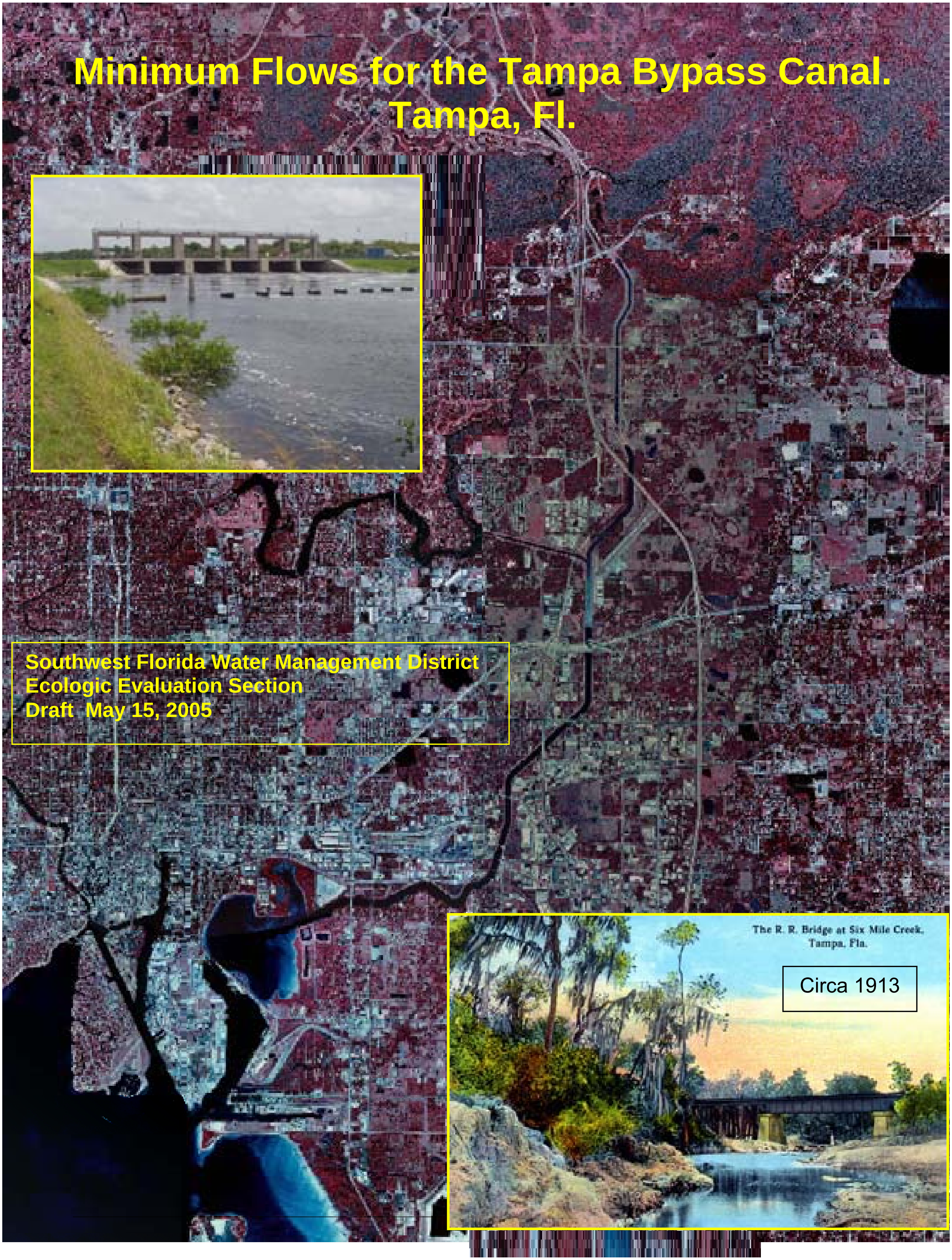
Minimum Flows for the Tampa Bypass Canal. Tampa, Fl.



Southwest Florida Water Management District
Ecologic Evaluation Section
Draft May 15, 2005

Minimum Flows for the Tampa Bypass Canal

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Ecologic Evaluation Section
Resource Conservation and Development Department
Southwest Florida Water Management District
Brooksville, Florida 34604-6899

EXECUTIVE SUMMARY

The Southwest Florida Water Management District (District) is mandated by the legislature (Section 373.042, Florida Statutes) to protect water resources and ecology from 'significant harm' due to withdrawals. The minimum flow is defined as the minimum amount of water (or water level) that will prohibit significant harm. It is termed the minimum flow and level (MFL). This document establishes the target goals for the resources a priori, and describes the tools used to evaluate the resource response to inflows.

In accordance with the Statutes, the MFL is based on best available data. It is not a restorative, optimal or historical flow, although a baseline flow condition was established for reference. The MFL statutes do not make provisions for existing consumptive use withdrawals and thus it was necessary to correct for historical withdrawals/transfers of TBC flow. In contrast and as provided in the law, structural alterations must be considered in establishing an MFL. The TBC was constructed from the Palm River by the Army Corps as part of the Four River Basins flood control project, and those functions take priority over resource protection. The District was formed in 1961 by the State legislature to be the local sponsor of the TBC construction project.

The large diversions from the Hillsborough River to the TBC are for flood control. High flows in the TBC causes several undesirable environmental consequences. Infrequent, but prolonged low salinities cause oyster mortality and establish vertical salinity stratification. The latter in turn cause hypoxic (low oxygen) conditions that result in depaupurate benthic communities. In many respects, the ecology of the TBC is at higher risk because of high flows than insufficient freshwater flow.

The construction of the TBC increased the volume of the Palm River by more than 10 times. The increased conveyance provides flood control, but also serves as an effective conduit for saline waters from Tampa Bay. Historically, a gallon of freshwater runoff into the Palm River would have been 10 times more effective at diluting saltwater because the volume of the Palm River was 10 times smaller. Consequently, it follows logically that both the hydrodynamic and empirical models developed for the TBC predict a system that is relatively insensitive to freshwater inputs. The freshwater input to TBC has increased dramatically, yet the system remains a relatively high saline system without a freshwater reach. This is despite the addition of an estimated 20 mgd of ground water caused by a breach of the Floridan aquifer during construction and the hydraulic connection to the Hillsborough River watershed that is 22 times larger than the original 28 square mile Palm River watershed. However, much of the Hillsborough discharge is captured for water supply, and existing users withdraw an additional amount from the TBC prior to discharge into McKay Bay.

At the outset of the evaluation, several ecological resources believed to be significant to McKay Bay/TBC were identified for evaluation. Those included oysters, birds, vegetation, benthic macroinvertebrate communities, fish and invertebrates. In the absence of clear breaks in resource/inflow relationships, an a priori goal of less than a fifteen percent loss of resource was established. In addition, a low flow threshold (LFT) of 30 cfs corresponding to the lowest 10 percent of baseline flows was initially chosen for evaluation.

Of the resources chosen for evaluation, only the fish and invertebrate response to inflow proved useful. The oyster evaluation revealed that even under zero discharge from S-160, the salinity in McKay Bay/TBC remains within optimal limits for oysters. In essence, McKay Bay/TBC will assume the salinity of East Bay (which in turn assumes the salinity of Hillsborough Bay etc) that is non-threatening for oysters.

The dominant vegetative structures in McKay Bay/TBC are mangroves. Contemporary research into mangrove ecology subscribes to the belief that the salinity in the water column is relatively unimportant to the health of mangroves. Of far greater importance is the salinity in the soil, which mangroves have been shown to regulate.

It was determined that birds were also a poor choice of resource related to inflow partly because of their mobility. Successful connections to freshwater inflow will likely be through qualitative relationships to vegetation or prey abundance.

Useful quantitative relationships between McKay Bay/TBC benthic infauna and freshwater inflow have yet to be published, although community gradients related to salinity have been noted. Circumstantial evidence indicates that hypoxia is a major factor in shaping the TBC community, but relationships quantitatively linking abundance, diversity or other community metrics with flow were unavailable at the time of the evaluation. The McKay Bay/TBC literature describing the role of salinity in shaping the benthic community is conflicting and inconclusive at this time.

The response of fish and invertebrates to varying inflow proved to be a useful tool for the MFL evaluation. Coupling the results of over 2,000 sampling episodes with the discharge from S-160 and estimates of ungaged flow below S-160 resulted in statistically significant (at α =0.05) relationships for 34 taxa, although flow alone accounts for only a small fraction of the abundance (median r^2 =0.24).

Three taxa were selected because of their positive response to freshwater and their significance to the regional ecology (bay anchovy and mysid shrimp) or their commercial value (pink shrimp). The abundance of each taxon was estimated for the median baseline flow condition (Flow at S-160 that would have occurred between 1983 and 2003 if no diversions or withdrawals had occurred for water supply reasons) and for a series of hypothetical reduced flow scenarios. The daily median of the 20-year flow was evaluated in order to allow for the natural variation in flow, recognizing that there are constraints to the extent that a regulated system designed primarily for flood-control can mimic natural conditions.

The percentage change in abundance relative to the daily median baseline flow (97 cfs) indicates that an average fifteen percent reduction will occur in these three taxa when S-160 flows are reduced to approximately 65 cfs. Greater losses occur with further reductions in median flow.

An infinite combination of low flow thresholds and percentage withdrawals will result in a median flow of 65 cfs. At lower withdrawal rates, a zero cfs LFT produces the same median flow and thus the same abundance as a 30 cfs LFT. At higher withdrawal rates the selection of LFT becomes more critical. Two scenarios were selected for further evaluation. A combination of 30 cfs LFT and forty percent withdrawal (scenario S-4) and a 30 cfs LFT with a sixty percent withdrawal (S-5) were further evaluated for salinity and dissolved oxygen response.

The difference between scenarios S-4, S-5 and the baseline flow (S-2) for average bottom salinity and percent saturation of dissolved oxygen is deemed ecologically negligible. (Percent saturation is a re-expression of the traditional dissolved oxygen concentration that is normalized for salinity and temperature.) Hydrodynamic model results support the empirically derived salinity/flow relationships for the three flow scenarios. In the areas of ecological concern (e.g. hypoxic conditions), cumulative distribution plots of both percent saturation and salinity were virtually indistinguishable between the flow scenarios.

The present evaluation was largely framed around relationships between the abundance of fish/invertebrates and freshwater inflow. A long-term median flow that limits resource loss to 15 percent was identified from these relationships. Using empirical and hydrodynamic models, this median flow was tested for effects on salinity and dissolved oxygen. The report concludes that the differences would be negligible.

However, no MFL is recommended at this time because the underlying biological response is only weakly related to inflows and inflow (and thus the MFL) accounts for less than the eighty-five percent of the resource response. This, coupled with the highly altered physical conditions and the need to retain the flood control functions suggest that maintaining a complete estuarine gradient will be impractical and the benefit of establishing an MFL is questionable.

Acronyms and Definitions	
ac	acres
BOD	Biochemical Oxygen Demand
CDF	Cumulative Distribution Function
cfs	Cubic feet per second
cms	cubic meters per second
COB	Center of Abundance
COT	City of Tampa
District	Southwest Florida Water Management District
DO	Dissolved oxygen
EPCHC or EPC	Environmental Protection Commission of Hillsborough County
F.A.C.	Florida Administrative Code
F.S.	Florida Statutes
FDEP	Florida Department of Environmental Protection
FMRI	Florida Marine Research Institute (Presently FWRI)
FWRI	Florida Fish and Wildlife Research Institute
GIS	Geographic Information Service
ha	hectares
HBMP	Hydro-Biological Monitoring Plan
HIMP	Hillsborough Independent Monitoring Program
Km	Kilometer
MFLs	Minimum Flows and Levels
mg/l	Milligrams per liter
mgd	Million gallons per day
NGVD	National Geodetic Vertical Datum
PBS&J	Post, Buckley, Schuh and Jernigan, Inc.
ppt	parts per thousand
PSU	Pracatical Salinity Units
SDI	SDI, Inc.
SJRWMD	St. Johns River Water Management District
TBC	Tampa Bypass Canal
TBEP or TBNEP	Tampa Bay Estuary Program (Tampa Bay National Estuary Program)
TBW	Tampa Bay Water
TDS	Total Dissolved Solids
TKN	Total Kjehldal Nitrogen
TN	Total Nitrogen
TSS	Total Suspended Solids
USF	University of South Florida
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WAR	Water and Air Reseach, Inc
WCRWSA	West Coast Regional Water Supply Authority (Presently TBW)

Conversion Table		
	Metric to U.S. Customary	
Multiply	By	To Obtain
cubic meters per second (m^3/s)	35.31	cubic feet per second (cfs)
cubic meters per second (m^3/s)	23	million gallons per day (mgd)
millimeters (mm)	0.03937	inches (in)
centimeter (cm)	0.3937	inches (in)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	statute miles (mi)
square meters (m^2)	10.76	square feet (ft^2)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	0.0008110	acre-ft
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
Celsius degrees (^oC)	$1.8*(^oC) + 32$	Fahrenheit (^oF)
	US Customary to Metric	
inches (in)	25.40	millimeters (mm)
inches (in)	2.54	centimeter (cm)
feet (ft)	0.3048	
statute miles (mi)	1.609	
square feet (ft^2)	0.0929	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
acres	0.4047	hectares (ha)
gallons (gal)	3.785	liters (l)
cubic feet (ft^3)	0.02831	cubic meters (m^3)
acre-feet	1233.0	cubic meters (m^3)
Fahrenheit (^oF)	$0.5556*(^oF-32)$	Celsius degrees (^oC)
	US Customary to US Customary	
acre	43560	square feet (ft^2)
square miles (mi^2)	640	acres
cubic feet per second (cfs)	0.646	million gallons per day (mgd)

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CHAPTER 1 - PURPOSE OF MINIMUM FLOWS AND LEVELS - BACKGROUND SETTING FOR THE TAMPA BYPASS CANAL

1.1 OVERVIEW

The Southwest Florida Water Management District (SWFWMD) is responsible for permitting the consumptive use of water within the District's boundaries. Within this context, the 1972 Florida statutes (Section 373.042) mandate that the District protect water resources from “significant harm” through the establishment of minimum flows and levels (MFLs) for streams and rivers within its boundaries. The District’s purpose in establishing MFLs is to create hydrologic and ecologic standards against which permitting or planning decisions can be made regarding water withdrawals, either surface or ground-water. Should an amount of withdrawal requested cause “significant harm” then a permit cannot be issued. If "significant harm" is found as a result of existing withdrawals, then a recovery plan must be developed and implemented.

As currently defined by statute, "... *the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area*." The legislature has not defined ‘*significantly harmful’* although Lowe (1994) proposed that significant harm to natural systems occurs when anthropogenic effects on hydrology have caused, or are likely to cause one of the following for a period of five years or more:

1) Local or regional extirpation of one of more native species,
2) . . . . reduction in abundance or reproductive success of a listed . . . species,
3) . . . . reduction in abundance or reproductive success of a keystone species
4) . . . . reduction in abundance or reproductive success of a commercially, or recreationally significant species, and
5) replacement of the dominant flora or fauna with another species or group that becomes significant, or a significant increase occurs in the abundance or productivity or a nuisance, exotic, or uncharacteristic species.

For purposes of the MFL evaluation for the Tampa Bypass Canal (TBC), the significant harm is assumed to occur when the abundance of mysid shrimp, bay anchovy (keystone species) or pink shrimp (commercially significant species) is reduced 15 percent or more.

1.2 LEGISLATIVE DIRECTION

Florida law requires the water management districts to establish MFLs for surface waters and aquifers within their jurisdictions (Section 373.042(1), F.S.). According to state law, minimum flows and levels are to be established based upon the “…*best available information…*” and shall be developed with consideration of *“...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 the affected watershed, surface water, or aquifer...* (Section 373.0421, F.S.). While the legislature has explicitly identified the need to consider physical changes, existing potable water withdrawals are not to be considered when developing minimum flows and levels. In essence, during development of an MFL existing uses will not be 'grandfathered' but the District is directed to evaluate and account for the effects of previous structural alterations on a watercourse when assessing the potential for withdrawals to cause significant harm.

Each water management district must also consider, and at its discretion may provide for, the protection of non-consumptive uses in the establishment of MFLs (Section 373.042, F.S.). In addition, a baseline condition for the protected resource functions must be identified through consideration of changes and structural alterations in the hydrologic system (Section 373.042(1), F.S.). In the case of the present evaluation, there are major physical alterations and several existing consumptive use withdrawals.

Given the above definitions, a basic function of minimum flows is to ensure that the hydrologic requirements of natural systems associated with lakes, streams, rivers and estuaries are met and not jeopardized by excessive withdrawals. In turn, establishing minimum flows is important for water supply planning, because it affects how much water is available for withdrawal. Mere adoption of minimum flows does not protect a waterbody from significant harm nor regulate water availability. It is the application of minimum flows through planning and regulatory mechanisms that ensure the hydrologic requirements of natural systems are met. Intrinsically this identifies the amount of water available for other uses.

As will be further developed within this report, the primary function of the TBC is to divert floodwaters from Temple Terrace and downtown Tampa. The TBC is fundamentally a stormwater conveyance system engineered to efficiently move large flood flows. That efficiency comes at the expense of shallow bathymetry, shoreline and vegetation. Much of the environmental harm can be traced to excessively high flows and the presence of physical structures, which truncate the estuary functions. For the TBC MFL determination, the flood control function may not be compromised and takes priority over protection of water resources. By statute, the structural alterations necessary to accomplish flood control must be accepted. While it may be possible to mitigate some of these impacts through operational changes, the statutory MFL mandate is to determine the point at which *less water* becomes ecologically damaging.

1.3 WATER RESOURCE FUNCTION

Each surface water body or aquifer serves an array of water resource functions. These functions must be considered when establishing MFLs as a basis for defining significant harm. The term "water resource" is used throughout Chapter 373, F.S. Water resource functions protected by Chapter 373, F.S. are broad, as illustrated in Section 373.016, F.S. These functions include flood control, water quality protection, water supply and storage, fish and wildlife protection, navigation, and recreation.

According to the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code) "…*consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic and wetlands ecology, including:*

1. *Recreation in and on the water;*
2. *Fish and wildlife habitats and the passage of fish;*
3. *Estuarine resources;*
4. *Transfer of detrital material;*
5. *Maintenance of freshwater storage and supply;*
6. *Aesthetic and scenic attributes;*
7. *Filtration and absorption of nutrients and other pollutants;*
8. *Sediment loads;*
9. *Water quality; and*
10. *Navigation."*

Minimum flows will also be used for long range planning. Since the establishment of minimum flows can potentially restrict the allocation of water, the setting of minimum flows will not go unnoticed, or unquestioned. For this reason, the science upon which a minimum flow is based, the assumptions made, and the policies used to establish an MFL need to be clearly specified. The District's policy is to convene an independent peer review panel to review individual MFLs or to review protocols used to establish MFLs.

The legislative consideration of structural alterations is particularly important to the TBC minimum flow and level because the system has been highly altered with hardened shorelines and multiple control structures. In addition, the presence of the control structure at the Hillsborough Reservoir regulates the quantity of water diverted into, or out of the TBC. These existing structural modifications also serve to direct the technical approach used to establish an MFL. For example, maintenance of riparian hydroperiods is an inappropriate criterion for this system, but maintenance of a healthy salinity regime is an appropriate evaluation metric.

1.4 GEOGRAPHIC DEFINITIONS

For purposes of this report, the term "TBC MFL" refers to development of a minimum flow, or flow regime for the ecological resources between structure S-160 and the 22nd Street Causeway crossing at the southern downstream end of McKay Bay. Distances in river km are measured from the Causeway, which by definition is km zero. Structure S-160 is located at river km 7.4. For analytical reasons, segmentation commences at a point coinciding with river km –0.2 in order to take advantage of a long-term monitoring station located just south of the Causeway.

"McKay Bay" refers to those waters northeast of the Causeway to the confluence of the former Palm River (approximately 2.1 km upstream of the Causeway) and "Palm River" refers to the dredged and channelized water body from that point to S-160. The "McKay Bay/TBC complex" refers to the waters included in the TBC MFL.

1.5 ECOLOGIC INTEGRITY AND SIGNIFICANT HARM

To justify adoption of a minimum flow for purposes of maintaining ecologic integrity, it will be necessary to demonstrate the effects of implementation and compliance with the proposed MFLs will have with site-specific information. As stated by Richter et al. (1966)

> "*A goal of ecosystem management is to sustain ecosystem integrity by protecting native biodiversity and the ecological (and evolutionary) processes that create and maintain that diversity. Faced with the complexity inherent in natural systems even in the absence of structural changes, achieving that goal will require that resource managers explicitly describe desired ecosystem structure, function, and variability; characterize differences between current and desired conditions; define ecologically meaningful and measurable indicators that can mark progress toward ecosystem management and restoration goals; and incorporate adaptive strategies into resource management plans"*.

As described in Florida's legislative requirement to develop minimum flows, the minimum flow is to prevent "significant harm" to the state's water resources. Within the context of the rule, an MFL is not a restorative, or optimal flow nor is it a return to historic flow (SWFWMD, 2001). The goal of a minimum flow is not to duplicate a pre-modification hydrologic regime, but rather to establish the threshold(s) at which significant harm occurs. If withdrawals have already significantly harmed the resource, it may be necessary to develop a recovery plan.

1.6 COMPONENTS OF A MINIMUM FLOW AND LEVEL

Beecher (1990) notes that in most statutes, *"it is difficult to either ascertain legislative intent or determine if a proposed instream flow regime would satisfy the legislative purpose"*. Beecher argues (as cited by Stalnaker et al. 1995) that an instream flow standard should include the following elements:

1) A goal, or goals
2) Identification of the resources of interest to be protected;
3) A unit of measure (e.g., flow in cubic feet per second, habitat in usable area, inundation to a specific elevation for a specified duration);
4) A benchmark period.

1.7 SUMMARY OF APPROACH

Several different approaches have been used by the District to determine the minimum flow regime for rivers. From a biological perspective, a minimum flow regime may be set with the intent of protecting a specific habitat type(s), or the MFL may be set on the basis of habitat requirements of one or several indicator species. It is anticipated that in the short term (over the next several years), minimum flows for biologic purposes will often be set from the perspective of protecting particular habitat types (e.g., macroinvertebrate habitat), particularly in situations where we do not yet have adequate data to do otherwise. In contrast and where sufficiently strong direct relationships between freshwater inflow and biological resources exist, the most conservative relationship will serve to protect the resources.

The determination of desirable minimum flows in TBC first involved identification of resources believed to be significant to the water body. In this regard, a rich database has been assembled through the efforts of Environmental Protection Commission Hillsborough County (EPCHC), Tampa Bay National Estuary Program (now Tampa Bay Estuary Program, TBEP), Tampa Bay Water (TBW), City of Tampa (COT), SWFWMD and their contractors. Much has been written about the region and a set of goals was identified from the results of prior studies. Thus, following the suggestion of Beecher, the elements of the TBC MFL become:

Goals:

1. Maintain appropriate salinity regime for maintenance of healthy riparian vegetation, oyster reefs, benthic infauna communities and fish.
    a. Establish and maintain adequate dissolved oxygen levels in support of the first goal.
2. Resource(s) Protected : Oysters, fish, invertebrates, riparian vegetation, and benthos
3. Measurement Unit : Salinity, abundance, diversity, acres
4. Benchmark Period : 1983 – Present

The ‘benchmark’ definition warrants additional clarification. Construction of the TBC was completed (see Chapter 2 for construction details) in December 1982. Thus, defining the start of the ‘<u>baseline period</u>’ in January 1983 is justifiable. However, significant withdrawals and diversions of water have occurred during the baseline period and the measured flows since 1983 do not represent a true baseline flow. For purposes of the present evaluation, the ‘<u>baseline flow’</u> represents a reconstructed flow at S-160 derived by reinstating all water supply diversion/withdrawals, but retaining all of the historical flood-control diversions in the flow record.

While the proposed approach takes into account several factors, ultimately what constitutes “significant harm” will be determined by the Governing Board of the SWFWMD.

Sometimes the relationship between flow and the protected resource(s) does not exhibit obvious inflection points that unequivocally identify ‘significant harm’, but rather exhibit a continuum of linear degradation. **Figure 1-1** illustrates the difference for a hypothetical response variable where there is a clear break in the non-linear response between 80 and 70 percent of the baseline flow. In cases of a linear response, it is necessary to establish a policy of what constitutes an unacceptable harm. For purposes of the present evaluation, a fifteen percent loss of resource from baseline was adopted as the acceptable limit. This choice is consistent with the District 's draft Alafia River MFL [SWFWMD, 2004] in which a 15% loss of habitat was deemed the maximum acceptable value. Although a fifteen percent loss is recommended as a measure of unacceptable loss, it is important to note that percentage changes employed for other instream flow determinations have ranged from ten to thirty-three percent. For example, Dunbar et al. (1998) in reference to the use of a habitat suitability model (PHABSIM) noted "an alternative approach is to select the flow giving 80% habitat exceedance percentile": which is equivalent to a twenty percent decrease. Jowette (1993) used a guideline of one-third loss existing habitat at naturally occurring low flows, but acknowledged that , "[n]o methodology exists for the selection of a percentage loss of "natural" habitat which would be considered acceptable".

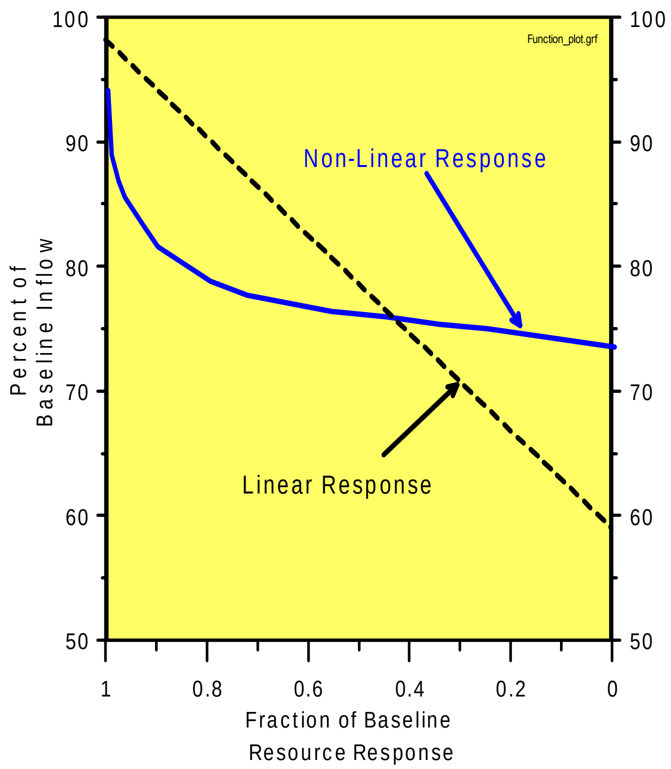

Figure 1-1 Examples of Linear and Non-Linear Response Variable

The State of Texas has used similar targets in establishing MFL for the Matagorda Bay. Under Texas water code (Sec. 11.1491) a task force of the Texas Parks and Wildlife Department and the Texas Natural Resource Conservation Commission are jointly tasked with the responsibility to determine inflow conditions necessary for bays and estuaries. In establishing the minimum flow for Matagorda Bay, one constraint imposed was that the productivity of nine species (from a list of finfish and shellfish) should be maintained at eighty percent of historical average [1].

In a like manner, a 10th percentile of the baseline flow record (*low-flow threshold, 'LFT'*) was adopted as the lowest flow evaluated. That is, only ten percent of the long-term flows will be lower or equal to this value. For the baseline flow, the 10th percentile S-160 value is 30 cfs (19.4 mgd). This choice is based on both District and State of Texas precedents. The current WUP for the Peace River is set at the 13th percentile and the District's *Regional Water Supply Plan* (SWFWMD, 2001) has chosen the 15th low-flow percentile as the lower limit of evaluation for planning purposes.

[1] http://www.tpwd.state.tx.us/texaswater/coastal/freshwater/matagorda/matagorda.phtml

In addition, in the nationally recognized and peer-reviewed report *Freshwater Inflows to Texas Bays and Estuaries*, (Longley, W.L, ed. 1994) the staff of the Texas Water Development Board and Texas Parks and Wildlife Department recommended use the 10th percentile low-flow threshold for evaluation of minimum flow. All Texas estuarine (Trinity-San Jacinto estuary[2], Guadalupe[3], Neuses[4]) MFL determinations have imposed a constraint that the optimal flows are found between the 10th percentile and the 50th percentile, effectively setting the lowest flow to be evaluated at the 10th percentile.

1.8 FLOWS AND LEVELS

Although somewhat semantical, there is a distinction between flows, levels and volumes that should be appreciated. All terms apply to the setting of "minimum flows" for flowing (lotic) waters. The term "flow" may most legitimately equate to water velocity. A certain flow or velocity of water may be required to physically move particles heavier than water. For example, silt and clay are moved by relatively low flows, but progressively higher flows are required to transport sand, or larger sized sediment downstream. In estuaries, these seaward flows are met with incoming flood tides that cause a reduction in net flow, resulting in settling and deposition of sediments. Thus, the velocity is an important factor is determining the sediment composition. Flows may be important as a cue for some organisms; for example, certain fish species search out areas of freshwater inflow for reproduction and may move against flow or into areas of reduced or low flow to spawn.

Discharge, on the other hand, refers to the volume of water moving past a point, and depending on the size of the stream (cross sectional area), similar volumes of water can be moved with quite large differences in the rate of flow (velocity). The volume of water moved through a stream can be particularly important to an estuary. It is the volume of freshwater that mixes with salt water that determines what the salinity in a fixed area of an estuary will be. This is especially important for organisms that require a certain range of salinity. The relative volumes of fresh and marine water determine salinity, not the flow rate per se; therefore, volume rather than flow is the important variable to these biota. As will be further discussed, in the present case the volume of the original Palm River is miniscule in comparison to the present dredged system. Thus, inflows comparable to historical freshwater flows are largely ineffective at diluting the large volumes of saline bay water moving upstream on flood tides.

Establishing a minimum water level is given less focus in estuarine settings because level is dominated by the tidal range. Changes in water level resulting from changes in freshwater input are generally masked by the tides. Thus, for the present evaluation, the minimum flow determination of the TBC MFL is expressed as a rate of freshwater discharge into the estuary.

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[2] http://www.tpwd.state.tx.us/texaswater/coastal/freshwater/galveston_bay/galveston.phtml
[3] http://www.tpwd.state.tx.us/texaswater/coastal/freshwater/guadalupe/guadalupe.phtml
[4] http://www.tpwd.state.tx.us/texaswater/coastal/freshwater/nueces/nueces.phtml

1.9 CONTENT OF REMAINING CHAPTERS[5]

Chapter One has summarized the requirements and rationale for developing minimum flows and levels in general. The remainder of this document considers the development of MFLs specific to the Tampa Bypass Canal system in particular. Chapter 2 provides a Basin Description and the History of the TBC including an overview of previous attempts to develop an MFL for this system. The hydrology and current water uses are also discussed in Chapter 2 along with pertinent prior and on-going studies. Studies commissioned specifically for the TBC MFL determination by the District are briefly described in Chapter 2.

A discussion of Ecological Resources can be found in Chapter 3, which establishes the ecological basis for the MFL. The Chapter opens with an evaluation of salinity requirements of oysters, followed by a description of vegetation and birds. Chapter 3 continues with a discussion of the use of McKay Bay/TBC by fish and invertebrates (a key resource of the system), followed by an examination of the of the benthic community. Water quality (salinity/dissolved oxygen/flow relationships) logically follows as the benthic community of McKay Bay/TBC is largely shaped by periods of hypoxia (acute low oxygen). Finally, the development of a mechanistic hydrodynamic/salinity model is described at the conclusion of Chapter 3. The Technical Approach is summarized in Chapter 4, followed by a discussion of the Recommended TBC MFL in Chapter 5.

[5] With the exceptions noted and for consistency with other SWFWMD documents, the British system of measurement units will primarily be used in this report. A table of conversion follows the Table of Contents. River distance is noted in kilometers from the mouth and water quality sample depths are reported in meters.

CHAPTER 2 - BASIN DESCRIPTION AND HISTORY

2.1 GEOGRAPHIC SETTING

The Tampa Bypass Canal system consists of McKay Bay and a box-cut drainage canal situated in the Northeast corner of Tampa Bay (**Figure 2-1**). The system consists of McKay Bay and the dredged remnants of the Palm River. Dredging activities by the Army Corps of Engineers (ACOE) have radically altered the physical characteristics.

Prior to 1970, the Palm River and Six Mile Creek drained about 40 square miles above McKay Bay and south/southeast of the Hillsborough River watershed (HDR, 1994). Originally the entire drainage was known as Six Mile Creek (USC&GS, 1879. USDA Bureau of Soils, 1916), but during the 1920's the name "Palm River" was used to identify the lower 2 miles at the confluence with McKay Bay (HDR, 1994). The headwaters were located east of Tampa Reservoir (also known as the Hillsborough River Reservoir) where flow originated from Eureka Springs and seepage springs in a flat, wet prairie called Harney Flats (Menke et al., 1961; Motz, 1975). These springs provided the base flow for Six Mile Creek, which flowed southward about 6.8 miles to join the Palm River and then flowed 1.9 mile to McKay Bay. The Palm River and Six Mile Creek were excavated to form the TBC during the period 1966 - 1982 in order to divert Hillsborough River floodwaters to McKay Bay, bypassing the cities of Temple Terrace and Tampa.

Historically, the Palm River at McKay Bay was approximately 650 feet wide, but narrowed to 200 feet above Maydell Drive. The width (USGS, 1956) at present day S-160 was 50 feet and nautical charts indicated a depth of 5.5 feet at McKay Bay and 3.5 feet at 0.5 mile (0.8 km) upstream. The width of the Palm River was increased by as much as twelve times over pre-construction and deepened. The cross section was increased as much as 100 times in some areas. Overall, the estimated post-construction volume is estimated to be 13 times greater than pre-development. Thus, for a given volume of freshwater introduced at this point, it would be approximately 10 times less effective at dilution than during pre-construction conditions. **Figure 2-2** is a photograph of the present (1999) land use illustrating recognizable landmarks and **Table 2-1** provides distances upstream of the 22nd Street Causeway. **Figure 2-3** is taken from a post card (circa 1913) and illustrates a shallow flood plain with a lightly incised and meandering riverbed.

Table 2-1
Upstream Distance of Structures

Place Name	Km Upstream
22nd St. Causeway	0.0
Palm River Begins	2.1
50th St.	3.2
Power Line / RR	3.6
Maydel Drive	5.0
CrossTown Exprwy	6.7
SR 60 / Adamo	6.9
RR	7.1
S-160	7.5
RR	8.4
Broadway	8.5
US 301	9.9
MLK Drive	10.7

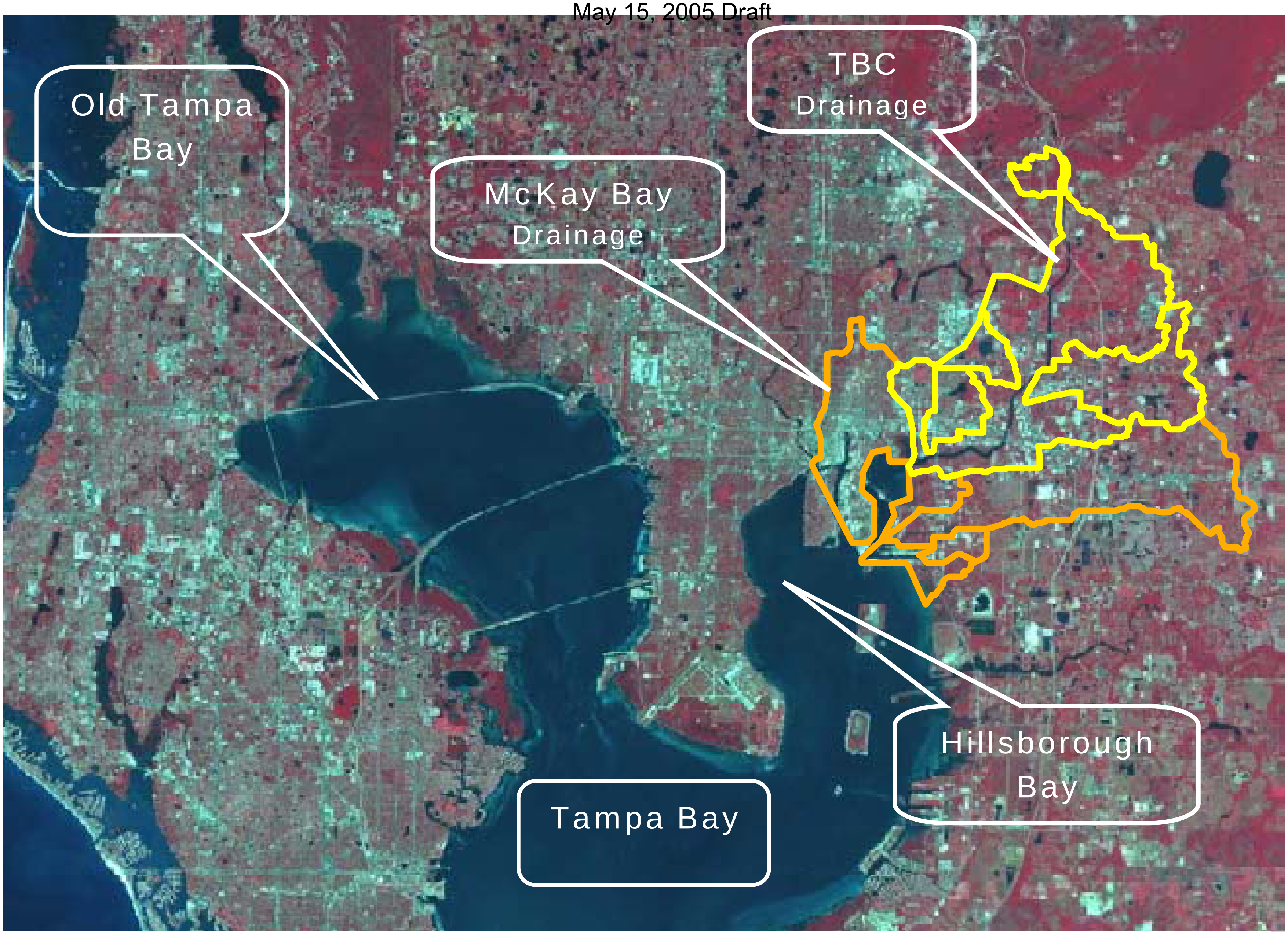


Figure 2-1 Location of McKay Bay / TBC Complex

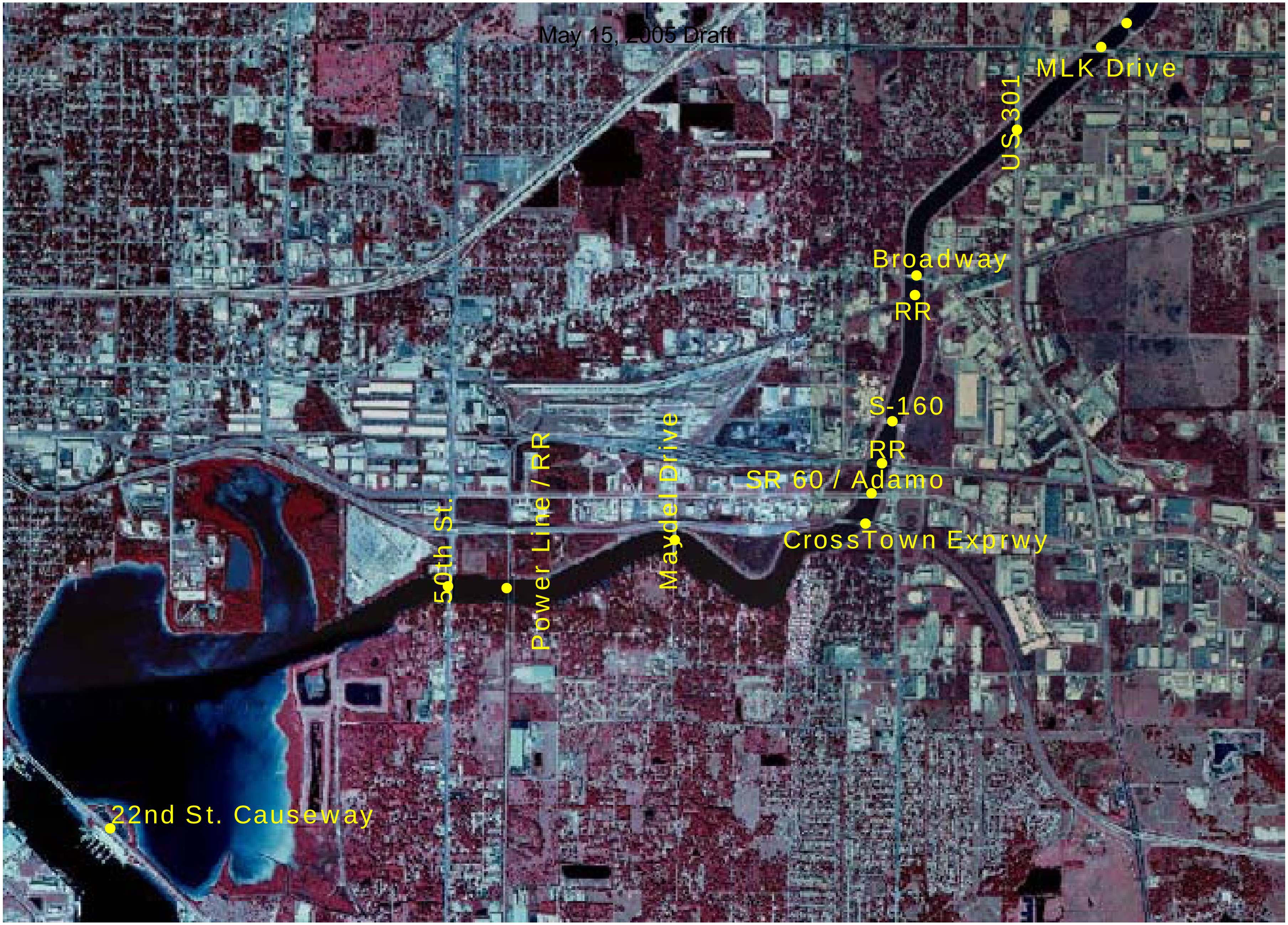


Figure 2-2 Present Land Use and Place Names

2.2 REGIONAL RAINFALL

Figure 2-3 Six Mile Creek circa 1913

Average daily rainfall in the Hillsborough/Palm River basin during 1983-2002 was estimated by calculating the mean daily rainfall from a series of long-term rainfall gages located throughout the watershed region (PBS&J, 2003a). Analyses of long-term rainfall patterns in the Hillsborough River watershed show that repeating patterns of sequential years with lower than average rainfall have occurred throughout the historic period of record (1976-1978, 1989-1991, 1999-2001). Over the 20-year period, the average yearly total was 51.6 inches for the Hillsborough River watershed. The lowest yearly total occurred in 1984 with 42.9 inches and the highest yearly total was observed in 1996 with 70.9 inches of rain over the watershed.

Long-term rainfall data shows that high monthly rainfalls commonly occur even during relatively very dry years. During periodic El Niño events, monthly rainfall totals during the typically drier months (from December to March) can be as high as those that are typically observed during a normal summer wet season. Conversely, years with relatively high total rainfalls characteristically have a number of months with low total monthly rainfall levels. Historically, the summer wet season has often started as early as late May, resulting in April being the overall driest month of the year in terms of rainfall, followed by October and November.

2.3 PALM RIVER / TAMPA BYPASS CANAL WATERSHED CHARACTERISTICS

The Palm River/Tampa Bypass Canal watershed is located in Hillsborough County, east of the City of Temple Terrace to the north and east of the COT to the south. Interstate 75 passes through the watershed in a north-south direction. The Seaboard Coastline Railroad roughly borders the watershed along its south side. The watershed is approximately 28 square miles, (18,000 acres) in size and is drained by two water bodies: the Tampa Bypass Canal (TBC) and the Harney Canal. The TBC flows in a north-south direction while the Harney Canal flows in an east-west direction in the Harney Flats area from the Hillsborough River before discharging into the middle of the TBC.

Land surface elevations range from near sea level to over 100 feet National Geodetic Vertical Datum (NGVD 1929) in the northeastern areas of the watershed. The majority of the TBC and the Harney Canal lie between elevations 0 and 25 feet NGVD. The northern section of the TBC, upstream from S-159, is between sand ridges of the City of Temple Terrace and the area south of Lake Thonotosassa. The TBC watershed is part of the Hillsborough River drainage basin, which lies in the Floridian Section of the Atlantic Coastal Plain.

The largest land use in the basin is residential at 32.1 percent. This category consists of low-, medium-, and high-density single-family housing and mobile homes. The second largest land use is agricultural at 26.3 percent (PBS&J, 2003a). The watershed is traversed by three major transportation arteries, Interstate 75, Interstate 4, and U.S. Highway 301, that make the TBC watershed a prime area for commercial, industrial, and residential development.

2.4 CONSTRUCTION OF TBC

The present TBC was constructed as an Army Corps of Engineering (ACOE) flood control project between 1967 and 1983. The Palm River and Six Mile Creek were excavated to depths of 20 feet, widened to 500 - 630 feet and armored with rip rap to divert flood waters around Temple Terrace and downtown Tampa. The project was one component of the ACOE state-wide Four River Basins drainage project that commenced following wide-spread flooding in the wake of Hurricane Donna in 1960. In 1961, the Florida legislature created SWFWMD to be the local sponsor of the Corps Four River Basins project.

Under its original concept, the project was to consist of an extensive system of flood storage reservoirs and control facilities extending south from the Green Swamp and encompassing the Oklawaha, Withlacoochee, Peace, and Hillsborough River basins. However, because of ecological and environmental considerations raised during the 1970's, the local project was condensed to the construction of the TBC (SWFWMD, 1990). The TBC extends about 14 miles from Cow House Creek in the Lower Hillsborough Flood Detection Area (LHFDA) to McKay Bay at the mouth of the Palm River.

Land acquisition along the canal right-of-way occupied early phases of the project. The initial phase of construction, begun in mid-1966 and completed in January of 1969, consisted of enlarging the natural channel of the Palm River to its confluence with McKay Bay and constructing S-160 (SWFWMD, 1990). Structure S-160 was completed in 1969 (**Table 2-2** and **Figure 2-4**). Since 1970, channelization has extended Six Mile Creek west and north to intersect the Hillsborough River at two points: the confluence of Trout Creek and near the midpoint of the Tampa Reservoir. Flow at the control structures is regulated by manipulation of vertical lift gates and slide gates (USGS, 1983).

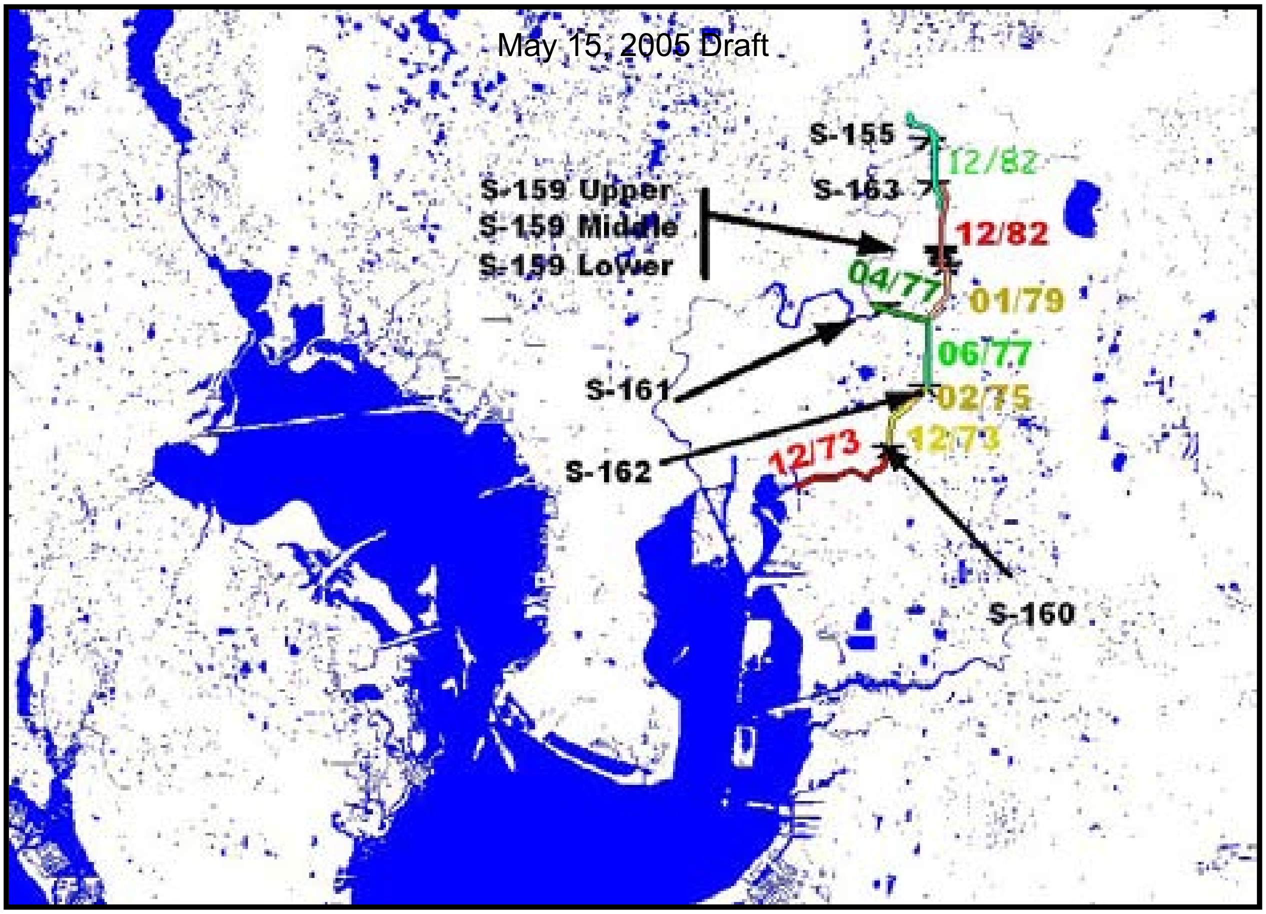


Figure 2-4 TBC Construction Completion Dates

Structures S-162 and S-159 are primarily used to minimize the TBC impact on the regional hydrology, particularly in the Harney Flats area. The TBC is made up of two canals; the Harney Canal (C-136) that runs from the Tampa Reservoir to join the second and longer canal, C-135, which connects the Hillsborough River at Trout Creek to the Palm River (SWFWMD, 1999).

The canal is divided into three principal pools: the upper, middle, and lower pools. The TBC pools are separated by flow control structures. Each structure consists of multiple vertical lift gates that seat on the crest of a weir. A collection of overflow weirs is located at the top of each lift gate to control the upstream pool stage during low and moderate flows. TBC bottom widths and elevations range from 400 feet at elevation –21.0 feet NGVD (1929) near McKay Bay to 200 feet at elevation 16.0 feet NGVD at Cow House Creek.

Structure 155, located on the Hillsborough River upstream of Fletcher Avenue, and Structure 163 on Cow House Creek control the flow into the upper pool. Closing Structure 155 causes water to back up into the LHFDA and flow into the TBC upper pool. Flow can also enter the upper pool from Cow House Creek. This flow, controlled by Structure 163, may back up into the LHFDA if Structure 159 is closed. The middle pool consists of the main channel and a reach called the Harney Canal. Structure 162 controls flow from the middle to the lower pool. At the downstream end of the lower pool, Structure 160 controls the flow into the remains of the Palm River and finally into McKay Bay (SWFWMD, 1999).

The Harney Canal, at 9,000 feet in length, connects the TBC middle pool to the COT's surface water reservoir on the Hillsborough River. Structure 161 is located near the confluence of the Harney Canal and Hillsborough River and controls flow from the reservoir during flooding. A pump station is located at S-161, which is used to augment the reservoir for the COT water supply. Hillsborough River flow can be diverted to the upper pool as water supply augmentation for Tampa Bay Water (TBW) through the control structure.

One construction artifact of significance is an elevated sill located where the US-41 bridge (50^{TH} St.) crosses the canal (km 3.2). The ACOE, fearful of undermining the bridge pilings, did not dredge close to the bridge leaving a physical sill that acts like a hydraulic barrier and traps deeper water upstream.

Table 2-2
Construction History of the TBC

Item	ID	Start Date	Completion Date
Canal	1A	May-66	Aug-67
Control Structure	S-160	May-67	Jan-69
Canal	1B	Apr-68	Jul-72
Canal	1C & 2	Nov-70	Dec-73
Canal	3A	Nov-72	Feb-75
Canal	3B	Feb-75	Jun-77
Control Structure	S-162	Apr-75	Mar-77
Canal	C-136	Jun-75	Apr-77
Control Structure	S-161	Jun-75	Nov-77
Canal	4A	Mar-76	Jan-79
Canal	4B	Jan-77	Dec-82
Levee	L-112 (South)	Jan-77	Dec-82
Control Structure	S-155	Apr-78	Nov-82
Control Structure	S-163	Apr-78	Nov-82
Levee	L-112 (North)	Apr-78	Nov-82
Control Structure	S-159 Middle	Mar-79	Aug-81
Control Structure	S-159 Lower	Mar-79	Aug-81
Control Structure	S-159 Upper	Jun-79	Nov-82

After Bacelo, 1985

The TBC can carry 12,000 cfs from the LHFDA for a combined total of 16,000 cfs at S-162. The lower pool, constructed in the channels of Six Mile Creek and Palm River, was designed to direct a maximum flow of 26,700 cfs. Besides controlling water levels, S-160 acts as a physical barrier and prevents the upstream migration of saline water from McKay Bay.

During construction of the TBC, a breach occurred to the underlying Upper Floridan Aquifer System at several locations. The breach resulted in a hydraulic connection between the Canal and the Floridan Aquifer and an exchange of water between the two systems

(Geraghty and Miller, Inc., 1982). This was predicted to produce considerable drainage from the aquifer and drawdown over a large area. Because of this, the District suggested, and the ACOE approved, the inclusion of an additional control structure (S-162) near the S.R. 574A Bridge over the TBC. The most severe impacts would have occurred in the Harney Flats – Eureka Springs section, where the potentiometric surface stood 8 to 10 feet above the design pool elevation. Whereas structure S-160 alone was intended to maintain a pool elevation of 10 feet above mean sea level, the additional structure (S-162) was designed to maintain a 12-15 feet above mean sea level pool level upstream to S-159 (SWFWMD, 1990).

A digital model-based study by USGS suggested that the total area within which the drop in the potentiometric surface would have been one foot or greater would be reduced from 48 to 24 square miles as a result of adding S-162 (Motz, 1975). Subsequently (Knutilla and Corral. 1984) the USGS showed that construction of the TBC had increased base flow by 1.5 to 2 times pre-construction values in the vicinity of Structure 160.

Construction of the TBC affected groundwater inflows and outflows to the Tampa Reservoir and the frequency of zero-discharge days. The breach of the Upper Floridan Aquifer System has increased groundwater inflow to the canal by approximately 31 cfs (20 mgd) (Knutilla and Corral, 1984). However, the fraction of this flow that originated in the vicinity of the Tampa Reservoir has not been quantified. Augmentation of the reservoir with water from the TBC since the mid 1980s has returned some or all of the water lost by increased groundwater seepage from the reservoir.

The canal system first operated for flood control purposes in September 1985, when Hurricane Elena stalled off the central Florida Gulf Coast. A storm in March 1987 marked the first time water was diverted from the Hillsborough River to the TBC system via the Harney Canal (C-136) (Water & Air Research, Inc., 1988). The system was operated twice during 1988 including the landfall of Tropical Storm Keith (SWFWMD, 1990). More recently, the system was operated at thirty-seven percent capacity during back-to-back hurricanes in the summer of 2004 when 10,000 cfs were discharged through S –160.

2.5 HYDROLOGY ABOVE S-160

n addition to the TBC drainage above S-160, there is an additional 13 square miles of ungaged drainage to the TBC and an additional 33 square miles which drain directly to McKay Bay as illustrated in **Figure 2-5** and summarized in **Table 2-3**. Of historical and hydrologic significance is the fact that that the 28 square mile watershed above S-160 in 1960 is now hydraulically connected to a watershed in excess of 630 square miles through the Harney Canal and structure S-161. Prior to construction of the TBC, the USGS maintained a gage (0231800) on Six Mile Creek at the present location of S-160 from 1957 until 1997, but no records exist for the period October 1974 until November of 1985.

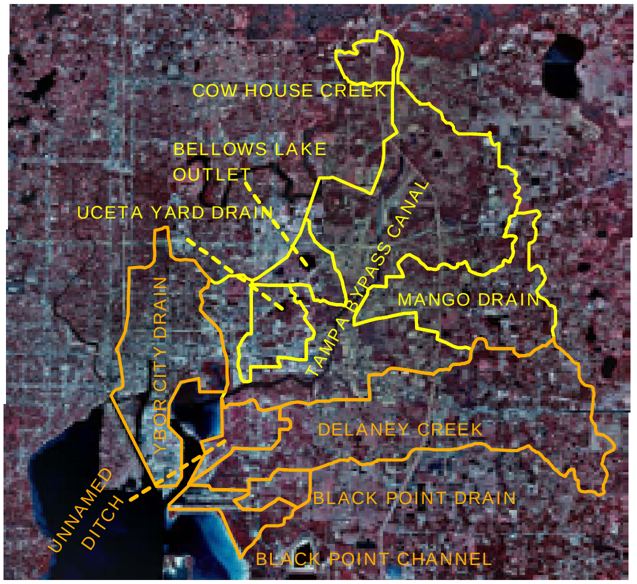


Figure 2-5 McKay Bay / TBC Drainage Basins

From October 1974 to June 1990, the USGS estimated flows (0231802) at a point slightly upstream of S-160 based on canal stage and gate operation records provided by the District. Since then, the District has estimated flow. Uncertainties exist in the estimated flows because the weir equations used to calculate flow have never been field calibrated and past structure operations records are poor (SWFWMD, 1999) and often the flow calculated at the upstream site is greater than at the downstream S-160 gage site. It is also likely that the flows measured at this point were affected by various upstream dredging and de-watering activities throughout the construction period.

In August 2002, TBW assumed the responsibility of operating the structures on the TBC except for flood control events. At the same time, TBW reconstructed what is generally accepted as the best estimate of S-160 discharges from 1974 to present. A fundamental hydrologic question is whether McKay Bay is receiving more, or less freshwater compared to pre-TBC conditions. On one hand, there is a potential for huge increases through the Harney Canal, but there have also been significant withdrawals and diversion to the Hillsborough reservoir.

Table 2-3
TBC/McKay Bay Drainage Areas

Sub-Basin	Drainage Area (mi^2)	Receiving Water
Tampa Bypass Canal	25.6	TBC
Uceta Yard Drain	2.8	TBC
Bellows Lake Outlet	2.0	TBC
Mango Drain	8.3	TBC
Ybor City Drain	9.7	McKay Bay
Delany Creek	18.4	McKay Bay
Black Point Channel	2.0	McKay Bay
Black Point Drain	1.2	McKay Bay
Unnamed Ditch	2.0	McKay Bay
Hillsborough River @ Fowler Avenue	630	Reservoir or TBC via Harney Canal

In order to characterize the change in rainfall/runoff response at S-160, the flow record for calendar years 1957 through 2001 was normalized to annual inches of runoff, (assuming the original 28 mi^2 watershed for consistency) and compared to similar sized watersheds in Tampa Bay. A list of watersheds used is given in **Table 2-4** provides the drainage area and period of record. **Figure 2-6** compares pre-1983 runoff at S-160 with post-1983 runoff and with surrounding watersheds. Figure 2-6 indicates that small, regional watersheds in the area averaged 13 inches of streamflow over the period of record. Six Mile Creek, because of additional spring flow was historically larger. However, since 1983, sixteen of the twenty annual yields at S-160 have exceeded 30 inches/year and the average for the decade ending in 2001 was 44 inches.

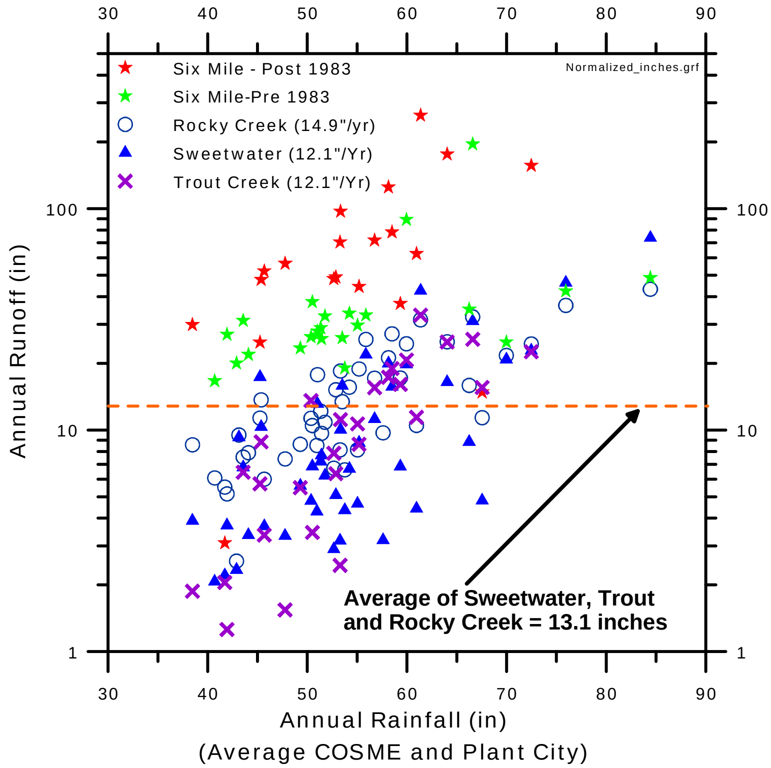


Figure 2-6 Regional Runoff/Rainfall Relationships (1957-2001)

It should be noted that these are "net" changes at S-160 after considering the increased groundwater input (~ 15 in/yr) , flood contol discharges and the diversions/withdrawals for water supply. Nevertheless, the results suggest that on average McKay Bay is probably receiving twice as much freshwater as it did historically and that this water is delivered through a conveyance that is approximately 10 times [See Section 2.0] larger than pre-construction. Yet, as will be subsequently discussed, the McKay Bay/Palm River system remains a moderately high-saline environment because the increase in conveyance efficiency works both ways and allows saline water from Tampa Bay to migrate upstream.

The rainfall/runoff comparison includes the impact of two extreme rainfall periods. The 1991-2001 decade included an extended 4-year drought with an estimated return interval in excess of 86 years as well as an El Niño event during 1997-98. **Figure 2-7** provides the mean and median annual discharge along with the annual average rainfall derived from the daily average of the Plant City gage (District RNF #259) and COSME gage (District RNF # 197). While there are presently gages within the watershed, these are the closest long-term gages (circa 1950-present) and are approximately equidistant to the watershed.

Table 2-4
Gage Sites Comparable to S-160

Gage Name	USGS #	Period of Record	Drainage Area (mi^2)
Six Mile Creek	2301800	1957-1997	28
Rocky Creek	2307000	1953-Present	35
Trout Creek	2303350	1974-Present	23
Sweetwater Creek	2306500	1951-Present	7.4

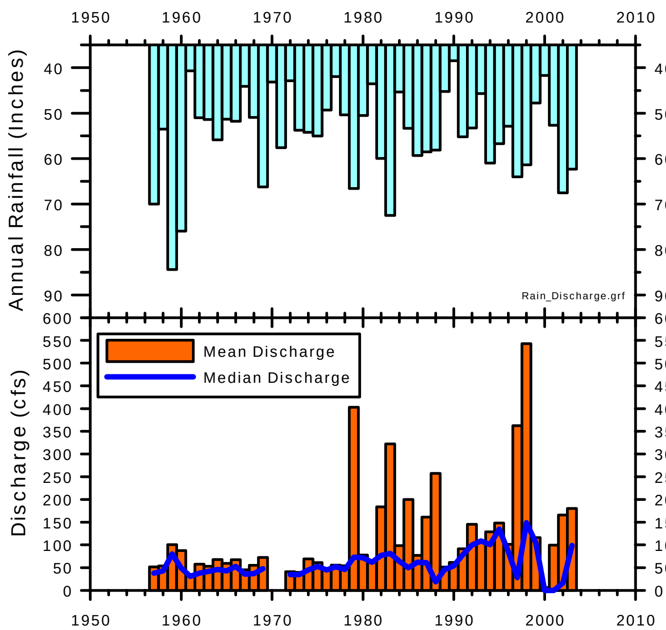


Figure 2-7 Historical Rainfall and Discharge for S-160

2.6 HYDROLOGY BELOW S-160

Freshwater discharge from the watershed above S-160 is controlled through operation of vertical lift gates (**Figure 2-8**). Additional freshwater enters the Palm River/McKay Bay system as ungaged runoff and groundwater, and as point source discharges. Ungaged flows downstream of S-160 were estimated by HSW (2004) from rainfall/runoff and rainfall/baseflow regressions developed from model results produced by an integrated groundwater/surface water model.

Point source discharge data were obtained as monthly averages from FDEP (Kevin Petrus, personal communication) and Janicki Environmental Inc. (Keith Hackett, personal communication). One of the discharges is from a domestic wastewater treatment facility (Faulkenburg Road AWT- FL0040614) operated by Hillsborough County and discharging an average (1985-2003) of 4.3 cfs (2.8 mgd) through a submerged discharge just below S-160. The second point source discharge is an industrial discharge from Trademark Nitrogen Corporation (FL0000647). This discharge averaged 0.14 cfs (0.09 mgd) for the same period and enters the Palm River through an unnamed ditch. For comparison, the discharge from S-160 averaged 158 cfs (102 mgd) for the same period.

The relative contribution of each source to McKay Bay is illustrated in **Figure 2-9.** Generally the contribution discharges through S-160 dominates the freshwater inputs, but during the drought conditions of 1999-2001 the downstream ungaged flow and the point source discharges constituted an average of sixty- eight percent of the total flow.

Figure 2-8 S-160 Lift Gates

The salinity in McKay Bay / TBC is the result of localized freshwater inflows and the salinity of the upper Hillsborough Bay which serves as a sort of boundary condition for TBC. It is therefore informative to compare the relative contribution of freshwater flows to upper

Hillsborough Bay near East Bay. Hillsborough Bay receives inflow from the Hillsborough River system, Alafia and the McKay Bay/TBC complex.

A first order approximation of flow from the Hillsborough River (USGS, 2004) was developed from reservoir release records (USGS # 2304500) plus an estimate of contribution from below the reservoir. A normalized yield (cfs/mi^2) was derived from the USGS gage upstream of the reservoir at Morris Bridge Road (USGS 23033330@375 mi^2) and applied to the 43 square mile drainage area below the reservoir. (It is recognized that the normalized yield is an underestimate for the highly urbanized areas downstream of the reservoir, but the assumption is considered adequate for a gross comparison of flow contributed to upper Hillsborough Bay.)

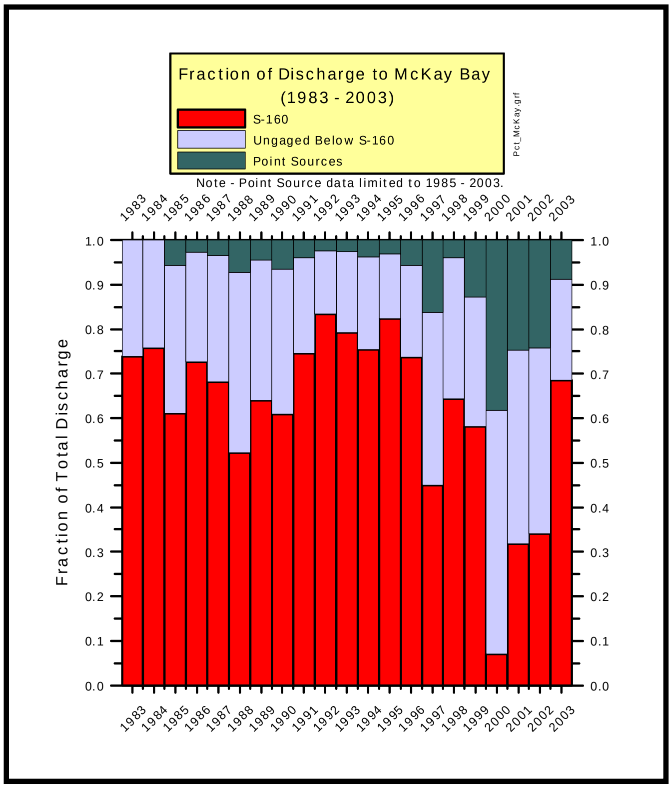


Figure 2-9 Relative Contribution of Freshwater to McKay Bay. Annual Average 1983-2003

The results are given in **Figure 2-10** and indicate that the boundary salinity in upper Hillsborough Bay is affected as much by the Hillsborough reservoir discharges and downstream flow as it is from the McKay Bay/TBC complex. On average (1983-2003) forty-four percent of the flow originates in the Hillsborough basin and fifty-six percent from the McKay Bay/TBC basin. Discharge from S-160 represents only thirty-two percent of all water discharging into upper Hillsborough Bay. Thus, from a resource management perspective, the S-160 discharge / salinity response is less direct because of the other freshwater sources affecting the boundary salinity.

2.7 EXISTING TBC WATER USERS

Presently the COT and TBW are permitted to withdraw water from the TBC for water supply. The COT was historically depended on four sources to meet water supply demands: the Tampa Reservoir, the Morris Bridge well field, the TBC, and Sulphur Springs. The COT's history of water use begins 1920 with the Tampa reservoir (an impoundment of the Hillsborough River near present day Rowlett Park). The first full year of recorded withdrawals from the Hillsborough reservoir was 1946 when 23 cfs (15 mgd) were withdrawn. Demand continuously increased and in 1985, the COT began to augment the reservoir from the TBC via the Harney Canal (SWFWMD, 1999). For the

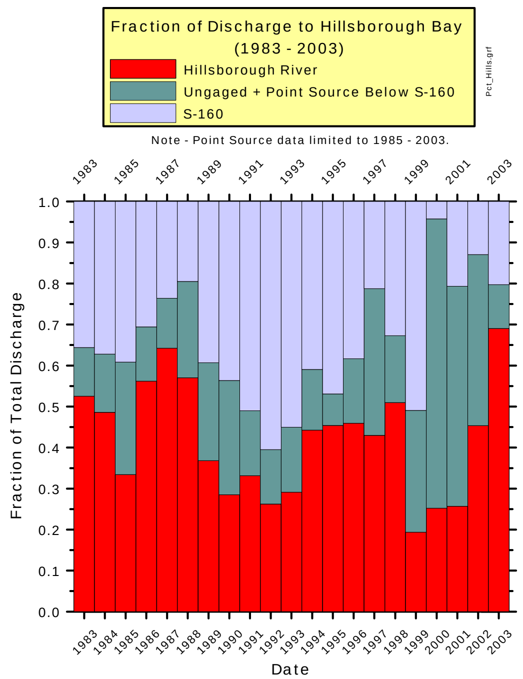


Figure 2-10 Relative Contribution of Freshwater to Upper Hillsborough Bay. Annual Average 1983-2003.

period 1985 through 2003, augmentation from the TBC by the COT has averaged 12.4 cfs (8.0 mgd), with daily peaks as high as 70 cfs (45 mgd).

Withdrawals from the TBC are regulated by augmentation schedules that are based on water levels in the Tampa Reservoir and Hillsborough River flows at Morris Bridge Road. A joint water use permit was issued to the COT and the West Coast Regional Water Supply Authority (WCRWSA, now Tampa Bay Water formed in 1998) in 1990 for withdrawals from the TBC. The permit established that augmentation from the TBC would not occur until water levels in the reservoir recede to 21.0 feet NGVD during the months of March through June, or to 19.0 feet NGVD during the months of July through February. To maintain the stability of Structure 161, withdrawals for augmentation would also not be allowed when water levels in the middle pool, including Harney Canal, are below 12.0 feet NGVD. Augmentation would also not be allowed when water levels in the Tampa Reservoir are above 22.5 feet NGVD, which is full reservoir stage. In addition to these limitations, provisions required additional "mitigation" augmentation from the TBC when withdrawals from the reservoir exceeded 96 cfs (62 mgd) during periods of low flow at the Hillsborough River Dam (SWFWMD, 1999).

In 1993, upon request from the WCRWSA and the COT, the District modified the joint water use permit so that augmentation from the TBC could occur when water levels in the reservoir recede to 21.0 feet NGVD on a year-round basis. Also, in response to the City and WCRWSA's request, the permit was modified so that augmentation would cease when water levels in the reservoir recovered to 22.0 feet NGVD (SWFWMD, 1999).

Table 2-5
Tampa Bay Water Permit Limits

TAMPA BYPASS WITHDRAWAL SCHEDULE

S-160 flow	Withdrawal Rate
< 7 mgd (11cfs)	0
7 – 35 mgd (11-54 cfs)	Excess above 7 mgd
35 – 81 mgd (54-125 cfs)	80% of total flow
> 81 mgd	65 mgd (100cfs)

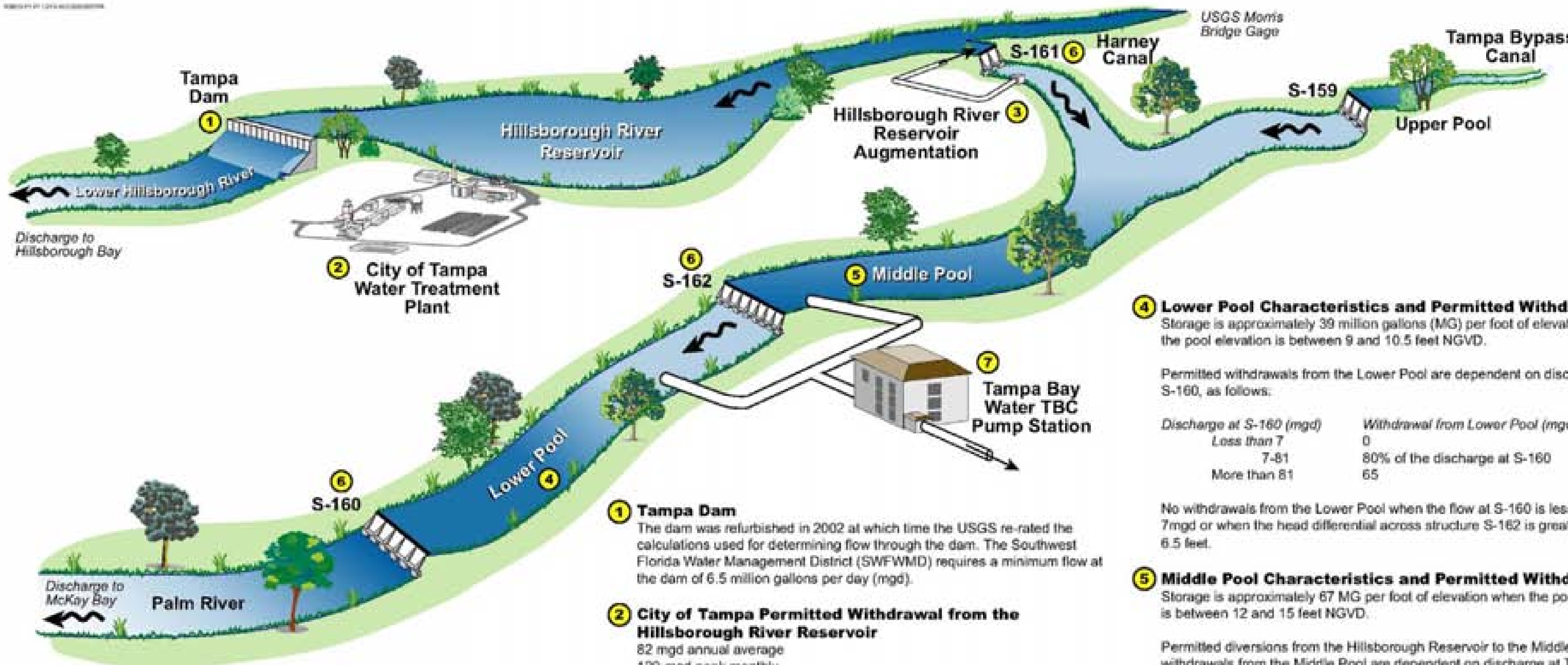
In November 1996, the District authorized the WCRWSA/COT to implement a trial schedule that would allow augmentation from the TBC anytime water levels in the reservoir fell below 22.5 feet NGVD. This schedule was formally adopted in the water use permit for augmenting the reservoir with water from the canal. Prior to 1999, the TBC was generally used to augment the Hillsborough Reservoir for short periods during the dry season months of April, May, June, and December (SWFWMD, 1999). **Figure 2-11** (reproduced with permission from TBW) illustrates the complex nature of these permits.

The current WUP allows TBW to both divert water to the TBC from the Hillsborough River and to withdraw water from the Middle and Lower pools of the TBC (Table 2-5). Diversion began in August 2002. During the period that COT transfers have occurred (1985 through 2003), TBW has diverted an average of 4.5 cfs (2.9 mgd) to the TBC for water supply from the Hillsborough River above the reservoir. Of this water, TBW has removed an average 2.8 cfs (1.8 mgd) from the middle pool and 1 cfs (0.6 mgd) from the lower pool during this period. Not all of the water transferred to the TBC for water supply has been withdrawn. Thus, the observed discharge at S-160 is at times augmented with water diverted from the Hillsborough River and baseline conditions will reflect a lower discharge than measured. These conditions are illustrated in **Table 2-6** which provides a portion of the water balance for a15-day period in September 2003. During this period, the measured discharge at S-160 was 42 percent augmented with water from the Hillsborough Reservoir.

TBC withdrawals by TBW occur from a pumping station located canal-side near the Dr. Martin Luther King Jr. Boulevard at S-162. Intakes above and below S-162 terminate at the pump station, allowing withdrawal for one or both sides of the control structure. The Tampa Bay Water's WUP application for the TBC anticipated withdrawing water up to a maximum of 100 cfs (65 mgd), with withdrawals beginning when the flow in the TBC is 11 cfs (7 mgd). Because of concerns about the effect of reduced freshwater inflow to the Tampa Bay system from additional freshwater withdrawals, the EPCHC and Hillsborough County filed for arbitration on this project in October 1998. This arbitration was resolved, which allowed for the permitting and construction to proceed. The regional water plant was completed in September 2002.

2.8 BASELINE FLOWS

As described in Chapter 1.6, for purposes of the present evaluation the baseline flow at S-160 is defined as the flow that would have existed between 1983 and 2003 in the absence of water supply manipulation. **Figure 2-12** presents a cumulative distribution function of observed flows (S1) at S-160 and the flows that would have existed (S2) without water supply while companion **Table 2-7** provides select percentile flows for each.



1 Tampa Dam
The dam was refurbished in 2002 at which time the USGS re-rated the calculations used for determining flow through the dam. The Southwest Florida Water Management District (SWFWMD) requires a minimum flow at the dam of 6.5 million gallons per day (mgd).

2 City of Tampa Permitted Withdrawal from the Hillsborough River Reservoir
82 mgd annual average
120 mgd peak monthly
120 mgd peak daily

3 Tampa Bay Water Permitted Augmentation of the Hillsborough River Reservoir from the Tampa Bypass Canal Middle Pool (Harney Canal)

20 mgd annual average
40 mgd peak monthly

Augmentation starts when the reservoir elevation at the Tampa Dam is less than 22.5 feet National Geodetic Vertical Datum (NGVD) ***and*** flow of the Hillsborough River at the USGS Morris Bridge Road gage is less than the City of Tampa's withdrawal from the reservoir.

Augmentation stops when the ***one*** of the following conditions exists:
- the elevation of the Middle Pool is less than or equal to 12 feet NGVD
- the head differential across structure S-161 (upstream elevation minus downstream elevation) is greater than or equal to 10 feet
- the elevation of the reservoir at the Tampa Dam is greater than or equal to 22.5 feet NGVD or the flow of the Hillsborough River at the USGS Morris Bridge Road gage is greater than the City of Tampa's withdrawal from the reservoir.

4 Lower Pool Characteristics and Permitted Withdrawals
Storage is approximately 39 million gallons (MG) per foot of elevation when the pool elevation is between 9 and 10.5 feet NGVD.

Permitted withdrawals from the Lower Pool are dependent on discharge at S-160, as follows:

Discharge at S-160 (mgd)	*Withdrawal from Lower Pool (mgd)*
Less than 7	0
7-81	80% of the discharge at S-160
More than 81	65

No withdrawals from the Lower Pool when the flow at S-160 is less than 7mgd or when the head differential across structure S-162 is greater than 6.5 feet.

5 Middle Pool Characteristics and Permitted Withdrawals
Storage is approximately 67 MG per foot of elevation when the pool elevation is between 12 and 15 feet NGVD.

Permitted diversions from the Hillsborough Reservoir to the Middle Pool and withdrawals from the Middle Pool are dependent on discharge at Tampa Dam, as follows:

Discharge at Tampa Dam (mgd)	*Withdrawal from Middle Pool (mgd)*
Less than 65	0
65-97	10% of the discharge at Tampa Dam
97-139	10-30% of the discharge
139-647	30% of the discharge
More than 647	194

No withdrawals from the Middle Pool at the Tampa Bay Water Pump Station when the elevation of the Middle Pool is less than or equal to 12.5 feet NGVD or if the head differential across structure S-161 is greater than 9.5 feet.

6 Automated Slide Gates
Tampa Bay Water operates certain slide gates at structures S-160, S-161 and S-162 in accordance with the Tampa Bypass Canal Coordination Plan 2002. The SWFWMD retains the responsibility of operating the main gates at these structures during periods of high flow.

7 TBC Pump Station
Maximum capacity of the Tampa Bypass Canal Pump Station is approximately 150 mgd.

Hillsborough River/Tampa Bypass Canal portion of the Tampa Bay Water Enhanced Surface Water System

TAMPA BAY WATER
Supplying Water To The Region

December 2004

Figure 3 – 11 (Reproduced with Permission, TBW)
TBC / Hillsborough Reservoir Permitted Withdrawals

Table 2-6
Example of TBC Augmentation from Hillsborough Reservoir (cfs)

Date	S-160 Measured	Lower Pool Withdrawals	Middle Pool Withdrawals	Net Diversion From Reservoir Into TBC	Baseline Flow @ S-160 if No Withdrawals or Diversions
09/15/03	127.3	0.0	58.0	115.4	69.9
09/16/03	149.0	0.0	47.1	110.3	85.8
09/17/03	120.7	0.0	77.3	102.7	95.3
09/18/03	102.8	21.0	69.7	112.2	81.3
09/19/03	121.6	3.4	83.2	115.0	93.2
09/20/03	152.9	0.0	70.6	112.5	111.0
09/21/03	146.7	0.0	65.8	112.3	100.2
09/22/03	143.8	0.0	48.3	115.1	77.0
09/23/03	127.8	0.0	73.3	115.9	85.2
09/24/03	171.2	0.0	8.5	120.9	58.8
09/25/03	172.2	0.0	49.9	85.4	136.7
09/26/03	158.8	0.0	65.4	107.6	116.6
09/27/03	155.7	0.0	50.5	115.5	90.7
09/28/03	135.8	16.7	57.5	118.3	91.6
09/29/03	167.3	0.0	64.5	82.7	149.2
09/30/03	90.1	28.6	29.5	29.9	118.2

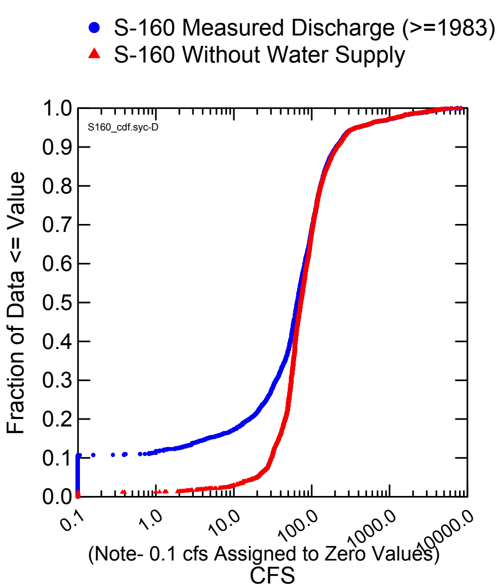


Figure 2-12 S-160 Flows - Measured (S1) and Baseline (S2)

Table 2-7
Percentile Flows (cfs) @ S160
S1=Observed, S2= Baseline

Percentile	S1	S2
1%	0	0
5%	0	20
10%	0	30
20%	16	45
30%	35	55
40%	54	61
50%	65	72
60%	82	86
70%	103	104
80%	130	130
90%	206	209
95%	386	390
99%	3011	3023

2.9 PERTINENT REPORTS AND SOURCES OF ENVIRONMENTAL DATA

Throughout the years, a number of environmental sampling and reporting efforts have included McKay Bay/TBC in the larger context of the Tampa Bay region, or have focused directly on the McKay Bay/ TBC complex. For example, the Environmental Protection Commission Hillsborough County (EPCHC) has sampled water quality at three stations in McKay Bay/TBC since 1974 but those stations were part of a suite of 154 regularly sampled ambient stations throughout the Tampa Bay region. In contrast, PBS&J is presently engaged in an intense monitoring effort of the TBC that began in 2000 as a condition of the TBW water use permit (WUP). For most reports, agencies have combined data from other sources for evaluation. This section identifies and summarizes both the sources of environmental data pertinent TBC and the major conclusions of prior reports.

2.10 TAMPA BAY NATIONAL ESTUARY PROGRAM – MINIMUM FLOWS ADVISORY GROUP

In 1996, the District requested that the Tampa Bay National Estuary Program (now Tampa Bay Estuary Program, TBEP) convene a technical advisory group to provide suggestions for ecological criteria suitable for setting minimum flows in the lower Hillsborough and the McKay Bay/TBC complex. The group met for eight months and issued the following summary statements (TBEP, 1997) pertaining to the TBC:

- The salinity gradient should be complete (zero to greater than 18 ppt)
- The number of fish species and abundances are reduced when DO falls below 4 mg/l.
- TBC below structure 160 (S-160) offers minimum opportunity for vegetation under its present condition.
- Maintaining a complete salinity gradient and meeting the dissolved oxygen (DO) criteria/goals may not be feasible using flow management on the Palm River/TBC
- Analytical tools used to predict salinity and DO were limited due to the lack of low-flow (1-30 cubic feet per second) data.
- Minimum flows on the Palm River/TBC should be set based on existing physical conditions, but should be re-evaluated if habitat restoration (e.g. filling of dredge hole, littoral zone habitat restoration on public lands) is completed.

2.11 PREVIOUS MINIMUM FLOWS AND LEVELS REPORT FOR THE TAMPA BYPASS CANAL

In 1996, amendments to the MFL (Section 373.042, F.S.) statute required that the District adopt minimum flows and levels for Hillsborough, Pasco, and Pinellas County for priority waters that are experiencing or may be expected to experience adverse impacts. In response to this legislative direction, the District established 41 minimum wetland levels, minimum levels for 15 lakes, seawater intrusion aquifer levels, narrative aquifer levels, and a minimum flow for the Tampa Bypass Canal (SWFWMD, 1999).

Section 373.042, F.S., required the District to use the best available data to set minimum flows and levels. The legislature required MFLs to be set by October 1, 1997; and therefore, there was a limited time to collect additional information. Because of this deadline, the District was constrained to use existing and limited data (SWFWMD, 1999).

The process to develop the methods for determining minimum flows and levels was an open public process. Interested parties were invited to participate in the developing of methodologies to determine the limit at which significant harm occurs to the lakes, wetlands, surface watercourses, and aquifers. Following this public process, District staff finalized methodologies and minimum levels and flows for approval by the Governing Board. However, effective July 1, 1997, subparagraph 373.042 (1)(a), F.S., was added, which directed the District to consider changes and structural alterations to watersheds, surface waters, and aquifers and the effects of such changes and alterations. At the Board's direction, staff reviewed the previous work, additional data, and 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 assimilated into the methodologies (SWFWMD, 1999).

On October 28, 1998, the Governing Board approved the subject minimum flows and levels. The determination of minimum flows for the TBC took into consideration the extensive changes and structural alterations of the system. The width, depth, and volume of the TBC are much greater than the previous Six Mile Creek and Palm River that were excavated to form the canal. These physical changes have greatly altered the hydrographic, water quality, and ecological characteristics of the estuarine resources associated with the former Palm River. Construction of the canal also altered surface water/groundwater interactions in the vicinity as well as the quantities of fresh water contributed from the local drainage basin to the tidal receiving waters.

Accounting for these changes, the District evaluated the effects of various rates of freshwater flow from Structure 160 on salinity distributions, water quality and biological communities in the present day Palm River/McKay Bay estuarine system. Because of unique physical characteristics of the Tampa Bypass Canal and its primary use for flood control, the District did not evaluate ecological changes that could result from withdrawals over the entire flow range of this system. Instead, the District examined flow releases that should be maintained during dry periods to sustain the downstream estuary. Such regulations would require reductions in water use from the canal if the minimum flows were not being met. The District concluded (SWFWMD, 1999) that the minimum flow at Structure 160 could be zero, stating there was not a logical rate of flow that should be maintained at Structure 160 and flows at the structure can periodically recede to zero cfs without requiring cutbacks in water use.

The District stated this did not imply that flows at Structure 160 should be maintained at zero cfs indefinitely, as historical streamflow and water use data from the canal indicated that zero flow at Structure 160 would occur only periodically when the canal was used to augment water supplies in the Hillsborough River Reservoir, which was the sole water use from the canal at the time of the 1999 report. Furthermore, the District stated that language in the proposed rule did not mean all waters discharging from the Tampa Bypass Canal above zero cfs are automatically available for withdrawal, as the allocation of water from the canal may be subjected to further technical analyses and regulatory restrictions on withdrawal quantities in order to protect natural resources.

The Palm River and McKay Bay system, in their current configuration, represent the "baseline" from which "significant harm" is to be determined. The District concluded that the existing alterations of the Palm River resulted in a truncated estuary that is relatively insensitive to freshwater flow at S-160. Moreover, the District concluded that even though this system has substantial habitat limitations, a minimum flow of zero cubic feet per second (cfs) would not significantly alter the existing habitat quality or biological communities using that habitat. According to the District, a minimum flow of zero cfs would not result in a significant change from the existing baseline conditions in the Palm River/McKay Bay system (SWFWMD, 1999).

2.12 PEER REVIEW

In October 1998, the District proposed minimum flows and levels for the Tampa Bypass Canal. Prior to formal rule adoption of the TBC MFL, a peer review was requested by Hillsborough County, the Hillsborough County Environmental Protection Commission, Pinellas County, Tampa Bay Water, and the Environmental Confederation of Southwest Florida. An independent scientific peer review panel (Panel) assembled, which was composed of recognized experts in the fields of estuarine biology/ecology, groundwater hydrology, hydrology, hydrogeology, limnology, and wetland biology/ecology (Bedient et al., 1999).

The Panel was directed to evaluate previous data and the methods used by the District for proposing each MFL and to determine whether the methodology was scientifically reasonable by evaluating the scientific and technical analyses used by the District to develop the MFL (Bedient et al., 1999).

On the surface, the analyses conducted by the District appeared to support this position. However, the Panel did not feel that the available data and the empirical approach taken provided an adequate basis for setting a Minimum Flow of zero at the time of the decision. The Panel reported that *' . . . . the most significant discrepancy is that the District assumes that it can set a Minimum Flow of zero without giving full consideration to the frequency or duration of zero flow periods'*. Thus, the panel felt that the Minimum Flow for the TBC was not supported by the data (Bedient et al., 1999).

The Panel was charged with specific tasks to determine if the data and analyses conducted by the District supported the District's decision. These include: (1) Summarize methodology used to establish MFL; (2) Evaluate scientific reasonableness; (3) Evaluate deficiencies; and (4) Evaluate preferred methodologies.

The Panel concluded that the majority of sources, especially those cited and used directly by the District (SWFWMD, 1999) were found to be highly reliable. The information utilized by the District for calculations, comparisons, and report findings were generally based on sound methodologies. The Panel also concluded that sufficient quality assurance assessments were performed on source data and specific data results were often repeated by independent sources with consistent results (Bedient et al., 1999).

Based on the Panel's review of the available information, it appeared that the District had considered most of the applicable information sources in its analysis. However, the "best information available" was only as of July 1997, and most of the reports made reference to the need for a more in-depth analysis to provide a greater number of sampling points to support the conclusions. These studies also had minimal data of either water quality or ecological function based on flows at or near the District's proposed zero Minimum Flow.

2.12.1 Peer Review -Technical Assumptions

The Panel discussed several basic flaws in the technical assumptions presented in the District's TBC analysis (SWFWD, 1999). In the Panel's opinion, the most significant discrepancy was that the District assumed that it could set a Minimum Flow of zero without giving full consideration to the frequency or duration of zero flow periods. The frequency and duration are critical factors in determining the impact of a Minimum Flow on the biological resources in the Palm River/McKay Bay system. However, the proposed Minimum Flow provided no constraints on the duration or frequency of zero flow periods (Bedient et al., 1999).

2.12.2 Peer Review – Analysis of Procedures

In the technical analysis, the District evaluated the relationship between rates of freshwater discharge at S-160 to a number of physical, chemical, and biological parameters measured in the Palm River/McKay Bay system. The Panel described several major flaws in this analysis. First, the data sets were substantially limited and did not provide an adequate basis for the conclusions presented in this analysis. Second, the statistics in the District's analysis did not provide a basis for accurately predicting the effects of zero flow conditions on the water quality or biota of the Palm River/McKay Bay system. Finally, the District failed to consider the effects of the frequency and duration of zero flow periods on the water quality or biota on the Palm River/McKay Bay system (Bedient et al., 1999). In essence, while the Panel acknowledged that the District had used the 'best available data'. The Panel opined that the best available data was insufficient to support the District's conclusions.

For the relationship between flow and DO during the WAR/SDI study, the regression analyses confirmed a strong negative correlation between DO levels and temperature. However, no significant correlations were observed between the 14-day average flow at S-160 and DO at each of the downstream stations over the 3-year period of study. The study reported that the analyses suggested that DO levels throughout the Palm

River/McKay Bay system were generally insensitive to changes in flow at S-160. However, these analyses did not directly address the potential effects of a zero minimum flow on the DO levels in the estuary (Bedient et al., 1999).

The panel felt that Coastal Environmental (1997) regression analysis that was designed to address the zero minimum flow as proposed by the District had several factors that limited its usefulness. First, the regression equations that were derived from the same data had the same limitations of the other analyses, i.e., temporal resolution. In addition, spatial resolution was significantly more limited than 0.1-mile intervals as the model suggested. Finally, the data set only included a few points at the critical zero flow ranges. As with the WAR/SDI (1997) study, the regression analyses employed were constrained by the quality of the data set.

The Coastal Environmental (1997) study also examined regression analysis of dissolved oxygen and flow. As previously discussed, the regression analyses were based on empirical relationships and were limited by the available data. Although these analyses support the District's conclusion that DO levels in the Palm River were relatively insensitive to variations in discharge from S-160 in the 0 to 200-cfs range, the limits of the data set and the regression analyses did not provide a sufficient basis for evaluating the effects of zero flow in the Palm River/McKay Bay system.

2.12.3 Peer Review - Evaluate Deficiencies

The Panel discussed several basic deficiencies in the technical approach employed by the District. The most important of these was the District's implicit assumption that it could set a minimum flow of zero without giving specific consideration to the frequency or duration of zero flow periods. The second deficiency the Panel discussed dealt with the adequacy of the data employed in the District's analysis. The lack of significant data in the critical zero flow range, and the limitations in temporal resolution of this analysis, significantly limited the usefulness of the data in evaluating the effects of zero flow. Finally, the District's evaluation of relationships between flow and the critical salinity and DO parameters was empirical and based entirely on regression statistics (Bedient et al., 1999).

2.12.4 Peer Review - Summary

The Panel recommended that the District undertake the development of a mechanistic model that could be used to evaluate and predict the effect of various minimum flow strategies on the Palm River/McKay Bay system. Additional data would be required for this modeling effort to improve spatial and temporal resolution in the critical zero flow range. The Panel recommended that these additional modeling and data collections be undertaken before any significant increased withdrawals were allowed from the TBC (Bedient et al., 1999). (Section 2.14 describes additional studies conducted by the District in response to the Peer Review recommendations.)

2.13 PRIOR WATER QUALITY DATA COLLECTION / STUDIES

The major sources of water quality information available are summarized below.

2.13.1 Environmental Protection Commission Hillsborough County

The Environmental Protection Commission Hillsborough County (EPCHC) collects ambient water quality data at two stations in the Palm River and one station in McKay Bay. Salinity and dissolved oxygen data were were collected at mid-depth from 1974 to 1995, and from surface and bottom water depths from 1987 to 1995 (EPHC, 1995). Since 1996, samples have been collected at mid-depth.

Hypoxia was frequently noted at stations in the Palm River, particularly in bottom waters. Minimum DO values of below 0.5 mg/L occurred at all depths at both the Palm River stations. DO values were generally higher in McKay Bay at all sampling depths. Periodic problems in deeper waters were observed during the warmer months.

In July 1998, Hillsborough County Water Resource Team and the EPCHC established and funded an independent water quality and biological monitoring program (EPCHC, 2000) named the Hillsborough Independent Monitoring Program (HIMP). The purpose of the HIMP is to monitor the Hillsborough River, Alafia River, Palm River, McKay Bay, and the Apollo Beach area and canal system for potential environmental changes, which may be caused by Tampa Bay Water's (TBW) new water supply projects scheduled to begin in 2004 and confirm the modeling results prepared for TBW.

Sample collection for the County's HIMP began in 1999, and will include three years of "pre-water withdrawal" sampling and a minimum of three years of "post-water withdrawal" sampling.

2.13.2 Hydrobiological Study of Lower Hillsborough River and Tampa Bypass Canal (WAR/SDI, 1995)

During 1991 through 1994, Water and Air Research (WAR) conducted water quality and biological sampling in the lower Hillsborough River and the TBC in compliance with the COT and West Coast Regional Water Supply Authority (WCRWSA) WUP requirement to conduct a hydrobiological study of the Lower Hillsborough River and the TBC. As part of that study, WAR/SDI established eight stations in the McKay Bay/TBC complex. This study and the stations established are frequently referred to as the “WAR study” and the “WAR” stations respectively. During 2001-2003, the District returned to these sites to collect additional water quality. **Figure 2-13** illustrates the location of the pertinent “WAR” stations along with the EPCHC ambient and HIMP water quality stations.

WAR teamed with SDI to evaluate the data and completed the evaluation in 1995. Some general findings from the WAR/SDI study relevant to the determination of minimum flows are summarized below.

- The TBC below S-160 (Palm River) had much higher salinity values than the lower Hillsborough River below the dam.
- Surface salinities just below S-160 averaged 19.6 parts per thousand (ppt) with a minimum value of 12.5 ppt.
- Bottom salinities just below S-160 averaged 24.6 ppt with a minimum value of 20.0 ppt.
- Surface dissolved oxygen (DO) values generally increased progressively downstream in the TBC/Palm River system.
- DO concentrations in the Palm River/McKay Bay system were not correlated with freshwater discharge at S-160.
- Pronounced declines in DO concentrations with depth were observed in the lower canal, with mean bottom dissolved oxygen values ranging from 0.7 mg/L to 3.0 mg/L.
- Minimum DO values near zero mg/L were recorded at all stations above McKay Bay.
- Although periodic problems occurred, DO concentrations were generally higher in McKay Bay because it is shallow and frequently wind mixed.
- Total suspended solids (TSS) values in the Palm River/McKay Bay system were considerably greater than in the Lower Hillsborough River. Large phytoplankton densities in the Palm River/McKay Bay system contributed to this difference.
- Other data have shown that high salinity areas in Tampa Bay had a higher TSS values than the fresh and low salinity areas of the bay’s tributaries. The higher TSS values in the Palm River/McKay Bay system reflected the higher salinity and greater influence of Tampa Bay.
- As with TSS, turbidity values were higher in the Palm River/McKay Bay system than in the lower Hillsborough River.
- Color was positively correlated with discharge in the Palm River.
- Secchi disk values were negatively correlated with discharge.
- Orthophosphorus was negatively corrected with discharge in the Palm River/McKay Bay system.
- Chlorophyll-a concentration was generally higher in the Palm River/McKay Bay system than in the Lower Hillsborough River.
- Chlorophyll-a was not correlated with discharge from S-160 at the Palm River/McKay Bay stations.

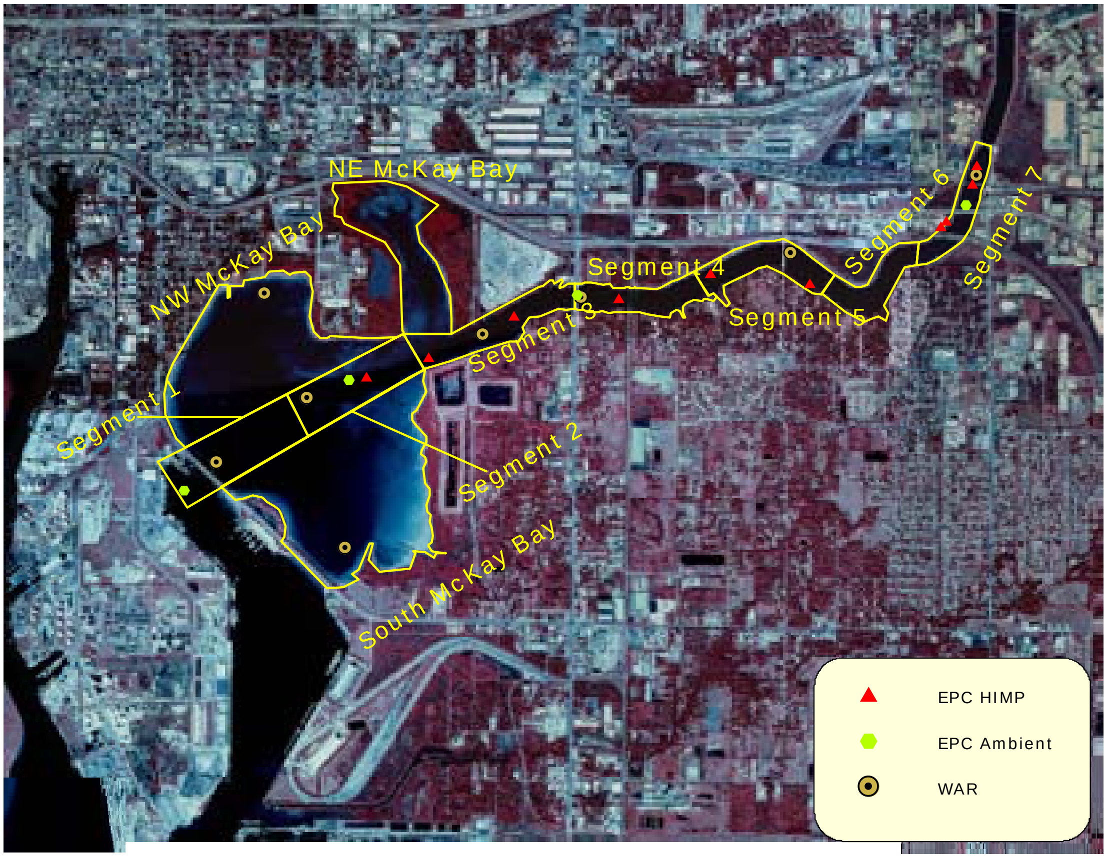


Figure 2-13 WAR, HIMP, EPCHC Ambient Stations

2.13.3 Hydrobiological Monitoring Program (HBMP) Year 3 Interpretive Report (PBS&J, 2003a).

Tampa Bay Water's WUP required design and implementation of a Hydrobiological Monitoring Program (HBMP) for both the Alafia and Tampa Bypass Canal Water Supply Projects Tampa Bay Water selected PBS&J to design and implement the HBMP. TBW selected PBS&J who designed and implemented a monitoring program in 2000 that included water quality, fish and invertebrates, benthos, and vegetation. The sampling design was based on a stratified random selection of stations. In addition to the X, Y stratification, the in-situ water quality design specified "deep" (> 2 m) and "shallow " samples. In addition to the monthly in-situ parameters and secchi depth, grab samples were collected and analyzed for chlorophyll-a, Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), Total Suspended Solids (TSS), color, and chloride. Continuous (15-minute capture) recording of surface/bottom conductivity, temperature and DO was conducted at two stations (Maydell Drive and 22nd Street Causeway) along with water level.

Data sources included in the HBMP evaluation included:

- Environmental Protection Commission Hillsborough County – EPCHC
- Florida Marine Research Institute – FMRI
- Southwest Florida Water Management District – District
- University of South Florida – USF
- City of Tampa (Water and Air Research) – COT (WAR)
- Tampa Bay Water HBMP Program (PBS&J and all subcontractors) – HBMP

The results of the monitoring efforts were summarized in 2003 as the *Hydrobiological Monitoring Program – Year 3 Interpretive Report.* **Figure 2-14** provides the location of the HBMP water quality monitoring stations.

A summary of some general findings from the HBMP study relevant to the determination of minimum flows follows:

- Surface salinities in both McKay Bay and the Palm River were much higher than those typically observed in a natural estuarine system. During characteristically prolonged periods of low flow, high surface salinities (28-33 ppt) typically extended from McKay Bay upstream to near Structure S-160. However, surface salinities in the Palm River varied widely during short time periods in response to periodic high freshwater discharges from S-160.
- During periods characterized by low to moderate flows at S-160, there was usually a weak longitudinal surface salinity gradient running from higher (20-25 ppt) concentrations in McKay Bay to somewhat lower levels upstream in the Palm River (15 to 20 ppt). During periods of very high flows at S-160, low (0-5 ppt) surface salinities typically extended throughout the Palm River and McKay Bay.
- During periods of moderate flow at S-160, near-bottom salinities were characteristically considerably higher than corresponding surface salinities from near the structure downstream through McKay Bay. Consequently, extensive reaches of both the Palm River and McKay Bay were typically characterized by marked salinity stratification.
- Surface dissolved oxygen concentrations along the entire sampling transect from McKay Bay upstream to Structure S-160 fell below the State standard for estuarine waters (4.0 mg/L). However, both the frequency and magnitude of low surface dissolved oxygen concentrations were far greater in the Palm River than McKay Bay.
- Instances of hypoxia (ambient DO less than 2.0 mg/L) or anoxia (less than 0.2 mg/L), were common in the surface waters of the Palm River, but were extremely rare in McKay Bay.
- Vertical salinity stratification resulted in hypoxic and even anoxic dissolved oxygen concentrations in near-bottom waters in both McKay Bay and the Palm River. This was especially true for the deeper, dredged areas of both McKay Bay and the Palm River.
- Intermittent occurrences of supersaturated surface DO concentrations have been observed in both the Palm River and McKay Bay, indicative of dense

phytoplankton blooms (measured as chlorophyll-a) during periods of low flow when residence times are high.

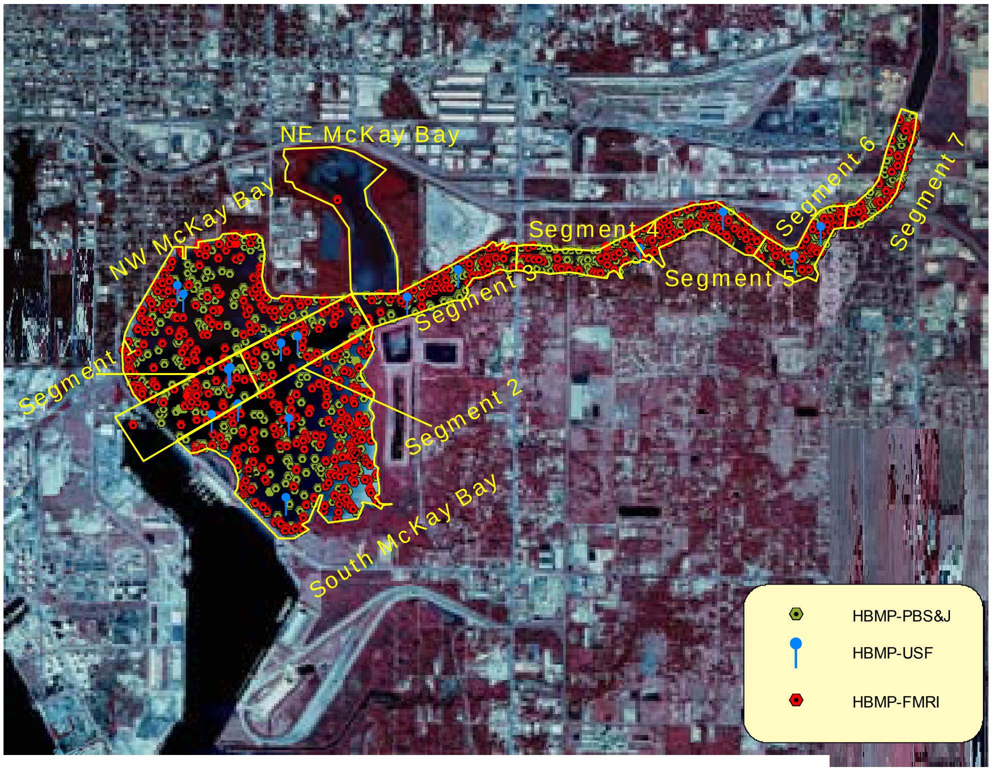


Figure 2-14 Location of All HBMP Stations

2.13.4 An Analysis of the Effects of Freshwater Inflows on Salinity Distribution, Dissolved Oxygen Concentrations, and Habitat Characteristics of the Hillsborough River and Palm River/Tampa Bypass Canal (Coastal Environmental, Inc., 1997).

This study was requested of the Tampa Bay Estuary Program (TBEP) by the District (see Section 2.3). The purpose was to convene a technical advisory committee that would provided recommendations of ecological criteria to be used in establishing MFLs for TBC and the Hillsborough River. The process required eight months and included an extensive collection of local, state and federal agencies, thus making the conclusions an excellent consensus of environmental concerns at all bureaucratic levels. The purpose of the study was to investigate the relationships between freshwater discharge and water quality conditions in the Hillsborough River and Palm River/Tampa Bypass Canal, and o develop a management tools based on the results to predict salinity and dissolved oxygen response to changes in freshwater inflows. TBEP contracted with Coastal Environmental to facilitate the process, conduct the evaluation and produce the management tools. By agreement of the participants, the study did not recommend specific minimum flow targets.

Coastal Environmental used the WAR, and EPHC ambient data along with the USGS continuous recordings for the evaluation. Regression analysis showed that relatively high salinity values persist in the Palm River at flows less than 100 cfs from S-160. The results showed the response of salinity to flow in the Palm River is curvilinear, with surface salinity being most responsive at low flows. By increasing flow from 0 to 40 cfs, surface salinities in the Palm River were predicted to decrease by 3.2 to 4.4 ppt resulting in low to mid-twenty ppt salinity. At the same flow rate (40 cfs), salinity at 1 meter was predicted to be in the range of 24.2 to 26.5 ppt.

The regression analyses performed on Palm River DO revealed that temperature was significantly related in all cases, but the slope for flow was not significantly different from zero ($p<0.05$) except at the station nearest to S-160 and at a depth of 3 meters. The most conclusive finding of the correlation analysis was that there is no positive relationship between flow and DO concentrations in the Palm River and McKay Bay system. The combined results indicate that reductions in flow from S-160 would not have a negative effect on DO in the Palm River or McKay Bay.

2.13.5 McKay Bay TMDL (Burger and Petrus, 2004)

Most recently, FDEP released a draft Total Maximum Daily Load (TMDL) report detailing nutrient (expressed as elevated chlorophyll values) and DO impairment. While the nutrient issue is of less concern to the present study, the further evaluation of DO is important because of the relationship between DO and the benthic community. The TMDL study identified nitrogen as the limiting nutrient and stated *Reductions in nitrogen will result in lower algal biomass levels in the water column, and lower algal biomass levels will result in smaller diurnal fluctuations in DO, fewer algal-based total suspended solids and reduced BOD*. The final recommendation was based on loading, but did not address whether reduced flows or reduced concentrations were needed to alleviate the DO problem.

2.14 SOURCES OF BIOLOGICAL STUDIES AND INFORMATION

The majority of biological data available for the McKay Bay/TBC complex was collected by EPCHC as part of the TBEP/ HIMP, by WAR/SDI as part of the COT/WCRWSA WUP or by PBS&J (and their subcontractors) as required by TBW's permit requirement to conduct a HBMP.

1. A hydrobiological study of the Lower Hillsborough River and the Tampa Bypass Canal (WAR/SDI, 1995) required by special conditions of WUPs issued to the COT and the West Coast Regional Water Supply Authority.

2. Assessment of Potential Impacts on Biological Communities of McKay Bay from Proposed Reductions in Freshwater Inflow from the Tampa Bypass Canal (PBS&J, 1998).

3. The Hydrobiological Monitoring Program (HBMP) for both the Alafia and Tampa Bypass Canal Water Supply Projects Year 3 Interpretive Report (PBS&J, 2003).

2.14.1 Hillsborough Independent Monitoring Program: Pre-Operational Characterization of Benthic Habitats in the Palm River, McKay Bay, & the Little Manatee River – Draft (Grabe et al., 2004)

Hillsborough County began collecting benthic samples in the Palm River in 1995 as part of a larger bay-wide benthic monitoring program intended to define the status of the bay and to provide data for development of a benthic index for Tampa Bay. In 1998, TBW developed a Master Water Plan that included withdrawals from the TBC. In response, Hillsborough County developed the HIMP benthic monitoring to collect baseline data. **Figure 2-15** illustrates the extent of Hillsborough County's HIMP sampling in the McKay Bay/TBC complex. The County used a 'Before-After-Control-Impact (BACI; Green 1979) to compare the benthos in Palm River/McKay Bay to the Little Manatee River (as the control site). In addition, relationships between benthic metrics and salinity were conducted for individual areas. The results indicated that there is no statistical relationship between numbers of taxa present and salinity. Sand habitats in McKay Bay were found to support a richer and denser assemblage than do the mud habitats. The McKay Bay assemblage was found to be 13% similar (SIMPER analysis) to the Palm River. An equivalent degree of similarity was found between the Little Manatee River community and the Palm River community.

2.14.2 Hydrobiological Study of Lower Hillsborough River and Tampa Bypass Canal (WAR/SDI, 1995).

The biological component of the WAR/SDI study included an evaluation of benthos, fish, ichthyoplankton and phytoplankton. Phytoplankton densities were generally higher and more variable in the Palm River/McKay Bay system than in the Hillsborough River. The Bacillariophyaceae (diatoms) were the most abundant algal group in McKay Bay. The highest algal populations were found in the freshwater portions of the TBC, and phytoplankton densities at the station below S-160 were positively correlated with discharges.

Many of the macroinvertebrate communities sampled in the Hillsborough River and Tampa Bypass Canal systems were indicative of stressed environments with low dissolved oxygen concentrations. Low values of organism abundance, species richness, and diversity were common during the study, but were most frequent at the station nearest the structure. Communities collected from shallow waters at several stations during the second year of study generally had one to three orders of magnitude more organisms than collections from mid-channel areas, apparently due to the higher dissolved oxygen concentrations in the shallower waters.

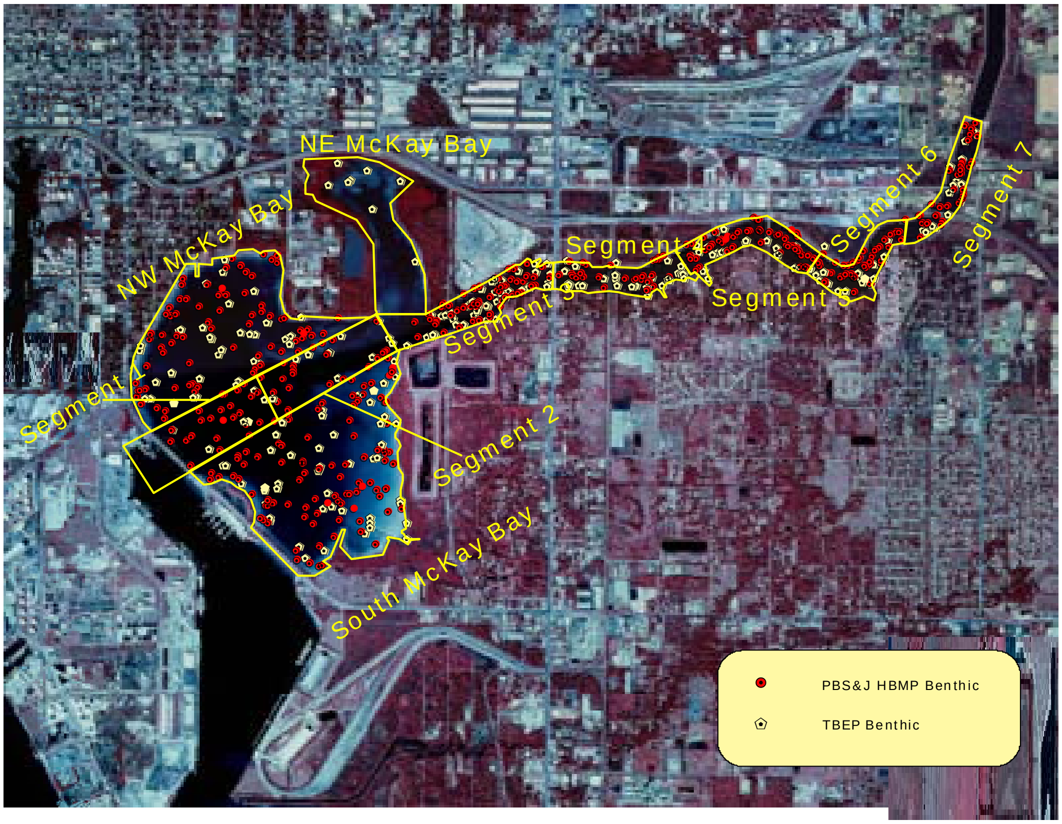


Figure 2-15 TBEP/EPCHC HIMP and PBS&J Benthic Stations

Because of the much higher salinity values and more subdued response to freshwater inflows, benthic macroinvertebrates in the Palm River/McKay Bay system did not show a clear response to changes in freshwater inflows when compared to the Hillsborough River. During periods of peak discharge in the Hillsborough River, a shift in community compositions from estuarine species to freshwater species occurred at the Hillsborough dam.

Ichthyoplankton captured in the Palm River/McKay Bay system were primarily the egg, larvae, and juvenile stages of marine-derived fishes that tend to spawn in high salinity waters. These species migrate into lower salinity waters as juveniles and utilize these estuarine habitats. The abundance of larval stages was lower than expected in the Palm River/McKay Bay system. The reduction may be related to benthic hypoxia, high salinities, rapid changes in freshwater flow or a combination of factors.

Fishes collected during the two-year period were primarily adults and juveniles of small-sized resident species and the juveniles of seasonally abundant migrant species. Juvenile fish abundance increased progressively downstream in the Palm River/McKay

Bay systems. The TBC/Palm River/McKay Bay system consistently harbored more individuals and a greater number of taxa than did the Lower Hillsborough River.

The juvenile fish populations within the study area were clearly influenced by differing salinity regimes. The Hillsborough River hosted more freshwater and estuarine taxa than did the Palm River/McKay Bay system, which harbored more marine taxa. The abundances of many taxa reflected responses to salinity regimes.

The transient fish community in the system was represented by juveniles of species of sport or commercial value. All transients were marine species that seasonally entered the study sites as young-of-year, using these systems as nursery areas.

2.14.3 Assessment of Potential Impacts on Biological Commmunities of McKay Bay from Proposed Reductions in Freshwater Inflow from the Tampa Bypass Canal (PBS&J, 1998).

PBS&J prepared this report for TBW to provide an assessment of the potential impacts on McKay Bay of proposed withdrawals from the Tampa Bypass Canal. The withdrawals from the TBC would alter freshwater inflows to McKay Bay and possibly impact natural communities associated with existing flow and salinity regimes.

This document addresses the expected influences of reduced freshwater inflows with respect to changes in salinity, both temporally and spatially, and with respect to flushing characteristics of McKay Bay. The major conclusions are as follows:

- The vegetation of McKay Bay is dominated by mangroves and saltmarsh cordgrass, although small areas of black rushes are located in the southeast corner of the bay, which may be sensitive to changes in salinity.
- The dominant benthic macroinvertebrates in McKay Bay have salinity tolerances that range from freshwater to estuarine. The fishes of McKay Bay are similar to those typically found in the Tampa Bay region in general and the Hillsborough Bay region in particular.
- The proportion of total flushing in McKay Bay due to tidal exchange is 96% compared with 4% due to freshwater inflows. The residence time in McKay Bay increases slightly due to the proposed freshwater withdrawals, from 1.08 days to 1.10 days.
- Under proposed withdrawals for the TBC project, predicted changes in salinities throughout most of the year are approximately 1-1.5 ppt; the greatest changes in salinity, 3-4 ppt, occur only during one or two months during the wet season. The resultant salinities in McKay Bay will be approximately 22-24 ppt, or 1-2 ppt greater than currently existing salinities.
- Comparisons of salinity tolerances and “preferences” of the predominant vegetation, benthos, and fish in McKay Bay to predicted salinity changes indicate that there will be no significant effect on the distribution and abundance of these critical components of the McKay Bay ecosystem. Given the lack of impact on

their habitat and food sources (fish and benthos), no impact on the resident or migratory bird communities is expected.

2.14.4 Hydrobiological Monitoring Program (HBMP) Year 3 Interpretive Report (PBS&J, 2003).

The HBMP program required by TBW's WUP also required collection and analyses of biological data from the McKay Bay/TBC complex. Biological studies during April 2000 through December 2002 included macroinvertebrate, fish, zooplankton, vegetation, and bird data recorded by the HBMP are presented.

Table 2-8 provides a brief description of the biological parameters measured and the objectives that were established by the HBMP. **Figure 2-16** provides the location of the FMRI and USF fish and zooplankton stations.
Data sources used in this study:

- Hillsborough County Environmental Protection Commission– EPCHC
- Florida Marine Research Institute – FMRI
- Southwest Florida Water Management District – District
- University of South Florida – USF
- City of Tampa (Water and Air Research) – COT (WAR)
- Tampa Bay Water HBMP Program (PBS&J and all subcontractors) – HBMP

The frequency, abundance and probability of occurrence of several macroinvertebrate taxa and orders were described for each river kilometer reporting unit. These statistics serve as good baselines with which to compare future data. Several patterns of occurrence emerge that may suggest how different taxa might indicate subtle changes in salinity regimes, patterns of primary productions, or other factors. These patterns are discussed below for the TBC/Palm River, and McKay Bay.

Table 2-8
Biological Components of the TBC HBMP

HBMP Element	Objective(s)	Parameters
Benthic Invertebrates	Evaluated changes in species composition, abundance, and/or distribution.	Monthly sampling of epifauna, infauna, grain size, and organic matter in freshwater and estuarine strata. More intense sampling in wet season and most likely potential impact areas.
Zooplankton and Larval Fishes	Evaluated changes in species composition, abundance, and/or distribution.	Monthly data were collected by University of South Florida.
Adult and Juvenile Fishes	Evaluated changes in species composition, abundance, and/or distribution.	Monthly trawl and seine data were collected by Florida Marine Research Institute.
Water Dependent Birds	Evaluated changes in abundance and richness over time, and any correlation with changes in water quality or other biological indicators.	Bimonthly surveys were conducted at three locations: Alafia Banks, ponds near month of Palm River, and upper McKay Bay.
Habitat/ Vegetation Indicators	Estimated areal extent, relative abundance, and upstream/downstream shifts of vegetative communities.	Annual linear shoreline and wetland polygon mapping, annual emergent and submerged aquatic vegetation survey by strata and fixed stations in the Alafia River.

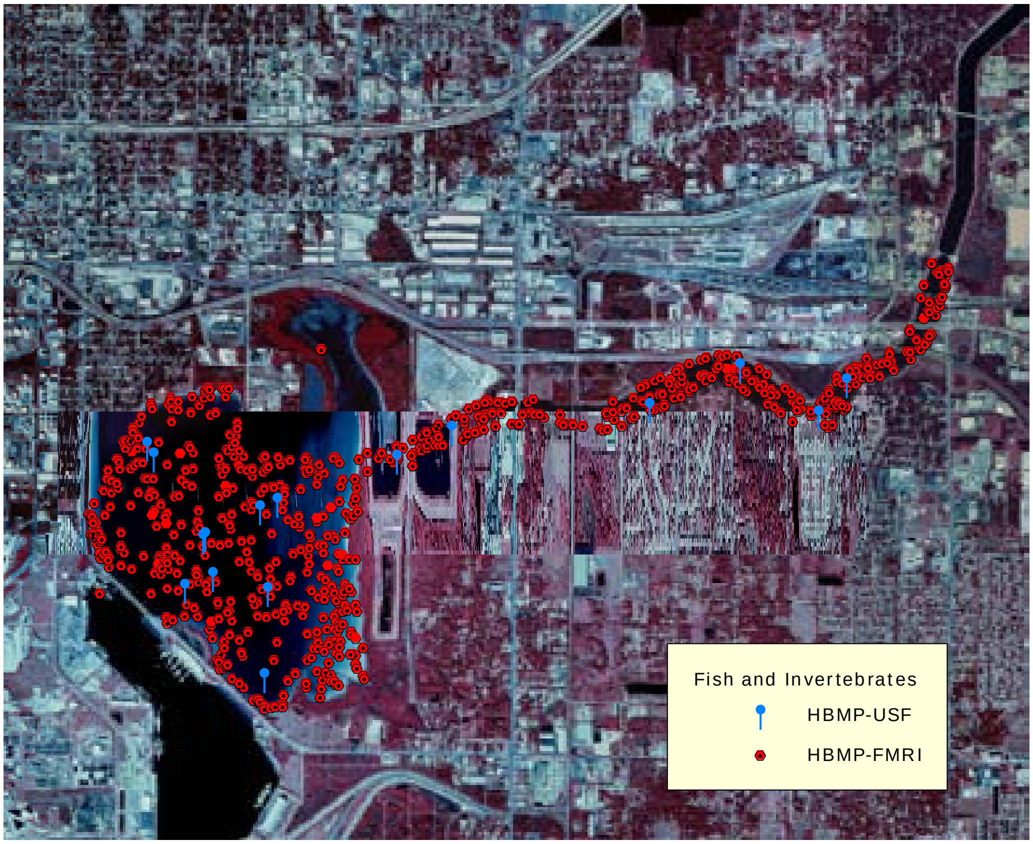


Figure 2-16 FMRI and USF Fish / Invertebrate Stations

Within the TBC/Palm River, the groups of indicator benthic macroinvertebrate taxa are somewhat different from those in the Alafia and Hillsborough Rivers. At approximately 4 miles in length, the Palm River is relatively short. The range of the most common taxa in the other two rivers typically extended over a distance of 4 miles or more. As a result, many more taxa occur in a high percentage of samples in the Palm River than the other rivers.

Also, low levels of oxygen seem to inhibit benthic macroinvertebrate production in the upper river kilometers of the Palm River. Thus, patterns of invertebrate distribution may be driven by factors other than salinity, flow, or primary production. In contrast, the temporal extent of benthic macroinvertebrate data in McKay Bay is much longer than that for the rivers. The Bay data lend themselves to more traditional analytical techniques such as statistical and indices of diversity. Various benthic indices, including the recently developed Tampa Bay Benthic Salinity Index (Janicki Environmental, 2003) may also be of value in post-operational analyses.

Zooplankton data collected as part of the HBMP include both invertebrate zooplankton (e.g., crab zoea) and ichthyoplankton (e.g., fish eggs and larvae). Zooplankton sampling is conducted monthly in the Alafia, Palm, and Hillsborough Rivers, and McKay Bay by Dr. Ernst Peebles of the University of South Florida under contract to PBS&J. Fish sampling is also conducted monthly in the Alafia, Palm, and Hillsborough Rivers, and McKay Bay, by Florida Marine Research Institute, Fisheries Independent Monitoring (FIM) program, under contract to PBS&J. Fish data collected as part of the HBMP include both juvenile and adults captured using seine nets and trawl nets.

The two primary measures of spatial distribution for fish and zooplankton with respect to inflow include the center of abundance (COA) and abundance weighted salinity (AWS). The baseline analyses presented in this report show that the selected zooplankton and fish indicator species generally exhibited a high degree of variability in both COA and AWS over a wide range of freshwater inflows during the study period. The results from this study indicate that the selected taxa either do not have a strong affinity for fixed habitats or preferred salinity regimes within the reporting units, or they lack behavioral and/or physical capabilities to control their horizontal position within the estuary (PBS&J, 2003).

It is likely that the spatial distribution of zooplankton and fish is controlled more by complex trophic factors such as the density and distribution of phytoplankton populations. Thus while inflow (and resultant salinity) is less directly related to fish and zooplankton, there may be an indirect relationship through relationships between phytoplankton and freshwater flows (PBS&J, 2003).

2.15 SUMMARY OF PRIOR STUDIES

Several recurring and important themes are apparent in the TBC studies done to date. First, the TBC tends to be a relatively high salinity environment with chronic dissolved oxygen problems, particularly at depth. The problem is more prevalent upstream than in McKay Bay. Yet, the lack of a statistically significant relationship between flow and DO suggest that more complex factors are involved. Heavy salinity stratification occurs during high flow and the presence of a ‘sill’ at US 41 greatly reduces mixing at depth.

Phytoplankton blooms are likely to occur during low-flow conditions, while ‘wash-out’ of phytoplankton is likely to occur during high flows.

Benthic macroinvertebrates do not show a clear quantitative response to changes in freshwater inflows but do appear to be influenced by hypoxic events. No statistically significant relationship with inflow could be found.

The spatial distribution of significant fish and zooplankton taxa does not suggest a preferred salinity regime.

2.16 RECENT STUDIES OF THE TBC

The 1999 Peer Review Panel made specific recommendations to the District for additional studies to support a zero flow MFL determination for the TBC. In response to those recommendations, the DISTRICT conducted, or contracted for additional studies totaling $ 247,000. Each is briefly summarized below.

2.16.1 Hydrodynamic Model

In 2001 and again in 2003, the DISTRICT contracted with Dr. Mark Luther of the University of South Florida (USF) to utilize an existing high-resolution 3-dimensional, hydrodynamic circulation model of Tampa Bay to evaluate the flow/salinity relationships the Palm River/TBC up to S-160. The model was used to simulate varying flow scenarios based on the 1990-1991 ambient flows and the 2001-2003 flows.

A companion purchase order was issued to HSW, Inc to provide estimates of ungaged flows to USF for inclusion in the hydrodynamic model.

2.16.2 Oysters

The District contracted with Mote Marine Laboratory (MML) in 2001 to conduct field and aerial surveys of the McKay Bay/TBC complex to locate mollusk communities. Potential oyster reefs identified from aerial reconnaissance and existing aerial photography were field-verified and the geographic locations identified by global position system (GPS) were converted to ArcView© geographic information system (GIS) database.

In 2004, the District issued a Purchase Order to Dr. Aswani Volety of the Florida Gulf Coast University (FGCU) to evaluate the health and salinity requirements of oysters in the McKay Bay / TBC complex as well as the Alafia River. Field support was furnished by MML and the previously located oyster communities were re-inspected.

2.16.3 Benthic Communities

The District contracted with Dr. Chet Reckinowski of the University of Southern Mississippi (USM) in 2001 to compile, standardize and analyze existing data on the benthic community in the Alafia River and the McKay Bay/TBC

2.16.4 Fishes / Invertebrates

The District contracted with Dr. Ernst Peebles of USF to compile and evaluate fish and invertebrate data collected within the TBC complex. The database was compiled from the results of 875 seine deployments, 325 trawl deployments and 768 plankton tows.

2.16.5 Water Quality Database Updates

Janicki Environmental, Inc. (JEI) was awarded a purchase order in 2004 to update previous water quality databases and regressions for both TBC and the Alafia River. In addition to updating the water quality databases, JEI re-evaluated salinity/flow regressions for five fixed location stations (frequently referred to as the “WAR” stations) and for the dataset collected by continuous recorders.

2.16.6 Compilation of Background / History

The District contracted with Florida Environmental (currently doing business as Earthbalance Inc.) to compile the history of the previous TBC MFL efforts and to summarize the peer review report. Mr. Don Ross (owner) served on the original Peer Review Panel convened by the District.

2.16.7 Dissolved Oxygen

Chronically low dissolved oxygen (DO) is a well-known water quality characteristic of the TBC. However, much of the literature regarding low DO is anecdotal. The District contracted with HSW, Inc. to conduct a literature search on either the sub-lethal effects of hypoxia or quantified effects of chronically low dissolved oxygen.

CHAPTER 3 ECOLOGICAL RESOURCES

3.1 RESOURCES

Despite the highly altered nature of the TBC, certain ecological resources are visually apparent and others may be deduced. For example, the presence of shoreline vegetation, birds and fish are readily apparent at any tide stage and oyster assemblages and benthic infauna are visible at low tide. For the present evaluation, those resources were chosen for evaluation. An evaluation of less obvious parameters of salinity and dissolved oxygen is also include in this section as these two water quality parameters have the potential to shape the biotic communities.

3.2 OYSTER REEFS

The majority of the McKay Bay/TBC substrate consists of sand or mud. With the exception of the northeast lobe of McKay Bay, there is little emergent vegetation. Thus, oyster reefs have the potential to be a significant habitat within the system and because of this it was decided to make preservation of the existing reefs a goal of the MFL. McKay Bay is defined by FDEP as a Class III waterbody that by definition prohibits shell fish harvesting.

While the Eastern oyster *Crassostrea virginica* is a popular food item, the real value of oyster reefs lie in the ecological significance that remains largely under-appreciated and under-studied (Coen et al. 1999a). Eastern oysters have been identified as a keystone species because of their ability to form biogenic reefs (Coen et al 1999a, Coen et al. 1999b. It has been suggested by Lenihan and Peterson (1998) that the "Loss of oysters and oyster reef habitat may have important negative consequences for the sustainability, economic value, and biodiversity of estuarine ecosystems." Individual oysters filter 5 liters of water per hour per gram of dry mass (Newell, 1988), removing phytoplankton, particulate organic carbon (Newell and Langdon 1986), sediments, pollutants, and microorganisms from the water column. This process results in greater light penetration immediately downstream, thus promoting the growth of submerged aquatic vegetation. Oysters assimilate the bulk of the organic matter that they filter; the remainder is deposited on the bottom where it provides food for benthic organisms (Dame and Patten 1981). Bivalves have also been demonstrated to increase concentrations of nutrients in the sediments making them available to seagrasses (Peterson and Heck 2001). Furthermore, oysters reefs have been found to harbor abundances of decapod crustaceans twice that of adjacent seagrass meadows and fifteen times that of adjacent marsh-edge habitat (Glancy et al. 2003).

3.2.1 Life history

C. virginica is a dioecious alternate hermaphrodite (Mackie 1984) with an annual reproductive cycle that results in spawning and external fertilization. Oysters respond to chemical stimuli and/or temperature and gametogenesis synchronized such that eggs and sperm are released concurrently to maximize fertilization success (Thompson et al. 1996). They are protandrous – males first and change into females in subsequent years. Reproductive season and frequency of reproduction varies widely due to seasonal changes and latitude. Reproduction is predominantly influenced by temperature and food availability (Langdon and Newell 1996). The synchronization of spawning is effected by environmental cues in the surrounding water and the presence of gametes that stimulate the onset of spawning in adjacent oysters (Thompson et al. 1996).

Salinity is also known to affect gametogenesis, condition index and spawning in oysters. Gametogenesis was impaired at low salinities (< 5 ppt), while normal gametogenesis occurred above 7.5 ppt (Loosanoff 1953a, b). Oysters from Texas showed suppressed gonadal activity at salinities < 6 ppt (Butler 1949). Similar trends were observed in the Caloosahatchee river oysters in 2003 when the river was significantly fresh water given the regulatory freshwater releases (Volety, unpublished results).

After external fertilization, oyster egg undergoes through a series of larval transformations and larval stages. The larval stages are planktotrophic and omnivorous, grazing on phytoplankton, detritus, and bacteria growing over a 2-3 week period. If appropriate stimuli occur, the oyster larva cements itself to the substrate on its left valve and metamorphoses, after which it is called "spat". Upon cementation, oyster spat (and ultimately juvenile and adult oyster) depends on the surrounding water column and water currents to bring food over the reef and transport waste ad sediment away (Kennedy 1996). This setting of spat is approximately 14-21 days after fertilization depending on the water temperature and salinity (Carriker 1996). Spat size ranges between 248 – 400 μm (Carriker 1986).

The gametogenic cycle of eastern oysters (Kennedy and Battle 1964) is similar to other marine invertebrates from temperate environments. The precise timing of gametogenesis varies by latitude and temperature. Oyster gametes ripen earlier in individuals that inhabit the southern end of the species distribution. This is undoubtedly influenced by temperature and food availability. In addition, the duration of spawning is latitudinally influenced. Oysters in southern areas have a longer spawning period compared to their northern counterparts. In the Gulf Coast and north up to Virginia coast on the east coast of the Atlantic, major spawning occurs in the spring, with minor spawning through the summer and another major spawning in the fall (Hayes and Menzel 1981). In oyster populations from SW Florida, Volety et al (2003) documented continuous oyster spawning from early spring (March) till late Fall (November). A combination of shallow environments, warm water temperature and food availability may account for the long spawning period. In contrast, in the northern latitudes, major spawning is restricted to the summer. This could be correlated with both declining temperatures and phytoplankton availability in the face of declining daylight hours. The fact that southern populations of oysters initiate gametogenesis and spawn earlier in the year compared to northern ones suggests that water temperature may be the most dominant factor influencing reproduction of oysters.

Other unfavorable conditions such as low salinities may also influence the phytoplankton composition and quantity affecting gametogenesis in oysters as evidenced in the Caloosahatchee River in 2003 (Volety et al., unpublished results). While variations in salinity appear to play a less important role in spawning, low salinities (< 5 ppt) can inhibit gametogenesis (Butler 1949, Loosanoff 1953a, Volety et al., unpublished results). In addition, investigations by Volety et al. (2003) revealed that exposure to salinities < 3 ppt for over 1 week are lethal to juvenile oysters from SW Florida.

These results suggest that larvae and juvenile are more sensitive to salinity requirements compared to the adult oysters, which can tolerate a wide variety of salinities (Wilson 1969). Salinity is an important and influential factor, limiting the distribution of many aquatic animals (Gunter 1961, Wells 1961) and is considered the single most important factor affecting oyster populations (Butler 1949). However, synergistic activities of temperature and salinity are strong and affect virtually every aspect of metabolic activity including feeding, respiration, utilization of energy reserves, gonadal development, time of spawning, host-parasite interactions, predation rates, growth, and distribution (Shumway 1996).

3.2.2 Distribution, tolerance and survival of adult oysters

Adult oysters can tolerate a wide range of salinities ranging from 0 – 42.5 ppt. While the normal range of salinity for survival varies between 1.2 – 40 ppt, normal species distribution occurs between 5 – 40 ppt (Ingle and Dawson 1953, Loosanoff 1953a, Wells 1961, Galtsoff 1964, Menzel et al. 1966). Oysters can indefinitely survive at salinities 4-5 ppt (Loosanoff 1932, Volety et al. 2003). Although the optimal salinity range varies latitudinally and geographically, it is widely accepted that optimal salinity range for oysters is between 14 – 28 ppt (Butler 1949, Chanley 1958, Galtsoff 1964), including those in SW Florida estuaries (Volety et al. 2003). In addition, oysters can survive salinities as low as 2 ppt for a month, or near zero salinity for several days when temperatures are low (Gunter 1953, Volety et al. 2003). Self sustaining populations occurred when salinities were as low as 0.2 – 3.5 ppt for five consecutive months annually (Butler 1952), including those in the upstream Caloosahatchee River and Faka-Union estuaries in SW Florida that encounter zero salinities for several months when regulatory fresh water releases are made (Volety and Savarese 2001, Savarese et al. 2003, Volety et al. 2003).

Juvenile oysters less than 1 year old survived salinities of 5 ppt (Chanley 1958, Volety et al. 2003), however, very little growth is observed below 5 ppt, slow growth observed at 12 ppt, and normal growth occurred between 12 – 27 ppt (Chanley 1958). Under laboratory conditions, Volety et al. (2003) observed high mortality (40-75%) of juvenile oysters exposed to <5 ppt and 35 ppt salinities for 2 weeks, while very little mortality (5%) was seen at salinities 15-25 ppt.

Butler (1954) described distinct types of oyster reefs at different salinity regimes in the Gulf of Mexico estuaries. Reefs near the head of an estuary experiencing salinity ranges of 0 – 15 ppt annually, oyster populations are small, rounded, and sparse given high annual mortality rates (Butler 1954, Volety et al. 2001, Savarese et al. 2003). Spat recruitment and growth rates are also low. Where salinities are between 15 – 20 ppt, populations are dense, reproductive activity high, predator numbers low, and spat recruitment and growth rates (high or low for spat/growth?). Near the mouth of a typical Gulf Coast estuary with a salinity of 25 ppt, growth and reproductive rates are typically high, however, predation and competition are also high. When the estuary opens into the high-salinity Gulf waters, oyster reefs are sparse, spat recruitment and growth are low, diseases and predators are high, and suitable cultch is lacking. Similar trends are observed by Volety et al. (2003), Volety and Savarese (2001), and Savarese et al. (2003).

High salinities also invite various predators such as crabs, starfish, boring sponges, oyster drills and diseases (see below). For example, oyster drills *Thais hemastoma*, *Thais lapillus*, *Urosalpinx cinera*, and *Eupleura caudata* dominate high salinity waters (Butler 1954, Galtsoff 1964, Manzi 1970, Shumway 1996). In addition, the boring sponge, *Cliona* spp. and xanthid crabs, stone crabs abound in high salinity waters (Hopkins 1962, Menzel et al. 1966, MacKenzie 1970). Other species that are tolerant of low salinities, but pose serious threat to oysters include starfish *Asteria forbesi*, whelk *Fasciolaria hunteria* (Loosanoff 1945, Wells 1961), flatworm Stylocus ellipticus (Loosanoff 1956), and blue crab *Callinectes sapidus* (Menzel et al. 1966).

In addition to the direct effects of high salinity and the indirect effect of increased predation, salinity is a controlling factor in the diseases caused by the protozoan parasite, *Perkinsus marinus*. *P. marinus* has devastated oyster populations in the Atlantic (Burreson and Ragone-Calvo 1996), where it is currently the primary pathogen of oysters, as well as in the Gulf of Mexico (Soniat 1996). Andrews (1988) estimated that *P. marinus* can kill ~80% of the oysters in a reef. The distribution and prevalence of *P. marinus* is influenced by temperature and salinity with higher values favoring the disease organism (Burreson and Ragone-Calvo 1996, Soniat 1996, Chu and Volety 1997, La Peyre et al. 2003). Soniat (1985) observed that the weighted incidence of *P. marinus* in the Gulf of Mexico oysters was explained by the interactive effects of temperature and salinity. In addition, laboratory studies by Volety (1995), and, Chu and Volety (1997) suggested that salinity to be the most important factor influencing the disease susceptibility and disease progression of *P. marinus* in oysters.

Volety and Tolley (2004) have summarized the habitat requirements for oysters. The results are provided in **Table 3-1.**

3.2.3 Management Implications

Clearly, both high salinity and extended low salinity can be detrimental to oysters. Under current water management practices, oysters in nearby Caloosahatchee Estuary are not stressed by low flows (< 300 cfs), but are stressed due to high flows exceeding 3,000 cfs for extended periods (2-4 weeks). In essence, the more important management issue is to set a maximum flow rather than a minimum flow. However, the MFL statute is explicit in specifying the limit at which . . . . *further withdrawals* would be significantly harmful. Clearly, water management operations can alter salinity regimes that result in significant harm to the ecology, but the cause is not excessive withdrawals.

Table 3 –1
Oyster Habitat Requirements

Variable	Value
Larvae	
salinity	Limits 5 - 35 ppt Optimal 10 - 30 ppt Peak 20 - 22 ppt Settlement Peak 25 - 29 ppt
temperature	Optimal 20 - 30^{o}C
substrate	Optimal - shells of live or dead oysters Other - rocks, wood material, gravel, solid refuse, calcareous remains of other mollusks.
Adult	
salinity	Normal 10 - 30 ppt Optimal 10 - 20 ppt Tolerate 5 - 40 ppt
temperature	Optimal 20 - 30^{o}C Tolerate 1 - 49^{o}C Stop Feeding 6 - 7^{o}C Physiological Function Cease 42^{o}C
substrate	Other - rocks, wood material, gravel, solid refuse, calcareous remains of other mollusks.

In the Caloosahatchee estuary, highly managed releases from Lake Okeechobee cause low salinity problems when discharges exceed 3,000 cfs. Volety and Tolley (2004) recommended that minimum and maximum flows from Lake Okeechobee into the Caloosahatchee Estuary be maintained at 500 and 2,000 cfs respectively, for the development of oyster reefs. These flows would result in a salinity regime of between 16 and 28 ppt. They also recommended that when freshwater releases are necessary, repeated pulsed releases of < 1 week duration during winter months be made instead of sustained releases of freshwater during summer or winter months.

3.2.4 Occurrence of Oysters in McKay Bay/TBC

During 2001-2002 MML conducted an aerial and field survey of mollusks in McKay Bay/TBC complex. Oysters were found on emergent substrate (mangrove roots, pilings, navigation aids etc.) as well as in patch reef communities in established in open water over hard level bottom. An estimated 8,100 m^2 in 26 locations were identified by MML as shown in **Figure 3-1** Large populations of mussels were also noted amongst the mangrove root systems.

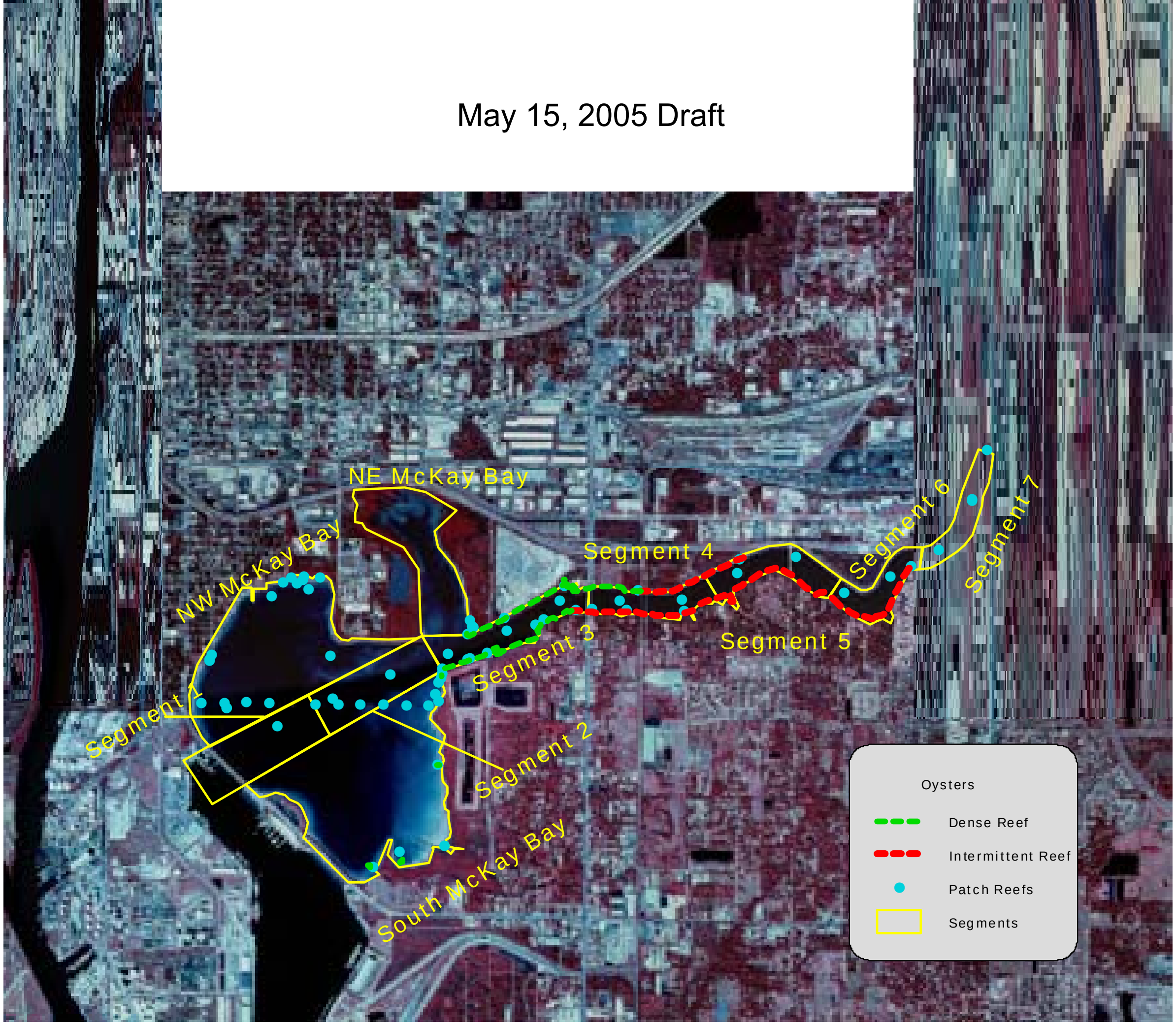


Figure 3-1 Oyster Communities Identified by Mote Marine Lab

3.2.5 TBC Oyster Community and S-160 Flows

Of note is the fact that oyster reefs are found along almost the entire length of TBC, suggesting that the salinity gradient is not limiting. A segmentation scheme of approximately 1 km (0.6 mile) lengths running along the thalweg was developed for the TBC (Figure 3-1) to evaluate whether a salinity gradient existed. Observed (1974-2003) salinities were compiled from all known monitoring programs, incorporated into a GIS database and assigned to the segments. The baseline (flood diversions only, no water supply withdrawals) S-160 flow for 1974 - 2004 was divided into five flow classes based on percentile rank as shown in **Table 3-2**.

Table 3-2
S-160 Baseline Flow

Percentile	(cfs)
5%	21
10%	30
20%	42
25%	48
30%	52
40%	59
50%	67
60%	78
70%	94
75%	103
80%	117
90%	184
95%	331

Box and whisker plots[6] of the observed salinities (**Figure 3-2)** were developed for each segment and flow category. Horizontal lines were added at the 10 and 30 ppt corresponding to the optimal range for larval oysters and the normal range for adult oysters. The results indicate that the majority of the time (between the 25-75th percentile box ends) optimal salinities exist for both larval and adult oysters. Of particular importance is that even for salinities observed at very low flow condition (e.g. corresponding to flows < 5th percentile), salinity throughout the TBC complex remained within tolerable limits. Further evaluation of the salinity response to low-flow conditions is given in **Table 3-3.** The results indicate that observed salinity at extreme low-flow conditions is still acceptable for oyster survival. The asymptotic salinity response is a reflection of the boundary salinity in East Bay responding to ungaged and point source flows in TBC below S-160 and from Hillsborough River flow. At some low flow, discharge from S-160 is no longer affecting the salinity. In time, the salinity in TBC will become the same as the salinity in East Bay.

Table 3-3.
Extreme Low-Flows and Observed Salinities

Baseline Flow S-160		Observed Salinity @ Indicated Flows			
Percentile	**cfs (<=)**	**25th**	**50th**	**75th**	**n =**
0.5%	0.1	28.3	29.8	30.8	271
1%	1.9	28.1	29.6	30.8	290
2%	7.3	28.0	29.4	30.7	310
3%	12	27.9	29.3	30.7	315
4%	17	27.3	28.8	30.5	365
5%	21	27.3	28.9	30.5	380

The salinity that occurs during low-flow conditions is not threatening to the oyster communities within the McKay Bay/TBC complex. After reviewing salinity and flow records and conducting a field study of the TBC, Volety and Tolley reported "*Salinities at all segments at zero flows were optimal for long-term survival and growth of oyster reefs in the TBC"* (2004b). However, the field investigation also revealed evidence of mortality due to low salinities. Salinity/flow regression developed by Janicki Environmental Inc. (2003) for the HBMP evaluation was used to re-construct a time series of daily salinity for the period 1999-2003 (average age of live oysters was estimated to be < 4 yr) as shown in **Figure 3-3.** The results indicated several periods where salinity fell below 5 ppt in response to high discharges from S-160. Significant mortality occurs if salinities less than 5 ppt persist for two weeks or more. (ibid). Based on the regression results, Volety and Tolley recommended that when high (2,000-3,000 cfs) S-160 discharges are unavoidable, the duration be limited to less than 14 days at a stretch.

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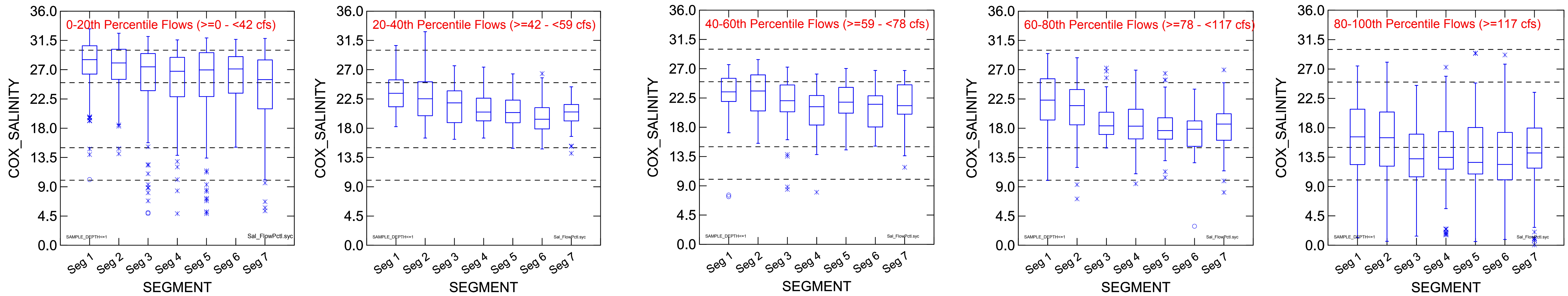
[6] [Where used in this report, the box and whisker plots follow Tukey's (1929) classic definition. That is, the hinges are the 25th and 75th percentiles respectively, the horizontal line is the 50th percentile and the whiskers extend to 1.5 times the distance between the hinges, or to the maximum (minimum) observed value, whichever is less. Outliers (values greater than 1.5 times inter-quartile distance) are plotted as individual points.]

Sample Depth <= 1 m



Sample Depth >= 3 m

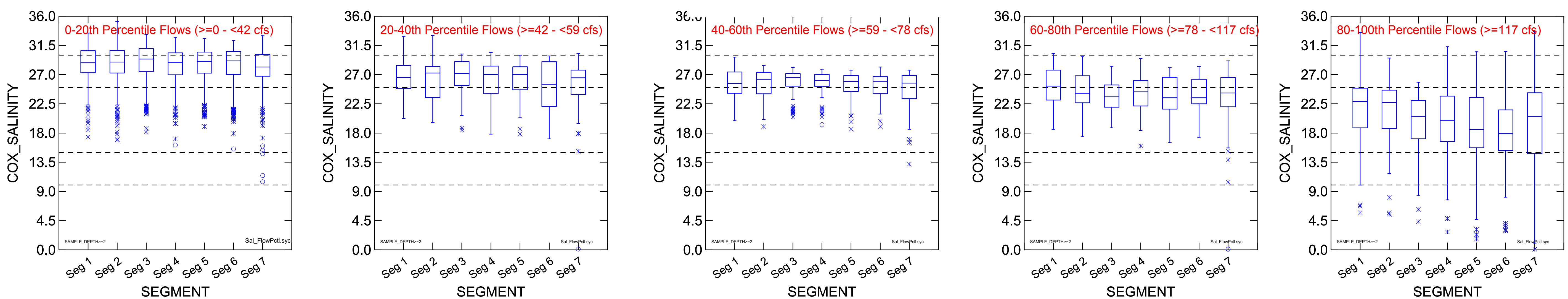


Figure 3-2 Salinity by Segment and Flow Class (1983 - 2003) (Horizontal Lines Represent Optimal (10 - 30 ppt) and Peak (15 - 25 ppt) Salinity for Oysters

In conclusion, the salinity resulting from zero and low-flow conditions is not threatening to the oyster community in McKay Bay/TBC complex. Thus, an MFL for the protection of the oyster community is not warranted. However, high flows are impacting the oyster community and to the extent possible without jeopardizing the flood control function of the TBC, discharge of flows higher than 2,000 cfs should be limited to a maximum duration of two weeks.

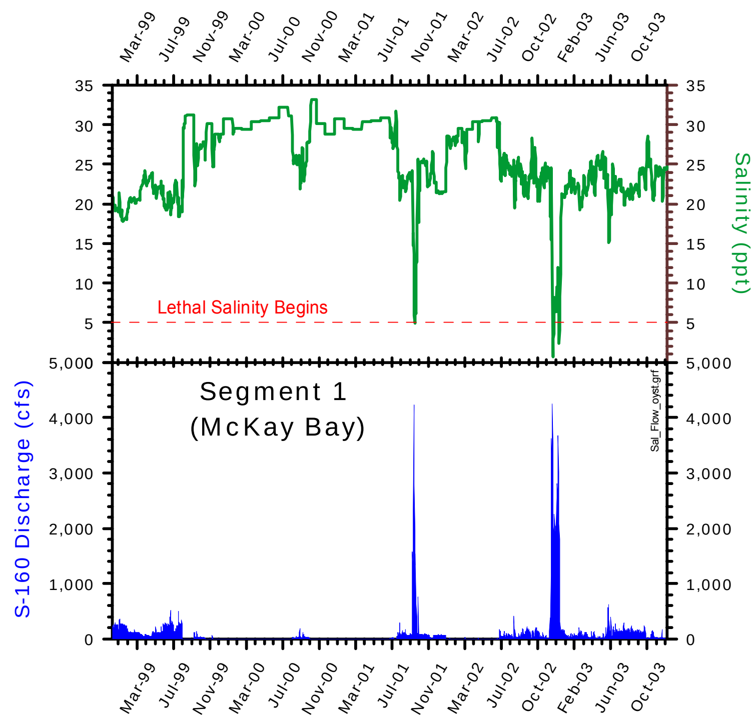


Figure 3-3 Modeled Salinity Time Series for TBC

3.3 VEGETATION

Descriptions of vegetation in McKay Bay/Palm River are limited to emergent wetland species and exotics. There is no known submerged aquatic vegetation (D. Tomasko, E. Estevez, personal communications) in the McKay Bay/TBC complex. A shoreline survey (WAR, 1993) of the Palm River above McKay Bay revealed 11,380 feet (3.4 km) of natural shoreline including 1,700 feet (0.52 km) of exotics. In relative terms, McKay Bay/ TBC has more natural shoreline (28 percent) than the lower Hillsborough (24 percent). The WAR study was purely descriptive and made no projections about the impact of altered fresh-water flows on the vegetative community.

As part of the TBEP MFL advisory group, Coastal Environmental (1997) made projections about longitudinal salinity changes resulting from various S-160 flow reductions. Coastal translated those results into change (**Table 3-4**) in shoreline length and area in contact with various salinity ranges. The results indicate that because of the inherently high saline Tampa Bay, increased flows below 100 cfs (2.8 m^3/s) are not effective at reducing salinity. At 200 cfs (5.7 m^3/s), 43,500 feet (13.3 km) of shoreline are reduced from > 20 ppt salinity to 10-20 ppt, but none of the shoreline is reduced below 10 ppt.

Table 3-4
Change in TBC Habitat With Increased Flow

		Release (cfs) From S-160				
Salinity Range	**Habitat**	0	20	40	100	200
0 - 10	Shoreline (ft)	0	0	0	0	0
	Area (ac)	0	0	0	0	0
10 - 20	Shoreline (ft)	0	0	0	9,919	43,500
	Area (ac)	0	0	0	52	233
> 20 ppt	Shoreline (ft)	0	0	0	- 9,919	- 43,500
	Area (ac)	0	0	0	- 52	-233
Adapted from Appendix N2 of TBNEP, 1997.						

During 2000-2002, PBS&J conducted fall and winter shoreline surveys as part of the HBMP for TBW. PBS&J (2003) reports a total of 55 hectares (136 acres) of emergent wetland vegetation surrounding McKay Bay and an additional 6.5 hectares (16 acres) along the Palm River. Five vegetative categories were defined, with the mangrove forest the overwhelmingly dominant category. **Table 3-5** provides an area distribution by classification and location and **Figure 3-4** illustrates the extent in 1999 as classified by Florida Department of Transportation's Florida Land Use, Land Cover Classification (FLUCC) codes.

Table 3-5
Emergent Vegetation in McKay Bay / Palm River

		McKay Bay		Palm River/TBC	
Classification	**FLUCC**	**hectares**	**acres**	**hectares**	**acres**
Mangrove Swamp	6120	49.1	121.2	0.3	0.7
Cattail	6412			0.0	0.0
Cordgrass	6421	5.7	14.1	0.1	0.2
Needlerush	6422	0.4	0.9		
Mixed Herbaceous wetland	6424			6.3	15.6

At the outset of the present study, it was intended to compare the salinity requirements of McKay Bay/Palm River to changes in salinity that might result from various reduced flow scenarios. Earlier work by Carter and others (Carter, 1973 as summarized by Lugo and Snedaker, 1974) suggest that there is a minimum energy expenditure associated with optimal chloride concentrations (from which salinity may be inferred). Carter found that an increase in the chloride gradient across the soil/water interface resulted in a slow-exponential decrease in the ratio of 24-hour respiration (R_{24}) to gross primary production (GPP). Within the range of salinities studied (8-30 ppt), the GPP increased as freshwater became more available, but the respiration rates also increased. The increase in respiration is a measure of the amount of energy expended to grow in a high salinity environment.

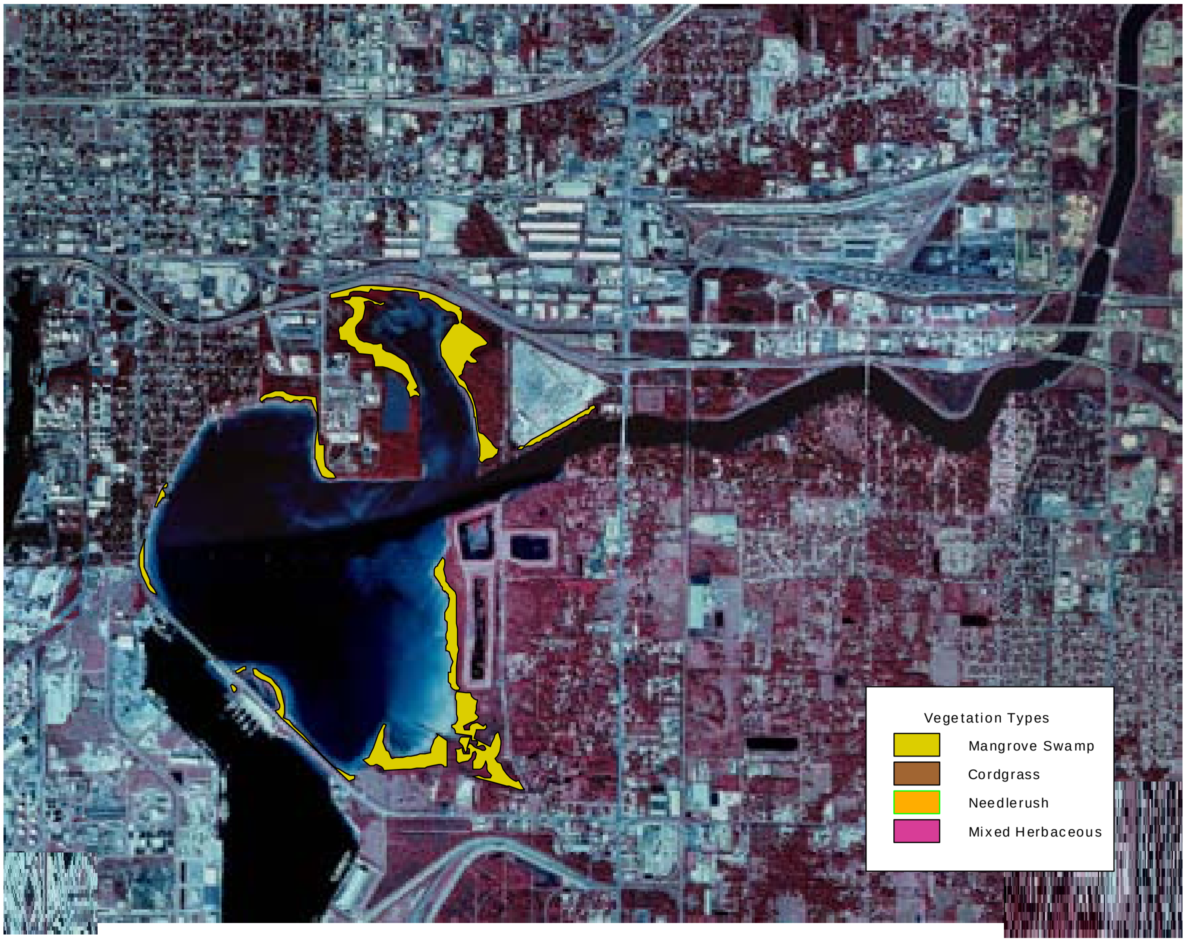


Figure 3-4 Emergent Vegetation in McKay Bay and Palm River

However promising the relationship of R_{24}/GPP to water column salinity initially appeared, contemporary mangrove research seems to focus more on the soil salinity and de-emphasize the importance of water column salinity. For example, the mangrove energy transfer model FORMAN (Chen and Twilley. 1998) of mangrove communities does not include an input term for surface water salinity and the growth algorithm assumes that there is no effect for salinities between 0 and 40 ppt. In essence, the pore water salinity is not directly related to water column salinity (R. Twilley, email communication). The lack of relationship is born out locally as USGS investigation (T. Jones, personal communication) of the mangrove communities in Bullfrog Creek revealed high soil salinities in the presence of low water column salinities. This may be partially result from the fact that mangroves can regulate soil salinity through transpiration (Passioura, et al. 1992).

PBS&J summarized TBC vegetation tolerance to salinity (**Table 3-6**), but pointed out that for mangroves at least, low salinity water is actually the preferred medium, but high salinity water excludes competition. Table 3-6 indicates that with the exception of cattail, all taxa present can tolerate the entire salinity range likely to exist in McKay Bay/Palm River even in the absence of freshwater inflow from S-160.

Table 3-6
Salinity Range of Existing Vegetation

	Salinity (ppt)	
Classification	**Tolerance**	**Optimal**
Mangrove, black	0 - > 50	~ 10
Mangrove, red	0 - 60	10 - 37
Mangrove, white	0 - 90	--
Cattail	0 - 10	0
Cordgrass, marsh hay	0 - 40	5 - 10
Cordgrass, saltmarsh	0 - 50	0 - 10
Needlerush, black	0 - 30	0

PBS&J, 1998

Furthermore, the recent Peace River HBMP Comprehensive Summary (PBS&J, 2004) calls into question the value of emergent vegetation as an indicator of salinity changes. Beginning in 1976 detailed aerial infrared photography of the lower river shoreline was taken providing 28 years of record. Since 1996 the photography has been taken in corrected, GIS compatible images suitable for change analysis. First/last occurrences of a large number of indicator species has developed biennially since 1976 and in 1979 permanent transects were established at three sites. During the monitoring period, an extended drought occurred producing salinity values far beyond what have been predicted to occur as a result of withdrawals. Despite these extreme events, little change could be detected. After evaluating this extensive database and in consideration of the inconclusive nature of the results, PBS&J has recommended that the first/last occurrence and the transect analyses be discontinued and that the aerial GIS based monitoring be reduced from a two-year schedule to a five-year schedule.

The lack of direct relationship of water column salinity to mangrove (the dominant vegetation present), coupled with the relative lack of response observed in the Peace system limits the use of vegetation as an indicator and suggests that an MFL goal for mangroves is probably not warranted.

3.4 BIRDS

The local population of wading birds in the Tampa Bay system is arguably the largest in the state (Paul and Schnapf, 1996) partly because of the decline in the Everglades. The Tampa Bay population is one of the largest in the nation, exceeding 34,000 breeding pairs of 20-25 species of colonial birds. Despite these impressive numbers, several of the common species including the brown pelican, snowy egret, herons (little blue, tri-color, black-crowned and yellow-crowned), white ibis, snowy plover, laughing gull and black skimmer are declining in response to loss of habitat or alteration of foraging habitat (PBS&J, 1998).

Despite its small size, McKay Bay is among the most important areas for birds in Florida (Paul and Woolfenden, 1985). It has had the largest number of individuals and species for over 20 years during the Audubon Christmas Bird Count (FDCA, 1995) with over two hundred species recorded over the years (FGFWC, 1994).

Given the extensive use of McKay Bay, birds represent a significant resource and if possible, warrant consideration in the development of an MFL. Bird usage was included in the TBW HBMP and PBS&J (2004) has attempted to conduct regular bird counts both in McKay Bay and at an upland site that is hydrologically isolated from McKay Bay. Two observation stations were established at the McKay Bay site, but the mangrove trees in front of one station grew too tall and obscured the view of the mud flats. Site two is undergoing the same growth and it is anticipated that this site will be abandoned in the near future. Both sites were too far removed for identification to the species level. No interpretation of the results was reported by PBS&J.

Like vegetation, it is difficult, if not impossible to quantitatively link bird usage with changing flows from S-160. If present, impacts resulting from changes in freshwater flow would be indirect – such as changes in benthic prey, or vegetation. Coupled with the fact that the aviary population (resident and migratory) is highly mobile, no further attempt to relate freshwater inflow and number of birds was undertaken.

3.5 FISH AND INVERTEBRATES

Fish and invertebrates are important resources to Tampa Bay. TBNEP identified ten species of fish and invertebrates as potential living resource targets. Several species concentrate primarily in tributaries during part of the year. Some species are important both for commercial (pink shrimp, mullet, crabs, and recreational purposes (snook, trout, tarpon).

3.5.1 Overview of Fish / Invertebrate Distribution and Abundance in McKay Bay/ Palm River

During the construction of the TBC, Brown (1971) predicted that estuarine fishes and invertebrates would be negatively impacted by the discharge of floodwaters from S-160. Soon after the completion of the construction, Price and Schlueter (1984) conducted a three-year fish survey in lower McKay Bay and concluded that large releases from S-160 were responsible for the reduced abundance of estuarine-dependent fishes encountered during the study. They also suggested that the community structure in McKay Bay might change because of S-160 discharges.

A recent evaluation (Peebles, 2004) commissioned for this report evaluated the change in community structure as part of a comprehensive evaluation of the use of McKay Bay/TBC by fish and invertebrates and the relationship to freshwater inflows. The database compiled and evaluated by Peebles consisted of 2,111 samples collected over a six-year period. Similarities among samples were compared across seasons, inflow levels, and locations along the estuarine gradient. Bray-Curtis dissimilarity was plotted (multidimensional scaling, MDS) and compared across these factors while looking at four biological groups: seine catch, trawl catch, ichthyoplankton catch, and invertebrate plankton catch.

Three types of change in community structure were detected. The first and most consistent change was seasonal, with ichthyoplankton demonstrating the strongest seasonal change. The second was change in invertebrate plankton composition caused by washout during high-inflow events. Average densities of small, truly planktonic organisms such as calanoid copepods tended to decrease during high-inflow months. The introduction of freshwater organisms was not a large contributor to changes in community structure during months of high discharge. The third and perhaps most significant change was in the shallow-water fish fauna. There were substantial differences in the compositions of the seine catches from McKay Bay and the Palm River, with the Palm River yielding more estuarine-dependent and estuarine-resident species.

When examined at a monthly or annual time step, discharges from S-160 were not found to cause large-scale changes in community structure within the Palm River and McKay Bay as a whole. However, the close association between many estuarine-dependent species and the area immediately below S-160 suggests that releases attract these animals either directly or indirectly. The control structure physically truncates the estuary functions and it is unclear if the attractiveness of freshwater releases is beneficial or detrimental to estuarine-dependent species. A study to compare the survival rates in the Palm River with those in other tidal would serve to answer this question.

The distributions of 25 taxa from the plankton-net collections were observed to shift in response to changes of freshwater inflow (**Table 3-7**). Most (> 60%) of these were upstream shifts in response to increasing inflow. The upstream shifts appeared to be related to two-layered estuarine circulation, in which surface outflow draws lower, saline water upstream. Planktonic animals, including fish eggs, appeared to be entrained in landward moving bottom water that transported them from McKay Bay into the Palm River when flow exceeded 100-400 cfs.

3.5.2 Habitat Preference

Another objective of Peebles' study was to determine the extent to which the Palm River-McKay Bay area was being used as nursery habitat by estuarine-dependent fishes and invertebrates, with emphasis on those species that are economically or ecologically important.

Estuarine-dependent animals are defined as species in which the adults, eggs, and larvae are most abundant in higher salinities while the juveniles are most abundant in relatively lower salinities. The adults of some estuarine-dependent species may also be common in reduced salinity habitats, but migrate to higher salinities to spawn. The extent of habitat shift is species-specific and is dependent on the lengths of local

Table 3-7
Significant Distribution Responses to Inflow

Description	Common Name	n	b	m	r^2 * 100	Lag Flow days
Palaemonetes pugio juveniles	daggerblade grass shrimp	10	-1.45	1.074	51	1
Saphirella spp.	copepods	17	-1.62	0.824	31	86
Gobiosoma spp. postflexion larvae	gobies	31	1.01	0.540	14	118
Anchoa mitchilli postflexion larvae	bay anchovy	31	0.41	0.449	13	52
polychaetes	sand worms, tube worms	46	1.03	0.445	18	1
decapod mysis	shrimp larvae	47	0.11	0.438	30	1
Pseudodiaptomus coronatus	copepod	40	0.22	0.406	11	118
Anchoa mitchilli eggs	bay anchovy	16	-0.20	0.363	39	6
Parasterope pollex	ostracod, seed shrimp	46	0.08	0.325	25	62
chaetognaths, sagittid	arrow worms	45	0.97	0.325	12	1
fish eggs, percomorph	fish eggs	32	0.10	0.308	16	6
decapod zoeae	crab larvae	47	0.78	0.293	18	1
Americamysis stucki	opossum shrimp, mysid	28	0.43	0.276	15	84
Erichsonella attenuata	isopod	18	0.38	0.241	23	65
amphipods, gammaridean	amphipods	47	0.89	0.178	12	1
Anchoa mitchilli adults	bay anchovy	47	0.68	0.143	10	10
Munna reynoldsi	isopod	20	1.66	-0.140	22	65
Oikopleura dioica	larvacean	38	2.27	-0.197	10	2
Lironeca sp.	parasitic isopod	47	2.73	-0.220	14	21
ostracods, podocopid	seed shrimps	29	3.72	-0.517	18	25
Limulus polyphemus larvae	horseshoe crab	17	4.51	-0.633	65	3
Mnemiopsis mccradyi	comb jelly, ctenophore	26	6.54	-0.758	27	1
Chrysaora quinquecirrha	sea nettle jellyfish	28	7.32	-0.771	29	14
Leptochela serratorbita	shrimp	13	5.64	-0.867	13	14
cirriped cypris	barnacle larvae	19	6.27	-0.957	19	45

estuarine gradients. Estuarine dependence is a matter of degree and may be either subtle or pronounced. For example, the young of some coastal marine species are most abundant at the mouths of estuaries, yet they remain in moderately high salinities.

The selected estuarine-dependent assemblage included12 fishes (bay anchovy, rainwater killifish, *Menidia* spp, snook, spotted seatrout, sand seatrout, spot, southern kingfish, red drum, striped mullet, clown goby and hogchoker) and three crustaceans (pink shrimp, blue crab and daggerblade grass shrimp). Most of these species favored shallow Palm River waters over shallow McKay Bay waters, whereas deep McKay Bay waters were favored over deep Palm River waters. Mud was generally preferred over sand bottom, with both mud and sand both being preferred over rocks and oysters. Shorelines with shrubs and trees ranked highest among shoreline types, with beaches ranked the lowest.

McKay Bay/Palm River Habitat Preference of Select Estuarine – Dependent Species	
1. Palm River Shallow 2. McKay Shallow 1. Mud 2. Sand 3. Rock/Oyster	1. McKay Deep 2. Palm River Deep 1. Shrubs / Trees 2.Beaches

In the present classification system, only those species with pronounced estuarine dependence are classified as such. In contrast, estuarine species are permanent residents. These species spend their entire life cycle within low-salinity habitats and do not undergoing predictable migrations to other habitats.

The distributions of the selected species were mapped and then compared with the distributions of 18 classes of potential prey types, four types of competitor/predator and two types of parasite. Pink shrimp and blue crabs were most abundant near the mouth of the Palm River, as were juvenile sand seatrout. Cumaceans, crab larvae, the crab *Pinnixa sayana*, amphipods and mysids are potential prey types that were also abundant in this area. However, other primarily benthic and infaunal food resources were not evaluated and may be relevant to the distributions of pink shrimp and blue crabs.

A second area of fish and invertebrate concentration was along shorelines at the upper end of the Palm River (below S-160). This area had relatively high densities of young bay anchovy, snook, spot, red drum, striped mullet, clown goby and hogchoker. All except the clown goby are estuarine-dependent; the clown goby is generally considered to be an estuarine resident. It is clear that many economically and ecologically important species are attempting to use the Palm River as nursery habitat, despite the dramatic alterations that have been made to its physical habitat, water quality and freshwater inflow pattern. A possible reason for the apparent preference for the upper Palm River is the abundance of certain prey types, such as grass shrimp, juvenile bay anchovies, the mysid *Americamysis almyra* and polychaetes. An alternative explanation is an olfaction-based attraction to chemical cues that are either delivered or created by freshwater inflows.

3.5.3 Relationship of Abundance to Inflow

Elevated inflows (>100 cfs) moved the gelatinous predator *Mnemiopsis mccradyi* downstream and reduced its overall number. This ctenophore is an efficient predator of fish eggs and larvae and competes with larval and juvenile fishes for zooplankton prey.

The inflow effects on *Mnemiopsis* distribution and abundance therefore enhance the Palm River as nursery habitat. Elevated inflows also tended to push another important fish predator, the sea nettle *Chrysaora quinquecirrha*, out of the Palm River and into McKay Bay, but the abundance of this animal tended to increase in conjunction with downstream displacement.

Where possible, the relationship between inflow and abundance was quantified. Both abundance (number organisms) and flow (cfs) was natural log-transformed prior to analysis. Flows included both releases from S-160 and ungaged flow (HSW, 2004) estimates below the structure. Lag flows (moving averages) were developed for 1 to 183 prior days of flow. The lag giving the highest correlation coefficient (**Figure 3-5**) was then tested for significance ($p<=0.05$). The inflow / abundance association of 34 taxa (**Table 3-8)** were significant at the 5% level, although some showed evidence of serial correlation (Durbin-Watson $p<0.05$). **Figure 3-6** illustrates the inflow / abundance response for two taxa collected in the Palm River.

Inflow/abundance relationships with lag flows less than 4 days are not shown as lags this low suggest a catchability reponse (organisms moved into a catch zone) instead of a true biotic response. Abundances of 34 taxa from the plankton-net collections changed in response to changing inflow. Most decreased in number as inflows increased. Polychaetes, which are worms that normally live within the bottom substrate, increased in abundance during elevated inflows, but this appeared to be caused by individuals moving from the substrate into the water column, probably in an effort to avoid the oxygen-depleted bottom waters that tend to form during periods of elevated inflow.

Using the regressions developed, a series of reduced flow scenarios were evaluated to determine the effect on abundance. A reference abundance was developed for the median flow for the baseline period (1983-2003) and the baseline flow (S-160 reconstructed without diversions/withdrawals). Median flows were derived for each lag period from this flow record and the baseline abundance calculated as shown in **Table 3-8**. For example, the median of the 22-day lag (needed to estimate *mysid* abundance) is 116 cfs and the median of the 60-day lag (needed to estimate pink shrimp) is 130 cfs. Using same base period and baseline flow record, a low-flow threshold (LFT) of 30 cfs. (corresponding to the 10th percentile of the flow record) was assumed and various reductions in flow (e.g. 10, 20, 30 . . . . 70, 80, 90 percent) were applied to the record. The median period flow for each reduced flow scenario was then calculated and applied to the abundance regressions. The percent difference from baseline conditions is illustrated in **Figure 3-7**. Figure 3-7 reveals that some taxa benefit from reduced flows and others benefit from increased inflow. The taxa that increase with decreasing flow are largely coastal or marine organisms that move into TBC when the flow decreases and the salinity increases. Thus, while a decrease in flow seems to favor an increase in abundance for many taxa, the opposite effect occurs with the estuarine-dependent taxa.

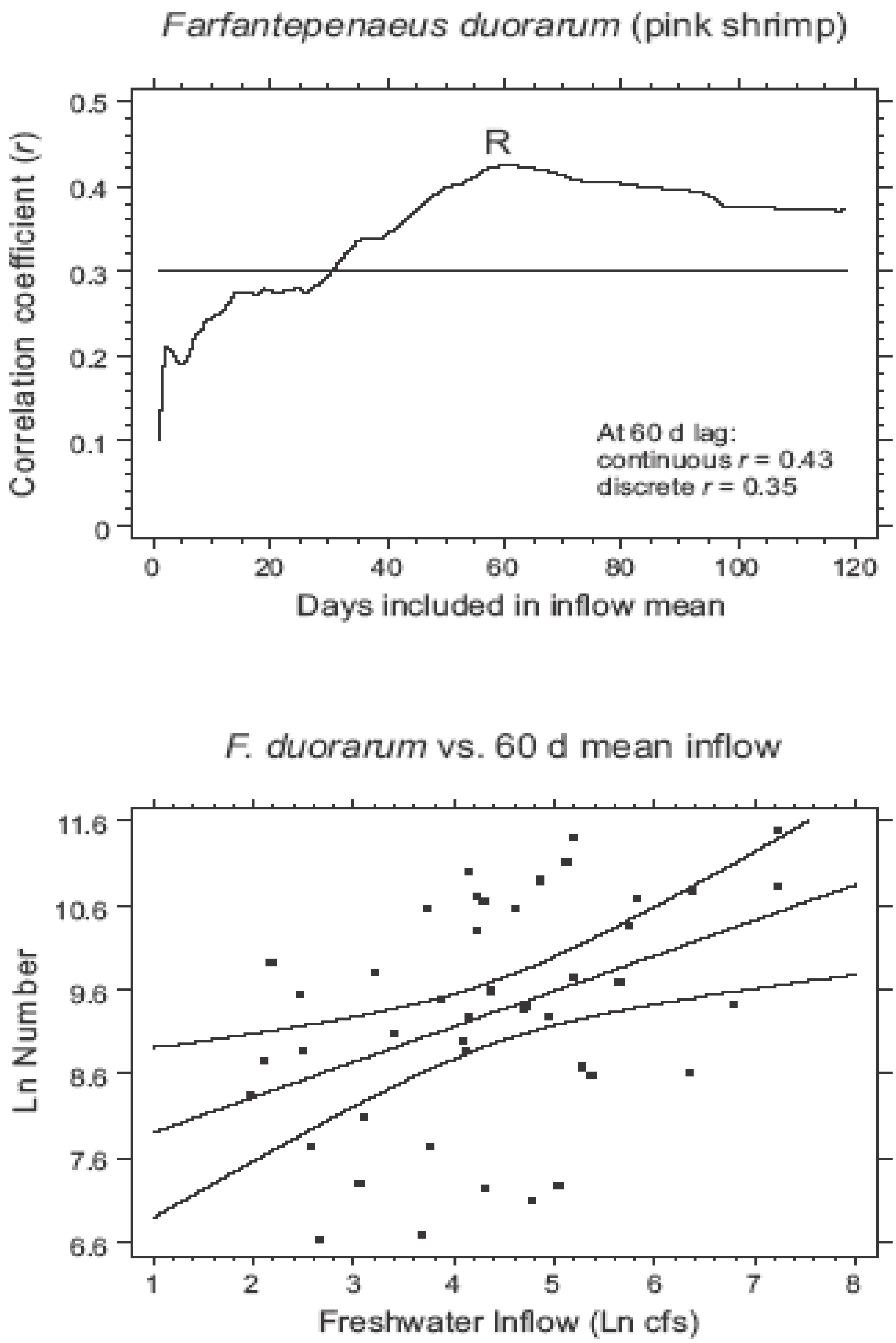
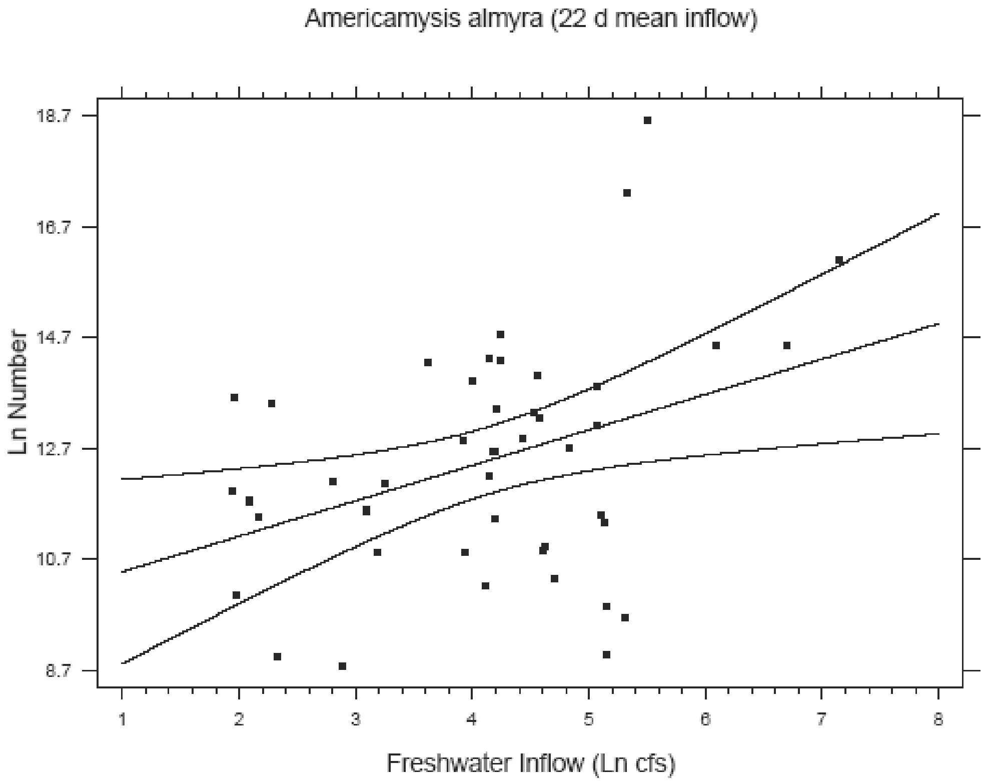


Figure 3-5 Example Lag Flow / Abundance Regression - Pink Shrimp



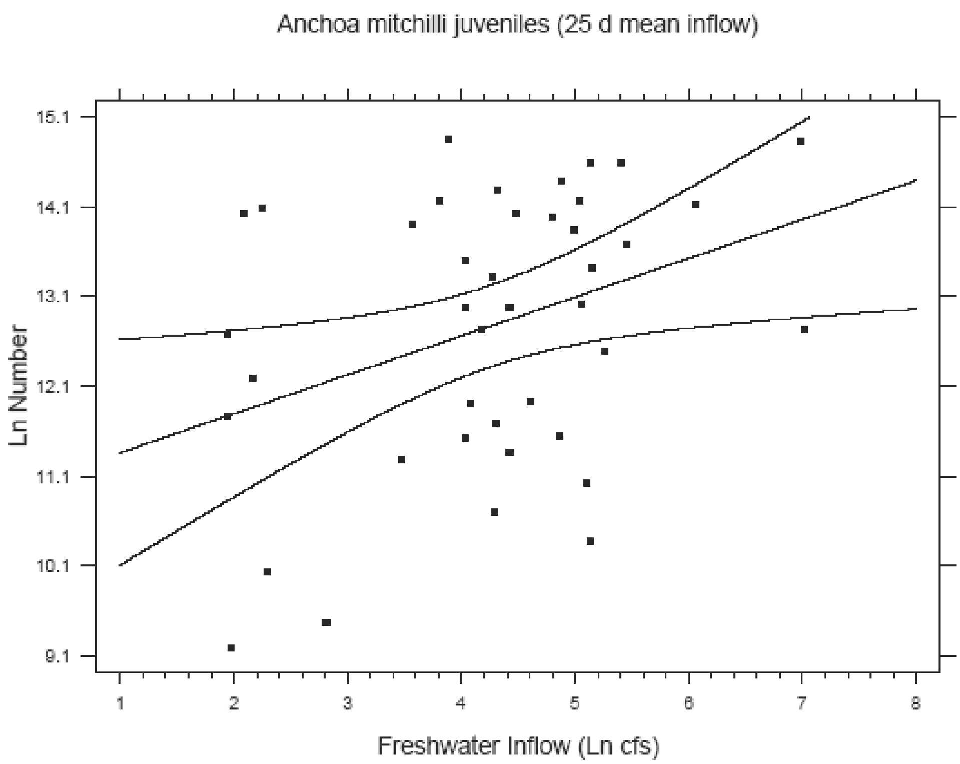


Figure 3-6 Example Lag Flow Abundance Regression - Mysids and Anchovies

Table 3-8
Abundance Regression and Example Calculations for 30 cfs LFT and 40% Withdrawal Above LFT

Plot Symbol Fig. 3-7	Description	Common Name	n	b	m	r^2 *100	Lag Flow - days	Median Flow, cfs Baseline 96.0	Median Flow, cfs Alternative 65.0	
								Number	Number	% Diff
S	Parasterope pollex	ostracod, seed shrimp	46	16.738	-0.5950	9	**118**	977,981	1,183,967	21.1
G	Anchoa mitchilli juveniles	bay anchovy	41	10.930	0.4330	13	**25**	439,311	381,500	-13.2
E	Americamysis almyra	opossum shrimp, mysid	44	9.841	0.6390	14	**22**	391,956	317,816	-18.9
K	Anchoa mitchilli adults	bay anchovy	47	9.768	0.3550	15	**3**	90,127	78,300	-13.1
X	Mnemiopsis mccradyi	comb jelly, ctenophore	26	17.336	-0.7340	15	**64**	945,629	1,203,540	27.3
Z	decapod zoeae	crab larvae	47	22.172	-0.7660	15	**94**	99,064,631	124,469,615	25.6
J	ostracods, podocopid	ostracods, seed shrimps	29	8.685	0.3680	16	**52**	35,312	31,163	-11.7
3	cirriped nauplius stage	barnacles	31	16.718	-1.0770	16	**92**	92,359	127,604	38.2
1	cumaceans	cumaceans	47	19.355	-0.7820	17	**15**	6,354,474	8,329,427	31.1
Q	blenniid preflexion larvae	blennies	36	12.985	-0.5290	18	**22**	35,244	41,925	19.0
R	decapod mysis	shrimp larvae	47	18.738	-0.5710	18	**118**	8,137,757	9,776,100	20.1
8	Farfantepenaeus duorarum	pink shrimp	44	7.486	0.4200	18	**60**	13,791	11,986	-13.1
P	amphipods, caprellid	skeleton shrimps	26	13.067	-0.4920	19	**93**	42,274	48,974	15.8
T	Anchoa mitchilli postflexion larvae	bay anchovy	31	15.125	-0.6470	20	**55**	159,301	198,801	24.8
L	Lolliguncula brevis juveniles	bay squid	23	10.770	-0.2590	21	**17**	13,958	15,246	9.2
C	Americamysis almyra	opossum shrimp, mysid	44	9.514	0.7450	23	**1**	408,954	303,051	-25.9
W	alphaeid postlarvae	snapping shrimps	31	15.178	-0.6960	23	**84**	128,623	161,363	25.5
F	Anchoa mitchilli juveniles	bay anchovy	41	10.551	0.5290	24	**2**	436,482	352,435	-19.3
I	foraminiferans	foraminiferans	20	8.300	0.4150	24	**18**	28,729	25,042	-12.8
H	Sphaeroma quadridentata	isopod	23	8.543	0.4250	25	**34**	39,488	34,127	-13.6
4	Anchoa mitchilli eggs	bay anchovy	16	19.012	-1.1630	25	**12**	758,349	1,151,838	51.9
U	Microgobius spp. postflexion larvae	gobies	22	13.902	-0.6600	26	**114**	41,876	51,578	23.2
5	fish eggs, percomorph	sciaenid eggs (primarily)	32	19.612	-1.6600	26	**96**	94,349	155,191	64.5
V	Eusarsiella zostericola	ostracod, seed shrimp	37	14.130	-0.6920	27	**118**	44,586	55,685	24.9
A	polychaetes	sand worms, tube worms	46	10.8	0.846	30	**14**	2,646,852	1,966,178	-25.7
Y	Squilla empusa larvae	mantis shrimp	22	13.986	-0.7420	30	**118**	30,143	38,257	26.9
6	Anchoa spp. preflexion larvae	anchovies	25	18.746	-1.2850	31	**44**	280,556	430,619	53.5
2	Evadne tergestina	water flea	15	15.789	-0.9590	32	**2**	87,011	128,222	47.4
D	Chrysaora quinquecirrha	sea nettle	28	9.471	0.7310	35	**1**	367,445	273,829	-25.5
B	Harrieta faxoni	isopod	15	9.871	0.7480	40	**2**	606,083	447,911	-26.1
M	Syngnathus scovelli juveniles	gulf pipefish	19	11.561	-0.4120	40	**118**	13,656	15,589	14.2
N	Cynoscion arenarius preflexion larvae	sand seatrout	13	11.515	-0.4330	46	**1**	13,830	16,462	19.0
O	Chasmodes saburrae postflexion larvae	Florida blenny	10	11.640	-0.4540	50	**3**	13,924	16,669	19.7
0	Chasmodes saburrae flexion larvae	Florida blenny	13	13.104	-0.7680	53	**21**	12,776	16,489	29.1
7	Anchoa spp. flexion larvae	anchovies	26	18.797	-1.3260	55	**49**	236,032	368,278	56.0
	Average loss of 3 significant taxa =	**15%**								

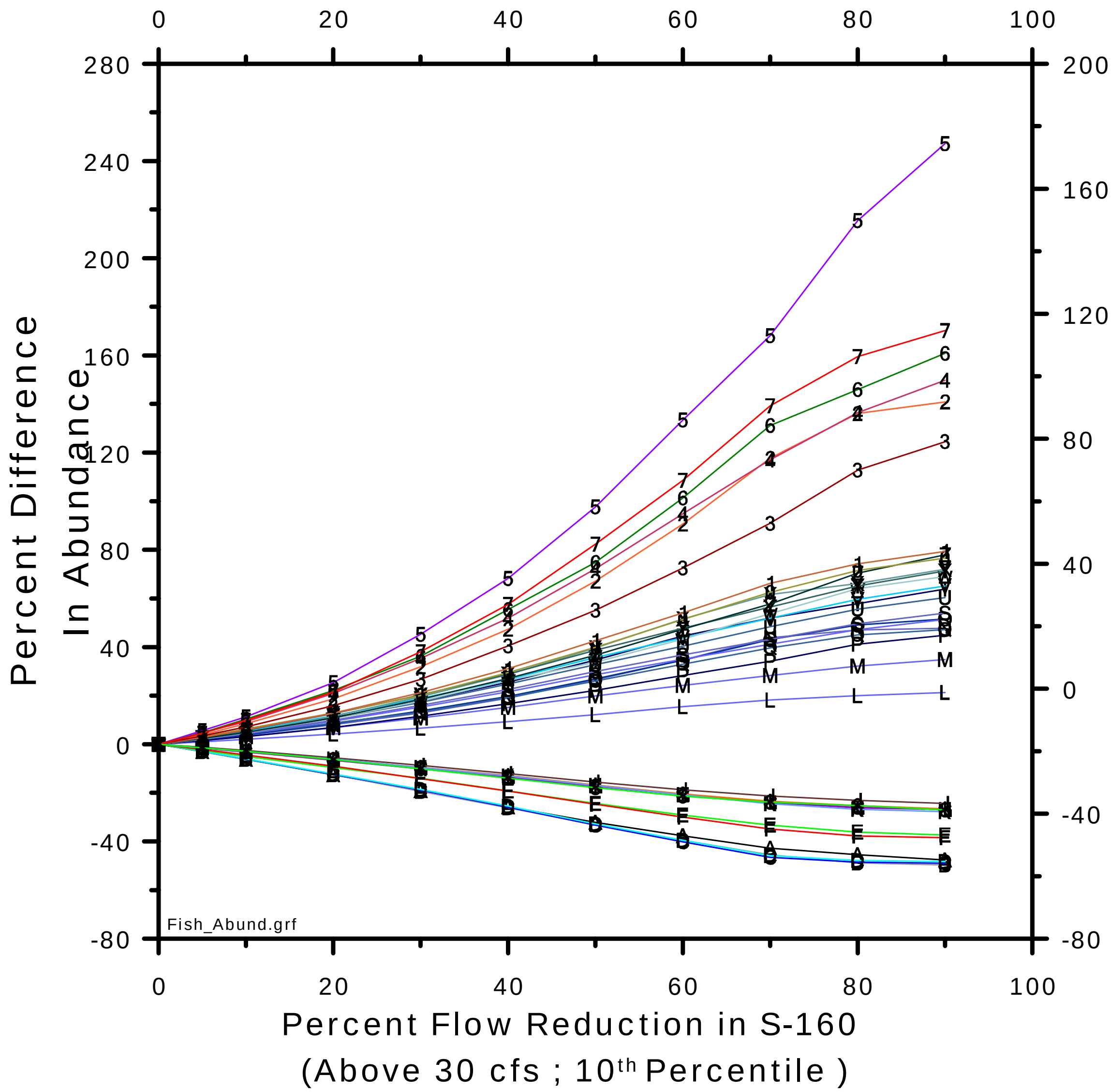


Figure 3-7 Change in Abundance as a Function of Reduced Flows - All Taxa

Three species of special significance were identified. The mysid *Americamysis almyra*, juvenile bay anchovy and pink shrimp juveniles increased in abundance after periods of increased inflow. All three have been observed to have positive inflow-abundance responses in other Southwest Florida estuaries. The mysid and bay anchovy juveniles are important prey for young estuarine-dependent fishes that use tidal rivers as nursery habitat, and the pink shrimp is an economically important species. **Figure 3-8** focuses on these three taxa and illustrates the impact of reduced flows on their abundance, while **Figure 3-9** illustrates the impact of varying the low-flow threshold.

In general, organisms' responses to freshwater inflow into the Palm River and McKay Bay were more subtle than those observed in other estuarine areas of Southwest Florida. The abundance of mysids and bay anchovy juveniles in the Palm River/McKay Bay estuarine system changed in response to inflow, but these changes in abundances were the lowest observed among seven estuarine areas surveyed using identical methods. While the response may not be as direct as noted elsewhere and the structural alterations have been significant, McKay Bay/Palm River flow/abundance relationships indicate that the system is still providing some semblance of estuarine functionality.

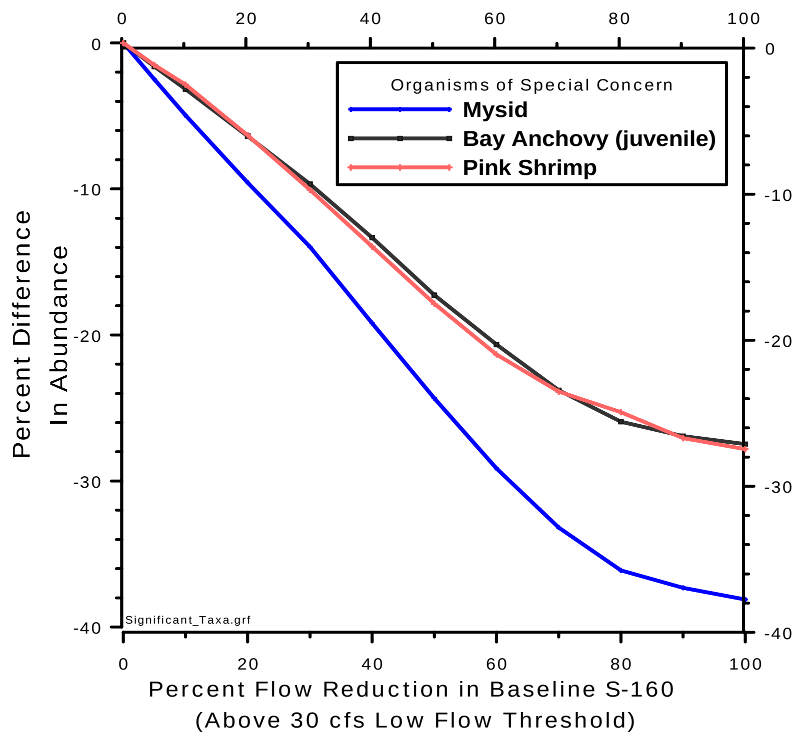


Figure 3-8 Abundance / Inflow Relationship for Three Significant Taxa

3.6 BENTHOS

The benthos represent an important food component, serving as prey for fish and other upper trophic -state components. The distribution, abundance and composition of the benthic community is a complex function affected by currents, physical and chemical sediment characteristics, overlying water quality and predation. Soft-bottom sand, sand-

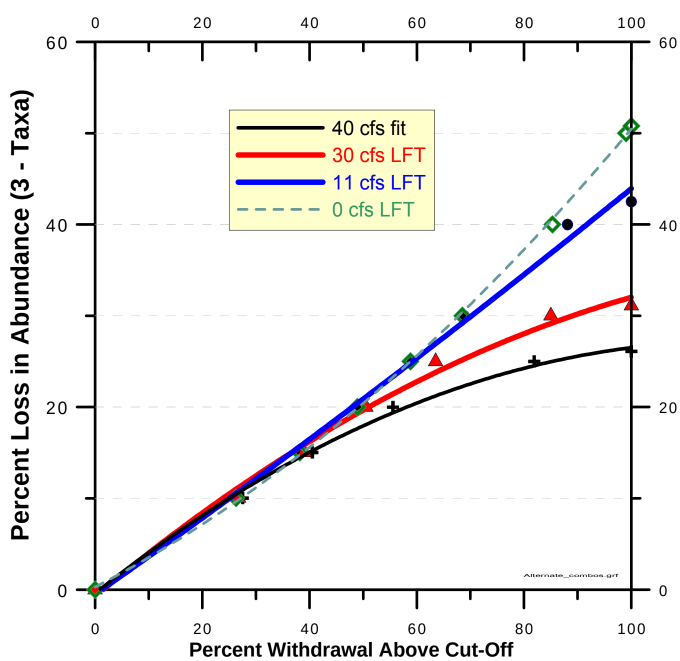


Figure 3-9 Effect of LFT on Abundance at Various Withdrawal Rates

gravel and shell are the most common along the coasts of Florida. The fauna is generally dominated by polychaete worms, crustaceans, mollusks and insect larvae (Livingston, 1991). Because benthic animals have limited mobility they are good indicators of environmental quality at the location in which they are found.

3.6.1 Benthos Characterization Metrics

Both species composition and abundance are important considerations when evaluating a benthic community. If the number of species is low, but the abundance is high it is likely that some stressor is impacting the community. Several metrics are commonly used to describe the benthic community. Abundance is a measure of the total number of individuals per unit area (typically #/m^2), irrespective of the number of different types of organisms present. In contrast, diversity is a measure of the number of different species present. (Diversity is commonly expressed as the Shannon-Weiner index (H')). A healthy community has high diversity.

Table 3-9
Frequency of Occurrence – McKay Bay

	Frequency of Occurrence			
	Ranking		Percent Occurrence	
Taxa	Shallow	Deep	Shallow	Deep
Capitella capitata	1	40	51%	1%
Glycinde soitaria	2	11	44%	5%
Nemertea sp.	3	17	41%	4%
Amygdalum papyrium	4	37	40%	1%
Paraprionospic pinnata	5	5	39%	10%
Steninonereis martini	21	1	20%	23%
Ampelisca cf. abdita	11	2	33%	20%
Clyclaspis cf. varians	25	3	18%	12%
Oxyurostylus cf. smithi	18	4	24%	10%

A benthic index, patterned on the index developed by the United State Environmental Protection Agency (EPA) EMAP for the Louisianian Province was developed for Tampa Bay (TBNEP, 1996). The index incorporates overall abundance, the Shannon-Weiner index and the abundance of tubificid oligochaetes, capitellid polychaetes, gastropods and amphipods. The Tampa Bay Benthic Index scores for benthic sample results from two stations in the un-dredged portion of McKay Bay were 14.8 and 14.4 that compares favorably with Hillsborough Bay (score of 13.3). In contrast Old Tampa Bay, Middle Tampa Bay, Lower Tampa Bay, Boca Ceiga Bay, Terra Ceia Bay and the Manatee River all had scores between 18.9 and 20.5.

3.6.2 Common Benthic Residents

Data sources specific to McKay Bay/TBC were identified in Chapter 2. In addition to these, the results of a number of studies encompassing the greater Tampa Bay area were summarized by PBS&J (1998).

The study conducted by WAR (WAR and SDI, 1995) during 1991 – 1993 identified the most abundant McKay Bay organisms as *Nereidae sp*. and *Paraprionospio pinnata* (both polychaetes) and amphipods (*Ampelisca abdita*). Those results were similar to the frequency of occurrence results developed by PBS&J (2004) during 2000 – 2002 as part of the HBMP study. The HBMP study made a distinction between the 'deep' stations in dredged canal and the 'shallow' strata (< 2 m in depth). (WAR stations were both in McKay Bay in a location equivalent to the PBS&J "shallow" strata). **Table 3-9** provides the ranking for the five most frequently encountered taxa in each stratum for 2000 – 2002.

3.6.3 Benthos Samples

Sample locations in McKay Bay/Palm River were presented in Figure 2-15. Grabe *et al*. (2004) analyzed Palm River TBEP HIMP results from 1995-1998 and using power analysis determined that a minimum of 520 samples would be necessary to detect a 20 percent change in mean number of taxa (at a five percent significance level). McKay Bay samples were less variable, and a power analysis suggested that 80 samples would be required to detect the same level of change.

3.6.4 Benthos Relationship to Abiotic Parameters

Grabe also reported that there was no statistically significant relationship between salinity and number of taxa for either the Palm River or for McKay Bay, although a significant relationship (at $p < 0.2$) was between species richness and sample depth and between richness and percent silt clay (%SC) in the sediment. Samples collected from 'deep' stations (> 2m) showed low densities and low number of taxa. Grabe cites low DO as common stressor for the deeper stations.

In contrast to Gabe's conclusions, but using a combined dataset of WAR results from McKay Bay/Palm River and the Lower Hillsborough river, Rakocinski (2004) reported that salinity was a significant variable correlating with community structure (followed by watershed position, season, depth and temporal sequence.)

All researchers who have investigated the benthic community in McKay Bay/Palm River have pointed to chronic hypoxic conditions as a major factor controlling structure and abundance. Additional efforts are currently underway to evaluate and quantifiy the salinity/benthos relationships for all coastal rivers within the District.

3.7 WATER QUALITY - SALINITY

In the previous TBC MFL, the District chose to focus on salinity and DO because these two parameters are believed to be the '*critical water quality variables affecting the abundance and distribution of organisms in the Lower Hillsborough River and the tidal reached of the Tampa Bypass Canal*' (SWFWMD, 1999). The TBNEP Minimum flow advisory group also deemed these two [TBNEP, 1997) to be the most important and the subsequent peer review identified (Bedient et al., 1999) these parameters as the primary factors affecting habitat quality in the McKay Bay/TBC system. Thus, in accordance with this guidance, the present evaluation is focused exclusively on these two water quality parameters.

Estuarine salinity varies with the distance from the source of higher saline water and the volume and ionic strength of freshwater inflows mixing with the saline source. As previously described (Chapter 3.2), East Bay water serves as the source of more saline water for McKay Bay/Palm River. If all of the freshwater inputs to McKay Bay/Palm River were terminated, given sufficient time for complete mixing the TBC complex would become isohaline with East Bay. During periods or low to moderate freshwater input at the head of a typical estuary, mixing is nearly complete and the salinity varies longitudinally, but not vertically. In contrast, during periods of high inflows, fresh(er) water tends to sheet flow at the surface over the top of more saline water at the bottom.

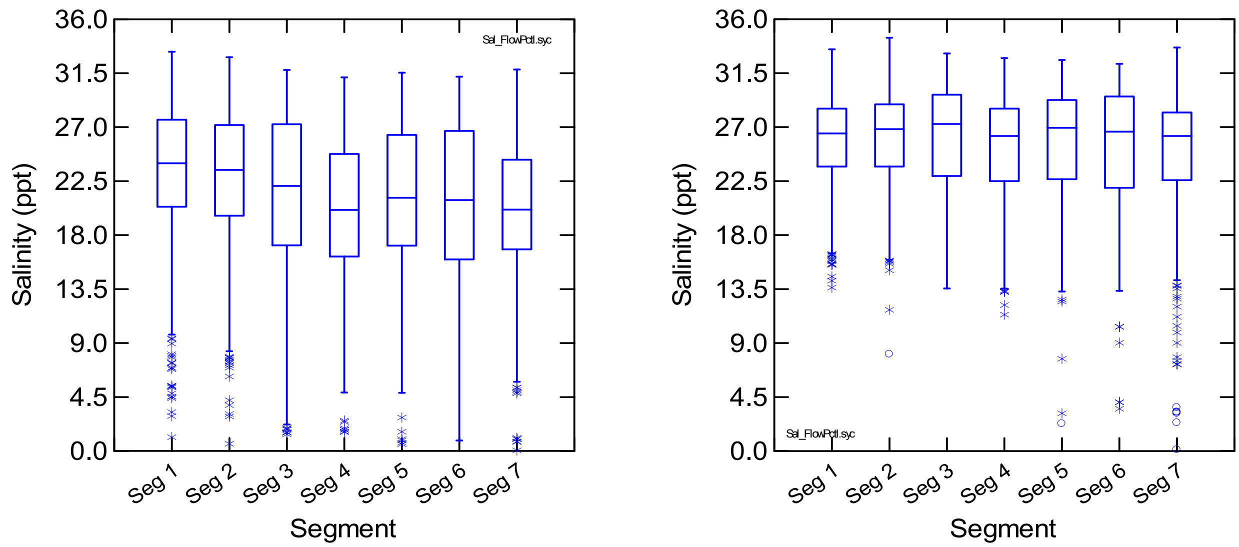


Figure 3-10 TBC Salinity 1974 -2003 at < 1 m (left) and ≥ 3 m (right)

The deepening and widening of Palm River that created the TBC also created a very efficient conduit for salt water. **Figure 3-10** provides a box plot comparison of observed surface salinity within each segment. **Table 3-10** provides May and September quantile values for each segment and portions of McKay Bay. From the box plots, it is evident that very little longitudinal variation exists in the Palm River.

Yet, despite the lack of longitudinal gradient, strong vertical salinity gradients set up in response to increased flow. **Figure 3-11** depicts a positive relationship between flow at S-160 and the vertical salinity difference within segment 3 (flows>= 5 cfs) for the period 1991-2003. **Figure 3-12** details the salinity profiles in Segment 3 when S-160 flows are greater than 180 cfs (90th percentile observed flow, 1974-2003) and indicates that a haloclyne develops approximately 2 meters below the surface.

Salinity, as presently estimated from conductivity, is a gross measure of ion activity in the water. In one sense, salinity may be considered a surrogate for freshwater inflow but it also has a more effect on the estuarine biota. To survive, estuarine organism must regulate the osmotic pressure resulting from changes in salinity. Osmoregulation consumes energy reserves and in some taxa (Chapter 3.1.5) lethality

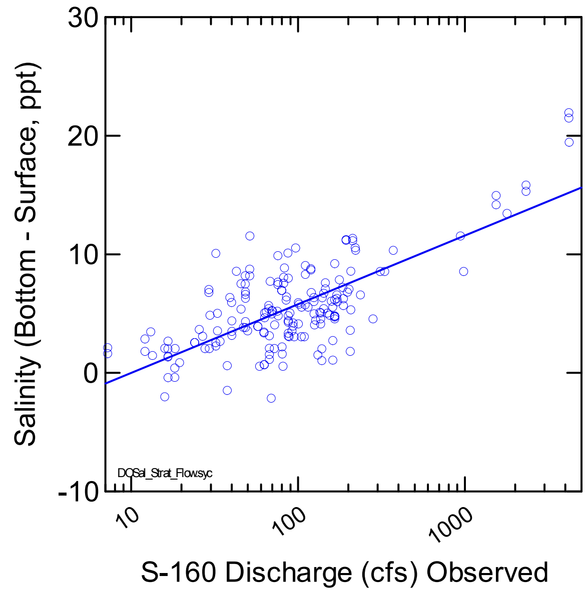


Figure 3-11 Salinity Stratification vs S-160 Flow (Segment 3)

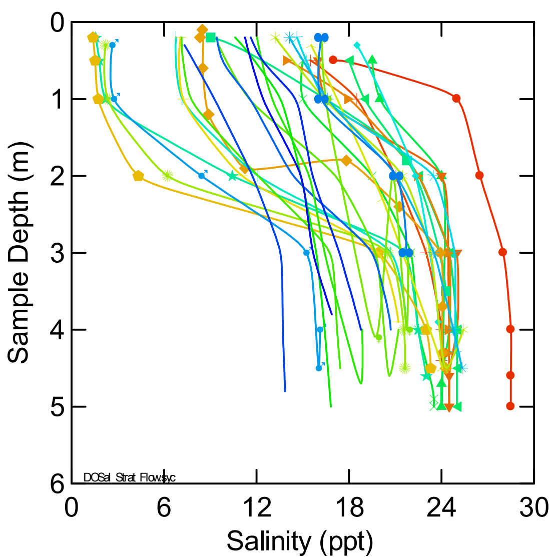


Figure 3-12 Salinity Profiles : Flows ≥ 180 cfs and Depth > 3 m (Segment 3)

may result when the energy expenditure is too great. Thus, the estimation of an estuarine MFL must consider the salinity changes likely to occur.

For the present study, regressions developed by Janicki Environmental for TBW's HBMP study were used to estimate the salinity response to flow at S-160. These regressions represent updated results to the regressions used in the prior MFL (Coastal Environmental, 1997), which the peer reviewers felt were deficient of low-flow observations. The original Coastal regressions were based on the WAR/SDI 1991-1993 study results and validated the EPCHC data (1974-1997) and USGS continuous recordings from 1981-1982 and 1991-1993. The development of the current regressions included observations from multiple monitoring programs including :

- EPCHC Ambient Water Quality Program (1983-2002)
- EPCHC Independent Monitoring Program (2000 – 2002)
- TBEP Benthic Program (1995-2001)
- TBW HBMP - FWRI Fish and PBS&J Water Quality Components. (2000-2002)

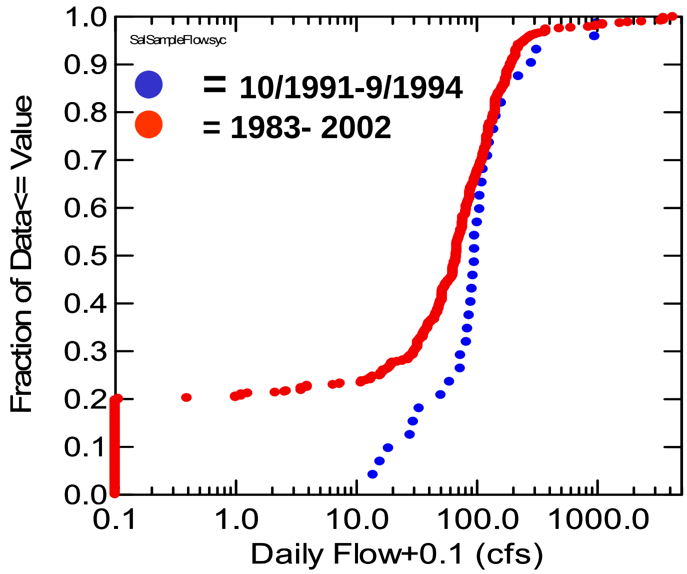


Figure 3-13 Comparison of S-160 Discharge on Sampling Days

Program results were used to develop monthly regressions for salinity at a) surface, b)1-meter depth, c)2-meter depth and d) bottom depth. Separate regressions were developed for the Palm River and McKay Bay. The development of the regressions is documented by Janicki Environmental in *Year 3 Interpretive Report* (PBS&J, 2003(b)). A distribution function of S-160 flows used to develop the regressions is given in **Figure 3-13** to illustrate the difference in flows available for the present and prior regressions. When the first regressions were developed, 20 percent of the monitoring day flows were ≤ 45 cfs. In contrast, for the updated regressions 20 percent of the monitoring day flows were ≤ 0.1 cfs.

With the exception of the 2-meter regression, longitudinal location in the Palm River was not a significant factor in the equations. Therefore, for a given flow and month, the surface and bottom salinity anywhere in the Palm River may be represented by a single value. The surface and bottom Palm River flow/salinity regressions were executed for a daily time series of flows representing the baseline period (1983-2003). Two flow scenarios were used; baseline flows (S1) in the absence of water supply manipulation and a withdrawal scenarios (S4) representing 40 percent withdrawal above a low-flow cut-off of 30 cfs. The S4 scenario was chosen because it is the flow that results in an approximate 15 percent reduction in abundance (see Figure 3-10) of regionally significant biota (fish, shrimp and mysids). The Palm River evaluation was chosen over a McKay Bay evaluation because salinity in the upstream and constrained reach of the estuary is more responsive to changes in freshwater inflow.

Figures 3-14 and 3-15 along with companion **Table 3-12** illustrate the differences that would exist between the baseline flow scenario (S2) and scenario S4 (40% withdrawal above a 30 cfs low-flow threshold). The maximum difference (4.7 ppt) occurs in the surface salinity under high-flow conditions (5^{th} percentile). This difference is clearly within the annual, or even diurnal range of variation and is considered biologically insignificant. The majority of comparisons resulted is less than a 5 percent difference between the two flow scenarios and indicate that the MFL based on fish abundance also protects against radical changes in salinity. These results are also consistent with previous investigations that indicated the Palm River is a high-salinity system that is relatively insensitive to changes in flow.

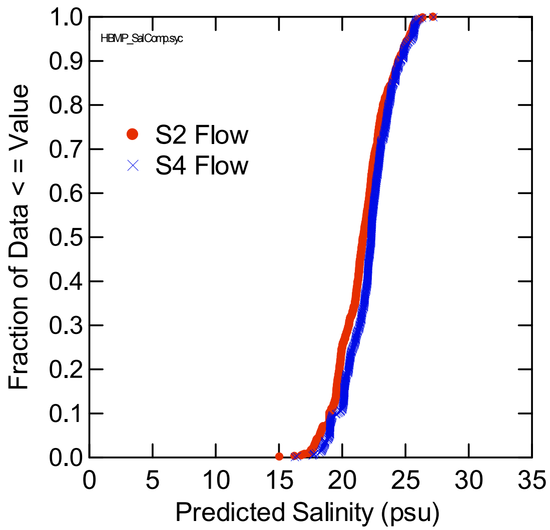


Figure 3-14 Palm River May Surface Salinities at Baseline and at Reduced Flow (see text)

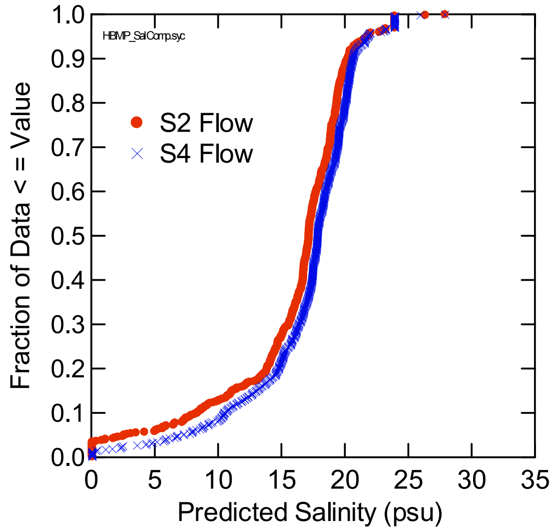


Figure 3-15 Palm River September Surface Salinities at Baseline and Reduced Flow (see text)

Table 3-12
Predicted Palm River Salinity Distribution for Flow Scenarios S2 and S4.

	May				September			
	Surface		Bottom		Surface		Bottom	
	S2	S4	S2	S4	S2	S4	S2	S4
5%	18.27	18.99	22.33	22.33	2.61	7.29	16.54	17.14
10%	19.03	19.61	22.72	22.72	8.39	10.52	17.14	17.14
20%	19.82	20.51	24.82	24.82	13.89	14.81	20.43	20.73
30%	20.57	21.38	26.36	26.40	15.59	16.39	21.73	21.83
40%	21.28	21.99	26.47	26.50	16.72	17.43	22.03	22.23
50%	21.70	22.29	26.51	26.52	17.18	17.85	22.35	22.53
60%	22.21	22.60	27.25	27.27	17.77	18.47	24.32	24.32
70%	22.69	23.02	28.08	28.12	18.78	19.44	24.42	24.42
80%	23.28	23.68	28.58	28.62	19.39	20.05	25.22	25.22
90%	24.50	24.64	29.30	29.29	20.26	20.65	26.32	26.32
95%	25.31	25.49	30.24	30.24	21.80	21.83	27.11	27.11

3.8 WATER QUALITY - DISSOLVED OXYGEN

Atmospheric oxygen partitions into water and is known as dissolved oxygen, or DO. The thermodynamic balance is also affected by photosynthesis within the water column and oxidation of both organic and inorganic compounds largely mediated by bacteria. All members of the animal kingdom, including marine vertebrates and invertebrates require oxygen and all metabolize DO directly from the water column. Thus, having an adequate oxygen supply is critical to the health of the marine system. Low oxygen levels between 2 and 0.2 mg/l are termed 'hypoxic' and water containing less than 0.2 mg/l are considered 'anoxic'.

When DO declines to unhealthy levels, motile taxa will leave the affected area. But the non-motile, largely benthic community responds selectively according to the sensitivity of each taxa to reduced levels. It is widely recognized that poor benthic community metrics are often accompanied by low ambient DO at the time of sampling. WAR/SDI (1995) attributed depauperate assemblages to hypoxic conditions in the Palm River and Grabe et al. (2004) reported significant DO associations for the McKay Bay assemblages. Chronic hypoxia in the upper reaches contribute to low abundances.

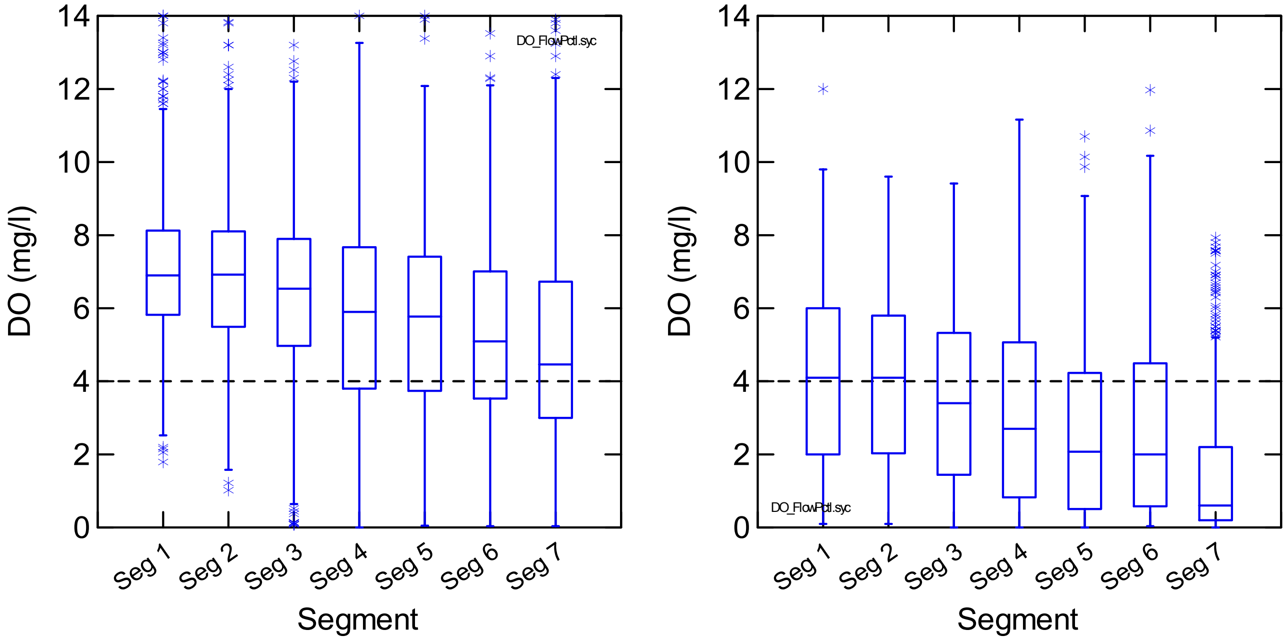
However, the field results do not provide insight on the sub-lethal effects of chronically low DO. The District contracted with HSW, Inc. to conduct a literature search on the sub-lethal effects. The results indicated that little research is published about chronic sub-lethal effects. Laboratory studies included the following

- reduced copepod egg production begins at 1.5 mg/l (Marcus, et al. 2003)
- copepod lethality begins around 0.7 mg/l. (ibid.)
- S. benedicti (common estuarine worm) can survive at least two weeks at 1.5 mg/, but lethality occurs within 55 hours when falls below 0.2 mg/l (Llanso, 1991)
- Atlantic menhaden and spot growth reduction (31-89%) at DO ranging 1.5-2.0 mg/l. (McNatt et al., 2004. Taylor et al.,2002).
- Most fish species are distressed at 2-4 mg/l and mortality begins at <2.0 mg/l (Francis-Floyd, 2002)
- Brown shrimp, juvenile spot, pinfish, croaker, menhaden, white mullet, and mummichog show aversion to DO <1.0 mg/l ranging from avoidance threshold to graded avoidance response (Wannamaker, et al. 2000).

In summary the laboratory studies indicate that response varies by life-stage, taxon and physiological adaption. Sensitivity to low DO is generally species-specific. Synergistic effects with poor sediment quality (often associated with hypoxic conditions) were also noted.

Dissolved oxygen in McKay Bay/TBC complex is characterized by chronically low values, but the values vary more longitudinally (both surface and bottom) than the salinity. **Figure 3-16** illustrates the range of surface (< 1m) and deep bottom (>= 3m) DO values for the period of record. The median bottom values are at, or below the

Florida water quality criterion (FAC 62-302) of 4.0 mg/l for all segments. As expected, the surface values are higher but the median values of upstream segment 7 approaches 4 mg/l.



Sample Depth < 1 meters **Sample Depth ≥ 3 meters**
Note – Florida Water Quality Criterion is ≥ 4 mg/l.

Figure 3-16 Dissolved Oxygen 1974-2003

Previous attempts to relate DO to flow have been unsuccessful. Coastal (1997) found that flow, and lag flow terms had an insignificant (at $p<0.05$) impact on DO, but temperature was the best overall predictor of DO. Temperature is involved in multiple processes affecting DO which may result in the unavoidable autocorrelation of independent variables. As a first principal, temperature and ionic strength inversely affect the thermodynamic saturation of DO. DO can be 'normalized' for temperature and salinity by re-expressing the concentration as a percentage of saturation. In the absence of biological activity, the DO of a water body would reach and maintain 100 percent saturation. In the environment however, DO is also a function of net primary production and biochemical oxygen demand (BOD) within the water column. Primary production is related to growth rates of ambient organism, which is also positively related to temperature. In addition to the water column processes, SOD (a combination respiration by benthic organisms and chemical reduction) exerts a vertical demand through the available water column. Thus, temperature directly and indirectly affects DO through many mechanisms.

Once stratification is established, the bottom waters cannot equilibrate with atmospheric oxygen, or be oxygenated by photosynthesis in the upper photic zone. Oxygen declines due to sediment oxygen demand (SOD), which consists of both chemical reduction of sediments and respiration of benthic organisms. Eventually, the oxygen content declines to levels lethal to the organisms. SOD kinetics are first-order temperature dependent, so oxygen levels will decline faster during warm conditions. Dixon et al. (2003) demonstrated that winter high flows in Charlotte Harbor were much less likely to produce hypoxic conditions than warm weather high flows resulting in equivalent salinity stratification. Most water quality models account for this by including a temperature correction factor for SOD ($gmO_2/m^2/d$) of the form $SOD_T = SOD_{20}*1.065^{(T-20)}$) which results in an SOD rate increase of 1.8 for a 10^{o}C rise in temperature (Bowie et al., 1985) which is roughly equivalent to a doubling for each ten degree rise. CDM (1998) calculated that a water column 3 meters deep at 6 mg/l DO would be reduced to hypoxic conditions in 7 days under typical summer-time conditions in Upper Charlotte Harbor.

Figure 3-17 illustrates the variation of DO with flow class. As previously described (Figures 3-11 and 3-12), salinity stratification is positively related to flow, but the box plots do not reveal as consistent a relationship with flow.

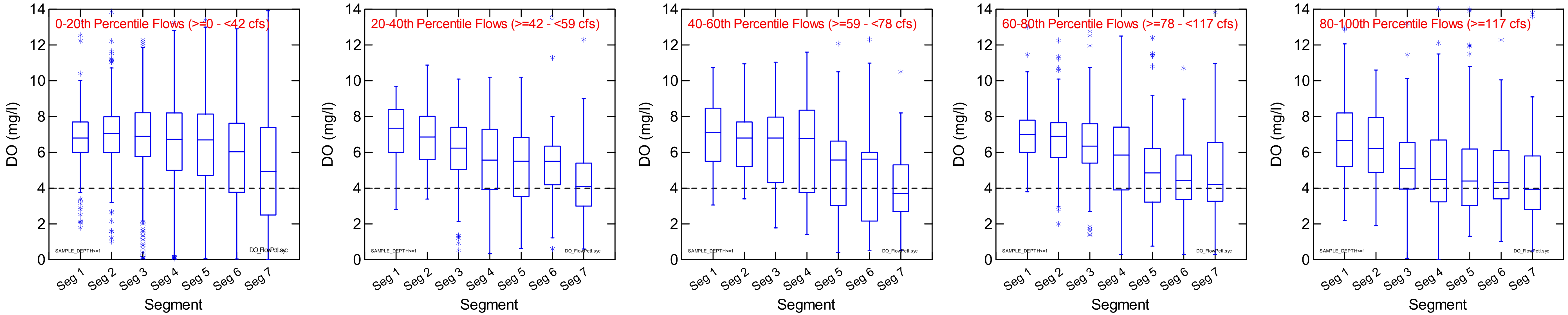
3.8.1 Re-Evaluation of DO / Flow Relationship(s)

A new evaluation of flow to DO relationship(s) was undertaken in order to take advantage of the extended data set. Similar to previous attempts, flow at S-160 and lag flows (moving averages of 3, 5, 10, 15, 20, 25,30, 35, 40, 45, 50, 55 and 60 days prior) were included as independent variables, as well as natural log transformed flow parameters (0.1 cfs was added to zero flow values). Additional candidate independent variables were calculated for each sampling date and site conditions. Percent DO saturation (PerSat) was calculated from the measured concentration, temperature and ionic strength. For the range of salinity (0-39.8 ppt) and temperature (10-33.9 ^{o}C) observed in the combined database, hypoxia begins at a PerSat of approximately 23 percent (range of 18-28 percent). The number of daylight hours was calculated from each sampling date and site latitude.

Step-wise multi-linear regression was used to determine the appropriate independent parameters for each segment and depth. The results are given in **Table 3-13**, which provides an adjusted multiple r^2 and standardized coefficients (β weights) for each significant independent term. Auto-correlation of the flow terms was of concern and step-wise selection of terms was used to eliminate some, but not all auto-correlated terms by maintaining tolerance (1 minus the r^2 of independent parameters) values above 0.1 (Systat, 1998). Thus, while the results should be considered with due respect to these limitations, the equations represent the best available estimate of DO response to flow for the system.

As a rule, the surface PerSat is poorly related to flow and with one exception surface correlation coefficients were generally poor to moderate ($r^2 <= 0.25$). The exception (NE McKay Bay) has an $r^2 > 0.5$ but does not include a flow term and is based on a relatively low number of observations (n=30).

Sample < 1 meter



Sample >= 3 meter

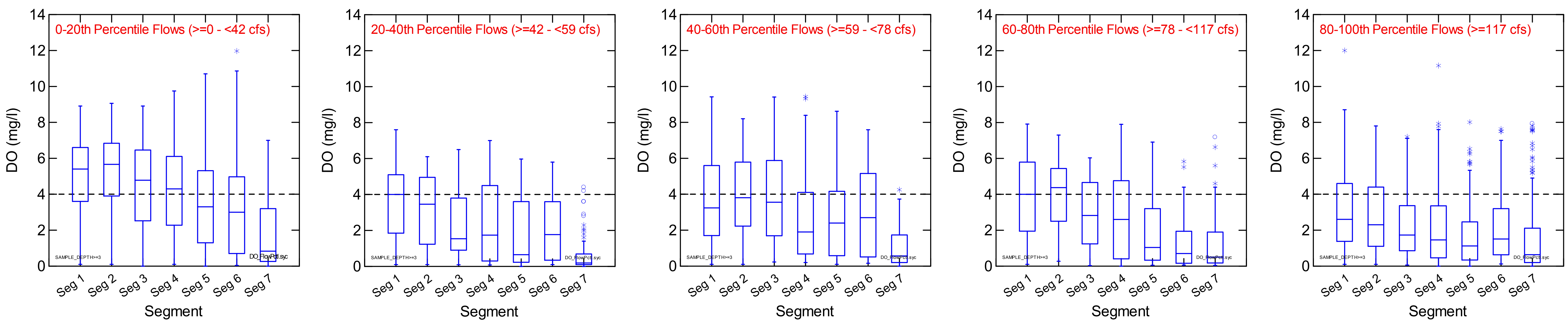


Figure 3-17 Dissolved Oxygen 1974-2003 at < 1 meter and $\geq$ 3 meter Depth by Flow Class

Table 3-13 (a)
Regression Summary for Surface (<=1m) Percent Dissolved Oxygen

	NW_McK	NE_McK	S_McK	Seg 1	Seg 2	Seg 3	Seg 4	Seg 5	Seg 6	Seg 7
r^2 =	0.029	0.532	0.061	0.050	0.064	0.161	0.209	0.217	0.218	0.140
p=	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Standardized Regression Coefficient (beta weights)									
Temp	0.136			0.097	-0.097	-0.121	-0.223	-0.220	-0.232	-0.382
Day_Light	-0.108	0.740								0.159
S160			0.238	-0.198	-0.270					
3D_Lag					0.398					
5D_Lag										
10D_Lag			-0.453							
15D_Lag					-0.294	-0.152				
20D_Lag					0.324					
25D_Lag			0.131							
30D_Lag										
35D_Lag										
40D_Lag						0.097				
45D_Lag										
50D_Lag										
55D_Lag					-0.374				0.107	
60D_Lag										
Ln(S160)				0.305			0.326	0.348	0.260	0.309
Ln(3D)										
Ln(5D)						0.422				
Ln(10D)										
Ln(15D)				-0.243		-0.690	-0.662			-0.440
Ln(20D)			0.270					0.653	-0.697	
Ln(25D)										
Ln(30D)										
Ln(35D)										
Ln(40D)										
Ln(45D)			-0.384							
Ln(50D)										
Ln(55D)										
Ln(60D)										
n =	1411	30	1016	857	897	1082	907	914	652	835
DW =	0.825	1.577	1.034	0.972	0.988	0.916	1.082	1.044	0.804	1.118
Tolerance <0.1	Yes	n/a		Yes	Yes					

Table 3-13(b) May 15, 2005 Draft

Regression Summary for Deep Bottom (>=3m) Percent Dissolved Oxygen

	NW_McK	NE_McK	S_McK	Seg 1	Seg 2	Seg 3	Seg 4	Seg 5	Seg 6	Seg 7
r^2 =	0.630		0.599	0.462	0.608	0.582	0.572	0.537	0.575	0.485
p =	0.013	n/a	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Standardized Regression Coefficient (beta weights)									
Temp				-0.422	-0.633	-0.499	-0.678	-0.579	-0.690	-0.564
Day_Light				-0.205		-0.144				
S160				0.318						0.164
3D_Lag										
5D_Lag	-0.785			-0.278						
10D_Lag										
15D_Lag				-0.323						
20D_Lag										
25D_Lag							0.149			
30D_Lag										
35D_Lag										
40D_Lag										
45D_Lag							-0.219	-0.134		
50D_Lag										
55D_Lag										
60D_Lag	0.553							0.232		0.227
Ln(S160)										
Ln(3D)										
Ln(5D)						-0.227				
Ln(10D)										
Ln(15D)					-0.353					
Ln(20D)			-0.816				-0.546	-0.312		
Ln(25D)						-0.143			-0.426	
Ln(30D)										
Ln(35D)										
Ln(40D)										
Ln(45D)										
Ln(50D)							0.317			-0.226
Ln(55D)									0.267	
Ln(60D)										
n=	10	3	7	910	568	711	672	696	487	637
DW=	1.071		2.742	1.396	1.493	1.218	1.346	1.347	1.282	1.315
Tolerance <0.1						Yes	Yes		Yes	

In contrast to the surface regressions, most of the PerSat regressions for deep water (>=3m) were much stronger with r^2 ranging from 0.46 to 0.63 as shown in Table 3-13(b). However, the McKay Bay segments (highlighted in yellow) are based on a relatively small number of observations owing to the shallow nature of McKay. In addition, the same caveats about auto-correlations should be noted for the bottom results.

The regressions were used to estimate changes in PerSat that would occur under a reduced flow scenarios, relative to a baseline flow. Lacking a continuous time series of temperature, a prediction of surface and deep bottom PerSat was developed for the historical monitoring dates using the ambient temperature recorded and the daylight hours appropriate for those sample dates. For the S1 flow scenario, the results are completely analogous to y-hat results of the forward regression expression. For the other two scenarios, only the flow (and lag flow) terms were substituted for the original observations.

The deep results are illustrated as cumulative distribution functions in **Figures 3-18** and **3-19** (results are trimmed to 150 percent saturation). For some segments there is an overall positive relationship between flow and PerSat, while in other segments the opposite is true. For surface values, this is likely related to chlorophyll and residence time. During low and moderate flows mixing is more complete, the residence time increases allowing algal blooms to develop and raise the DO levels. Higher flows tend to wash-out the blooms and initiate stratification. The higher flows isolate the bottom waters allowing SOD to exert a demand on a shorter water column without atmospheric recharge. A complete predictive scheme for DO will probably require a hydrodynamic model coupled with a full benthic and eutrophication algorithms. Nevertheless, the current regressions do incorporate a wider range of flows than available for the earlier efforts, including long periods of zero flow.

In general, there is little difference in the scenarios. The results indicates that for segments 1 through 6, the reduced flow scenario S4 will result in an increase in PerSat, with the greatest improvements below the critical 20-30 percent saturation where hypoxia begins. The DO response in Segment 7 (immediately below S-160) was opposite to the others and declined with declining flows. **Table 3-14** compares percent change (relative to S2) in PerSat for deep waters at each segment . The maximum predicted reduction in PerSat at Segment 7 is ten percent which is within the MFL goal to allow no more than a 15 percent deterioration.

The results of the water quality evaluation indicate that stratification commonly occurs in the TBC but that the salinity regime is relatively insensitive to flow. The results also indicate that hypoxic conditions are prevalent, but r^2 values suggest that flow accounts for only about 50 percent of the variation. However, using the tools identified in this section flow scenario S4 (30 cfs LFT and 40 percent withdrawal above LFT) will result in less than a 15 percent degradation of dissolved oxygen.

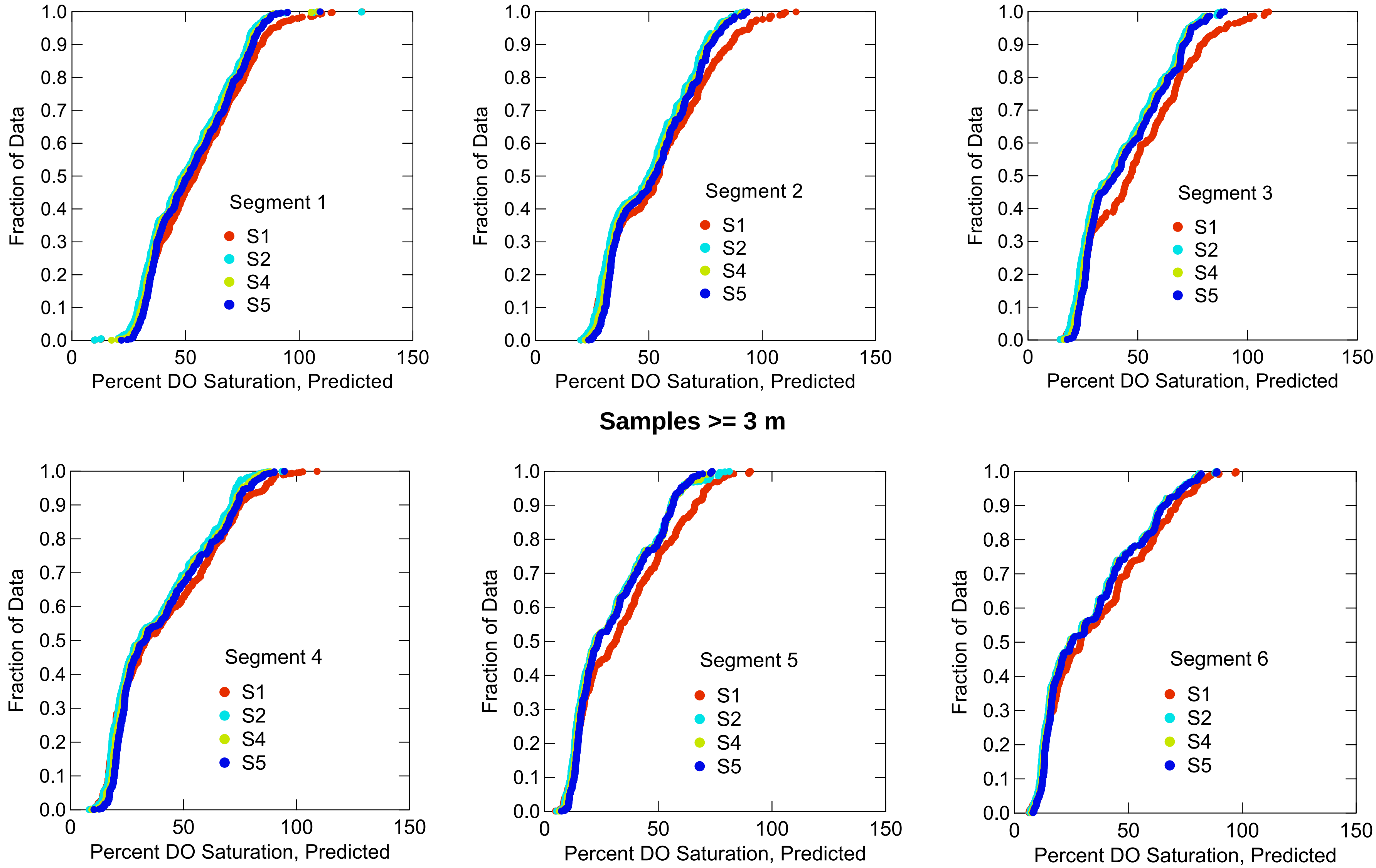


Figure 3-18 Predicted Percent Saturation for Observed (S1), Baseline (S2) , 40% Withdrawal (S4) and 60% Withdrawal (S5) Scenarios

3.9 HYDRODYNAMIC MODEL

Similar to the empirical relationships of flow and salinity, a hydrodynamic model was developed to further assess the changes in salinity that might occur with alteration of the inflows. In 2001, the District contracted with Dr. Mark Luther of USF to conduct preliminary hydrodynamic modeling of the TBC using their existing bay-wide model. The University's Tampa Bay model is based on the 3-dimensional Princeton Ocean Model and consists of 10 layers in

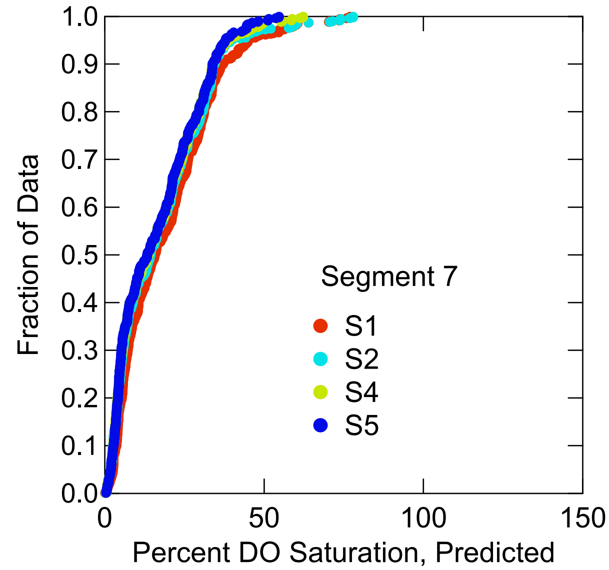


Figure 3-19 Predicted Percent DO Saturation for Observed (S1), Baseline (S2), 40% Withdrawal (S4) and 60% Withdrawal (S5) Scenarios

the vertical and 2,244 grids in the horizontal (average size = 425,000 m^2). In 2003, the District again contracted with USF to develop of regional model (Luther and Meyers, 2005) by increasing the resolution of the model grid (average grid size = 44,790 m^2) and the number of cells (185) within East Bay, McKay Bay and the Palm River. In practice, boundary conditions are extracted from the coarser Bay-wide model for the regional model. Both models are driven by high frequency water levels, winds (daily), freshwater inflows, precipitation, evaporation, temperature and salinity.

Table 3-14
Percent Difference in Predicted PerSat for S4 Flow Scenario Relative to Baseline (S2). (Samples>=3 m)

	NW McKay	S. McKay	Seg 1	Seg 2	Seg 3	Seg 4	Seg 5	Seg 6	Seg 7
Pctl 5	163%	12%	6%	8%	9%	10%	11%	8%	-4%
Pctl 10	101%	12%	6%	7%	8%	9%	9%	6%	-2%
Pctl 20	68%	12%	5%	6%	7%	9%	5%	5%	-5%
Pctl 25	67%	12%	4%	5%	7%	7%	7%	7%	-6%
Pctl 30	67%	11%	4%	5%	7%	7%	6%	4%	-5%
Pctl 40	63%	10%	3%	4%	4%	5%	5%	5%	-10%
Pctl 50	45%	10%	3%	3%	4%	5%	4%	2%	-6%
Pctl 60	15%	10%	4%	3%	3%	3%	3%	1%	-2%
Pctl 70	3%	8%	5%	3%	3%	3%	1%	1%	-1%
Pctl 75	3%	7%	5%	3%	3%	3%	2%	2%	-2%
Pctl 80	-1%	6%	4%	3%	2%	3%	2%	1%	-3%
Pctl 90	-4%	6%	3%	2%	2%	2%	1%	1%	-2%
Pctl 95	-4%	6%	5%	2%	1%	4%	0%	1%	-2%

NE McKay - Insufficient Data

3.9.1 Flow Scenarios

Five flow scenarios were provided by the District based on ambient conditions in 2001-2003. The initial flow scenarios were 1) S-1: observed flows from S-160, 2) S-2: a 'baseline' flow condition at S-160 of no withdrawals or diversions. The third (S-3) is a flow condition at S-160 simulating the maximum permitted lower pool withdrawal by TBW where S-3 is the equivalent of an 80% withdrawal rate above an 11 cfs cut-off. The two additional S-160 flow scenarios reflect fixed withdrawal percentages above the a selected low flow threshold of 30 cfs representing the 10th percentile low-flow of baseline scenario S-2. **Figure 3-20** illustrates the cumulative distribution of flows for each scenario and the accompanying **Table 3-15** provides a summary of flows for each scenario for the same time period. Ungaged flow (runoff and baseflow) below S-160 are not included in the accompanying figures and tables, but were developed by HSW, Inc (2004) for the District and provided to USF.

REDUCED FLOW SCENARIOS

S-160 flow	S-3
< 11 cfs	0
11 – 54 cfs	Excess above 11 cfs
54 – 125 cfs	80% of total flow
> 125 cfs	100 cfs

S-160 flow	S-4
< 30 cfs	0
30 – 50 cfs	Excess above 30 cfs
>50 cfs	40% of total flow

S-160 Flow	S-5
< 30 cfs	0
30 – 75 cfs	Excess above 30 cfs
>75 cfs	60% of total flow

Table 3-15
Average Flow (cfs) by Model Period and Scenario

Model Period	Days In Period	S-1	S-2	S-3	S-4	S-5
1	**195**	1	42	11	30	29
2	**93**	334	339	265	204	137
3	**91**	55	88	18	54	38
4	**151**	1	35	11	28	28
5	**107**	74	64	18	41	33
6	**107**	767	773	704	464	312
7	**151**	72	71	16	43	33
8	**122**	172	135	51	81	55
9	**78**	54	63	14	39	32

Further discussion of the flow scenarios is warranted because on the short term evaluations the pattern of estimated discharge is not consistent or straight-forward. As previously described, there are times when more water is transferred from the Hillsborough River than is removed for water supply. Thus, the observed discharge may at times be artificially augmented and the baseline flow will actually be less than the observed. It should also be emphasized that scenario S-3 (which is based on TBW's permit for middle and lower pool withdrawals) has an upper limit which is not included in scenarios S-4 and S-5. Thus, during high flow periods, while the percentage withdrawal of S-4 or S-5 is lower than S-3, the total amount of water removed may actually be greater in the S-4/S-5 scenarios due to withdrawals above 100 cfs. Finally, the S-3 withdrawal scenario does not include diversions by the COT. **Figures 3-21 and 3-22** illustrate the historic diversions

3.9.2 Hydrodynamic Results

The 2001-2003 evaluation period included extended periods of no discharge from S-160 and discharge periods in excess of 4,500 cfs. Nine output periods were identified for evaluation as illustrated in **Figure 3-23.** A comparison of modeled results to observed results at Maydell Drive is given in **Figure 3-24**.

Figures 3-25 and **3-27** provide a description of spatial differences in bottom salinity for a dry period (Figure 3-23) and for a wet period (Figure 3-24) for the five flow scenarios. Average surface and bottom salinity conditions for the various flow scenarios are summarized in **Table 3-16** for three points in the Palm River – a) at the confluence of the Palm River, b) a point located at approximately the Maydell Drive crossing and c) a point approximately 400 meters south of S-160 (See Figure 2-3 for geographic reference). On average, there is less than a 1.2 ppt difference in the resultant surface salinity when compared across the five flow scenarios. The maximum differences noted were 2.9 ppt and as expected, the largest differences occurred at the highest simulated withdrawal rate (S-3). The predicted difference in bottom salinity is even less, with an average difference of less than 0.9 ppt across flow scenarios (maximum difference of 2.2 ppt).

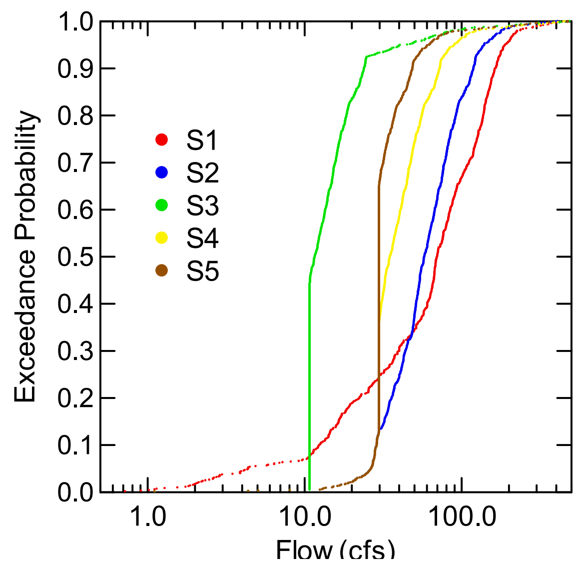


Figure 3-20 Flow Scenario CDFs (2001-2004) [View is trimmed 0.5 - 500 cfs]

During time of low S-160 inflow the salinity shows weak vertical stratification throughout the model domain. As the flow increases the stratification in the TBC increases and spreads into eastern McKay Bay. During periods of extremely high flows, the hydrodynamic model predicts 20-30 ppt vertical stratification, roughly analogous to the salinity stratification illustrated previously in Figure 3-12.

These periods of stratification are the probably the most ecologically significant hydrodynamic events. The stratification leads to the following:

- o wash-out of fish and invertebrates (Chapter 3.4
- o low salinities lethal to oysters (Chapter 3.1)
- o set-up hypoxic events that are lethal to benthos (Chapter 3.7)

Despite these extreme high-flow events, typical stratification is on the order of 3-5 ppt as shown in **Table 3-17.** These results are derived from the 'Palm River' results of Table 3-16(a) and 3-16(b).

Vertically averaged TBC (S-160 to McKay Bay) pulse residence times (PRT) were estimated for four representative flow conditions. The results indicate that residence time is relatively short (e.g. < 4 days) even under low flow conditions. For purposes of the evaluation, PRT is defined as the time for 50% of ' particle tracers' introduced as a pulse at the head of the model (S-160) to be flushed through a defined length of the estuary (in this case, to the confluence of the Palm River / McKay Bay.)

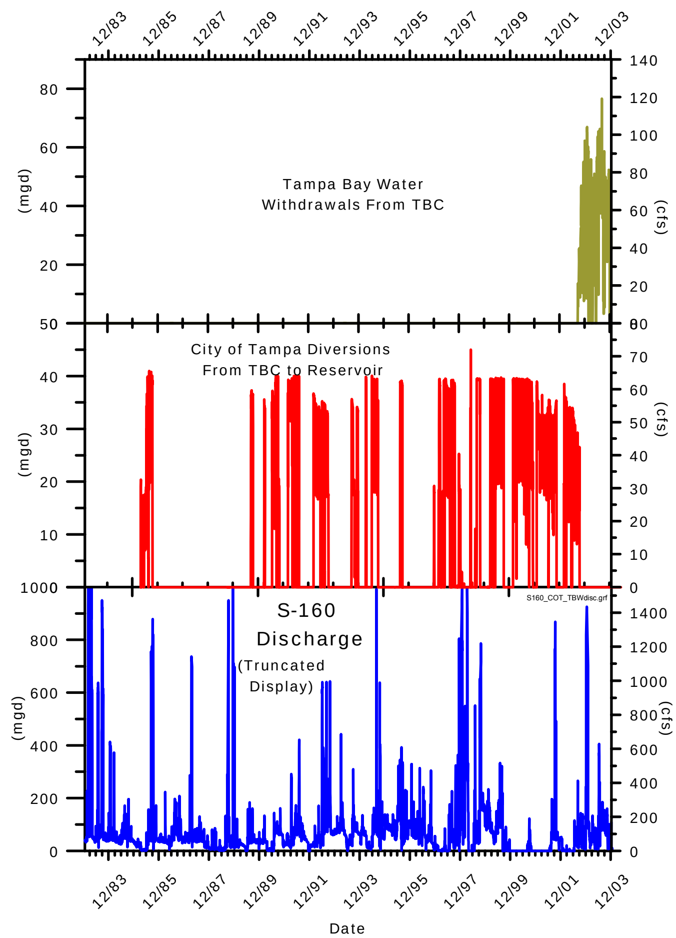


Figure 3-21 TBC Diversions and Discharges

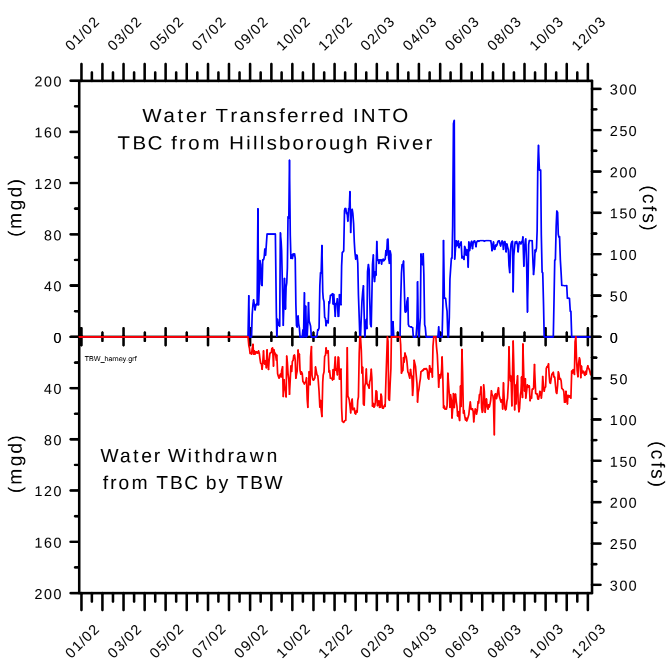


Figure 3-22 TBW Diversions and Withdrawals from TBC

Similar to the empirical salinity results previously described, the results derived from the hydrodynamic model also suggest that the TBC is generally insensitive to changes in flow from S-160.

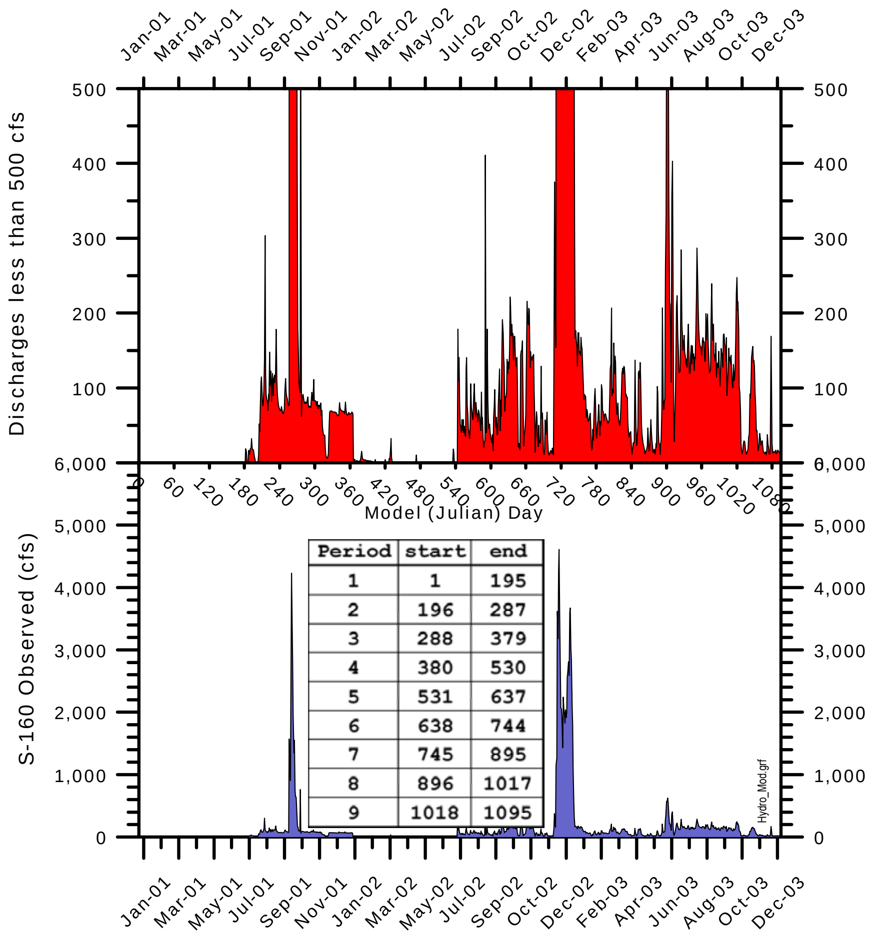


Figure 3-23 S-160 Discharge and Model Periods Evaluated.

[Top graph truncated at 500 cfs for legibility.]

Table 3-17
Vertical Salinity Stratification, ppt .
(Derived From Table 10-3)

Average Stratification @ Palm River (~ 2.1 km Upstream of 22nd St. Causeway)					
Bottom - Surface Salinity					
Period	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**
1	2.9	4.4	3.5	4.1	4.2
2	4.2	4.3	4.0	4.3	4.2
3	4.3	5.3	2.9	4.2	3.6
4	2.4	3.7	2.8	3.4	3.4
5	7.4	7.2	6.0	6.7	6.5
6	4.8	4.7	3.5	4.9	5.2
7	2.8	2.8	2.3	2.5	2.5
8	7.9	7.2	5.4	6.2	5.7
9	4.3	4.5	2.8	3.8	3.5
Compare all time periods and flow scenarios :					
25th Percentile				3.4	ppt
Median				4.2	ppt
75th Percentile				5.2	ppt

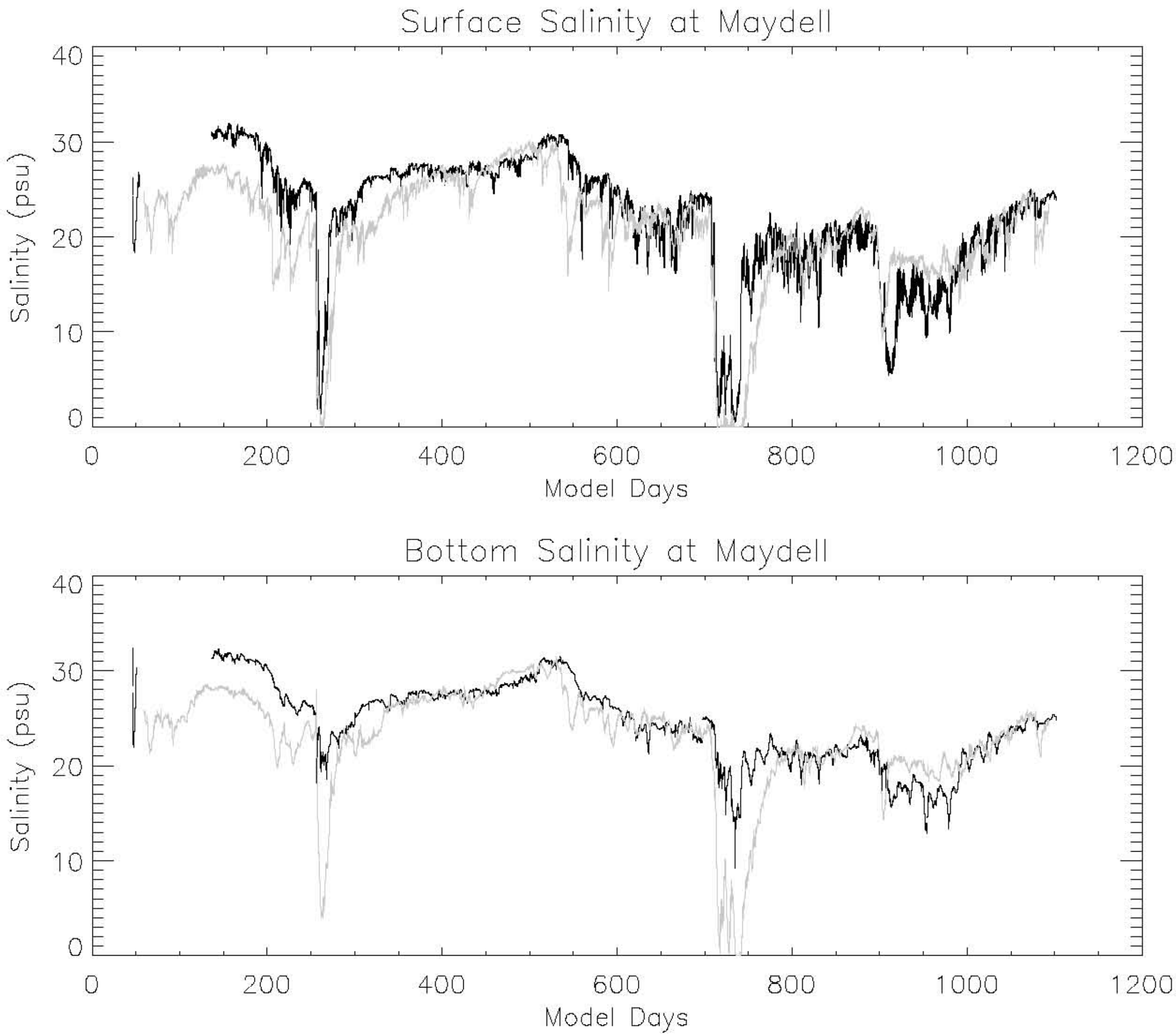


Figure 3-24 Modeled (grey) and Observed (black) Salinity at Maydell Drive (2001-2003)

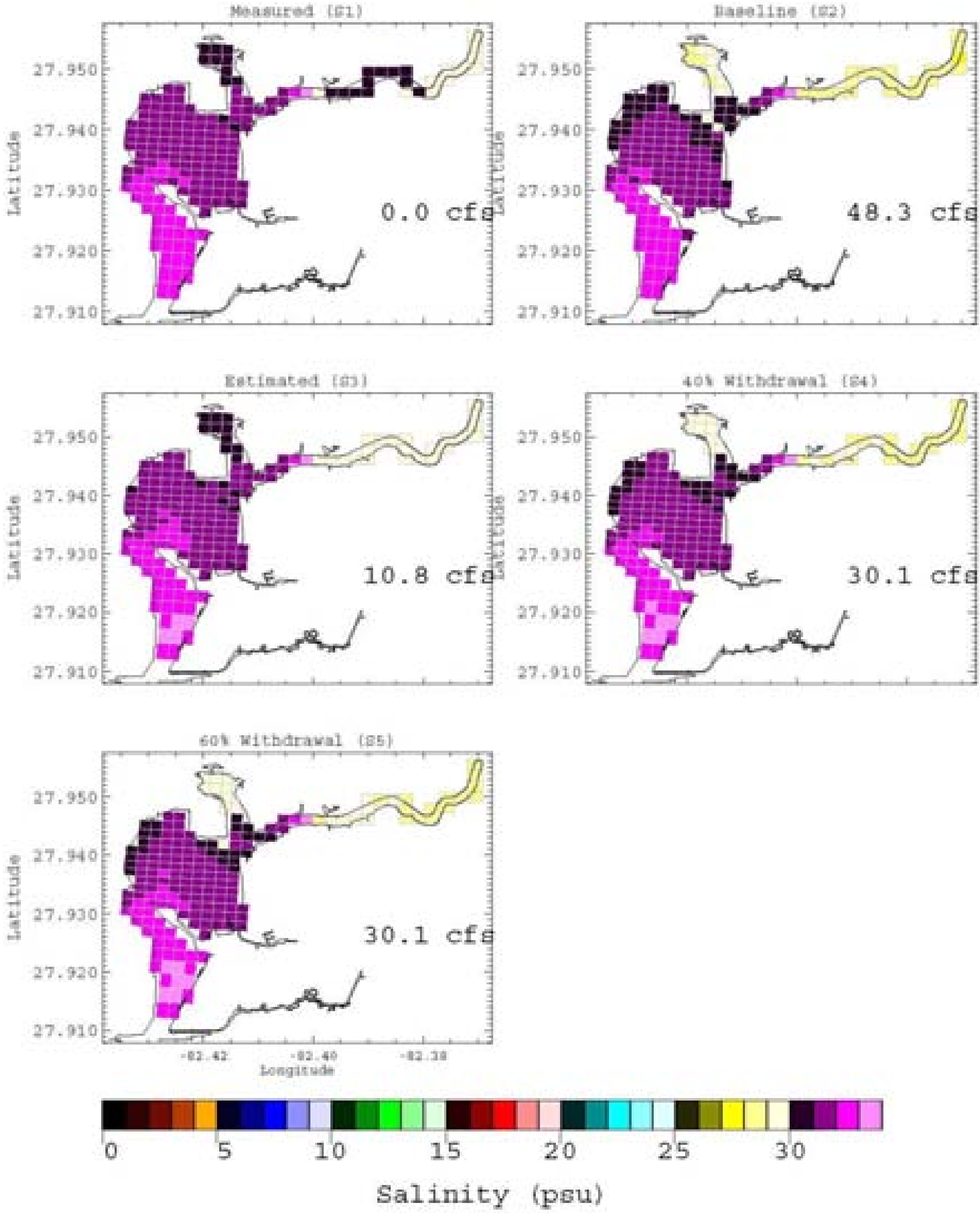


Figure 3-25 Modeled 25-Hour Average Bottom Salinity (Feb 15, 2001) for Five Flow Scenarios

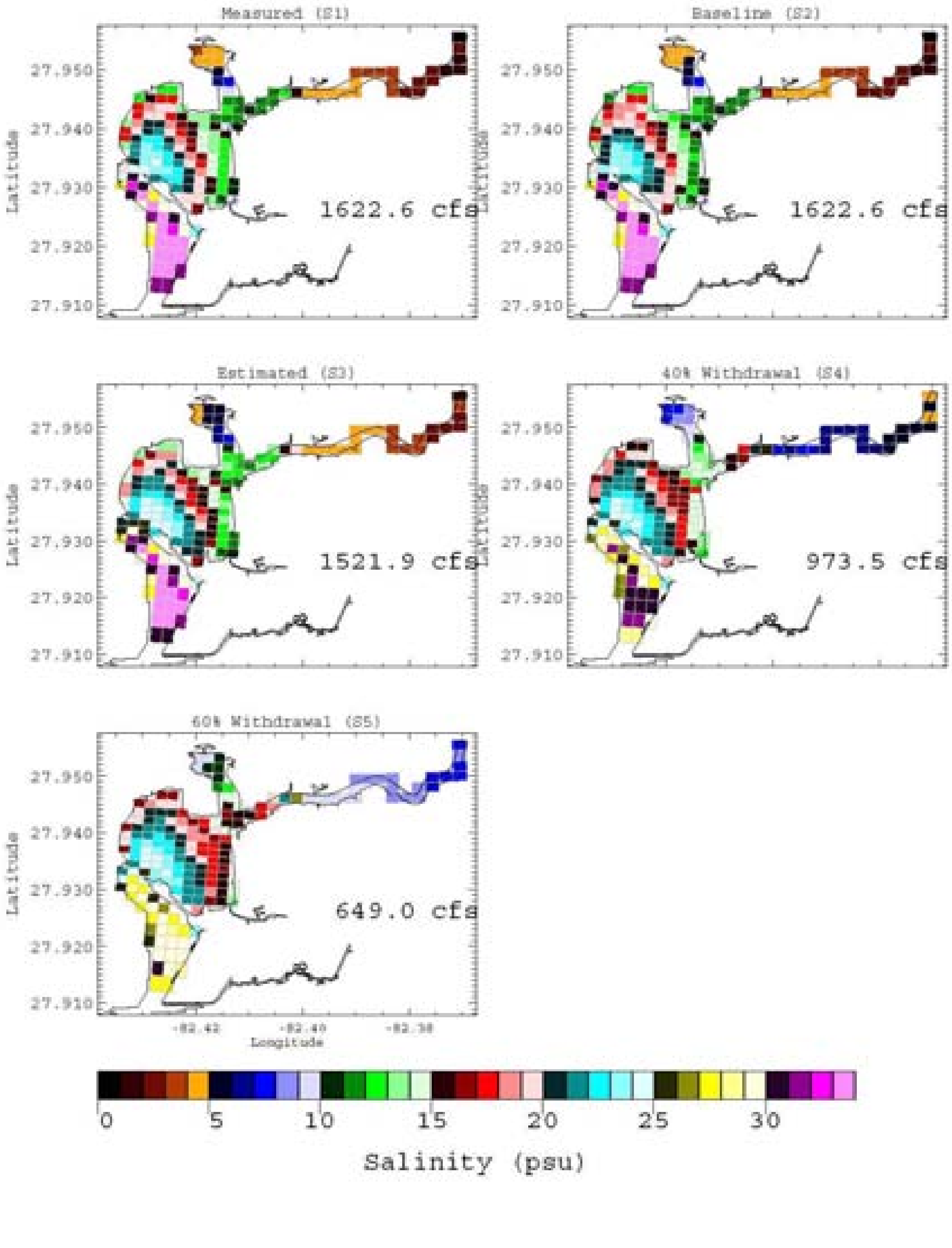


Figure 3-26 Modeled 25-Hour Average Bottom Salinity (Feb 23, 2001) for Five Flow Scenarios

Table 3-16(a)
Average Modeled Surface Salinity for Three Locations in Palm River and Percent Difference with Baseline Flow (S-2). [Maximum Difference Highlighted]

Average Surface Salinity @ Palm River (~ 2.1 km Upstream of 22nd St. Causeway)						Average Surface Salinity Near Maydel (~4.7km Upstream of 22nd St. Causeway)						Average Surface Salinity Near S-160 (~7.1 km Upstream of 22nd St. Causeway)					
Period	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**
1	27.8	25.7	26.9	26	25.9	**1**	27.6	25.5	26.8	25.9	25.8	**1**	27.0	24.7	26.1	25.1	25.0
2	18.3	18.1	18.9	18.9	19.3	**2**	15.4	15.1	16.6	16.2	17.0	**2**	14.7	14.4	16.0	15.5	16.2
3	20.7	19.5	22.4	20.9	21.6	**3**	20.1	19.0	21.9	20.4	21.1	**3**	19.6	18.4	21.3	19.8	20.5
4	25.8	24.0	25.2	24.3	24.3	**4**	25.6	23.8	25.0	24	24.1	**4**	25.3	23.4	24.6	23.6	23.7
5	20.1	20.3	21.5	20.6	20.9	**5**	21.5	21.7	22.7	21.9	22.2	**5**	21.0	21.1	22.2	21.3	21.7
6	13.7	13.8	15.5	14.8	15.5	**6**	13.7	13.7	15.4	14.6	15.4	**6**	13.2	13.2	14.9	14.0	14.8
7	18.7	18.7	19.8	19.4	19.5	**7**	16.8	16.8	18.7	17.8	18.2	**7**	16.0	16.0	17.9	17.0	17.3
8	14.2	15.0	17.0	16.1	16.8	**8**	15.6	16.4	18.1	17.3	17.9	**8**	15.5	16.2	17.8	16.9	17.6
9	20.1	19.9	21.9	20.8	21.1	**9**	19.7	19.4	21.4	20.3	20.6	**9**	19.0	18.6	20.7	19.5	19.9

Percent Difference @ Palm River, Surface (~ 2.1 km Upstream of 22nd St. Causeway) = 100 * (Sx-S2) / S2						Percent Difference Near Maydel, Surface (~4.7km Upstream of 22nd St. Causeway) = 100 * (Sx-S2) / S2						Percent Difference Near S-160, Surface (~7.1 km Upstream of 22nd St. Causeway) = 100 * (Sx-S2) / S2					
Period	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**
1	8%	0%	5%	1%	1%	**1**	8%	0%	5%	2%	1%	**1**	9%	0%	6%	2%	1%
2	1%	0%	4%	4%	7%	**2**	2%	0%	10%	7%	13%	**2**	2%	0%	11%	8%	13%
3	6%	0%	15%	7%	11%	**3**	6%	0%	15%	7%	11%	**3**	7%	0%	16%	8%	11%
4	8%	0%	5%	1%	1%	**4**	8%	0%	5%	1%	1%	**4**	8%	0%	5%	1%	1%
5	-1%	0%	6%	1%	3%	**5**	-1%	0%	5%	1%	2%	**5**	0%	0%	5%	1%	3%
6	-1%	0%	12%	7%	12%	**6**	0%	0%	12%	7%	12%	**6**	0%	0%	13%	6%	12%
7	0%	0%	6%	4%	4%	**7**	0%	0%	11%	6%	8%	**7**	0%	0%	12%	6%	8%
8	-5%	0%	13%	7%	12%	**8**	-5%	0%	10%	5%	9%	**8**	-4%	0%	10%	4%	9%
9	1%	0%	10%	5%	6%	**9**	2%	0%	10%	5%	6%	**9**	2%	0%	11%	5%	7%

Table 3-16(b)
Average Modeled Bottom Salinity for Three Locations in the Palm River and Percent Difference with Baseline Flow (S-2). [Maximum Difference Highlighted]

Average Bottom Salinity @ Palm River (~ 2.1 km Upstream of 22nd St. Causeway)						Average Bottom Salinity Near Maydel (~4.7km Upstream of 22nd St. Causeway)						Average Bottom Salinity Near S-160 (~7.1 km Upstream of 22nd St. Causeway)					
Period	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**
1	30.7	30.1	30.4	30.1	30.1	**1**	29.4	28.2	28.8	28.3	28.2	**1**	28.7	27.4	28.1	27.5	27.5
2	22.5	22.4	22.9	23.2	23.5	**2**	19.6	19.3	20.5	20.3	20.9	**2**	18.6	18.4	19.5	19.4	20.1
3	25.0	24.8	25.3	25.1	25.2	**3**	22.6	22.0	23.6	22.8	23.2	**3**	21.4	20.8	22.5	21.6	22.1
4	28.2	27.7	28.0	27.7	27.7	**4**	27.0	26.0	26.7	26.1	26.2	**4**	26.4	25.3	26.1	25.4	25.6
5	27.5	27.5	27.5	27.3	27.4	**5**	25.1	25.2	25.6	27.3	27.4	**5**	24.7	24.7	25.1	24.5	24.8
6	18.5	18.5	19.0	19.7	20.7	**6**	16.5	16.5	17.6	17.5	18.5	**6**	15.3	15.3	16.4	16.4	17.4
7	21.5	21.5	22.1	21.9	22.0	**7**	19.2	19.3	20.4	20	20.2	**7**	18.5	18.6	19.7	19.2	19.5
8	22.1	22.2	22.4	22.3	22.5	**8**	19.3	19.7	20.7	20.2	20.7	**8**	18.9	19.3	20.2	19.7	20.2
9	24.4	24.4	24.7	24.6	24.6	**9**	22.3	22.1	23.1	22.6	22.8	**9**	21.1	20.9	22.2	21.5	21.7

Percent Difference @ Palm River, Bottom (~ 2.1 km Upstream of 22nd St. Causeway)						Percent Difference Near Maydel, Bottom (~4.7km Upstream of 22nd St. Causeway)						Percent Difference Near S-160, Bottom (~7.1 km Upstream of 22nd St. Causeway)					
= 100 * (Sx-S2) / S2						**= 100 * (Sx-S2) / S2**						**= 100 * (Sx-S2) / S2**					
Period	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**	**Period**	**S-1**	**S-2**	**S-3**	**S-4**	**S-5**
1	2%	0%	1%	0%	0%	**1**	4%	0%	2%	0%	0%	**1**	5%	0%	3%	0%	0%
2	0%	0%	2%	4%	5%	**2**	2%	0%	6%	5%	8%	**2**	1%	0%	6%	5%	9%
3	1%	0%	2%	1%	2%	**3**	3%	0%	7%	4%	5%	**3**	3%	0%	8%	4%	6%
4	2%	0%	1%	0%	0%	**4**	4%	0%	3%	0%	1%	**4**	4%	0%	3%	0%	1%
5	0%	0%	0%	-1%	0%	**5**	0%	0%	2%	8%	9%	**5**	0%	0%	2%	-1%	0%
6	0%	0%	3%	6%	12%	**6**	0%	0%	7%	6%	12%	**6**	0%	0%	7%	7%	14%
7	0%	0%	3%	2%	2%	**7**	-1%	0%	6%	4%	5%	**7**	-1%	0%	6%	3%	5%
8	0%	0%	1%	0%	1%	**8**	-2%	0%	5%	3%	5%	**8**	-2%	0%	5%	2%	5%
9	0%	0%	1%	1%	1%	**9**	1%	0%	5%	2%	3%	**9**	1%	0%	6%	3%	4%

CHAPTER 4 TECHNICAL APPROACH

4.1 OVERVIEW

Goals for the TBC MFL were stated in Chapter 1 and the ecological resources targeted for protection from significant harm were described in Chapter 3. Where appropriate and possible, analytical tools that can be applied to relate freshwater inflow and resource health were developed and described in Chapter 3. Chapter 4 describes the results of applying those empirical and modeling tools to arrive at an MFL.

4.2 GOALS

At the outset, five ecological resources and two forcing parameters (salinity, DO) were identified. The goal was to establish an MFL for each resource and to chose the most conservative/protective from the individual MFLs. If no clear break-point response could be described, an alternative policy of no more than a 15 percent loss of resource due to withdrawals was proposed in Chapter 1.

Each resource/parameter was investigated and after review of the quantifiable responses, no break points were obvious. The presumptive 15 percent goal was applied. This approach is consistent with both on-going District MFL efforts in other water bodies and is similar to the approach adopted by other coastal states.

In addition to the loss term, a low flow threshold (LFT) was proposed in Chapter 1. The proposed value is the 10th percentile low flow for the baseline evaluation period and baseline flow. Essentially, the LFT goal is that the MFL must be found at, or above the flows that occur 90 percent of the time. The LFT goal for discharge from S-160 was initially set at 30 cfs, although as described later this goal was not supported by the technical analysis and was subsequently eliminated from consideration.

4.3 CONSIDERATION OF EXISTING USES

The statutes that authorize and require the establishment of MFLs do not provide for recognition of existing potable uses of the water, although non-consumptive uses may be considered in the determination. In the present case, a synthetic baseline flow record was reconstructed in which all water removed, or added to the TBC for water supply was removed from the record. Flood flows were retained. The MFL evaluation was based on this baseline flow record, rather than the observed flows.

4.4 APPLICATION OF GOALS TO RESOURCE RESPONSE

4.4.1 Oysters

Protecting oyster communities from lethal high salinity levels resulting from withdrawals was initially a concern. The technical approach protecting this resource was a comparison of the measured (1974 to present) salinities during low S-160 flows periods. The results indicated that even during prolonged conditions of zero flow, 75 percent of the recorded salinity values in McKay Bay/Palm River were within the optimal zone for oysters. The boundary salinity in East Bay, along with other freshwater inflows into McKay Bay, East Bay and Hillsborough Bay maintain the salinity within acceptable limits. No MFL is warranted for protection of oysters.

4.4.2 Vegetation (Mangroves)

Mangroves are the dominant vegetation in McKay Bay/TBC and were targeted for evaluation because there was concern that reduced flow and high salinity would be damaging to this resource. However, current research into mangrove / salinity relationships indicate that soil salinity is important to mangrove health, but water column salinity has little effect on mangrove health. Thus, no further technical evaluation was conducted as there appears to be no justification for a mangrove MFL.

4.4.3 Fish and Invertebrates

Fish and invertebrate response to inflow was quantitatively documented for 34 taxa. Three taxa significant to the region (mysid shrimp, bay anchovy and pink shrimp) were selected for further evaluation. Inflow / abundance regressions were selected as the evaluation tool and a series of reduced flow scenarios in the form of percentage withdrawal above the LFT were defined. Abundance at the median flow (1983-2003) of each scenario was calculated and compared to the abundance at the baseline flow conditions. Comparisons were made based on percent loss in abundance.
The flow scenario resulting in a 15 percent abundance loss of the three significant taxa was further evaluated for sensitivity to the LFT by varying the assumed LFT and fixing the percentage withdrawal.

In keeping with the initial goals, loss of abundance averaged 15 percent at an inflow of approximately 65 cfs. Any number of combinations of LFTand percentage withdrawals will produce a median 65 cfs flow. One combination corresponds to a withdrawal of approximately 40 percent above an LFT of 30 cfs. **Table 4-1** provides a tabular form of the data used to derive Figure 3-9. However, further analysis (**Table 4-2**) revealed that at a forty percent withdrawal rate, the abundance is virtually independent of the LFT. Thus, at a forty percent withdrawal rate, an LFT is not necessary to restrict fish/invertebrate losses to fifteen percent over baseline. More importantly and as shown in Table 4-2, **t**here are an infinite number of LFT/percent withdrawal scenarios that result in a fifteen percent loss of abundance, all of which produce an approximately 65-70 cfs flow.

4.4.4 Benthos

The results of the benthos evaluation were inconclusive for setting an MFL. In general, the TBC benthic community appears to be more responsive to the occurrence of hypoxia rather than high salinity. Hypoxia is related to high flow more often than low-flow conditions. In the absence of further work, an MFL could not be evaluated for the benthic communities.

Table 4-1
Abundance Loss at Various Withdrawal Rates above 30 cfs.

			Percent Loss Over Baseline			
Low Flow Cut off (cfs)	% Withdrawal	Median Flow (cfs)	Mysid	Anchovy	Pink Shrimp	average loss
n/a	0	97	0	0	0	0.0
30	26.8	75	12.6	8.7	8.8	10.0
30	39.0	66	18.6	13	13.5	15.0
30	50.5	56	24.6	17.4	18	20.0
30	63.5	46	30.8	21.8	22.4	25.0

Table 4-2
Representative LFT and Withdrawal Rates
Resulting in 15 Percent Loss of Abundance

			Percent Loss Over Baseline			
Low Flow Cut off (cfs)	% Withdrawal	Median Flow (cfs)	Mysid	Anchovy	Pink Shrimp	average loss
n/a	0	97	0	0	0	0.0
0	38.2	66	18.5	13.1	13.4	15.0
10	38.2	66	18.5	13.1	13.4	15.0
30	39.0	66	19.2	13.3	13.9	15.5
40	40.6	65	18.6	12.9	13.5	15.0
50	46.0	64	18.4	12.8	13.8	15.0
60	62.0	69	18.5	12.7	13.7	15.0

4.4.5 Birds

Bird population dynamics appear to be related to both vegetation (as habitat) and the benthic community (as prey). In the absence of quantitative inflow relationships of either vegetation or benthos, aviary populations cannot be related to potential withdrawals. Consequently, no MFL was established for birds.

4.4.6 Changes to Salinity and Dissolved Oxygen

Salinity and dissolved oxygen, while not ecological resources per se, are important factors in determining the ecological resources. Goals of limiting changes were not established a priori, but regressions were developed to estimate the changes that would occur if the overall MFL was based on limiting fish and invertebrate abundance to a 15 percent change.

The salinity/inflow response was evaluated using two separate approaches. Empirical (regression modeling) and hydrodynamic modeling were used independently to estimate the changes in salinity resulting from various trial reduced flow scenarios. The hydrodynamic evaluation included simulation of three scenarios and comparison with the response to baseline flows. Percent difference (surface and bottom) from baseline conditions was calculated for three locations spanning the Palm River and for nine simulation periods.

The empirical evaluation was restricted to one segment within the channelized Palm River where response is expected to be the greatest. Technical comparison was based on superimposed cumulative distribution functions and tabular results.

Both approaches indicated that the TBC salinity is relatively insensitive to changes in freshwater inflow, probably due to the large volume and efficient transport of more saline water from Tampa Bay. The hydrodynamic model results confirmed that extremely high flows can cause steep vertical stratification (which in turn is related to hypoxic conditions).

The approach to evaluating DO was similar to the empirical evaluation of salinity. Regression models were developed, tested and applied to estimate changes in the percent saturation of dissolved oxygen as a function of freshwater inflow. Surface and bottom waters were evaluated separately. In general, the surface water percent saturation is only moderately responsive to changes in inflow (r^2 generally less than 0.25). Response of bottom water percent saturation to inflow was usually more pronounced (r^2 typically >0.5). Changes to bottom DO were evaluated for two reduced flow scenarios and compared to the baseline results using a CDF plot. While there were some notable differences in the higher levels of DO, the increased frequency of damaging hypoxic conditions (relative to baseline) was less than 10 percent.

CHAPTER 5 RESULTS OF MFL EVALUATION

5.1 RESULTS

Five significant ecological resources (oysters, benthic infauna, birds, vegetation and fish/invertbrates) found in McKay Bay/TBC were evaluated for sensitivity to inflows and/or salinity. Of those, quantitative relationships with inflow were developed for fish/invertebrate abundance and location. Three regionally significant taxa (mysid, anchovy and pink shrimp) were identified for further analysis. Statistically significant (at $p \leq 0.05$) positive relationships were developed, but the predictive power (expressed as r^2) remains low (ca 15%). Thus, while a significant relationship exists, inflow alone accounts for only fifteen percent of the variation in abundance. The remaining eighty-five percent variation is unrelated to inflow, or the MFL.

Average change in abundance was evaluated as the difference between abundance during a 20-year baseline flow, and at reduced flows. Fifteen percent of the baseline abundance was lost when median daily flows were reduced from ninety seven cfs to sixty five cfs. Subsequent analysis indicated that the median flow could be maintained at sixty five cfs or greater under zero LFT conditions, provided the percentage of daily withdrawals did not exceed forty percent.

The dredging of Six Mile Creek and commensurate increase in volume prohibits development of a complete salinity gradient in the TBC. In addition, the primary function of the TBC is flood control and that function necessitates periodic high discharges. In consideration of the combination of weak or non-existent relationships between inflow and the ecologic resources, coupled with the significant physical alterations and the need to provide flood control, the District has declined to establish an MFL for the TBC at this time.

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