TAMPA BAY NATIONAL ESTUARY PROGRAM
TECHNICAL PUBLICATION #08-97

AN ANALYSIS OF THE EFFECTS OF FRESHWATER INFLOWS ON SALINITY DISTRIBUTIONS, DISSOLVED OXYGEN CONCENTRATIONS, AND HABITAT CHARACTERISTICS OF THE HILLSBOROUGH RIVER AND PALM RIVER/TAMPA BYPASS CANAL

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FOREWORD

This project was completed for the Tampa Bay National Estuary Program through the Tampa Bay Regional Planning Council with support from the Tampa Bay National Estuary Program, the Southwest Florida Water Management District, and the City of Tampa.

ACKNOWLEDGMENTS

This project was completed in support of and with the assistance of the Hillsborough River and Palm River/Tampa Bypass Canal Minimum Flows Advisory Group.

The following entities participated on the Advisory Group and subcommittees:

West Coast Regional Water Supply Authority,
Southwest Florida Water management District,
USF Marine Science Department,
City of Tampa Water Department,
City of Tampa Stormwater Department,
City of Tampa Sanitary Sewers,
Tampa Bay Watch,
Palm River Management Committee,
Environmental Protection Commission of Hillsborough County,
U.S. Fish and Wildlife Service,
FDEP Florida Marine Research Institute,
FDEP Water Standards,
U.S. Geological Survey,
Florida Game and Freshwater Fish Commission,
National Audubon Society Florida Coastal Islands Sanctuary,
Manatee County Planning Department,
Manatee County Water Department,
Concerned Citizen,
Canoe Escape,
NOAA National Marine Fisheries Service,
The Planning Commission,
Hillsborough River Greenways Task Force,
FDEP Hillsborough River Ecosystem Management,
Mote Marine Laboratory,
ASHORE Civic Group,
Hillsborough River Interlocal Planning Board, and
Technical Advisory Committee to Hillsborough River Board.

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TABLE OF ACRONYMS

CCMP	Comprehensive Conservation and Management Plan
DO	Dissolved Oxygen Concentration
EPCHC	Environmental Protection Commission of Hillsborough County
SWFWMD	Southwest Florida Water Management District
TBNEP	Tampa Bay National Estuary Program
TBRPC	Tampa Bay Regional Planning Council
USGS	United States Geological Survey

1. BACKGROUND

The purpose of this study was to investigate the relationships between freshwater discharge and water quality conditions (i.e., salinity and dissolved oxygen concentration) in the Hillsborough River and Palm River/Tampa Bypass Canal, and to apply the results to a management tool to predict water quality condition responses to changes in freshwater inflows.

The Southwest Florida Water Management District (SWFWMD) requested the Tampa Bay National Estuary Program (TBNEP) to convene a technical advisory group to provide recommendations for ecological criteria for setting minimum flows for the Hillsborough River and Palm River/Tampa Bypass Canal systems. The Hillsborough River and Palm River/Tampa Bypass Canal Minimum Flows Advisory Group was originally convened in October of 1996 and met monthly through May of 1997. The participating entities of the Advisory Group and subcommittees included:

West Coast Regional Water Supply Authority,
Southwest Florida Water management District,
USF Marine Science Department,
City of Tampa Water Department,
City of Tampa Stormwater Department,
City of Tampa Sanitary Sewers,
Tampa Bay Watch,
Palm River Management Committee,
Environmental Protection Commission of Hillsborough County,
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Hillsborough River Greenways Task Force,
FDEP Hillsborough River Ecosystem Management,

Mote Marine Laboratory,
ASHORE Civic Group,
Hillsborough River Interlocal Planning Board, and
Technical Advisory Committee to Hillsborough River Board.

The objective of the Advisory Group was:

> " *Provide technically sound recommendations to SWFWMD staff for identifying and evaluating the water resources and ecological criteria necessary to establish minimum flows on the Hillsborough River downstream of the dam and on the Palm River/Tampa Bypass Canal downstream of Structure 160 .* "

The primary issues that were defined at the initial meeting were:

1. *Low-salinity habitats in each of the river systems*
2. *Low levels of dissolved oxygen (hypoxia)*
3. *"Truncated" salinity regime on the Palm River/Tampa Bypass Canal*

Coastal Environmental, a Division of Post, Buckley Schuh & Jernigan, Inc., was tasked to provide general technical support to the Advisory Group, and the results of that work are presented in this report.

1.1 The Study Area

The study area for this project includes the Hillsborough River downstream of the dam and the Palm River/Tampa Bypass Canal downstream of Structure 160. Figure 1-1 presents an overview of the study area. The important and relevant features of the Hillsborough River and Palm River/Tampa Bypass Canal systems are presented in the following text as an introduction to this investigation. More in-depth discussions of the anthropogenic features, natural features, and important management issues of the Hillsborough River and their relevance to Tampa Bay as a whole were discussed in a Tampa Bay Comprehensive Conservation and Management Plan recently completed by the TBNEP (TBNEP, 1997).

The Hillsborough River is the largest freshwater tributary to the Tampa Bay estuary. The river drains approximately 1,800 square kilometers of mixed agricultural, urban, and undeveloped lands, and discharges to Hillsborough Bay, a northern subsegment of Tampa Bay. The Hillsborough River has been impounded in various forms since the late 1800s, and the present dam was constructed on the downstream portion of the river in 1944 to provide a potable water supply to the City of Tampa. This reservoir remains the primary source of drinking water for the city, and withdrawals from the reservoir are regulated through Water Use Permit 220262. The Hillsborough River Reservoir is also directly connected to the Tampa Bypass Canal by the Harney Canal. Downstream of the reservoir and dam, this portions of the river flows through the city of Tampa (Figure 1-1), and this portion of the river and the habitat it provides are the focus of this study. The salinity regimes and dissolved oxygen (DO) characteristics downstream of the dam are affected by the amount of freshwater which is released from the dam. Concurrent with the development of the dam, the physical characteristics of this portion of the river have been altered by dredging, channelization, hardening of shorelines, and filling of associated estuarine wetlands.

The Tampa Bypass Canal was constructed to divert floodwaters from the urbanized portions of the Hillsborough River to the nearby Palm River. The Palm River then discharges to McKay Bay which, like the Hillsborough River, is tributary to Hillsborough Bay. Three control structures regulate the flow from the Hillsborough River through the Palm River/Tampa Bypass Canal. These structures are S-161, S-162, and S-160 (Figure 1-1). Structure S-160 is the most downstream structure on the Palm River/Tampa Bypass Canal, and it regulates the quantity of freshwater which enters the downstream estuarine portion of the conveyance. When conditions warrant, water is also pumped from the Tampa Bypass Canal to augment the Hillsborough River reservoir system via the Harney Canal. This pumping is regulated under Water Use Permit 206675.

Sulphur Springs is a natural freshwater point source adjacent to the Hillsborough River between the dam and Hillsborough Bay (Figure 1-1). Due to its large volume of freshwater that is discharged, consideration of Sulphur Springs was included in the investigation of the relationships between freshwater inflows and water quality conditions. Under specific conditions, water may be pumped from Sulphur Springs to augment the City of Tampa drinking water supply. These conditions are regulated under Water Use Permit 2202062.

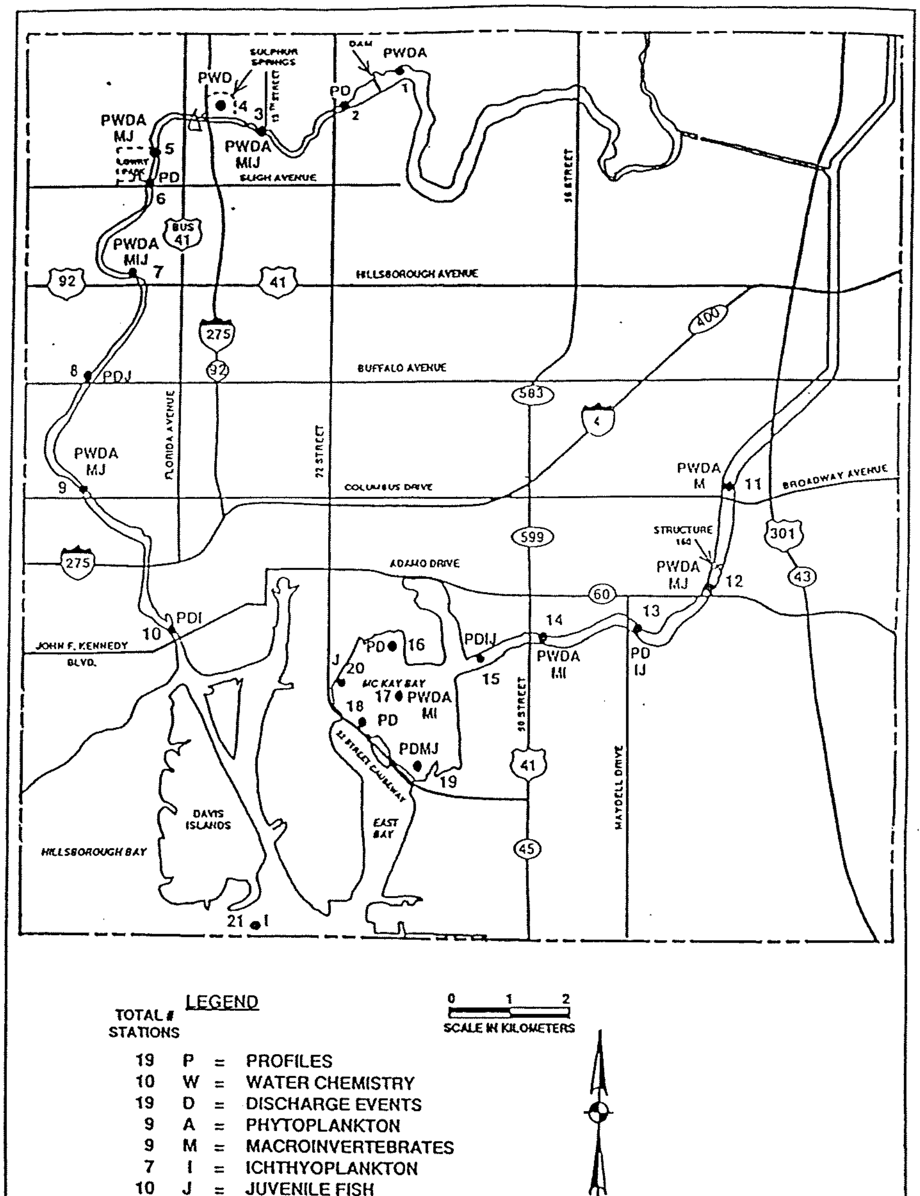


FIGURE 1. WCRWSA Hillsborough River/Palm River Sampling Locations

Water and Air Research, Inc. — Consulting Environmental Engineers, Scientists, and Planners
WCRWSA HR/PR 7/1/92

Figure 1-1 The downstream portions of the Hillsborough River and the Palm River/Tampa Bypass Canal. (Map from Water and Air Research, Inc and SDI Environmental Services, Inc. 1995).

1.2 Resources of Concern

The resources of concern for this investigation were defined as the waters and aquatic biota downstream of the dam on the Hillsborough River and downstream of Structure 160 on the Palm River/Tampa Bypass Canal. Habitats located where freshwater mixes with saltwater have a potential to be highly productive, and may provide critical nursery habitats for important recreational and commercial fish populations in the bay. These populations include large growing species which are directly harvested such as spotted sea trout (*Cynoscion nebulosa*), red drum (*Sciaenops ocellatus*), tarpon (*Megalops atlanticus*), and snook (*Centropus undecimalis*), and they also include smaller growing species which are harvested and provide a forage base such as bay anchovy (*Anchoa mitchilli*) and menhaden (*Brevortia* spp.).

1.3 Purpose of this Study

The purpose of this study was to investigate the relationships between freshwater discharge and water quality conditions (i.e., salinity and DO concentration) in the Hillsborough River and Palm River/Tampa Bypass Canal, and to develop a management tool based on the results to predict water quality condition responses to changes in freshwater inflows.

This project was completed to provide information for one part of a larger effort to protect the resources of concern. The larger effort was formally stated in the form of an Action Plan in the recently completed TBNEP, Comprehensive Conservation and Management Plan for Tampa Bay. The Action Plan was titled "To Establish and Maintain Minimal Seasonal Freshwater Inflows Downstream of Dams," and it was developed and agreed to by the cooperating members of the TBNEP including the South Florida Water Management District, the City of Tampa, and other local governments (TBNEP, 1997). The Action was defined as follows:

> "*Action Plan:* *Establish and Maintain Minimum Seasonal Freshwater Flows Downstream of Dams.*
>
> *Action:* *While safeguarding water supply and flood control functions, establish and maintain minimum seasonal freshwater inflows downstream of dams on the Hillsborough, Manatee, and Braden rivers, and below Control Structure S-160 on the Palm River, to restore and preserve the biological productivity of the estuary's critical juvenile fisheries habitat.*
>
> *Strategy:* *This action is to evaluate and set minimum seasonal freshwater inflows to Tampa Bay from rivers impounded by dams to protect the ecological integrity of vital downstream fisheries habitats."*

In support of one part of this larger effort, this study was completed to provide information and a management tool which the governmental agencies could use to predict salinity and DO concentrations as a response to freshwater inflows to the Hillsborough River and Palm River/Tampa Bypass Canal. As defined by the participating local governments in the Action Plan, the final selection of specific minimum flow targets will include consideration of safeguarding water supply, flood control, and ecological integrity of fisheries habitats. Hence, neither the results of this study, nor the TBNEP have provided recommendations for specific minimum flow targets. This study provides a management tool which was developed for the governmental agencies involved in the selection of the final target.

2. ANALYSIS OBJECTIVES

Four specific objectives were defined for this study.

- **Characterization of Existing Conditions** - Complete the characterization of existing salinity and DO conditions in the Hillsborough River and Palm River/Tampa Bypass Canal.

- **Development of Management Tool** - Continue the development of an empirically-based management tool to predict salinity and DO distributions in the Hillsborough River and Palm River/Tampa Bypass Canal using recently observed water quality data.

- **Development of Management Tool for Freshwater Zone** - Evaluate the effects of small changes in freshwater flow releases (e.g., 5 to 10 cfs) during periods of low flow on salinity and DO conditions in the Hillsborough River.

- **Link Environmental Benefits to Water Quality** - Develop a method to estimate environmental benefits of maintaining/ restoring various salinity and DO distributions in the Hillsborough River and Palm River/Tampa Bypass Canal.

The spatial focus of these four objectives was on the previously described downstream portions of the two river systems, and although data from other time periods were used, the temporal focus was on the current time period extending from 1985 to 1993.

This study was based on information reported by other studies which have been or are currently being completed. This empirical study was intended to build upon observations and analyses previously reported for this area in a comprehensive Hydro-Biological Monitoring Program completed for the West Coast Regional Water Supply and the City of Tampa and funded by the City of Tampa (Water and Air Research, Inc. And SDI, Inc., 1995).

3. STUDY AREA

Figure 3-1 presents the operational definition of Hillsborough River study area for this study. The study area extends from the Hillsborough River Dam to its confluence with Hillsborough Bay. River Mile measurements were defined from upstream to downstream with the Hillsborough River Dam assigned a river mile of 0 and the river mouth assigned a river mile of 10. Using this measurement system, the confluence of Sulphur Springs with the Hillsborough River main channel occurs at river mile 2.1.

Figure 3-2 presents the operational definition of the Palm River/Tampa Bypass Canal study area for this study. The study area extends from Control Structure S-160 downstream to the Palm River confluence with Hillsborough Bay. Mile measurements were defined from upstream to downstream with Control Structure S-160 assigned a river mile of 0 and the mouth of the Palm River assigned a river mile of 3.1.

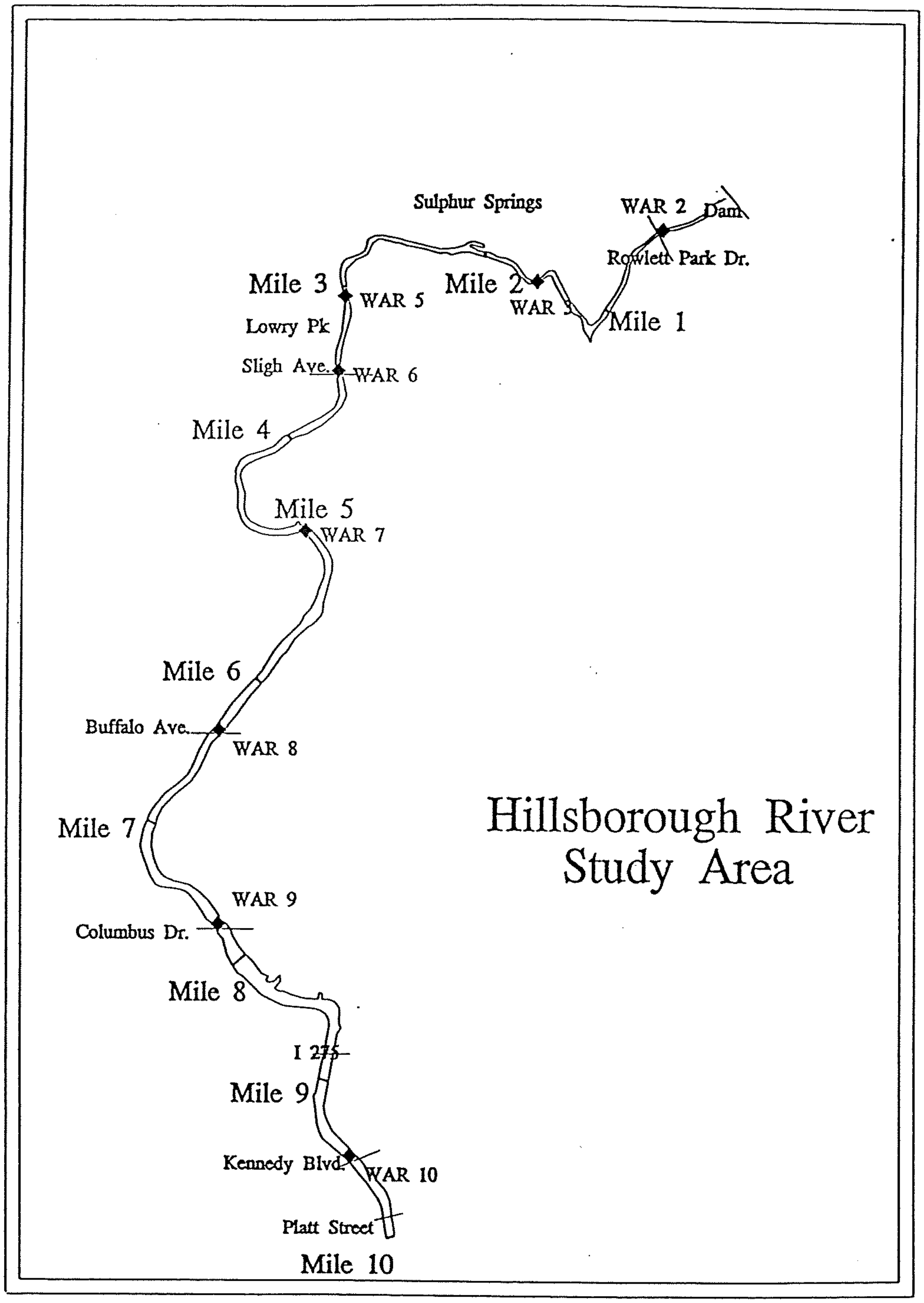


Figure 3-1 Operational definition of the Hillsborough River study area for this study.

4. DATA SOURCES

The primary data sources used for this study included:

- Geographic Information System Data,
- Freshwater Inflow Data,
- Periodical Sampled Water Quality Data,
- Continuously Sampled Water Quality Data, and
- Existing and Potential Habitat Data.

Current, appropriate, and peer-reviewed data sets were available for each of these categories of data except the existing and potential habitat data. A 1997 site visit was funded by the TBNEP in conjunction with this study to fill this data gap, and the results were integrated with the other available data sets.

4.1 Geographic Information System Data

Geographic Information System (GIS) data were created specifically for this study based on available GIS data sources and the study objectives. These data included river mile measurements, shoreline length, surface area, and river volume. All databases were created and analyzed using Unix Workstation versions of Arc Info 6.1 GIS software (ESRI, 1996). All of these databases are available from the GIS library of the TBNEP.

River Mile Measurements

We developed a set of 1/10 mile river segments for each of the two rivers using a GIS-based approach. For the first step of this approach, a center line was delineated for each of the two rivers using an existing 1990, 1:24,000 scale shoreline delineated by the SWFWMD (as described below). The Arc Info Dynamic Segmentation software was then used to measure and mark points along each of the centerlines in 1/10 mile increments. Using these reference points and the existing shoreline data as a guide, transverse river segment boundaries were delineated perpendicular to the left and right shorelines and the delineated center line. Maps of the operational definitions of the river mile measurements for the two rivers were previously discussed in Section 3 (Figures 3-1 and 3-2).

Shoreline Length

Shoreline data were compiled from an existing GIS data set delineated by the (SWFWMD) for 1990 Land Use/ Land Cover data. The features in these original land use coverages were delineated by the District from infrared aerial photographs at a scale of approximately 1:24,000. The waterward edges of mangroves and saltmarshes were operationally defined as shoreline for this data set.

The previously described 1/10 river mile segments were overlaid on the shoreline coverage to assign each length of shoreline to the 1/10 river mile segment in which it lies. Thus, the total shoreline in each segment consists of the sum of the shoreline length for each of the two banks and the shorelines of any islands present in the segment.

River Surface Area

River surface area data were also compiled from the existing 1:24,000 scale, SWFWMD, 1990 land use/ land cover data. The previously described 1/10 river mile segments were overlaid on the river surface area coverage to assign each length of shoreline to the 1/10 river mile segment in which it lies. Thus the total river surface area in each segment consisted of the sum of the area bounded by the upstream and downstream river segment divides and the two banks less the area of any islands present in the segment.

River Volume

River volume estimates for the Hillsborough River were computed as the product of estimated cross section areas and the distance between cross sections. Volumes were not estimated for the Palm River/Tampa Bypass Canal. Hillsborough River data from 39 cross sections were compiled by the SWFWMD from observations collected by SWFWMD and by the City of Tampa. Cross section area was estimated using the equation:

$$A_i = \sum_{j=1}^{J_i} \left(\frac{(X_{i,j+1} - X_{i,j})(Z_{i,j}) + (X_{i,j+1} - X_{i,j})(Z_{i,j+1})}{2} \right)$$

where A_i = the total estimated area for the ith cross section,

J_i = the number of depth samples reported for the ith cross section,

$X_{i,j}$ = the distance from the shoreline of the jth depth sample of the ith cross section, and

$Z_{i,j}$ = the depth of the jth depth sample of the ith cross section.

4.2 Freshwater Inflow Data

Freshwater inflow data were available in the form of continuous daily discharge estimates for the two rivers and Sulphur Springs. For each of these data sets, an average daily flow value was calculated for each day in the time series, and moving average flows for the previous 2 to 14 days were also computed.

Hillsborough River Dam

The USGS reports flow data observed at the Hillsborough River dam from 1959 to present. The USGS named the flow monitoring site "Hillsborough River Near Tampa, Florida" and numbered the site 02304500. The flow values reported for this site ranged from 0 cfs to over 13,500 cfs over the period of record, with a mean daily value of approximately 300 cfs. However, there is much variability in the flow quantities with many days having lower flows. Daily flow values recorded on the days sampled for water quality for the WAR Study and USGS observations were defined as a subset from the data set, and these flow values were used for this study.

Figure 4-1 presents the distribution of flow observations for the Hillsborough River dam for 1985 to 1993 and on days during which the water quality data used for this study were sampled. Figure 4-2 presents a subset of this same information for flows less than 200 cfs.

Palm River/Tampa Bypass Canal Control Structure 160

The SWFWMD estimates flow data at Structure 160 on the Palm River/Tampa Bypass Canal beginning in 1990 based on water levels in the canal and reported gate openings. In the Water Year Reports, the USGS reported the flow monitoring site "Tampa Bypass Canal at Structure 160 near Tampa, Florida," and numbered the site 02301802. The flow values reviewed for this study from

1985 to 1993 ranged from 0 cfs to more than 1000 cfs, with a mean daily value of approximately 100 cfs. However, as previously noted for the Hillsborough River flow monitoring station, there is much variability in the flow quantities with many days having lower flows. Daily flow values recorded on the days sampled for the WAR and USGS water quality programs were defined as a subset from the data set and used for this study.

Figure 4-3 presents the distribution of flow observations for Structure 160 for 1985 through 1993 and for the period during which the water quality data used for this study were sampled. Figure 4-4 presents a subset of this same information for flows less than 200 cfs.

Sulphur Springs

The USGS reports flow data observed at Sulphur Springs at a flow monitoring site named "Sulphur Springs at Sulphur Springs, Florida" and numbered the site 02306000. The flow values reported for this site ranged from 0 cfs to 40 cfs, and were relatively more constant than the variable quantities previously noted for the Hillsborough River Dam and Structure 160. Daily flow values recorded on the days sampled for water quality were subset from the period of record data set and used for this study.

Ungaged Portions of the Watershed

Freshwater inflow estimates to the Hillsborough River and the Palm River/Tampa Bypass Canal were obtained from an empirical watershed hydrology model developed for the TBNEP (Zarbock et al., 1995). Estimates of stormwater runoff and point source discharges were computed for each water quality sample for the month in which water quality sample was collected.

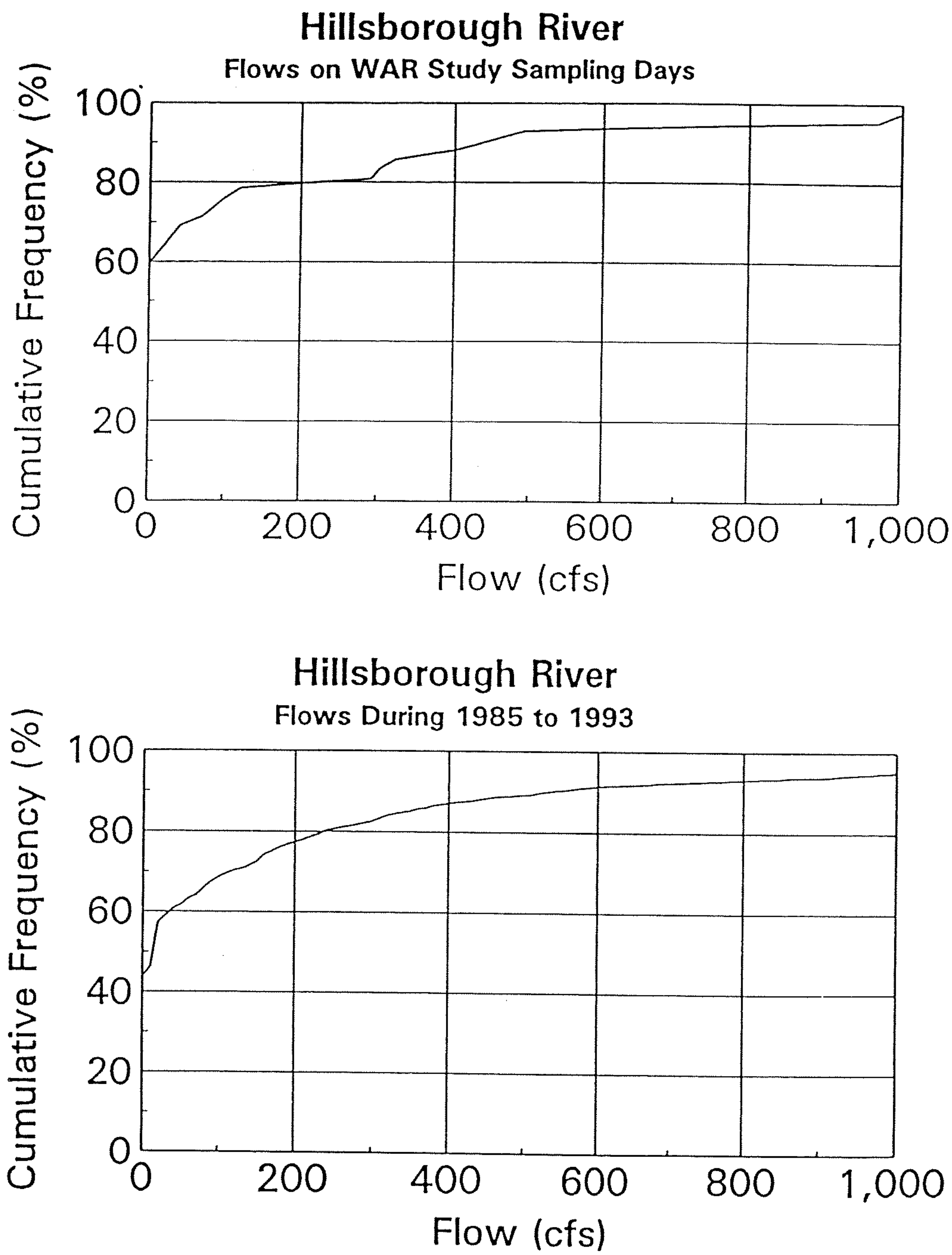
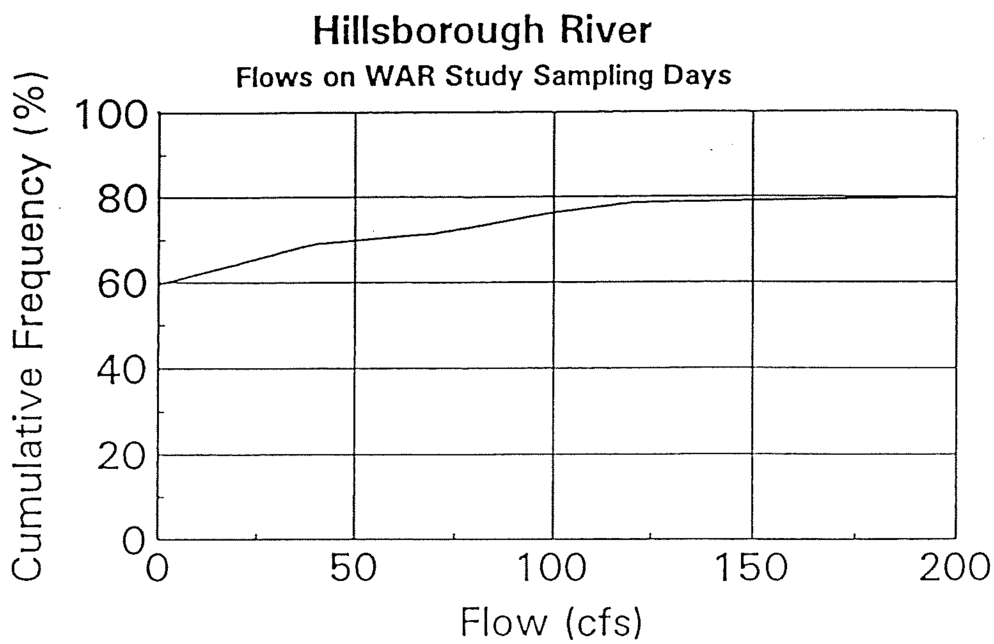


Figure 4-1 Hillsborough River Dam flow data.



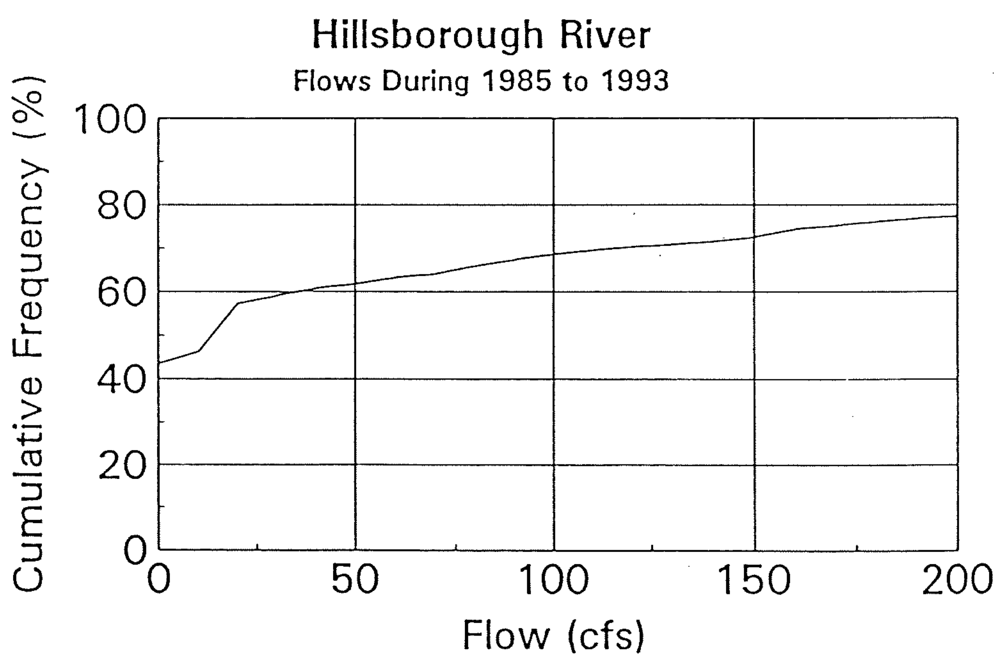


Figure 4-2 Hillsborough River Dam flow data, 0-200 cfs.

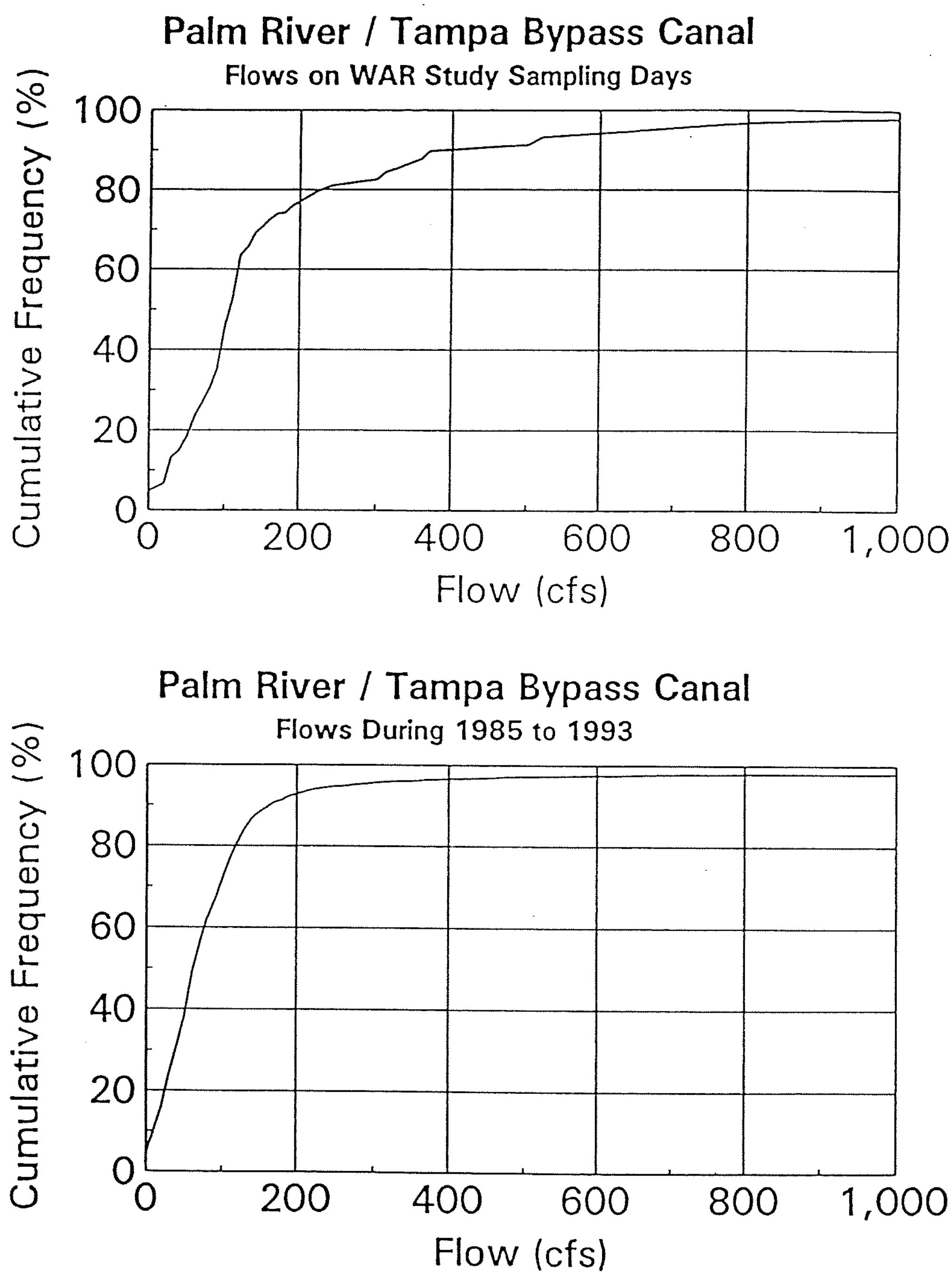
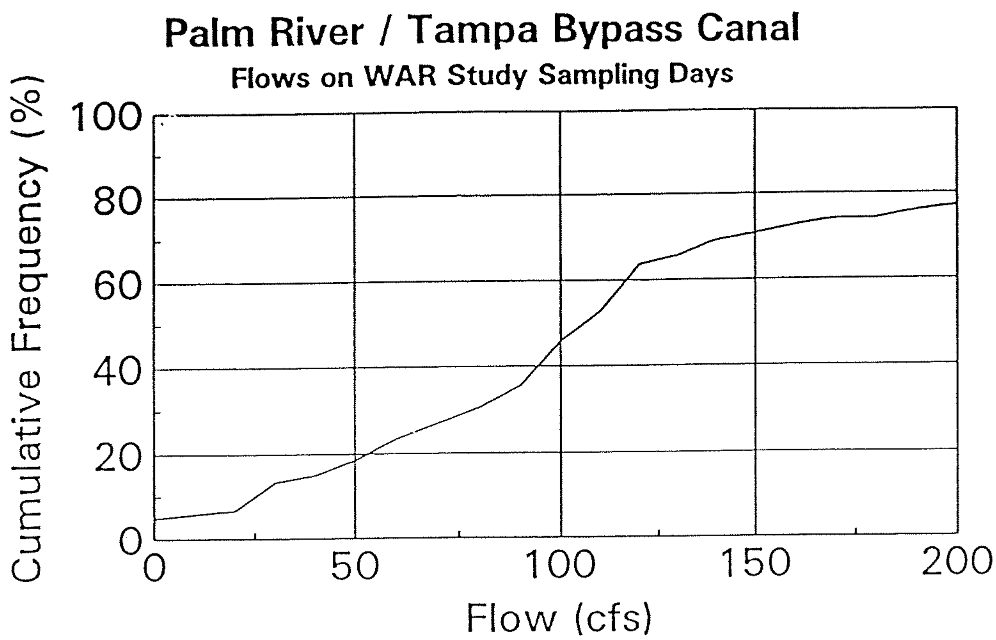


Figure 4-3 Palm River/Tampa Bypass Canal, flow data from Structure 160.



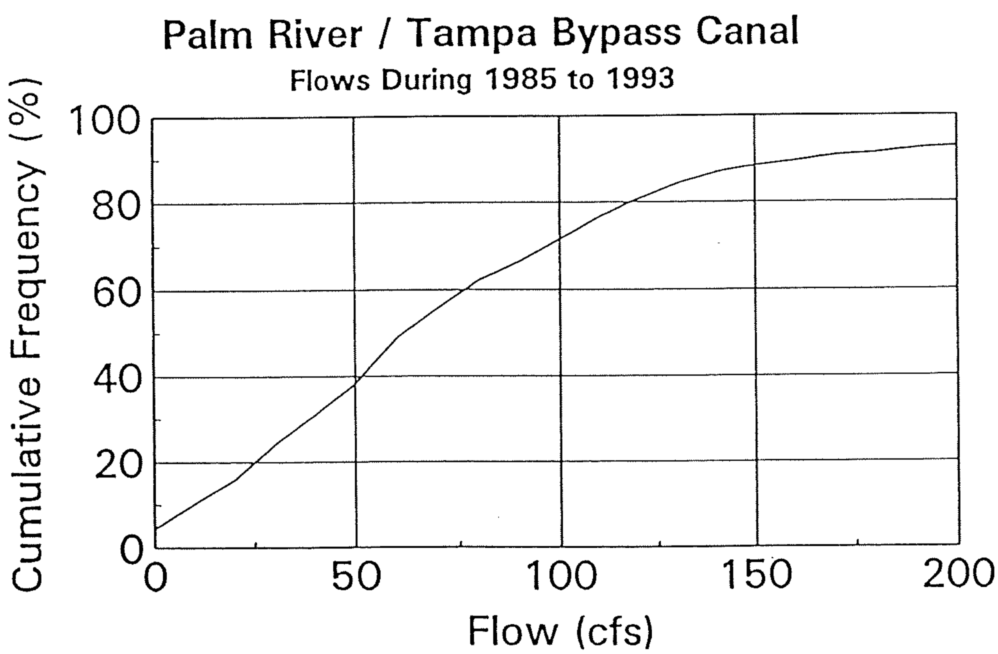


Figure 4-4 Palm River/Tampa Bypass Canal, flow data from Structure 160, 0-200 cfs.

4.3 Monthly Sampled Water Quality Data

Monthly sampled salinity and DO data were the primary data sets used to investigate the relationships between flow and water quality in the two rivers. The monthly temporal resolution of these data sets did not allow full use of the temporal resolution of the daily flow data as was the case for the continuously monitored water quality studies described below. However, the monthly water quality data were chosen as the primary water quality data because they were sampled over many more locations in the rivers and over many years.

City of Tampa/West Coast Regional Water Supply Study

Monthly water quality observations were reported for the Hillsborough River and Palm River/Tampa Bypass Canal from a hydro-biological monitoring program (Water and Air Research and SDI Environmental Service, Inc, 1995). These data were collected between 1991 and 1993, and are often informally cited as "the WAR Study." These data comprised the primary salinity and DO data for this study. DO was measured during at approximately midday (i.e., 1000 to 1400 hours).

In accordance with the river mile segmentation scheme defined for this study, these stations were located at the following river locations.

Hillsborough River Station Locations	
Station No.	River Mile (from dam)
2	0.45
3	1.65
5	3.1
6	3.5
7	5.0
8	6.3
9	7.8
10	9.5

Palm River/Tampa Bypass Canal Station Locations Station No.	River Mile (from Structure S-160)
13	1.4
14	2.5
15	3.1

All stations were sampled close to the surface, at 1 meter depth increments starting from 1 meter below the surface, and close to the bottom.

Environmental Protection Commission of Hillsborough County Ambient Monitoring Program

The Environmental Protection Commission of Hillsborough County (EPCHC) has reported monthly water quality observations from a set of fixed stations in these two rivers from 1974 to present. Salinity and DO observations were used from this data set as a secondary data source for this study. The data were used to validate relationships observed using the WAR Study data describe above. Similar to the WAR Study, the EPCHC DO observations were recorded during an approximately midday time period (i.e., 1000 to 1400 hours).

In accordance with the river mile segments defined for this study, three EPCHC stations were located within the Hillsborough River. These stations were Station 105 at river mile 0.45, Station 137 at river mile 7.8, and Station 2 at river mile 10.

4.4 Continuously Sampled Water Quality Data: U.S. Geological Survey Data

Approximately continuous water quality observations were reported for the Hillsborough River by the U.S. Geological Survey (USGS). These USGS data were collected from 1981 to 1982, and from 1991 to 1993. These data were used as secondary sources of salinity and DO observations to validate the relationships developed using the WAR Study data.

Continuously sampled data were reported for the following locations:

Continuously Sampled Water Quality Station Locations	
Station Name	Years Sampled
Rowlett Park Drive	1981, 1982
Sligh Avenue	1981, 1982
Columbus Drive	1981, 1982
Platt Street	1981, 1982, 1991, 1993

All of these stations were sampled at a "mid-depth" location.

The following text provides a summary of the water quality observations from upstream near the Hillsborough River Dam (Rowlett Park Drive) to downstream near the mouth of the river (Platt Street):

Rowlett Park Drive salinity measurements ranged from 0.01 ppt to 11.3 ppt with an average value of 1.6 ppt. DO concentrations were not reported for this sampling location.

Sligh Avenue salinity measurements ranged from 0.02 ppt to 20.1 ppt with an average value of 5.0 ppt. Minimum daily DO concentration ranged from 0.02 mg/L to 8.1 mg/L with an average value of 3.6 mg/L, and average midday DO concentration ranged from 0 mg/L to 9.3 mg/L with an average value of 4.4 mg/L.

Columbus Drive salinity measurements ranged from 0.08 ppt to 26.8 ppt with an average value of 12.36 ppt. Minimum daily DO concentration ranged from 0 mg/L to 7.4 mg/L with an average value of 2.8 mg/L, and average midday DO concentration ranged from 0.5 mg/L to 9.7 mg/L with an average value of 4.1 mg/L.

Platt Street salinity measurements ranged from 0.8 ppt. to 29.3 ppt. with an average value of 20 ppt. Minimum daily DO concentration ranged from 0 mg/L to 6.1 mg/L with an average value of 1.7 mg/L, and average midday DO concentration ranged from 0 mg/L to 8.5 mg/L with an average value of 3.6 mg/L.

The DO measurements from the WAR Study were measured during an approximately midday time period (i.e., 1000 to 1400 hours). Thus, the continuous DO data reported by the USGS were particularly valuable to investigate the relationships between the biologically-meaningful minimum daily DO concentrations and the average midday DO concentrations.

4.5 Existing and Potential Habitat Data

Current data sets were not available at an appropriate level of resolution for existing and potential habitat data. A 1997 site visit was funded by the TBNEP in conjunction with this study to fill this data gap, and the results were integrated with the other available data sets. The results of this study were characterized into two classes, existing habitat and potential habitat, and the locations and areal measurement for each site were tabulated.

5. APPROACH

An empirical regression-based approach was used to investigate the relationships between flow and salinity and between flow and DO. The quantitative results of the regression models were then used to predict salinity and DO responses to a range of management alternatives.

5.1 The Nature of the Empirically-based Approach

As previously discussed, the objective of this work was to estimate the relationships between freshwater flow and water quality (i.e., salinity and DO). The empirical approach used measured data to describe observed relationships between freshwater flow and salinity responses without regard to the myriad internal processes which affect the response (e.g., tide stage, wind effects, stratification, internal circulation, temperature, etc ...). The variation in these relationships due to the factors listed above and others was reported with the empirical regression results. Under any given managed flow value, this variation represents the range of salinity and DO that the fish and other biota in the rivers will likely be exposed to.

The advantages of using an empirical approach include the following.

- It will provide a simple, net explanation of the observed data.
- It does not require important assumptions to be made regarding internal processes.
- It is robust to prediction errors.
- It is more efficient to model, and, thus, it allows project resources to be used to explore a wide range of spatial and temporal resolutions, effects of outliers, and many combinations of explanatory variables

The disadvantages of using an empirical approach include the following.

- It is subject to potential prediction errors caused by autocorrelation of the independent variables. For example, if flow and salinity were affected by a third variable and did not affect each other, then one might still observe a clear pattern between flow and salinity in monthly data and falsely conclude that salinity varied as a response to flow.
- It provides predictions limited to the range of observed data.
- It only addresses external processes, and does not consider the internal processes such as wind driven circulation.

5.2 *A priori* Definition of Physical Relationships

The physical relationships to be investigated by the empirical approach were selected *a priori* based on the following criteria:

- they follow a hypothesized physical relationship,
- they include a manageable explanatory variable (e.g., flow from a control structure),
- they include a biologically important response variable (e.g., DO concentration), and
- they describe a relationship between the manageable explanatory variable and the important response variable, where the unexplained variation in the observed relationship is believed to be largely unmanageable.

Using these criteria, four relationships were defined and investigated for this study. They were:

- salinity = f(freshwater flow);
- minimum daily DO = f(midday DO) = f(freshwater flow), a two-step relationship; and
- mean daily DO = f(midday DO) = f(freshwater flow), a two-step relationship; and
- the proportion of samples with DO less than a target value = f(freshwater flow).

The two-step relationships for DO were necessary because the midday DO data recorded in the primary WAR Study were deemed by representatives of the local governments and participating scientists to be less biologically important than mean and minimum daily DO concentrations.

5.3 Selection of Functional Forms

A number of mathematical functions were reviewed for use as the functional forms of the regression models. Models were run iteratively with various functional forms, and the most suitable functional forms were selected in an effort to minimize lack of fit of the models to the observed data.

Functional Form of Model: salinity = *f*(freshwater flow)

In order to fit the wide variety of curve forms in the observed salinity and flow data, the functional form of these models was required to be very flexible. A multiple parameter curve form such as a polynomial could have been fit to these data, but because there were a limited number of observed samples, it was also desired to have a very small number of parameters to explain the relationships in order to maintain robustness to prediction error.

A regression model was selected for these relationships which fit the shape of the observed data distributions well, was very flexible, and had very few parameters to be fit:

$$\ln(Salinity) = \alpha + \beta \ln(flow)$$

where, α and β were parameters fit by least squares regression analysis. To fit this model, the salinity data were paired with the daily flow reported for the same day on which the data were recorded. Stepwise linear regression analysis was used to determine that an average flow from the day of the salinity sample, one day previous, and two days previous explained the greatest amount of variation in the salinity observations.

The observed flow data from the period of record contained a number of zero flow observations. Since the natural log of zero is undefined, and the natural log of a distribution of numbers has a very extreme range for numbers near zero, the flow data were coded before entered into the regression equation by the addition of a constant (K).

The final functional form for the freshwater flow and salinity relationships was:

$$\ln(Salinity_t) = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K\right)$$

where Salinity$_t$ = the monthly salinity measured on day t > 0 ppt,

K = 50, and

I = the number of lag days over which to compute a moving average of flow.

Zero salinity values were observed at higher flows. Since the natural log of zero is undefined mathematically, using this equation had the effect of excluding zero salinities from the analysis. Excluding the zero salinity values from the regression input was not found to adversely effect the goodness of fit of the regression models. The regression models were still capable of predicting approximately zero salinities for the days on which the zero salinities were observed based on the observed flow data.

These salinity models were run using two approaches. The first approach was to assign an independent model for each station where data were sampled. The second approach was to combined data from all stations into a single model, and to add a river mile term to the regression relationship. The second form of the analyses was used when a relationship was observed between river mile and the residuals from the independent station models. As presented in the results section of this report (Section 6), a combination of these two methods was used for the final results.

General Forms of the Dissolved Oxygen Models

The continuous DO monitoring data collected by the USGS studies were used to relate the midday DO collected by the WAR Study to more biologically meaningful minimum daily DO and mean daily DO estimates.

Functional Form of Model: minimum daily DO = *f*(midday DO) = *f*(freshwater flow)

For the first link in this relationship, a similar final functional form was selected for the freshwater flow and midday DO concentration relationships:

$$Midday\ DO_t = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K\right) + \beta' \ln(temperature_t)$$

where Midday DO_t = the monthly DO measured on day t > 0 mg/L, and

For the second link in this relationship, the observed data were best explained by a simpler linear model:

$$Mean\ Daily\ DO_t = \delta + \gamma\ Mid\text{-}day\ DO_t$$

where δ and γ were parameters fit by least squares regression analysis.

Functional Form of Model: mean daily DO = *f*(midday DO) = *f*(freshwater flow)

A similar set of functional forms was selected for the two-step relationship:

$$Midday\ DO_t = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{i+1} + K\right) + \beta' \ln(temperature_t)$$

where Midday DO_t = the monthly DO measured on day $t > 0$ mg/L.

And:

$$Minimum\ Daily\ DO_t = \delta + \gamma\ Mid\text{-}day\ DO_t$$

Functional Form of Model: % DO<target value = *f*(freshwater flow)

The functional form of this model was:

$$\ln(P_t) = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K \right)$$

where P_t = the proportion of observations with DO < a target value in a group of data.

In order to regress the data using this model, it was necessary to compute the proportion values by grouping the observations based on the management variable of interest (i.e., flow). Unfortunately, there were not sufficient numbers of observations to group the data by additional variables such as temperature.

6. RESULTS

The regression parameters from the previously discussed regression models were estimated using ordinary least squares regression analyses. Regression output data are presented in appendices as listed in the text below. Diagnostic tests were performed to assess the goodness of fit of the models using comparisons of R-square values, plots of residual values, and plots of predicted versus observed values.

6.1 Hillsborough River Salinity and Flow Relationships

Regression parameters were fit for the Hillsborough River using a combination of fixed station models and a river-wide model for the lower portion of the river for each depth analyzed. The river-wide models were fit by adding river mile and river mile*flow interaction terms to the functional forms previously discussed.

The final combined results were selected using a combination of fixed station results and the river-wide results. The results are presented in the order they were selected from upstream to downstream.

River mile 0 (Hillsborough River Dam) to river mile 0.5 (War Station 2 = mile 4.5)

Based on the observed data at Station 2, the best resulting relationship between salinity and freshwater flow for Station 2 was as follows: For each depth at zero flow conditions, salinity was estimated to be the average salinity observed at that depth during zero flow conditions. For all flows greater than zero, salinity was estimated to be zero. The observed data used to determine this relationship for Station 2 are presented in Appendix A.

River mile 0.5 (War Station 2) to river mile 1.6 (War Station 6 = mile 1.65)

A linear interpolation between the model for river mile 0 to 0.5 and the model for river mile 1.65 was computed for this portion of the river. The results for the model for river mile 1.65 are presented below.

River mile 1.65 (War Station 3)

The results of regression analyses using the previously discussed model:

$$\ln(Salinity_t) = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K \right)$$

was examined for each depth (0m, 1m, 2m, 3m, and bottom) using the observations from WAR station 3. The surface observations from the WAR Study were collected from 0.2 meters below the surface, and for purposes of this report were labeled as "0m."

A stepwise linear regression analysis was first used to determine the best value of the moving average duration parameter *I* from a set of models having *I* values from 0 to 14 days. A *I* value of 2 was consistently selected for the Station 3 data for all depths. Thus, an average flow value from the current day and the 2 previous days provided the best explanation of the observed salinity data.

A linear regression analysis was then performed for each depth using an *I* value of 2 to estimate the parameters α and β. The resulting regression model fit the observed data well with slope and intercept parameters significantly different from zero at the probability level of 0.0001. The R-square values for these regressions were computed using the corrected sum of squares of the untransformed salinity data and the uncorrected sum of squares for the untransformed salinity residuals (i.e., not the log transformed values). The R-square values were 0.72 for surface, 0.68 for 1 meter depth, 0.60 for 2 meter depth, 0.57 for 3 meter depth, and 0.63 for the bottom depth.

Pooling the residuals from all depths, an overall R-square value of 0.66 was recorded. Thus, approximately two thirds of the variation in the observed salinity data could be explained by the variation in freshwater flow from the dam. The remaining unexplained variation in the observed salinity data represent the relatively unmanageable fluctuations in salinity to which the biota would be exposed to under a given flow management strategy.

An exploratory attempt was made to explain more of the variation in the salinity observations by adding covariates to the regression model. These covariate parameters were added without regard to whether the parameters could be effectively managed (e.g., tide stage estimated by the WAR Study, non-point source freshwater loads below the dam). No useful improvements in the R-square values were observed. In general, the addition of covariates was not found to be useful for any of the empirical models for this study.

Plots of the resulting predicted and observed values for the Hillsborough River salinity and flow relationship models for independent stations are presented in Appendix B. Other diagnostic plots from these models are also presented in Appendix B.

Additional independent station analyses were conducted using the same methods as the WAR data using the USGS fixed station data. The results from these analyses are presented in Appendix C. Predicted salinities from all of the fixed station models for various dam flow values are presented in Appendix M.

River mile 1.65 (WAR Station 3) to river mile 2.1 (Sulphur Springs)

A linear interpolation between the model for river mile 1.65 and the model for river mile 2.1 through 10 was computed for this portion of the river. The results for the model for river mile 2.1 through 10 are presented below.

River mile 2.1 (Sulphur Springs) to river mile 10 (River Mouth)

The results from a river-wide regression model with a river-mile term and a river-mile interaction were examined for each depth (0m, 1m, 2m, 3m, and bottom) using the previously presented model:

$$\ln(Salinity_t) = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K\right) + \gamma \ln\left(\frac{river\ mile}{1}\right) + \theta \left[\ln\left(\frac{river\ mile}{1}\right)\left(\ln\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K\right)\right]$$

where all salinity observations downstream of Sulphur Springs (river mile 2.1) were paired with a total flow value of the measured dam flow plus the measured Sulphur Springs flow.

A stepwise linear regression analysis was first used to determine the best values of the moving average duration parameter I from a set of models having I values from 0 to 14 days. An I value of 2 was consistently selected for the 0 depth data at all stations. Thus, an average flow value from the current day and the 2 previous days provided the best explanation of the observed surface salinity data. An I value of 0 was selected for the depths 1m, 2m, 3m, and bottom. Thus, the flow on the current day provided the best explanation of the salinity on that day for subsurface observations.

A series of least squares regression analyses were then completed to estimate the parameters α, β, γ, and θ. The resulting regression models fit the observed data well with all slope and intercept parameters significantly different from zero at the probability level of 0.0001. As previously discussed, the R-square values for these regressions were computed using the corrected sum of squares of the untransformed salinity data and the uncorrected sum of squares for the untransformed salinity residuals. The R-square values were 0.87 for surface, 0.78 for 1 meter depth, 0.73 for 2 meter depth, 0.83 for 3 meter depth, and 0.76 for the bottom depth. Pooling the residuals from all depths, an overall R-square value of 0.78 was obtained.

Plots comparing the observed salinities at the downstream fixed stations with the predicted salinities form the regression model, the regression output, and the resulting predicted and observed values for these models are presented in Appendix D. The salinity estimate residuals from these results were plotted in this appendix by river mile, month, rainfall for the day each salinity sample was measured, and nps runoff for the month each salinity sample was measured. Predicted salinities from the river-wide model for various dam flow values are presented in Appendix N.

6.2 Palm River/Tampa Bypass Canal Salinity and Flow Relationships

These salinity and flow relationships were fit using the model form previously discussed in Section 5. The results of the regression analyses indicated that, a river-wide model having a river mile term and a river mile interaction term would not fit the data for the Tampa Bypass Canal well. The best regression results were obtained by fitting independent regression models to the data from each of the four sampling stations and each depth.

The results of the regression analyses indicated that the best fit was obtained with the model:

$$\ln(Salinity_t) = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K\right)$$

where Salinity$_t$ = the monthly salinity measured on day t > 0 ppt.

An I value of 2 was chosen by stepwise linear regression analysis, and a least squares regression was complete to estimate the parameters α and β for each depth. These models fit the observed salinity and flow data well. Regression output data for these analyses are presented in Appendix E. All of the slope and intercept estimates for each depth and station were significantly different from 0 at a probability level of 0.0001, except for Station 15 at 2m depth. The probability level for this station and depth was 0.0003.

The resulting R-square values for these regression analyses were as follows:

Palm River/Tampa Bypass Canal Flow and Salinity Regression Analyses R-square Values		
Station	Depth	R-square
Station 12	0m	0.44
	1m	0.54
	2m	0.61
Station 13	0m	0.63
	1m	0.67
	2m	0.63
Station 14	0m	0.72
	1m	0.70
	2m	0.60
Station 15	0m	0.67
	1m	0.71
	2m	0.42

An overall R-square value of 0.69 was obtained for these analyses by pooling the residuals from all stations and depths. Although an overall river-wide model was not developed using a river-mile explantory term, an overall predictive model was constructed using these results by estimating salinity for each 1/10 river mile using the regression results from the station nearest each 1/10th river mile.

Plots of the resulting predicted and observed values are also presented with the complete regression results in Appendix E. Predicted salinities from the fixed station models for various dam flow values are presented in Appendix O.

6.3 Hillsborough River Dissolved Oxygen and Flow Relationships

The relationships for minimum daily DO concentration as a function of flow and for mean daily DO concentration as a function of flow were fit using the two-step functional forms presented in Section

5. The resulting regression output data are presented in Appendices F through H.

Results of Analysis of Relationship Between Minimum and Mean Daily DO and Midday DO

Regression results were obtained for the relationships between minimum and mean daily DO concentrations and midday (1000 to 1400 hours) DO concentration using the following two previously discussed models:

$$Minimum\ Daily\ DO_t = \alpha + \beta\ Midday\ DO_t$$

and

$$Mean\ Daily\ DO_t = \delta + \gamma\ Midday\ DO_t$$

These two regression analyses were completed using the continuous USGS continuous monitoring data discussed in Section 4.4.

Regression results for the relationships between minimum and mean daily DO concentration and midday DO concentration and plots of the predicted and observed values are presented in Appendix F. The best fit as obtained by using input data from the Columbus Avenue monitoring site and the Sligh Avenue monitoring site. No DO concentration data were reported for the Rowlett Park Drive monitoring site, and relationships between the parameters of interest were not evident in the data from Platt Street monitoring site near the river mouth. Daily summarized data from Columbus (n=265 days) and Sligh (n=288 days) Avenues were combined in approximately equal proportions for the regression analysis. The residual values for a regression analysis of these data from these two combined monitoring sites indicate that data from both stations follow approximately the same linear relationship.

Both regression relationships fit the observed data from Columbus and Sligh Avenues very well. For the regression relating minimum daily DO and midday DO, the slope was significantly different from 0 at an alpha level of 0.0001, and the R-square value was 0.89. For the regression relating mean daily DO and midday DO, the slope was significantly different from 0 at an alpha level of 0.0001, and the R-square value was 0.74.

Results of Analysis of Relationship Between Midday DO and Freshwater Flow

A series of regression analyses were completed using the previously presented model:

$$Midday\ DO_t = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K\right) + \beta' \ln(temperature_t)$$

The results of these analysis can be summarized as follows, where the notation "NS" indicates that the null hypothesis that the parameter is equal to 0 could not be rejected at an alpha level of 0.05:

Hillsborough River
Flow and Midday DO Analyses

Station	Depth	Selected Value of I	(Flow) P>[T] H0: β =0	(Temperature) P>[T] H0: β'=0	R-square
Station 2	0m	2	0.047	0.0001	0.42
	1m	2	0.002	0.0001	0.51
	2m	2	0.0007	0.0001	0.53
	Bottom	2	0.0005	0.0001	0.54
Station 3	0m	2	0.0001	0.0001	0.63
	1m	2	0.0001	0.0001	0.64
	2m	2	0.0001	0.0015	0.70
	Bottom	2	0.0001	0.0001	0.72
Station 5	0m	0	NS	0.0001	0.43
	1m	2	0.0002	0.0011	0.47
	2m	2	0.0001	0.0032	0.58
	Bottom	2	0.0001	0.0014	0.60
Station 6	0m	0	NS	0.0005	0.35
	1m	2	0.003	0.004	0.37
	2m	2	0.0001	0.019	0.59
	Bottom	2	0.0001	0.0142	0.61
Station 7	0m	14	NS	0.0002	0.41
	1m	14	NS	NS	0.16
	2m	14	0.0037	NS	0.28
	Bottom	14	0.0013	0.018	0.35
Station 8	0m	14	NS	0.0006	0.35
	1m	14	NS	0.0015	0.29
	2m	14	NS	0.038	0.18
	Bottom	14	0.026	0.0043	0.30

Hillsborough River
Flow and Midday DO Analyses

Station - Depth		Selected Value of I	(Flow) P>[T] H0: $\beta = 0$	(Temperature) P>[T] H0: $\beta' = 0$	R-square
Station 9	0m	14	NS	0.002	0.37
	1m	14	NS	0.002	0.32
	2m	14	NS	0.0001	0.46
	Bottom	14	NS	0.0001	0.57
Station 10	0m	14	0.014	0.0001	0.56
	1m	14	0.0003	0.0001	0.64
	Bottom	14	0.0014	0.0001	0.67

The relationship between DO concentration and water temperature was always significant at all stations and depths, except for the middepths at Station 7. The models for the upstream stations 2 through 6 fit the observed DO and flow data relatively well, with the exception of the surface depths for Station 5 and Station 6. The moving average durations of $I = 2$ selected for the upstream stations also appeared to be consistent with those previously selected for the salinity and flow relationships. For the downstream stations, a 14 day moving average period for flow was selected. Many of the slope parameters for DO concentration and flow for Stations 7 through 10 were not significantly different from 0 at an alpha level of 0.05. Regression output data for these analyses are presented in Appendix G.

An overall predictive model for DO was constructed using these results by estimating DO for each 1/10 river mile using the regression results from the station nearest each 1/10th river mile. Although the observed data did not exhibit an unequivocal relationship between midday DO concentration and flow for Stations 7, 8, and 9; these stations were kept in the overall predictive model built from these regression results. Thus for all values of flow for Stations 7, 8, and 9, the overall predictive model will estimate a typical value of DO for that station given a specified temperature and station location. An overall R-square value of 0.62 was obtained for these analyses by pooling the residuals from all stations and depths using an overall predictive model.

Results of Analysis of Relationship of Proportion of Observations with DO< Target and Flow

The proportion of observations with DO less than a specified target was regressed against cumulative average flow. The WAR data from all depths and stations were analyzed using the model:

$$\ln(P_f) = \alpha + \beta \ln\left[f\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K \right) \right]$$

where f represents a rounding function which assigned flow to the nearest 10 cfs class,

P_f represents the proportion of observations in flow class f with DO < a target value, and

α and β are parameters which were estimated with least squares regression analysis.

These analyses were conducted for DO concentration target values of 1, 2, 3, 4 and 5 mg/L. 13 flow classes were present in the observed data, and thus, 13 data points were input into the regression for each of the DO concentration target values. The results of the analyses were as follows, where the notation "NS" represents a slope parameter not significantly different from 0 at an alpha level of 0.05.

Proportion of DO<Target and Flow Regression Results Summary

DO Target	P>[T] H0:β=0	R-square
1 mg/L	0.0006	0.61
2 mg/L	0.0011	0.66
3 mg/L	0.0008	0.56
4 mg/L	0.03	0.17
5 mg/L	NS	NS

A significant component of the variation in the proportion of observations with DO less than 1, 2 and 3 mg/L was explained by the variation in flow. This relationship was not evident in the proportion of observations with DO less than 4 and 5 mg/L. A complete set of regression results for this analysis is presented in Appendix H.

Results of Analysis of Vertical Water Quality Gradients

An analysis of vertical water quality gradients in the Hillsborough River was conducted using the

WAR Study data to investigate how these gradients vary with freshwater flow from the dam. The WAR data were collected at 1 meter depth intervals from 1 meter below the surface to the 1 meter interval nearest the bottom. Thus, the depths of gradients were assigned a midpoint between the two selected sample depths. WAR data were also used from surface observations, and the gradient depth between surface and 1 meter was operationally defined as 0.5 meters for this analysis.

The following results are presented in Appendix I:

- the depth of maximum vertical salinity gradient plotted against freshwater flow,
- the depth of maximum vertical DO gradient plotted against freshwater flow, and
- the depth of maximum vertical salinity gradient plotted against the depth of maximum vertical DO gradient.

The results of the maximum vertical salinity gradient analysis were plotted by station against freshwater flow. Dam flow was used for Stations 2 and 3, and the sum of dam flow and Sulphur Springs flow was used for Stations 5 through 10. For Station 2, most of the salinities were zero at all levels of flow. Thus, very few points appear on the plot. For Station 3, the depths occurred from 0.5 to 3.5. For Stations 5 through 9, the results indicated that the deepest maximum gradients were generally associated with higher flows. This is particular apparent for Station 9. For Station 10 there was not a clear relationship between depth of maximum salinity gradient and flow.

The results of the maximum vertical DO concentration gradient were also plotted by station against flow. A similar pattern was evident in these plots as was seen in the depth of maximum salinity gradient data.

Lastly, the depth of maximum vertical salinity gradient was plotted against the depth of maximum vertical DO concentration gradient. These plots reflected the previously noted general agreement between the depths for salinity and DO maximum change. Of the 265 pairs of observations analyzed, approximately two thirds of the salinity depths matched the DO depths (180 observations).

6.4 Palm River/Tampa Bypass Canal Dissolved Oxygen and Flow Relationships

A series of regression analyses were completed using the previously presented model:

$$Midday\ DO_t = \alpha + \beta \ln\left(\sum_{i=0}^{I} \frac{flow_{t-i}}{I+1} + K\right) + \beta' \ln(temperature_t)$$

Although the slope parameter for temperature was highly significantly different from 0 in all cases, the slope parameters for flow were not significantly different from 0 with the exception of one case at Station 13 and depth 3m. It can be concluded from these results that the sum of the other sources of variability DO (e.g., BOD, COD, water column circulation, and measurement error of DO, flow and temperature) had a greater effect than flow on the days sampled. Thus, the two-step relationships developed for the Hillsborough River could not be developed. The results of the regression analyses are presented in Appendix J.

7. APPLICATION OF RESULTS: MANAGEMENT TOOLS

The results of the regression models discussed in the Section 6 were applied in the form of several management tools to predict salinity and DO concentrations as a function of candidate freshwater flow targets. The salinity and DO data were classified into regimes according to ranges of values and linked by depth and river mile with the GIS data developed for this project. The resulting management tools present the expected shoreline, surface area, and river volumes in each salinity and DO concentration regime as a function of the candidate freshwater flow targets. Isohaline maps were also prepared to present the expected distribution of salinity as a function of selected freshwater flow values.

7.1 Hillsborough River Salinity and Flow Relationships

The expected changes in habitat extent by salinity regime associated with increased flows are presented in Table 7-1. The following habitat metrics are presented by salinity regime as a response to freshwater flow from the Hillsborough River Dam: total river miles (Figure 7-1), segment shoreline miles (Figure 7-2), segment surface area (Figure 7-3), total volume (Figure 7-4), extent of likely restorable shoreline habitat (Figure 7-5), extent of potentially restorable shoreline habitat (Figure 7-6), and extent of existing emergent wetland habitat (Figure 7-7).

A series of isohaline maps is presented for selected freshwater flow values for the Hillsborough River in Appendix K. These maps indicate the most downstream extent of the salinity values labeled for the surface depth and for 1 meter below the surface.

7.2 Palm River/Tampa Bypass Canal Salinity and Flow Relationships

The expected changes in habitat extent by salinity regime associated with increased flows are presented in Table 7-2. The following habitat metrics are presented by salinity regime as a response to freshwater flow from Structure 160: total river miles (Figure 7-8), segment shoreline miles (Figure 7-9), segment surface area (Figure 7-10).

7.3 Hillsborough River Dissolved Oxygen and Flow Relationships

The expected changes in habitat extent by minimum daily DO concentration associated with increased flows are presented in the upper portion of Table 7-3. These results were compiled by estimating DO for each 1/10 river mile using the regression results from the station nearest each 1/10th river mile. The expected changes in habitat extent by mean daily DO concentration associated with increased flows are presented in the lower portion of Table 7-3.

Hillsborough River
Changes in Habitat Associated With Increased Flow

Salinity Range Habitat Type	Baseline Condition (0 Release)	Change from Baseline for 10 cfs Flow Releases									
		10	20	30	40	50	60	70	80	90	100
0-0.5 ppt											
Shoreline Length (ft)	0	5,513	6,600	7,657	7,657	8,719	9,778	10,846	11,899	13,296	14,385
Surface Area (ac)	0	8	10	11	11	12	14	15	17	19	21
Volume (ac-ft)	0	16	19	21	26	33	36	42	58	66	75
0-1 ppt											
Shoreline Length (ft)	0	7,657	8,719	9,778	11,899	13,296	15,435	16,487	25,012	28,270	32,551
Surface Area (ac)	0	11	12	14	17	19	23	25	37	42	49
Volume (ac-ft)	0	21	28	36	51	61	77	88	123	135	157
0-4 ppt											
Shoreline Length (ft)	0	31,450	39,954	47,351	52,684	57,148	61,430	64,670	67,899	70,158	73,338
Surface Area (ac)	0	47	62	79	89	99	112	121	130	137	145
Volume (ac-ft)	0	114	157	205	287	350	411	469	516	583	625
2-14 ppt											
Shoreline Length (ft)	79,781	-4,386	-668	1,911	-7,741	-10,946	-13,029	-17,237	-21,473	-24,675	-27,874
Surface Area (ac)	164	4	18	26	20	20	21	16	10	5	1
Volume (ac-ft)	649	154	318	421	466	517	566	574	550	538	526
5-11 ppt											
Shoreline Length (ft)	58,227	-22,651	-25,780	-28,077	-28,947	-29,430	-31,134	-31,265	-32,309	-33,426	-34,489
Surface Area (ac)	118	-24	-25	-24	-19	-18	-21	-20	-21	-23	-25
Volume (ac-ft)	376	60	146	171	227	233	230	221	208	214	194
11-18 ppt											
Shoreline Length (ft)	24,529	-1,848	-2,943	-6,179	-9,561	-13,406	-15,970	-19,193	-20,266	-22,374	-23,457
Surface Area (ac)	83	0	-2	-14	-31	-44	-54	-64	-68	-75	-80
Volume (ac-ft)	630	23	27	-14	-91	-117	-172	-221	-265	-313	-339

Note: Salinity response to dam flow between station 2 and dam is consistent (i.e., flow>0 = 0 salinity at station 2)

Table 7-1: Changes in habitat metrics associated with changes in increased flow from the Hillsborough River Dam.

Palm River / Tampa Bypass Canal
Changes in Habitat Associated With Increased Flow

Salinity Range Habitat Type	Baseline Condition (0 Release)	Change from Baselinefor 10 cfs Flow Releases						
		10	20	30	40	50	100	200
0-0.5 ppt (Freshwater)								
Shoreline Lenght (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
0-1 ppt								
Shoreline Lenght (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
0-4 ppt								
Shoreline Lenght (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
2-14 ppt								
Shoreline Lenght (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
5-11 ppt								
Shoreline Lenght (ft)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Surface Area (ac)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
11-18 ppt								
Shoreline Lenght (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	37,531 (---)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	195 (---)

Table 7-2: Changes in habitat metrics associated with changes in increased flow from Structure 160 on the Palm River/Tampa Bypass Canal.

Hillsborough River

Changes in Habitat 1 Meter Below Surface that are Estimated with Increased Flow

Minimum Daily DO Habitat Type	Baseline Condition (0 Release)	Change from Baselinefor 10 cfs Flow Releases									
		10	20	30	40	50	60	70	80	90	100
0-2 mg/L											
Shoreline Length (ft)	34,375	0	0	0	-20,505	-34,375	-34,375	-34,375	-34,375	-34,375	-34,375
Surface Area (ac)	59	0	0	0	-36	-59	-59	-59	-59	-59	-59
2-4 mg/L											
Shoreline Length (ft)	42,198	0	18,335	18,335	38,839	52,710	52,710	52,710	52,710	52,710	56,874
Surface Area (ac)	95	0	68	68	105	127	127	127	127	127	163
>4 mg/L											
Shoreline Length (ft)	33,344	0	-18,335	-18,335	-18,335	-18,335	-18,335	-18,335	-18,335	-18,335	-22,498
Surface Area (ac)	119	0	-68	-68	-68	-68	-68	-68	-68	-68	-104

Mesn Daily DO Habitat Type	Baseline Condition (0 Release)	Change from Baselinefor 10 cfs Flow Releases									
		10	20	30	40	50	60	70	80	90	100
0-2 mg/L											
Shoreline Length (ft)	0	0	0	0	0	0	0	0	0	0	0
Surface Area (ac)	0	0	0	0	0	0	0	0	0	0	0
2-4 mg/L											
Shoreline Length (ft)	51,683	0	0	0	0	0	-17,307	-17,307	-17,307	-28,318	-28,318
Surface Area (ac)	100	0	0	0	0	0	-41	-41	-41	-58	-58
>4 mg/L											
Shoreline Length (ft)	58,235	0	0	0	0	0	17,307	17,307	17,307	28,318	28,318
Surface Area (ac)	173	0	0	0	0	0	41	41	41	58	58

Table 7-3: Changes in habitat metrics associated with changes in increased flow from the Hillsborough River Dam.

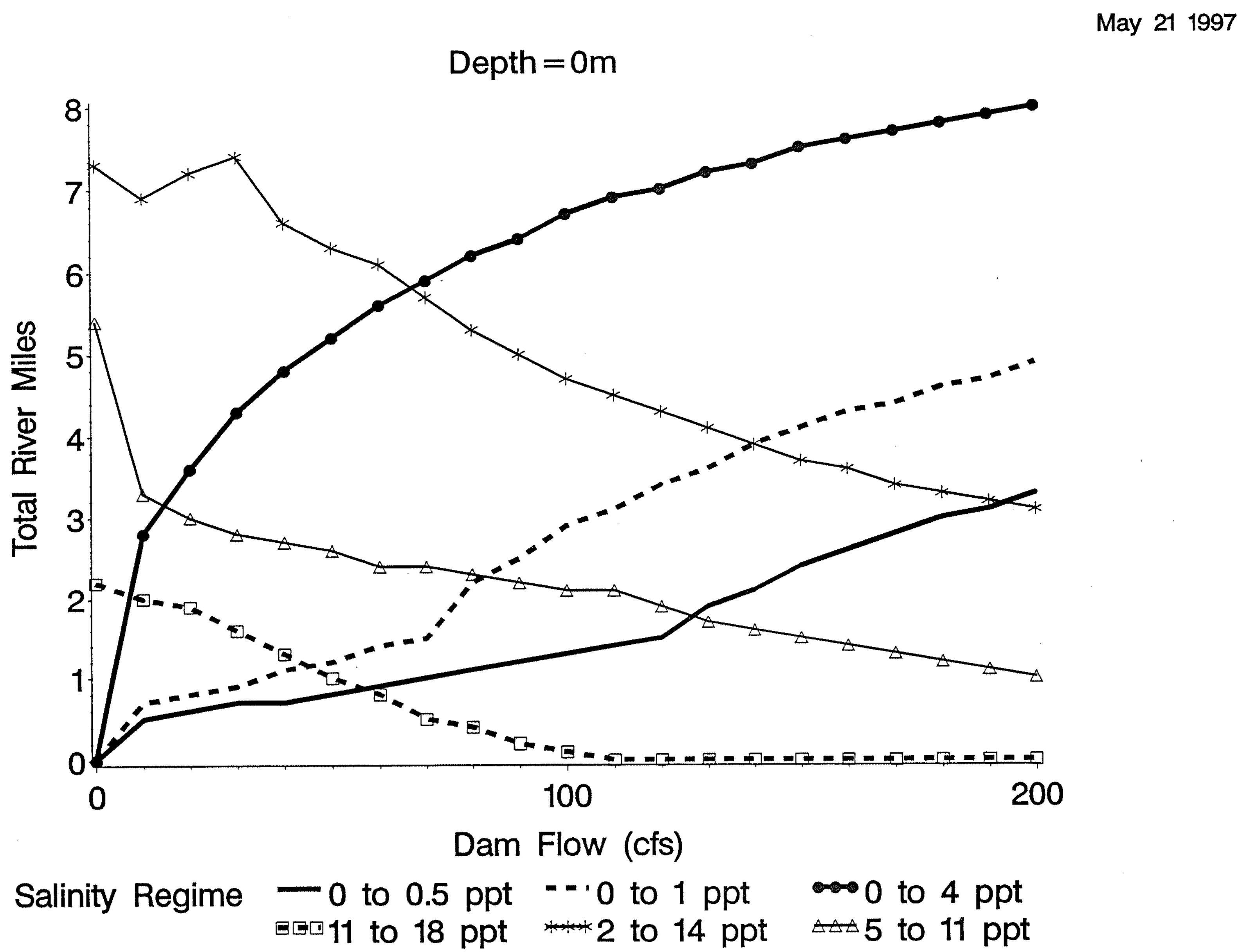


Figure 7-1: Estimated Hillsborough River river miles plotted by salinity regime and flow.

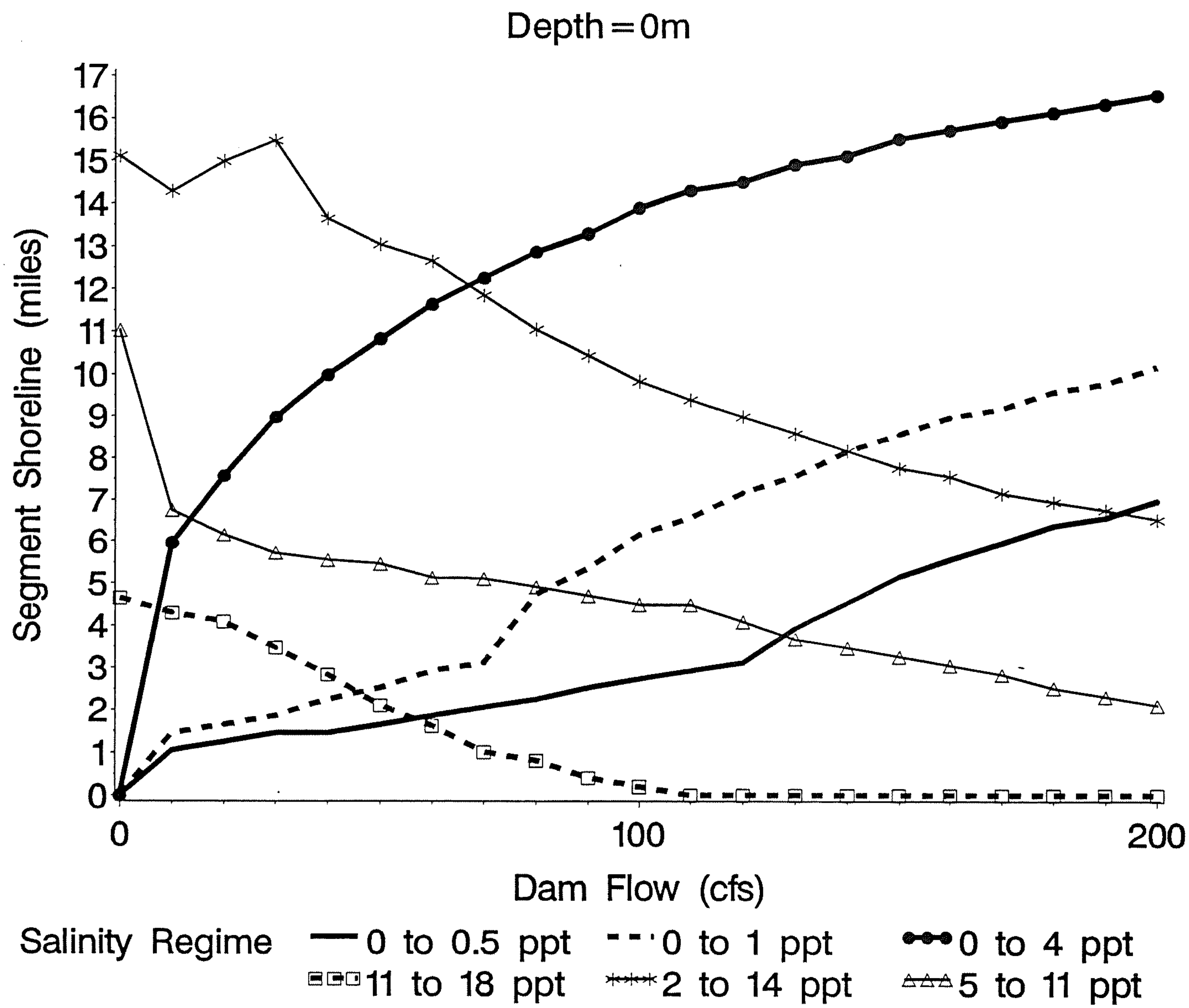


Figure 7-2: Estimated Hillsborough River shoreline miles plotted by salinity regime and flow.

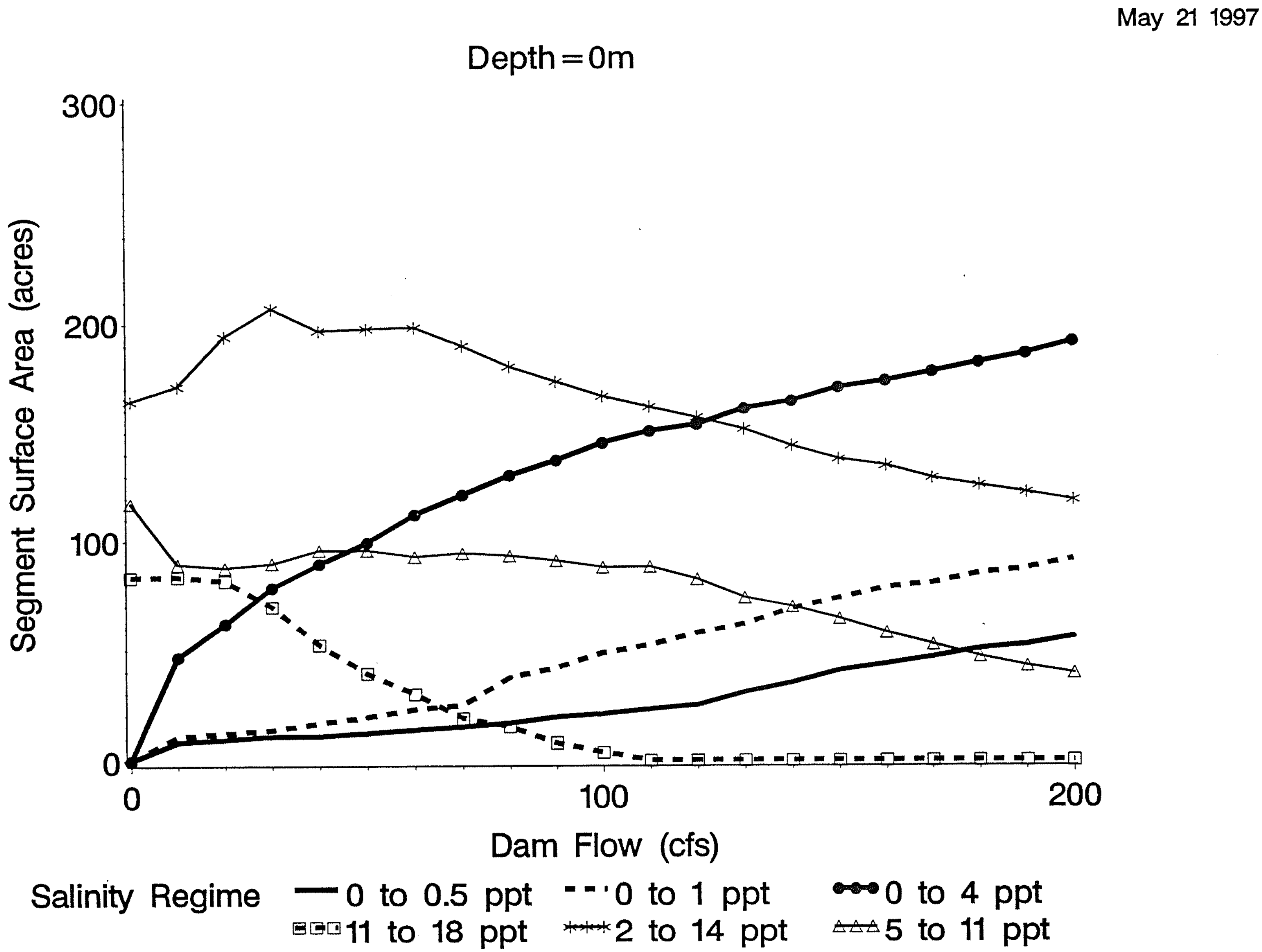


Figure 7-3: Estimated Hillsborough River surface area plotted by salinity regime and flow.

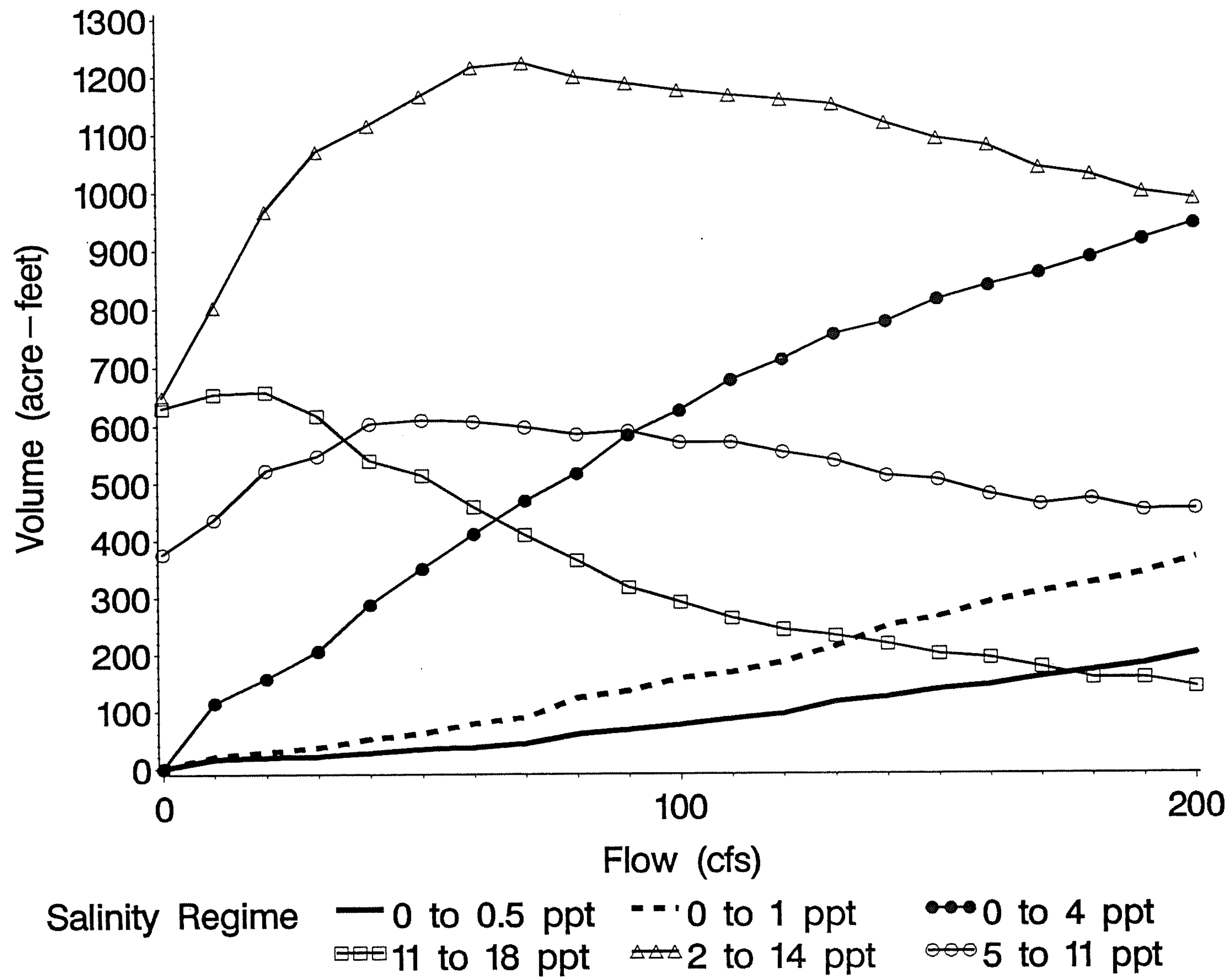


Figure 7-4: Estimated Hillsborough River volume miles plotted by salinity regime and flow.

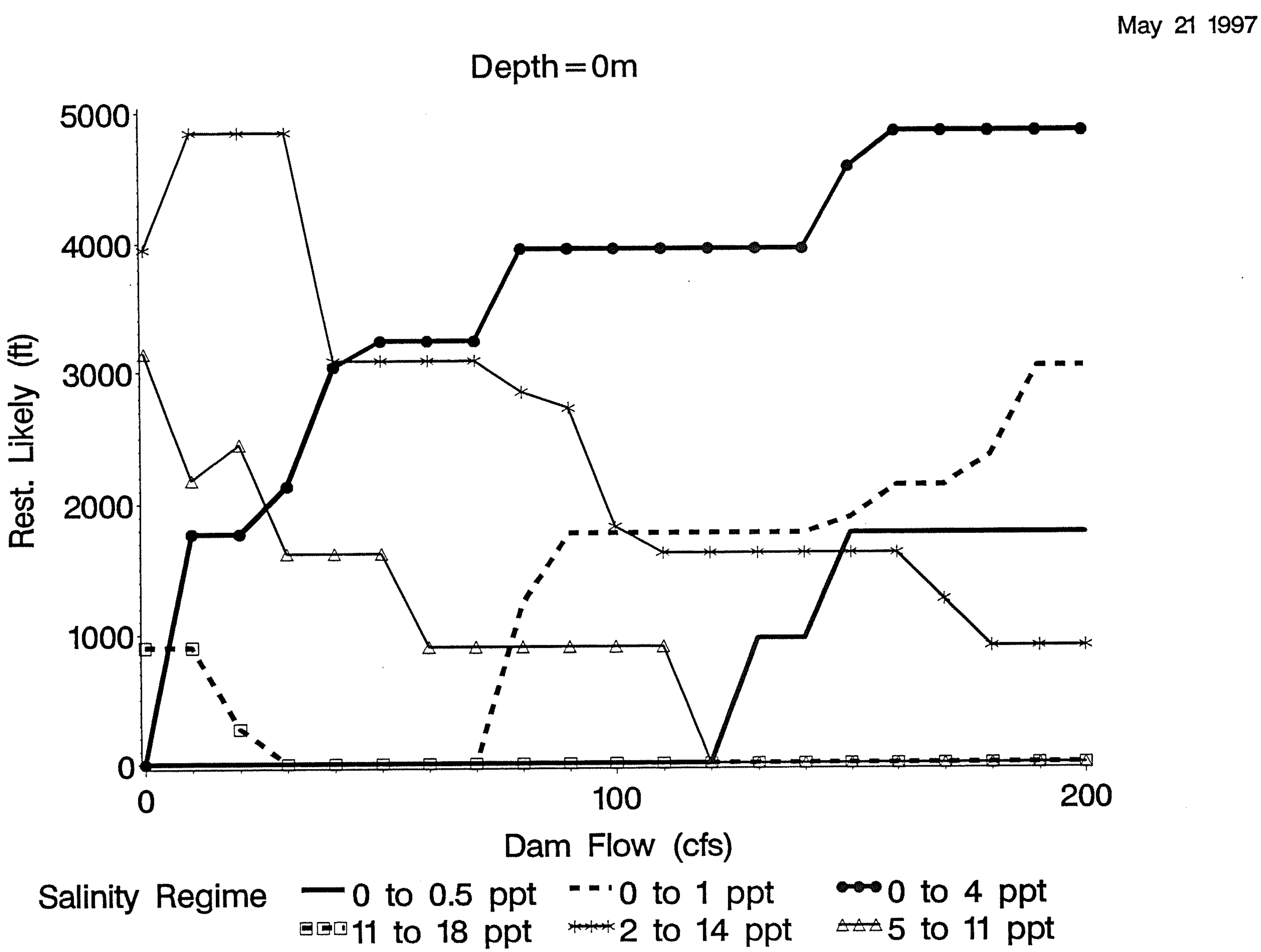


Figure 7-5: Estimated Hillsborough River likely restorable habitat plotted by salinity regime and flow.

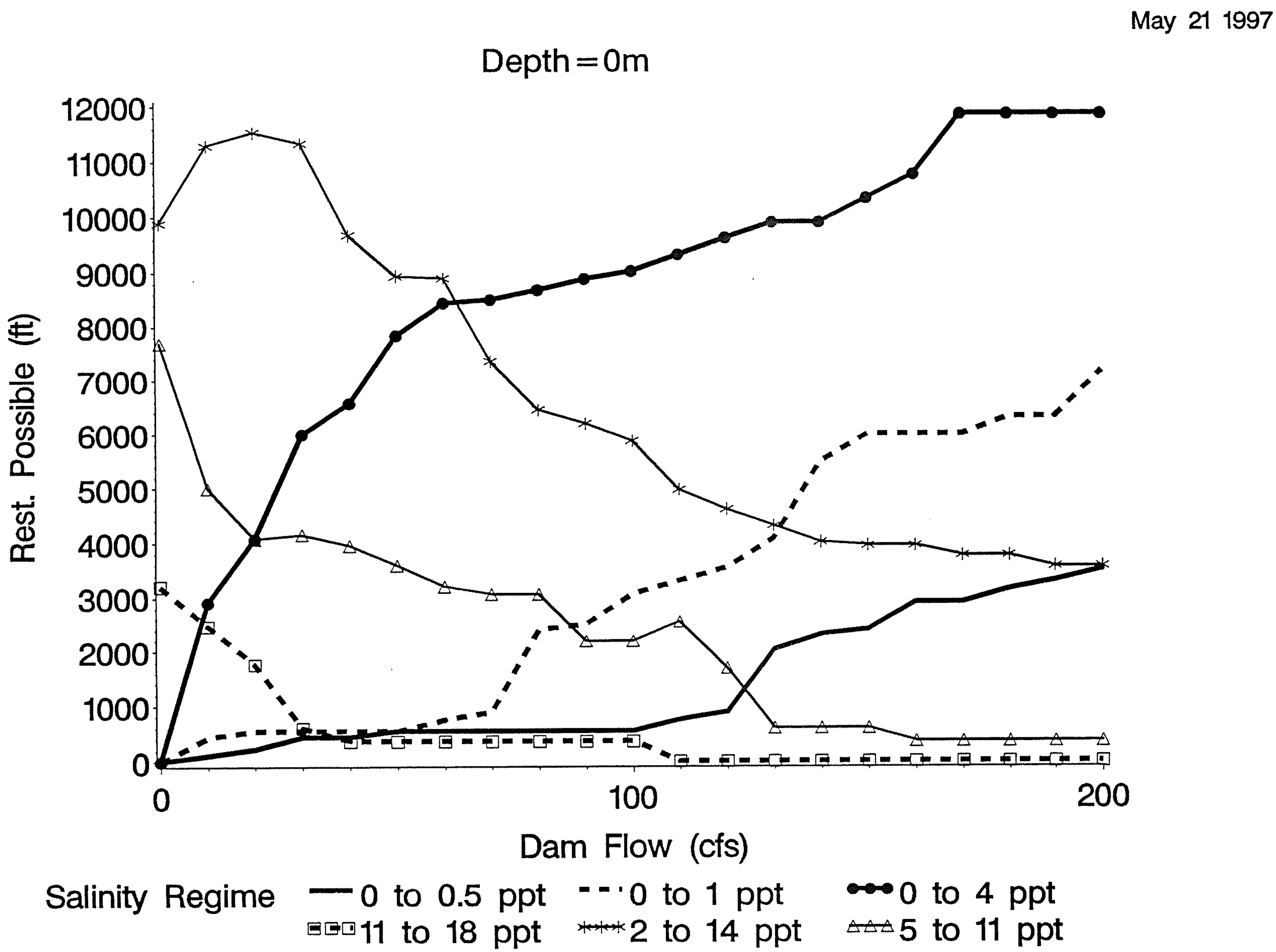


Figure 7-6: Estimated Hillsborough River potentially restorable habitat plotted by salinity regime and flow.

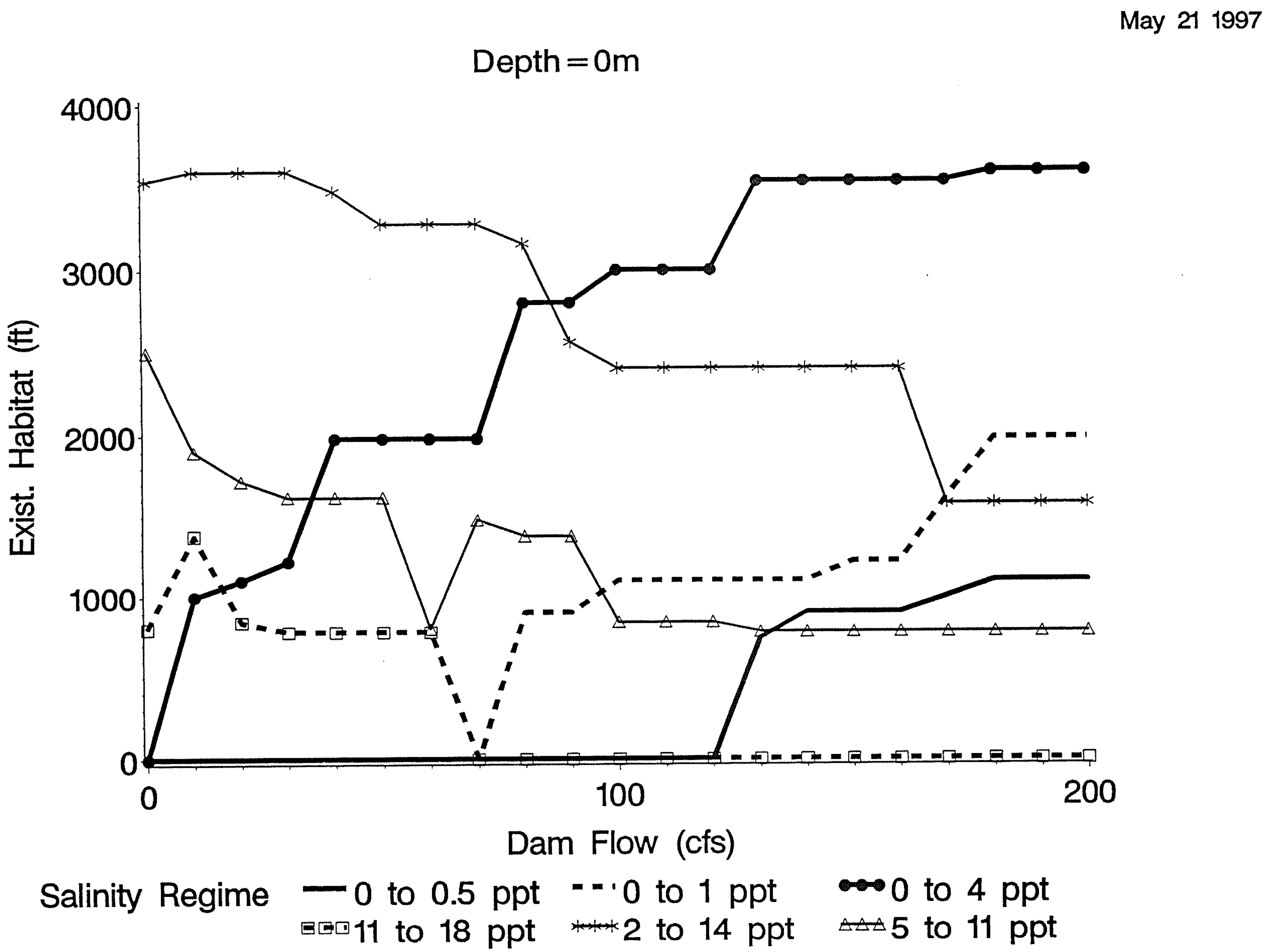


Figure 7-7: Estimated Hillsborough River existing habitat plotted by salinity regime and flow.

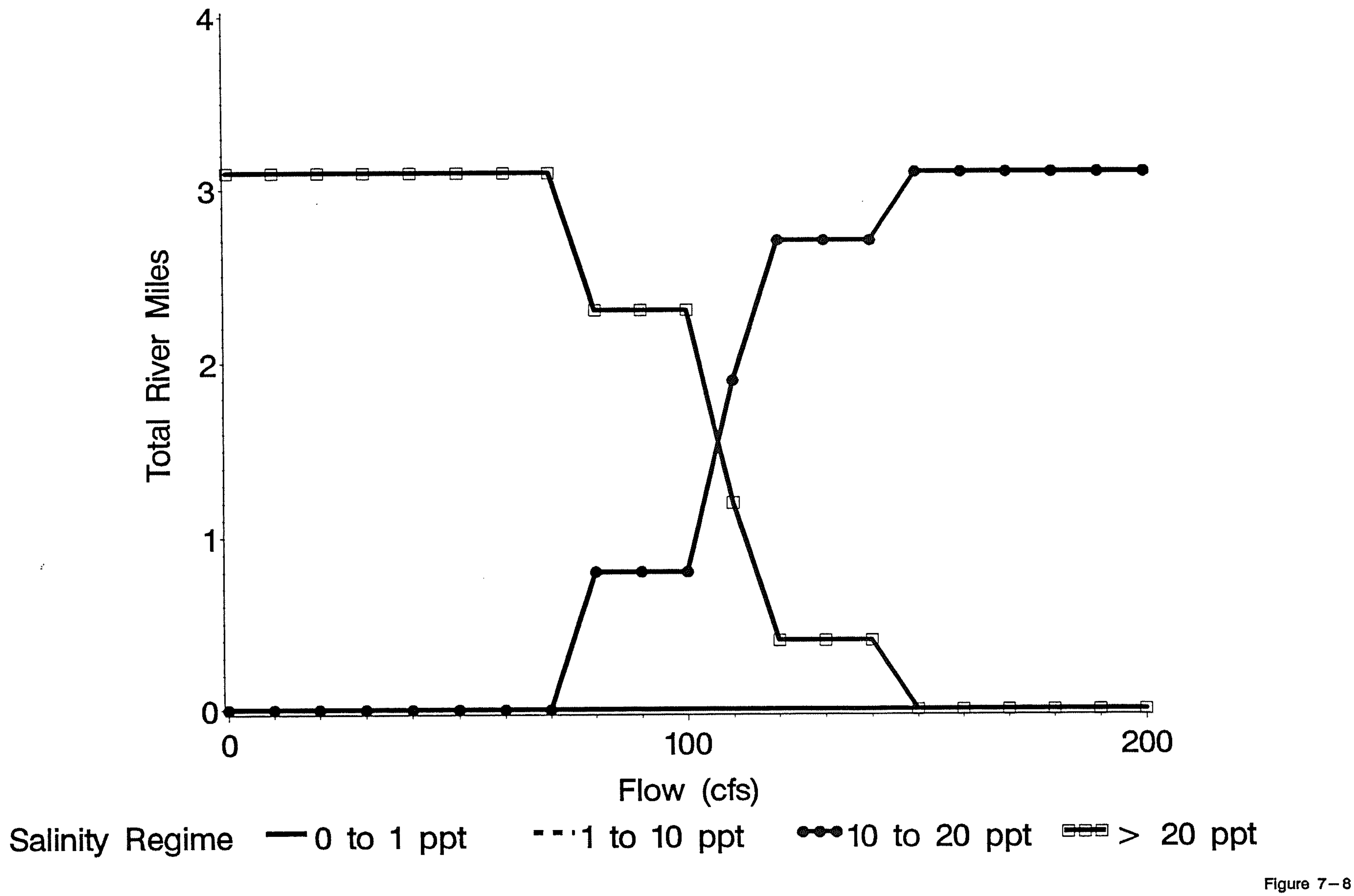


Figure 7-8: Estimated Palm River/Tampa Bypass Canal river miles plotted by salinity regime and flow.

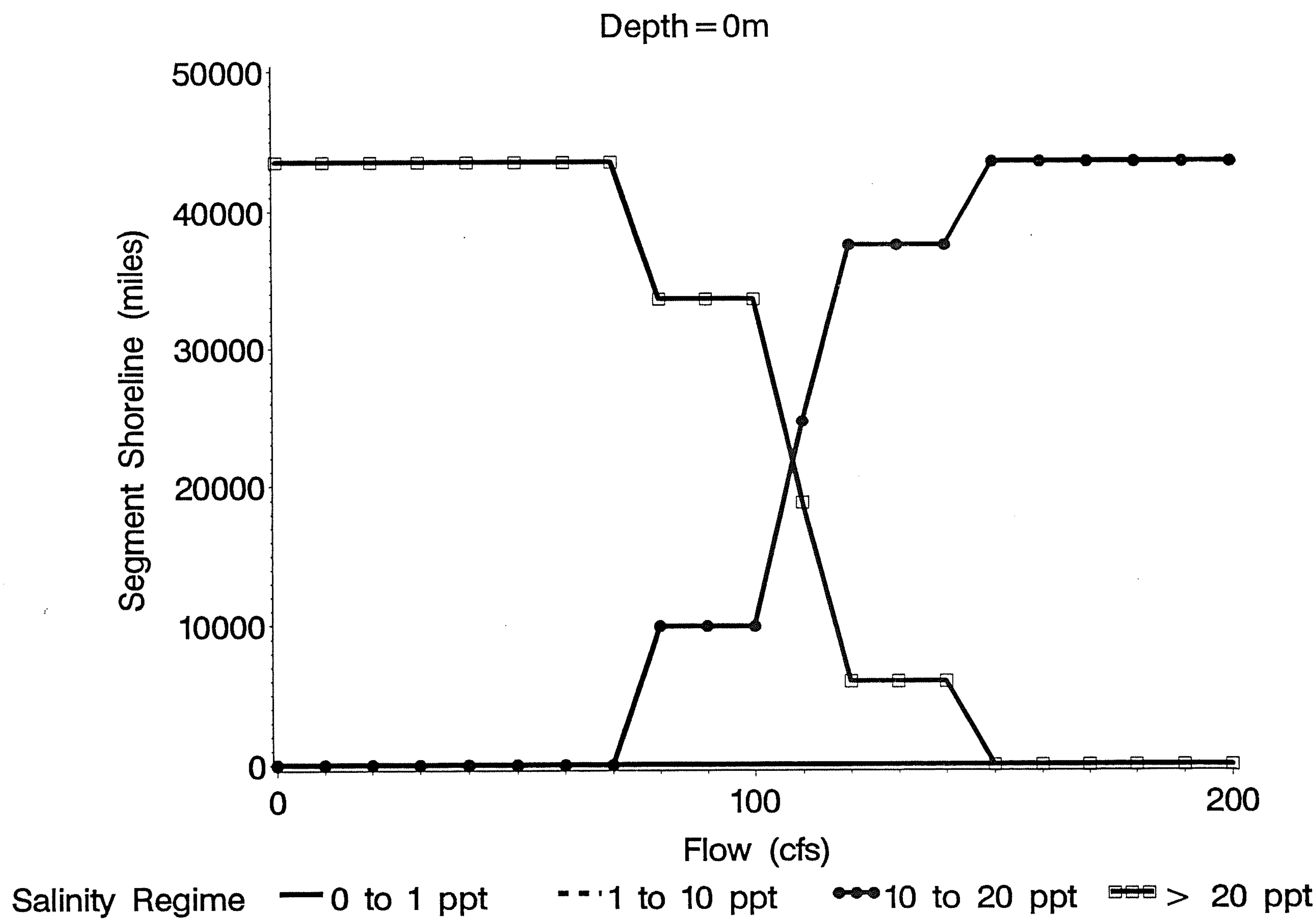


Figure 7-9: Estimated Palm River/Tampa Bypass Canal shoreline miles plotted by salinity regime and flow.

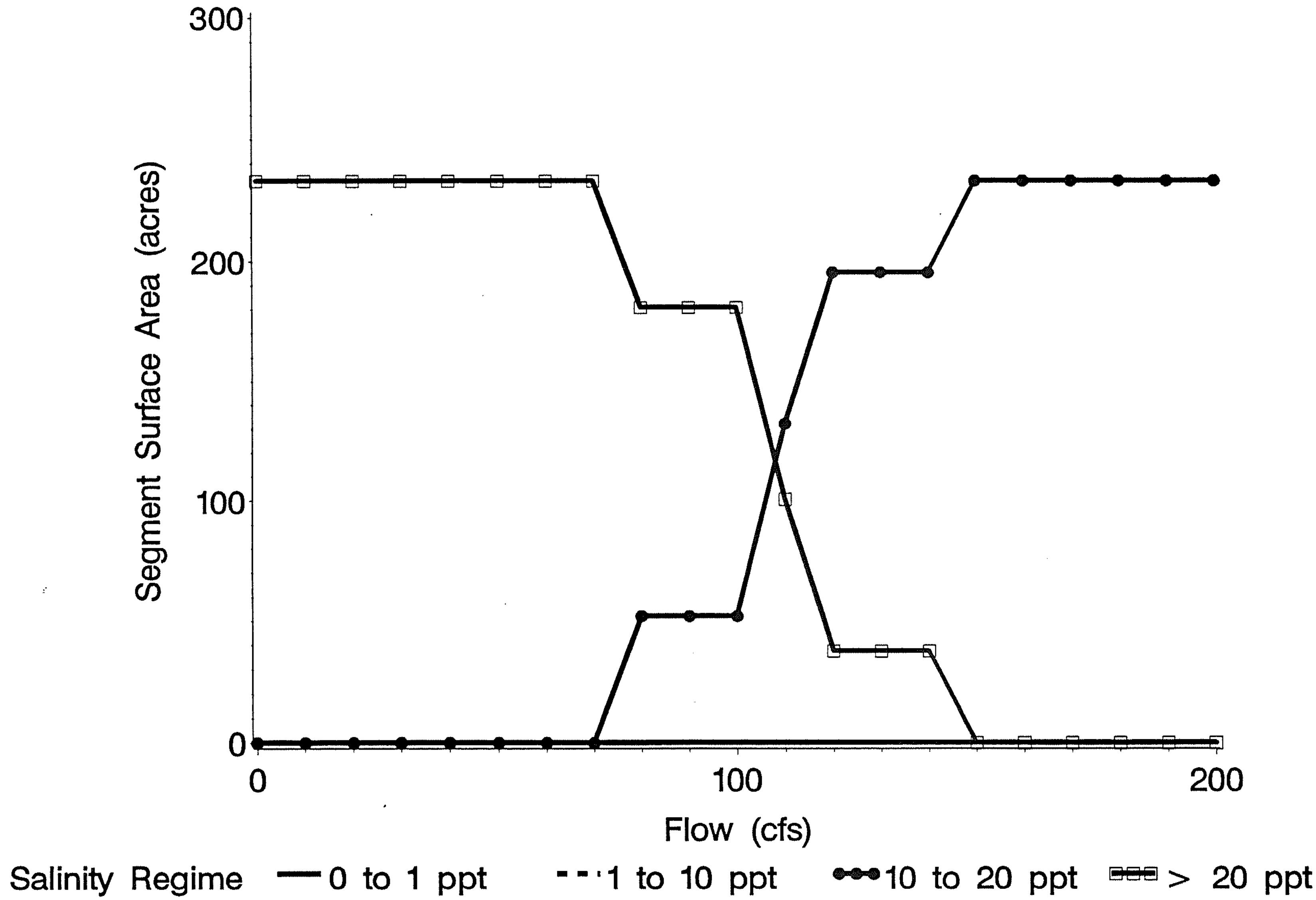


Figure 7-10: Estimated Palm River/Tampa Bypass Canal surface area plotted by salinity regime and flow.

8. LITERATURE CITED

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NOTE: APPENDICES AVAILABLE UPON REQUEST
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