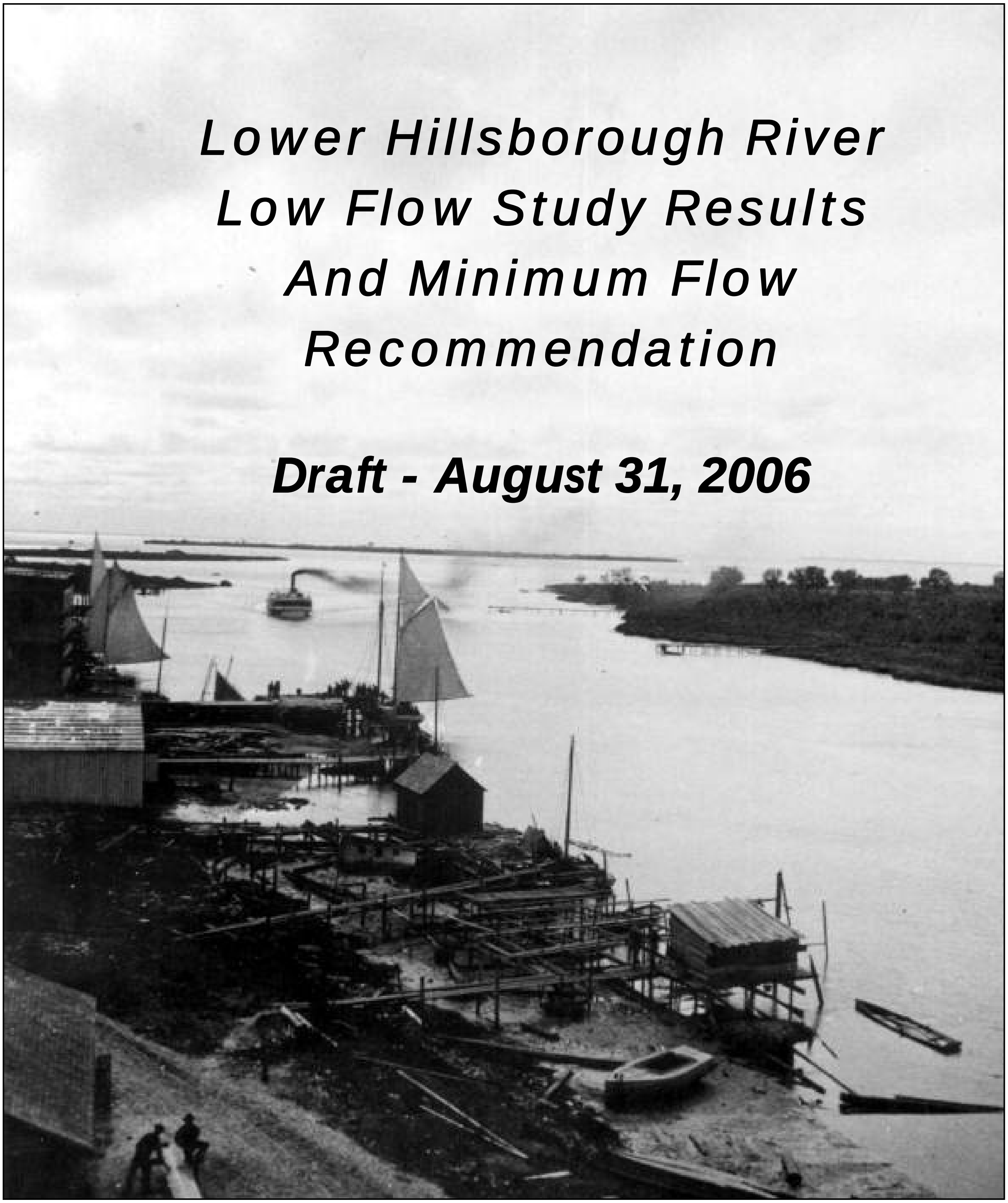
Lower Hillsborough River Low Flow Study Results And Minimum Flow Recommendation

Draft - August 31, 2006



Southwest Florida Water Management District

EXECUTIVE SUMMARY

The purpose of this document is to summarize the work completed to reevaluate the current minimum flow of 10 cubic feet per second for the Lower Hillsborough River (LHR). The reevaluation study was agreed to as a part of a settlement between the Southwest Florida Water Management District (District), the City of Tampa (CoT), Sierra Club, Crystal Springs Recreational Preserve, Inc., Two Rivers Ranch, Inc., Friends of the River, Inc., Philip Compton, B. John Ovink, Barbara R. Lewis, Ed Ross, Pamela G. Stein, Paul F. Stein, and Elizabeth Taylor. The settlement called for low flow (0 – 30 cfs) experiments to increase the available data under low flow conditions. The settlement agreement was codified by the District into its rule Chapter 40D-30, F.A.C. as part of the recovery strategy for the Lower Hillsborough River. In compliance with the District rule, the CoT has been diverting 10 cfs of Sulphur Springs water to the base of the Hillsborough River Dam since 2002 for minimum flow compliance.

The LHR extends approximately 16.3 km from the mouth to the dam. Most of the LHR watershed is urban. The shoreline has been substantially modified with the exception of the section of shoreline from the dam toward Hannah's Whirl, which represents the most natural shoreline in the LHR. The shoreline from Hannah's Whirl toward Sulphur Springs has some hardened shoreline, but not nearly as much as downstream of the Spring. Freshwater inflows to the LHR consist primarily of flow over the Hillsborough River Dam, nonpoint source runoff that enters the river below the dam, small springs and rainfall. In addition, water enters the LHR from Sulphur Springs, which is located 3.5 km downstream of the Hillsborough River Dam. The water entering from Sulphur Springs is not strictly fresh, having an average salinity of 1.2 to 1.3 ppt.

Due primarily to permitted withdrawals from the reservoir for water supply, flow over the dam has been zero for extended periods of time. For example, for the ten-year period before a minimum flow was in effect (1992-2001), there was minimal to no flow (less than 0.3 cfs) over the dam 51 percent of the days.

In the years intervening since the adoption of the recovery strategy, extensive chemical and biological data have been collected in the LHR as part of Tampa Bay Water's Hydrobiological Monitoring Program (HBMP) and other ongoing monitoring activities (e.g., USGS, Hillsborough County EPC). These data were analyzed as part of the MF re-evaluation. Additionally, considerable effort was put into updating the District's hydrodynamic model for the river (LAMFE) by recalibrating the model with higher resolution bathymetry and utilizing salinity data collected from several new recorders distributed at different depths throughout the lower river. The LAMFE model was the principal tool used to evaluate the selected minimum flow scenarios.

<u>Key findings from this re-evaluation are:</u>

- This study included a series of actual experimental releases in the range of 10 to 30 cfs, as well as other low-flow events that occurred during the course of the study. Model simulations of these and other flows were also performed, including finer-scale intervals to evaluate differences among many flows in the range of 10 to 30 cfs. As anticipated, different flows provided different salinity regimes in the LHR, generally as a function of distance from the dam and depth in the water column.

- New data confirm that the existing 10 cfs minimum flow provides some meaningful benefits in terms of salinity reduction (Figures 7-2 through 7-13), and that incremental movement toward a higher required minimum flow will extend those benefits over a larger volume of the lower river. At the same time, recently acquired data, similar to that used to develop the existing minimum flow for the LHR, indicate that there is no threshold or optimum flow which yields the "best" (or even a constant) volume of low salinity habitat.

- The primary water quality and ecological factor affected by freshwater inflows at the base of the dam is salinity, although tides and other factors (e.g., stormwater, winds, and salinity in Tampa Bay) complicate this relationship. The LAMFE model was used to examine the relationship between freshwater inflows at and below the base of the dam and salinity in the lower river under various freshwater inflow scenarios. Natural tidal forces restrict the ability to maintain lower salinity habitat as distance from the dam increases. Even when a constant minimum flow is present, there is considerable within-day variability in salinity through most of the river as a result of tides, wind, antecedent flow conditions, rainfall and stormwater inputs, etc. Thus there will be some difference in the proportion of time that <5 ppt conditions are present from Hanna's Whirl to Sulphur Springs compared to the segment from the dam to Hanna's Whirl.

- Prior to implementation of the current 10 cfs minimum flow, long-term data for the LHR showed that during periods of no-flow at the dam, tidal fresh and oligohaline waters were frequently eliminated from the lower river. The TBNEP advisory group accordingly recommended that creation of a salinity gradient below the dam that ranges from fresh to polyhaline waters is an important criterion for establishing minimum flows for the LHR. Biological sampling has indicated that the lower river is inhabited by a variety of native fishes and invertebrates, and that the distribution of these aquatic organisms generally shifts between estuarine and freshwater communities based on the rate of inflow and the predominant salinity conditions at the time.

- The TBNEP (1996) has concluded that river habitats with salinities in the oligohaline (i.e., low salinity, 0.5 to < 5 ppt) range have been disproportionately lost throughout the Tampa Bay watershed. There is an opportunity to maintain such habitats in the LHR given an appropriate minimum flow.

- Principal components analysis (PCA) performed on biological sampling results identified four salinity ranges utilized by invertebrates and four similar ranges utilized by fish. The findings for benthic macroinvertebrate community structure (Figure 5-9) showed that a distinct group of these organisms occur in river habitats with salinity in the range of <5 ppt. However, here was a high degree of species overlap among adjacent salinity zones and few estuarine species were identified as requiring a single salinity zone. Because some invertebrate species and some fish species are restricted to the lower salinity range, maintaining an essentially permanent area of the lower river with a salinity of <5 ppt would provide habitat for those predominantly oligohaline and fresh water species, assuming other habitat requirements are also present.

- The creation of a < 5 ppt salinity zone was chosen as the principal ecological criterion on which to establish minimum flows for the LHR. In addition to creating a low salinity zone for benthic macroinvertebrates, juvenile stages of important estuarine dependent fish species concentrate in oligohaline waters

- Benefits (in terms of provision of low salinity habitat) accruing from fresh (or nearly fresh) water inputs at the dam are most pronounced near the dam, with the magnitude of the effect diminishing downstream (Figures 6-60 through 6-64). Logically, greater flows extend the benefits farther downstream than lesser flows. For a given discharge rate, the strongest effects are realized nearest the dam and decrease incrementally downstream.

- The uppermost section of the LHR from the dam to Hannah's Whirl represents the segment of the river with the least degree of artificially hardened shoreline. The segment from Hannah's Whirl to Sulphur Springs also has relatively unaltered shoreline, but seawalls and other structural alterations are more common there. In both of these segments, the typically steep banks and urban shoreline development generally limit habitat above the water line to the immediate riparian zone.

- Improvements in dissolved oxygen (DO) concentrations are generally apparent nearer the dam with increasing flow, but in a much less predictable manner than for salinity. There is evidence that increasing flows in order to improve dissolved oxygen levels nearer the dam may actually depress oxygen levels farther downstream. Thus, freshwater inflows cannot be used as a general mechanism for mitigating the overall dissolved oxygen deficit throughout the lower river. However, the improvements in DO concentrations in the oligohaline zone that occur during low flows outweigh the slight decreases in DO that would occur in the more downstream reaches.

Commenting on the earlier LHR MF document and salinity modeling using the LAMFE model, the peer review panel (Montagna et al. 1999) noted, "There [do] not appear to be any breakpoints in this analysis. The decision on the appropriate instream flow value could be based on the distance downstream, and the depth, that low salinity water is desired." Essentially a MF recommendation based on a desired salinity environment requires a decision on the appropriate duration and spatial extent, of the desired salinity gradient.

The LHR Minimum Flow management goal is:

To provide a minimum flow that would extend a salinity range of <5 ppt from the Hillsborough Reservoir Dam toward Sulphur Springs.

The use of a salinity-based criterion as a management goal for a LHR minimum flow is based upon a biologically-relevant critical salinity range and includes a target spatial extent for that salinity range.

Consideration of the desired spatial extent of the desired low salinity habitat area is essential. The highly urbanized nature of the entire LHR watershed and the virtual absence of upland or floodplain area available for any significant ecological enhancement or restoration restrict biological considerations to the river channel itself. Sulphur Springs is a natural source of low salinity water that flows into the river 3.5 kilometers downstream of the dam. Providing a source of water above Sulphur Springs sufficient to produce a <5 ppt zone from the dam to Sulphur Springs provides a low salinity continuum from a truncated estuary (i.e., the base of the dam) to a natural source of low salinity water. It also has the added benefit of minimizing or eliminating the "reverse salinity" gradient which develops just upstream of Sulphur Springs when upstream flows are insufficient. Given the location of Sulphur Springs and the expressed Sulphur Springs MF management goal (SWFWMD, 2004b) of maintaining a low salinity habitat in this portion of the river, it is reasonable and ecologically desirable to define a spatial extent that considers Sulphur Springs, and in effect creates a low salinity (oligohaline) corridor between the base of the dam and Sulphur Springs.

While <5 ppt is viewed as an important biological range for salinity, the available biological data itself does not allow for determination of the optimal volume of this habitat for fish or invertebrate communities in the LHR. Because of its highly altered status and urbanized condition, the District considered the benefits of incremental gains in the volume and duration of the < 5 ppt zone in relation to freshwater inflows. Given the goal of establishing a < 5 ppt salinity zone above Sulphur Springs, the District considered how much benefit would be gained increasing flows in 2 cfs increments in the 0 – 30 cfs range.

The duration and spatial extent of change in oligohaline habitats in the LHR are non-linear but monotonic functions of the freshwater flow at the dam. For example, as the flow increases the volume of low salinity water increases, but the rate of change is not constant. Thus, an approach based on incremental gains in the spatial extent (i.e., volume) and duration (i.e., time) was employed to evaluate the time and volume that a low salinity zone could be established. It is apparent that a number of different flows will provide some <5 ppt habitat above Sulphur Springs; however, the percent of the time and the percent of the volume that a <5 ppt zone is provided varies with the flow rate supplied. The amount of <5 ppt habitat steadily increases as flow increases, but there is a change in the rate of increase. Although one can continue to increase the amount of <5 ppt habitat toward Sulphur Springs (both spatially and temporally) by continuing to increase flow, the maximum return per flow invested begins to level off at 20 cfs and declines after 24 cfs. For this reason and the fact that the reverse salinity gradient is virtually eliminated at 20 cfs of freshwater flow, 20 cfs freshwater equivalent is recommended as the MF.

Due to the unusually severe hydrologic conditions experienced in 2000-2001, some allowance should be made in the proposed MF during extreme hydrologic conditions to reflect natural climatic variations that can occur. Water to make up minimum flows will probably come from a mix of several potential sources (Sulphur Springs, Tampa Bypass Canal, Blue Sink, Aquifer Storage and Recovery, treated wastewater, etc.), and the availability of only one of these sources (i.e., treated wastewater) is independent of natural hydrologic conditions. Therefore, it is proposed that the 20 cfs freshwater equivalent MF be seasonally adjusted based on naturally varying hydrologic conditions. The low flows in the upper Hillsborough River are largely sustained by spring discharges. Although annual variation in spring flow is typically much less than river flow, the Zephyrhills gage on the upper Hillsborough River does provide a good measure of the flow that would be supplied in the upper watershed under low flow conditions. It is recommended that when the low flows, as measured at the Zephyrhills gage, drop below a given threshold, the minimum flow on the lower Hillsborough River be adjusted accordingly. It is recommended that the minimum flow be adjusted for seasonal hydrologic conditions. The suggested method of adjustment is tied to flow in the Hillsborough River as measured at the USGS Zephyrhills gage and the annual 90% exceedance flow at this site for the period 1990-1999.

The minimum flow recommendation for the Lower Hillsborough River is for the equivalent of 20 cfs of fresh water, based on extending a <5 ppt salinity zone from the base of the Hillsborough River Reservoir toward Sulphur Springs under low flow conditions. It is recognized that if a mix of waters involving sources that may not be strictly fresh or already flow to the river (e.g., Sulphur Springs) is used to meet the minimum flow, the minimum flow requirement will be greater than 20 cfs.

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1.0 PURPOSE AND BACKGROUND OF MINIMUM FLOWS AND LEVELS

1.1 Overview

The Southwest Florida Water Management District (District) is responsible for permitting the consumptive use of water within the District's boundaries. Within this context, the Florida Statutes (Section 373.042) mandate that the District protect water resources from "significant harm" through the establishment of minimum flows and levels for streams and rivers within its boundaries. The purpose of minimum flows and levels (MFLs) is to create hydrologic and ecological standards against which permitting or planning decisions can be made concerning withdrawals from either surface or ground waters.

In establishing an MFL for the LHR, the District evaluated potential flow scenarios and their associated impacts on the downstream ecosystem (SWFWMD 1999). The determination of minimum flows is a rigorous technical process in which extensive physical, hydrologic, and ecological data are analyzed for the water body in question.

This chapter provides an overview of how the District applied legislative and water management directives in the determination of minimum flows for the LHR. The rationale and basic components of the District approach are also summarized. Greater details regarding the District's technical approach, including data collection efforts and analyses to determine minimum flows, are provided in subsequent chapters.

1.2 Legislative Directives

Section 373.042, F.S. defines the minimum flow for a surface watercourse as *"the limit at which further withdrawals would be significantly harmful to water resources or ecology of the area".* Section 373.042, F.S. defines the minimum level of an aquifer or surface water body to be "*the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area*".

Due to environmental stress to the water resources in the Northern Tampa Bay area, Section 373.042 Florida Statutes (F.S.), as amended by the Florida Legislature in 1996, directed the District to establish minimum flows and levels for priority water bodies in the region before October 1, 1997. The Northern Tampa Bay area is comprised of the counties of Pinellas, Pasco and the northern portion of Hillsborough. Priority waters are those that are experiencing or may be expected to experience adverse impacts due to the effects of withdrawals. In response to this legislative direction, the District established minimum levels and flows, one of those minimum flows being for the LHR.

Section 373.042, F.S. required the District to use the best data available to set minimum flows and levels. The legislative requirement to set the levels by October 1, 1997 allowed a limited time to collect additional information. Because of the time deadline, and the associated requirement to use the best information available, the District was constrained to use existing data in the establishment of the original MFL for the LHR.

The original process to develop the methods for determination of minimum flows and levels was an open public process with all interested parties invited to participate in the development of methodologies for determining the limit at which significant harm occurs. For the original LHR MFL, the Tampa Bay National Estuary Program (TBNEP) facilitated a technical advisory group that represented the various interests concerned with the LHR. The purpose of this advisory group was to make recommendations to District staff for identifying and evaluating water resources and ecological criteria necessary to establish minimum flows for the LHR.

Following this process, District staff finalized methodologies and the minimum levels and flows for approval by the Governing Board. However, effective July 1, 1997, paragraph 373.0421(1), F.S. was added. The legislation reads as follows:

> **373.0421 Establishment and implementation of minimum flows and levels.**--
> (1) ESTABLISHMENT.--
> (a) *Considerations.*--When establishing minimum flows and levels pursuant to s. 373.042, the department or governing board shall consider changes and structural alterations to watersheds, surface waters, and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of an affected watershed, surface water, or aquifer, provided that nothing in this paragraph shall allow significant harm as provided by s. 373.042(1) caused by withdrawals.
> (b) *Exclusions.*--
> 1. The Legislature recognizes that certain water bodies no longer serve their historical hydrologic functions. The Legislature also recognizes that recovery of these water bodies to historical hydrologic conditions may not be economically or technically feasible, and that such recovery effort could cause adverse environmental or hydrologic impacts. Accordingly, the department or governing board may determine that setting a minimum flow or level for such a water body based on its historical condition is not appropriate.
> 2. The department or the governing board is not required to establish minimum flows or levels pursuant to s. 373.042 for surface water bodies less than 25 acres in area, unless the water body or bodies, individually or cumulatively, have significant economic, environmental, or hydrologic value.
> 3. The department or the governing board shall not set minimum flows or levels pursuant to s. 373.042 for surface water bodies constructed prior to the requirement for a permit, or pursuant to an exemption, a permit, or a reclamation plan which regulates the size, depth, or function of the surface water body under the provisions of this chapter, chapter 378, or chapter 403, unless the constructed surface water body is of significant hydrologic value or is an essential element of the water resources of the area.

> The exclusions of this paragraph shall not apply to the Everglades Protection Area, as defined in s. 373.4592(2)(h).
> (2) If the existing flow or level in a water body is below, or is projected to fall within 20 years below, the applicable minimum flow or level established pursuant to s. 373.042, the department or governing board, as part of the regional water supply plan described in s. 373.0361, shall expeditiously implement a recovery or prevention strategy, which includes the development of additional water supplies and other actions, consistent with the authority granted by this chapter, to:
> (a) Achieve recovery to the established minimum flow or level as soon as practicable; or
> (b) Prevent the existing flow or level from falling below the established minimum flow or level.
> The recovery or prevention strategy shall include phasing or a timetable which will allow for the provision of sufficient water supplies for all existing and projected reasonable-beneficial uses, including development of additional water supplies and implementation of conservation and other efficiency measures concurrent with, to the extent practical, and to offset, reductions in permitted withdrawals, consistent with the provisions of this chapter.
> (3) The provisions of this section are supplemental to any other specific requirements or authority provided by law. Minimum flows and levels shall be reevaluated periodically and revised as needed.

Therefore, at the Board's direction, staff reviewed the previous work, additional data as appropriate, continued meetings and workshops with affected parties and held public workshops with the Governing Board to ensure that the changes to the statute had been taken into account. On February 23, 1999, the Governing Board approved a minimum flow of ten cfs for the Lower Hillsborough River.

The District is committed to voluntary, independent scientific peer review of MFL documents. The purpose of this report is to document the scientific and technical data and methodologies that will be used for the reevaluation of the minimum flow for the LHR.

1.3 Existing Minimum Flow Rule

On February 23, 1999, the Governing Board adopted a minimum flow for the LHR of 10 cubic feet per second (cfs) at the base of the Hillsborough River Reservoir dam as measured at the Rowlett Park Bridge station. Because the existing database for the river during low flows was limited, the District and the CoT commenced a study to evaluate the effects of flows in a range of up to at least 30 cfs.

1.4 Recommendations from Peer Review and TBEP Advisory Group

Two sources of review were obtained during the initial MFL for the LHR. The District requested that the TBNEP facilitate a minimum flow advisory group to provide technically sound recommendations to District staff for evaluating water resource and ecological criteria necessary to establish minimum flows on the LHR. The complete document from the advisory group is included in Appendix 1-4. The District held several meetings with this group and received their technical input along with the following recommendations:

1. Define ecological criteria or goals for dissolved oxygen concentrations in the Hillsborough River as a minimum of 4.0 mg/l and average of 5.0 mg/l for optimizing fish utilization. If these criteria cannot by feasibly met at all times and in all locations, minimize time and areas in the river where dissolved oxygen is less than 4.0 mg/l.
2. Maintain a salinity gradient from the estuary to the dam ranging from polyhaline (>18 ppt) to fresh (<0.5 ppt), to optimize estuarine-dependent fish species utilization.
3. Maintain a freshwater segment below the dam to provide a refuge for freshwater biota.
4. Evaluate other ecological issues and analytical tools related to freshwater flow management, including impacts on manatees and changes in water quality related to diverting a portion of the Sulphur Springs discharge.
5. Test the reliability of the management tools through a series of controlled releases of freshwater from the reservoir. Commencement of this work should be contingent upon a determination by SWFWMD and the City of Tampa of the need for a controlled release experiment.

At the request of outside parties, as provided in the enacting legislation, independent scientific peer review of the proposed minimum flow was requested. The independent peer review panel was tasked to determine if the proposed ten cfs minimum flow was based on defensible scientific analyses. The panel reviewed the report and supplemental documentation to determine if a justification for selecting ten cfs was provided, and to determine the impact this flow would have on the environmental quality of the LHR. The report from the peer review panel is included in Appendix 1-4. The peer review panel concluded that the District's primary technical report and supplemental documents did not state clear management objectives for establishing the minimum flow rule. In summary, the panel concluded:

> *"At best, the ten cfs rule should be considered an improvement over the current condition and an experiment in adaptive management. The scientific and technical data indicate that an adaptive management approach should be taken, because there is no scientific evidence for choosing one instream flow over another. The process of adaptive management requires a clear management goal (e.g., maintaining 1 or 2 km of oligohaline habitat during certain seasons), monitoring (which can be restricted to the region a short distance downstream from the dam within the managed segment), determining if the expected changes are occurring (within an acceptable range of uncertainties), and reevaluating the minimum flow rule on short-term intervals. Setting the management goal will require evaluation of the biological communities and*

> *environmental setting of the region to be managed, and policy decisions on which sustainable resources are to be protected or optimized."*

The District incorporated the recommendations in the design of the LHR Minimum Flow study. The technical elements of the study plan and data on which the reevaluation is based are presented in the following chapters.

1.5 Content of Remaining Chapters

This general introduction is followed by seven chapters that describe the technical information that will be used to re-evaluate the minimum flow for the LHR. In Chapter 2 the physical and hydrologic characteristics of the Hillsborough River watershed are described. In Chapter 3 the physical characteristics of the LHR are discussed. Chapter 4 contains a description of the salinity and water quality characteristics of the LHR. The biological characteristics of the LHR are described in Chapter 5. In Chapter 6, relationships between flow and water quality constituents are explored for empirical data. In addition, relationships between flow and salinity are examined for model simulation data in Chapter 7. Chapter 8 gives major conclusions of this study and includes the District's minimum flow recommendation. Chapter 9 identifies the literature cited in the report.

2.0 PHYSICAL AND HYDROLOGIC CHARACTERISTICS OF HILLSBOROUGH RIVER AND ITS WATERSHED

This chapter presents a brief description of the Hillsborough River and its watershed, with emphasis on the portion of the river below the Hillsborough River Dam that is referred to throughout this report as the Lower Hillsborough River (LHR).

2.1 Physical Characteristics

The Hillsborough River originates in the Green Swamp, which is located in Hernando, Lake, Pasco, Polk, and Sumter counties. The Hillsborough River is approximately 87 km (54 miles) long (Figure 2-1). Flows in both the upper and lower reaches of the Hillsborough River are partially derived from spring discharges. Crystal Springs, located near the city of Zephyrhills, discharges an average of 58 cubic feet per second (cfs) in the upper watershed (SWFWMD 1999), while Sulphur Springs in the Tampa area discharges an average of 34.3 cfs (SWFWMD 2004b). The Hillsborough River drains an area that is approximately 1,750 square km (675 square miles). The river ultimately discharges to Tampa Bay in the northwestern portion of Hillsborough Bay (Figure 2-2).

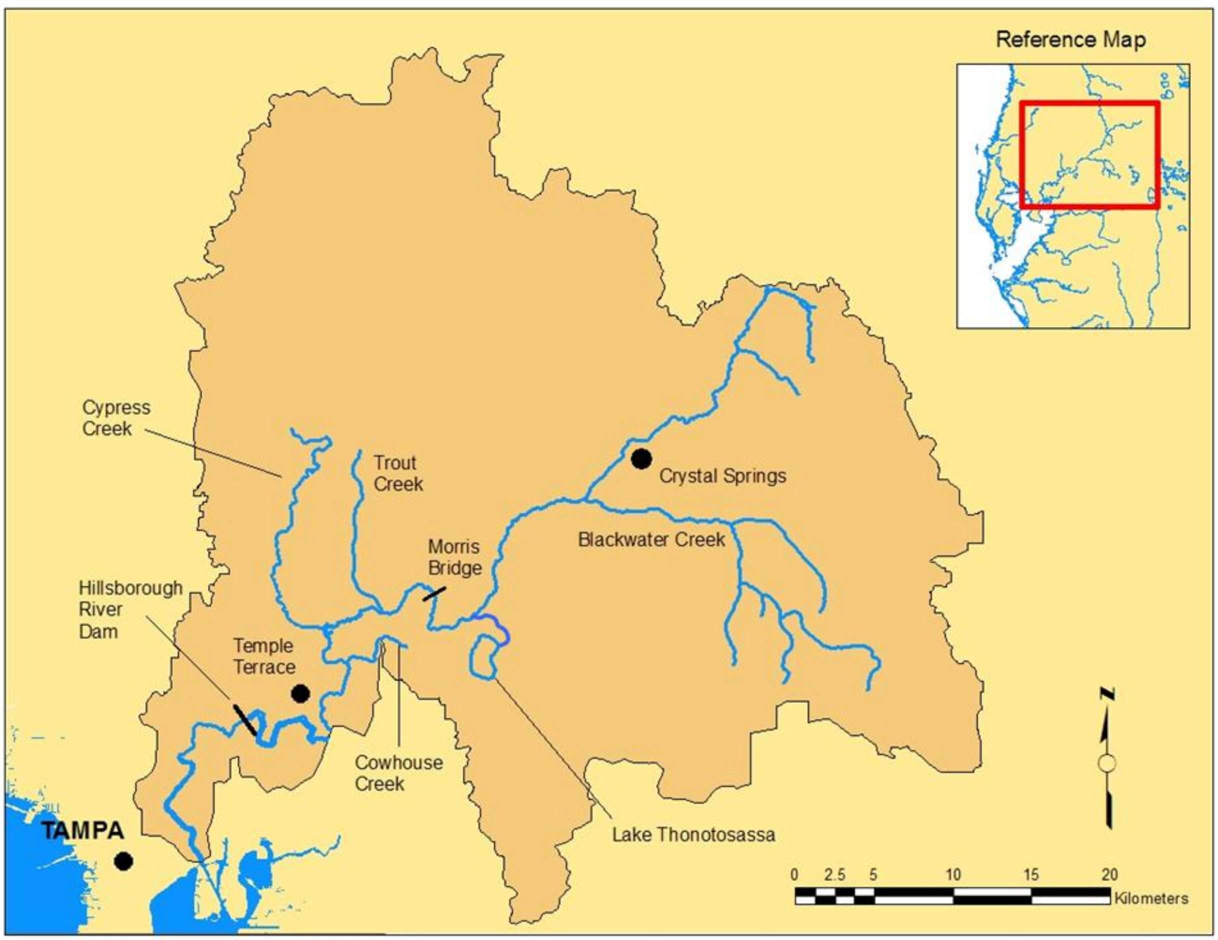


Figure 2-1 The Hillsborough River drainage basin and major tributaries.

The Hillsborough Dam is located 16 river kilometers (RKM) upstream of the mouth. The first dam at this site was constructed in 1898, and the present dam was built in 1945 (SWFWMD 1999). The reservoir, upstream of the dam, has a surface area of approximately 5.3 km^2 (1,300 acres). At a maximum stage of 22.5 feet NGVD, the reservoir has a capacity of nearly two billion gallons (Goetz, et al., 1978). The storage for the minimum observed stage of 14.9 feet, which occurred in 1977, is about 540 million gallons (Goetz, et al., 1978). Sulphur Springs, a second magnitude spring, is connected to the LHR at RKM 12.9 (Figure 2-2).

The reservoir is connected to the Tampa Bypass Canal (TBC) by the Harney Canal (Figure 2-2). The TBC was constructed during the period 1966 to 1982. The canal was excavated in the channels of the former Six-Mile Creek/Palm River drainage systems. The purpose of the canal was to divert Hillsborough River floodwaters to McKay Bay, bypassing the cities of Tampa and Temple Terrace (SWFWMD 1999). The TBC extends approximately 22.5 km (14 miles) from Cow House Creek in the Lower Hillsborough River Flood Detention Area to McKay Bay near the mouth of the Palm River. Structure S-161 is used to control flows between the reservoir and the TBC. The Harney Canal joins the TBC upstream of S-162. In addition to the above-mentioned structures, there are three other water control structures within the TBC: S-159, S-160, and S-163 that control flow to Hillsborough Bay.

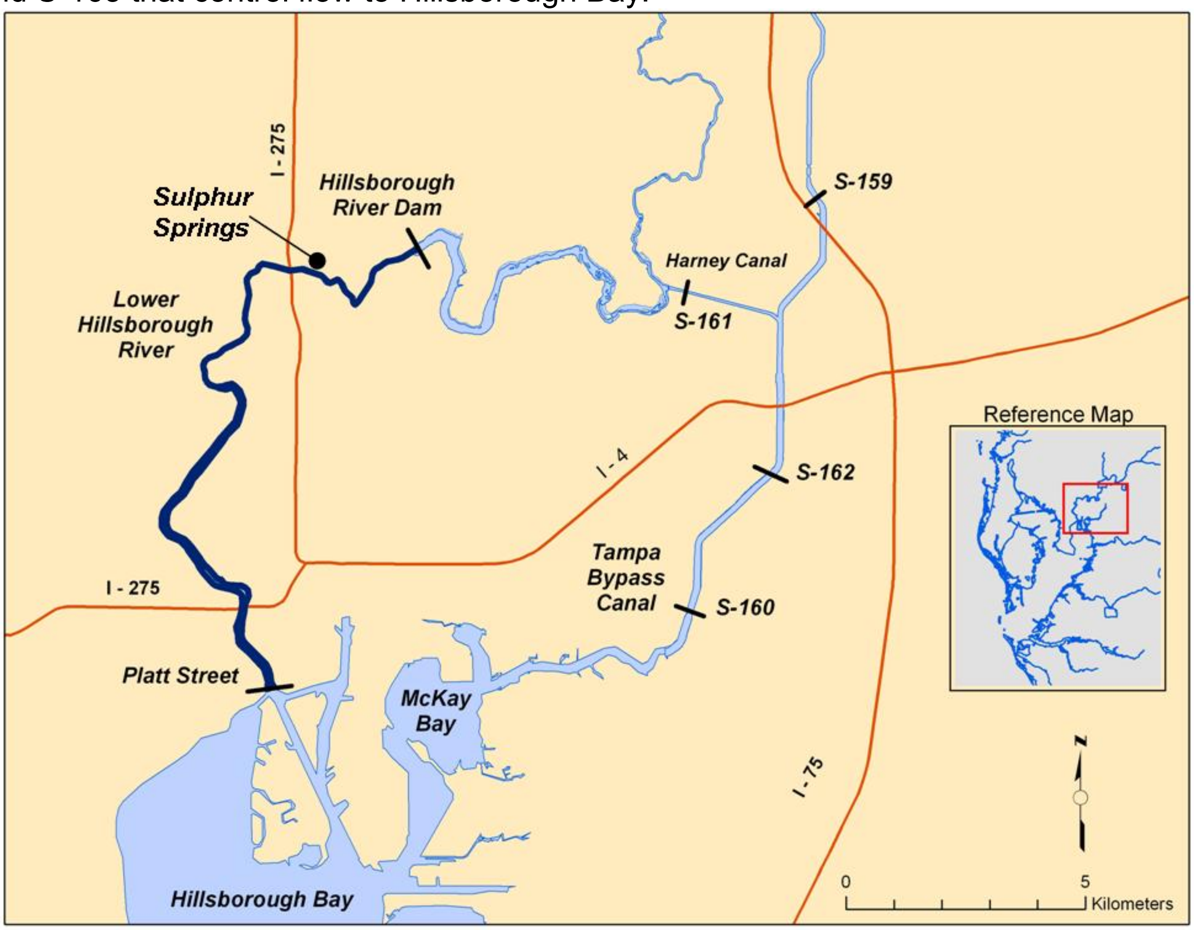


Figure 2-2 Map of the Lower Hillsborough River and connections to the Tampa Bypass Canal.

The Hillsborough River watershed encompasses approximately 1,750 km^2. Predominant land uses in the watershed are urban (33%) and pasture/rangeland (28%) (Table 2-1; Figure 2-3). The estuarine LHR is the most urbanized (93% residential and commercial land uses; SWFWMD 1999) of the tributaries to Tampa Bay.

Table 2-1 Summary of land use/cover in the Hillsborough River Watershed in 1999 (adapted from SWFWMD 2004b).

Land Use/Cover	Area (km^2)
Agriculture	55.48
Mining	11.03
Pasture/Rangeland	274.36
Upland Forest	88.84
Urban	318.11
Water	31.86
Wetlands	186.86

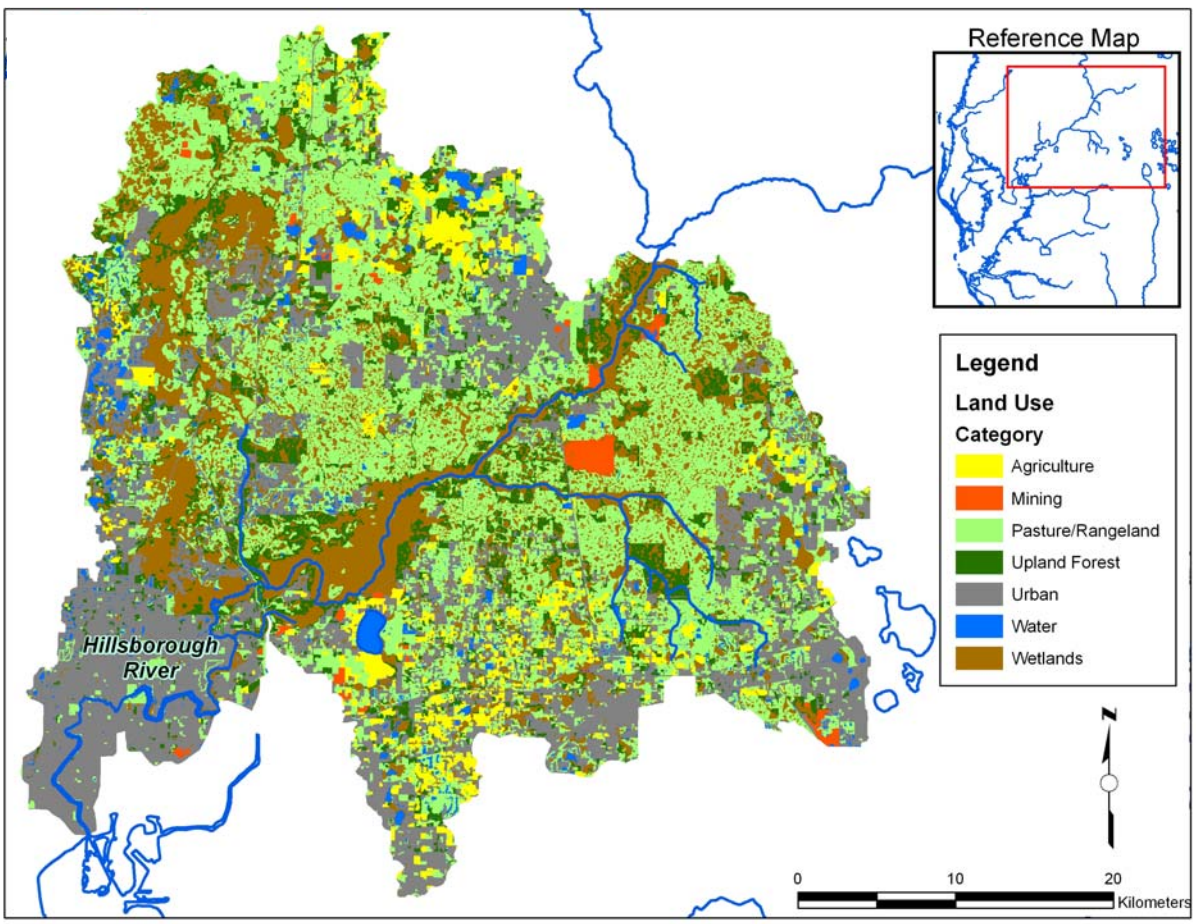


Figure 2-3 Map of land uses/cover in the Hillsborough River watershed in 1999.

2.2 Rainfall

In peninsular Florida, there is typically a June through September high rainfall season. Superimposed on this general seasonal cycle are the effects of larger scale events, notably the El Niño-Southern Oscillation (ENSO). Typically El Niño years are wetter than La Niña years (Schmidt and Luther, 2002). However, El Niño effects during the summer wet season are somewhat attenuated by the seasonal occurrence of thunderstorms. Mean monthly rainfall at the Hillsborough River State Park exhibits the typical June-September rainfall peak and lower values during the remainder of the year (Figure 2-4). Long-term trends for rainfall in the basin are shown in Figure 2-5. The higher rainfall observed in 1997 coincided with the El Niño-Southern Oscillation (ENSO) event of spring 1997 through spring 1998 that was one of the strongest since 1950 (NOAA-CIRES, 2004). The 1999-2000 drought coincided with a La Niña event (National Weather Service, 2004).

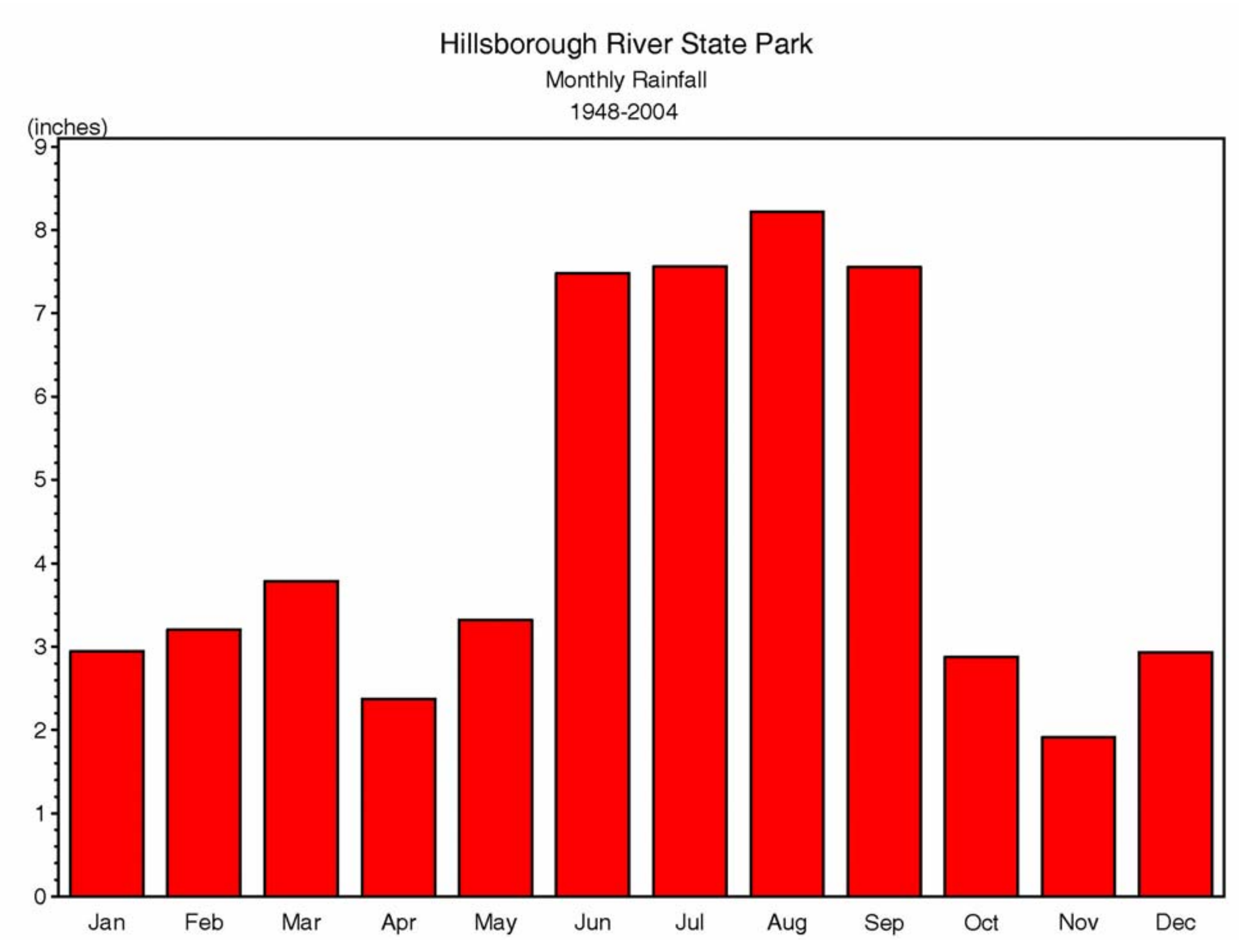


Figure 2-4 Mean monthly rainfall (total inches) at the Hillsborough River State park, 1948-2004.

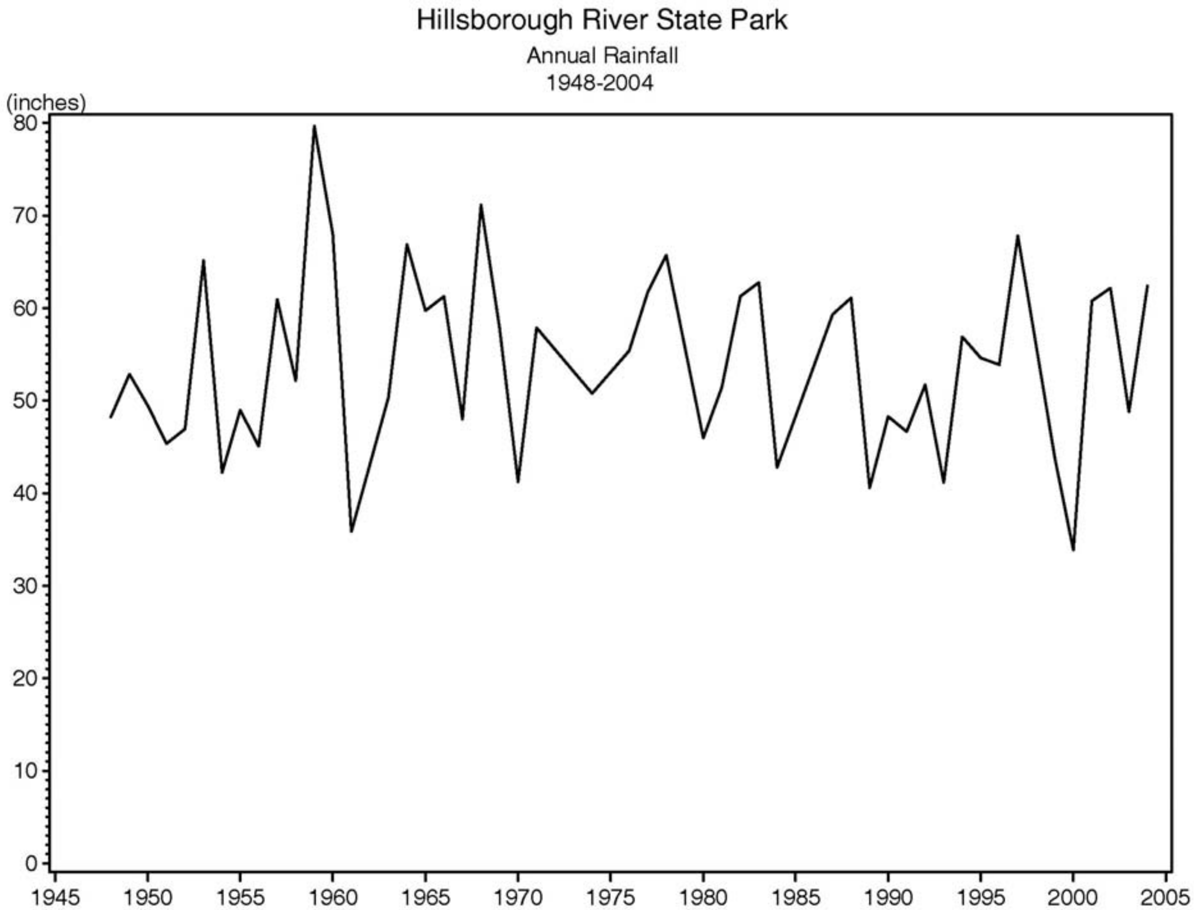


Figure 2-5 Annual rainfall (inches) at Hillsborough River State Park, 1948-2004.

2.3 Freshwater Flows

Streamflow represents the sum of the contributions of groundwater, runoff, direct rainfall, and anthropogenic discharges (e.g., wastewater) minus the volume of water that is lost due to evapotranspiration, groundwater, and withdrawals. Streamflow is a component of aquatic ecosystem health, and long-term alteration of inflow characteristics can produce large changes in aquatic ecosystem structure and function. The physical, chemical, and biological properties of aquatic ecosystems are all affected by the magnitude and frequency of flow. Chemical and biological processes in estuaries are affected by changes in water residence time, which is a function of freshwater inflow. Similarly, the structure and function of biological communities associated with aquatic ecosystems depend in large part on the hydrologic regime (Poff and Ward, 1989, 1990; Sparks, 1992). In tidal rivers, freshwater flow is a critical determinant of the spatial and temporal variation in salinity. In turn, salinity is a critical determinant of the structure and function of the tidal river ecosystem and that of the estuary into which it flows.

Highest freshwater inflows to rivers in the Tampa Bay area typically lag one to two months behind the periods of maximum rainfall (Schmidt *et al*., 2001). El Niño effects during the summer wet season are somewhat attenuated by the seasonal occurrence of thunderstorms. Fall flows are elevated during both El Niño and La Niña years. Schmidt *et al*. (2001) suggested that this may be due to more frequent tropical storms during La Niña summers. El Niño winters are wetter than normal winters, and therefore, river flows are higher (Schmidt *et al*., 2001; Schmidt and Luther, 2002).

2.3.1 Inflows to Reservoir

Reservoir inflows can be estimated based on upstream watershed areas and gaged flows from Trout Creek (POR June 1974-present), Cypress Creek, and the Hillsborough River at Morris Bridge. Groundwater flows from Crystal Springs, which are included in the records for the Hillsborough River at Morris Bridge, can be subtracted from the combined gaged record so that flows that are predominantly surface runoff can be multiplied by a watershed area ratio to estimate runoff from downstream ungaged areas (Flannery, Pers. Comm.).

This method to estimate inflows to the Hillsborough River Reservoir does not account for loss terms from the reservoir such as evaporation or seepage. Since the equation relies on a watershed area ratio to estimate flows from ungaged areas, it assumes daily streamflow rates from the ungaged areas of the reservoir catchment are similar to those reported at the upstream USGS gages. Other work on the Hillsborough River (Wolansky and Thompson 1987, SDI Environmental Services 2001) indicates that gains and losses from the river to the groundwater system in the region below the gages vary seasonally, with the river losing flow during dry periods. However, because the ungaged area represents only 16.5% of the total catchment for the reservoir, inaccuracies in the estimate of flows from ungaged areas represent a relatively small potential error in the overall estimate of total reservoir inflows. The period of record at the Trout Creek gage goes back to 1974, thus limiting the period for which inflows to the reservoir can be estimated. Daily estimates of reservoir inflows were developed for the period 1974 to 2004 and are presented in the flow duration curve in Figure 2-6. Also, as described in the following section, CoT periodically supplements reservoir inflows by pumping water from Sulphur Springs and the TBC into the reservoir for the purpose of increasing available water supplies.

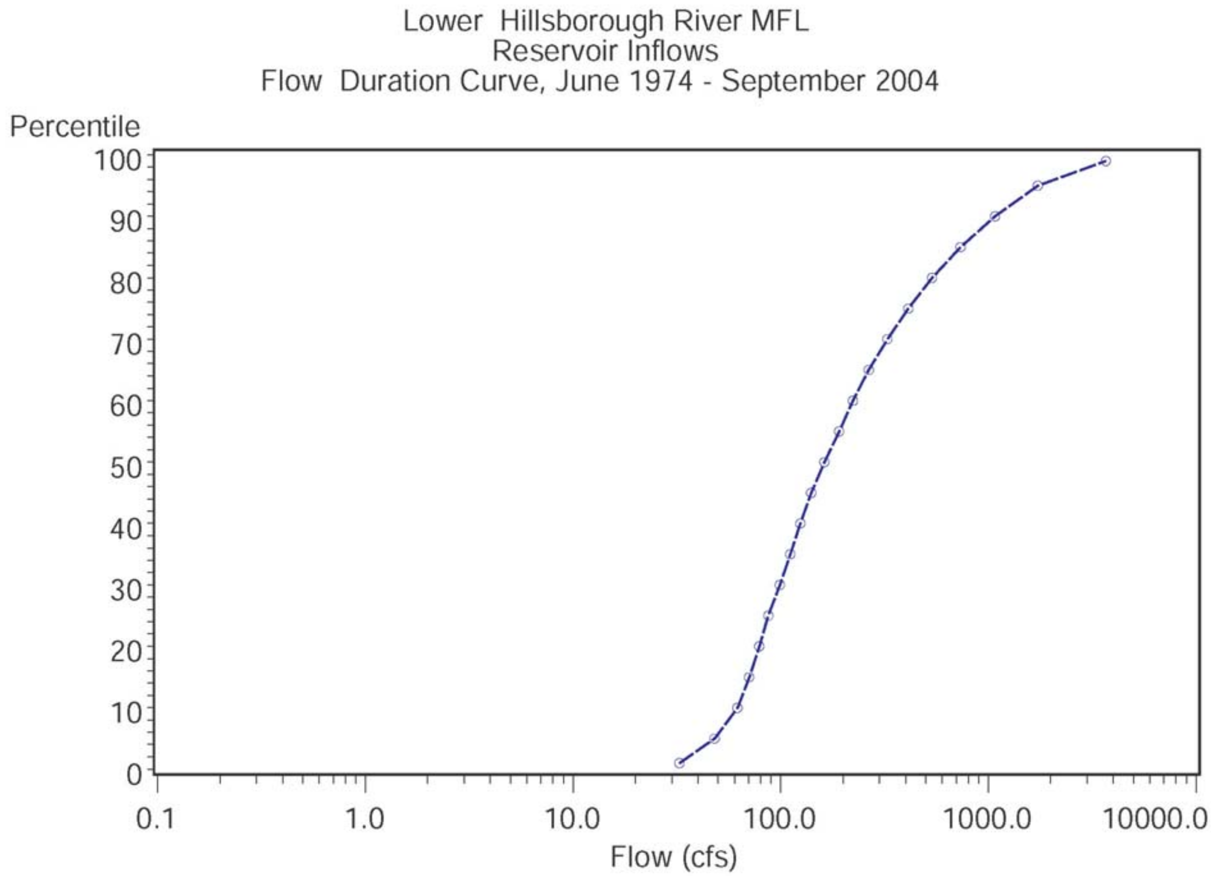


Figure 2-6 **Flow duration curve of estimated inflows to the Hillsborough River Reservoir, 1974-2004.**

2.3.2 Gaged Outflows from the Reservoir

The seasonal variation in flows from the reservoir to the LHR are similar to other Florida rivers in the area in that flows are highest in the July to October wet season and lower during the November to June dry season. However, withdrawals for public water supply have caused a significant increase in zero flow days, and historically (in the absence of significant withdrawals) flow would never have approached zero.

A box plot of the daily flow over the Hillsborough River Dam by year for the period 1940 to 2004 is presented in Figure 2-7. Measurements of zero flow from the dam on a given day are rare as a leakage estimate has been included during most of the period of record. The calculated estimates of leakage have varied, but are generally less than two cfs. In 14 of the years since 1974, the median flow was near zero (Figure 2-7). So, in the last three decades, it was not unusual for the flow from the dam to be near zero for at least half of the year. A further analysis of the number of days per year when flow over the dam was estimated to be less than two cfs is presented in Figure 2-8.

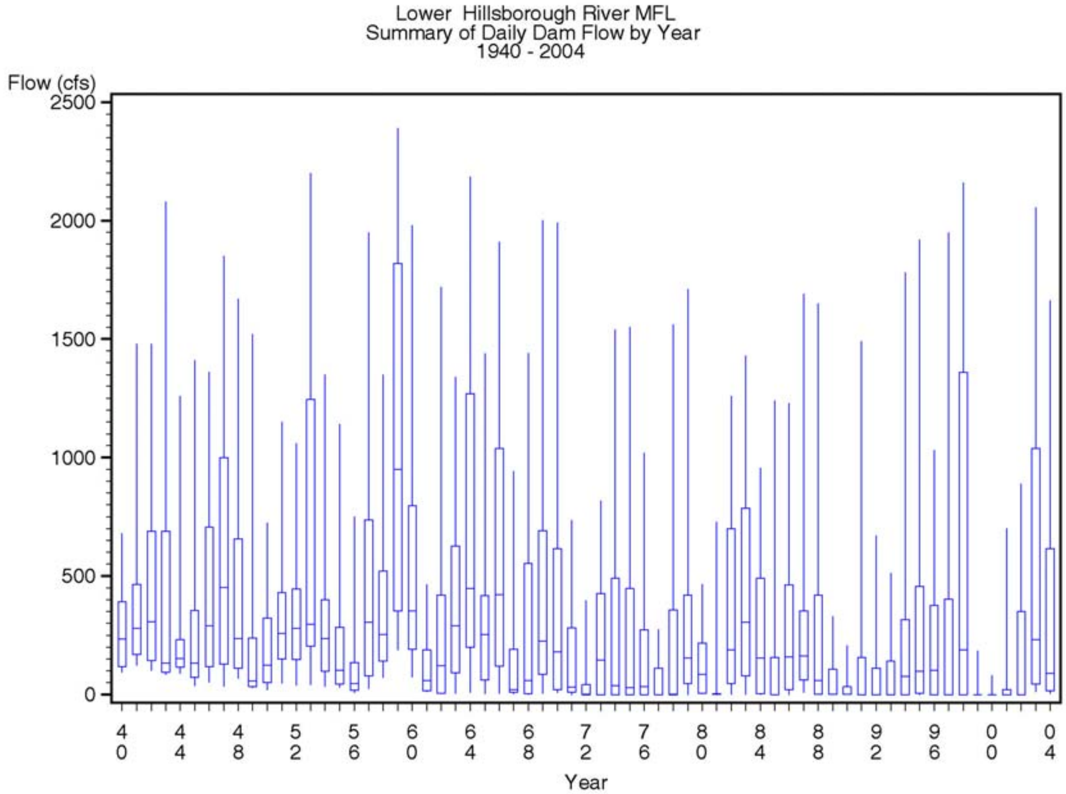


Figure 2-7 Box and whisker plot of daily Hillsborough River Dam flows by year, 1940-2004. Whiskers represent the 5th and 95th percentiles.

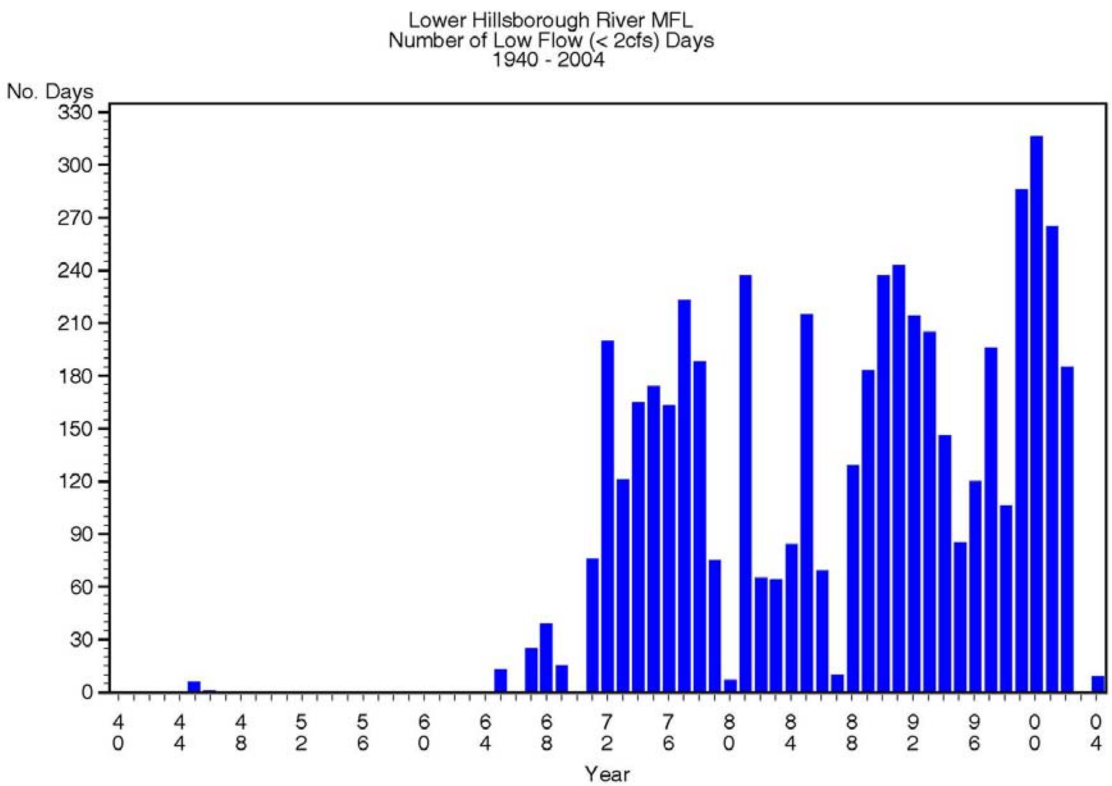


Figure 2-8 Hillsborough River Dam low flow (< 2 cfs) days by year, 1940-2004.

For the period 1974 to 2004, the number of days per year that flow was less than two cfs varied from zero days in 2003 to 316 days in 2000. For this period, the median number of days the flow was less than two cfs was 165 days. The 25th and 75th percentile number of days the flow was less than two cfs were 75 and 215 days, respectively. Prior to the 1970's there were very few days when flows less than 2 cfs were recorded (Figure 2-8).

A box plot of the daily flow over the Hillsborough River Dam by month for the period 1940 to 2004 is presented in Figure 2-9. The highest median values are during the wet season (July-October) and lower flows were observed during the dry season (November-June). The monthly median flows range from a minimum of 5 cfs in May to a maximum of 635 cfs in September.

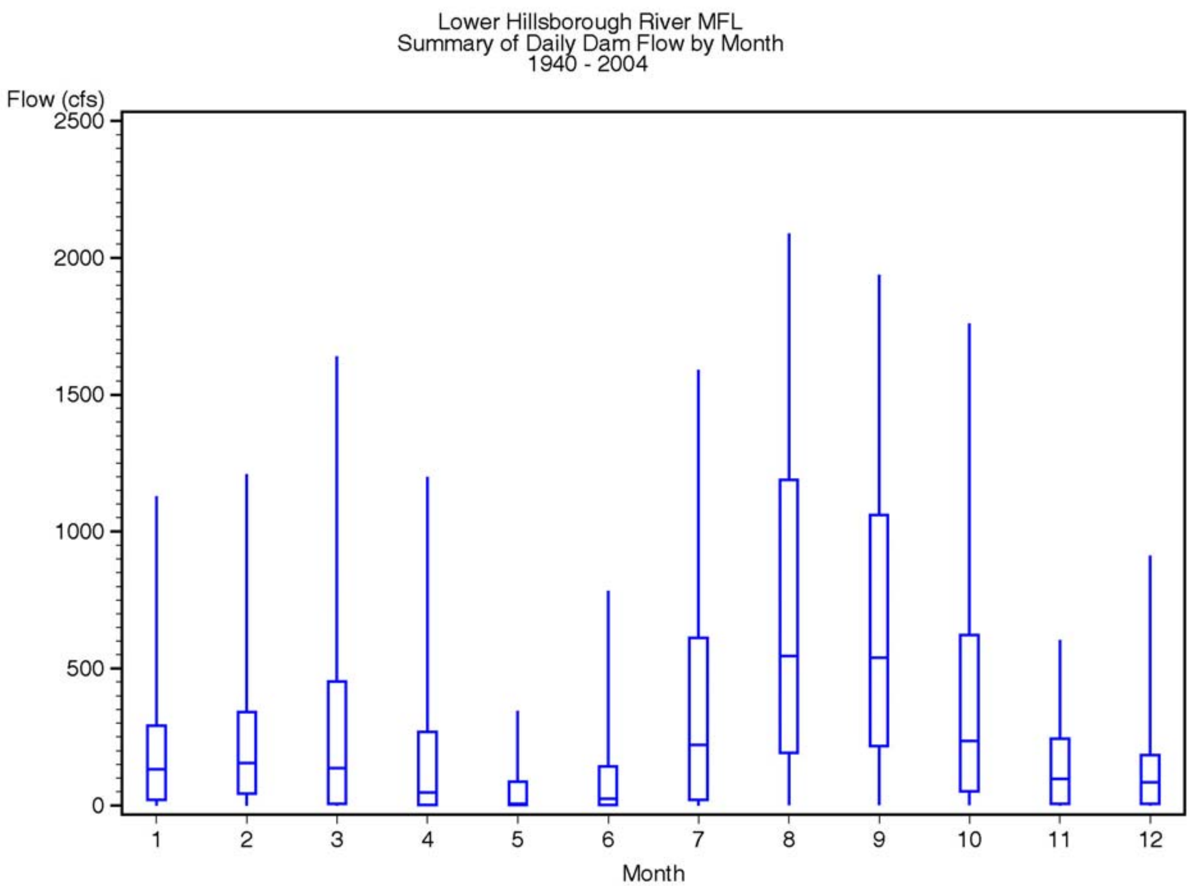


Figure 2-9 Box and whisker plot of daily Hillsborough River Dam flows by calendar month, 1940-2004. Whiskers represent the 5th and 95th percentiles.

For the period 1974 to 2004, mean annual flows over the Hillsborough River Dam ranged from 10 to 698 cfs. In addition, Sulphur Springs typically contributes approximately 31 cfs (SWFWMD 2004b) to the LHR. In 2002, the CoT began diverting Sulphur Springs flows of up to 10 cfs to the base of the Hillsborough River Dam for minimum flow compliance. The rationale is that the translocation of lower salinity water to the base of the Hillsborough River Dam will contribute to the occurrence and persistence of oligohaline habitats in the upper river.

A summary of daily values of reservoir outflows for the period 1974 to 2004 are also presented in the flow duration curve in Figure 2-10. For the period 1974 to 2004, the 25th percentile flow was 0.2 cfs, the 50th percentile was 27 cfs and the 75th percentile flow was 288 cfs. A summary of daily values of reservoir outflows for the period 1940 to 1973 are presented in the flow duration curve in Figure 2-11. For the period 1940 to 1973, the 25th percentile flow was 81 cfs, the 50th percentile was 216 cfs and the 75th percentile flow was 603 cfs.

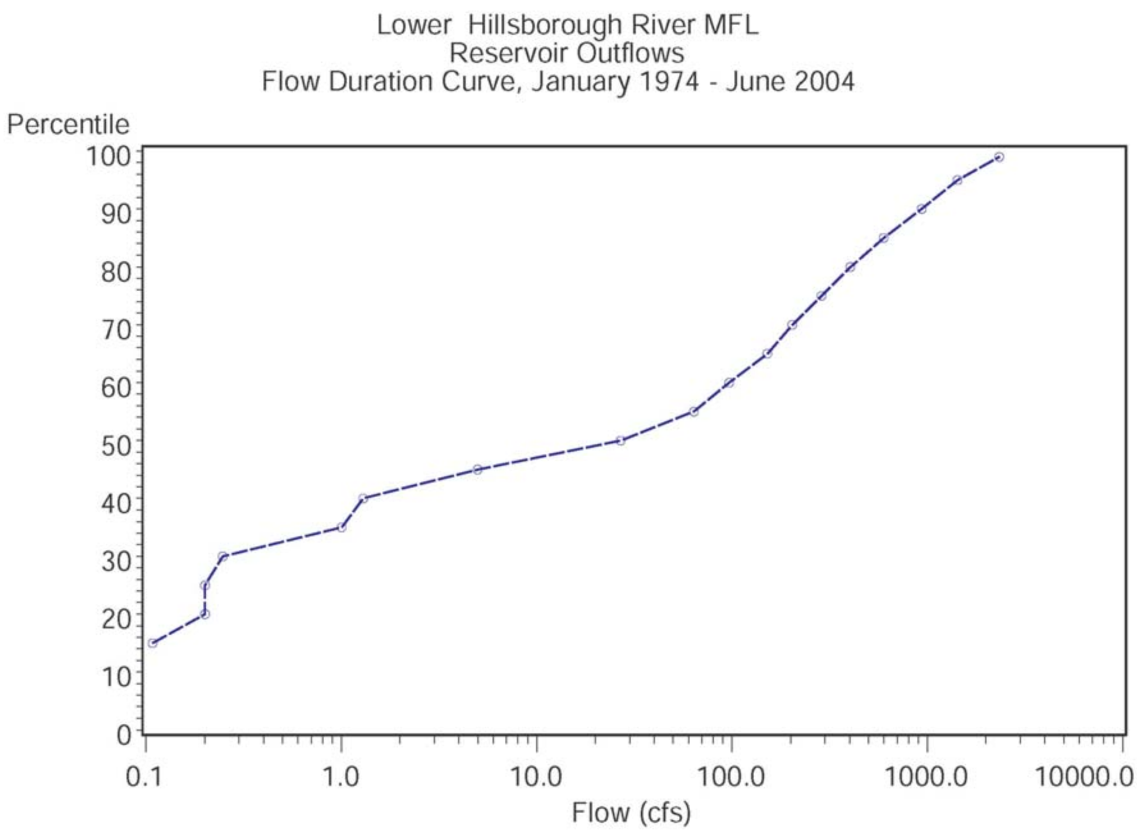


Figure 2-10 Flow duration curve of outflows from the Hillsborough River Reservoir, 1974-2004.

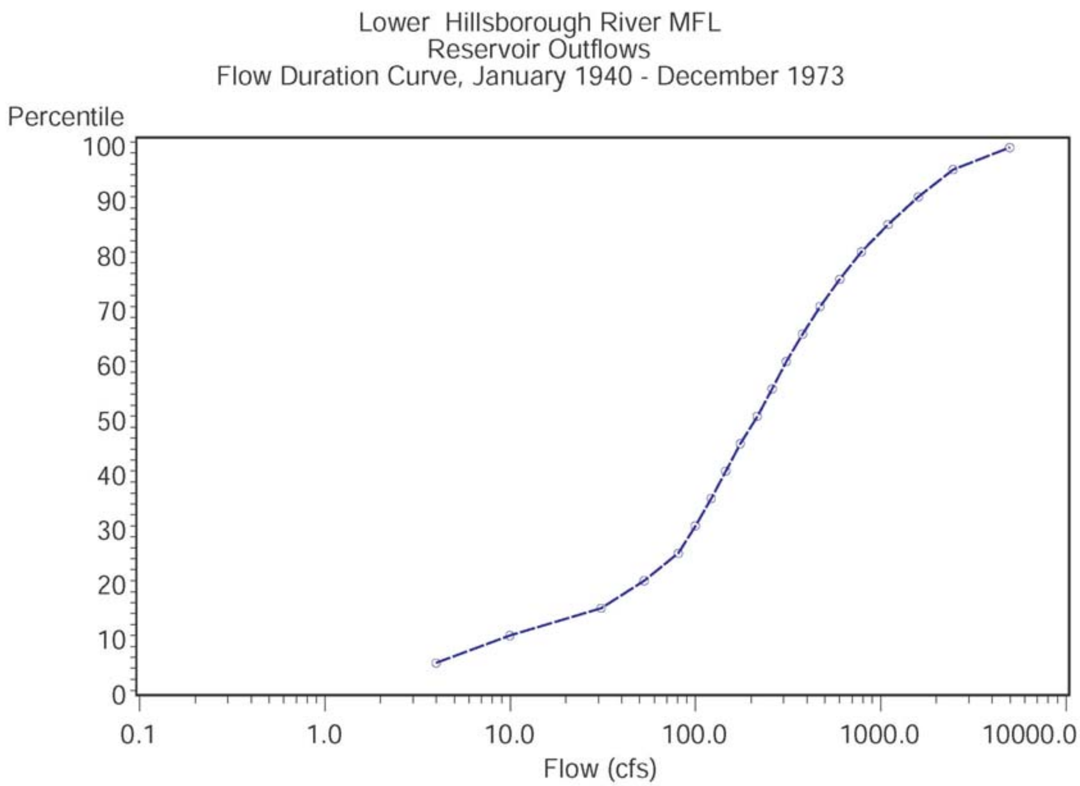


Figure 2-11 Flow duration curve of outflows from the Hillsborough River Reservoir, 1940-1973.

2.3.3 Water Supply Diversions to and from the Tampa Bypass Canal

When inflows to the reservoir have been low, diversions of water from the Tampa Bypass Canal to the Hillsborough River Reservoir have been accomplished by pumping water via the Harney Canal (Figure 2-2). This augmentation of the reservoir was particularly significant during the recent drought years of 1999 and 2000. Since 2003, Tampa Bay Water has diverted water from the reservoir to the Tampa Bypass Canal as part of the Enhanced Surface Water Supply System (see section 2.4.2 for further details).

2.3.4 Ungaged Flows to LHR

Ungaged runoff that is generated from the catchment below the dam is an additional source of fresh water to the LHR. When flow over the dam has been zero or nearly so, ungaged runoff becomes a major source of freshwater to the river. From 1997 through 2002, estimated ungaged runoff provided approximately 9% of the total freshwater flow in the LHR, ranging from a low of 5% in 1998 to a high of 27% in 2000 (Janicki Environmental, Inc. 2005a).

There is one point source located below the Hillsborough River Dam. The Lowry Park Zoo has an NPDES permit which allows the discharge of stormwater from the park to the LHR. Examination of discharge records reveals that the Zoo rarely discharges (Janicki Environmental, Inc. 2005a).

2.3.5 Sulphur Springs Flows to River and Diversions

Sulphur Springs is an artesian spring from which groundwater discharges due to hydrostatic pressure in the underlying aquifers. The average flow for Sulphur Springs is 31.4 cfs for the period 1991 through 2002. Correcting this value for withdrawals by the CoT (adding withdrawals to flow) yields an average flow of 34.3 cfs. Flows from Sulphur Springs exhibit slight seasonal variation in response to the progression of dry and wet seasons in west-central Florida. Average monthly withdrawal-corrected flows range from 28.9 cfs in June, just after the spring dry season, to 39.4 cfs in September (Figure 2-12). Duration curves for flows at Sulphur Springs are presented in Figure 2-13 for two sets of data. The blue line represents days when there were no diversions from the spring to the reservoir or the base of the dam. The red line represents all daily records. The curves are relatively similar but diverge at low flows, showing the effect of periodic withdrawals by the CoT. As with most other springs, flows from Sulphur Springs are much more stable than flows in freshwater streams that receive surface runoff. Eighty percent of the daily flow values with no withdrawals range between 26 and 48 cfs (Figure 2-13).

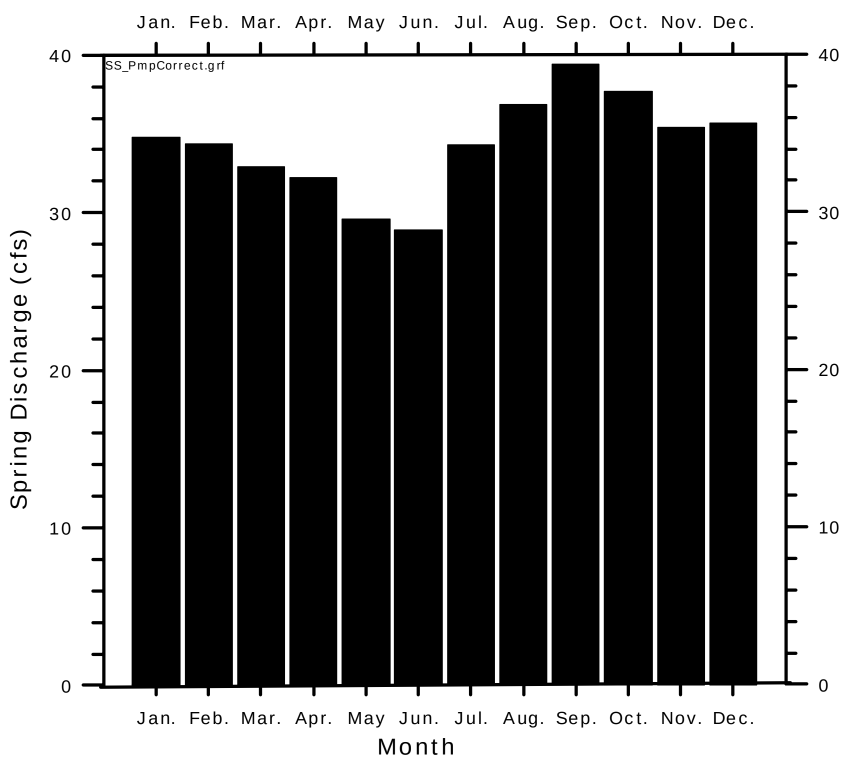


Figure 2-12 Average monthly flows from Sulphur Springs corrected for withdrawals for 1991 – 2002. (Source: SWFWMD, 2004b)

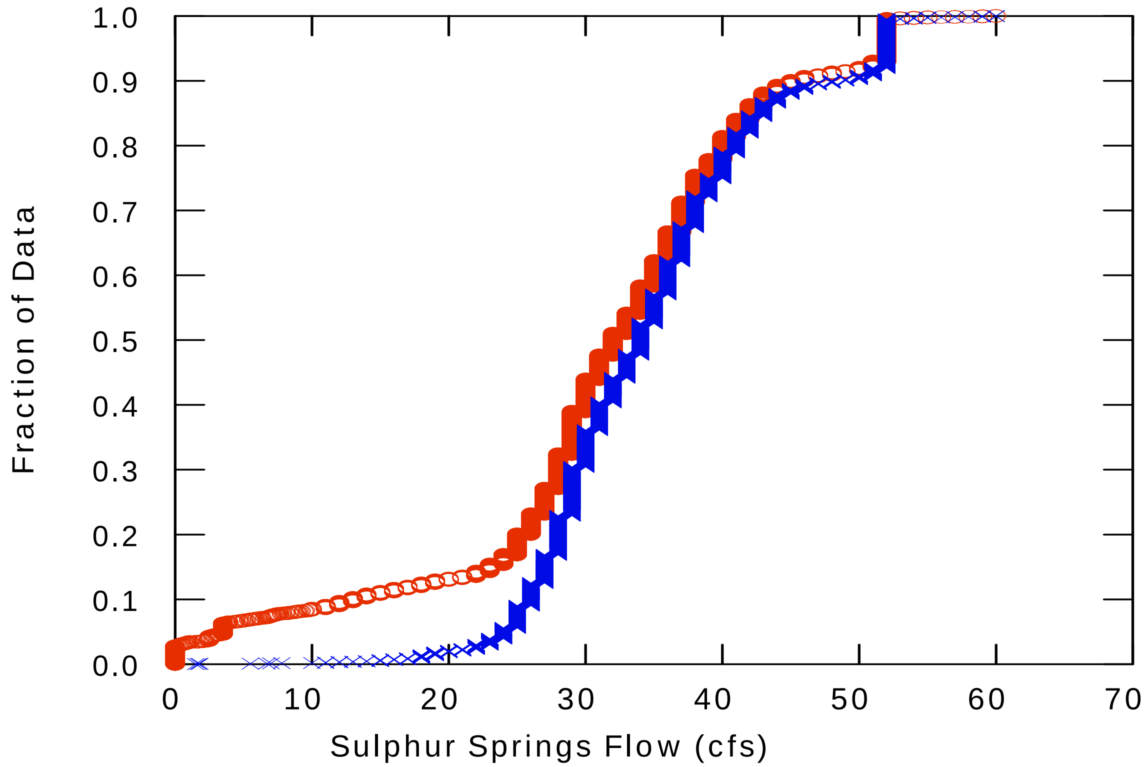


Figure 2-13 **Flow duration curves for daily flows from Sulphur Springs, 1991–2002. Blue represents days with no withdrawals, red includes all daily records. (From: SWFWMD, 2004b)**

A water use permit held by the CoT allows up to 20 mgd (31 cfs) to be diverted from Sulphur Springs to the Hillsborough Reservoir when the reservoir levels are reduced. Additionally, 6.4 mgd (10 cfs) may be piped to the base of the dam to help ensure that the existing minimum flow is maintained (SWFWMD 2004b).

Since 1965, the CoT has periodically diverted water from Sulphur Springs to the Hillsborough River Reservoir to augment water supplies. The average annual pumping rates from 1984 to 2002 for Sulphur Springs to the reservoir are shown in Figure 2-14. Waters have been diverted from the spring pool through an intake pipe to a pump house that enclosed a centrifugal pump that ran at a constant rate of 30.5 cfs when in operation. An underground pipe extends approximately two miles from this pump house to the western shore of the reservoir just upstream of the dam (SWFWMD, 2004b).

Modifications were made to the water diversion facilities associated with Sulphur Springs during 2001 to allow for better management of flows from the spring pool (Vilagos, pers. comm., 2005). As part of the minimum flow rule for the LHR that was adopted in 2000, it was concluded that diversions from Sulphur Springs could be used to provide the 10 cfs minimum flow at the base of the Hillsborough River Dam. To accomplish this objective, a junction was put in the pipe that leads from Sulphur Springs to the reservoir so that spring waters can be released to the lower river near the base of the dam. A valve and flow meter were installed at this junction so that varying amounts

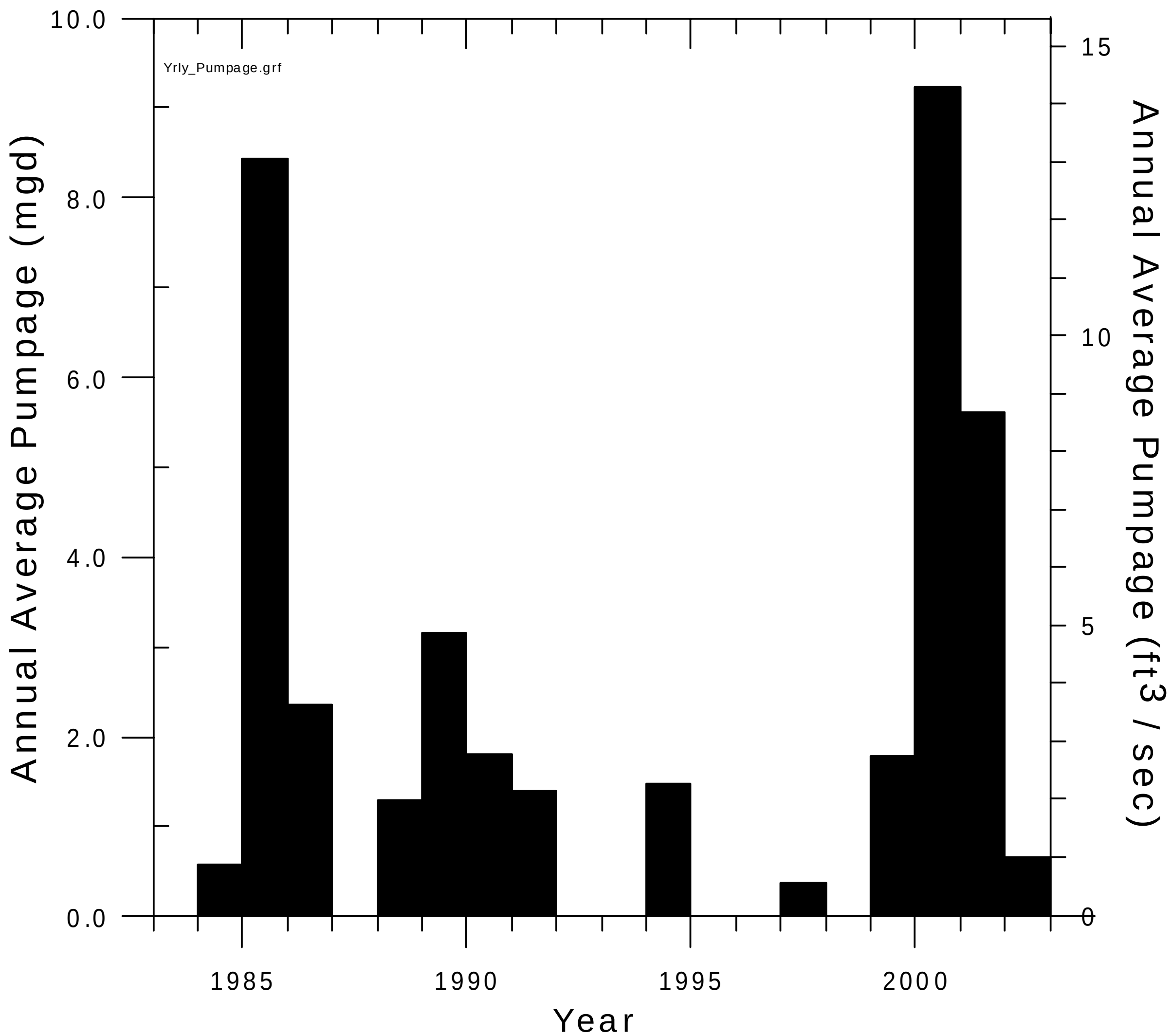


Figure 2-14 Average annual pumpage rates from Sulphur Spring by the City of Tampa for 1984-2002. (From: SWFWMD, 2004b)

of spring water could be diverted either into the reservoir or to the base of the dam (Vilagos, pers. comm., 2005). A 100 ft. long flume was constructed that extends from this junction to the river below the dam. The turbulence created by this flume aerates the spring water before it is released to the river (SWFWMD, 2004b). A time series of the diversions from Sulphur Springs to the base of the dam is presented in Figure 2-15.

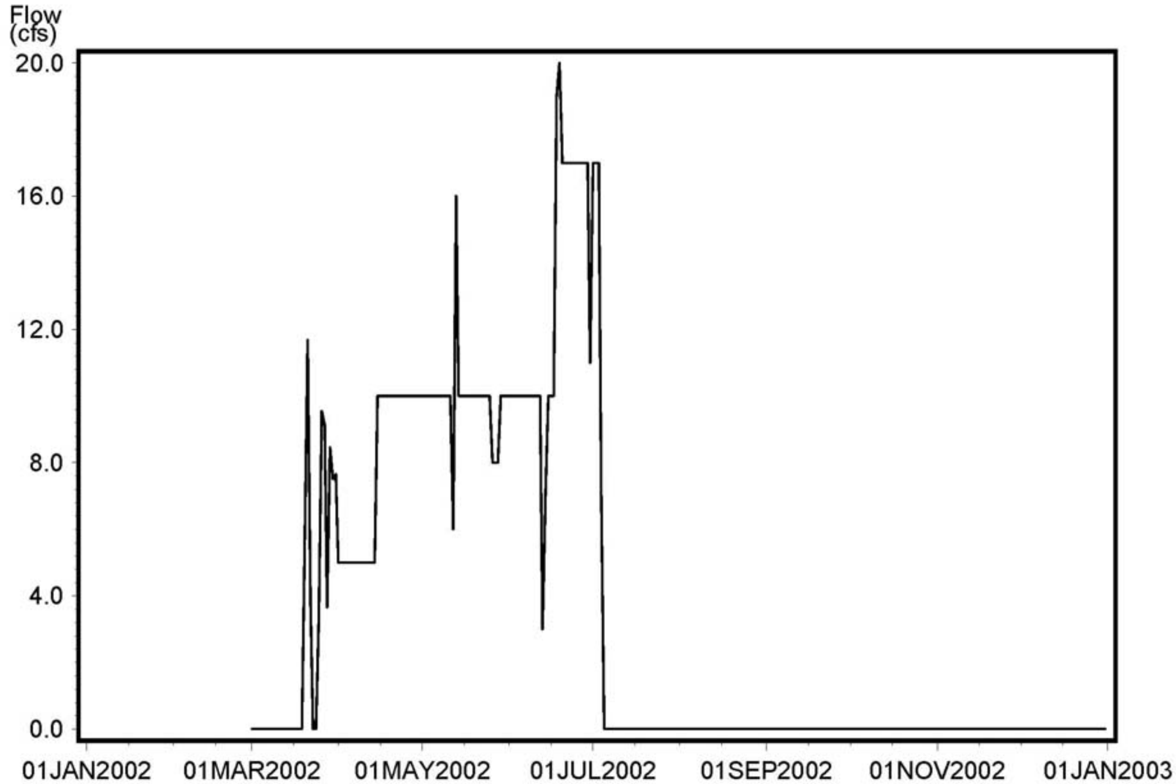


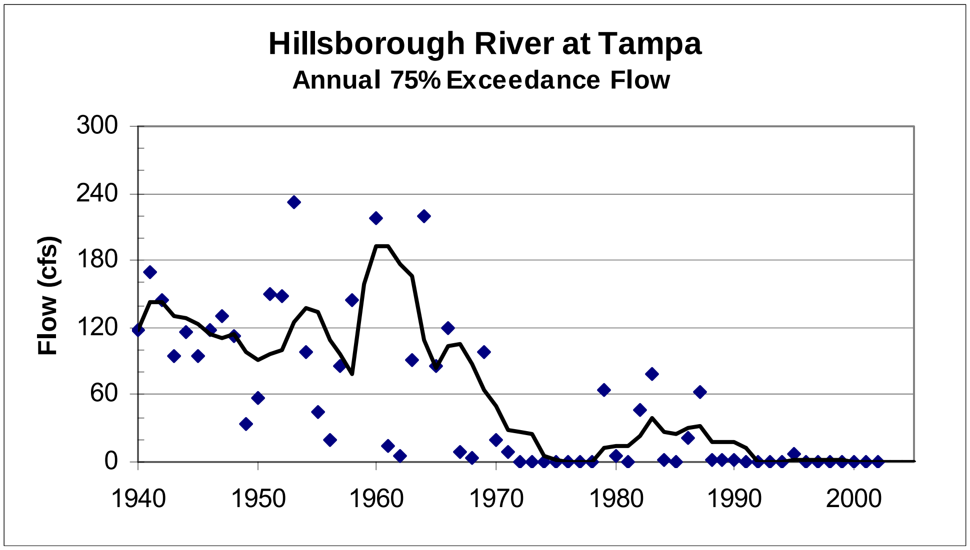
Figure 2-15 Time series of daily Sulphur Springs diversions to the base of the dam for MFL compliance.

2.3.6 An Assessment of Historical Flows

Figure 2-16 is presented to indicate that historically, in the absence of significant permitted withdrawals, flow below the dam would be substantially greater than currently exists. The figure also demonstrates that any minimum flow implemented will often be the only flow to the lower river for six months (50% exceedance) in many years. The 75% exceedance flow is the flow that is exceeded 75% of the time on an annual basis and, therefore, represents a generally low flow condition.

2.4 Water Use

The District has permitted two agencies to take water from the Hillsborough River Reservoir, the CoT and Tampa Bay Water.



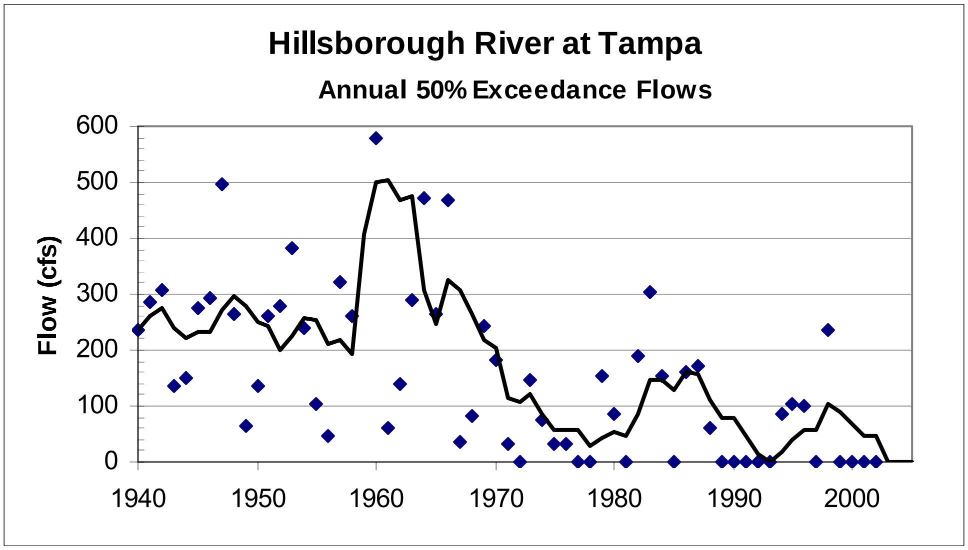


Figure 2-16 **Annual 75% and 50% exceedance flows as measured on the Hillsborough River below the dam. The dark line is the 5-year moving average.**

2.4.1 City of Tampa (CoT)

In 2004, CoT obtained a renewal of an existing Water Use Permit Number 20002062.006 with a modification that included aquifer storage and recovery (ASR). The annual permitted withdrawal of 82 mgd from the reservoir remains unchanged from the previous permit. The monthly peak of 92 mgd has been eliminated and the maximum daily withdrawal has been increased from 104 mgd to 120 mgd. Elimination of the monthly peak and the increase in the daily peak provides the flexibility to store surface water in the ASR wells during periods of time when river flows are high.

2.4.2 Tampa Bay Water

Tampa Bay Water has authority to harvest water for regional use from the Hillsborough River and the Tampa Bypass Canal through Water Use Permit Number 2011796. The permit allows for regional diversions from the Hillsborough River Reservoir in accordance with the schedule shown in Table 2-2. Quantities available for harvest are based on calculated discharge for the previous day at the Hillsborough River Dam.

Figure 2-17 shows the general system configuration. Quantities available to the Region from the Hillsborough River are diverted through TBC Structure S-161 to the Harney Canal and are harvested through intakes on the TBC Middle Pool immediately upstream of S-162.

The maximum permitted (WUP 2011796) diversion for regional supply from the Hillsborough River is 193.8 mgd (300 cfs). The current pumping capacity of the TBC Regional Pumping Station is approximately 145 mgd, however, the facility has been designed to accommodate expansion up to 259 mgd (the total permitted capacity).

Table 2-2 Tampa Bay Water permitted withdrawal schedule for the Hillsborough River.

Discharge Rate at Hillsborough Dam (MGD)	Maximum Diversion Rate (MGD)
< 65	0
65 – 97	6.5 – 9.7 (10% of flow)
97 – 139	9.7 – 42 (10% to 30% of flow)
139 – 647	42 – 194 (30% of flow)
> 647	194

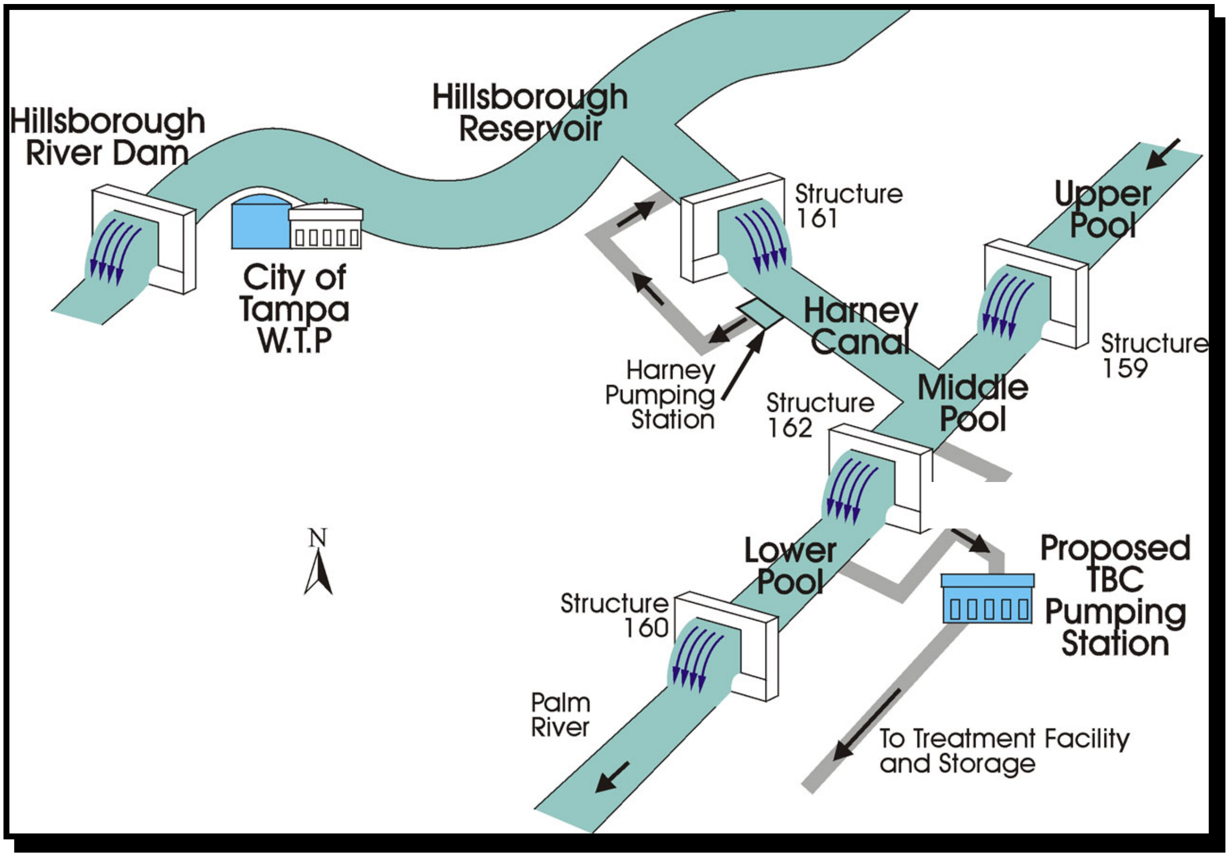


Figure 2-17 **General configuration of the Hillsborough River and Tampa Bypass Canal system.** ***Note: The Harney Pumping Station is used to augment the Hillsborough reservoir during times of low stage and flow in accordance with Water Use Permit 2006675.005.***

3.0 PHYSICAL CHARACTERISTICS OF THE LHR

The LHR (Figure 3-1) extends approximately 16.3 km from the mouth in the northwestern portion of Hillsborough Bay to the Hillsborough River Dam. The Hillsborough River Reservoir is upstream of the dam. The section of the river north of Sligh Avenue is typically less than 100 m wide, with sections as narrow as 40 m. Downstream of Sligh Avenue the river is greater than 100 m wide, with sections as wide as 250 m.

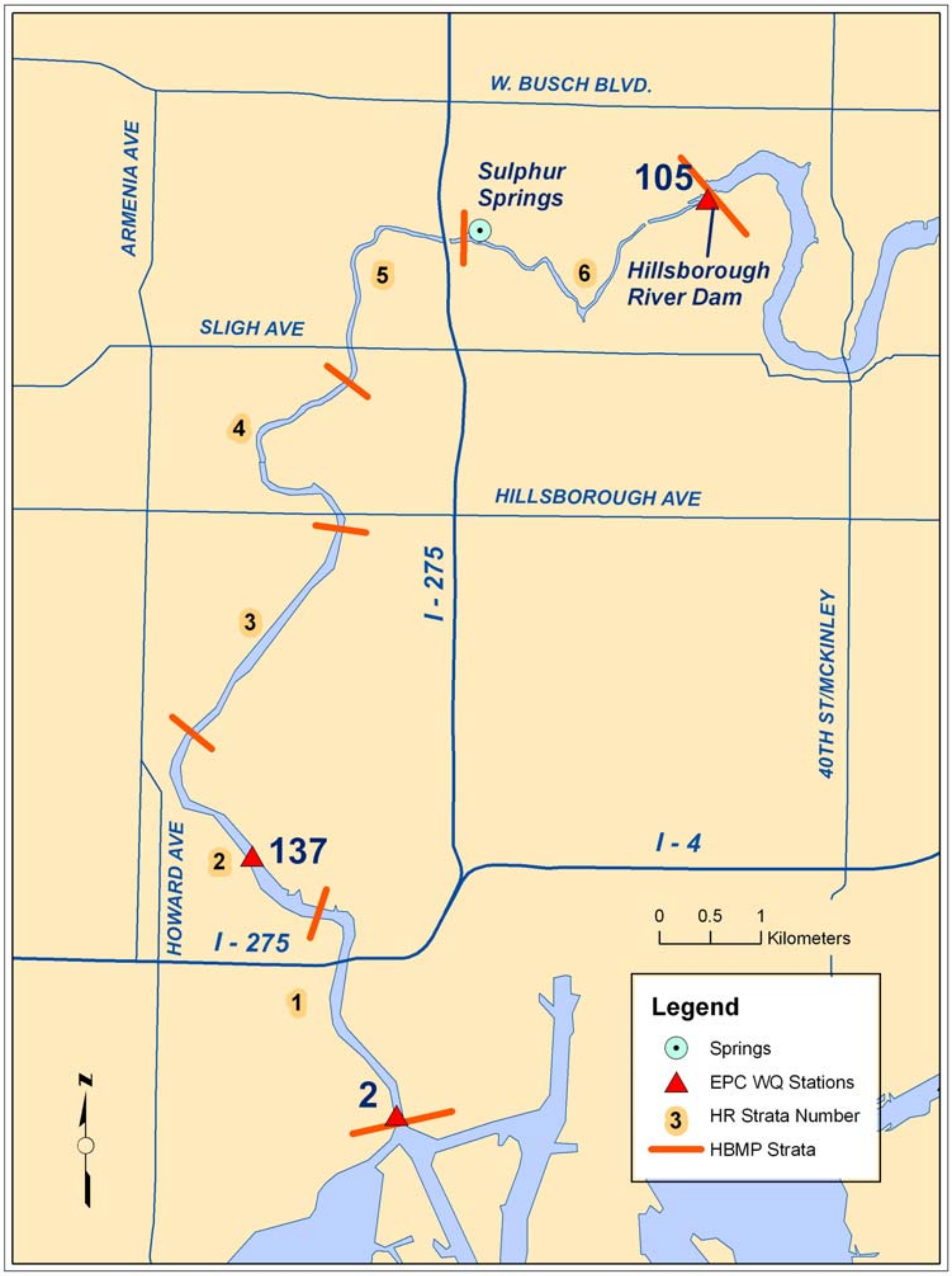


Figure 3-1 The LHR, including locations of EPCHC Ambient Water Quality sampling stations (2, 137, and 105) and HBMP sampling strata (1-6).

3.1 Bathymetry

The bottom profile of the LHR (Figure 3-2) is such that downstream of the dam to approximately RKM 13.5 there is a general deepening of the river. The LHR reaches its greatest depth near RKM 10. There is a plateau from RKM 7 through RKM 2, after which the river deepens slightly at the mouth in the northwest portion of Hillsborough Bay.

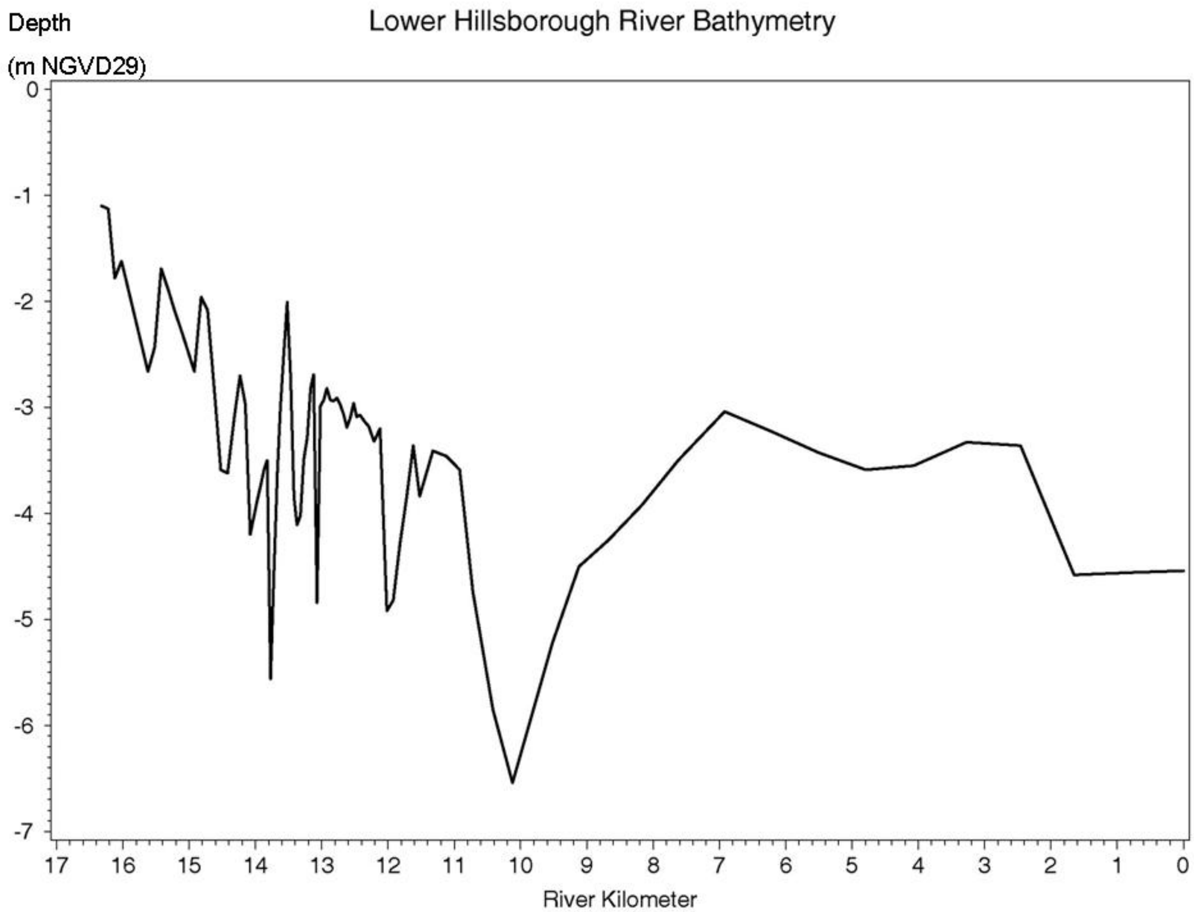


Figure 3-2 Longitudinal representation of bottom depths in the LHR. RKM16=Hillsborough River Dam; RKM0=mouth of the river.

The surface area of the LHR is approximately 2.2 km^2 (550 acres) and the estimated volume is greater than 6,000,000 m^3. Both cumulative surface area (Figure 3-3) and volume (Figure 3-4) increase rapidly from RKM 0 to RKM 9, after which the increases are smaller. This is expected as the river becomes more narrow upstream of RKM 9.

3.2 Sediment Characteristics

Generally, abundance and diversity increase with increasing sediment grain size, although the abundance of benthic organisms may be high where the organic content is relatively high (Gray, 1981; Grizzle, 1984). Sediment contaminants, including metals and organic compounds, preferentially bind to smaller sediment particles (e.g., silts and clays) (Seidemann, 1991; Birch and Taylor, 2000). Therefore, coarser sediments, such as sands, typically support a more diverse biotic assemblage than do muds which are more likely to be sinks for contaminants.

Sediment grain-size characteristics have been quantified by measuring the percentage of silt+clay (%SC) particles <63μ diameter in the LHR. Data collected for the HBMP are geographically distributed among six longitudinal strata that extend along the length of the lower river (Figure 3-1). Sediment data analyzed for the HBMP(PBS&J, 2004) show that in the most upstream stratum, Stratum 6, sediments are generally coarser (lower %SC) than downstream (Figure 3-5). Plots of sediment grain-size characteristics by year are presented in Appendix 3-2.

The longitudinal trend in the percentage of organic matter in the LHR sediments is somewhat similar to that of %SC (Figure 3-6). The percentages were less variable and lower in the most upstream stratum, Stratum 6. The percentages were generally higher and more variable in the downstream strata

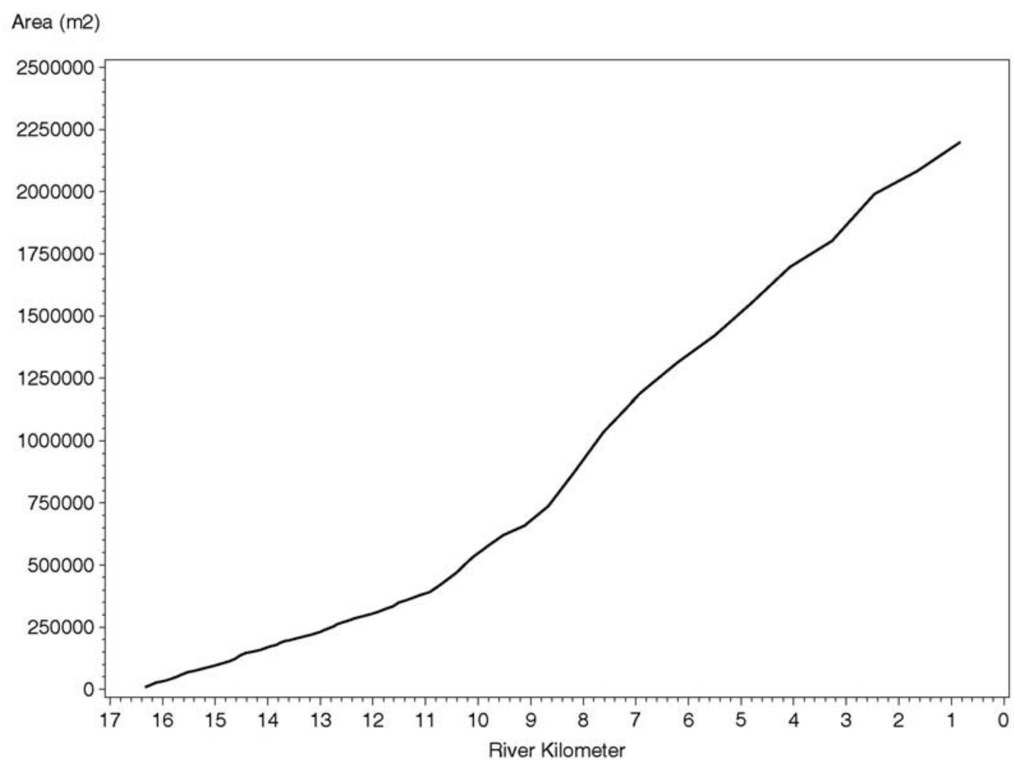


Figure 3-3 Cumulative surface area by river kilometer in the LHR.

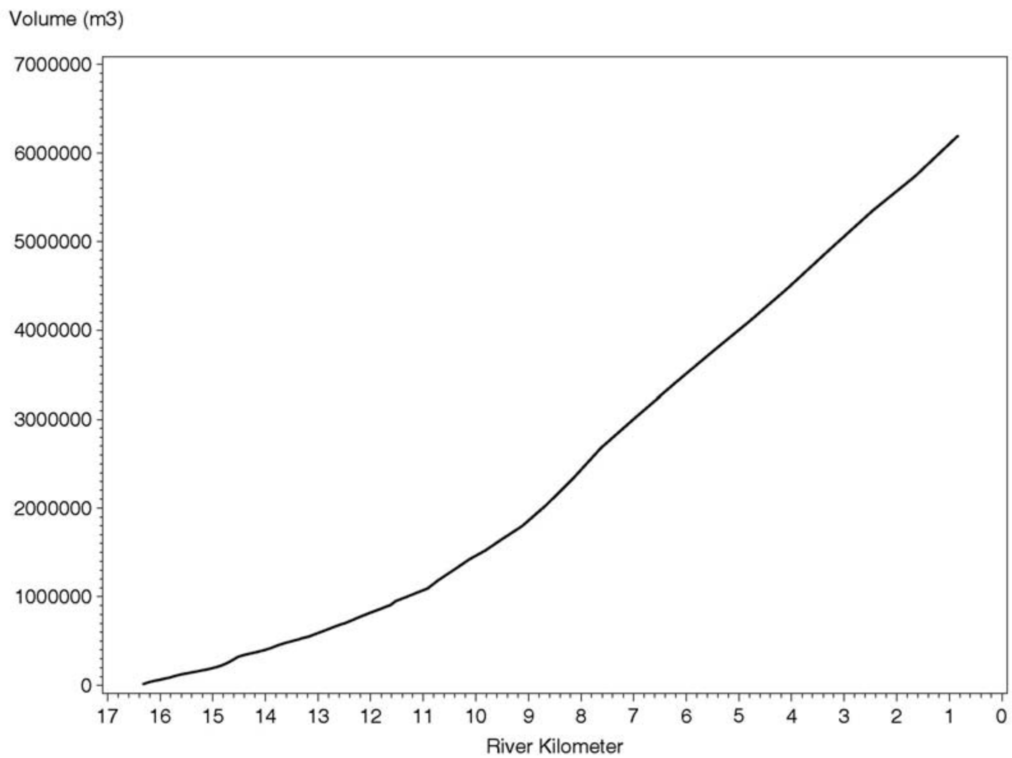


Figure 3-4 Cumulative volume by river kilometer in the LHR.

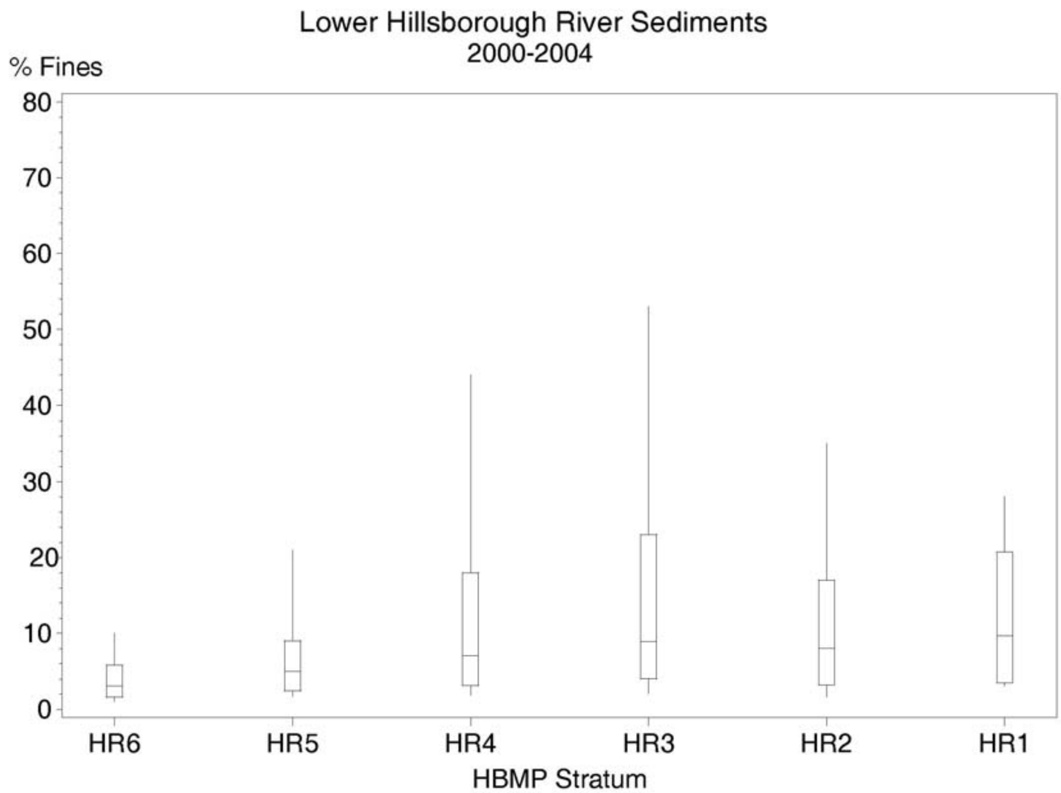


Figure 3-5 Longitudinal distribution of percent fines (=%silt+clay) in LHR sediments, 2000-2004. (From: PBS&J 2004; 2005). Stratum 1 is downstream, Stratum 6 is upstream.

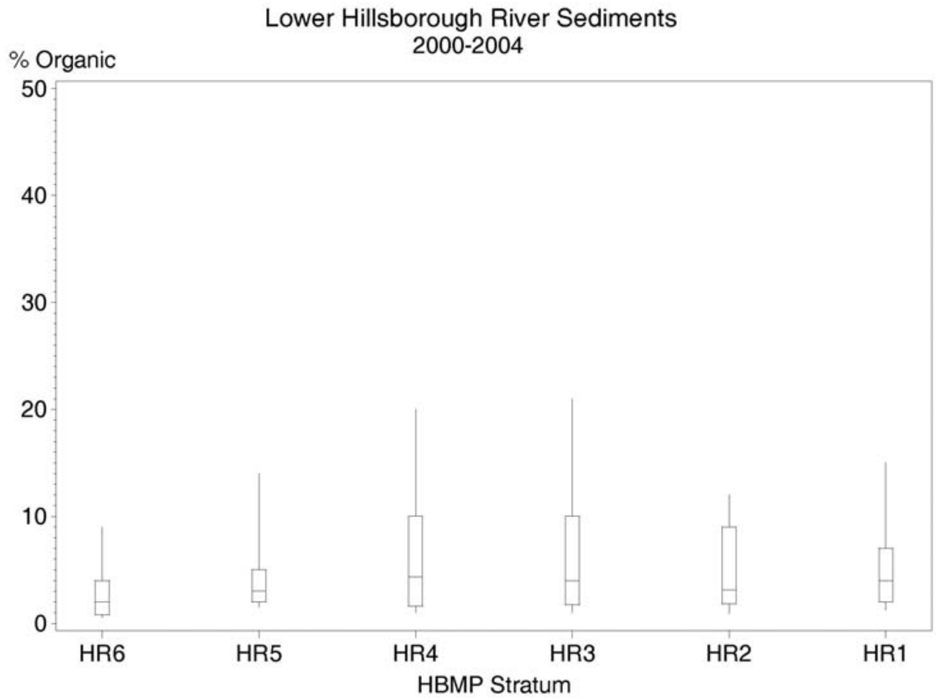


Figure 3-6 Longitudinal distribution of percent organics (=loss on ignition) in LHR sediments (From: PBS&J 2004; 2005). Stratum 1 is downstream, Stratum 6 is upstream.

Sediment contaminant studies have shown that metals, PAHs, pesticides, and PCBs are all present in the LHR at concentrations likely to be inimical to aquatic life (Grabe *et al*., 2002; Grabe *et al*., 2003a; Grabe and Barron, 2004). The occurrence of PAHs and chlordane is widespread in the LHR, whereas metals, such as lead, and the pesticide DDT are more localized in their distribution. Stormwater runoff is the likely source of the majority of these contaminants (Grabe and Barron, 2004).

3.3 Shoreline

Approximately three-quarters of the LHR shoreline has been modified (*e.g*., riprap and associated residential development), while one quarter is natural. There are no natural shoreline covers downstream of North Boulevard (between Hillsborough Avenue and Sligh Avenue), although natural shoreline (with native and exotic species) increased proceeding upstream (WAR/SDI 1995).

Downstream of I-275, narrow bands of emergent vegetation have become established in shallow areas waterward of seawalls and other hard shoreline structures in the lower river. Of the approximately 20,000 m^2 of emergent vegetation, 35% is found in Stratum 6 (Sulphur Springs to the Dam) and 39% is found in Stratum 3 (PBS&J 2002). In Stratum 3, the vegetation is composed primarily of *Typha*, which can tolerate brackish conditions (eFloras.org 2004), as well as some mixed wetland forest (PBS&J 2002). In Stratum 6, the vegetated acreage is composed largely of golden leather fern, *Acrostichum aureum*, and mixed herbaceous wetland (PBS&J 2002). *Acrostichum aureum* is a pantropical salt-tolerant species, typically associated with mangrove swamps and salt marshes (eFloras.org 2004).

4.0 SALINITY AND WATER QUALITY CHARACTERISTICS OF THE LHR

This chapter describes the water quality characteristics of the LHR. The purpose of this description is to review spatial and temporal variation in physical and water quality characteristics in order to place the minimum flow reevaluation into the context of the dynamic LHR environment.

For descriptive purposes, the example plots focus on the upstream portion of the river near the Hillsborough River Dam. This upstream area represents a suite of low salinity habitats that are expected to be particularly responsive to MFL selection. Hence, this initial section focuses on providing a descriptive framework to place the later discussions in context. However, plots for all locations in the river, key parameters, and data sources listed below are provided in Appendices 4-1 through 4-4. The responses of salinity and water quality to various levels of freshwater inflow are considered more explicitly in Chapter 6 where plots of constituent concentrations and the results of empirical and mechanistic modeling are presented.

4.1 Data Sources

The physical and water quality data described in this ection were compiled from various data sources. The majority of the data are from ongoing monitoring programs. The data sources consisted of the following five sources:

- Environmental Protection Commission of Hillsborough County (EPCHC) Ambient Water Quality Monitoring Program (1974 – present), (Figure 4-1)
- Tampa Bay Water Hydro-Biological Monitoring Program (HBMP) (2000 – present), (Figure 4-1)
- EPCHC Hillsborough Independent Monitoring Program (2000 – present),
- U.S. Geological Survey continuous recorders (1996 – present), and
- District monitoring for controlled-flow experiments (2002 – 2005).

4.2 Temporal Variation in Salinity, Temperature, DO, and Other Water Quality Constituents

As expected, temporal variation in water quality constituents was evident at varying time scales. The following sections describe the spatial and temporal variation at the annual, within-year, and daily scales. Plots for temporal variation at all locations in the river, key parameters, and data sources listed above are provided in Appendix 4-1 (physical parameters) and Appendix 4-2 (water quality parameters).

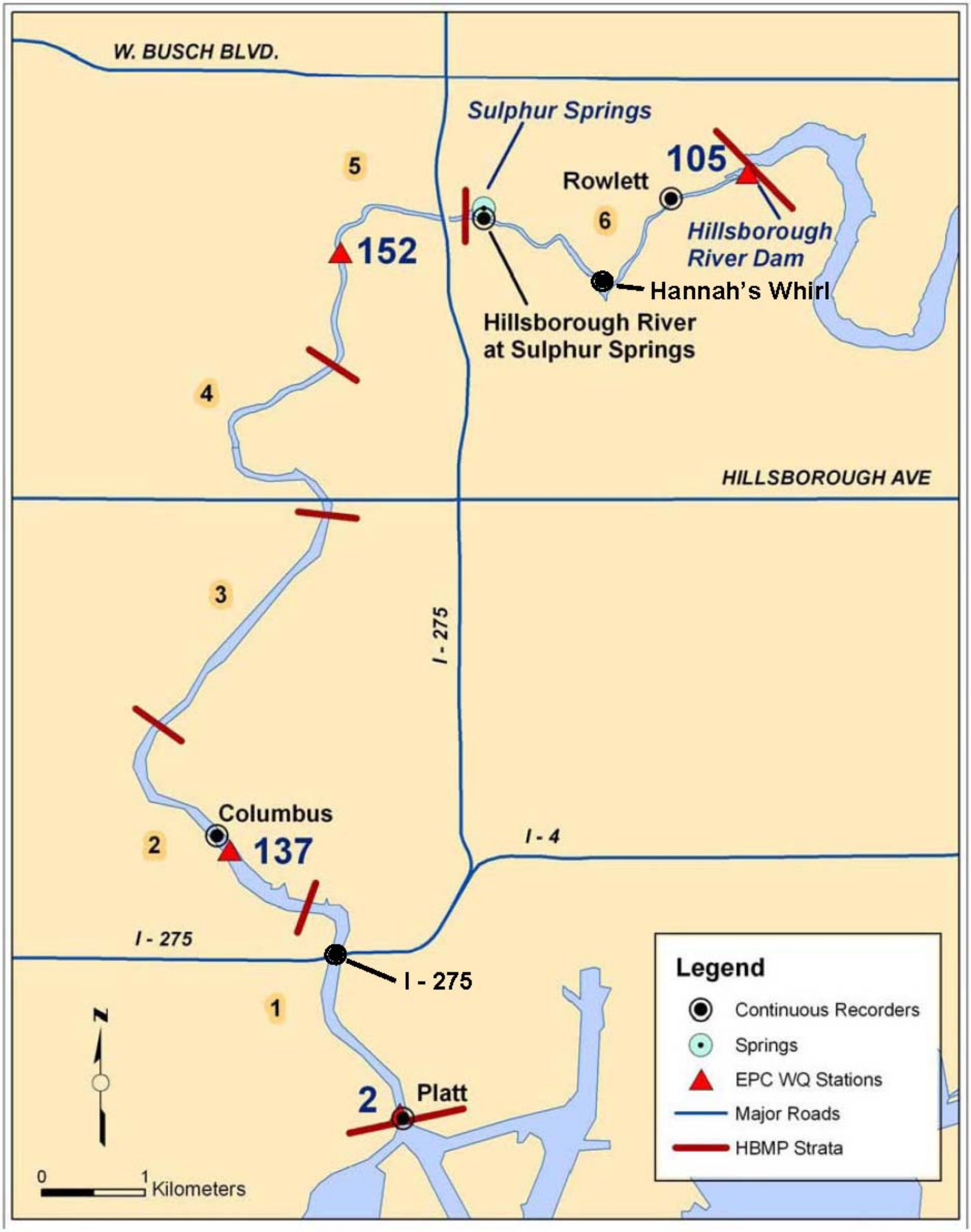


Figure 4-1 Sampling locations and strata for the physical and water quality data used to describe temporal and spatial variation in the LHR.

4.2.1 Annual Variation

No long-term trends were detected in surface or bottom salinity values from the EPCHC Ambient Water Quality Monitoring Program stations in the LHR. However, fluctuations are evident over multi-year time scales that relate to large-scale meteorological phenomena such as reduced salinity in 1998 associated with an El Niño weather pattern. Figure 4-2 presents the annual variation in salinity at a station (EPCHC 105) which is approximately 0.5 km downstream of the Hillsborough River dam (Rowlett Park). These data indicate that salinity varied greatly (0 ppt to 15 ppt) from wet season to dry season within each year, and that salinity trended higher and lower over three to five year intervals. There were several periods where salinity was near 0 ppt at this location.(1) The river is a managed system, and these salinity values near the dam are a function of the freshwater release history, including the effects of withdrawals from the reservoir on flow from the dam. However, the dam operation is also linked to meteorological conditions, and this time series is indicative of annual salinity variation. The variation in surface, middle, and bottom salinities was similar at the annual scale across longitudinal locations. The vertical variation in all physical parameters is discussed later in this section.

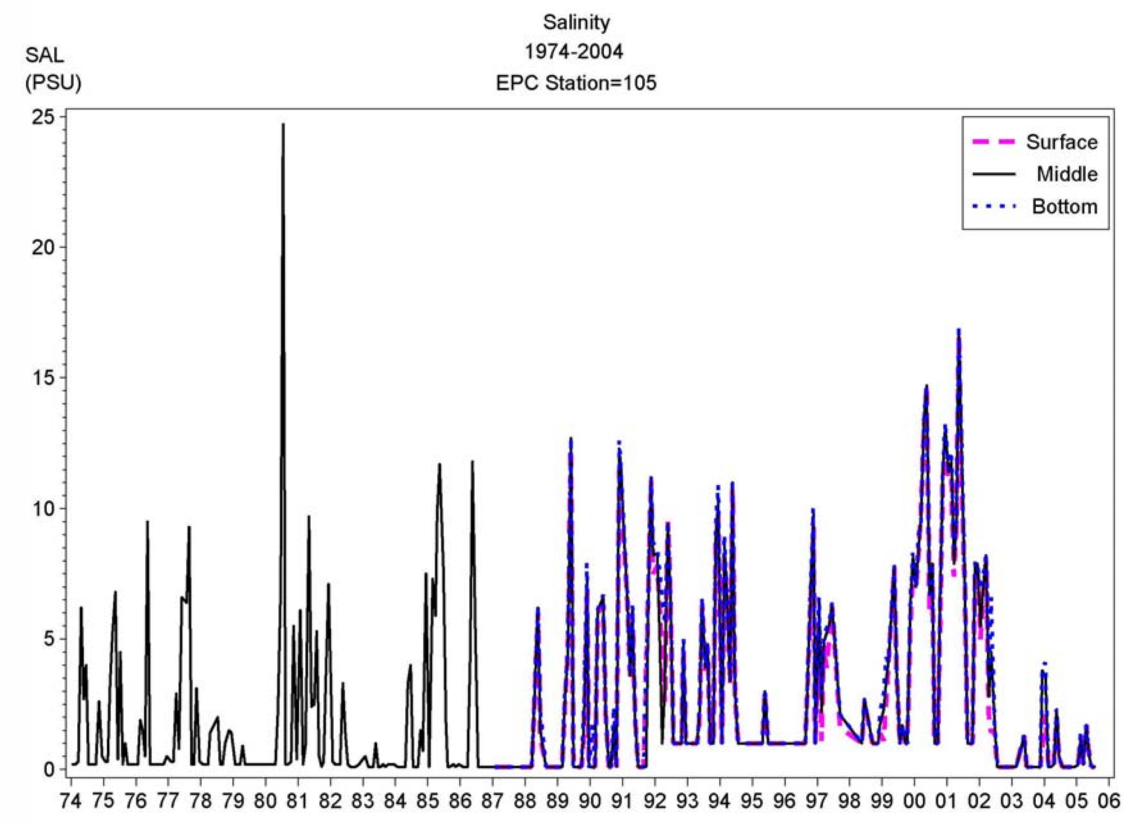


Figure 4-2 Monthly time series of surface, middle, and bottom salinity at EPCHC Station 105 (near Rowlett Park).

(1) There appears to be a problem with the minimum salinity values from 1992 to 2002 that is most likely due to the calculation of salinity from conductivity.

As expected temperature in the LHR predictably cycles from a summer peak of approximately 30 degrees C to a winter low of 15 degrees C (Figure 4-3). Little variation was observed from this basic pattern over annual scales. The surface, middle, and bottom variation in temperature was similar at the annual scale at all locations in the river.

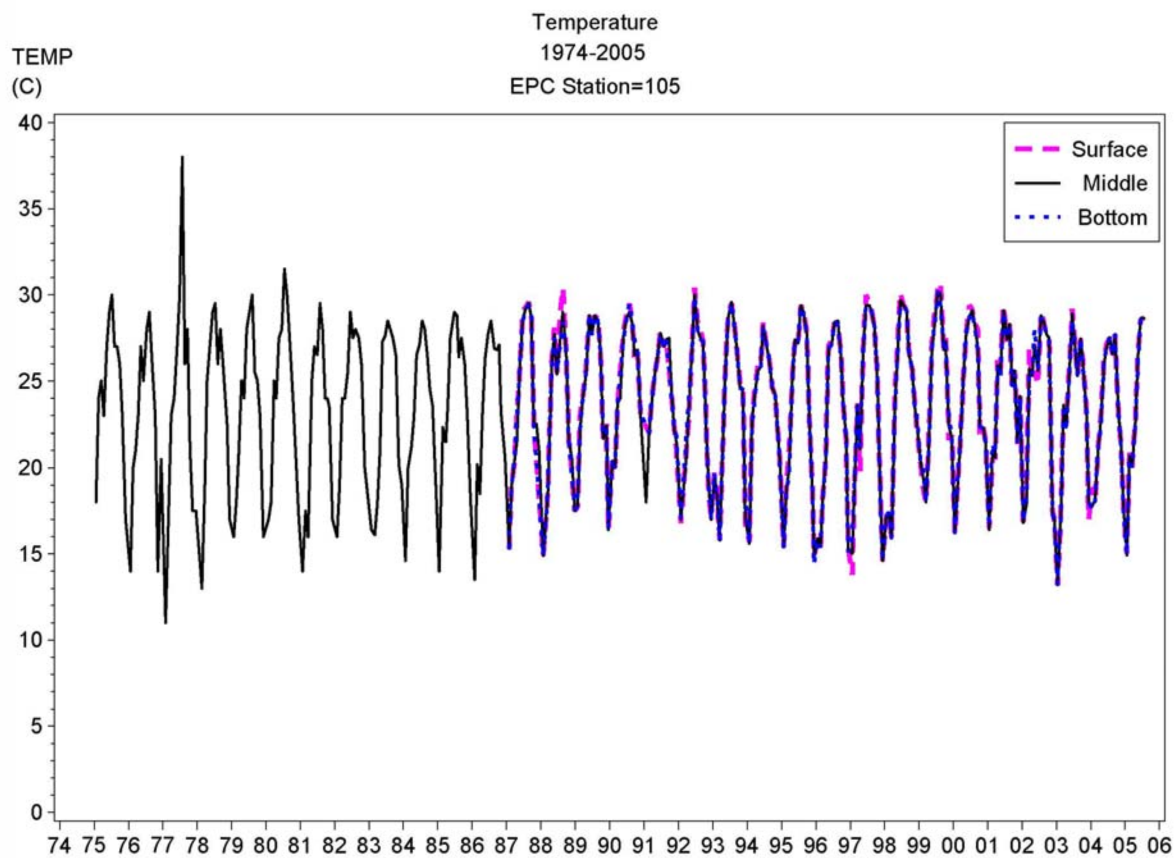


Figure 4-3 Monthly time series of surface and bottom temperature at EPCHC Station 105 (near Rowlett Park).

The annual variation in dissolved oxygen (DO) varied over multi-year time scales with several consecutive years of high DO and several consecutive years of low DO. This multi-year variation is apparent in Figure 4-4 above the typical summer and winter cycling of DO. For example, during the drought period of 1999-2001, DO values were observed to be at the low end of the annual variation range for several consecutive years. There was a rebound in DO values in the wet years 2003 and 2004.

Chlorophyll *a* concentrations were observed to be quite variable at an annual scale. From 1974 to 2005, the mean chlorophyll a concentration was 14.8 μg/L and the median 6.1 μg/L; 10% of the values exceeded 39 μg/L. Figure 4-5 presents the annual variation in chlorophyll *a* concentrations near the Hillsborough River Dam. There is apparent trend in these data over the period of record; however, there is a time interval from 1987 to 1994 where the higher peaks in chlorophyll *a* concentrations were visibly less frequent (Figure 4-5).

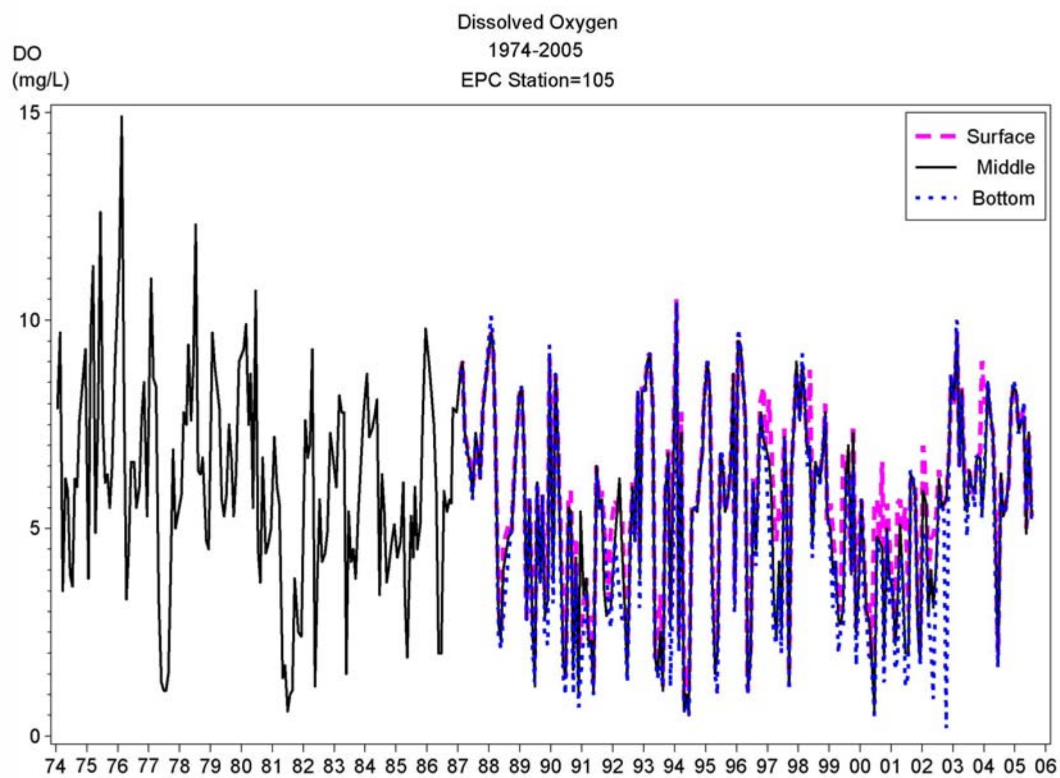


Figure 4-4 Monthly time series of surface and bottom DO at EPCHC Station 105 (near Rowlett Park).

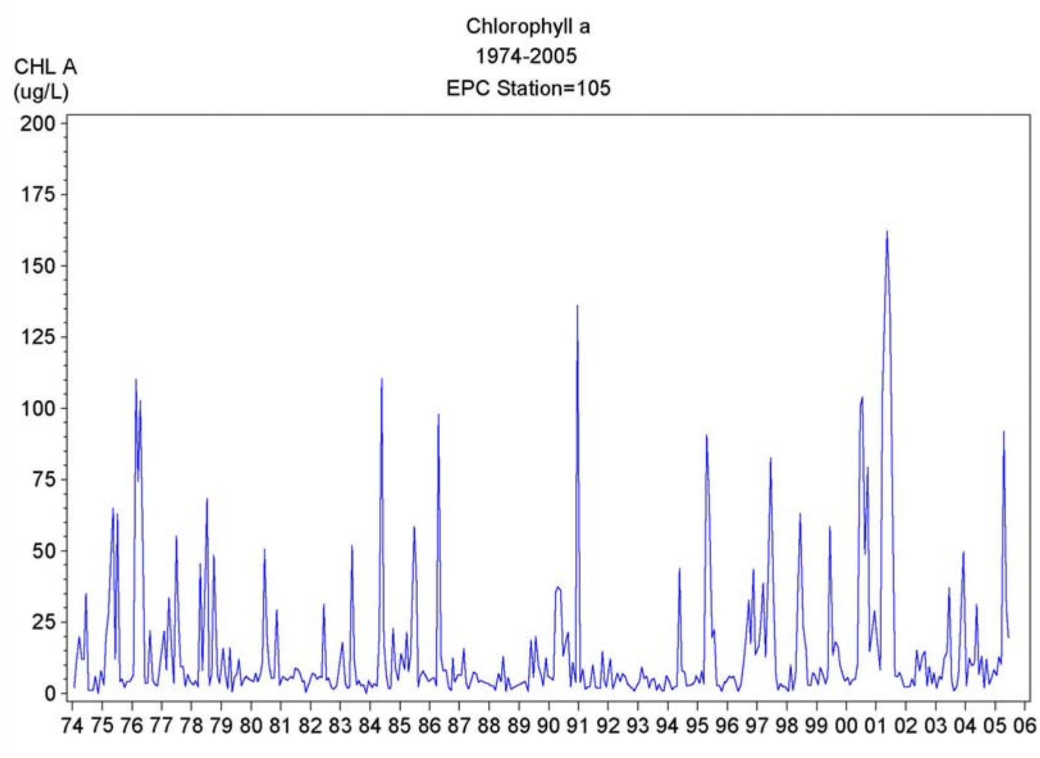


Figure 4-5 Monthly time series of chlorophyll a at EPCHC Station 105 (near Rowlett Park).

The observed total nitrogen concentrations near the Hillsborough River Dam are presented in Figure 4-6. These data indicate that total nitrogen ranged between approximately 1 and 2 mg/L over this period of record. Occasional multi-year patterns are visible in the observed data. For example, a period of relatively lower total nitrogen concentrations was observed between 1996 and 1999, and this was followed by a period of relatively higher concentrations from 2000 to 2002.

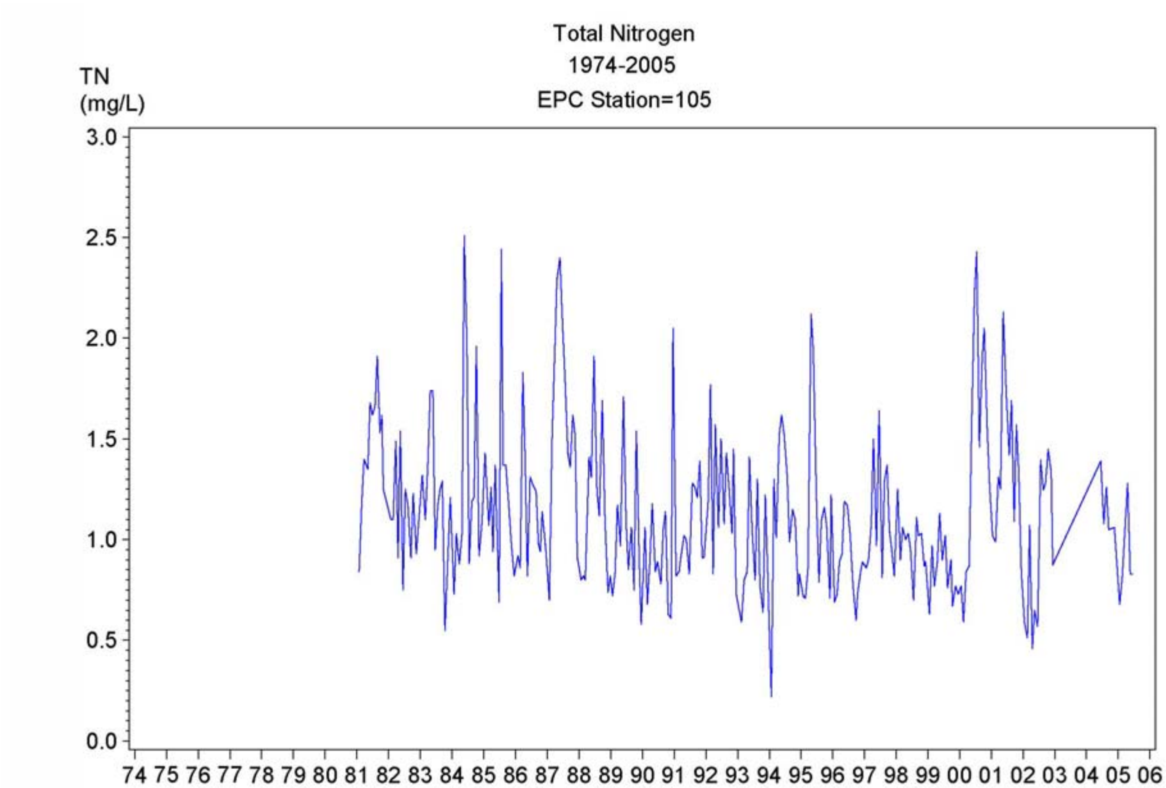


Figure 4-6 Monthly time series of total nitrogen at EPCHC Station 105 (near Rowlett Park).

After an initial period of higher total phosphorous concentrations, total phosphorous was observed to have little annual variation across the period of record. The observed total phosphorous concentrations near the Hillsborough River Dam are presented in Figure 4-7. These data indicate that after 1981, total phosphorous ranged between approximately 0 and 0.5 mg/L.

Secchi disk depths were observed to be quite variable at an annual scale. Typical Secchi disk depths were in the range of 0.5 to 2.0 meters; both the mean and median for the period 1974 to 2004 was 1.1 meters. The annual variation in Secchi disk depths near the Hillsborough River Dam is presented in Figure 4-8. Between 1989 and 1991 and also between 2002 and 2004, Secchi disk depths greater than station depths were rather common. These events were the result of both water clarity and the tide driven water depth at the time of sampling.

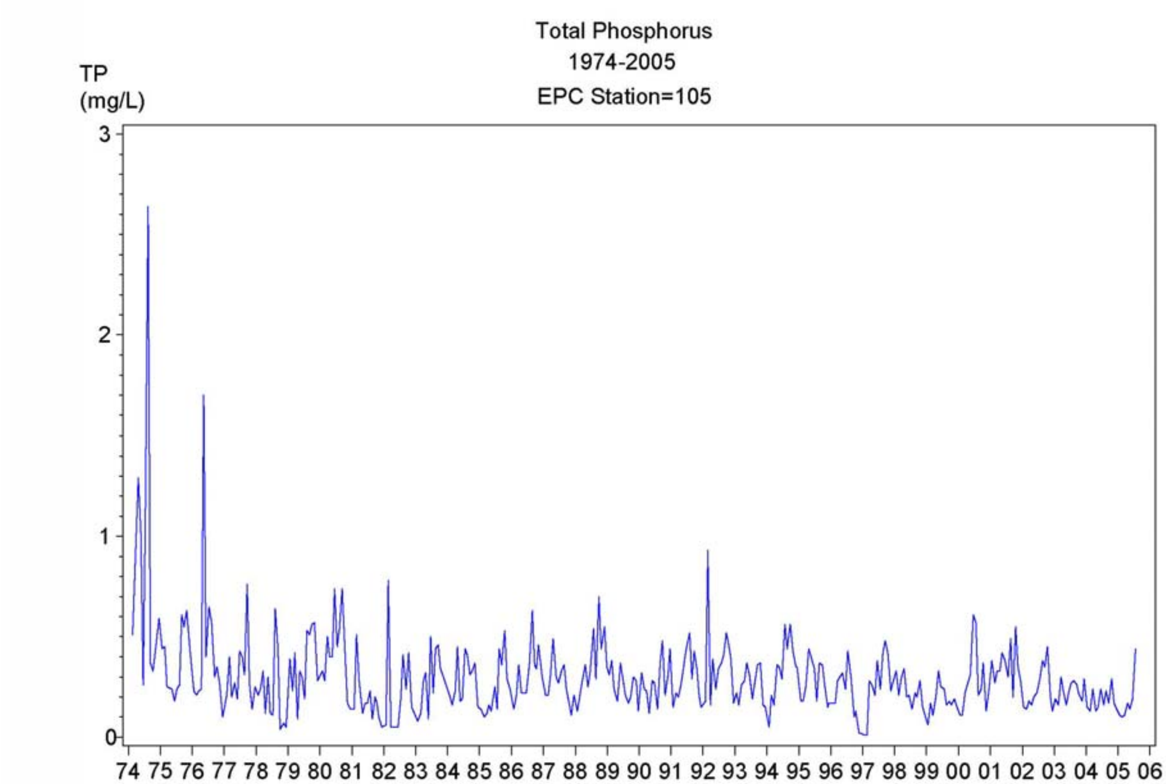


Figure 4-7 Monthly time series of total phosphorous at EPCHC Station 105 (near Rowlett Park).

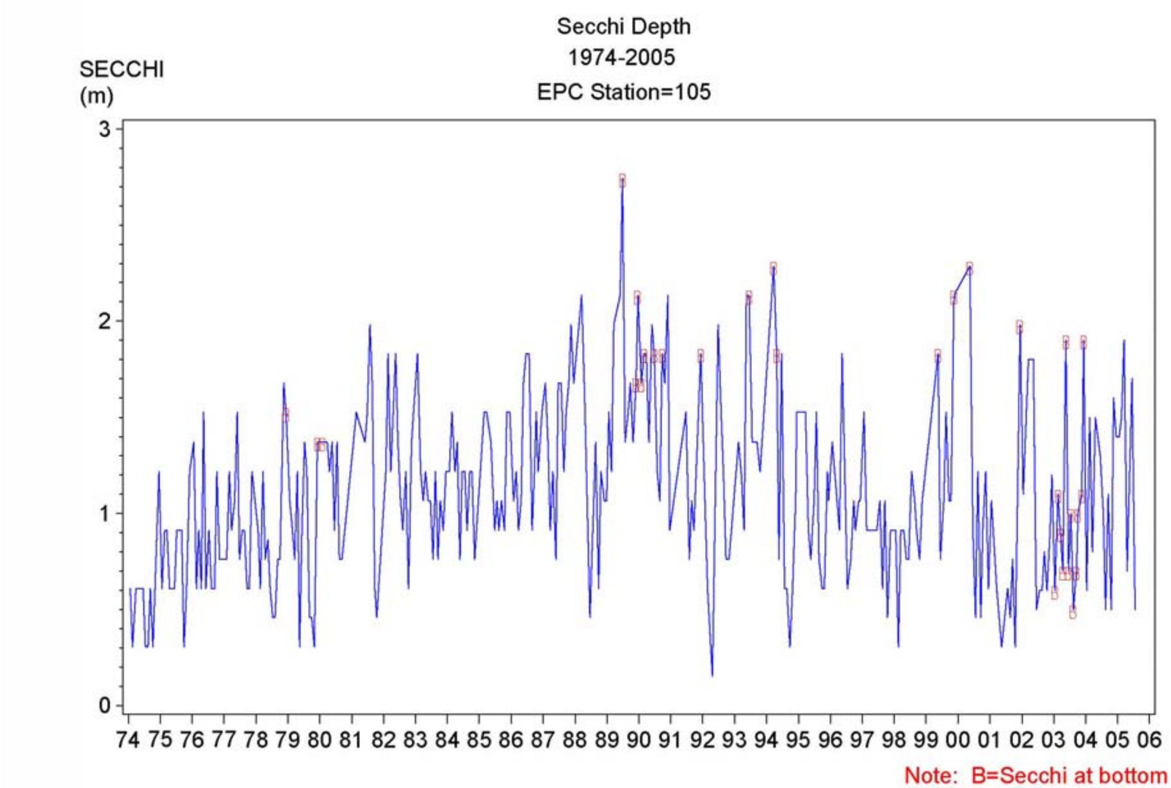


Figure 4-8 Monthly time series of Secchi disk depth at EPCHC Station 105 (near Rowlett Park).

4.2.2 Within-Year Variation

Within each year the physical and water quality characteristics of the LHR vary on a cycle driven by the summer warmer/wet and winter cooler/dry season cycle of the local climate. However, the frequent occurrence of no-flow conditions in the dry season strongly influences these seasonal patterns, compared to what would be expected under a more natural flow regime. Similar patterns were observed across the upstream to downstream axis of the river. Detailed plots for all locations and constituents are presented in Appendix 4-1.

As expected, salinity was higher in the winter dry season months and lower in the summer wet season months. Figure 4-9 presents the within-year salinity variation at surface and bottom near the Hillsborough River Dam. During July through October, the river was nearly fresh at this location, and ranged from 0 ppt to 10 ppt during the other months of the year. The response is almost a discrete shift in winter and summer salinity distributions at this upstream location, which is related to the typical summer onset of flows from the dam (Figure 2-9).

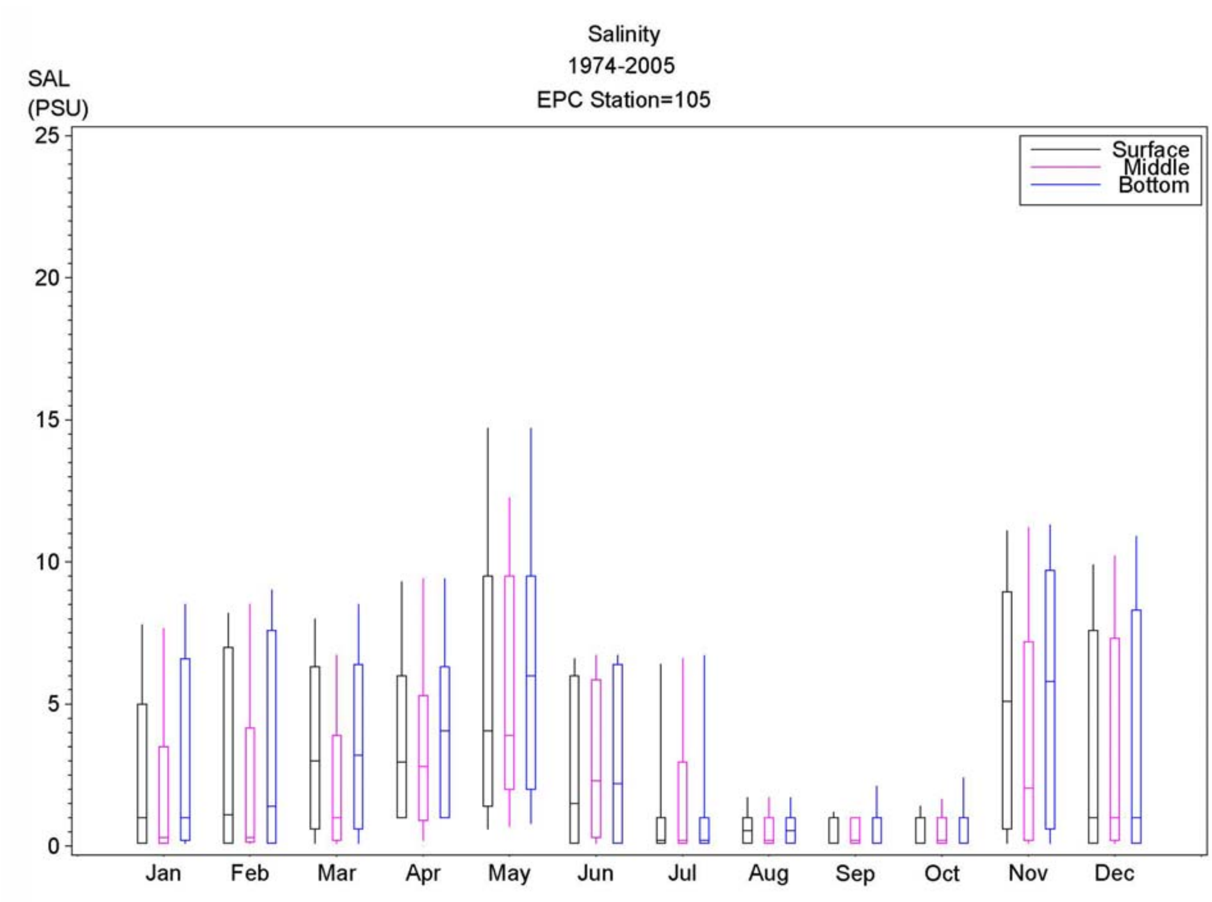


Figure 4-9 Monthly distributions of surface and bottom salinity (1987 – 2004) and middle salinity (1974 – 2004) at EPCHC Station 105 (near Rowlett Park) across multiple years. Boxes represent the 25th, 50th and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

Similar to salinity, temperature was observed to follow a strong seasonal pattern over the period of record at all locations and depths. Figure 4-10 presents the typical within-year temperature variation near the Hillsborough River Dam over the EPCHC period of record.

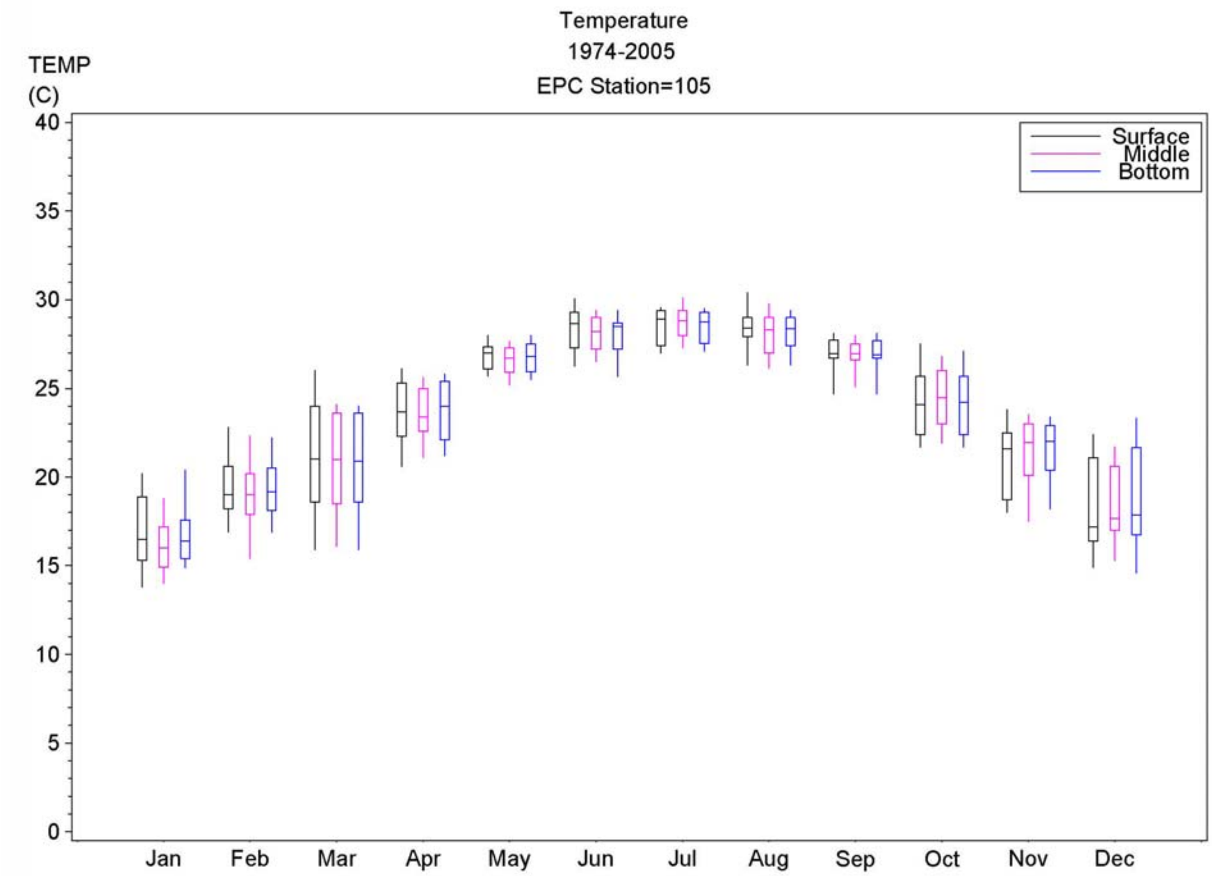


Figure 4-10 Monthly distributions of surface and bottom temperature (1987 – 2004) and middle temperature (1974 – 2004) at EPCHC Station 105 (near Rowlett Park) across multiple years. Boxes represent the 25th, 50th and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

Similar to salinity and temperature, DO concentrations were observed to have a repeating within-year cycle. The DO concentrations were generally higher in the winter months and lower in the summer months across all stations. DO concentrations are expected to be lower during the summer months when organic carbon supplies are higher and higher water temperatures lead to lower DO saturation potential. Unlike salinity and temperature, DO concentrations demonstrate significant localized variation as will be discussed in some detail in Chapter 6. Figure 4-11 presents within year variation in DO concentrations near the Hillsborough River Dam over the EPCHC period of record. At this location in the river, low bottom DO concentrations typically occur at the end of the dry season, April-June. Higher DO values, typically greater than 6 mg/L, occur from July to March. The inter-quartile ranges of bottom DO at this site are smallest in the summer wet season when there is typically flow from the dam.

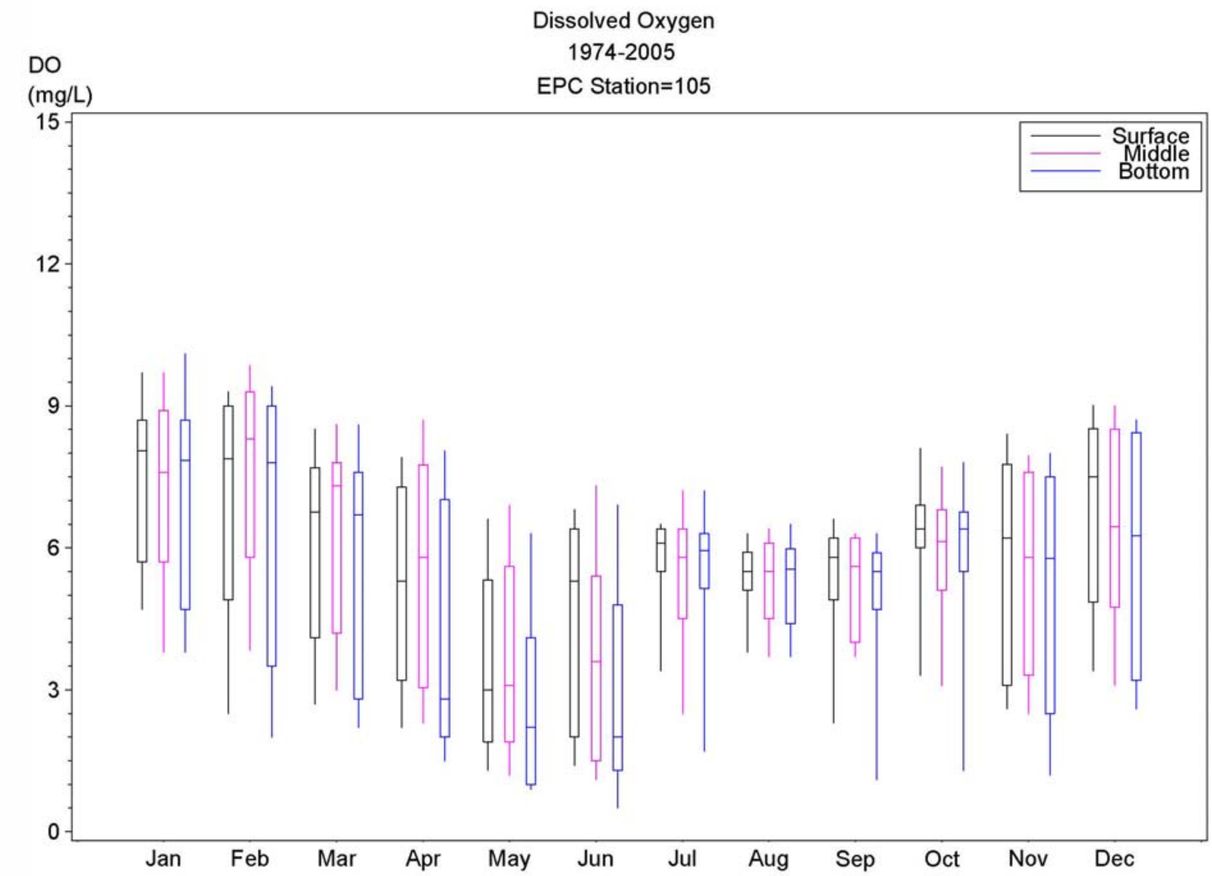


Figure 4-11 Monthly distributions of surface and bottom (1987 – 2004) DO and middle DO (1974 – 2004) at EPCHC Station 105 (near Rowlett Park) across multiple years. Boxes represent the 25th, 50th and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

The within-year variation in chlorophyll *a* concentrations follows a strong seasonal pattern of higher chlorophyll *a* concentrations during April through July and lower concentrations during the remainder of the year. The hydrologic and ecological nature of this pattern is discussed further in Chapter 6. Figure 4-12 presents the within-year variation in chlorophyll *a* concentrations near the Hillsborough River Dam. These observations are typical of the spring/early summer peak chlorophyll *a* pattern observed throughout the river.

A within-year pattern in total nitrogen concentrations was apparent in the observed data in the monthly distributions across multiple years. Figure 4-13 presents within-year variation in total nitrogen concentrations near the Hillsborough River Dam. These concentrations were observed to follow an annual pattern with higher concentrations in the spring/early summer months similar to chlorophyll.

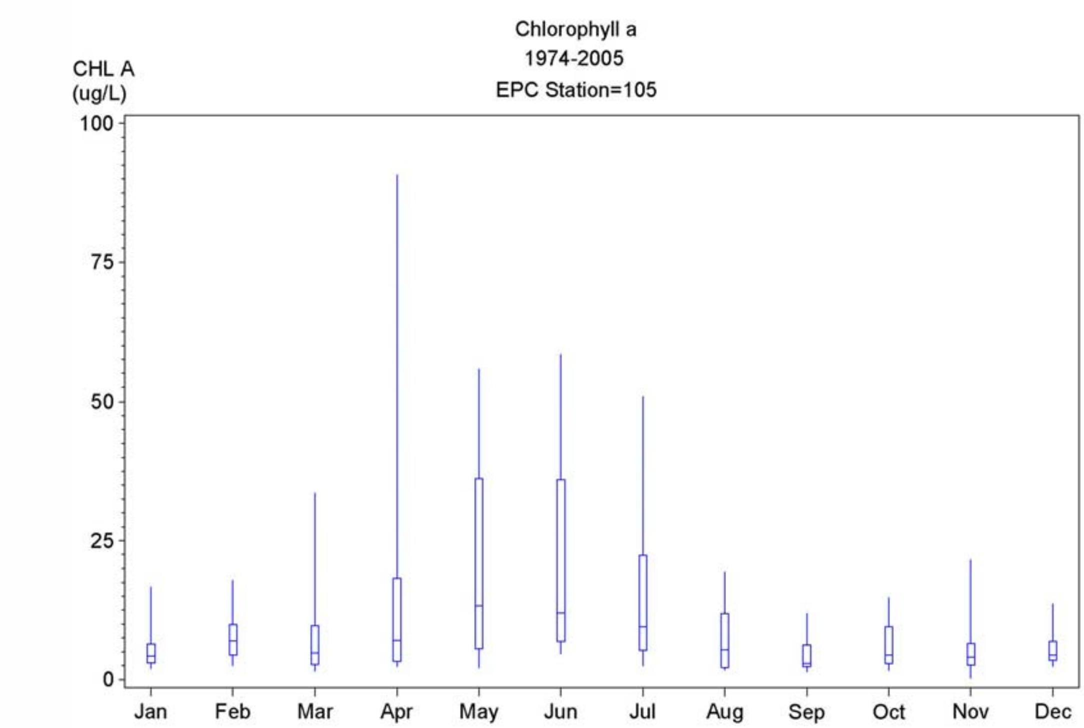


Figure 4-12 Monthly distributions of chlorophyll *a* at EPCHC Station 105 (near Rowlett Park) across multiple years. EPCHC chlorophyll samples are taken at mid-depth. Boxes represent the 25th, 50th and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

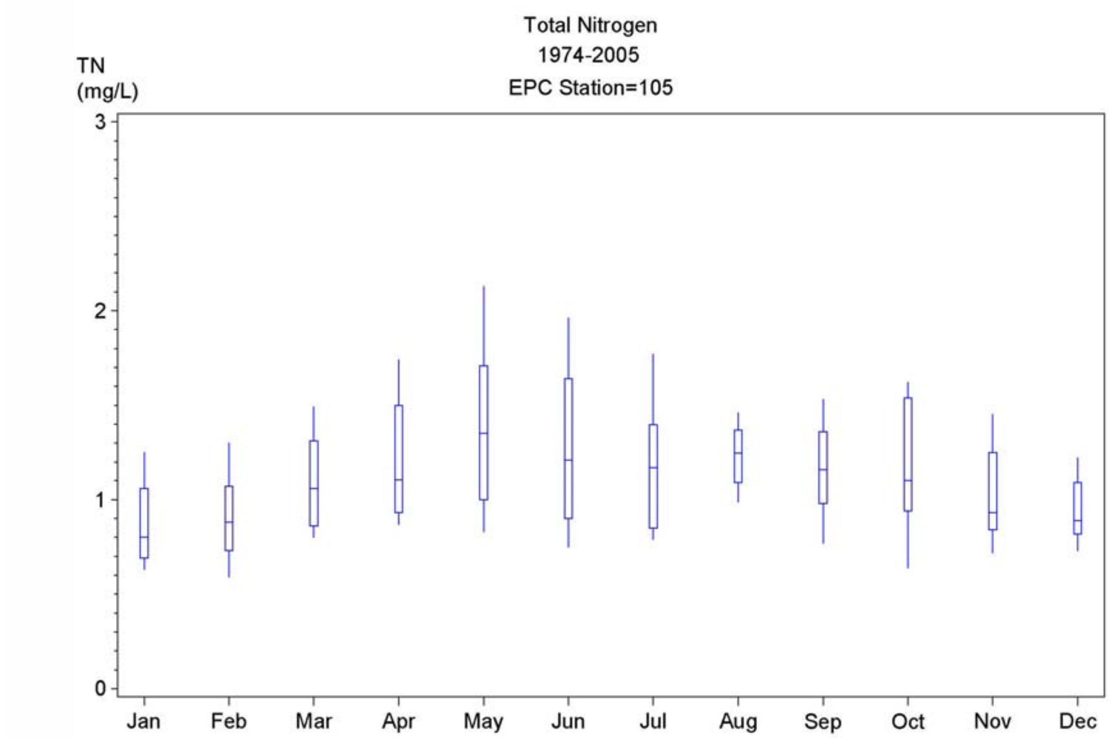


Figure 4-13 Monthly distributions of total nitrogen at EPCHC Station 105 (near Rowlett Park) across multiple years.

Figure 4-14 presents within-year variation in total phosphorous concentrations near the Hillsborough River Dam. These concentrations were observed to follow an annual cycle with higher concentrations in the late summer and fall months. The peak phosphorous concentrations were observed to occur later in the year than the peak nitrogen and chlorophyll concentrations (Figure 4-14 compared to Figures 4-12 and 4-13).

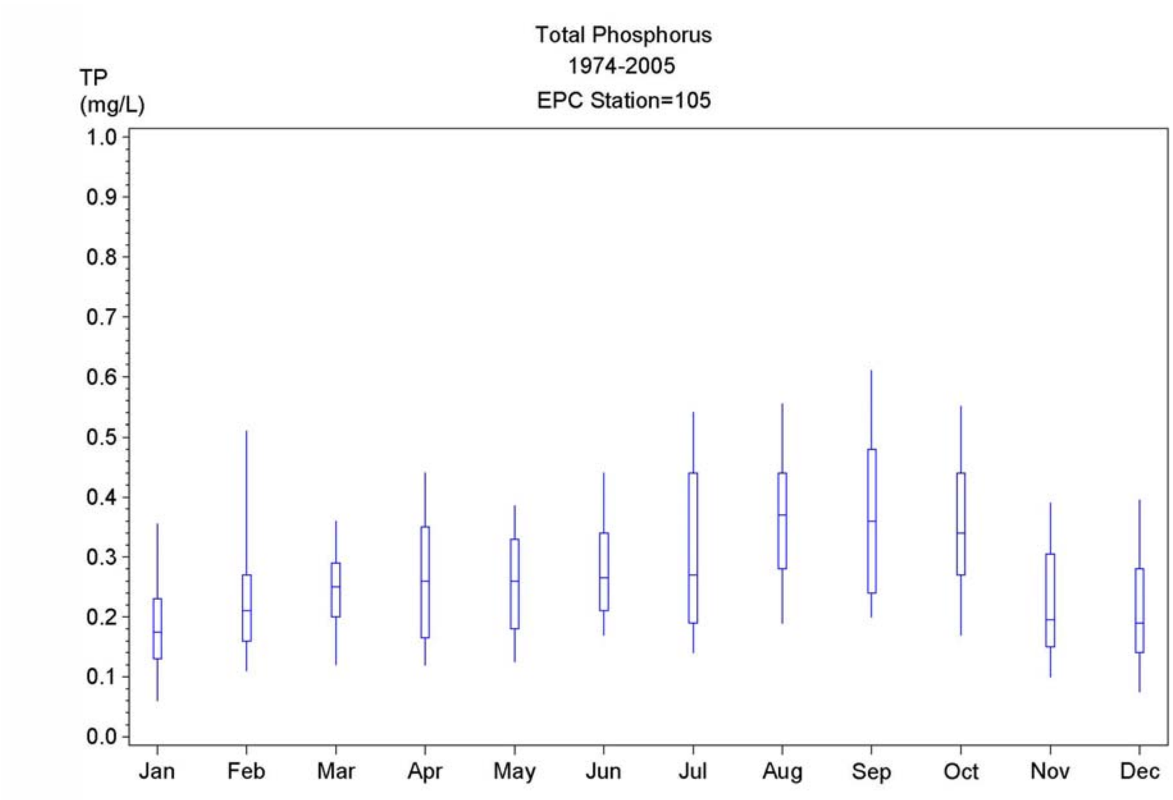


Figure 4-14 Monthly distributions of total phosphorous at EPCHC Station 105 (near Rowlett Park) across multiple years.

4.2.3 Daily Variation

Daily variation was reported for physical constituents measured by continuous recorders. Data are available for continuous recorders located at several locations (Rowlett Park, Hannah's Whirl, Sulphur Springs, I-275 near Sulphur Springs, Columbus Drive, and Platt Street). Salinity and temperature were reported at 15-minute intervals for periods extending over multiple years. DO was also reported on 15 minute intervals; however, due to logistic constraints of the measuring equipment, DO was only reported reliably for periods up to 72 consecutive hours. Salinity and temperature data for I-275 near Sulphur Springs and Rowlett Park are presented in the text. Salinity and temperature data for Hannah's Whirl, Sulphur Springs, Columbus Drive, and Platt Street are presented in Appendix 4.1.

Salinity was observed to vary considerably on a daily basis at most times and locations in the river. The exception to this general pattern was observed during high freshwater inflow periods when salinities were nearly constantly fresh at the more upstream locations in the river. Due to the actions of tides, rainfall, and flow variations, the salinity at any one location in the river often is expected to vary greatly over the course of each day and from day to day.

The variation in mean daily salinity is presented graphically for two sites in Figures 4-15 (I-275 bridge crossing just downstream of Sulphur Springs) and 4-16 (Rowlett Park). At the I-275 station (Figure 4-15), stratification exists during much of the period. As described by SWFWMD (2004b), this site is close to the outflow from Sulphur Springs run, and during the dry season flows from the spring layer over the more saline water in the river resulting in density stratification. While salinity measurements at Rowlett Park are variable; there is no vertical stratification during the period of record. Importantly, this figure and others like it (Appendix 4.1) provide a depiction of the salinity variation that relatively immobile organisms such as benthic macroinvertebrates are exposed to on a daily basis.

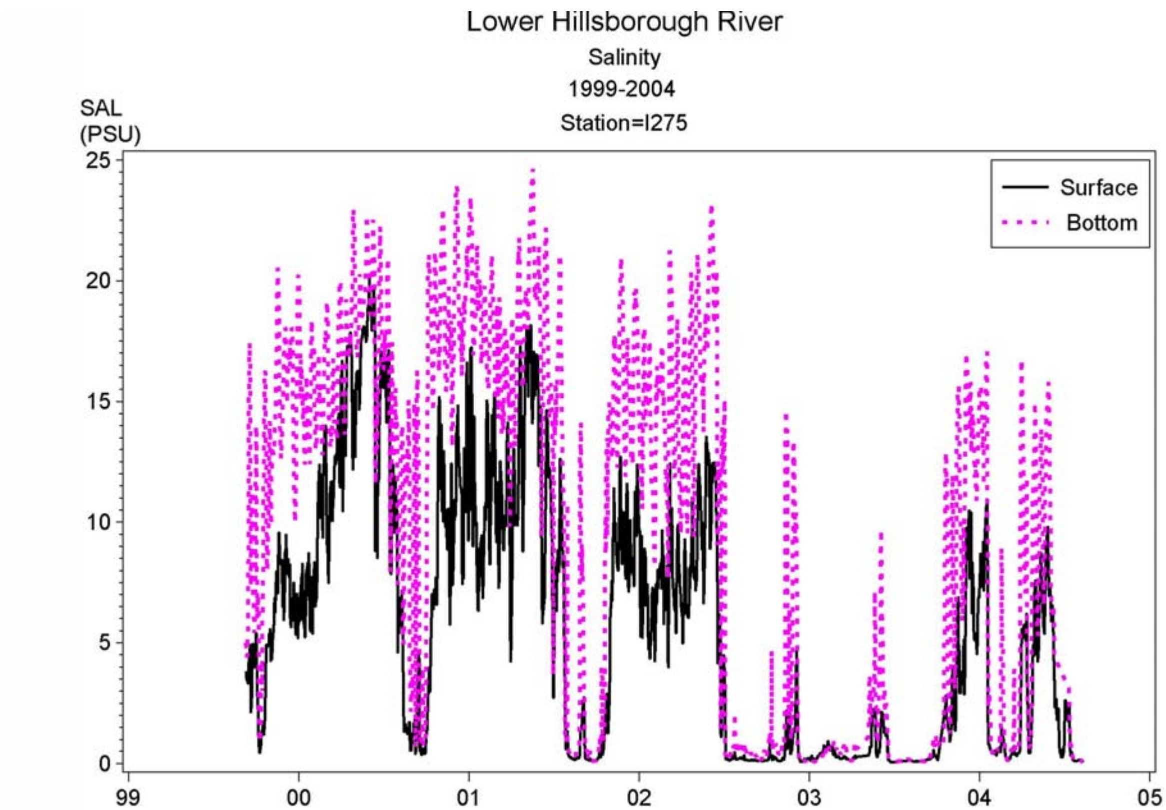


Figure 4-15 **Observed USGS/District continuous recorder time series of mean daily surface and bottom salinity near I-275.**

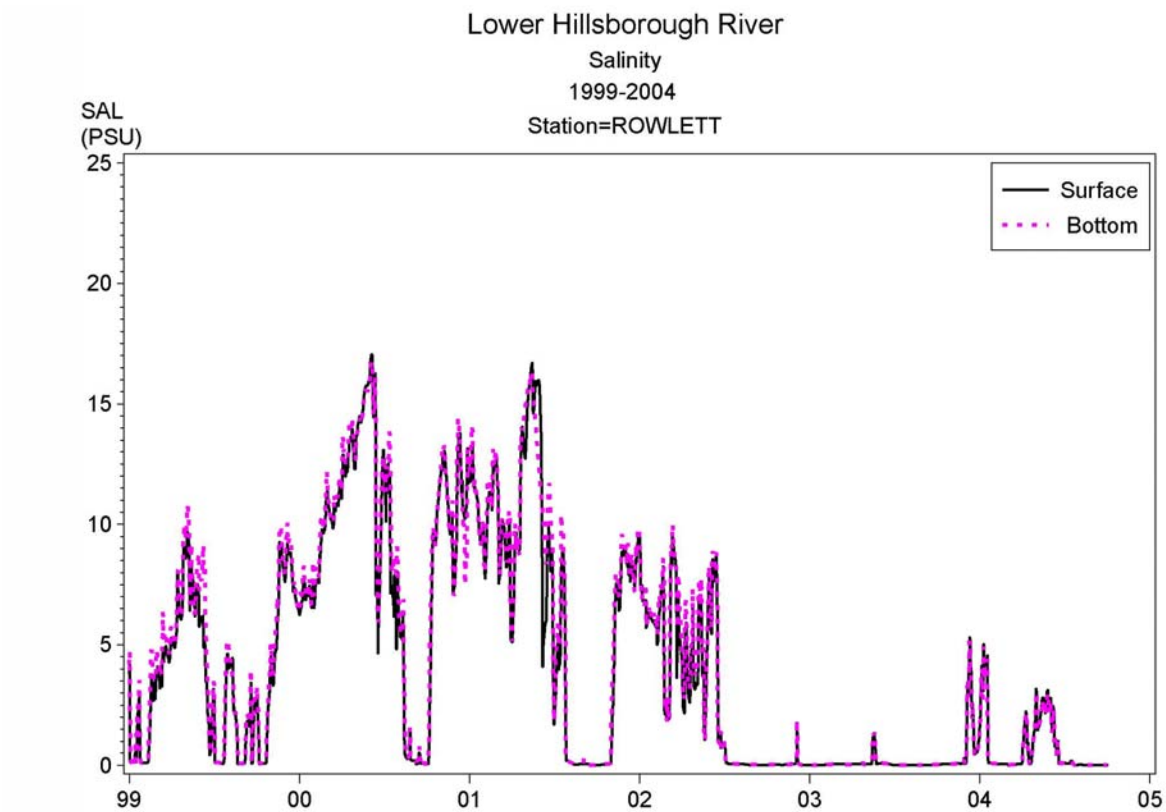


Figure 4-16 Observed USGS/District continuous recorder time series of surface and bottom salinity at Rowlett Park.

The daily variation in temperature is presented graphically at two locations in Figures 4-17 (I-275 bridge crossing just downstream of Sulphur Springs) and 4-18 (Rowlett Park). The daily temperature variation is much less than that observed for salinity. Winter water temperatures are slightly warmer at I-275 due to the discharge of isothermal waters from Sulphur Springs (SWFWMD 2004b). Water temperatures fell below 15°C during only one year at I-275, but in all six years of record at Rowlett Park.

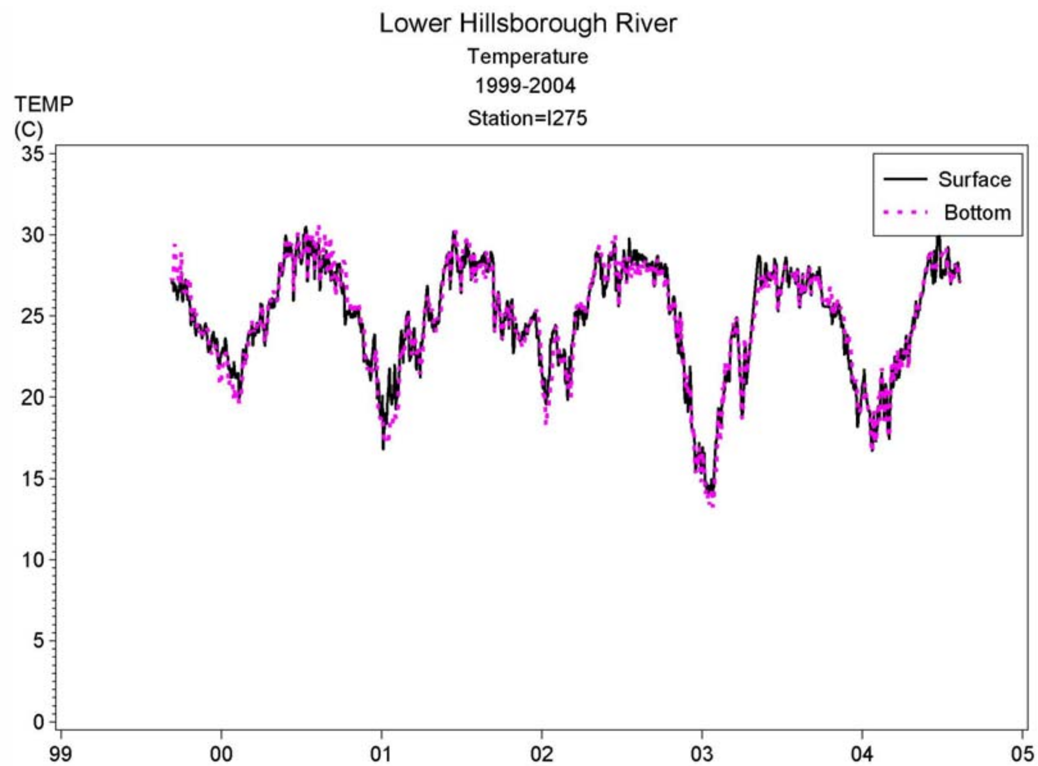


Figure 4-17 Observed USGS/District continuous recorder time series of surface and bottom temperature near I-275.

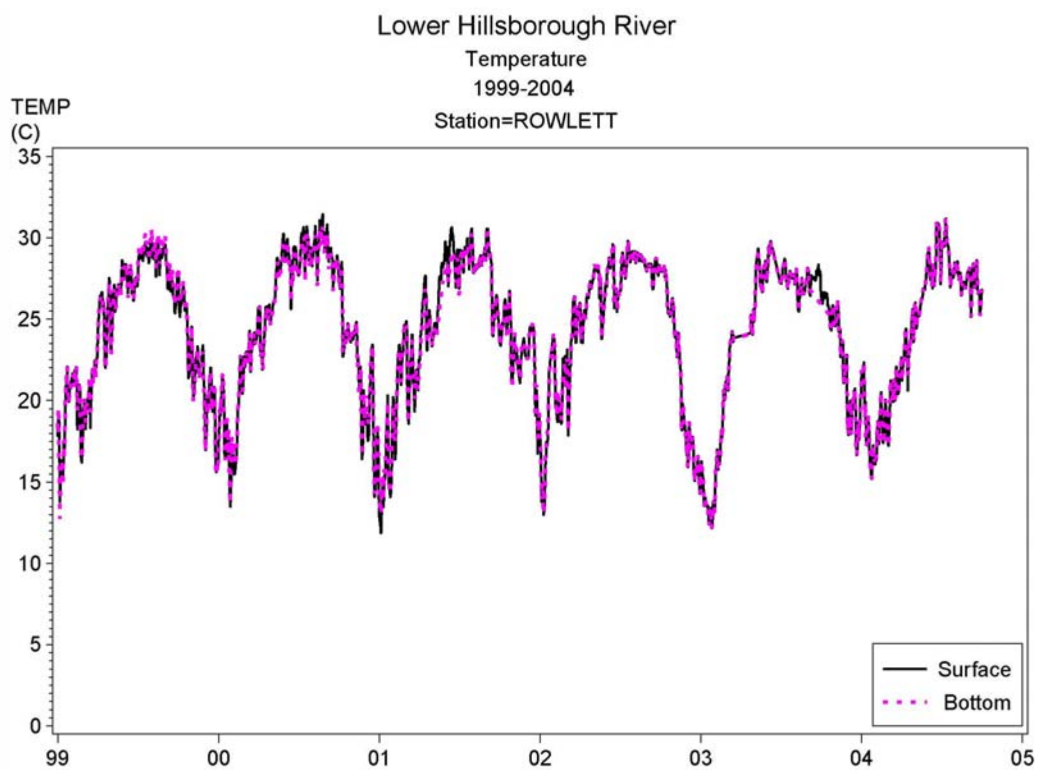


Figure 4-18 Observed USGS/District continuous recorder time series of surface and bottom temperature at Rowlett Park.

4.3 Spatial Variation in Salinity, Temperature, DO, and Other Water Quality Constituents

Spatial variation in physical and water quality constituents were observed both longitudinally and vertically. The following sections describe this spatial variation. Plots for spatial variation for all key constituents, and relevant data sources are provided in Appendix 4-3 (physical constituents) and Appendix 4-4 (water quality constituents). Lateral variation, although it does exist locally in the LHR, was expected to be much less than longitudinal and vertical variation.

4.3.1 Longitudinal Variation

Patterns in longitudinal variation were observed as expected from upstream near the Hillsborough River Dam to downstream near the river mouth. The Tampa Bay Water HBMP program provides a useful data set for reviewing longitudinal variation because it is comprised of a spatial probabilistic sampling design (Figure 3-1). The many locations sampled in the LHR for the HBMP data outweigh the limitation of the shorter period of record (2000-2004). Importantly, an additional fortuitous consideration is that the HBMP period of record from 2000 to 2004 encompassed a wide range of rainfall conditions from very dry (2000) years to very wet years (2003). Thus, a wide range of conditions occurred during this period of record.

As expected, salinity values were observed to be higher near the river mouth and lower near the Hillsborough River Dam. Figure 4-19 presents the longitudinal distribution of HBMP salinity observations over the geographic domain of the LHR. These salinities cover an important and full range of salinity habitats from very low salinities less than 5 ppt, to mid-range salinities, to typical Hillsborough Bay salinities.

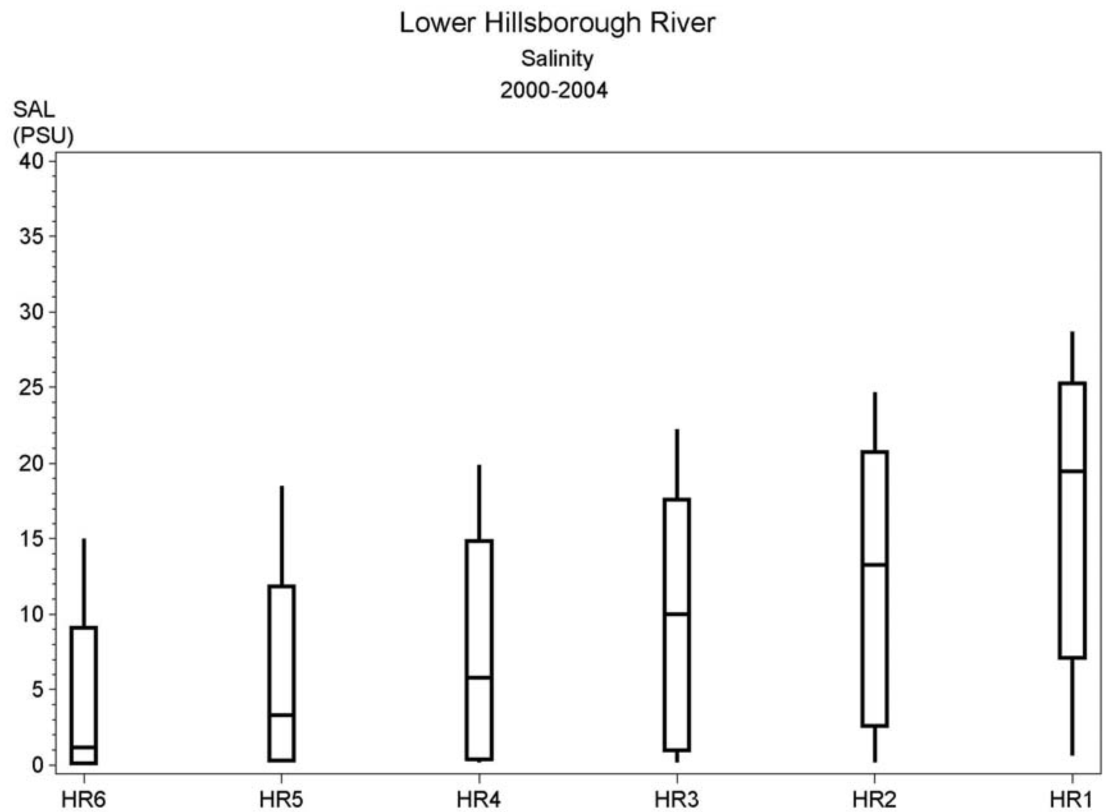


Figure 4-19 Observed longitudinal distributions of salinity for the Tampa Bay Water HBMP program period of record.

The distributions of temperature values were observed to be relatively similar from the river mouth to the Hillsborough River Dam. Figure 4-20 presents the longitudinal distribution of HBMP temperature observations over the geographic domain of the LHR.

Figure 4-21 presents the longitudinal distribution of HBMP DO observations over the geographic domain of the LHR. Localized variations in DO distributions were observed during particular times of the year.

The distributions of chlorophyll *a* concentrations were observed to reach a peak midway between the Hillsborough River Dam and the river mouth. Figure 4-22 presents the longitudinal distribution of HBMP chlorophyll *a* observations over the geographic domain of the LHR.

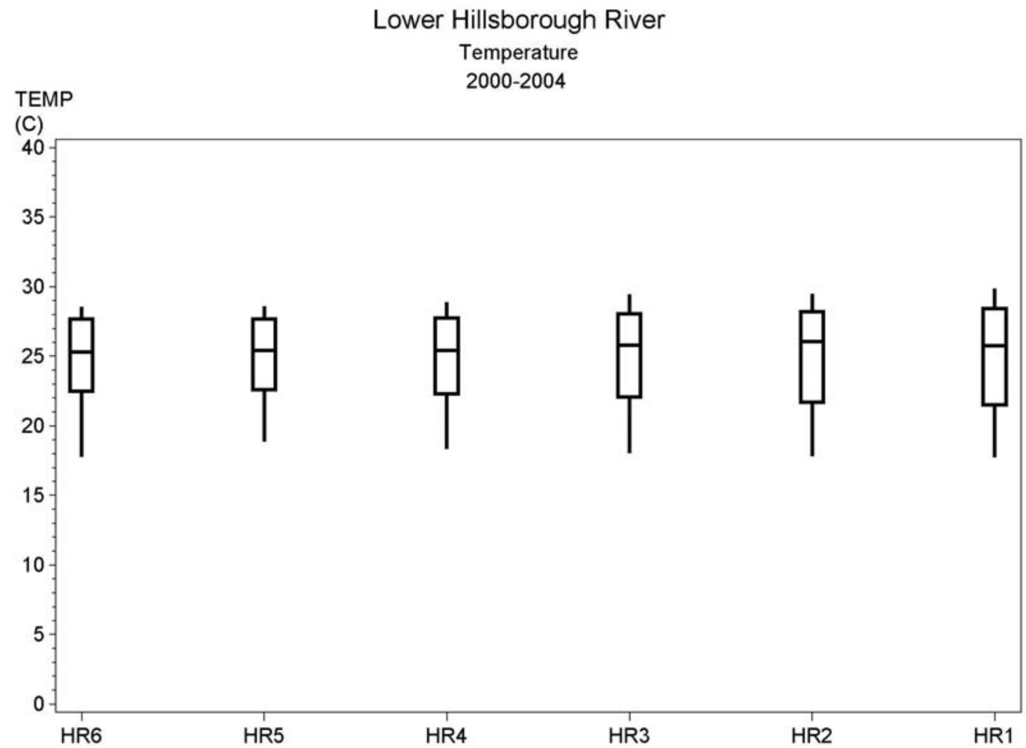


Figure 4-20 Observed longitudinal distributions of temperature for the Tampa Bay Water HBMP program period of record.

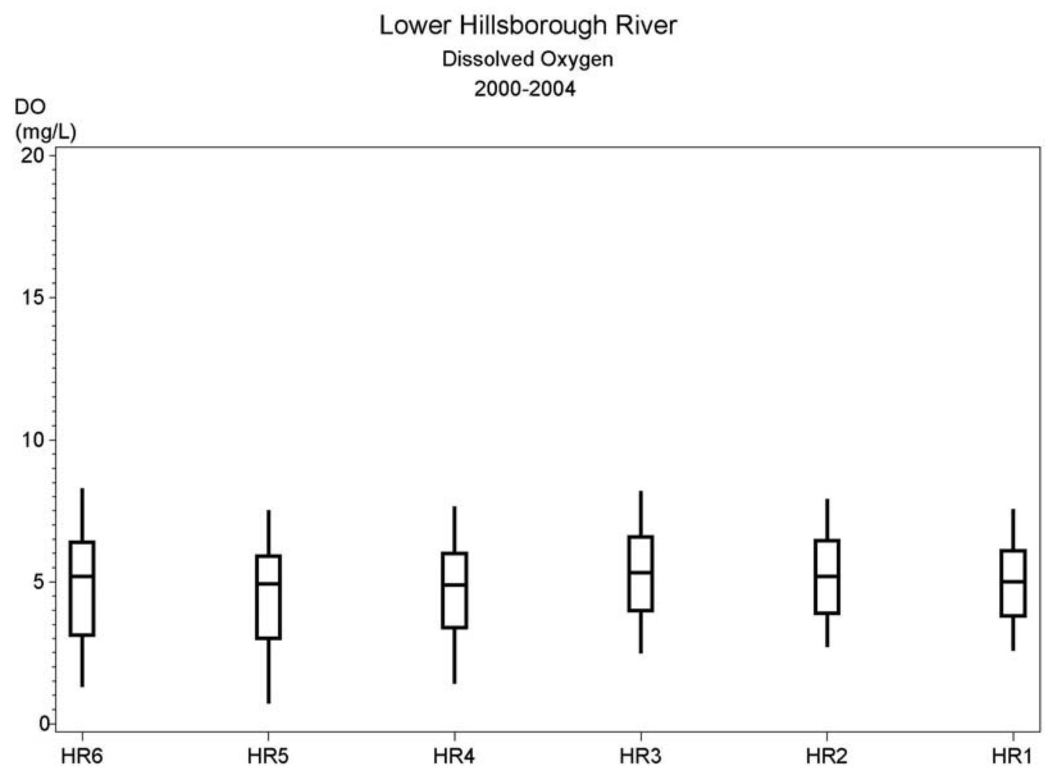


Figure 4-21 Observed longitudinal distributions of DO for the Tampa Bay Water HBMP program period of record.

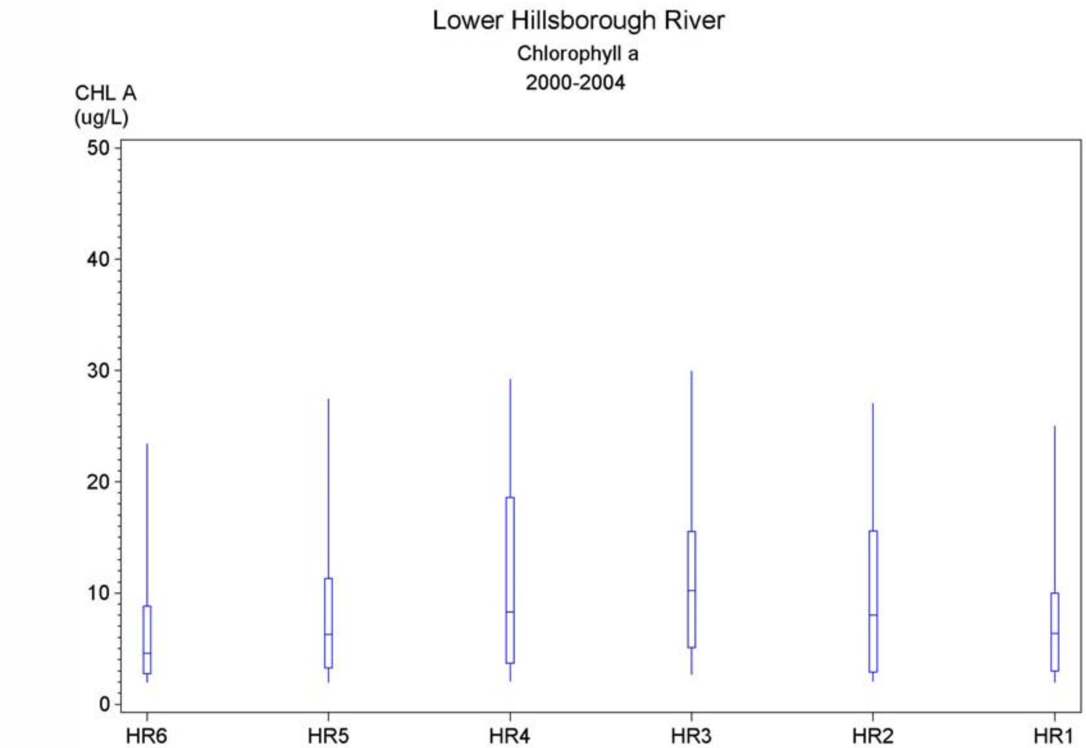


Figure 4-22 Observed longitudinal distributions of chlorophyll *a* for the Tampa Bay Water HBMP program period of record.

The distributions of total nitrogen concentrations were observed to reach a peak midway between the Hillsborough River Dam and the river mouth (Figure 4-23). The location of these peak nitrogen concentrations was similar to that observed for chlorophyll *a* concentrations indicating that much of the total nitrogen may be incorporated in algal biomass.

The distributions of total phosphorous concentrations were observed to reach a peak midway between the Hillsborough River Dam and the river mouth. The location of these peak phosphorous concentrations was similar to that observed for total nitrogen and chlorophyll *a* concentrations. Figure 4-24 presents the longitudinal distribution of HBMP total phosphorous observations over the geographic domain of the LHR.

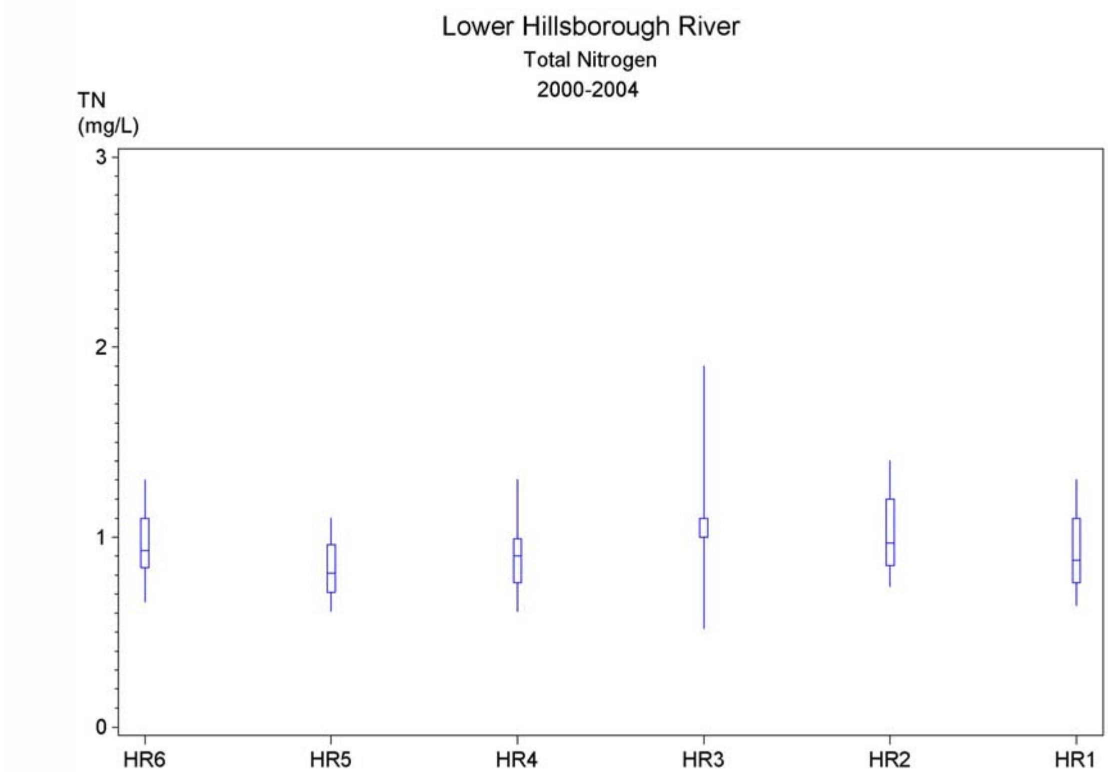


Figure 4-23 **Observed longitudinal distributions of total nitrogen for the Tampa Bay Water HBMP program period of record.**

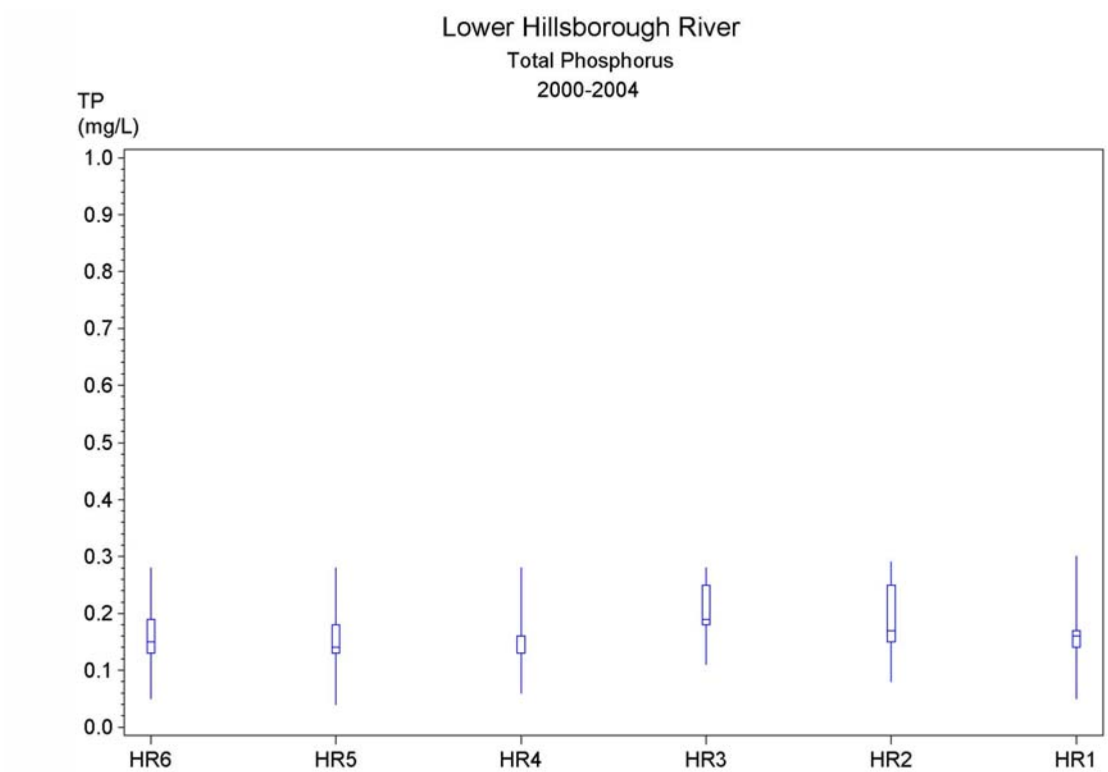


Figure 4-24 **Observed longitudinal distributions of total phosphorous for the Tampa Bay Water HBMP program period of record.**

4.3.2 Vertical Variation

The vertical variation in physical constituents is apparent graphically from the figures discussed above, and follows the general expectations for an estuarine system. These expectations are that more saline, cooler, and lower DO waters will be found on the bottom of the water column relative to the surface.

An overall pattern of less stratification upstream near the Hillsborough River Dam and more stratification near the river mouth was observed. The vertical variation in responses to freshwater inflow changes is discussed further in Chapter 6.

5.0 BIOLOGICAL CHARACTERISTICS OF THE TIDAL RIVER

This chapter provides a description of the key biological components of the LHR ecosystem. Importantly, summaries of recent studies and analyses of newly collected data from work funded by the District and other local agencies are included. A summary of shoreline plant communities was presented in Section 3.3.

5.1 Phytoplankton

SWFWMD (1999) summarized the results of the quarterly phytoplankton data collected by Water & Air Research, Inc. and SDI Environmental Services, Inc. (1993; 1994; 1995). The data presented in these reports suggested that community structure in the LHR was influenced by flows over the Hillsborough River Dam. In fact, Water & Air Research, Inc. and SDI Environmental Services, Inc. (1994) concluded that after periods of high discharge the riverine community downstream of the dam was quite similar to that above the dam. For example, prior to the release of water in January 1993, the dominant upstream taxa were the blue-green *Polycystis incerta* and the lentic green alga *Ankistrodesmus nannoselene* (Water & Air Research, Inc. and SDI Environmental Services, Inc. 1993). Further downstream, *Eutreptiella* sp., a brackish water red tide-forming euglenoid was dominant. Subsequent to these releases, the dominant phytoplankton taxa in the more saline reaches of the river shifted to *Cryptomonas erosa*, a lentic cryptophyte. At higher flows the blue-green algae *Aphanocapsa delicatissima* and the colonial *Merismopedia tenuissima* were abundant immediately downstream of the dam. The latter species was also a subdominant as far downstream as Hillsborough Avenue. Regardless of flow, blue-green algal species are dominant below the dam.

5.2 Benthos

Investigations of LHR benthos began with a study by Mote Marine Laboratory (1984) in 1982 and now include on-going monitoring by Hillsborough County Water Resource Team (1999 to present) and Tampa Bay Water's HBMP (2000 to present). In addition, the abundance and distribution of macroinvertebrates in the river reach from the Hillsborough Dam downstream to Sulphur Springs were surveyed on two dates in 2003 by the FFWCC for the District in support of the reevaluation of minimum flows for the Lower Hillsborough River.

In this Section we review the findings from various technical reports characterizing the benthic assemblages of the Lower Hillsborough River and examine recent data collected by Tampa Bay Water as part of their HBMP for the District (WUP2011796).

5.2.1 Lower Hillsborough River Benthos 1982-2003

River-wide surveys of benthic community structure and composition within the LHR have been conducted by:

- Mote Marine Laboratory (1984) (four stations; two seasons; 1982);
- Water & Air Research, Inc. and SDI Environmental Services, Inc. (1993; 1994; 1995) (five fixed stations; quarterly sampling; 1992-1993);
- Environmental Protection Commission of Hillsborough County for the Tampa Bay Estuary Program (1995-1997), the District (1998-2000), and the Hillsborough Independent Monitoring Program (1999 to present) (Grabe *et al*. 2002; Grabe *et al*. 2003a; Grabe *et al*. 2004) (5 to 20 random samples; wet season);
- Tampa Bay Water's HBMP (PBS&J 2001; 2002; 2003; 2004) (stratified random samples; January-March and July-September; 2000 to present). The results to date from the HBMP are summarized in Section 5.2.2.

More spatially restricted surveys have taken place at:

- Sulphur Springs run (2000-2003; SWFWMD, 2004b);
- Sulphur Springs to the Dam by FFWCC (February and November 2003; Appendix 5-1);
- The "upper" portion of the Lower Hillsborough River (SWFWMD unpublished data) (21 random samples June 2003).

5.2.1.1 Taxonomic Composition

Approximately 300 distinct macroinvertebrate taxa were identified from the LHR from 1982 through 2003:

- Mote Marine Laboratory (1984) identified at least 63 taxa during wet and dry season sampling at four stations in 1982;
- Grabe *et al*. (2003a) identified 240 taxa from 110 samples collected during the 1995-2002 wet seasons;
- Collections from Sulphur Springs run yielded >80 taxa (SWFWMD, 2004b);
- The FFWCC reported that at least 104 and 94 taxa, respectively, were identified from quantitative and qualitative samples collected between Sulphur Springs and the Hillsborough River Dam during February and November 2003, respectively. These collections took place after extended periods of release of water from the reservoir.

Numerically dominant and/or frequently occurring taxa reported from the LHR (Mote Marine Laboratory 1984; Water & Air Research, Inc. and SDI Environmental Services, Inc. 1993, 1994, 1995; Grabe *et al*. 2002; Grabe *et al*. 2003a) include (Table 5-1):

- Polychaetes, especially *Laeonereis culveri, Stenoninereis martini, Monticellina dorsobranchialis, Hobsonia florida, Neanthes succinea,* and *Streblospio gynobranchiata*
- Oligochaetes, especially immature Tubificidae
- The bivalves *Mytilopsis leucophaeta and Corbicula fluminea*
- *Cyathura polita* (Isopoda)
- The amphipods *Grandidierella bonnieroides* and *Ampelisca abdita*
- *Rhithropanopeus harrissii* (Decapoda, Panopeidae)
- Larval dipterans, primarily *Chironomus* sp. and those in the *Polypedilum halterale and Polypedilum scalaenum* species groups*.*

Table 5-1. Ranked numerical dominants (number m^{-2}) in the Lower Hillsborough River (1995-2002 wet seasons) (Adapted from: Grabe *et al.* 2003a).

Taxa	**number m^{-2}**
Monticellina dorsobranchialis	890
Stenoninereis martini	560
Laeonereis culveri	481
Tubificidae- genera undetermined	358
Mytilopsis leucophaeata	276
Tubificoides brownae	275
Grandidierella bonnieroides	251
Ampelisca holmesi	141
Ampelisca abdita	133
Melinna maculata	105
Aricidea taylori	75
Capitella capitata complex	65
Corbicula fluminea	54
Melita elongata elongata	48
Tagelus plebeius	42
Edotia montosa	39
Tubificoides motei	38
Cyclaspis cf. varians	37
Carazziella hobsonae	36
Streblospio gynobranchiata	35
Crassostrea virginica	26
Littoridinops palustris	26
Pyrgophorus platyrachis	26
Paraprionospio pinnata	25

Numerical dominants in samples collected from Sulphur Springs (SWFWMD, 2004b) during 2000-2003 included:

- The exotic bivalve *Tarebia granifera*
- Tubificid oligochaetes
- The gastropod *Pyrgophorus platyrachis*
- The amphipod *Grandidierella bonnieroides*
- The isopods *Uromunna reynoldsi* and *Cassidinidea ovalis*

The FFWCC (Appendix 5-1) reported numerical dominants by substrate type from the most upstream portion of the Lower Hillsborough River:

- Cobble: The chironomid *Dicrotendipes neomodestus* and the naid oligochaetes *Nais communis* group and *Nais variabilis*
- Mud/sand: The chironomid *Polypedilum halterale*
- Organic matter: Hydracarina (mites) and the chironomid *Polypedilum halterale*
- Sand: The bivalve *Corbicula fluminea*, the naid oligochaete *Nais variabilis*, the chironomid *Polypedilum halterale*, and tubificid oligochaetes
- Sand/Shell: Hydracarina and chironomid larvae in the *Polypedilum halterale* and *Polypedilum scalaneum* groups

5.2.1.2 Seasonality

Dry season (winter-spring) samples collected by Mote Marine Laboratory (1984) generally contained a greater number of both taxa and individual macroinvertebrates than wet season (summer) samples.

5.2.1.3 Spatial Distribution

Mote Marine Laboratory (1984) did not describe any clear upstream-downstream trend for total benthic abundance. They did report higher numbers of taxa at their most downstream site during the dry season sampling. The spatial distribution differed during the wet season, with species richness highest upstream.

Water & Air Research, Inc. and SDI Environmental Services, Inc. (1993; 1994; 1995) reported that the lowest abundance, species richness and species diversity values typically occurred at their most upstream station, near the dam. Mid-channel organism densities were generally less than in the more littoral areas. This was attributed to depressed dissolved oxygen concentrations in the deeper waters.

Grabe *et al*. (2003a) showed that, during the wet season, salinity had little apparent effect on the numbers of taxa when salinities ranged from 0 to 25 ppt (Figure 5-1). Thereafter, species richness increased with increasing salinity.

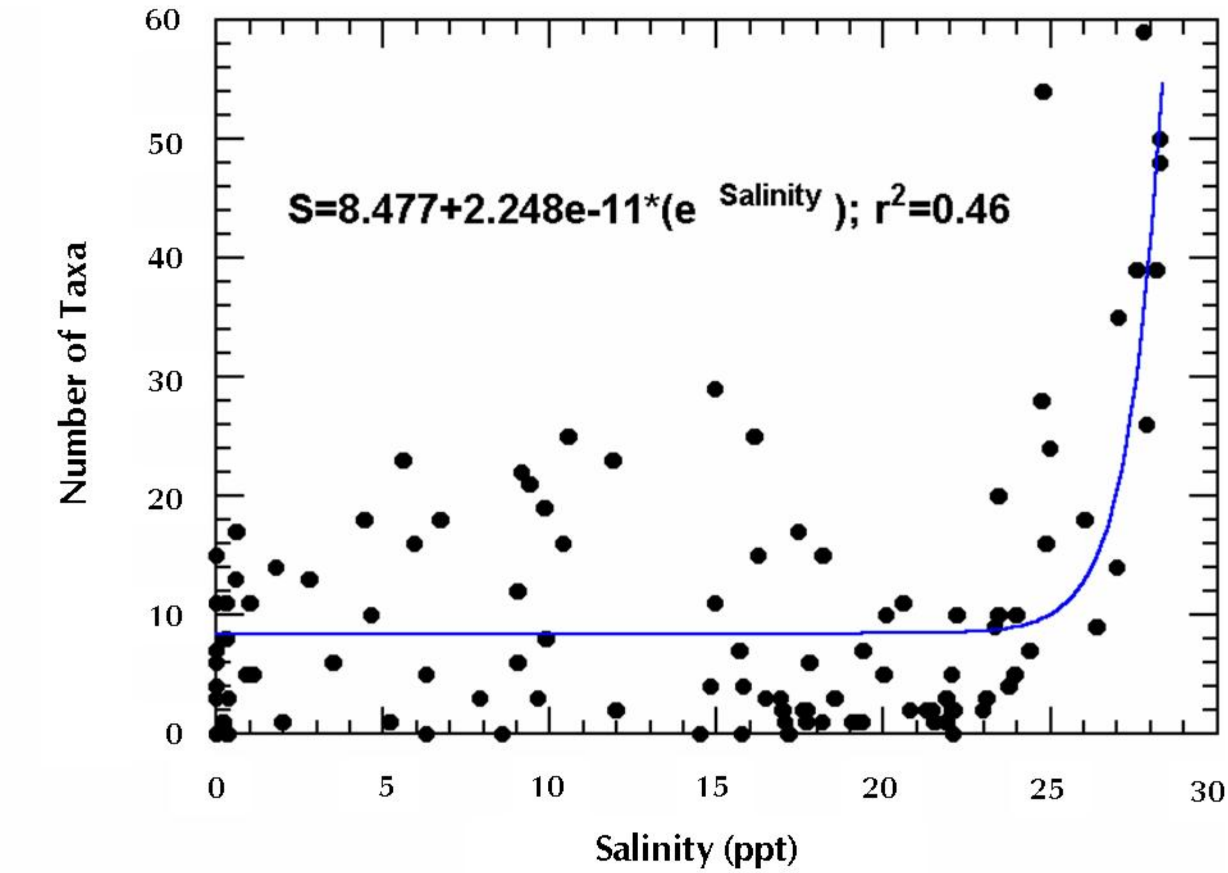


Figure 5-1. **Relationship between numbers of taxa and salinity, 1995-2002 wet seasons, Lower Hillsborough River (adapted from Grabe *et al*. 2003a).**

5.2.1.4 Salinity and Spatial Distributions

Studies by Water & Air Research, Inc. and SDI Environmental Services, Inc. (1993; 1994; 1995) in the early 1990s suggested that, as flows over the Hillsborough River Dam increased (and dissolved oxygen concentrations were relatively high), estuarine fauna near the dam were replaced by more limnetic species such as *Limnodrilus hoffmeisteri* and *Chironomus decorus* group chironomid larvae. Once discharges were terminated a more estuarine fauna again replaced the limnetic community. However, Water & Air Research, Inc. and SDI Environmental Services, Inc. (1994) did not find any statistically significant relationship between total density and salinity.

As salinities exceeded 25 ppt there was an increase in numbers of taxa (Figure 5-1). Taxa richness was significantly (p<0.001; forward stepwise multiple regression) positively associated with temperature, salinity, dissolved oxygen, cumulative flows over 14 and 112 days and negatively associated with density stratification of the water column and cumulative flows over 28 and 56 days; these explained >50% of the total variance (Grabe *et al.* 2003a).Total abundance ranged to approximately 50,000 individuals m^{-2} in the EPCHC's (Grabe *et al*. 2003a) wet season collections; the frequency distribution of abundances within oligohaline waters differed (generally higher) from the other salinity zones. Total abundance was positively associated (*p*<0.001; forward stepwise multiple regression) with salinity, dissolved oxygen, cumulative flows over 7 days and negatively associated with density stratification of the water column and cumulative flows over 56 days; explaining 35% of the variance in benthic abundance.

EPCHC's studies (Grabe *et al*. 2003a) also showed that, using non-metric multidimensional scaling (Clarke and Warwick 2001), there was overlap in benthic community structure across three of the four Venice salinity zones in the Lower Hillsborough River (Figure 5-2) during the wet season. The different assemblages, however, ranged only from 16.0% (oligohaline *vs*. polyhaline) to 20.2% similar (tidal-freshwater *vs*. mesohaline).

The distributions of two nereidid polychaetes, *Laeonereis culveri* and *Stenoninereis martini**, accounted for much of this overlap. *Stenoninereis martini* was dominant in each of the four salinity zones; *Laeonereis culveri* was dominant in the oligohaline and tidal freshwater zones. Additionally, the amphipod *Ampelisca abdita* was dominant in both oligohaline and mesohaline salinities.

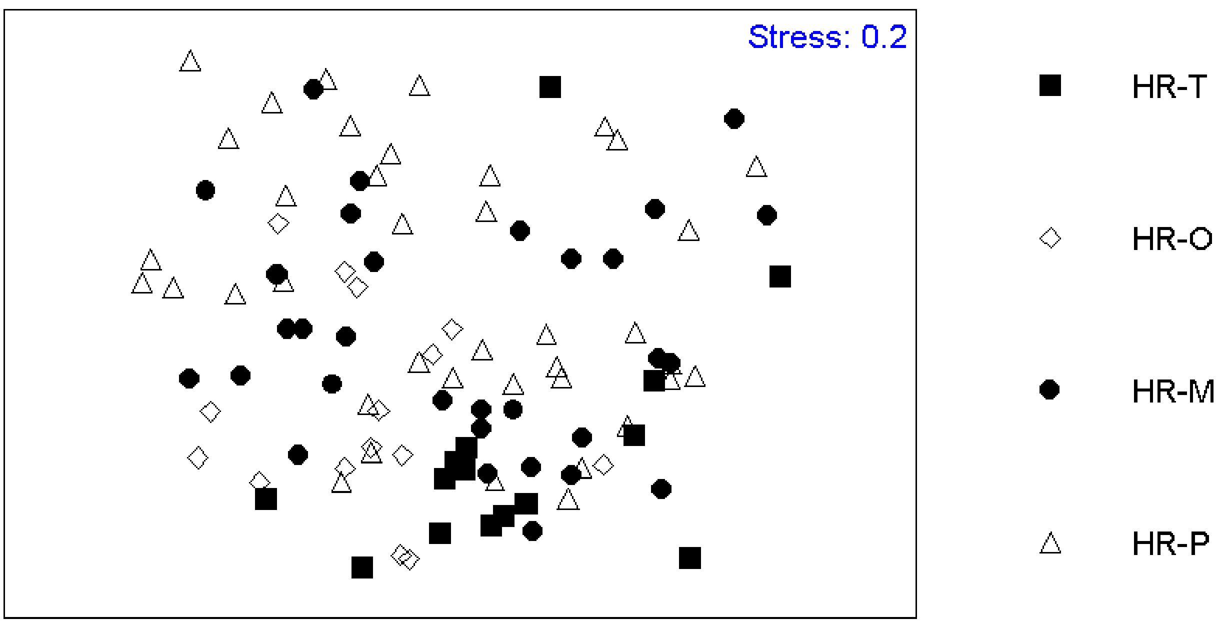


Figure 5-2. Non-metric multidimensional scaling plot of benthic samples collected by EPCHC during the wet season from the Lower Hillsborough River, 1995-2002, demarcated by Venice salinity zone (adapted from Grabe *et al*. 2003). T=tidal freshwater (<0.5 ppt); O=oligohaline (0.5-5.0 ppt); M=mesohaline (5-18 ppt); P=polyhaline (18-30 ppt).

* *likely Nereididae A in the Water & Air Research, Inc. and SDI Environmental Services, Inc. reports (1993; 1994; 1995)*

The tidal freshwater and oligohaline assemblages differed primarily in the distributions of *Laeonereis culveri* and *Stenoninereis martini,* and the bivalve *Mytilopsis leucophaeata*. Both *Laeonereis culveri* and *Mytilopsis leucophaeata* were more abundant in the oligohaline zone whereas *Stenoninereis martini* was more abundant in the tidal freshwater zone. Oligohaline and mesohaline assemblages also differed in the distribution of the two nereidids (both more abundant in oligohaline habitats). The mesohaline and polyhaline assemblages differed in the densities of *Stenoninereis martini* (a numerical dominant in mesohaline habitats), the polychaete *Melinna maculata*, and tubificid oligochaetes (each numerical dominants in the polyhaline zone).

Laeonereis culveri inhabits intertidal brackish habitats and sandy shoals; it is apparently tolerant of wide-ranging salinities including freshwater (Mazurkiewicz 1970; Pettibone 1971; Janicki Environmental, Inc. 2005b). *Stenoninereis martini* has also been collected from waters of wide-ranging salinities as well as sediments of high organic content (Williams 1976; de Leon-Gonzalez and Solis-Weiss 1997; Janicki Environmental, Inc. 2005b). *Mytilopsis leucophaeta* is typically found in low salinity waters (Abbott 1954; Janicki Environmental, Inc. 2005b) and Harrel *et al.* (1976) considered it to be a pollution sensitive species.

Grabe *et al*. (2003), analyzing data from Hillsborough County's HIMP, found that the association between the biotic community structure and abiotic variables (excluding sediment contaminants) for the Lower Hillsborough River was significant at 0.2% (Rho=0.12). The highest Spearman rank correlation coefficients were 0.20 (depth, salinity), 0.18 (cumulative 28 day flow, depth, salinity), and 0.18 (7 day cumulative flow, depth, salinity).

Grabe *et al*. (2004) identified at least four multispecies assemblages in numerical classification analysis (presence-absence of the 50 most frequently occurring taxa in 110 samples) during the wet season (Figure 5-3). Logistic regression was then applied to identify the "tolerance range" of several abiotic variables, including salinity, for each of these four groups (Figure 5-4, Table 5-2).

Species Groups 1 and 4 were composed of polyhaline species that were most often found only in the lower river. Sediment preferences served to distinguish their preferred habitats (Table 5-2). Species in these groups were also tolerant of hypoxia (Table 5-2). Species Group 2 preferred low mesohaline salinities (5 to 12 ppt) and fine-grained sediments. These species were also tolerant of subnominal dissolved oxygen (Table 5-2). Group 2 taxa were most often found together in the lower half of the river. Species Group 3 preferred even lower salinities, oligohaline to low mesohaline, and coarser sediments. These taxa were less tolerant of hypoxia (Table 5-2). The species in this group were generally restricted to the upper two-thirds of the LHR.

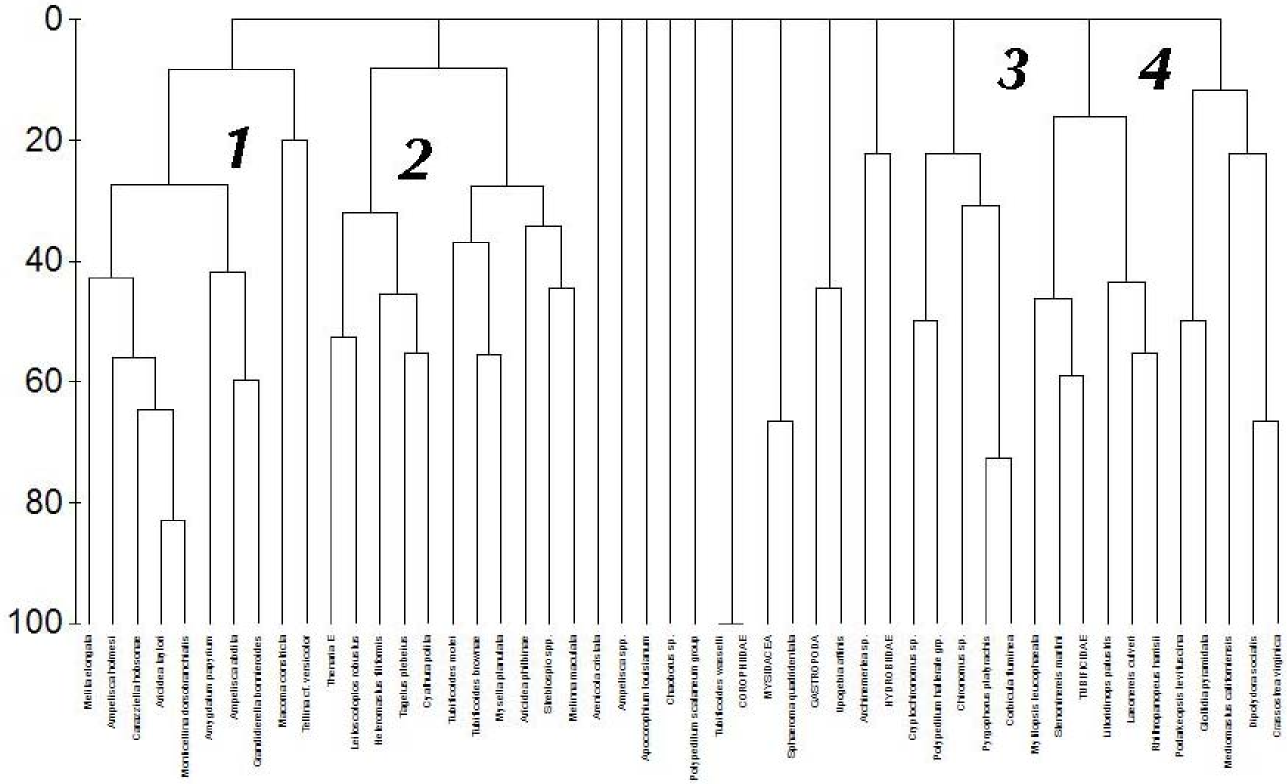


Figure 5-3. Dendogram depicting the resemblance of taxonomic groups in the Lower Hillsborough River, 1995-2002: Presence–absence of 50 most frequently occurring taxa; complete linkage clustering. (From Grabe *et al*. 2004).

Within the Sulphur Springs system, the macroinvertebrate assemblages varied by habitat (*e.g.*, sand *vs.* filamentous algae)—as well as by salinity regime. The salinity of the spring run was altered by the diversion of spring discharge to the Hillsborough River Dam (SWFWMD 2004b). Under low or no flow conditions, species tolerant of brackish water such as the bivalve *Tarebia granifera*, the polychaetes *Neanthes succinea* and *Stenoninereis martini*, and larvae of insects tolerant of low salinities, such as some chironomid larvae, were established. When spring discharges resumed, *Tarebia* abundance declined, diversity increased and freshwater fauna became more abundant.

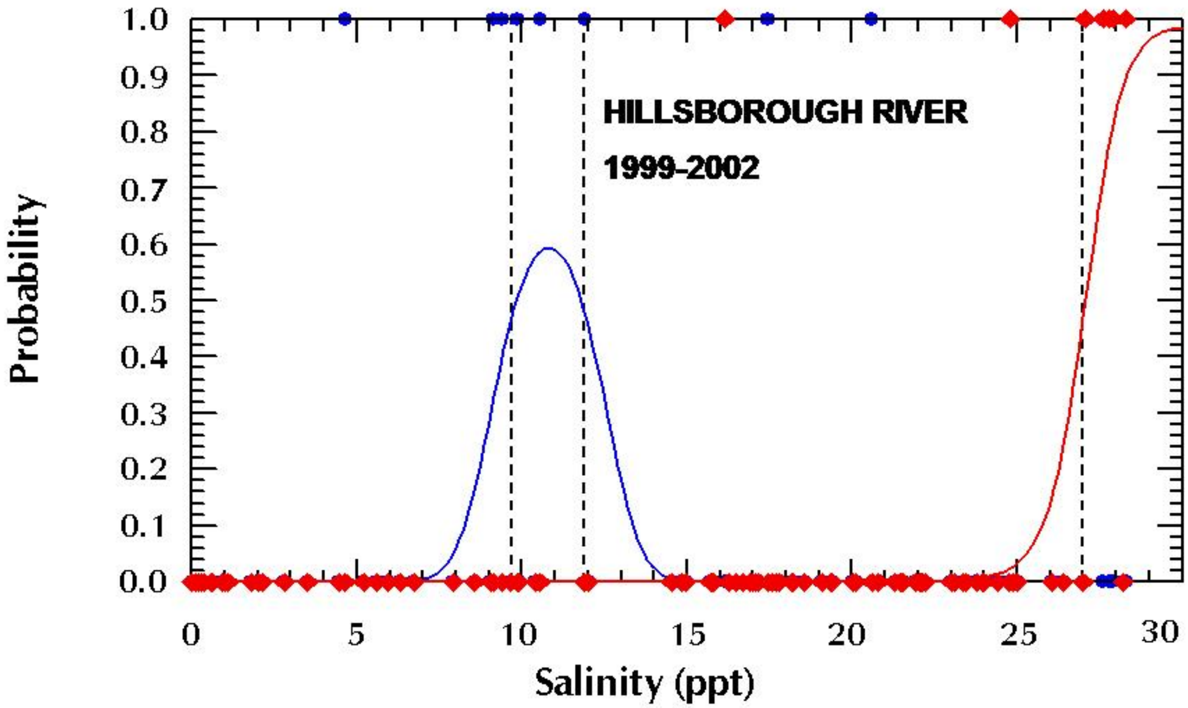


Figure 5-4. **Probability of occurrence vs. wet season salinity (binary logistic regression) of species assemblages identified in numerical classification analysis (From: Grabe *et al*. 2004).**

- <u>LOW-MESOHALINE SALINITY GROUP:</u> *Melinna maculata, Stenoninereis martini, Heteromasus filiformis, Laeonereis culveri, Streblospio gynobranchiata, Leitoscoloplos robustus, Capitella capitata complex (Polychaeta), Tubificidae, Archinemertea sp., Thenaria sp. E, Tagelus plebius (Bivalvia), Cyatura polita & Edotea montosa (Isopoda)*
- <u>POLYHALINE SALINITY GROUP</u>: *Carazziella hobsonae, Paraprionospio pinnata, Aricidea taylori, Monticellina dorsobranchialis (Polychaeta); Mysella planulata, Amygdalum papyrium (Bivalvia); Cyclaspis varians (Cumacea); Melita elongata, Ampelisca abdita, Ampelisca holmesi, Grandidierella bonnieroides (Amphipoda)*

Table 5-2. **Habitat "preferences" for selected faunal assemblages in the Lower Hillsborough River, 1995-2002 wet seasons: "optimum" (tolerance range) (adapted from Grabe *et al*. 2004)**

	Species Group			
	1	**2**	**3**	**4**
Salinity (ppt)	>30 (>30)	11.4 (10.5-12.3)	8.2 (4.1-12.3)	>30 (>30)
Silt + clay (%)	14.8 (4.8-24.8)	38.9 (38.5-39.3)	0 (Not calculated)	25.7 (24.2-27.2)
Depth (m)	3.2 (1.6-4.8)	0.0 (0.0-1.2)	0.5 (0.0-1.6)	4.0 (3.9-4.1)
Dissolved oxygen (mg/l)	1.4 (0.9-1.9)	2.1 (1.0-3.0)	3.8 (1.9-5.6)	1.2 (0.5-1.9)

5.2.1.5 Hypoxia and Benthos

The EPCHC has shown that approximately 60% of the dissolved oxygen measurements taken in conjunction with late summer benthic samples were hypoxic (DO < 2 mg/l) (Grabe *et al.* 2003a). These surveys have shown that low dissolved oxygen concentrations were typically found in the middle and lower reaches of the river. River-wide, there did not appear to be any relationship between the Tampa Bay Benthic Index (whose scores are primarily driven by Shannon-Wiener diversity) and dissolved oxygen concentrations over the period 1995-2000 (Grabe *et al*. 2002).

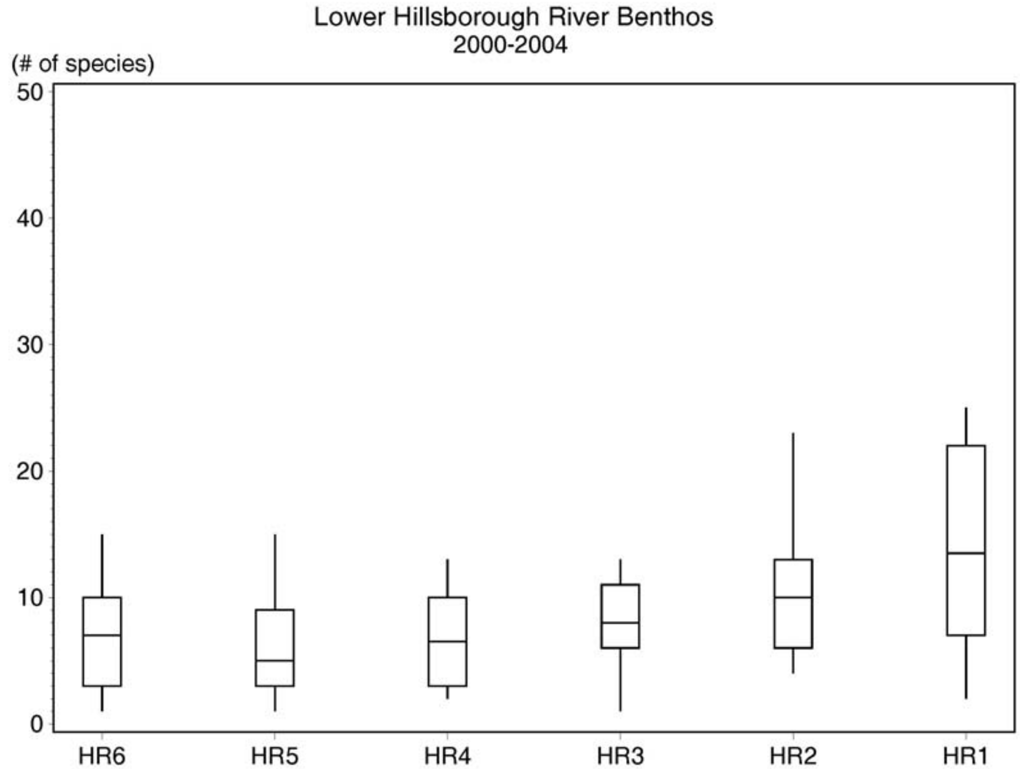
Water & Air Research, Inc. and SDI Environmental Services, Inc. (1994) did not find any statistically significant relationship between total density of benthos and near-bottom dissolved oxygen. However, in the last year of the study, they found that macroinvertebrate abundance was greater at several shallow littoral stations compared to the adjacent, deeper, mid-channel sites. They also reported a trend of lowered numbers of taxa, diversity, and abundance immediately downstream of the dam during no flow periods when dissolved oxygen concentrations were depressed. These studies suggest that, with no discharge from the reservoir, hypoxia contributes to the impoverished benthos immediately downstream of the dam rather than any salinity-induced shifts.

5.2.2 Analysis of Recent (2000-2004) Tampa Bay Water HBMP Data

The HBMP data (PBS&J 2004) generally confirm Mote Marine Laboratory's (1984) observation that dry season samples typically contain a greater number of both taxa and individual macroinvertebrates than do wet season samples. PBS&J (2004) described a general decline in numbers of taxa upstream to Stratum HR3 (RKM 7.64), above which taxa richness is more constant (Figure 5-5). Neither the Mote Marine Laboratory (1984) nor the PBS&J (2002; 2003; 2004) data revealed any clear upstream-downstream trend for total benthic abundance (Figure 5-5).

Interannual trends in both numbers of taxa and overall density of macroinvertebrates were examined for the two most upstream strata. Within Stratum HR5, there was a general increase in median numbers of taxa from 2000 through 2003, followed by a slight decline in 2004 (Figure 5-6). The median number of taxa per sample was < 10 during all years except 2003. There was more interannual variation within Stratum HR6, but again, median numbers of taxa were always < 10. Median macroinvertebrate densities were generally < 200 m^{-2} in both Strata 5 and 6. Numbers were somewhat higher during 2004 (Figure 5-7).

The assemblages of the two most upstream strata (5 and 6) were only 11% similar (ANOSIM R statistic=0.05; p=0.04). Taxa preferring freshwater, though tolerant of low salinity, were the major contributors to the fauna in Stratum 6. Taxa that are more typical of estuaries predominate in Stratum 5 (Table 5-3). The longitudinal distributions of some of these taxa are shown in Figure 5-8.



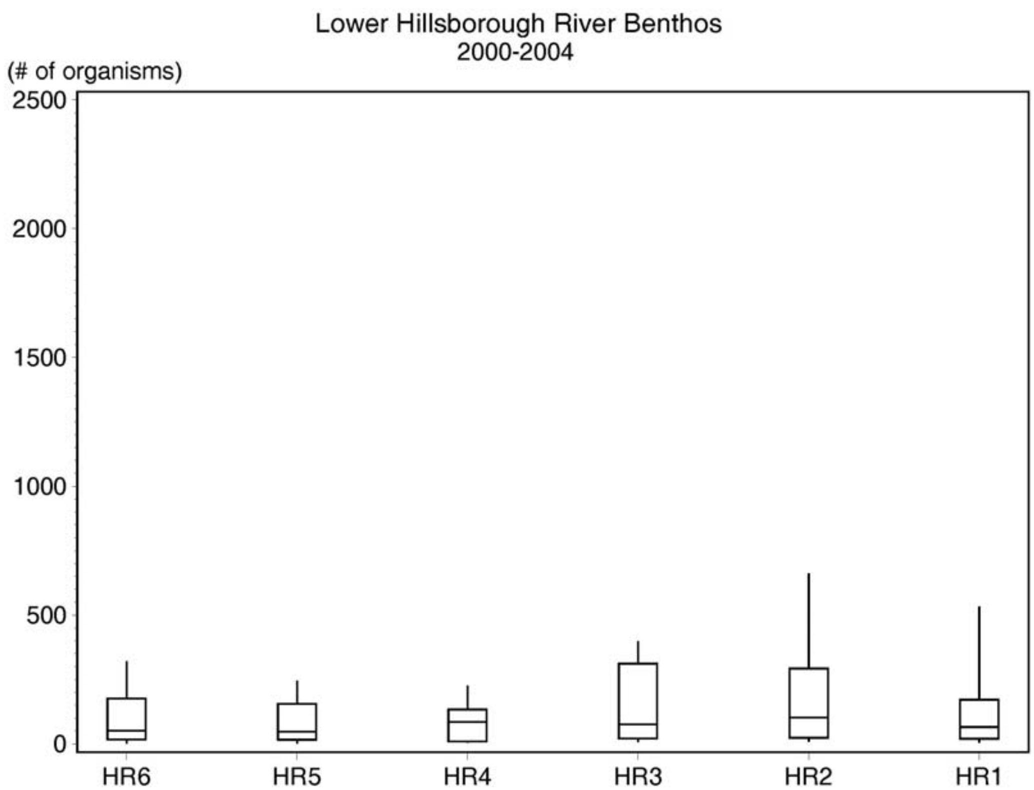


Figure 5-5. **Lower Hillsborough River benthos species richness and total abundance by stratum, Tampa Bay Water HBMP data 2000-20004.**

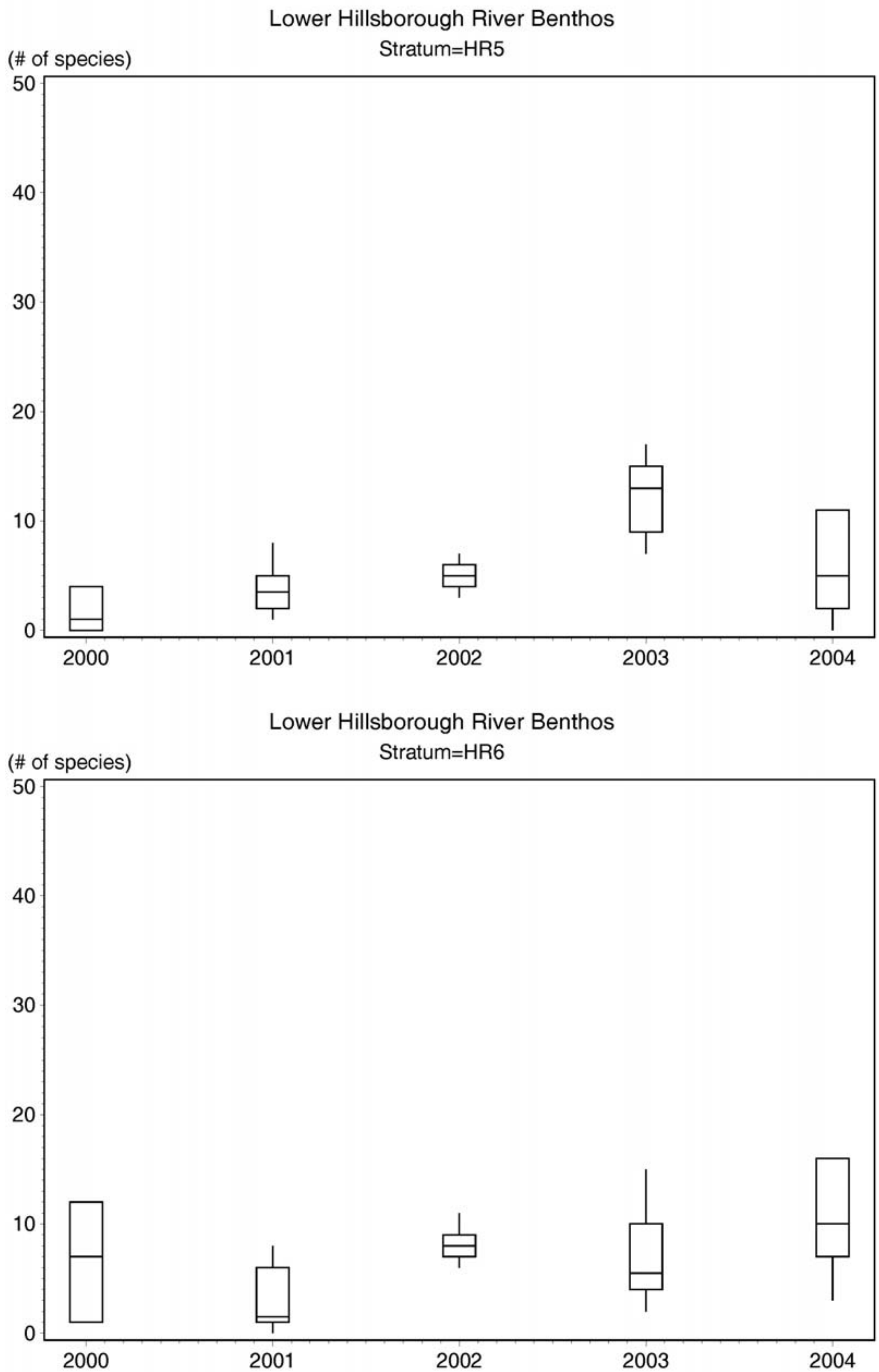
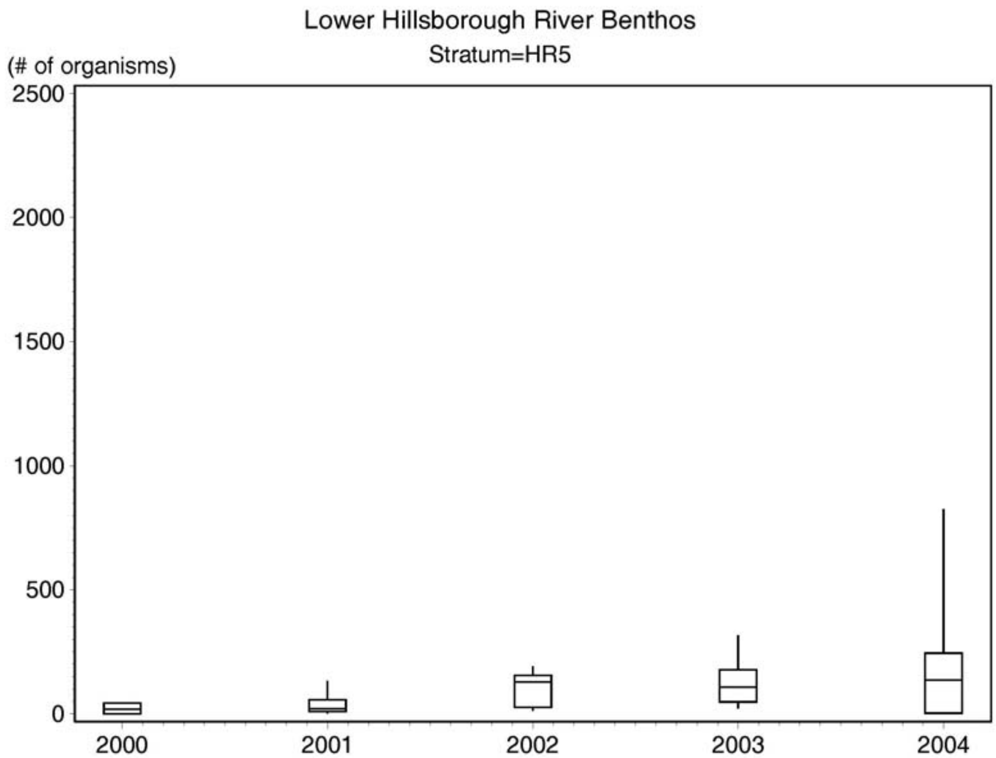


Figure 5-6. Numbers of taxa in Lower Hillsborough River HBMP strata 5 and 6, by year, 2000-



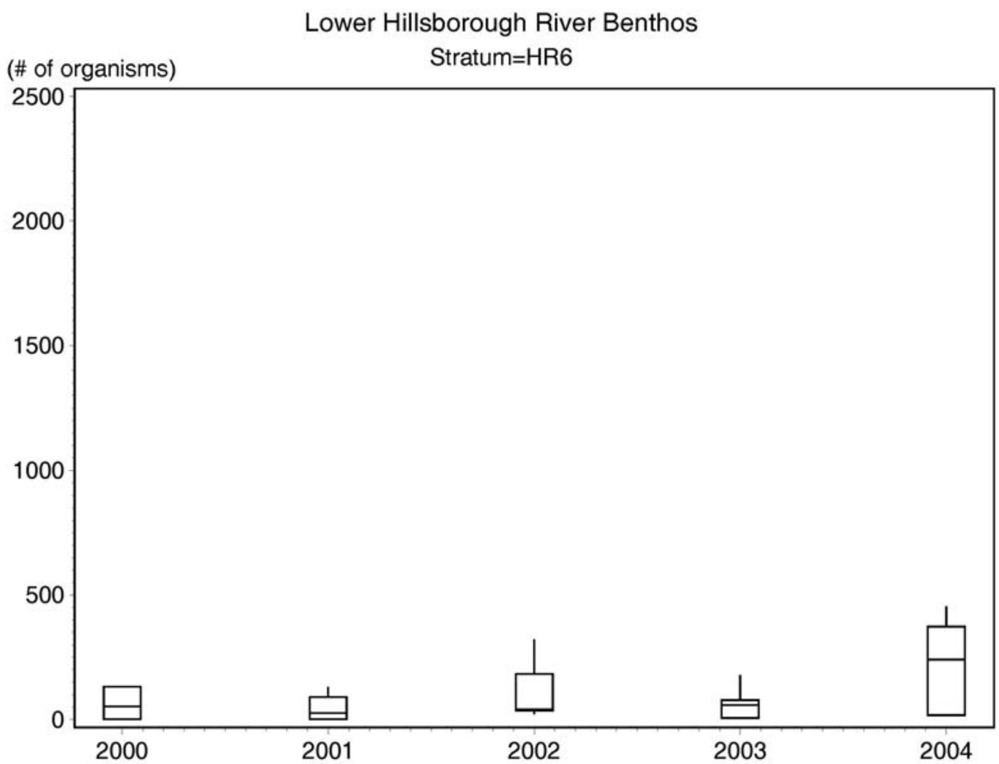


Figure 5-7. Total numbers of benthic macroinvertebrates m^{-2} in Lower Hillsborough River HBMP strata 5 and 6, by year, 2000-2004.

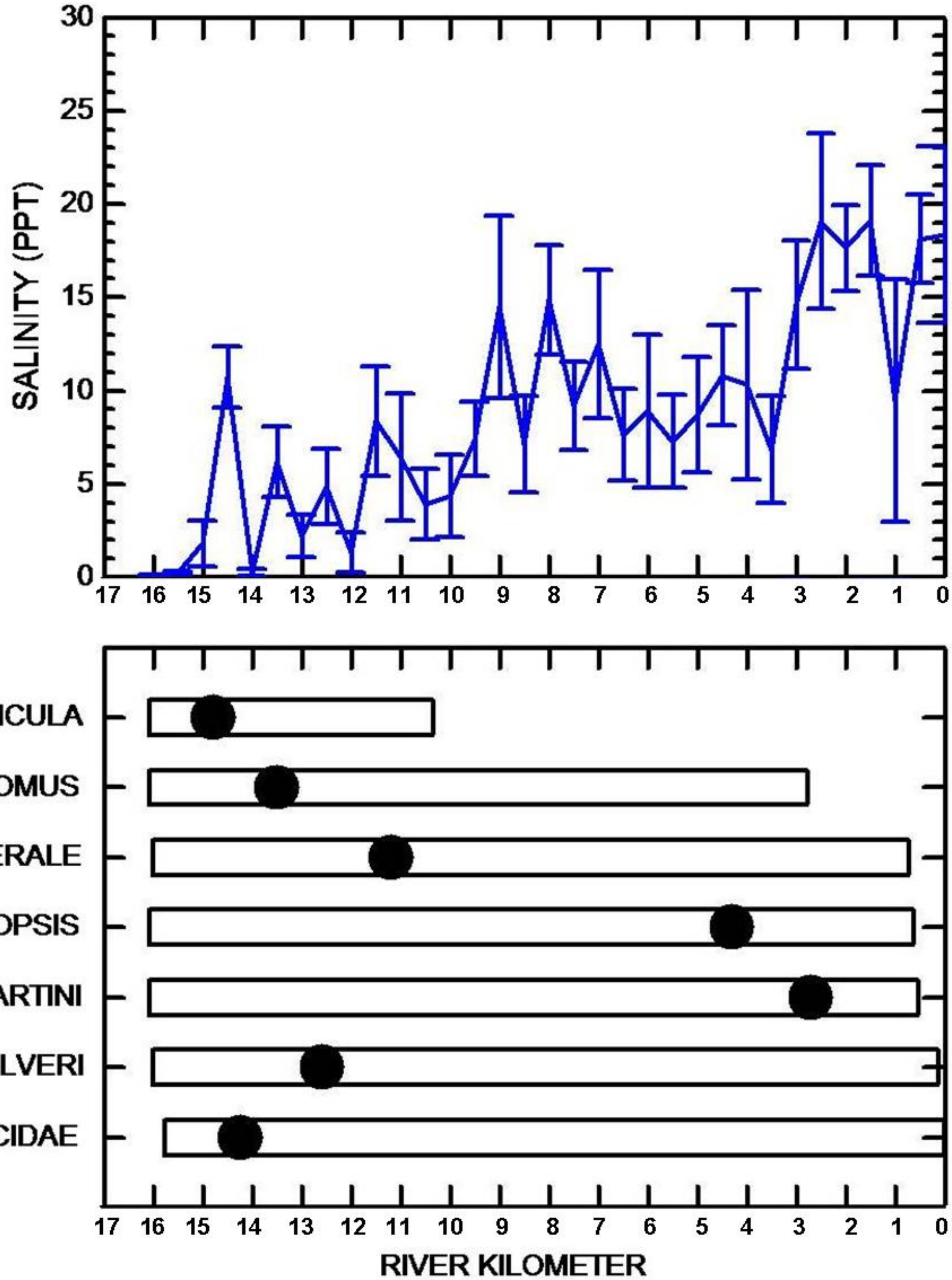


Figure 5-8. **Mean (standard error) of salinity by river kilometer in the Lower Hillsborough River, 2000-2004 (top). Spatial distribution within the Lower Hillsborough River of taxa characteristic of HBMP strata 5 and 6 (bottom). Solid circles indicate the locations of maximum abundance for each taxon. Taxon key: CORBICULA= *Corbicula fluminea*; CHIRONOMUS=*Chironomus* sp.; P. HALTERALE=*Polypedilum halterale*; MYTILOPSIS=*Mytilopsis leucophaeata*; S. MARTINI= *Stenoninereis martini*; L. CULVERI= *Laeonereis culveri*; TUBIFICIDAE= Tubificidae.**

Table 5-3. SIMPER analysis (n+0.1 4th root transformed numbers m^{-2}) of Lower Hillsborough River benthos (Tampa Bay Water HBMP): Taxa contributing to the dissimilarity of the benthos within HBMP strata 5 and 6 (2000-2004).

Taxon	Stratum 5	Stratum 6	% Contribution to the dissimilarity between strata
Laeonereis culveri	2.18	1.33	11.30
Stenoinereis martini	1.44	0.73	9.96
Tubificidae	0.92	1.76	9.67
Chironomus sp.	1.17	1.36	8.14
Polypedilum halterale group	0.96	1.06	5.15
Corbicula fluminea	0.14	0.95	4.89
Mytilopsis leucophaeata	0.51	0.78	4.71

5.2.3 Community Structure Analysis

To assess the relationship between benthic community structure and salinity in the LHR, Principal Components Analysis (PCA) was used to identify generalized salinity classes based upon the ranges over which the benthic taxa occurred. Bulger *et al*. (1993) used this approach in developing taxa specific salinity classes for mid-Atlantic estuarine nekton. The analysis described below is a critical element in the identification of various habitat types as defined by their salinity and resultant benthic community structure.

The approach initially involves establishment of a data matrix of salinities (in 1 ppt increments) and taxa presence. The matrix is completed by noting the ranges of salinity where each of the taxa are present (1) and absent (0). PCA was then used to identify Principal Components Axes that express commonalities with respect to the occurrence among taxa across the range of salinities encountered in the LHR. Factor loadings from Varimax rotation of the PCA axes were plotted against the original salinity increments and scores greater than 0.60 were used as a criterion for identifying the significantly correlated salinity zones.

Four salinity zones were identified (Figure 5-9):

- Zone 1 = 0 - 5 ppt,
- Zone 2 = 6 - 16 ppt,
- Zone 3 = 17 - 28 ppt, and
- Zone 4 = 29 - 31 ppt.

The benthic community in Zone 1 and Zone 2 were 91% similar. Benthic assemblages were similar when compared between sequential salinity zones.

Benthic assemblages were different between non-sequential salinity zones (Table 5-4). Analysis was done using the computer software package PRIMER – Plymouth Routines in Multivariate Ecological Research (Clarke and Warwick 2001). The benthos of Zone 1 differed from that of the Zone 3 mainly due to higher densities of *Laeonereis culveri* and lower densities of both *Grandidierella bonnieroides* and *Stenoninereis martini* in Zone 1. Benthic assemblages in Zone 2 differed from that of the Zone 4 primarily due to lower densities of *Monticellina dorsobranchialis* and higher densities of *Laeonereis culveri* and *Grandidierella bonnieroides.*

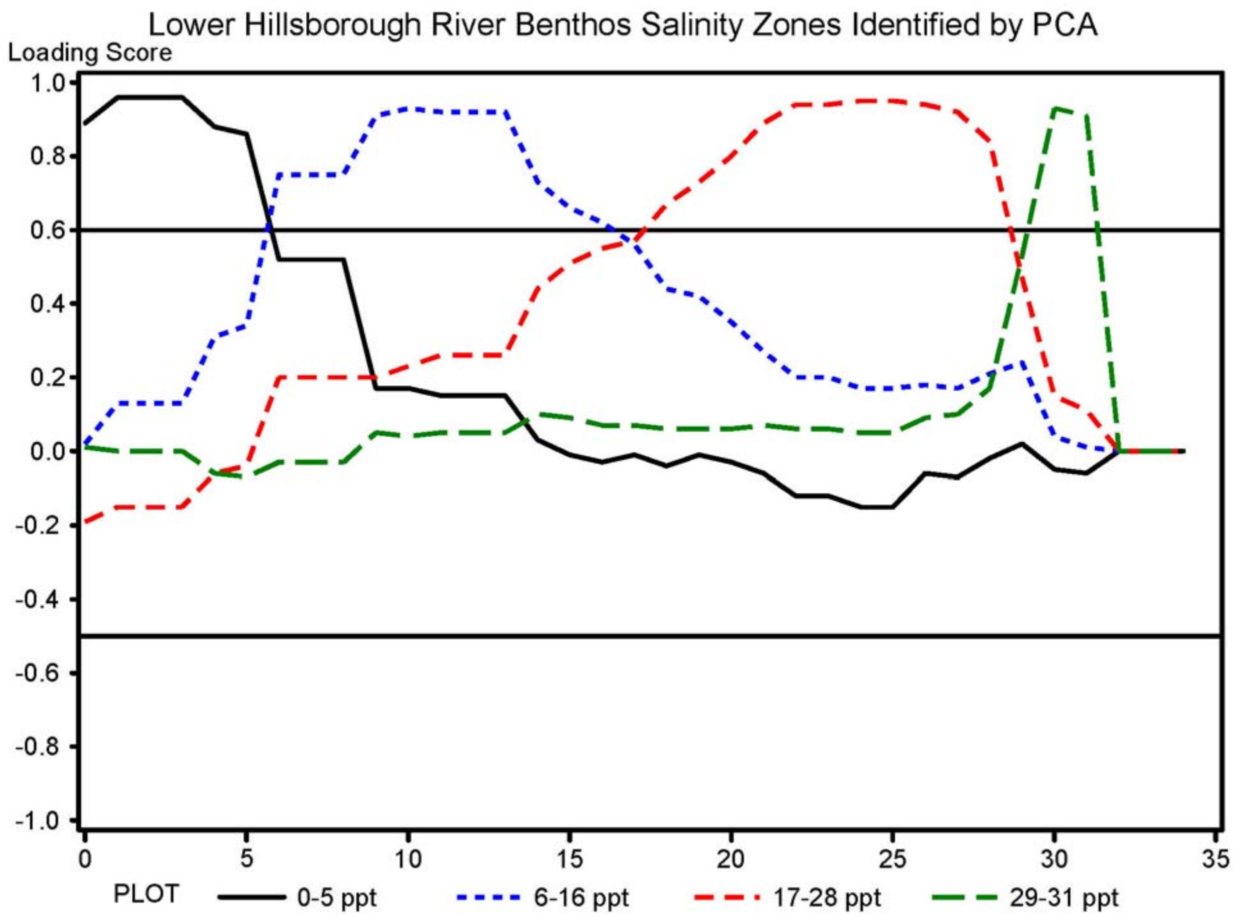


Figure 5-9. **Salinity zones identified by Principal Component Analysis indicative of the distribution of benthic macroinvertebrates in the Lower Hillsborough River, HBMP data 2000-2004.**

Table 5-4. SIMPER (SIMilarity PERcentages using PRIMER software package) analysis (n+0.1 4th root transformed numbers m^{-2}) of Lower Hillsborough River benthos (Tampa Bay Water HBMP): Taxa contributing to the dissimilarity of the benthos within salinity classes with statistically different assemblages (HBMP data 2000-2004).

A. Salinity Zones 0 - 5 ppt *vs*. 17 - 28 ppt (Average dissimilarity = 10.99)

Taxon	0-5 ppt	17-28 ppt	% Contribution to the dissimilarity between salinity classes
Laeonereis culveri	2.56	1.67	7.78
Grandidierella bonnieroides	1.27	1.74	5.28
Stenoninereis martini	1.15	1.69	5.03
Tubificidae	1.41	1.06	3.82
Ampelisca abdita	0.58	1.70	3.80
Polypedilum halterale group	1.63	0.64	3.79
Capitella capitata	0.58	1.62	3.55
Streblospio gynobranchiata	0.74	1.47	3.46
Chironomus sp.	1.51	0.60	3.39
Cyathura polita	1.21	0.99	3.06
Mytilopsis leucophaeata	1.10	1.03	3.03
Nemertea	0.88	1.15	2.63
Polypedilum scalaneum group	1.24	0.66	2.54

B. Salinity Zones 6 - 16 ppt *vs*. > 28 ppt (Average dissimilarity = 12.66)

Taxon	6 - 16 ppt	>28 ppt	% Contribution to the dissimilarity between salinity classes
Monticellina dorsobranchialis	0.72	3.43	8.18
Laeonereis culveri	2.39	0.56	5.41
Grandidierella bonnieroides	1.72	1.08	4.25
Stenoninereis martini	1.49	1.01	3.53
Nemertea	1.24	1.22	2.92
Paraprionospio pinnata	0.63	1.32	2.57
Schistomeringos rudolphi	0.56	1.43	2.52
Capitella capitata	1.05	1.11	2.48
Corophiidae	0.59	1.37	2.39
Ampelisca holmesi	0.59	1.42	2.39
Streblospio gynobranchiata	1.20	0.80	2.30
Glycera americana	0.56	1.27	2.09
Aricidea taylori	0.64	1.16	1.86
Typosyllis amica	0.61	1.15	1.80
Melita elongata	0.69	1.07	1.76
Pinnixa	0.59	1.16	1.72
Scoloplos rubra	0.60	1.14	1.71
Ampelisca abdita	0.76	1.01	1.70

5.2.4 Discussion

The Lower Hillsborough River has been characterized by a number of investigators as a highly stressed tributary to Tampa Bay. Altered freshwater inflows, hypoxia, and sediment contamination from stormwater runoff (Mote Marine Laboratory 1984; Water and Air Research and SDI Environmental Sciences Inc., 1995; Southwest Florida Water Management District 1999; Grabe *et al*. 2003a; Grabe and Barron 2004) have contributed to this condition. Data collected by the EPCHC (Grabe *et al*. 2002; Grabe *et al*. 2003a) confirm that stress from hypoxia and sediment contaminants is widespread in the LHR during the wet season.

The total number of distinct taxa identified to date from all surveys of the Lower Hillsborough River proper, 1984 to present, is now approaching 300. Virtually all the studies of Lower Hillsborough River have shown that the benthic community is to some extent more impoverished, both with respect to mean numbers of taxa and mean numbers of organisms per sample, in all but the lowest reaches of the estuary. Although a survey of benthic macroinvertebrates during February and November 2003 recorded >100 taxa from the upper reach of the river (Appendix 5-1)**,** this may be an artifact of that particular study design. The decision to employ directed (targeting a variety of substrates) qualitative sampling should yield more taxa than a probabilistic design using soft-sediment grab samples of 0.04 m^{-2}. This study did show, however, that a relatively rich fauna inhabits the most upstream portion of the LHR following prolonged flows from the Hillsborough River dam.

Water & Air Research, Inc. and SDI Environmental Services, Inc. (1993; 1994; 1995) showed that community structure immediately downstream of the dam was related to freshwater inflow. During low or no flow periods an estuarine fauna was established only to be replaced by a freshwater assemblage as flows over the dam increased. The composition of the macroinvertebrate community inhabiting Sulphur Springs and its run also changed under different discharge regimes. At reduced flows a more salt tolerant assemblage replaced the freshwater assemblage.

Kalke and Montagna (1989) developed a conceptual model to explain the effects of freshwater inflow on Texas estuarine benthic communities:

1) Shortly after a period of high freshwater inflow there is an increase in species tolerant of lower salinities and capable of exploiting the pulse of nutrients to the estuary.
2) Estuarine species that are less tolerant of these lowered salinities die.
3) As the volume of freshwater entering the estuary is attenuated, salinity again increases and the more salt tolerant species reinvade.
4) Species richness increases as the salinity increases.
5) The returning estuarine species compete for the available nutrients with the less salt tolerant fauna. As the amount of available nutrients decreases, the benthic community stabilizes such that with the additional competition, nutrient

availability declines and gross secondary production is balanced by the effects of predation and mortality.

This model is wholly consistent with the results reported by Water & Air Research, Inc. and SDI Environmental Services, Inc. (1993; 1994; 1995). There is less consistency between this model and results of the EPCHC's surveys. This may be related to the study design, since the EPCHC surveys were confined to only the wet season and hence a period during which large releases from the dam were more likely to occur. Both stepwise multiple regressions and multivariate analysis of the degree of association between univariate and multivariate community metrics and cumulative flows produced results that may be, only in part, explained by the above model.

The general conclusion is that the structure of the LHR benthos is more closely related to the salinity regime the benthos is exposed to and less related to the location along the longitudinal axis of the river. The salinity regime of the estuary is dynamic—not static. Hence organisms whose distribution is primarily related to a preferred salinity regime would be expected either to move up and down the river or die off. The actual response would be related to the:

- *absolute change* in salinity;
- the *rate* at which the salinity changes; and
- the *duration* of the change.

5.3 Fish

Several fish studies have been conducted since 1990 in the LHR. Summaries of the earlier studies and of the most recent field and data analysis studies conducted for Tampa Bay Water and the District are presented below.

5.3.1 Earlier Studies

Surveys of ichthyoplankton and juvenile fish were conducted in the LHR by Water and Air Research Inc. and SDI Environmental Services, Inc. (WAR/SDI, 1995) as part of a hydro-biological assessment of the area. This study was conducted to determine an optimal withdrawal and augmentation schedule for the Hillsborough River Reservoir, TBC and Sulphur Springs, with the intent of minimizing downstream impacts while still meeting water needs (WAR/SDI, 1995). A secondary goal of this project, in relation to fish analysis, was to compare results from the LHR/TBC and previously reported results in the Little Manatee River (Peebles and Flannery, 1992). More natural hydro-biological conditions are considered to exist in the Little Manatee River (LMR), compared to other tributaries to Tampa Bay.

5.3.1.1 WAR/SDI Ichthyoplankton Summary

Two replicate ichthyoplankton samples were collected monthly for 2 years at 7 stations along the LHR (WAR/SDI, 1995). A 0.5 meter-mouth-diameter, 505-μm-mesh, conical (3:1) plankton net was used. Additionally, temperature, salinity, and dissolved oxygen profiles were measured.

Over 159,000 eggs and 28,247 larval, juvenile and adult fish were collected, representing at least 44 species (WAR/SDI, 1995). The ichthyoplankton surveys consisted primarily of marine derived fish that spawn in higher saline waters and then move into tidal rivers. Dominant taxa were the bay anchovy and goby (*Gobiosoma spp*.) followed by another goby (*Microgobius spp.)* Twenty percent of the total catch consisted of freshwater species, while another 20% consisted of inshore species and the remaining 60% consisted of a combination of inshore/nearshore-offshore spawners (WAR/SDI, 1995). Relatively few adults, 185, were collected during the ichthyoplankton surveys. Juveniles of bay anchovy (*Anchoa mitchilli)* were the most frequently collected species, occurring in over half (>50%) of all samples. The station furthest downstream (Hillsborough Bay) had the highest density of ichthyoplankton taxa (WAR/SDI, 1995).

When compared to diversity in the Little Manatee River, fewer species were collected in the LHR. The LHR had 69% of the species reported for the LMR; the difference in species was likely the result of a combination of factors including substrate availability, hypoxia and the salinity regime in each of the rivers. This difference in diversity was attributed to a poor representation of substrate associated species in the LHR, which in turn, was likely related in part to frequent hypoxia in bottom waters in the LHR. It was reported that the low larval to egg ratio observed indicated that problems with fish production were occurring before the young reached the estuarine-dependent stage (WAR/SDI, 1995). Additionally, it can be concluded that substrate characteristics and possible contamination effects could also impact overall benthic productivity, which affects the abundance of substrate associated fishes.

In terms of observed seasonality, species richness was highest in the spring and summer, which is typical for estuaries in southwest Florida. While most species spawn in the spring and summer, some species were reported to spawn during the remainder of the year (fall and winter) meaning that changes in discharge will always have the potential to affect ichthyoplankton (WAR/SDI, 1995). During the second year of this study, higher discharge was associated with a decrease in ichthyoplankton abundance, meaning higher flows probably pushed spawning locations seaward into the bay. However, this was not considered detrimental, but noted because it would affect comparisons and interpretation of diversity, abundance, and other metrics at the same station between years, or when comparing data from the river to the bay (WAR/SDI, 1995).

5.3.1.2 WAR/SDI Juvenile and Adult Fish Summary

Juvenile fish were collected monthly at 5 stations using a 23-meter-long bag seine with 3.2-mm mesh. This sampling method targeted the ichthyofaunal community associated with shallow, near shore habitats but did not address the mid-channel community (WAR/SDI, 1995).

In this study, 344,125 fish specimens representing 70 species were collected over the two year period (WAR/SDI, 1995). Most specimens were adults and juveniles of small sized resident species. The four most abundant species represented 85% of the total catch: bay anchovy 65.8%, inland silverside (*Menidia beryllina)*) 9.2%, yellowfin menhaden (*Brevoortia smithi)* 6.2%, and the tidewater silverside (*Menidia peninsulae)* 3.9%. These four species had clumped distributions and were all found in large motile schools, being captured either in very large numbers or with none being present at all. All were considered year long residents, with the exception of yellowfin menhaden, which appears seasonally as juveniles. Five species of killifish [rainwater killifish (*Lucania parva)*, striped killifish (*Fundulus similes)*, goldspotted killifish (*Floridichthys carpio)*, sheapshead minnow (*Cyrinodon variegates)*, Gulf killifish (*Fundulus grandis)*], and the tidewater mojarra (*Eucinostomus harengulus)* were next in terms of abundance, representing 11% of the total catch (WAR/SDI, 1995).

Resident species were numerically dominant (92% of total catch including bay anchovy; 76% of total catch excluding bay anchovy) (WAR/SDI, 1995). The freshwater resident community was small but important, representing a number of freshwater game species such as largemouth bass (*Micropterus salmoides)*, redear sunfish (*Lepomis microlophus)*, and bluegill (*Lepomis machrochirus)*. Transient species included juveniles of important sport or commercial fish such as yellowfin menhaden and several members of the drum family Sciaenidae. Other transients that used the study sites as nursery area included snook (*Centropomus undecimalis)*, spotted seatrout (*Cynoscion nebulosus)*, bonefish (*Albula vulpes)*, ladyfish (*Elops saurus)*, and sheapshead (*Archosargus probatocephalus)* (WAR/SDI, 1995).

In terms of observed seasonality, the bay anchovy exhibited seasonal, bi-modal abundance with large peaks occurring in December-February and May-June (WAR/SDI, 1995). This was in synch with the bimodal seasonal salinity patterns suggesting that distribution of the bay anchovy was related to high salinity periods. Additionally, seasonal patterns for the following two transient species matched results reported in the LMR (Peebles and Flannery, 1992): red drum (*Sciaenops ocellatus)* first appeared in October and were abundant until March, and spot (*Leiostomus xanthurus)* first appeared in January, with greatest abundance occurring between March and June (WAR/SDI, 1995).

Species richness was greatest in the warm water months (May-October) and lowest in the cool water months (November-April) (WAR/SDI, 1995). This seasonal pattern of species richness matched the observations in the LMR (Peebles and Flannery, 1992).

5.3.2 Recent Studies

Surveys of fish in the LHR have been conducted by Tampa Bay Water's HBMP (PBS&J, 2003), Florida Fish and Wildlife Research Institute and University of South Florida (MacDonald *et al*., 2005), and University of Florida (Catalano *et al*., 2005).

Tampa Bay Water's HBMP was developed and implemented as a condition of approval for Water Use Permits for the Alafia River, LHR, and TBC Water Supply Projects (PBS&J, 2000). The goal of the HBMP is to provide information at a scale and resolution appropriate for determining if the water supply projects are in compliance with District rules (PBS&J, 2000). The HBMP has a number of reporting units, including the LHR. The LHR reporting unit extends from the mouth of the river at Platt Street to the HR Dam, spanning a distance of approximately 16.3 kilometers and comprising a total of 6 spatial strata (Figure 3-1). The temporal sampling strategy for the LHR was designed to allow inferences to be drawn, on a quarterly basis, about river wide status.

The HBMP defines three monitoring program elements including hydrology/water quality, biota, and habitat/vegetation. Each program element has a list of critical indicators; the biota element comprises a series of indicators including but not limited to ichthyoplankton/zooplankton, and adult/ juvenile fishes. Ichthyoplankton/zooplankton are sampled using a 0.5 meter-mouth-diameter, 505-μm-mesh, conical (3:1) plankton net. Juvenile and adult fish are sampled using beach, off-shore and shoreline seines (21 m center bag seine with 3.2 mm mesh). In deeper areas (>1.8m) 20 foot otter trawls with 1.5 inch stretch mesh and 1/8 inch stretch liner are used (PBS&J, 2000). Results from the HBMP program have been summarized and reported in a series of Data and Interpretive Reports (PBS&J, 2002; 2003; 2004).

The FFWCC and University of South Florida (USF) analyzed data for the District to support the establishment of minimum flows for the LHR (MacDonald *et al*., 2005). Specifically the project was designed to enable the District to assess the fish nursery function of the LHR estuary and the relationship to freshwater inflows. The main objective was to develop regression models that explained the distribution and abundance responses of estuarine biota (early life stages of fish and the invertebrate prey species) to varying freshwater inflows and associated salinities (MacDonald *et al*., 2005).

Data used in this study were the same as analyzed by PBS&J in the HBMP program, as the HBMP data is collected by the FFWCC and USF.Sampling was conducted between April 2000 and December 2004. Based on the initial analysis of the temporal responsiveness of various taxa to inflow variations, a sub-set of taxa were further subdivided into "pseudo-species" groups based on analysis of monthly length frequency plots and the delineation of taxa specific size groups (*e.g.*, menhaden (*Brevoortia spp*.) is divided into the following two pseudo-species groups: *Brevoortia spp.* 0-29 mm and *Brevoortia spp.* 30-999mm) (MacDonald *et al*., 2005).

The University of Florida, Department of Fisheries and Aquatic Sciences, conducted a study evaluating the relationships between varying freshwater flows, water quality, salinity gradients, and fish community composition in the LHR for the District (Catalano *et al*., 2005). This study was conducted between October 2002 and July 2004 and the geographic range was limited to the reach of the river between the dam and Florida Avenue, which is approximately 4.1 kilometers below the Hillsborough River dam. The emphasis of this study was to focus on shifts in the fish community in the upper part of the tidal river during low flow and moderate flow conditions.

A number of physiochemical variables were sampled, as well as catch-per-effort (CPE) and species composition of the fish community (Catalano *et al*., 2005). Fish were collected using three methods (fyke nets, gill nets, seines), but only the fyke net data was comprehensive enough to draw any conclusions. Fyke nets were deployed at each of the 12 physiochemical transects located in the stretch of river below the dam down to the I-275 bridge. Each fyke net was constructed of 6.4-mm square mesh, with a 61-cm diameter opening, were 2.1-m long, with two wings measuring 7.62-m by 0.91-m and deployed for 24 hours at a time (Catalano *et al*., 2005).

It should be noted that the summary of the Catalano *et al.,* (2005) study is contained as a separate sub-section (5.3.2.6), rather than being integrated throughout this section due to the following:

- the study focused only on the most upstream reach of the river (from the base of the dam to just downstream of Sulphur Springs),
- limited flow conditions were observed during the five sampling events, and
- salinity increases were concomitant with decreases in DO, and the relative importance of these variables was not determined.

5.3.2.1 Taxonomic Composition

PBS&J (2003) reported a total of 119 taxa of juvenile and adult fish in the LHR, as reported during the comprehensive monthly sampling, using seine and trawl nets. Average species richness per sample was between 7-12 (Figure 5-10) (PBS&J, 2003). A more limited study, consisting of 5 sampling events in the reach of the river from Sulphur Springs to the dam, reported species richness in the range of 9-22 species per sample (Catalano *et al*., 2005).

Silversides (*Menidia spp*.) was the most frequently collected taxon, with an 80 percent probability of collection (Table 5-5) (PBS&J, 2003). Other frequently collected taxa included the following invertebrate and fish species: daggerblade grass shrimp (*Palaeomonetes pugio)*, hog choker (*Trinectes maculatus*), goby (*Gobiosoma bosci*) and the bay anchovy (*Anchoa mitchilli*) (Table 5-5). The most abundant species by far was the bay anchovy, followed by silversides, daggerblade grass shrimp, menhaden (*Brevoortia spp.),* and mosquitofish *(Gambusia holbrooki)* (Table 5-6*)* (PBS&J, 2003). It should be noted that several species had centers of abundance located above rkm 9.

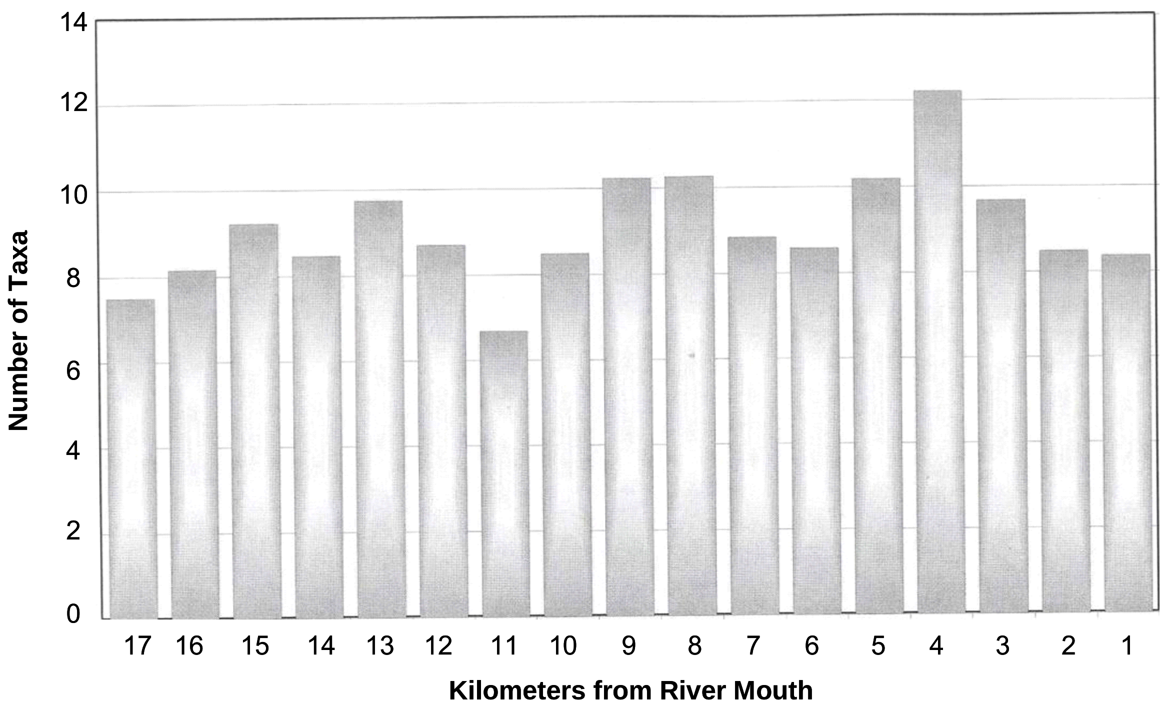


Figure 5-10 **Average number of fish taxa per sample in the HR by river kilometer, May 2000 through December 2002 (From: PBS&J, 2003).**

Table 5-5. **Top 20 HR fish taxa (May 2000-December 2002) ranked by frequency with probability of collection. (Table from PBS&J, 2004). It should be noted that no. 2, *Palaeomonetes pugio* (daggerblade grass shrimp) is an invertebrate.**

Rank	Taxa	Frequency of Collection	Probability of Collection
1	*Menidia spp.*	416	80%
2	*Palaeomonetes pugio*	301	58%
3	*Trinectes maculatus*	278	53%
4	*Gobiosoma bosc*	244	47%
5	*Anchoa mitchilli*	231	44%
6	*Microgobius gulosus*	211	41%
7	*Poecilia latipinna*	177	34%
8	*Callinectes sapidus*	176	34%
9	*Cyprinodon variegates*	175	34%
10	*Gambusia holbrooki*	166	32%
11	*Lucania parva*	161	31%
12	*Fundulus grandis*	149	29%
13	*Gobiosoma spp.*	131	25%
14	*Lagodon rhomboides*	118	23%
15	*Eucinostomus harengulus*	97	19%
16	*Mugil cephalus*	94	18%
17	*Leiostomus xanthurus*	92	18%
18	*Tilapia sp.*	83	16%
19	*Cynoscion arenarius*	82	16%
20	*Fundulus majalis*	72	14%

Table 5-6. Top 20 HR fish taxa (May 2000-December 2002) ranked by abundance with center of abundance. (Table from PBS&J, 2004). It should be noted that no. 3, *Palaeomonetes pugio* (daggerblade grass shrimp) is an invertebrate.

Rank	Taxa	Number Collected	Center of Abundance (Rkm)
1	*Anchoa mitchilli*	234130	5.4
2	*Menidia spp.*	119047	9.5
3	*Palaeomonetes pugio*	54326	9.2
4	*Brevoortia spp.*	25923	12.1
5	*Gambusia holbrooki*	15057	13.6
6	*Leisostomus xanthurus*	9122	6.3
7	*Lucania parva*	6539	12.3
8	*Poecilia latipinna*	6457	12.1
9	*Mugil cephalus*	4295	5.0
10	*Anchoa hespatus*	3724	1.8
11	*Lagodon rhomboides*	3176	5.5
12	*Cyprinodon variegates*	2739	9.1
13	*Fundulus grandis*	2378	8.6
14	*Microgoius gulosus*	2280	6.7
15	*Trinectes maculates*	2209	8.0
16	*Fundulus majalis*	1499	5.2
17	*Gobiosoma bosc*	1293	6.3
18	*Palaemonetes spp.*	1007	7.0
19	*Eucinostomus harengulus*	857	5.2
20	*Gobiosoma spp*.	834	5.7

The study by FWRI and USF for the District (MacDonald *et al*., 2005) used data collected under the HBMP program (PBS&J, 2000) through 2004, and consisted of several different gears, with dominant catch varying accordingly. Plankton net fish catches were dominated by juvenile bay anchovies and post-flexion gobies. Shoreline seines were dominated by bay anchovy, silversides, menhaden, mosquitofish, spot (*Leiostomus xanthurus*), rainwater killifish (*Lucania parva*), and striped mullet (*Mugil cephalus*). In this study, the listed seine net species comprised nearly 94% of the total seine catches. Trawl net samples from the channel were composed of mainly spot, hogchoker, bay anchovy, sand seatrout (*Cynoscion arenarius*), and southern kingfish (*Menticirrhus americanus*). In this study, the previously listed trawls species accounted for over 77% of the total trawl catch (MacDonald *et al*., 2005).

Plankton net invertebrate catches were dominated by the following taxa, with primary species in parenthesis: larval crabs (decapod zoeae, *Rhithripanopeus harrisii*), hydromedusae (*Clytia sp.),* calanoid copepods (*Acartia tonsa* and *Labidocera aestiva*), mysids (*Americamysis almyra*), chaetognaths (*Sagitta tenuis, Ferosagitta hispida*), the freshwater cyclopoid copepod *Mesocyclops edax*, gammaridean amphipods, polychaete worms (nereids), the parasitic isopod *Lironeca sp*., larval shrimps (*Palaemonetes*) and dipteran larvae (*Chaoborus punctipennis*) (MacDonald *et al*., 2005). Seine net invertebrate catches were dominated by daggerblade grass shrimp (*Palaemonetes pugio*), which made up over 97% of the invertebrate catch. Ninety seven percent of the trawl net invertebrate catches were made up of the following three species: blue crab

(*Callinectes sapidus*), daggerblade grass shrimp, and pink shrimp (*Farfantepenaeus duorarum*) (MacDonald *et al*., 2005).

In 1991, a hydrobiological study of the LHR was conducted by the City of Tampa and the West Coast Regional Water Supply Authority (HSW Engineering, 1992 as cited in SWFWMD, 1999). Icthyoplankton catches consisted primarily of the egg, larval, and juvenile stages of marine-derived fish (SWFWMD, 1999). These species spawn in high salinity waters and then juveniles migrate into lower salinity habitat. These results were compared by the authors to the findings in a study conducted on the Little Manatee River (Peebles and Flannery, 1992), and it was concluded that the LHR had lower taxonomic diversity, richness, and evenness. This was attributed to what was considered to be a poor representation of substrate associated fish in the LHR (SWFWMD, 1999). Fish collected during this study were adults and juveniles of small resident species, as well as juveniles of seasonally abundant immigrant species. Abundance of juvenile fish increased progressively downstream in the lower portion of the river. Although small in terms of abundance, and restricted to the most upstream locations, the freshwater resident community was noted as an important component of the river system (SWFWMD, 1999).

5.3.2.2 Indicator Species

Fish found within a tidal river can have varying salinity/flow preferences and it can be useful to describe different taxa based on the following groups of fish:

- *Freshwater* - species are typically residents of freshwater origin, which may have an extended range that includes low salinity areas.
- *Estuarine* - estuarine resident species that spend their entire lifecycles, including spawning, in estuaries or tidal rivers, or species of marine origin which are frequently found in estuaries but may travel back and forth between the Gulf of Mexico and Tampa Bay.
- *Estuarine-Dependent* - typically marine species, spawned at offshore locations and enter tidal rivers during at least one important phase of their lifecycles. They often enter as late larval or early juveniles stages and utilize the tidal rivers as a nursery area.

Based on the large number of taxa collected in the river, a number of estuarine and estuarine-dependent indicator species were identified as part of the HBMP efforts. These taxa are presented in Table 5-7 and include both juveniles and adults, their ecological affinity, and their typical responses to freshwater inflow or other indicator status (PBS&J, 2003).

Table 5-7. Estuarine indicator species identified through the HBMP program (Table from PBS&J, 2004)

Species	Life Stage	Indicator Status
Anchoa mitchilli (bay anchovy)	juveniles (<30mm)	respond to low inflow by moving upstream and decreasing in number; maybe displaced downstream during high flow
Anchoa mitchilli (bay anchovy)	adults, associated with zooplankton maxima, schools may extend into bay during wet season and then retract into river	appearance of large adults in the river may indicate that low flow conditions have shifted zooplankton maxima upstream
Trinectes maculatus (hog choker)	estuarine (marine derived)	responds to low flow by moving further upstream ; may be displaced downstream during high flow
Gobiesox strumosus (skilletfish)	estuarine	indicate presence of hard substrate (oyster reefs, rocks or artificially hardened shoreline); absent from the estuary during wet season high flows
Cynoscion arenarius (sand sea trout)	estuarine-dependent; juveniles congregate in tidal rivers, associated with prey species (mysid shrimp and juvenile bay anchovies)	respond to low flow by moving upstream, decreasing in number; may be displaced downstream during high flow
Brevoortia smithi (yellowfin menhaden)	estuarine dependent, seasonally abundant	respond to low flow by moving upstream ; absent from the estuary during wet season high flows
Microgobius gulosus (clown goby)	estuarine resident; juveniles and adults are benthic dwellers and feed on benthos	indicators of adequate bottom dissolved oxygen
Leistomus xanthurus (spot)	estuarine dependent	May be displaced downstream during high flow

5.3.2.3 Seasonality

Based on the FWRI and USF study (MacDonald *et al.,* 2005), several observations about seasonality can be made. Based on plankton net data, taxa richness was greater in the spring and summer months and lowest from July through February (Figure 5-11). This same seasonal pattern in taxonomic richness was observed in other tidal rivers in the region. Taxa richness was high in early summer (May-July) and reduced in fall/winter (December-January) for seine collections (Figure 5-12). Trawl data did not exhibit similar peaks and was relatively consistent (Figure 5-12).

Based on the seine and trawl catch, peaks were identified for offshore spawners, estuarine spawners and residents based on three months with maximum abundance (Figure 5-13). Abundances indicate that the tidal river is extensively used during all months, but seasonality among species is evident. Peaks for offshore spawners and residents occur in all months, whereas those for estuarine spawners occur in all months except December.

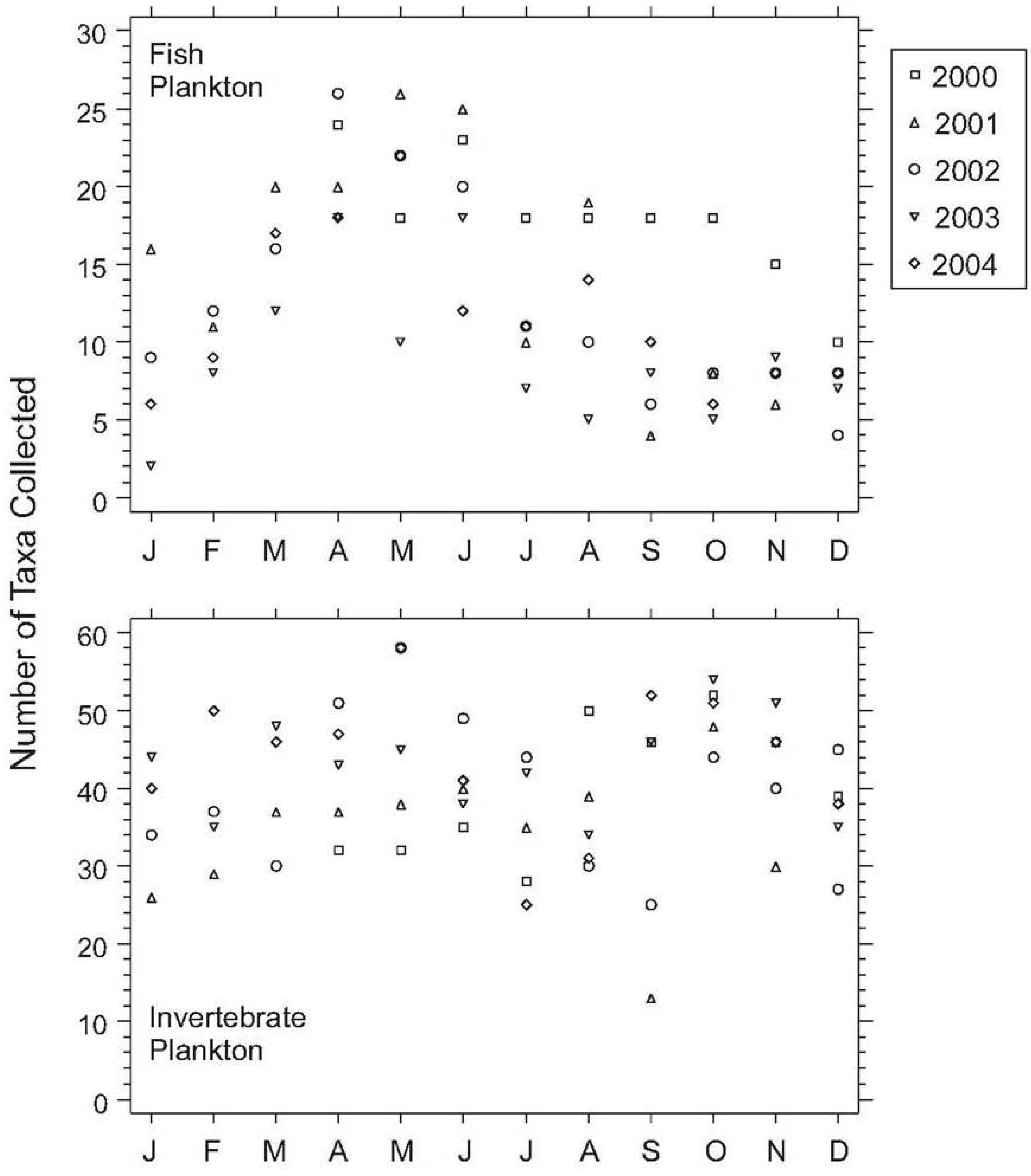


Figure 5-11 **Number of taxa collected by month by plankton net (Figure from MacDonald *et al*., 2005).**

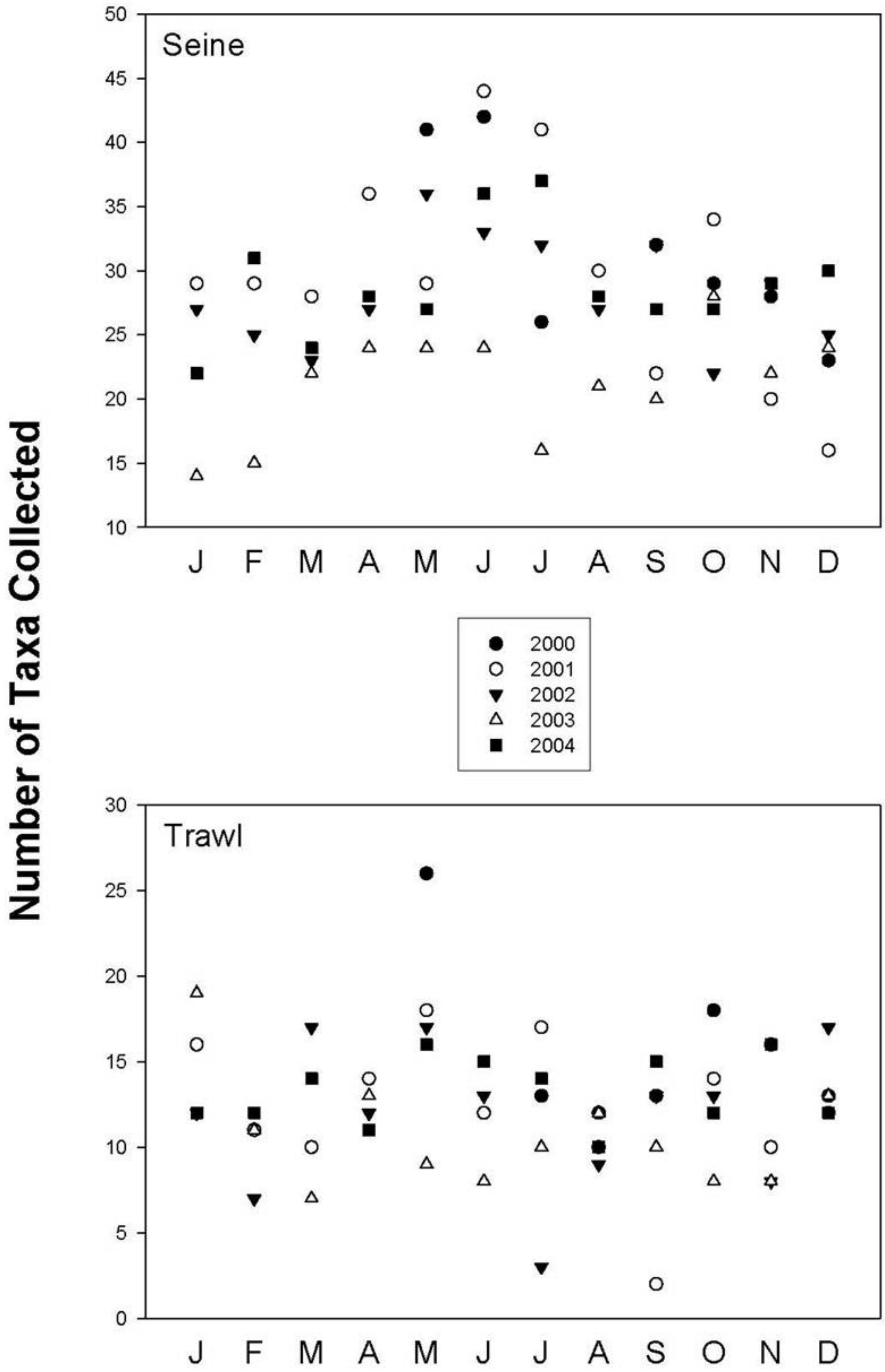


Figure 5-12 Number of fish taxa collected per month by seine and trawl (Figure from MacDonald *et al*., 2005).

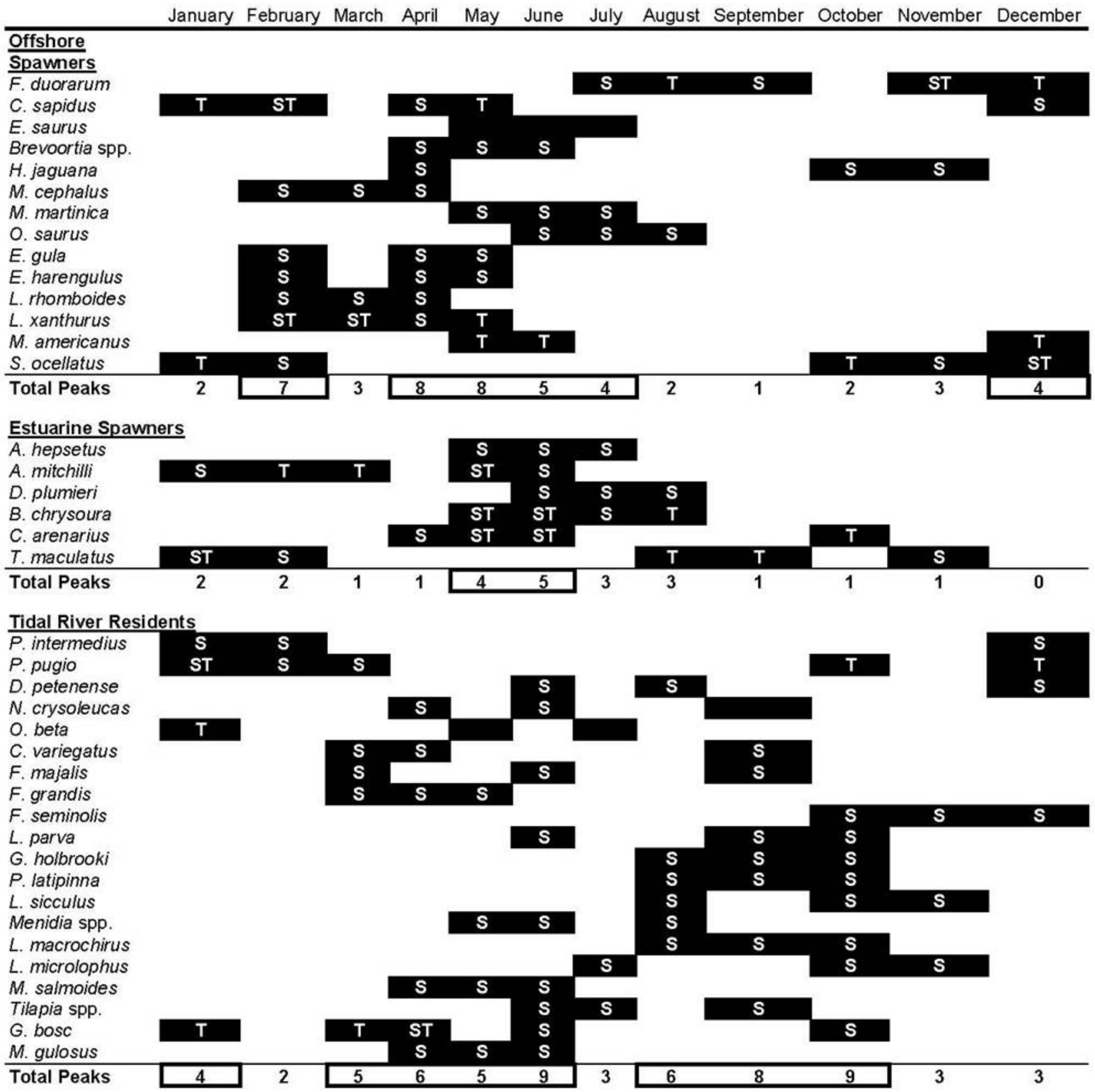


Figure 5-13 **Top three months of relative abundance for all individual fish collected in seines (S) and trawls (T) (Figure from MacDonald *et al*., 2005).**

All three life history groups contain species that are most abundant during spring and early summer, while several resident species have peak abundance during late summer or early autumn (Figure 5-13). Figure 5-14 shows months of occurrence and peak abundance for new recruits. As with overall abundance (Figure 5-13), peak recruitment for at least some species occurs during every month (Figure 5-14). Recruitment peaks for offshore spawners occur most in late autumn and winter, while estuarine spawners and residents tend to have peaks concentrated in spring and early autumn (Figure 5-14) (MacDonald *et al*., 2005).

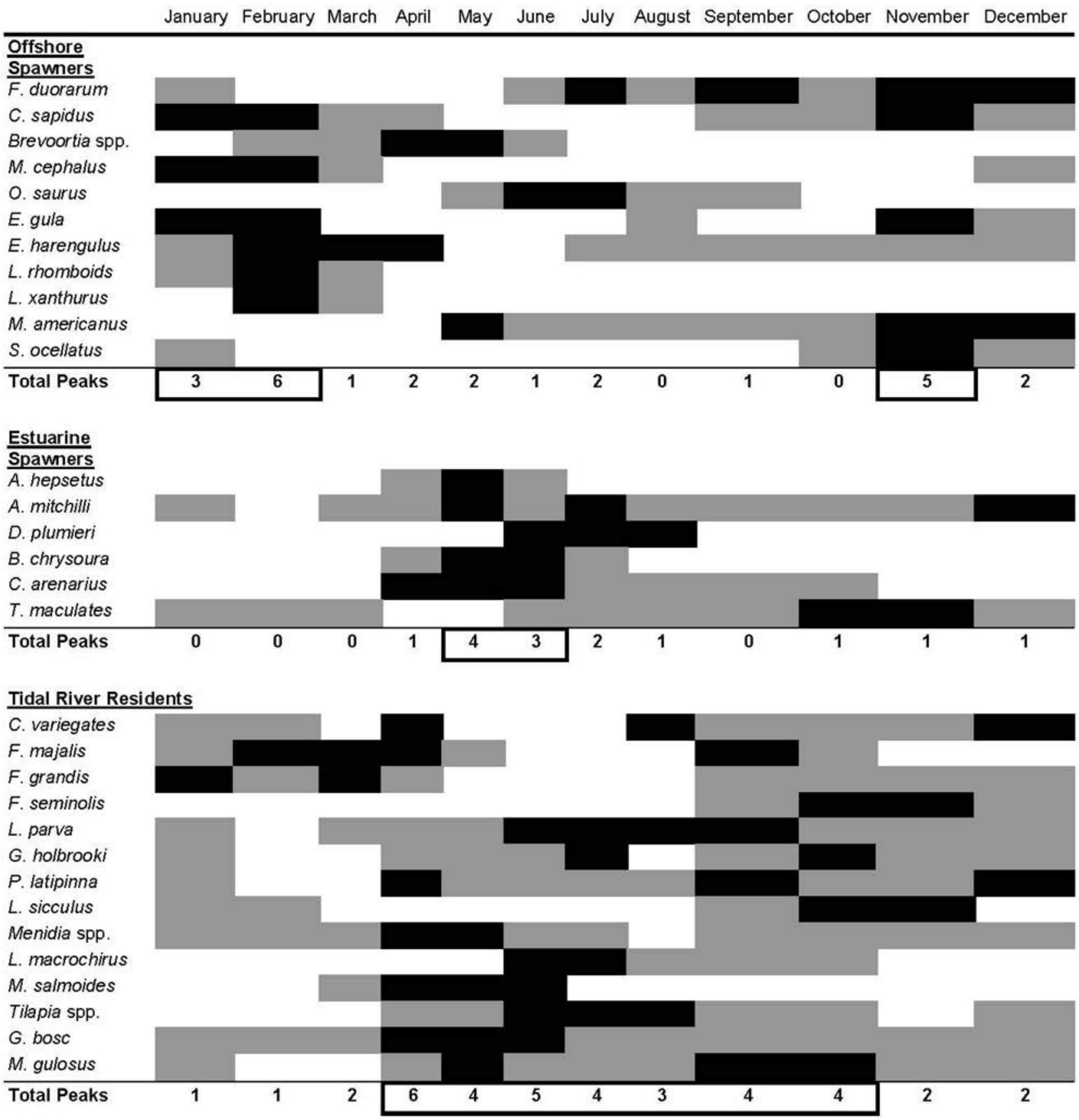


Figure 5-14 Months of occurrence (gray) and peak abundance (black) for new recruits collected by seine and trawl nets (Figure from MacDonald *et al*., 2005).

Overall, the spring is a sensitive time, but there are species that enter the estuary in fall and winter. This indicates that while the potential for impacts is high in spring, there is no time of the year when freshwater inflow management is free from potential impacts to estuarine nursery habitat (MacDonald *et al.,* 2005).

5.3.2.4 Distributional and Abundance Responses

While general responses of indicator species to flow can be seen in Table 5-7, an objective of the study by MacDonald *et al.,* (2005) was to develop regressions to model the distribution and abundance responses of fish and invertebrate taxa to variations in freshwater inflows.

Based on plankton catch data, approximately half (49%) of the 108 plankton-net species exhibited significant distribution responses to freshwater flow; all were negative responses (moved downstream with increasing inflows) except two (MacDonald *et al.,* 2005). While the full range of response lags was 1 to 120-d, most distribution response lags were 10 d or less and many 5 d or less (Figure 5-15). Taxa with most predictable distribution responses (r^2>50%) were estuarine dependent and estuarine resident species (i.e. not freshwater species); estuarine species that move far upstream in tidal rivers during low flow periods respond to increased inflow in a stronger, more predictable way than freshwater species below the dam or higher salinity species that occur near the river mouth (MacDonald *et al.,* 2005).

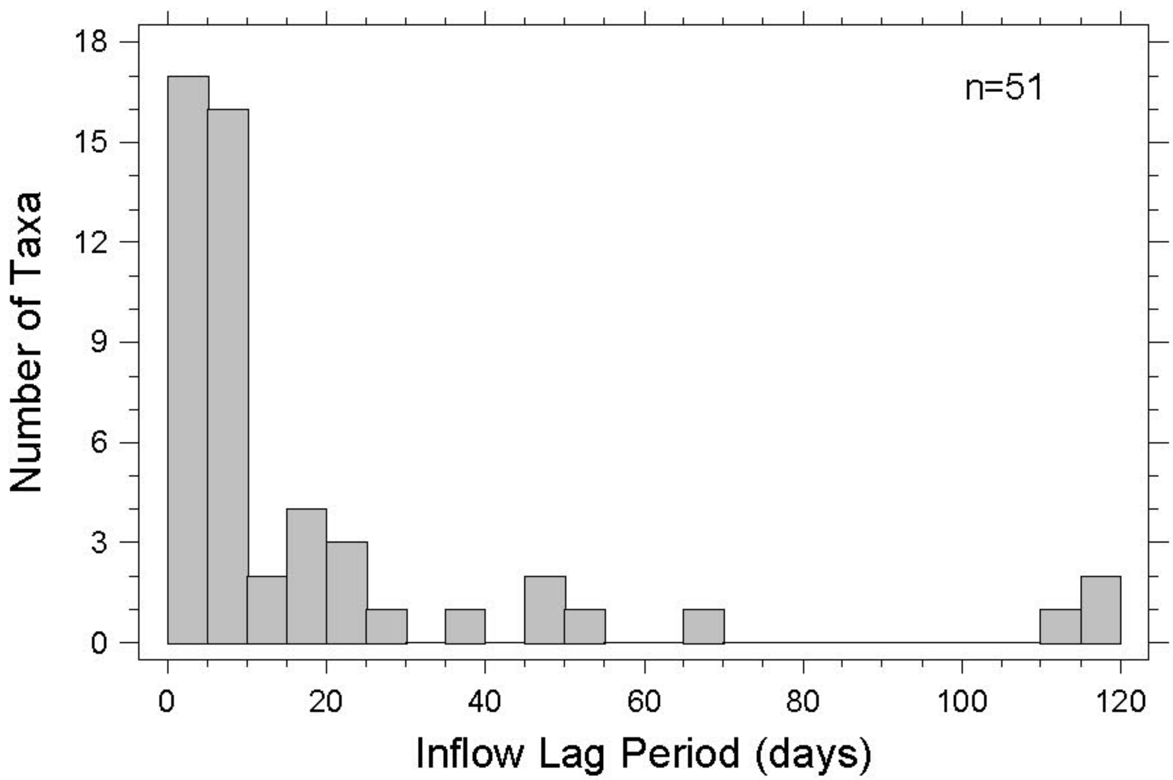


Figure 5-15 Summary figure of distributional response lags for plankton net taxa (Figure from MacDonald *et al*., 2005).

In terms of plankton abundance approximately half (51%) of the 108 plankton-net species exhibited significant responses to freshwater flow; these were split between freshwater taxa which had positive responses to inflow and higher salinity taxa which had negative responses (moved out of the river and into Hillsborough Bay) (Table 5-8;

Figure 5-16 and 5-17) (MacDonald *et al*., 2005). Freshwater invertebrate taxa in the plankton samples that had significant positive responses to inflow included dipterans, caddisflies, and damselflies, among other taxa. The larval and juvenile stages of freshwater fishes in the plankton samples did not show significant responses to freshwater inflow, but significant positive responses were observed for size classes of two freshwater species (bluegill and largemouth bass) that were caught by seines. Positive responses to flow were shown by the following estuarine organisms *Nereids* (polychaetes), larval *Menidia spp.* (silversides), adult *A. mitchilli* (bay anchovy), and juvenile *Trinectes maculatus* (hogchokers) (Table 5-8). The negative responses of estuarine dependent juveniles (moved into Hills. Bay at high inflows) reduced abundances in the river but may have enhanced abundances in the bay (Table 5-8).

Reductions in the abundance of the hydromedusa (*Clytia sp.)* were associated with increased freshwater inflow. Hydromedusa compete with and consume early stages of fish and their displacement downstream away from tidal nursery areas can be considered a benefit of high inflows. When hydromedusa blooms are present the diversity of the plankton community is reduced, the inflow levels that reduce hydromedusa are generally lower than the inflow levels that reduce fish abundance (MacDonald *et al*., 2005).

Based on seine and trawl data almost one-third (32%) of the 69 taxon-size class combinations (pseudo-species) exhibited significant distribution responses; in all cases taxa moved downstream with increasing inflow (Figure 5-18) (MacDonald *et al*., 2005). Resident taxa responded to inflow averaged over medium to long-term lag periods (90-365 days); taxa spawning within Tampa Bay tended to be associated with short inflow lags (0-14 days); offshore spawning taxa were evenly distributed over lagged inflows ranging from 0-365 days (Figure 5-18) (MacDonald *et al.,* 2005).

In terms of seine and trawl abundance data, among the 69 taxon-size class combinations (pseudo-species), 49% had significant abundance response to inflow; the most common response was decreased abundance with increased inflow (most notable is the precipitous decline of high salinity species, *e.g. A. mitchilli,* with higher flows) (Table 5-9) (MacDonald *et al*., 2005). However, positive responses were found among some resident and offshore spawning taxa (e.g., juvenile *L. xanthurus* were rare at low flows and greatly increased with higher inflows). Some size classes for resident and offshore spawning taxa also exhibited intermediate inflow relationships, in which the best models indicated either maximum or minimum abundance at intermediate rates of inflow (Figure 5-19). In general, the strongest abundance inflow relationships incorporated longer lags for resident taxa and shorter lags for estuarine spawners (Figure 5-20). The strongest relationship for estuarine spawners was interpreted as avoidance of low salinity waters by *Anchoa hepsetus* (striped anchovy), which are generally only abundant in the lower portion of tidal rivers. For offshore spawners, relationships were equally distributed among lag periods and varying abundance-inflow relationships were observed. It was suggested the strongest abundance-inflow relationships (r^2 > 49%) among resident taxa may reflect inflow-related changes in the catchability of fishes living along the shoreline, rather than actual changes in abundance.

Table 5-8. Plankton-net organism abundance responses to mean freshwater inflow (*LnF*), ranked by linear regression slope (*slope*). Additional regression statistics are provided: sample size (*n*), intercept (*Int.*), slope probability (*P*) and fit (r^2, as %). *DW* identifies where serial correlation is possible (x indicates *p<0.05* for Durbin-Watson statistic). *D* is the number of daily inflow values used to calculate mean freshwater inflow (MacDonald *et al*., 2005). (Table from MacDonald *et al*., 2005).

Description	*Common Name*	*n*	*Int.*	*Slope*	*P*	*r2*	*DW*	*D*
Latona setifera	water flea	14	0.045	1.658	0.003	53		120
dipterans, pupae	flies, mosquitoes	40	2.700	1.547	0.000	76		9
ephemeropteran larvae	mayflies	22	1.106	1.469	0.000	66		41
dipterans, chironomid larvae	midges	47	5.014	1.110	0.000	64	x	32
Simocephalus vetulus	water flea	26	4.632	1.012	0.000	52		5
trichopteran larvae	caddisflies	16	3.454	0.973	0.003	48		27
dipteran, *Chaoborus punctipennis* larvae	phantom midge	34	7.109	0.954	0.000	43	x	6
Ilyocryptus sp.	water flea	22	5.017	0.913	0.018	25		7
Cassidinidea ovalis	isopod	35	5.897	0.781	0.001	28	x	120
Oligochaetes	freshwater worms	31	5.930	0.735	0.000	57		1
Mesocyclops edax	copepod	32	9.423	0.599	0.040	13		6
Sida crystalline	water flea	19	6.367	0.597	0.012	32		1
odonates, zygopteran larvae	damselflies	20	5.061	0.580	0.000	51		35
Acari	water mites	20	5.601	0.573	0.002	44	x	1
ostracods, podocopid	ostracods, seed shrimps	40	6.910	0.508	0.000	40		12
Trinectes maculatus juveniles	hogchoker	29	7.002	0.454	0.005	25		47
dipterans, ceratopogonid larvae	biting midges	13	5.981	0.399	0.041	33		11
Hargeria rapax	tanaid	12	7.074	0.358	0.033	38		4
Menidia spp. flexion larvae	silversides	11	6.294	0.354	0.001	60		120
Hirudinoideans	leeches	26	6.516	0.352	0.000	45		36
Polychaetes	sand worms, tube worms	57	11.568	0.326	0.006	13		10
Sphaeroma terebrans	isopod	25	7.261	0.319	0.017	22		20
gastropods, prosobranch	snails	55	9.045	0.296	0.014	11		19
Menidia spp. preflexion larvae	silversides	38	8.166	0.236	0.008	18	x	1
Anchoa mitchilli adults	bay anchovy	46	8.585	0.222	0.022	11		11
Pelecypods	clams, mussels, oysters	49	10.995	-0.264	0.045	8		120
coleopterans, curculionid adults	beetles	10	9.775	-0.314	0.012	57		1
Edotea triloba	isopod	52	13.418	-0.324	0.017	11	x	6
amphipods, gammaridean	amphipods	57	15.143	-0.330	0.029	8		53
Palaemonetes pugio juveniles	daggerblade grass shrimp	46	11.844	-0.334	0.014	13	x	120
Anchoa mitchilli juveniles	bay anchovy	57	15.565	-0.338	0.002	16	x	1
Americamysis almyra	opossum shrimp, mysid	52	15.014	-0.358	0.045	8	x	1
Brevoortia spp. postflexion larvae	menhaden	10	10.735	-0.399	0.027	48	x	1
Parasterope pollex	ostracod, seed shrimp	21	11.223	-0.409	0.005	35		1
Cyclops spp.	copepods	22	11.889	-0.425	0.042	19		3

Table 5-8 (cont'd)

Description	*Common Name*	*n*	*Int.*	*Slope*	*P*	*r2*	*DW*	*D*
Microgobius spp. flexion larvae	gobies	31	11.741	-0.450	0.005	24		23
Gobiesox strumosus preflexion larvae	skilletfish	25	11.950	-0.454	0.034	18		51
decapod megalopae	post-zoea crab larvae	45	15.529	-0.558	0.011	14	x	16
Palaemonetes spp. postlarvae	grass shrimp	44	14.379	-0.589	0.004	18	x	51
Brevoortia spp. metamorphs	menhaden	17	12.328	-0.612	0.034	27	x	4
decapod mysis	shrimp larvae	55	16.183	-0.620	0.000	32		36
Anchoa mitchilli postflexion larvae	bay anchovy	25	13.774	-0.696	0.034	18		6
Petrolisthes armatus juveniles	porcelain crab	18	13.953	-0.708	0.012	34		120
Limulus polyphemus larvae	horsehoe crab	17	12.310	-0.732	0.043	25		119
gobiid preflexion larvae	gobies	40	14.785	-0.739	0.000	28		6
Labidocera aestiva	copepod	39	15.659	-0.804	0.004	21	x	2
chaetognaths, sagittid	arrow worms	47	17.308	-0.941	0.000	29	x	24
Squilla empusa larvae	mantis shrimp	15	13.174	-0.958	0.017	37		8
cymothoid sp. a (*Lironeca*) juveniles	isopod	50	16.713	-0.971	0.000	65	x	6
gobiid flexion larvae	gobies	39	15.846	-1.000	0.000	51		7
Acartia tonsa	copepod	40	17.327	-1.014	0.005	19		1
Gobiosoma spp. postflexion larvae	gobies	35	16.385	-1.030	0.002	27	x	15
decapod zoeae	crab larvae	51	21.593	-1.047	0.000	34	x	8
cirriped nauplius stage	barnacles	13	13.901	-1.055	0.017	42		12
Clytia sp.	hydromedusa	31	21.768	-1.630	0.000	54		69

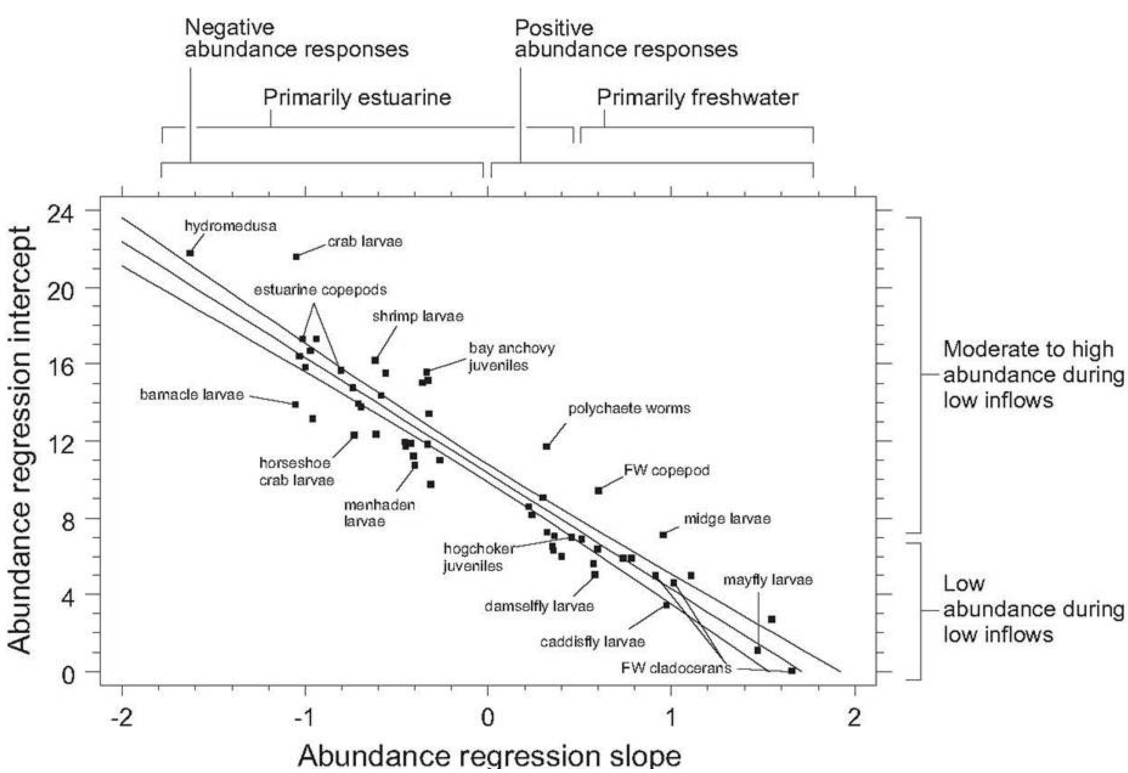
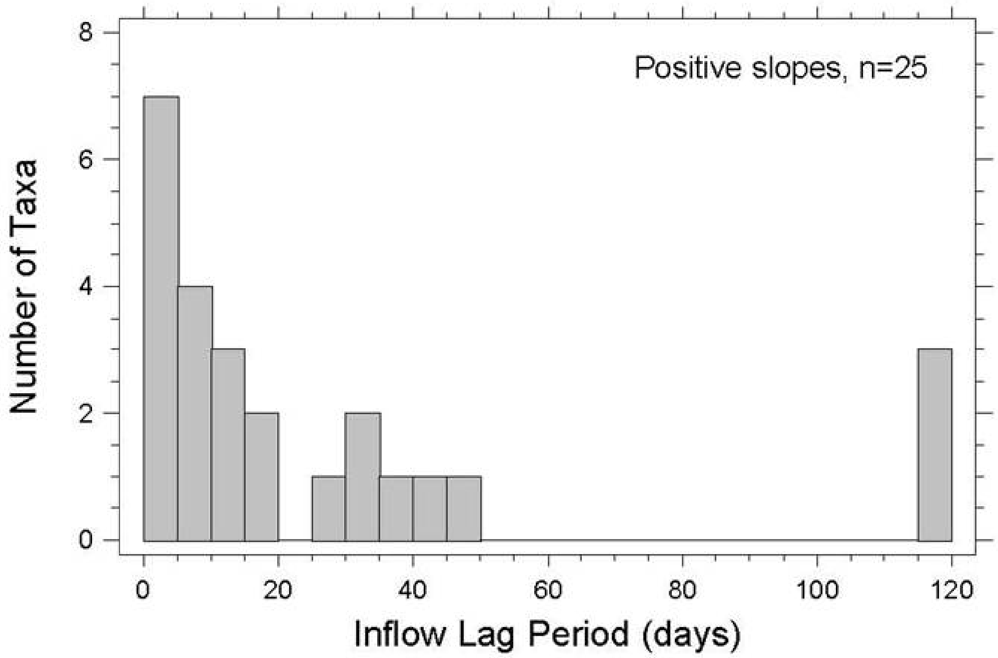


Figure 5-16 **Relationship between intercepts and abundances of plankton-net taxa, described by a regression developed in MacDonald *et al*.,2005 (Figure from MacDonald *et al*., 2005).**



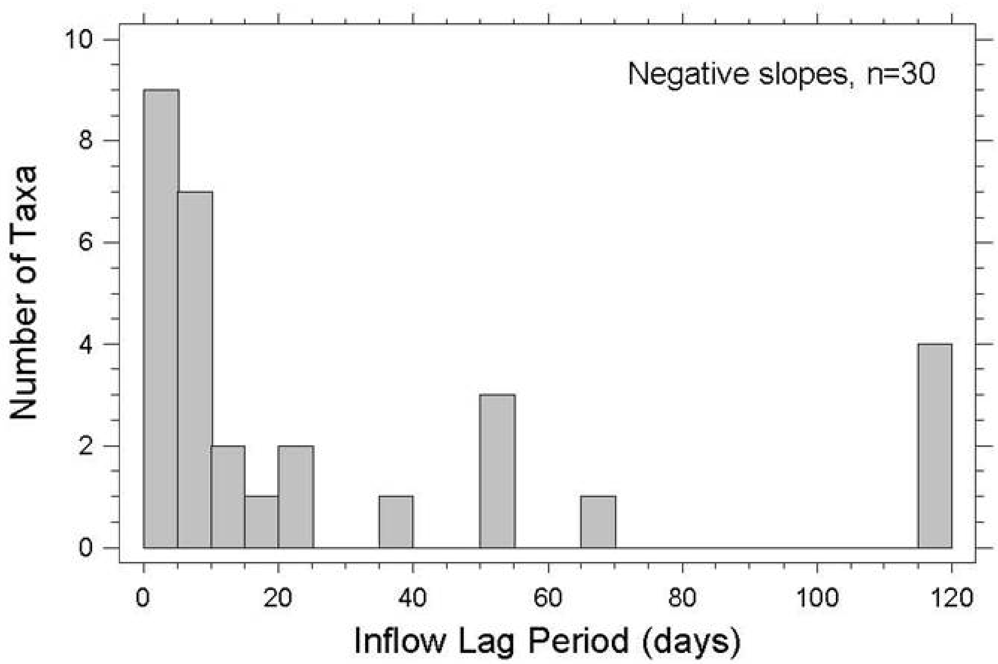


Figure 5-17 **Distribution of the abundance response lags for fish taxa exhibiting positive and negative response slopes (Figure from MacDonald *et al*., 2005).**

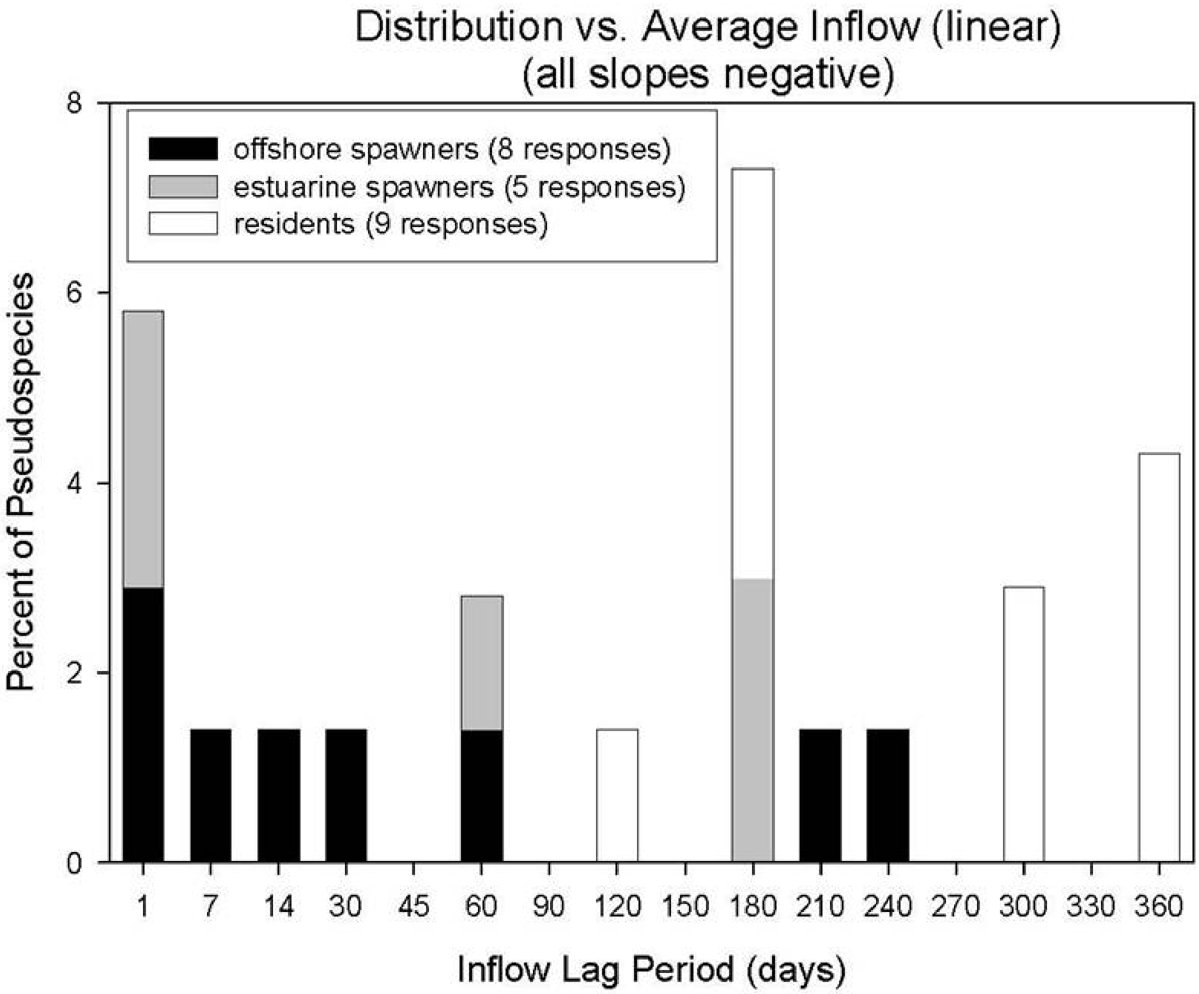


Figure 5-18 **Summary of linear regression results assessing distribution (*km*u) in relation to inflow and lag period, developed by MacDonald *et al*., 2005 (Figure from MacDonald *et al*., 2005).**

The strongest abundance-inflow relationships incorporated longer lags for resident taxa and shorter lags for estuarine spawners (Figure 5-20). The strongest relationship for estuarine spawners was interpreted as the avoidance of low salinity waters by *Anchoa hepsetus* (striped anchovy), which are generally only abundant in the lower portion of tidal rivers. For offshore spawners, relationships were equally distributed among lag periods and varying abundance-inflow relationships were observed (MacDonald *et al.,* 2005).

Table 5-9 **Best-fit seine and trawl-based pseudo-species abundance (*N)* response to continuously lagged mean freshwater inflow [ln(cpue) vs. ln(inflow)] for the HR estuary. The type of response is either quadratic (Q) or linear (L). Degrees of freedom (*df*), intercept, slope (*Linear coef.*), probability that the slope is significant coefficient is significant *(Linear P)*, quadratic coefficient (*Quad. P*), and fit (r^2) are provided. The number of days in the continuously-lagged mean inflow is represented by *D.* An "x" in *DW* indicates the Durbin-Watson statistic as significant *($p<0.05$),* a possible indication that a correlation was present (MacDonald *et al*., 2005). (Table from MacDonald *et al*., 2005).**

Species	*Gear*	*Size*	*Months*	*Response*	*df*	*Intercept*	*Linear coef.*	*Linear P*	*Quad. coef.*	*Quad. P*	r^2	*DW*	*D*
Palaemonetes pugio	Seines	All	Jan. to Dec.	L	54	6.885	-0.782	<0.0001			0.251	x	60
Callinectes sapidus	Trawls	0 to 49-mm	Nov. to Feb.	Q	15	4.821	-1.875	0.048	0.181	0.044	0.264	x	240
Elops saurus	Seines	0 to 149-mm	May to Jun.	L	18	1.321	-0.161	0.044			0.207	x	1
Brevoortia spp.	Seines	0 to 29-mm	Mar. to Jun.	Q	15	8.610	-2.866	<0.0001	0.233	0.004	0.755		7
Anchoa hepsetus	Seines	0 to 34-mm	Apr. to Jul.	Q	16	9.463	-3.199	0.004	0.269	0.023	0.674	x	30
Anchoa hepsetus	Seines	≥35-mm	Jul. to Aug.	Q	7	6.545	-2.282	<0.0001	0.196	0.001	0.947		150
Anchoa mitchilli	Seines	0 to 24-mm	Jan. to Dec.	L	54	8.172	-1.022	<0.0001			0.310	x	30
Anchoa mitchilli	Seines	25 to 34-mm	Jan. to Dec.	L	54	9.398	-1.221	<0.0001			0.472	x	60
Cyprinodon variegatus	Seines	0 to 29-mm	Jan. to Dec.	Q	53	-6.703	3.732	0.023	-0.415	0.010	0.357	x	360
Fundulus majalis	Seines	0 to 34-mm	Jan. to Jun.	Q	23	-14.888	6.882	0.017	-0.719	0.012	0.361		360
Fundulus majalis	Seines	≥35-mm	Jan. to Jun.	Q	23	5.957	-2.211	0.016	0.208	0.035	0.371	x	90
Fundulus grandis	Seines	0 to 44-mm	Sep. to Jun.	L	44	2.788	-0.361	<0.0001			0.244	x	120
Fundulus grandis	Seines	≥45-mm	Jan. to Dec.	L	54	3.302	-0.455	<0.0001			0.296	x	180
Fundulus seminolis	Seines	0 to 80-mm	Oct. to Dec.	Q	16	-4.469	1.976	0.011	-0.188	0.014	0.361		14
Lucania parva	Seines	0 to 24-mm	May to Jan.	L	42	5.497	-0.847	<0.0001			0.459	x	330
Gambusia holbrooki	Seines	0 to 24-mm	Jan. to Dec.	L	54	7.668	-1.102	<0.0001			0.529	x	330
Gambusia holbrooki	Seines	≥25-mm	Jan. to Dec.	L	54	6.868	-0.962	<0.0001			0.502		300
Poecilia latipinna	Seines	0 to 34-mm	Jan. to Dec.	L	54	6.077	-0.950	<0.0001			0.516		330
Poecilia latipinna	Seines	≥35-mm	Jan. to Dec.	L	54	4.406	-0.666	<0.0001			0.378		210
Lepomis macrochirus	Seines	20 to 69-mm	Jun. to Nov.	L	28	-1.084	0.298	0.001			0.347	x	240
Micropterus salmoides	Seines	0 to 74-mm	Apr. to Jun.	L	17	-0.850	0.298	0.003			0.410		30
Oligoplites saurus	Seines	All	May to Jul.	L	13	2.171	-0.316	0.035			0.299		180
Eucinostomus gula	Seines	All	Feb. to May	L	15	3.679	-0.559	0.012			0.349		300
Lagodon rhomboids	Seines	0 to 34-mm	Jan. to Mar.	Q	9	45.954	-15.965	0.028	1.392	0.039	0.666		180
Lagodon rhomboids	Seines	≥35-mm	Apr. to Oct.	L	32	1.824	-0.200	0.023			0.151	x	14
Leiostomus xanthurus	Seines	≥50-mm	Apr. to Jul.	L	17	2.232	-0.270	0.018			0.289		1
Leiostomus xanthurus	Trawls	0 to 49-mm	Feb. to May	Q	14	5.658	-3.085	0.001	0.397	<0.0001	0.822	x	90
Sciaenops ocellatus	Seines	0 to 49-mm	Oct. to Feb.	Q	20	-9.165	4.595	0.008	-0.471	0.006	0.348		30
Tilapia spp.	Seines	0 to 34-mm	Jun. to Aug.	L	13	2.604	-0.400	0.030			0.312	x	210
Tilapia spp.	Seines	≥35-mm	Oct. to Nov.	Q	7	18.442	-6.017	0.003	0.487	0.005	0.844		60
Mugil cephalus	Seines	0 to 29-mm	Jan. to Mar.	L	10	8.918	-1.223	0.027			0.403		300
Microgobius gulosus	Seines	0 to 29-mm	May to Oct.	L	28	2.280	-0.286	<0.0001			0.413		14
Trinectes maculates	Seines	0 to 34-mm	Jan. to Dec.	L	54	2.148	-0.142	0.032			0.083	x	1
Trinectes maculates	Seines	≥35-mm	Jan. to Dec.	Q	53	1.916	-0.547	0.021	0.048	0.046	0.153	x	45

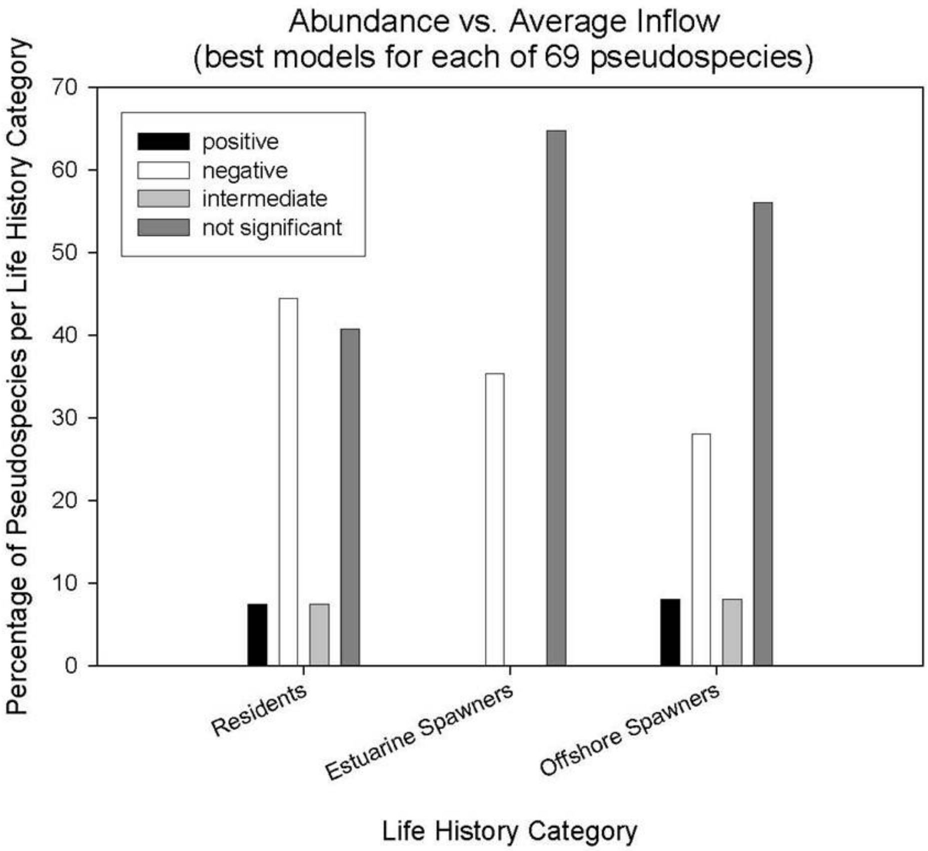


Figure 5-19 **Summary of regression results assessing fish abundance in relation to inflow. Positive and negative indicate increases and decreases in abundance with increasing flow, while intermediate indicates maximum or minimum abundances at intermediate flows. (Figure from MacDonald *et al*., 2005).**

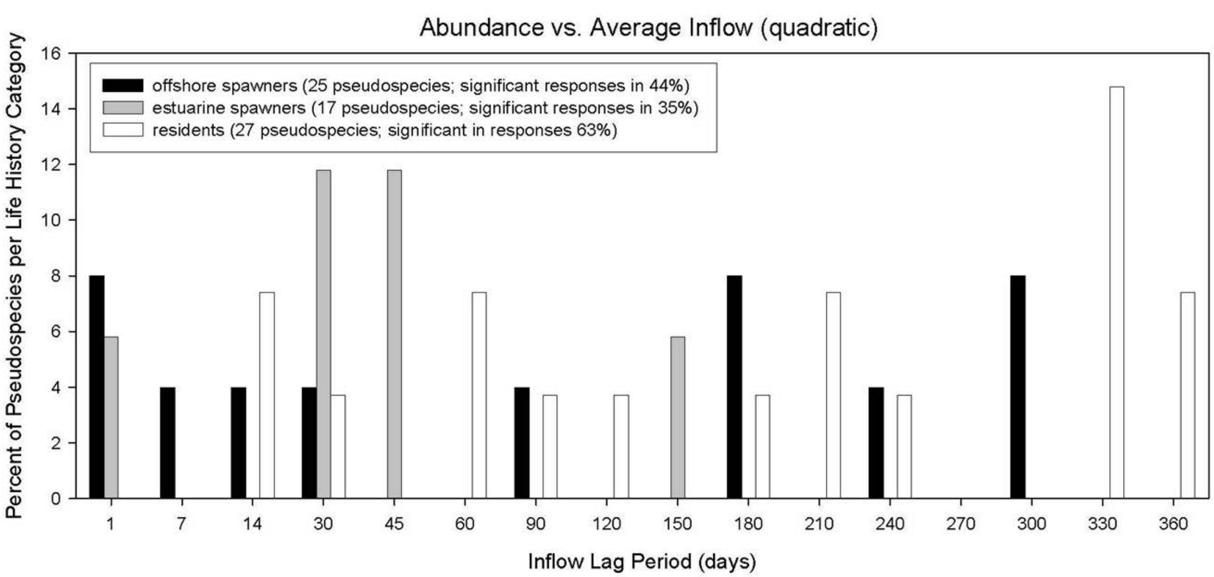


Figure 5-20 **Summary of regression results assessing abundance in relation to inflow and lag period. (From MacDonald *et al*., 2005).**

5.3.2.5 Relationship with Hypoxia

MacDonald *et al.,* (2005) reported that dissolved oxygen (DO) concentrations were an important determinant of organism abundance in the river channel. Trawl data, which sample channel habitat, indicated that both abundance and species richness decreased with decreasing DO (particularly when DO ≤ 2mg/l) (Figures 5-21 and 5-22). Conversely, the seine data, which samples shoreline habitat, showed no significant relationship between richness and DO (Figure 5-23). However, abundance was reported to have increased with decreasing DO, although it was noted that hypoxic conditions in the nearshore areas were rare and this limited data and complicated the interpretation of these results (MacDonald *et al*., 2005). Also, limited evidence existed for organisms avoiding low dissolved oxygen in the river channel by moving into adjacent, shallower margins. Very weak, statistically significant declines in abundance and taxon richness were noted in seines with increasing dissolved oxygen levels in the adjacent river channel.

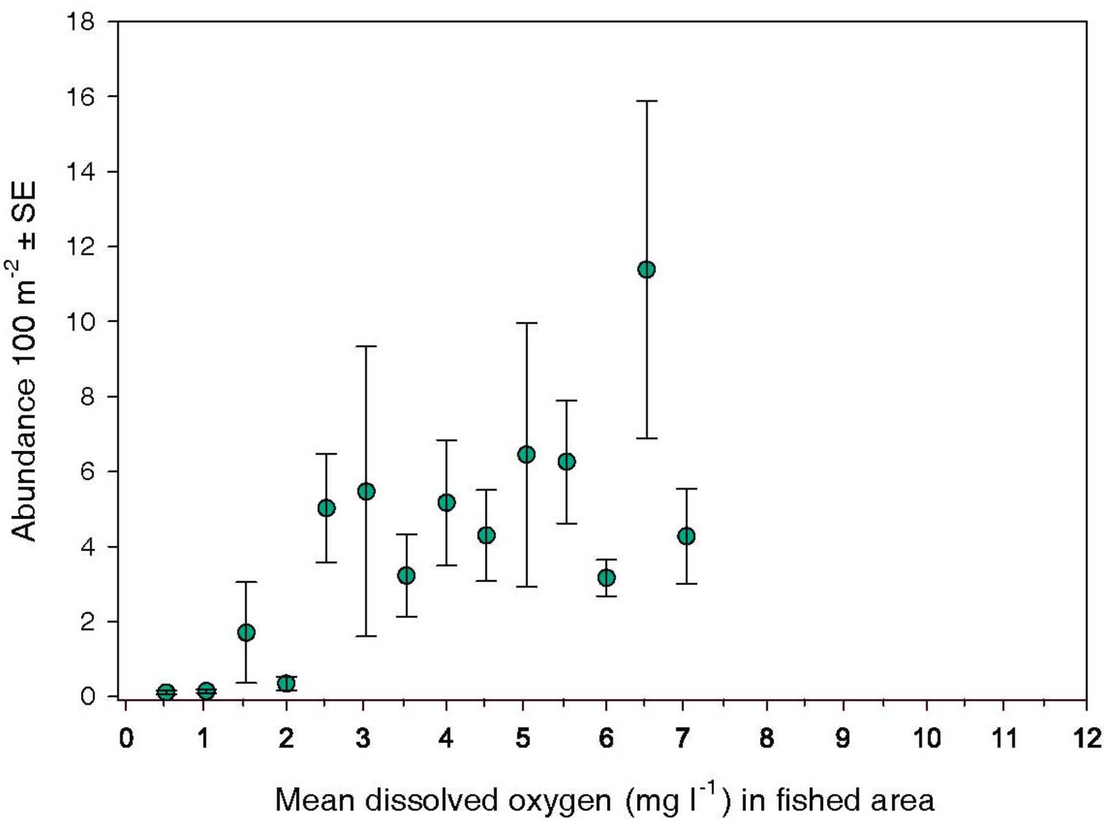


Figure 5-21 Linear relationship between mean animal abundance in trawls and dissolved oxygen in the HR (Figure adapted from MacDonald *et al*., 2005).

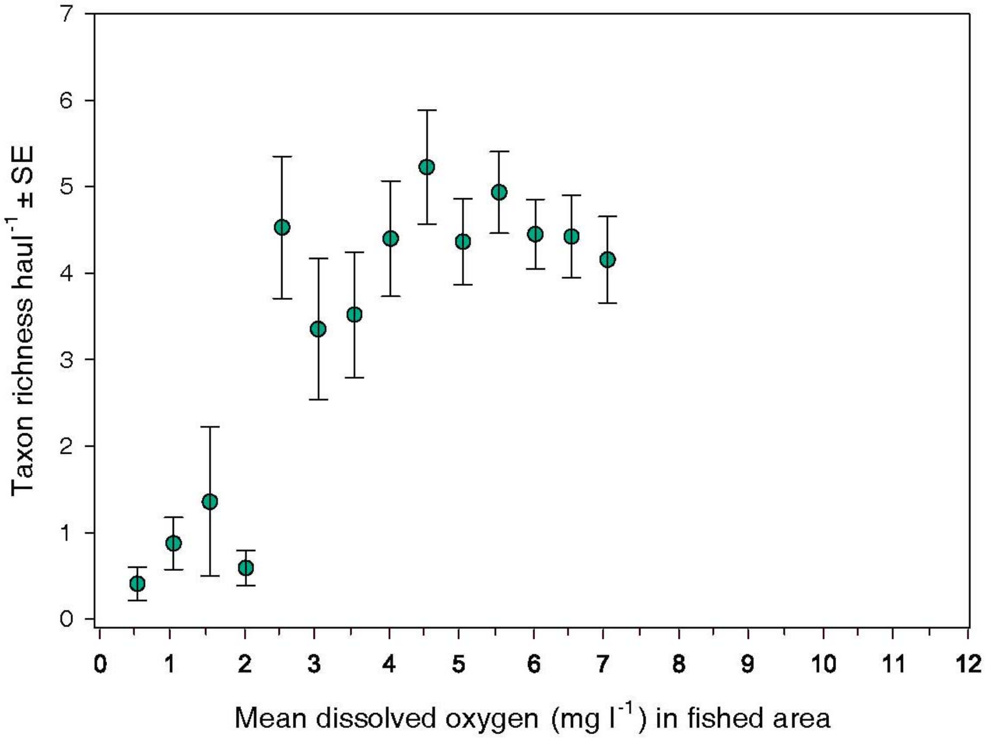


Figure 5-22 Linear relationship between mean taxon richness in trawls and dissolved oxygen in the HR (Figure adapted from MacDonald *et al*., 2005).

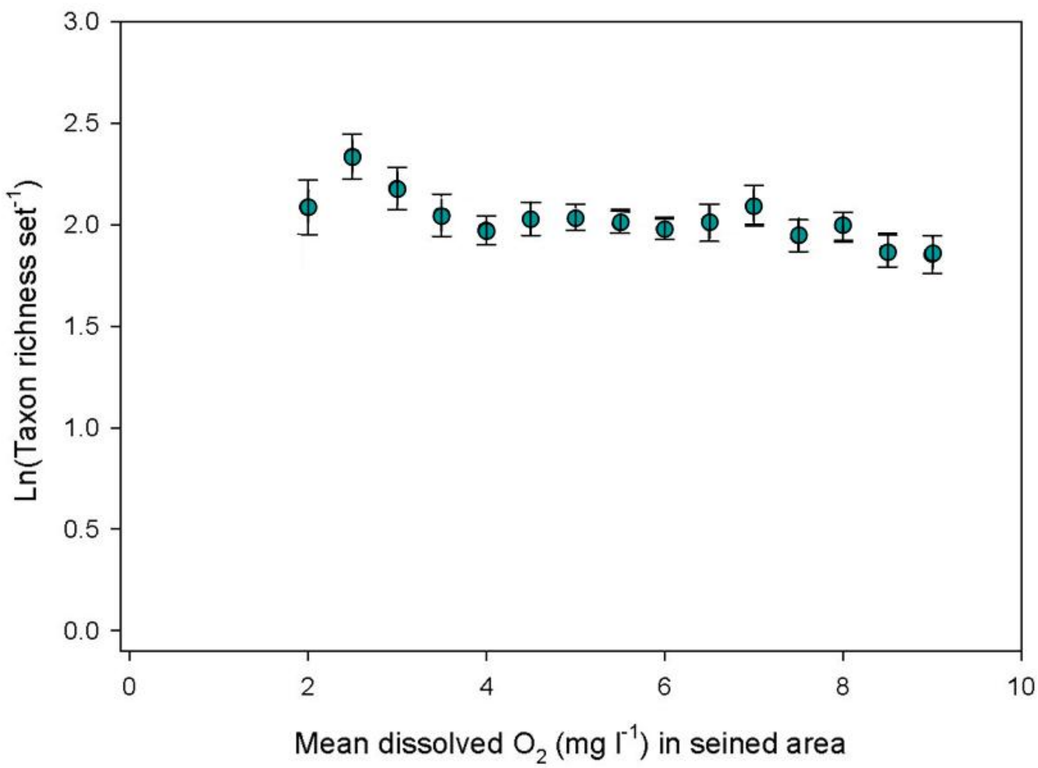


Figure 5-23 Linear relationship between mean taxon richness in seines and dissolved oxygen in the HR (Figure adapted from MacDonald *et al*., 2005).

5.3.2.6 Additional Information

MacDonald et al., (2005) also reported catch responses of stenohaline and euryhaline freshwater taxa to flows <50 cfs. Similar responses were seen such as decreased flow being associated with movement upstream, decreased abundance and decreased taxon richness. The authors suggested that components of both stenohaline and euryhaline freshwater taxon groups might be established below the dam if consistent, relatively small and long term increases in inflow were achieved, particularly inflows >20-30 cfs (MacDonald et al., 2005). Aside from the establishment of a permanent freshwater zone below the dam, estuarine and marine species would also benefit from the oligohaline waters that they recruit to during their juvenile life history stages. Reduction of the oligohaline zone could lead to crowding among species that seek low salinity habitats. Even in altered rivers, such as the LHR, economically important species (e.g., snook) utilize low salinity habitats when available (MacDonald et al., 2005).

A separate data collection effort for fishes in the upper end of the tidal river was conducted for the District by the University of Florida in order to examine the response of fish communities between the dam and Sulphur Springs to low rates of inflow (Catalano *et al.,* 2005). A number of physiochemical variables were sampled, as well as catch-per-effort (CPE) and species composition of the fish community (Catalano *et al*., 2005). Fish were collected using three methods (fyke nets, gill nets, seines), but only the fyke net data was comprehensive enough to draw any conclusions. Fyke nets were deployed at each of the 12 physiochemical transects located in the stretch of river below the dam down to the I-275 bridge. Each fyke net was constructed of 6.4-mm square mesh, with a 61-cm diameter opening, were 2.1-m long, with two wings measuring 7.62-m by 0.91-m and deployed for 24 hours at a time (Catalano *et al*., 2005).

This study found that during flows in the range of 42-194 cfs, species that were considered freshwater/oligohaline (FO - requiring salinities ≤ 5 ppt) were distributed throughout the study site. While catches of FO fish species were found to be similar across the 42-194 cfs flow range, during periods of prolonged low flows (as experienced in May 2004 when median 30-d flow =0.4cfs) the spatial distribution of fish shifted upstream and these fish were only found within 1660 m of the dam (which represented the remaining suitable habitat of salinity ≤ 5 ppt and DO ≥ 4mg/l). A concluding concern of this study was that if very low flow conditions (<4cfs) were continuous, the fish community would be substantially altered based on decreased habitat volume. Data suggest flows ≥ 42 cfs are adequate to maintain habitat for freshwater/oligohaline species below the dam. Low flows (<4cfs) caused substantial decrease in suitable habitat downstream of the dam. A threshold flow between 4 and 42 cfs was not identified because flows in this range were not experienced during sampling events in this study (Catalano *et al*., 2005).

5.3.3 Community Structure Analysis

To assess the relationship between fish community structure and salinity in the LHR, Principal Components Analysis (PCA) was used to identify generalized salinity classes based upon the ranges over which the fish taxa occurred. Bulger *et al*. (1993) used this approach in developing taxa specific salinity classes for mid-Atlantic estuarine nekton. The analysis described below is a critical element in the identification of various habitat types as defined by their salinity and resultant fish community structure.

The approach initially involves establishment of a data matrix of salinities (in 1 ppt increments) and taxa presence. The matrix is completed by noting the ranges of salinity where each of the taxa are present (1) and absent (0). PCA is then used to identify Principal Components Axes that express commonalities with respect to the occurrence among taxa across the range of salinities encountered in the LHR. Factor loadings from Varimax rotation of the PCA axes were plotted against the original salinity increments and scores greater than 0.60 were used as a criterion for identifying the significantly correlated salinity classes.

Since different life stages of a particular fish species may exhibit different salinity preferences within the LHR, "pseudo-species" were created by separately considering the salinity ranges for each species in size classes of: less than 40 mm standard length; 40-150 mm standard length and greater than 150 mm in standard length. If the total catch for any species or "pseudo-species" was less than 30 individuals, they were removed prior to analysis to avoid the influence of rare catch on the PCA groupings. In a post-hoc comparison, the species contributing most to differences among the PCA groups were identified using SIMPER analysis (Clarke and Warwick 2001).

Four salinity zones were identified using PCA (Figure 5-24):

- Zone 1= 0 - 2 ppt,
- Zone 2 = 2 - 15 ppt,
- Zone 3 = 15 -27 ppt, and
- Zone 4 = 27 - 32 ppt.

Hogchoker and silversides were commonly collected in Zones 1-3 and contributed most to the similarity among the catch in these zones. Blue crab and pinfish were the most consistent species captured in Zone 4. Differences between zones were mostly due to differences in the frequency of occurrence of these species between zones; however, noticeable was the increased frequency of occurrence of bluegill and mosquitofish in Zone 1 and the increased frequency of occurrence of blue crab, pinfish, and bay anchovy in Zone 4. Differences between Zone 1 and Zone 2 were primarily due to increased occurrence of gobies and daggerblade grass shrimp in Zone 2 and an increased occurrence of bluegill and hogchoker in Zone 1.

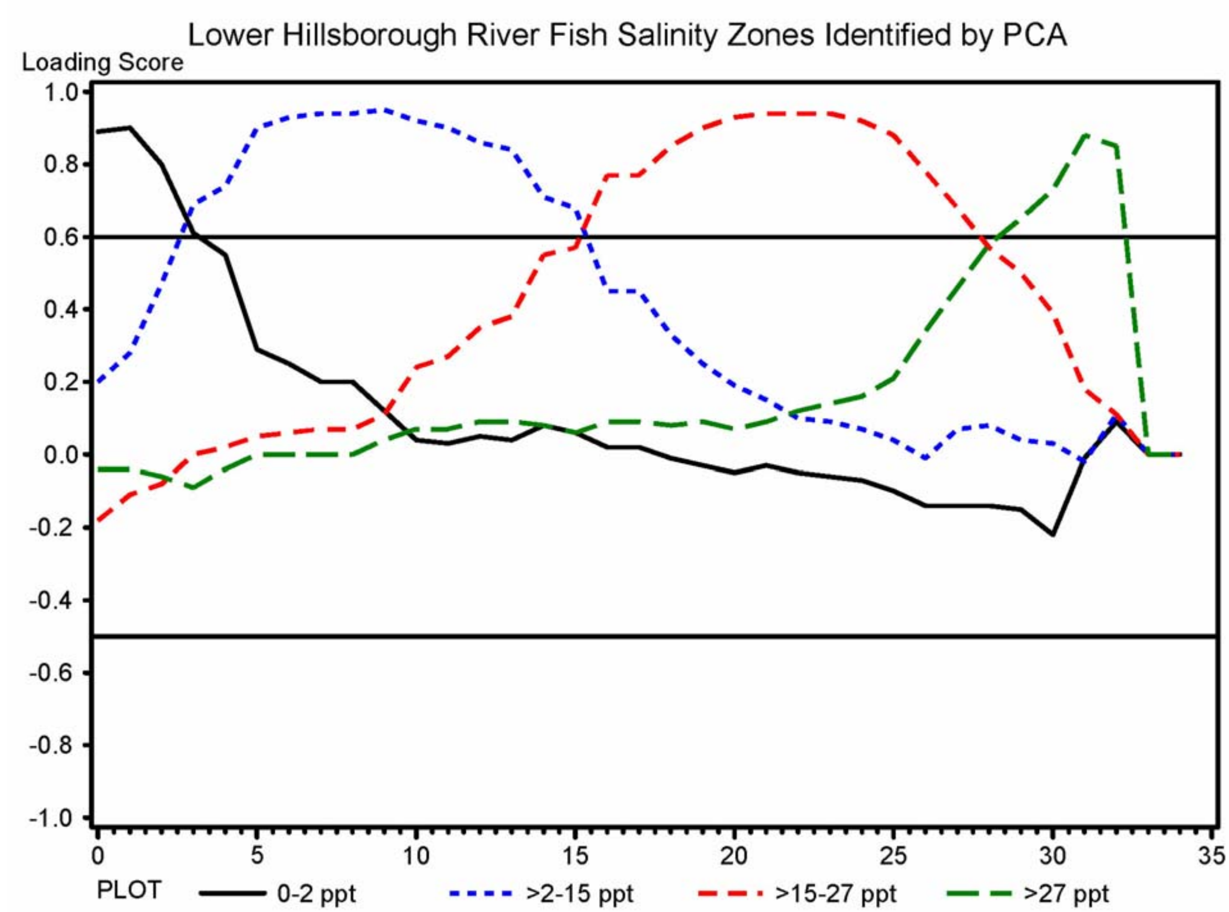


Figure 5-24 Principal Component Analysis of LHR adult/juvenile fish data.

5.3.4 Summary of Fish Observations

The LHR is inhabited by a diverse number of taxa, including freshwater, estuarine, estuarine-dependent, and marine species. A number of these taxa may be present in the river for one or more life stages. Estuarine dependent species, in particular, rely on the presence of low salinity habitat within the tidal river for nursery and foraging grounds.

Abundance responses were identified by MacDonald et al. (2005). Over half (51%) of the plankton-net species analyzed exhibited significant responses to freshwater flow, both positive (freshwater taxa increased in abundance) and negative (higher salinity taxa had a decrease in abundance as they moved out of river). Almost half (49%) of the taxa in the seine and trawl data exhibited significant responses to freshwater flow. The most common response to increased flow was negative (i.e., a decrease in abundance). However, some positive responses were seen and some resident and offshore taxa exhibited either a maximum or minimum abundance at intermediate flows (MacDonald et al., 2005).

Distributional responses were also identified by MacDonald et al., (2005). Almost half (49%) of the plankton-net species exhibited significant distribution responses to freshwater flow. Almost all were negative responses, meaning taxa moved downstream as flows increased. Estuarine dependent and estuarine resident species had more predictable distribution responses than either freshwater taxa below the dam or higher salinity taxa near the river mouth. Approximately one third (32%) of the pseudo-species (taxon-size class combinations) in the seine and trawl data exhibited significant distributional responses to freshwater flow. In all cases taxa moved downstream as flow increased.

Seasonality was reported by previous and recent studies. MacDonald et al., (2005) reported several observations about seasonality, including: taxa richness in plankton data was greater in spring and summer months, and lowest from July-Feb.; in seine collections, richness was high in the early summer months (May-July) and reduced in winter (Dec.-Jan.); seasonality was not observed in the trawl data (MacDonald *et al*., 2005).

Relationships between dissolved oxygen and abundance were also reported by MacDonald et al. (2005). Specifically it was noted that in the trawl data, which samples channel habitat, both abundance and species richness decreased as DO decreased (particularly below 2 mg/L).

To examine the fish community structure, principal components analysis was used to identify generalized salinity classes over which the fish taxa occurred. The following four salinity zones were delineated: Zone 1 = 0 - 2 ppt, Zone 2 = 2 - 15 ppt, Zone 3 = 15 -27 ppt, and Zone 4 = 27 - 32 ppt. Common species to Zones 1-3 were the hogchoker and silversides. The lowest salinity zone (Zone 1) had high numbers of bluegill and mosquitofish, while Zone 2 had gobies and daggerblade grass shrimp. Blue crab, pinfish and bay anchovies were the most common species in the highest salinity zone (Zone 4).

6.0 RELATIONSHIP BETWEEN FLOW AND WATER QUALITY CONSTITUENTS

The objective of this element of the MFL assessment was to review observed empirical relationships that describe how freshwater inflow near the Hillsborough River Reservoir dam affects responses in salinity, DO, chlorophyll *a*, and other water quality constituents in the LHR. These relationships can then be used to compare expected responses in the river to alternative minimum flow levels.

Two approaches were taken to apply the best available observed data. These approaches were:

- Empirical analysis of the observed data using graphical and statistical methods (Section 6.1), and

- A simulation modeling approach calibrated with observed data (Section 6.2).

The empirical analyses are fitted directly to the field observations. In comparison to the simulation modeling, these empirical analyses involve few underlying mechanistic assumptions. However, important constraints of the empirical analyses are that these analyses may not provide suitable predictions outside of the domains of the observed data used to derive the relationships, and the response prediction ranges of most interest (i.e., inflow rates between zero and 100 cfs) are not always well represented in the observed data. In addition, the simulation analyses allow factors such as tide and background salinity in Hillsborough Bay to be held at the same levels (or time series of levels) when comparing alternative freshwater inflow scenarios. The simulation modeling presented in Section 6.2 requires more underlying mechanistic assumptions, but it is not expected to be as constrained by the domains of the observed data.

6.1 Empirical Analyses

The objective of the empirical analyses was to increase the knowledge of the observed relationships that describe how freshwater inflow near the Hillsborough River Reservoir dam affects responses in salinity, DO, chlorophyll *a*, and other water quality constituents in the LHR. The relationships include the response of salinity at a series of continuous recorders during flow tests conducted by CoT and the District.

6.1.1 Salinity Empirical Analyses

In the LHR, the general expectations for salinity response to freshwater inflow are well known based on many years of review of the observed data and knowledge from other similar systems.

Salinity is expected to decline in the lower river in response to increasing freshwater inflow (Figure 6-1). In the absence of freshwater inflow for an extended period of time, salinity is expected to increase to nearly the concentrations existing in Hillsborough Bay. However, even in the absence of freshwater inflow through the discharge gates of the Hillsborough River Reservoir dam, salinity in the lower river is expected to be lower than salinity in Hillsborough Bay due to freshwater inflow from Sulphur Springs, dam leakage, storm water runoff, and groundwater sources. Due to higher salinity waters being denser than lower salinity waters, salinity concentrations are expected to be lower near the water surface and higher near the water bottom for any particular location in the lower river.

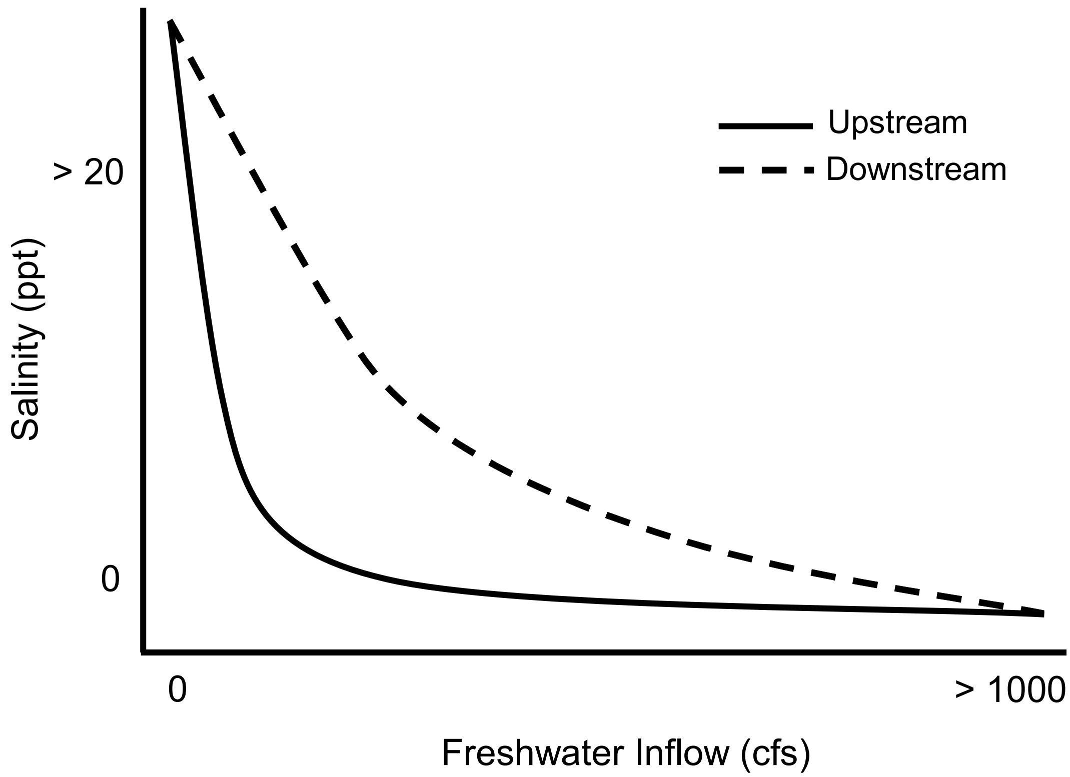


Figure 6-1 Conceptual expected response of salinity in the Lower Hillsborough River to freshwater inflow.

As the freshwater inflow rate increases, salinity is expected to initially decrease rapidly (Figure 6-1). This is particularly true for the upstream areas of the lower river where the volume of the river is relatively small compared to the volume of the discharges. Further increases in freshwater inflow are expected to result in further decreases in salinity but at a lower rate of change. At even higher freshwater inflow rates, salinity is expected to level off near zero ppt in the upper portion of the river near the dam. A similar response is expected in the downstream portion of the lower river. However, the larger volumes of the downstream portion of the lower river are expected to result in a much more gradual response to freshwater inflow (Figure 6-1). Salinity declines to near freshwater conditions are expected downstream only for the highest freshwater inflow rates. A high degree of variation in salinity is expected due to the influences of tide, wind driven water levels, and vertical stratification. Salinity can vary significantly over the course of each day as the tide moves upstream and downstream. At particular locations in the river, such as where the Sulphur Springs run joins the main river channel, lateral variation in salinity is also expected.

6.1.1.1 Salinity vs. Flow Relationships

Salinity field observations from the EPCHC Ambient Monitoring Program and the Tampa Bay Water HBMP were plotted against freshwater inflow to empirically describe the relationship of freshwater inflow near the Hillsborough River Reservoir dam to salinity in the LHR (Appendix 6-1). The inflow consisted of the sum of the flow over the dam plus Sulphur Springs diversions to the base of the dam which occurred after March 2003. The salinity observations were in agreement with the expectations described above. Surface and bottom salinity observations for a location near the dam (EPCHC Station 105), a location mid-way down the river (EPCHC Station 137), and a station near the river mouth (EPCHC Station 2) are presented in Figures 6-2 through 6-7. At all of these stations salinity decreased with increasing flow, and bottom salinity values were higher than surface salinity values. As expected, salinity was more responsive to freshwater inflow at the most upstream station (Station 105 – near the dam), and least responsive to flow at the most downstream station (Station 2 – near the river mouth).

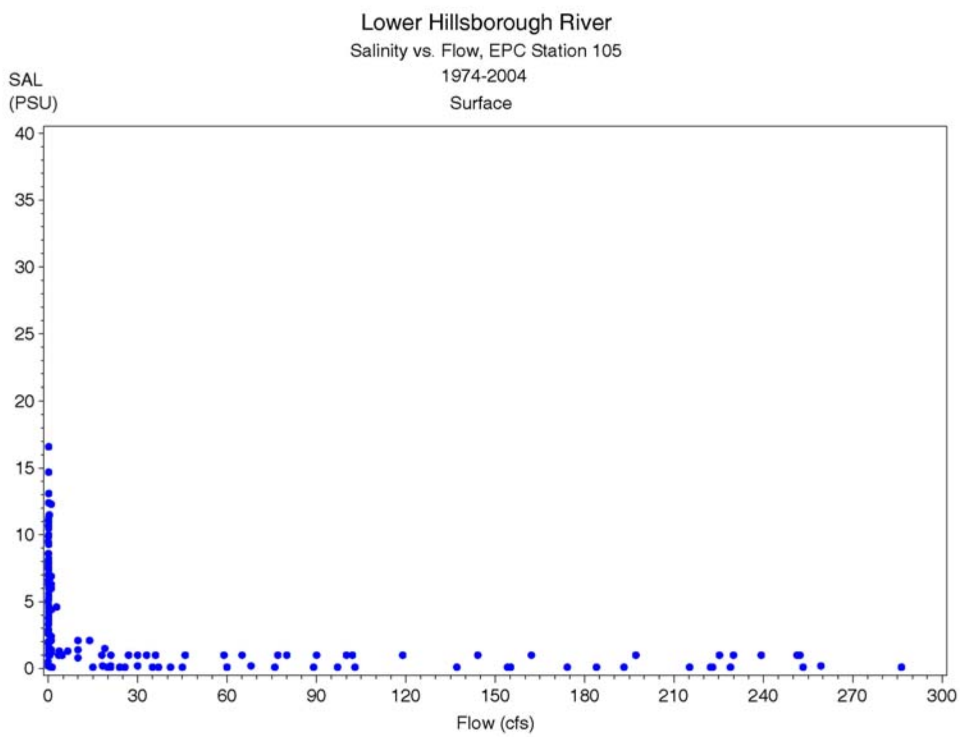


Figure 6-2 **Long term EPCHC surface salinity observations at EPC Station 105 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.**

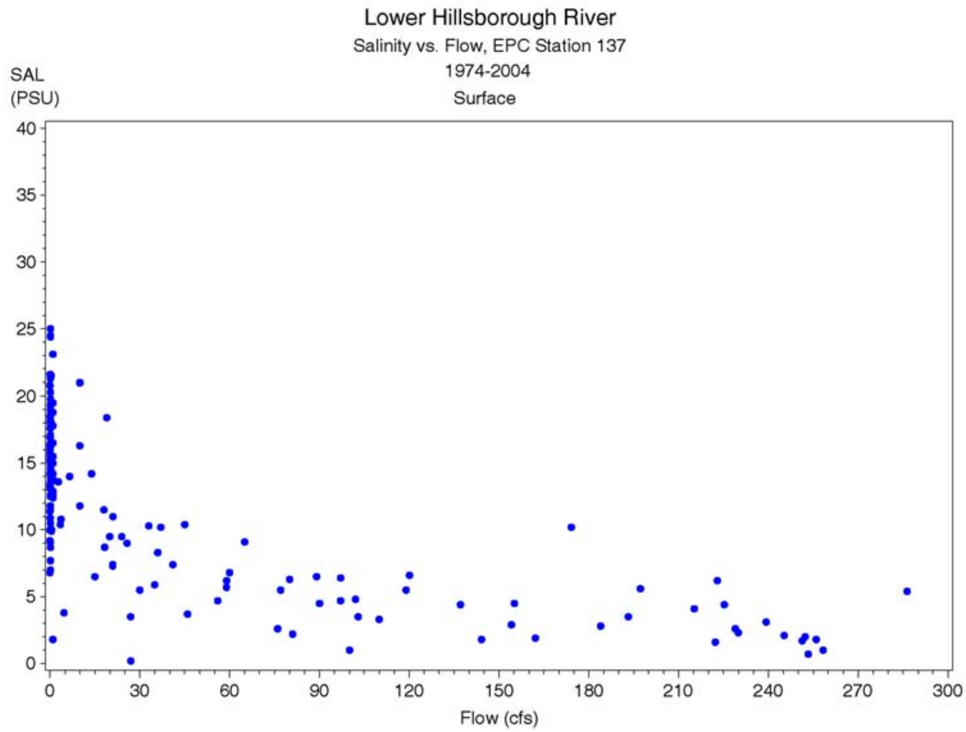


Figure 6-3 **Long term EPCHC surface salinity observations at EPC Station 137 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.**

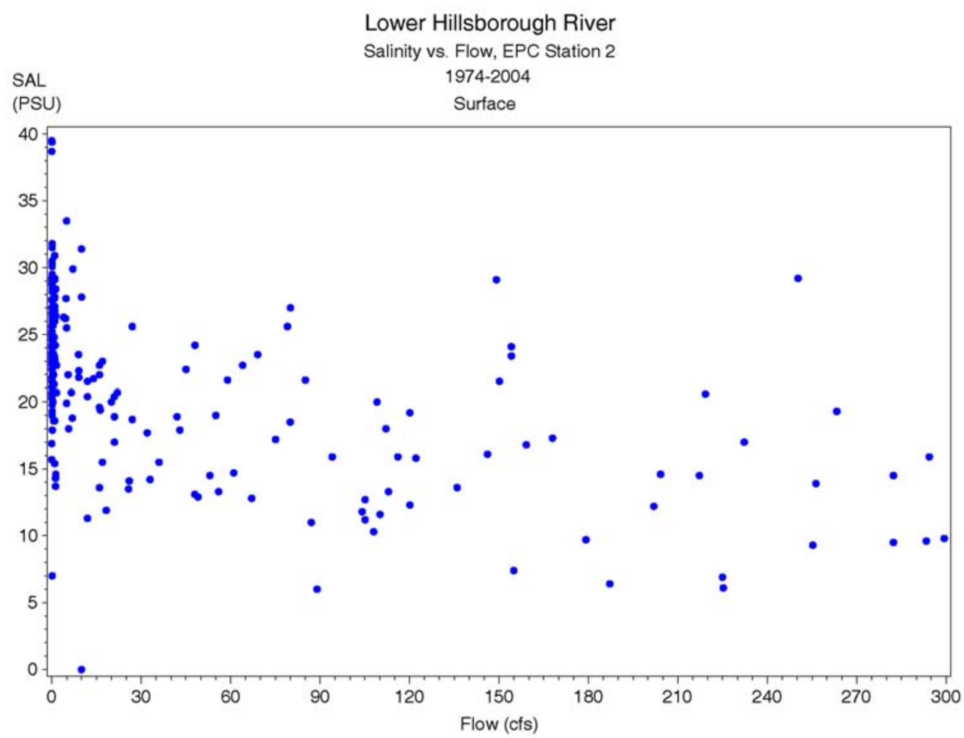


Figure 6-4 **Long term EPCHC surface salinity observations at EPC Station 2 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.**

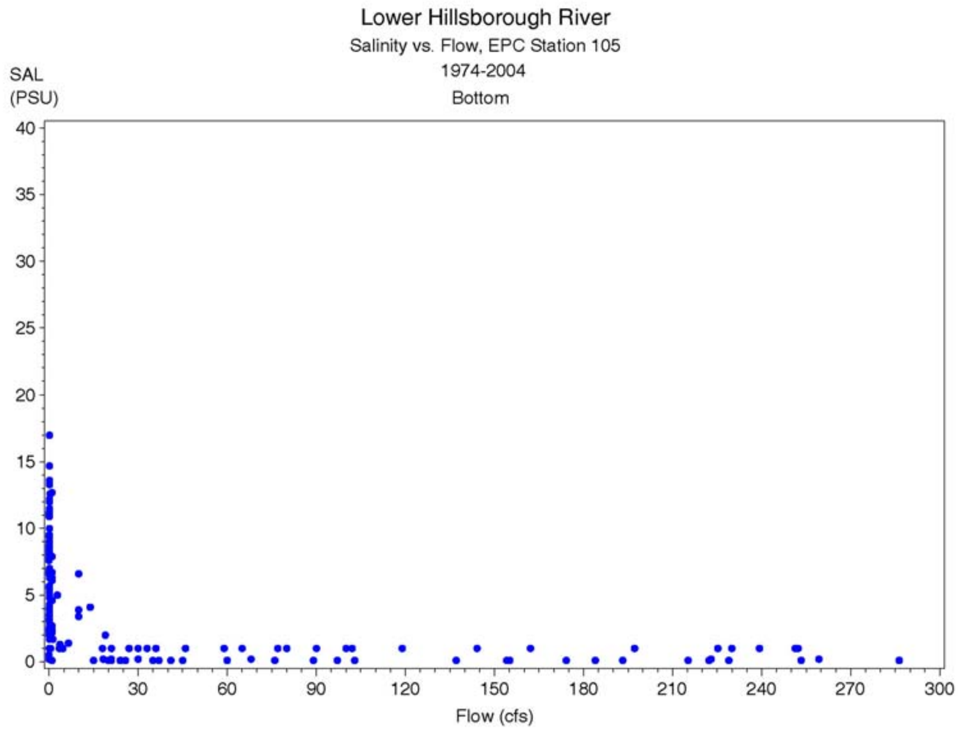


Figure 6-5 **Long term EPCHC bottom salinity observations at EPC Station 105 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.**

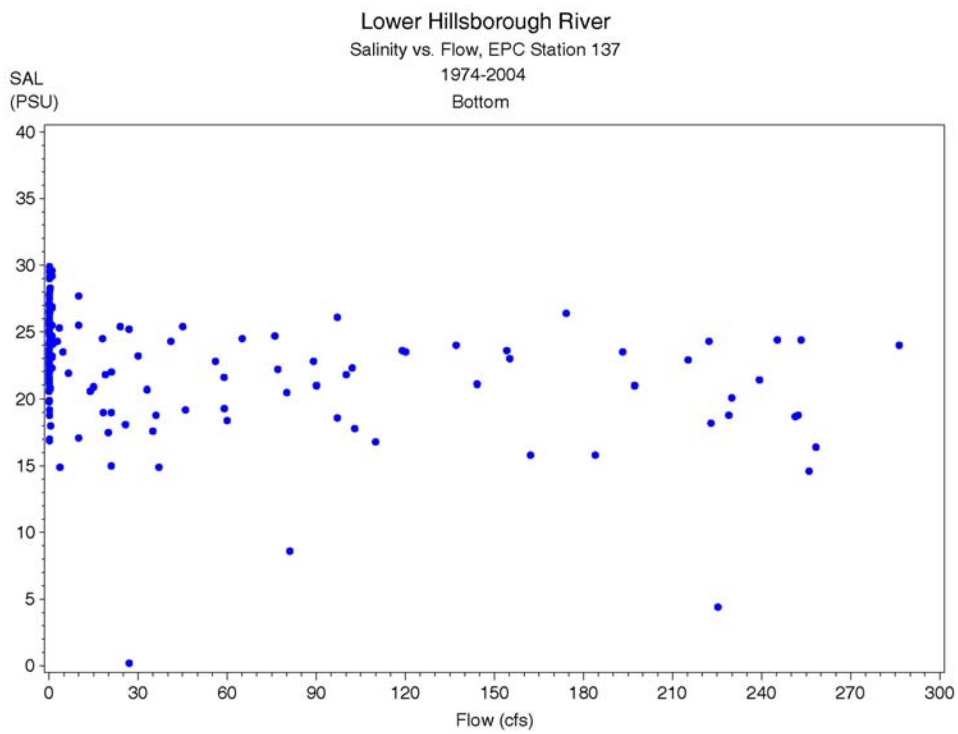


Figure 6-6 **Long term EPCHC bottom salinity observations at EPC Station 137 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.**

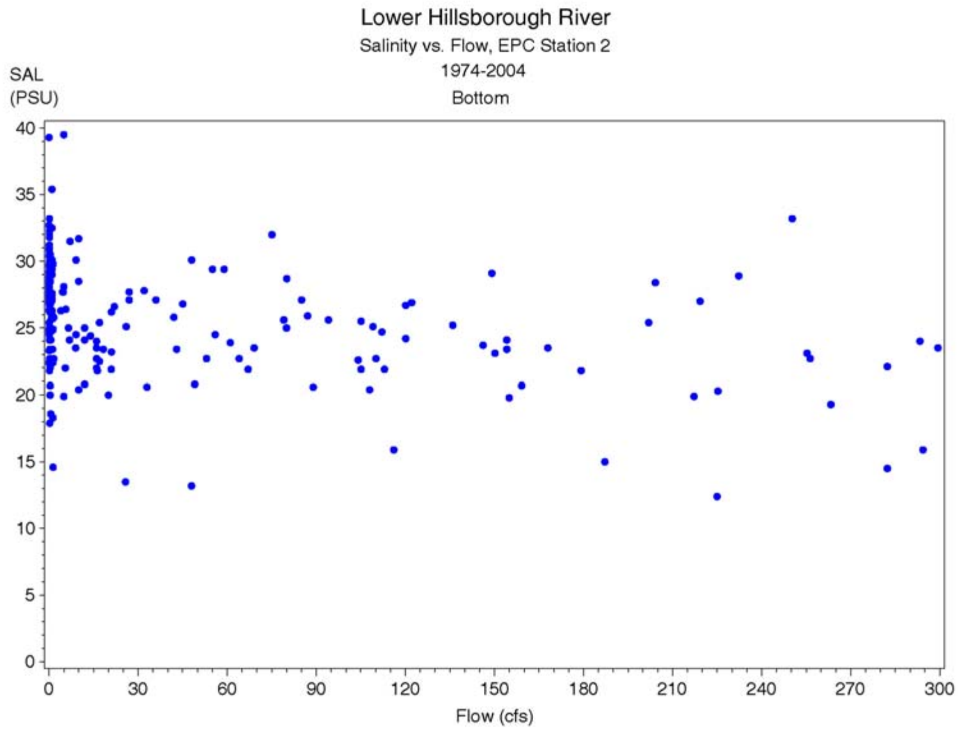


Figure 6-7 **Long term EPCHC bottom salinity observations at EPC Station 2 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.**

6.1.1.2 Controlled Release Experiments

As discussed previously, the CoT and the District conducted several experiments during which controlled flow rates of freshwater were introduced to the river near the dam, and salinity was monitored in the river during these experiments. These studies were conducted following the guidance provided by a plan of study developed in 2002 (Janicki Environmental, 2002), and taking advantage of suitable flow and rainfall conditions as they arose in the field. The source of freshwater for these experiments was freshwater from the reservoir above the dam and/or very low salinity water from Sulphur Springs rerouted to the base of the dam ("spring diversion"). In general, these experiments were conducted during the dry season when freshwater inflow was considered to be a more limiting resource. It was originally envisioned that both increasing and decreasing flow experiments would be performed in which flows would slowly increase or decrease over time; however, for logistical reasons, the majority of the experiments were declining (decreasing) flow experiments. The intention was to allow the experiments to proceed long enough for salinities in the LHR to stabilize.

The primary objective of these experiments was to provide quantitative information to verify and refine the District's LAMFE model for use in testing a range of freshwater inflows between 10 cfs and up to and including 30 cfs. The usefulness of the LAMFE model is assessed in Section 6.2.1.

As a secondary objective, the observed salinity responses during the controlled experiments are compared in this subsection. Although flow was controlled during these experiments, it is important to note that other factors could not be controlled (e.g., tide incursions, rainfall, ambient bay salinity, and antecedent flow conditions), and these other factors make direct comparison of responses between pairs of experiments difficult. However, the LAMFE model runs described elsewhere in this document allowed these other factors between flow scenarios to be controlled, so that balanced comparisons can be made of the river responses between flow scenarios. To reiterate, the primary importance of the river response data collected during the experiments was that they allowed the District to expand the verification and refinement of the LAMFE model under conditions (including measured tides, rainfall, bay salinity, and antecedent flows) where flows between 10 cfs and 30 cfs were previously not abundant.

In addition, the observed data from the controlled release experiments were used as important supplements to the previously existing observed data for global empirical analyses. For example, Section 6.1.2 provides statistical analyses of DO responses to flows for all observed data, including data collected during the controlled release experiments.

Seven controlled release experiments were conducted between 2002 and 2004. Descriptions of the controlled flows during these seven test periods are provided in the following text and are summarized in Table 6-1.

Test Period 1 – In March 2002, a flow test was initiated that involved diverting low salinity water from Sulphur Springs to the base on the dam with no freshwater releases from the reservoir. During this test period, a prolonged test of the 10 cfs spring diversion occurred in April, May, and June.

The bottom salinity response in the river near Rowlett Park during Test Period 1, 10 cfs spring diversion and 0 cfs dam release, is presented in Figure 6-8. The most evident initial observation from these data is that salinity in the river is quite variable, even during times when freshwater inflow rates were held relatively constant. This short-term cyclical variability is driven primarily by tidal incursions of higher salinity water from downstream reaches of the river and rainfall, and the variability was only reduced when the freshwater inflow rate increased from 10 cfs to 20 cfs in mid June and the river salinity at this location was reduced to the low salinity of the diverted spring water (approximately 1.3 ppt).

Table 6-1. Controlled release experiments. Flow regime quantities are typical mean values during relatively stable flow periods for Hillsborough River dam and diversions of water from Sulphur Springs to base of Hillsborough River dam.

Experiment	Experiment Period	Flow Regime
1	15 Apr – 12 Jun 2002	0 cfs Dam, 10 cfs Diversion
2	13 Jun – 17 Jun 2003	20 cfs Dam, 0 cfs Diversion
3	6 Jan – 17 Jan 2004	0 cfs Dam, 13 cfs Diversion
4a	10 Apr – 12 Apr 2004	0 cfs Dam, 11 cfs Diversion
4b	26 Apr – 16 May 2004	0 cfs Dam, 12 cfs Diversion
4c	19 May – 23 May 2004	0 cfs Dam, 12 cfs Diversion
4d	25 May – 3 Jun 2004	11.5 cfs Dam, 0 cfs Diversion
4e	5 Jun – 16 Jun 2004	0 cfs Dam, 0 cfs Diversion
5a	28 Jun – 8 Jul 2004	20 cfs Dam, 0 cfs Diversion
5b	10 Jul – 12 Jul 2004	30 cfs Dam, 0 cfs Diversion
6	18 Dec – 23 Dec 2004	15.5 cfs Dam, 11.5 cfs Diversion
7a	31 Jan – 10 Feb 2005	16 cfs Dam, 0 cfs Diversion
7b	15 Feb – 3 Mar 2005	6 cfs Dam, 10 cfs Diversion

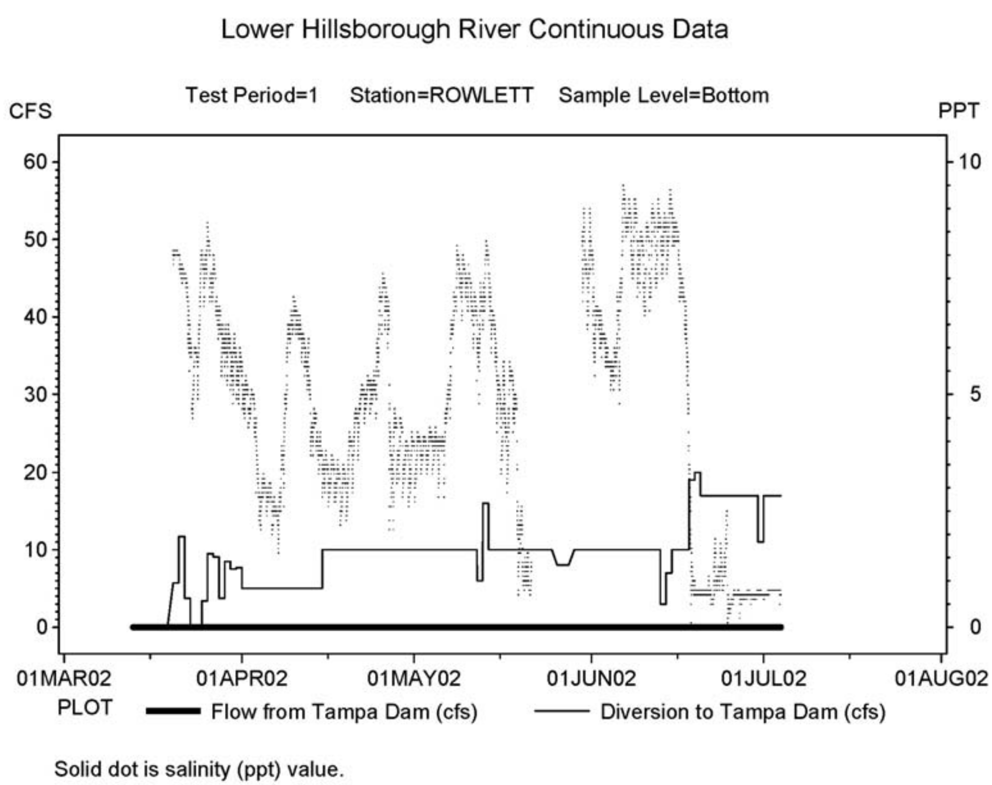


Figure 6-8 Dam flow and spring diversion flow during Test Period 1 (left axis), and observed Rowlett Park continuous recorder bottom salinity (right axis- solid circles).

Test Period 2 - A period of low flows from the dam (<50 cfs) occurred between May and June of 2003. This period was preceded by a period of high flows (>1400 cfs) in early April.

A similar salinity variation range of 3 to 9 ppt bottom salinities was observed in the river at Hillsborough River at Sulphur Springs gage during a prolonged 10 cfs controlled flow rate during Test Period 2 (Figure 6-9), and the short-term cyclical tidal driven variation was also evident. The example observations provide initial information on the timing of salinity responses to flow changes. During this period, Hannah's Whirl bottom salinities were extremely responsive to freshwater inflows of 60 to 80 cfs, but returned to the 3 to 9 ppt salinity range relatively quickly after the 60 to 80 cfs flow was halted.

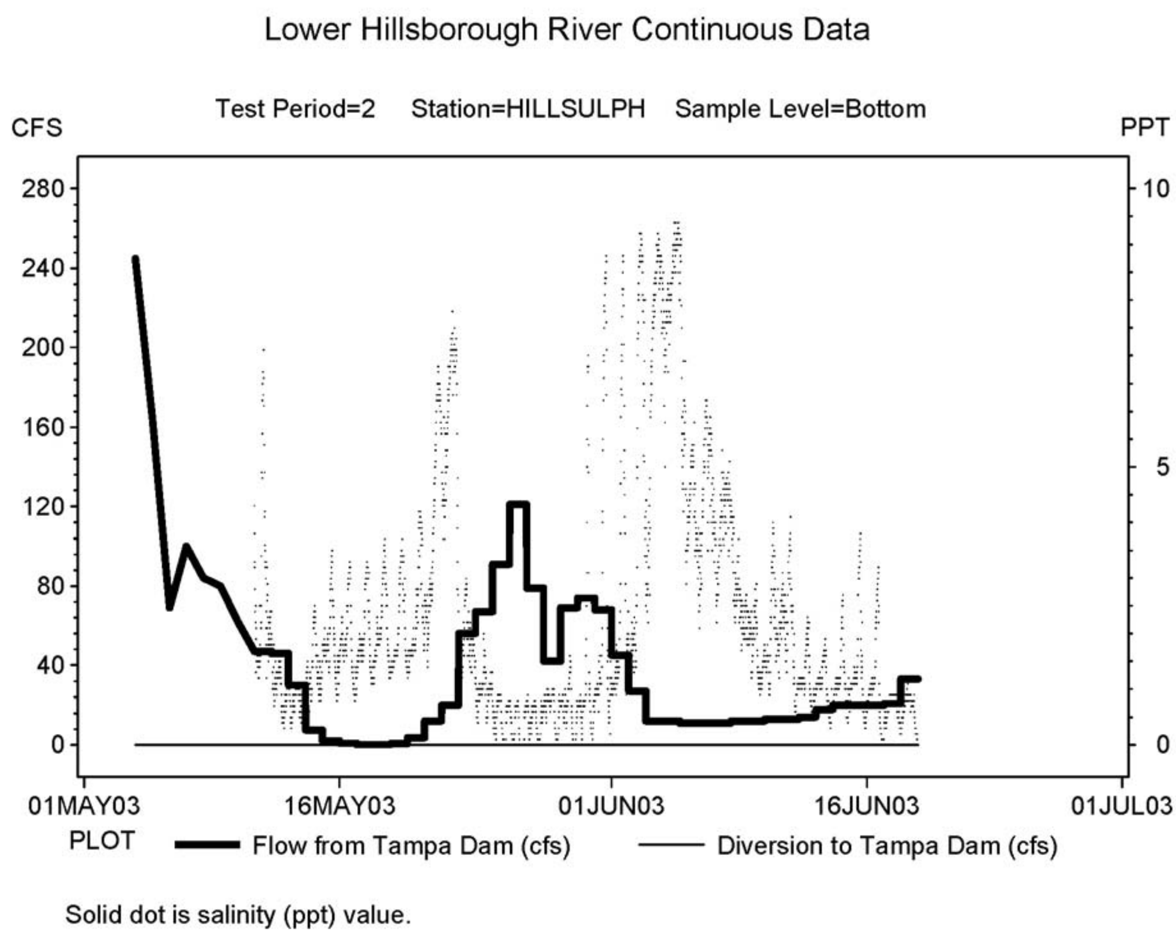


Figure 6-9 **Dam flow and spring diversion flow during Test Period 2 (left axis), and observed Hillsborough River at Sulphur Springs continuous recorder bottom salinity (right axis – solid circles).**

Test Period 3 – A prolonged declining flow test began on October 16, 2003. This test was preceded by high flows in the summer of 2003. Additional dam releases combined with spring diversions occurred in December of 2003.

Surface salinity observations from the river near Rowlett Park during Test Period 3 are presented in Figure 6-10. These data indicate how a threshold effect in the response of salinity to freshwater inflow may be observed at times depending on location of the salinity observations, downstream salinity conditions, and freshwater inflow magnitudes. These observations indicate that salinities varied between 0 and 5 ppt at this location in December of 2003 in response to a relatively constant inflow, and this was regardless of whether the source of the inflow was from the Tampa Dam or spring diversion. When the Tampa Dam flow and diversion were provided together for a test at the end of December, the salinities rapidly responded by approaching 0 ppt, and the salinities returned to their previous range after the Tampa Dam flow ceased. These observations indicate that the initial downward salinity response to a new inflow source was more rapid than the subsequent upward salinity response when the new inflow source was halted.

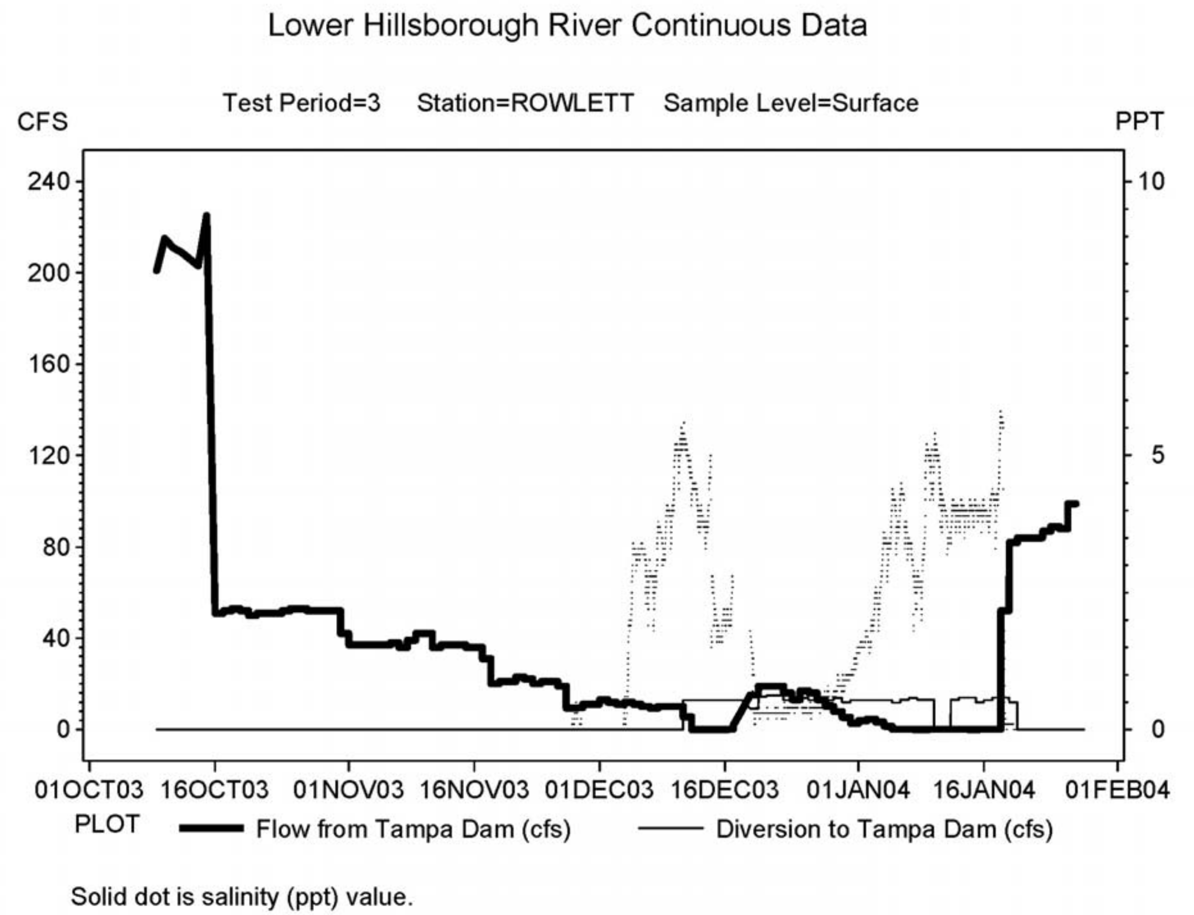


Figure 6-10 Dam flow and spring diversion flow during Test Period 3 (left axis), and observed Rowlett Park continuous recorder surface salinity (right axis – solid circles).

Test Period 4 – A period of spring diversions with periodic dam releases occurred from April to June of 2004.

Bottom salinity observations at Hannah's Whirl are presented during Test Period 4 in Figure 6-11. These observations indicate that the cyclical variation in salinity observed upstream near Rowlett Park was also observed at downstream locations. The salinity responses at Hannah's Whirl to near April 16, 2004 were a rapid decline to freshwater for a 60 to 80 cfs pulse of water from the Tampa Dam followed by a more gradual return to the higher salinity range following the halting of the freshwater inflow pulse.

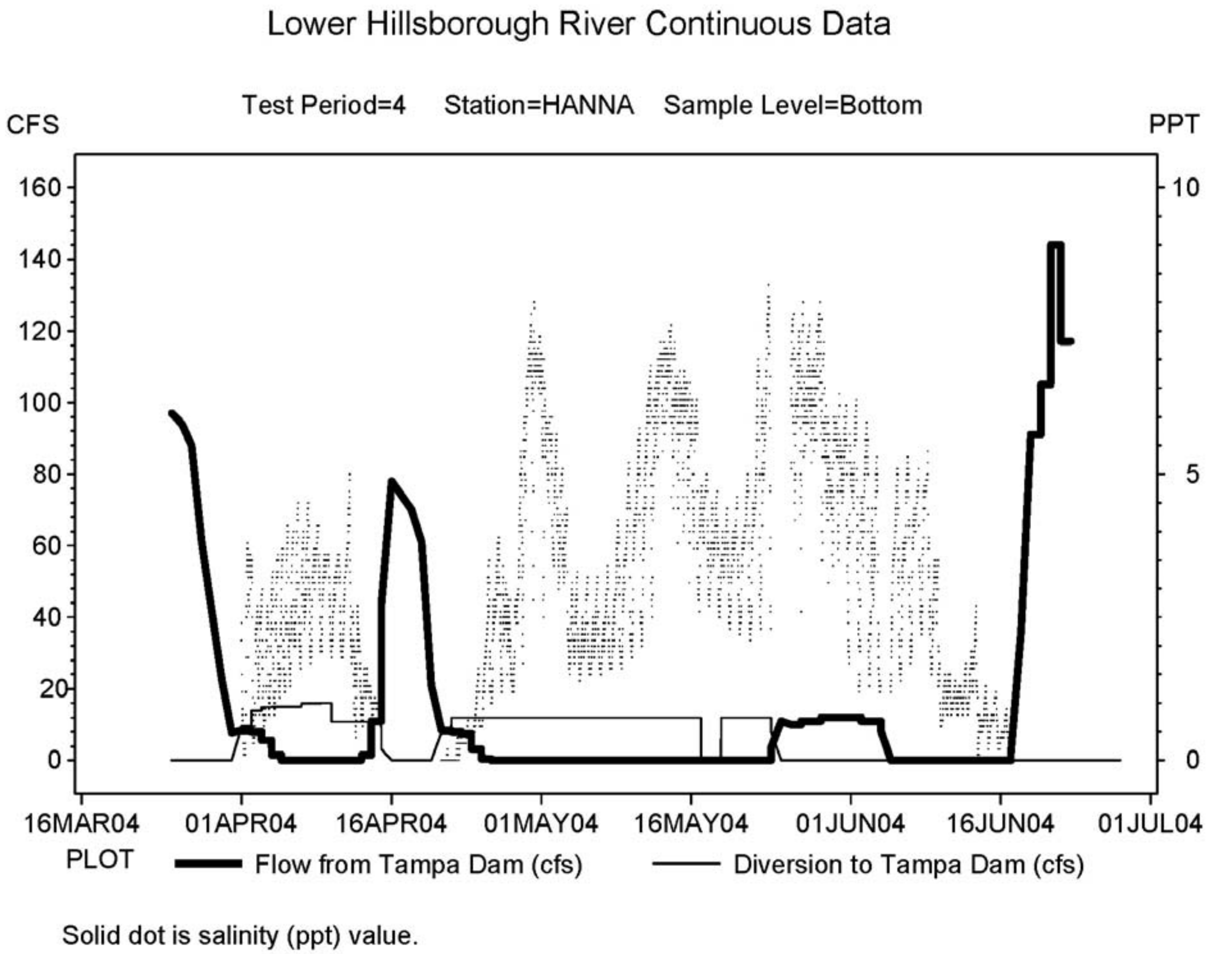


Figure 6-11 **Dam flow and spring diversion flow during Test Period 4 (left axis), and observed Hannah's Whirl continuous recorder bottom salinity (right axis – solid circles).**

Test Period 5 – A period of low flows from the dam occurred between high dam flow pulses during late June and early July of 2004.

Surface salinity observations from a station at Platt Street near the river mouth are plotted during Test Period 5 in Figure 6-12. These observations indicated that the cyclical tidal variation in salinity near the river mouth remained relatively constant over the half month observed with respect to maximum salinity after a series of Tampa Dam inflows were reduced. However, a gradual increase in the minimum salinity was observed over an approximately one week period following halting of Tampa Dam inflows.

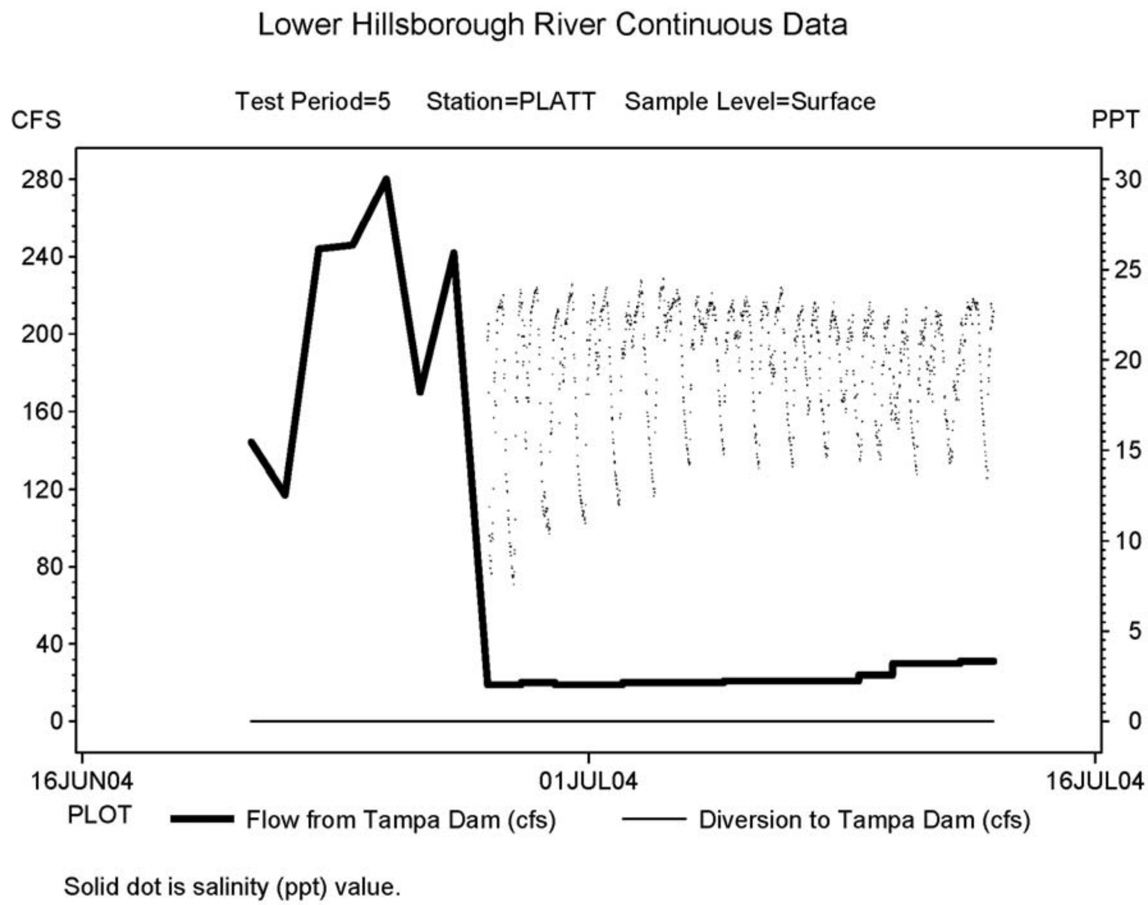


Figure 6-12 Dam flow and spring diversion flow during Test Period 5 (left axis), and observed Plat Street continuous recorder surface salinity (right axis – solid circles).

Test Period 6 – A prolonged period of low flow dam discharges occurred with several spring diversions between November of 2004 and January of 2005.

Figures 6-13 and 6-14 present the surface and bottom salinity responses to Tampa Dam inflows during Test Period 6. No spring diversions were conducted during this test period. Although surface salinity was observed to respond to a decrease in inflow, bottom salinity was not observed to have a similar response threshold for the same flow test period.

The conclusions to be drawn from these controlled release periods are that inflow rates affect the cyclical tide-driven variation in salinity at particular flow thresholds depending on location in the river, depth, and flow magnitude. Increases in flow were observed to result in more rapid changes in salinity than decreases in flow. Importantly, these data provided comprehensive information for the range of freshwater inflow between 0 cfs and 100 cfs that had previously been lacking.

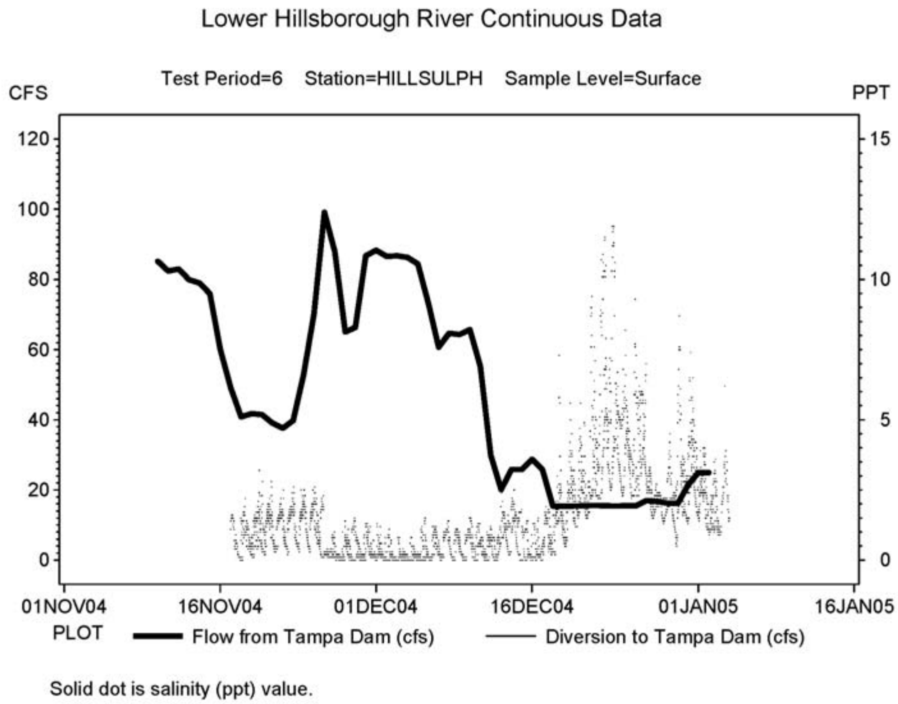


Figure 6-13 **Dam flow and spring diversion flow during Test Period 6 (left axis), and observed Hillsborough River at Sulphur Springs continuous recorder surface salinity (right axis – solid circles). There were no spring diversions during this test period.**

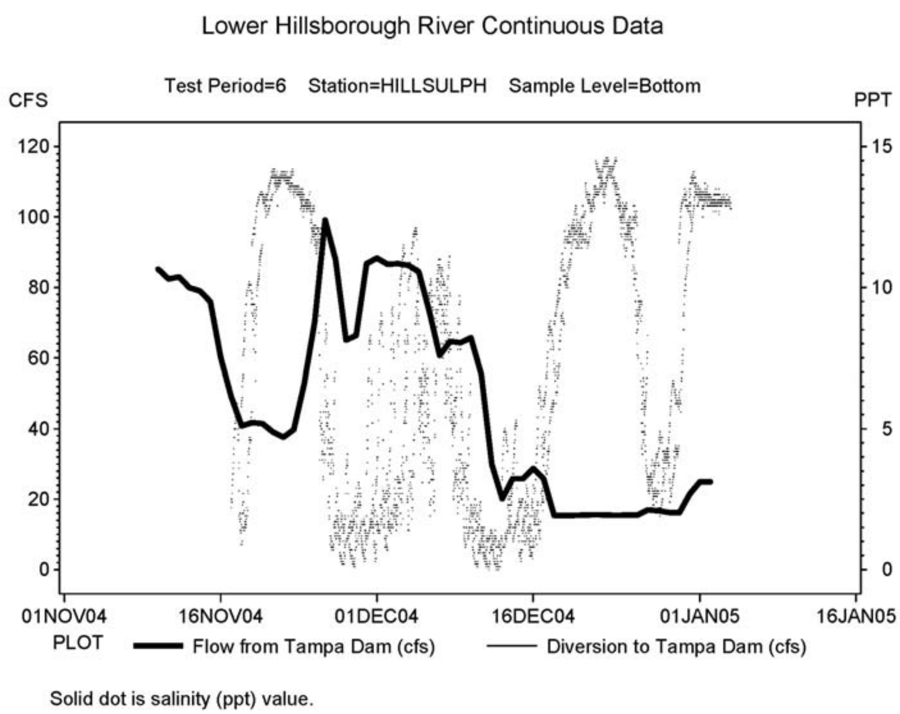


Figure 6-14 **Dam flow and spring diversion flow during Test Period 6 (left axis), and observed Hillsborough River at Sulphur Springs continuous recorder bottom salinity (right axis – solid circles). There were no spring diversions during this test period.**

Test Period 7 – A period in the winter of 2005 where a 16 cfs flow from the dam was compared to a 16 cfs combination of dam flow and Sulphur Springs diversion.

The empirical salinity responses during these experimental periods followed the expected salinity responses described above. The salinity responses at various river regions and depths are summarized in Appendix 6-2 (Tables A6-1 through A6-20). A complete set of plotted dam flow, Sulphur Springs diversion flow, and observed salinity responses during the experimental periods is presented in Appendix 6-3 for the USGS continuous recorder data, EPCHC Hillsborough Independent Monitoring Data, and the District Profile Monitoring data.

Salinity field data from many previously described independent sources operating during the controlled release experiments were compiled into a combined database. These observations represent a broad range of geographic locations, depths, seasons, and flow conditions for the LHR from the dam to the mouth at Platt Street.

The salinity data were summarized for comparison between experiments by computing the mean salinity and peak salinity (95th percentile) during each experiment (Tables A6-1 through A6-20). Data are presented using two approaches. In the first approach, the salinity values were summarized for each experiment across the entire experiment period defined in Table 6-1. In the second approach, data were summarized for each experiment for the last two days of the experiment only. The intention was to present information for the entire experiment and also for the period (at the end of each experiment) for which the salinity responses were most likely to have stabilized with respect to flow. For the continuous recorder data, the mean and peak salinity were first calculated for each 24 hour calendar day, and then the grand mean and mean peak salinity were computed across the multiple days of the experiment. For the 72 hour recorder data, complete 24 hour periods were slotted to calendar sampling days starting with the calendar day of the first observation from the 72 hour deployment, and the data were then summarized in the same manner as the continuous recorder data. For the profile data, mean salinities and peak salinities (95th percentiles) were computed during the experiments for surface, middle, and bottom depths. Surface and bottom samples were defined as the shallowest and deepest sample from each profile.

Since the source of saline water in the LHR is from tidal incursions from Hillsborough Bay, background Hillsborough Bay salinities were computed as the mean bottom salinity during each experiment at EPCHC Station 55. Although, the salinity in Hillsborough Bay is itself influenced by flow from the Hillsborough River, the mid bay Station 55 provides an appropriate background reference value at these low flow conditions.

Upstream Salinity Responses During the Controlled Release Experiments

Upstream of Sulphur Springs, the salinity regime in the LHR was expected to respond to the rate of discharge of freshwater from the dam and nearly fresh (approximately 1.2 ppt) Sulphur Springs water diverted to the base of the dam. Tables A6-1 through A6-

10 compare the salinity results of the controlled release experiments using the methods described above. The columns in these tables are ordered from the least total flow (i.e., dam flow plus spring diversion flow) to the greatest total flow. The rows in the table present salinity results from different sampled depths as groups of rows and the groups of rows are ordered from upstream to downstream. Mean and peak salinity responses are compared for the entire period of each experiment and from the final two days of each experiment.

The salinity responses compared in Tables A6-1 through A6-10 are the result of all of the environmental influences that were acting during each experiment. Important environmental influences on salinity in this portion of the river during each experiment include:

- the total flow rate from the dam and Sulphur Springs diversions to the base of the dam during the experiment,
- the antecedent flow conditions immediately prior to the experiment,
- the background salinity in Hillsborough Bay during the experiment,
- the rainfall and associated nonpoint source runoff during the experiment and immediately prior to the experiment, and
- the height and duration of the high tide incursions into the river upstream of Sulphur Springs during the experiment.

Within the context of the combined influence of all of these factors, the strongest results from the experiments were that total flows greater than or equal to 20 cfs resulted in nearly fresh (i.e., less than 1 ppt) salinities at Rowlett Park under all experimental conditions. For a more limited set of observations, salinities at the Hannah's Whirl continuous recorders, were always nearly fresh at total flows of 30 cfs. At total flows less than 20 cfs, the salinity responses upstream of Sulphur Springs were influenced to a greater degree by factors other than total flow. Notably, salinity during and at the end of Experiment 1 was relatively high (mean > 5ppt) all the way upstream to Rowlett Park. Salinity downstream in Hillsborough Bay was high during Experiment 1 (30.4 ppt).

Similar results were obtained for analyses of the data from the entire LHR from the dam to Platt Street. The diversion of Sulphur Springs water that relocated low salinity water inflows to the base of the dam was expected to have little net effect on salinities downstream of Sulphur Springs. Tables A6-11 through A6-20 compare the salinity results of the controlled release experiments using the methods described above for the entire LHR. The columns in these tables are ordered from the lowest dam flow to greatest flow. The rows in the table present salinity results from different sampled depths as groups of rows, and the groups of rows are ordered from upstream to downstream. Mean and peak salinity responses are compared for the entire period of each experiment and for the final two days of each experiment.

The link between Hillsborough Bay background salinities and LHR salinities extending upstream is more apparent in the summarized results for the entire LHR (Tables A6-11 through A6-20). At the higher flow ranges, Experiments 2 and 5a had the same dam flow rates of 20 cfs. However, Experiment 2 had a lower Hillsborough Bay background salinity (24 ppt) than Experiment 5a (27.8 ppt). The salinity responses in the LHR were observed to be higher for Experiment 5a than Experiment 2 in the downstream portions of the LHR, and the salinity responses were nearly the same between these two experiments upstream of and including Hannah's Whirl. These experiments show the effect that Hillsborough Bay background salinity has on salinities in the LHR.

The value of the experimental results was primarily in providing the important 10 to 40 cfs flow response data needed for verification and refinement of the District's LAMFE model. The LAMFE model was then used to describe the expected salinity responses between alternative flow scenarios as described in the next section of this document. It is important to remember that unlike the controlled release experiments, the LAMFE model analyses were able to examine the effects of freshwater inflow alternative scenarios while maintaining the same conditions for the other influencing factors (e.g., antecedent flow, Hillsborough Bay salinity, rainfall, nonpoint source runoff, tidal incursions).

6.1.2 DO Empirical Analysis

DO responses to freshwater inflow are expected to be pronounced in the upstream portion of the Lower Hillsborough River near the dam. In this upstream area, nearly any freshwater inflow is expected to physically mix and aerate the river water and result in higher DO values. The general expectations for the downstream portions of the lower river are that DO concentrations will generally increase with increasing flow. However, localized exceptions to this general expectation are likely due to complex freshwater inflow driven stratification relationships. Importantly, as freshwater inflow increases organic carbon supply is increased and may contribute to lower DO concentrations. However, as freshwater inflow increases, residence time decreases and may contribute to higher DO concentrations. The variation in DO is expected to be relatively high, and it is expected to be particularly responsive to depth, temperature, and time of day.

DO field data from water column profiles were compiled into a combined database of 12,409 observations from the following monitoring programs:

- SWFWMD fixed station monitoring from the dam to just downstream of Sulphur Springs (March 2002 to February 2005),

- EPCHC probabilistic benthic monitoring from just downstream of Sulphur Springs to Platt Street (September 1995 to August 2003),

- EPCHC profile monitoring for the LHR (March 2000 to August 2005),

- Tampa Bay Water HBMP probabilistic benthic monitoring for the LHR (June 2000 to February 2004),

- Tampa Bay Water HBMP probabilistic fish monitoring for the LHR (May 2000 to December 2003), and

- Tampa Bay Water HBMP probabilistic water quality monitoring for the LHR (April 2000 to March 2004).

These observations represent a broad range of geographic locations, depths, seasons, and flow conditions for the LHR from the dam to Platt Street.

A series of empirical analyses were conducted using these profile data to quantify the expected relationship of dissolved oxygen responses to freshwater inflow. Based on initial review of the data, a conservative decision was made to apply the final empirical analyses to the DO observations from the bottom sample (i.e., deepest depth for which DO was reported) in each profile. The lowest dissolved oxygen conditions are expected to be found in the deepest portion of the water column near the river bottom. At these bottom locations, the least mobile biological resources are also expected (e.g., benthic macroinvertebrates).

Compiled together, the data from all of these monitoring programs provide a large representative sample of bottom DO conditions for the LHR between the dam and Platt Street. Figure 6-15 presents the range of depths sampled for the bottom samples in the LHR. Sampling for the District and EPCHC HIMP monitoring were generally directed towards the center of the river channel and tended to collect bottom DO observations in deeper waters. The other monitoring programs were based on probabilistic sampling designs and collected DO observations from a wider range of depths.

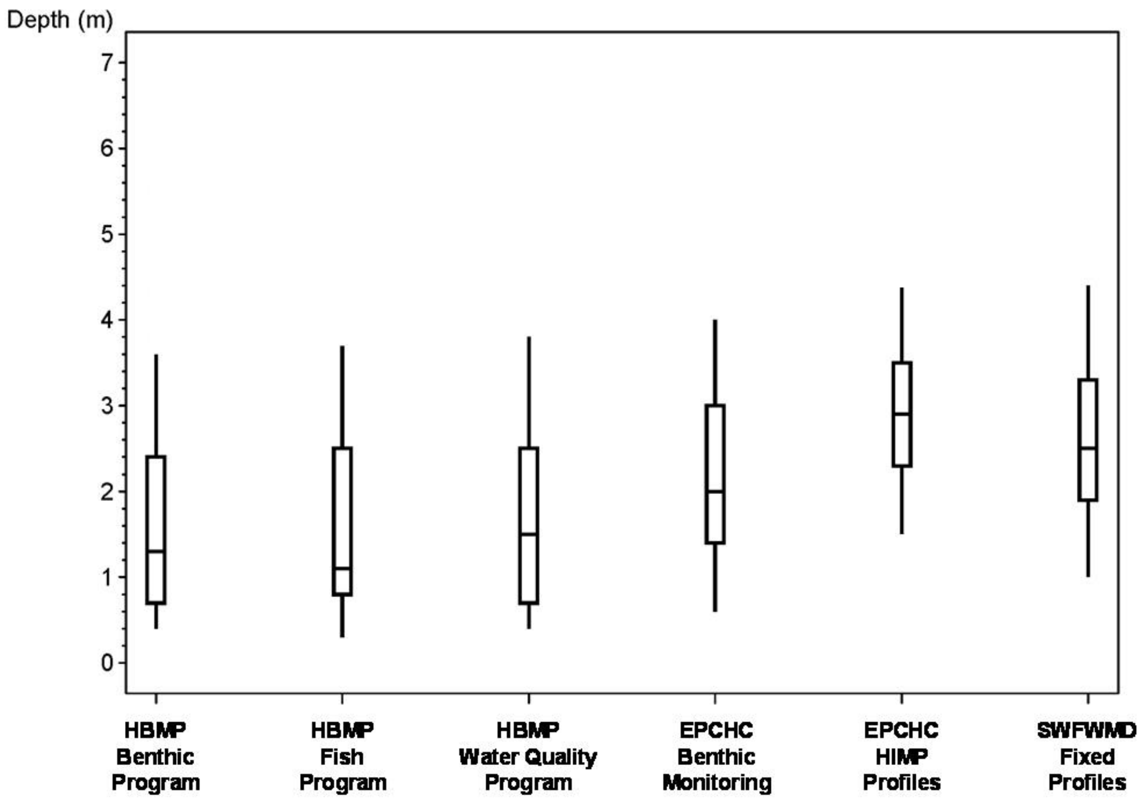


Figure 6-15 Depths reported for each monitoring program for bottom DO samples in the LHR. The boxes extend from the 25th to 75th percentiles, and the whiskers extend from the 5th to 95th percentiles.

The first consideration addressed using the observed DO data was to determine if DO concentrations responded to variation in flow from the dam. Figures 6-16 and 6-17 present the observed relationship of low DO conditions to flow in Strata 5 and 6, respectively. Stratum 5 extends approximately from Sligh Avenue to Sulphur Springs and Stratum 6 extends from Sulphur Springs to the dam (Figure 3-1). A summary of the percent of DO observations less than 2.5 mg/L by flow class is presented in Table 6.2. District staff operationally defined low DO conditions for these empirical analyses as DO concentrations less than 2.5 mg/l.Based on these analyses, one may conclude that low DO conditions are responsive to flow from the dam. At flows less than 20 cfs, low DO conditions were observed to be common. At flows greater than 60 cfs, low DO conditions were observed to be relatively rare. At intermediate flows between 20 and 60 cfs, low DO conditions were observed to occur for a portion of the time.

Table 6.2 Summary of percent of DO observations less than 2.5 mg/L by flow class for Strata HR5 and HR6.

Stratum	Percent of DO observations less than 2.5 mg/L		
	< 20 cfs	20 <= flow < 60 cfs	60 <= flow < 300 cfs
HR5	60%	48%	17%
HR6	46%	19%	2%

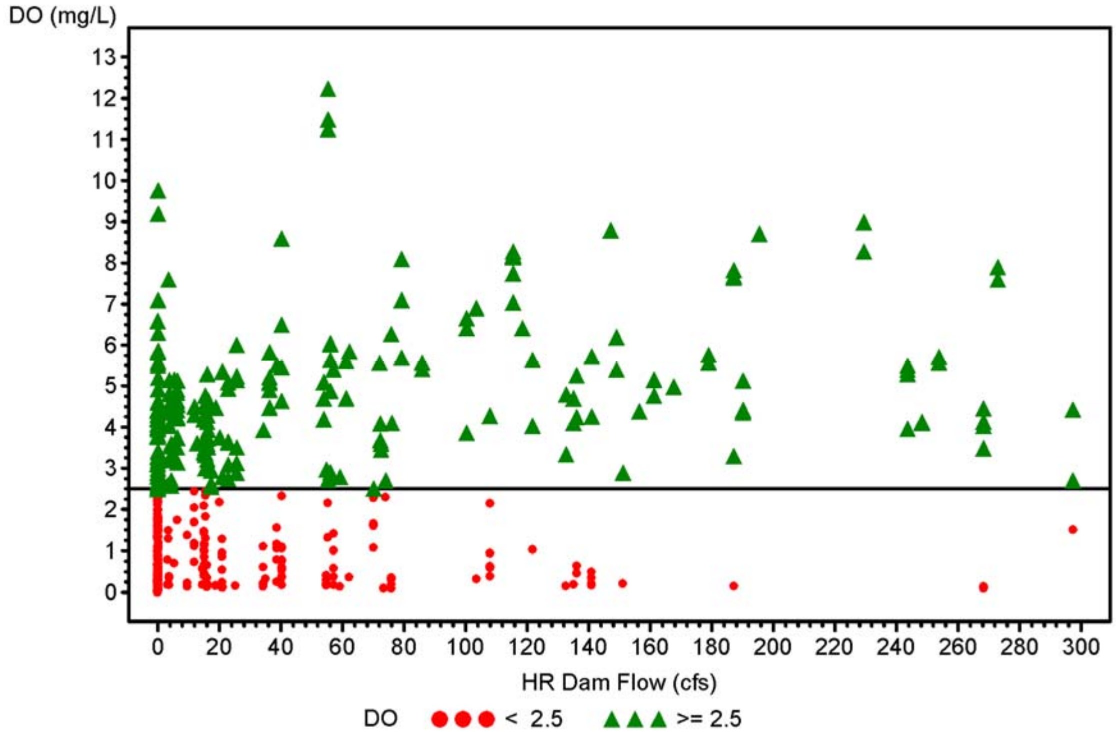


Figure 6-16 **Bottom DO in LHR Stratum 5 (approximately from Sligh Avenue to Sulphur Springs) as a function of dam flow.**

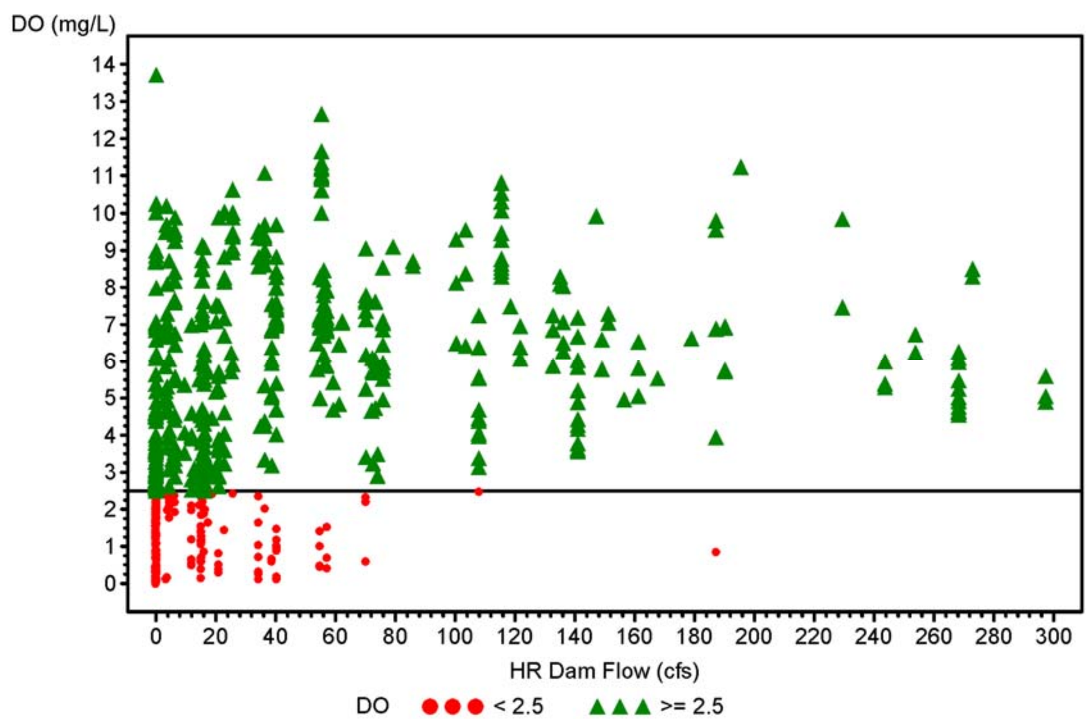


Figure 6-17 **Bottom DO in LHR Stratum 6 (approximately from Sulphur Springs to the dam) as a function of dam flow.**

The next consideration was to determine where in the river low DO conditions occurred when dam flows ranged between 20 and 60 cfs. Figure 6-18 presents bottom DO observations for this flow range as a function of river kilometer and bottom depth. The data presented in this plot indicate that low DO conditions primarily occurred at locations where the bottom depth was greater than 1.5 meters between River Kilometers 10 and 14. Kilometers 10 through 14 extend from an area downstream of Hannah's Whirl to an area downstream of Sligh Avenue (Figure 6-19).

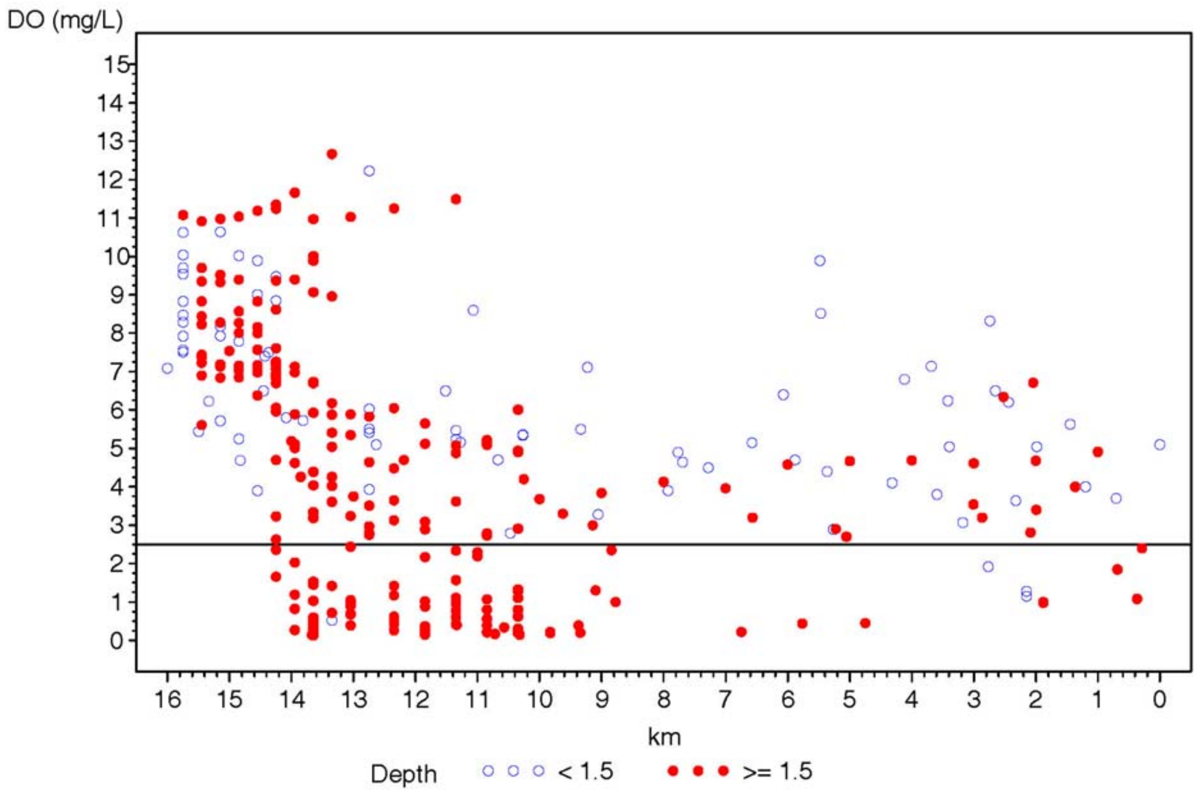


Figure 6-18 Bottom DO in the LHR as a function of river kilometer and depth for dam flows between 20 and 60 cfs.

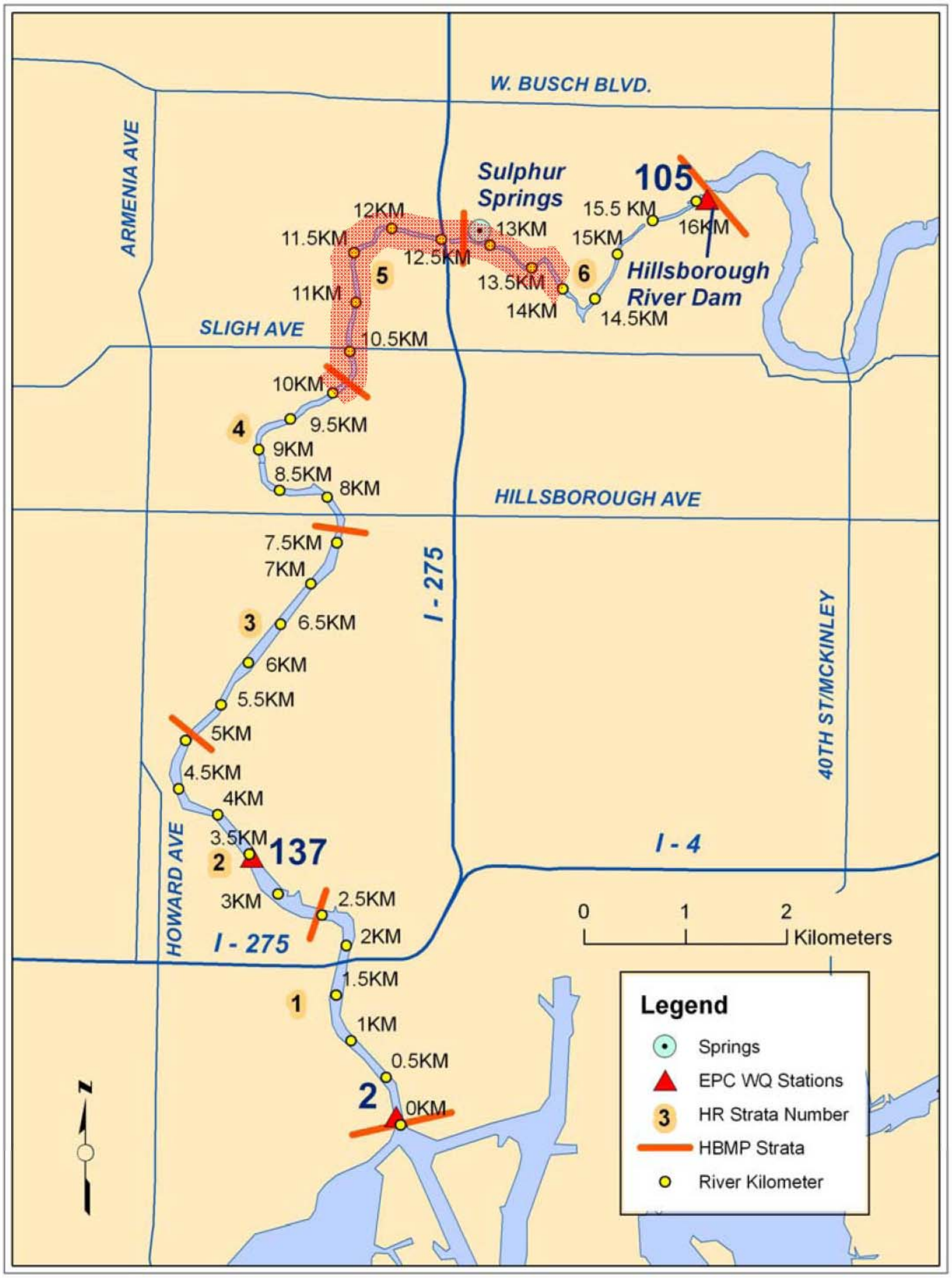
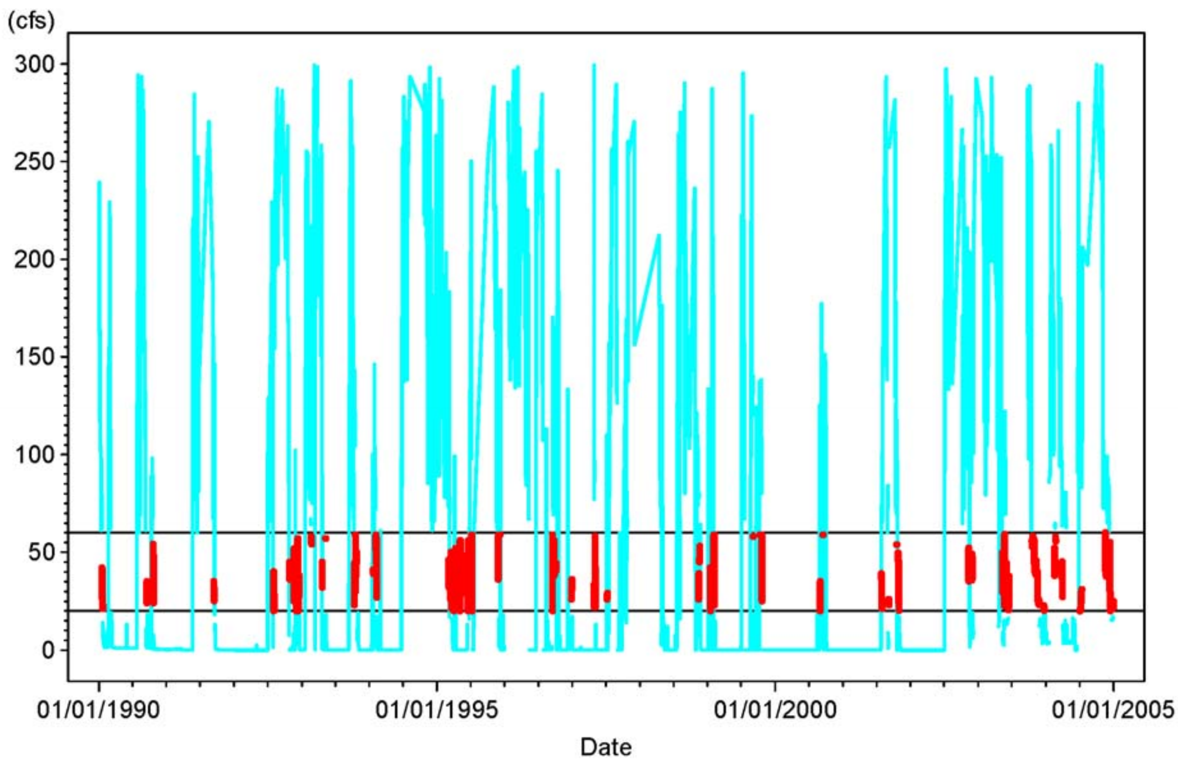


Figure 6-19 **The most prevalent region (River Kilometer 10 to 14) of low bottom DO conditions in the LHR for flow conditions between 20 and 60 cfs.**

The next consideration was to determine how frequent and persistent the low DO conditions are expected to be in the river based on the historical data. With respect to the frequency of the flow conditions most closely related to low DO conditions, the 20 to 60 cfs flow interval described above was observed to commonly occur over the period of record in most years reported. The occurrence of 20 to 60 cfs flows for the most recent 15 year period is presented in Figure 6-20. For graphical purposes, high flows were truncated in this figure to 300 cfs. Actual peak daily flows during this period exceeded 3000 cfs. With respect to persistence of the 20 to 60 cfs flow interval, the events were typically short lived and lasted only a few days. Fifty-six percent of the occurrences (75 events) of flows in this range during 1990 to 2004 persisted for one day, eighteen percent (24 events) persisted for two consecutive days, thirteen percent (17 events) persisted for three consecutive days, and nine percent (12 events) persisted for five to twelve consecutive days. The longest duration event between 1990 and 2004 lasted for 41 days. Table 6-3 presents the cumulative percent occurrence for flows between 20 and 60 cfs for the period 1990 to 2004.



(Flow Scale Truncated at 300 cfs)

Figure 6-20 Daily flow values for the Hillsborough River Dam with flows between 20 and 60 cfs highlighted in red. High flow values truncated at 300 cfs for graphical purposes.

Table 6-3 Cumulative percent occurrence of daily flows from the Hillsborough River Dam for the period 1990 to 2004 inclusive.

Daily Flow (cfs)	Cumulative Percent Occurrence
20	54.0
25	55.4
30	56.2
35	56.8
40	57.5
45	58.2
50	58.8
55	59.4
60	60.3

With respect to the frequency of low DO conditions, the probability of occurrence of low bottom DO conditions (i.e., bottom DO < 2.5 mg/L) was statistically described as a function of flow from the dam and river bottom depth of the observation. The relationships were described using logistic regression models (Peeters and Gardeniers 1998, Ysebaert et al. 2002) for observations where the dam flow was between 0 and 300 cfs. A separate logistic regression model was fit to each of three regions in the LHR based on river kilometer (Hillsborough River Dam to km 14, km 10 to 14, km 10 to Platt Street) using the following equation:

$$g(x) = \log\left[\frac{p(x)}{1-p(x)}\right] = \beta_0 + \beta_1 flow + \beta_2 depth$$

where x = a bottom low DO event (DO < 2.5 mg/L),

p(x) = probability of a bottom low DO event,

g(x) = linear transformation of p(x), and

$\beta_0, \beta_1 and \beta_2 =$ regression coefficients.

The parameter estimates and parameter specific goodness of fit statistics from the logistic regression analyses are presented in Table 6-3. The overall models were highly statistically significant (Pr > chi-square < 0.0001) based on likelihood ratio chi-square tests, which compared the likelihood of each fitted model with a model without any explanatory variables. Similarly, the individual parameters for each model were highly significant (Table 6-4). Concordant pairs tabulation was used as a measure of classification success for the model. Every possible combination of pairs of bottom DO samples was tabulated with respect to concordance. For each pair of observations, the pair was defined as “concordant” if the observation of the presence of a bottom low DO condition (i.e., bottom DO < 2.5 mg/L) was estimated to have a higher predicted value (p(x)) based on the model, than the observation of the absence of a low DO condition. If the reverse was found to be true, that the observation of the absence of a low DO condition had a higher predicted value from the model than an observation of the presence of a low DO condition, then the pair was defined as "discordant." If both observations had the same predicted value, it was defined as a tie (Allison 1991). Thus, a perfect model would be expected to have a concordance of 100%, and a poor model that had a classification success rate equal to random chance would be expected to have a concordance of 50%.

Table 6-4 Logistic Regression Model Results for estimation of probability of the presence of low bottom DO condition (DO < 2.5 mg/L) as a function of dam flow (cfs) and sample depth (m).

Geographic Region (River Km)	Number of Presences of Low DO Condition	Number Of Absences Of Low DO Condition	$ß_0$ Estimate and (Std Error) [Pr > X^2]	$ß_1$ Estimate and (Std Error) [Pr > X^2]	$ß_2$ Estimate and (Std Error) [Pr > X^2]	Concordance
> 14	73	224	-2.2062 (0.437) [<.0001]	-0.0974 (0.018) [<.0001]	1.2507 (0.236) [<.0001]	88.1 %
10 – 14	358	290	-1.1661 (0.210) [<.0001]	-0.0171 (0.002) [<.0001]	0.8810 (0.092) [<.0001]	80.2 %
< 10	354	796	-2.6927 (0.170) [<.0001]	0.00719 (0.001) [<.0001]	0.6915 (0.062) [<.0001]	76.5%

In order to summarize the relationships between Hillsborough River Dam flow and bottom DO conditions, the fitted logistic regression models for the three river regions were used to estimate the probabilities of low DO conditions (i.e., bottom DO less than 2.5 mg/L) as a function of several example dam flow conditions (i.e., 10 cfs, 20, cfs, 30, cfs, 40 cfs). As described above, the depth of the river bottom was a highly significant and continuous parameter in each of the logistic models, and the probabilities of low DO condition was presented for several example river bottom depths (i.e., 0^{th}, 25^{th}, 50^{th}, and 75^{th} percentiles and the deepest depth for which bottom DO data were reported). In order to present the overall probabilities of low DO conditions across expected bottom depths in each region for the example dam flow conditions, the depth-specific probabilities were averaged across estimates for the 0^{th}, 25^{th}, 50^{th}, 75^{th}, and 100^{th} percentiles from District bathymetric data for the river (i.e., the District's LAMFE model bathymetry data).

The logistic regression results are summarized by the three river regions in Figures 6-21 through 6-32 and Tables 6-4 through 6-6. The strongest relationships between the probability of low DO conditions and dam flow were found in the two upstream portions of the LHR (Hillsborough River Dam to Km 14 and Km 10 to 14). The higher the flow in these two regions, the less likely it is that low DO conditions would occur. The relationship with flow is strongest upstream of river kilometer 14. These results agree with the expectations for the relationship between DO and flow discussed above. The relationship between probability of low DO conditions and flow was not as strong in the region downstream of river kilometer 10, and in opposition to the upstream results, the probability of low DO conditions increased with increasing flow. As freshwater inflow increases, organic carbon supply is expected to increase and contribute to the likelihood of lower DO concentrations. As freshwater inflow increases above the 300 cfs flow used to fit the logistic regression models, residence time would also be expected to decrease and would likely contribute to higher DO concentrations downstream of river kilometer 10. This expectation was not tested, as the focus of this minimum flow analysis was on the responses at the low flow ranges.

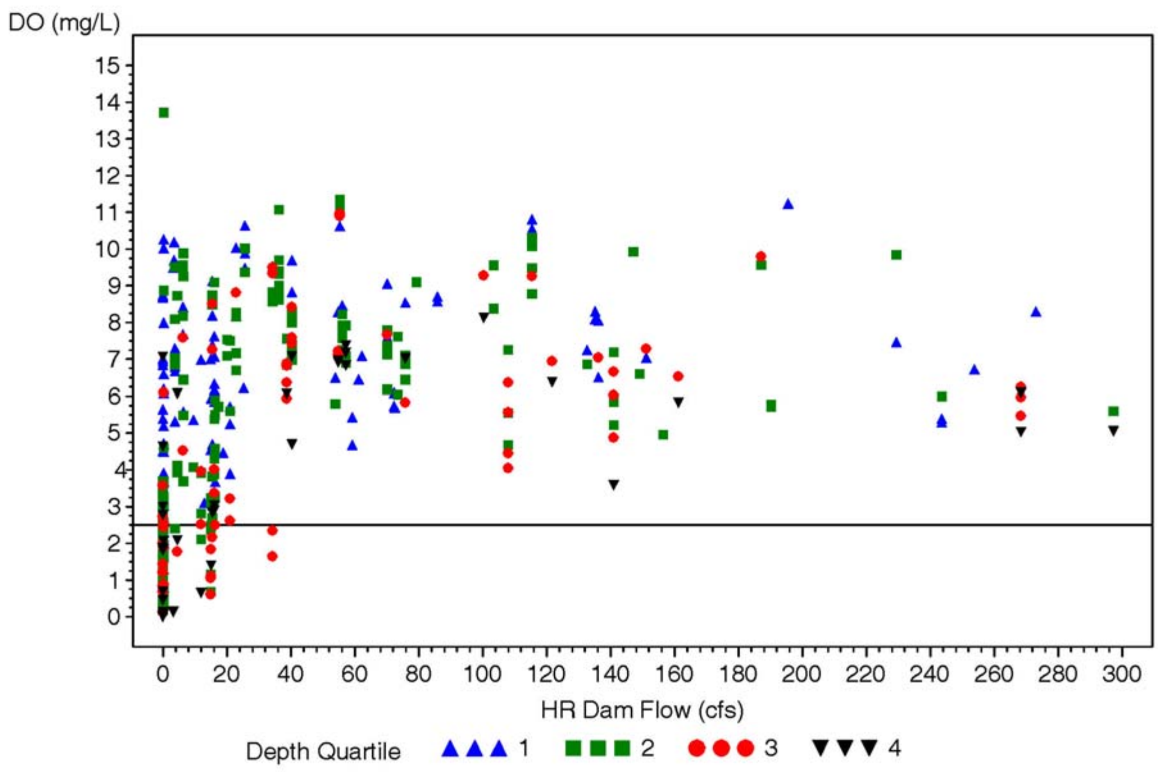


Figure 6-21 **Bottom DO between Km 14 and the dam as a function of dam flow and depth for flows between 0 and 300 cfs. Symbols are categorized by depth quartiles based on bottom area bathymetry for this region of the river.**

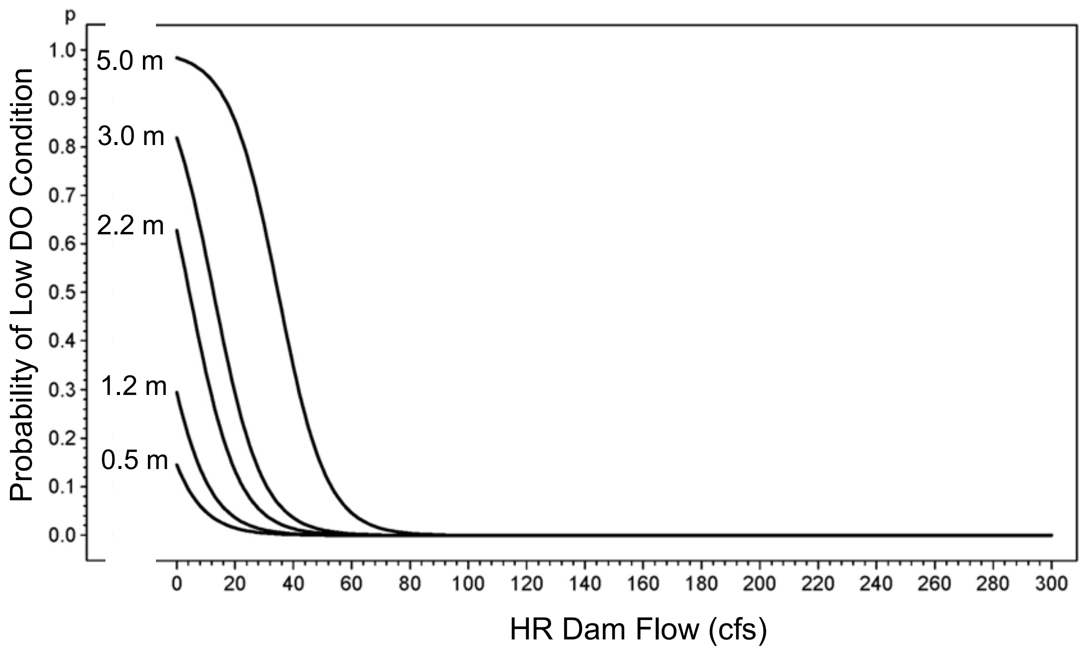


Figure 6-22 **Probability of bottom DO<2.5 mg/L between Km 14 and the dam as a function of dam flow and depth for dam flows between 0 and 300 cfs. Estimates are shown for depth percentiles (0^{th},25^{th}, 50^{th}, 75^{th}) and the deepest depth (5.0 m) for which DO data were reported based on bottom area.**

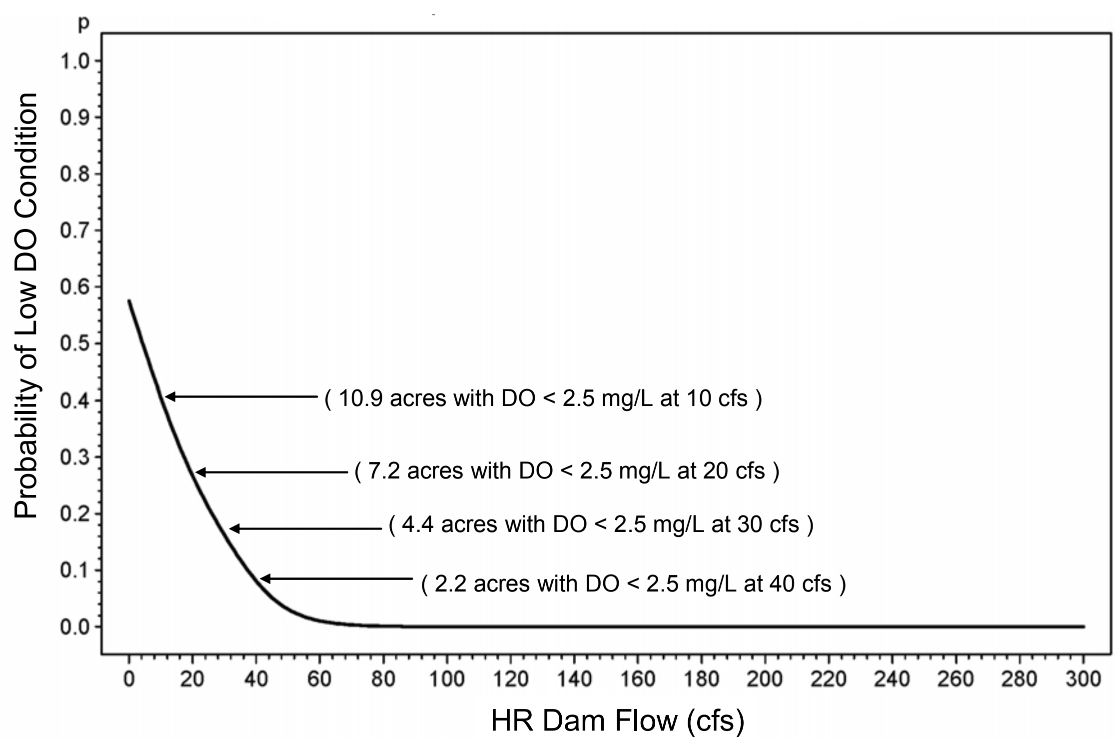


Figure 6-23 **Probability of bottom DO<2.5 mg/L between Km 14 and the dam as a function of dam flow (calculated as the mean of estimates by 0^{th}, 25^{th}, 50^{th}, 75^{th}, and 100^{th} depth percentile). For reference, the probabilities are expressed as acres of river bottom for several example flow values (more precisely, the probabilities represent joint probabilities over time and space).**

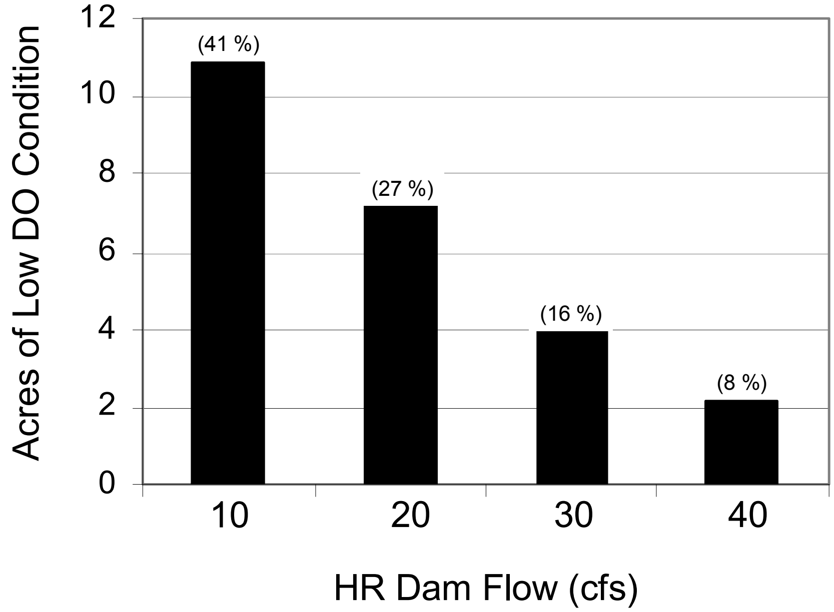


Figure 6-24 **Acres of bottom DO<2.5 mg/L between Km 14 and the dam as a function of dam flow. Corresponding percent of bottom habitat in this region of the river indicated in parentheses.**

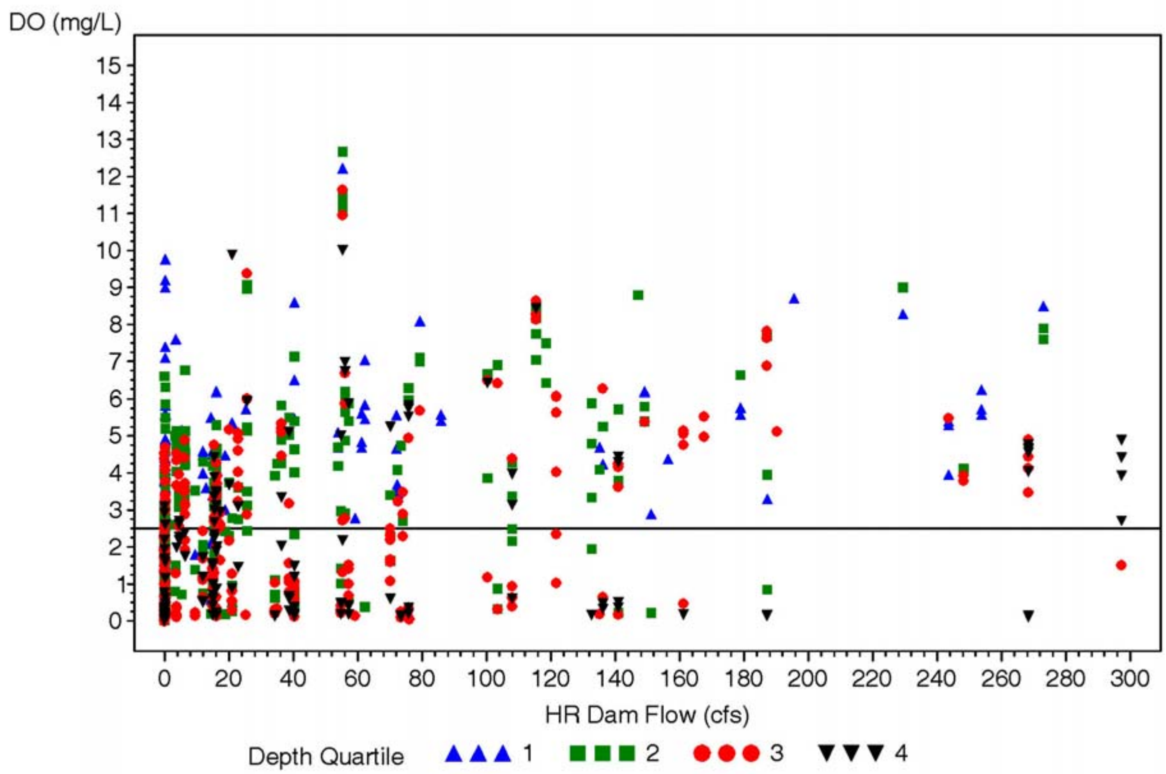


Figure 6-25 **Bottom DO between Km 10 and 14 as a function of river kilometer and depth for dam flows between 0 and 300 cfs. Symbols are categorized by depth quartiles based on bottom area bathymetry for this region of the river.**

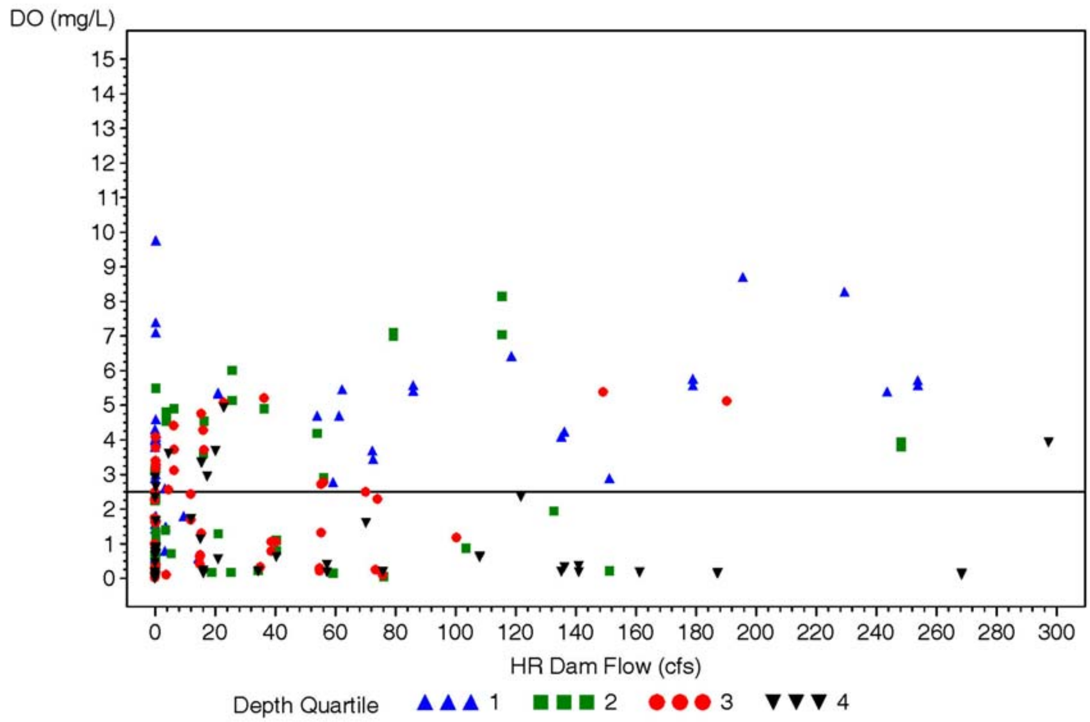


Figure 6-25a. Bottom DO for river km 10 as a function depth for dam flows between 0 and 300 cfs. Symbols are categorized by depth quartiles based on bottom area bathymetry for this region of the river.

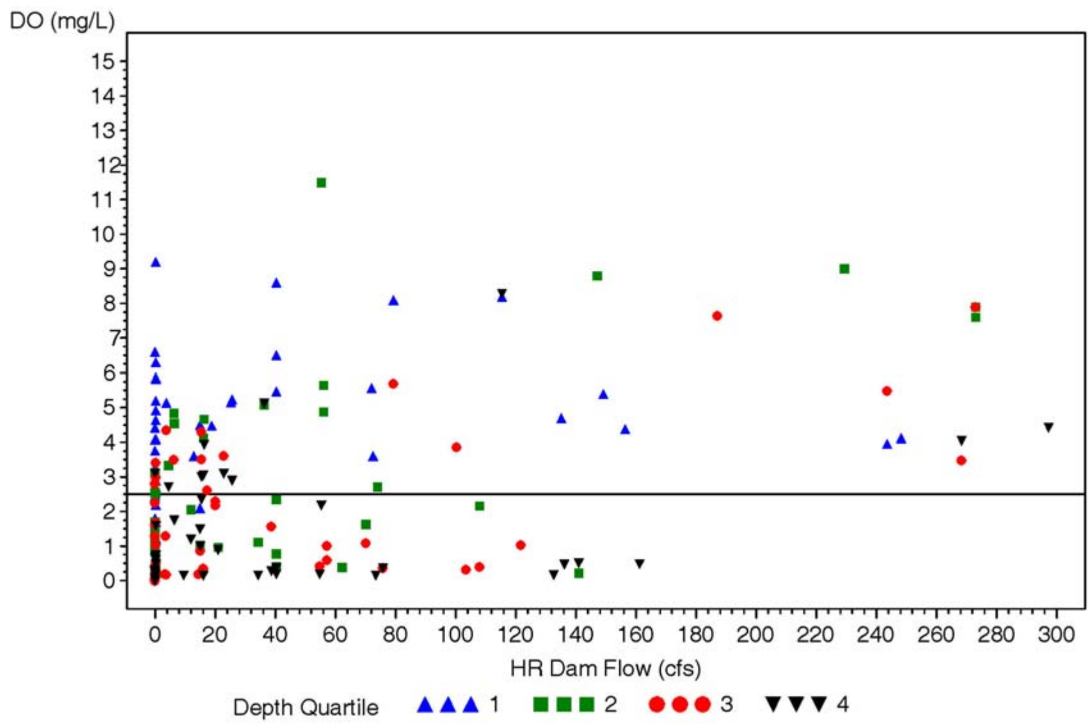


Figure 6-25b. Bottom DO for river km 11 as a function depth for dam flows between 0 and 300 cfs. Symbols are categorized by depth quartiles based on bottom area bathymetry for this region of the river.

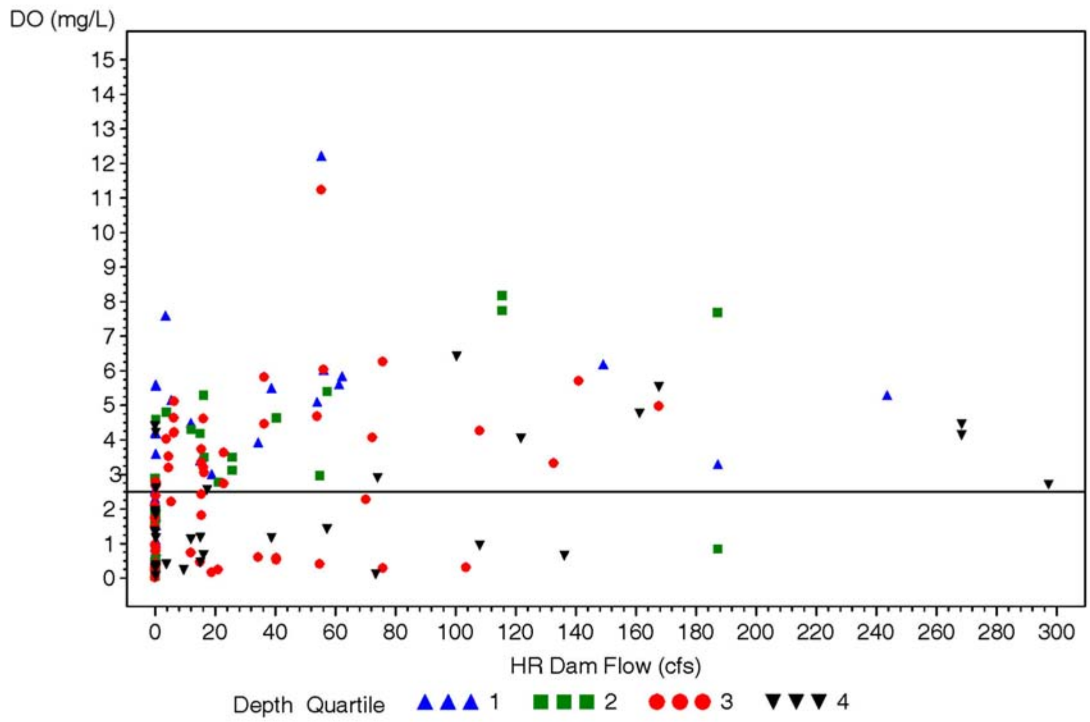


Figure 6-25c. **Bottom DO for river km 12 as a function depth for dam flows between 0 and 300 cfs. Symbols are categorized by depth quartiles based on bottom area bathymetry for this region of the river.**

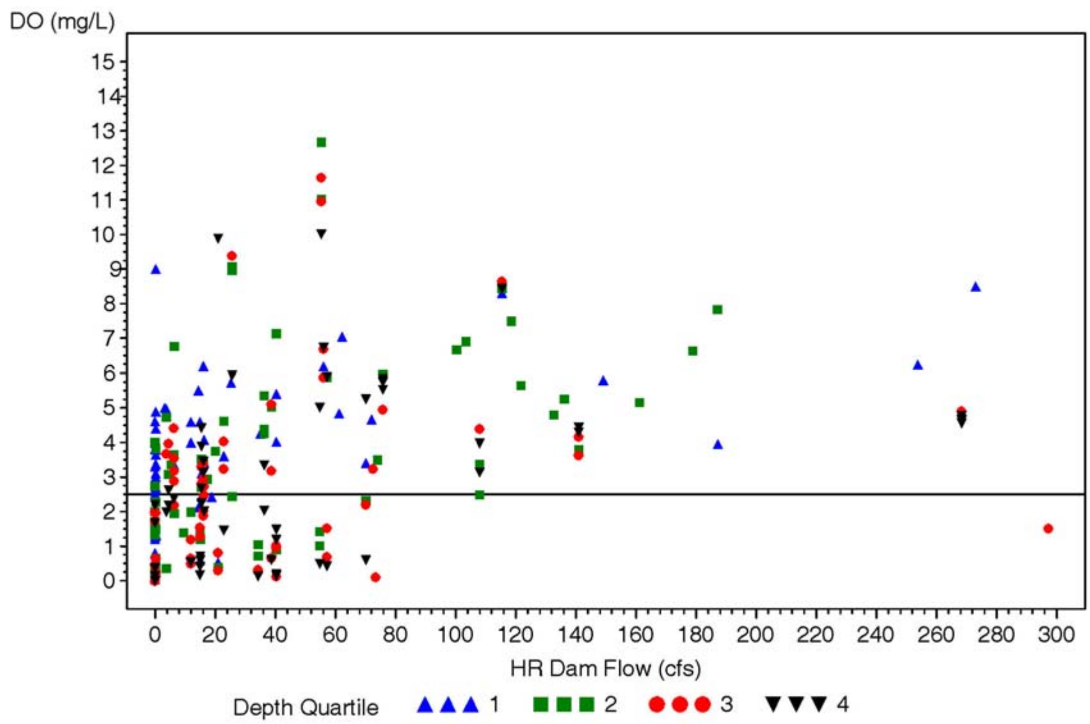


Figure 6-25d. **Bottom DO for river km 13 as a function depth for dam flows between 0 and 300 cfs. Symbols are categorized by depth quartiles based on bottom area bathymetry for this region of the river.**

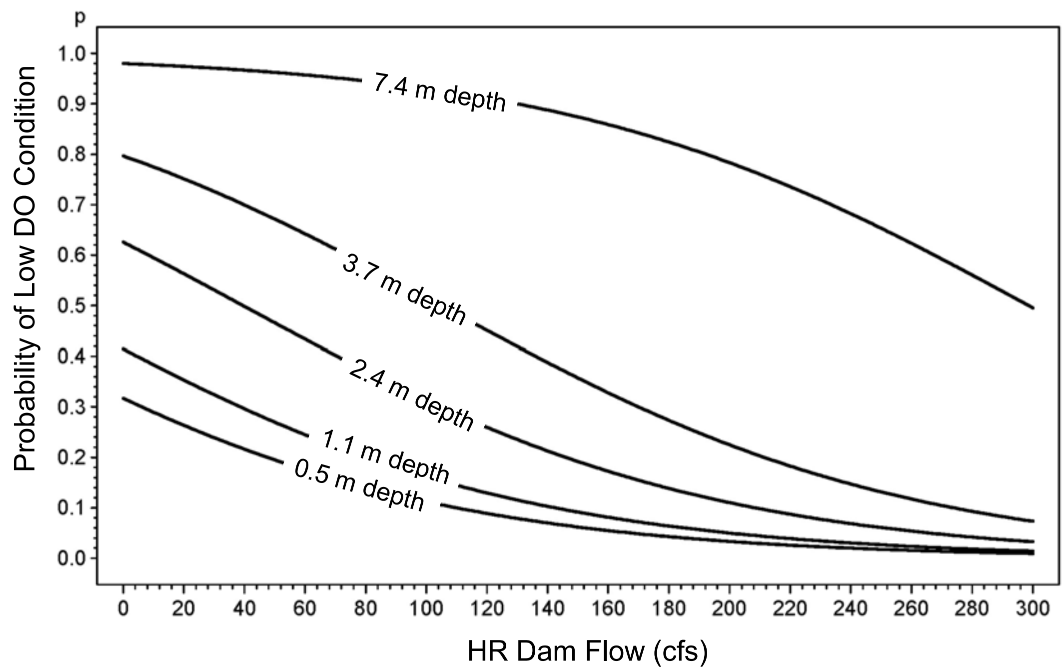


Figure 6-26. Probability of bottom DO<2.5 mg/L between Km 10 and 14 as a function of river kilometer and depth for dam flows between 0 and 300 cfs. Estimates are shown for depth percentiles (0th, 25th, 50th, 75th) and the deepest depth (7.4 m) for which DO data were reported based on bottom area.

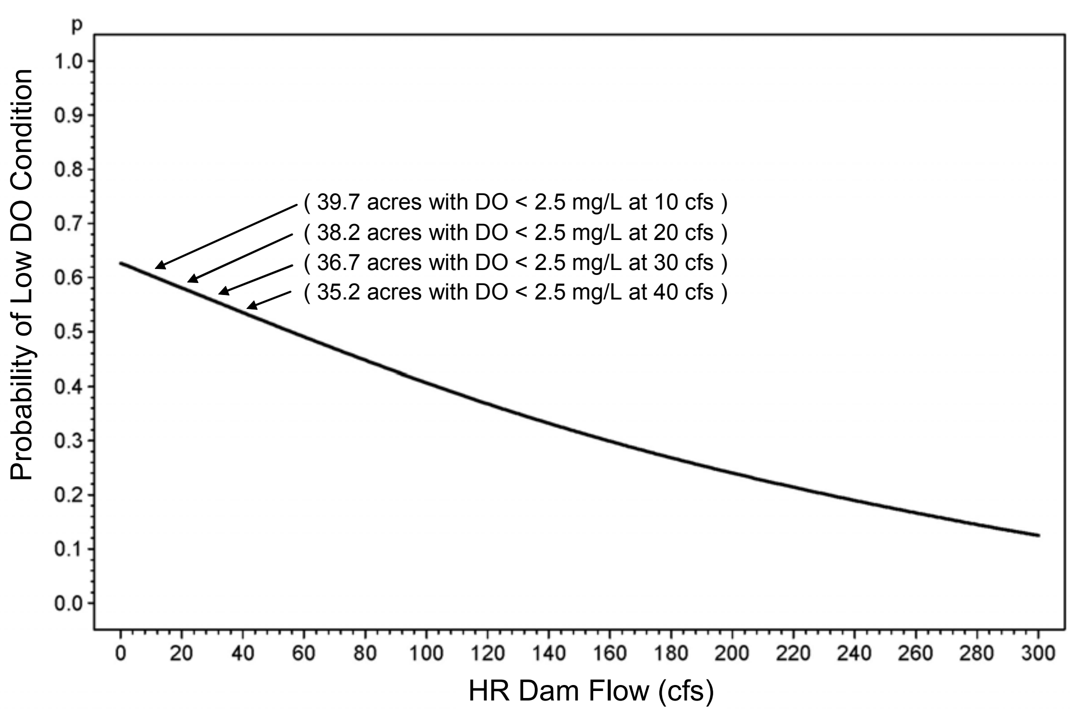


Figure 6-27 Probability of bottom DO<2.5 mg/L between Km 10 and 14 as a function of dam flow (calculated as the mean of estimates by 0th, 25th, 50th, 75th, and 100th depth percentile). For reference, the probabilities are expressed as acres of river bottom for several example flow values (more precisely, the probabilities represent joint probabilities over time and space).

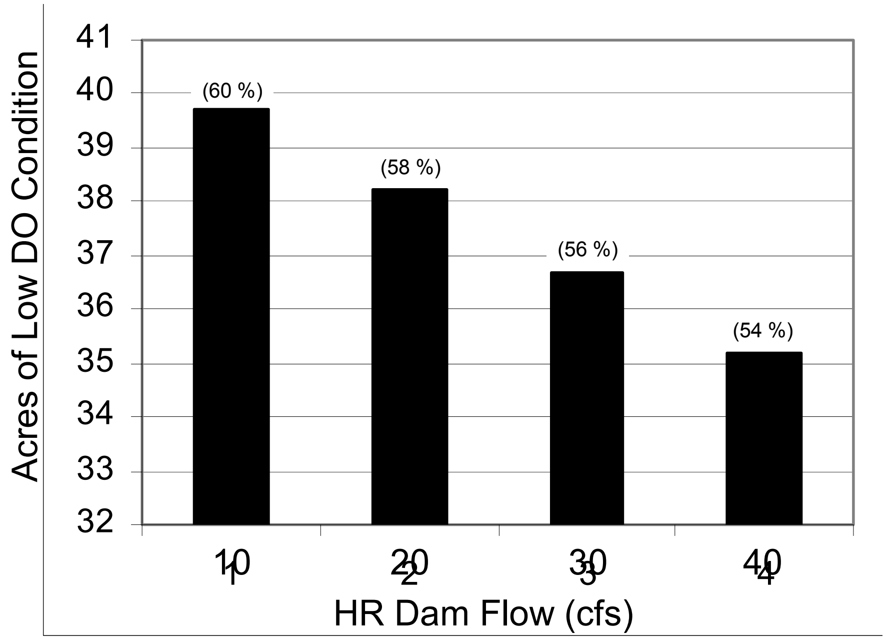


Figure 6-28 **Acres of bottom DO<2.5 mg/L between Km 10 and 14 as a function of dam flow. Corresponding percent of bottom habitat in this region of the river indicated in parentheses.**

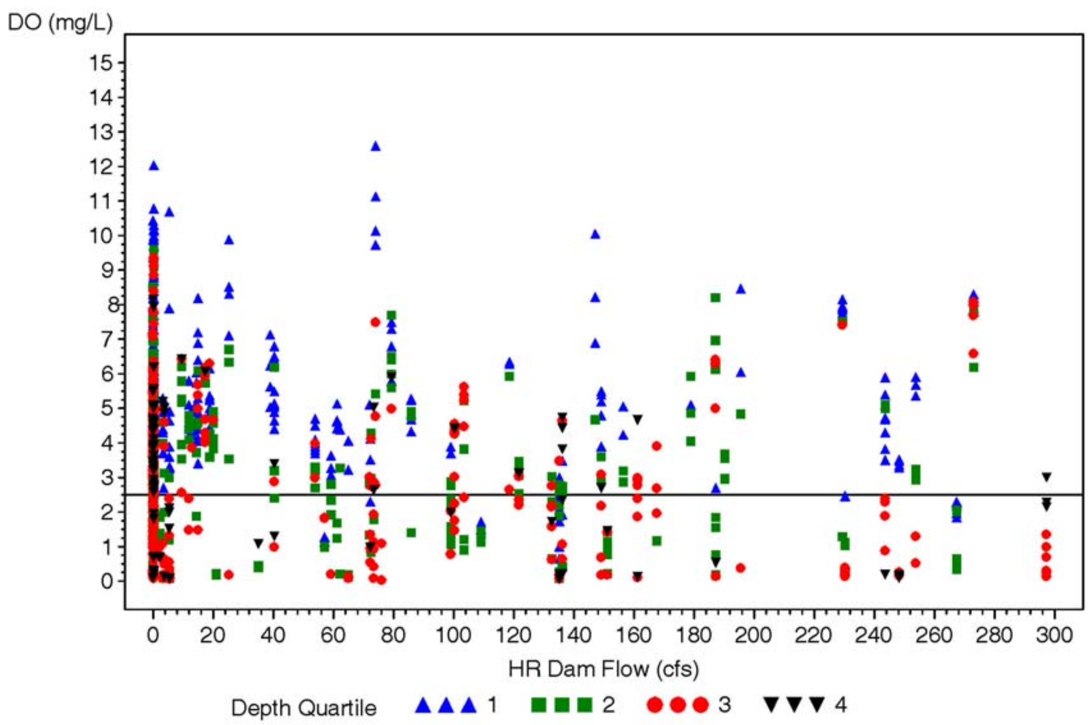


Figure 6-29 **Bottom DO between Km 10 and Platt Street as a function of river kilometer and depth for dam flows between 0 and 300 cfs. Symbols are categorized by depth quartiles based on bottom area bathymetry for this region of the river.**

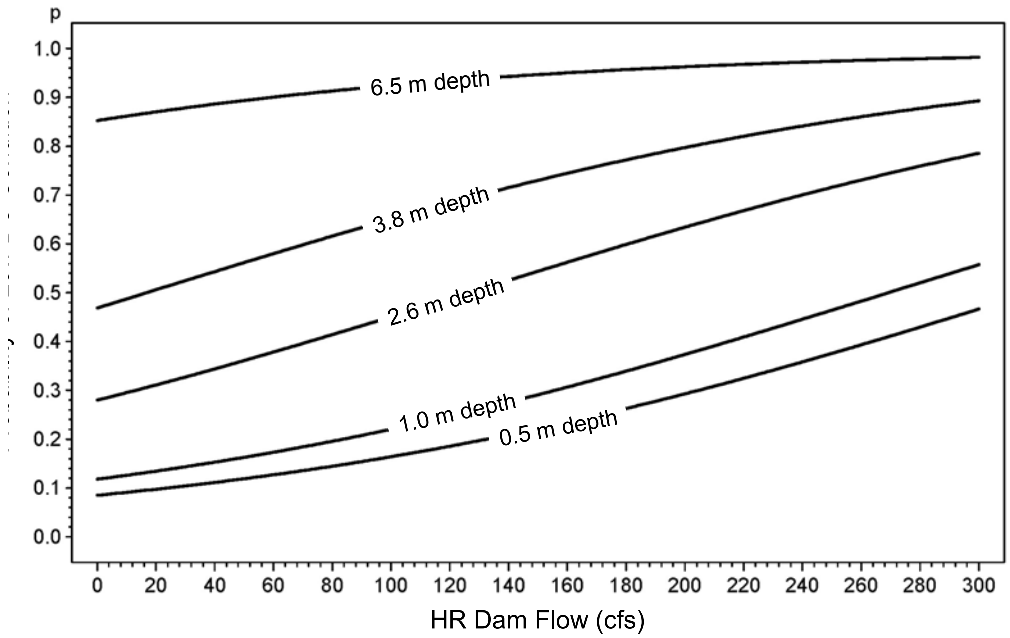


Figure 6-30 **Probability of bottom DO<2.5 mg/L between Km 10 and Platt Street as a function of river kilometer and depth for dam flows between 0 and 300 cfs. Estimates are shown for depth percentiles (0th, 25th, 50th, 75th) and the deepest depth (6.5 m) for which DO data were reported based on bottom area.**

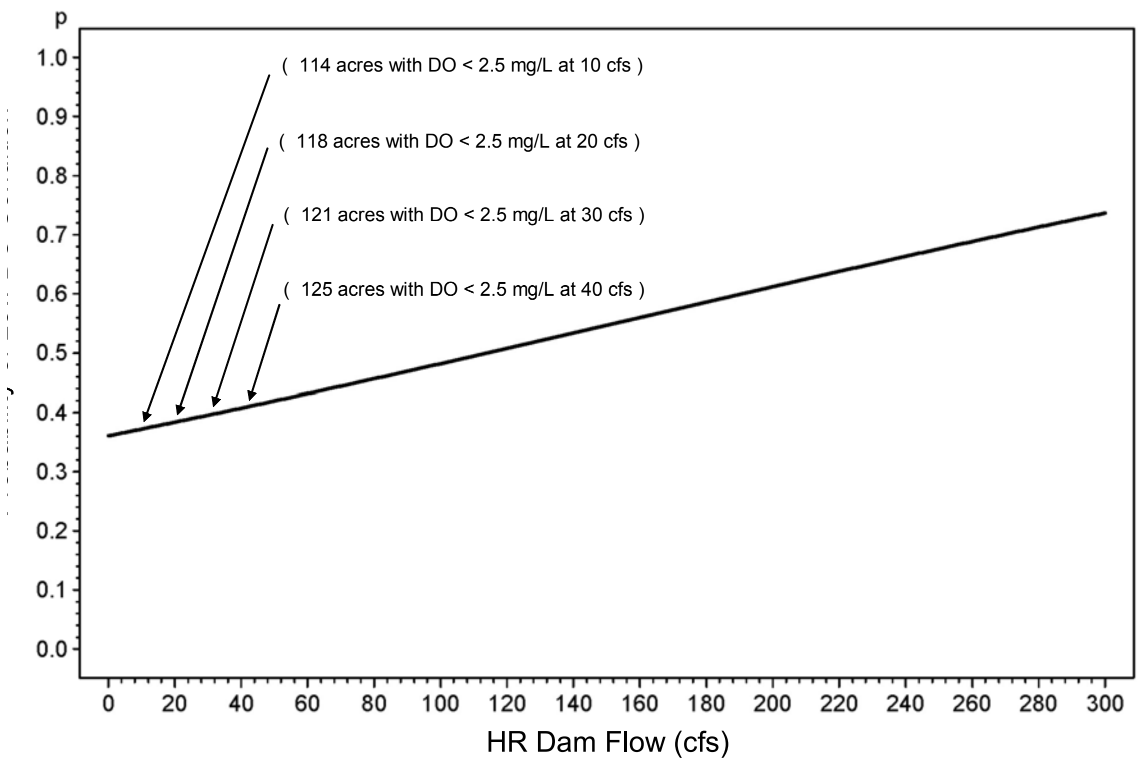


Figure 6-31 **Probability of bottom DO<2.5 mg/L between Km 10 and Platt Street as a function of dam flow (calculated as the mean of estimates by 0th, 25th, 50th, 75th, and 100th depth percentile). For reference, the probabilities are expressed as acres of river bottom for several example flow values (more precisely, the probabilities represent joint probabilities over time and space).**

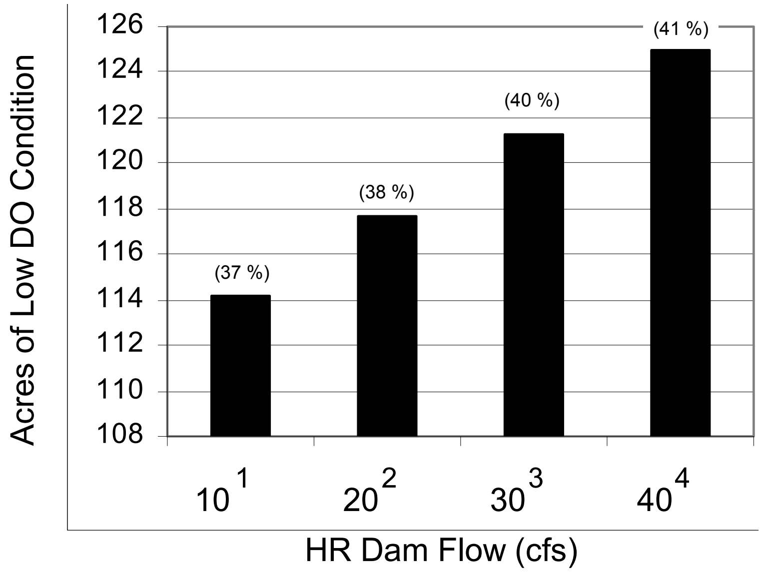


Figure 6-32 Acres of bottom DO<2.5 mg/L between Km 10 and Platt Street as a function of dam flow. Corresponding percent of bottom habitat in this region of the river indicated in parentheses.

Table 6-4 Probability of bottom DO<2.5 mg/L between Km 14 and the dam as a function of dam flow and depth.

Depth Percentile	Depth (m)	p(DO < 2.5 mg/L) at 0 cfs flow	p(DO < 2.5 mg/L) at 10 cfs flow	p(DO < 2.5 mg/L) at 20 cfs flow	p(DO < 2.5 mg/L) at 30 cfs flow	p(DO < 2.5 mg/L) at 40 cfs flow
0	0.50	0.15	0.05	0.02	0.00	0.00
25	1.18	0.29	0.11	0.04	0.01	0.00
50	2.24	0.63	0.34	0.13	0.04	0.01
75	2.99	0.82	0.58	0.29	0.11	0.04
100	5.00	0.98	0.95	0.85	0.64	0.35

Table 6-5. Probability of bottom DO<2.5 mg/L between Km 10 and 14 as a function of dam flow and depth.

Depth Percentile	Depth (m)	p(DO < 2.5 mg/L) at 0 cfs flow	p(DO < 2.5 mg/L) at 10 cfs flow	p(DO < 2.5 mg/L) at 20 cfs flow	p(DO < 2.5 mg/L) at 30 cfs flow	p(DO < 2.5 mg/L) at 40 cfs flow
0	0.50	0.32	0.29	0.26	0.24	0.22
25	1.13	0.41	0.38	0.35	0.32	0.30
50	2.41	0.63	0.59	0.56	0.53	0.50
75	3.68	0.80	0.77	0.75	0.73	0.70
100	7.44	0.98	0.98	0.97	0.97	0.97

Table 6-6 Probability of bottom DO<2.5 mg/L between Km 10 and Platt Street as a function of dam flow and depth.

Depth Percentile	Depth (m)	p(DO < 2.5 mg/L) at 0 cfs flow	P(DO < 2.5 mg/L) at 10 cfs flow	p(DO < 2.5 mg/L) at 20 cfs flow	p(DO < 2.5 mg/L) at 30 cfs flow	p(DO < 2.5 mg/L) at 40 cfs flow
0	0.50	0.08	0.09	0.10	0.10	0.11
25	1.03	0.12	0.13	0.13	0.14	0.15
50	2.58	0.28	0.30	0.31	0.33	0.34
75	3.77	0.47	0.49	0.51	0.52	0.54
100	6.50	0.85	0.86	0.87	0.88	0.89

6.1.3 Chlorophyll *a*-Flow Relationships

Although chlorophyll *a* concentrations are expected to be highly variable in the LHR, they are expected to follow a predictable pattern in response to the combined effects of nutrient supply and residence time. Managing nutrient loading is expected to be the primary driver for aquatic eutrophication (Smith et al., 1999), and the best understanding of this relationship depends upon knowledge of the other confounding factors such as residence time. Borsuk et al. (2002) and Conrads et al. (2003) have shown that the relationship between nutrient loading and estuarine responses (such as changes in algal biomass) is mediated significantly by hydrologically-controlled residence times. As freshwater inflow initially increases from a near zero flow condition, chlorophyll *a* is expected to increase in response to the increased nutrient supply. As inflow rate increases even higher, the increase in nutrient supply becomes offset by the reduction in residence time, and the resulting chlorophyll *a* concentrations will peak. At higher inflow rates, the negative effects of shortening residence time become greater than the positive effects of increasing nutrient supply, and the chlorophyll *a* concentrations decline. The effects are expected to be less responsive downstream than upstream due to physical dilution effects (Figure 6-33).

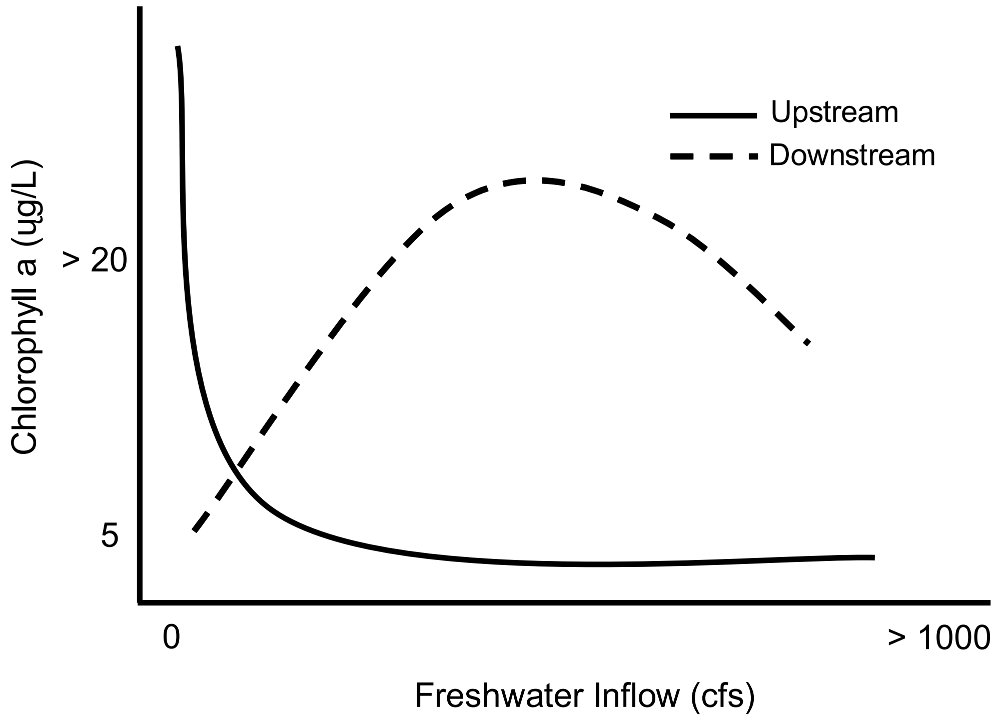


Figure 6-33 Conceptual expected response of chlorophyll a concentrations in the Lower Hillsborough River to freshwater inflow.

Chlorophyll *a* field observations from the EPCHC Ambient Monitoring Program and HBMP were plotted against freshwater inflow to describe responses in chlorophyll *a* in the LHR to freshwater inflow (Appendix 6-4). The EPCHC chlorophyll *a* values (Figure 6-34 through 6-36) and the HBMP chlorophyll *a* values (Figures 6-37 and 6-38) were found to generally follow the expected relationships described above. However, a relatively high degree of variation was observed in the chlorophyll *a* observations. Upstream at the EPCHC Rowlett Park and HBMP Stratum HR6, chlorophyll *a* concentrations were observed to peak at relatively low freshwater inflow rates (e.g., less than 50 cfs). Downstream at the EPCHC Platt Street station and HBMP Stratum HR1 peak chlorophyll *a* values were observed at freshwater inflow rates between 100 cfs and 1000 cfs. At freshwater inflow rates higher than 1000 cfs, residence times in the river are short in duration, and chlorophyll *a* values higher than approximately 10 μg/L were not observed.

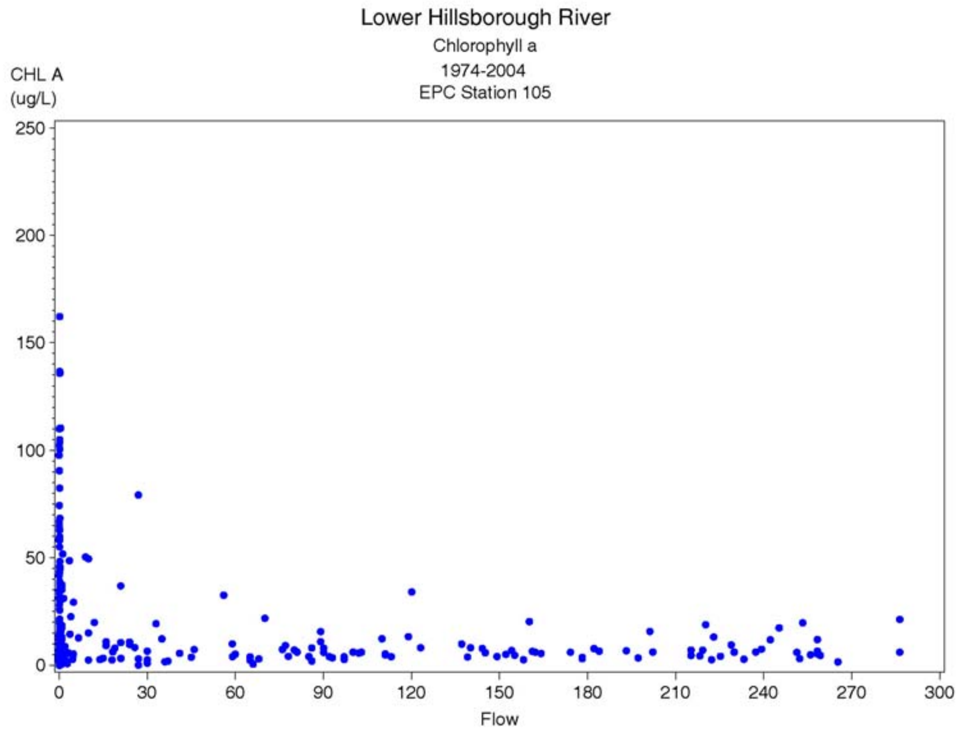


Figure 6-34. Observed response of chlorophyll *a* at EPC Station 105 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.

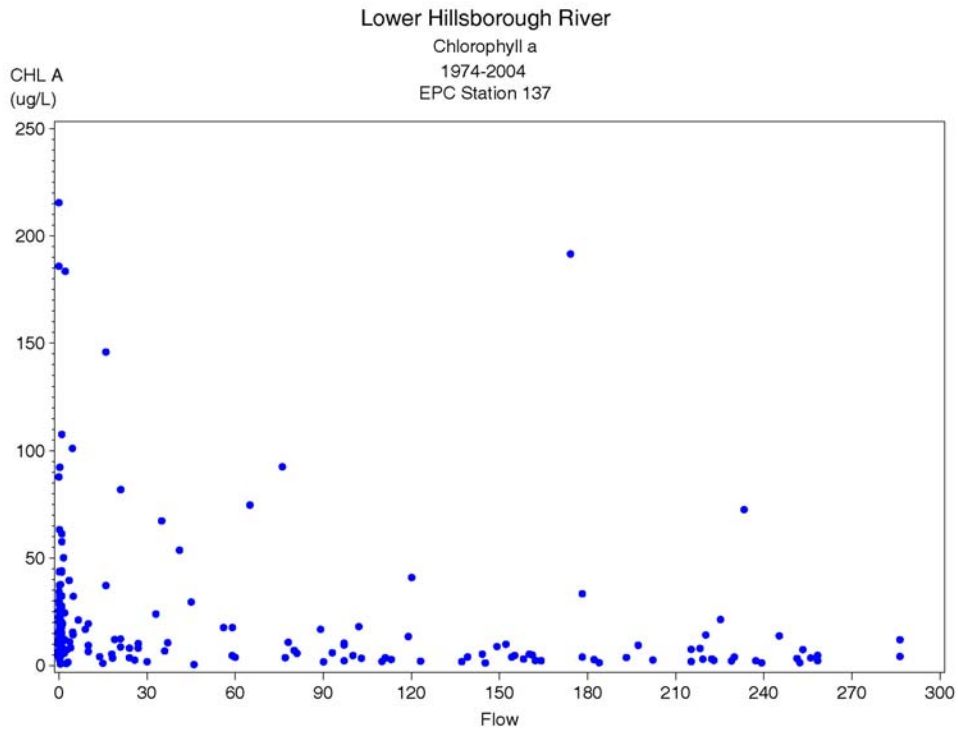


Figure 6-35. Observed response of chlorophyll *a* at EPC Station 137 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.

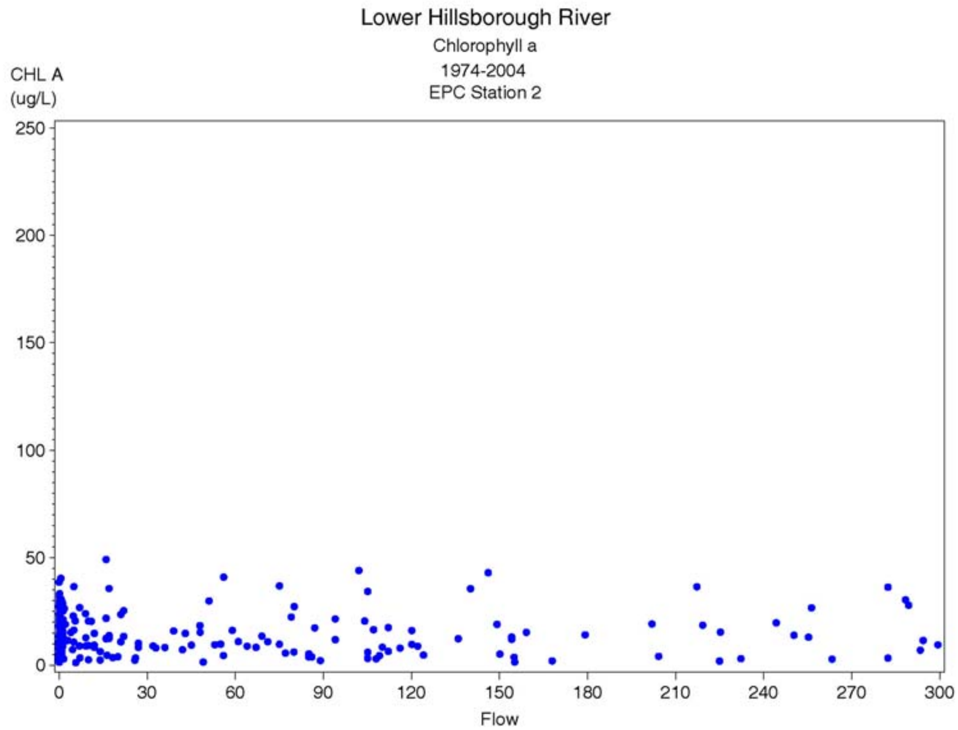


Figure 6-36. Observed response of chlorophyll *a* at EPC Station 2 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data subset to flows less than 300 cfs for this figure.

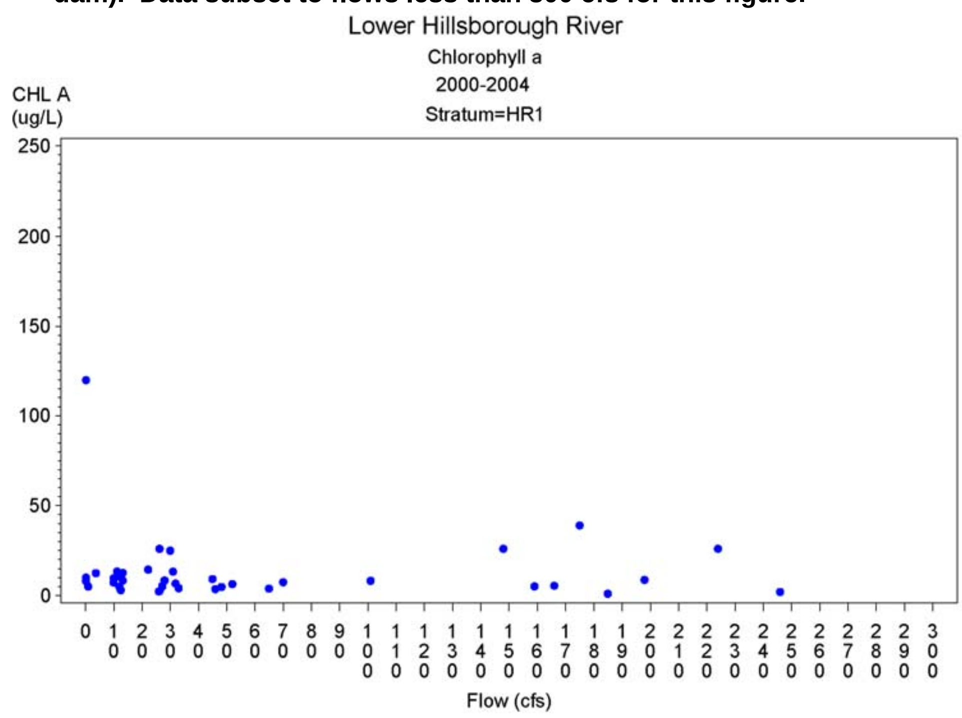


Figure 6-37 Observed response of Chlorophyll a concentrations to total freshwater inflow in Tampa Bay WaterHBMP Monitoring Program Stratum 1. Data subset to flows less than 300 cfs for this figure.

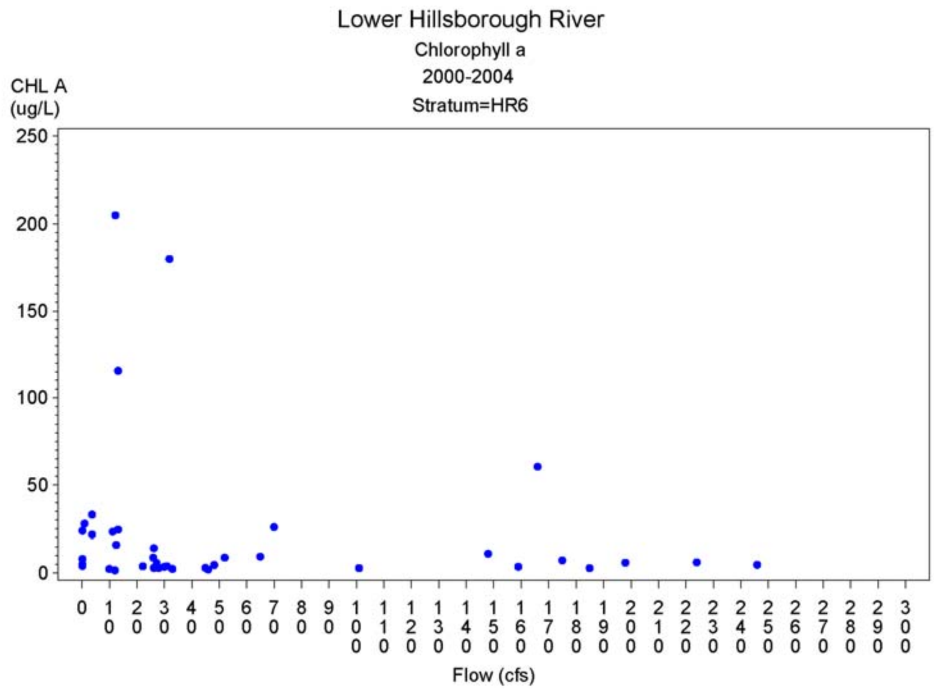


Figure 6-38 **Observed response of Chlorophyll a concentrations to total freshwater inflow in Tampa Bay Water HBMP Monitoring Program Stratum 6. Data subset to flows less than 300 cfs for this figure.**

6.1.4 Other Water Quality Constituents

Nutrient concentrations are not expected to be strongly correlated with freshwater inflow rates.

6.1.4.1 Total Nitrogen-Flow Relationships

Total nitrogen field observations from the EPCHC Ambient Monitoring Program and the Tampa Bay Water HBMP Program were plotted against freshwater inflow to describe responses (Appendix 6-5). Figures 6-39 through 6-41 present these data for the EPCHC stations. The total nitrogen concentrations were not observed to have a strong relationship to freshwater inflow.

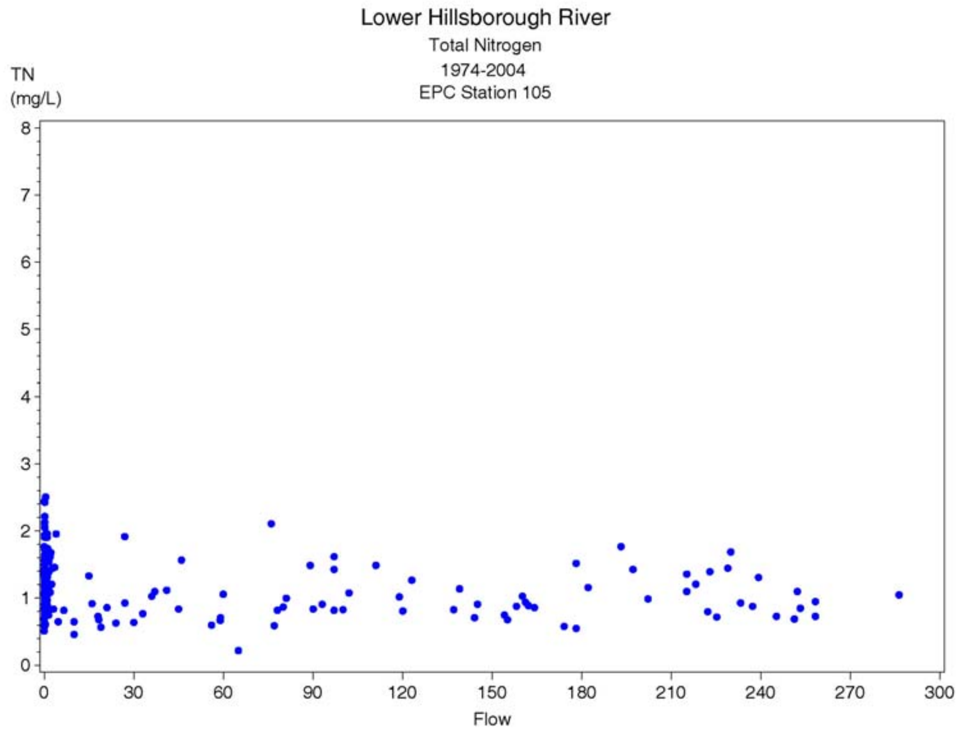


Figure 6-39 **Observed response of total nitrogen concentration at EPC 105 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs for this figure.**

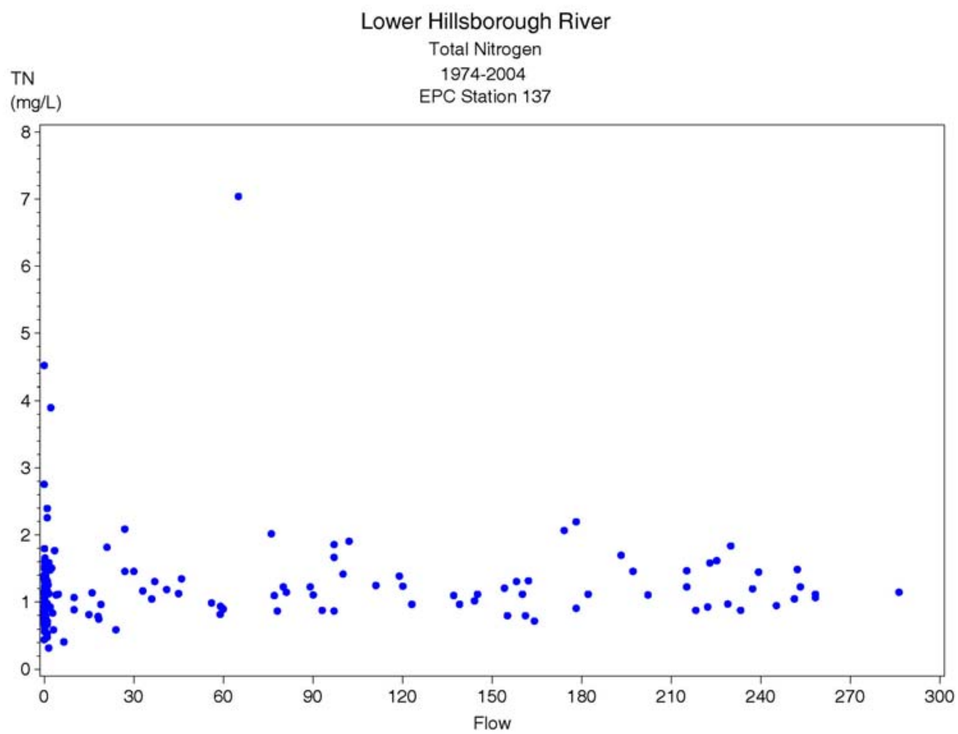


Figure 6-40. **Observed response of total nitrogen concentration at EPC 137 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs for this figure.**

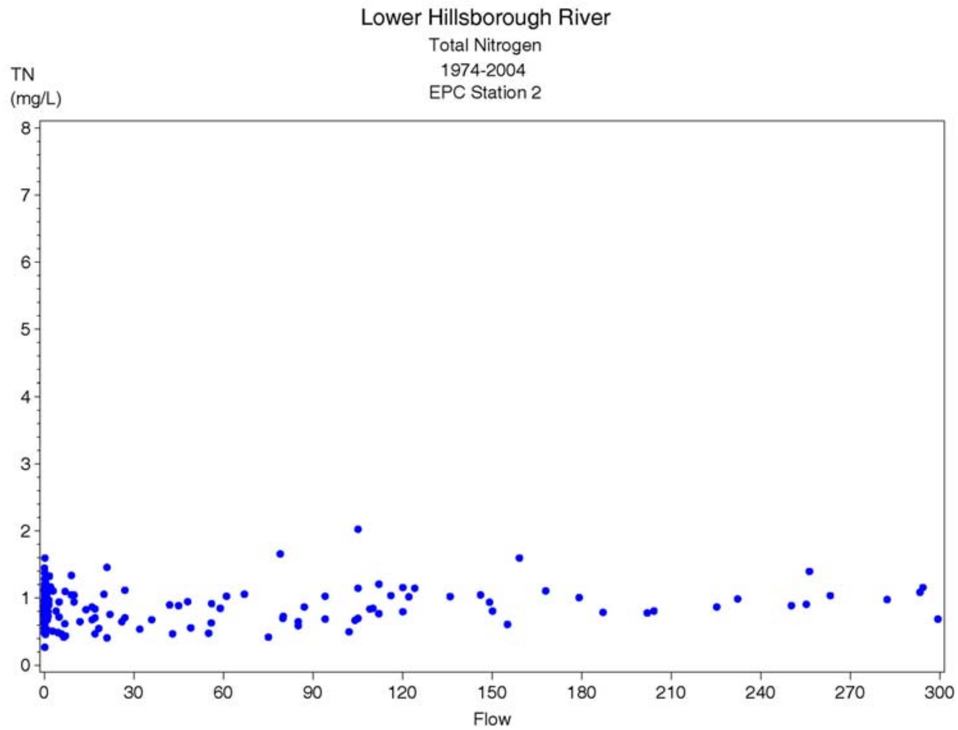


Figure 6-41. Observed response of total nitrogen concentration at EPC Station 2 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs for this figure.

6.1.4.2 Total Phosphorus-Flow Relationships

Total phosphorous field observations from the EPCHC Ambient Monitoring Program and the Tampa Bay Water HBMP Program were plotted against freshwater inflow to describe responses (Appendix 6-5). Figures 6-42 through 6-44 present these data for the EPCHC stations. Similar to total nitrogen, the total phosphorous concentrations were not observed to have a strong relationship to freshwater inflow.

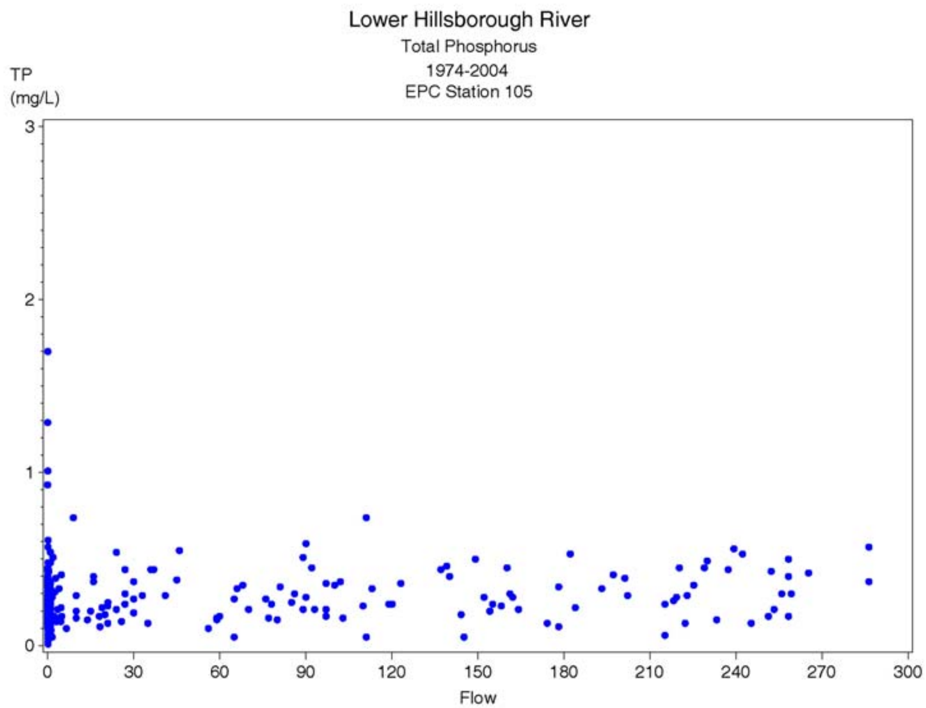


Figure 6-42 **Observed response of total phosphorous concentration at EPC Station 105 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs and TP values less than 4 for this figure.**

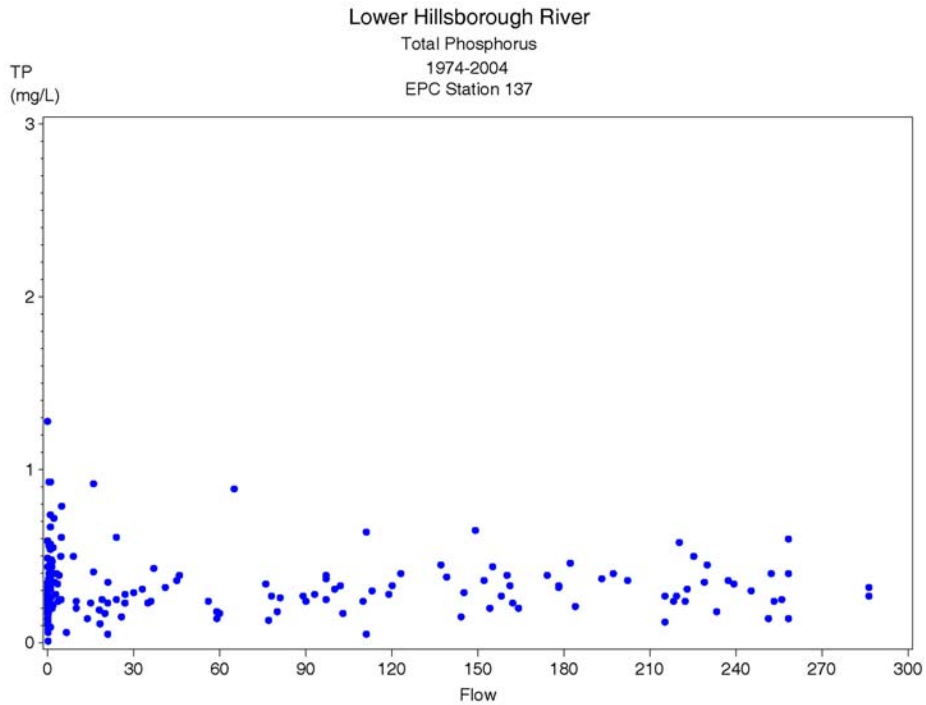


Figure 6-43. **Observed response of total phosphorous concentration at EPC Station 137 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs and TP values less than 4 for this figure.**

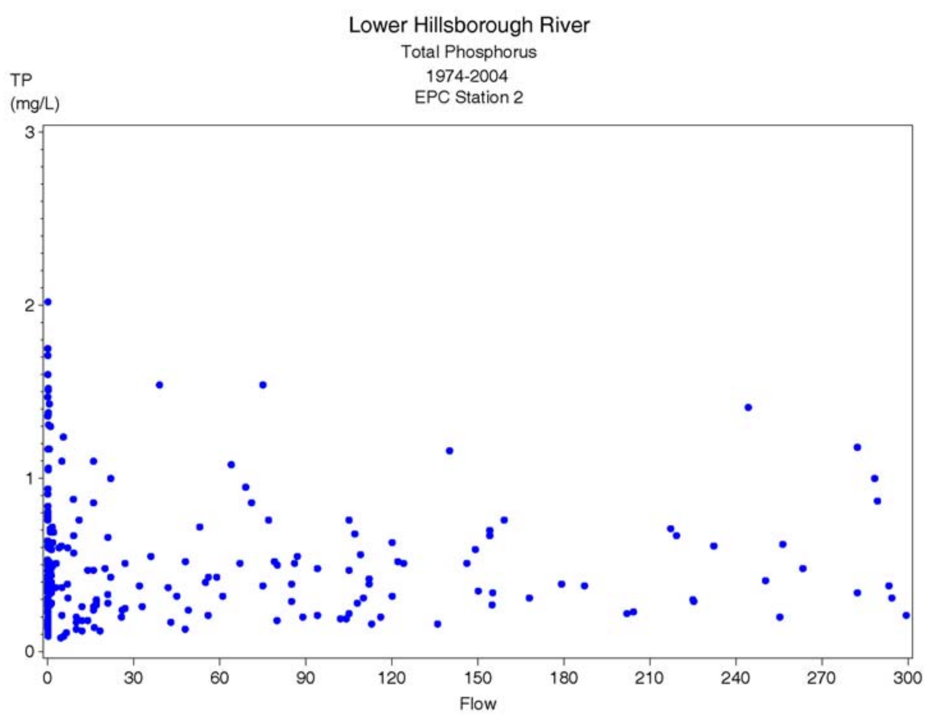


Figure 6-44. **Observed response of total phosphorous concentration at EPC Station 2 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs and TP values less than 4 for this figure.**

6.1.4.3 Total Suspended Solids-Flow Relationships

Total suspended solids (TSS) field observations from the EPCHC Ambient Monitoring Program and the Tampa Bay Water HBMP Program were plotted against freshwater inflow to describe observed responses (Appendix 6-5). The TSS values were not observed to have a strong relationship with flow (Figures 6-45 through 6-47).

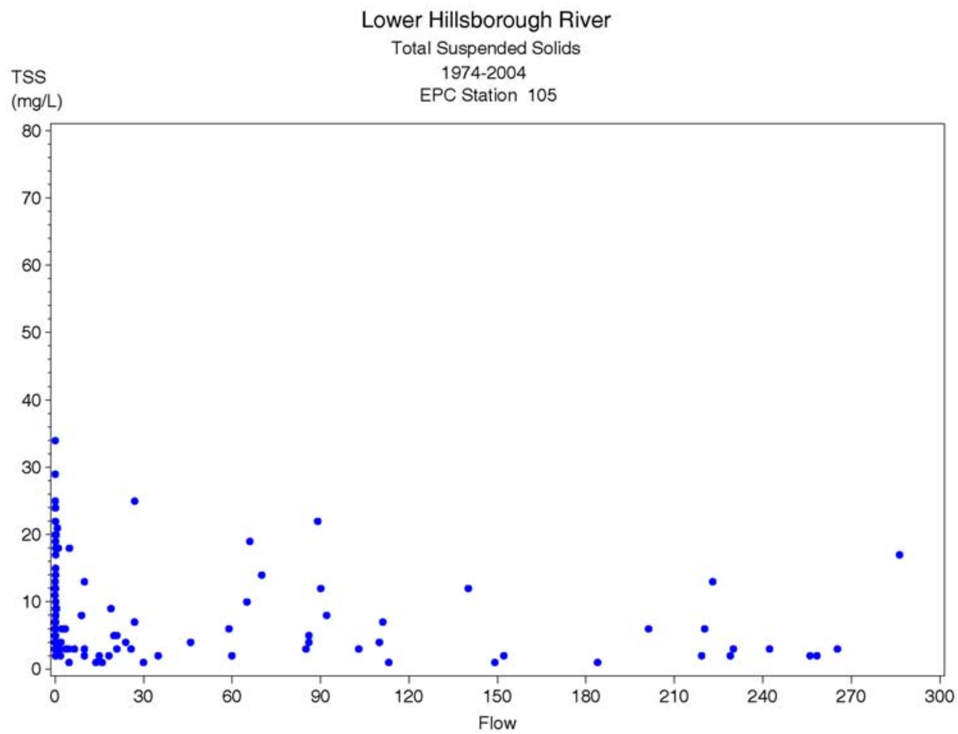


Figure 6-45 Observed response of total suspended solids concentration at EPC Station 105 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs.

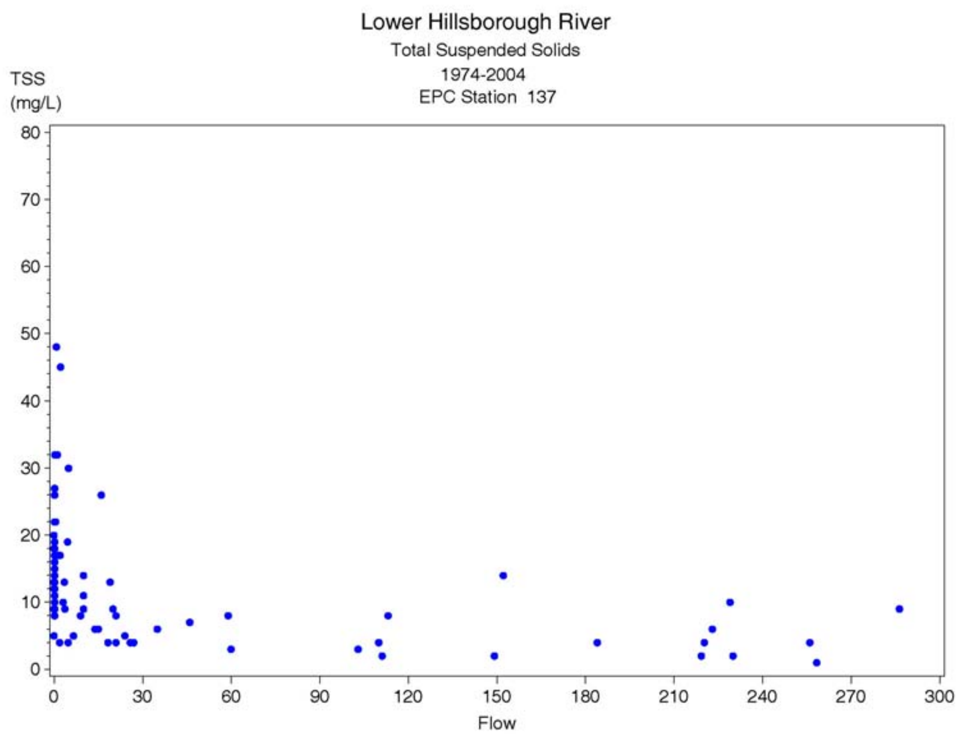


Figure 6-46. Observed response of total suspended solids concentration at EPC Station 137 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs.

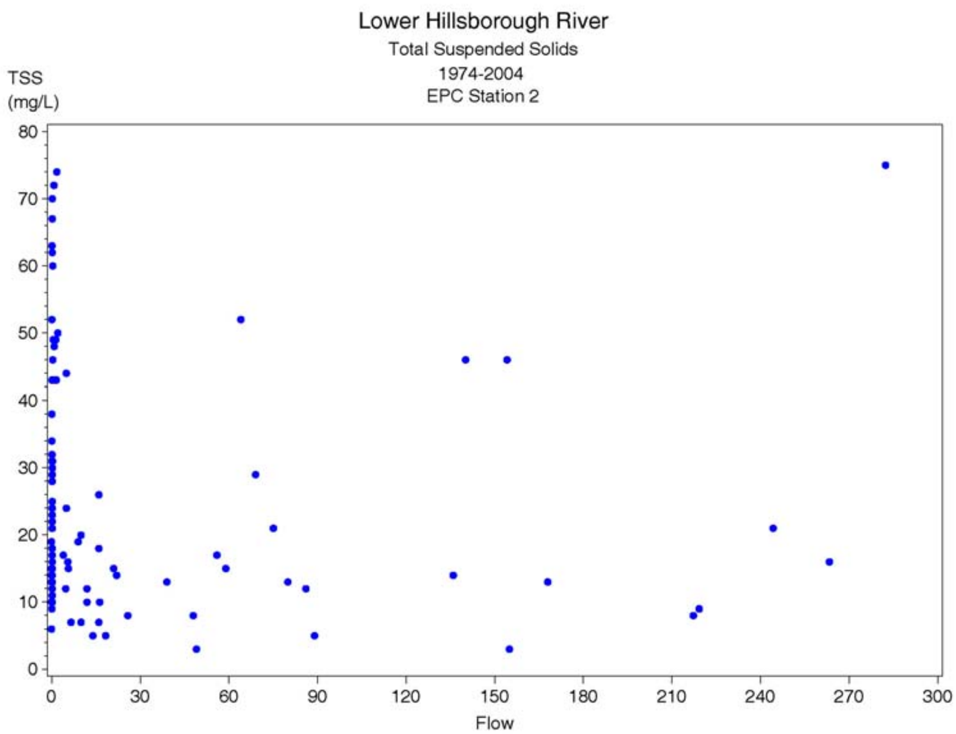


Figure 6-47. Observed response of total suspended solids concentration at EPC Station 2 as a function of flow at the Hillsborough River Dam (Dam flow + Sulphur Springs diversions to the base of the dam). Data were subset to flows less than 300 cfs.

6.2 Simulation Modeling Relating Flow and Salinity

The objectives of this subchapter are three-fold. The first section, 6.2.1, describes the evaluation of the LAMFE model. The second section, 6.2.2, describes the initial model scenarios which were run for the reevaluation of the LHR MFL. The last section, 6.2.3, discusses the results of the freshwater scenarios. The purpose is to investigate the response in the river demonstrated by the various scenarios. The next chapter will evaluate model output versus criterion to identify a revised minimum flow for the LHR.

6.2.1 Assessment of LAMFE

The LAMFE model (Chen 1999, Chen 2003, Chen 2004a, Chen 2004b) was used as a tool in the development of the original LHR minimum flow in 1999. At the time of the development of the first minimum flow for LHR, the existing data base for the river during low flows was limited. Therefore, the District and the CoT commenced the LHR Minimum Flow Study to fill this data gap and to allow reevaluation of the minimum flow for the LHR once the currently established minimum flow of 10 cfs had been implemented.

For the study, a series of controlled-flow experiments were conducted by the CoT and the District between 2002 and 2005. The primary objective of the controlled-flow experiments was to verify and refine the LAMFE model developed by District staff. In addition to the increased data for low flow conditions collected during the controlled-flow experiments, several additional improvements were made to the LAMFE model. These improvements included a refined bathymetry and changes to the model code

The LAMFE model was recalibrated and verified for the period, February 7, 2001 to December 8, 2002. In the recalibration process, model parameters, including the bottom and sidewall friction coefficients and a limited number of parameters of the turbulence closure model, were tuned to achieve the best fit between model results and measured data. Once the model was calibrated, the model was run to predict water levels and salinities for the two verification periods without tuning the model parameters.

A complete analysis of the LAMFE model developed by the District is presented in Appendix 6-6 (Janicki Environmental, Inc. 2005c). The assessment concluded that the LAMFE model is robust and useful for predicting the temporal and spatial trends in salinity in the LHR and is a satisfactory tool for the reevaluation of the LHR MFL.

6.2.2 Initial Model Scenarios

The settlement agreement established that the reevaluation of the LHR minimum flow would evaluate flows up to at least 30 cfs. The existing minimum flow rule allows for the use of water from Sulphur Springs or other sources of freshwater. For the remainder of this report, the term freshwater refers to any potential source of water having salinity near zero ppt.

A series of five initial model simulation scenarios were examined:

- Baseline – no minimum flow,
- 10 cfs freshwater minimum flow,
- 20 cfs freshwater minimum flow,
- 30 cfs freshwater minimum flow, and
- 40 cfs freshwater minimum flow.

Note that the baseline scenario was defined as having no diversions of Sulphur Springs water to the base of the dam or additional inputs of freshwater.

6.2.3 New Water Scenarios Results

The freshwater scenarios consist of adding 10, 20, 30 or 40 cfs of freshwater to the system. As mentioned previously, no assumption is made regarding the source of this water, only that the salinity of the water is approximately 0 ppt. In order to understand the general impact of variation in freshwater inflow on salinity in the LHR, time series plots of the surface, middle and bottom salinity are presented for the model cells where the EPCHC stations (105, 152, 137, and 2) are located (Figure 3-1). In addition, 2-dimensional plots of median salinity by calendar month are presented for the baseline and the 10, 20, 30, and 40 cfs freshwater scenarios. A selection of the 2-dimensional plots are included in the text for illustrative purpose.

Spatially, it is clear that the greatest benefit in increasing freshwater inflows was observed in the upper portion of the river. For example, the median daily surface salinity at EPCHC Station 105 is 5 to 10 ppt lower than the baseline with as little as 10 cfs of freshwater being added to the river (Figures 6-48 through 6-50). The additional benefit from greater freshwater inputs (*i.e.*, 20, 30, 40 cfs of freshwater) can also be seen. The benefits derived from the freshwater inputs can also be seen in the middle to lower portions of the river, but not to the same extent as that seen upstream (Figures 6-51 through 6-59).

Temporally, the observed benefit of adding freshwater to the river, as expected, is most notable during low flow days when MFL compliance is necessary. This response is most apparent in the surface water layer, but is also apparent in the middle and lower water layers.

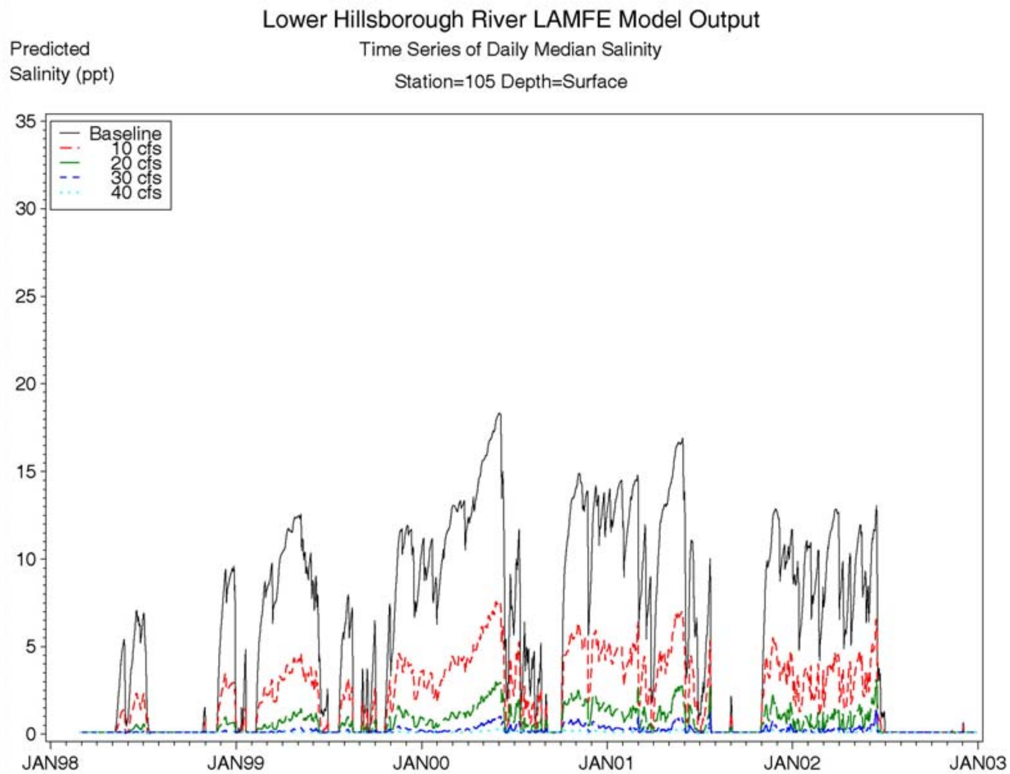


Figure 6-48 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 105, surface layer.

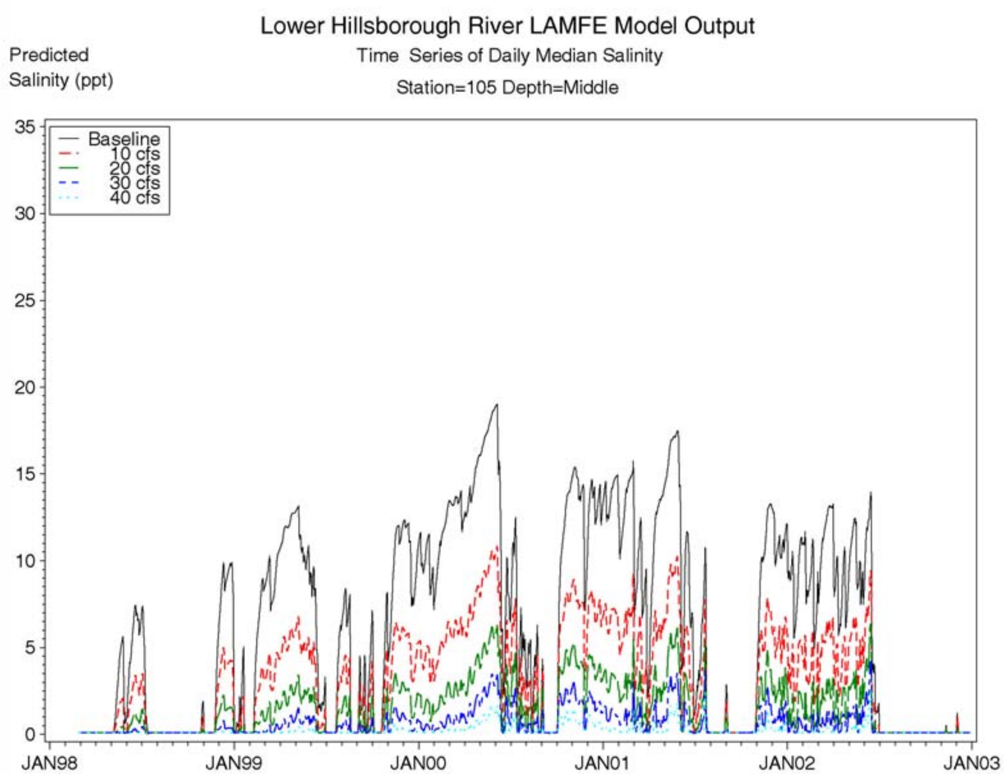


Figure 6-49 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 105, middle layer.

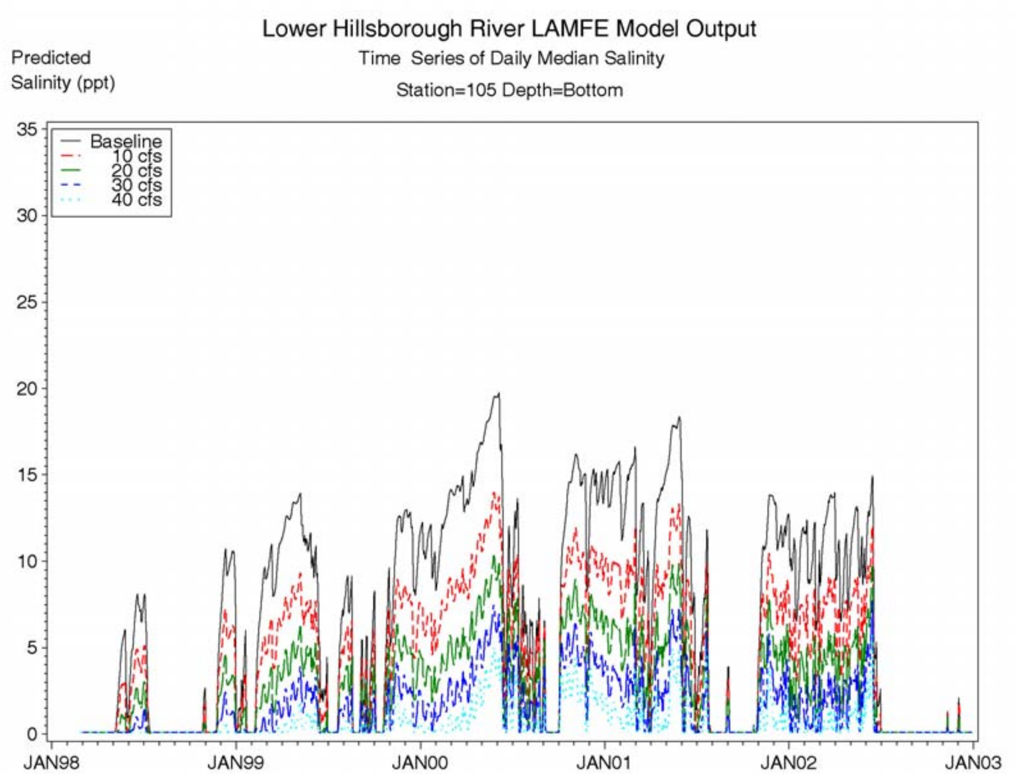


Figure 6-50 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 105, bottom layer.

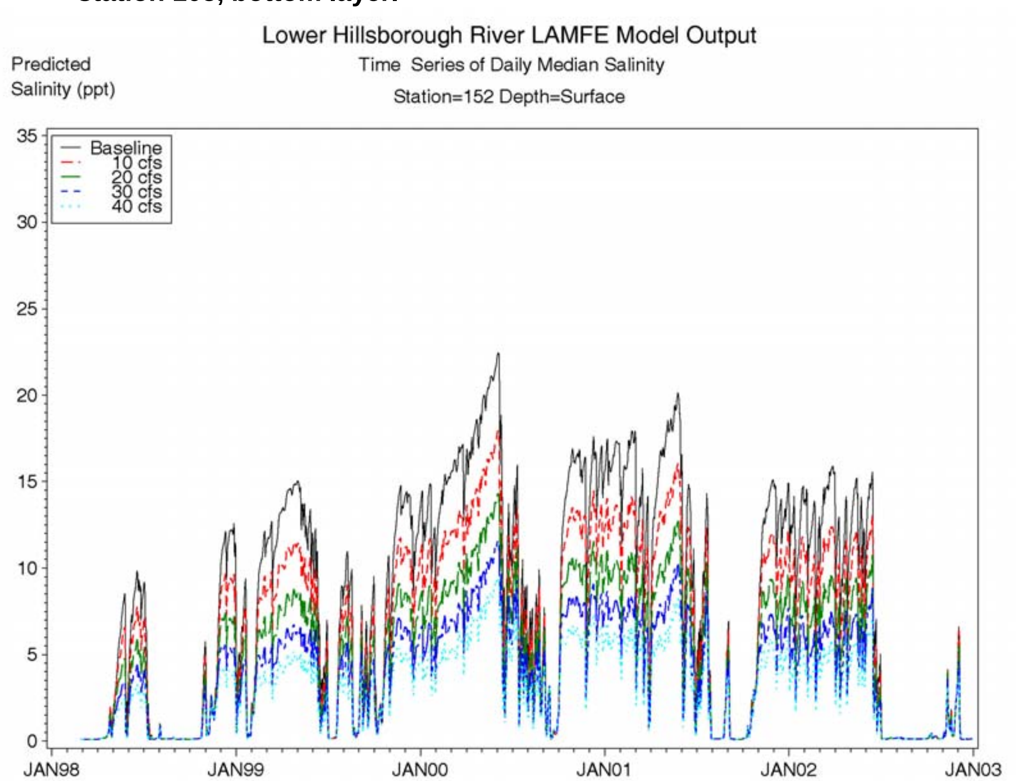


Figure 6-51 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 152, surface layer.

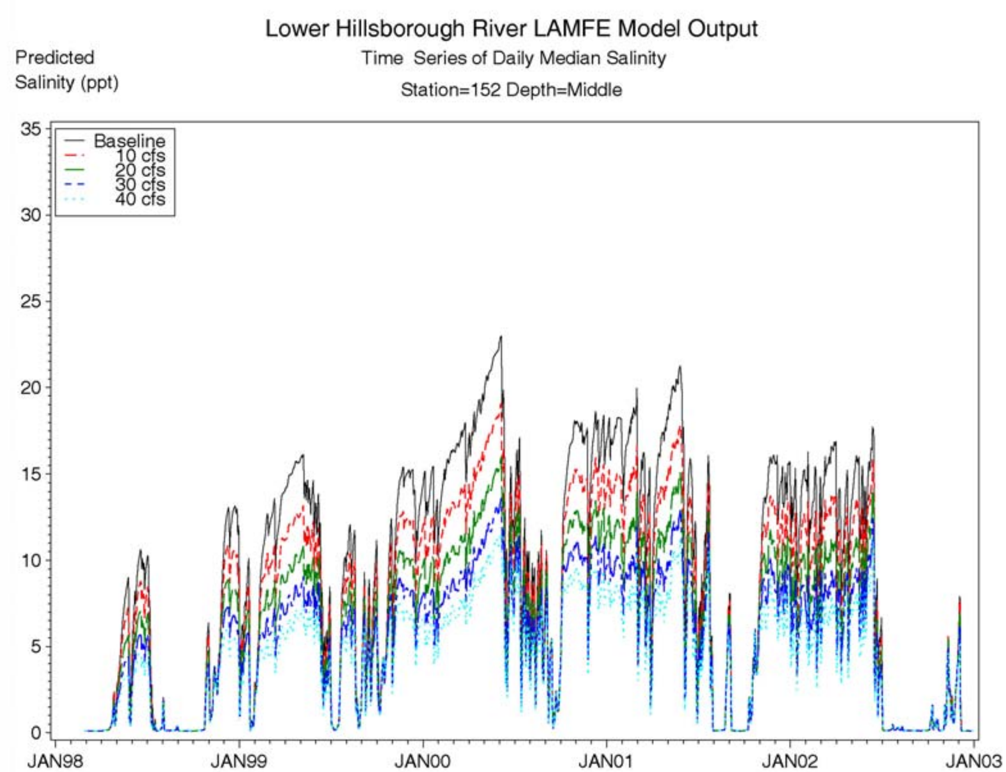


Figure 6-52 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 152, middle layer.

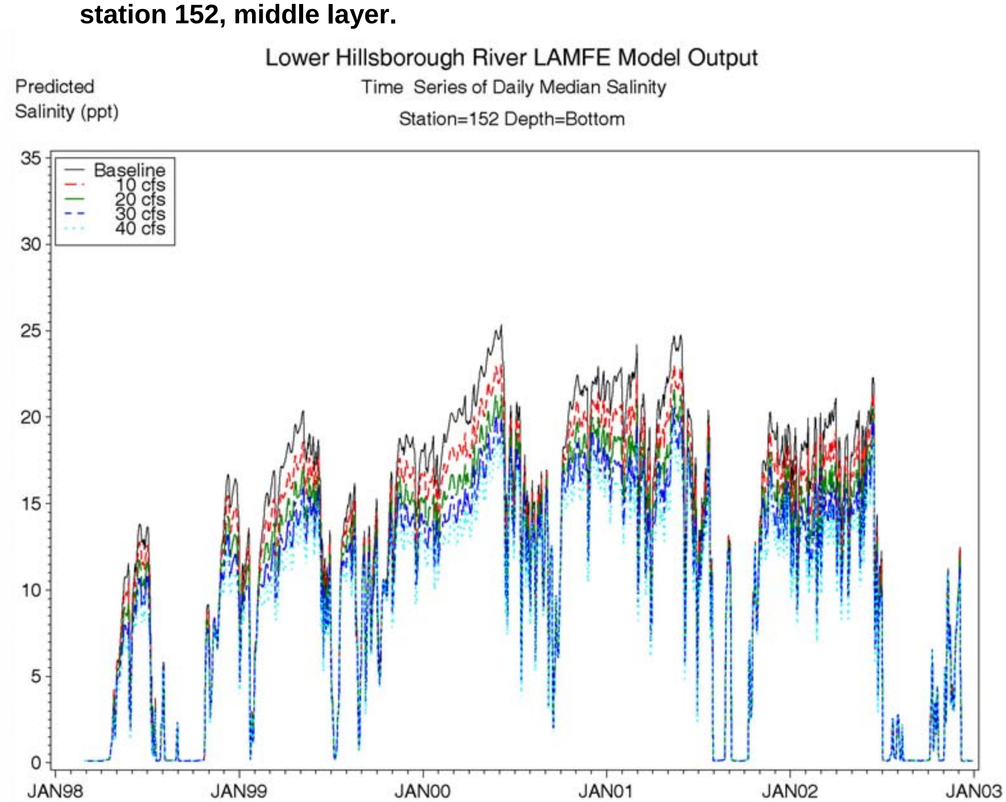


Figure 6-53 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 152, bottom layer.

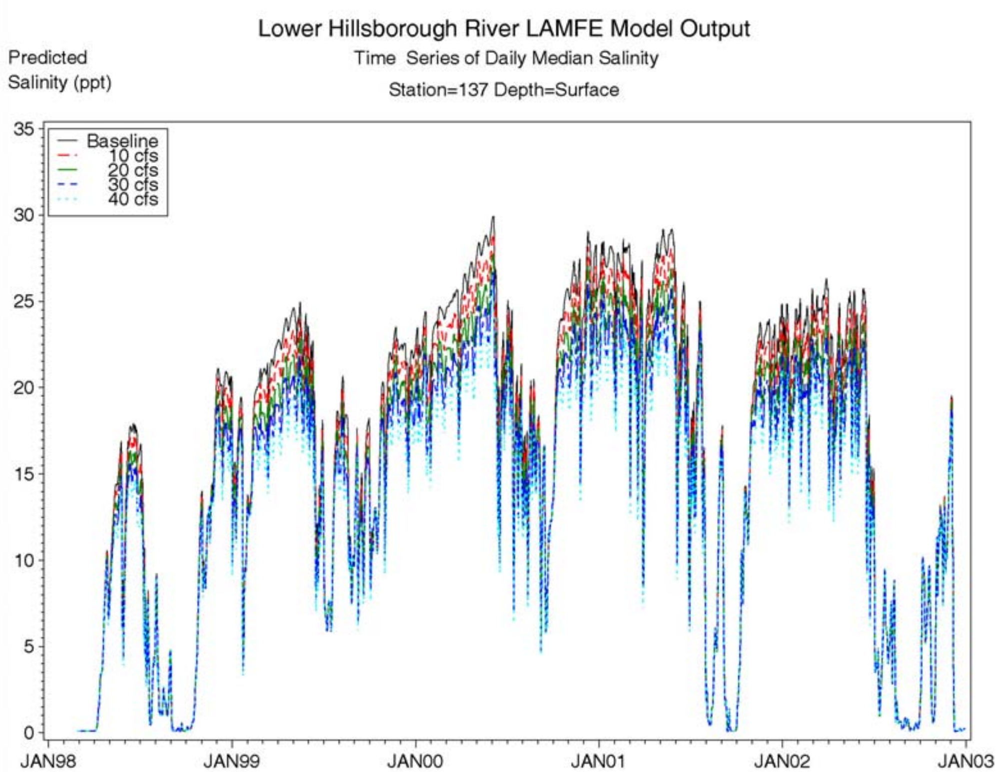


Figure 6-54 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 137, surface layer.

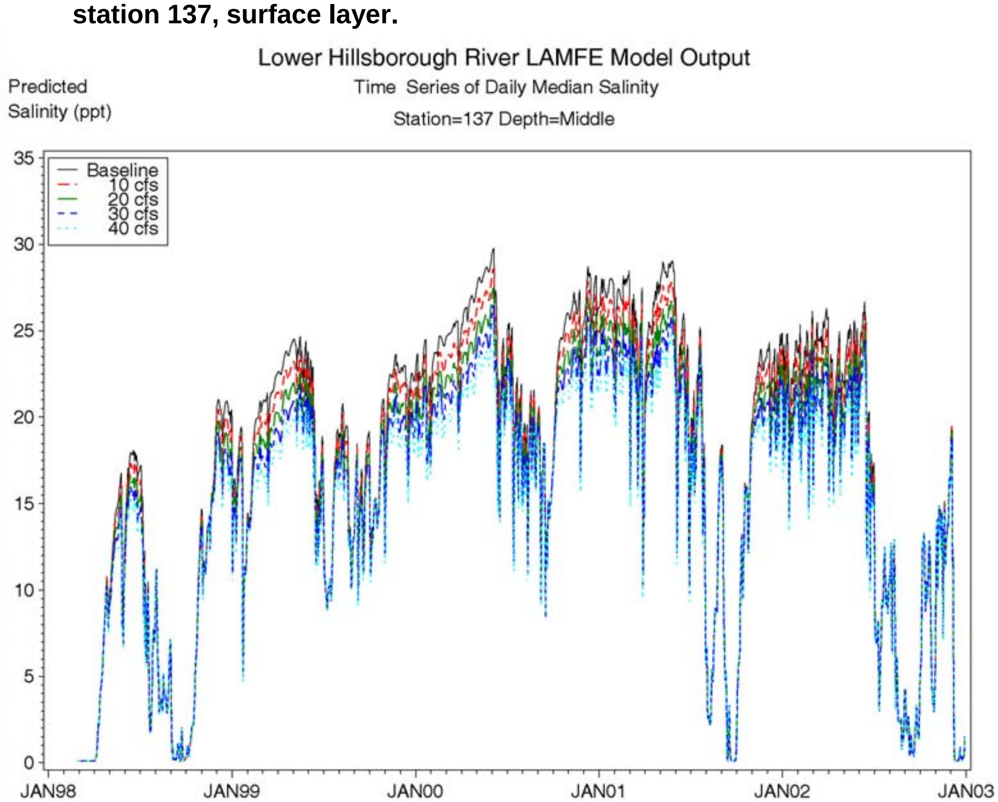


Figure 6-55 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 137, middle layer.

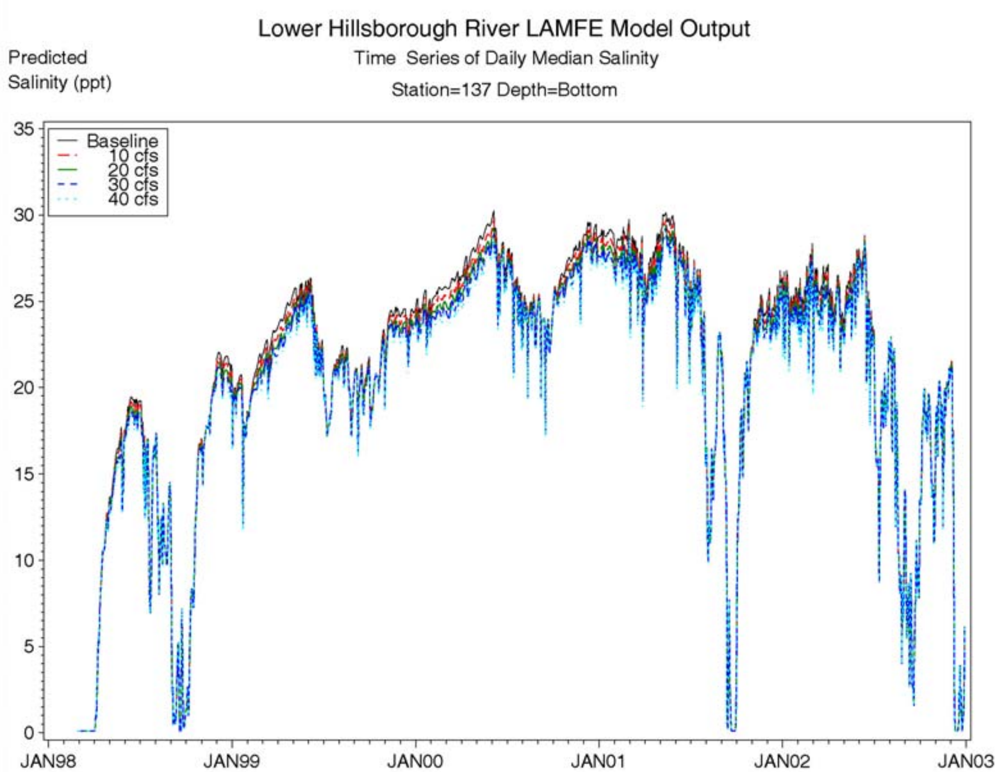


Figure 6-56 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 137, bottom layer.

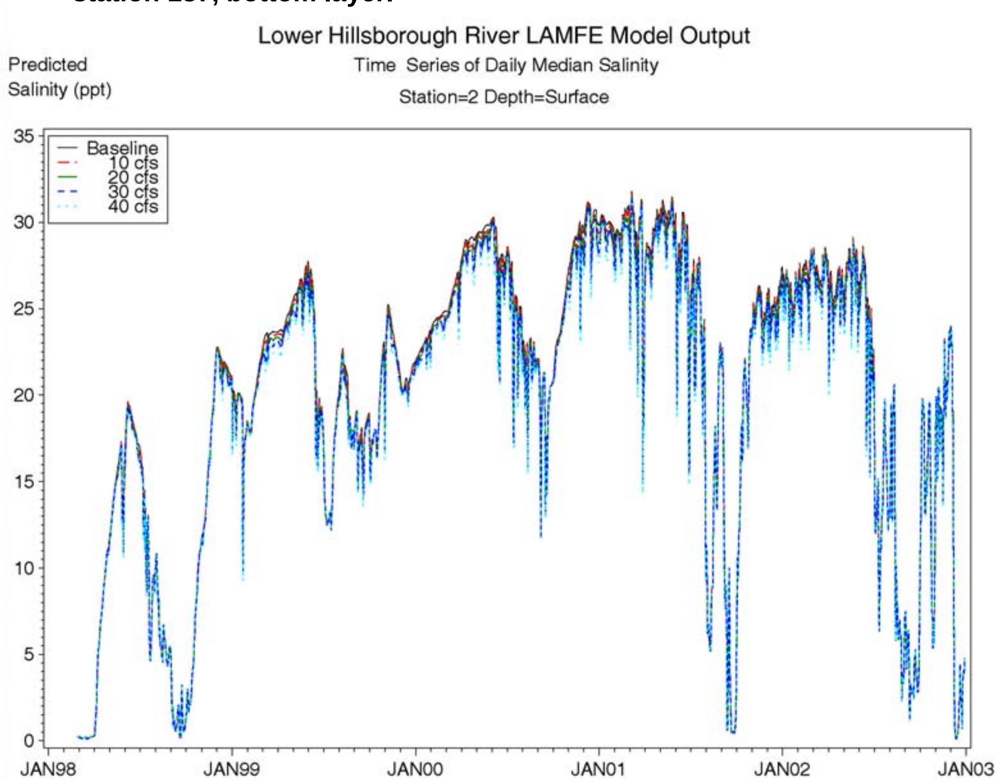


Figure 6-57 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 2, surface layer.

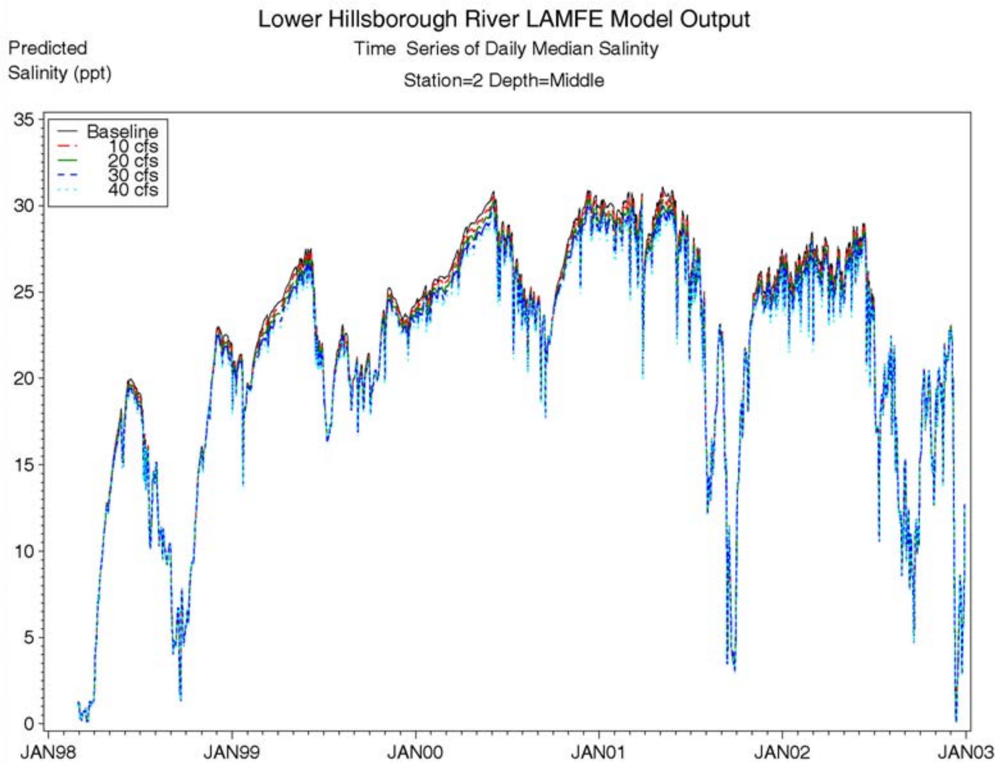


Figure 6-58 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 2, middle layer.

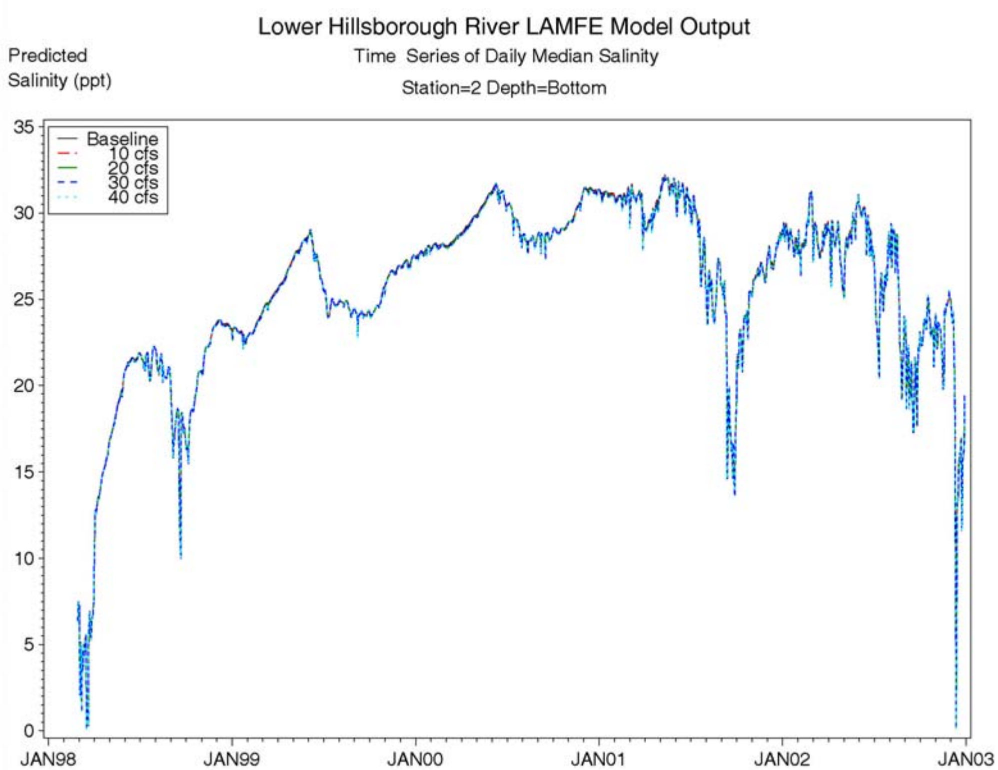


Figure 6-59 Predicted daily median salinity for the baseline and freshwater scenarios at EPCHC station 2, bottom layer.

The model simulation results can also be viewed in two dimensions that allow further interpretation of the manner in which the river responds to various freshwater inflows. This is accomplished by calculating the median salinity in each model cell for a given period of time. For this presentation, the median monthly salinities have been calculated for each month for the period of 1998 to 2002. Commenting on the previous LHR MFL document, the peer review panel (SWFWMD 1999) noted that, "Salinity values upstream of the [Sulphur Springs] outfall at the base of the dam are higher than just above or below the outfall. This indicates that a 'reverse estuary' condition exists during no flow periods. This would be very detrimental to estuarine communities." Figures 6-60 through 6-64 indicate that this reverse salinity gradient does not exist at flows greater than 20 cfs. The following discussion focuses on the observed model responses during the month of May, 1999 that represents an extremely dry period. During this month, flows over the dam were less than 1 cfs every day. Two-dimensional monthly median salinity plots are presented for May 1999 for the baseline and 10, 20, 30, and 40 cfs freshwater scenarios (Figures 6-60 to 6-64).

In Figure 6-60, modeled salinity responses were observed to vary spatially in both the longitudinal and vertical dimensions. From river kilometer 12 to upstream, no portion of the water column is less than 5 ppt (most of the water column being between 8 and 12 ppt). From river kilometer 10 downstream to the river mouth, the bottom salinities are 20 ppt or greater. From river kilometer 2 downstream to the river mouth, the entire water column is greater than 24 ppt. There is no portion of the river within the low salinity range (0 to 5 ppt).

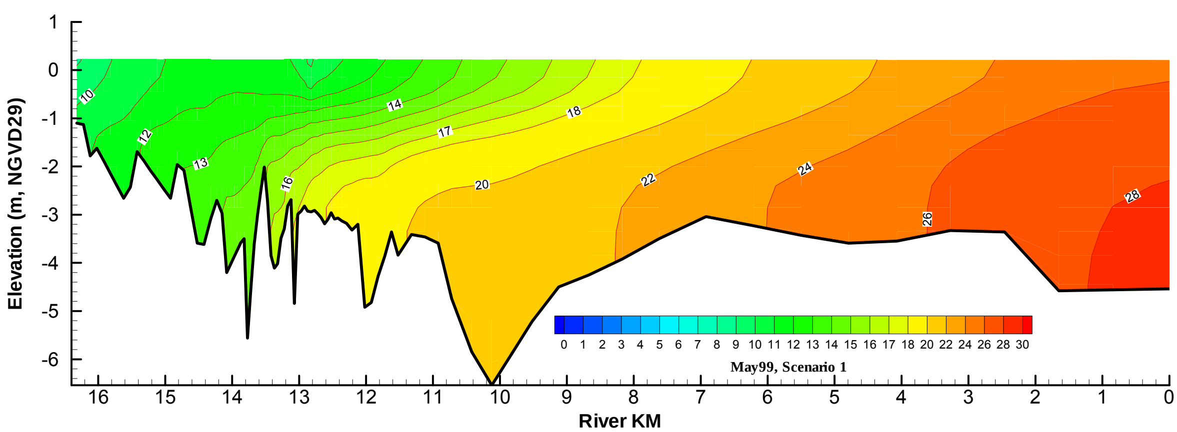


Figure 6-60 Predicted monthly median salinity for the Baseline Scenario, May 1999.

The model results from the 10 cfs freshwater scenario (Figure 6-61) can be compared to the baseline scenario (Figure 6-60). Several differences can be seen. First, the 10 cfs freshwater addition results in salinity less than 5 ppt from approximately river kilometer 15 to the dam. Second, moderate salinities (10 to 12 ppt) can be seen as far downstream as river kilometer 10. There is no appreciable difference in salinities in the lower river.

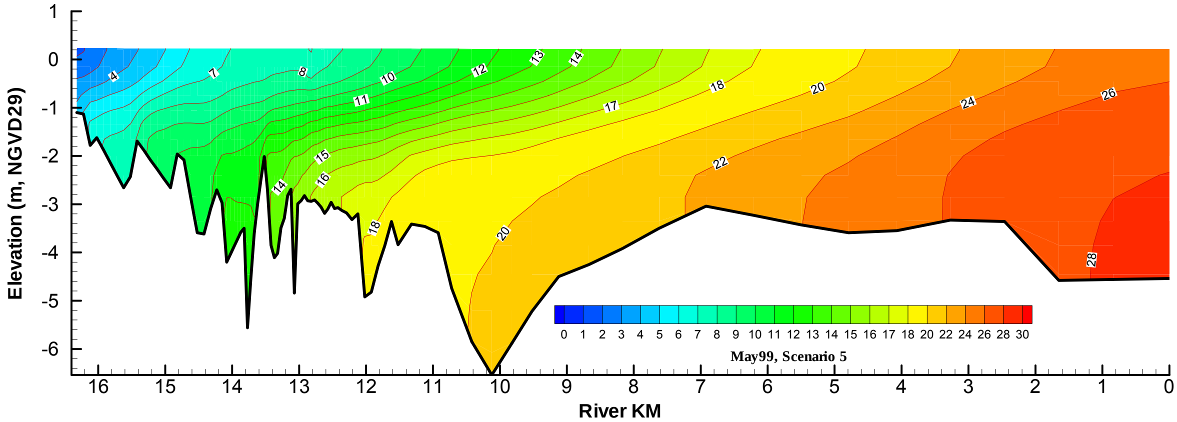


Figure 6-61 Predicted monthly median salinity for the 10 cfs freshwater Scenario, May 1999.

The model results from the 20 cfs freshwater scenario (Figure 6-62) can be compared to the baseline scenario (Figure 6-60). Several differences can be seen. First, the 20 cfs freshwater addition results in salinity less than 5 ppt from approximately river kilometer 13 to the dam. Second, moderate salinities (10 to 12 ppt) can be seen as far downstream as river kilometer 9. In the most downstream portion of the river, salinities are approximately 25 ppt.

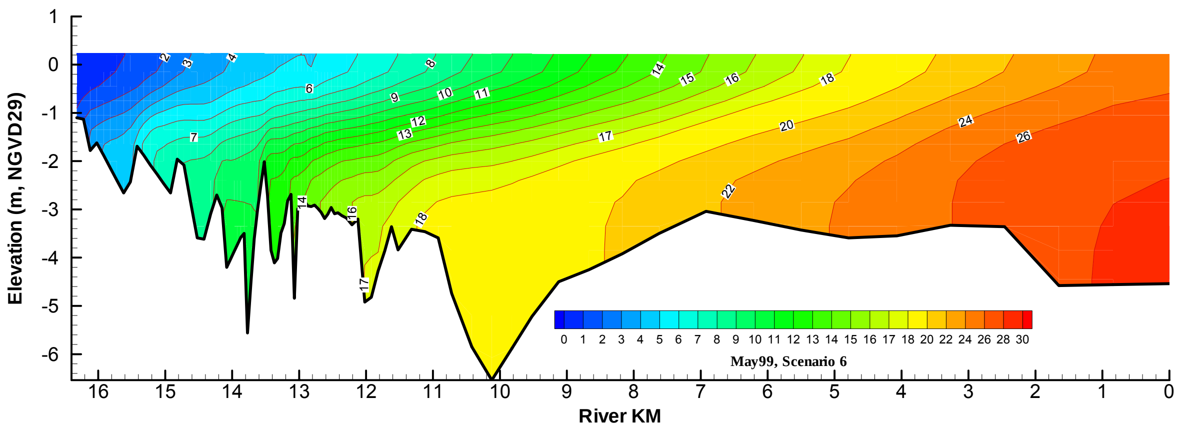


Figure 6-62 Predicted monthly median salinity for the 20 cfs freshwater Scenario, May 1999.

The model results from the 30 cfs freshwater scenario (Figure 6-63) can be compared to the baseline scenario (Figure 6-60). Several differences can be seen. First, the 30 cfs freshwater addition results in salinity less than 5 ppt from approximately river kilometer 12 to the dam. Second, moderate salinities (10 to 12 ppt) can be seen as far downstream as river kilometer 8. In the most downstream portion of the river, salinities remain approximately 25 ppt.

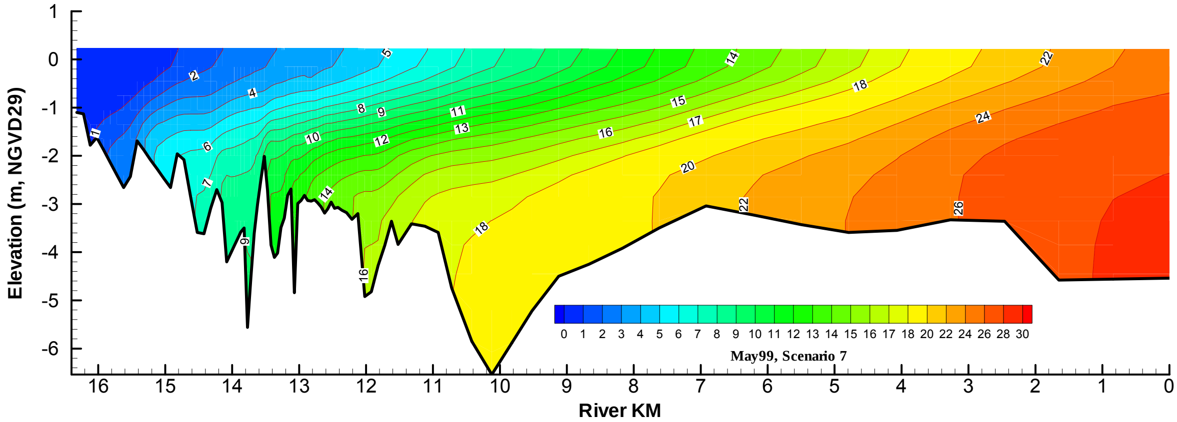


Figure 6-63 Predicted monthly median salinity for the 30 cfs freshwater Scenario, May 1999.

The model results from the 40 cfs freshwater scenario (Figure 6-64) can be compared to the baseline scenario (Figure 6-60). Several differences can be seen. First, the 40 cfs freshwater addition results in salinity less than 5 ppt from approximately river kilometer 11 to the dam. Second, moderate salinities (10 to 12 ppt) can be seen as far downstream as river kilometer 7. In the most downstream portion of the river, salinities are less than 25 ppt.

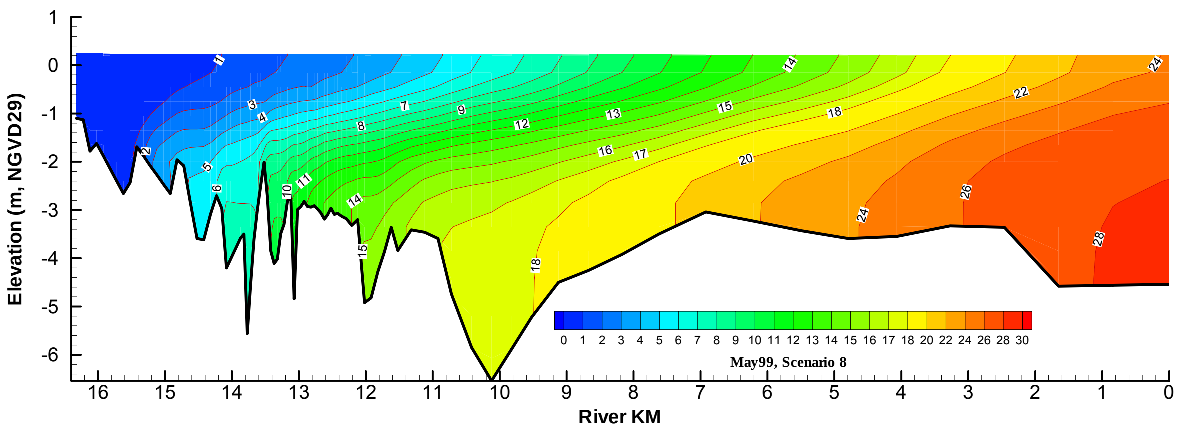


Figure 6-64 Predicted monthly median salinity for the 40 cfs freshwater Scenario, May 1999.

6.3 Conclusions

Based on both the examination of empirical relationships between flow and salinity and the simulation modeling efforts, the following conclusions can be drawn:

- The response in salinity to variation in freshwater flows was most pronounced and predictable in comparison to other water quality constituents (e.g., DO, chlorophyll, nutrients). The responses in these other constituents reflect less direct relationships with flow than exists for salinity.

- Continuous salinity measurements show that even at a relatively constant minimum flow, there is considerable within-day variability in salinity through most of the river.

- The existing minimum flow of 10 cfs provides additional low salinity habitat as compared to conditions observed in the absence of a minimum flow.

- The addition of freshwater above 10 cfs results in an incremental increase in low salinity habitat. This is particularly true for the low (0 to 5 ppt) and mid-range (8 to 12 ppt) salinities.

- The reverse salinity gradient observed just upstream of Sulphur Springs in the absence of a minimum flow is ameliorated with the addition of freshwater at flows of 20 cfs or higher.

7.0 APPLICATION OF MODELING RESULTS TO EVALUATE A RANGE OF POSSIBLE MINIMUM FLOWS

Based on the conclusions drawn from the previous chapters, it is clear that salinity response to changes in flows is the most pronounced and most predictable of the biologically-relevant water quality responses. As discussed above, the TBNEP advisory group recommended that in order to offer maximum benefit to the most species of fish, the salinity gradient in a river should be complete (i.e., freshwater to greater than 18 parts per thousand (ppt) of salinity).

It is important to recognize that river habitats with salinities in the range of 0 to 5 ppt have been disproportionately lost throughout the Tampa Bay watershed (TBNEP, 1996), and that there is an opportunity to maintain such a habitat in the LHR given an appropriate minimum flow. Analysis of benthic macroinvertebrate and fish community structures shows that distinct groups of these organisms thrive in river habitats with salinity in the range of 0 to 5 ppt. One of the goals established for the proposed Sulphur Springs minimum flow (SWFWMD, 2004b) is maintenance of low salinity habitats in the LHR. Therefore, in recognition of the importance of the 0 to 5 ppt salinity range, subsequent evaluations focused on this range.

The strategy adopted for this evaluation was to quantify the incremental change in terms of the number of days per year when salinity in the portion of the river downstream from the dam at three locations, Rowlett Park, Hannah's Whirl, and Sulphur Springs is maintained in the 0 to 5 ppt range as a function of increases in freshwater inflow.

In addition to primary salinity range evaluated, several additional salinity ranges were defined and evaluated. Both the 5 to 11 ppt and 11 to 18 ppt salinity ranges support other important benthic macroinvertebrate and fish taxa, and therefore, the secondary criteria are to optimize the available habitat in each of these important salinity ranges.

7.1 Comparison of Simulation Model Results to Salinity Criteria

The objective of this evaluation is to quantify the spatial extent and temporal persistence of conditions meeting the salinity criteria.

To facilitate the evaluation of the model results, three tools are used.

- simple bar charts that present the increase in the volume of the river meeting the salinity criteria under candidate minimum flows at one of several locations,
- cumulative distribution function (CDF) plots that present the incremental gain in terms of temporal persistence and spatial extent of water meeting the salinity criteria under candidate minimum flows, and

- tabular presentation of entire river volumes by salinity ranges under candidate minimum flows.

Because of the specific interest in the low-flow conditions, these three tools were applied only to the important subset of days when the flow over the Hillsborough River Dam was less than 40 cfs.

Both the simple bar charts and tabular data presentations are relatively self-explanatory. However, the CDF plots are less so, and an example plot is discussed to aid in the interpretation of these plots presented later in this chapter.

Figures 7-1a and 7-1b present the same hypothetical CDF plot. The CDF plot in Figure 7-1a presents the manner in which the CDF plot can be used to estimate the incremental benefit in terms of the proportion of the volume of river water with salinity from 0 to 5 ppt for different degrees of temporal persistence. The CDF plot in Figure 7-1b presents the manner in which the CDF plot can be used to estimate the incremental benefit in terms of the proportion of low flow days that have 0 to 5 ppt salinities for different degrees of spatial extent. In these examples two flows are compared; more fresh water is being put into the system in Scenario B than in Scenario A.

For example, by drawing a vertical line from the x-axis in Figure 7-1a to the intersection of Scenario A (green line) and then extending the line to the y-axis, we see that at least 75% of the volume is less than 5 ppt 26% of the time. For Scenario B (blue line), we see that at least 75% of the volume is less than 5 ppt 53% of the time. Therefore, if the goal is to maximize the amount of time that at least 75% of the volume is less than 5 ppt, Scenario B would clearly be preferred to Scenario A.

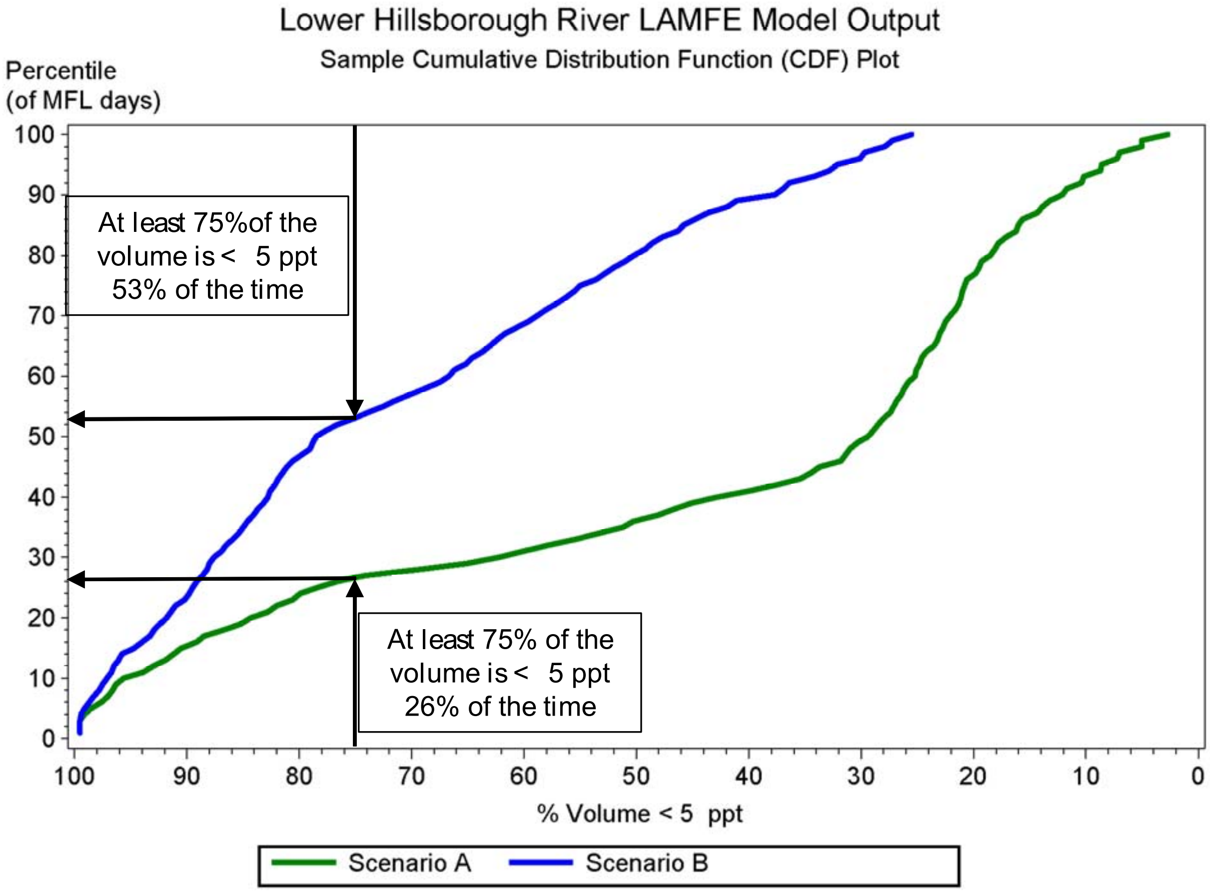


Figure 7-1a Example CDF plot. See discussion above.

In the second example, by drawing a horizontal line from the y-axis in Figure 7-1b to the intersection of Scenario A (green line) and then extending the line to the x-axis, we see that at least 55% of the volume is less than 5 ppt 75% of the time. Drawing a horizontal line to the green line and then continuing down to the x-axis reveals that at least 21% of the volume is less than 5 ppt 75% of the time. Therefore, Scenario B again would clearly be preferred to Scenario A.

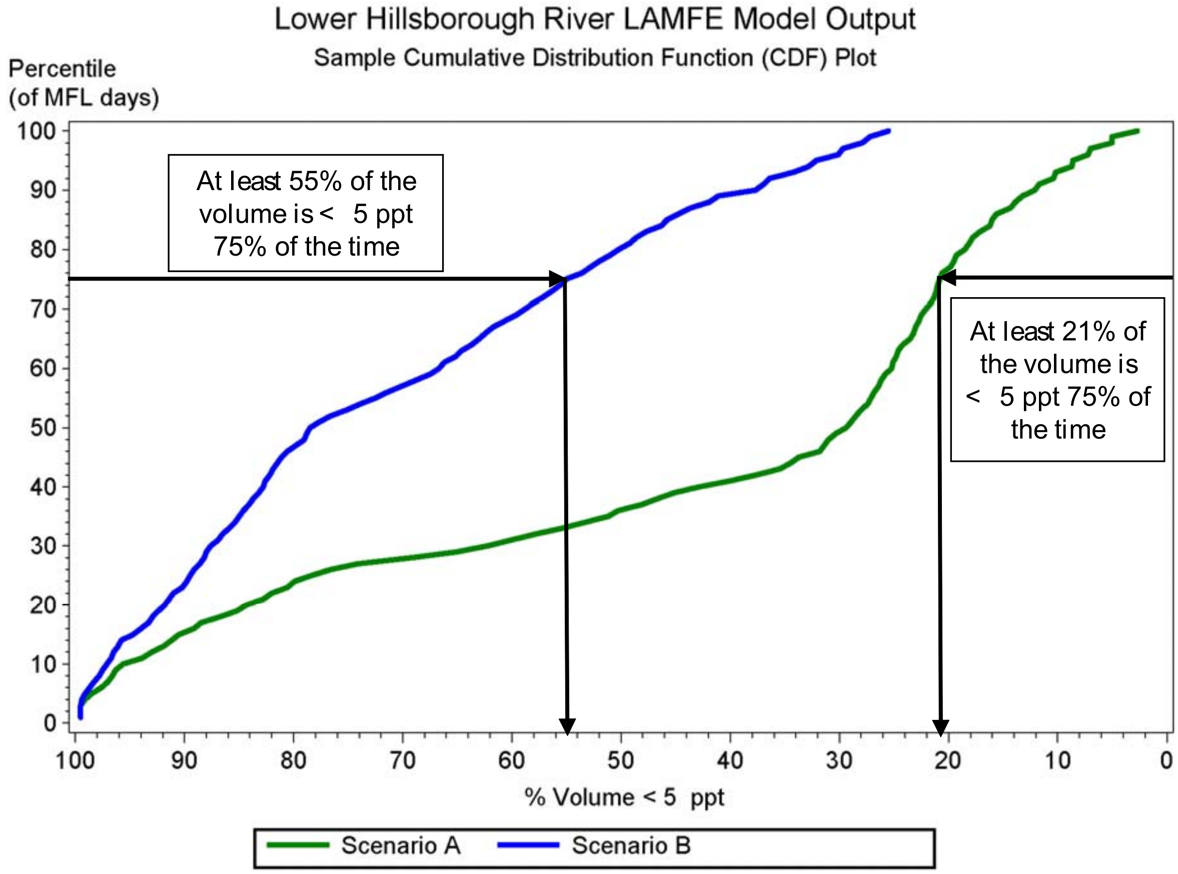


Figure 7-1b Example CDF plot. See discussion above.

As these samples exhibit, the CDF plots provide a powerful tool to compare multiple scenarios with regard to percentile volume or the percentile of time that a particular salinity range is achieved.

7.1.1 Comparison of Simulation Model Results: Freshwater Scenarios

The freshwater scenarios evaluated are 10, 20, 30, and 40 cfs. These scenarios are compared to the Baseline Scenario using the methods described above. The volume between the Hillsborough River Dam and Rowlett Park, Hannah's Whirl, and Sulphur Springs will first be analyzed using bar charts and then CDF plots.

Examination of Figures 7-2 through 7-10 shows that:

- The volume of water less than 5 ppt is a substantially increased between the baseline and the 10 cfs minimum flow scenario, and between the 10 cfs and 20 cfs minimum flows evaluated for all plots except the 25th percentile for the dam to Rowlett Park, where there is no difference in the scenarios.

- There is an additional incremental gain in percent volume less than 5 ppt at the 75th percentile between 20 cfs and 30 cfs.

- Though there is an additional increase in percent volume less than 5 ppt at flows between 30 cfs and 40 cfs, the incremental increase is much less than that observed between lower minimum flows.

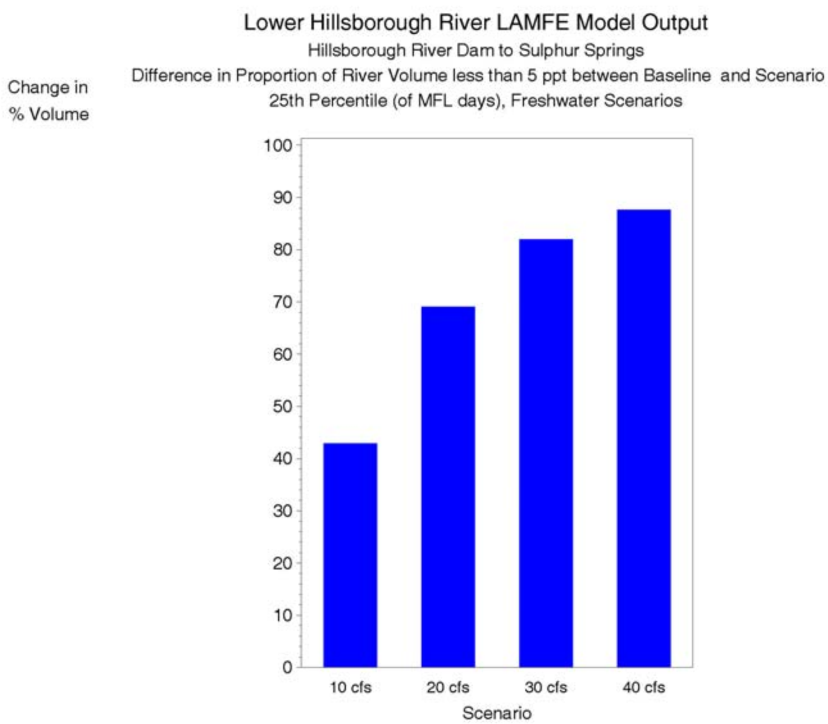


Figure 7-2 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 25th percentile of MFL days, Dam to Sulphur Springs.

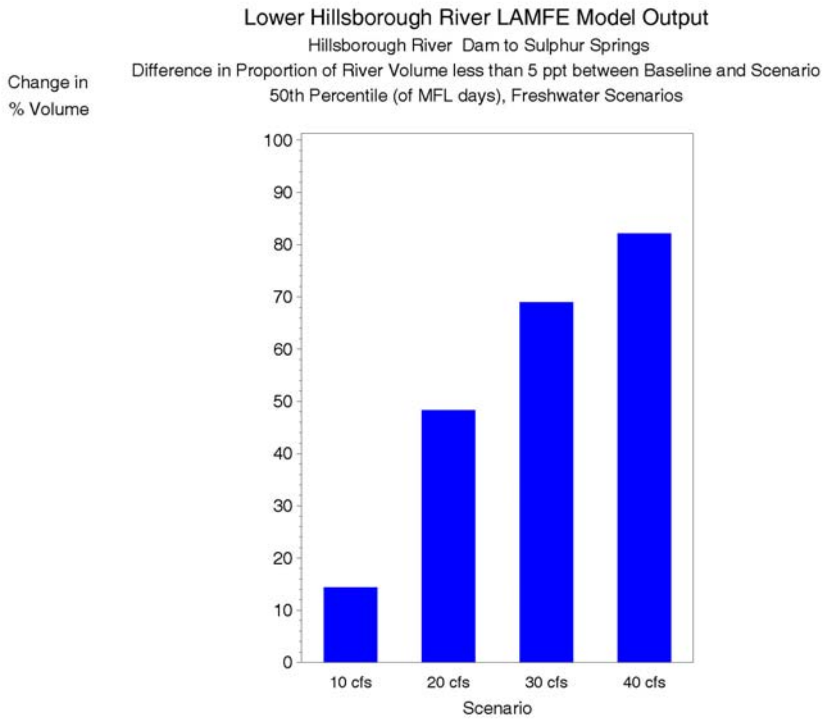


Figure 7-3 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 50th percentile of MFL days, Dam to Sulphur Springs.

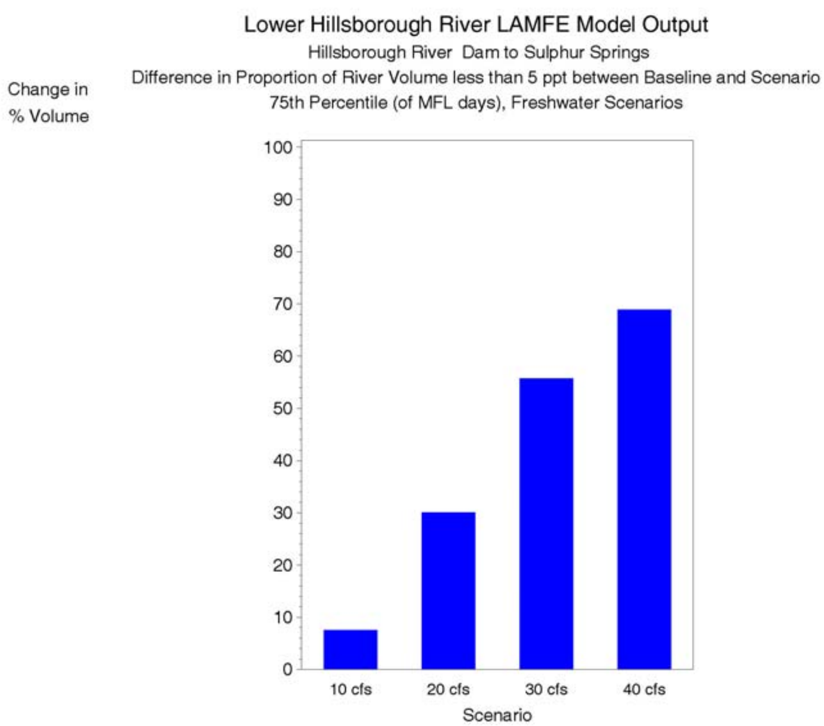


Figure 7-4 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 75th percentile of MFL days, Dam to Sulphur Springs.

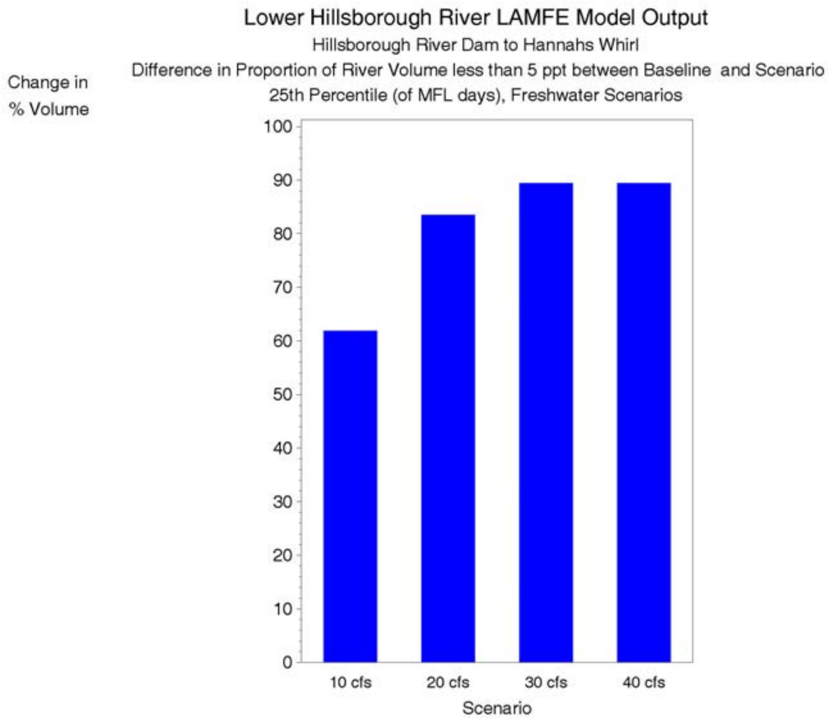


Figure 7-5 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 25th percentile of MFL days, Dam to Hannah's Whirl.

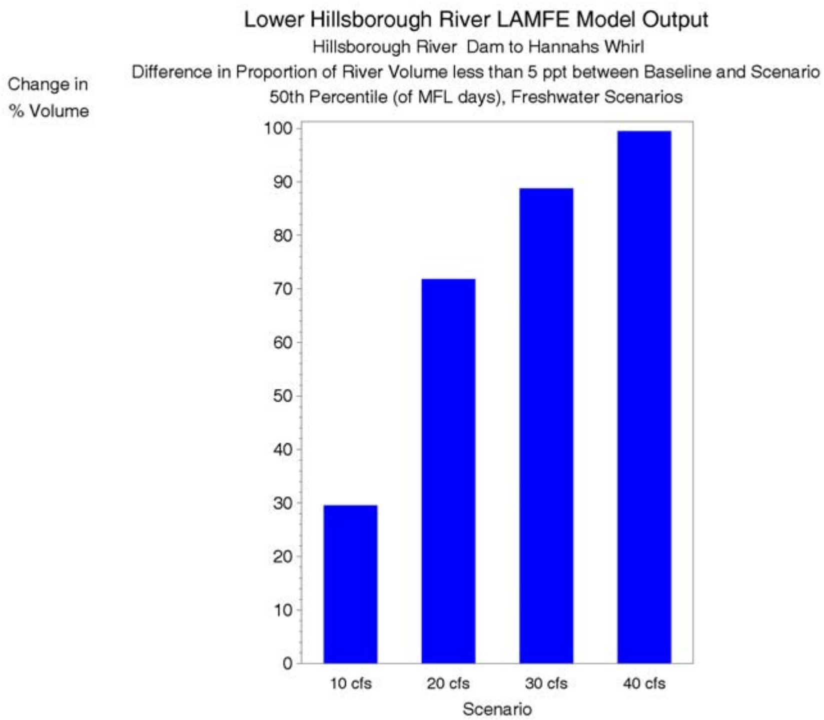


Figure 7-6 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 50th percentile of MFL days, Dam to Hannah's Whirl.

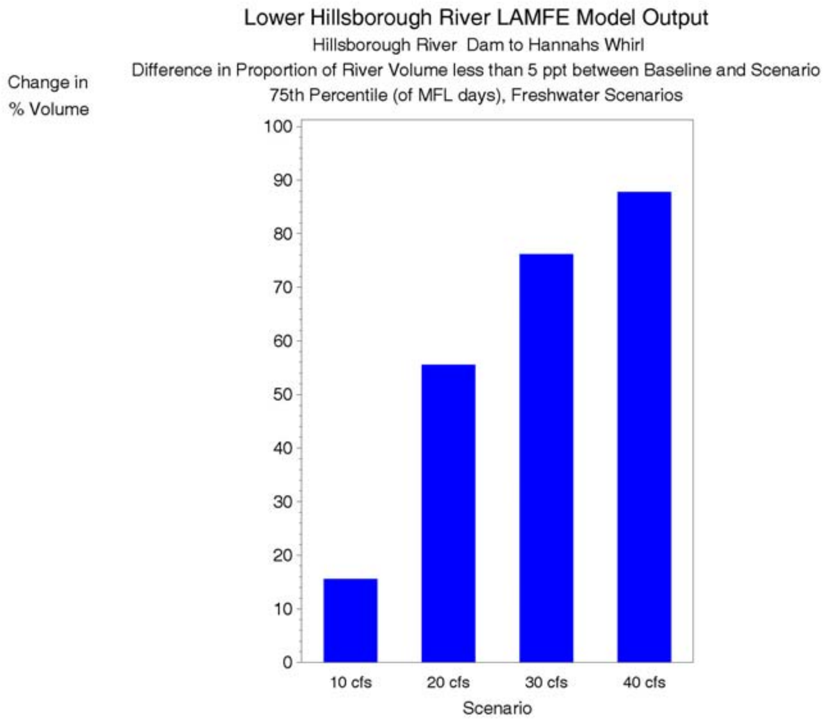


Figure 7-7 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 75th percentile of MFL days, Dam to Hannah's Whirl.

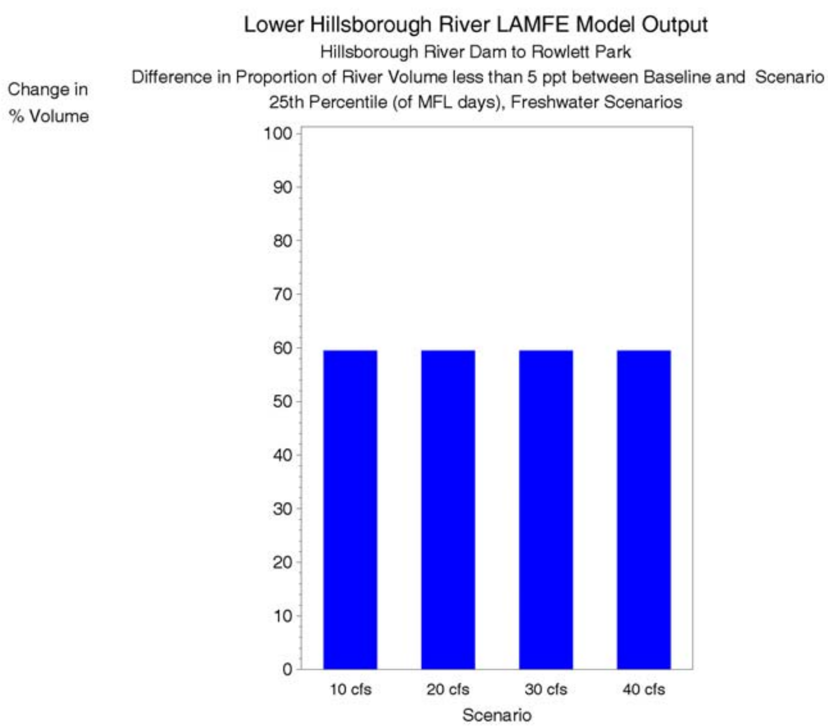


Figure 7-8 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 25th percentile of MFL days, Dam to Rowlett Park.

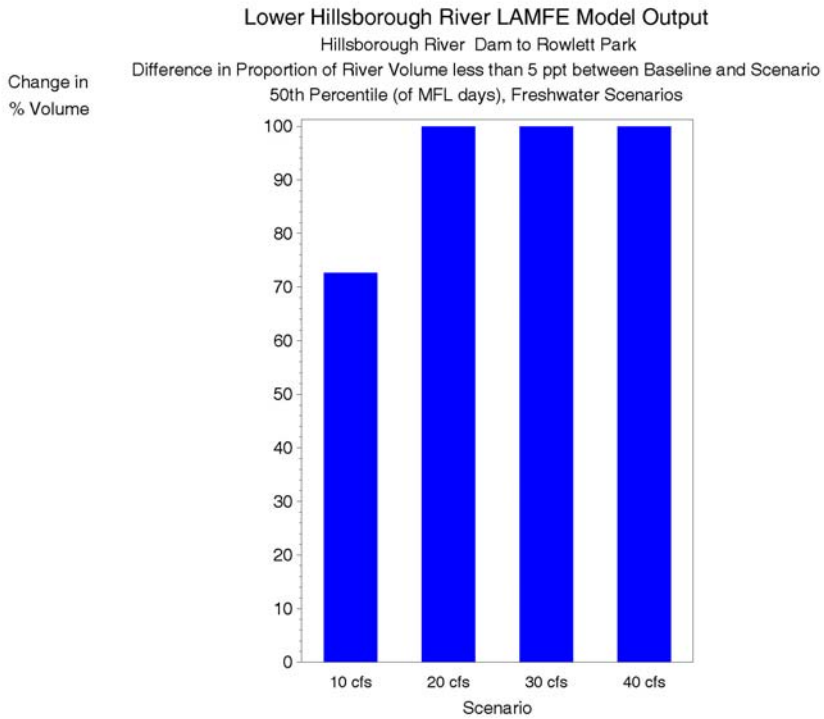


Figure 7-9 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 50th percentile of MFL days, Dam to Rowlett Park.

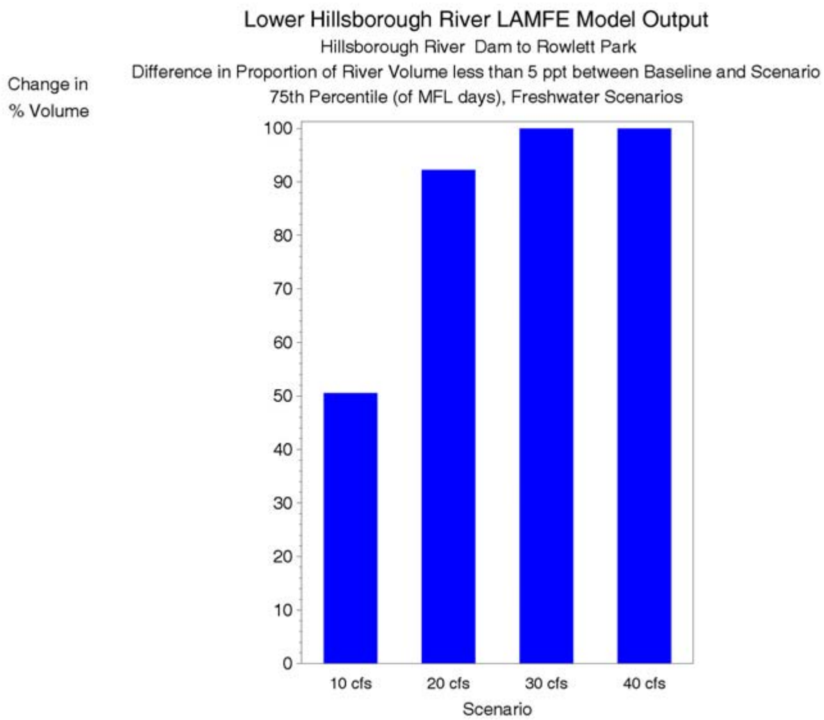


Figure 7-10 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 75th percentile of MFL days, Dam to Rowlett Park.

Examination of the CDF plot in Figure 7-11 through 7-13 shows that:

- The 10 cfs minimum flow provides substantial benefit compared to the baseline for all three spatial domains.
- There are large incremental increases in both temporal persistence and spatial extent in providing less than 5 ppt salinity between the 10 cfs and 20 cfs minimum flows.
- There is an additional incremental gain in both temporal persistence and spatial extent in water less than 5 ppt when the minimum flow is between 20 cfs and 30 cfs.
- Though there is an additional increase in both temporal persistence and spatial extent in achieving 5 ppt salinity between 30 cfs and 40 cfs, the incremental increase is much less than that observed between lower minimum flows.

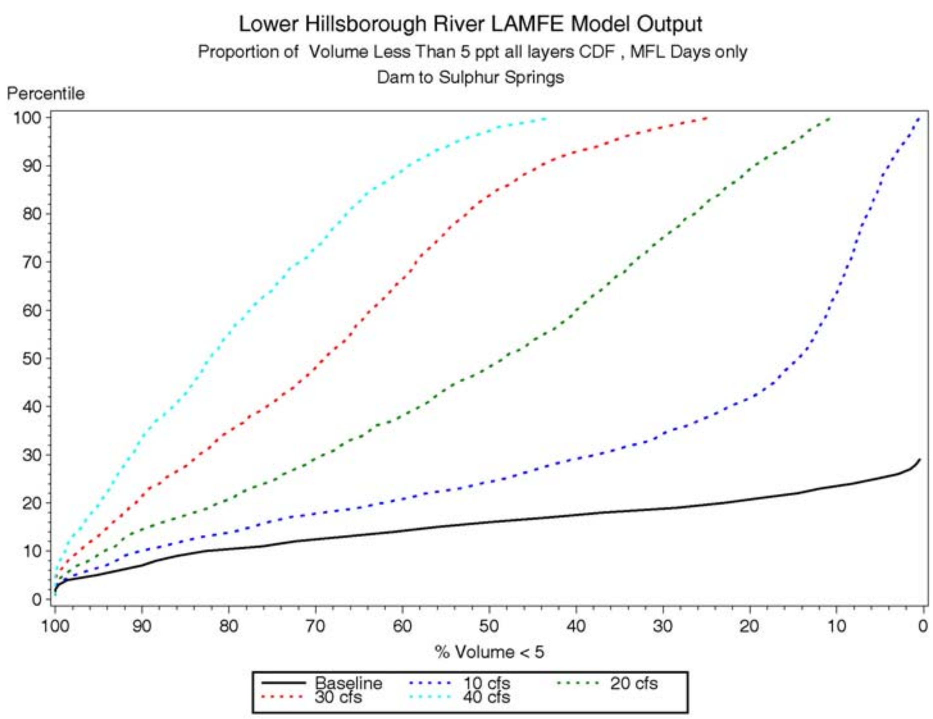


Figure 7-11 CDF plot of percent volume from the dam to Sulphur Springs less than 5 ppt for MFL days for freshwater scenarios.

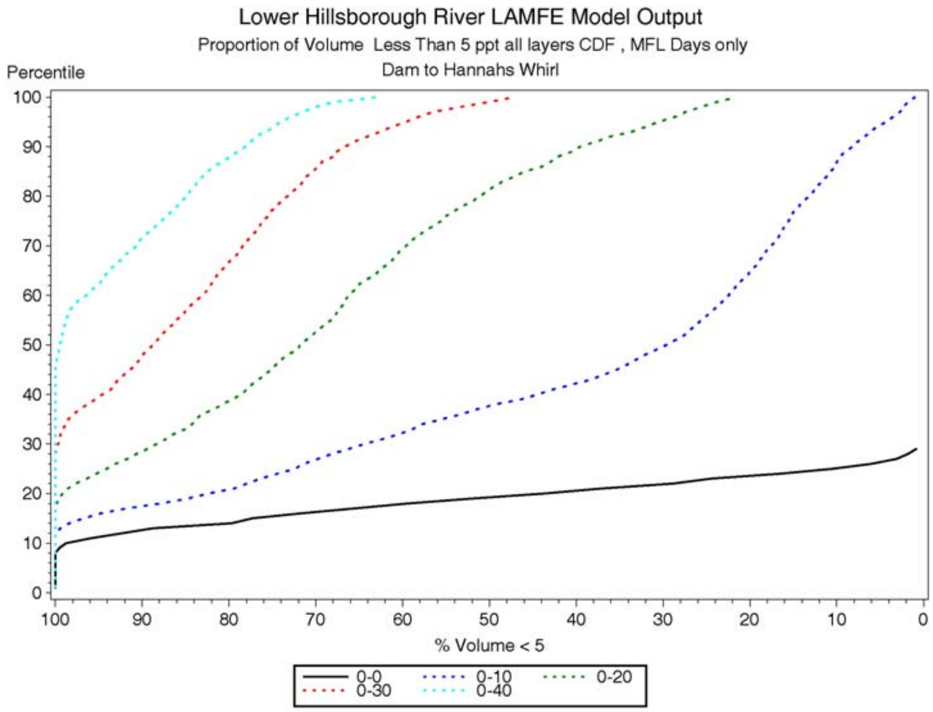


Figure 7-12 CDF plot of percent volume from the dam to Hannah's Whirl less than 5 ppt for MFL days for freshwater scenarios.

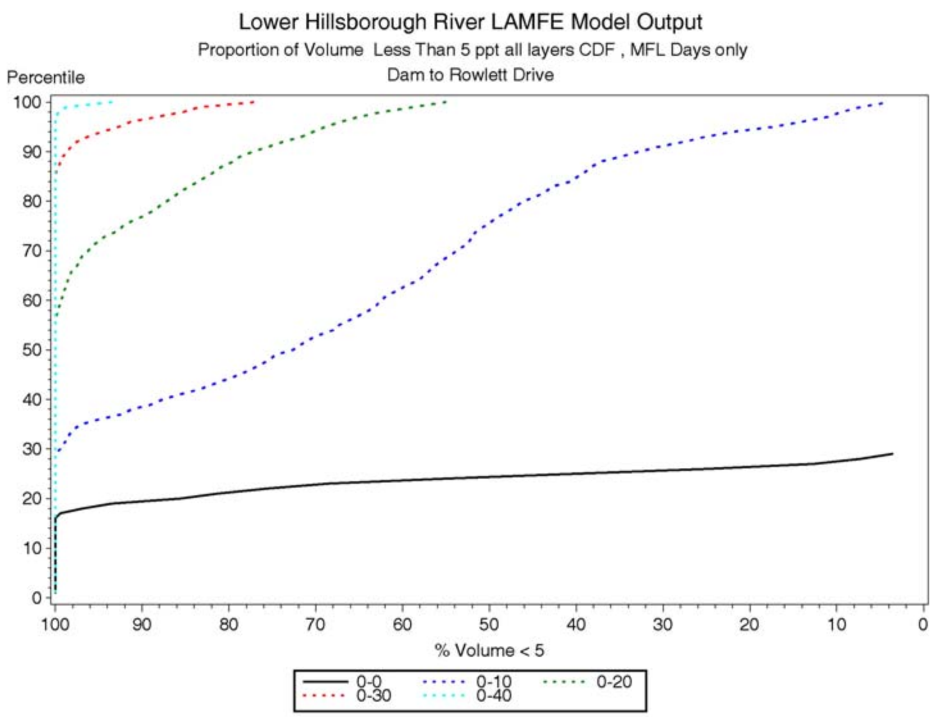


Figure 7-13 CDF plot of percent volume from the dam to Rowlett Park less than 5 ppt for MFL days for freshwater scenarios.

To evaluate model results relative to the salinity ranges evaluated, the percent of the entire river volume within each salinity range is presented for each freshwater scenario (Table 7-1). Examination of these data shows that:

- There is substantial increase in volume of these salinity ranges from the existing 10 cfs minimum flow when compared to the Baseline.
- There are additional benefits in the primary < 5 ppt salinity range as the flow increases from 10 cfs to 40 cfs.
- For the secondary 5 to 11 ppt salinity range, there is also an incremental increase in volume as the flows increase from 10 cfs to 40 cfs.
- For the secondary 11 to 18 ppt salinity range, there is also an incremental increase in volume as the flows increase from 10 cfs to 40 cfs.

Table 7-1 Percentage of the entire river volume within each salinity range, data are for the freshwater scenarios for MFL days only.

Scenario	Percent of Entire River Volume, Salinity Ranges			
	< 5 ppt	5 – 11 ppt	11 – 18 ppt	18 + ppt
Baseline	2.8	8.5	23.9	64.9
10 cfs	4.5	11.9	24.8	58.8
20 cfs	7.3	13.2	26.4	53.0
30 cfs	9.9	14.0	27.9	48.2
40 cfs	12.2	14.9	28.6	44.3

To more precisely define the incremental benefit, additional model runs were conducted for 12, 14, 16, 18, 22, 24, 26, and 28 cfs of freshwater.

The bar charts of the 25th, 50th, and 75th percentiles for these additional scenarios are presented in Figures 7-14 through 7-22. In addition, CDF plots of all freshwater scenarios are presented in Figures 7-23 through 7-25.

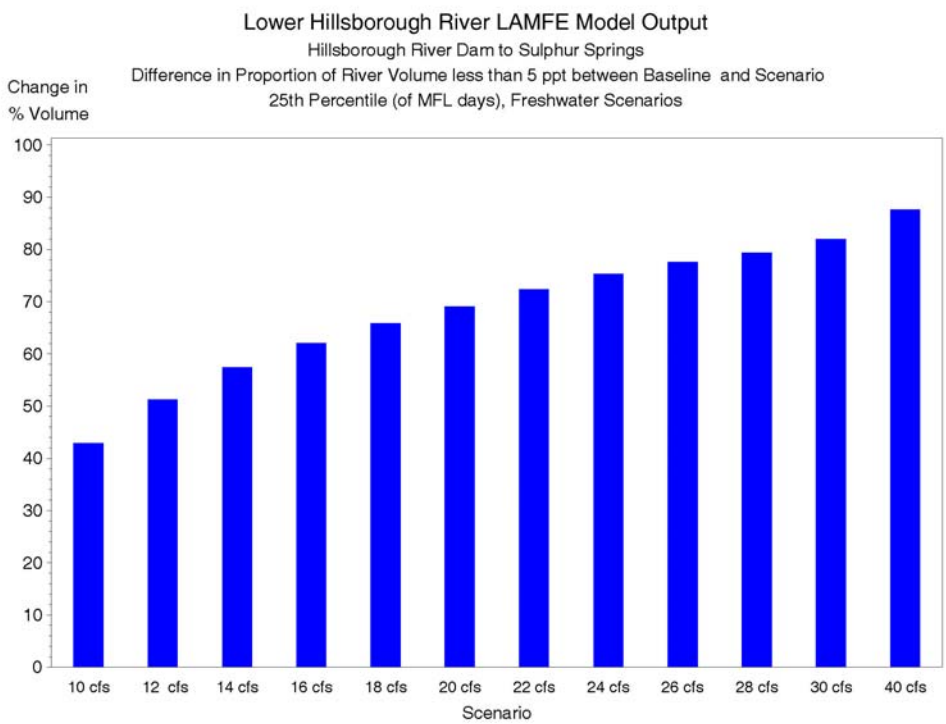


Figure 7-14 **Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 25th percentile of MFL days, Dam to Sulphur Springs.**

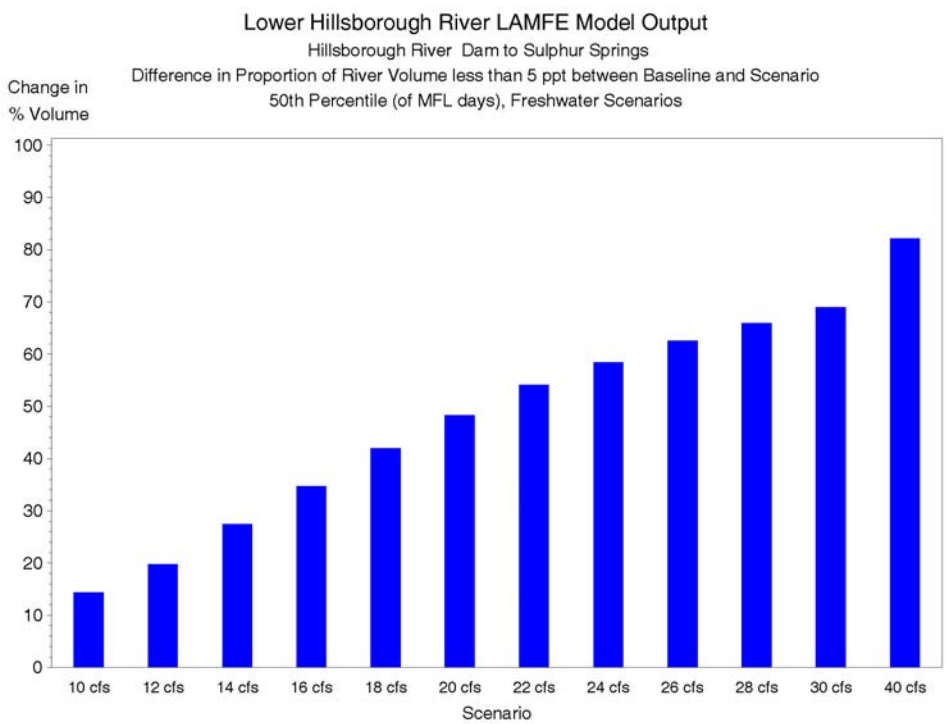


Figure 7-15 **Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 50th percentile of MFL days, Dam to Sulphur Springs.**

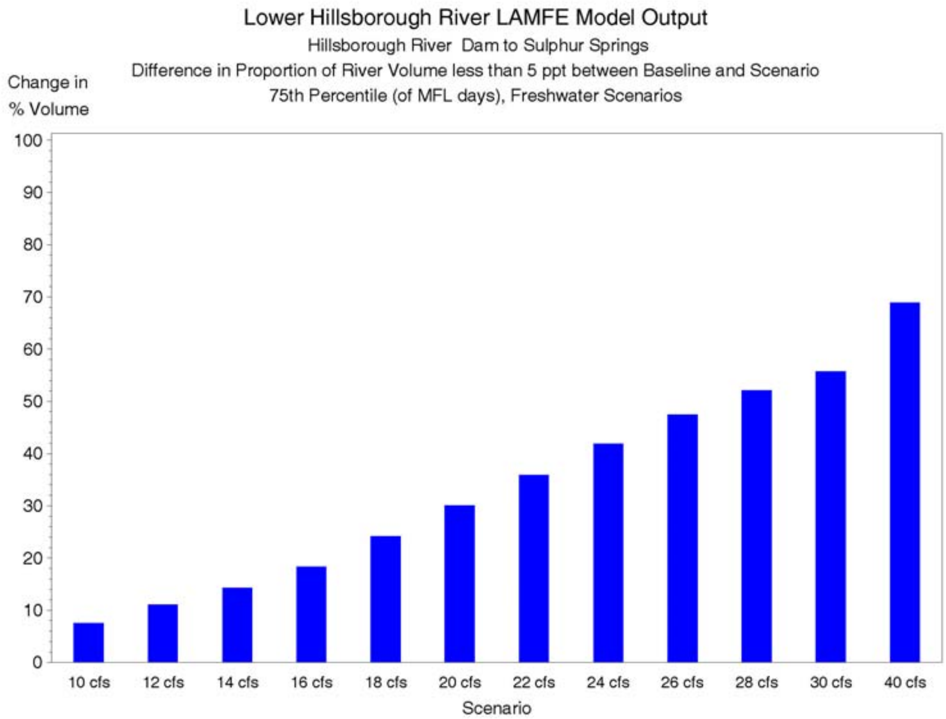


Figure 7-16 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 75th percentile of MFL days, Dam to Sulphur Springs.

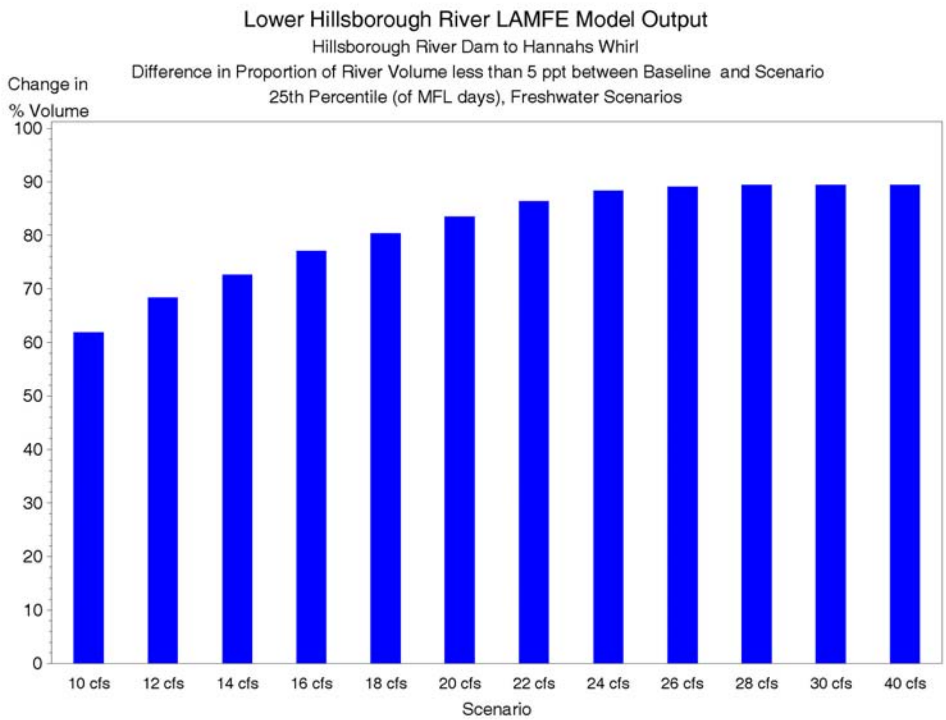


Figure 7-17 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 25th percentile of MFL days, Dam to Hannah's Whirl.

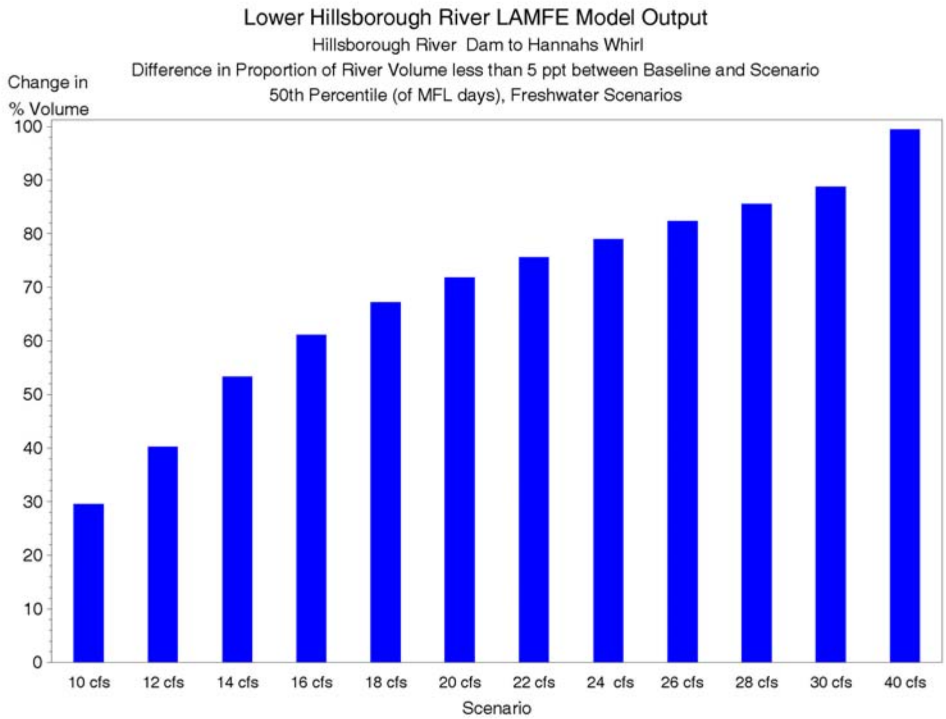


Figure 7-18 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 50th percentile of MFL days, Dam to Hannah's Whirl.

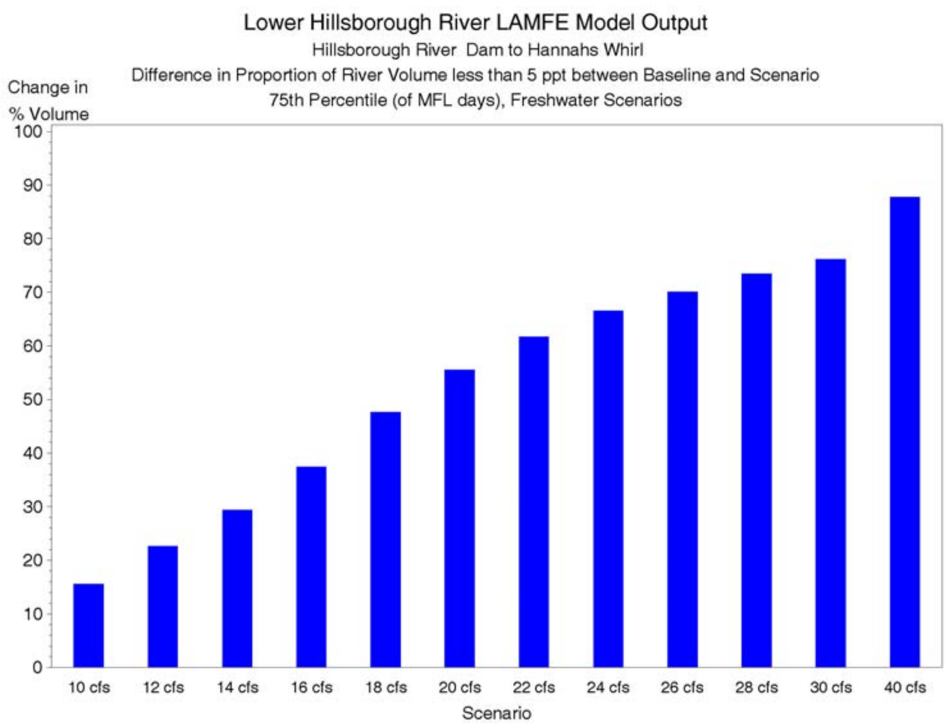


Figure 7-19 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 75th percentile of MFL days, Dam to Hannah's Whirl.

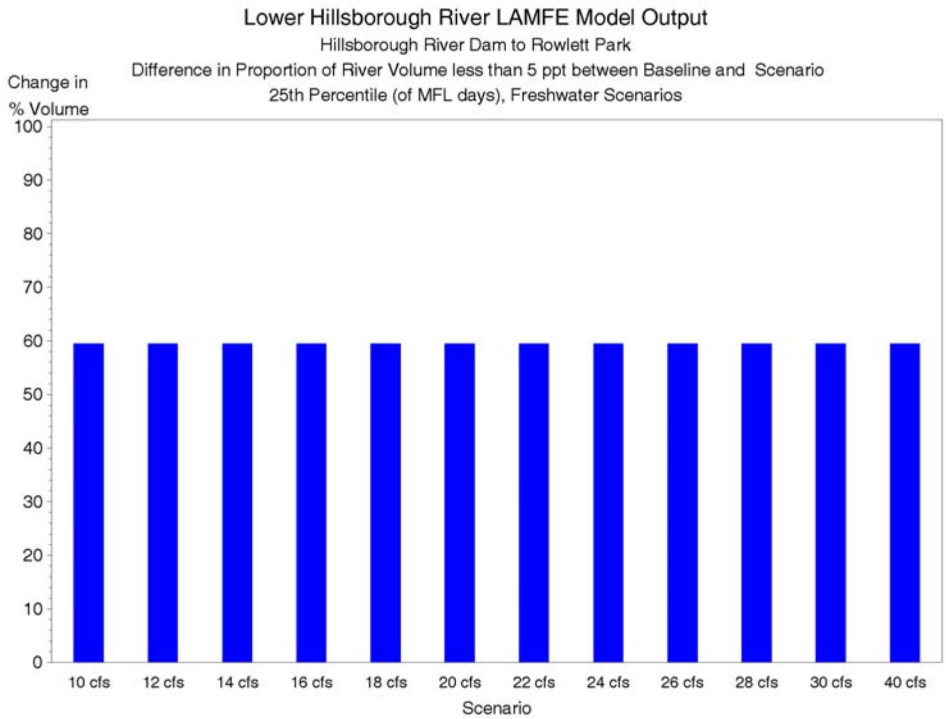


Figure 7-20 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 25th percentile of MFL days, Dam to Rowlett Park.

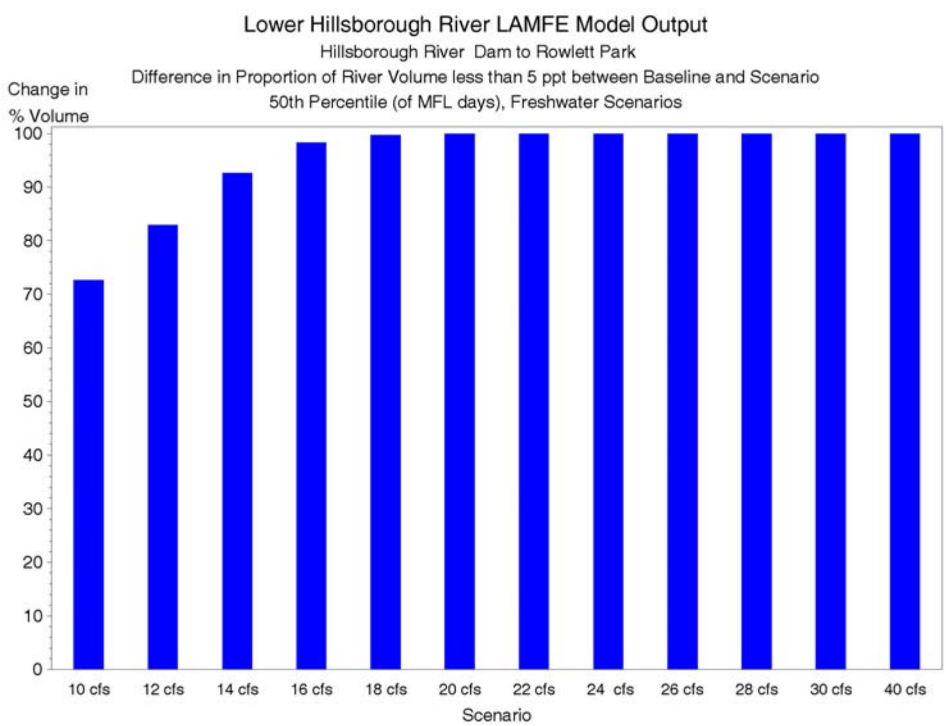


Figure 7-21 Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 50th percentile of MFL days, Dam to Rowlett Park.

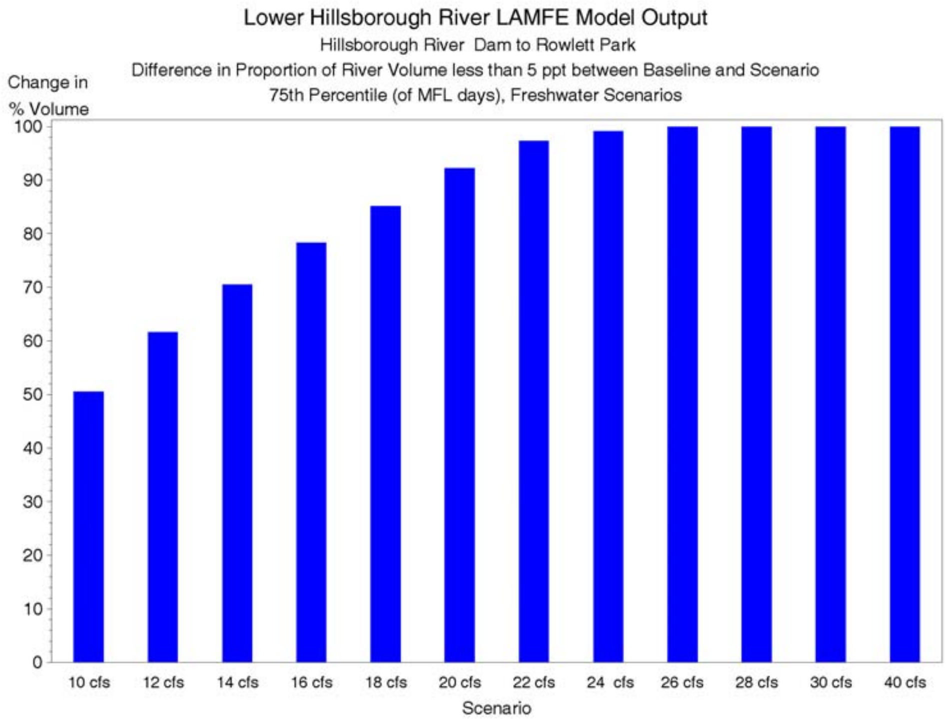


Figure 7-22 **Difference in the proportion of volume less than 5 ppt between the baseline and freshwater Scenarios (Scenario - Baseline), 75th percentile of MFL days, Dam to Rowlett Park.**

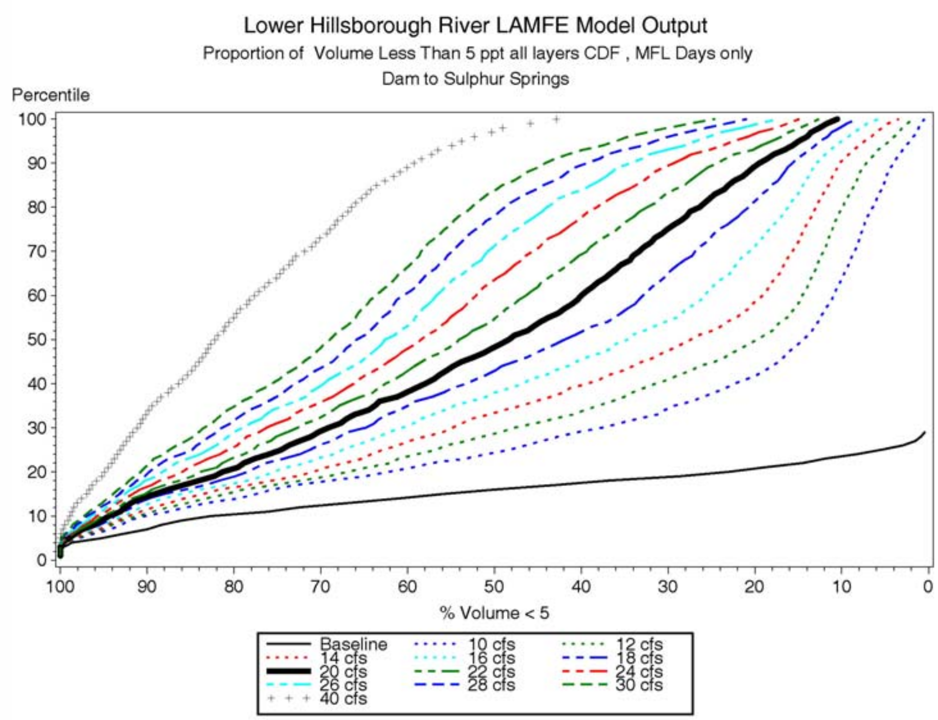


Figure 7-23 **CDF plot of percent volume less than 5 ppt from the dam to Sulphur Springs versus percentile of MFL days for the additional freshwater Scenarios.**

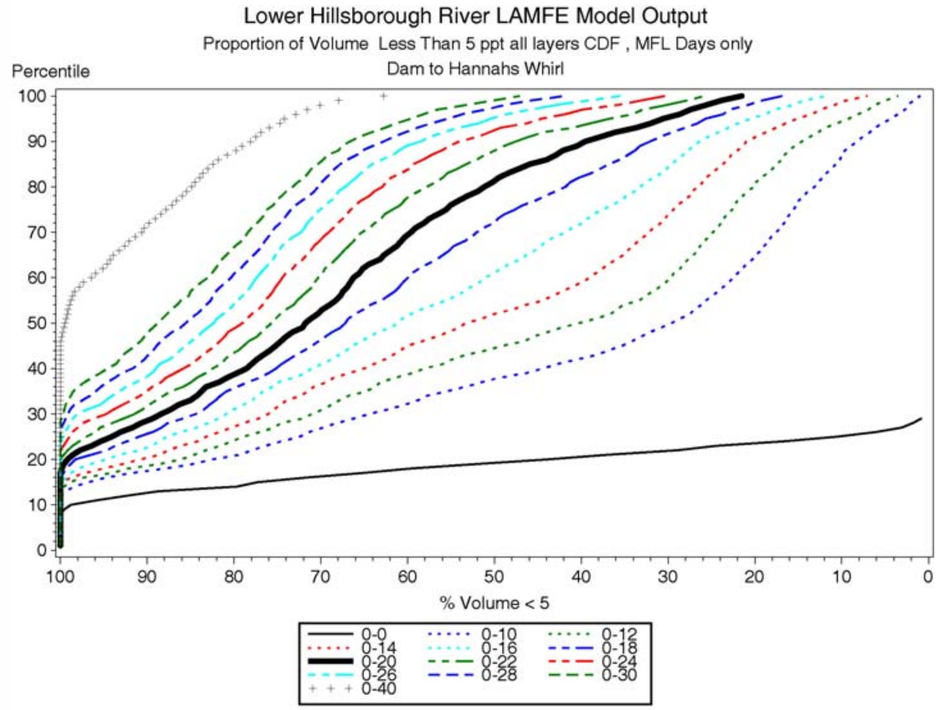


Figure 7-24 CDF plot of percent volume less than 5 ppt from the dam to Hannah's Whirl versus percentile of MFL days for the additional freshwater Scenarios.

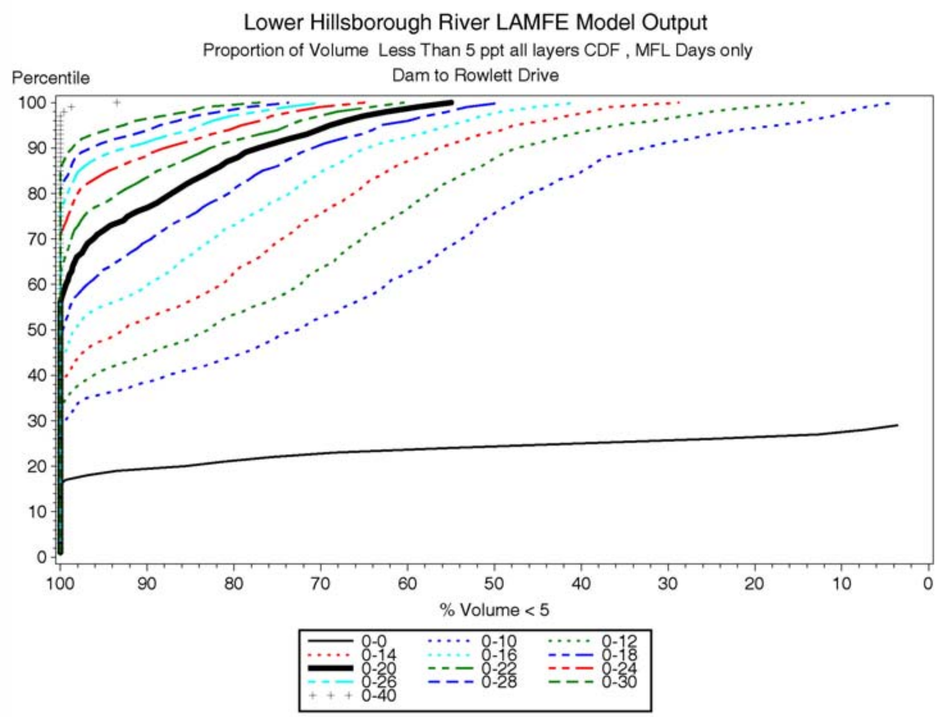


Figure 7-25 CDF plot of percent volume less than 5 ppt from the dam to Rowlett Park versus percentile of MFL days for the additional freshwater Scenarios.

To better quantify the difference between the various scenarios, the normalized area under the curve was calculated from the CDF plots for the various scenarios. This calculation was preformed be dividing the difference in areas under the curves by the difference in freshwater flows (equation below) for each scenario.

$$\frac{AOC(Scenario) - AOC(Baseline)}{Flow(Scenario) - Flow(Baseline)}$$

Thus, each scenario is compared to the baseline which allows for a relative comparison of the different scenarios. Using this analysis, you can identify the point at which the incremental gain begins to decrease. The results of this analysis are presented in Figures 7-26 to 7-28.

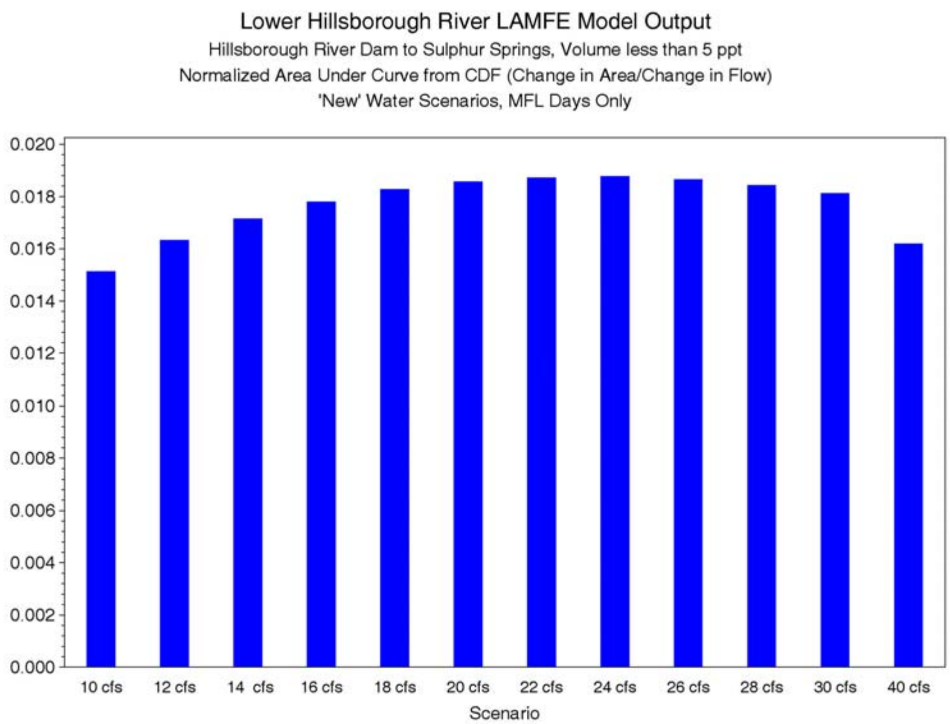


Figure 7-26 **Normalized area under the curve based on CDF plot of percent volume less than 5 ppt from the dam to Sulphur Springs versus percentile of MFL days for the additional freshwater Scenarios.**

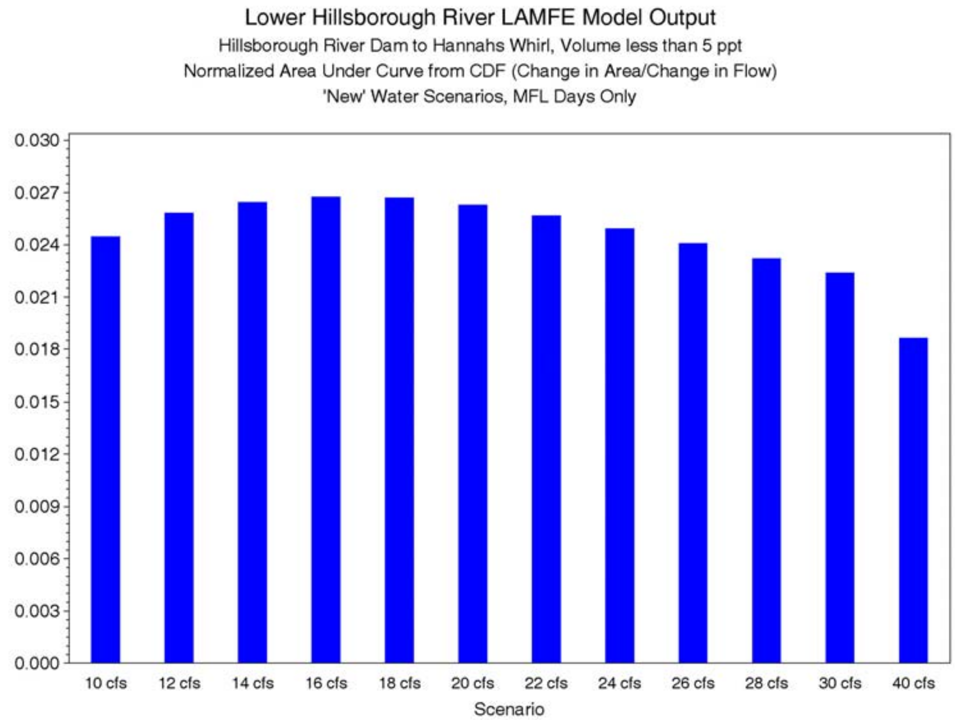


Figure 7-27 Normalized area under the curve based on CDF plot of percent volume less than 5 ppt from the dam to Hannah's Whirl versus percentile of MFL days for the additional freshwater Scenarios.

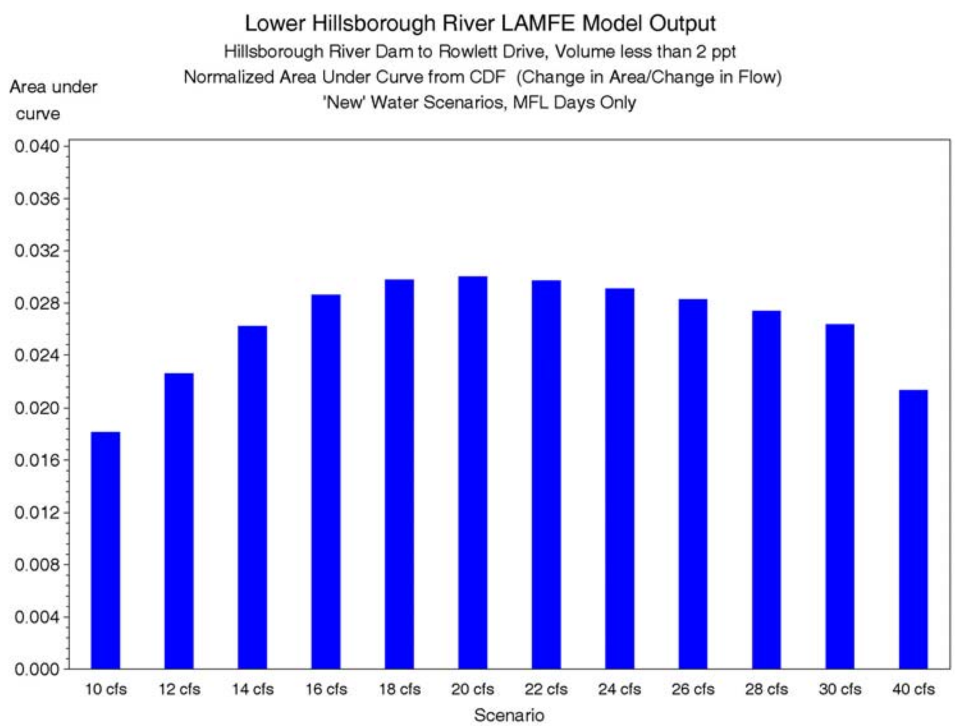


Figure 7-28 Normalized area under the curve based on CDF plot of percent volume less than 5 ppt from the dam to Rowlett Park versus percentile of MFL days for the additional freshwater Scenarios.

7.1.2 Comparison of Simulation Model Results: Sulphur Springs Diversion Scenarios

The existing 10 cfs minimum flow rule identified Sulphur Springs as one potential source of water to meet the existing minimum flow. The CoT is currently implementing the existing minimum flow by diverting 10 cfs of Sulphur Springs water to the base of the dam. The LAMFE model has been applied to a series of Sulphur Springs diversion scenarios to evaluate the ability of such a strategy to satisfy the primary and secondary salinity criteria to the same level of benefit as achieved by an equivalent freshwater scenario. The Sulphur Springs diversion scenarios evaluated were 10 cfs, 15 cfs, and 20 cfs.

Examination of data in Figures 7-29 through 7-40 shows that none of the Sulphur Springs diversions evaluated would achieve the same level of benefit as that provided by an equivalent amount of freshwater. However, it is important to acknowledge that the diversion of water from Sulphur Springs is not a "zero sum game", as there is clearly a benefit from diverting Sulphur Springs water to the base of the dam. After the substantial improvement from the baseline to the 10 cfs diversion, the incremental changes are relatively constant between the Sulphur Springs diversion scenarios.

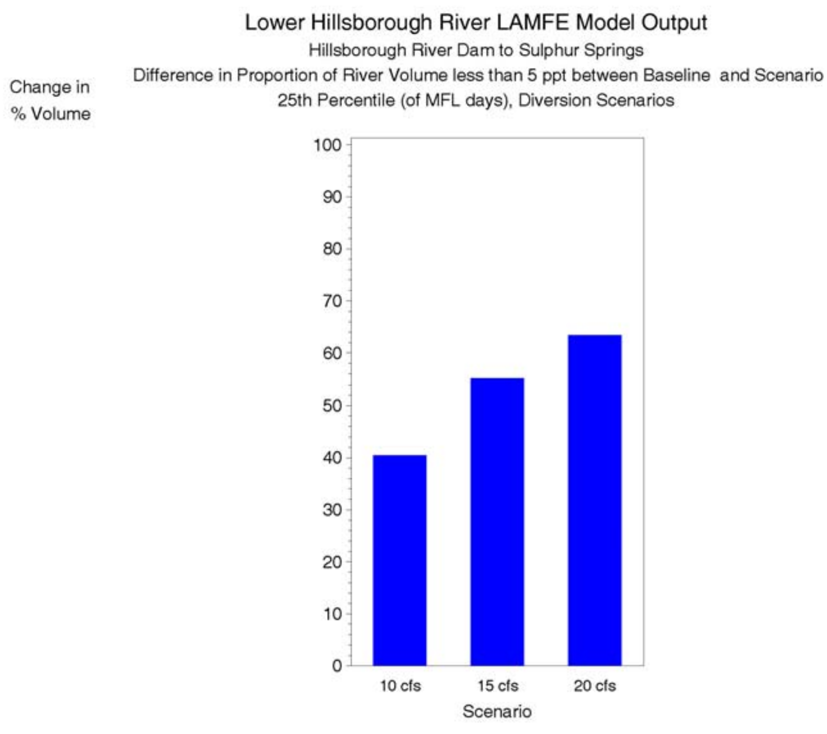


Figure 7-29 Difference in the proportion of volume less than 5 ppt between the baseline and Sulphur Springs diversion scenarios (scenario - baseline), 25th percentile of MFL days.

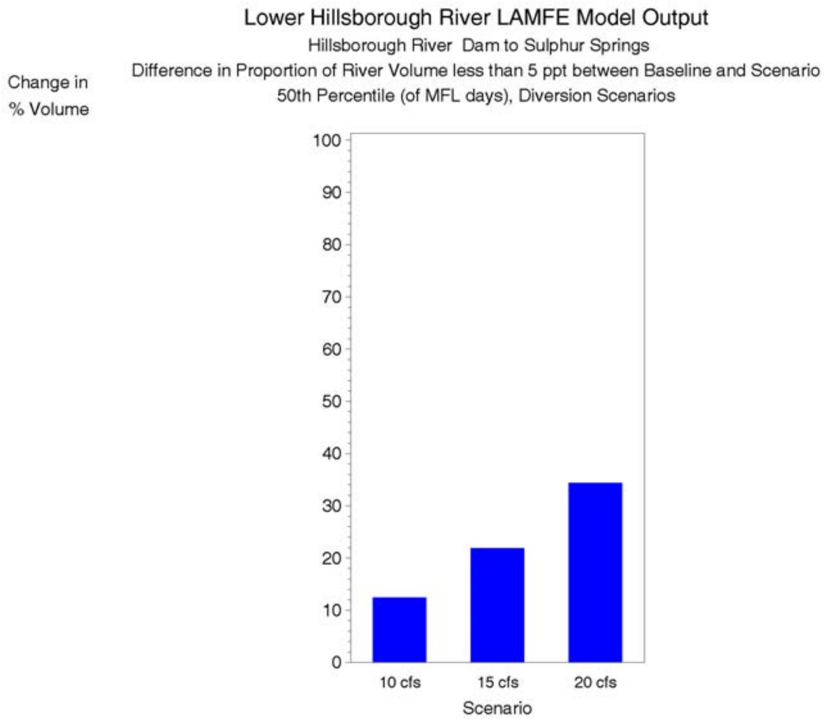


Figure 7-30 Difference in the proportion of volume less than 5 ppt between the baseline and Sulphur Springs diversion scenarios (scenario - baseline), 50th percentile of MFL days.

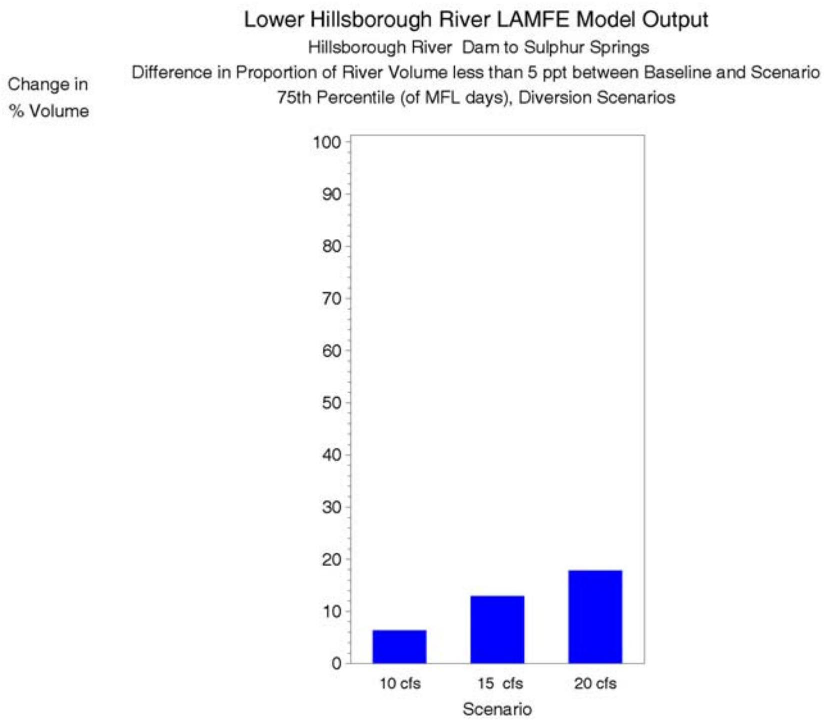


Figure 7-31 Difference in the proportion of volume less than 5 ppt between the baseline and Sulphur Springs diversion scenarios (scenario - baseline), 75th percentile of MFL days.

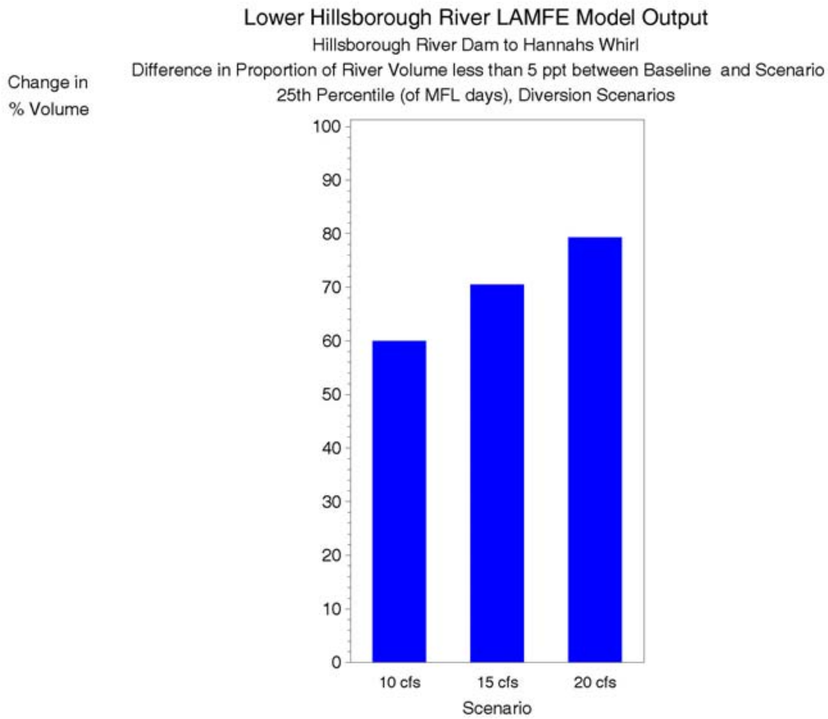


Figure 7-32 Difference in the proportion of volume less than 5 ppt between the baseline and Hannah's Whirl diversion scenarios (scenario - baseline), 25th percentile of MFL days.

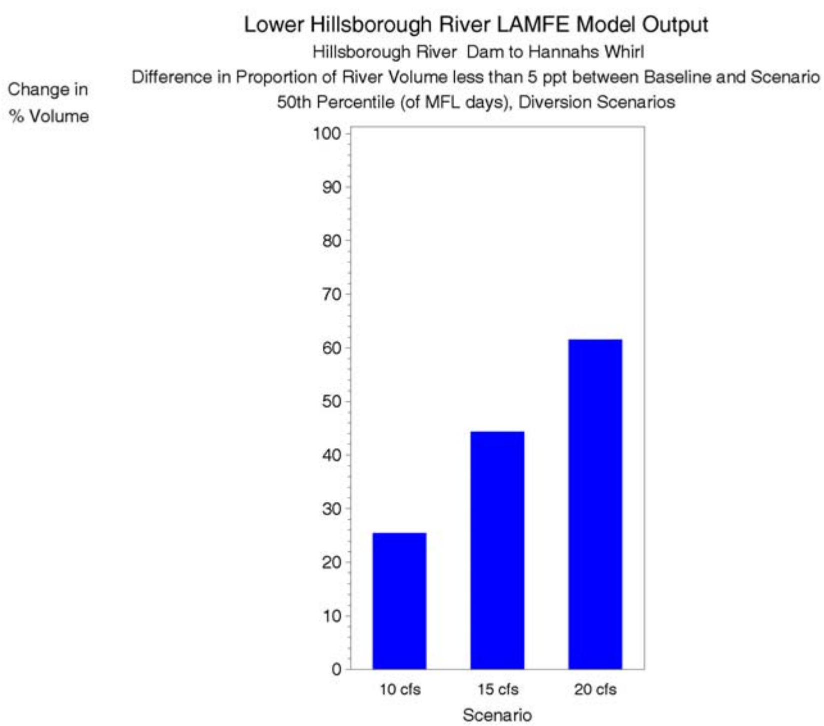


Figure 7-33 Difference in the proportion of volume less than 5 ppt between the baseline and Hannah's Whirl diversion scenarios (scenario - baseline), 50th percentile of MFL days.

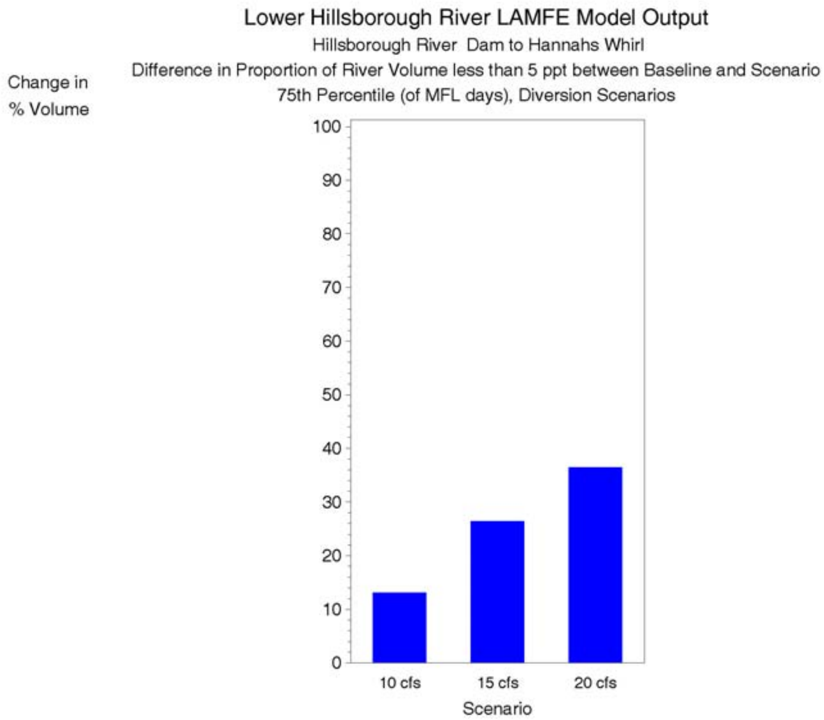


Figure 7-34 Difference in the proportion of volume less than 5 ppt between the baseline and Hannah's Whirl diversion scenarios (scenario - baseline), 75th percentile of MFL days.

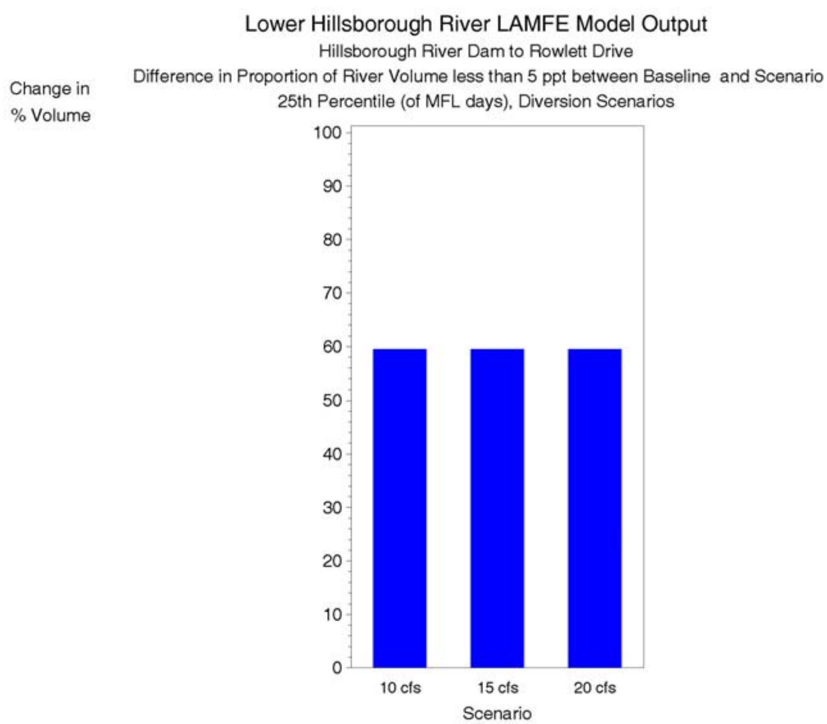


Figure 7-35 Difference in the proportion of volume less than 5 ppt between the baseline and Rowlett Park for the diversion scenarios (scenario - baseline), 25th percentile of MFL days.

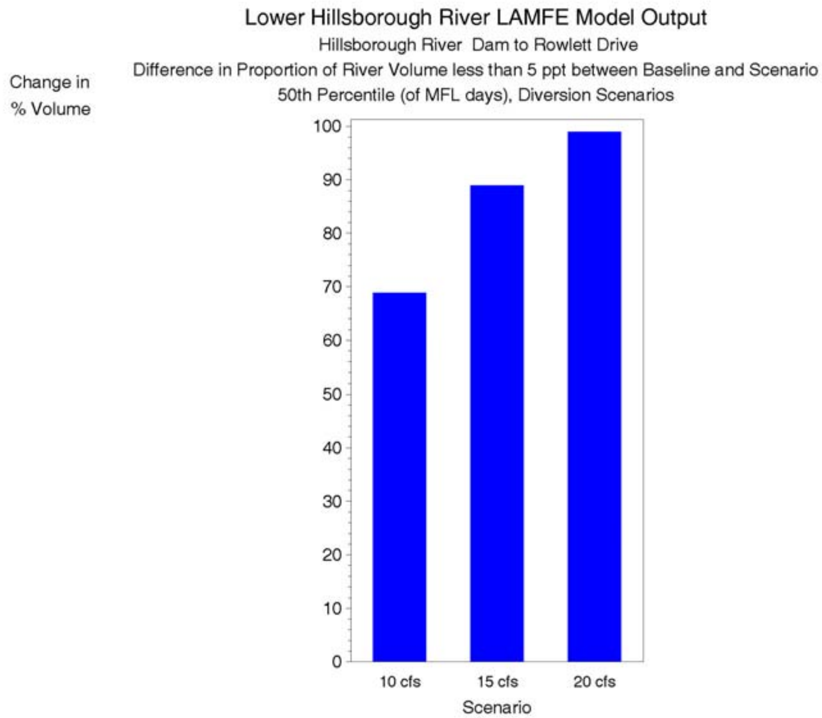


Figure 7-36 **Difference in the proportion of volume less than 5 ppt between the dam and Rowlett Park for the diversion scenarios (scenario - baseline), 50th percentile of MFL days.**

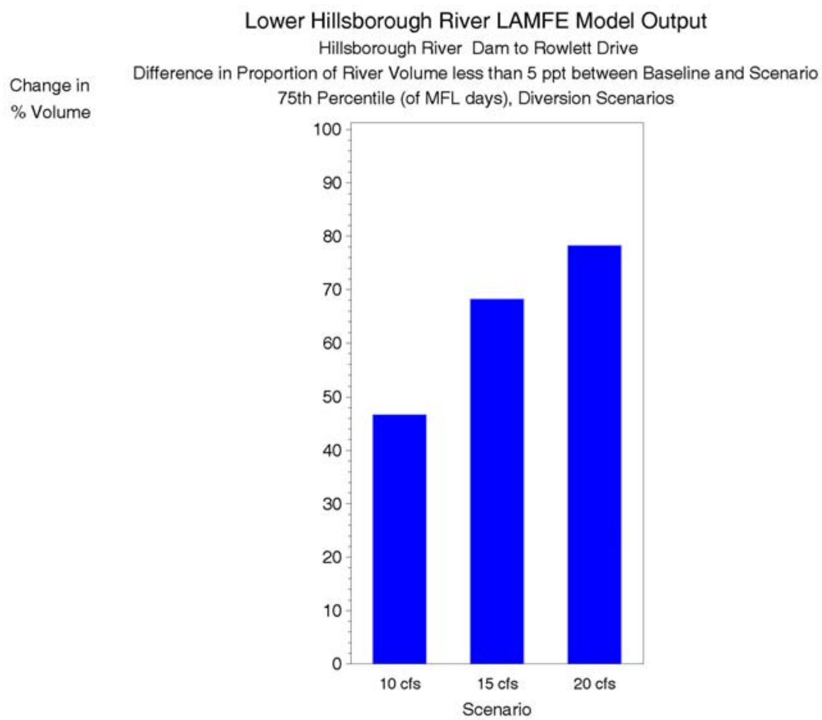


Figure 7-37 **Difference in the proportion of volume less than 5 ppt between the dam and Rowlett Park for the diversion scenarios (scenario - baseline), 75th percentile of MFL days.**

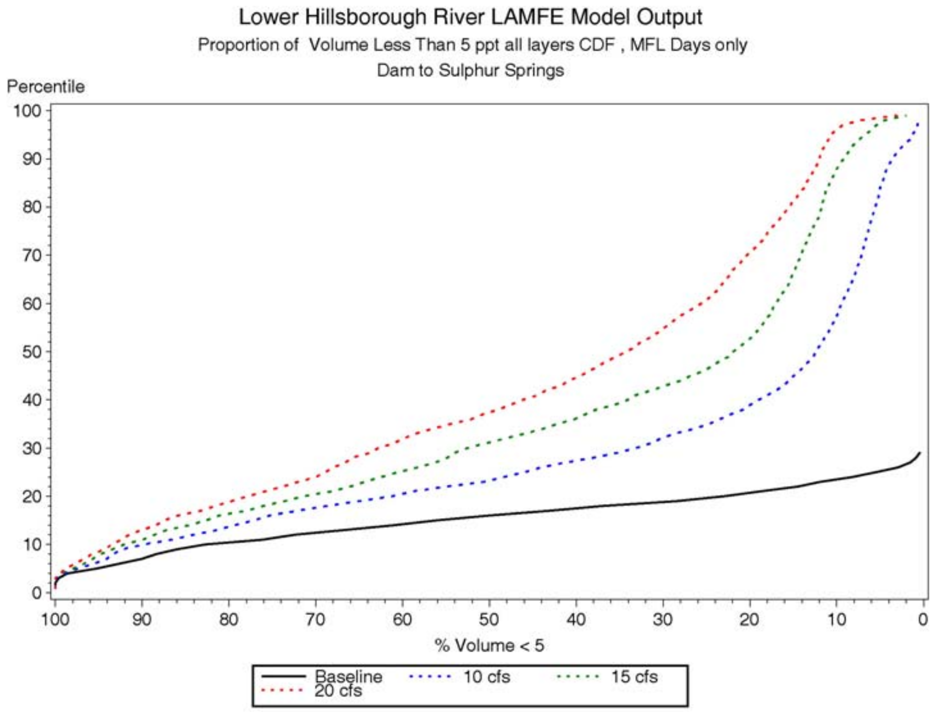


Figure 7-38 CDF plot of percent volume less than 5 ppt between dam and Sulphur Springs versus percentile of MFL days for Sulphur Springs diversion scenarios.

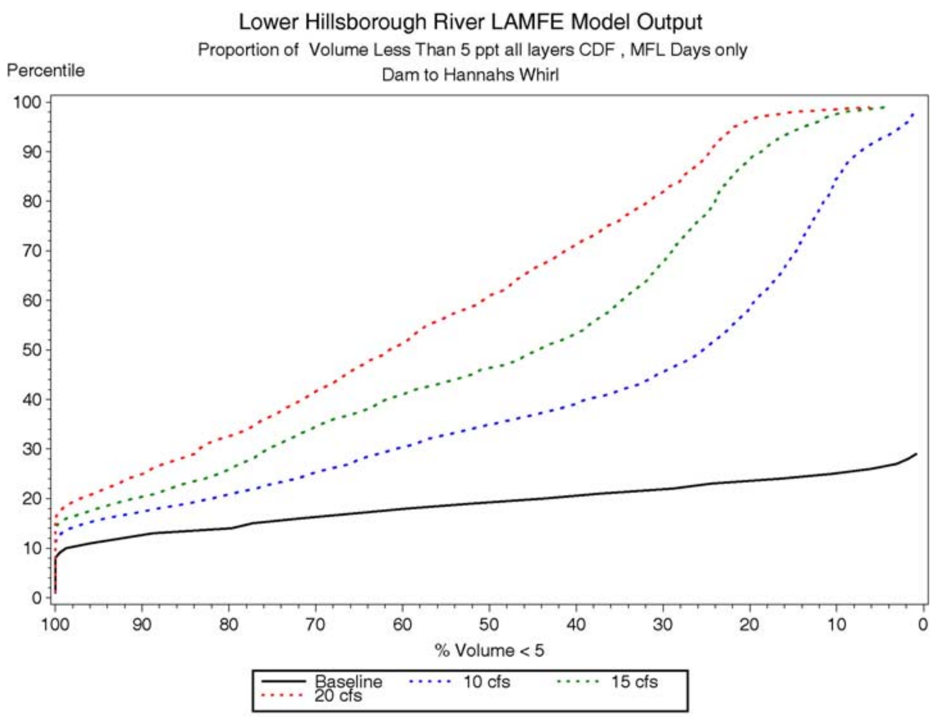


Figure 7-39 CDF plot of percent volume less than 5 ppt between dam and Hannah's Whirl versus percentile of MFL days for Sulphur Springs diversion scenarios.

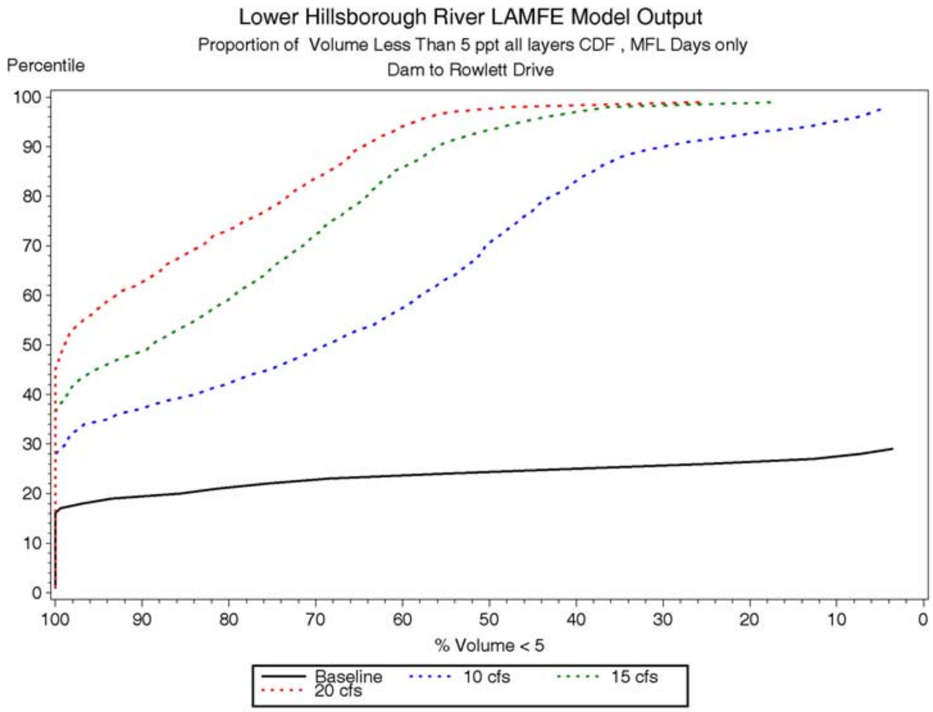


Figure 7-40 CDF plot of percent volume less than 5 ppt between dam and Rowlett Park versus percentile of MFL days for Sulphur Springs diversion scenarios.

Since there is clearly a benefit by adding freshwater and by diverting Sulphur Springs water to the base of the dam, one potential management strategy to achieve a given salinity criterion may involve some combination of both freshwater and Sulphur Springs diversions. In order to provide a preliminary examination of such a strategy, the LAMFE model was applied to two scenarios:

- 10 cfs freshwater plus 10 cfs of Sulphur Springs diversion, and
- 15 cfs freshwater plus 15 cfs of Sulphur Springs diversion.

It is important to recognize that there is some constraint on the amount of Sulphur Springs water that may be available for diversion. Such a constraint will be defined by the minimum flow to be established for Sulphur Springs.

Clearly, various combinations of freshwater and diversions from Sulphur Springs can result in good agreement with a selected freshwater scenario. Bar charts and CDF plots of the scenarios mentioned above are presented in Figures 7-41 through 7-52.

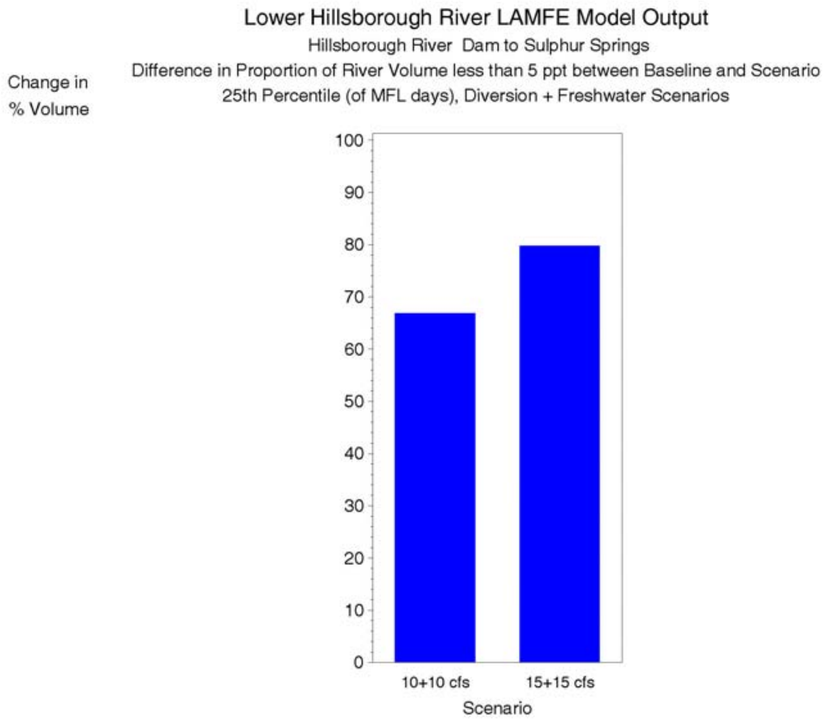


Figure 7-41 Difference in the proportion of volume less than 5 ppt between the baseline and Sulphur Springs for the diversion scenarios (scenario - baseline), 25th percentile of MFL days.

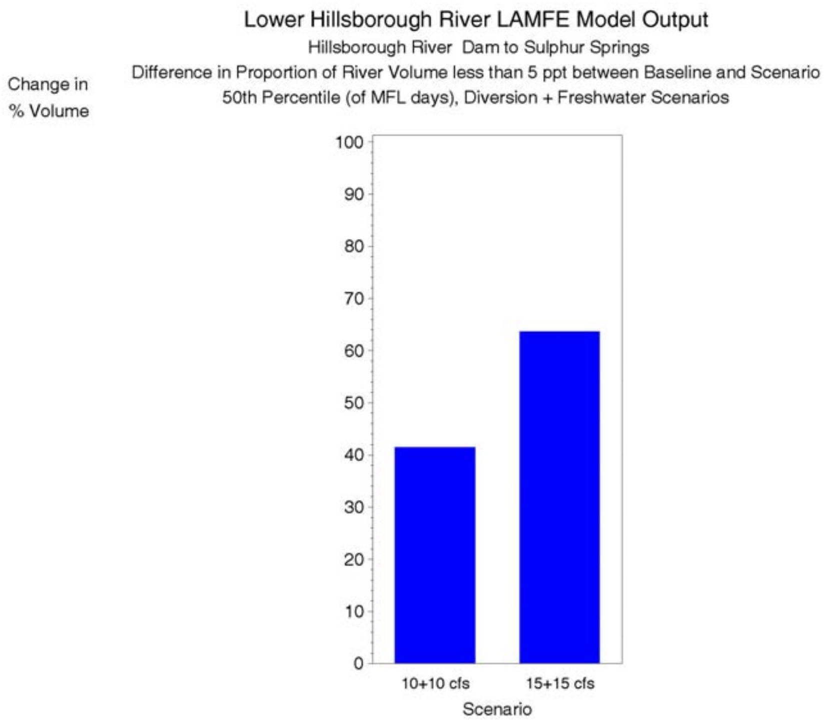


Figure 7-42 Difference in the proportion of volume less than 5 ppt between the baseline and Sulphur Springs for the diversion scenarios (scenario - baseline), 50th percentile of MFL days.

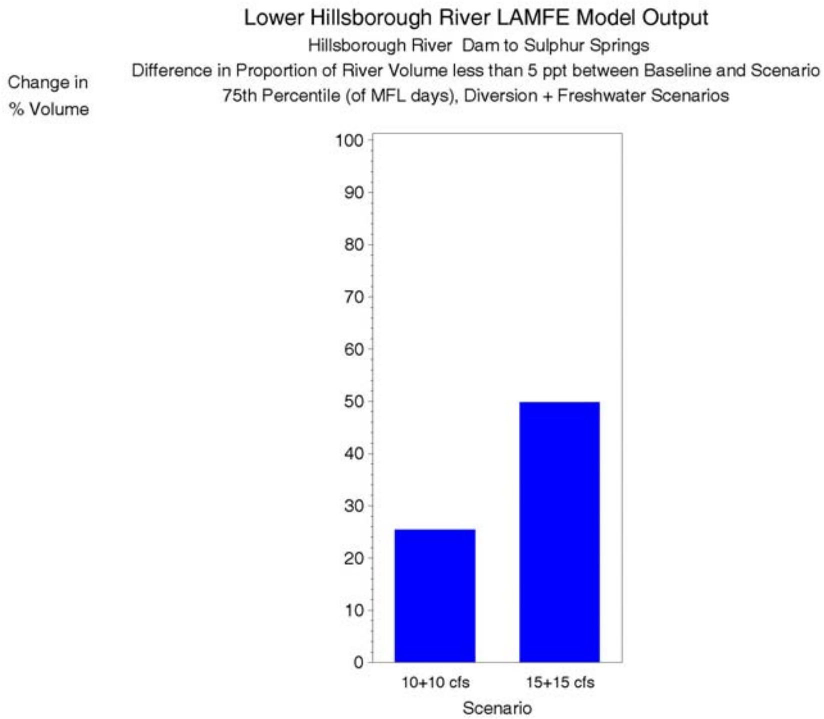


Figure 7-43 Difference in the proportion of volume less than 5 ppt between the baseline and Sulphur Springs for the diversion scenarios (scenario - baseline), 75th percentile of MFL days.

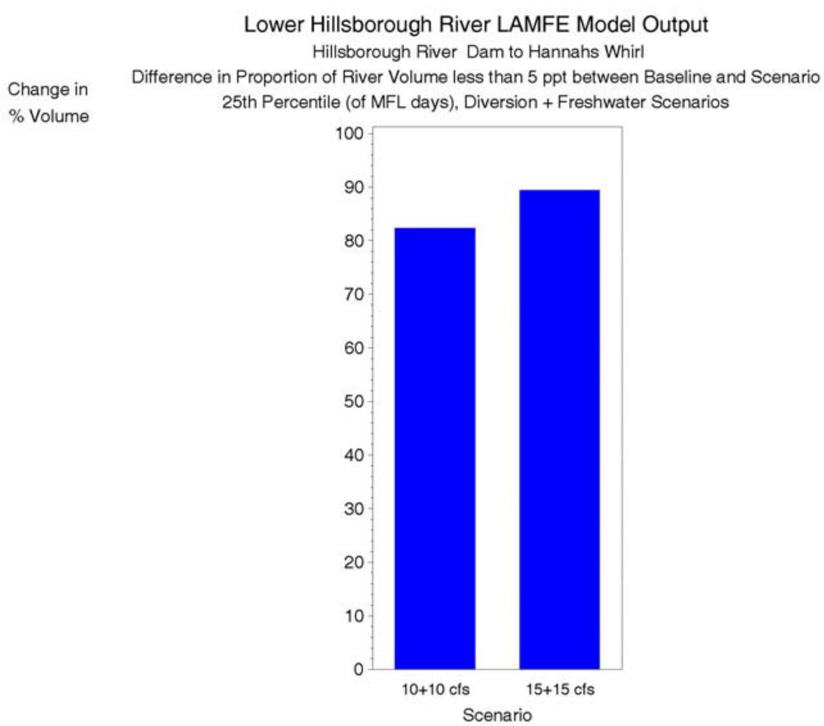


Figure 7-44 Difference in the proportion of volume less than 5 ppt between the baseline and Hannah's Whirl for the diversion scenarios (scenario - baseline), 25th percentile of MFL days.

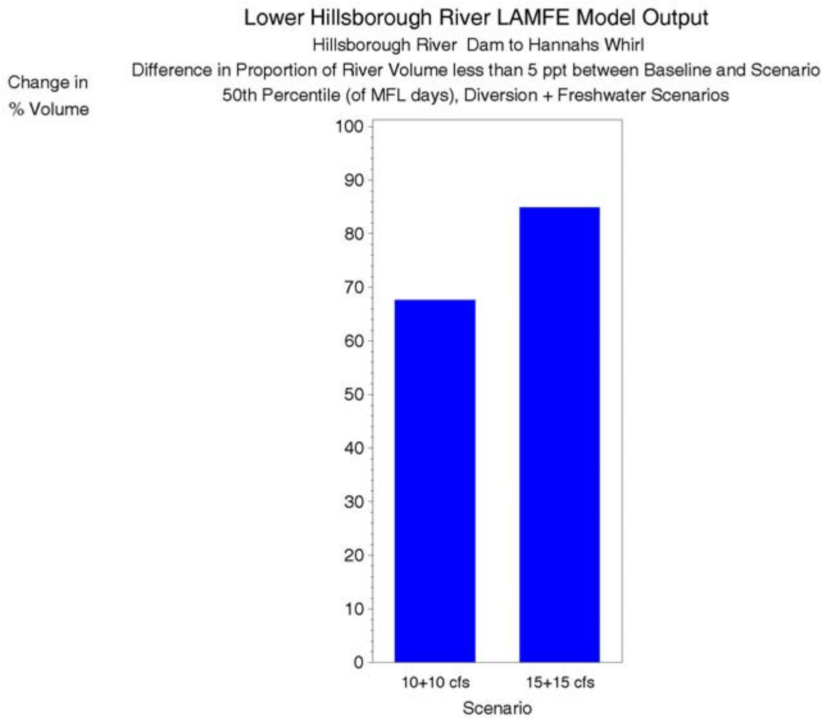


Figure 7-45 Difference in the proportion of volume less than 5 ppt between the baseline and Hannah's Whirl for the diversion scenarios (scenario - baseline), 50th percentile of MFL days.

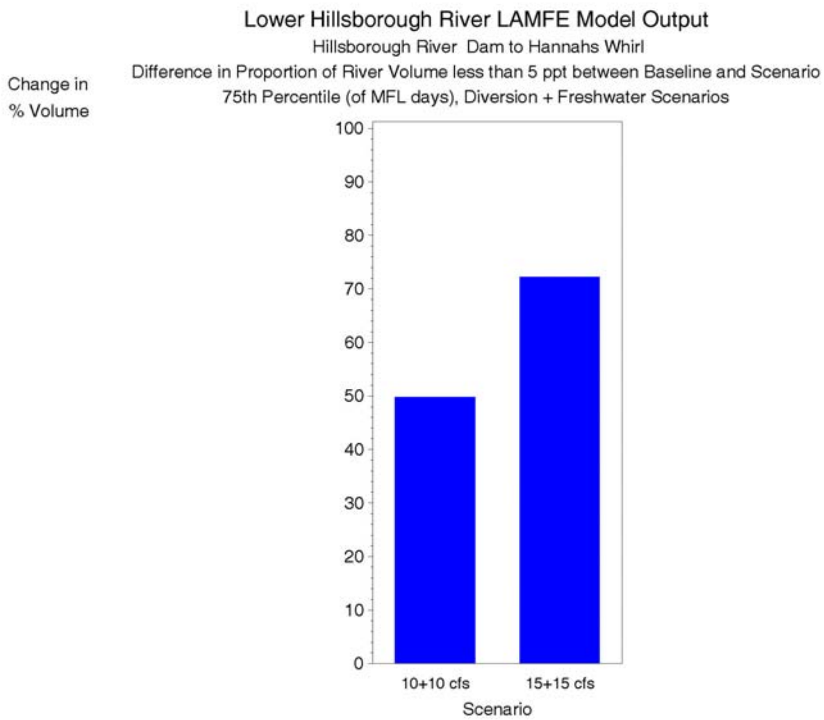


Figure 7-46 Difference in the proportion of volume less than 5 ppt between the baseline and Hannah's Whirl for the diversion scenarios (scenario - baseline), 75th percentile of MFL days.

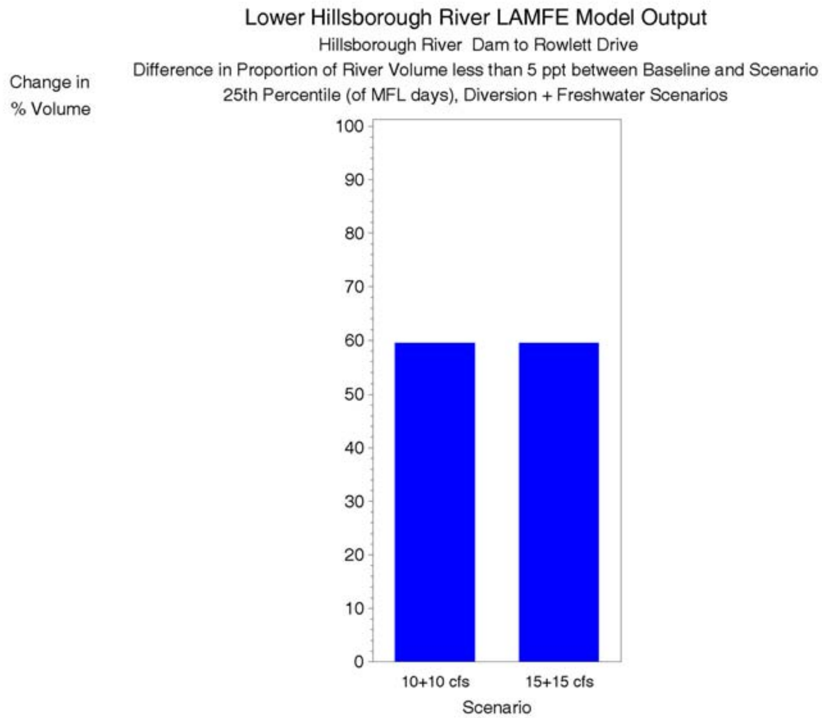


Figure 7-47 Difference in the proportion of volume less than 5 ppt between the baseline and Rowlett Park for the diversion scenarios (scenario - baseline), 25th percentile of MFL days.

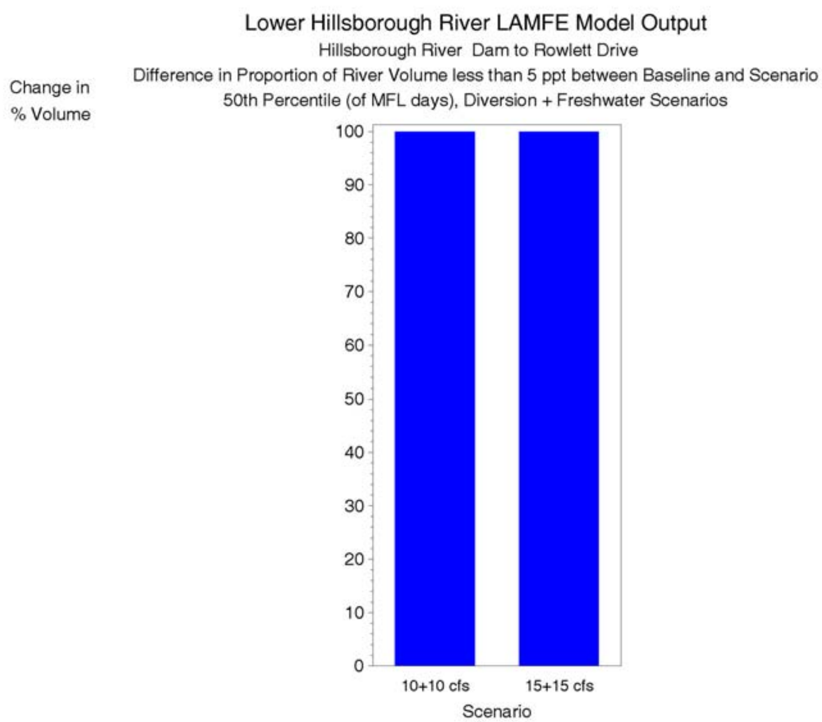


Figure 7-48 Difference in the proportion of volume less than 5 ppt between the baseline and Rowlett Park for the diversion scenarios (scenario - baseline), 50th percentile of MFL days.

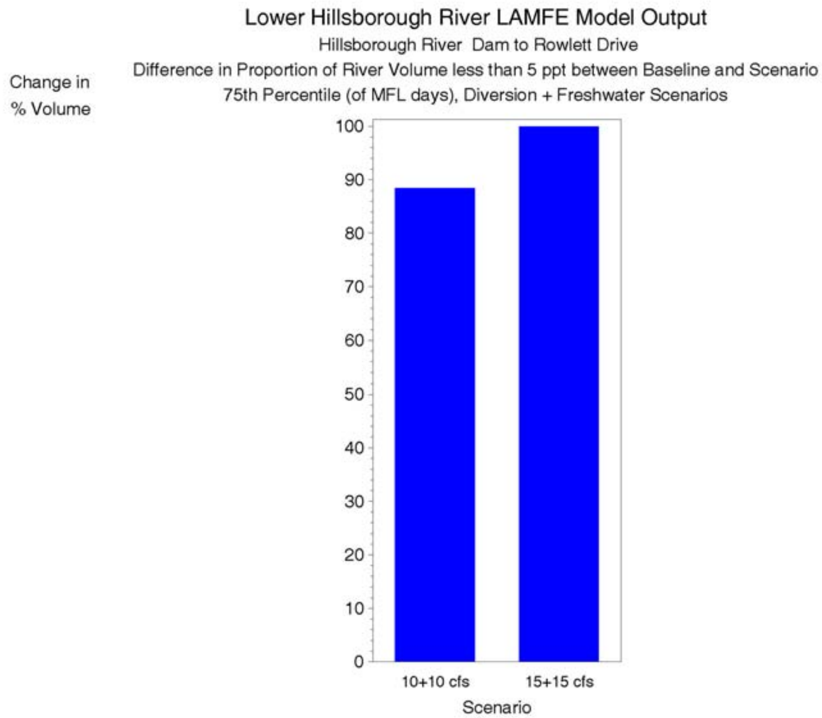


Figure 7-49 Difference in the proportion of volume less than 5 ppt between the baseline and Rowlett Park for the diversion scenarios (scenario - baseline), 75th percentile of MFL days.

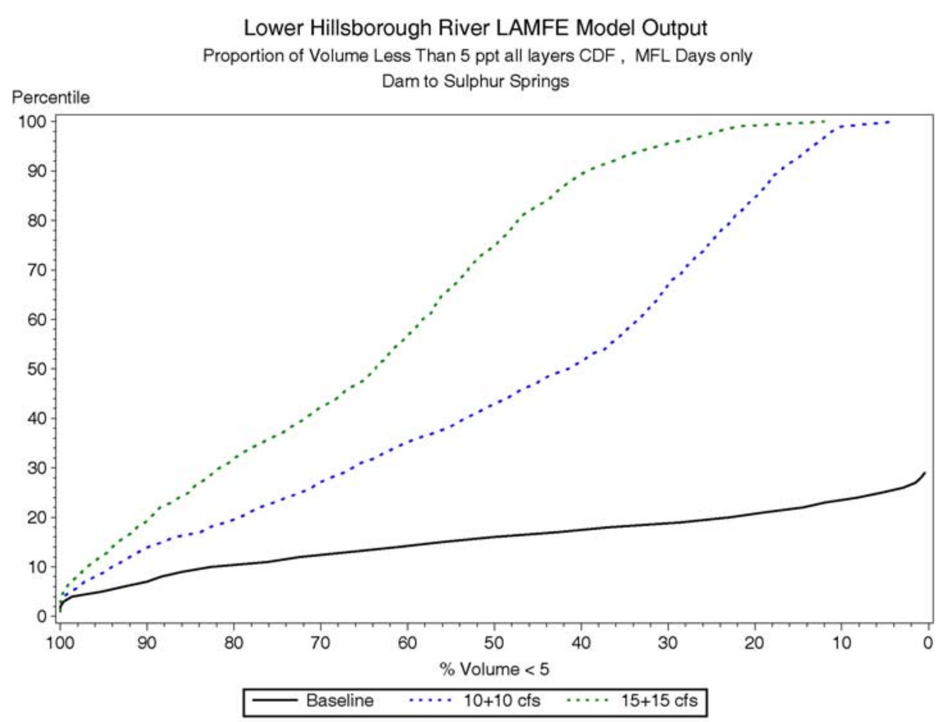


Figure 7-50 CDF plot of percent volume less than 5 ppt from the dam to Sulphur Springs versus percentile of MFL days for combination scenarios as well baseline.

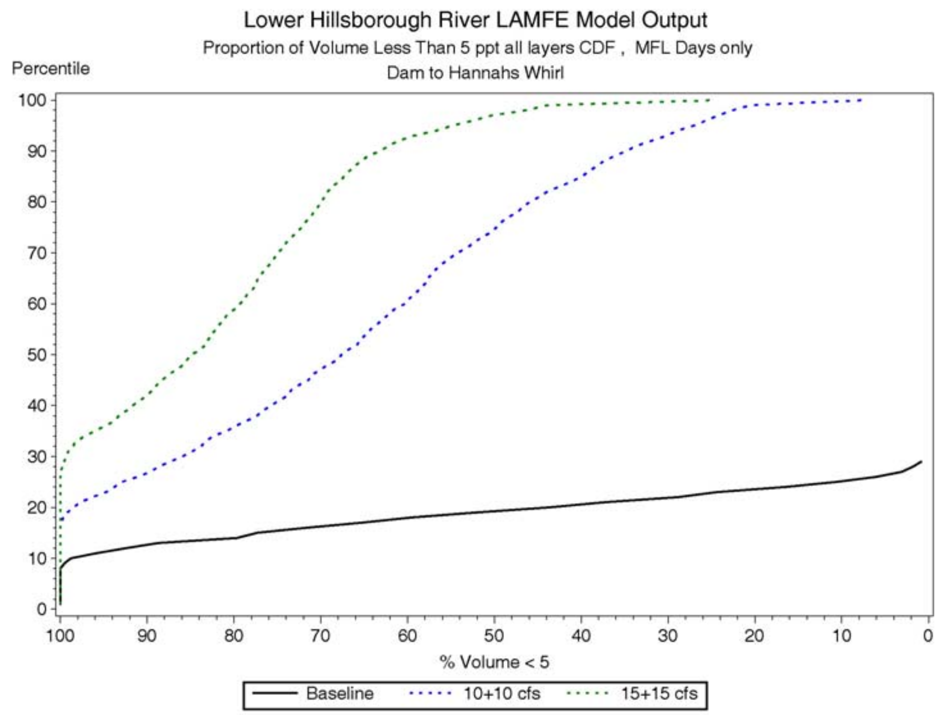


Figure 7-51 **CDF plot of percent volume less than 5 ppt from the dam to Hannah's Whirl versus percentile of MFL days for combination scenarios as well baseline.**

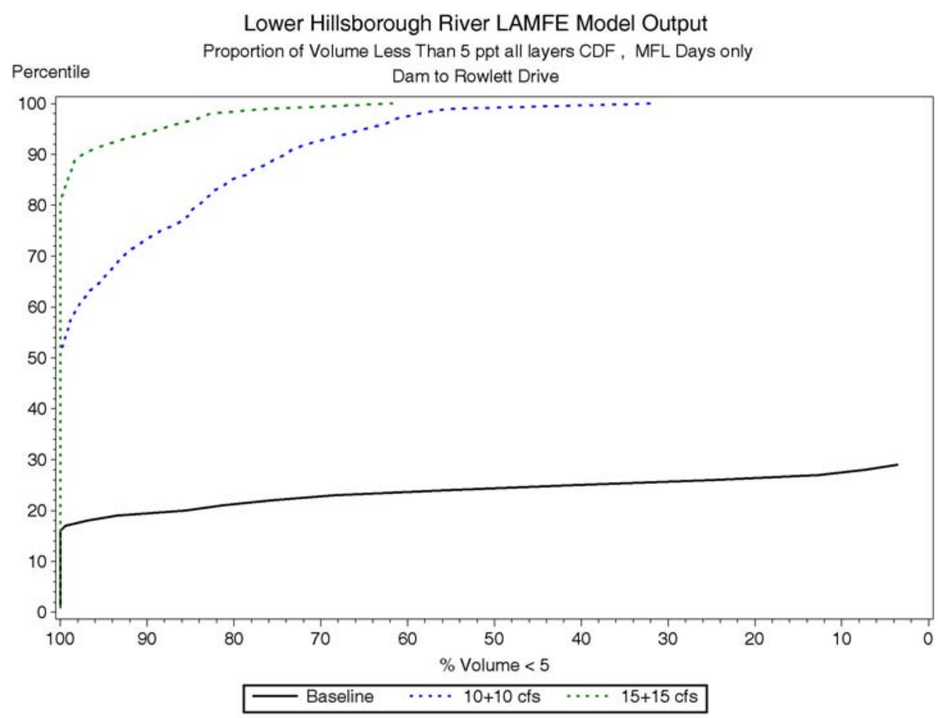


Figure 7-52 **CDF plot of percent volume less than 5 ppt from the dam to Rowlett Park versus percentile of MFL days for combination scenarios as well baseline.**

8.0 CONCLUSIONS AND DISTRICT RECOMMENDATION FOR THE LOWER HILLSBOROUGH RIVER MINIMUM FLOW

8.1 Historical Perspective

During March 1999, the Southwest Florida Water Management District (District) Governing Board adopted a minimum flow of 10 cubic feet per second (cfs) at the base of the Hillsborough Reservoir dam as the Lower Hillsborough River (LHR) minimum flow (MF). Prior to adoption of the minimum flow, the District requested that the Tampa Bay National Estuary Program (TBNEP) host a series of meetings to facilitate input from various interests to recommend ecological criteria for the establishment of minimum flows for the LHR. On July 10, 1997 the TBNEP Advisory Group issued their findings and recommendations. District staff utilized this input and completed their evaluation and recommended a LHR minimum flow.

Subsequent to adoption, several interested parties (City of Tampa, Environmental Protection Commission Hillsborough County and Tampa Bay Water) petitioned for an independent review of the assumptions and methodologies used to determine the minimum flow. The District convened an independent scientific peer review panel and asked the panel to determine if the proposed ten cfs was based on defensible scientific analyses. The peer review agreed that the District had used the best available information, but raised several questions regarding the ten cfs selected by the District. Their report stated in part:

> *"At best, the ten cfs rule should be considered an improvement over the current condition and an experiment in adaptive management. The scientific and technical data indicate that an adaptive management approach should be taken, because there is no scientific evidence for choosing one instream flow over another. The process of adaptive management requires a clear management goal (e.g., maintaining 1 or 2 km of oligohaline habitat during certain seasons), monitoring (which can be restricted to the region a short distance downstream from the dam within the managed segment), determining if the expected changes are occurring (within an acceptable range of uncertainties), and reevaluating the minimum flow rule on short-term intervals. Setting the management goal will require evaluation of the biological communities and environmental setting of the region to be managed, and policy decisions on which sustainable resources are to be protected or optimized."*

Following the issuance of the peer review panel's report, legal challenges to the proposed ten (10) cfs were filed, but a settlement agreement was entered into between the District and the petitioners on May 5, 2000. The agreement stipulated that the District and City of Tampa (CoT) would jointly participate in a "study of the biological communities below the dam, taking into account the loss of hydrologic functions, water quality, water quantity and existing changes and structural alterations to reevaluate the Minimum Flow requirement to maintain the existing biological communities in the Lower Hillsborough River. The study will provide recommendations to enhance or improve the biological communities below the dam in the Lower Hillsborough River. The study shall include a range of sufficient releases up to at least 30 cfs of fresh water (less than or equal to 0.5 parts per thousand of salinity) to examine the effects on the biological communities in the Lower Hillsborough River".

The agreement also directed that, "If the study demonstrates the need for revisions to the Minimum Flow for the Lower Hillsborough River established in paragraph 40D-8.04(1), F.A.C., then the District shall initiate rulemaking within one year of study completion to adopt a revised Minimum Flow considering this study, and the study results on the Minimum Flow requirement shall be binding on the City and the District in any rulemaking proceeding on the revised Minimum Flow."

In the years intervening since the settlement agreement, extensive chemical and biological data have been collected in the LHR as part of Tampa Bay Water's Hydrobiological Monitoring Program (HBMP) and other ongoing monitoring activities (e.g., USGS, Hillsborough County EPC). These data were analyzed as part of the minimum flow re-evaluation. Additionally, considerable effort was put into updating the District's hydrodynamic model for the river (LAMFE) by recalibrating the model with higher resolution bathymetry and utilizing salinity data collected from several new recorders distributed at different depths throughout the lower river. The LAMFE model was the principal tool used to evaluate the selected minimum flow scenarios.

8.2 General Study Findings

Key findings from this re-evaluation are:

- This study included a series of actual experimental releases in the range of 10 to 30 cfs, as well as other low-flow events that occurred during the course of the study. Model simulations of these and other flows were also performed, including finer-scale intervals to evaluate differences among many flows in the range of 10 to 30 cfs. As anticipated, different flows provided different salinity regimes in the

LHR, generally as a function of distance from the dam and depth in the water column.

- New data confirm that the existing 10 cfs minimum flow provides some meaningful benefits in terms of salinity reduction (Figures 7-2 through 7-13), and that incremental movement toward a higher required minimum flow will extend those benefits over a larger volume of the lower river. At the same time, recently acquired data, similar to that used to develop the existing minimum flow for the LHR, indicate that there is no threshold or optimum flow which yields the "best" (or even a constant) volume of low salinity habitat.

- The primary water quality and ecological factor affected by freshwater inflows at the base of the dam is salinity, although tides and other factors (e.g., stormwater, winds, and salinity in Tampa Bay) complicate this relationship. The LAMFE model was used to examine the relationship between freshwater inflows at and below the base of the dam and salinity in the lower river under various freshwater inflow scenarios. Natural tidal forces restrict the ability to maintain lower salinity habitat as distance from the dam increases. Even when a constant minimum flow is present, there is considerable within-day variability in salinity through most of the river as a result of tides, wind, antecedent flow conditions, rainfall and stormwater inputs, etc. Thus there will be some difference in the proportion of time that <5 ppt conditions are present from Hanna's Whirl to Sulphur Springs compared to the segment from the dam to Hanna's Whirl.

- Prior to implementation of the current 10 cfs minimum flow, long-term data for the LHR showed that during periods of no-flow at the dam, tidal fresh and oligohaline waters are frequently eliminated from the lower river. The TBNEP advisory group accordingly recommended that creation of a salinity gradient below the dam that ranges from fresh to polyhaline waters is an important criterion for establishing minimum flows for the LHR. Biological sampling has indicated that the lower river is inhabited by a variety of native fishes and invertebrates, and that the distribution of these aquatic organisms generally shifts between estuarine and freshwater communities based on the rate of inflow and the predominant salinity conditions at the time.

- The TBNEP (1996) has concluded that river habitats with salinities in the oligohaline (i.e., low salinity, 0.5 to < 5 ppt) range have been disproportionately lost throughout the Tampa Bay watershed. There is an opportunity to maintain such habitats in the LHR given an appropriate minimum flow.

- Principal components analysis (PCA) performed on biological sampling results identified four salinity ranges utilized by invertebrates and four similar ranges utilized by fish. The findings for benthic macroinvertebrate community structure (Figure 5-9) showed that a distinct group of these organisms occur in river habitats with salinity in the range of <5 ppt. However, here was a high degree of species overlap among adjacent salinity zones and few estuarine species were identified as requiring a single salinity zone. Because some invertebrate species and some fish species are restricted to the lower salinity range, maintaining an essentially permanent area of the lower river with a salinity of <5 ppt would provide habitat for those predominantly oligohaline and fresh water species, assuming other habitat requirements are also present.

- The creation of a < 5 ppt salinity zone was chosen as the principal ecological criterion on which to establish minimum flows for the LHR. In addition to creating a low salinity zone for benthic macroinvertebrates, juvenile stages of important estuarine dependent fish species concentrate in oligohaline waters

- Benefits (in terms of provision of low salinity habitat) accruing from fresh (or nearly fresh) water inputs at the dam are most pronounced near the dam, with the magnitude of the effect diminishing downstream (Figures 6-60 through 6-64). Logically, greater flows extend the benefits farther downstream than lesser flows. For a given discharge rate, the strongest effects are realized nearest the dam and decrease incrementally downstream.

- The uppermost section of the LHR from the dam to Hannah's Whirl represents the segment of the river with the least degree of artificially hardened shoreline. The segment from Hannah's Whirl to Sulphur Springs also has relatively unaltered shoreline, but seawalls and other structural alterations are more common there. In both of these segments, the typically steep banks and urban shoreline development generally limit habitat above the water line to the immediate riparian zone.

- Improvements in dissolved oxygen (DO) concentrations are generally apparent nearer the dam with increasing flow, but in a much less predictable manner than for salinity. There is evidence that increasing flows in order to improve dissolved oxygen levels nearer the dam may actually depress oxygen levels farther downstream. Thus, freshwater inflows cannot be used as a general mechanism for mitigating the overall dissolved oxygen deficit throughout the lower river. However, the improvements in DO concentrations in the oligohaline zone that occur during low flows outweigh the slight decreases in DO that would occur in the more downstream reaches.

8.3 District Goal, Justification and Minimum Flow Recommendation

The Study results and discussion prior to this point have been reviewed and mutually agreed upon by both the City of Tampa and the District. Discussion and conclusions which follow represent the District's statutory responsibility to re-evaluate the minimum flow for the Lower Hillsborough River in accordance with 40D-8.041(1) (b) which states in part "Following completion of the District and City study described in Rule 40D-80.073(4)(d), F.A.C., the Minimum Flow shall be re-established, as necessary, based on the results of the study."

8.4 Minimum Flow Criteria and Management Goal

Commenting on the earlier LHR minimum flow document and salinity modeling using the LAMFE model, the peer review panel (Montagna et al. 1999) noted, "There [do] not appear to be any breakpoints in this analysis. The decision on the appropriate instream flow value could be based on the distance downstream, and the depth, that low salinity water is desired." Essentially a minimum flow recommendation based on a desired salinity environment requires a decision on the appropriate duration and spatial extent, of the desired salinity gradient.

The LHR Minimum Flow management goal is:

> **To provide a minimum flow that would extend a salinity range of <5 ppt from the Hillsborough Reservoir Dam toward Sulphur Springs.**

The use of a salinity-based criterion as a management goal for a LHR minimum flow is based upon a biologically-relevant critical salinity range and includes a target spatial extent for that salinity range. It is also emphasized that a minimum flow based on a < 5 ppt salinity zone upstream of Sulphur Springs will provide for lower salinity waters (e.g., <2 ppt) in closer proximity to the dam. These upstream areas will be where organisms with the least salinity tolerance will concentrate in the dry season. Further justification and considerations related to the development of this goal are provided below.

8.5 Justification

Consideration of the desired spatial extent of the desired low salinity habitat area is essential. The highly urbanized nature of the entire LHR watershed and the virtual absence of upland or floodplain area available for any significant ecological enhancement or restoration restrict biological considerations to the river channel itself. Sulphur Springs is a natural source of low salinity water that flows into the river 3.5 kilometers downstream of the dam. Providing a source of water above Sulphur Springs sufficient to produce a <5 ppt zone from the dam toward Sulphur Springs provides a low salinity continuum from a truncated estuary (i.e., the base of the dam) to a natural source of low salinity water. It also has the added benefit of minimizing or eliminating the "reverse salinity" gradient which develops just upstream of Sulphur Springs when upstream flows are insufficient. Given the location of Sulphur Springs and the expressed Sulphur Springs minimum flow management goal (SWFWMD, 2004b) of maintaining a low salinity habitat in this portion of the river, it is reasonable and ecologically desirable to define a spatial extent that considers Sulphur Springs, and in effect creates a low salinity (oligohaline) corridor between the base of the dam and Sulphur Springs.

It should be appreciated that, in the absence of significant permitted withdrawals, the naturally occurring oligohaline zone would have extended considerably past Sulphur Springs (see Section 2.3.6).

Commenting on the previous LHR minimum flow document, the peer review panel (SWFWMD 1999) noted that, "Salinity values upstream of the [Sulphur Springs] outfall at the base of the dam are higher than just above or below the outfall. This indicates that a 'reverse estuary' condition exists during no flow periods. This would be very detrimental to estuarine communities." Implicit in this statement is the desire for a minimum flow that would alleviate this condition. Examination of salinity data shows that the low salinity habitats downstream of the dam and at Sulphur Springs can be disconnected by higher salinity water during times of no flow from the dam. Model simulations also show that at no flow or very low flows a reverse salinity gradient may exist in this portion of the river, resulting in higher salinity water occurring upstream of the fresher Sulphur Springs flow. Implementation of the existing 10 cfs minimum flow has improved this condition, but increasing the minimum flow would further reduce the potential for adverse effects. Therefore, the spatial extent of the critical salinity range is considered to be that portion of the river from the dam downstream toward Sulphur Springs. While <5 ppt is viewed as an important biological range for salinity, the available biological data itself does not allow for determination of the optimal volume of this habitat for fish or invertebrate communities in the LHR. Because of its highly altered status and urbanized condition, the District considered the benefits of incremental gains in the volume and duration of the < 5 ppt zone in relation to freshwater inflows. Given the goal of establishing a < 5 ppt salinity zone above Sulphur Springs, the District considered how much benefit would be gained increasing flows in 2 cfs increments in the 0 – 30 cfs range.

The duration and spatial extent of change in oligohaline habitats in the LHR are non-linear but monotonic functions of the freshwater flow at the dam. For example, as the flow increases the volume of low salinity water increases, but the rate of change is not constant. Thus, an approach based on incremental gains in the spatial extent (i.e., volume) and duration (i.e., time) was employed to evaluate the time and volume that a low salinity zone could be established. As shown in Figure 7-23, it is apparent that a number of different flows will provide some <5 ppt habitat above Sulphur Springs; however, the percent of the time and the percent of the volume that a <5 ppt zone is provided varies with the flow rate supplied. As indicated by Figure 8-1, the amount of <5 ppt habitat steadily increases as flow increases, but there is a change in the rate of increase. Although one can continue to increase the amount of <5 ppt habitat to Sulphur Springs (both spatially and temporally) by continuing to increase flow, the maximum return per flow invested begins to level off at 20 cfs and declines after 24 cfs. For this reason and the fact that the reverse salinity gradient is virtually eliminated at 20 cfs of freshwater flow, 20 cfs freshwater equivalent is recommended as the minimum flow.

In addition to providing a desirable salinity gradient, the recommended minimum flow is also expected to reduce the occurrence of low DO concentrations (<2.5 mg/l) in the upper reaches of the river. Table 6.4 and Figure 6-21 illustrate a significant reduction in the occurrence of low DO concentrations in the upper river when flows are greater than or equal to 20 cfs, although the frequency of low DO concentrations in the lower reaches (near the mouth) can show a slight increase at flows in this range. It was concluded that the large percent decrease in the frequency of low DO in the targeted oligohaline zone at low flows offers a net benefit to the river when compared to the relatively small percent increases in low DO in the lower reaches. As noted earlier in the text, District staff operationally defined low DO conditions as concentrations less than 2.5 mg/l. Although the state DO standard (i.e., 4 mg/l) is higher than this operational criteria, the data for the LHR, at least for fish abundance (Figure 5-21) and species richness (Figure 5-22), suggest a rather sharp (step) break in DO tolerance between 2.0 and 2.5 mg/l.

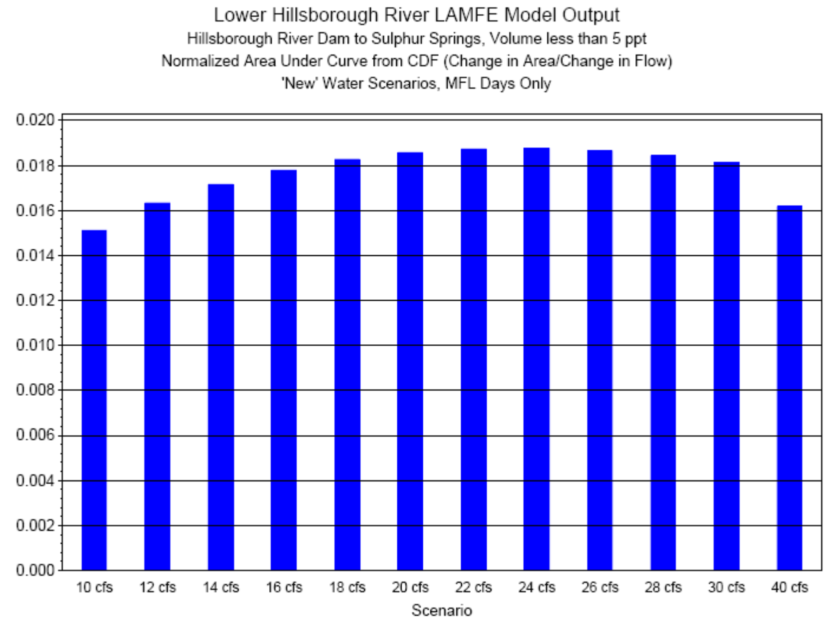


Figure 8.1. Difference in rate of change in unit area per unit flow from Hillsborough River Dam to Sulphur Springs as flow is increased in 2 cfs increments.

8.6 Seasonally Adjusted Minimum Flow

Due to the unusually severe hydrologic conditions experienced in 2000-2001, some allowance should be made in the proposed minimum flow during extreme hydrologic conditions to reflect natural climatic variations that can occur. Water to make up minimum flows will probably come from a mix of several potential sources (Sulphur Springs, Tampa Bypass Canal, Blue Sink, Aquifer Storage and Recovery, treated wastewater, etc.), and the availability of only one of these sources (i.e., treated wastewater) is independent of natural hydrologic conditions. Therefore, it is proposed that the 20 cfs freshwater equivalent minimum flow be seasonally adjusted based on naturally varying hydrologic conditions. The low flows in the upper Hillsborough River are largely sustained by spring discharges. Although annual variation in spring flow is typically much less than river flow, the Zephyrhills gage on the upper Hillsborough River does provide a good measure of the flow that would be supplied in the upper watershed under low flow conditions. It is recommended that when the low flows, as measured at the Zephyrhills gage, drop below a given threshold, the minimum flow on the lower Hillsborough River be adjusted accordingly.

The annual 90% exceedance flow as measured at the Zephyrhills gage for the decade of the 1990's is proposed as a threshold. The median of the annual 90% exceedance flow at the Zephyrhills gage is approximately 58 cfs. It is proposed that as long as the flow at the Zephyrhills gage exceeds 58 cfs, a minimum flow of 20 cfs freshwater equivalent would have to be met on the lower Hillsborough River. However, if flows at the Zephyrhills gage drop below 58 cfs due to naturally occurring hydrologic conditions, the minimum flow would be reduced proportionately. For each one cfs drop in flow below 58 cfs, the minimum flow requirement below the dam would be reduced by 0.35 cfs (20/58 = 0.35). For example, as long as the flow at the Zephyrhills gage exceeds 58 cfs, then a minimum flow of 20 cfs fresh water (or equivalent) is required on the LHR below the dam; if the Zephyrhills flow drops to 50 cfs or 8 cfs below the 58 cfs threshold then only 17 cfs (20 cfs minus 0.35 * 8 cfs) is required; if Zephyrhills flow drops to 47 then a 16 cfs minimum flow is required on the LHR, etc. (see Table 8.2). This proposed seasonal adjustment to the minimum flow would most often result in an adjusted minimum flow in the month of May by a few cfs; however, under extreme conditions such as occurred in 2000-2001, it could be adjusted for a number of months in a row.

Table 8.1. Proposed table of adjustments to be applied to Lower Hillsborough River minimum flow of 20 cfs freshwater equivalent in recognition of seasonal hydrologic conditions. The 20 cfs freshwater equivalent minimum flow would apply whenever the Zephyrhills flow is less than 58 cfs.

Zephyrhills Flow (cfs)	Hydrologically Adjusted MFL (cfs)
58	20
55	19
53	18
51	18
48	17
46	16
44	15
42	14
40	14
37	13
35	12
33	11
31	11
28	10

8.7 The Equivalent of a 20 cfs Freshwater Minimum Flow

The minimum flow recommendation is for the equivalent of 20 cfs of freshwater subject to seasonal variation. This is reiterated, since one potential source for meeting the minimum flow is flow diverted from Sulphur Springs. Since Sulphur Springs is not technically freshwater, if it is used in combination with some other source to meet the minimum flow, a total addition of more than 20 cfs will be required to meet the 20 cfs freshwater equivalent. To emphasize this point, the LAMFE model was run and a CDF plot was constructed comparing a true 20 cfs freshwater minimum flow with a mixture of 15 cfs Sulphur Springs and various amounts of fresh water (i.e, 5, 7, 8 and 9 cfs; Figure 8.2). From this plot, it is apparent that a combination of 15 cfs from Sulphur Springs and 8 cfs of fresh water provides the closest analog to 20 cfs of fresh water. In addition to reducing the quantity of freshwater required to achieve the desired salinity zone, routing spring water to the base of the dam may improve the vertical mixing characteristics of the river near the spring outfall by reducing the density stratification that occurs there.

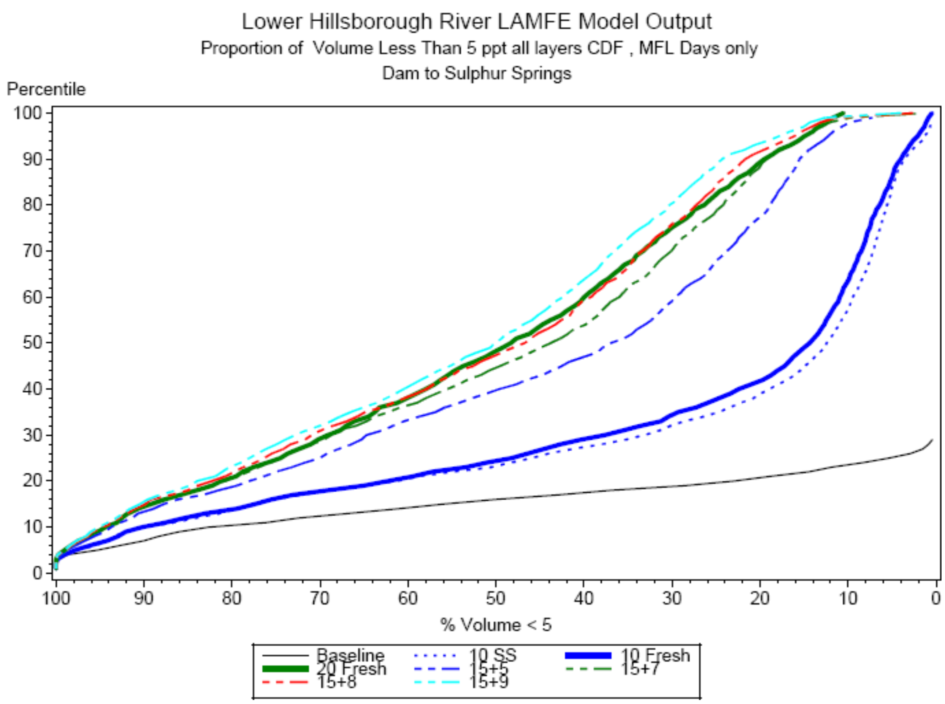


Figure 8.2. Comparison of the effect of 20 cfs freshwater against various blends of Sulphur Springs and freshwater.

8.8 Minimum Flow Recommendation

The minimum flow recommendation for the Lower Hillsborough River is for the equivalent of 20 cfs of fresh water, based on extending a <5 ppt salinity zone from the base of the Hillsborough River Reservoir toward Sulphur Springs under low flow conditions. It is recognized that if a mix of waters involving sources that may not be strictly fresh or already flow to the river (e.g., Sulphur Springs) is used to meet the minimum flow, the minimum flow requirement will be greater than 20 cfs.

It is recommended that the minimum flow be adjusted for seasonal hydrologic conditions. The suggested method of adjustment is tied to flow in the Hillsborough River as measured at the USGS Zephyrhills gage and the annual 90% exceedance flow at this site for the period 1990-1999.

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