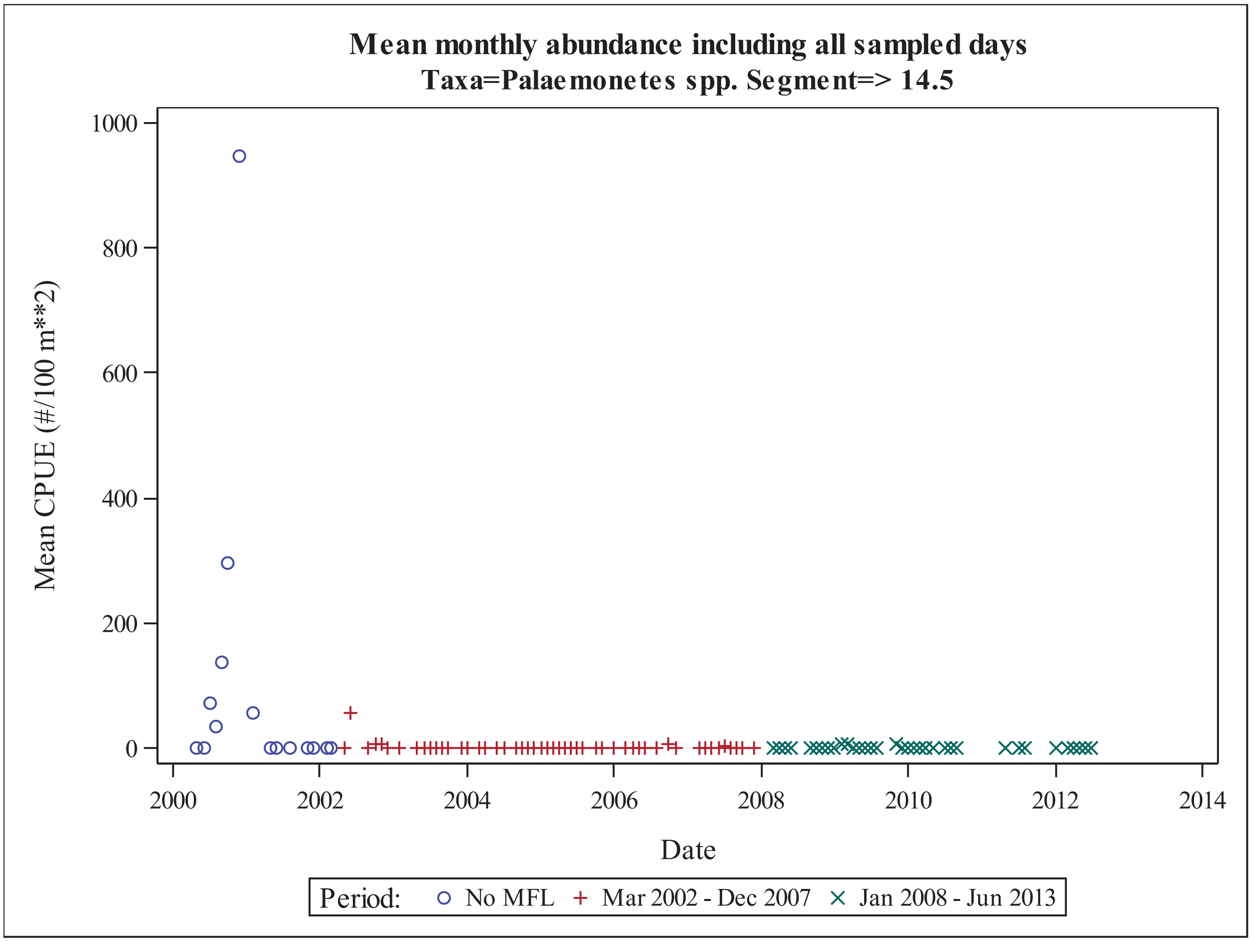
24. Micropterus salmoides

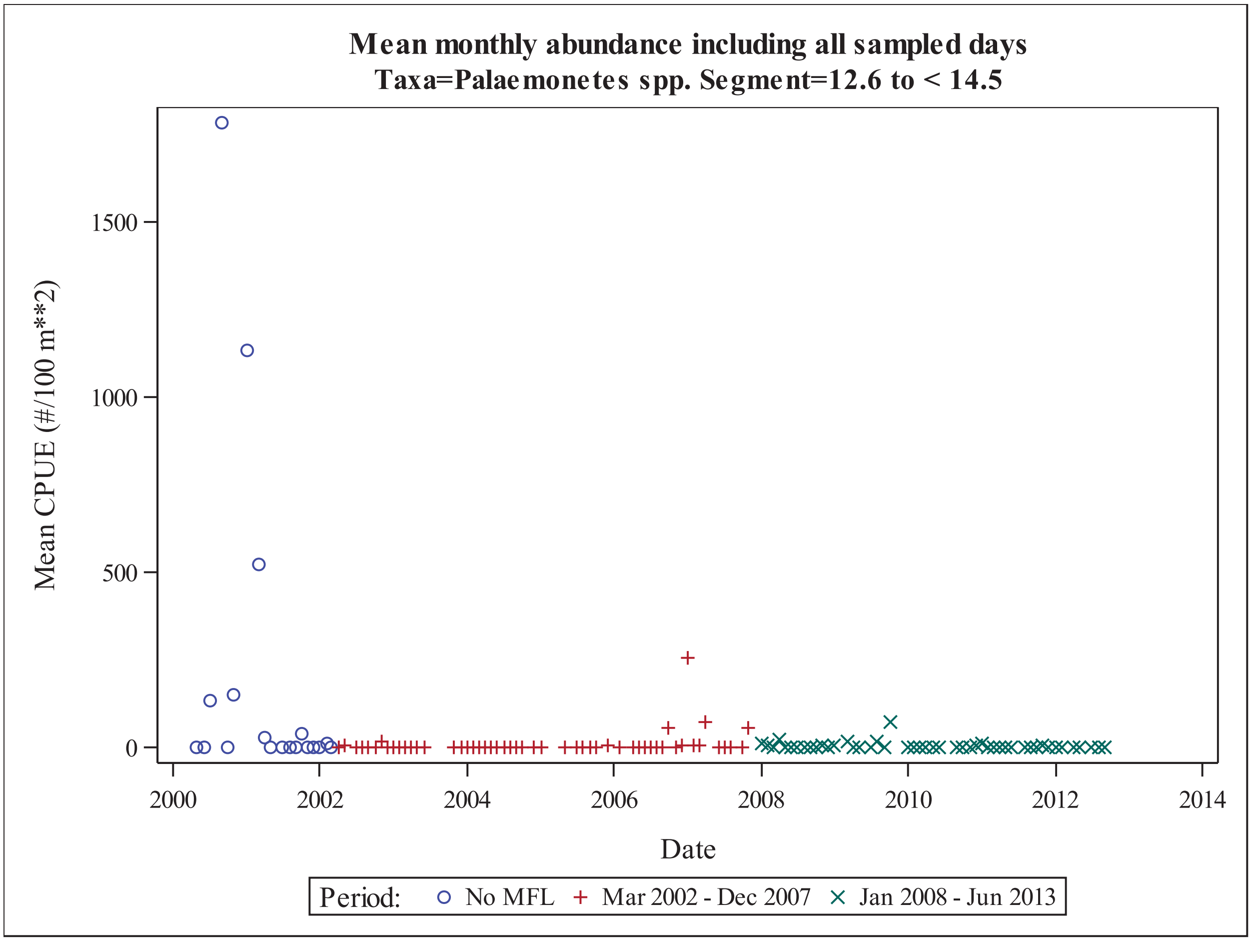


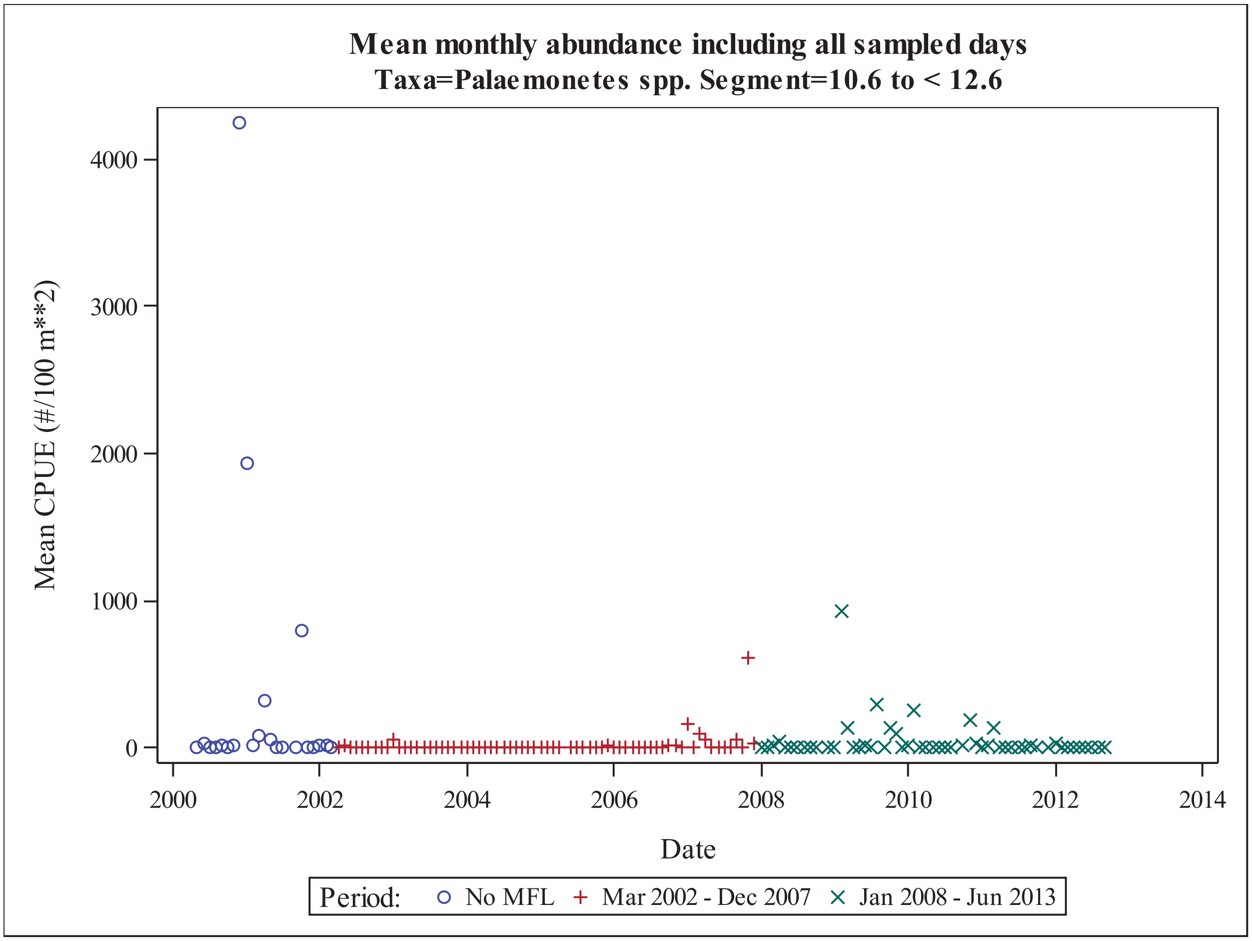

Mean monthly abundance including all sampled days
Taxa=Micropterus salmoides Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
1
2
3
4
5
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Micropterus salmoides Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
1
2
3
4
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

25. Palaemonetes spp

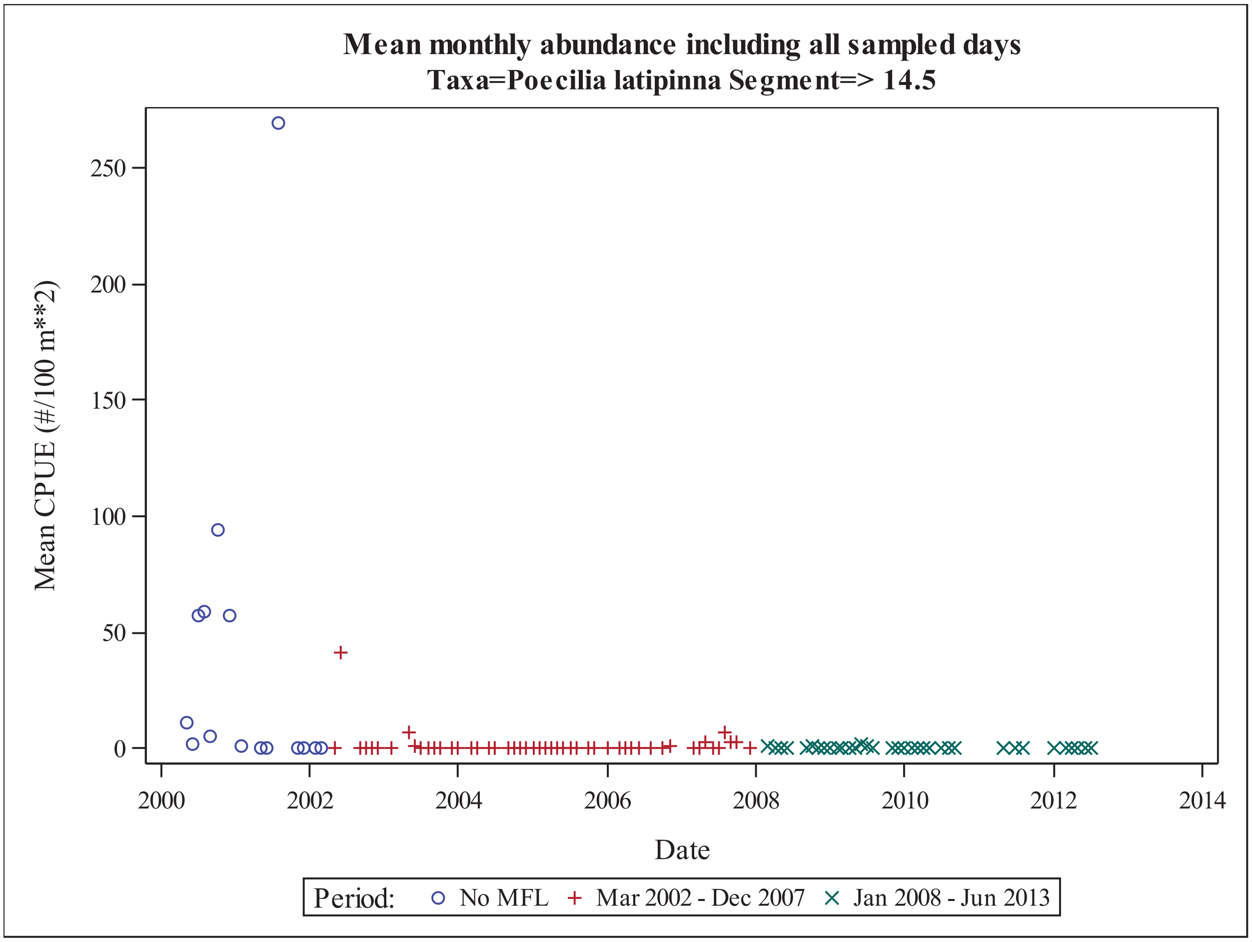


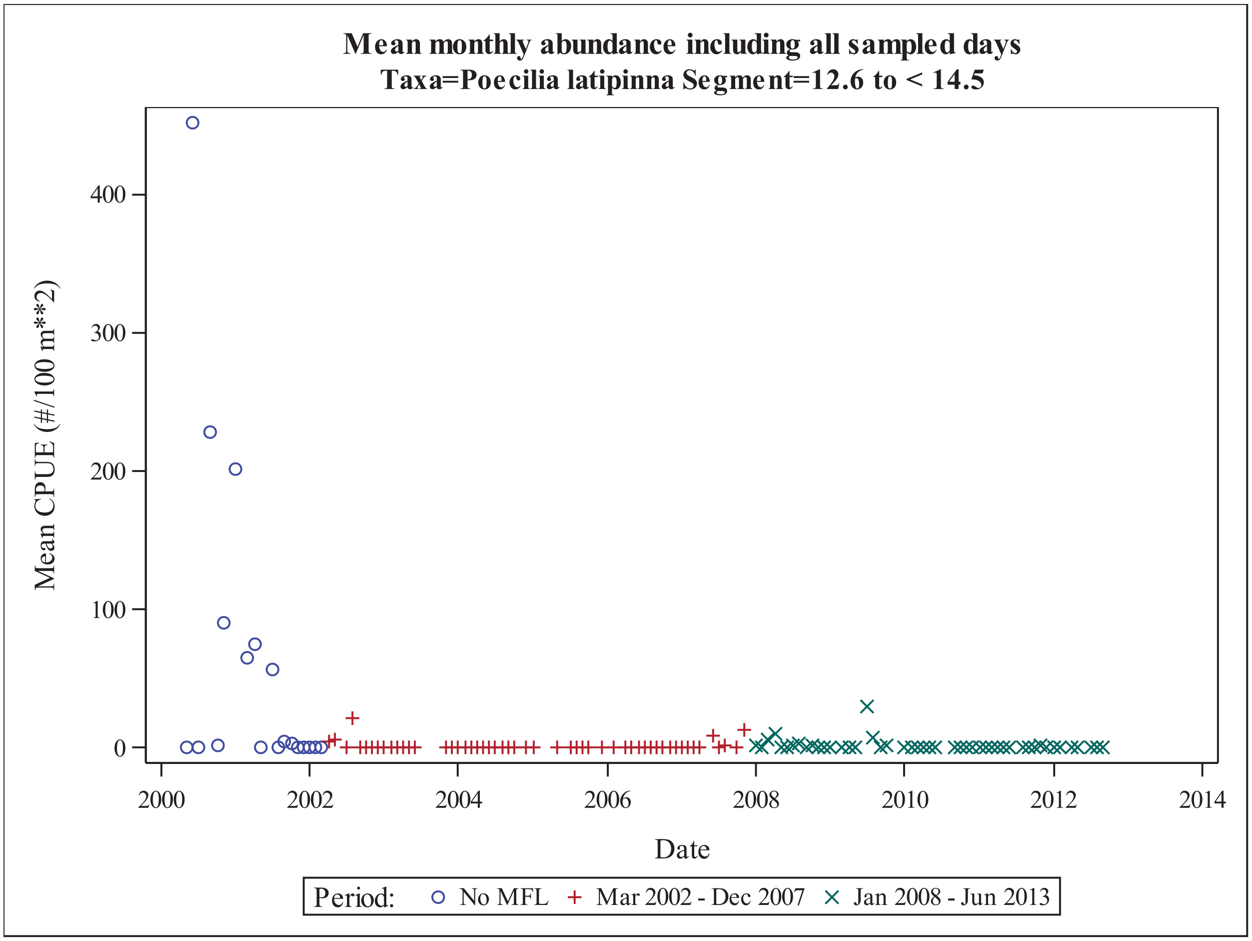

Mean monthly abundance including all sampled days
Taxa=Palaemonetes spp. Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
1500
1000
500
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013



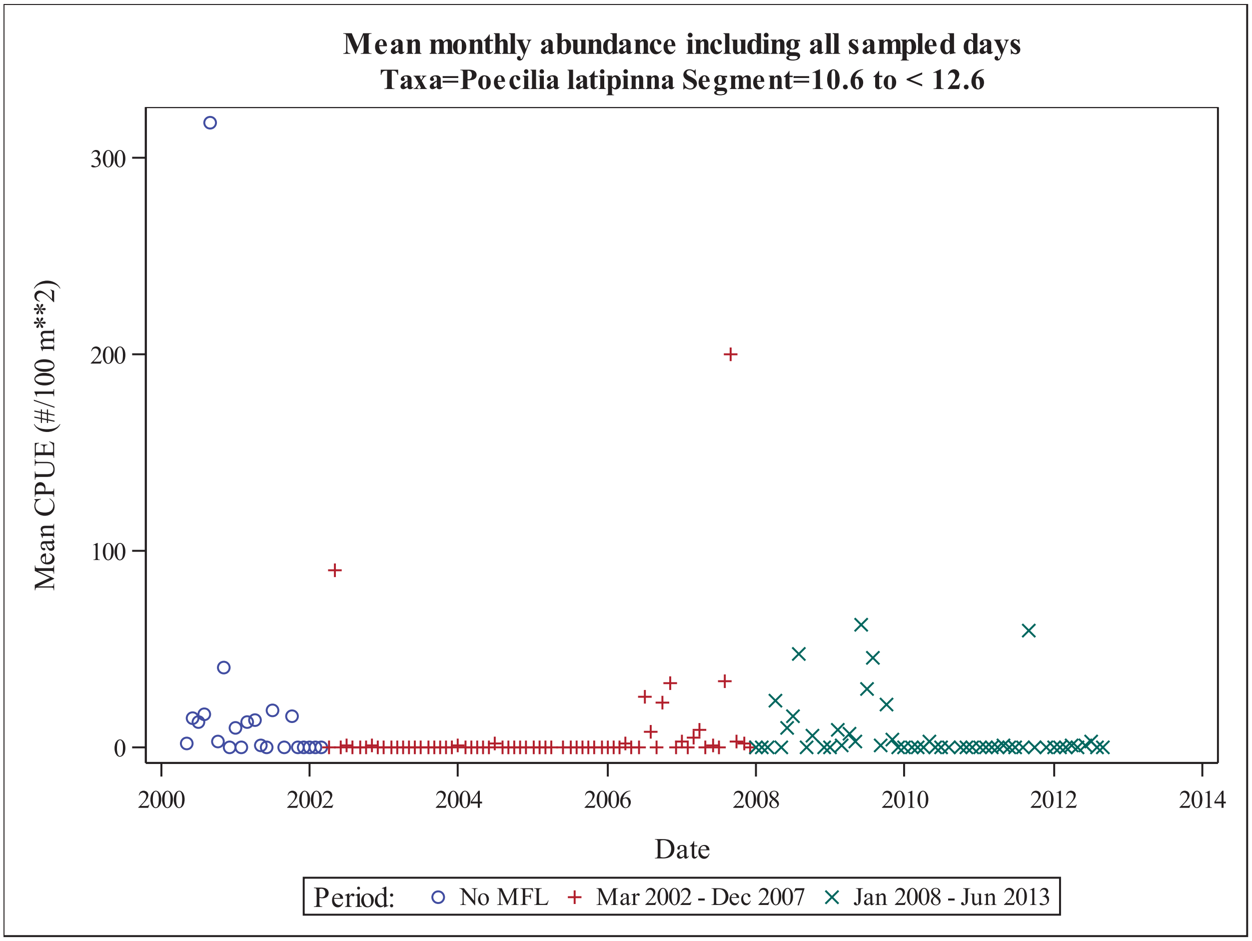
Mean monthly abundance including all sampled days
Taxa=Palaemonetes spp. Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
1000
2000
3000
4000
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

26. Poecilia latipinna

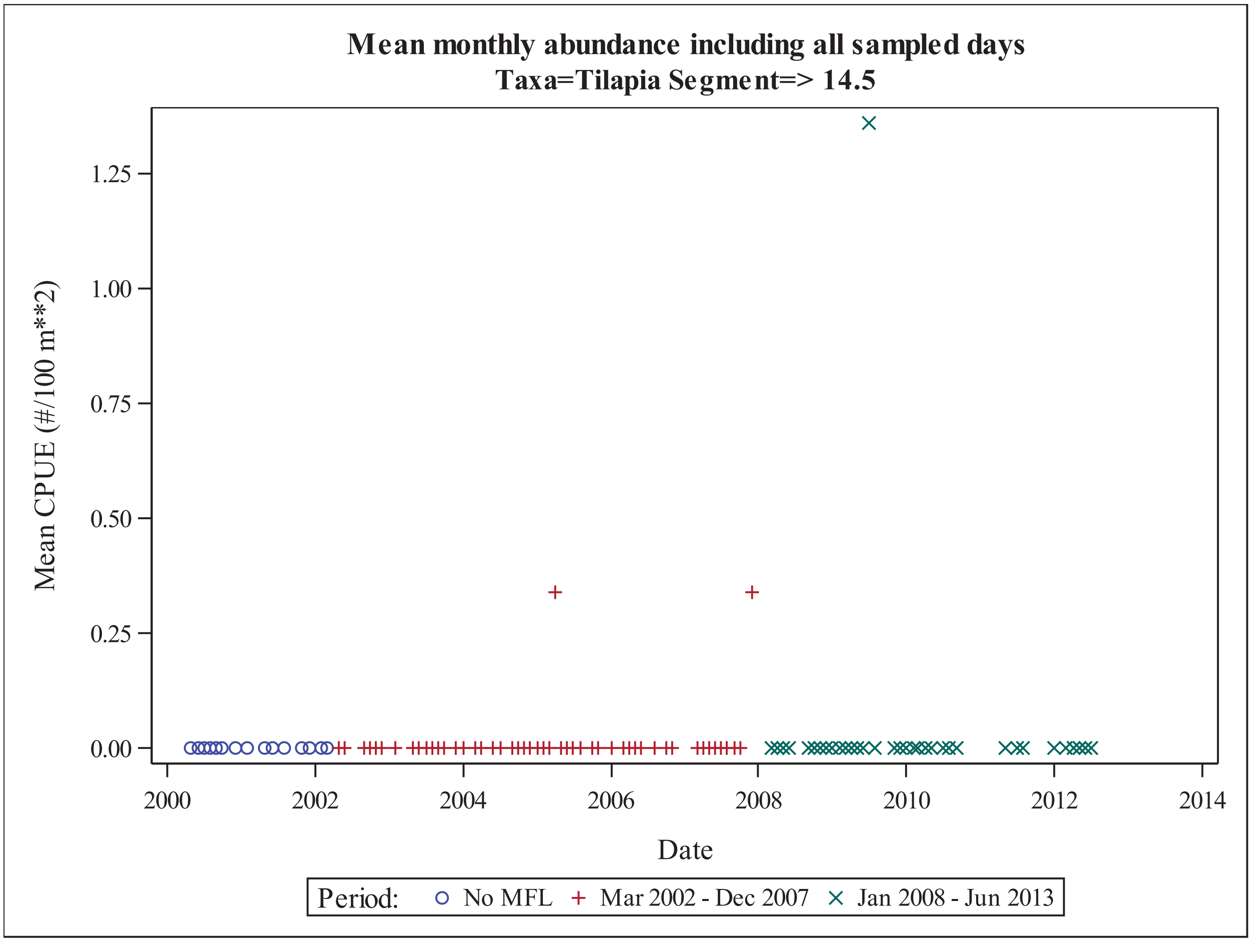


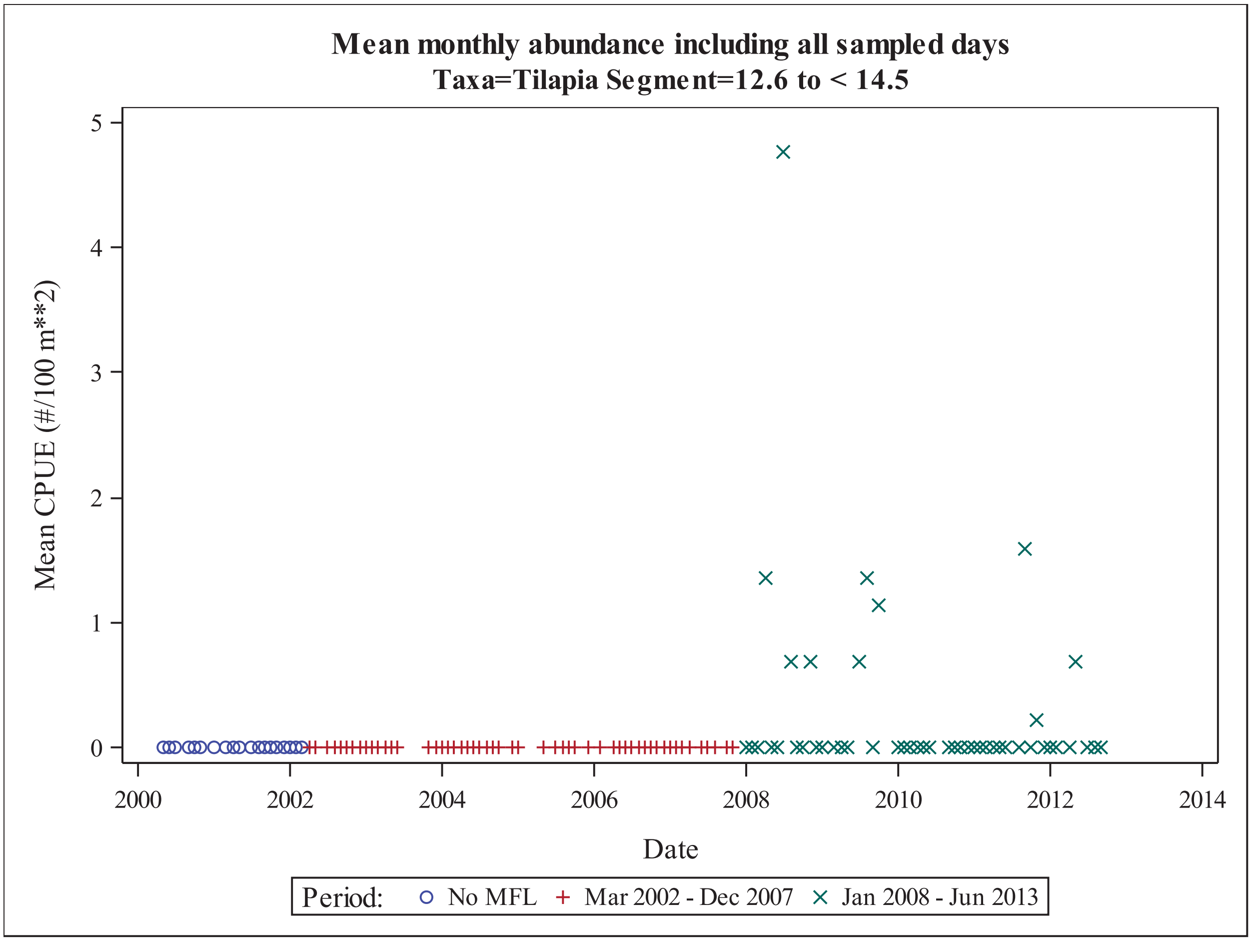


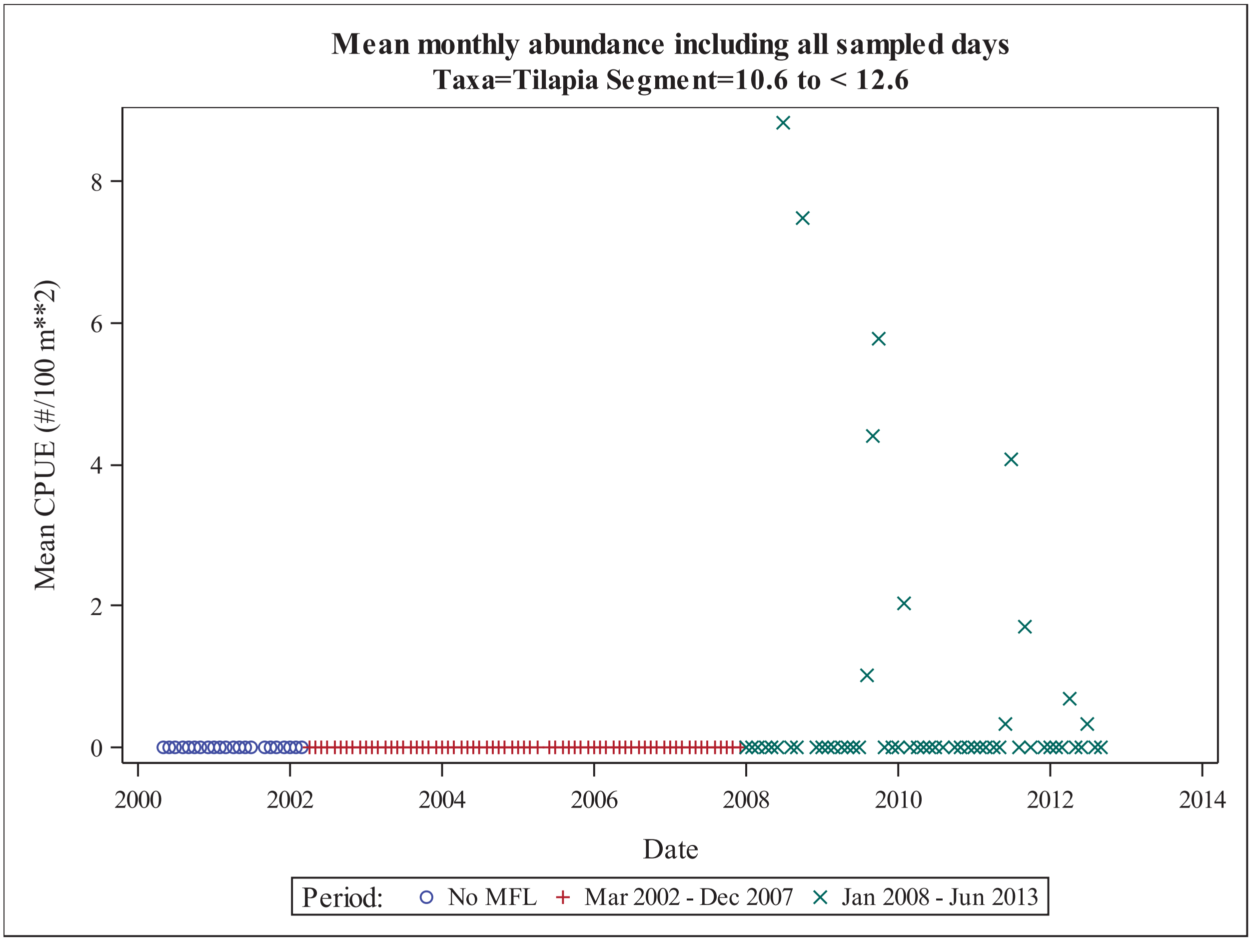
Mean monthly abundance including all sampled days
Taxa=Poecilia latipinna Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
100
200
300
400
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Poecilia latipinna Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
300
200
100
0
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

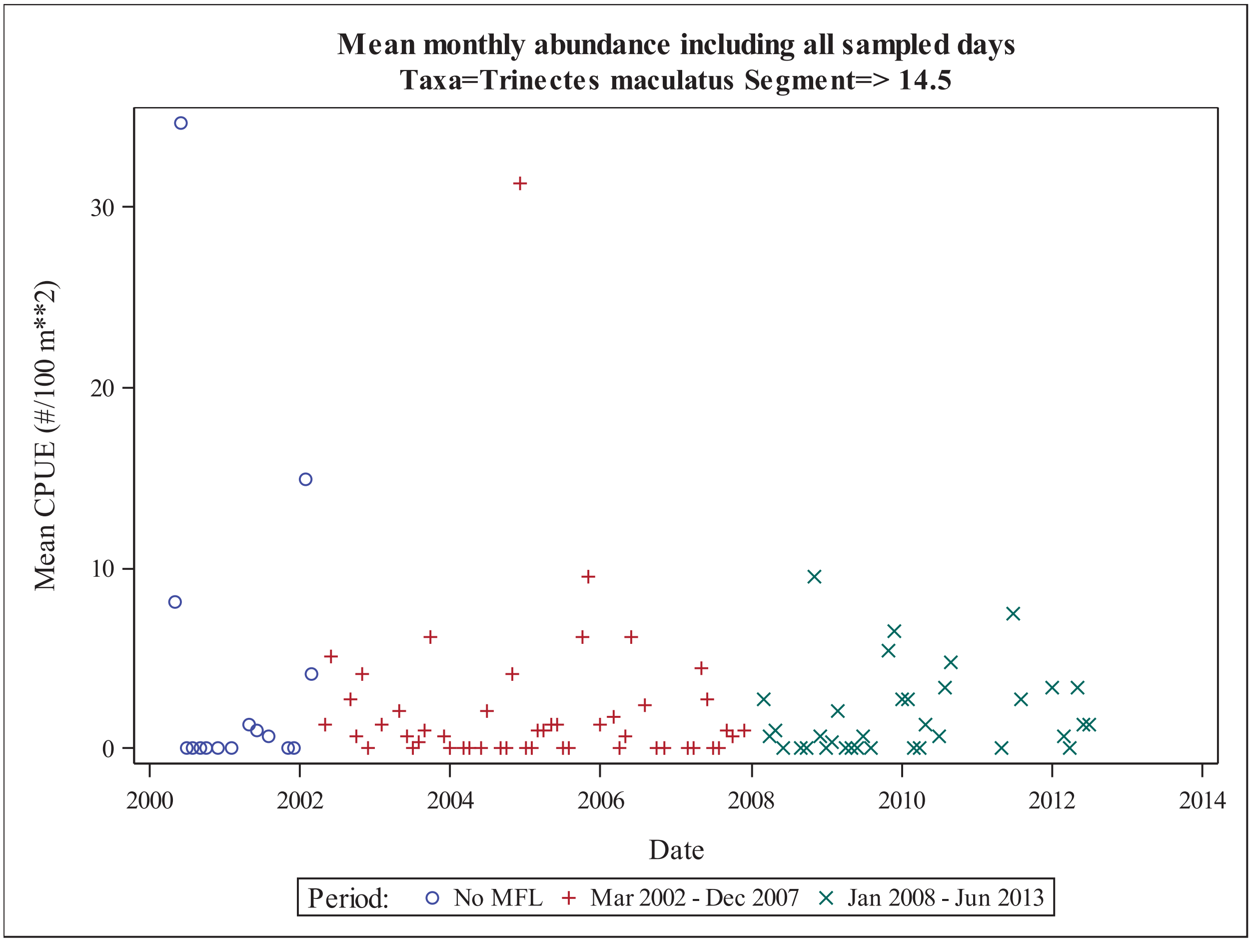
27. Tilapia

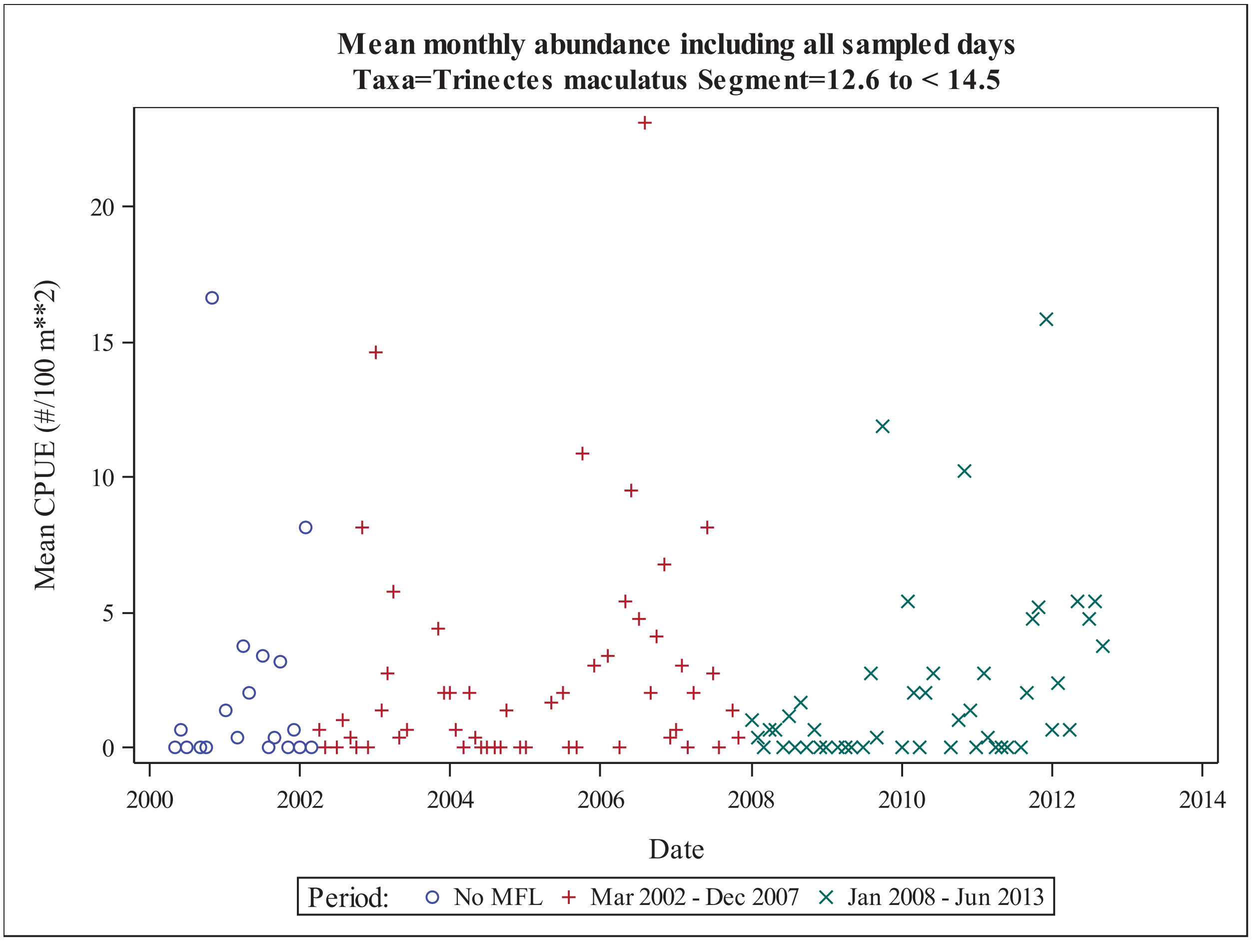

Mean monthly abundance including all sampled days
Taxa=Tilapia Segment=> 14.5
Mean CPUE (#/100 m**2)
1.25
1.00
0.75
0.50
0.25
0.00
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

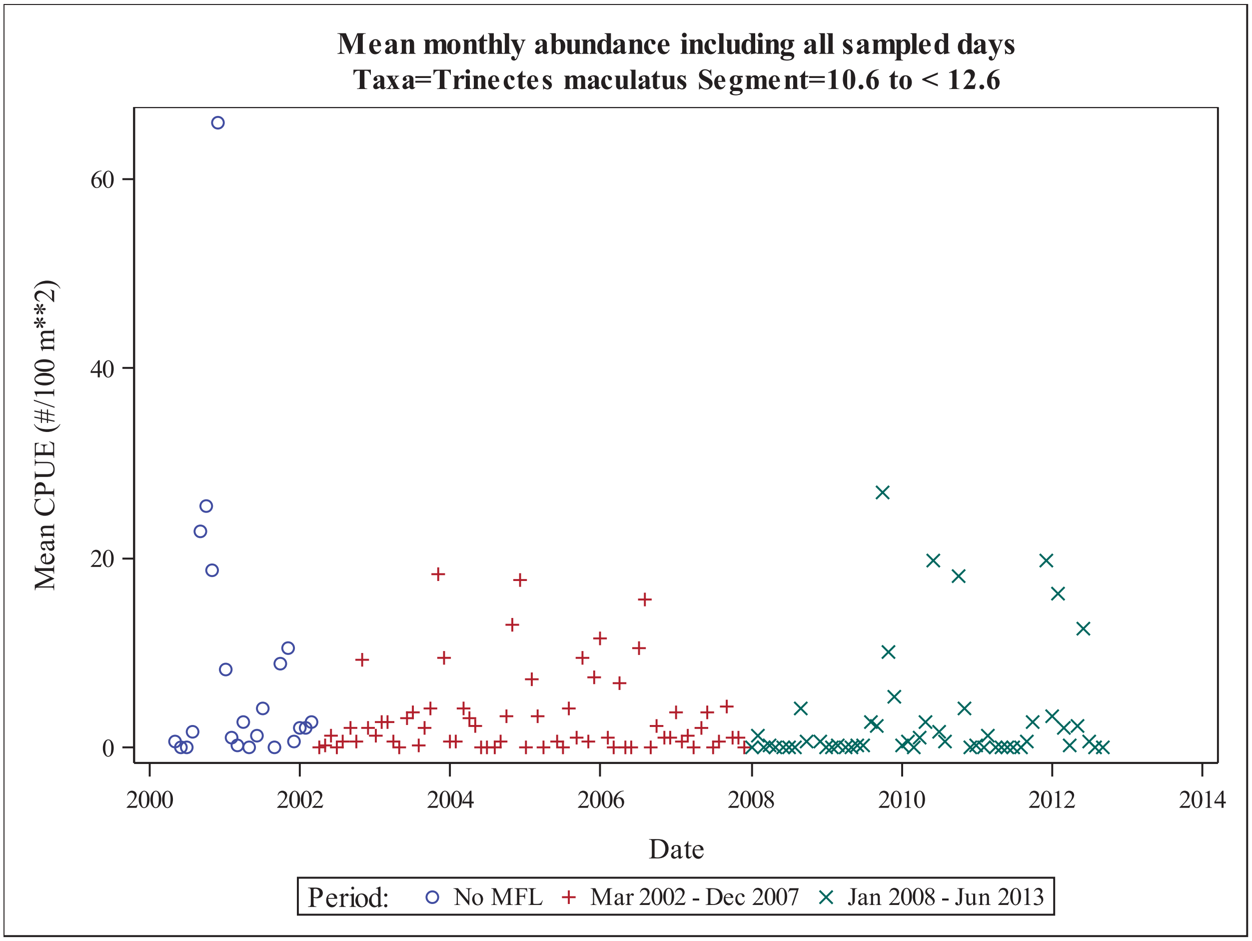

Mean monthly abundance including all sampled days
Taxa=Tilapia Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
1
2
3
4
5
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Tilapia Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
2
4
6
8
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period:
No MFL
Mar 2002 - Dec 2007
Jan 2008 - Jun 2013

28. Trinectes maculatus




Mean monthly abundance including all sampled days
Taxa=Trinectes maculatus Segment=12.6 to < 14.5
Mean CPUE (#/100 m**2)
0
5
10
15
20
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013


Mean monthly abundance including all sampled days
Taxa=Trinectes maculatus Segment=10.6 to < 12.6
Mean CPUE (#/100 m**2)
0
20
40
60
2000
2002
2004
2006
2008
2010
2012
2014
Date
Period: No MFL Mar 2002 - Dec 2007 Jan 2008 - Jun 2013

**Mean abundances of benthic macroinvertebrate taxa collected in three river segments during two minimum flow periods. Taxa ranked by the average abundance calculated from the mean abudance values listed for each segment and time period. All values are expressed as individuals per m$^2$. Results**

| | | | Kilometer 10.6 to < 12.6 | | Kilometer 12.6 to < 14.5 | | Kilometer ≥ 14.5 | |
|---|---|---|---|---|---|---|---|---|
| Rank | Taxon | Overall mean | Apr 2006 - Dec 2007 | Jan 2008 - Jun 2012 | Apr 2006 - Dec 2007 | Jan 2008 - Jun 2012 | Apr 2006 - Dec 2007 | Jan 2008 - Jun 2012 |
| 1 | Melanoides tuberculatus | 2,796 | 348 | 98 | 3,744 | 134 | 11,350 | 1,104 |
| 2 | Hydrobiidae spp. | 2,131 | 28 | 0 | 2,833 | 28 | 7,975 | 1,921 |
| 3 | Stenoninereis martini | 1,763 | 1,358 | 2,125 | 3,492 | 2,691 | 863 | 50 |
| 4 | Streblospio gynobranchiata | 874 | 0 | 5,035 | 0 | 119 | 0 | 88 |
| 5 | Tubificoid Naididae spp. | 622 | 388 | 0 | 481 | 56 | 1,788 | 1,021 |
| 6 | Mytilopsis leucophaeata | 335 | 75 | 73 | 204 | 1,084 | 25 | 550 |
| 7 | Laeonereis culveri | 323 | 85 | 123 | 335 | 650 | 738 | 8 |
| 8 | Streblospio spp. | 249 | 1,385 | 0 | 96 | 0 | 13 | 0 |
| 9 | Limnodrilus hoffmeisteri | 152 | 0 | 0 | 169 | 6 | 575 | 163 |
| 10 | Grandidierella bonnieroides | 147 | 5 | 208 | 56 | 153 | 313 | 150 |
| 11 | Cassidinidea ovalis | 131 | 0 | 5 | 15 | 25 | 25 | 717 |
| 12 | Corbicula fluminea | 90 | 0 | 0 | 44 | 0 | 63 | 433 |
| 13 | Polydora cornuta sp. complex | 80 | 8 | 95 | 71 | 281 | 0 | 25 |
| 14 | Pyrgophorus platyrachis | 78 | 0 | 0 | 6 | 0 | 0 | 463 |
| 15 | Chironomus spp. | 67 | 0 | 5 | 98 | 41 | 50 | 208 |
| 16 | Dicrotendipes spp. | 59 | 0 | 5 | 15 | 69 | 13 | 254 |
| 17 | Anopsilana jonesi | 40 | 0 | 0 | 0 | 6 | 0 | 233 |
| 18 | Polydora spp. | 36 | 0 | 215 | 0 | 0 | 0 | 0 |
| 19 | Boccardiella ligerica | 30 | 0 | 0 | 0 | 0 | 0 | 179 |
| 20 | Panopeidae spp. | 19 | 0 | 10 | 2 | 100 | 0 | 0 |
| 21 | Tarebia granifera | 17 | 0 | 0 | 0 | 63 | 0 | 42 |
| 22 | Rhithropanopeus harrisii | 17 | 0 | 5 | 23 | 59 | 13 | 0 |
| 23 | Hyalella spp. | 12 | 0 | 0 | 0 | 0 | 0 | 71 |
| 24 | Sphaeroma terebrans | 10 | 0 | 0 | 17 | 0 | 0 | 46 |
| 25 | Libellula spp. | 8 | 0 | 0 | 0 | 0 | 50 | 0 |
| 26 | Spionidae spp. | 8 | 0 | 0 | 0 | 0 | 0 | 50 |
| 27 | Ablabesmyia rhamphe group | 7 | 0 | 0 | 0 | 0 | 0 | 42 |
| 28 | Asheum beckae | 6 | 0 | 0 | 0 | 0 | 0 | 38 |
| 29 | Gammarus mucronatus | 6 | 0 | 0 | 0 | 0 | 38 | 0 |
| 30 | Amphibalanus spp. | 6 | 0 | 35 | 0 | 0 | 0 | 0 |
| 31 | Amphibalanus venustus | 6 | 0 | 0 | 0 | 0 | 0 | 33 |
| 32 | Stenochironomus spp. | 6 | 0 | 0 | 0 | 0 | 0 | 33 |
| 33 | Dero pectinata | 4 | 0 | 0 | 0 | 0 | 0 | 25 |
| 34 | Ephemeroptera spp. | 4 | 0 | 0 | 0 | 0 | 25 | 0 |
| 35 | Nereis sp. A | 4 | 0 | 0 | 0 | 25 | 0 | 0 |
| 36 | Paranais litoralis | 4 | 0 | 0 | 0 | 0 | 0 | 25 |
| 37 | Ficopomatus spp. | 4 | 0 | 15 | 6 | 0 | 0 | 0 |
| 38 | Procladius (Holotanypus) spp. | 3 | 0 | 0 | 0 | 0 | 13 | 8 |
| 39 | Ceratopogonidae spp. | 3 | 0 | 0 | 0 | 0 | 0 | 21 |
| 40 | Dicrotendipes lobus | 3 | 0 | 0 | 21 | 0 | 0 | 0 |
| 41 | Polypedilum halterale group | 3 | 0 | 0 | 2 | 0 | 0 | 17 |
| 42 | Almyracuma bacescui | 3 | 0 | 0 | 19 | 0 | 0 | 0 |
| 43 | Euhirudinea spp. | 3 | 0 | 0 | 0 | 6 | 0 | 13 |
| 44 | Uromunna reynoldsi | 3 | 0 | 0 | 0 | 0 | 0 | 17 |
| 45 | Edotia triloba | 3 | 0 | 10 | 0 | 6 | 0 | 0 |
| 46 | Gastropoda spp. | 3 | 0 | 0 | 0 | 3 | 0 | 13 |
| 47 | Limnodriloidinae spp. | 3 | 0 | 15 | 0 | 0 | 0 | 0 |
| 48 | Chironomidae spp. | 2 | 0 | 0 | 0 | 6 | 0 | 8 |
| 49 | Monopylephorus rubroniveus | 2 | 0 | 0 | 0 | 13 | 0 | 0 |
| 50 | Nemertea spp. | 2 | 0 | 0 | 2 | 6 | 0 | 4 |

**continued on following page.**

Appendix 8A - Mean Abundances for Benthic Macroinvertebrate Taxa Collected in Three River Segments During Two Minimum Flow Periods

| | | | Kilometer 10.6 to < 12.6 | | Kilometer 12.6 to < 14.5 | | Kilometer > 14.5 | |
|---|---|---|---|---|---|---|---|---|
| Rank | Taxon | Overall mean | Apr 2006 - Dec 2007 | Jan 2008 - Jun 2012 | Apr 2006 - Dec 2007 | Jan 2008 - Jun 2012 | Apr 2006 - Dec 2007 | Jan 2008 - Jun 2012 |
| 51 | Oecetis spp. | 2 | 0 | 0 | 0 | 0 | 0 | 13 |
| 52 | Cyclaspis varians | 2 | 5 | 0 | 6 | 0 | 0 | 0 |
| 53 | Melita nitida complex | 2 | 0 | 5 | 0 | 6 | 0 | 0 |
| 54 | Polypedilum scalaenum group | 2 | 5 | 0 | 6 | 0 | 0 | 0 |
| 55 | Arhynchobdellida spp. | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 56 | Bratislavia unidentata | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 57 | Chironominae spp. | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 58 | Cladotanytarsus sp. F | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 59 | Cryptotendipes spp. | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 60 | Erpobdella punctata | 1 | 0 | 0 | 2 | 6 | 0 | 0 |
| 61 | Parachironomus carinatus | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 62 | Pristina spp. | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 63 | Procladius spp. | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 64 | Tanytarsus sp. G | 1 | 0 | 0 | 0 | 0 | 0 | 8 |
| 65 | Eudendrium spp. | 1 | 0 | 0 | 0 | 3 | 0 | 4 |
| 66 | Alitta succinea | 1 | 0 | 0 | 0 | 6 | 0 | 0 |
| 67 | Cyrenoida floridana | 1 | 0 | 0 | 6 | 0 | 0 | 0 |
| 68 | Ficopomatus miamiensis | 1 | 0 | 0 | 6 | 0 | 0 | 0 |
| 69 | Hargeria/Leptochelia sp. complex | 1 | 0 | 0 | 0 | 6 | 0 | 0 |
| 70 | Minuspio perkinsi | 1 | 0 | 0 | 0 | 6 | 0 | 0 |
| 71 | Mysella planulata | 1 | 0 | 0 | 0 | 6 | 0 | 0 |
| 72 | Carazziella hobsonae | 1 | 5 | 0 | 0 | 0 | 0 | 0 |
| 73 | Cerapus sp. C | 1 | 0 | 5 | 0 | 0 | 0 | 0 |
| 74 | Dubiraphia spp. | 1 | 0 | 5 | 0 | 0 | 0 | 0 |
| 75 | Gammarus spp. | 1 | 0 | 5 | 0 | 0 | 0 | 0 |
| 76 | Glottidia pyramidata | 1 | 5 | 0 | 0 | 0 | 0 | 0 |
| 77 | Leitoscoloplos foliosus | 1 | 0 | 5 | 0 | 0 | 0 | 0 |
| 78 | Onuphidae spp. | 1 | 0 | 5 | 0 | 0 | 0 | 0 |
| 79 | Ampelisca abdita | 1 | 0 | 0 | 4 | 0 | 0 | 0 |
| 80 | Aoridae spp. | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 81 | Apedilum spp. | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 82 | Chaoborus punctipennis | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 83 | Cirolana parva | 1 | 0 | 0 | 4 | 0 | 0 | 0 |
| 84 | Enallagma spp. | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 85 | Hydrozoa spp. | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 86 | Melinna maculata | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 87 | Naidinae spp. | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 88 | Polycladida spp. | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| 89 | Gammarida spp. | 1 | 0 | 0 | 0 | 3 | 0 | 0 |
| 90 | Oxyurostylis smithi | 1 | 0 | 0 | 0 | 3 | 0 | 0 |
| 91 | Polymesoda caroliniana | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 92 | Ampelisca spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 93 | Bezzia/Palpomyia spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 94 | Capitella capitata sp. complex | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 95 | Orchestia spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 96 | Rhabditophora spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 97 | Sparganophilus spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 |