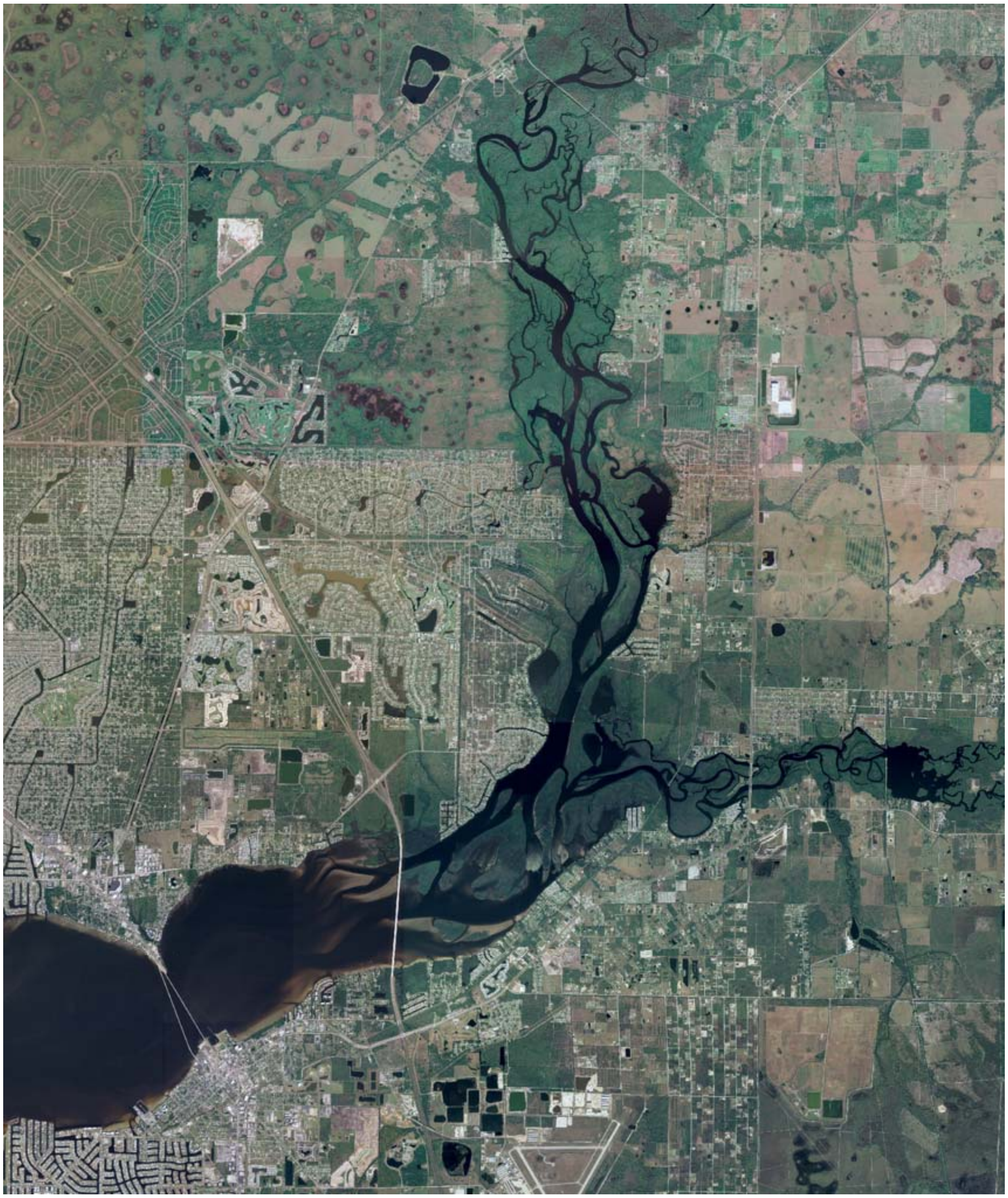
Proposed Minimum Flows and Levels for the Lower Peace River and Shell Creek



Southwest Florida Water Management District

August 24, 2007 **PEER REVIEW DRAFT**

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Executive Summary

The Southwest Florida Water Management District, by virtue of its responsibility to permit the consumptive use of water and a legislative mandate to protect water resources from “significant harm", has been directed to establish minimum flows and levels (MFLs) for streams and rivers within its boundaries (Section 373.042, Florida Statutes). 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." In this report, minimum flows are proposed for the lower segment of the Peace River, defined as the stretch of the river from the United States Geological Survey Peace River at Arcadia gage downstream to Charlotte Harbor and includes the total inflow from the Peace River at Arcadia gage, Joshua Creek at Nocatee gage, and Horse Creek near Arcadia gage. Additionally, minimum flows are proposed for Shell Creek, which extends downstream from the City of Punta Gorda dam to the confluence of Shell Creek with the lower Peace River.

Fundamental to the approach used for development of minimum flows and levels is the realization that a flow regime is necessary to protect the ecology of the river system. The initial step in this process requires an understanding of historic and current flow conditions to assess the extent to which withdrawals or other anthropogenic factors have affected flows. To accomplish this task, the District has evaluated the effects of climatic oscillations on regional river flows and has identified two benchmark periods for evaluating flows in the middle segment of the Peace River. It has also been demonstrated that flow declines in the lower Peace River can be ascribed to both climatic variation and anthropogenic effects.

Seasonal blocks corresponding to periods of low, medium, and high flows, previously defined for the development of minimum flows in the middle Peace River, were used to establish minimum flows for both the lower Peace River and Shell Creek. Short-term minimum flow compliance standards for the sum of the flows from the Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia, as well as for the Shell Creek flows, were developed for each of these seasonal periods using a "building block" approach. The concept of defining “building blocks” to establish MFLs is to get the “right flow at the right time.” If the variability in flow within a block is appreciable, then it is prudent to refine the recommended MFL within a block by accounting for this variability. To account for the variability of flow within a block, the salinity response to changes in flow under relatively high (i.e., above the median flow for the block) or relatively low (i.e., below the median flow for the block) was also examined. The compliance standards include prescribed flow reductions based on limiting potential changes in aquatic and wetland habitat availability that may be associated with seasonal changes in flow.

Definition of the minimum flow regime often includes a low flow threshold. The low flow threshold is defined to be a flow that serves to limit withdrawals, with no withdrawals permitted unless the threshold is exceeded. After examination of the relationships between flow and several habitat variables, including salinity, chlorophyll *a*, and dissolved oxygen (DO) in Shell Creek, no clear, defensible, low flow threshold was discovered.

The criterion selected for Shell Creek was two ppt. This biologically-relevant salinity helps to maintain the integrity of fish and benthic community structures in Shell Creek. Based on this criterion, the minimum flows in Shell Creek were defined for each block and flow condition as the percentage of the Shell Creek dam flow that can be withdrawn. The allowable percent reductions in flow are:

- Block 1 (April 20 to June 25)
    - 10% of the flow below the median for Block 1 (84 cfs)
    - 23% of the flow above the median for Block 1 (84 cfs)
- Block 2 (October 27 to April 19)
    - 18% of the flow below the median for Block 2 (98 cfs)
    - 42% of the flow above the median for Block 2 (98 cfs)
- Block 3 (June 26 to October 26)
    - 35% of the flow below the median for Block 3 (424 cfs)
    - 83% of the flow above the median for Block 3 (424 cfs)

For example, in Shell Creek there is no low flow threshold is in effect. If the flow on a given day in Block 1 is 50 cfs (i.e., below the median for Block 1), then the maximum allowable withdrawal would be 50*10% = 5 cfs. If the flow on a given day in Block 1 is 100 cfs (i.e., above the median for Block 1), then the maximum allowable withdrawal would be 10% of 84 cfs plus 23% of the difference between 100 cfs and the median ([84cfs * 10%] + [(100 – 84)* 23%] = 8.4 + 3.7 = 12.1 cfs).

The minimum flow regime for the lower Peace River included a low flow threshold. Attempts were made to develop empirical models that relate flow to ecological criteria for the Lower Peace River, but no defensible relationship was found. Therefore, it was not possible to establish a low flow cutoff based on ecological criteria. However, the PRMRWSA plant withdraws water from the lower Peace River for potable water supply. It is important to maintain freshwater at the PRMRWSA withdrawal point because saline water hinders the treatment process for the plant. Therefore, an operational criterion of maintaining freshwater (< 0.5 ppt) at the PRMRWSA plant was chosen as an acceptable criterion. An empirical analysis yielded a low flow cutoff of 90 cfs for the sum of the flows from Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia in order to maintain freshwater at the PRMRWSA plant.

The salinity criteria selected for the lower Peace River were two, five, and 15 ppt. These biologically-relevant salinities help to maintain the integrity of fish, benthic, and vegetation community structures in the lower Peace River. In addition to examining the extent of the biologically-relevant salinities river-wide, a more spatially-specific assessment of salinity within a portion of the lower Peace River was also deemed critical. Studies have shown that a specific area in the river has a significantly abundant and diverse fish community and salinities in this area are typically in the range of 8 to 16 ppt. Therefore, the volume of water meeting the appropriate salinity range (8 to 16 ppt) in this area was also analyzed.

Based on these criteria, the minimum flows in the lower Peace River were defined for each block and flow condition as the percentage of the total combined flow above 90 cfs from Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia that can be withdrawn. The allowable percent reductions in flow are:

- Block 1 (April 20 to June 25)
  - 10% of the flow below the median for Block 1 (221 cfs)
  - 26% of the flow above the median for Block 1 (221 cfs)
- Block 2 (October 27 to April 19)
  - 14% of the flow below the median for Block 2 (330 cfs)
  - 21% of the flow above the median for Block 2 (330 cfs)
- Block 3 (June 26 to October 26)
  - 12% of the flow below the median for Block 3 (1,370 cfs)
  - 15% of the flow above the median for Block 3 (1,370 cfs)

For example, a low flow threshold of 90 cfs is in effect for the LPR. Therefore, the combined flow (Arcadia + Joshua Creek + Horse Creek) is never allowed to go below 90 cfs as a result of withdrawals. Therefore, the percentages in Table 8-10 should be applied as described in the following example. For example, if the flow on a given day in Block 1 is 95 cfs (i.e., below the median for Block 1), then the maximum allowable withdrawal would be 95*10% = 9.5 cfs. However, a reduction of 9.5 cfs would cause a flow below the low flow threshold. Therefore, only 5 cfs would be taken thus maintaining the 90 cfs low flow threshold. If the flow on a given day in Block 1 is 300 cfs (i.e., above the median for Block 1), then the maximum allowable withdrawal would be 10% of 221 cfs plus 26% of the difference between 300 cfs and the median ([221cfs * 10%] + [(300 – 221)* 26%] = 22.1 + 20.5 = 42.6 cfs).

1 PURPOSE AND BACKGROUND OF MINIMUM FLOWS AND LEVELS

1.1 Overview

The Southwest Florida Water Management District (District) is responsible for permitting the consumptive use of water within the District's boundaries. Within this context, the Florida Statutes (Section 373.042) mandate that the District protect water resources from “significant harm” through the establishment of minimum flows and levels for streams and rivers within its boundaries. In establishing MFLs for the Lower Peace River (LPR) and Shell Creek (SC), the District evaluated potential flow scenarios and their associated impacts on the downstream ecosystem. The determination of minimum flows is a rigorous technical process in which extensive physical, hydrologic, and ecological data are analyzed for the water body in question.

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

1.2 Legislative Directives

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

The District is committed to voluntary, independent scientific peer review of MFL documents. The purpose of this report is to document the scientific and technical data and methodologies that were used to develop minimum flow recommendations for the LPR and SC.

1.3 Conceptual Approach to Establishing Minimum Flows

The District applied the percent-of-flow method to determine minimum flows for the LPR and SC. The percent-of-flow method allows water users to take a percentage of streamflow at the time of the withdrawal. The percent-of-flow method has been used for the regulation of water use permits since 1989, when it was first applied to withdrawals from the Lower Peace River.

The LPR and SC are two of a series of tidal river estuaries in which the percent-of-flow method will be used to establish minimum flows during 2007 and 2008 (Lower Alafia, Myakka, Anclote, and Little Manatee Rivers). The method is oriented for use on unimpounded rivers that still retain a largely natural flow regime (Flannery et al. 2002).

The percent-of-flow method has been applied to determine and adopt minimum flows for a series of unimpounded freshwater streams in the District, including the freshwater reaches of the Alafia River, the Myakka River, and the middle reach of the Peace River.

A goal of the percent-of-flow method is that the natural flow regime of the river be maintained, albeit with some flow reduction for water supply. Natural flow regimes have short-term and seasonal variations in the timing and volume of streamflow that reflect the drainage basin characteristics of the river in question and the climate of the region. In recent years, there has been considerable progress in the field of freshwater stream ecology and flow management in identifying the physical and biological processes that are linked to and dependent upon natural flow regimes (Poff *et al.* 1997, Instream Flow Council 2002, Postel and Richter 2003). As summarized in the District's MFL report for the freshwater reach of the Alafia River, these processes include geomorphic and biological processes. The geomorphic processes are related to sediment transport and channel maintenance. The biological processes are related to fish passage, the inundation of instream and floodplain habitats, and maintenance of adequate water levels and velocities to provide habitat suitable for the growth and reproduction of fishes and invertebrates (SWFWMD 2004).

As with freshwater stream ecology, management issues regarding freshwater inflows to estuaries have received considerable attention in recent decades. A national symposium on inflows to estuaries was held in 1980 (Cross and Williams 1981), and a special issue of the journal *Estuaries* devoted to freshwater inflows was produced by the Estuarine Research Federation in 2002 (Montagna *et al.* 2002), which included the paper by Flannery *et al.* (2002). Since its introduction, the District's percent-of-flow method has received attention as a progressive method for water management in the national technical literature (Alber 2002, Postel and Richter 2003, and the National Research Council 2005), and its use for water supply planning and regulation has been established regionally in District documents (SWFWMD 1992, 2001, 2006).

1.4 Content of Remaining Chapters

This general introduction is followed by eight additional chapters. In these chapters, the technical information that was used to evaluate the minimum flows for the LPR and SC has been described. In Chapter 2 the physical and hydrological characteristics of the LPR and SC watersheds have been described. In Chapter 3 the spatial and temporal variation in physical and water quality characteristics of the LPR and SC have been discussed. Chapter 4 contains a description of the benthic macroinvertebrate community of the LPR and SC. The characteristics of the LPR and SC fish communities are described in Chapter 5. In Chapter 6, relationships between flow and water quality constituents are explored. In addition, relationships between flow and salinity are examined for model simulation data in Chapter 7. Major conclusions of this study along with the District’s minimum flow recommendations for the LPR and SC are presented in Chapter 8. Chapter 9 identifies the literature cited in the report.

2 DESCRIPTION OF THE LOWER PEACE RIVER AND SHELL CREEK

A brief description of the LPR and SC and their associated watersheds is presented in this section.

2.1 Physical Characteristics of the LPR Watershed

Three major tributaries that drain to Charlotte Harbor, the Peace and Myakka Rivers in the north, and the Caloosahatchee River in the south (Figure 2-1). The Peace River basin is approximately 2,350 square miles and extends from the headwaters in Polk County to the river mouth in Charlotte Harbor (PBS&J 1999a). The Peace Creek Drainage Canal and Saddle Creek join near Bartow, FL to form the Peace River (Hammett 1990). The River flows south for approximately 75 miles through Polk, Hardee, De Soto, and Charlotte Counties. The Peace River represents a major source of fresh water to Charlotte Harbor, as its watershed comprises nearly half of the total 4,670 square miles of the Greater Charlotte Harbor watershed (Stoker *et al.* 1992). Streamflows in the Peace and Myakka Rivers are unregulated, except for one low-water dam in the upper Myakka basin and one in SC. Therefore, discharges from the Peace and Myakka Rivers tend to correspond to rainfall patterns in the respective basins. Streamflow in the Caloosahatchee River is also influenced by rainfall in the basin, but discharge to the harbor is regulated by Franklin Lock (Stoker 1992).

Hammett (1990) estimated that total freshwater inflow to Charlotte Harbor from the three major tributaries, the coastal area, and direct rainfall at between 5,700 and 6,100 cfs. Hammett (1990) estimated the average inflows to Charlotte Harbor from the various sources as:

- Caloosahatchee River - 1,900 to 2,100 cfs,
- Peace River - 2,010 cfs,
- Myakka River - 630 cfs,
- Direct rainfall - 1,030 cfs, and
- Coastal area - 200 to 400 cfs.

The Peace River, with approximately three-times the freshwater flow as the Myakka River, is a major influence on the freshwater inflow to upper Charlotte Harbor. The physical and hydrologic characteristics of the LPR watershed, including an assessment of trends in freshwater inflows to the LPR estuary will be discussed in the following sections. Additional information pertaining to the portion of the Peace River upstream of Arcadia can be found in SWFWMD (2002, 2005a).

The LPR is defined as the portion of the river below the USGS gage (02296750) at Arcadia (Figure 2-2). Upstream from Arcadia the channel of the Peace River is very well defined (Hammett 1990). Downstream from Arcadia the LPR flood plain widens and the channel becomes braided.

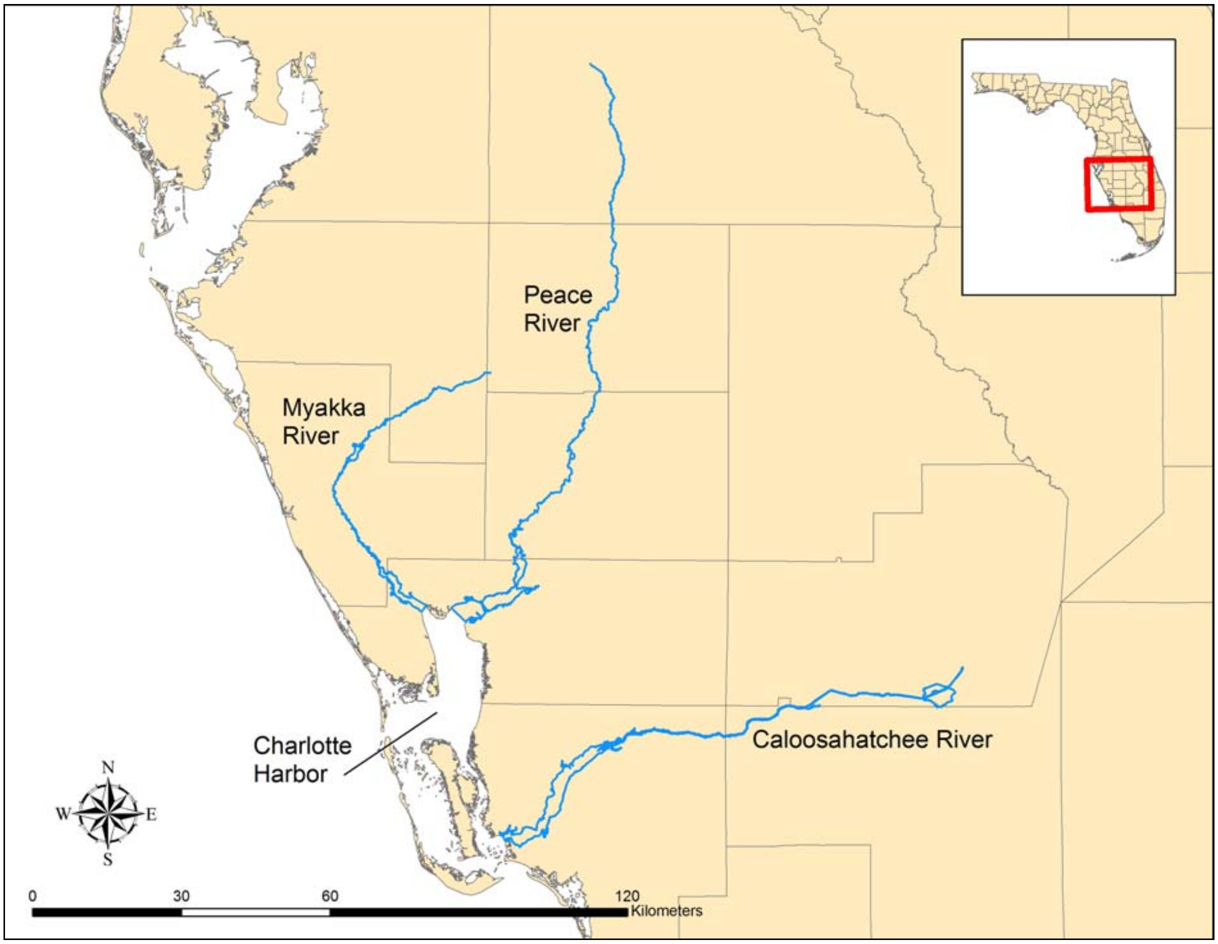


Figure 2-1. Map of Charlotte Harbor and Major Tributaries.

The portion of the watershed downstream of Arcadia represents approximately 42% (990 mi^2) of the entire Peace River watershed. There are three major tributaries that flow into the LPR: Joshua Creek, Horse Creek, and SC (Figure 2-2). Of these three tributaries, SC is the largest at 434 mi^2, Horse Creek is the second largest at 245 mi^2, and Joshua Creek is the smallest at 121 mi^2.

The LPR river kilometer system and the Peace River Manasota Regional Water Supply Authority (PRMRWSA) Hydrobiological Monitoring Program (HBMP) fixed location water quality sampling stations are presented in Figure 2-3. Mixed tides (two high waters and two low waters of unequal height each day) occur in the Peace River (Stoker 1992). The tidal reach of the Peace River extends from the mouth upstream to approximately river kilometer 42 (26 miles). The location of the freshwater-saltwater interface (where salinity is 0.5 ppt) moves upstream and downstream daily with the tide and seasonally with volume of freshwater inflow (Stoker 1992).

LPR land use is depicted in Figure 2-4. Wetlands buffer the river channel and the remaining dominant land uses are agricultural, pasture and range land, and urban development (near the mouth of the river). PBS&J (2007) summarized changes in land use in the Peace River basin between 1940 and 1999 (Table 2-1).

Table 2-1. Land Use in the Peace River Watershed: 1940s – 1999 (Reproduce from PBS&J 2007).

Land Use	Acres (Percent) in Land Use Class		
	1940s	1979	1999
Developed			
Improved Pasture	39,640 (2.8)	356,925 (25.6)	379,346 (27.2)
Intense Agriculture	107,115 (7.7)	191,496 (13.7)	229,832 (16.5)
Mined lands	7,495 (0.5)	64,437 (4.6)	143,487 (10.3)
Urban Land Use	14,659 (1.0)	73,049 (5.2)	133,571 (9.6)
Undeveloped			
Native Upland Habitat	834,311 (59.7)	419,449 (30.0)	242,849 (17.4)
Wetlands	354,674 (25.4)	249,255 (17.8)	218,232 (15.6)
Water			
Lakes and open water	33,779 (2.4)	35,432 (2.5)	43,027 (3.1)
Other Water	5,011 (0.4)	6,641 (0.5)	6,338 (0.5)
Total	1,396,683 (100)	1,396,683 (100)	1,396,683 (100)

Soils within the watershed (Figure 2-5) are primarily classified as B/D (mix of moderate infiltration rate and very slow infiltration rate) and D (very slow infiltration rate and high runoff potential). Class D buffers the river channel, with isolated areas of Class A (high infiltration rate and low run off potential) further from the channel but still within the floodplain.

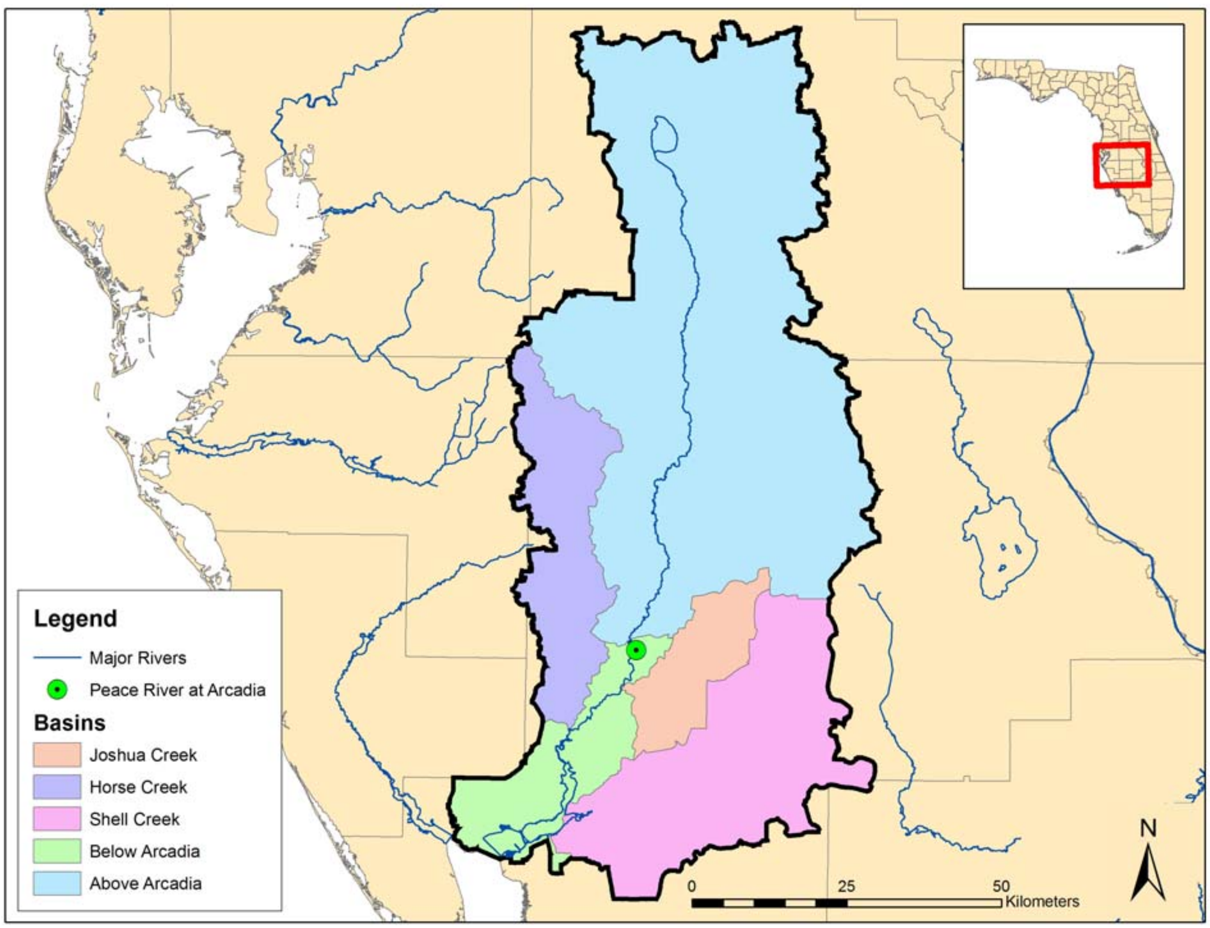


Figure 2-2. Map of Peace River Watershed including Watersheds of LPR Tributaries.

As previously mentioned, the LPR consists of the portion of the river from Arcadia, FL to the mouth of the Peace River where it flows into Charlotte Harbor. The following sections describe the physical characteristics of the LPR as well as the hydrology of the system.

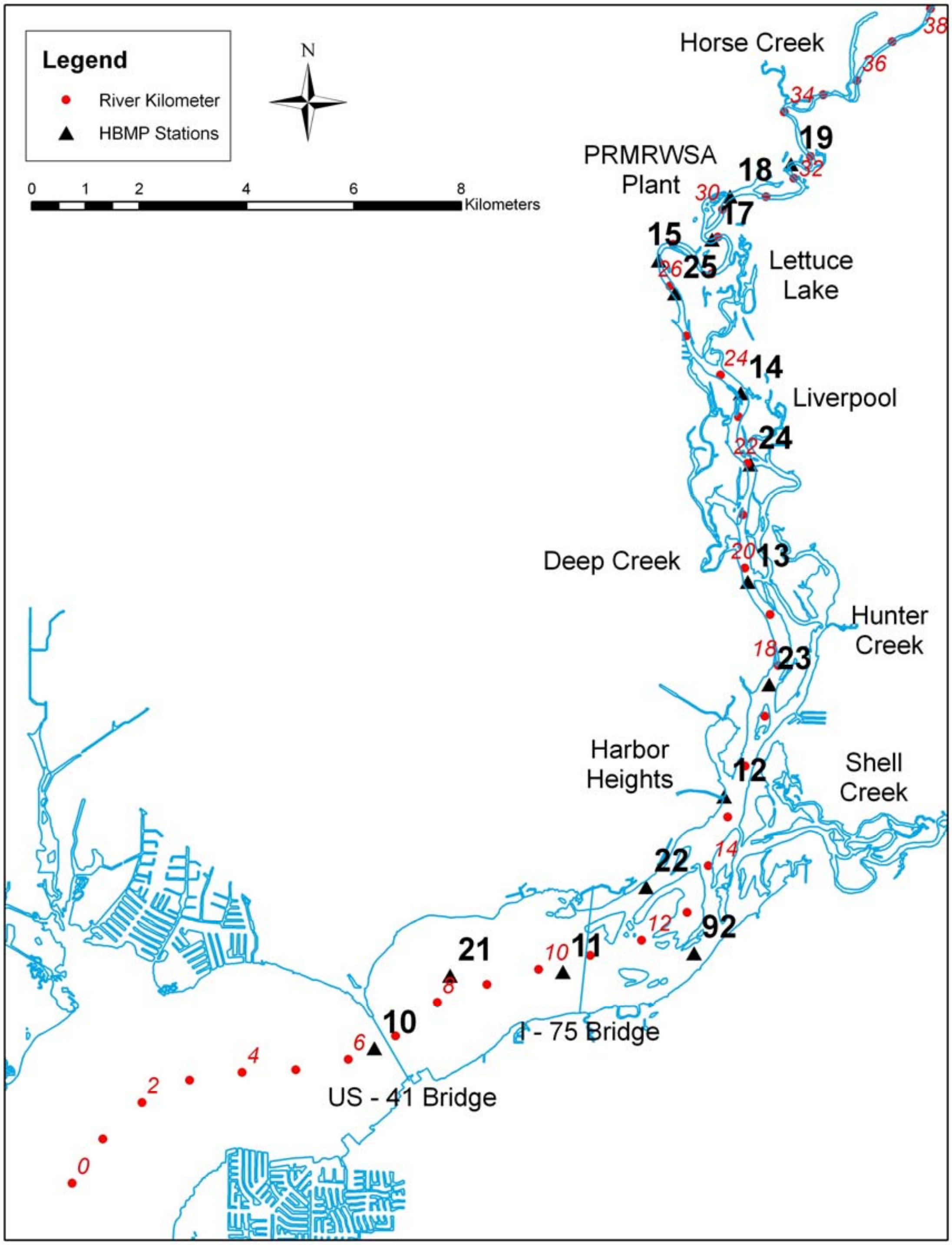


Figure 2-3. Location of the river kilometer system and location of HBMP fixed Stations in the Lower Peace River.

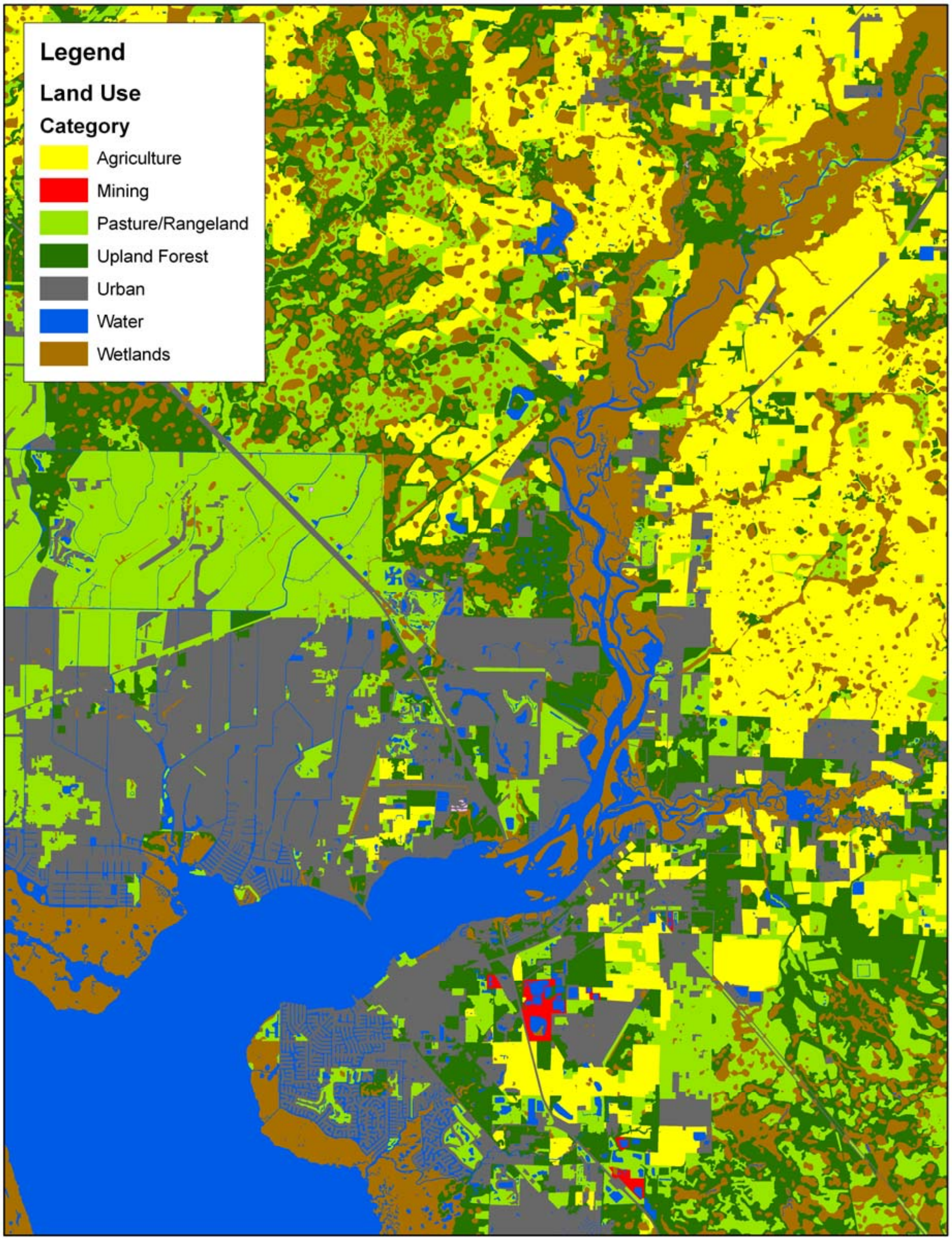


Figure 2-4. Land use map of the Lower Peace River Watershed (Source: SWFWMD 1999).

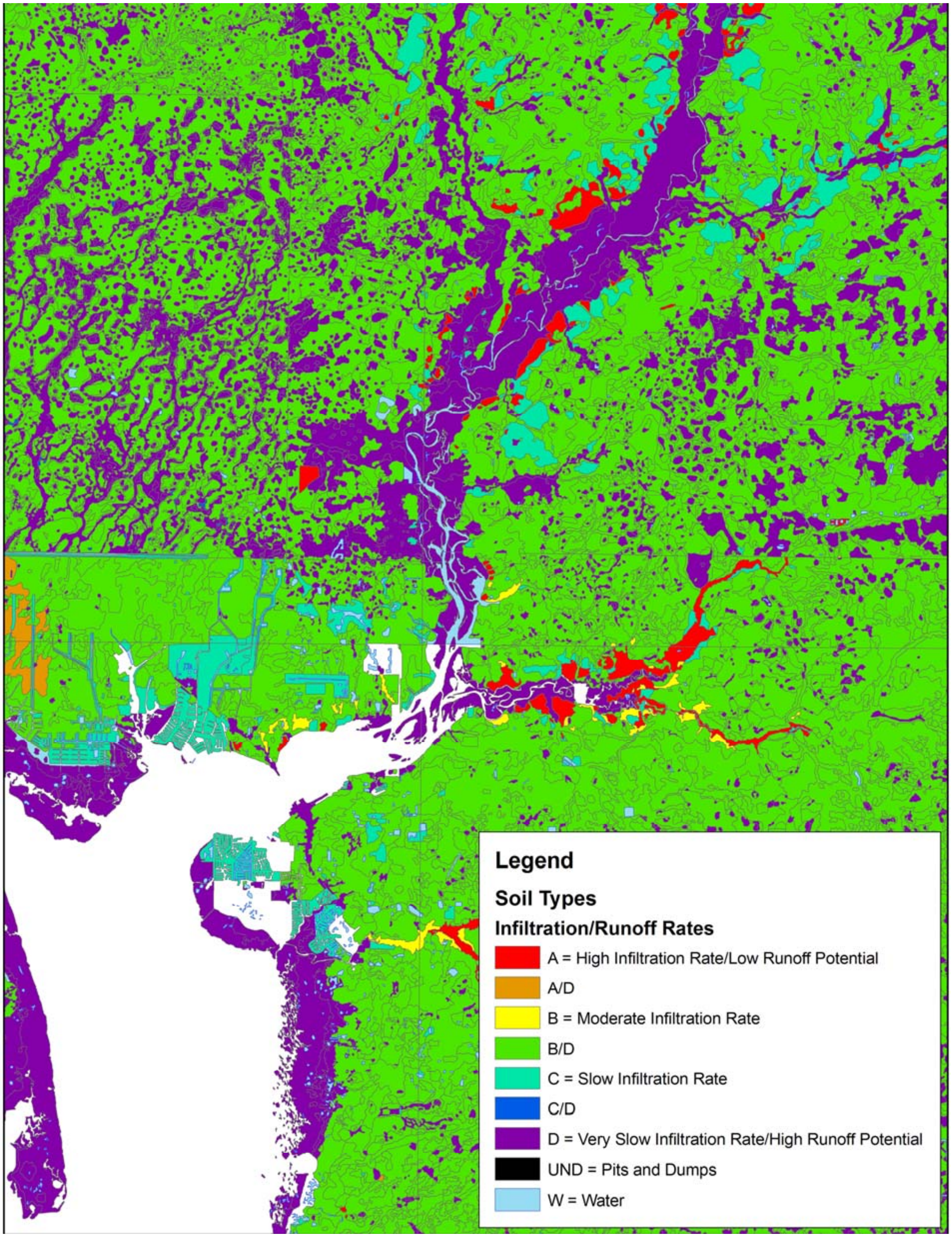


Figure 2-5. Soil types in the Lower Peace River watershed. (Source: SWFWMD 2002).

2.1.1 Bathymetry and Morphometry

The morphology of a riverine system can influence the biology of the system in several ways. The shape of the river affects current speed, and also sediment composition. Sediment composition has obvious impacts for benthic dwelling organisms. Additionally, the shape of the river determines the volume of water, which can affect habitat zonation and availability. Information on morphology and bathymetry in the LPR are available from PBS&J (1998) and Mote Marine Lab (2002).

The bathymetry of the LPR is shown in Figure 2-6 (Wang 2004). Generally depths are less than four meters throughout the whole river, and are less than three meters in most areas. The greatest depths of around six meters are seen downstream near the mouth of the river.

2.1.2 Shoreline Vegetation

Shoreline vegetative communities (including wetlands) are important components of riverine and estuarine systems. Vegetation communities along tidal rivers, such as the LPR, display a transition from the forested freshwater segments upstream, to tidal freshwater forest/marsh communities, to the brackish and salt marsh communities in the mid to lower segments of the system. Descriptive information on the vegetation communities located along the Lower Peace River were available from a 1994 vegetation map (FMRI 1998) and from a summary report prepared by PBS&J (1999a). The general distribution of major vegetative communities along the lower river was mapped by FMRI (1998) and is shown in Figure 2-7.

Bottomland Hardwood and Mixed Wetland Forests

Bottomland hardwoods are a type of wetland forest that includes a diverse assortment of hydric hardwood species, and are typically found along the riverbank in areas of river overflow. Generally they occur on rich alluvial silt- and clay-rich sediments deposited along rivers and are characterized by an overstory of water hickory (*Carya aquatica*), overcup oak (*Quercus lyrata*), swamp chestnut oak (*Quercus michauxii*), river birch (*Betula nigra*), American sycamore (*Platanus occidentalis*), red maple *(Acer rubrum)*, Florida elm (*Ulmus americana*), bald cypress *(Taxodium distichum),* blue beech/ironwood (*Carpinus caroliniana*) and swamp ash (*Fraxinus nigra*). This forest type is heavily influenced by overflow from the river and distinct species assemblages or zones have been documented based on distance from the riverbank and micro-topography of the site. The variability in forest composition is related to local site characteristics such as the size and slope of the watershed, in combination with soil type and slight elevation differences (Wharton *et al*. 1982). Mixed wetland forests are communities where neither hardwoods nor conifers dominate. The mix can include hardwoods, pine or cypress and can represent a mixed hydric site or a transition between hardwoods and conifers on a hydric/mesic site. This community type is not typically tidally influenced, otherwise it would be referred to as a hydric hammock community.

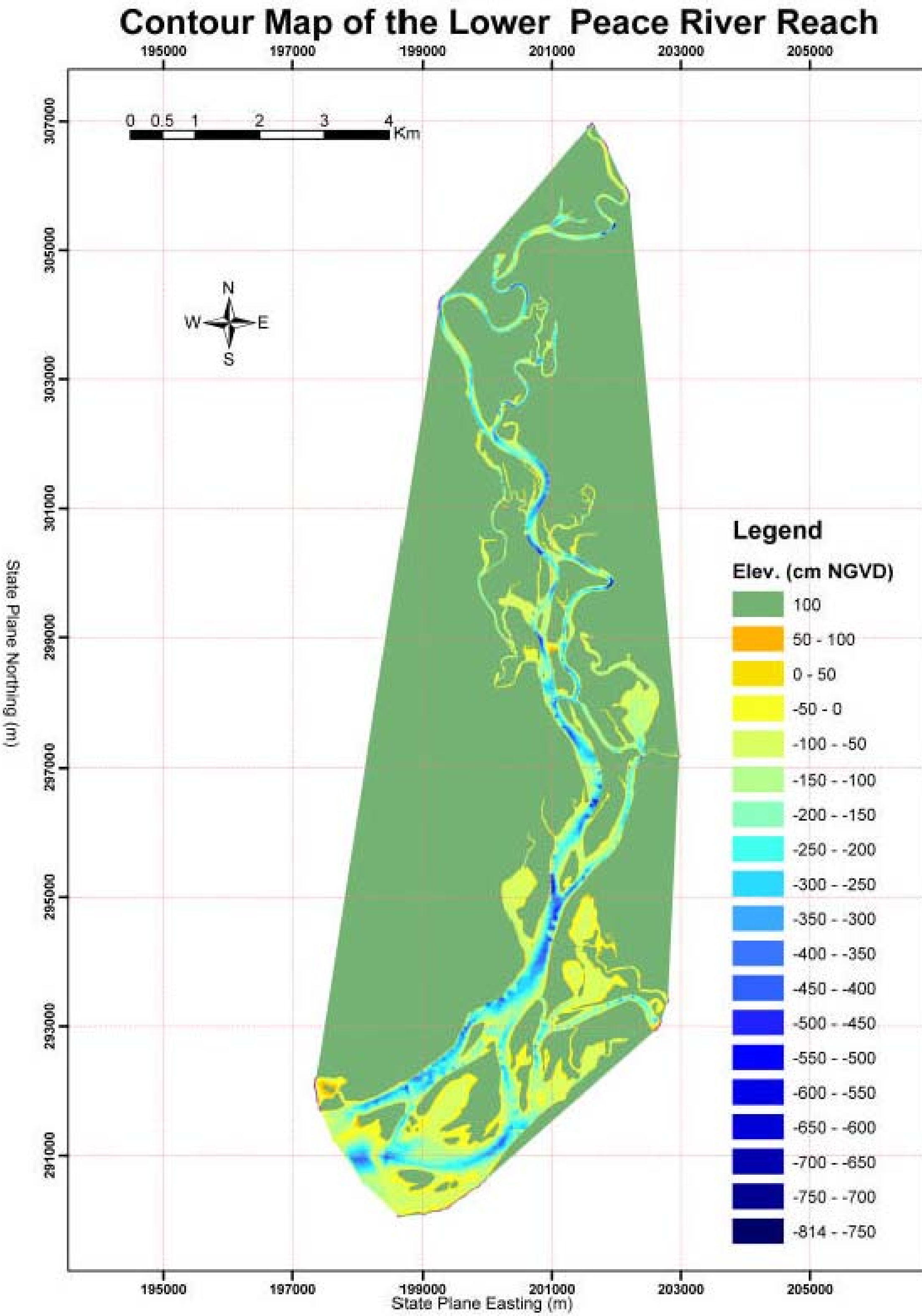


Figure 2-6. Bathymetry of the Lower Peace River (from Wang 2004).

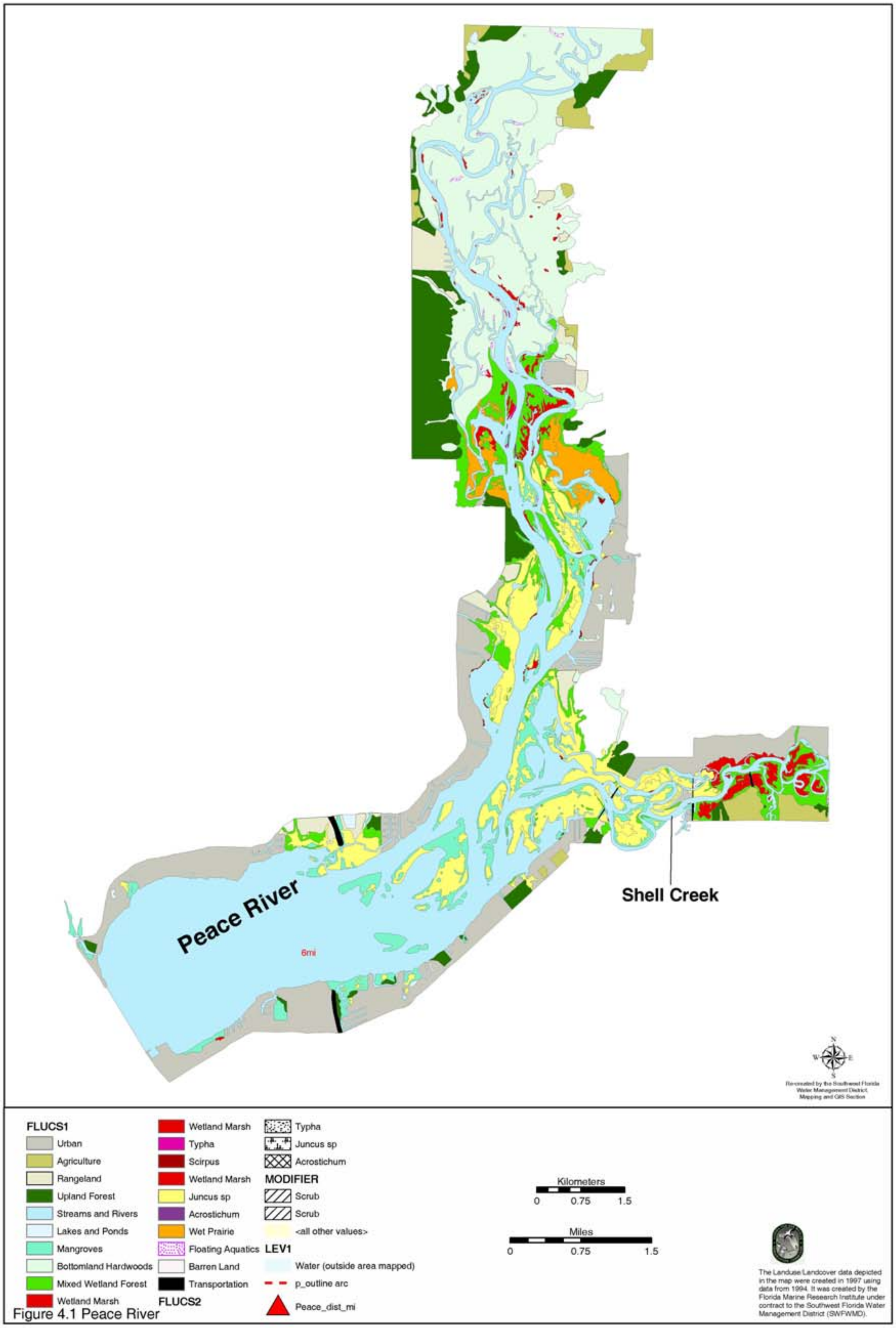


Figure 2-7. Depiction of Lower Peace River Vegetation (from FMRI 1998).

Forest species documented on the LPR include bald cypress, American elm, water ash and red maple (PBS&J 1999a).

Tidal Marshes

Tidal marshes provide important habitat for numerous species of fishes and crustaceans. Extensive studies have been conducted in salt marshes, while tidal fresh-water and oligohaline marshes are less studied (Figure 2-8). However, existing studies have concluded tidal fresh-water and oligohaline marshes also provide valuable habitat for fishes and crustaceans (McIvor *et al.* 1989, Odum *et al.* 1988). The marsh may serve several functions for these species, such as providing extended foraging ground, temporary refuge from predation, or essential nursery habitat. The habitat value of tidal marshes (particularly salt or brackish marshes) and estuaries for nektonic organisms has been documented for various geographic areas, including Texas, Louisiana, Georgia, the Carolinas, New Jersey and Delaware (Able *et al.* 2001, Yozzo and Smith 1998, Rozas and Reed 1993, Rozas and Hackney 1984).

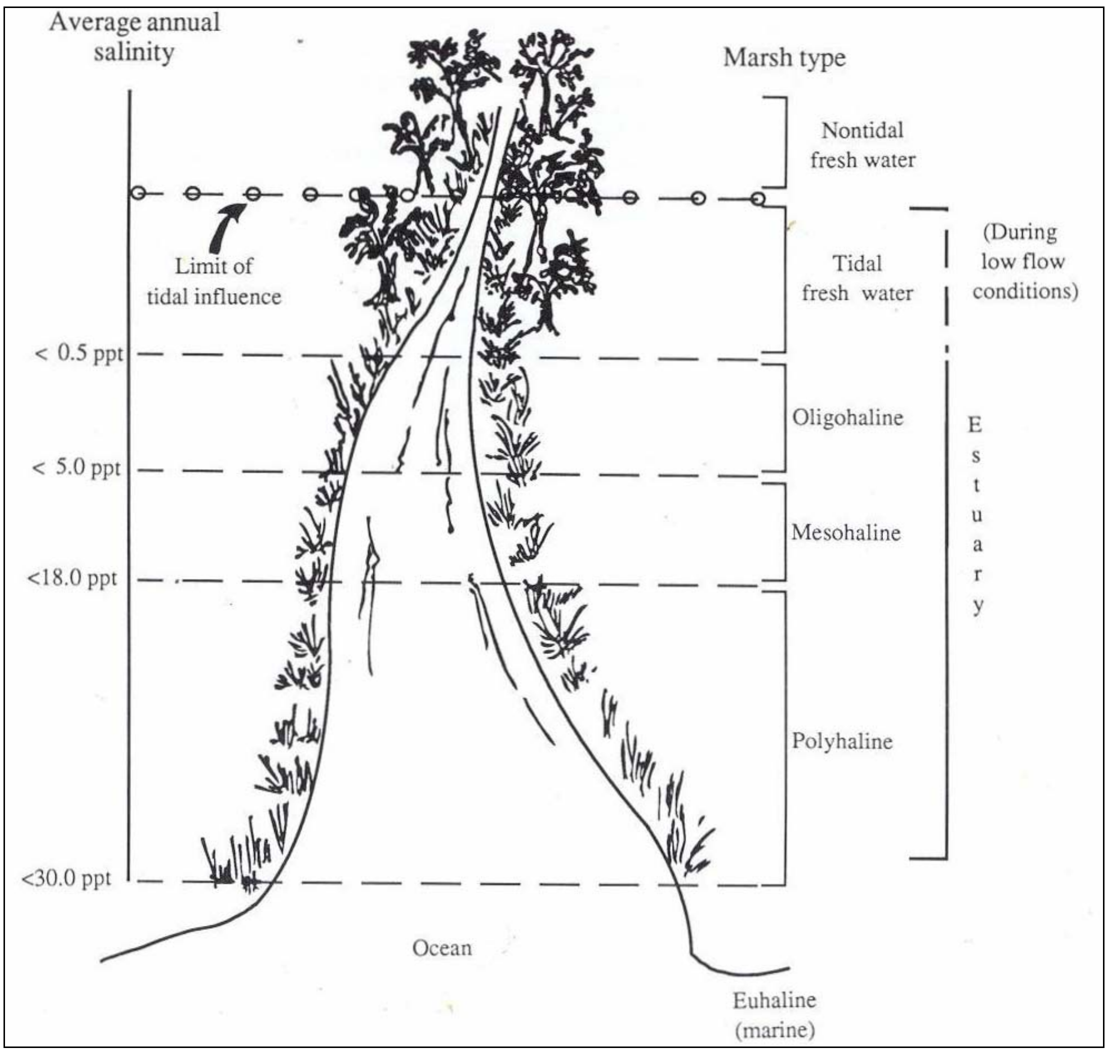


Figure 2-8. Marsh types present in a tidal river system, classified by surface salinity (from Odum *et al.* 1984).

Species inhabiting a saltmarsh are the most tolerant of high salinities. Polyhaline (salinity 18-30 ppt) conditions typically dominate, although mesohaline conditions (5-<18 ppt) could also occur. Oligohaline or brackish tidal marshes occur upstream of the saltmarshes. Dominant plants in these marshes include sawgrass, black needlerush, bulrushes (*Scirpus sp.),* cordgrasses, and lance-leaved arrowhead (*Sagitarria spp*.) (Clewell *et al.* 1999). As with the tidal, fresh-water marsh communities, few studies have been made on these low-salinity wetlands in Florida. These low-salinity marshes, in association with their complex of tidal creeks, are known to provide critical nursery habitat for many fishes of commercial or recreational importance (Rozas and Hackney 1984, Comp and Seaman 1985), particularly during the earliest larval stages.

"Oligohaline saltmarsh" was identified as a priority Habitat Target for conservation in the northern Gulf of Mexico by Beck *et al.* (2000). The oligohaline or intermediate marsh is characterized by salinities between 0.5 and 5 ppt. As salinities decrease, diversity increases because more species are able to tolerate the conditions. Several species of bulrush as well as black needlerush and sawgrass are considered representative of this type of marsh. Another intertidal wetland community is the tidal fresh-water marsh. Dominant plants include sawgrass, bulrushes, wild rice (*Zizania aquatica*), cattail (*Typha domingensis*), arrowhead, water parsnip (*Sium suave*), pickerelweed (*Pontedaria cordata*), spatterdock (*Nuphar luteum*), and other fresh-water emergent marsh plants (Clewell *et al.* 1999). Overall they have the highest plant diversity of the various tidal marsh community types (Clewell *et al.* 1999). The general structure and function of tidal fresh-water marsh communities were described by Odum *et al.* (1984), but few surveys of these coastal wetland types have been made in Florida. The fisheries habitat value of a tidal freshwater marsh is likely equivalent to those of downstream, higher salinity marshes (Odum *et al.* 1984). Beck *et al.* (2000) identified "tidal fresh marshes" as a high priority Habitat Target for conservation in the northern Gulf of Mexico. The tidal fresh-water marsh is characterized by salinities <0.5 ppt. This is the most diverse marsh type.

Marsh species reported in the LPR include the following freshwater species with a tolerance for low (brackish) salinities: sawgrass, bulrush and cattails. *Juncus roemerianus* was the dominant salt marsh species, first occurring upstream along with the freshwater species, then replacing them further downstream.

Mangroves

Mangroves are tropical trees that occur in brackish and saltwater environments, typically near the mouths of tidal rivers. While mangroves can physiologically grow in freshwater, mangrove communities only become established in salt water systems, because of the absence of competition from freshwater species (Odum *et al.* 1982). Red and white mangroves *(Rhizophora mangle* and *Laguncularia racemosa)* commonly occur around New Harbor Heights and their dominance increases towards the mouth of the river.

2.1.3 Rainfall

In peninsular Florida, there is typically a June through September high rainfall season. Superimposed on this general seasonal cycle are the effects of larger scale events, notably the El Niño-Southern Oscillation (ENSO) and the Atlantic Multidecadal Oscillation (AMO) (Kelly 2004). Typically El Niño years are wetter than La Niña years (Schmidt and Luther 2002). However, El Niño effects during the summer wet season are somewhat attenuated by the seasonal occurrence of thunderstorms. Mean monthly rainfall at the Arcadia gage exhibits the typical June-September rainfall peak and lower values during the remainder of the year (Figure 2-.9). Long-term trends for rainfall in the basin are shown in Figure 2-10. The total annual rainfall at Arcadia ranged from 29 to 80 inches, while the mean and median were 51.9 and 52.0 inches, respectively.

2.1.4 Freshwater Flows

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

There are four USGS gages that record flows that enter the LPR, Peace River at Arcadia (USGS gage 02296750), Horse Creek near Arcadia (USGS gage 02297310), Joshua Creek at Nocatee (USGS gage 02297100), and SC near Punta Gorda (USGS gage 02298202). There is one permitted surface water withdrawal on the LPR at the Peace River Manasota Regional Water Supply Authority (PRMRWSA) plant and one by the City of Punta Gorda from the reservoir behind the Hutchinson dam on SC. PRMRWSA began withdrawing water in 1980. The SC flows are described in section 2.2.2.3 while flows from other gages and the PRMRWSA withdrawals are described below.

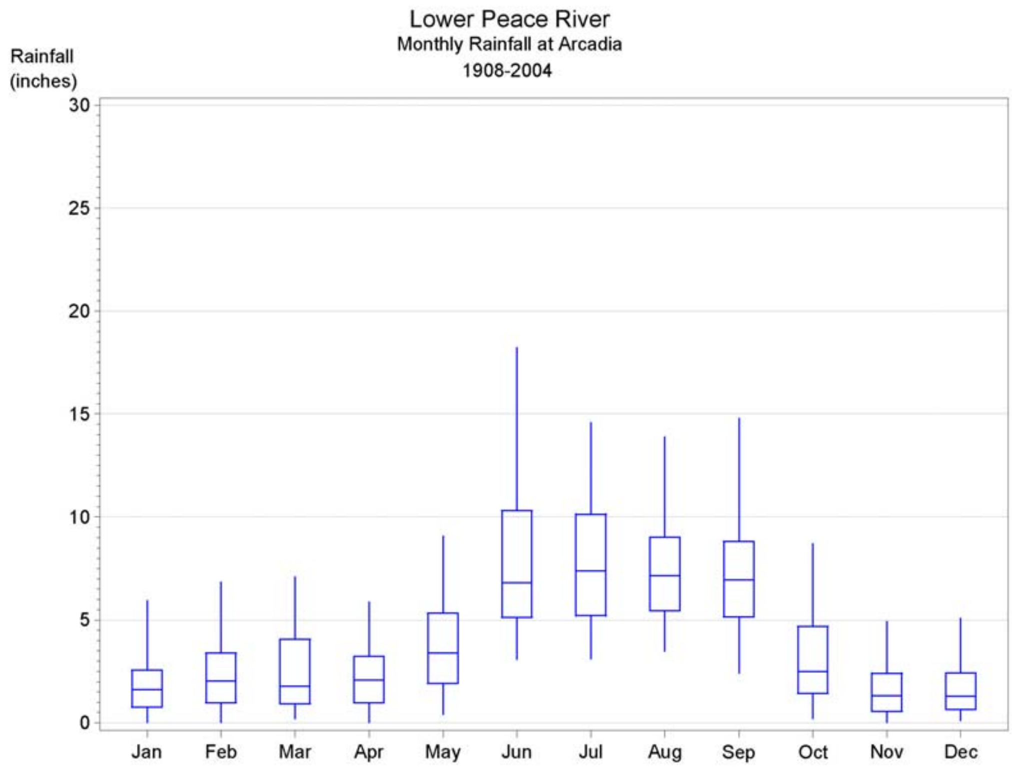


Figure 2-9. **Box and Whisker of monthly rainfall (total inches) at Arcadia, 1908-2004. Whiskers represent the 5th and 95th percentile monthly rainfall.**

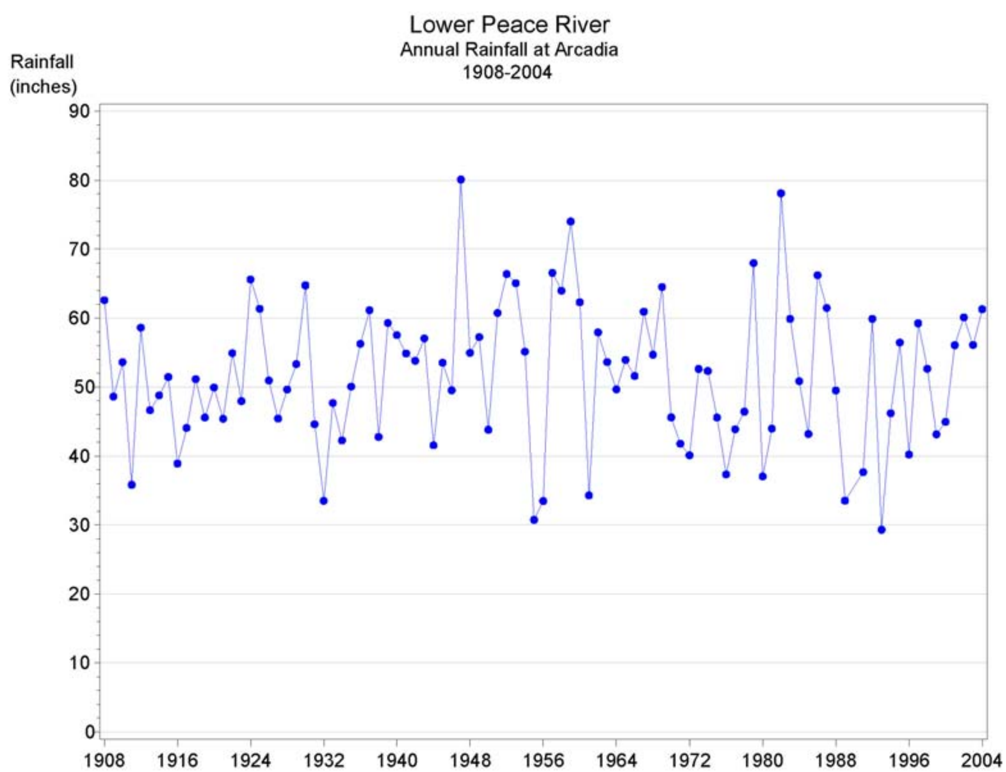


Figure 2-10. **Annual rainfall (inches) at Arcadia, 1908-2004.**

Flows have been measured at the Peace River at Arcadia gage since 1932. The annual median flows from the Peace River at Arcadia gage are presented in Figure 2-11. The annual median flows ranged from a minimum of 63 cfs in 2000 to a maximum of 1,740 cfs in 1953. A box and whisker plot of the daily flow from the Peace River at Arcadia gage is presented in Figure 2-12. The seasonal pattern of higher flows from July to October and lower flows from November to June can be clearly seen. September is typically the month with the highest flows while May has the lowest flows. Finally, a flow duration curve of the daily flows from the Peace River at Arcadia gage is shown in Figure 2-13. Daily flows ranged from 6 cfs to 34,700 cfs. The 25th percentile, median, and 75th percentile flows over the entire period of record were 205, 461, and 1,210 cfs, respectively.

The period of record for the Horse Creek near Arcadia gage is 1950 to present. The annual median flows from the Horse Creek near Arcadia gage are shown in Figure 2-14. The minimum annual median flow of 3 cfs occurred in 1974 and the maximum of 211 cfs in 1953. A box and whisker plot of the daily flow from the Horse Creek near Arcadia gage is presented in Figure 2-15. As with the Peace River at Arcadia gage, the seasonal pattern of higher flows from July to October and lower flows from November to June is clear. September is typically the month with the highest flows while May has the lowest flows. A flow duration curve of the daily flows from the Horse Creek near Arcadia gage in shown in Figure 2-16. The daily flows ranged from 0 cfs to 10,700 cfs. The 25th percentile, median, and 75th percentile flows over the entire period of record were 10, 46, and 189 cfs, respectively.

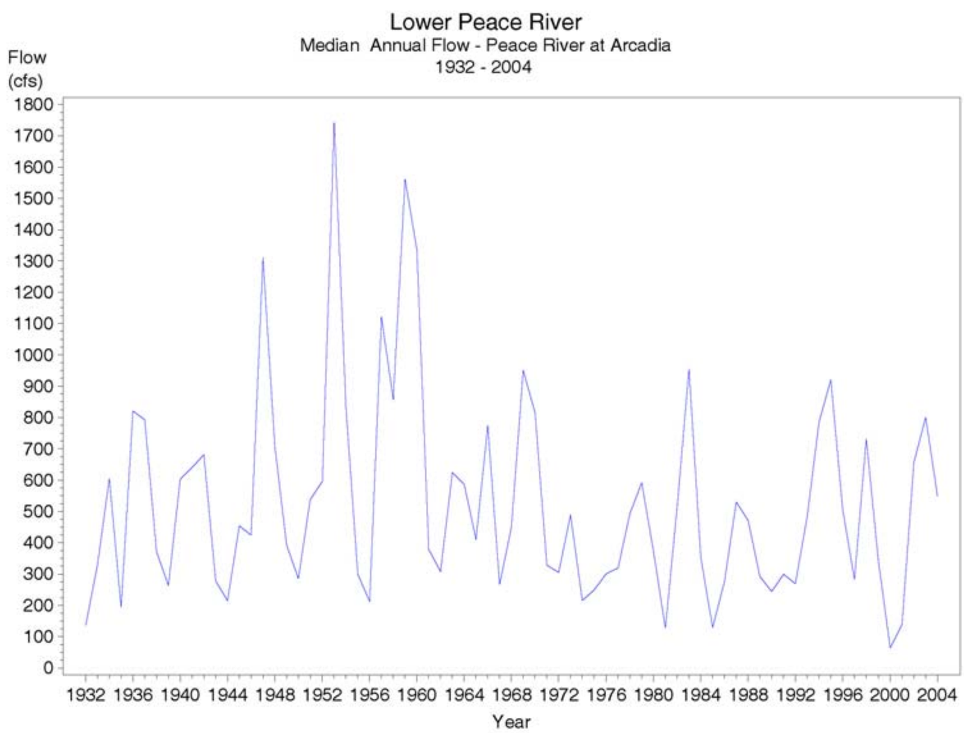


Figure 2-11. Time series of annual median flows (cfs) from the Peace River at Arcadia gage (USGS 02296750) for the period 1932 to 2004.

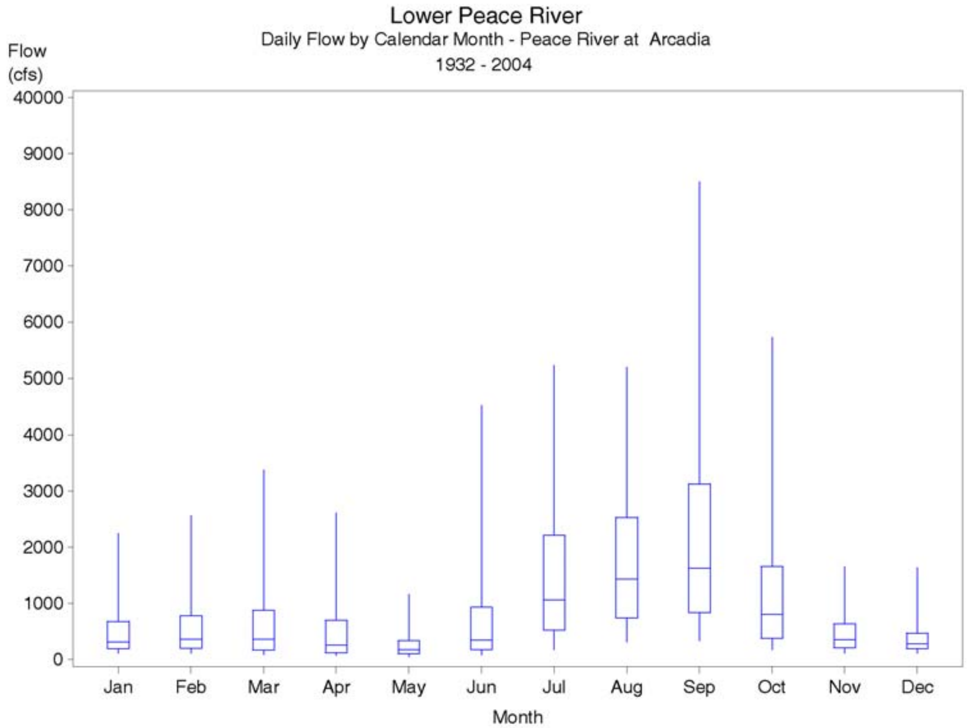


Figure 2-12. **Box and whisker plot of daily flows (cfs) by calendar month from the Peace River at Arcadia gage (USGS 02296750) for the period 1932 to 2004. Boxes represent the inter-quartile range while the whiskers represent the 5th and 95th percentiles.**

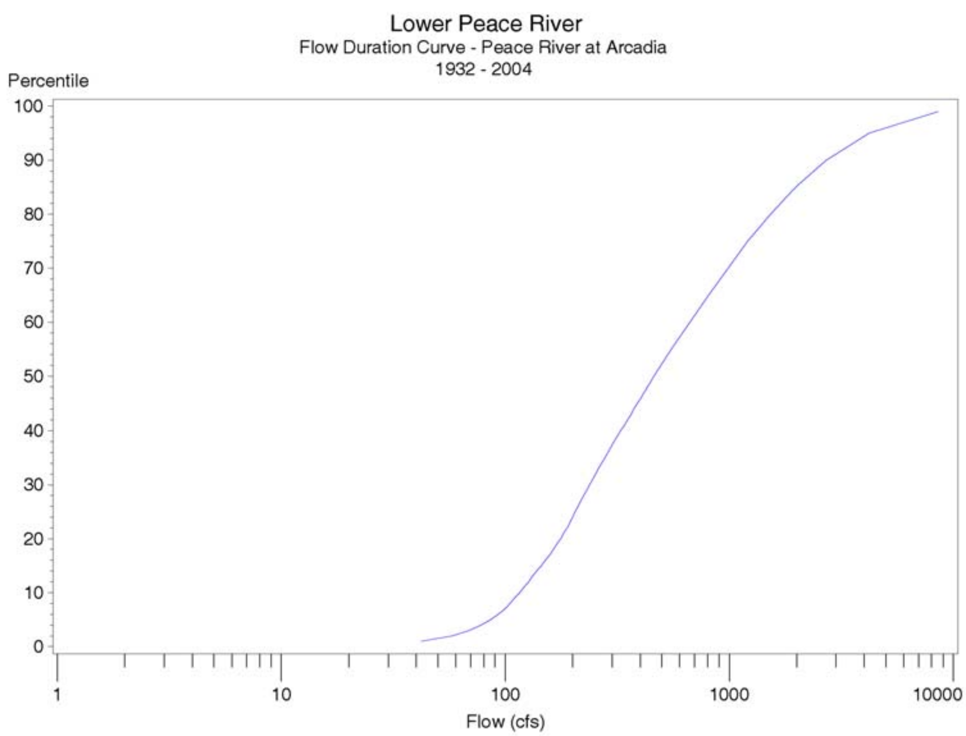


Figure 2-13. **Flow duration curve of daily flows (cfs) from the Peace River at Arcadia gage (USGS 02296750) for the period 1932 to 2004.**

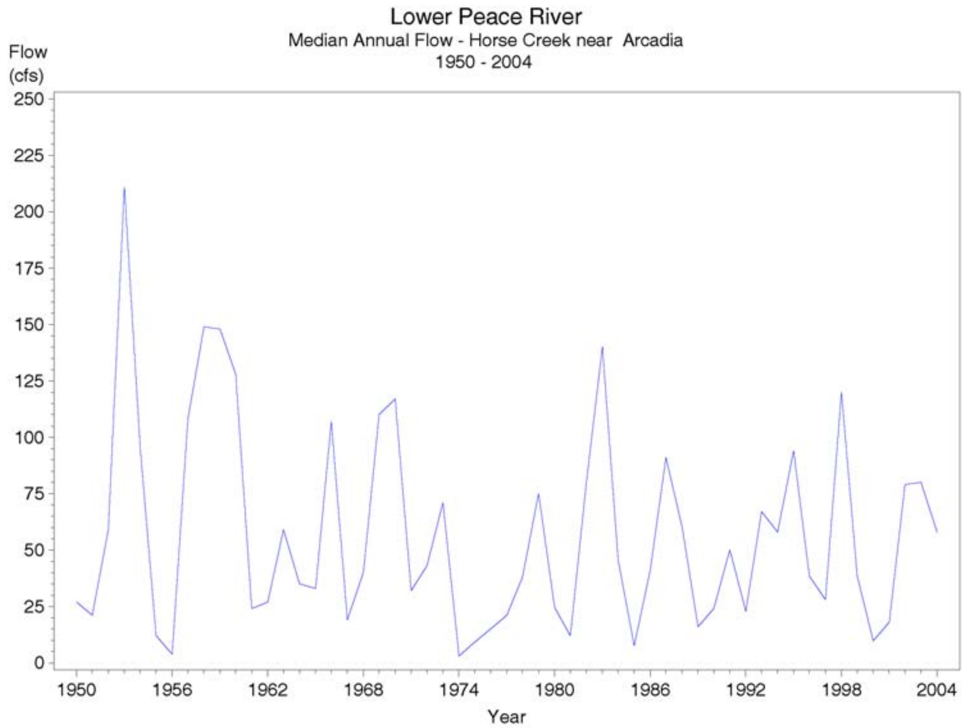


Figure 2-14. **Time series of annual median flows (cfs) from the Horse Creek near Arcadia gage (USGS 02297310) for the period 1950 to 2004.**

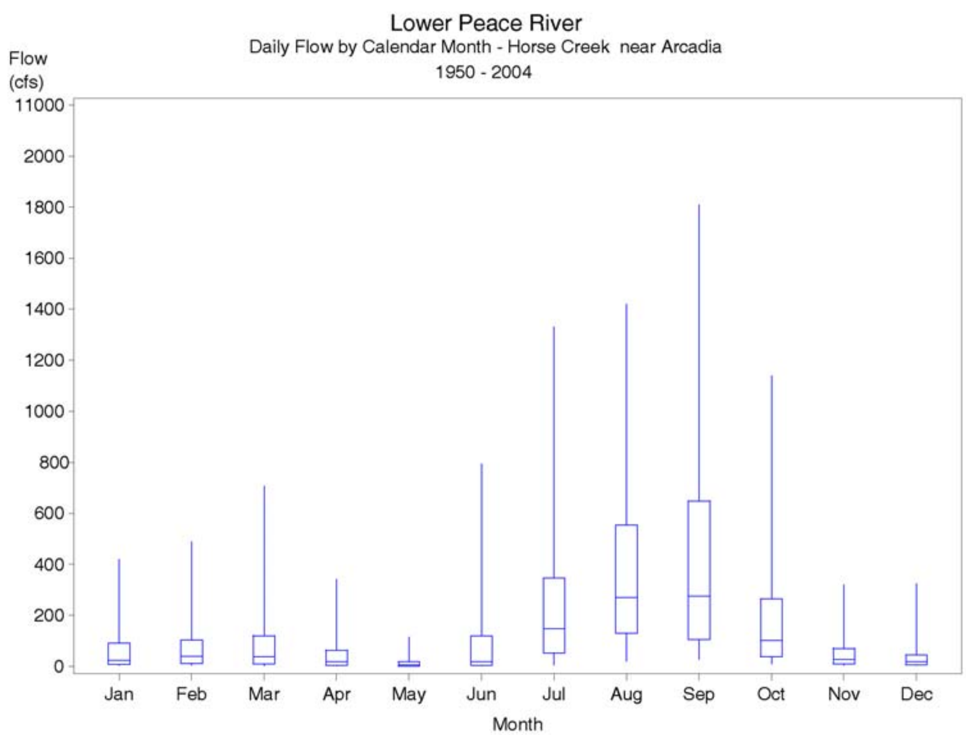


Figure 2-15. **Box and whisker plot of daily flows (cfs) by calendar month from the Horse Creek near Arcadia gage (USGS 02297310) for the period 1950 to 2004. Boxes represent the inter-quartile range while the whiskers represent the 5^{th} and 95^{th} percentiles.**

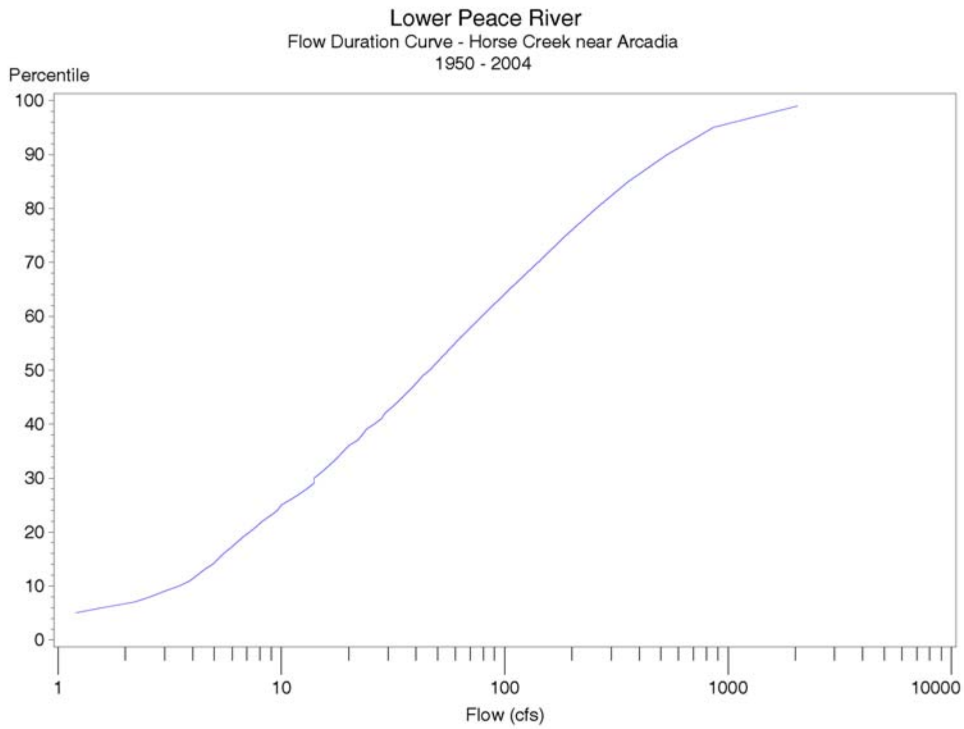


Figure 2-16. Flow duration curve of daily flows (cfs) from the Horse Creek near Arcadia gage (USGS 02297310) for the period 1950 to 2004.

The period of record for the Joshua Creek at Nocatee gage is from 1950 to 2004. The annual median flows from the Joshua Creek at Nocatee gage are presented in Figure 2-17. The annual median flows ranged from a minimum of 2 cfs in 1956 to a maximum of 73 in 1958. There is a trend of increasing flows in Joshua Creek (PBS&J 2007). A box and whisker plot of the daily flow from the Joshua Creek at Nocatee gage is presented in Figure 2-18. The seasonal pattern of higher flows from July to October and lower flows from November to June can be seen clearly. September is typically the month with the highest flows while May has the lowest flows. Finally, a flow duration curve of the daily flows from the Joshua Creek at Nocatee gage in shown in Figure 2-19. The daily flows ranged from 0 cfs to 7,910 cfs. The 25th percentile, median, and 75th percentile flows over the entire period of record were 10, 28, and 92 cfs, respectively.

The WUP (#2010420.02) held by the PRMRWSA, as modified on 18 December 1998, permits:

- withdrawals on days when the previous days flow at the USGS Arcadia gage was at least 130 cfs,
- a daily maximum withdrawal of 139 cfs (90 mgd),
- a monthly maximum of 59 cfs (38.1 mgd); and
- an annual average of 51 cfs (32.7 mgd).

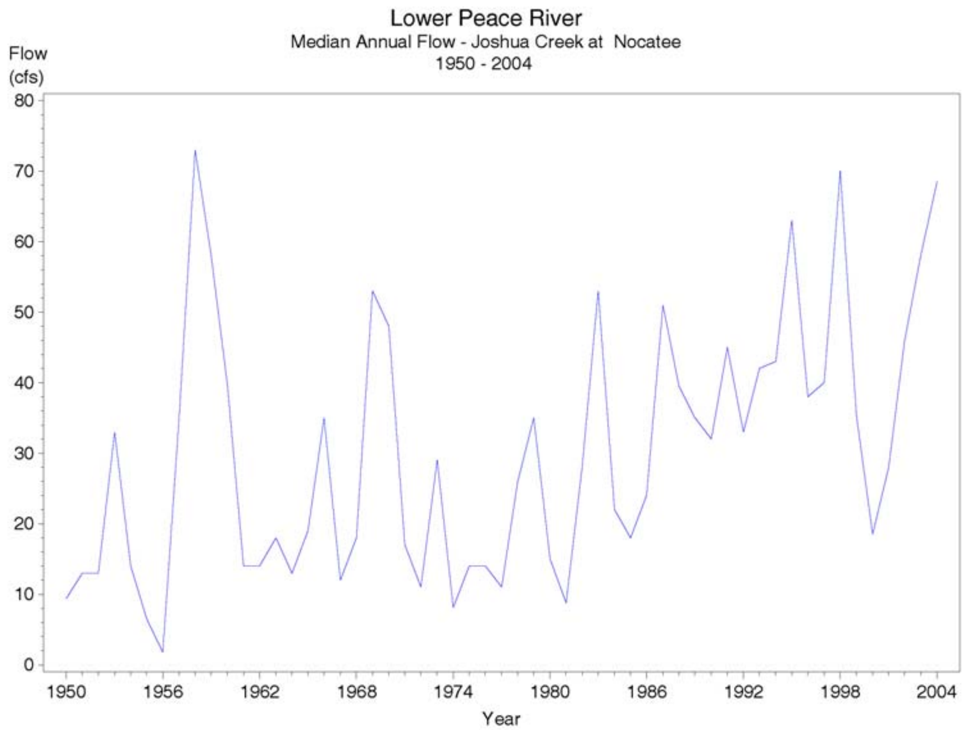


Figure 2-17. Time series of annual median flows (cfs) from the Joshua Creek near Nocatee gage (USGS 02297100) for the period 1950 to 2004.

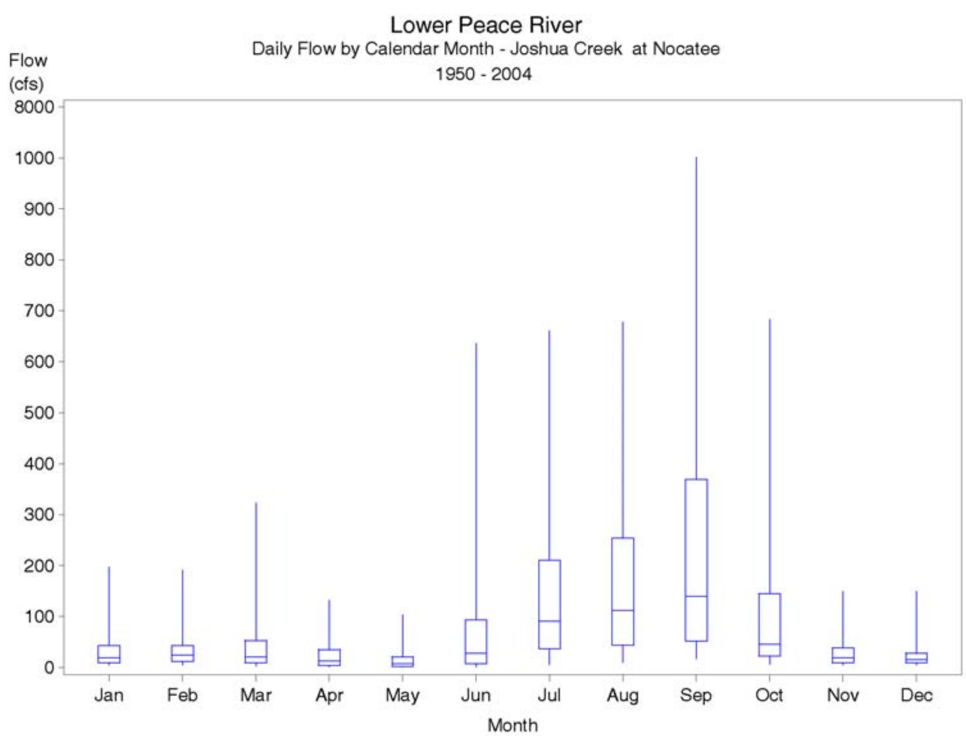


Figure 2-18. Box and whisker plot of daily flows (cfs) by calendar month from the Joshua Creek near Nocatee gage (USGS 02297100) for the period 1950 to 2004. Boxes represent the inter-quartile range while the whiskers represent the 5th and 95th percentiles.

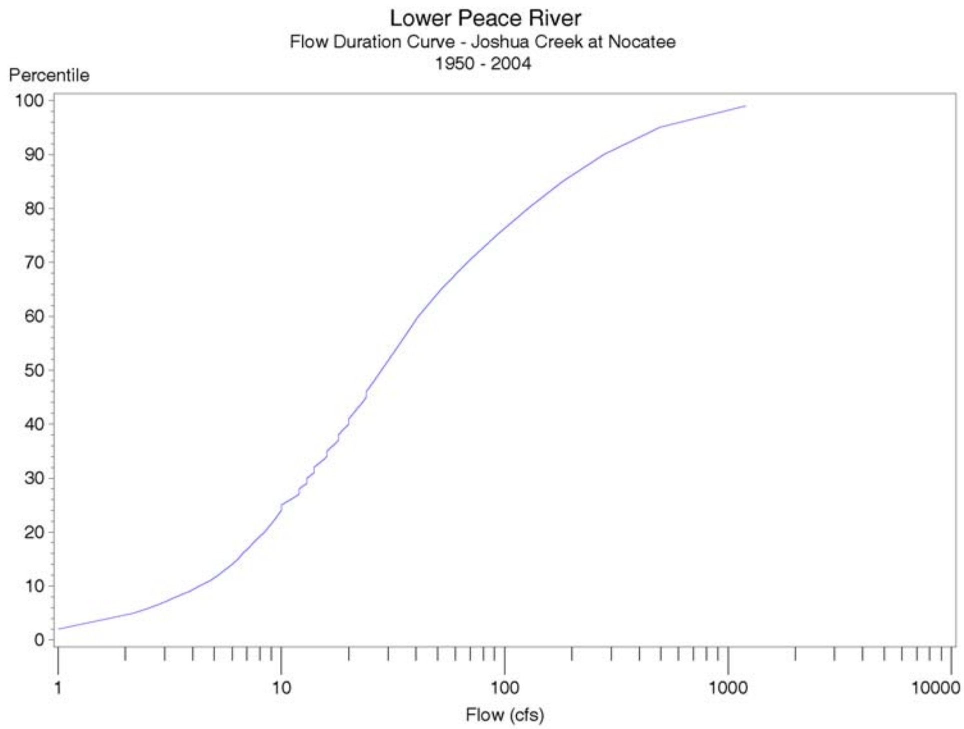


Figure 2-19. Flow duration curve of daily flows (cfs) from the Joshua Creek near Nocatee gage (USGS 02297100) for the period 1950 to 2004.

The annual median withdrawals from the PRMRWSA plant are shown in Figure 2-20. The minimum annual median withdrawal was 0 cfs and it occurred in five years (1981, 1984, 1985, 2000, and 2001). The maximum median annual withdrawal was 26 cfs, and it occurred in 2003 and 2004. A box and whisker plot of the daily withdrawals from the PRMRWSA is presented in Figure 2-21. There was some evidence of a seasonal cycle to the withdrawals, with the highest median withdrawal in October and the lowest in May—although the interquartile ranges for all months did overlap. A flow duration curve of the daily withdrawals from the PRMRWSA plant in shown in Figure 2-22. The daily withdrawals ranged from 0 cfs to 69 cfs. The 25th percentile, median, and 75th percentile flows over the entire period of record were 0, 9, and 16 cfs, respectively.

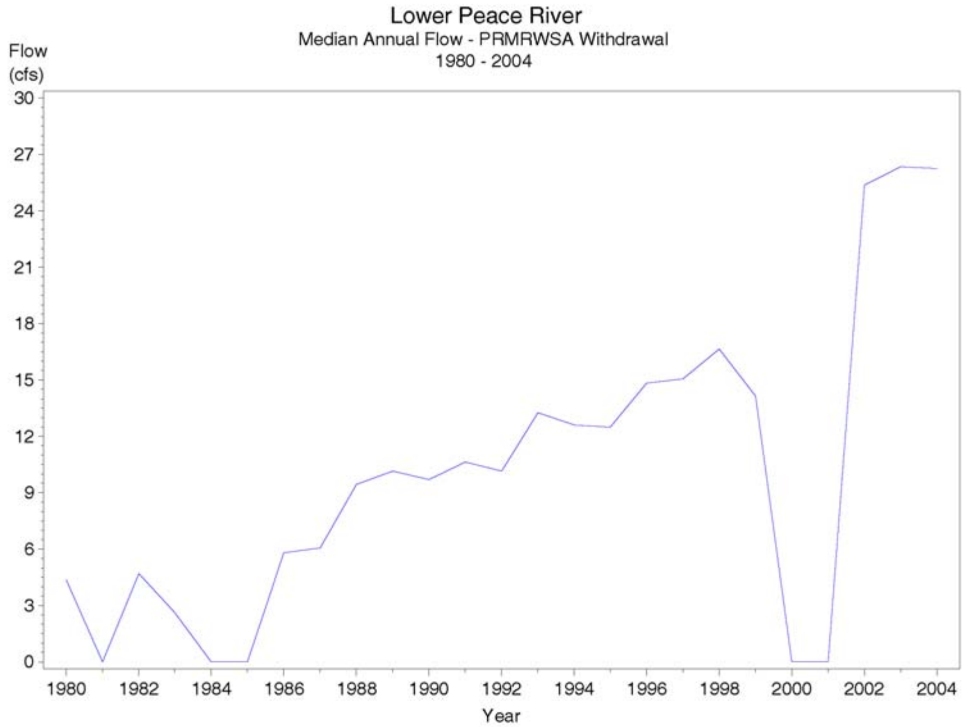


Figure 2-20. Time series of annual median flows (cfs) from the PRMRWSA for the period 1980 to 2004.

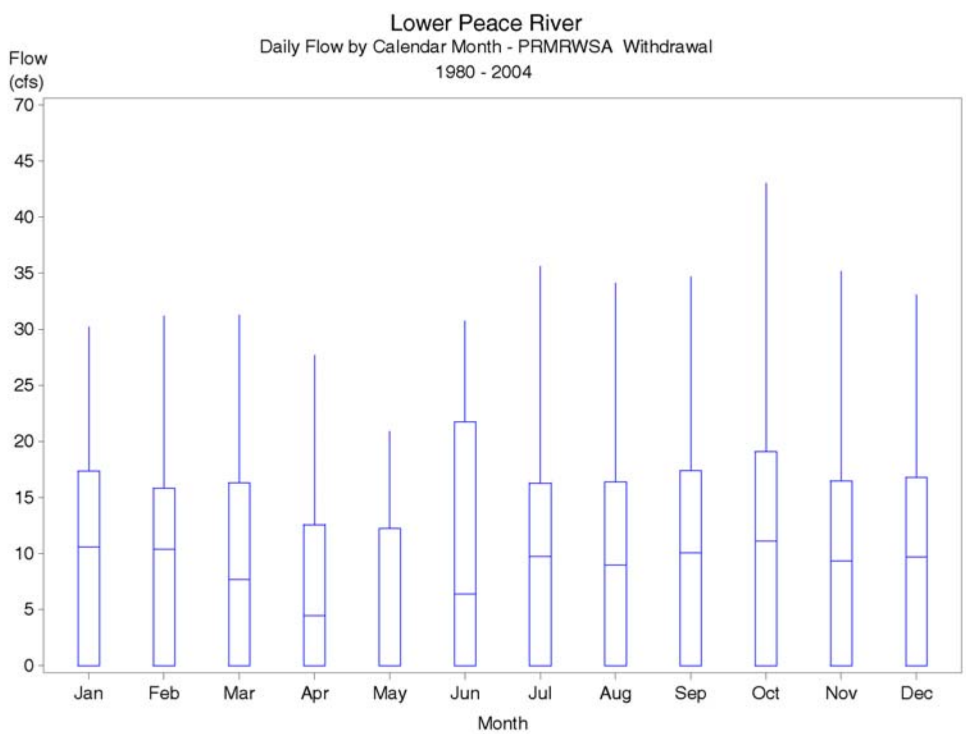


Figure 2-21. Box and whisker plot of daily flows (cfs) by calendar month from the PRMRWSA for the period 1980 to 2004. Boxes represent the inter-quartile range while the whiskers represent the 5th and 95th percentiles.

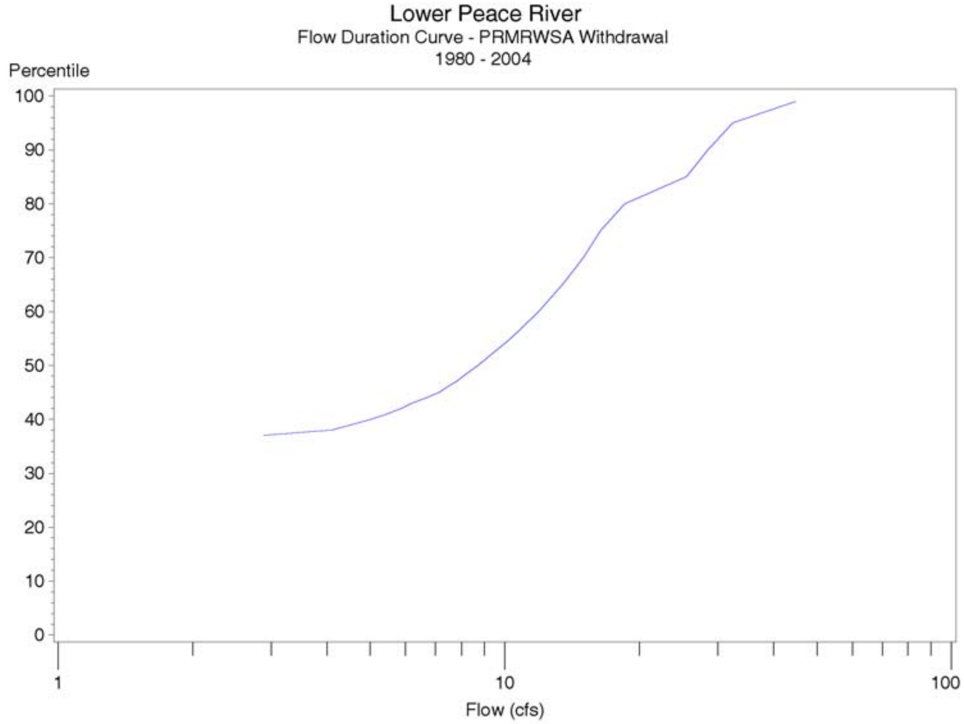


Figure 2-22. Flow duration curve of daily flows (cfs) from the PRMRWSA for the period 1980 to 2004.

Kelly (2004) examined the impact of the Atlantic Multidecadal Oscillation (AMO) in Florida by looking at river flows. For the Peace River, flows at the Arcadia gage were compared to flows from two major subbasins, Charlie Creek and Horse Creek. When normalized for watershed area (i.e., flows expressed as cfs/sq mile), Charlie Creek, Horse Creek and the Peace River at Arcadia show very similar flow patterns, both pre and post 1970. Plots for Peace River at Arcadia and Horse Creek are presented in Figures 2-23 and 2-24. When percent decreases in median daily flows where compared between periods, both Charlie and Horse Creeks showed almost identical flow declines to that observed for the Peace River at Arcadia. Kelly (2004) suggested that most of the flow decline observed between the two periods investigated must be attributable largely to climate. While declines in flow attributable to AMO were documented for the Peace River at Arcadia and Horse Creek near Arcadia gages, the same was not seen at Joshua Creek (Figure 2-25). The increase in flows after 1980 seen at Joshua Creek was attributed to increased runoff due to increased agricultural activities in the basin (Kelly 2004).

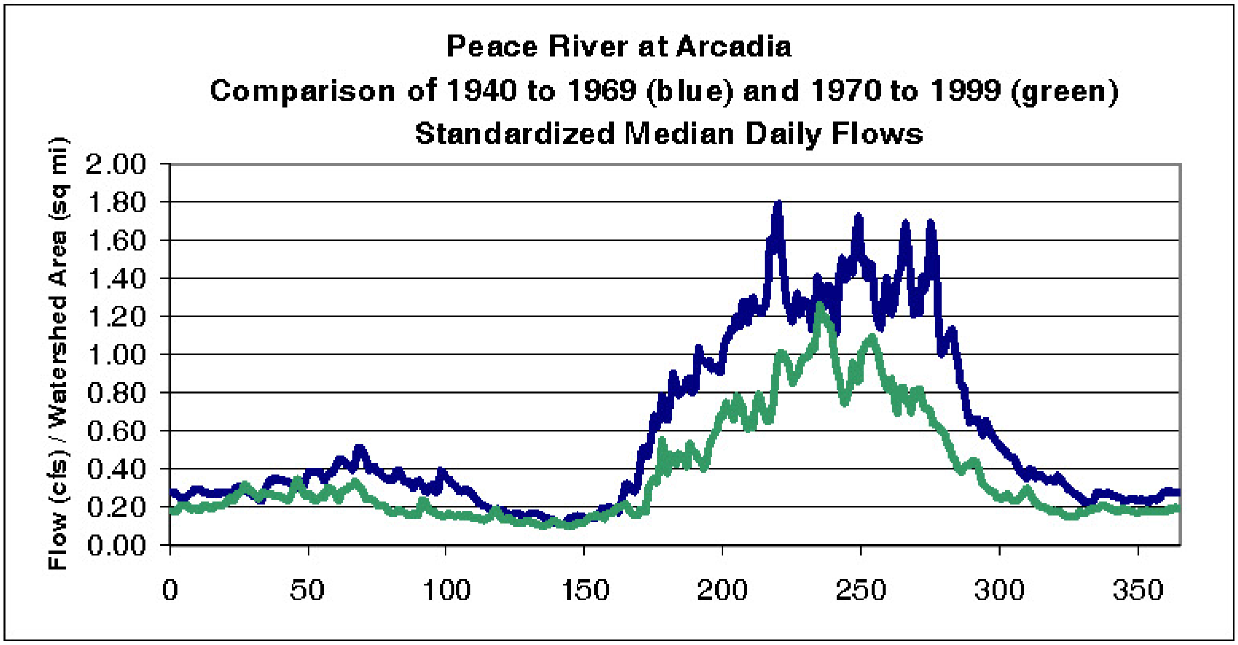


Figure 2-23. **Median daily flow normalized for watershed area for the wet (1940-1969) and dry (1970-1999) AMO periods for the Peace River at Arcadia gage. (Source: Kelly 2004)**

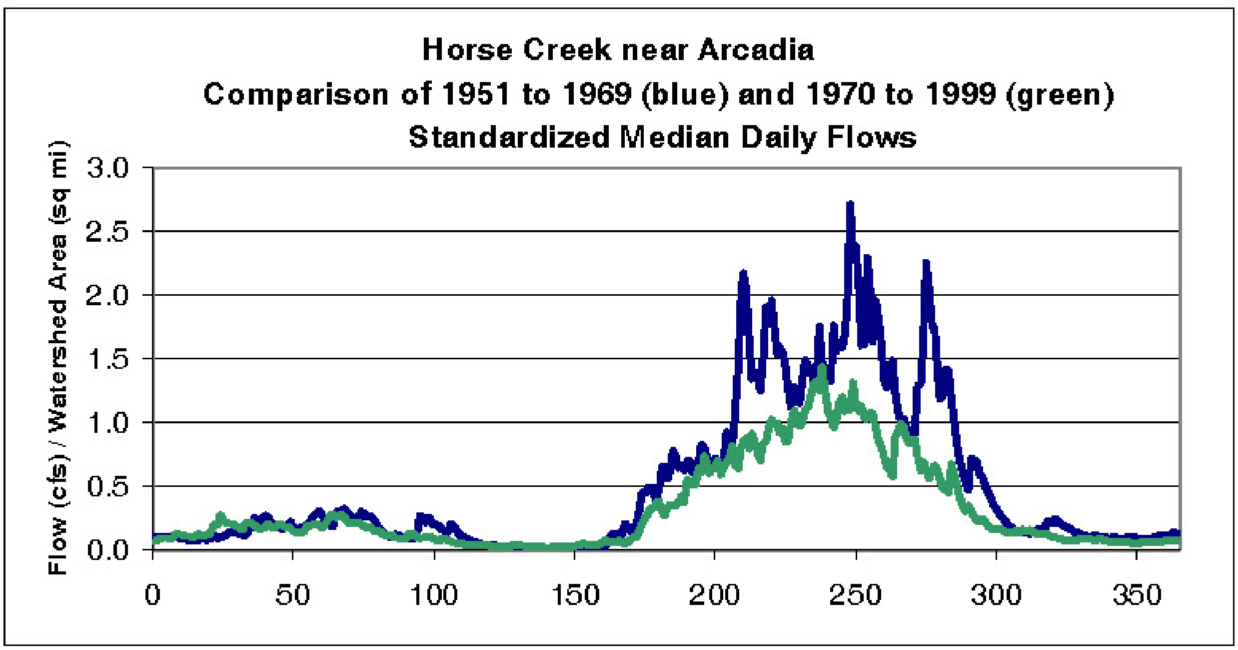


Figure 2-24. **Median daily flow normalized for watershed area for the wet (1951-1969) and dry (1970-1999) AMO periods for the Horse Creek near Arcadia gage. (Source: Kelly 2004)**

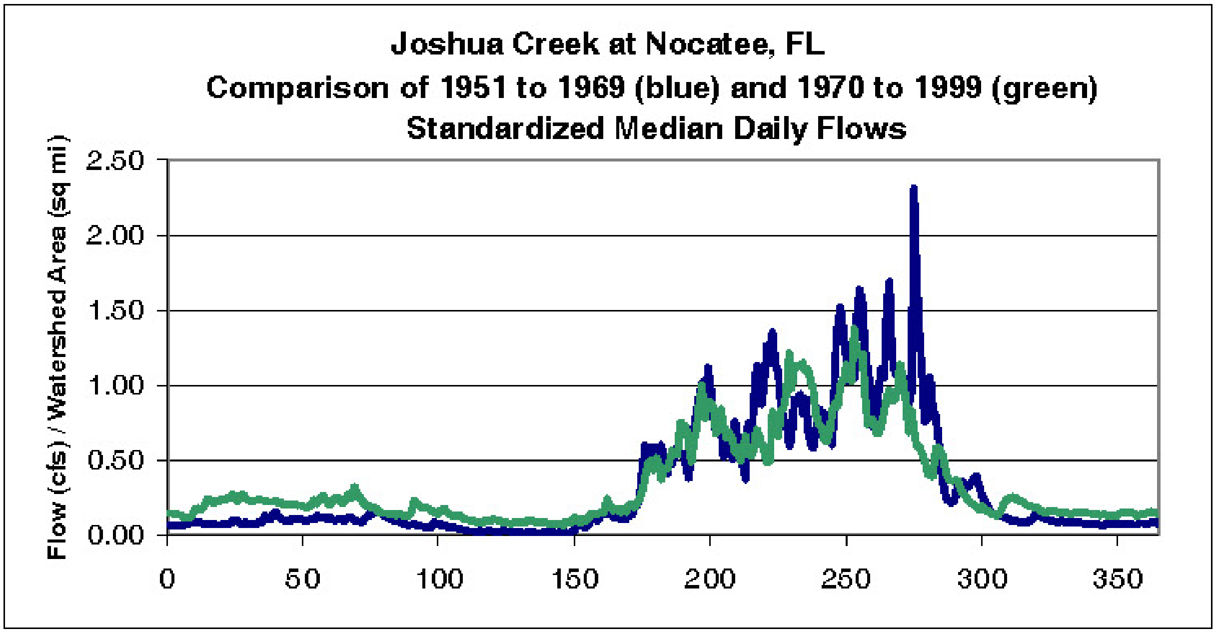


Figure 2-25. **Median daily flow normalized for watershed area for the wet (1951-1969) and dry (1970-1999) AMO periods for the Joshua Creek near Arcadia gage. (Source: Kelly 2004)**

2.1.5 Sediment Characteristics

Sediments in the LPR during November 1998 ranged from mud-sized (<62 μ) to coarse sands (500-1000 μ). Mud-sized sediments were only found in Zone3. Based upon median grain sizes, sediments in Zones 2, 3 and 4, Hunter Creek and Lettuce Lake were generally fine sands; medium sand-sized sediments were predominant in Zone 1 and Deep Creek.

2.2 Physical Characteristics of the Shell Creek Watershed

The portion of SC covered by the MFL extends from the mouth of SC to the SC dam, a distance of approximately 10 km (Figure 2-26). Land use throughout the watershed is presented in Figure 2-27. Wetlands buffer the channel of SC and the remaining land uses are a mix of agricultural, pasture and range land, and upland forest. Soils within SC (Figure 2-28) are primarily classified as A (high infiltration rate and low runoff potential) and D (very slow infiltration rate and high runoff potential).

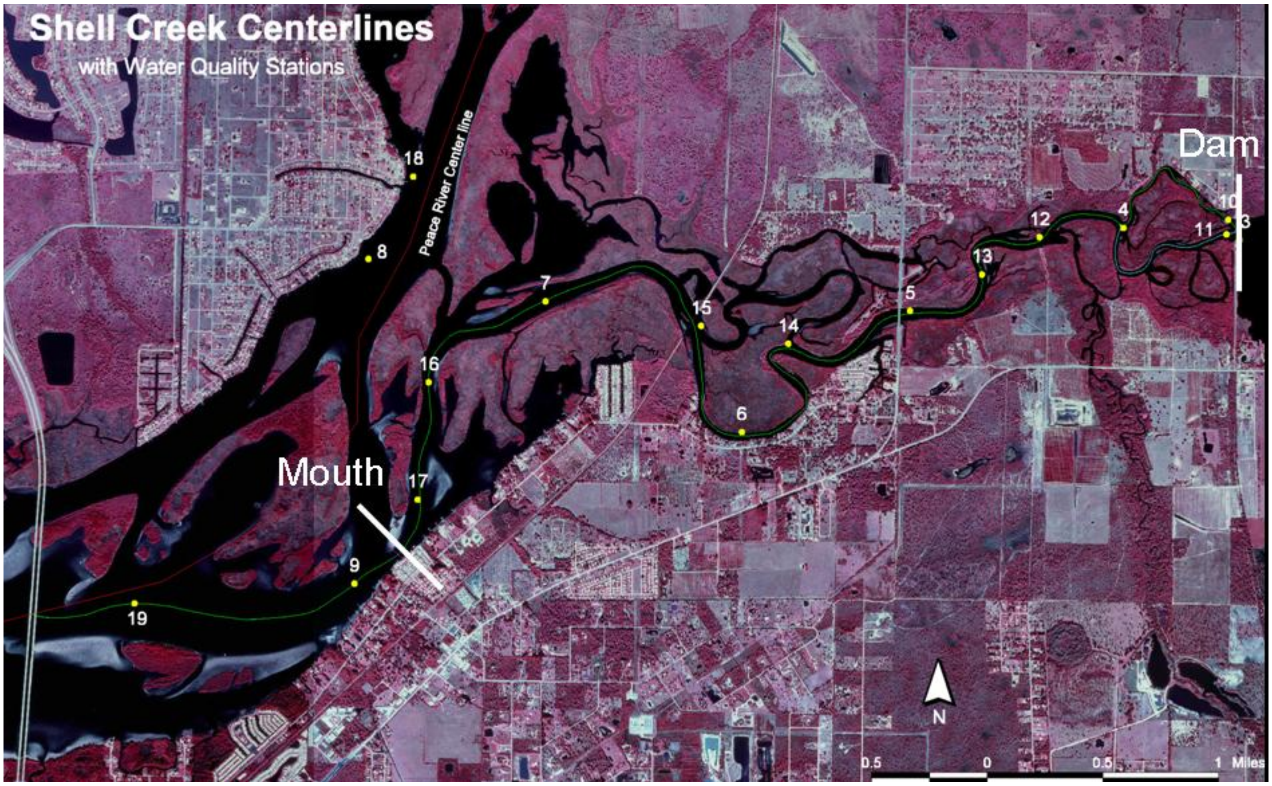


Figure 2-26. **Map of SC with centerline and HBMP fixed stations (From PBS&J 2006).**

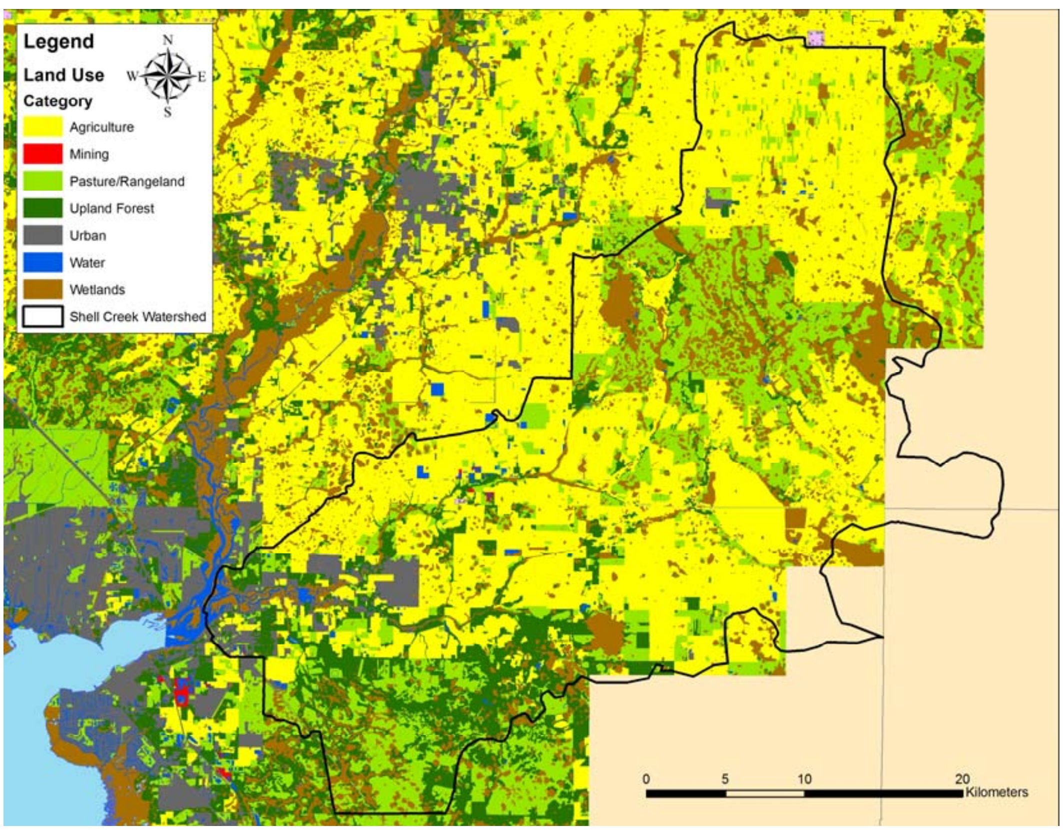


Figure 2-27. **Land use map of the SC Watershed (source: SWFWMD 1999).**

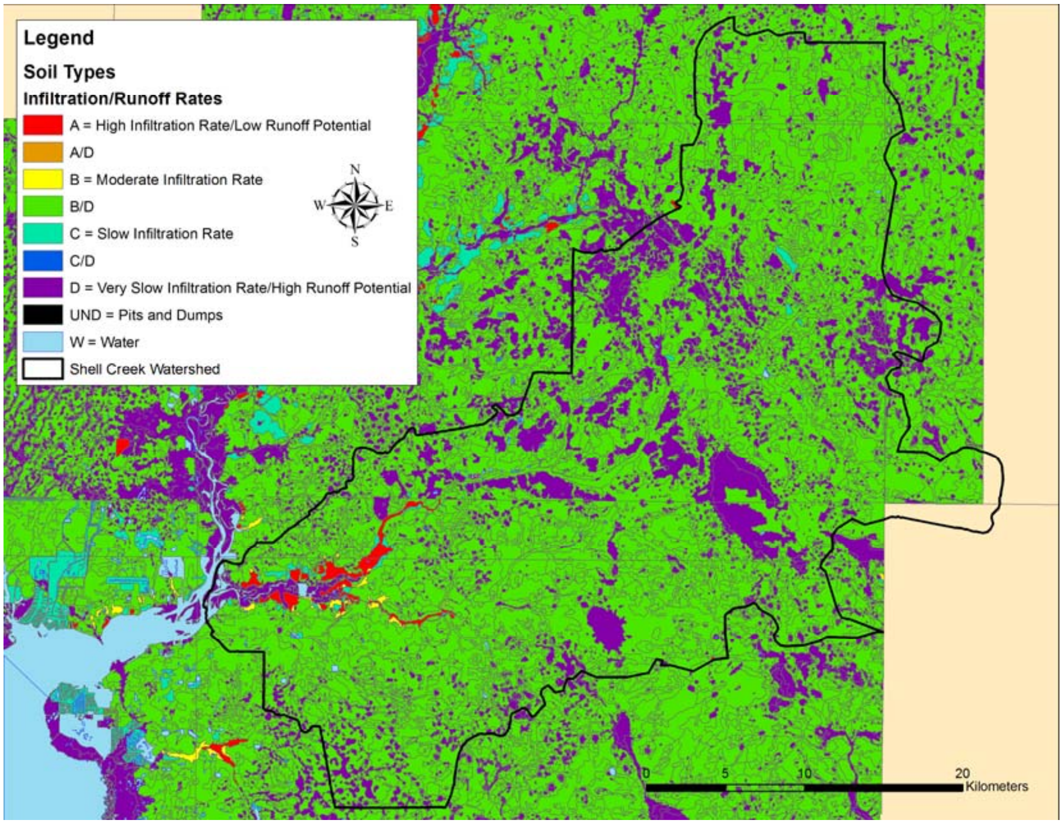


Figure 2-28. Soil types in the SC Watershed (source: SWFWMD 2002).

2.2.1 Bathymetry and Morphometry

The morphology of a riverine system can influence the biology of the system in several ways. The shape of the river affects current speed, and also sediment composition. Sediment composition has obvious impacts for benthic dwelling organisms. Additionally, the shape of the river determines the volume of water, which can affect habitat zonation and availability. Information on morphology and bathymetry in SC are available from PBS&J (1998) and Mote Marine Lab (2002). Bathymetry in SC is primarily less than 2 meters deep (Figure 2-29).

2.2.2 Shoreline Vegetation

Shoreline vegetative communities (including wetlands) are important components of riverine and estuarine systems. Vegetation communities along tidal rivers, and their tributaries, such as SC, display a transition from the forested freshwater segments upstream, to tidal freshwater forest/marsh communities, to the brackish and salt marsh communities in the mid to lower segments of the system. Descriptive information on the vegetation communities located along SC was available from a 1994 vegetation map (FMRI 1998) and from a Shell Creek Gap Report prepared by PBS&J (2006). The general distribution of major vegetative communities along the lower river were mapped by PBS&J (2006) and shown in Figure 2-30. A complete set of vegetation maps from PBS&J (2006) are presented in Appendix 2-1.

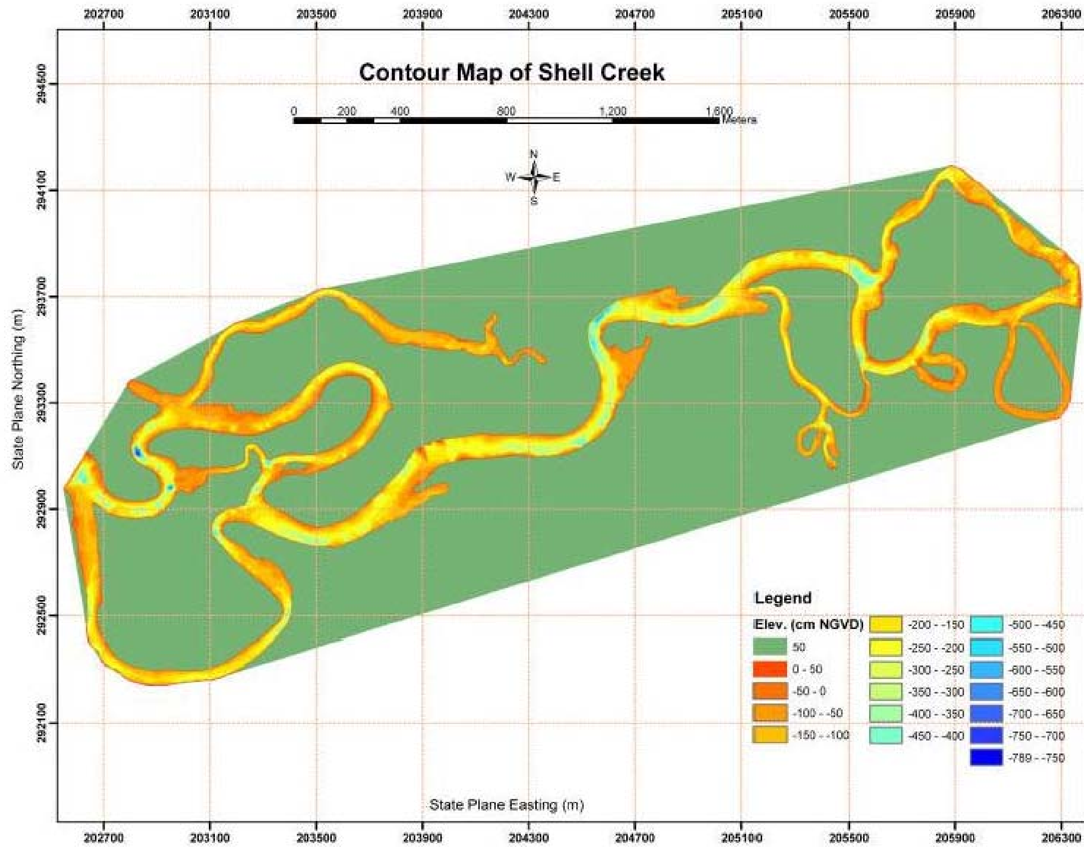


Figure 2-29. **Bathymetry of tidally influenced portion of SC (from Wang 2004).**

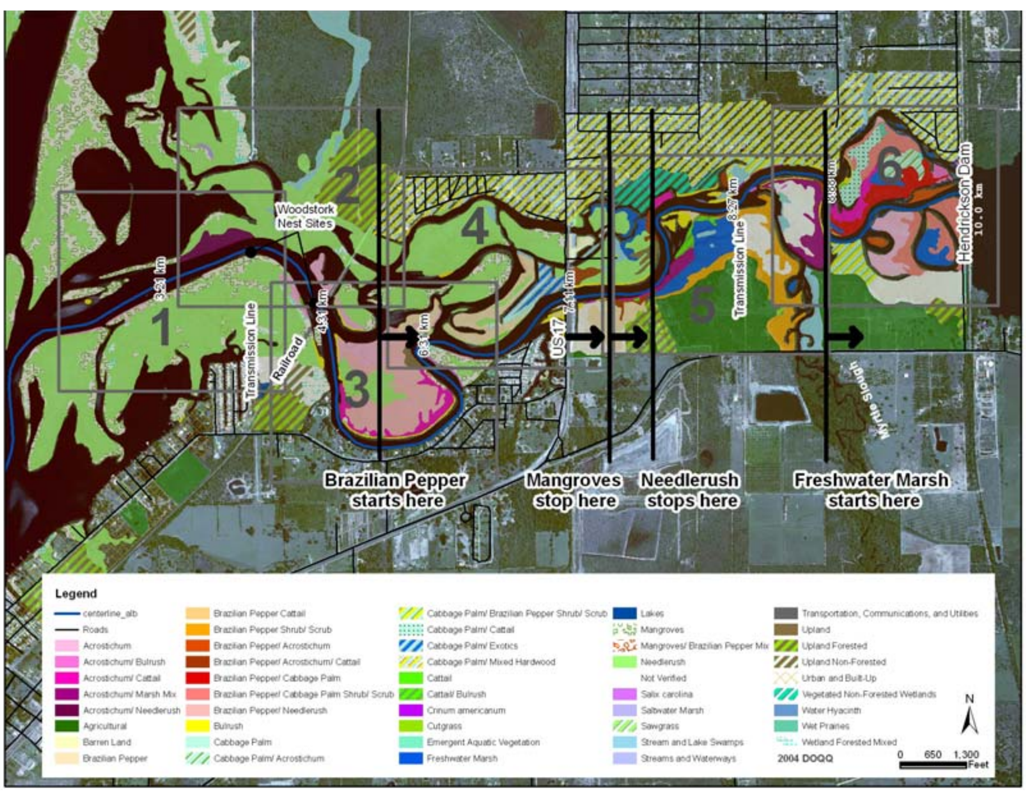


Figure 2-30. **Map of SC Vegetation (from PBS&J 2006).**

Mixed Wetland Forests

Mixed wetland forests are communities where neither hardwoods nor conifers dominate. The mix can include hardwoods, pine or cypress and can represent a mixed hydric site or a transition between hardwoods and conifers on a hydric/mesic site. This community type is not typically tidally influenced, otherwise it would be referred to as a hydric hammock community.

Tidal Marshes

Tidal marshes provide important habitat for numerous species of fishes and crustaceans and these benefits were documented under section 2.1.2. Oligohaline marshes were dominated by *Scirpus* and the saltmarshes by *Juncus,* as was documented by FMRI's (1998) mapping effort.

2.2.3 Rainfall

In peninsular Florida, there is typically a June through September high rainfall season. Superimposed on this general seasonal cycle are the effects of larger scale events, notably the El Niño-Southern Oscillation (ENSO) and the Atlantic Multidecadal Oscillation (AMO) (Kelly 2004). Mean monthly rainfall at Punta Gorda, FL exhibits the typical June-September rainfall peak and lower values during the remainder of the year (Figure 2-31). Long-term trends for rainfall in the basin are shown in Figure 2-32. The total annual rainfall at Punta Gorda ranged from 30 to 88 inches, while the mean and median were 50.7 and 50.3 inches, respectively.

2.2.4 Freshwater Flows

As discussed in section 2.1.4, streamflow represents the sum of the contributions of groundwater, runoff, direct rainfall, and anthropogenic discharges (e.g., wastewater) minus the volume of water that is lost due to evapotranspiration, groundwater, and withdrawals.

In addition to nonpoint source runoff there is one gage that records flows that enter SC, Shell Creek near Punta Gorda (USGS gage 02298202). The City of Punta Gorda withdraws water from the SC reservoir upstream of the SC dam. The withdrawals are taken according to WUP (#200871.06) held by the City of Punta Gorda. The current permit allows for an average permitted withdrawal of 5.38 mgd (8.3 cfs) and a maximum peak monthly withdrawal of 6.9 mgd (10.7 cfs).

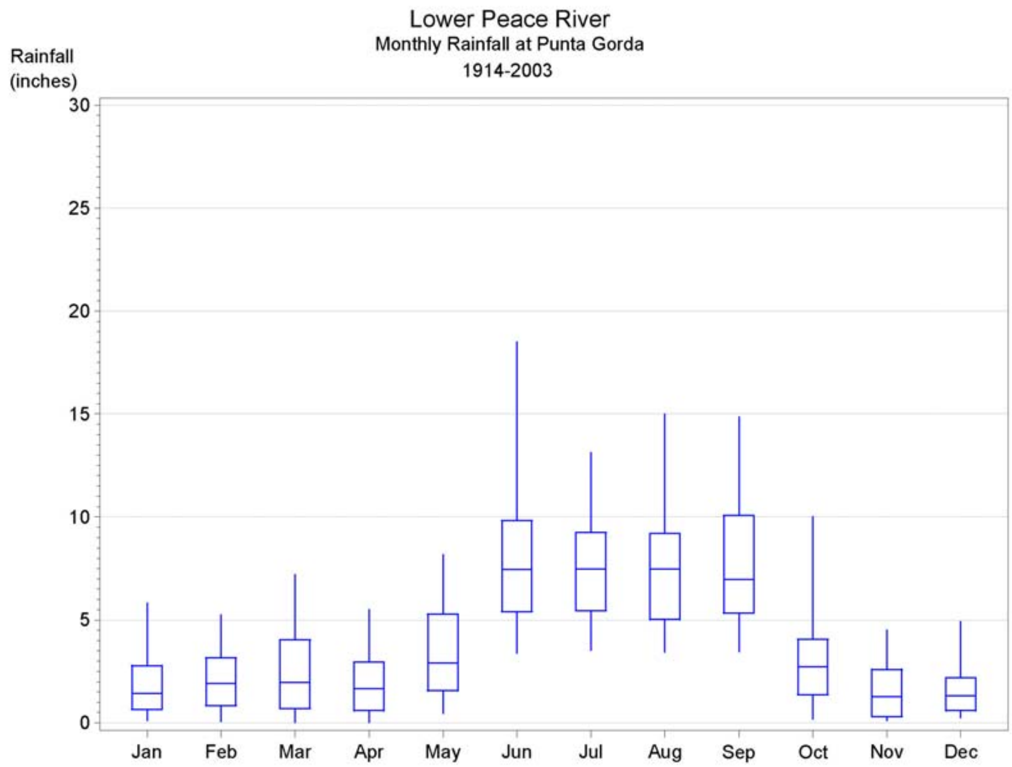


Figure 2-31. Box and Whisker of monthly rainfall (total inches) at Punta Gorda, 1914-2003. Whiskers represent the 5th and 95th percentile monthly rainfall.

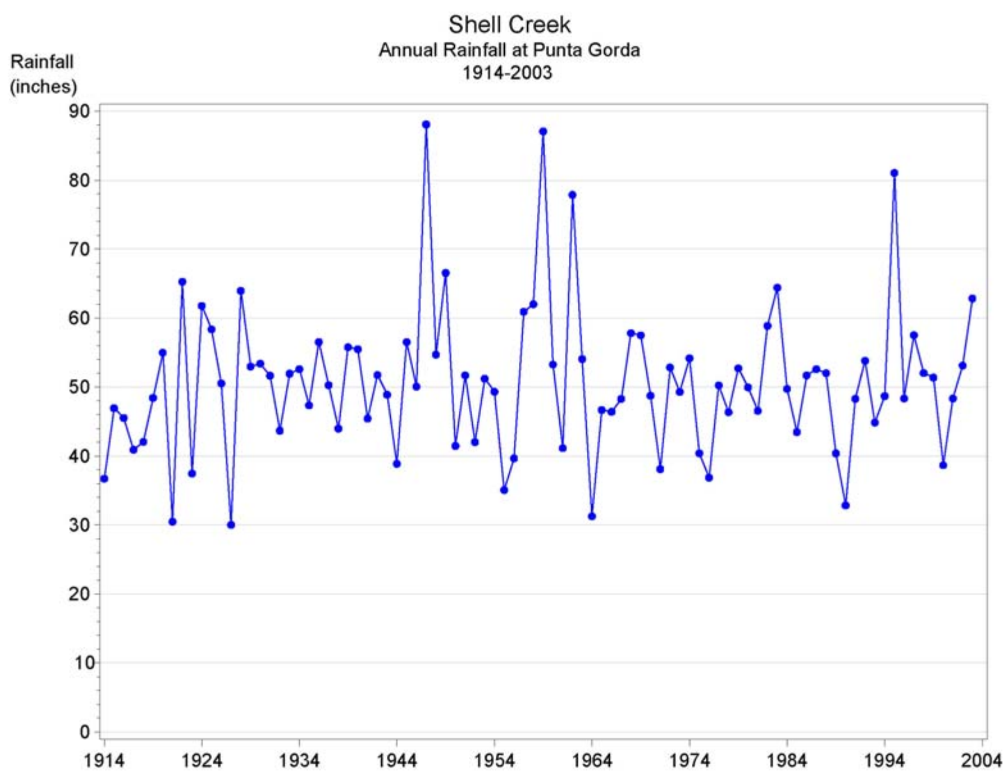


Figure 2-32. Annual rainfall (inches) at Punta Gorda, 1914-2003.

The period of record for the Shell Creek near Punta Gorda gage is from 1966 to 2004. The annual median flows from the Shell Creek near Punta Gorda gage are presented in Figure 2-33. The annual median flows ranged from a minimum of 29 cfs in 1981 to a maximum of 362 cfs in 1970. A box and whisker plot of the daily flow from the Shell Creek near Punta Gorda gage by calendar month is presented in Figure 2-34. The seasonal pattern of higher flows from July to October and lower flows from November to June is again documented. August is typically the month with the highest flows while May has the lowest flows. Finally, a flow duration curve of the daily flows from the Shell Creek near Punta Gorda gage is shown in Figure 2-35. The daily flows ranged from 0 cfs to 7,590 cfs. The 25th percentile, median, and 75th percentile flows over the entire period of record were 61, 149, and 377 cfs, respectively.

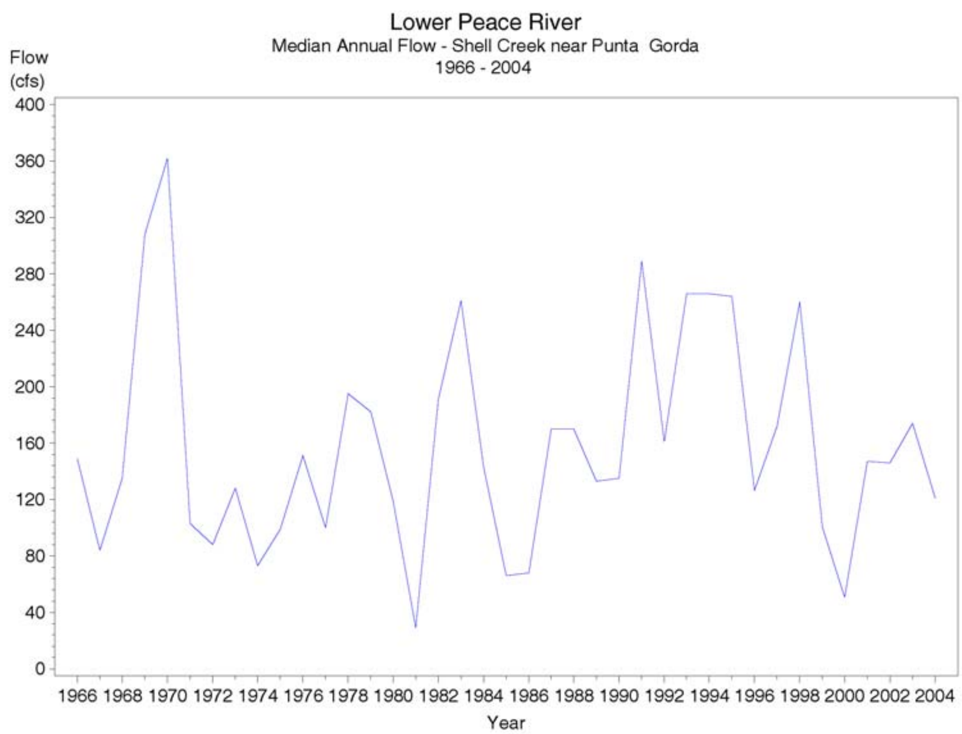


Figure 2-33. Time series of annual median flows (cfs) from the Shell Creek near Punta Gorda gage (USGS 02298202) for the period 1966 to 2004.

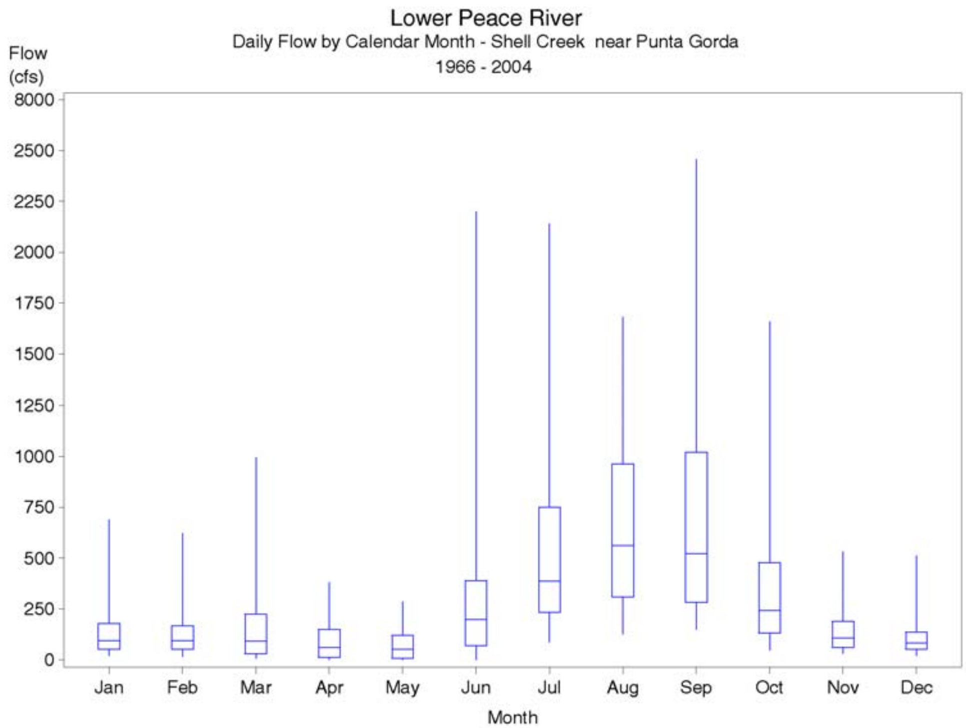


Figure 2-34. Box and whisker plot of daily flows (cfs) by calendar month from the Shell Creek near Punta Gorda gage (USGS 02298202) for the period 1966 to 2004. Boxes represent the inter-quartile range while the whiskers represent the 5th and 95th percentiles.

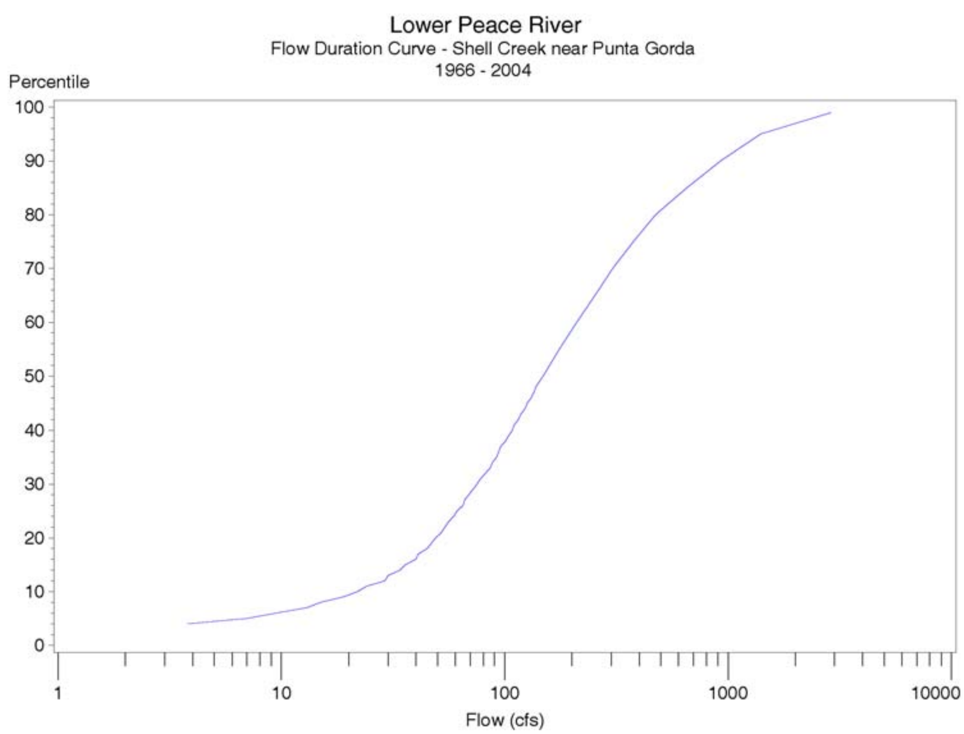


Figure 2-35. Flow duration curve of daily flows (cfs) from the Shell Creek near Punta Gorda gage (USGS 02298202) for the period 1966 to 2004.

3 WATER QUALITY CHARACTERISTICS

In this chapter, the water quality characteristics of the LPR and SC are described. The purpose of this chapter is to review spatial and temporal variation in physical and water quality characteristics in order to place the minimum flow evaluation into the context of the dynamic LPR and SC.

3.1 Lower Peace River

In this subchapter, a historical review of previous studies that addressed water quality in the LPR is presented. In addition, data from ambient monitoring are presented and described.

3.1.1 Lower Peace River Historical Review

This section provides a brief overview of historical studies in the Peace River and the Charlotte Harbor Estuary. Specifically, this review will focus on those studies which include data and analysis on the Lower Peace River. The documents reviewed were by:

- the U.S. Geological Survey (USGS),
- Florida Department of Environmental Protection (FDEP),
- the District,
- Coastal Environmental, Inc.,
- Camp, Dresser & McKee,
- the Charlotte Harbor National Estuary Program (CHNEP) and,
- PBS&J

The following section provides brief summaries of scientific reports prepared or sponsored by the U.S. Geological Survey.

Stoker *et al.* (1989) investigated hydraulic and salinity characteristics of the tidal reach of the Peace River. The report provides an in-depth analysis of the relationship between freshwater inflow and salinity in the river. Long-term trends in streamflow at the Peace River at Arcadia gaging station indicated a significant decreasing trend in annual mean discharge. Stoker *et al.* (1989) concluded that salinity characteristics in the tidal river are influenced by freshwater inflows, tide, and harbor salinity. Vertical salinity stratification is common as expected in typical estuarine circulation. Freshwater replacement time in the tidal river ranged from 2 days during high flow to 40 days during low-flow periods (Stoker *et al.* 1989).

Fraser (1986) published long term water quality data summarized by major chemical and physical water quality constituents. Data were collected monthly over an eight year period, from 1976 through 1984 for Charlotte Harbor (Fraser 1986). Samples were taken from one station in Charlotte Harbor near the mouth of the Peace River. Data analysis included multilinear regression models and a seasonal Kendall test was used to determine trends. Increasing trends were shown for both temperature and orthophosphate. The Peace River was cited as the major source for phosphate in the basin. Concentrations of orthophosphate as P ranged from 0.07 mg/L to 0.66 mg/L with a surface water average of 0.59 mg/L. The three month moving average of orthophosphate concentration indicated an increasing trend. Fraser (1986) concluded that:

> "These changes were related to changes observed in the discharge of this constituent (orthophosphate) from the Peace River. The source of this material was from above Arcadia, and the trends were of such magnitude as to suggest that a relation exists with the economic conditions of the phosphate mining and fertilizer industry."

The range of concentrations for total phosphate ranged from 0.03 mg/L to 1.05 mg/L with a mean of 0.70 mg/L in surface waters and 0.99 mg/L in bottom waters (Fraser 1986). High and low values were consistent with low and high flows in the Peace River (Fraser 1986). Dissolved oxygen decreased in surface waters but showed no change in bottom water. Results showed that for all constituents, the 3-month moving averages appeared to have distinct seasonal variation as a result of freshwater flow from the Peace River (Fraser 1986). No changes were found for organic nitrogen, silica, and total phosphate. Ammonia and nitrate concentrations were to low for trend analysis.

Montgomery *et al.* (1991) conducted a study to evaluate the effects of inorganic nitrogen and phosphorus additions on phytoplankton productivity and chlorophyll *a* concentrations in the Peace River and Charlotte Harbor. Data were collected from two stations in the Peace River and two stations in Charlotte Harbor. *In situ* Experiments were performed on two occasions, during one low flow and one high flow period. Experiments were conducted at 6 ppt salinity in the lower Peace River and at approximately 20 ppt in upper Charlotte Harbor. Low flow experiments were performed during May 1985, and high flow during September of the same year. Results from nutrient addition experiments showed that during low freshwater inflow, the availability of nitrogen may limit the production of phytoplankton through the system. During low flow, at 6 ppt salinity, chlorophyll a increased slightly by the additions of the nitrogen and phosphorus. At 20 ppt salinity there were significant increases of both forms of nitrogen. During high flow periods in the summer, the estuary was conceptually divided into a low-salinity zone where high color impacts light availability which mediates phytoplankton growth and a high-salinity zone where phytoplankton growth is nitrogen limited (Montgomery *et al.* 1991). Montgomery *et al.* (1991) conclude that: "exclusive of seasonal riverine influences that affect light penetration of the water column, nitrogen availability normally limits phytoplankton production within the Charlotte Harbor estuarine system."

Hammett (1990) described land use, water use, streamflow, and river water quality in the Charlotte Harbor estuarine system. The relationships between water quality changes and land use as well as changes related to increasing growth and development were also discussed. Hammett (1990) concluded that the main sources of water quality contaminants to the Lower Peace River were citrus processing and phosphate industry ore-processing plants. The concentrations of phosphorus are naturally high in the Peace River because of phosphate deposits in the area (McPherson *et al.* 1996). Hammett listed 114 facilities permitted to discharge domestic or industrial effluent to tributary waters of Charlotte Harbor, 88 of those were located in the Peace River Basin. Other potential sources of nutrient and pollutant loads impacting water quality included septic-tank drain fields, runoff from agricultural and pasture land, marinas and, nonpoint sources from residential areas (Hammett 1990). Hammett (1990) applied the Kendall tau trend test to the furthest downstream station, Peace River at Arcadia (1933-1989). Using a significance level of 0.10, statistically significant increases in specific conductance, pH, total organic nitrogen, dissolved chloride, dissolved sulfate, and dissolved solids were documented. A statistically significant decrease in total phosphorus was documented. Hammett (1990) suggested that "the increasing trend in total organic nitrogen may reflect inflow of effluent from wastewater treatment plants. Increases in chloride, sulfate, and dissolved solids probably represent an increased contribution of ground water from irrigation runoff and industrial processing. The increasing trend in specific conductance could result from either wastewater effluent or mineralized ground water. Although the decreasing trend in total phosphorus at the Peace River at Arcadia was reported previously by Smith *et al.* (1982), it is unexpected."

Using the Kendall Tau trend test with a significance level of 0.10, statistically significant declines in streamflow at the Peace River stations at Bartow (1939-1989), Zolfo Springs (1933-1989), and Arcadia (1931-1989) were documented. Decreases in flow may have been related to ground water withdrawals causing long-term declines in the potentiometric surface of the underlying Floridan aquifer. Hammett also provided population projections through 2020 for the ten counties within the Charlotte Harbor basin and calculated water supply needs, wastewater generation and projected increases in nutrient loads. Declining streamflow data showed reduced freshwater flow to Charlotte Harbor.

McPherson *et al.* (1996) conducted a geological survey of Charlotte Harbor which included water quality data. Water quality data were collected at one station in upper Charlotte Harbor just below the most southern portion of the Peace River. Mixing diagrams (property-salinity plots) were used to estimate the riverine load of chemicals into the estuary**.** Linear mixing relationships indicate net conservative mixing behavior whereas non-linear or highly scattered mixing relationships indicate non-conservative behavior. The construction of salinity plots is based upon an assumption of steady-state hydrodynamic conditions, which implies that the temporal evolution of the estuarine environment is dictated only by biogeochemical transformations occurring within the system. Results showed that distributions of phosphorus were nearly conservative and a function of river phosphorus concentration, flow, and physical mixing. Large discharges from the Peace River resulted in high concentrations throughout the northern part of the estuary, but the southern part was not greatly affected. Dissolved silica and ammonia concentrations were highly variable along the salinity gradient. At times dissolved silica concentrations were below the curve suggesting uptake by diatoms. Ammonia concentrations showed no clear trend. Nitrite plus nitrate concentrations were nonconservative and decreased sharply along the salinity gradient, which would signify substantial removal from the water column.

An extensive synthesis of existing information was completed for the Charlotte Harbor Estuary Program by PBS&J (1999a). Data from multiple sources were used to examine long-term water quality conditions in the Peace River Basin and Charlotte Harbor. The data sources were:

- EQL long-term monthly data collected between 1975 and 1996
- USGS data from gauged monitoring stations ; and
- SWFWMD monitoring data collected on a monthly basis.

No significant trends in conductivity were detected in either the Lower Peace River or the Peace River Estuary. The Peace River and its tributaries are all characterized as being black water freshwater streams. The narrow photic zone limits the growth of submerged aquatic vegetation and can also results in phytoplankton populations adapted to stay near the surface. Increases in turbidity were found in the Peace River at Arcadia, Horse Creek at SR 70, and the Lower Peace River from 1976 through 1990. Increases in turbidity most likely result from land uses shifts to agriculture and development in the region. Concentrations of inorganic nitrogen exhibit seasonal changes throughout the entire system. Periods of low flow and reduced color typically result in nitrogen concentrations at or near detection limits. In Horse Creek, nitrate and nitrite concentrations showed a significant increase along with chloride, which may have resulted from increased agriculture. A significant decline in nitrate and nitrite concentrations was documented in the lower Peace River. Decreases in TKN concentrations were documented at Arcadia and in the Lower Peace River. Increased concentrations were seen in Horse Creek and at the lowest reaches of the Peace River. High concentrations of dissolved and total phosphorus were observed from 1976 through 1982. Since 1982 concentrations and variability have decreased, although still remaining high relative to other Florida streams. Concentrations of chlorophyll *a* were typically below 20 µg/L, and values increased with distance upstream. Chlorophyll *a* concentrations in the Lower Peace River ranged from 0 to 240 µg/L.

The following section provides brief summaries of scientific reports prepared or sponsored by the District.

SWFWMD (2005) investigated trends in water quality constituents in the Peace River as part of the development of minimum flows and levels for the Middle Peace River. The authors concluded: "While elevated phosphorus concentrations in streams can potentially be ascribed to numerous sources (e.g., waste water treatment plant discharges, some industrial discharges, fertilizer applications in agriculture or residential areas), there is little doubt that the elevated concentrations seen in the Peace River from approximately 1960 (when routine water quality analysis began) to the early to mid 1980's are directly associated with phosphate mining activities in the watershed. Beginning in the early 1980's, there was a rather sudden decline in phosphorus and other chemical constituents found in association with phosphate ore (e.g., fluoride, silica). Concomitant declines in fluoride and phosphorus are evidence of a change in mining practices that led to dramatic reductions in phosphorus (and other constituent) loading to the Peace River system around 1980." In addition to phosphorus and other constituents related to mining activities, statistical analysis of dissolved potassium revealed a significant increase that was not related to changes in flow (SWFWMD 2005).

Coastal Environmental (1996) identified and inventoried potential sources of pollution within the Charlotte Harbor watershed. The study estimated existing and future pollutant loadings by subbasin. Coastal Environmental (1996) also investigated historical, existing, and future freshwater conditions of estuarine inflows. Major sources of nutrient and solids loading, including nonpoint sources, domestic point sources, industrial point sources, atmospheric deposition, groundwater, and springs, were identified. The potential for loadings from septic tanks was also evaluated. Pollutant loadings were estimated for both current (1985-1991) and projected future (circa 2010) conditions.

Average annual TN loads to the LPR totaled almost 1,800 tons/year. Average TP loads were estimated to be about 640 tons/year, and TSS loads to the LPR were estimated at 14,400 tons/year. Of this load 80% of the TN load, 60% of the TP load, and 88% of the TSS load were of nonpoint source origin. Of the remaining sources of TN loading, point sources contributed about 15%, atmospheric deposition accounted for 3%, septic tank leakage accounted for 3% and groundwater and springs were negligible. The TP loads to the LPR harbor segment are similarly distributed among these sources and TSS is derived mainly from nonpoint sources, with some point source contribution.

TN, TP, and TSS loadings under projected future conditions were estimated to be slightly higher, but similar to existing conditions in most cases. Nonpoint sources and industrial point sources were estimated to contribute most of the LPR loads.

Coastal Environmental (1996) reviewed meteorological, flow, and water quality data from the Charlotte Harbor Estuarine System. Statistical tests were conducted for significant long-term trends in water quality characteristics at three of the U.S. Geological Survey gaging station in the Upper Peace River (Bartow, Zolfo Springs, and Arcadia) and Horse Creek. Analyses were conducted for USGS data collected from the early 1970's to the early 1990's for physical characteristics which included specific conductance and dissolved oxygen as well as concentrations and total loadings of inorganic nitrogen, total Kjeldahl nitrogen, nitrate+ nitrite nitrogen, nitrate nitrogen, total organic carbon, and total phosphorus.

A significant decline in conductivity was documented at the Peace River at Bartow station. Conductivity ranged from about 200 to 800 umhos/cm from 1970 to 1976, then dropped to a range of about 170 to 400 umhos/cm after 1982. The decline may be related to decreases in point source discharges due to improved regulations. Significant increases in conductivity were evident during the dry season at Arcadia and in Horse Creek. These increases may be attributed to heavy agricultural water uses of mineralized water from the Floridan aquifer draining into those gaging stations.

Trends in dissolved oxygen varied among the sites. Increasing trends were observed at Zolfo Springs for dry season months and at Horse Creek during wet season months. A decreasing long-term trend was observed at Arcadia for wet season months.

A significant decrease in dry season nitrate nitrogen concentration was documented at Zolfo Springs and Arcadia. This region contains several fertilizer processing plants which had undergone increased regulatory constraints resulting in reduction of nutrient loads. A significant increase in nitrate nitrogen concentration was documented at the Horse Creek station, which may be a result of higher loads from increased agricultural activities.

Total phosphorus concentrations showed significant declines during both dry and wet season conditions at all three gaging stations on the Peace River. Concentrations and loadings of total phosphorus exhibited the largest decline of any measured constituent. This decline was the result of improved regulations and production declines in the phosphate industry.

PBS&J (1997) investigated empirical and mechanistic approaches to establishing Pollutant Load Reduction Goals (PLRGs) in the Tidal Peace River. Water quality and loading data were used to develop empirical and mechanistic models to set PLRGs to support the development of trophic state goals and nitrogen management targets for the tidal reach of the Peace River.

For the empirical approach, water quality variables included TN, TP, TN:TP, chlorophyll *a*, and photosynthetic compensation depth. Trend tests of long term data showed an increasing trend in the median annual TN:TP which resulted from decreasing TP concentrations. Higher nutrient loads in the Peace River are associated with higher color and lower water clarity in the tidal river segment. Regression analysis showed no significant relationships in the LPR segments.

The mechanistic approach utilized a submodel of the U.S. EPA's WASP5 model system. A lack of fit between the modeled and observed data resulted from limitations of the existing data and the inability of the model to vary phytoplankton growth rates temporally and spatially, which may be necessary to accurately stimulate algal growth production and concentrations in this highly dynamic system.

Camp Dresser & McKee (1998) investigated seasonal and spatial patterns of hypoxia in Upper Charlotte Harbor by summarizing previous studies by Environmental Quality Laboratory, U.S. Geological Survey, Southwest Florida Water Management District, and Mote Marine Laboratory. Studies showed that hypoxic bottom water originate in the Lower Peace River during June and spread throughout the harbor during subsequent months, peaking in September when a mean of 34 square miles of the upper harbor experiences hypoxic bottom waters (Camp Dresser & McKee 1998). During October, the areal extent decreased dramatically. By November, bottom waters across the harbor were equal to or greater than 4.0 mg/L (Camp Dresser & McKee 1998).

PBS&J (2007), as part of the Peace River Cumulative Impact Study, assessed the individual and cumulative impacts of certain anthropogenic and natural stressors in the Peace River watershed, including stream flow, water quality, and ecological indicators. Historical changes to water quality constituents were presented for the subbasins of LPR. At the Horse Creek near Arcadia monitoring site, changes in water quality were attributed to discharges of mineralized ground water from agricultural activities into Horse Creek, and in the southern portion of the Peace River watershed in general. The long-term data at the Horse Creek near Arcadia monitoring site indicated increases in inorganic nitrite+nitrate nitrogen concentrations during the mid-1980s (PBS&J 2007). The period-of-record for the Joshua Creek at Nocatee monitoring site extends back to the mid-1960s. Analysis of the data indicate comparatively large historical increases in conductivity, total dissolved solids, sodium, chloride, and sulfate levels (PBS&J 2007). Slightly smaller increases in calcium, magnesium, and silica concentrations were also observed. Observed changes in water quality were attributed to agricultural discharges of mineralized ground water to surface waters. PBS&J 2007 hypothesized that the recent large increases in observed inorganic nitrite+nitrate nitrogen in the Joshua Creek basin were also likely attributed to increases in intensive agriculture.

3.1.2 Variation in Water Quality Constituents

The physical and water quality data described in this section were complied from various data sources. The majority of the data were obtained from ongoing monitoring programs. Data sources included:

- PRMRWSA Hydro-Biological Monitoring Program (HBMP) (1996 - present) and
- U.S. Geological Survey continuous recorders (1997 - present).

In the following sections, spatial and temporal variations in water quality constituents in the LPR are described. Because there are numerous sampling stations in the LPR, a representative group of stations was selected for presentation in this section. The selected stations, which span the longitudinal distribution of HBMP sampling stations (Figure 2-3), include:

- Station 10 (rkm 6.6),
- Station 12 (rkm 15.5), and
- Station 14 (rkm 23.6).

Plots of spatial and temporal variation for all HBMP sampling locations in the LPR (Figure 2-3) are provided in Appendix 3-1.

3.1.2.1 Annual Variation in Water Quality Constituents

No long-term trends were detected in surface or bottom water salinity values from the HBMP stations in the LPR. However, fluctuations are evident over multi-year time scales that relate to large-scale meteorological events such as reduced salinity in 1998, associated with an El Niño event. Higher salinities were found during 2000 and 2001, associated with extended drought periods during these years. Typical yearly patterns showing higher salinities during the dry season and lower salinities during the wet season are evident. Annual variation in salinity at stations 10 (rkm 6.6), station 12 (rkm 15.5), and station 14 (rkm 23.6) are presented in Figures 3-1 through 3-3, respectively. Salinity plots of the 13 remaining stations can be found in Appendix 3-1. For the furthest downstream station, station 10, salinity ranged from 0 to 35 psu (Figure 3-1). Characteristic of typical riverine flow, salinity was typically higher in the bottom water as compared to surface water. Salinity at station 12 (rkm 15.5) is presented in Figure 3-2. Salinities at station 12 were slightly lower, ranging from 0 to 27 psu in both surface and bottom waters. The annual variation in salinity at station 14 (rkm 23.6) is presented in Figure 3-3. As expected, salinities at station 14 were lower compared to the downstream stations. While the observations ranged from 0 to 19 psu, the majority of the salinity measurements at station 14 were less than 5 psu.

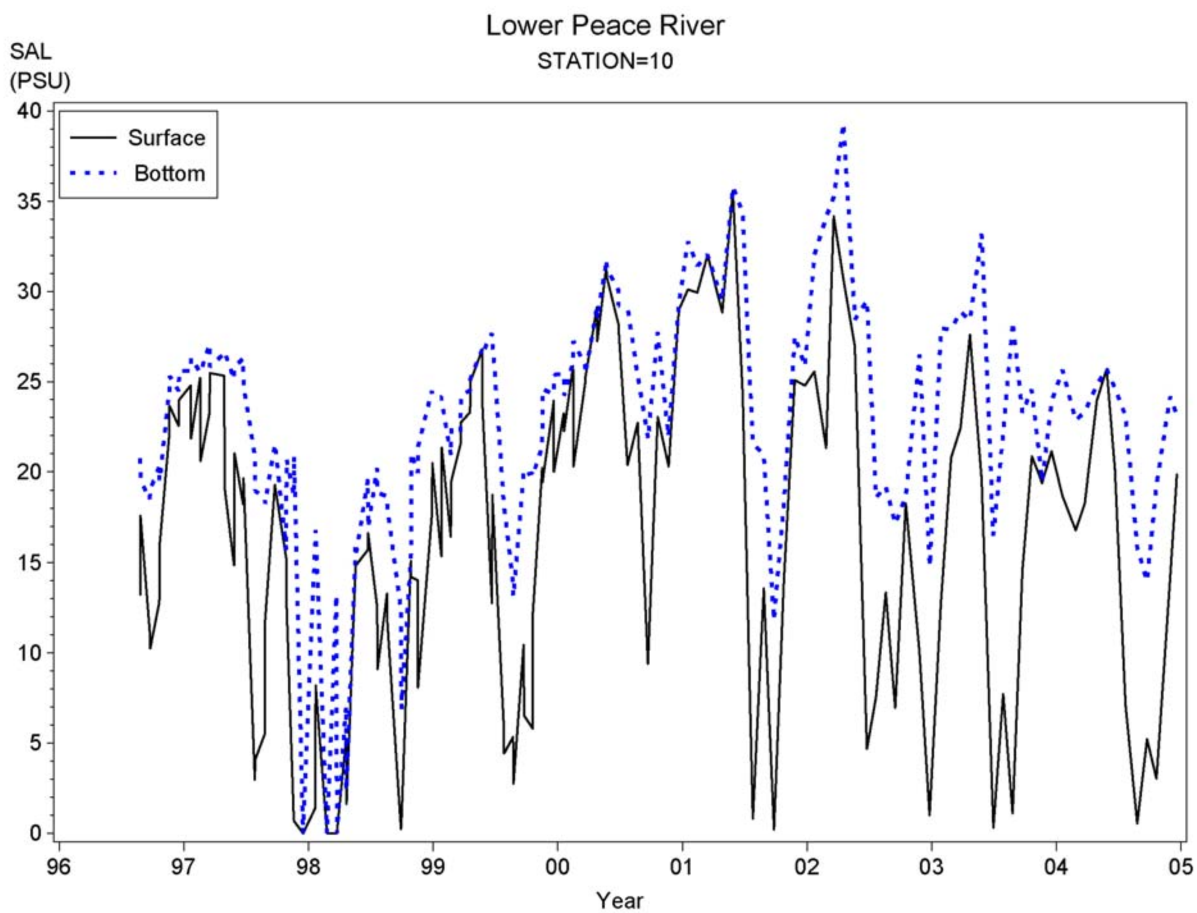


Figure 3-1. **Time series of surface and bottom salinity at LPR station 10.**

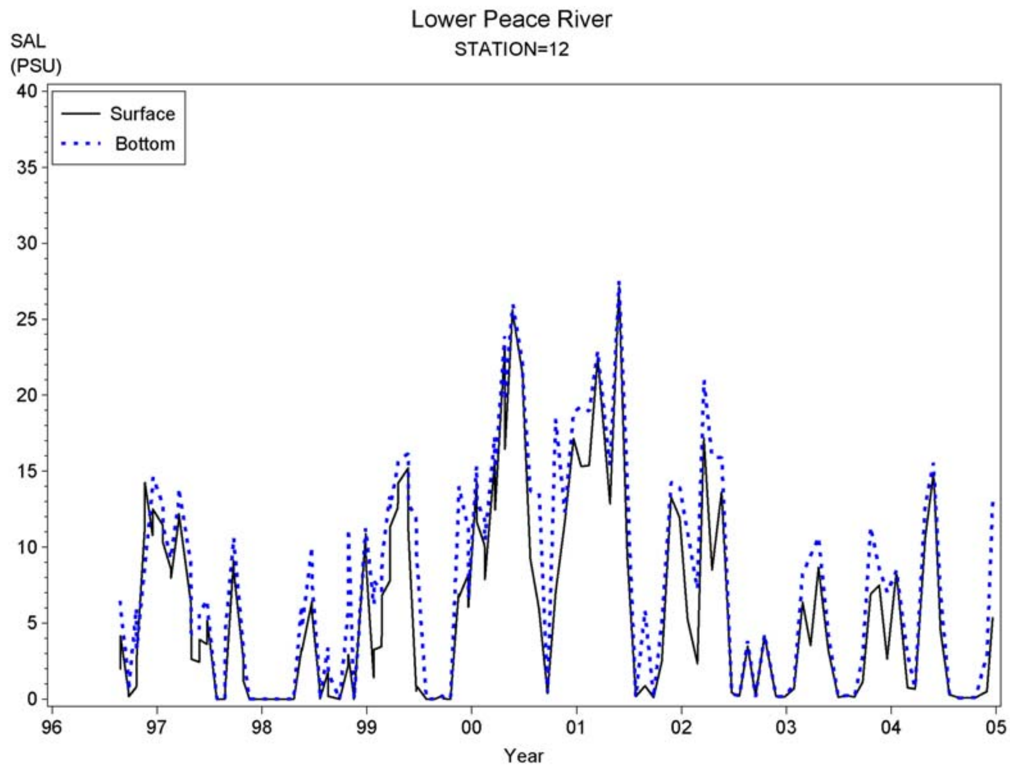


Figure 3-2. **Time series of surface and bottom salinity at LPR station 12.**

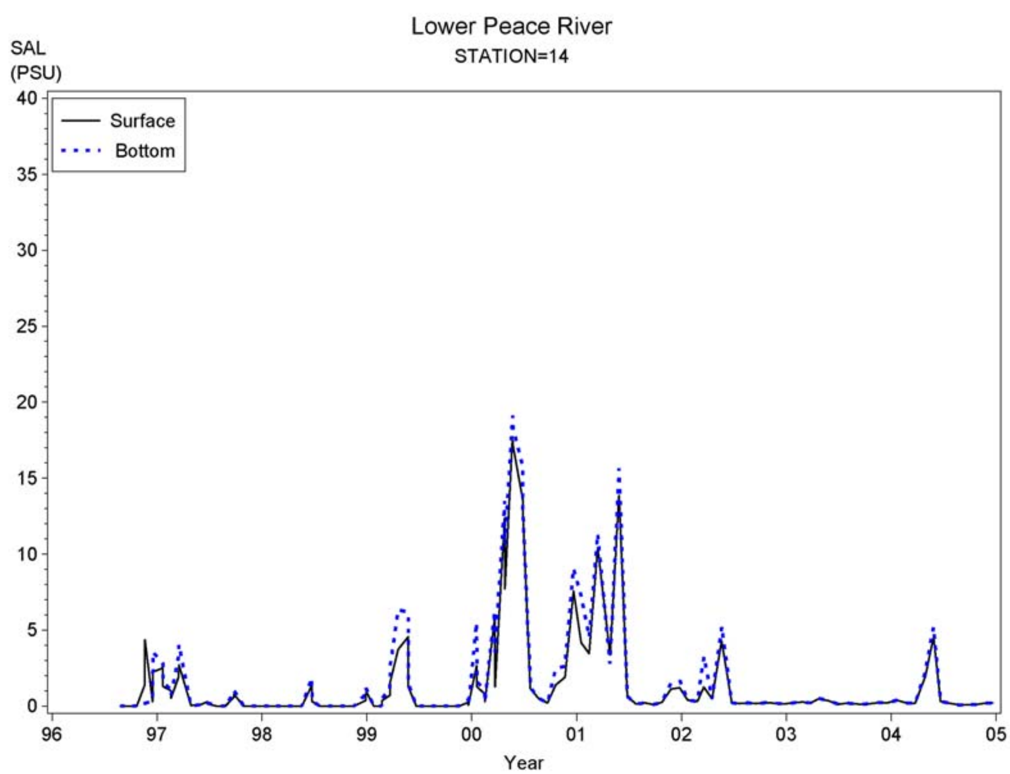


Figure 3-3. **Time series of surface and bottom salinity at LPR station 14.**

Temperature in the LPR showed typical seasonal cycles ranging from a summer peak of approximately 34 degrees C to a winter low of 13 degrees C (Figure 3-4 through 3-6). At all locations the surface and bottom ranges were very similar with slightly higher surface temperatures during the entire period-of-record.

The annual variation in dissolved oxygen (DO) was consistent over multi-year time scales, with typical summertime lows followed by higher concentrations in the cooler months. In the downstream portion of the LPR there were large differences in DO between the surface and bottom waters, with higher values in the surface water at the downstream stations. Values in the surface water for station 10 ranged from 0 to 14 mg/L and from 0 to 11 mg/L in bottom waters (Figure 3-7). Values in the surface water for station 12 ranged from 0 to 14 mg/L and from 0 to 10 mg/L in bottom water (Figure 3-8). Differences between surface and bottom water decreased with distance upstream as salinity decreased (Figure 3-9). Values in surface water for station 14 ranged from 0 mg/L to 12 mg/L for both surface and bottom waters. Lower values in bottom waters for the downstream portion are directly related to stratification inhibiting mixing of the water column, and therefore resulting in lower dissolved oxygen concentrations in bottom waters. The uncharacteristically low concentrations seen at several stations in late 2004, however, are the consequence of multiple hurricanes that hit Florida and contributed a substantial dissolved and particulate organic load to the river (Tomasko et. al. 2006).

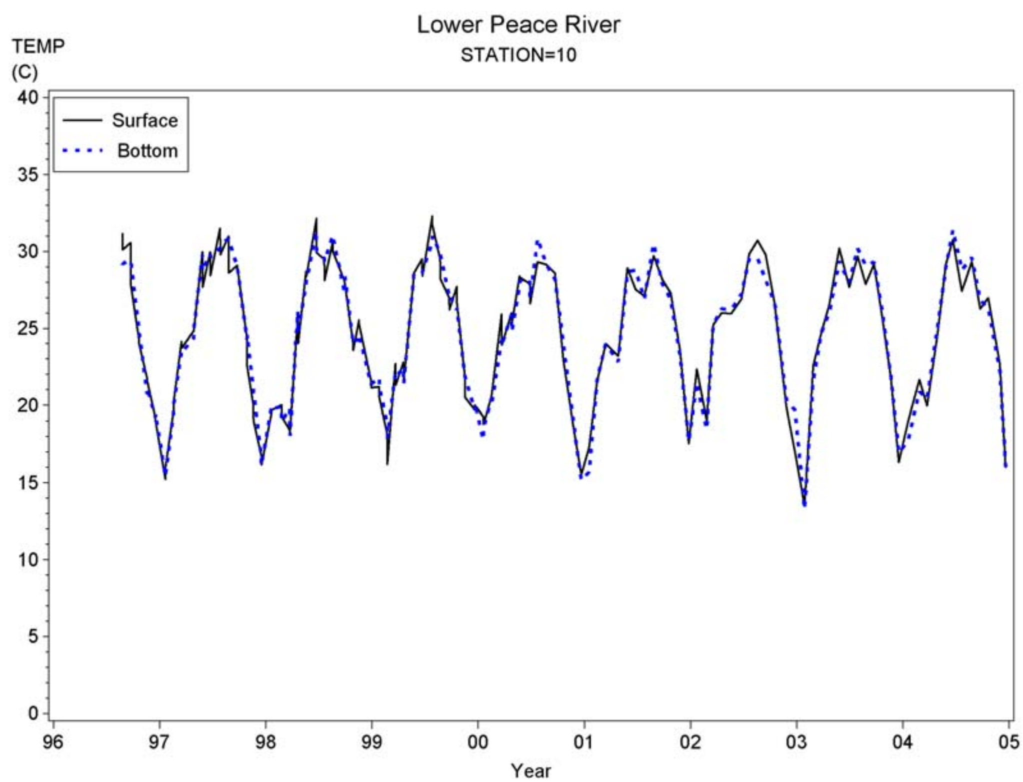


Figure 3-4. Time series of surface and bottom temperature at LPR station 10.

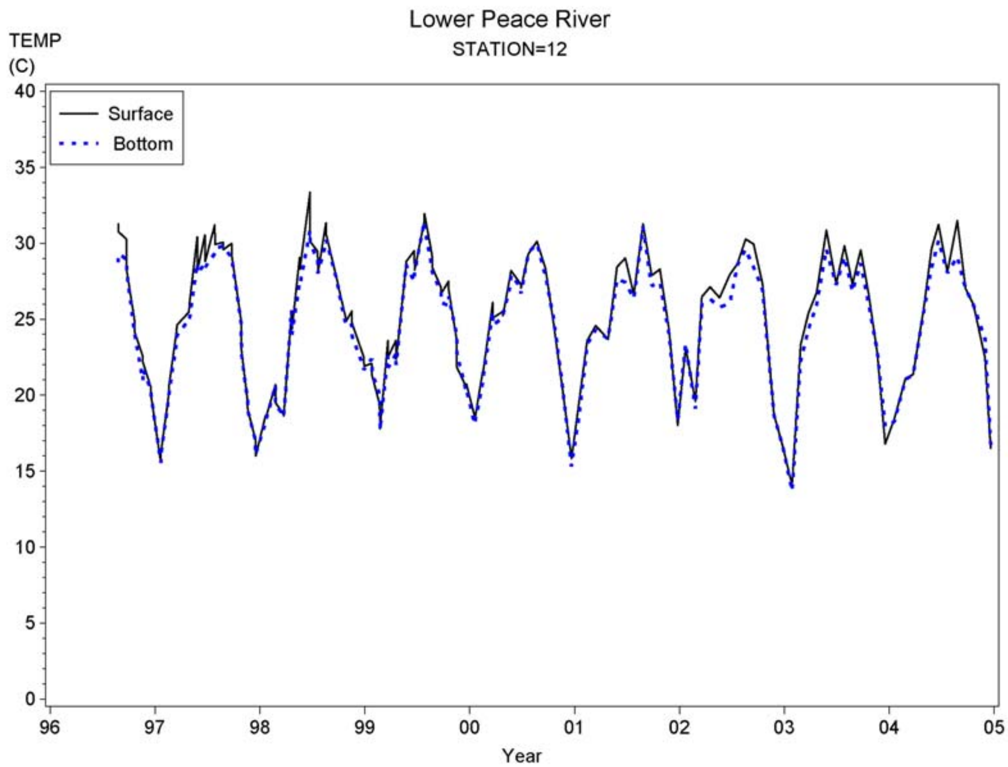


Figure 3-5. Time series of surface and bottom temperature at LPR station 12.

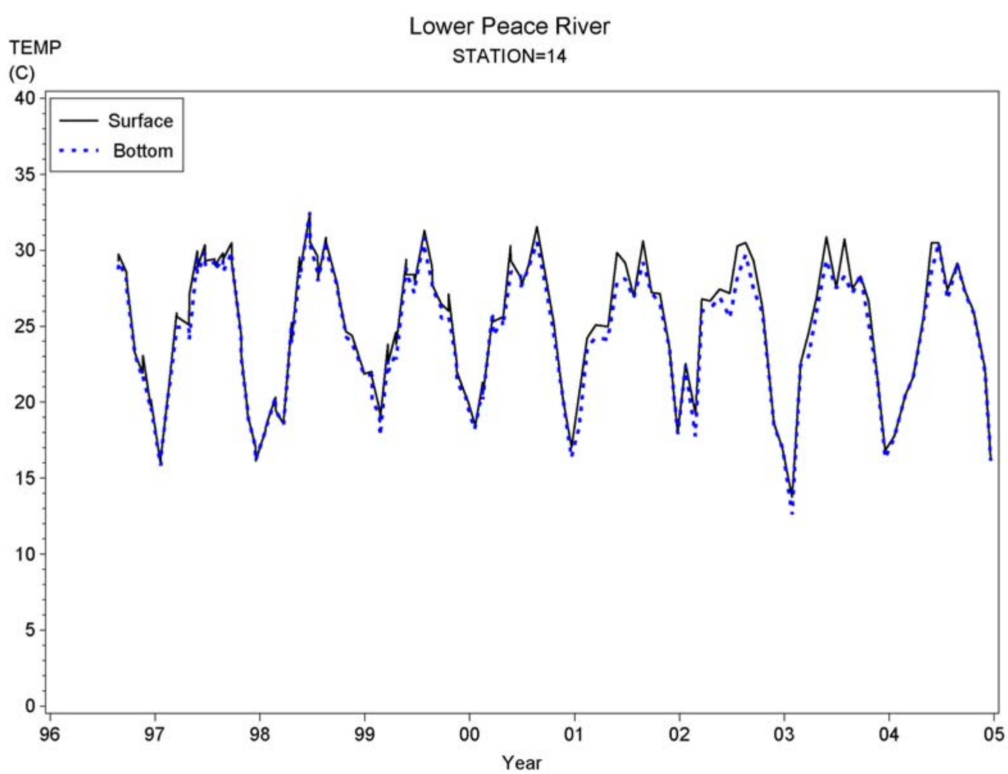


Figure 3-6. Time series of surface and bottom temperature at LPR station 14.

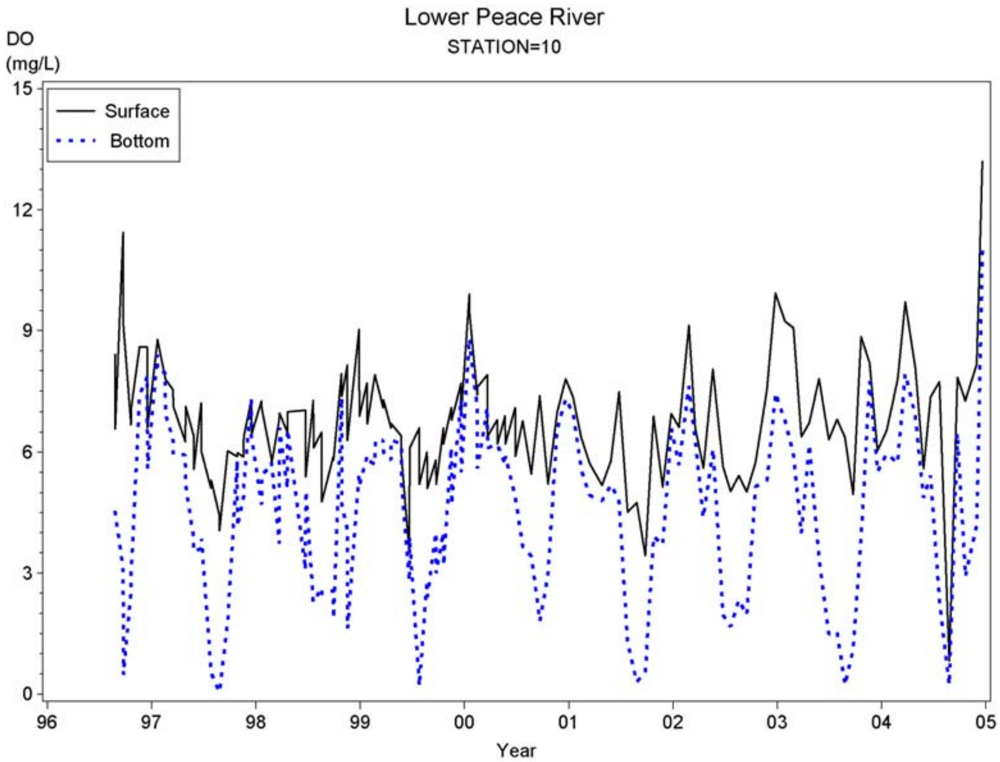


Figure 3-7. Time series of surface and bottom DO at LPR station 10.

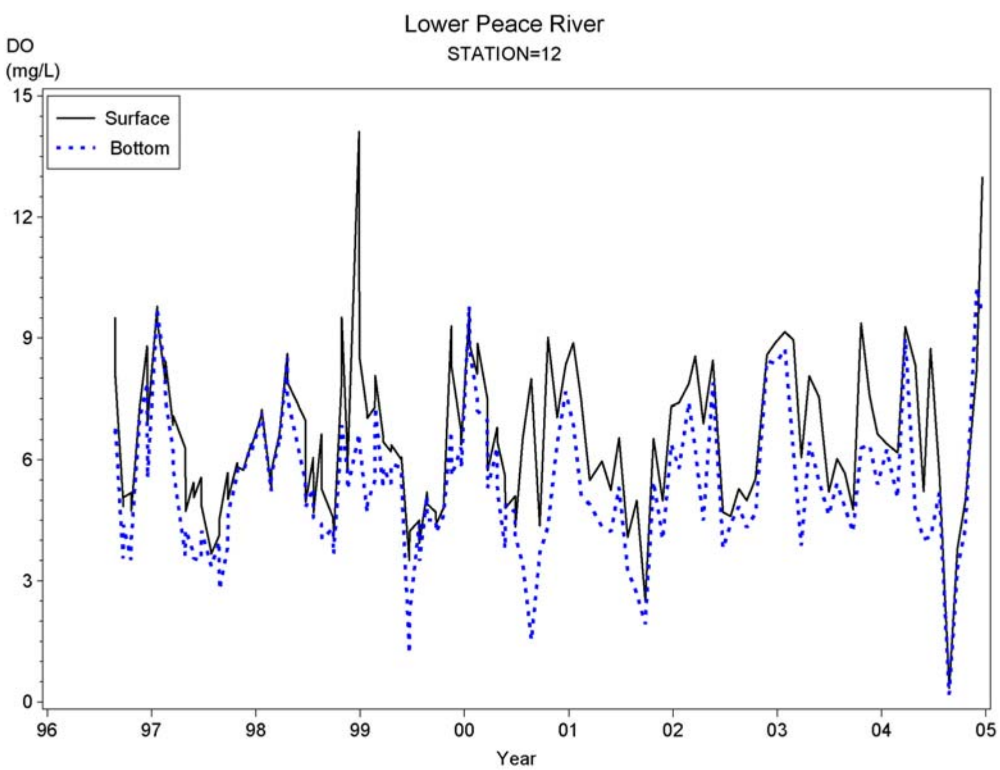


Figure 3-8. Time series of surface and bottom DO at LPR station 12.

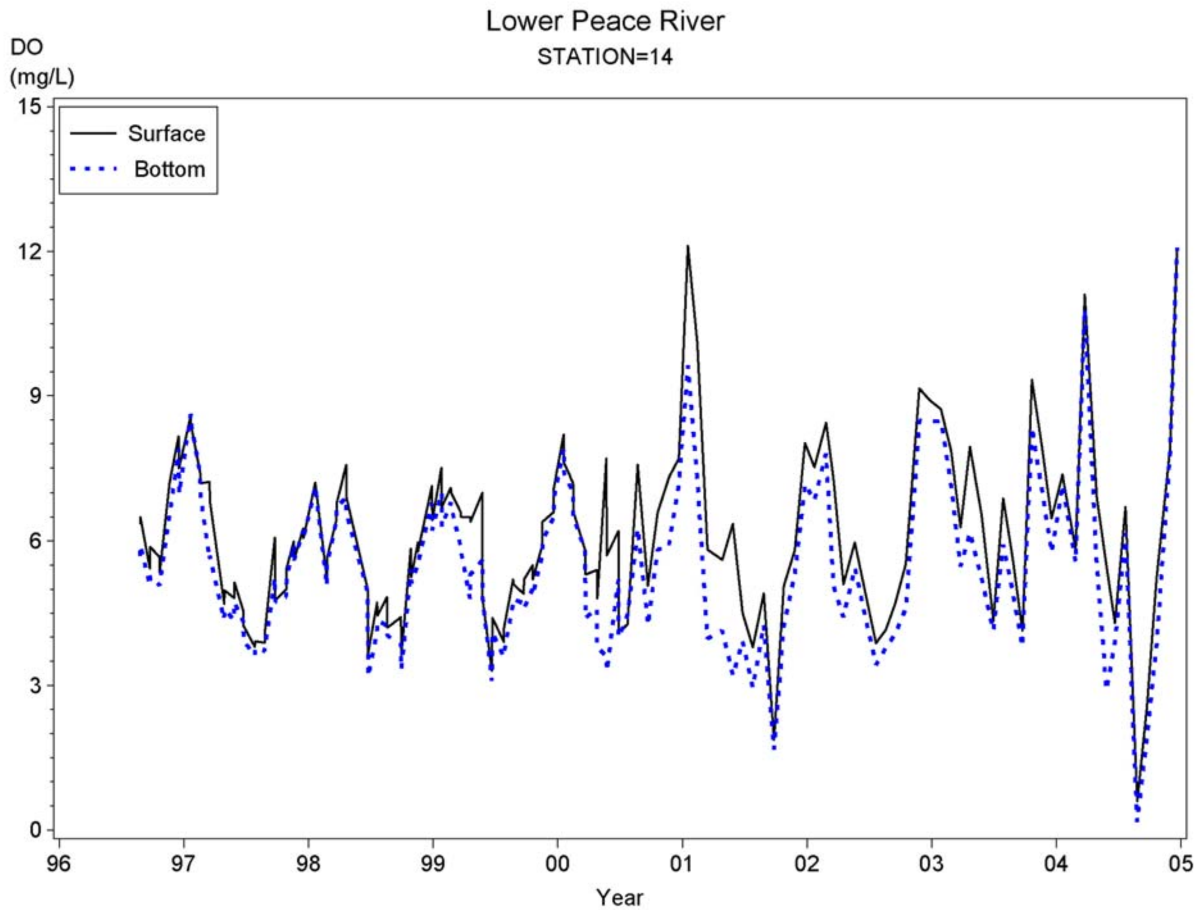


Figure 3-9. **Time series of surface and bottom DO at LPR station 14.**

The annual variation in chlorophyll *a* concentrations was highly variable between stations (Figures 3-10 to 3-12). Chlorophyll concentrations ranged from 5 to 150 µg/L. Concentrations were slightly lower in bottom water as compared to surface water. It is likely, however, that uncharacteristically high concentrations in 2004 are again related to the effects of multiple hurricanes that crossed the Florida peninusula at this time (see Tomasko et al. 2006).

The observed total nitrogen (TN) concentrations for the LPR are shown in Figures 3-13 through 3-15. These data indicated that TN ranged from 0 to 6 mg/L. TN concentrations increased slightly with distance upstream towards fresher water.

Total phosphorus (TP) showed annual variation across the period of record. Higher TP concentrations were evident during extremely wet years (the 1998 El Niño). Higher concentrations were also found during dry hot years (the later half of 2001) after a prolonged drought as shown in Figures 3-16 through 3-18. TP concentrations ranged from 0.3 to 1.4 mg/L and, increased slightly with distance upstream towards the fresher reaches of the river.

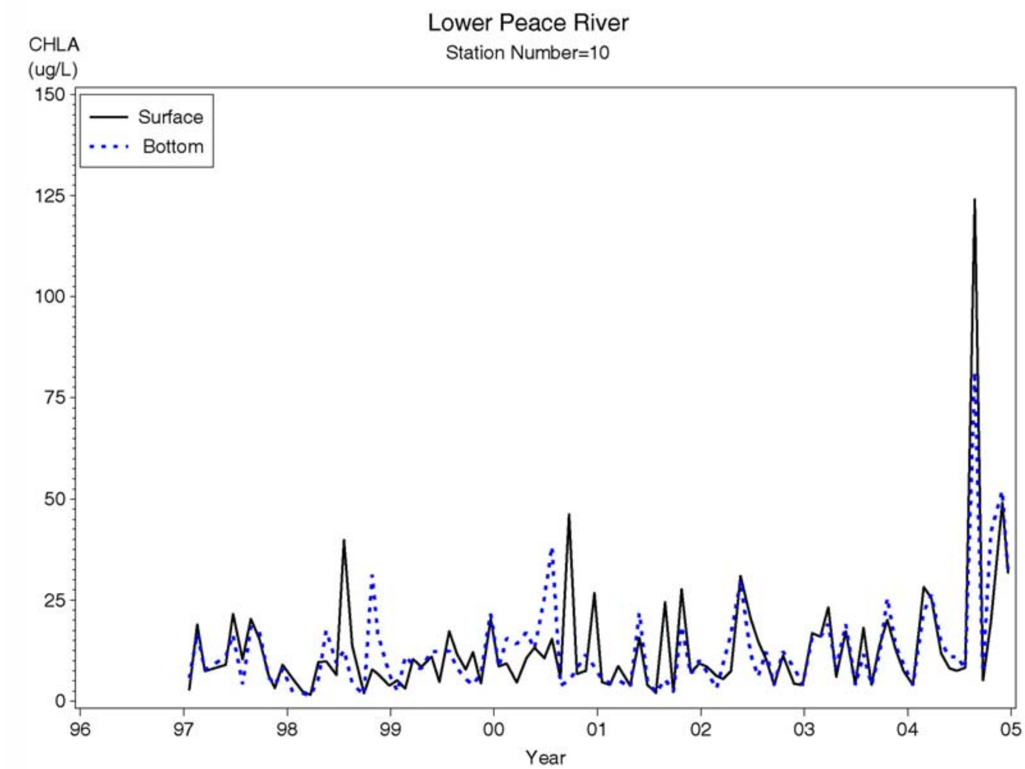


Figure 3-10. Time series of surface and bottom chlorophyll *a* at LPR station 10.

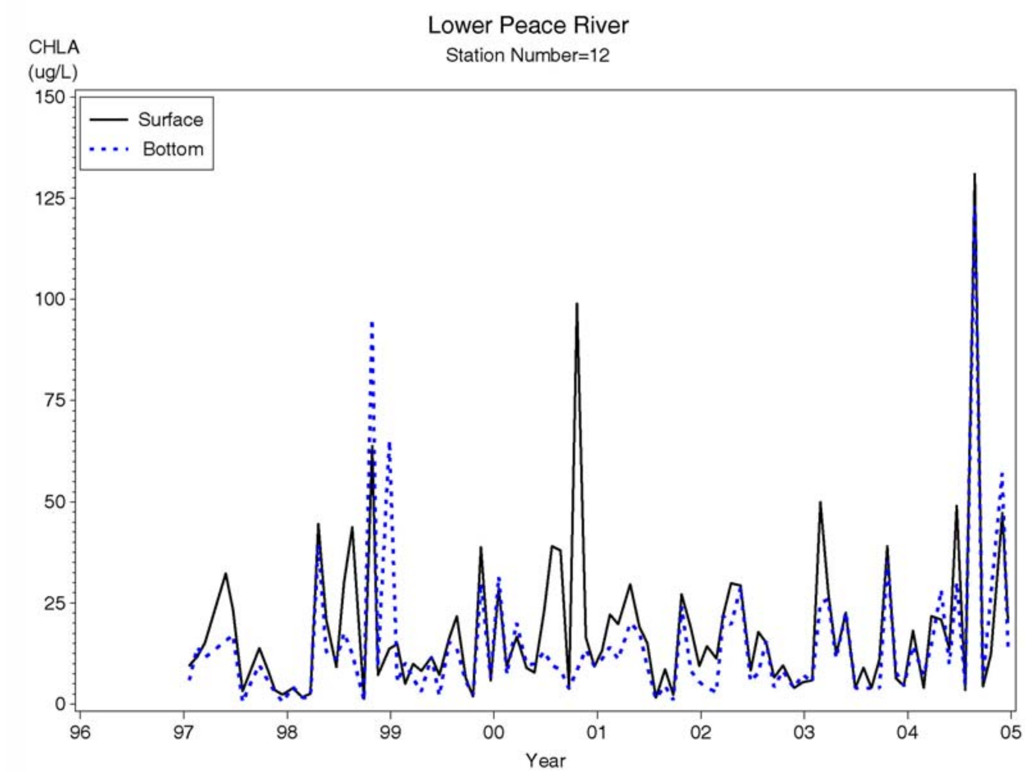


Figure 3-11. Time series of surface and bottom chlorophyll *a* at LPR station 12.

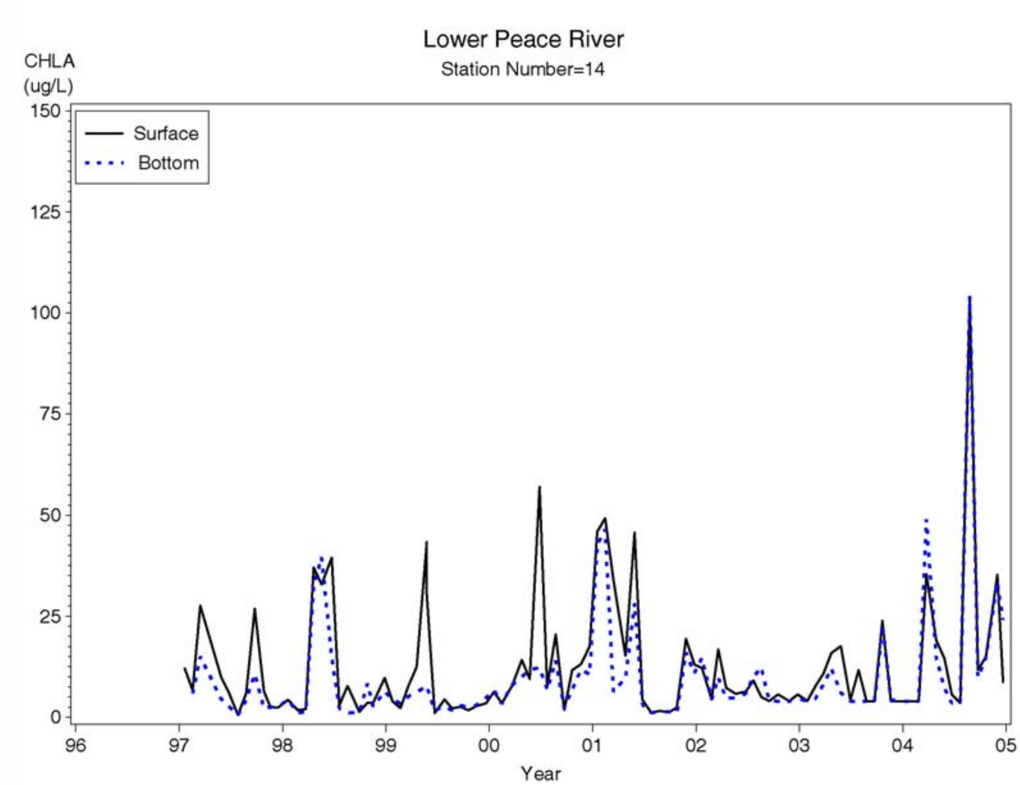


Figure 3-12. Time series of surface and bottom chlorophyll *a* at LPR station 14.

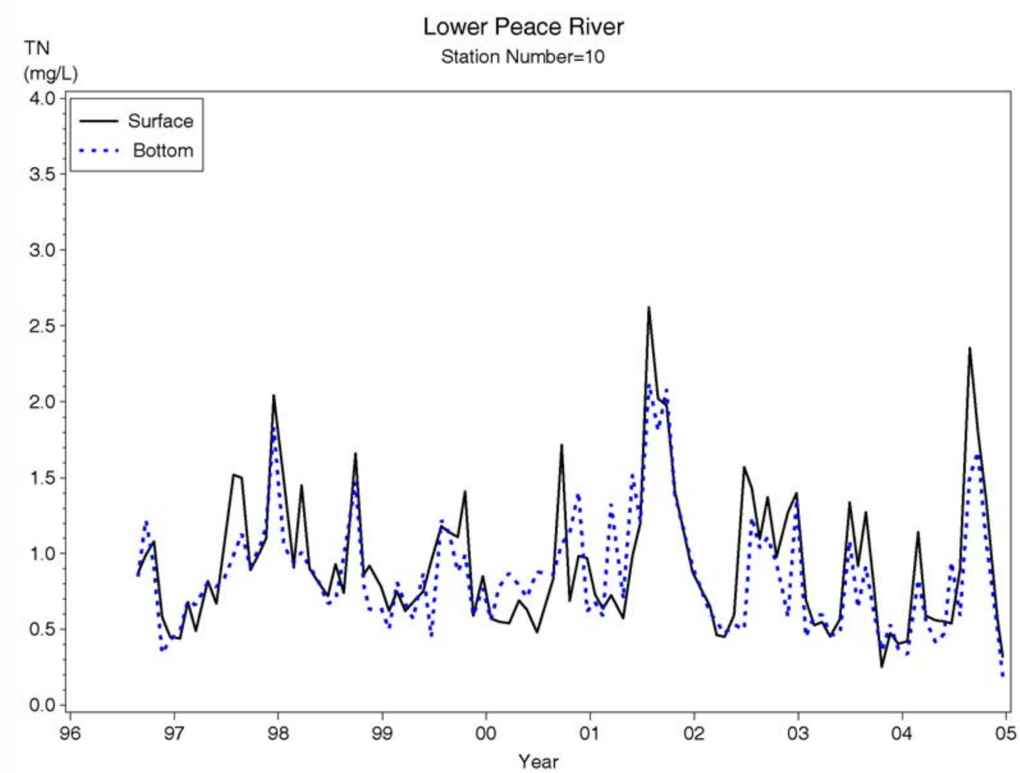


Figure 3-13. Time series of surface and bottom TN at LPR station 10.

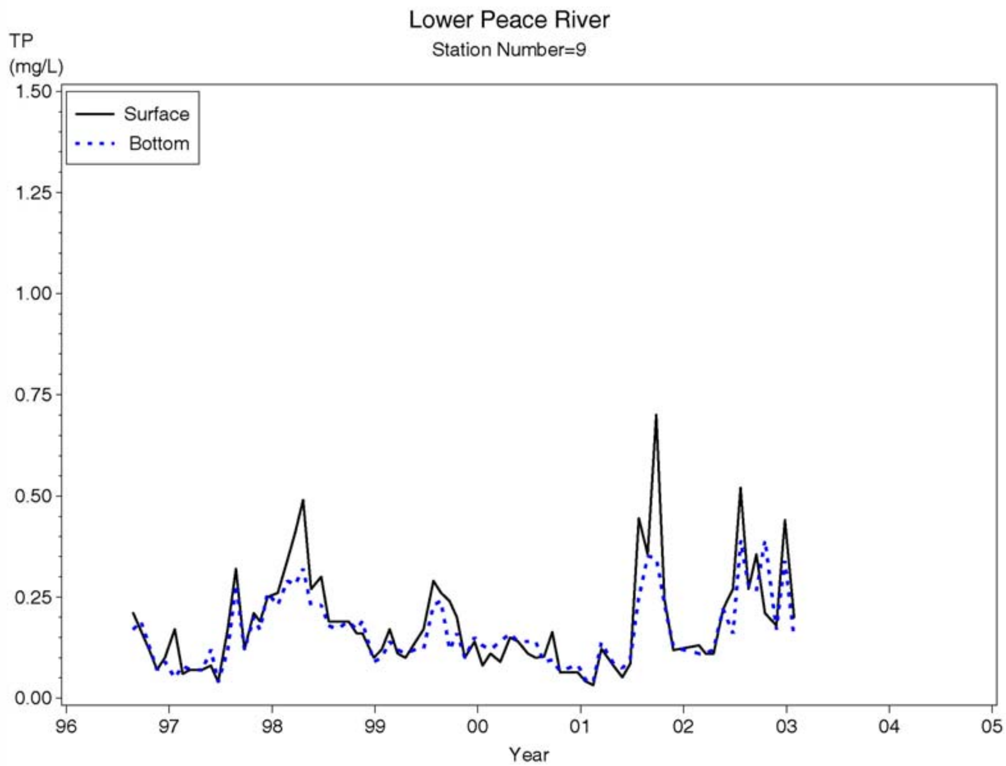


Figure 3-14. Time series of surface and bottom TN at LPR station 12.

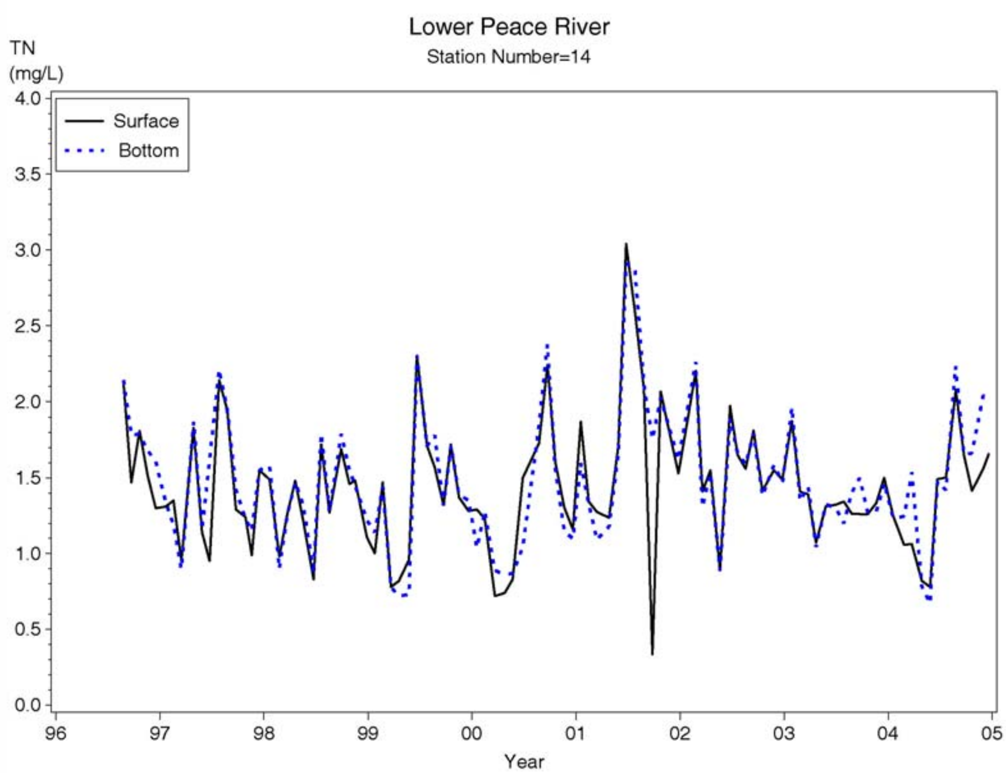


Figure 3-15. Time series of surface and bottom TN at LPR station 14.

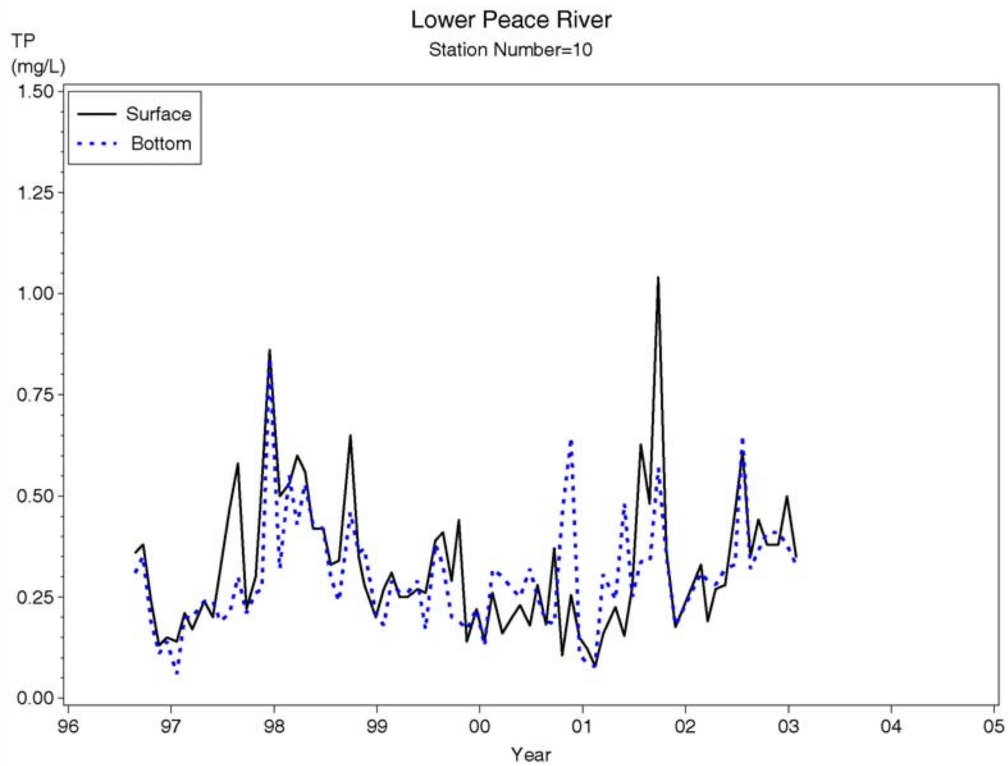


Figure 3-16. **Time series of surface and bottom TP at LPR station 10.**

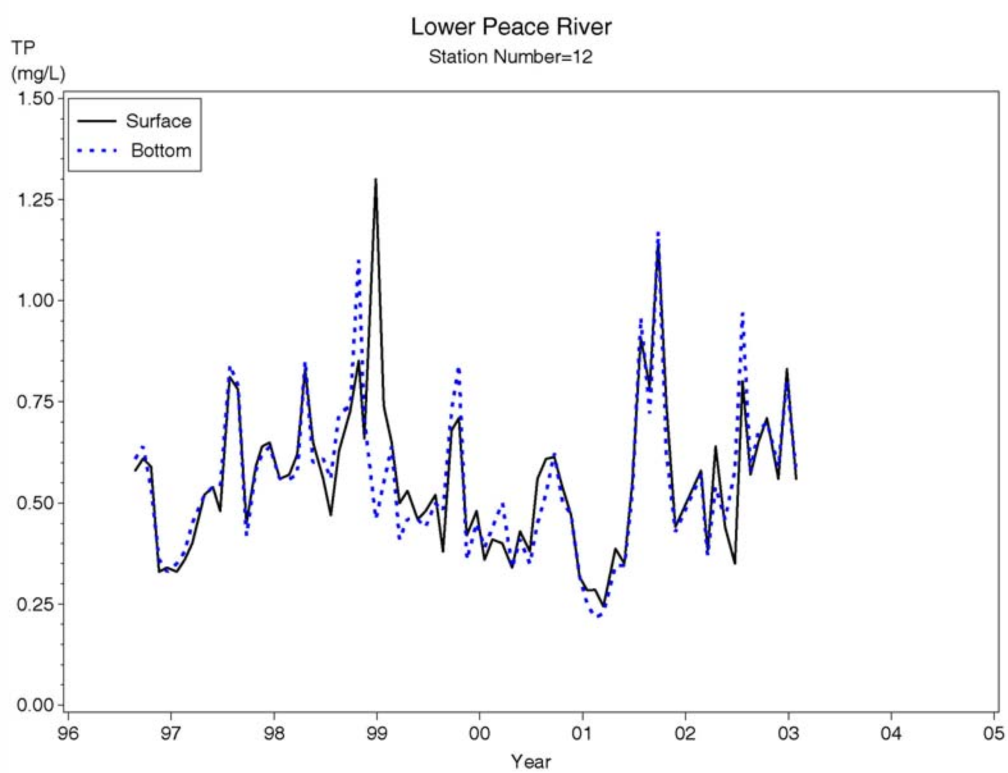


Figure 3-17. **Time series of surface and bottom TP at LPR station 12.**

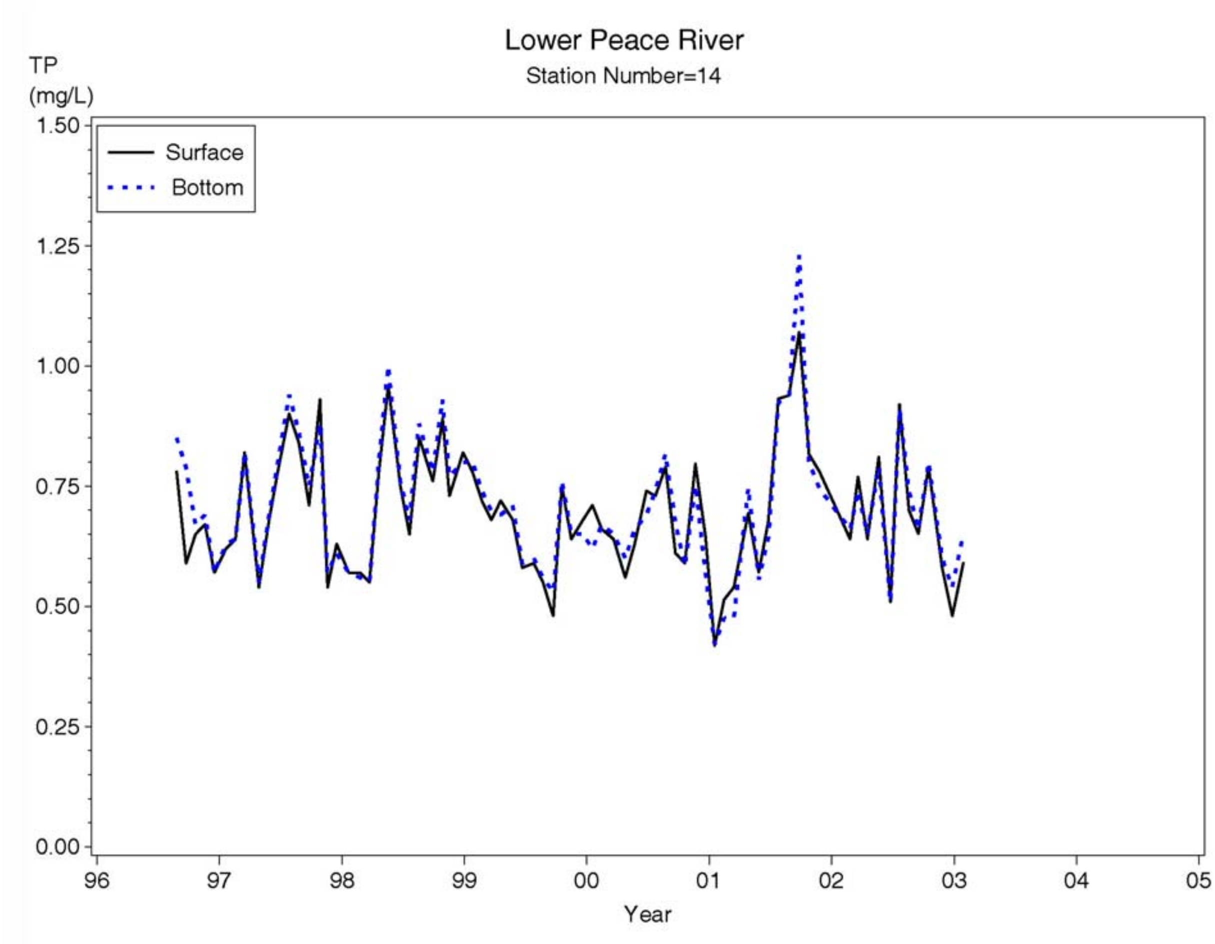


Figure 3-18. **Time series of surface and bottom TP at LPR station 14.**

3.1.2.2 Within-Year Variation in Water Quality Constituents

The physical and water quality characteristics of the LPR vary predictably based on the seasonal cycle of the local climate. Detailed plots for all locations and constituents are presented in Appendix 3-2.

Salinity concentrations were higher in the winter (dry season) months and lower in the summer (wet season) months. Within-year variation in salinity concentrations at the surface and bottom for station 10 in the LPR are presented in Figure 3-19. Less variation exists between bottom water salinities during the dry and wet season with evident fresh water flows resulting in low surface water salinities from July through October. With distance upstream, surface and bottom water salinities are more similar as shown for station 12 in Figure 3-20. High freshwater flow resulted in no differences between surface and bottom salinities from July through October at the most upstream stations as shown at station 14 (Figure 3-21).

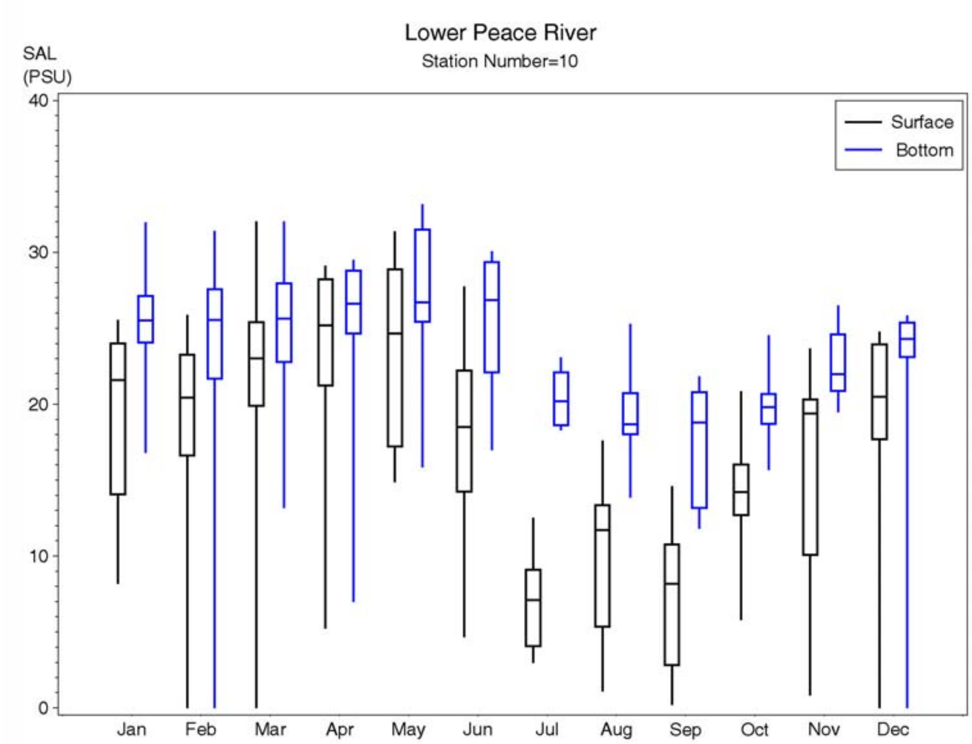


Figure 3-19. **Monthly distribution of surface and bottom salinity (1997-2004) at LPR Station 10. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

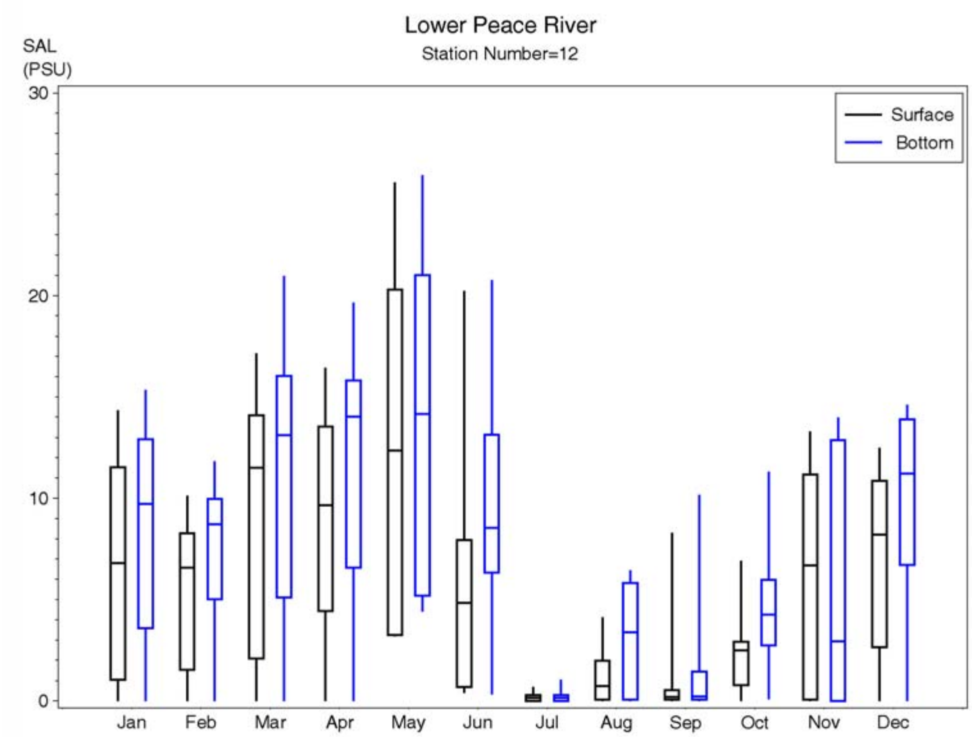


Figure 3-20. **Monthly distribution of surface and bottom salinity (1997-2004) at LPR Station 12. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

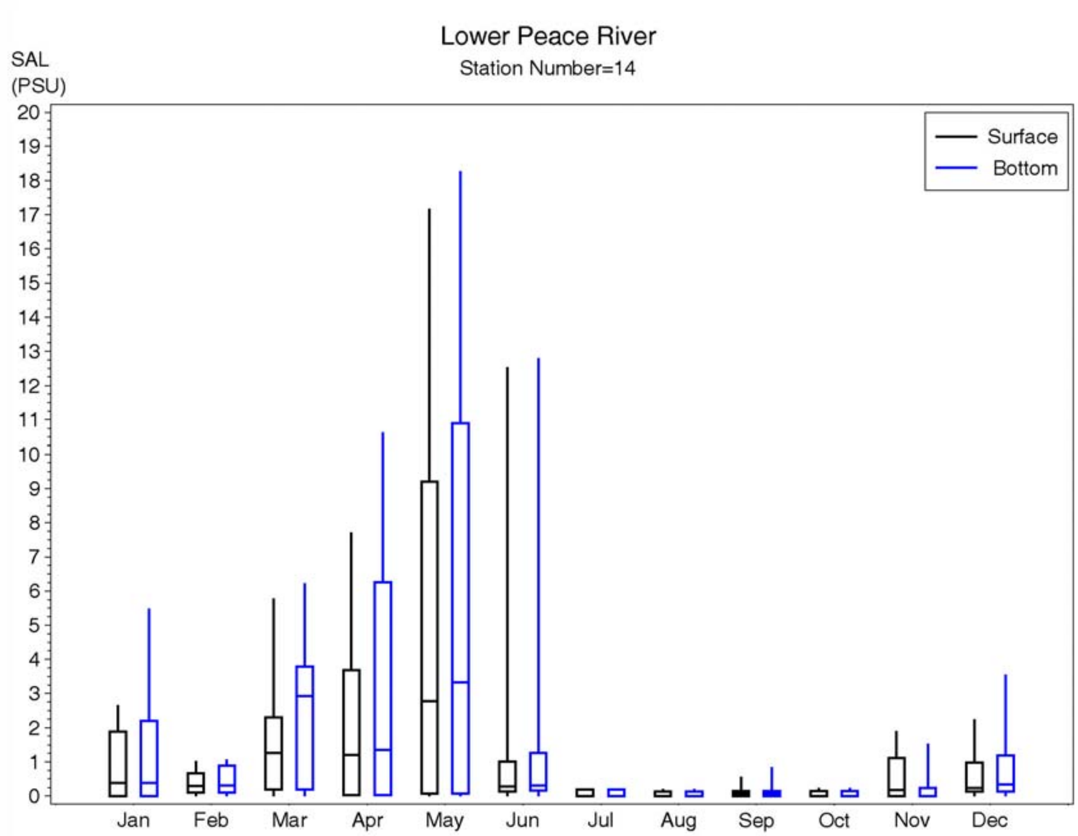


Figure 3-21. Monthly distribution of surface and bottom salinity (1997-2004) at LPR Station 14. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

Similar to salinity, temperature was observed to follow a strong seasonal pattern over the period of record for all locations and depths. Lowest temperatures were observed during December and January. Highest temperatures were observed during July and August. The typical within-year temperature variation for Station 10 in the LPR is presented in Figure 3-22.

Dissolved oxygen (DO) exhibited typical seasonal trends with higher concentrations during cooler months and lower concentrations during warmer months. Lower DO concentrations occurred during July, August and September, resulting from higher water temperatures and thus lower saturation potential as well as higher productivity from primary producers using available nutrients. As shown in the yearly time series plots discussed previously, larger differences between surface and bottom water were evident downstream and decreased with distance upstream (Figures 3-23 to 3-25).

Monthly distributions of chlorophyll *a* concentrations were variable for all stations (Figures 3-26 through 3-28). Highest variability occurred during August for all stations. Additionally, higher concentrations were evident in response to the wet season (July through September) resulting in higher nutrient availability.

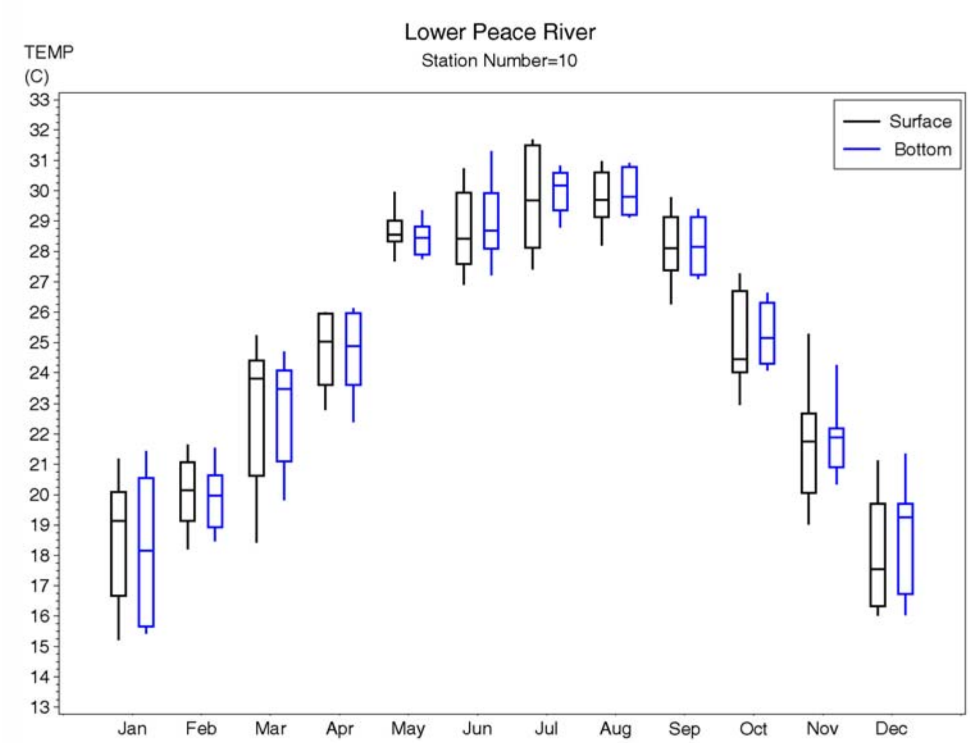


Figure 3-22. Monthly distribution of surface and bottom temperature (1997-2004) at LPR Station 10. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

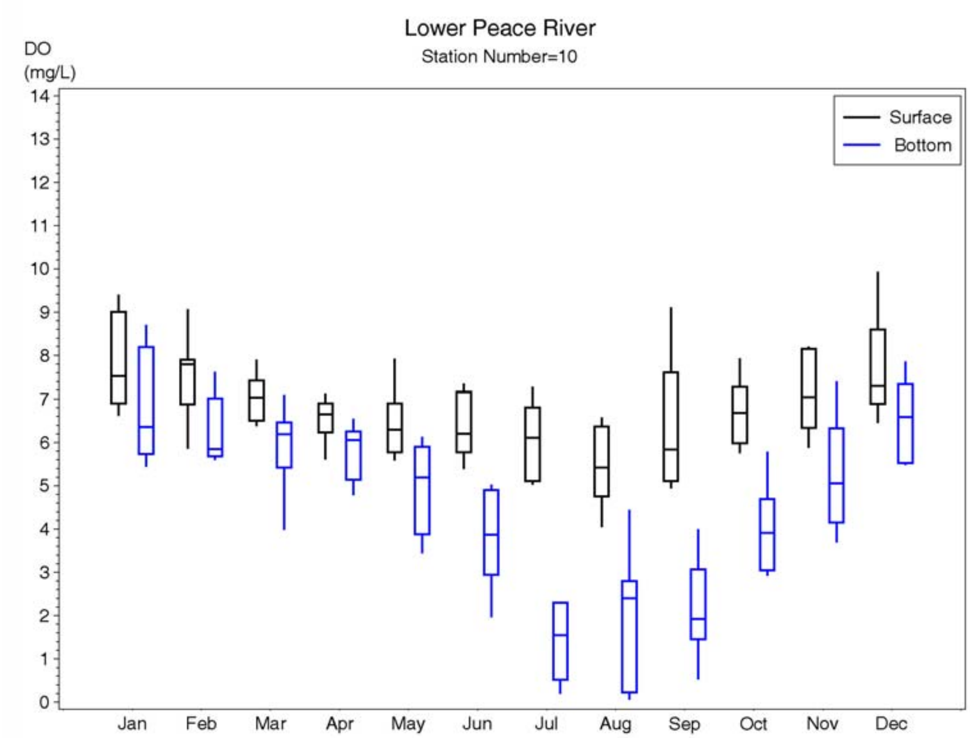


Figure 3-23. Monthly distribution of surface and bottom DO (1997-2004) at LPR Station 10. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

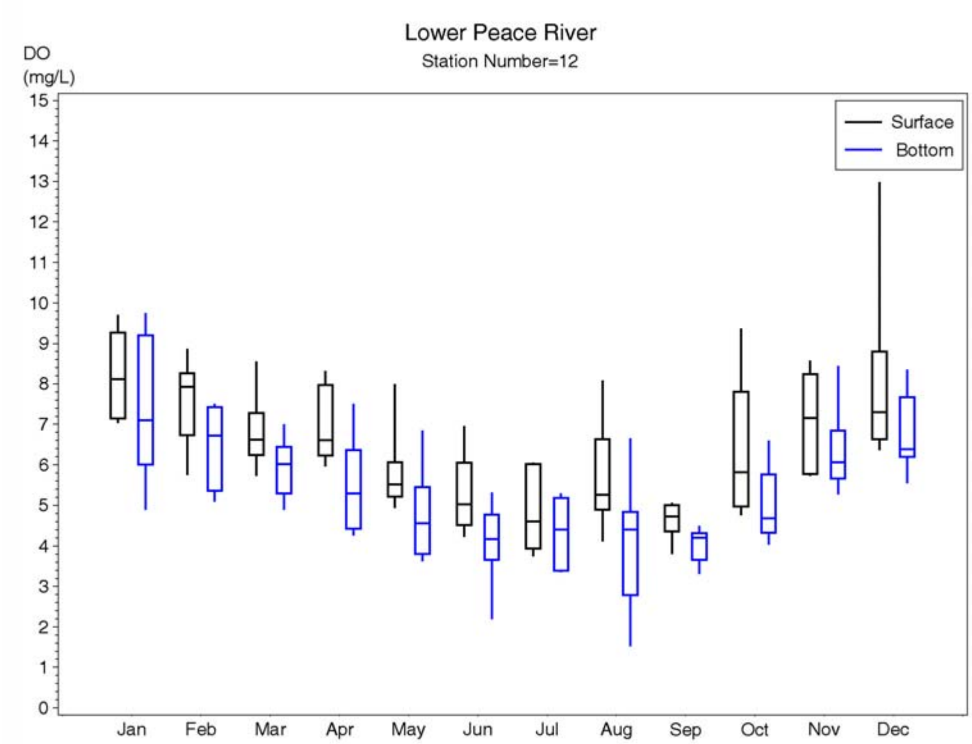


Figure 3-24. **Monthly distribution of surface and bottom DO (1997-2004) at LPR Station 12. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

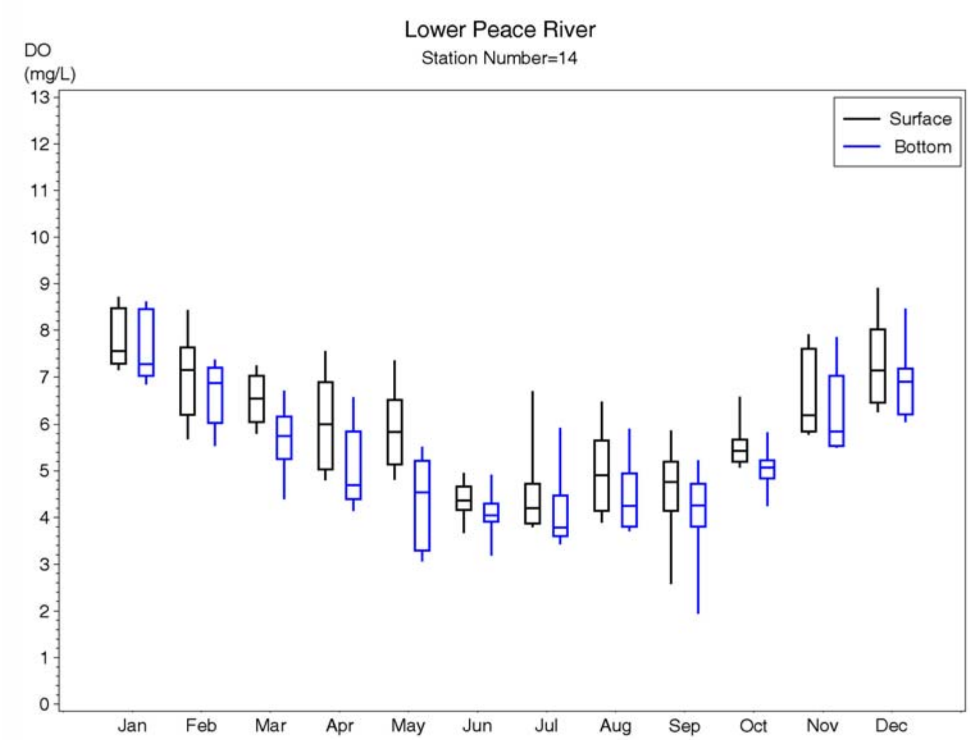


Figure 3-25. **Monthly distribution of surface and bottom DO (1997-2004) at LPR Station 14. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

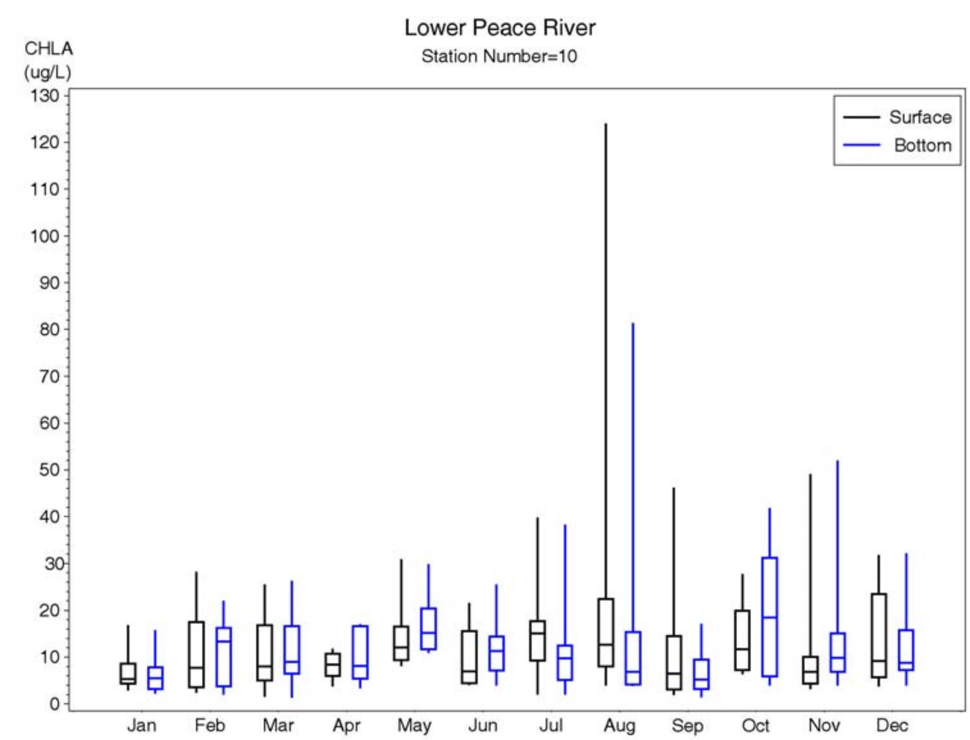


Figure 3-26. **Monthly distribution of surface and bottom chlorophyll *a* (1997-2004) at LPR Station 10. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

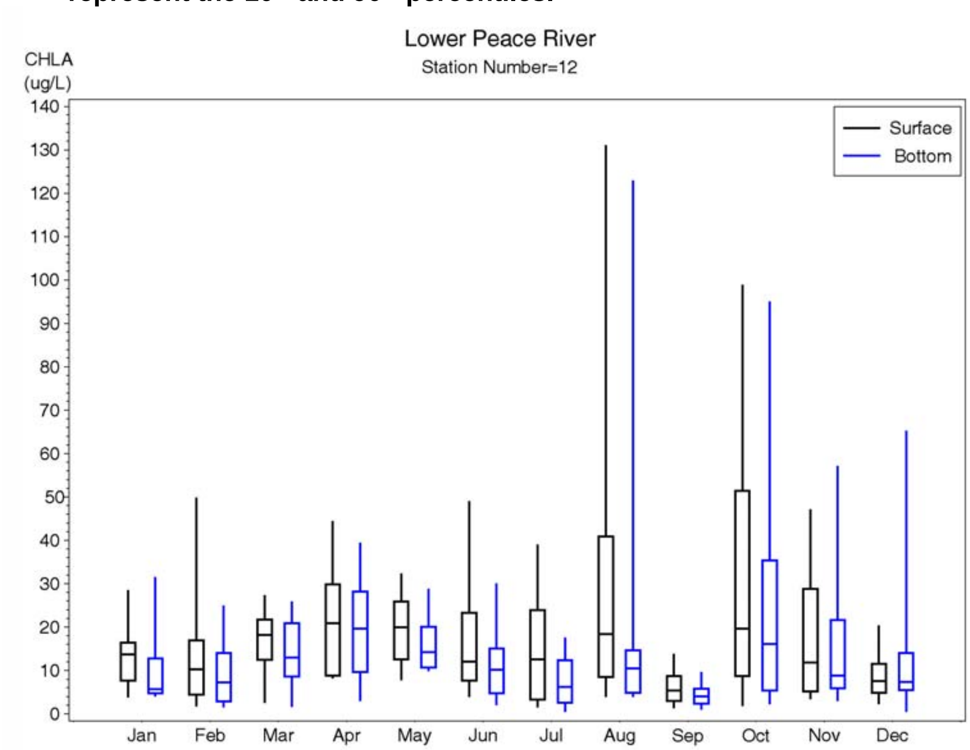


Figure 3-27. **Monthly distribution of surface and bottom chlorophyll *a* (1997-2004) at LPR Station 12. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

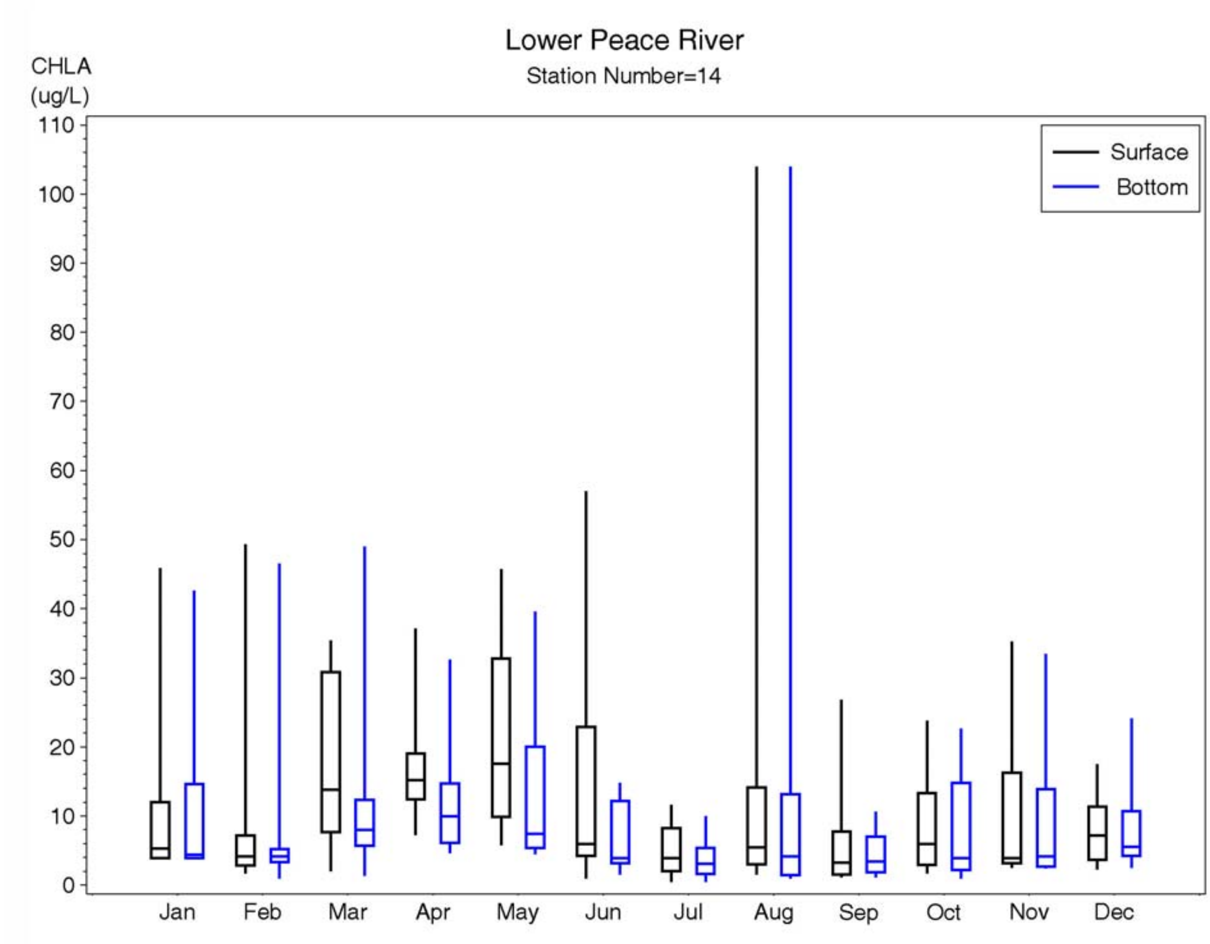


Figure 3-28. Monthly distribution of surface and bottom chlorophyll *a* (1997-2004) at LPR Station 14. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

A within-year pattern of total nitrogen (TN) concentrations was evident in the monthly distributions across multiple years (Figures 3-29 through 3-31). Increased concentrations of TN during warmer high flow periods correspond with increased chlorophyll *a* values signaling the availability of inorganic nutrients in the LPR.

Within-year variation in total phosphorus (TP) concentrations for LPR stations are presented in Figures 3-32 through 3-34. Monthly concentrations of TP were higher during the late summer months of July, August and September. In typical estuarine/riverine systems TP lags behind TN and chlorophyll *a*, as is found in the LPR. This lag is often associated with the breakdown of primary producers and the flux of phosphorus from the sediments associated with low dissolved oxygen.

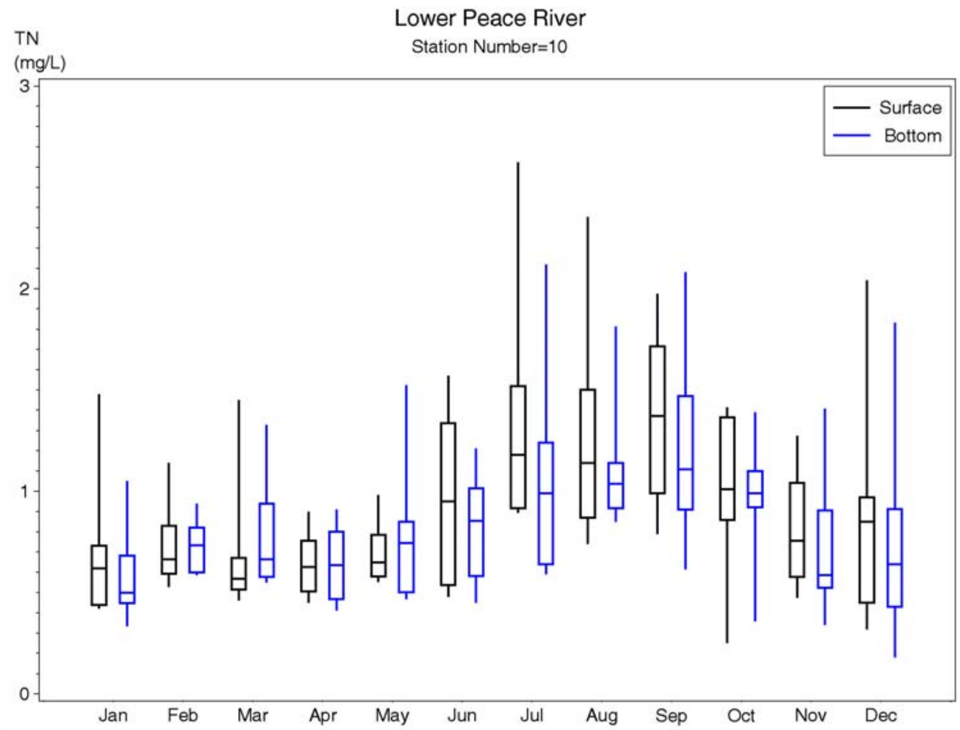


Figure 3-29. Monthly distribution of surface and bottom TN (1997-2004) at LPR Station 10. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

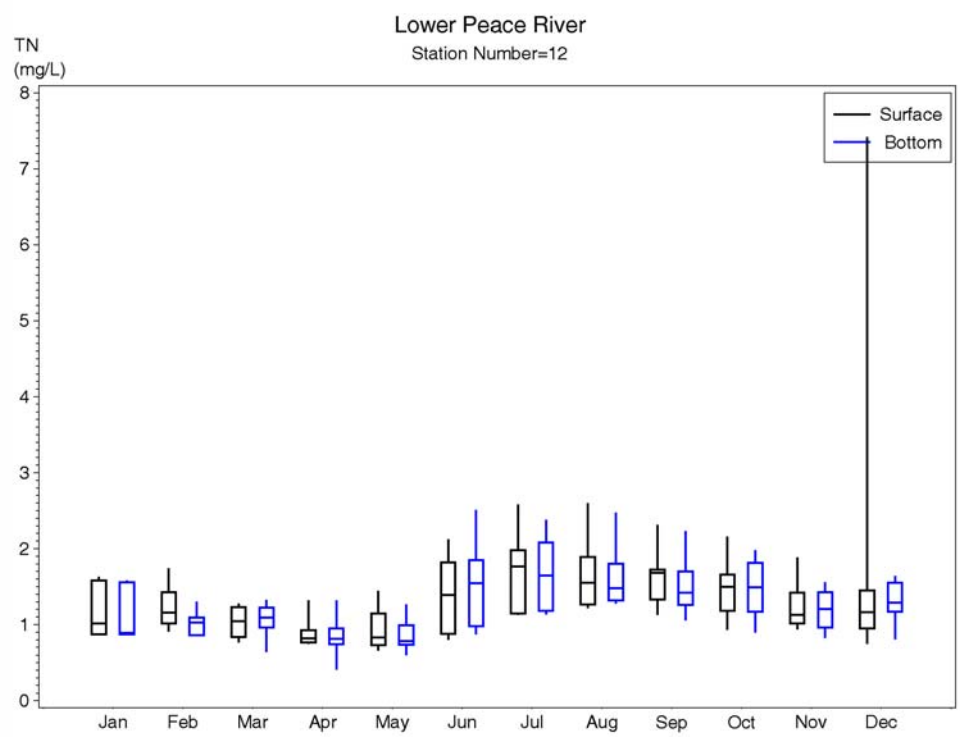


Figure 3-30. Monthly distribution of surface and bottom TN (1997-2004) at LPR Station 12. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

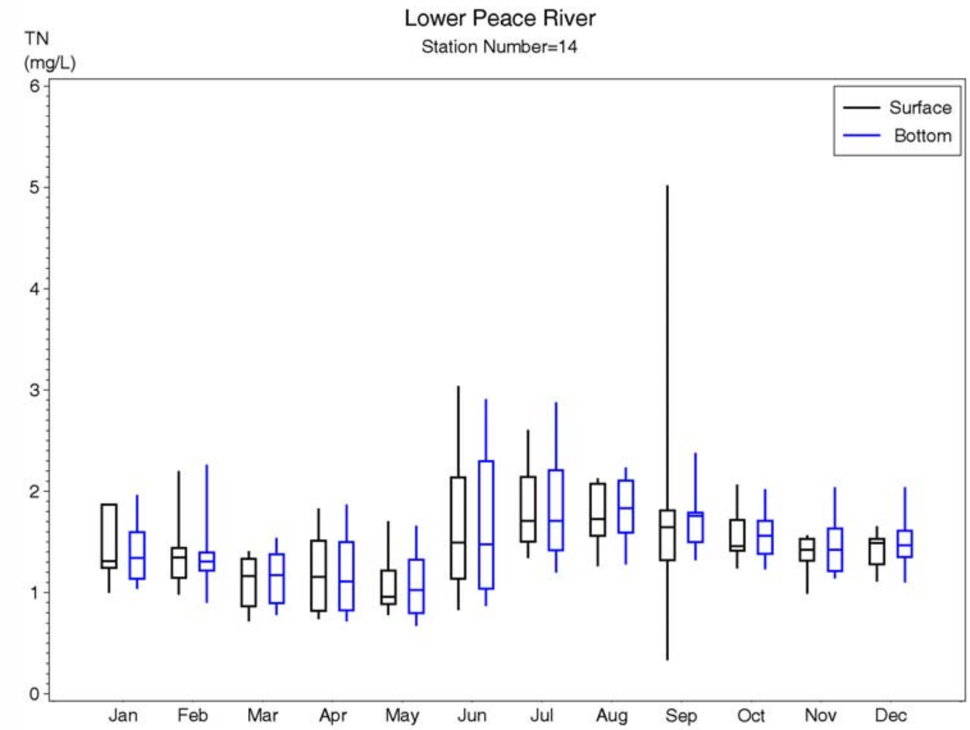


Figure 3-31. Monthly distribution of surface and bottom TN (1997-2004) at LPR Station 14. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

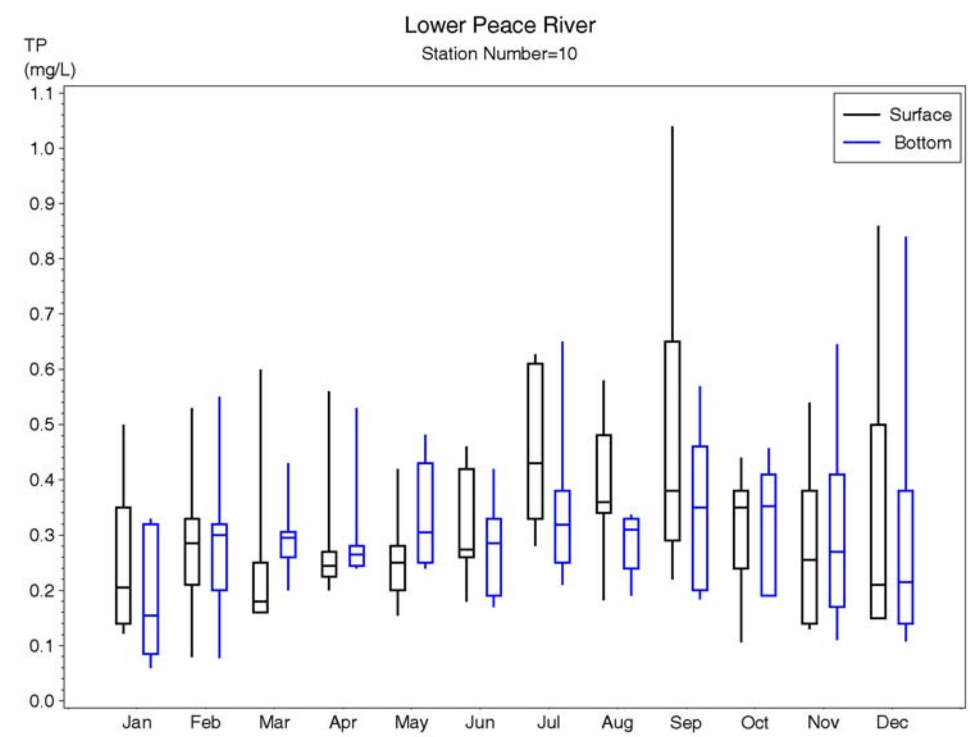


Figure 3-32. Monthly distribution of surface and bottom TP (1997-2004) at LPR Station 10. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

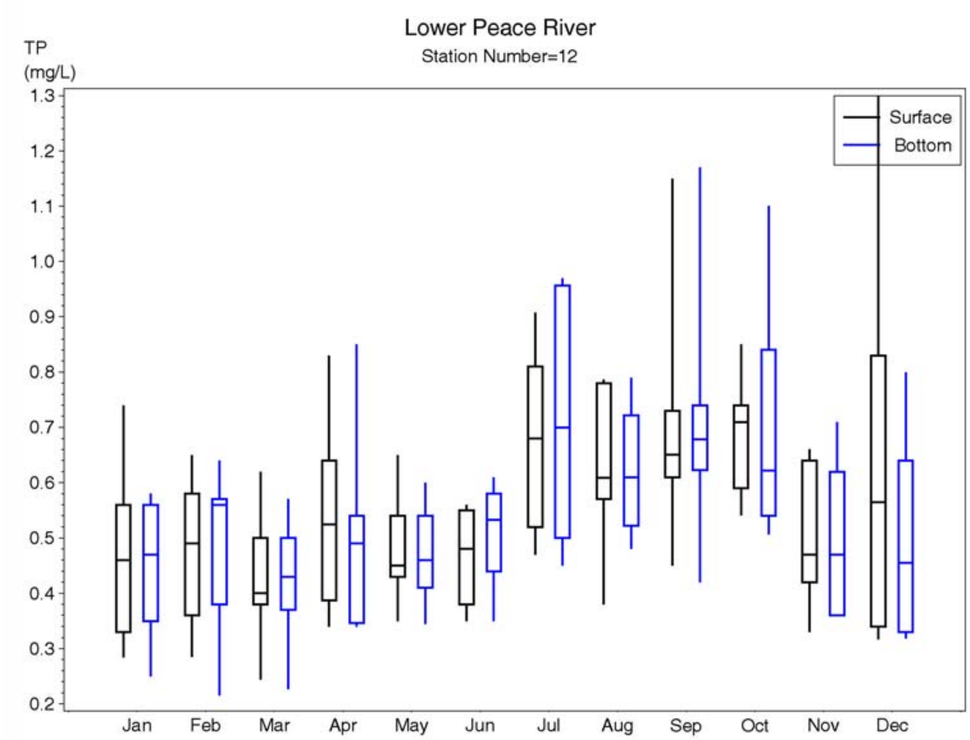


Figure 3-33. Monthly distribution of surface and bottom TP (1997-2004) at LPR Station 12. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

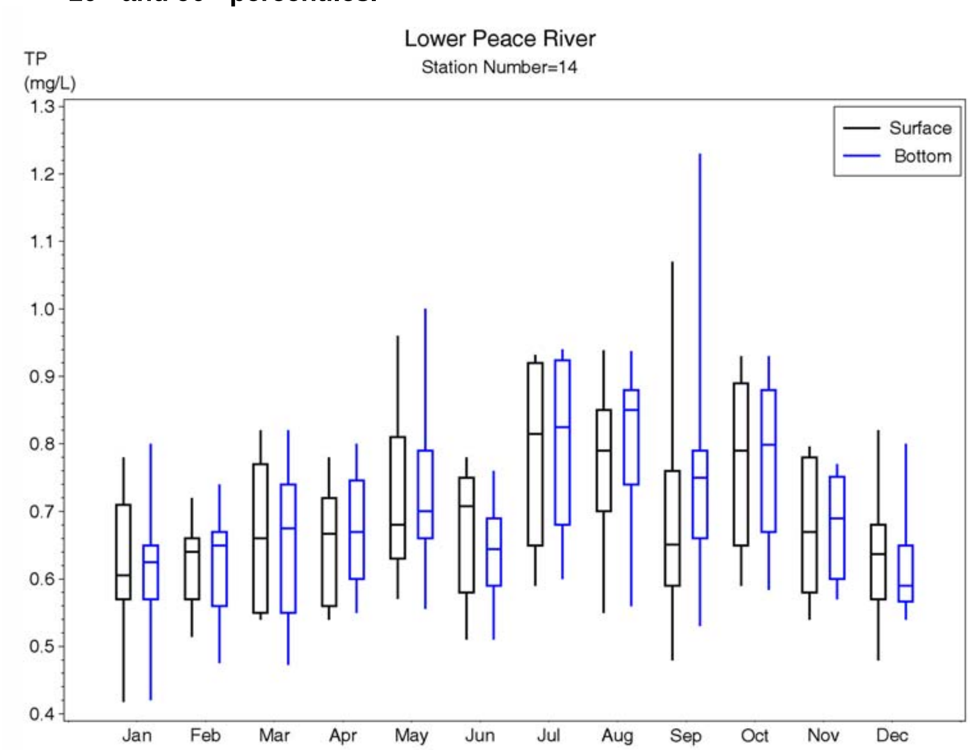


Figure 3-34. Monthly distribution of surface and bottom TP (1997-2004) at LPR Station 14. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

3.1.2.3 Spatial Variation in Water Quality Constituents

Spatial variation in physical constituents is shown by river kilometer for all stations for all years (1997-2004). Water quality constituents were observed longitudinally for Stations 9 (2.4 km), Station 10 (6.6 km), Station 12 (15.5 km), Station 14 (23.6 km), and Station 18 (30.4 km).

As expected, salinity values decreased with distance upstream. Typical estuarine circulation resulted in lower salinities in surface water and higher salinities in bottom water. Salinity differences between surface and bottom water decreased as tidal influence decreased (Figure 3-35)

The distribution of temperature values was observed to be relativity similar from the river mouth to Station 19. Figure 3-36 presents the longitudinal distribution of temperature observations over the geographic domain of the LPR. Temperature was slightly lower in bottom waters for the majority of stations.

Figure 3-37 presents the longitudinal distribution of DO over the geographic domain of the LPR. Bottom waters had slightly lower DO than surface water and DO did not show large variations among stations. Slightly higher DO was found downstream and decreased at the river's narrowest portion (km 21.9).

The distributions of chlorophyll *a* concentrations were observed to reach a peak at 15.5 km (station 9) and decreased again with distance upstream, as shown in Figure 3-38. As previously discussed, lower concentrations were found in bottom waters with greater light attenuation.

Total Nitrogen concentrations increased with distance upstream, as shown in Figure 3-39. Higher concentrations upstream result from freshwater sources and the potential greater availability due to reduced concentrations of primary producers.

Total Phosphorus showed similar behavior with increasing concentrations with distance upstream as shown in Figure 3-40.

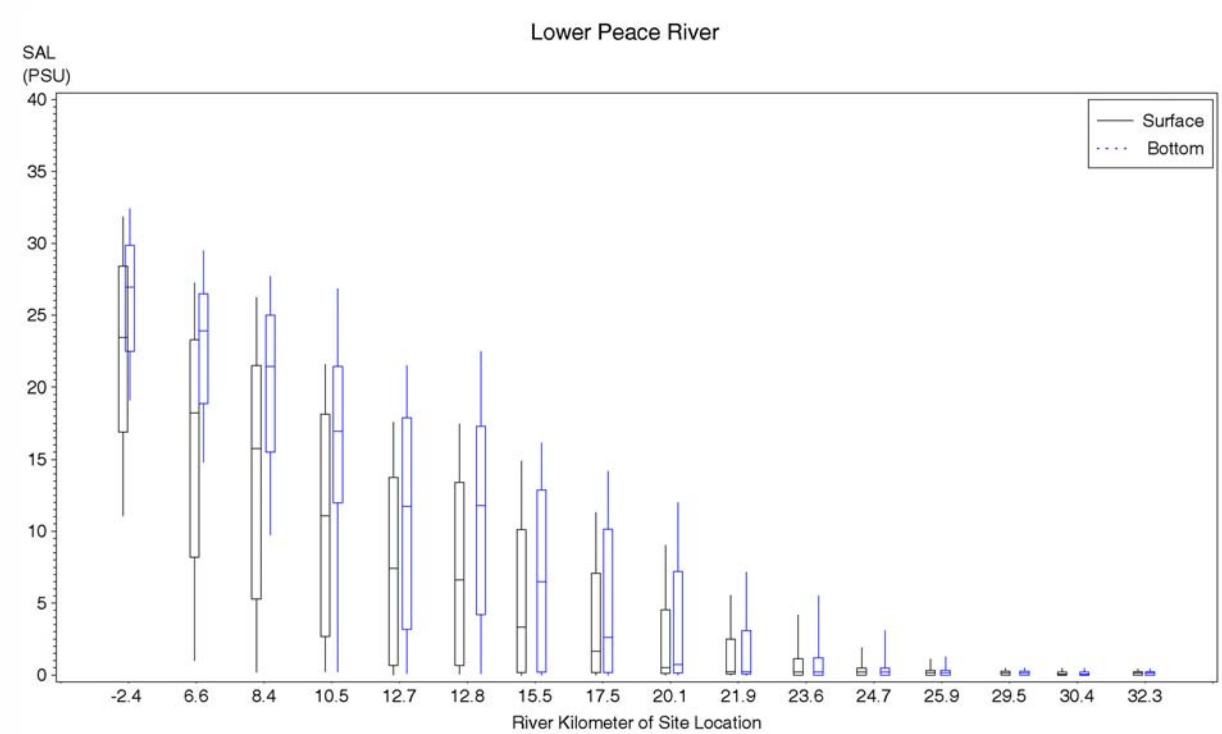


Figure 3-35. Observed longitudinal distributions of salinity for the LPR.

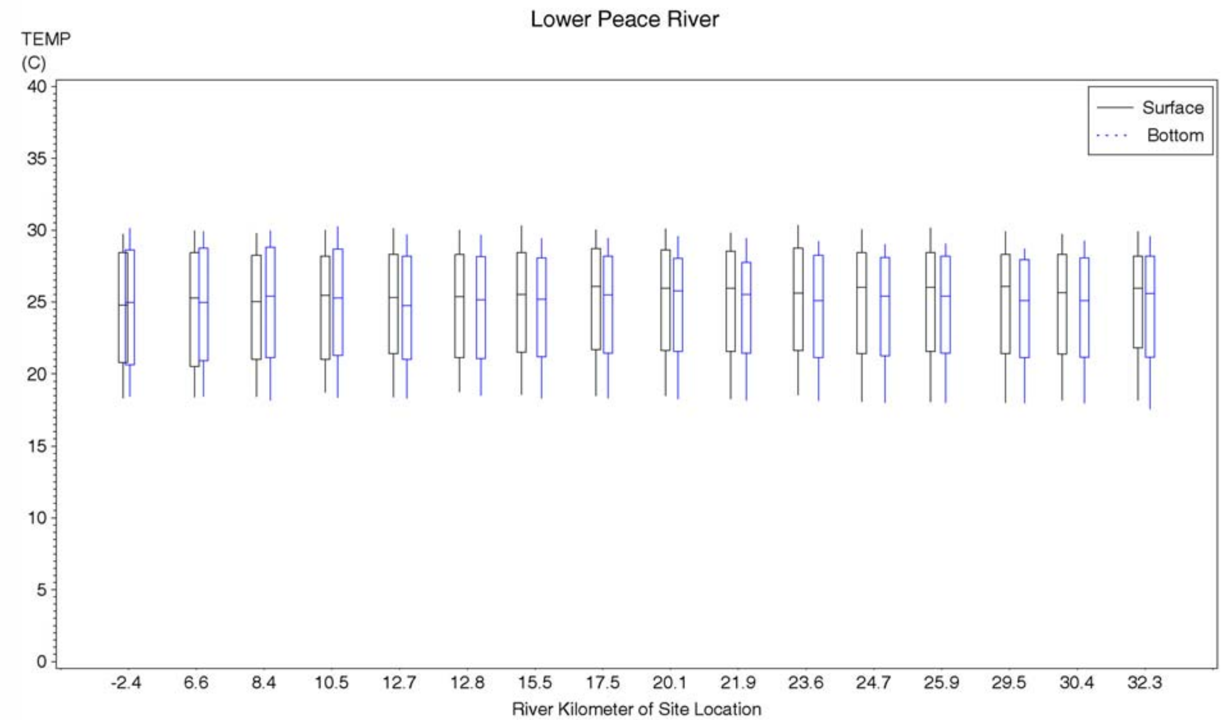


Figure 3-36. Observed longitudinal distributions of temperature for the LPR.

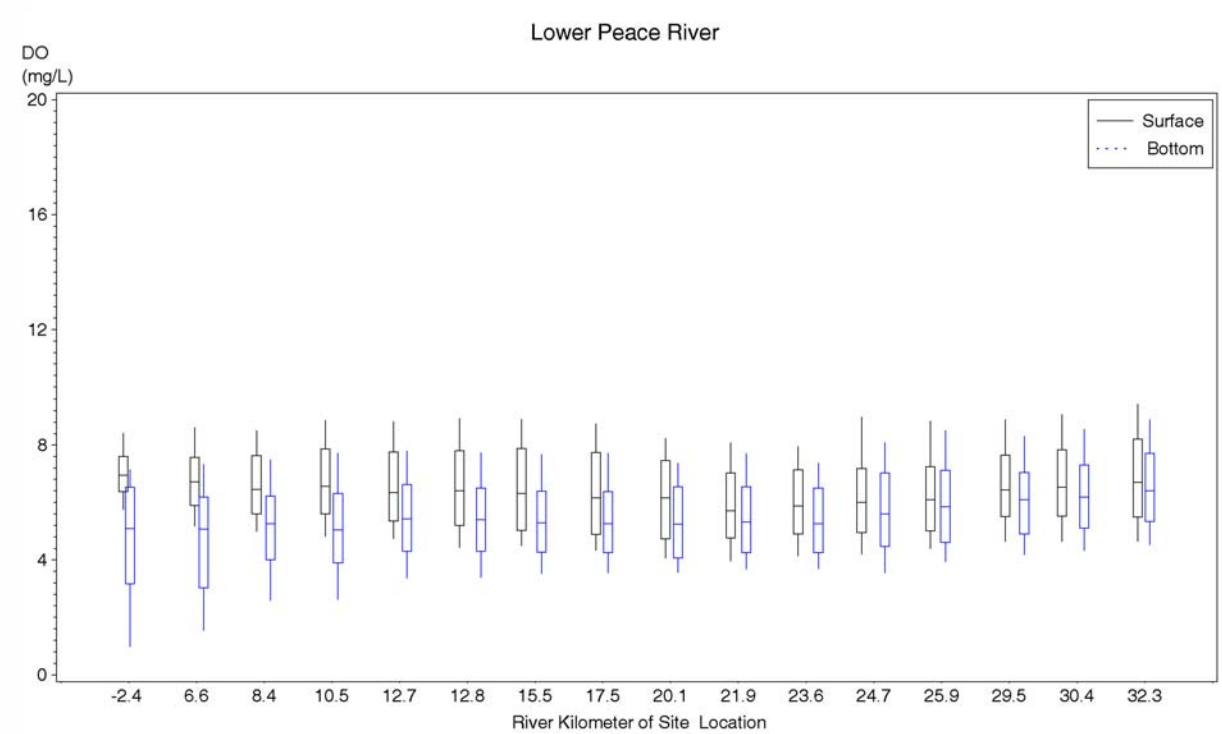


Figure 3-37. Observed longitudinal distributions of DO for the LPR.

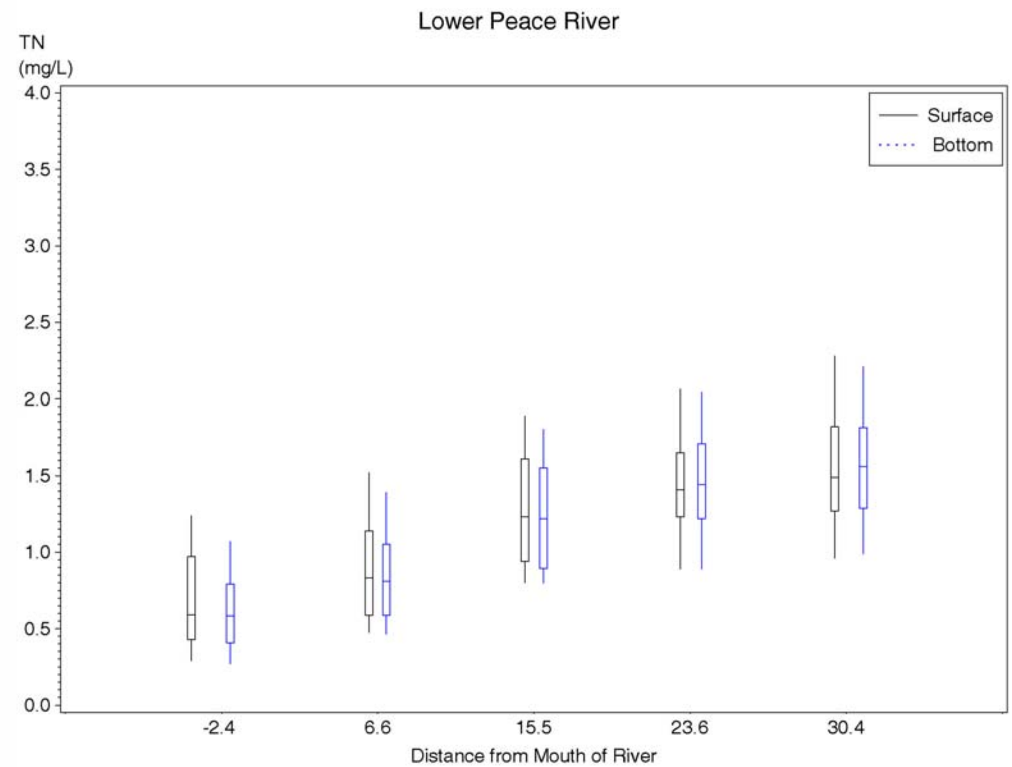


Figure 3-38. Observed longitudinal distributions of chlorophyll *a* for the LPR.

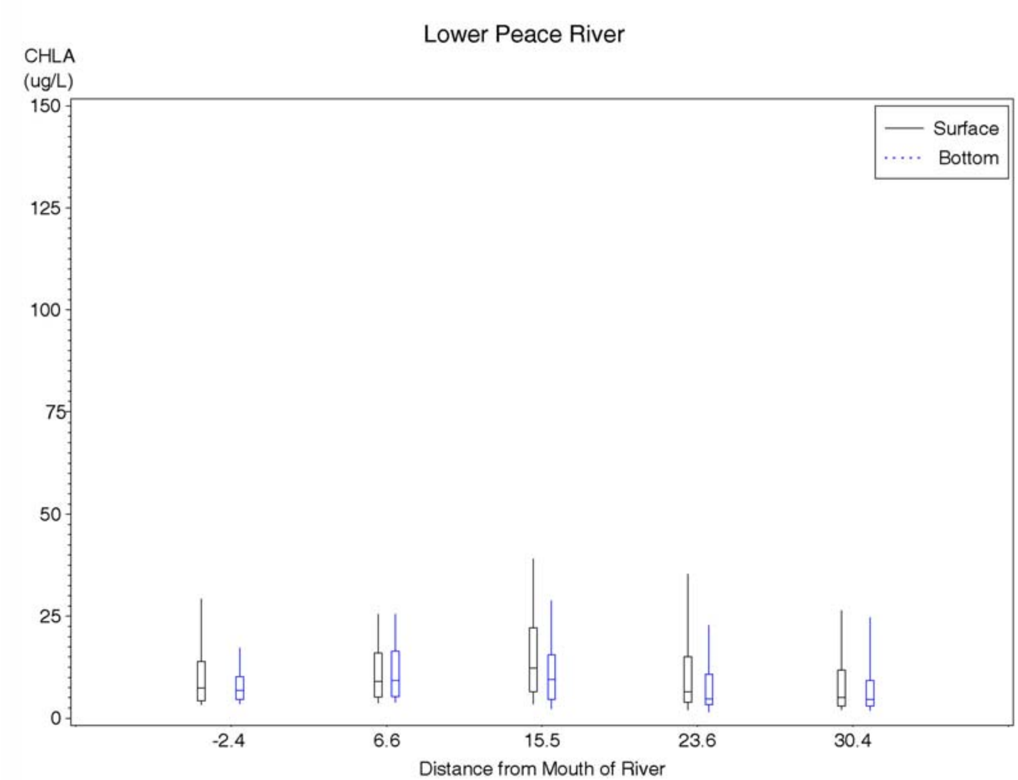


Figure 3-39. Observed longitudinal distributions of TN for the LPR.

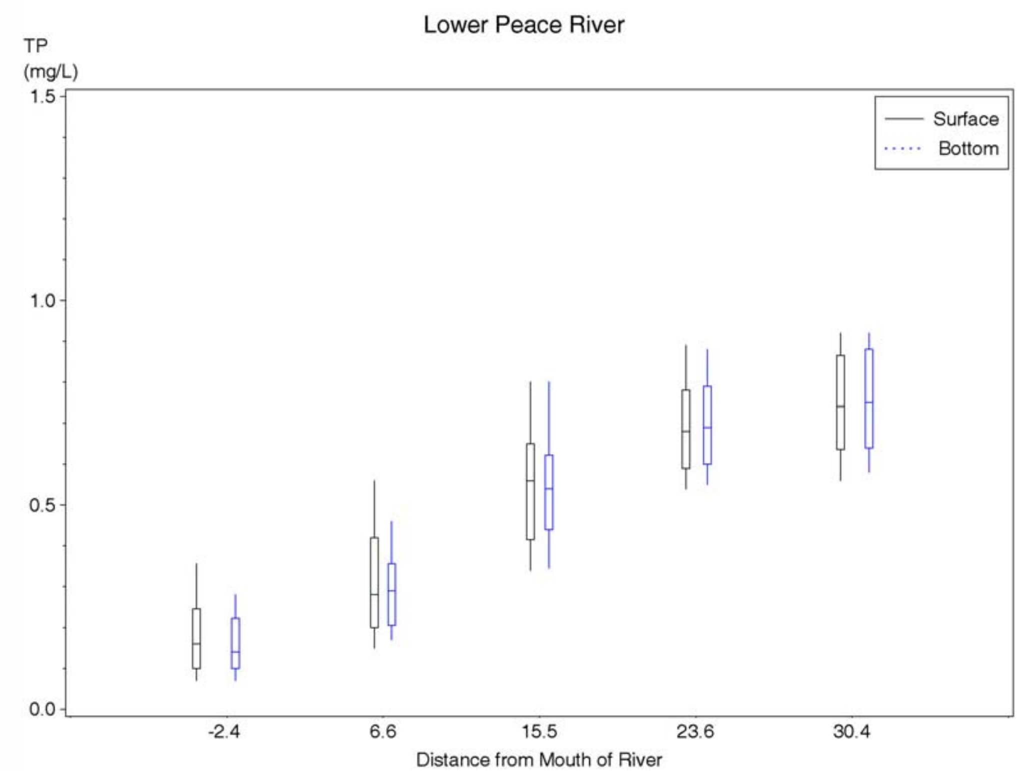


Figure 3-40. Observed longitudinal distributions of TP for the LPR.

3.2 Shell Creek

In this subchapter, a historical review of previous studies that addressed water quality in the SC is presented. In addition, data from ambient monitoring are presented and described.

3.2.1 Shell Creek Historical Review

The following section provides brief summaries of scientific reports which include data and analysis of SC. PBS&J (1999b) assessed the potential SC impacts resulting from changes in City of Punta Gorda Facility withdrawals. The purpose of the document was to assess if the biological communities of the SC/LPR estuarine system may be adversely impacted as a result of the proposed increase in permitted freshwater withdrawals. Data included use of the SC Hydrobiological Monitoring Program (HBMP) which began in 1991 and provides comprehensive seasonal and long-term water quality data. Relationships between flow on salinity, dissolved oxygen and chlorophyll a were determined.

Under no flow conditions, surface salinities near the dam can reach nearly 15 psu. As flow increases, salinities decrease to zero. Variability increases in the salinity flow relationship with movement downstream as a result of tidal influences. Bottom DO values were typically lower than surface DO values regardless of flow, although differences lessen during high flow. Analyses of chlorophyll *a* levels showed *a* decline with decreasing flows. Increases in flow caused an increase in water color and decreases in residence time.

Janicki Environmental (2003) conducted a study for the Charlotte Harbor National Estuary Program to asses the status and trends of water quality conditions within the Charlotte Harbor National Estuary Program (CHNEP) study area. An extensive review was conducted that included the Peace River. Within the study area, a historical and current database of rainfall, flow, surface water quality, and groundwater quality were linked using a GIS system with respect to hydrology and geographic location to develop an integrated watershed database. Water Quality was assessed by comparing recent period rainfall, stream flow, and water quality across basins. Times series trends were assessed by applying seasonal Kendall tau analyses to rainfall, stream flow, and water quality data to each individual station in the study area. Statistical results were integrated at the drainage basin level by mapping trends across basins.

For the SC Basin, significant increasing salinity trends were identified for Station 1 at both surface and bottom. The salinity was observed to be increasing at 6.6% of the median value per year for the bottom measurements and at 5.5% of the median value per year for the surface measurements. The period of record for which the trends were detected was from 1991 to 2001. Matching surface and bottom conductivity trends were also detected for this station, but at a slightly lesser rate. A significant decreasing turbidity trend was also observed for SC for Station 2 for the same time period.

PBS&J (2007), as part of the Peace River Cumulative Impact Study, assessed the individual and cumulative impacts of certain anthropogenic and natural stressors in the Peace River watershed, including stream flow, water quality, and ecological indicators. Historical changes to water quality constituents were presented for the subbasins of LPR, including SC. Several water quality parameters exhibited long-term increasing patterns and were measured at or near historically high levels during the recent 1999-2001 drought. Available water quality data indicate comparatively large historical increases in levels of measured conductivity in Prairie Creek and the SC Reservoir. Similar patterns of increasing chloride and silica concentrations have also occurred (PBS&J 2007).

3.2.2 Variation in Water Quality Constituents

The physical and water quality data described in this section were complied from various data sources. The majority of the data were obtained from ongoing monitoring programs. Data sources included:

- PRMRWSA Hydro-Biological Monitoring Program (HBMP) (1996 - present) and
- U.S. Geological Survey continuous recorders (1997 - present).

In the following sections, spatial and temporal variations in water quality constituents in SC are described. Because there are numerous sampling stations in the SC, a representative group of stations was selected for presentation in this section. The selected stations, which span the longitudinal distribution of HBMP sampling stations (Figure 2-3), include:

- Station 7 (rkm 2.3),
- Station 5 (rkm 6.7), and
- Station 4 (rkm 8.7).

Plots of spatial and temporal variation for all HBMP sampling locations in the SC (Figure 2-26) are provided in Appendix 3-3.

3.2.2.1 Annual Variation in Water Quality Constituents

Annual time series plots of salinity show typical estuarine conditions for SC. Salinity decreased with distance upstream and was slightly lower in surface waters as compared to bottom water. Downstream salinity ranged from 0 to 30 psu and upstream salinity was usually 0 psu with occasional increases of less than 5 psu. Typical yearly patterns showed higher salinities during the dry season and lower salinity during the wet season. Over annual cycles, lower salinities were found during wet years with relation to large meteorological events such as the El Nino event of 1998. Higher salinities were found during 2000 and 2001 associated with the continuation of extended drought periods. Annual variation in salinity at stations 7, 5, and 4 at river kilometers 2.3 km, 6.7

km and 8.7 km, respectively, are presented in Figures 3-41 through 3-43. Salinity plots of the remaining stations can be found in Appendix 3-3.

Temperature in SC showed typical seasonal cycles with summer peaks ranging from 30 to 34 degrees C and winter lows ranging from 15 to 12 degrees C (Figure 3-44, 3-45, and 3-46). Little variation was observed from the basic seasonal pattern over annual scales. At all locations the surface and bottom ranges were very similar with slightly higher surface temperatures during the entire period at all locations.

Times series data of DO concentrations are shown in Figures 3-47 through 3-49. DO concentrations ranged from 1 to 13 mg/L. Surface concentrations were higher than bottom water concentrations for most stations with larger differences with distance upstream.

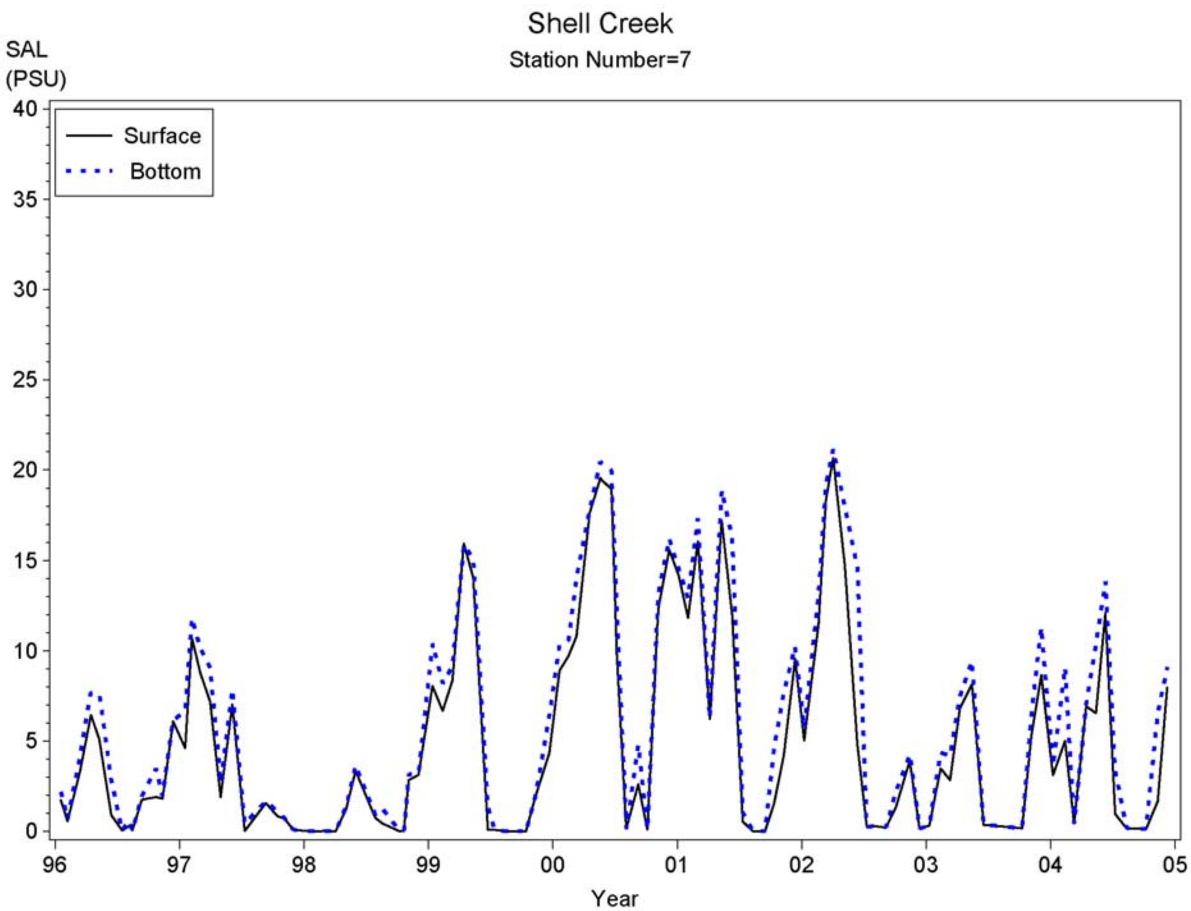


Figure 3-41. Time series of surface and bottom salinity at SC station 7.

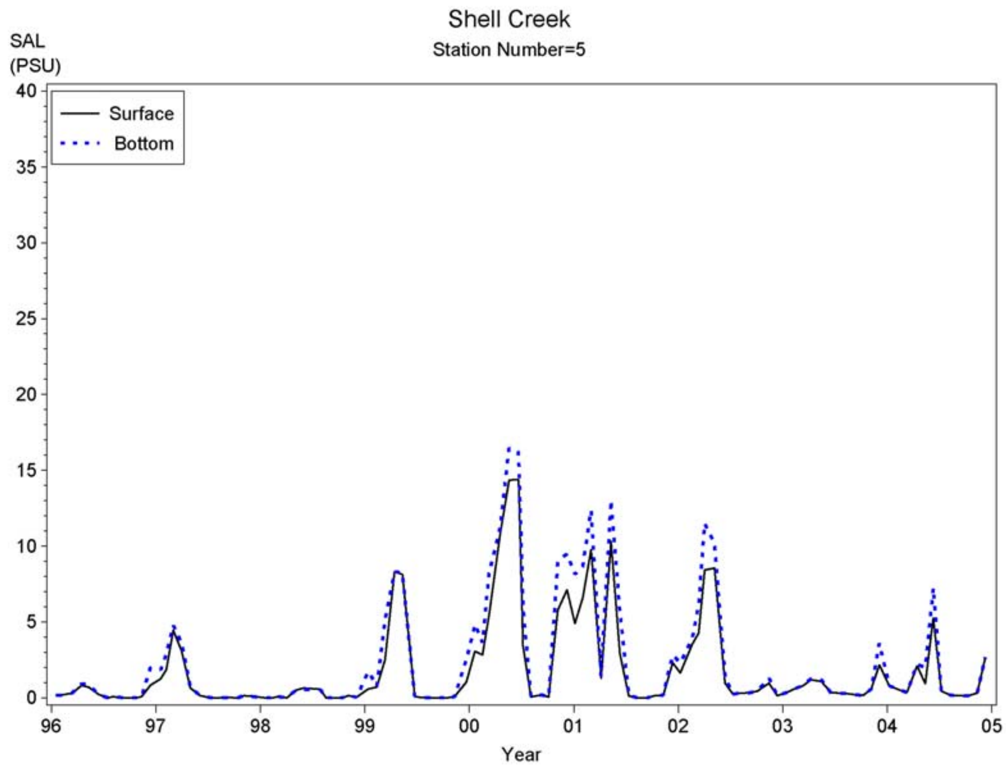


Figure 3-42. Time series of surface and bottom salinity at SC station 5.

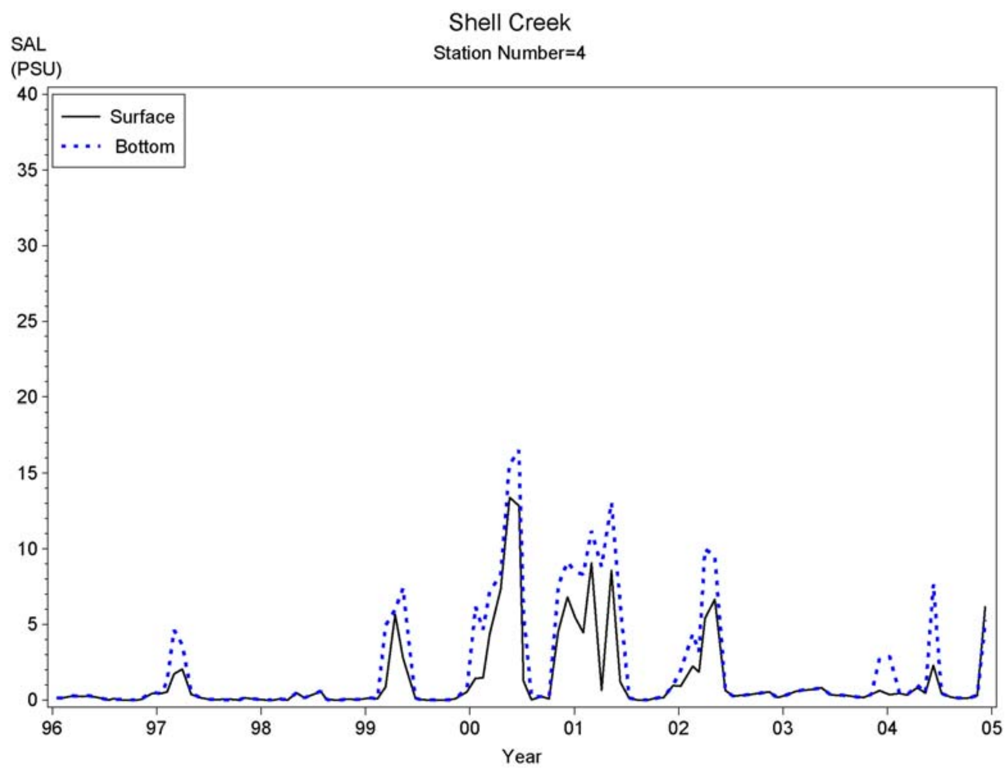


Figure 3-43. Time series of surface and bottom salinity at SC station 4.

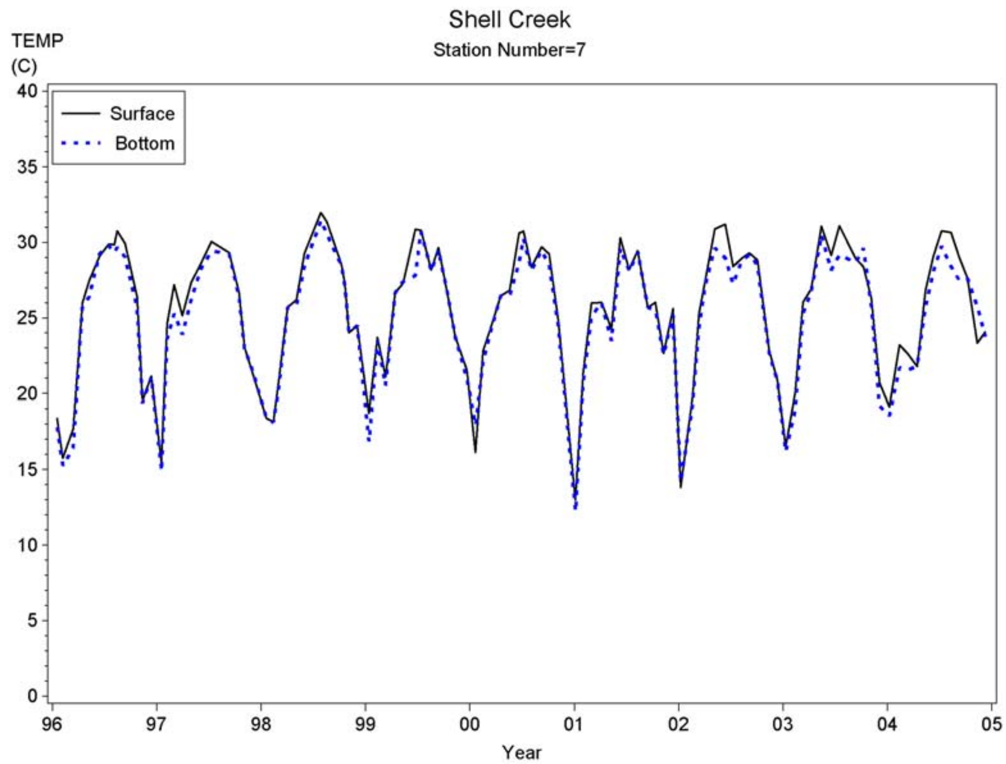


Figure 3-44. Time series of surface and bottom temperature at SC station 7.

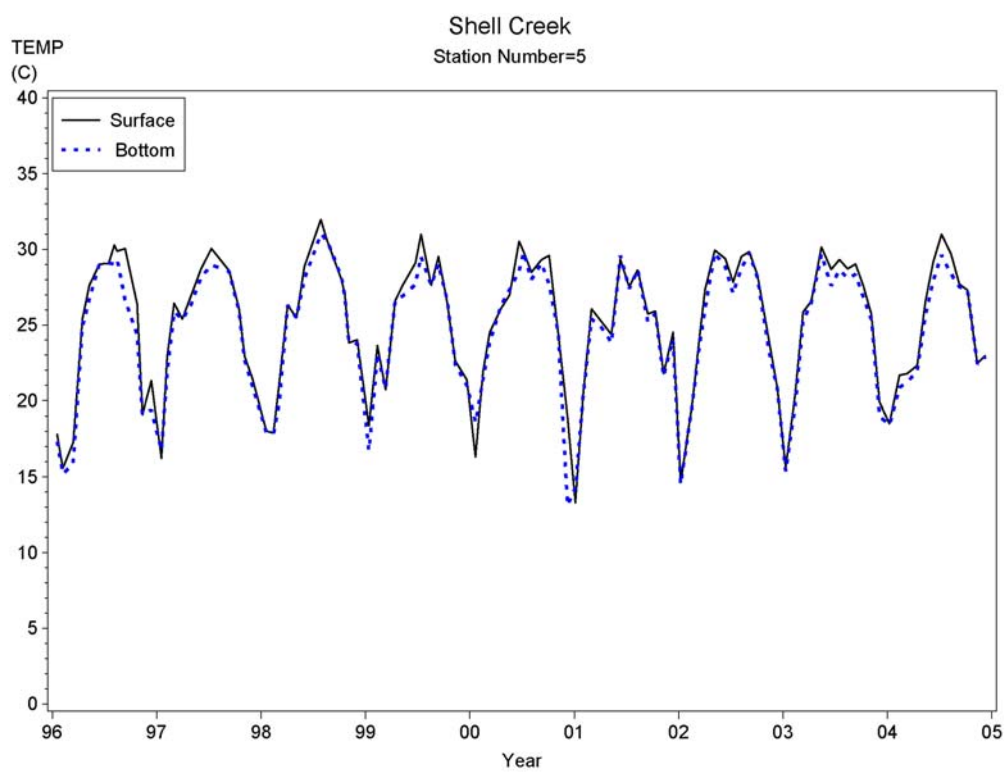


Figure 3-45. Time series of surface and bottom temperature at SC station 5.

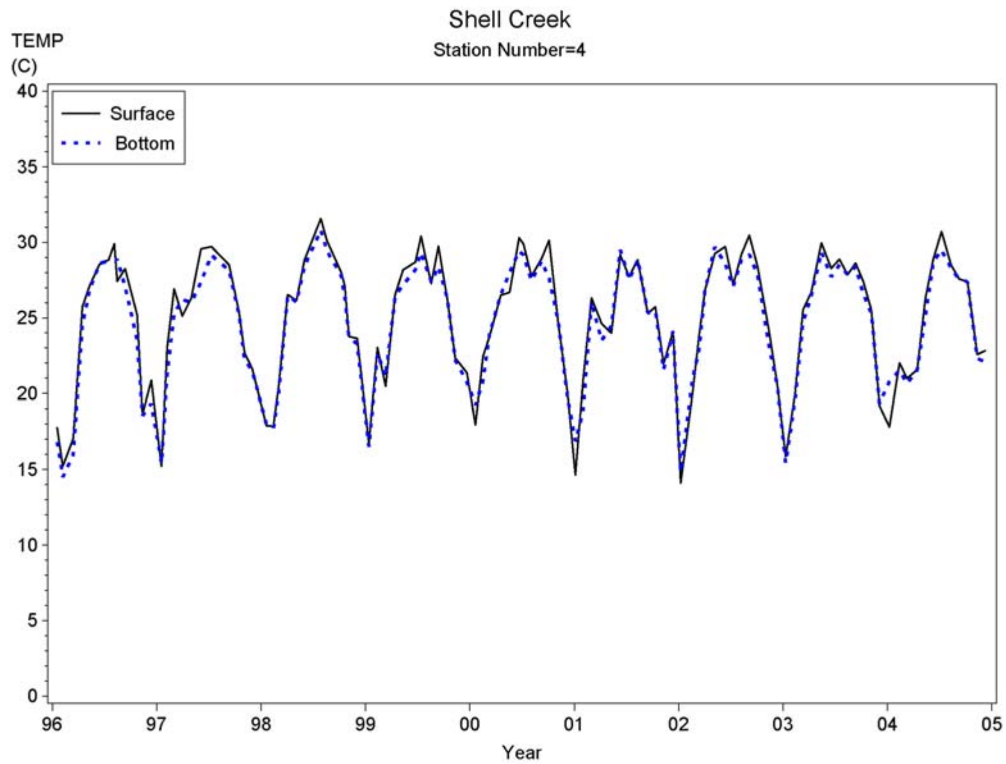


Figure 3-46. **Time series of surface and bottom temperature at SC station 4.**

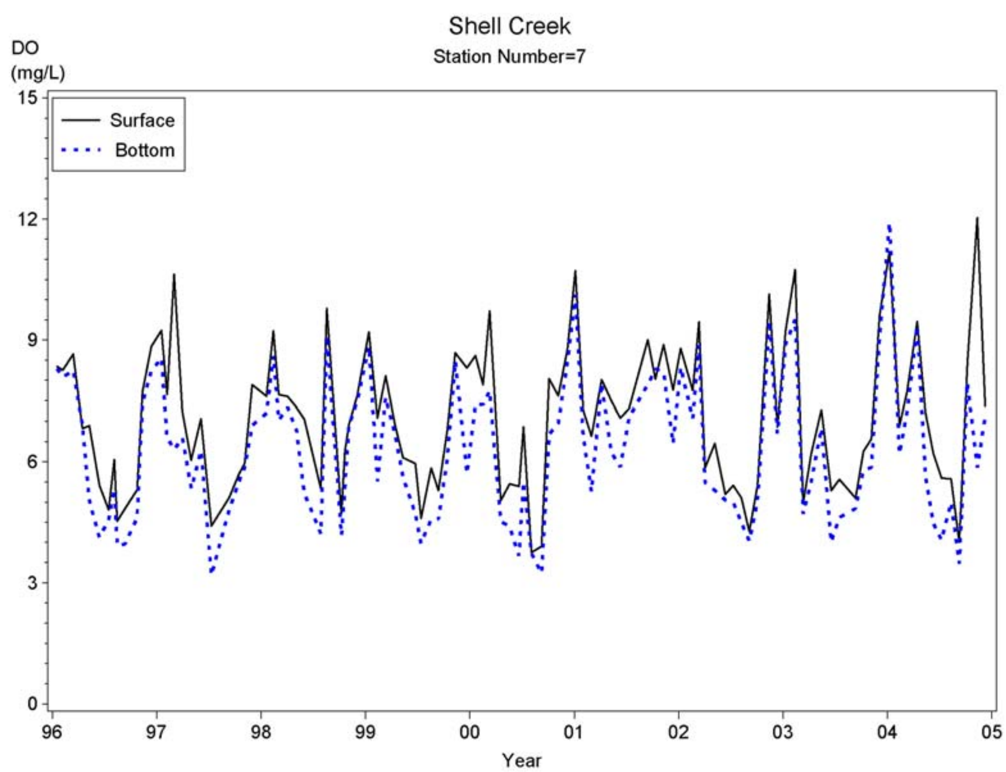


Figure 3-47. **Time series of surface and bottom DO at SC station 7.**

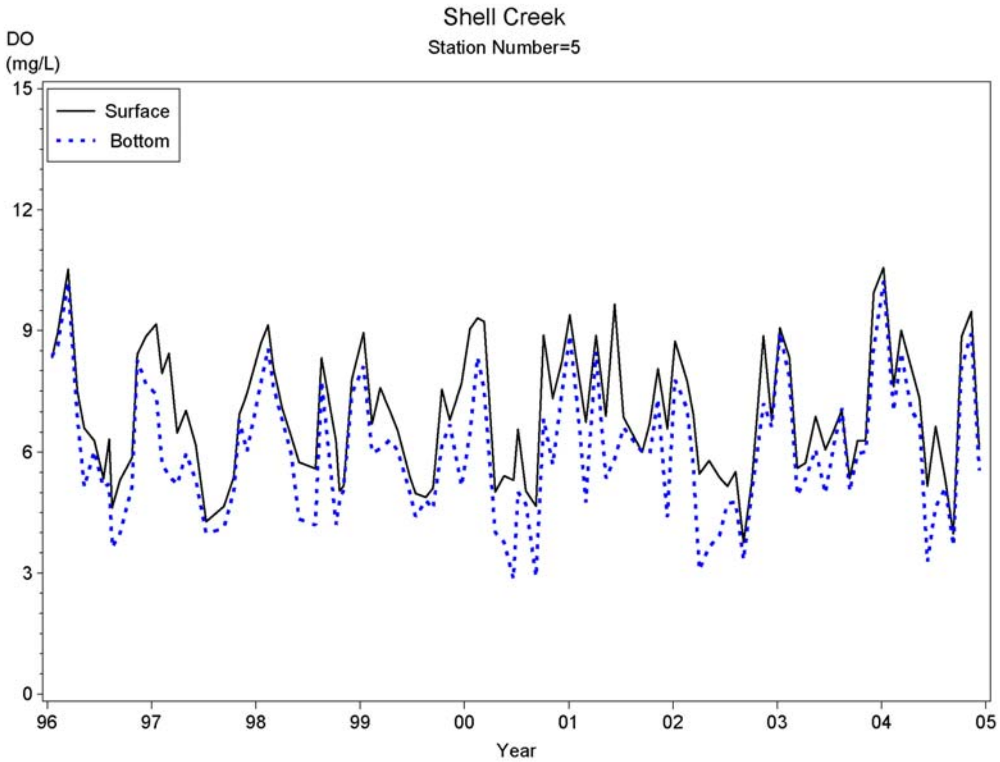


Figure 3-48. **Time series of surface and bottom DO at SC station 5.**

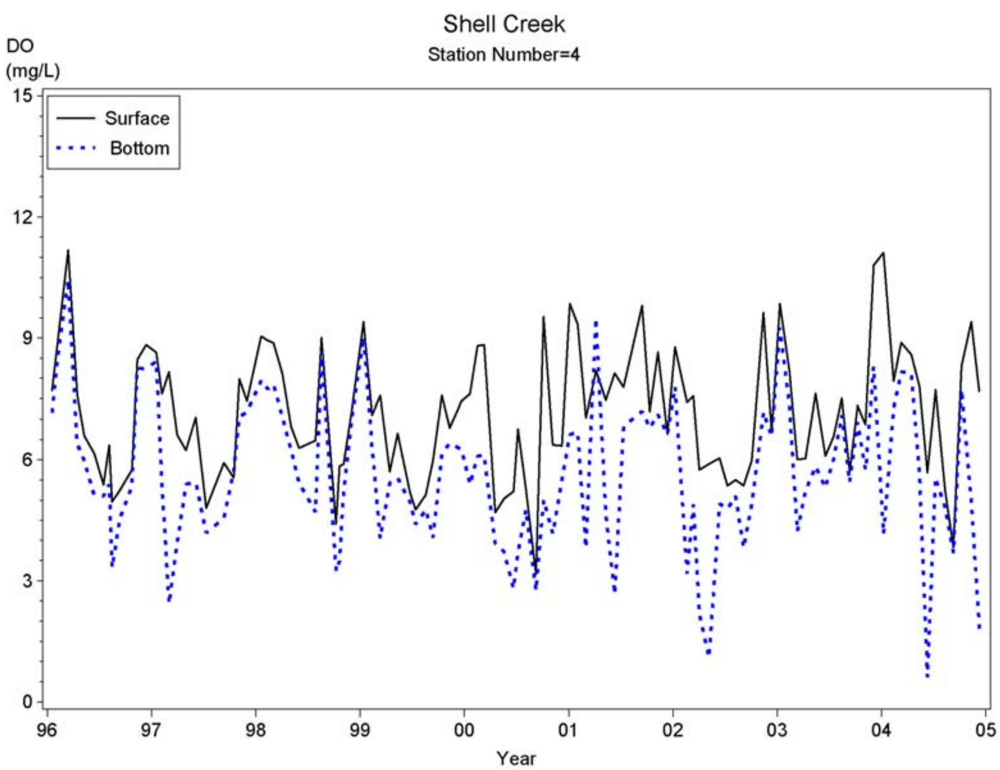


Figure 3-49. **Time series of surface and bottom DO at SC station 4.**

Annual time series of chlorophyll *a* are shown in Figures 3-50 through 3-52. There was considerable annual variation in chlorophyll *a* concentrations between stations. Overall chlorophyll *a* was higher downstream and decreased with distance upstream. Chlorophyll *a* concentrations typically ranged from 25 to 50 µg/L. There were no differences between surface and bottom values for all stations. Higher chlorophyll *a* values were evident during 1998 and 2002, which correspond to periods of higher rainfall, hence higher nutrient loading resulted in increased primary production.

Concentrations of TN are shown in Figures 3-53 through 3-55. Concentrations of TN ranged from approximately 0.5 to 4 mg/L. On annual time scales, values were typically lower during the dry season and higher during the wet season, as expected with increased flow.

TP showed annual variation across the period of record. Concentrations of TP ranged from 0.2 to 1.3 mg/L. Higher TP concentrations were evident during wet years for example the 1998 El Nino. On an annual scale lower TP concentrations were found during the dry season and higher during the wet season (Figures 3-56 through 3-58).

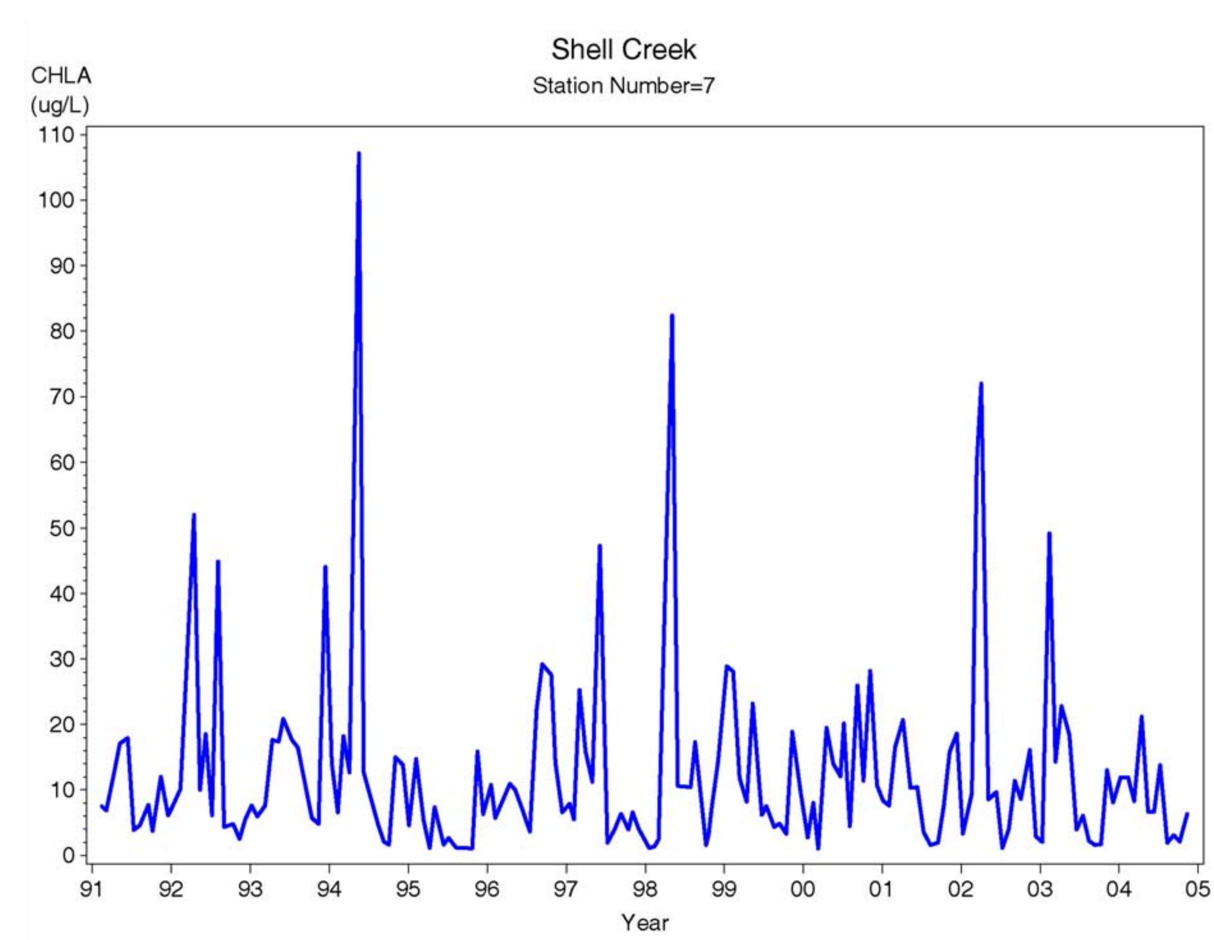


Figure 3-50. Time series of chlorophyll *a* at SC station 7.

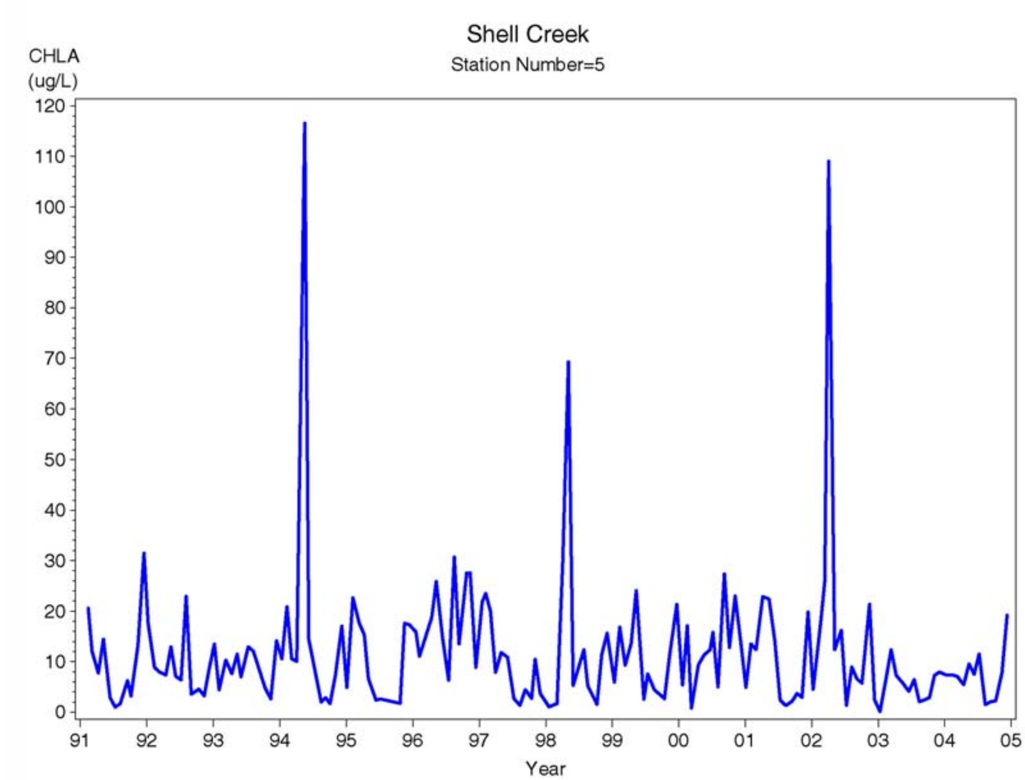


Figure 3-51. Time series of chlorophyll *a* at SC station 5.

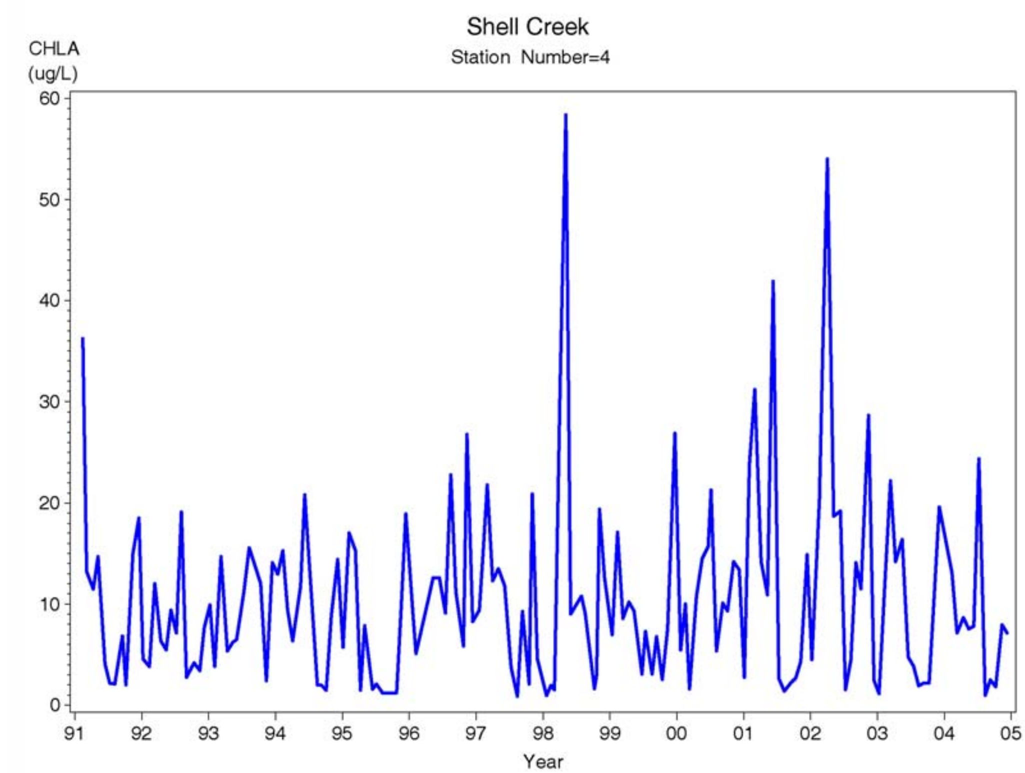


Figure 3-52. Time series of chlorophyll *a* at SC station 4.

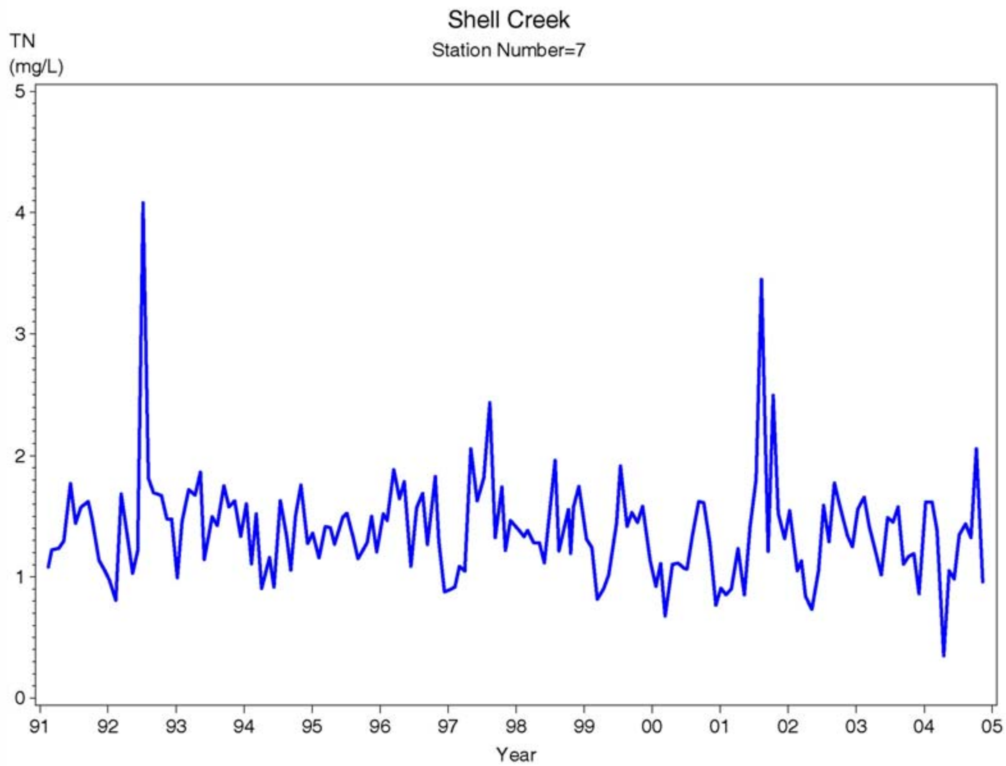


Figure 3-53. **Time series of TN at SC station 7.**

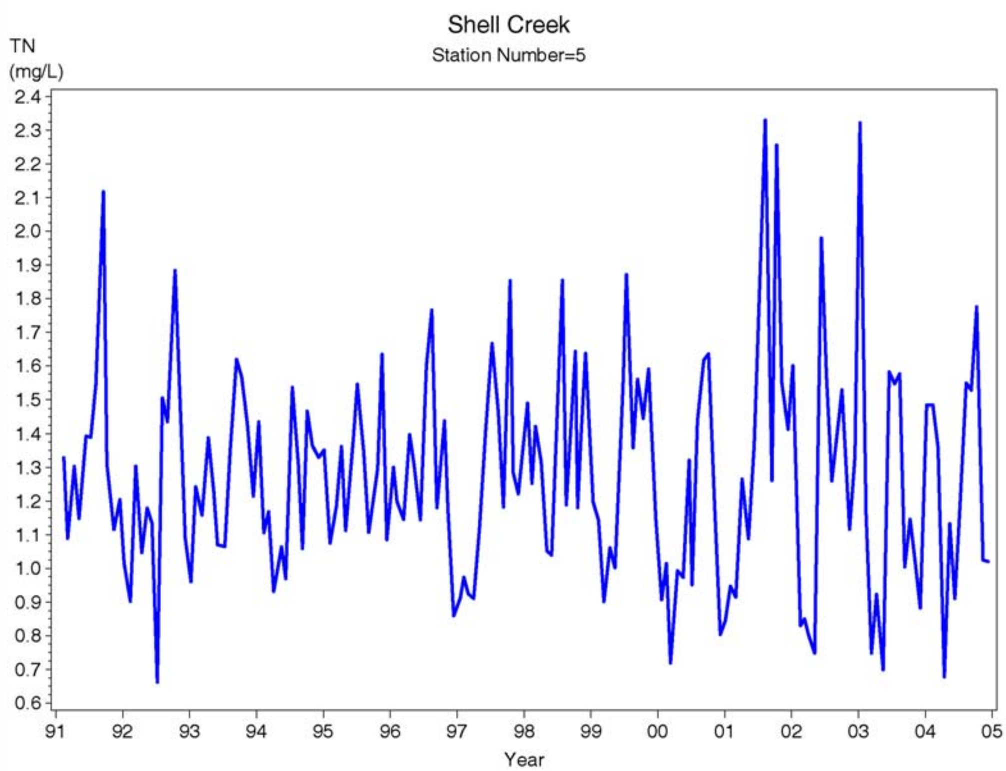


Figure 3-54. **Time series of TN at SC station 5.**

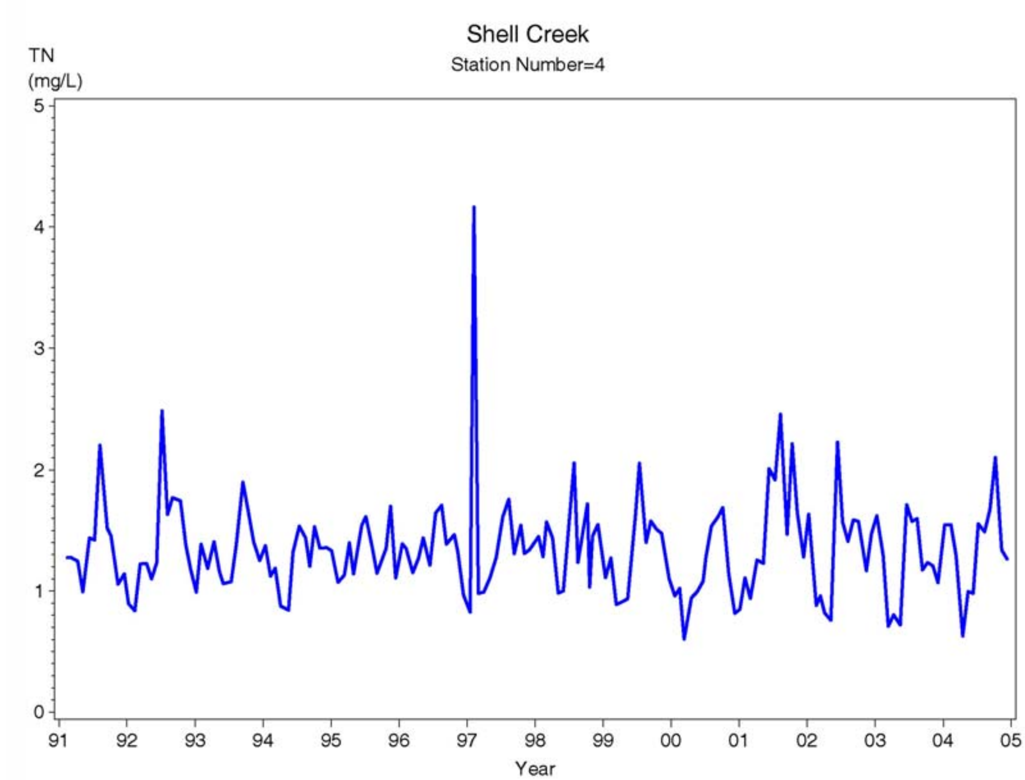


Figure 3-55. **Time series of TN at SC station 4.**

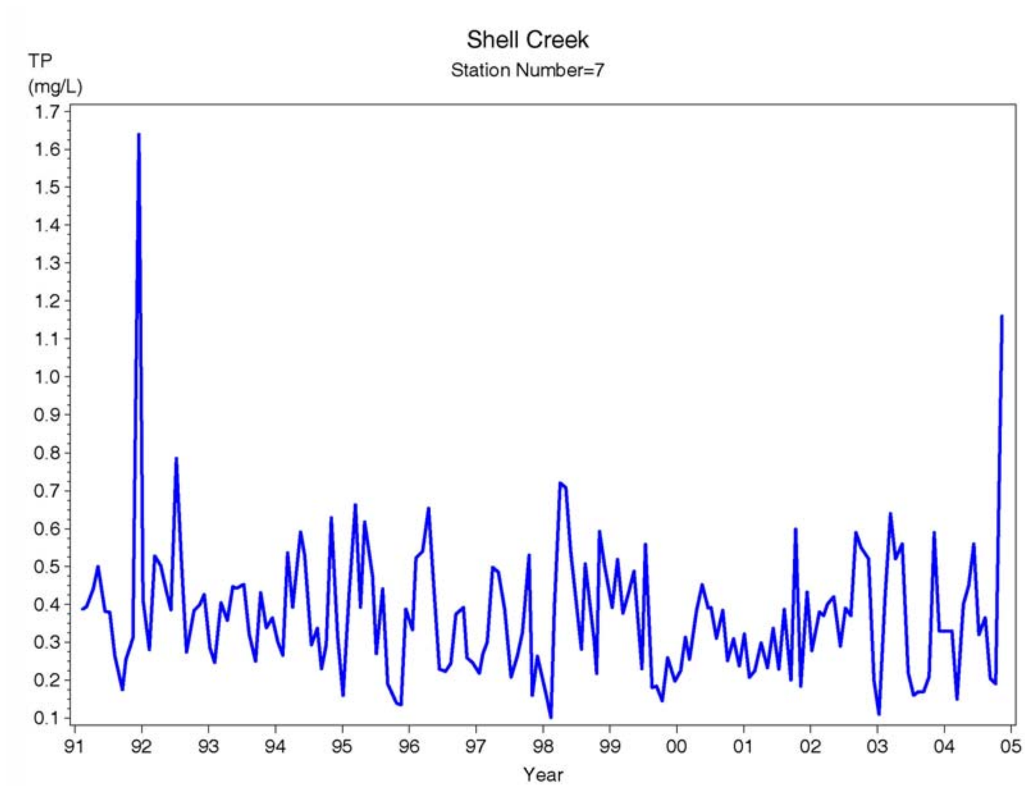


Figure 3-56. **Time series of TP at SC station 7.**

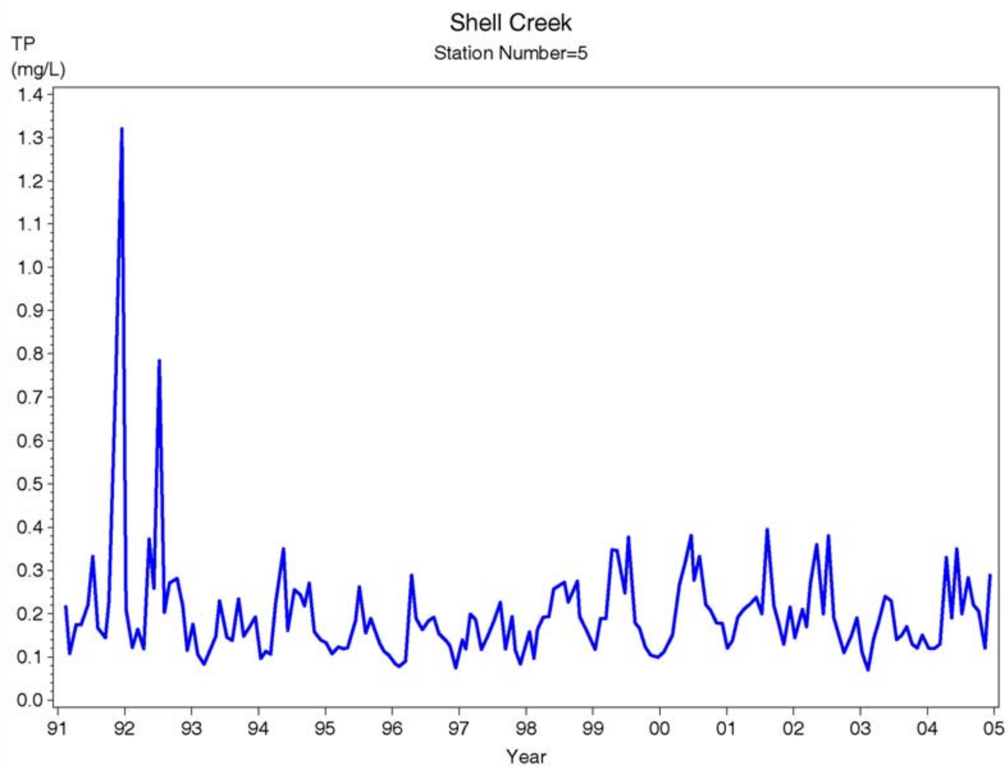


Figure 3-57. Time series of TP at SC station 5.

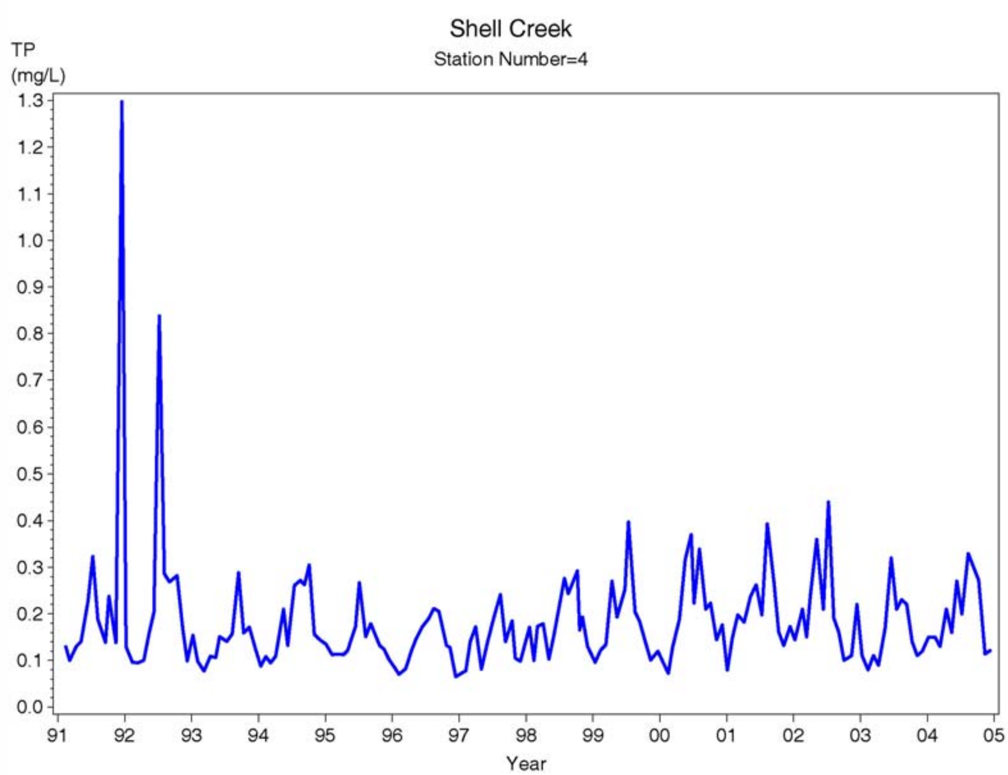


Figure 3-58. Time series of TP at SC station 4.

3.2.2.2 Within-Year Variation in Water Quality Constituents

The physical and water quality characteristics of the SC vary predictably based on the seasonal cycle of the local climate. Detailed plots for all locations and constituents are presented in Appendix 3-2.

Within each year the physical and water quality characteristics of SC vary on a predictable cycle driven by the summer warmer/wet and winter cooler/dry season cycle of the local climate.

Within-year variation in salinity at Stations 7, 5, and 4 are presented in Figures 3-59 through 3-61. Salinity was higher during the dry season months (November through May) and lower in the summer wet season (June through October). Salinity was typically lower in surface water and higher in bottom waters. High freshwater flow resulted in little or no differences between surface and bottom salinities from July through October for most stations.

Temperature also followed seasonal patterns (Figures 3-62 through 3-64) over the period of record for all locations and depths. Lowest temperatures were observed ruing December and January. Highest temperatures were observed during July and August.

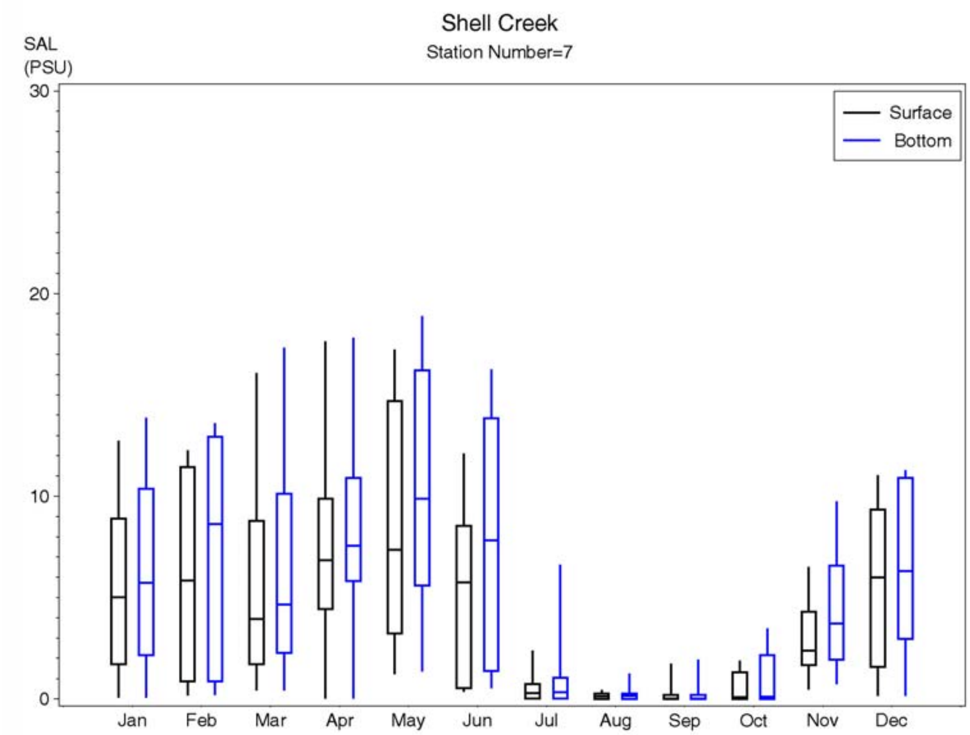


Figure 3-59. Monthly distribution of surface and bottom salinity (1997-2004) at SC Station 7. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

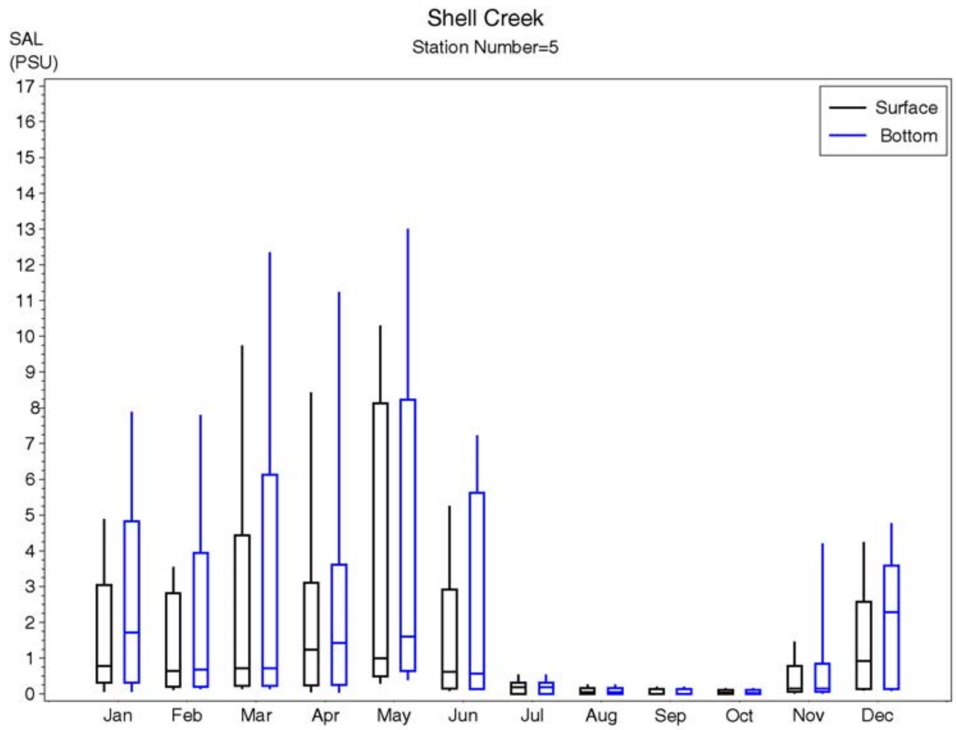


Figure 3-60. Monthly distribution of surface and bottom salinity (1997-2004) at SC Station 5. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

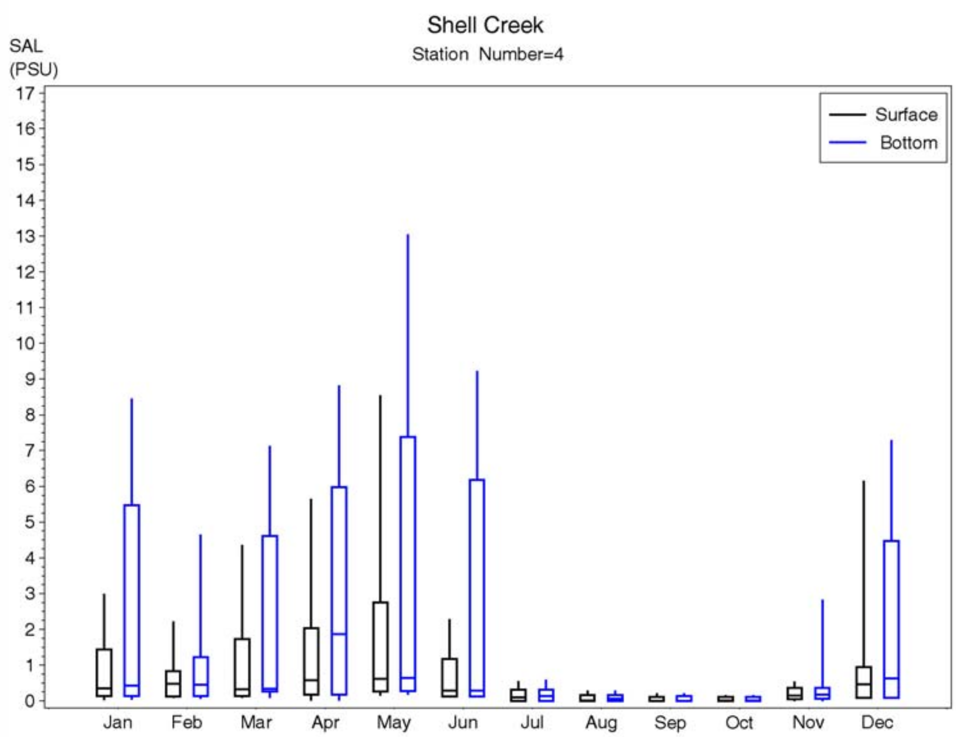


Figure 3-61. Monthly distribution of surface and bottom salinity (1997-2004) at SC Station 4. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

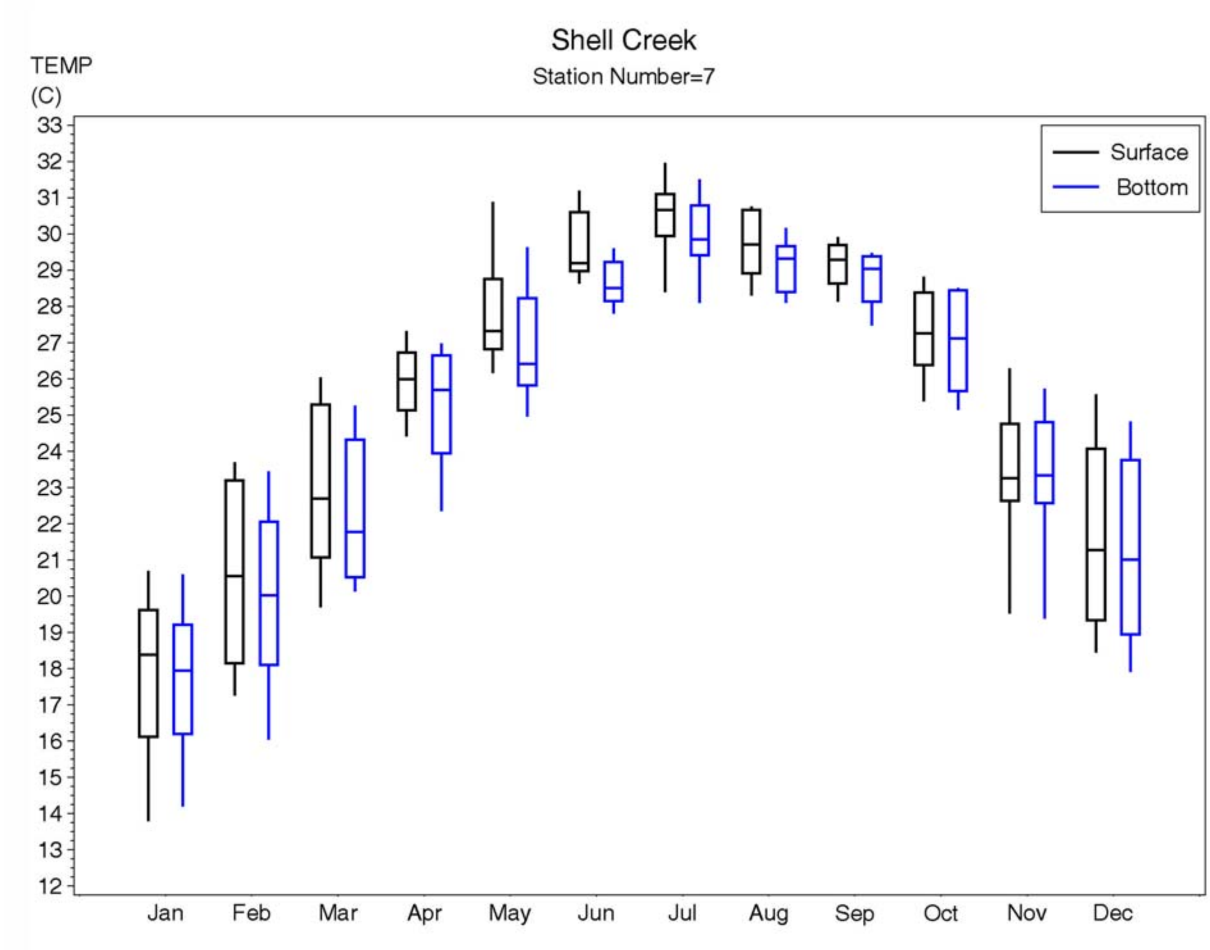


Figure 3-62. Monthly distribution of surface and bottom temperature (1997-2004) at SC Station 7. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

DO showed typical seasonal trends (Figures 3-63 to 3-65), with higher concentrations during cooler months and lower concentrations during warmer months. DO was lower in bottom waters as compared to surface waters for all stations.

Overall, chlorophyll *a* did not follow any distinct seasonal cycles (Figures 3-66 to 3-68). Higher variability was evident at downstream stations as compared to upstream stations. The monthly median chlorophyll a concentrations ranged from five to 20 μg/L for all stations.

TN concentrations were higher during the wet season months and lower during the dry season (Figures 3-69 to 3-71). The monthly median TN concentrations ranged from one to two mg/L for all stations.

TP concentrations were higher during the wet season months and lower during the dry season (Figures 3-72 to 3-74).

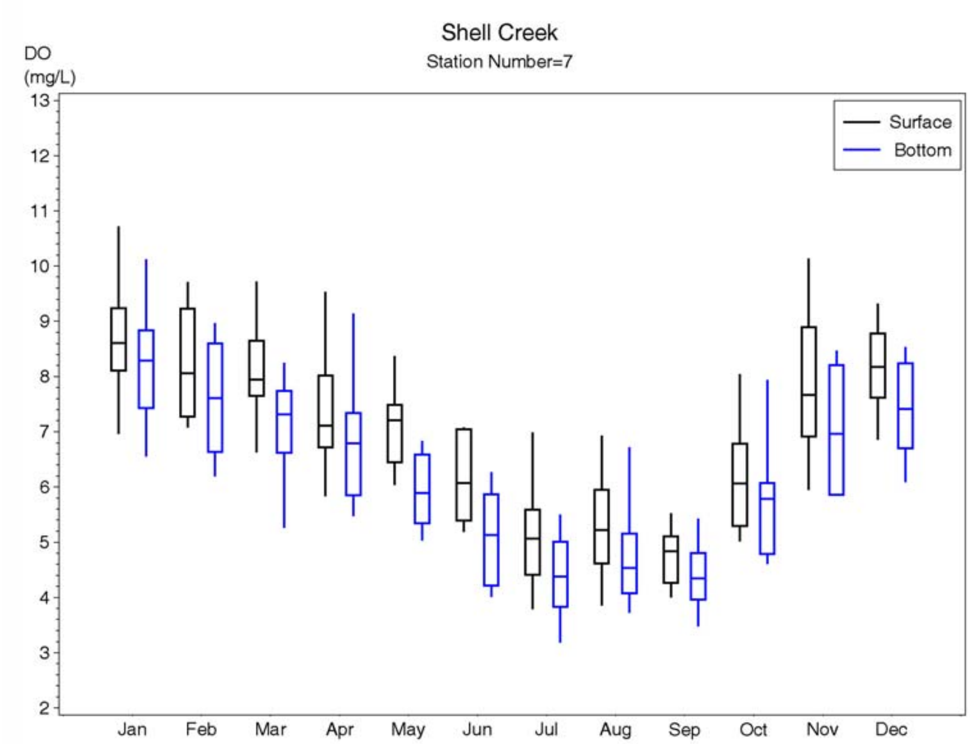


Figure 3-63. Monthly distribution of surface and bottom DO (1997-2004) at SC Station 7. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

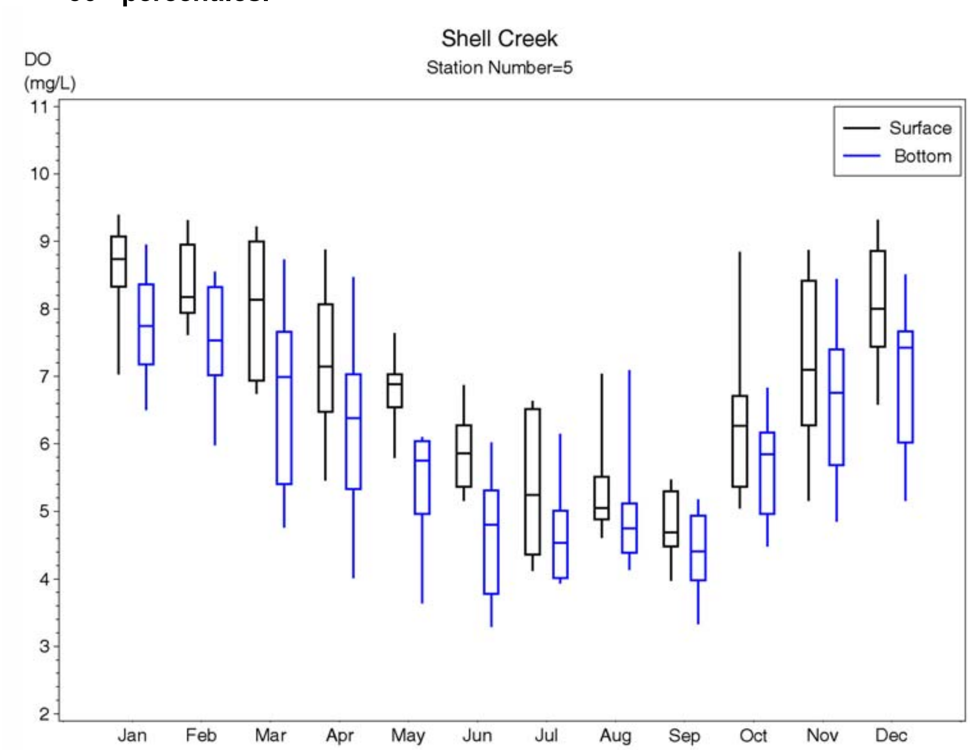


Figure 3-64. Monthly distribution of surface and bottom DO (1997-2004) at SC Station 5. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

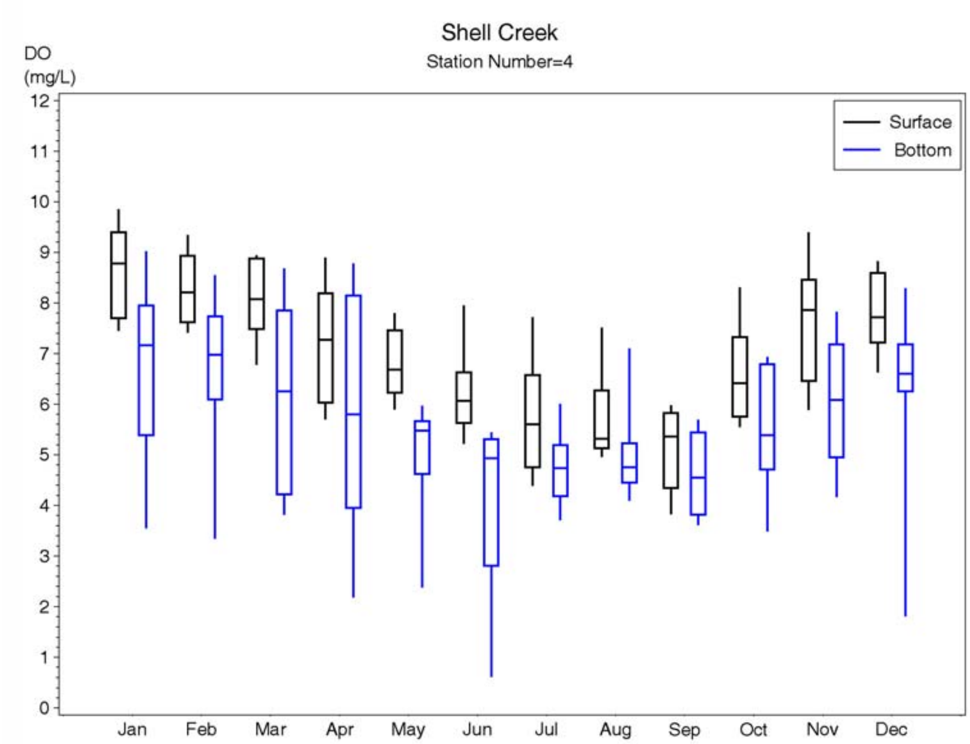


Figure 3-65. **Monthly distribution of surface and bottom DO (1997-2004) at SC Station 4. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

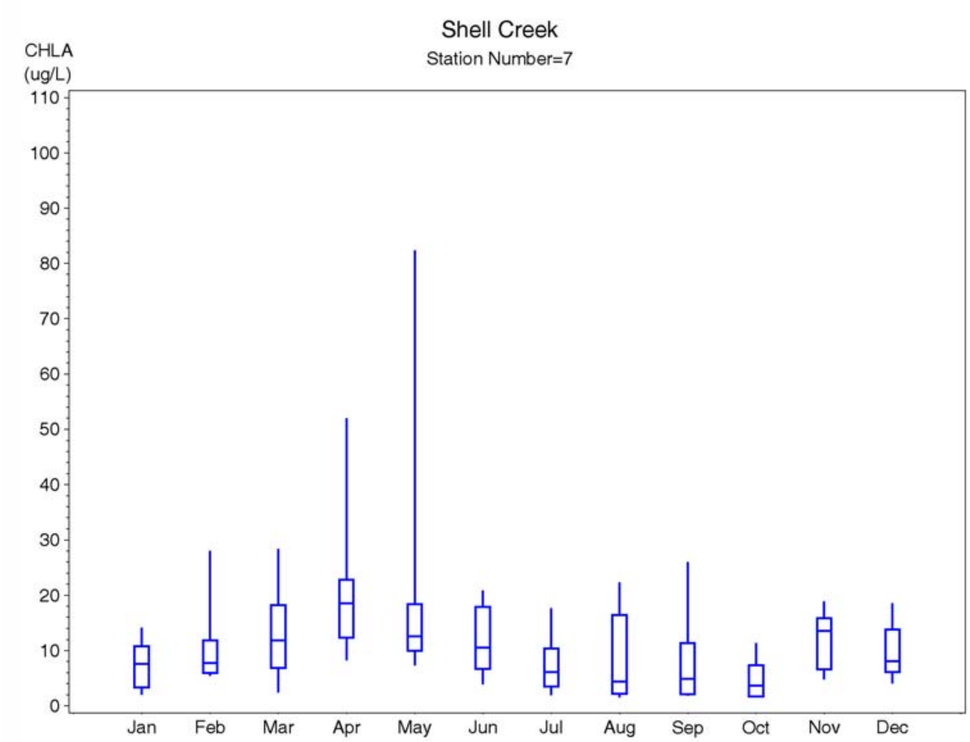


Figure 3-66. **Monthly distribution of chlorophyll *a* (1997-2004) at SC Station 7. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

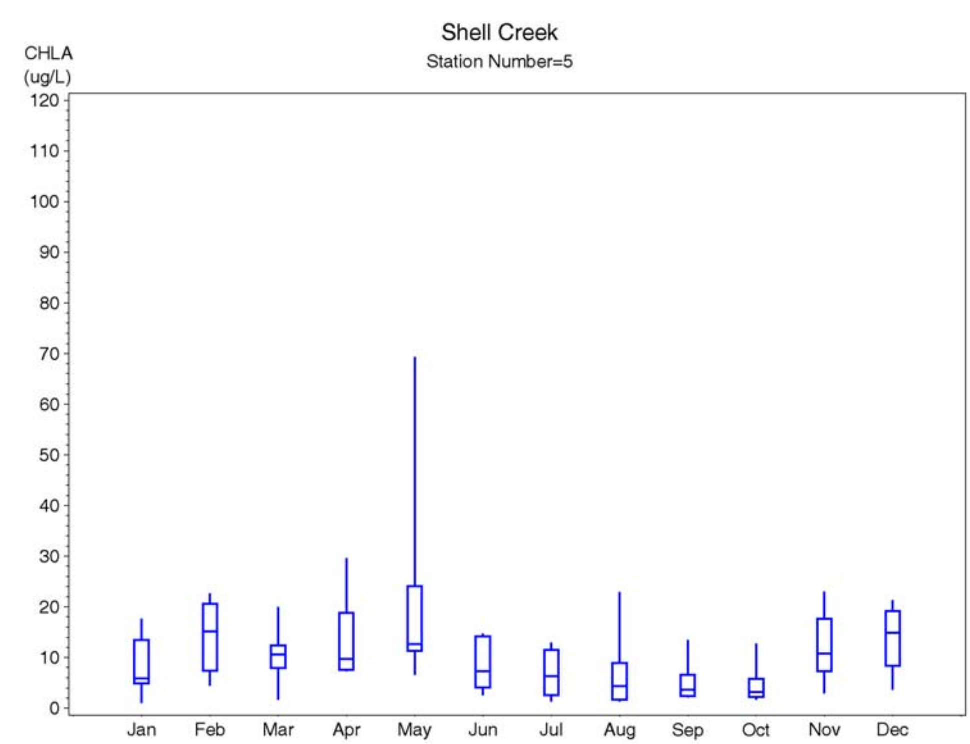


Figure 3-67. **Monthly distribution of chlorophyll *a* (1997-2004) at SC Station 5. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

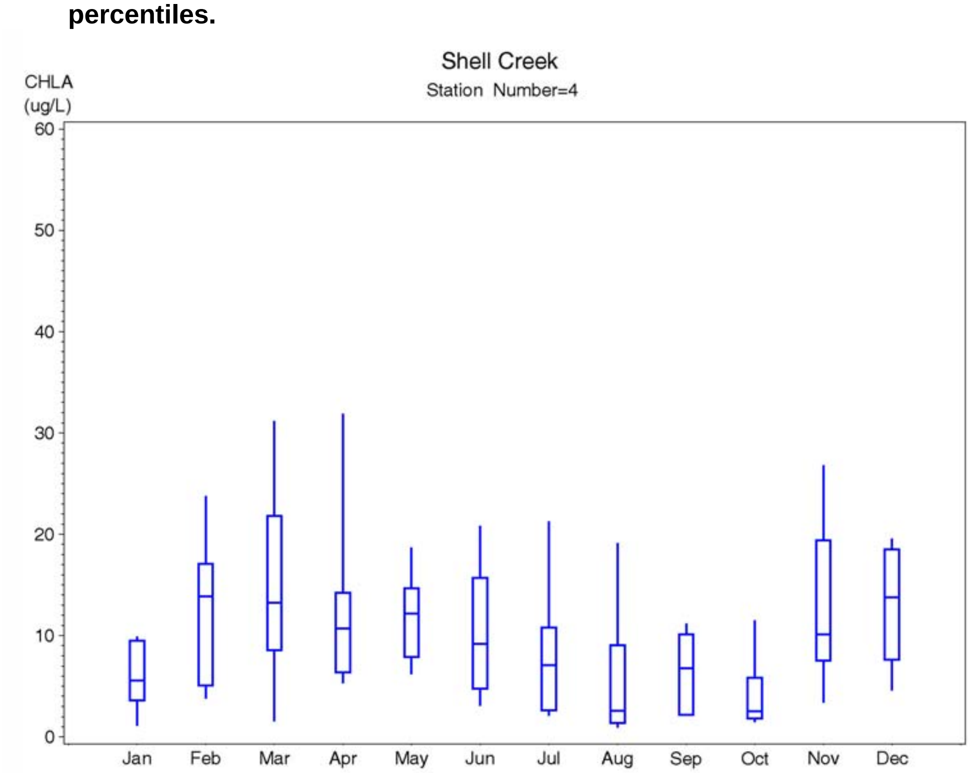


Figure 3-68. **Monthly distribution of chlorophyll *a* (1997-2004) at SC Station 4. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.**

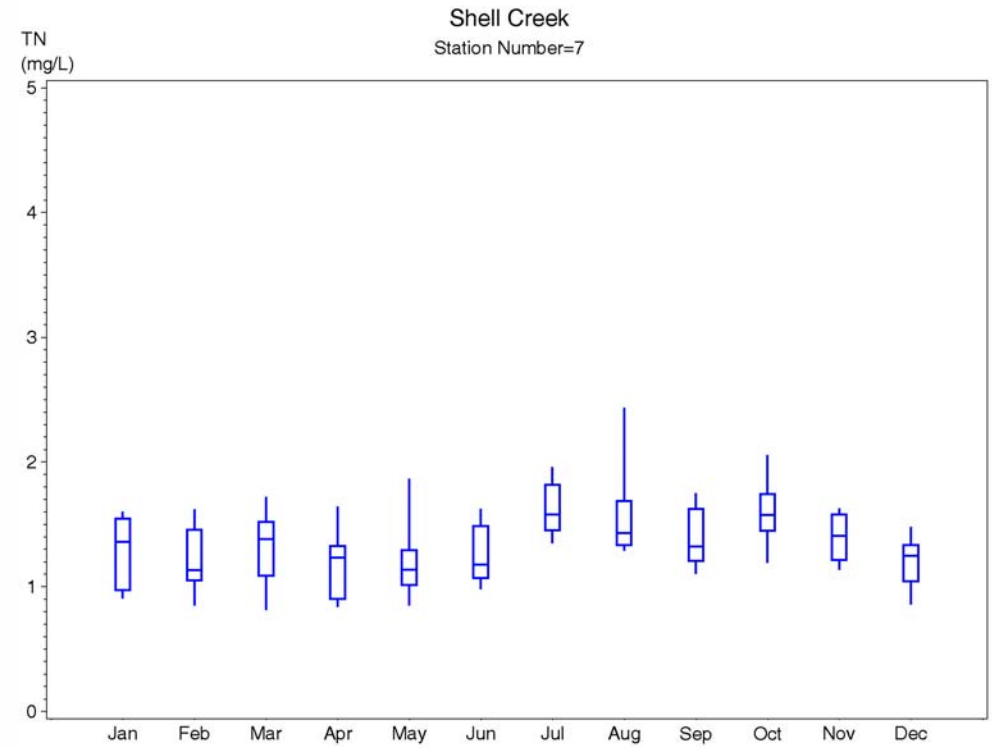


Figure 3-69. Monthly distribution of TN (1997-2004) at SC Station 7. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

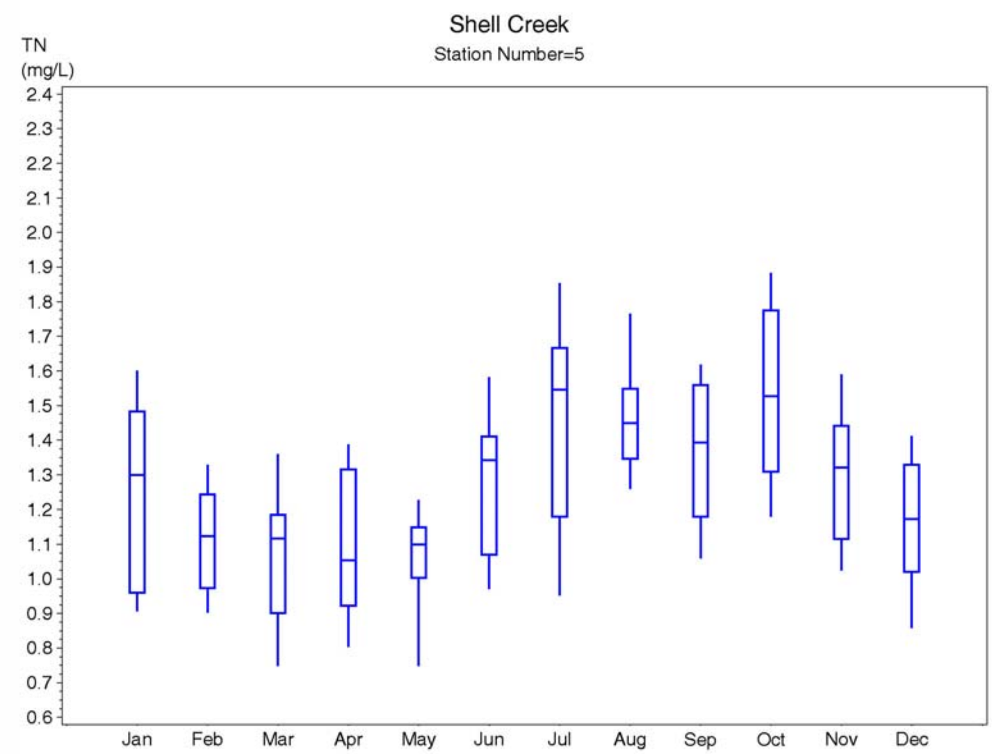


Figure 3-70. Monthly distribution of TN (1997-2004) at SC Station 5. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

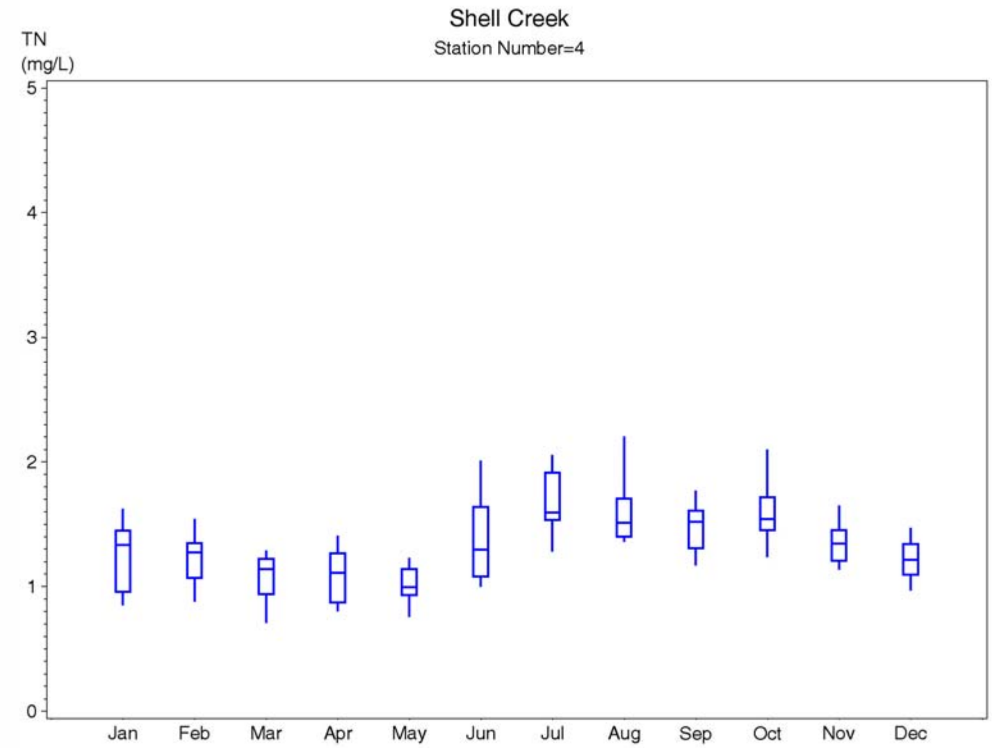


Figure 3-71. Monthly distribution of TN (1997-2004) at SC Station 4. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

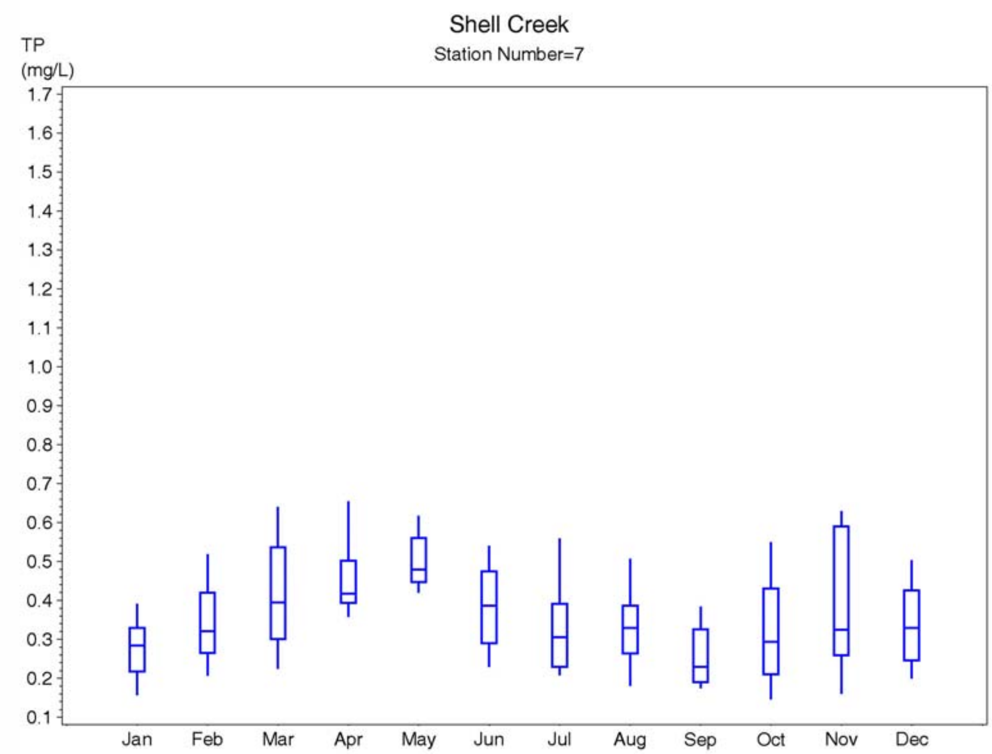


Figure 3-72. Monthly distribution of TP (1997-2004) at SC Station 7. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

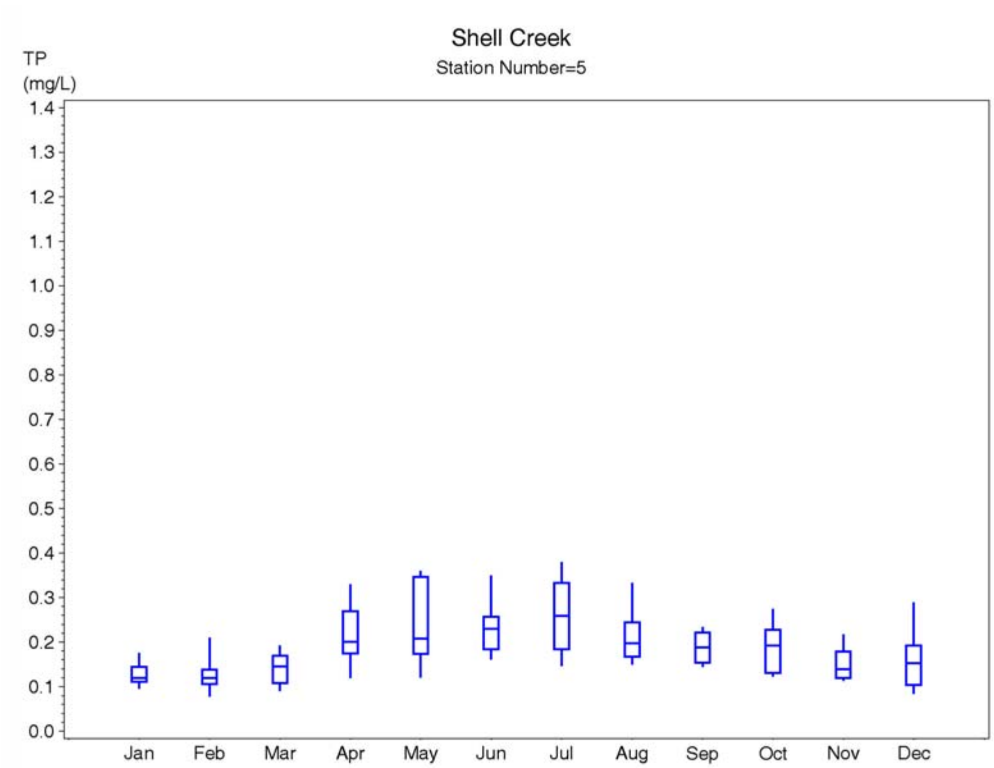


Figure 3-73. Monthly distribution of TP (1997-2004) at SC Station 5. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

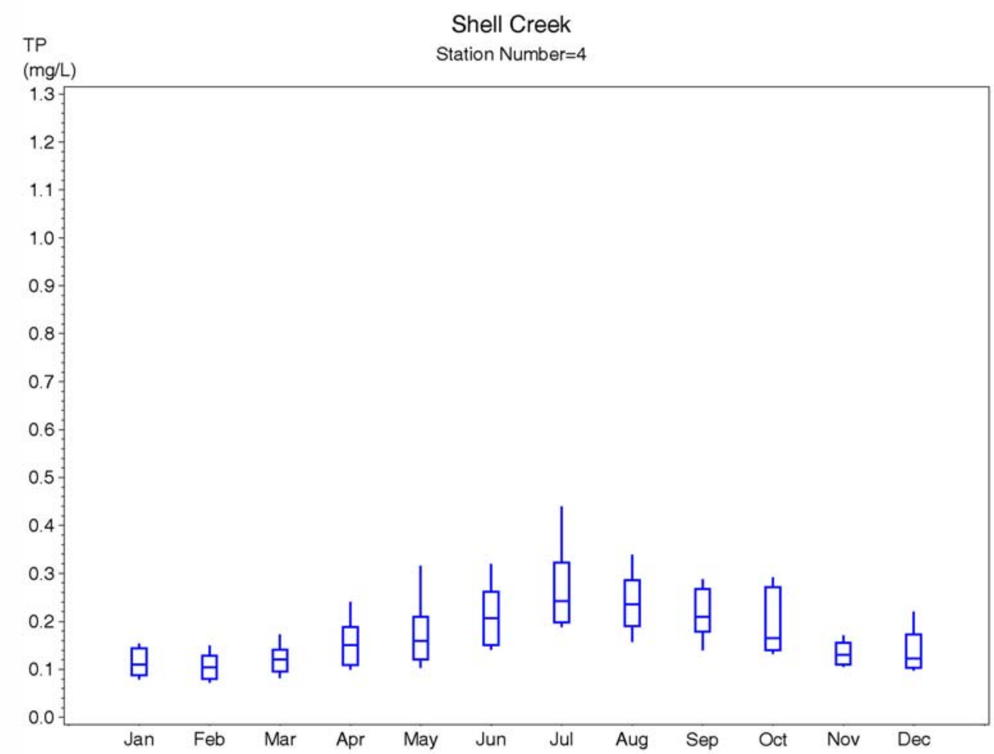


Figure 3-74. Monthly distribution of TP (1997-2004) at SC Station 4. Boxes represent the 25th, 50th, and 75th percentiles, while whiskers represent the 10th and 90th percentiles.

3.2.2.3 Spatial Variation in Water Quality Constituents

To describe the spatial variation in water quality constituents, plots are presented by river kilometer for all stations for all years (1997-2004).

As expected, salinity values decreased with distance upstream. Typical estuarine circulation resulted in lower salinities in surface water and higher salinities in bottom water. Salinity differences between surface and bottom water decreased as tidal influence decreased (Figures 3-75). The distribution of temperature values was observed to be relativity similar throughout SC. The longitudinal distribution of temperature observations over the geographic domain of the LPR is presented in Figure 3-76. Temperature was slightly lower in bottom waters for the majority of stations. The longitudinal distribution of DO over the geographic domain of SC is shown in Figure 3-77. Bottom waters had slightly lower DO than surface water and DO did not show large variations among stations.

The distribution of chlorophyll *a* concentrations did not vary spatially (Figure 3-78). TN concentrations did not vary with distance upstream (Figure 3-79). TP concentrations decreased with distance upstream, as shown in Figure 3-80. Higher concentrations downstream result from higher ambient TP concentrations in LPR relative to SC.

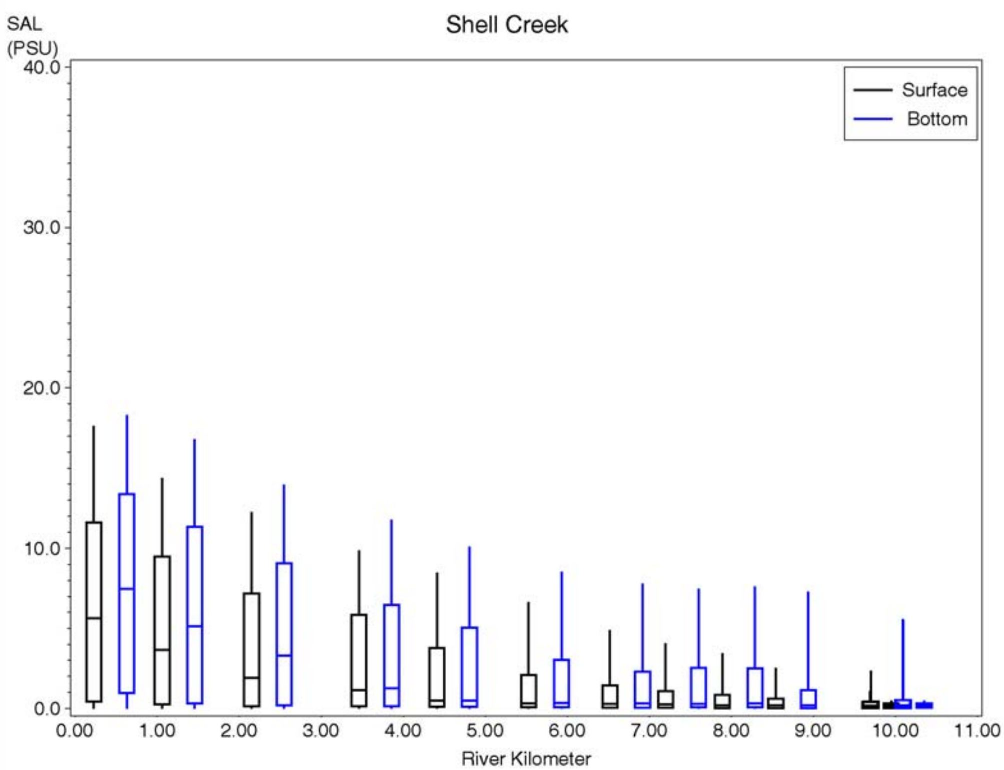


Figure 3-75. Observed longitudinal distributions of salinity for the SC.

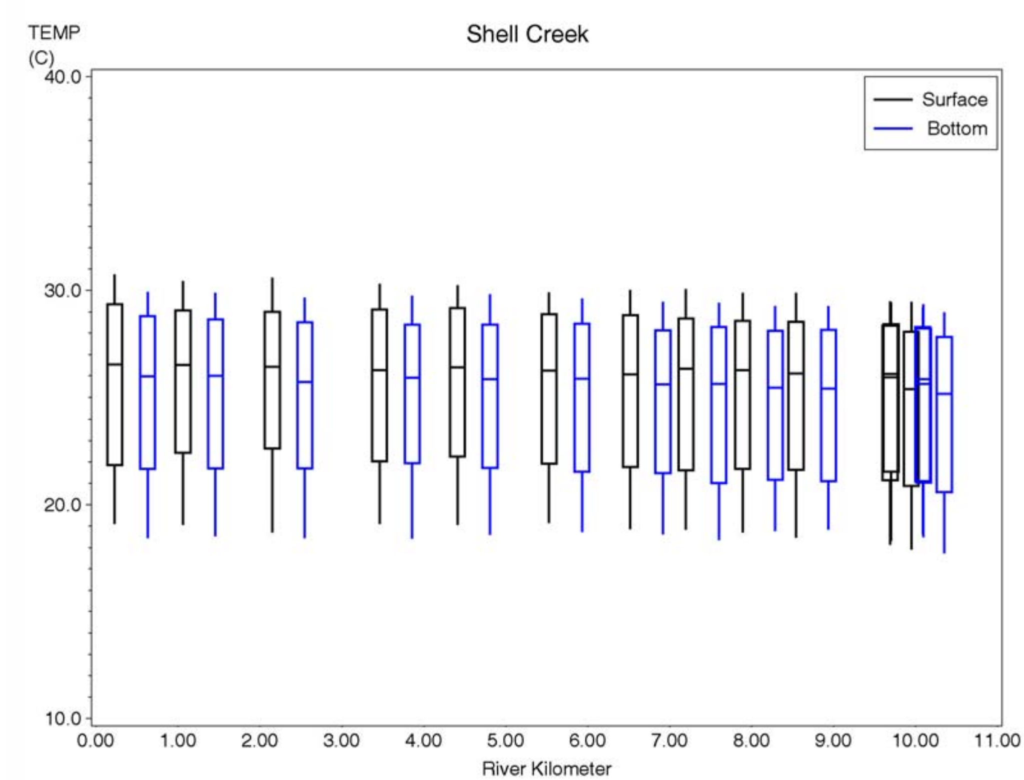


Figure 3-76. Observed longitudinal distributions of temperature for the SC.

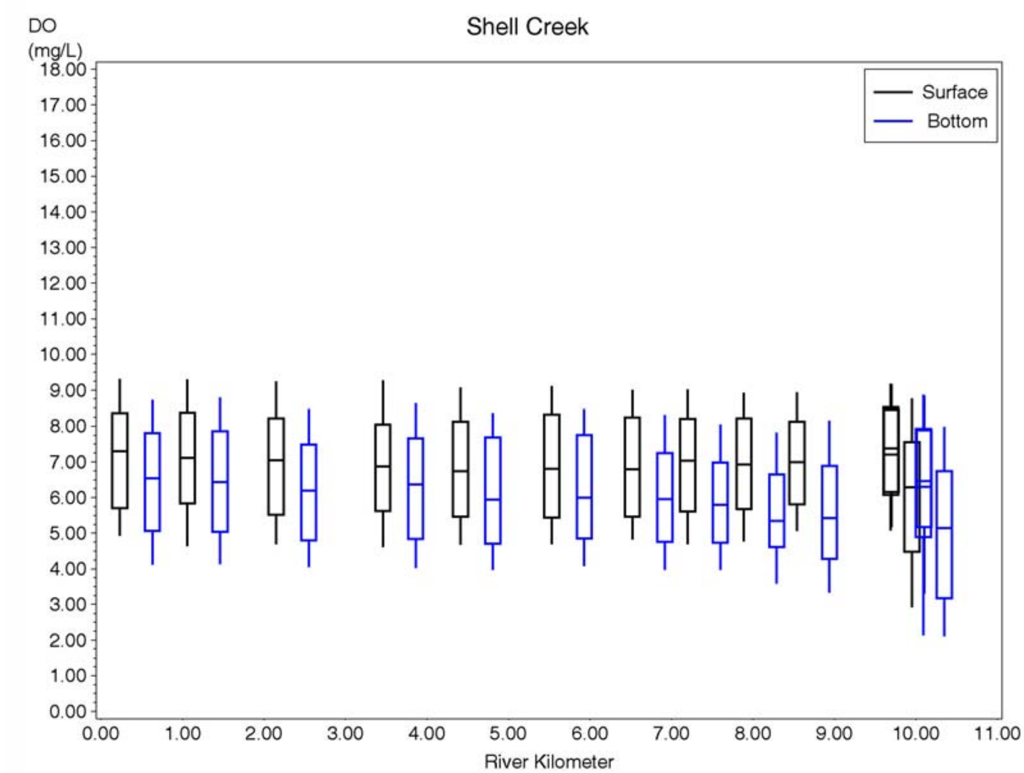


Figure 3-77. Observed longitudinal distributions of DO for the SC.

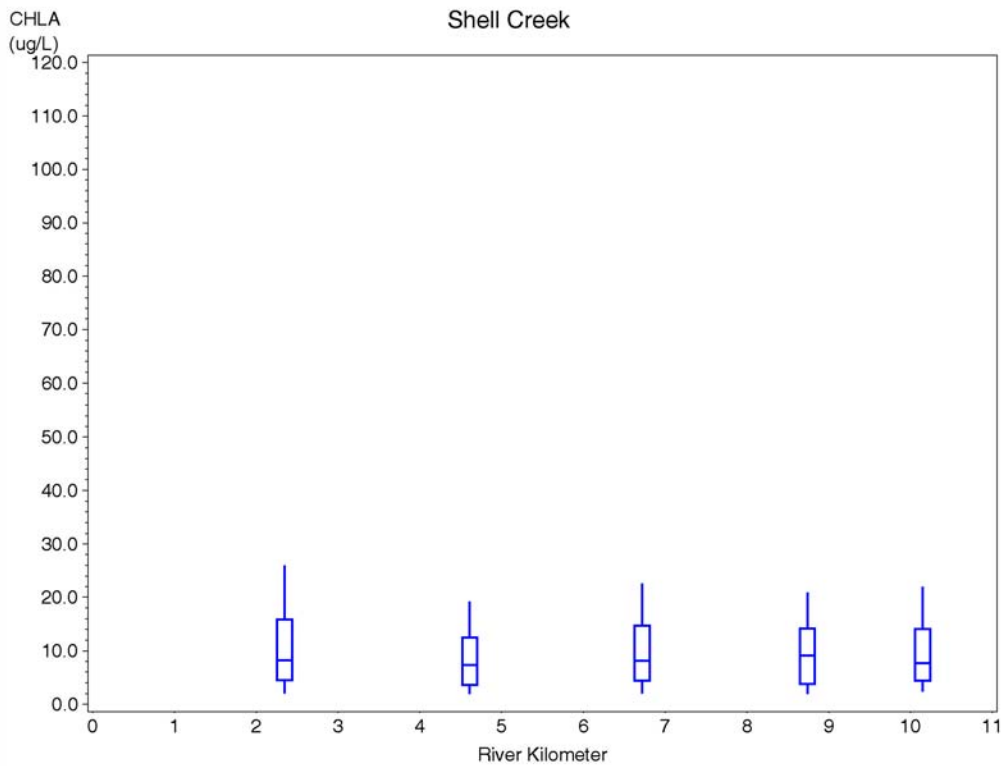


Figure 3-78. Observed longitudinal distributions of chlorophyll *a* for the SC.

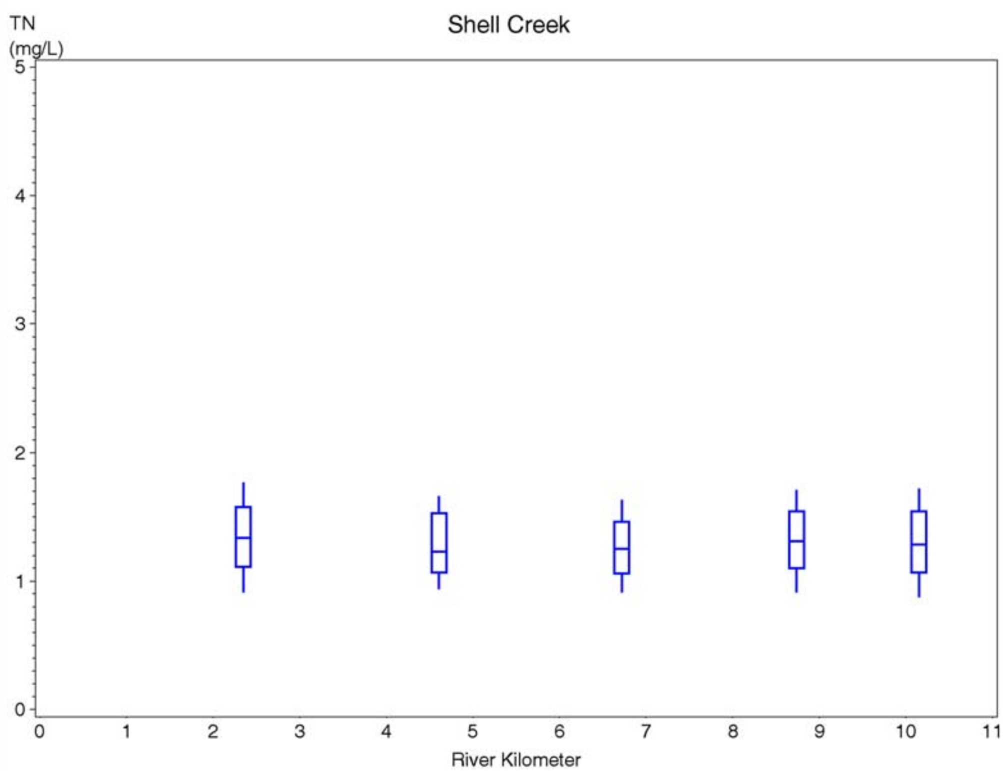


Figure 3-79. Observed longitudinal distributions of TN for the SC.

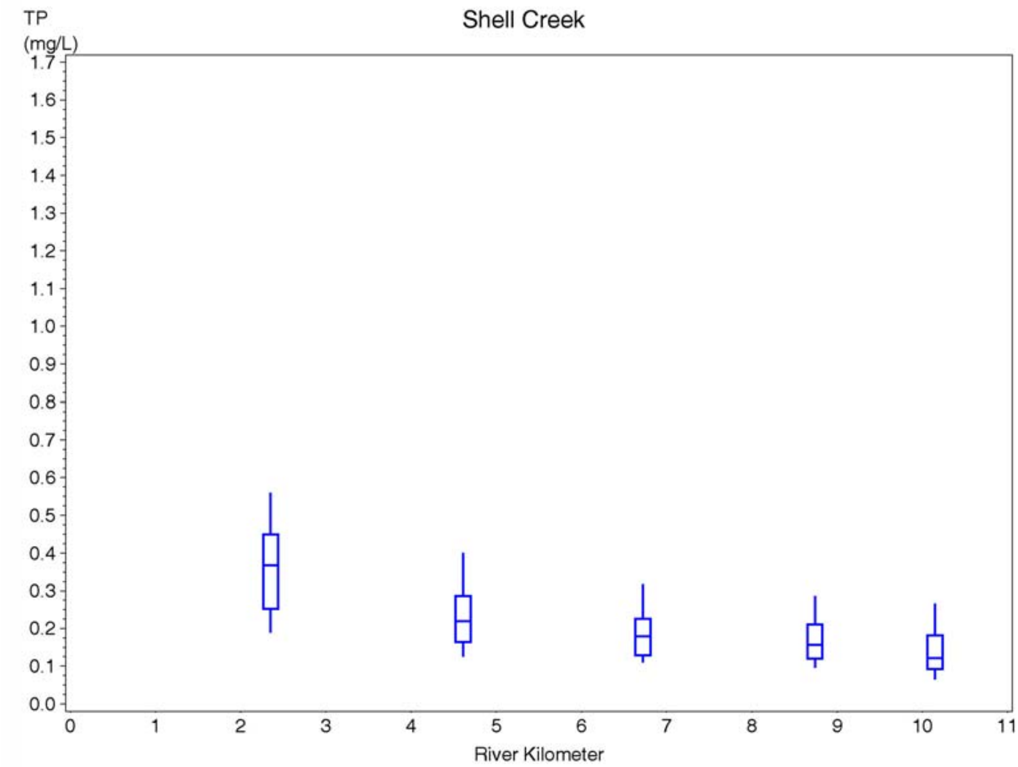


Figure 3-80. Observed longitudinal distributions of TP for the SC.

3.3 Summary of Water Quality Constituents

As expected, surface salinities are lower than bottom salinities and as one moves upstream surface and bottom salinities decrease. SC joins LPR at approximately rkm 15.5. Therefore, rkm zero for SC is equivalent to approximately rkm 15.5 for the LPR. Rkm zero to ten in SC are similar to the salinities in LPR from rkm 15 to rkm 25. As with salinity, DO in SC is similar to DO in LPR between rkm 15 and rkm 25. As anticipated, there is a general trend in both systems of higher DO concentrations in surface waters compared to bottom waters. The lowest DO concentrations were observed in the bottom water of LPR downstream of rkm ten.

Chlorophyll *a* concentrations were slightly lower in SC compared to LPR. The highest chlorophyll *a* concentrations were documented in the LPR at the confluence of SC. TN concentrations in LPR are more variable than those in SC and increase in the upstream direction. The lowest TN concentrations were documented in the downstream portion of LPR. TP concentrations in SC are generally lower than TP concentrations in LPR. For LPR, as with TN, TP concentrations increase in the upstream direction. In SC, TP concentrations decrease in the upstream direction.

4 BENTHIC MACROINVERTEBRATE COMMUNITY

Benthic macroinvertebrates are important living resources that can be sensitive to changes in flow regimes, and their relationship to flow is explored in this section. Flow is an influential component of estuarine and riverine systems, and changes to the flow regime can potentially affect many ecological and environmental variables (Figure 4-1). Flow affects the volume and velocity of the river, which directly affects benthos. During extremely high flows, benthic organisms may be physically washed out of the system. The transport of macroinvertebrates, known as “drift”, is important as a mechanism for the establishment of new populations downstream (Benson and Pearson 1987, Matthaei *et al.* 1997). Aquatic drift can reduce overcrowding and facilitate feeding. Additionally, flow affects the following abiotic parameters, which influence the abundance and distribution of benthos: salinity, dissolved oxygen, sediments, and nutrients.

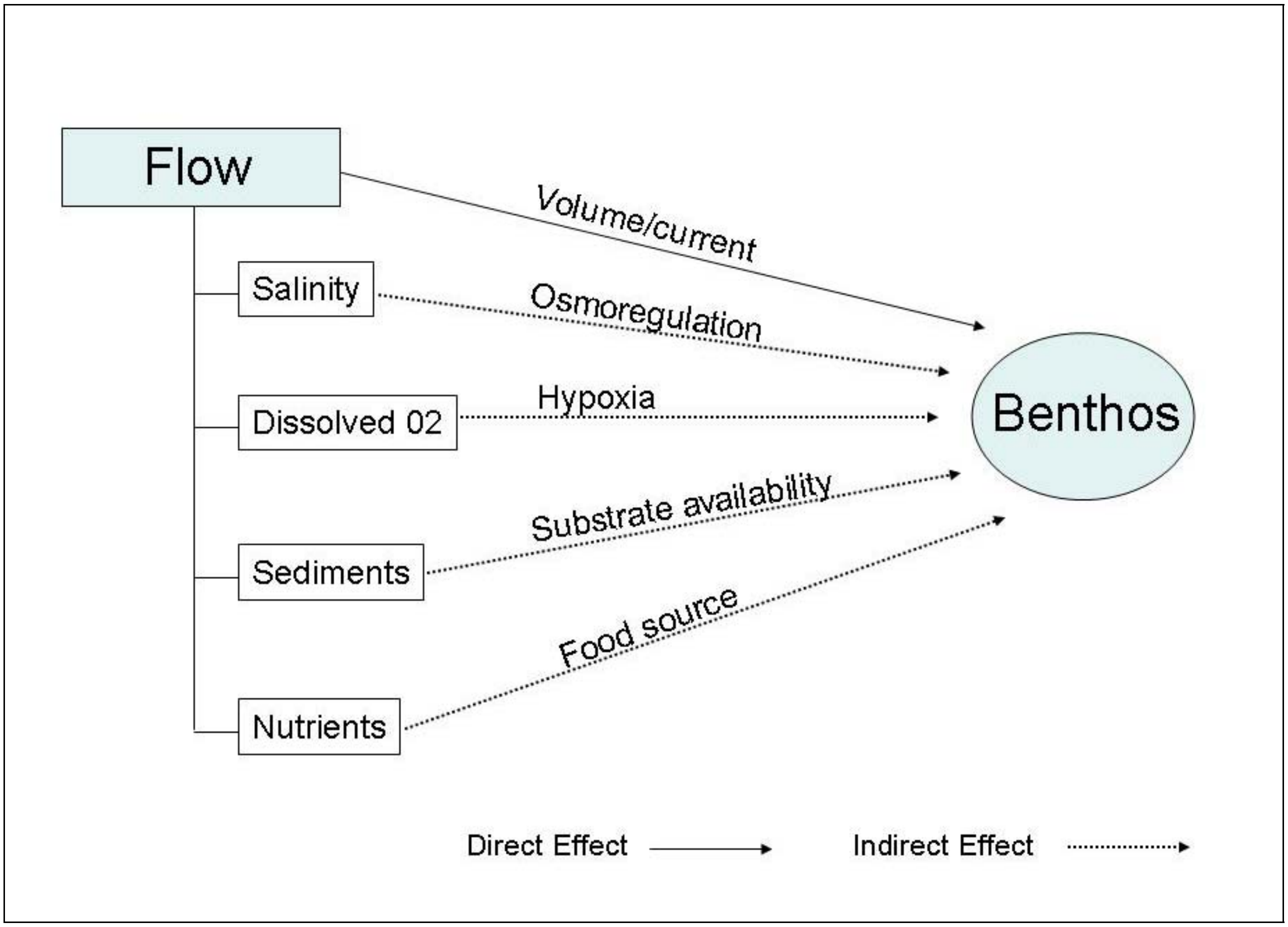


Figure 4-1. Conceptual diagram showing the direct (solid line) and indirect (dashed line) effects of flow on benthos.

Salinity is considered to be the primary physical factor that affects the biota of tidal rivers. In a tidal system, the salinity gradient will shift upstream or downstream due to natural variations in flow. Salinity is largely influenced by the amount of fresh-water inflow entering the system, and it is typically negatively correlated with flow in tidal rivers. A secondary contributor to fresh water in an estuarine system is precipitation. During high flow periods, salinity at a particular location is expected to be lower than during an average or low flow year, expanding the habitat available for freshwater and oligohaline organisms. During low flow periods, saline water may extend further upstream, facilitating habitat expansion for estuarine species while contracting the habitat available for freshwater organisms (Alber 2002).

Many benthic species are limited in range by the physiological challenges and stresses associated with variable salinity environments. Osmotic limitations restrict the ability of many freshwater species from using habitats in downstream portions that are tidally influenced. Marine species also face osmotic problems, which restrict access to low salinity and fresh-water habitats. Estuarine species typically tolerate a wide range of salinities, although they may have discrete “preferences” for optimal reproduction and growth. Salinity is less of an acute stressor and more a chronic stressor for estuarine invertebrates. For example, a common estuarine isopod, *Cyathura polita*, can complete its life cycle over salinities ranging from 0 to 30 ppt, although northern populations are capable of osmoregulation in distilled water for up to 12 hours (Kelly and Burbanck 1976).

Changes in the timing and amount of fresh-water inflow may alter the salinity regime such that shifts in dominant species occur as the physical environment becomes less favorable for some species and more favorable for others. That is, the “preferred” salinity regime may now occur at a different time, in a different location, or occupy a smaller/larger area of the system. For example, the displacement could move a preferred salinity regime to a reach of the river where the sedimentary factors are unfavorable (*cf.* “stationary” *vs.* “dynamic” habitats of Browder and Moore 1981). Since sediment type is also a key abiotic factor affecting the structure of benthic communities, community structure and function could be altered.

Freshwater inflow can affect sediments in both the tidal river and the receiving waters. Current velocity, available source material, and organic input determine substrate composition. The important components of substrate composition are the size of the sediment grains, interstitial space between the grains, and the presence or absence of organic detritus. Typically, coarser grained sediments drop out from the current first, and are deposited furthest upstream. Finer grained sediments are carried further downstream, with the finest sediments being carried the furthest. The translocation of these finer grained sediments provide habitat for emergent vegetation lower in the estuary (Flemer and Champ 2006). Since contaminants such as metals and organic compounds preferentially bind to smaller particles (Seidemann 1991), they may be removed from the estuary at higher flows.

At lower flows, downstream sediment transport is diminished. This may adversely affect habitat availability for emergent vegetation and may contribute to the retention of contaminants in the estuary (Alber 2002). Additionally, if freshwater flows are diminished, tidal currents may displace coarser sediments upstream (Flemer and

Champ 2006), altering the physical habitat of benthic organisms. Generally, biotic abundance and diversity increases with increasing substrate stability and the presence of organic detritus (Allan 1995).

The magnitude and timing of fresh-water inflows affect the amount of nutrients and organic matter that enters a waterway. Higher flows are associated with increased nutrient loading and lower nutrient concentrations. Low flows contribute to decreased turbidity, increased water clarity (Alber 2002, Flemer and Champ 2006). Under extreme low flows primary production could even shift from a phytoplankton-based system to one driven by benthic algae (Baird and Heymans 1996). Increased secondary production by benthic organisms is typically observed some time after a period of increased flow (Kalke and Montagna 1989, Bate *et al.* 2002).

Flow can affect dissolved oxygen concentrations in different ways. Decreased flows may increase hydraulic residence time in embayments, and backwater regions of tidal rivers which, in turn, maintains density stratification and leads to lowered levels of dissolved oxygen (Figure 4-2). This may also facilitate development of algal blooms, especially cyanobacteria. Conversely, decreased flows may also contribute to increases in dissolved oxygen. By reducing the amount of density stratified water in the estuary there is more opportunity for oxygenated surface waters mixing with bottom waters (Alber 2002, Flemer and Champ 2006). Any adverse effects of flow on dissolved oxygen could impact the benthos.

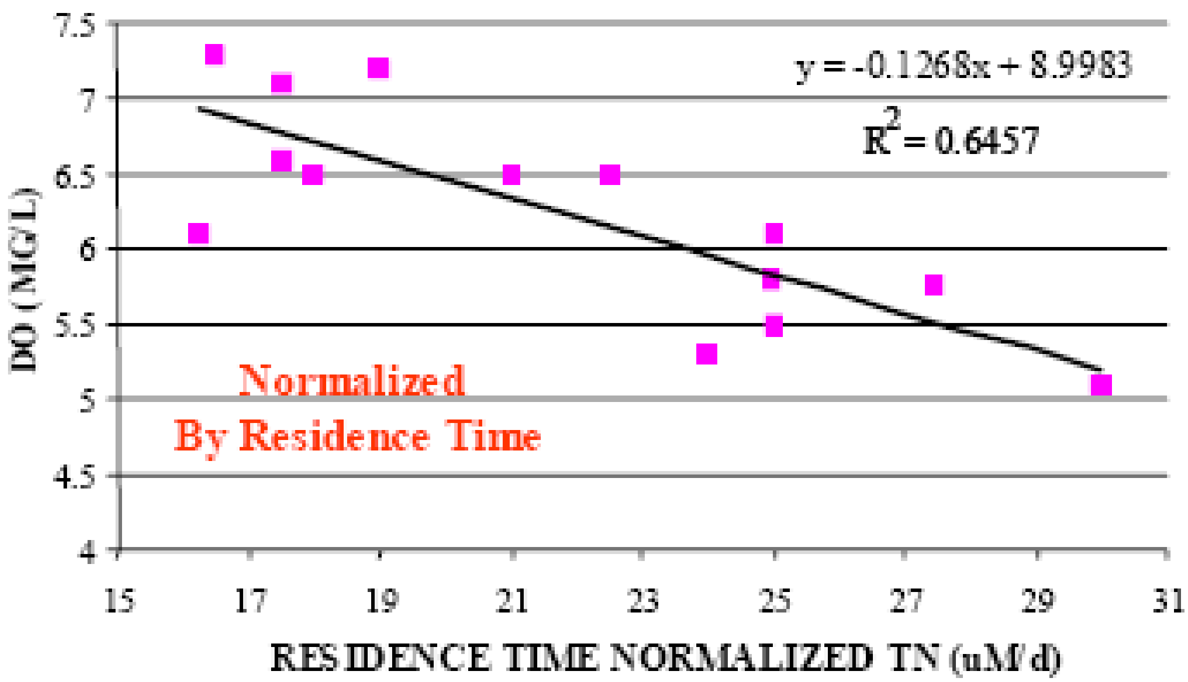


Figure 4-2. The relationship between dissolved oxygen and residence time in embayments of Maine estuaries From: Latimer and Kelly, 2003 (modified from Kelly *et al.* 1997).

The following describes a series of data analyses conducted to assess the benthic community structure of the LPR, with an emphasis on exploring relationships to salinity and freshwater inflows.

4.1 Sources of Benthic Macroinvertebrate Data

Mote Marine Laboratory collected 581 “core” samples from the Lower Peace River during 1998-1999 (Mote Marine Laboratory 2002) and 39 core samples from SC during 2003 (Mote Marine Laboratory 2005) (Table 4-1; Figure 4-3). Estevez (1986) did collect benthic samples at 25 stations in Charlotte Harbor in 1980. However, only two stations were located in the area we consider to be the Lower Peace River and a different sampling gear was used. Therefore these data were not included in this report.

Mote Marine Laboratory (2002) divided the Lower Peace River into four longitudinal zones. These zones were based upon an analysis of long-term salinity data. Zone 1 had mean bottom salinities of <0.5 ppt. This Zone extended from river kilometer (RKM) 34 downstream to RKM 21.5. Zone 2 had mean bottom salinities ranging from 0.5 to 8.0 ppt. Zone 2 encompassed rkm 16.0 to 21. Zone 3 had mean bottom salinities ranging from 8.0 to 16.0 ppt. Zone 3 extended from rkm 6 to 15.5. Zone 4 had mean bottom salinities >16 ppt and extended downstream from rkm 6.

The sampling gear was a 7.62-cm (3”) diameter core sampler (area= 45.6 cm^2). Non-quantitative samples were collected with a sweep net and are not considered in this report.

Near-bottom salinity data were available for 540 of these samples. Other abiotic data collected in concert with many of these samples included temperature, pH, dissolved oxygen, and sample depth.

Additional samples were collected for particle size analysis. The sediment data were not incorporated into any quantitative analyses because the sample size was relatively small (n=121) and, for the 1998-1999 Lower Peace River sampling, only the November 1998 samples were analyzed (Mote Marine Laboratory 2002).

4.2 Sample Processing

Core samples were sieved through a 0.5-mm mesh sieve and fixed with a 10% solution of buffered formalin. Samples were sorted in their entirety and the organisms identified to the lowest practical taxonomic level and counted.

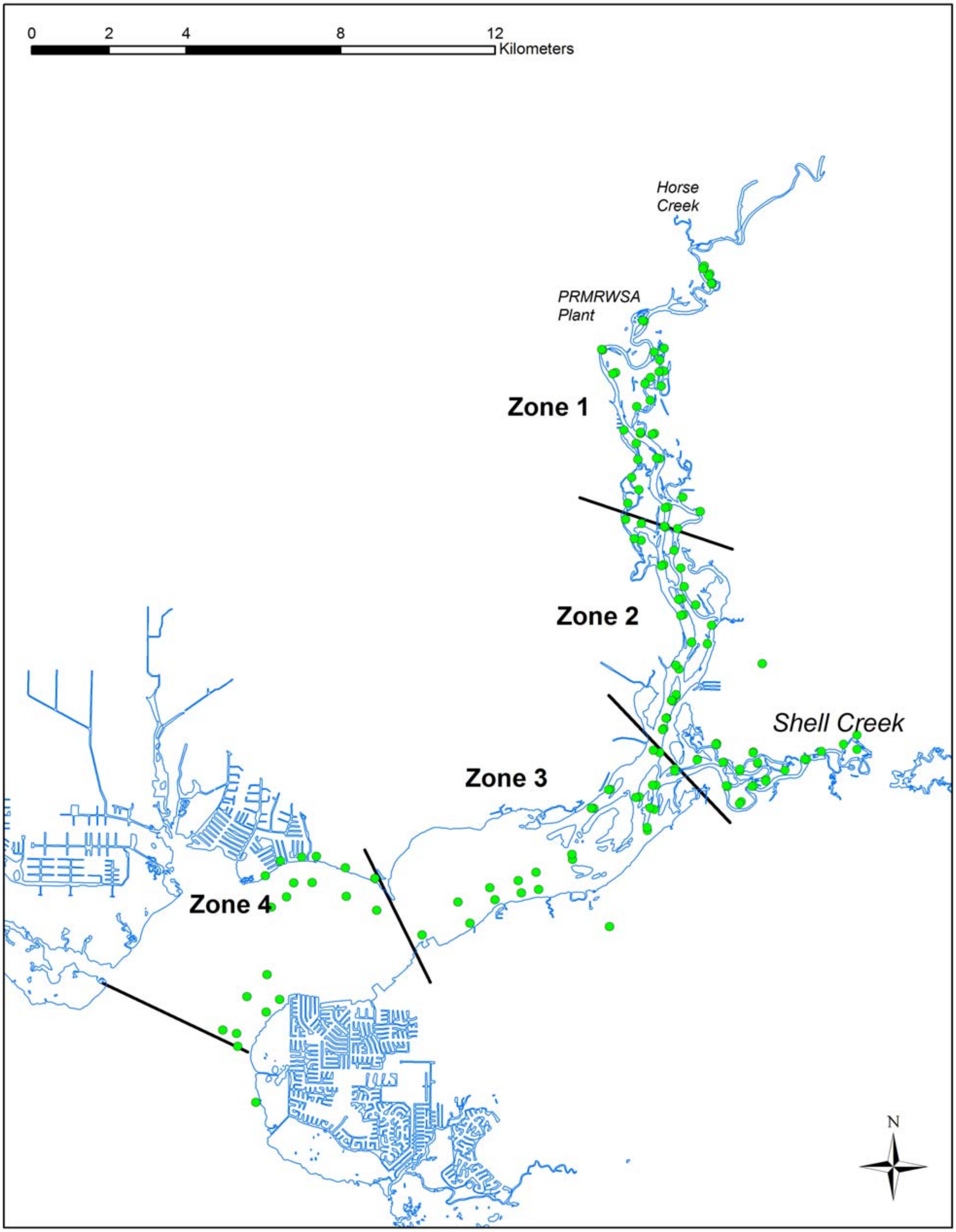


Figure 4-3. Location of benthic sampling stations in the LPR (1998 and 1999) and SC (2003).

Table 4-1. **Number of benthic samples collected from the LPR, by river zone and subarea (Mote Marine Laboratory 2002, 2005).**

Zone and Subarea	Number of Samples
Peace River Zone 1	95
Lettuce Lake	46
Deep Creek	46
Peace River Zone 2	95
Hunter Creek	49
Peace River Zone 3	100
Peace River Zone 4	100
SAV Sites RKM 0	50
Subtotal: Lower Peace River	581
Shell Creek	39
TOTAL	620

4.3 Data Analysis Objectives

Data were analyzed to satisfy the following objectives:

- Identify the "dominant" benthic taxa within the four previously defined zones (Mote Marine Laboratory 2002) of the LPR and SC;
- Define resource-based salinity classes, based upon the distribution of the benthos, for the LPR, including SC;
- Quantify the spatial characteristics of the structure of the benthos within and between zones of the LPR, including SC, Deep Creek, Hunter Creek, Lettuce Lake, and samples collected from SAV (submerged aquatic vegetation) beds at the mouth of the river;
- Quantify the association between a suite of abiotic variables, including salinity and cumulative flows for the LPR. and three biotic variables:
  - The abiotic (independent) variables included:
    - Salinity;
    - Cumulative flow over 7, 15, 30, 60, 90, and 180 days preceding sample collection, as well as the flow on each sample date (Montagna and Kalke 1992). The contributions to these flows differed by zone within the river, reflecting contributions not only upstream at Arcadia, but also contributions from Horse Creek (Zones 1 to 4),
  - The biotic (dependent) variables included:
    - Numbers of taxa;
    - Shannon-Wiener diversity;
    - Benthic standing crop (as total numbers of individuals)

- Determine which abiotic variables, including a large number of flow-related variables, were most highly correlated with multivariate benthic community structure;
- Evaluate the optimum salinity and tolerance ranges for selected taxa in the Lower Peace River.

These analyses should provide insight into the extent to which salinity and flow-related variables affect the composition and structure of the benthos within the Lower Peace River study area.

4.4 Results

4.4.1 Abiotic Characteristics of the Study Area

The 25th percentile salinities were generally similar within zones 1 and 2 of the LPR, including Lettuce Lake, Deep Creek, and Hunter Creek (Table 4-2a). The 75th percentile salinities increased moving downstream. Salinity in Zones 3 and 4 were typically in the mesohaline to polyhaline ranges of the Venice classification. Dissolved oxygen concentrations were typically >4 ppm throughout the study area (Table 4-2). pH values were generally circumneutral except in Zone 4 (slightly alkaline) (Table 4-2a). Sediments within Zone 1 had the lowest median percentage of fine-grained particles (silt+clay) and those in Zone 3 had the highest (Table 4-2a).

Salinities in SC were oligohaline and, therefore, more similar to those of Zones 1 and 2 (Table 4-2b). There was no evidence of hypoxia during the single sampling event in SC, and pH was slightly acidic.

4.4.2 Taxonomic Composition and Dominance

At least 176 distinct taxa have been identified from benthic collections in the LPR and SC combined (Appendix 4-1). Approximately 40 of these taxa (23%) are generally considered fresh water or tolerant of very low salinities (*e.g.*, chironomid larvae, some oligochaetes).

"Dominance" was calculated as the geometric mean of a taxon's Percent Occurrence and Percent Composition. This metric integrates a measure of how widespread an organism is in the study area (Percent Occurrence) with its contribution to the overall standing crop (Percent Composition). "Dominant taxa" (Table 4-3a) of the Lower Peace River varied between the previously defined zones.

Dominant taxa *within* Zone 1 were predominantly freshwater taxa that can tolerate low salinities. These include the invasive bivalve *Corbicula fluminensis*, hydrobiid gastropods and larvae of chironomids (Table 4-3a). Estuarine taxa such as some amphipods were more highly ranked in Deep Creek and the Peace River proper, than in Lettuce Lake.

Table 4-2. Median (interquartile ranges) of selected abiotic variable, by zone (Mote Marine Laboratory 2002) and subarea of the LPR and SC.

A. Lower Peace River

	Temperature (^oC)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	% Silt+Clay	Depth (m)
Peace River Zone 1	27.2 (22.0-28.1)	0.2 (0.1-0.4)	5.9 (5.2-6.6)	7.14 (6.86-7.25)	1.2 (0.0-17.5)	0.6 (0.3-1.4)
Lettuce Lake	26.6 (21.8-26.8)	0.2 (0.2-1.2)	5.5 (4.5-6.5)	7.08 (6.85-7.15)	No Data	0.5 (0.2-0.7)
Deep Creek	26.4 (22.0-27.8)	0.2 (0.2-6.2)	5.9 (4.5-6.6)	7.09 (6.66-7.18)	2.2 (0.8-14.6)	1.4 (0.3-1.6)
Peace River Zone 2	27.6 (22.3-28.4)	1.2 (0.2-15.2)	6.0 (4.6-6.4)	7.07 (6.86-7.51)	12.0 (5.4-21.2)	0.6 (0.2-1.7)
Hunter Creek	27.0 (22.9-28.2)	0.3 (0.2-7.9)	6.0 (5.3-6.3)	7.07 (6.79-7.23)	4.2 (3.3-23.6)	0.8 (0.2-1.4)
Peace River Zone 3	27.0 (22.9-28.2)	17.7 (7.0-22.2)	6.0 (4.7-6.7)	7.52 (7.24-7.70)	9.9 (7.4-16.2)	1.0 (0.2-1.8)
Peace River Zone 4	26.2 (22.7-28.6)	25.9 (21.5-27.9)	6.9 (5.4-7.8)	7.71 (7.60-7.84)	6.2 (4.6-16.6)	0.6 (0.1-1.7)
SAV Sites	No Data	No Data	No Data	No Data	5.4 (4.8-6.0)	No Data

B. Shell Creek

Temperature (^oC)	Salinity (ppt)	Dissolved Oxygen (ppm)	pH	% Silt+Clay	Depth (m)
29.8 (28.9-30.5)	1.3 (0.7-2.7)	5.3 (4.5-6.2)	6.82 (6.60-6.93)	6.4 (4.0-10.0)	2.9 (2.0-5.7)

Within Zone 2, including Hunter Creek, estuarine taxa were included among the more highly ranked dominants (Table 4-3a). Examples include the amphipods *Apocorophium lacustre* and *Grandidierella bonnieroides*. Some freshwater taxa (e.g., chironomid larvae) were also ranked.

Estuarine taxa predominated within Zone 3 in the Lower Peace River proper (Table 4-3a). Unlike Zone 2, bivalves (*Mulinia lateralis*, *Amygdalum papyrium*, and *Polymesoda caroliniana*) were more highly ranked. Amphipods were less important in Zone 3 than in Zone 2.

Freshwater taxa were not among the ranked dominants in Zone 4 (Table 4-3a). Bivalves and crustaceans remained highly ranked in Zone 4 and both polychaetes and amphipods were dominants in the SAV sites.

Dominants in SC (Table 4-3b) included *Polymesoda caroliniana, Grandidierella bonnieroides*, and hydrobiid gastropods.

Table 4-3. Median (interquartile ranges) of selected abiotic variable, by zone (Mote Marine Laboratory 2002) and subarea of the LPR and SC.

A. Lower Peace River

A-1 Peace River Zone 1, Lettuce Lake, and Deep Creek

Lower Peace River Zone 1	%Comp	%OCC	Dom		Lettuce Lake	%Comp	%OCC	Dom		Deep Creek	%Comp	%OCC	Dom
Corbicula fluminea	17.06	65.26	33.37		*Cladotanytarsus*	19.47	41.30	28.36		*Apocorophium lacustre*	22.57	56.52	35.72
Cladotanytarsus	15.69	43.16	26.02		*Hydrobiidae*	9.60	54.35	22.84		*Cladotanytarsus*	10.22	39.13	20
Gammarus cf tigrinus	11.46	47.37	23.29		*Apocorophium lacustre*	15.02	28.26	20.60		*Hydrobiidae*	8.77	41.3	19.04
Apocorophium lacustre	14.82	35.79	23.03		*Corbicula fluminea*	9.60	32.61	17.69		*Gammarus cf tigrinus*	5.88	50	17.14
Hydrobiidae	9.57	45.26	20.81		*Polypedilum scalaenum group*	7.09	32.61	15.21		*Corbicula fluminea*	8.26	32.61	16.41
Grandidierella bonnieroides	7.33	30.53	14.96		*Polypedilum halterale group*	3.89	43.48	13.01		*Grandidierella bonnieroides*	6.39	41.3	16.24
Polypedilum scalaenum group	3.37	30.53	10.14		*Gammarus cf tigrinus*	4.66	34.78	12.73		*Tanytarsus*	4.86	30.43	12.16
Tanytarsus	1.86	29.47	7.40		*Grandidierella bonnieroides*	5.22	23.91	11.17		*Polypedilum scalaenum group*	4.51	26.09	10.85
Polypedilum halterale group	2.13	21.05	6.70		*Tanytarsus*	2.78	32.61	9.52		*Polypedilum halterale group*	3.75	30.43	10.68
Chironomidae	1.24	25.26	5.60		*Chironomidae*	2.92	28.26	9.09		*Laeonereis culveri*	3.24	34.78	10.61
Laeonereis culveri	1.54	20.00	5.54		*Laeonereis culveri*	2.99	23.91	8.46		*Coelotanypus*	2.39	28.26	8.21
Apocorophium louisianum	1.70	12.63	4.63		*Tanytarsus sp*	2.29	21.74	7.06		*Apocorophium louisianum*	2.39	15.22	6.02
Chironomus	1.21	12.63	3.91		*Stictochironomus*	1.67	28.26	6.87		*Edotea montosa*	1.62	21.74	5.93
Taphromysis bowmani	0.78	16.84	3.63		*Coelotanypus*	1.25	28.26	5.95		*Chironomus*	1.79	19.57	5.92
Cryptochironomus	0.57	17.89	3.18		*Chironomus*	1.53	13.04	4.47		*Tanytarsus sp o*	1.79	17.39	5.58
Ceratopogonidae	0.51	15.79	2.84		*Fissimentum*	0.97	19.57	4.36		*Amakusanthura magnifica*	1.53	17.39	5.16
Edotea montosa	0.57	11.58	2.56		*Stempellina*	0.83	17.39	3.81		*Procladius*	1.36	19.57	5.16
Polymesoda caroliniana	0.51	12.63	2.54		*Dicrotendipes*	1.46	8.70	3.56		*Fissimentum sp*	1.19	17.39	4.55
Procladius	0.54	10.53	2.38		*Procladius*	0.56	17.39	3.11		*Cryptochironomus*	0.85	19.57	4.08
Coelotanypus	0.49	10.53	2.26		*Edotea montosa*	1.04	8.70	3.01		*Chironomidae*	0.85	17.39	3.85

A-2 Peace River Zone 2 and Hunter Creek

Lower Peace River Zone 2	%Comp	%OCC	Dom		Hunter Creek	%Comp	%OCC	Dom
Apocorophium lacustre	31.99	47.37	38.93		*Grandidierella bonnieroides*	19.00	59.18	33.53
Grandidierella bonnieroides	11.75	44.21	22.79		*Apocorophium lacustre*	19.64	40.82	28.31
Ampelisca abdita	8.17	29.47	15.52		*Hydrobiidae*	7.18	40.82	17.11
Hydrobiidae	5.07	42.11	14.61		*Laeonereis culveri*	5.15	53.06	16.53
Polypedilum scalaenum group	3.80	55.79	14.56		*Streblospio gynobranchiata*	7.22	28.57	14.36
Laeonereis culveri	3.60	57.89	14.43		*Apocorophium louisianum*	8.10	24.49	14.08
Apocorophium louisianum	5.57	29.47	12.81		*Hobsonia florida*	3.59	40.82	12.10
Streblospio gynobranchiata	3.14	38.95	11.05		*Edotea montosa*	2.58	38.78	9.99
Cyclaspis cf varians	3.03	26.32	8.92		*Polymesoda caroliniana*	3.63	26.53	9.82
Edotea montosa	2.47	30.53	8.69		*Polypedilum scalaenum group*	2.07	32.65	8.22
Corbicula fluminea	3.25	23.16	8.67		*Gammarus cf tigrinus*	1.98	24.49	6.96
Polymesoda caroliniana	2.36	27.37	8.04		*Coelotanypus*	1.56	28.57	6.68
Amakusanthura magnifica	1.59	31.58	7.08		*Amygdalum papyrium*	3.08	10.20	5.61
Hobsonia florida	1.38	32.63	6.72		*Polydora ligni*	2.99	8.16	4.94
Amygdalum papyrium	2.36	18.95	6.69		*Corbicula fluminea*	1.29	16.33	4.59
Gammarus cf tigrinus	1.83	17.89	5.72		*Amakusanthura magnifica*	0.78	24.49	4.38
Polydora ligni	1.51	17.89	5.20		*Chironomus*	0.78	20.41	3.99
Cryptochironomus	0.81	26.32	4.62		*Rangia cuneata*	1.15	12.24	3.75
Tagelus plebeius	0.70	17.89	3.54		*Ampelisca abdita*	0.92	10.20	3.06
Almyracuma proximoculi	0.85	14.74	3.54		*Ceratopogonidae*	0.41	14.29	2.43

A-3 Peace River Zone 3

Lower Peace River Zone 3	%Comp	%OCC	Dom
Mulinia lateralis	25.71	52.00	36.56
Cyclaspis cf varians	19.63	58.00	33.75
Amygdalum papyrium	10.96	61.00	25.85
Ampelisca abdita	10.74	47.00	22.47
Streblospio gynobranchiata	5.11	48.00	15.67
Polymesoda caroliniana	2.95	30.00	9.41
Assiminea succinea	3.65	24.00	9.36
Laeonereis culveri	1.80	36.00	8.06
Nereis succinea	1.27	36.00	6.77
Amakusanthura magnifica	1.26	28.00	5.94
Polypedilum scalaenum group	1.20	27.00	5.70
Apocorophium lacustre	2.19	13.00	5.34
Tagelus plebeius	1.05	27.00	5.31
Hobsonia florida	1.37	17.00	4.83
Grandidierella bonnieroides	0.95	24.00	4.76
Edotea montosa	0.83	24.00	4.46
Almyracuma proximoculi	0.63	15.00	3.07
Pectinaria gouldii	0.43	19.00	2.86
Cryptochironomus	0.36	18.00	2.54
Capitella capitata complex	0.57	11.00	2.51

A-4 Peace River Zone 4 and SAV Sites

Lower Peace River Zone 4	%Comp	%OCC	Dom		Lower Peace River SAV Sites	%Comp	%OCC	Dom
Cyclaspis cf varians	16.68	60.00	31.64		*Capitella capitata complex*	53.91	40.00	46.44
Ampelisca abdita	13.05	65.00	29.13		*Nereis succinea*	6.60	50.00	18.17
Mulinia lateralis	6.76	53.00	18.93		*Ampelisca abdita*	5.15	58.00	17.28
Capitella capitata complex	9.65	36.00	18.63		*Cymadusa compta*	4.31	40.00	13.13
Mysella planulata	9.87	34.00	18.32		*Erichthonius brasiliensis*	4.25	36.00	12.36
Amygdalum papyrium	5.27	54.00	16.87		*Mulinia lateralis*	2.82	30.00	9.20
Nereis succinea	4.98	39.00	13.93		*Streblospio gynobranchiata*	2.73	22.00	7.75
Oxyurostylis smithi	3.70	52.00	13.87		*Polydora ligni*	2.48	22.00	7.39
Streblospio gynobranchiata	6.45	19.00	11.07		*Laeonereis culveri*	2.42	22.00	7.29
Pectinaria gouldii	1.57	32.00	7.09		*Amygdalum papyrium*	1.39	34.00	6.89
Laeonereis culveri	3.66	13.00	6.90		*Glycinde solitaria*	0.99	32.00	5.63
Glottidia pyramidata	3.22	13.00	6.47		*Mysella planulata*	2.32	12.00	5.28
Paramphinome sp b	1.07	21.00	4.74		*Erichsonella attenuata*	1.05	24.00	5.03
Polydora ligni	1.21	17.00	4.54		*Bemlos sp*	0.96	22.00	4.60
Glycinde solitaria	0.69	28.00	4.40		*Dipolydora socialis*	0.81	22.00	4.21
Nemertea sp	0.73	21.00	3.90		*Apocorophium lacustre*	0.68	16.00	3.30
Paraprionospio pinnata	0.66	20.00	3.62		*Nudibranchia*	0.65	12.00	2.79
Bemlos sp	0.74	16.00	3.45		*Astyris lunata*	0.34	20.00	2.61
Tagelus plebeius	0.90	11.00	3.14		*Nemertea sp f*	0.37	16.00	2.44
Acteocina canaliculata	0.50	17.00	2.92		*Diopatra cuprea*	0.34	16.00	2.34

B. Shell Creek

Shell Creek	%Comp	%OCC	Dom
Polymesoda caroliniana	34.54	66.67	47.98
Grandidierella bonnieroides	20.90	71.79	38.74
Hydrobiidae	25.96	43.59	33.64
Mesanthura pulchra	3.07	48.72	12.23
Laeonereis culveri	2.30	38.46	9.41
Polypedilum scalaenum group	1.76	48.72	9.26
Edotea montosa	1.44	25.64	6.09
Rangia cuneata	0.90	28.21	5.05
Cryptochironomus	0.54	23.08	3.54
Boccardiella	1.26	7.69	3.12
Procladius	0.63	15.38	3.12
Chironomus	0.45	17.95	2.85
Hobsonia florida	0.45	15.38	2.64
Rhithropanopeus harrisii	0.45	15.38	2.64
Tanytarsus sp g	0.59	10.26	2.45
Dicrotendipes lobus	0.59	7.69	2.12
Djalmabatista pulchra	0.32	12.82	2.01
Heteromysis formosa	0.32	10.26	1.80
Cyclaspis cf varians	0.23	12.82	1.70
Sphaeroma terebrans	0.23	10.26	1.52

4.4.3 Relationship Between Salinity and Benthic Community Structure

Janicki Environmental (2006a) showed that the benthos within 12 southwest Florida tidal rivers, including the Peace River and SC, was distributed across four salinity ranges that were generally similar to the traditional Venice classification scheme (Anonymous 1959, Weisberg *et al*. 1997):

- o Oligohaline <8 ppt
- o Mesohaline 8 to 15 ppt
- o Polyhaline 16 to 28 ppt
- o Euhaline >28 ppt

Since the database for matched benthos and salinity data for the Lower Peace River included 540 samples, rather than use the regional salinity classification scheme developed previously (Janicki Environmental 2006a), a classification scheme specific to the study area was developed using the methods outlined in Bulger *et al*. (1993) and Janicki Environmental (2006a).

For this principal components analysis the database was trimmed to exclude taxa that were only identified to Class or Order. Similarly, Family and Genus level identifications were excluded if there were representatives identified to genus or species, respectively. For example: two species of amphipods in the genus *Apocorophium* (*Apocorophium lacustre* and *Apocorophium louisianum*) were identified and included. These species may distribute themselves somewhat differently along salinity gradients. For example, in the Anclote River, *Apocorophium lacustre* was more abundant in salinities <8 ppt whereas *Apocorophium louisianum* was more abundant at salinities of 8 to 15 ppt (Janicki Environmental, Inc., 2006b). Therefore, animals identified as *Apocorophium* sp. were excluded. The result was that the PCA was run for 31 salinity increments (<1 to 31 ppt in 1 ppt increments) and 119 taxa.

Four principal components (PC), representing four salinity classes, explained >85% of the variation distribution of the benthos (Figure 4-4). These salinity classes are:

Tidal Freshwater:	<1 ppt	(5.5% of variance)
Oligohaline-Mesohaline:	≥ 1<18 ppt	(42.6% of variance)
Mesohaline-Polyhaline:	≥ 16<28 ppt	(29.2% of variance)
Euhaline:	≥ 28.0 ppt	(8.0% of variance)

PRIMER's (PRIMER-E Ltd. 2001) SIMPER (similarity percentage) program was used to rank the contribution different taxa made to community structure within each of the four salinity classes (Clarke and Warwick 2001).

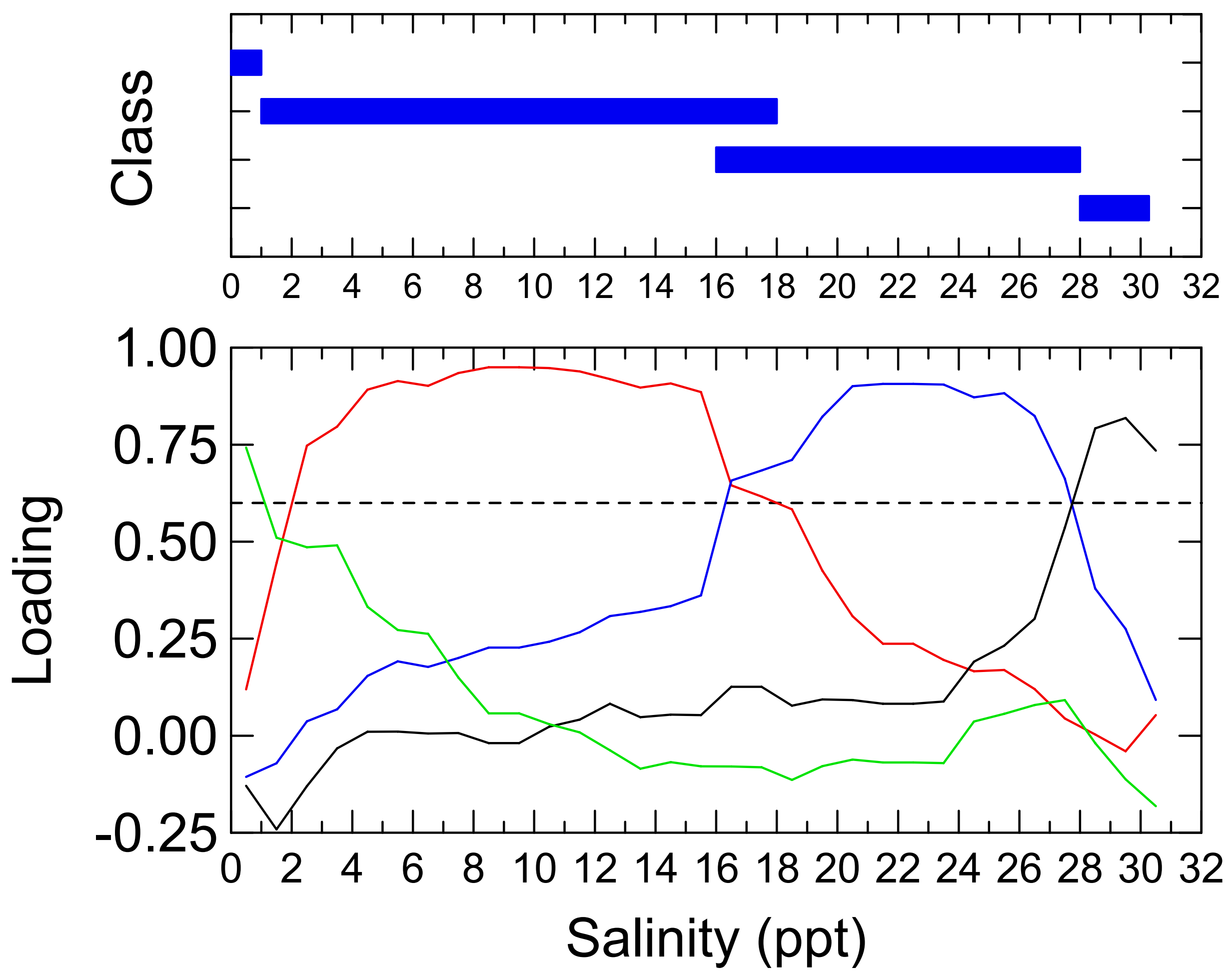


Figure 4-4. Salinity classes identified by Principal Components Analysis for the LPR (1998-1999) and SC (2003), based upon the distribution of 119 benthic taxa.

Community structure was defined as Bray-Curtis similarity (Boesch, 1973) using 4^{th} root transformed numbers of individuals. Organism counts were 4^{th} root transformed for all multivariate community analyses. The 4^{th} root transformation in multivariate analyses permits a greater number of taxa to influence the results (Clarke and Warwick, 2001). The use of untransformed data yields results strongly influenced by the most abundant taxa. Cao *et al.* (1998) argue that "rare" taxa may be more sensitive to environmental perturbation than common species. Therefore, an analytical approach that is more responsive to the "community" rather than to only a few, numerically abundant taxa was desirable. Thorne *et al.* (1999) have also demonstrated that the 4^{th} root transformation is preferred in multivariate community analyses because it represents a "good compromise between untransformed and binary data". Therefore the 4^{th} root transformation was employed where possible in the multivariate analyses.

The Tidal Freshwater salinity class was characterized by the presence of *Corbicula fluminea* whereas the Oligohaline-Mesohaline class was dominated by *Grandidierella bonnieroides*, *Laeonereis culveri*, and *Streblospio gynobranchiata* (Table 4-4). *Apocorophium lacustre* was abundant in both salinity classes. As salinity increased to the Mesohaline-Polyhaline class, freshwater taxa were no longer ranked. The cumacean *Cyclaspis cf. varians*, the amphipod *Ampelisca abdita*, and the bivalves *Amygdalum papyrium* and *Mulinia lateralis* were abundant in both the Mesohaline-Polyhaline and Euhaline salinity classes (Table 4-4).

A comparison of the regional salinity classification scheme and that specific to the Lower Peace River showed that:

- The Lower Peace River supports a distinct Tidal Freshwater assemblage, whereas in the regional analysis there was a Tidal Freshwater-Oligohaline fauna.

- Within the Lower Peace River, there were two salinity classes overlapping the upper end of the Mesohaline range.

- The regional classification scheme produced classes that essentially represented Polyhaline and Euhaline zones. The Lower Peace River included a salinity class that embraced the upper Mesohaline and Polyhaline salinity zones.

- A Euhaline salinity class was evident in both analyses.

Table 4-4. SIMPER analysis showing the taxa that explained ≥25% of the within PCA-salinity class similarity (4th root n+0.1 transformed counts; Bray-Curtis similarity) for the LPR and SC.

A. Tidal Freshwater Salinity Class (< 1 ppt)

Taxa	Mean Number of Individuals (4th Root n+1)	% Contribution to Within Class Similarity
Corbicula fluminea	0.97	0.09
Apocorophium lacustre	0.91	0.08
Polypedilum scalaenum group	0.85	0.08
Cladotsanytarsus	0.90	0.08
Hydrobiidae	0.84	0.08
Grandidierella bonnieroides	0.90	0.08
Gammarus cf tigrinus	0.83	0.08
Laeonereis culveri	0.77	0.08
Polypedilum halterale group	0.70	0.08
Tanytarsus	0.69	0.08
334 taxa:	≤0.69	0.07

B. Oligohaline-Mesohaline Salinity Class (1 – 18 ppt)

Taxa	Mean Number of Individuals (4th Root n+1)	% Contribution to Within Class Similarity
Grandidierella bonnieroides	1.05	0.09
Laeonereis culveri	0.95	0.09
Streblospio gynobranchiata	0.93	0.09
Apocorophium lacustre	0.99	0.09
Polypedilum scalaenum group	0.85	0.08
Hydrobiidae	0.93	0.08
Polymesoda caroliniana	0.92	0.08
Cyclaspis cf varians	0.87	0.08
Edotea montosa	0.79	0.08
Amygdalum papyrium	0.86	0.08
Ampelisca abdita	0.79	0.08
Hobsonia florida	0.73	0.08
Gammarus cf tigrinus	0.74	0.08
Cryptochironomus	0.69	0.08
Amakusanthura magnifica	0.69	0.08
677 taxa:	≤0.74	0.07

C. Mesohaline-Polyhaline Salinity Class (16 - 28 ppt)

Taxa	Mean Number of Individuals (4th Root n+1)	% Contribution to Within Class Similarity
Cyclaspis cf varians	1.30	0.11
Ampelisca abdita	1.23	0.11
Amygdalum papyrium	1.03	0.10
Mulinia lateralis	1.10	0.09
Nereis succinea	0.83	0.08
Oxyurostylis smithi	0.82	0.08
Streblospio gynobranchiata	0.82	0.08
Pectinaria gouldii	0.72	0.08
Capitella capitata complex	0.78	0.08
Laeonereis culveri	0.74	0.08
Amakusanthura magnifica	0.71	0.08
333 taxa:	≤0.77	0.07

Table 4-4. Continued
D. Euhaline Salinity Class (> 28 ppt)

Taxa	**Mean Number of Individuals (4th Root n+1)**	**% Contribution to Within Class Similarity**
Cyclaspis cf varians	1.60	0.15
Mysella planulata	1.45	0.14
Ampelisca abdita	1.30	0.11
Mulinia lateralis	1.21	0.11
Glottidia pyramidata	1.26	0.11
Amygdalum papyrium	0.98	0.10
Pectinaria gouldii	0.97	0.09
Oxyurostylis smithi	0.92	0.09
Macoma tenta	0.93	0.09
Nereis succinea	0.86	0.09
Bemlos	0.83	0.08
Acteocina canaliculata	0.78	0.08
Spiochaetopterus costarum oculata	0.79	0.08
Nemertea sp f	0.77	0.08
Paramphinome sp b	0.74	0.08
Paraprionospio pinnata	0.71	0.08
Uromunna	0.74	0.08
Asychis elongate	0.69	0.08
324 taxa :	≤0.72	0.07

4.4.4 Spatial Characteristics of Lower Peace River Benthos

ANOSIM and SIMPER analyses (Clarke and Warwick, 2001) were applied to determine whether community structure differed between Zones of the Lower Peace River (Mote Marine Laboratory 2002) proper as well as between subareas (e.g., Deep Creek, Lettuce Lake) within each of the zones.

Test results, then, were only included if they represented comparisons between Zones and subareas that were contiguous. That is, Peace River Zone 1 was compared to Peace River Zone 2, Lettuce Lake, and Deep Creek, but not to SC (discharging mainly to Zone 3). If the ANOSIM test was not significant ($p>0.05$), than the data from the two zones/subareas were combined for a “within group” SIMPER analysis

The ANOSIM test showed that community structure differed:

- between each of the four zones of the Lower Peace River proper, as defined by Mote Marine Laboratory (2002);
- between Deep Creek and Lettuce Lake within Zone 1;
- between the SAV sites in the vicinity of RKM 0 and Zone 4 of the Lower Peace River; and
- between SC and Zone 3 of the LPR.

Freshwater taxa, such as hydrobiid gastropods and Chironomidae larvae were characteristic of the fauna in Zone 1 of the river proper, Deep Creek, and Lettuce Lake

(Table 4-5). ANOSIM showed that the assemblage in Zone 1 of the river was similar to that of both Deep Creek and Lettuce Lake.

The assemblages of Lettuce Lake and Deep Creek, however, were different (Table 4-5). SIMPER analysis showed that the assemblage of Lettuce Lake had higher mean densities of hydrobiids and chironomids and lower densities of estuarine amphipods than did Deep Creek

The fauna in Zone 2 differed from that of Zone 1 in that freshwater organisms declined in numbers and estuarine taxa increased. Notably, mean numbers of larvae of the chironomid *Polypedilum scalaneum* increased from Zone 1 to Zone 2. The benthos of Hunter Creek and Zone 2 of the river proper were not significantly different.

Zones 2 and 3 also differed in the composition of the benthos. Mean numbers of *Cyclaspis varians*, *Mulinia lateralis*, and *Amygdalum papyrium* were much higher in Zone 3 whereas *Apocorophium lacustre, Grandidierella bonnieroides*, and *Polypedilum scalaneum* numbers declined moving downstream. The benthos of Zone 4 also differed from that of Zone 3. Taxa whose mean numbers declined downstream included *Cyclaspis, Mulinia, Amygdalum*, and *Streblospio gynobranchiata* (Table 4-5). Organisms whose numbers increased downstream included *Ampelisca abdita* and *Mysella planulata*. The benthos associated with the SAV beds near RKM 0 also differed from that of Zone 4 as a whole. The polychaetes *Capitella capitata* and *Nereis succinea* were more abundant in the SAV samples.

SC, a low salinity habitat, joins the LPR primarily within Zone 3 (Figure 4-3), where salinities typically range between 7 and 22 ppt (Table 4-2). The benthos of SC was different from that of Zone 3 (Table 4-5). *Grandidierella bonnieroides, Polymesoda caroliniana*, and hydrobiids were much more abundant in SC than in Zone 3. ANOSIM showed that SC was similar (p=0.32) in structure to Zone 2.

Table 4-5. ANOSIM and SIMPER analyses comparing benthic community structure between Zones and subareas of the Lower Peace River (4th root n+0.1 transformed counts; Bray-Curtis similarity). ANOSIM table shows the R statistic for comparison of community structure between zones and the *p* value for the test (Clarke and Warwick, 2001).

A. ANOSIM Test

Groups	R Statistic	*p*
Zone 1 vs. Deep Creek	0.009	0.401
Zone 1 vs. Lettuce Lake	0.012	0.377
Deep Creek vs. Lettuce Lake	0.025	0.019
Zone 1 vs. Zone 2	0.121	0.001
Zone 2 vs. Hunter Creek	-0.012	0.609
Zone 2 vs. Zone 3	0.125	0.001
Zone 3 vs. Shell Creek	0.144	0.006
Zone 3 vs. Zone 4	0.091	0.001
Zone 4 vs. SAV Sites	0.084	0.015

Table 4-4. Continued

B. SIMPER Analyses

B-1 Peace River Zone 1 and Lettuce Lake (Combined)

Taxa	Mean Number of Individuals (4th Root n+1)	% Contribution to Within Class Similarity
Corbicula fluminea	1.13	0.10
Hydrobiidae	0.98	0.09
Cladotanytarsus	1.03	0.09
Gammarus cf tigrinus	0.95	0.09
Apocorohium lacustre	0.91	0.08
Polypedilum scalaenum group	0.81	0.08
Grandidierella bonnieroides	0.83	0.08
Tanytarsus	0.76	0.08
Polypedilum halterale group	0.76	0.08
Chironomidae	0.73	0.08
Laeonereis culveri	0.72	0.08
334 Taxa	≤0.65	0.07

B-2 Peace River Zone 1 and Deep Creek (Combined)

Taxa	Mean Number of Individuals (4th Root n+1)	% Contribution to Within Class Similarity
Corbicula fluminea	1.11	0.10
Gammarus cf tigrinus	0.97	0.09
Apocorophium lacustre	1.01	0.09
Cladotanytarsus	0.99	0.09
Hydrobiidae	0.93	0.09
Grandidierella bonnieroides	0.86	0.08
Polypedilum scalaenum group	0.78	0.08
Tanytarsus	0.76	0.08
Laeonereis culveri	0.72	0.08
Polypedilum halterale group	0.73	0.08
Chironomidae	0.69	0.08
334 taxa	<0.69	0.07

B-3 Deep Creek vs. Lettuce Lake

Taxa	Deep Creek (Mean Number of Individuals (4th Root n+1)	Lettuce Lake (Mean Number of Individuals (4th Root n+1)	% Contribution to Between Group Dissimilarity
Apocorophium lacustre	1.14	0.84	8.34
Cladotanytarsus	0.89	1.03	7.53
Hydrobiidae	0.89	1.02	6.69
Corbicula fluminea	0.84	0.90	6.15
Gammarus cf tigrinus	0.91	0.85	5.55
Grandidierella bonnieroides	0.88	0.78	5.34
Polypedilum scalaenum group	0.75	0.85	4.99
Polypedilum halterale group	0.77	0.85	4.65
Tanytarsus	0.78	0.76	4.16

Table 4-4. Continued

B-4 Peace River Zone 1 vs. Peace River Zone 2

Taxa	Zone 1 (Mean Number of Individuals (4th Root n+1)	Zone 2 (Mean Number of Individuals (4th Root n+1)	% Contribution to Between Group Dissimilarity
Apocorophium lacustre	0.94	1.20	7.73
Corbicula fluminea	1.24	0.79	7.05
Grandidierella bonnieroides	0.86	1.06	6.22
Hydrobiidae	0.96	0.91	5.28
Cladotanytarsus	1.03	0.60	5.02
Gammarus cf tigrinus	0.99	0.70	4.89
Polypedilum scalaenum group	0.80	0.99	4.75
Laeonereis culveri	0.70	0.98	4.42
Apocorophium louisianum	0.67	0.87	3.78
Ampelisca abdita	0.57	0.88	3.36

B-5 Peace River Zone 2 and Hunter Creek (Combined)

Taxa	Mean Number of Individuals (4th Root n+1)	% Contribution to Within Class Similarity
Grandidierella bonnieroides	1.12	0.10
Laeonereis culveri	0.97	0.10
Apocorophium lacustre	1.16	0.09
Polypedilum scalaenum group	0.92	0.09
Hydrobiidae	0.92	0.09
Streblospio gynobranchiata	0.86	0.08
Hobsonia florida	0.80	0.08
Edotea montosa	0.81	0.08
Apocorophium louisianum	0.86	0.08
Polymesoda caroliniana	0.79	0.08
Amakusanthura magnifica	0.75	0.08
Ampelisca abdita	0.80	0.08
Corbicula fluminea	0.75	0.08
Cyclaspis cf varians	0.74	0.08
330 taxa	<0.74	0.07

B-6 Peace River Zone 2 vs. Peace River Zone 3

Taxa	Zone 2 (Mean Number of Individuals (4th Root n+1)	Zone 3 (Mean Number of Individuals (4th Root n+1)	% Contribution to Between Group Dissimilarity
Cyclaspis cf varians	0.80	1.33	7.10
Mulinia lateralis	0.60	1.26	6.43
Amygdalum papyrium	0.73	1.24	6.24
Apocorophium lacustre	1.20	0.68	6.14
Ampelisca abdita	0.88	1.06	5.63
Grandidierella bonnieroides	1.06	0.72	4.91
Streblospio gynobranchiata	0.87	1.00	4.65
Polypedilum scalaenum group	0.99	0.75	4.06
Laeonereis culveri	0.98	0.82	4.03
Polymesoda caroliniana	0.80	0.84	3.64

Table 4-4. Continued

B-7 Peace River Zone 3 vs. Peace River Zone 4

Taxa	Zone 3 (Mean Number of Individuals (4^{th} Root n+1)	Zone 4 (Mean Number of Individuals (4^{th} Root n+1)	% Contribution to Between Group Dissimilarity
Cyclaspis cf varians	1.33	1.26	7.88
Mulinia lateralis	1.26	1.04	7.06
Ampelisca abdita	1.06	1.15	6.21
Amygdalum papyrium	1.24	1.00	6.14
Streblospio gynobranchiata	1.00	0.80	4.97
Mysella planulata	0.61	0.98	4.08
Nereis succinea	0.79	0.90	3.77
Oxyurostylis smithi	0.63	0.95	3.67
Capitella capitata complex	0.65	0.90	3.50
Laeonereis culveri	0.82	0.71	3.18

B-8 Peace River Zone 4 vs. SAV sites

Taxa	Zone 4 (Mean Number of Individuals (4^{th} Root n+1)	SAV Sites (Mean Number of Individuals (4^{th} Root n+1)	% Contribution to Between Group Dissimilarity
Capitella capitata complex	0.90	1.31	8.07
Cyclaspis cf varians	1.26	0.58	6.50
Ampelisca abdita	1.15	1.05	5.64
Nereis succinea	0.90	1.04	5.14
Mulinia lateralis	1.04	0.82	4.96
Mysella planulata	0.98	0.71	4.54
Amygdalum papyrium	1.00	0.80	4.26
Streblospio gynobranchiata	0.80	0.80	3.73
Oxyurostylis smithi	0.95	0.64	3.58
Cymadusa compta	0.57	0.91	3.27
Erichthonius brasiliensis	0.59	0.90	3.23

B-9 Shell Creek vs. Peace River Zone 3

Taxa	Shell Creek (Mean Number of Individuals (4^{th} Root n+1)	Zone 3 (Mean Number of Individuals (4^{th} Root n+1)	% Contribution to Between Group Dissimilarity
Grandidierella bonnieroides	1.41	0.72	7.49
Polymesoda caroliniana	1.36	0.84	7.39
Cyclaspis cf varians	0.62	1.33	7.08
Mulinia lateralis	0.56	1.26	6.52
Amygdalum papyrium	0.56	1.24	6.32
Hydrobiidae	1.09	0.56	4.99
Ampelisca abdita	0.56	1.06	4.62
Streblospio gynobranchiata	0.61	1.00	4.11
Laeonereis culveri	0.85	0.82	3.60

4.4.5 Relationships Between the Benthos and Abiotic Variables

4.4.5.1 Multiple Regression Analyses and Univariate Community Metrics

Forward stepwise multiple linear regression was applied to quantify relationships between taxa richness, diversity, and abundance and a suite of environmental variables. The environmental variables considered included:

- Water temperature, salinity, pH, and dissolved oxygen measured at the time of collection;
- Flow variables (flow on the day of collection and the cumulative flows over the 7, 15, 30, 60, 90, and 180 days preceding the collection of the benthic samples). Montagna and Kalke (1992) used this approach to examine the effects of flow on the benthos of Texas estuaries.

The resultant relationships and equations may be used to predict expected responses of the benthos within each of the four zones of the Lower Peace River to the "best fit" combination of abiotic variables.

Statistically significant (p<0.05) relationships were found between numbers of taxa, diversity, or total abundance and the abiotic variables within each of the four river zones. However, each of the r^2 values were $\leq$0.41 (Table 4-6). The best fitting equation (r^2=0.41) was for the relationship between numbers of individuals, temperature, salinity, the 7-day cumulative flow, and the flow on the date of collection within Zone 2. The second best fitting relationship (r^2=0.39) was between numbers of taxa, the 7-day cumulative flow, and the flow on the date of collection within Zone 2 as well.

Based upon the low r^2 values, none of the three univariate community metrics are considered to demonstrate any ecologically meaningful relationships with salinity, dissolved oxygen, sample depth or flow, based upon forward stepwise multiple regression.

Table 4-6. **Summary of forward stepwise multiple regression estimating numbers of taxa (S), Shannon-Wiener diversity (H'), and total numbers of individuals per sample, by zone, in the LPR, including SC. Dependent variables: Log_{10} n+1 transformed temperature, salinity, dissolved oxygen, and Log_{10} flow on the date of collection and 7, 15, 30, 60, 90, and 180-day cumulative flows. *p* values: NS=$\geq$0.05 *<0.05 ** <0.01 ***<0.001**

A. ZONE 1 (INCLUDING LETTUCE LAKE AND DEEP CREEK) (n=186)

	Log_{10} n+1 Numbers of Taxa (S)	Shannon Diversity (H')	Log_{10} n+1 Total Numbers of Individuals
p	***	***	***
Adjusted Multiple R^2	0.32	0.25	0.19
Constant	8.05	24.87	12.30
Temperature			
Salinity			
Dissolved Oxygen			
pH			
Daily Flow	-0.96	-3.11	-1.45
7-Day Cumulative Flow	0.64	2.04	1.01
15-Day Cumulative Flow			
30-Day Cumulative Flow			
60-Day Cumulative Flow			
90-Day Cumulative Flow			
180-Day Cumulative Flow	-1.45	-4.58	-2.23

B. ZONE 2 (INCLUDING HUNTER CREEK) (n=139)

	Log_{10} n+1 Numbers of Taxa (S)	Shannon Diversity (H')	Log_{10} n+1 Total Numbers of Individuals
p	***	***	***
Adjusted Multiple R^2	0.39	0.29	0.41
Constant	8.52	-2.30	-5.10
Temperature		5.99	5.67
Salinity			-0.62
Dissolved Oxygen			
pH			
Daily Flow	-1.02	-3.10	-2.96
7-Day Cumulative Flow	0.73	3.13	1.41
15-Day Cumulative Flow			
30-Day Cumulative Flow		-2.00	
60-Day Cumulative Flow			
90-Day Cumulative Flow			
180-Day Cumulative Flow	-1.57		

Table 4-6. Continued

C. ZONE 3 (INCLUDING SHELL CREEK) (n=133)

	Log_{10} n+1 Numbers of Taxa (S)	Shannon Diversity (H')	Log_{10} n+1 Total Numbers of Individuals
p	***	***	***
Adjusted Multiple R^2	0.23	0.18	0.23
Constant	1.75	-29.72	9.03
Temperature	-0.62		-4.02
Salinity	0.14	-0.57	0.74
Dissolved Oxygen	0.61	1.69	1.29
pH			
Daily Flow	-0.28		-0.43
7-Day Cumulative Flow			
15-Day Cumulative Flow			
30-Day Cumulative Flow		4.93	
60-Day Cumulative Flow			
90-Day Cumulative Flow		-21.19	
180-Day Cumulative Flow		21.67	-0.52

D. ZONE 4 (EXCLUDES SAV SITES) (n=97)

	Log_{10} n+1 Numbers of Taxa (S)	Shannon Diversity (H')	Log_{10} n+1 Total Numbers of Individuals
p	***	**	***
Adjusted Multiple R^2	0.17	0.06	0.25
Constant	-3.28	-2.07	-6.67
Temperature	2.22	3.00	4.90
Salinity			
Dissolved Oxygen			-0.73
pH			
Daily Flow			
7-Day Cumulative Flow			-0.71
15-Day Cumulative Flow			1.08
30-Day Cumulative Flow			
60-Day Cumulative Flow	0.23		
90-Day Cumulative Flow			
180-Day Cumulative Flow			

4.4.5.2 Relationship with Dissolved Oxygen

Dissolved oxygen was included in the variable subsets predicting numbers of taxa, diversity, as well as abundance within Zone 3. Dissolved oxygen also was related to

the numbers of taxa in Zone 2. However as noted above, the overall relationships developed by multiple regression analyses explained little of the variance.
Notwithstanding these analyses, the relationship between benthic community metrics and dissolved oxygen is an important consideration in a region where hypoxia is a concern-- even though there was little evidence of hypoxia in this database.

The relationship between numbers of taxa, diversity, and abundance with dissolved oxygen was slightly U-shaped, although all of the interquartile ranges overlapped (Figure 4-5).

4.4.5.3 Relationship Between Multivariate Community Structure and Abiotic Variables

PRIMER's BIO-ENV procedure (Clarke and Warwick 2001) was used as an exploratory tool to ascertain whether benthic community structure within each zone of the Lower Peace River was associated with one or more abiotic variables. These variables included salinity, temperature, pH, dissolved oxygen, and cumulative flow statistics.

The objective was to find a matrix of some combination of standardized abiotic variables that provided a "best fit" with the structure of the benthic community in the study areas. The abiotic matrix is formed by calculating Euclidean distances between all station combinations for each subset of abiotic variables tested. In Euclidean distance, stations are more similar if they are closer together in n-dimensional space then if they are further apart. If there are three abiotic variables under consideration, than it is the distance in three-dimensional space; if it is five variables, then it is five-dimensional space, etc. The statistic used to describe the degree of association is the Spearman rank correlation coefficient ($\rho_{s,}$ Clarke and Ainsworth 1993). It is not appropriate to assign significance values to ρ_s values (Clarke and Warwick 2001), and thus this approach can only be used in an exploratory manner.

Salinity measured at the time of collection exerted the primary influence on benthic community structure within the Lower Peace River in this analysis as it was either the best fitting single variable or was included with the "best fit" combinations of variables (Table 4-6). Cumulative flows were only included among the "best fit" variables in the two most downstream zones. The interquartile salinities in Zones 2 and 3 were the most wide-ranging (>13 ppt; Table 4-2). Mean salinities underwent the greatest changes from Zone 2 to Zone 3 (15.5 ppt) and from Zone 3 to Zone 4 (8.2 ppt) (Table 4-2, Figure 4-4). Median salinities were so low in both Zones 1 and 2 that only extremely low flows should affect salinity.

Mote Marine Laboratory (2002) also observed in their analysis of these same data that salinity was more highly correlated with biotic changes in zones 3 and 4 than more upstream. Montagna (2006), using the same analytic approach, showed that salinity was the single abiotic variable that was most highly correlated with the structure of the mollusk community in six southwest Florida tidal rivers; secondary variables included temperature, pH, and some sediment variables.

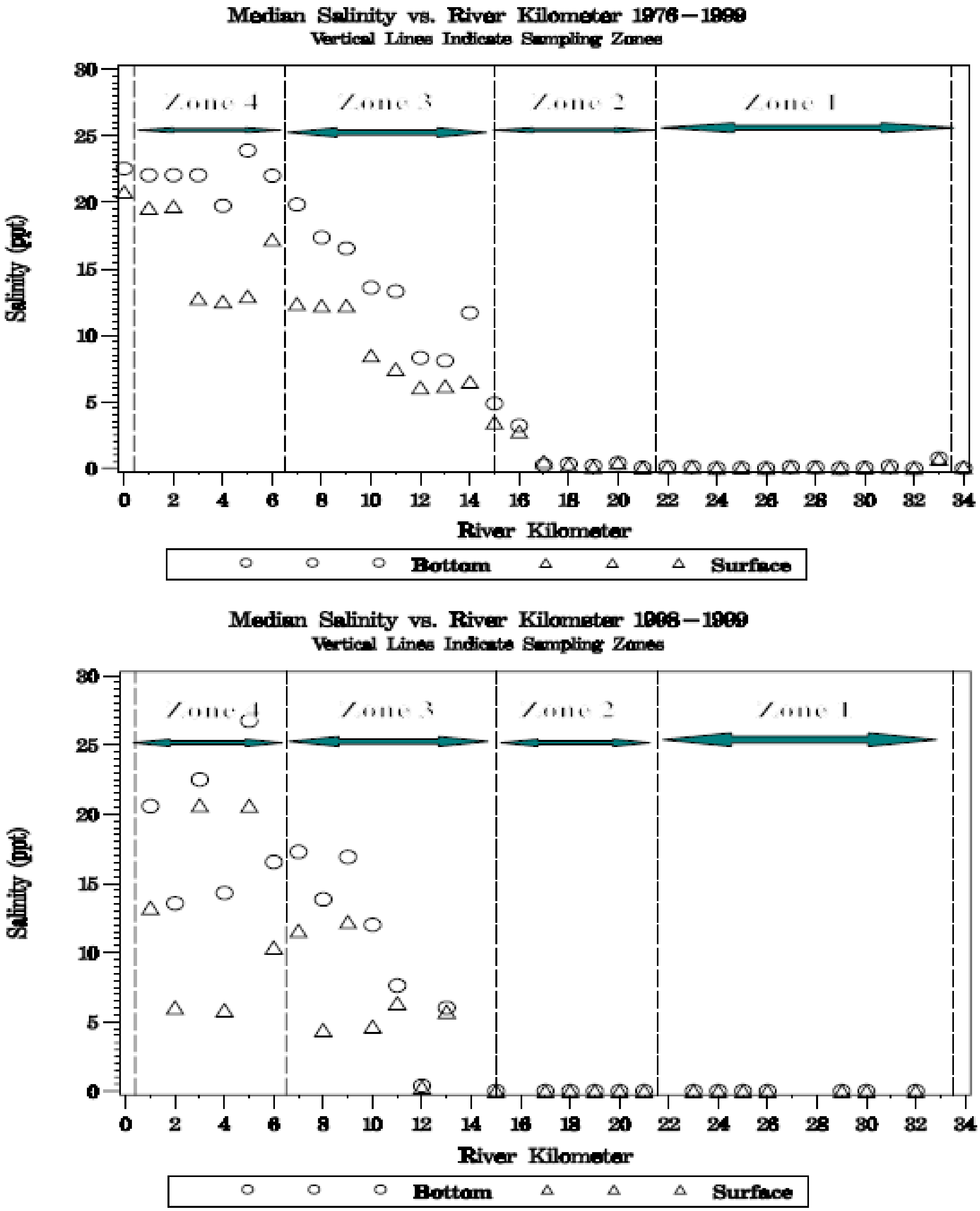


Figure 4-5. **Median salinity, by Zone, in the Lower Peace River, 1976-1999 and 1998-1999 (From: Mote Marine Laboratory, 2002).**

4.4.5.4 Relationships Between Salinity and the Distribution of Selected Taxa (Logistic Regression Analyses

Univariate logistic regression analyses developed for the District from three tidal rivers in the Charlotte Harbor area (LPR, SC, and Myakka River) (Janicki Environmental, Inc. 2006a) were used to identify salinity optima and tolerance ranges for taxa characteristic of the LPR.

Twenty-four taxa, including eight crustaceans, six bivalves, and five polychaetes, exhibited statistically significant relationships between salinity and their probability of occurrence within the Charlotte Harbor area (Janicki Environmental, Inc., 2006a). The probability of occurrence of three of the species (*Chironomus sp., Corbicula fluminea,* and *Polypedilum halterale*) generally declined as salinity increased (Figure 4-6). The distributions of *Chironomus* and *Corbicula* extended from Zone 1 into Zone 2; *Polypedilum halterale* was confined to Zone 1. Montagna (2006) reported a similar distribution for *Corbicula*.

Nine taxa had salinity optima in the Oligohaline-Mesohaline salinity class (Figures 4-7 to 4-9). Four taxa (*Edotea montosa, Grandidierella bonnieroides, Laeonereis culveri*, and *Streblospio gynobranchiata*) were found in each of the four Zones of the river. *Polypedilum scalaneum* was most abundant in Zone 1, the two *Apocorophium* species, *Edotea*, and *Grandidierella* attained maximum abundance in Zone 2, *Polymesoda caroliniana* in Zone 3, and *Laeonereis, Streblospio*, and *Tagelus plebeius* in Zone 4. Montagna (2006) reported *Polymesoda* to be common at salinities up to 20 pp.

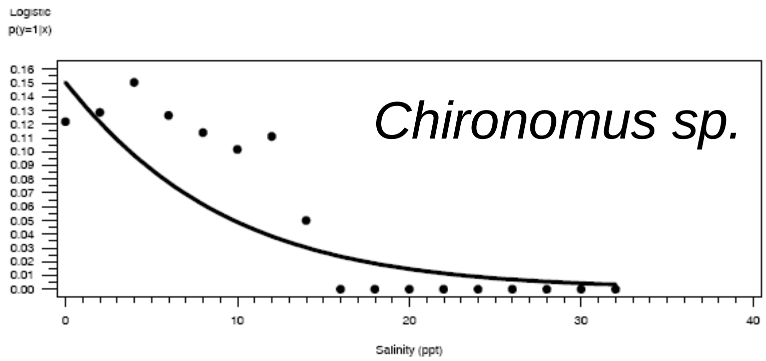
Five taxa (Figures 4-10 to 4-11) were most often encountered in salinities within the Mesohaline-Polyhaline salinity class. These species were not found in Zone 1 and were most abundant in zones 3 and 4.

Six taxa preferred salinities within the Euhaline class (Figures 4-12 through 4-13). The most widely distributed species in this group, *Mulinia lateralis*, was found as far upstream as Zone 1 and *Paraprionospio pinnata* was found at the demarcation point between zones 1 and 2. *Gammarus mucronatus* was found in both zones 3 and 4 and *Acteocina canaliculata, Glottidia pyramidata*, and *Xenanthura brevitelson* were only found in Zone 4.

The salinity “tolerance range” is the range of salinities ±25% of the optimum (Peeters and Gardeniers, 1998). Eight species had a narrow (≤5 ppt range) tolerance range within the Charlotte Harbor estuarine system (Appendix 4-2). Three species (*Corbicula, Chironomus*, and *Polypedilum halterale*) were found in tidal freshwaters, whereas the other five were found at the highest salinities in this system. Reductions in freshwater inflows could expand the penetration of the river by *Glottidia, Xenanthura, Gammarus mucronatus, Acteocina*, and *Paraprionospio* and diminish the available habitat of the three freshwater species. The distributions of the taxa with the wider tolerance ranges (>10 ppt) (Appendix 4-2) could be modified but they would be more difficult to detect. Salinities vary widely seasonally, annually, and may vary by 4 to 5 ppt over a tidal cycle in parts of the river (Mote Marine Laboratory, 2002).

In SC, where the measured salinities averaged 1.3 ppt, dominants included *Polymesoda, Grandidierella*, unidentifiable hydrobiid gastropods (Figure 4-14), and the anthurid isopod *Mesanthura pulchra.* The joint salinity tolerance ranges for *Polymesoda* and *Grandidierella* encompassed 5 and 17 ppt (Figure 4-8). Since the hydrobiids can include both freshwater and estuarine genera (Thompson, 2004) interpreting the salinity tolerances and preferences at the Family level is not particularly meaningful. The dominance of *Mesanthura pulchra* in this low salinity habitat is unexpected. This is more typically a coastal species. Marilyn Schotte (Personal communication), wrote "My impression is that it (*M*. *pulchra*) needs salinities above 18-20 ppt but can't verify it."

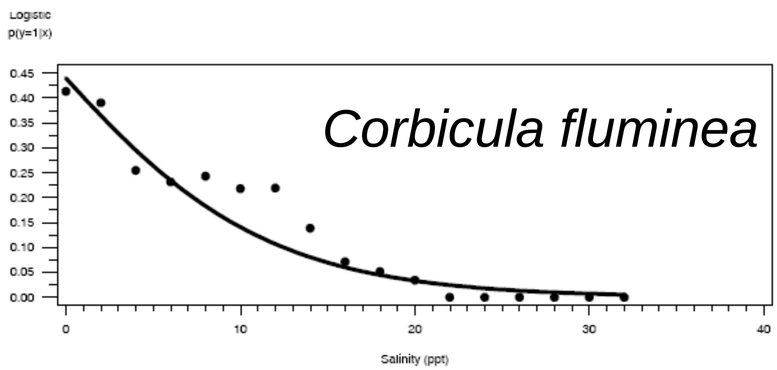
Were salinities in SC to depart markedly (e.g., >5 ppt) from the range observed during this single sampling event, it is possible that purely freshwater taxa relinquish habitat to the more typically estuarine species that are typical of Zone 2 (ANOSIM tests showed SC was similar to Zone 2 fauna but not to Zone 1 fauna).



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001

Association Statistics: 64.4% Concordant 26.3% Discordant 9.3% Ties Sample Size: Present in 51 of 602 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)



Probability Statistics: Prob > Chi-Square: Intercept=0.056 x=<.001

Association Statistics: 73.3% Concordant 22.2% Discordant 4.5% Ties Sample Size: Present in 134 of 530 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

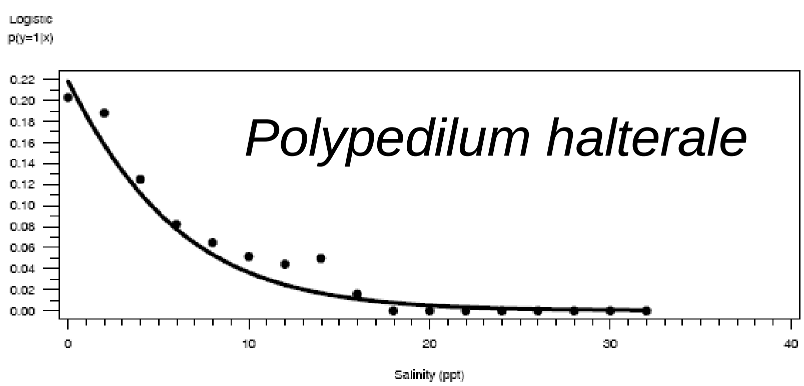
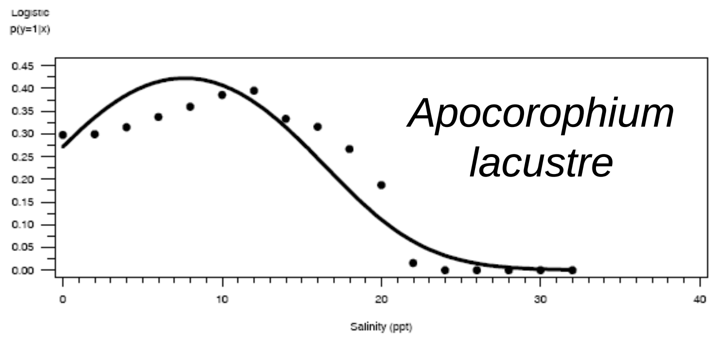


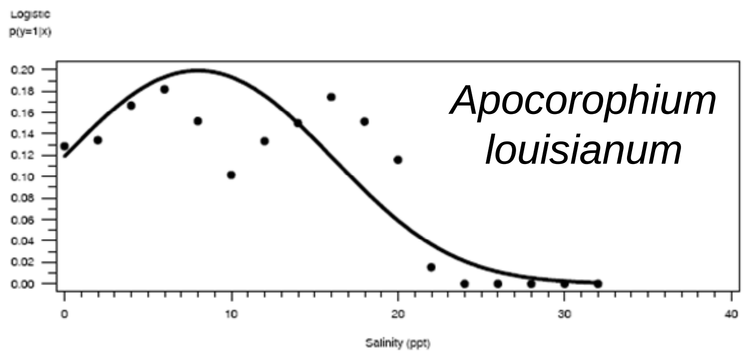
Figure 4-6. Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Tidal Freshwater salinity class (cf. Figure 4-4): *Chironomus* sp., *Corbicula fluminea*, and *Polypedilum halterale* in Charlotte Harbor tidal rivers, all months.



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 64.4% Concordant 30.3% Discordant 5.3% Ties Sample Size: Present in 142 of 573 samples

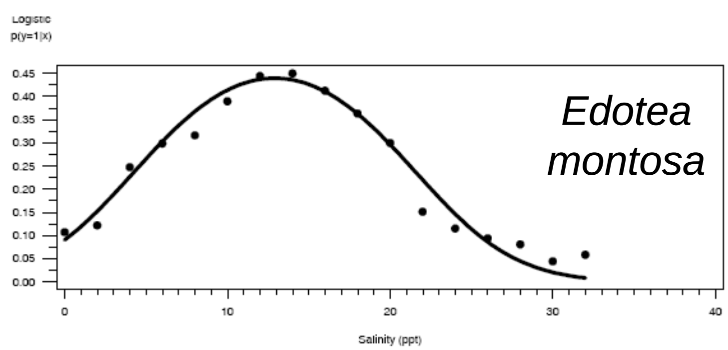
Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=0.010 x2=0.001

Association Statistics: 58.3% Concordant 31.7% Discordant 10% Ties Sample Size: Present in 68 of 603 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 72.6% Concordant 25.8% Discordant 1.6% Ties Sample Size: Present in 111 of 602 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

Figure 4-7. **Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Oligohaline-Mesohaline salinity class (cf. Figure 4-4): *Apocorophium lacustre, Apocorophium louisianum,* and *Edotea montosa* in Charlotte Harbor tidal rivers, all months.**

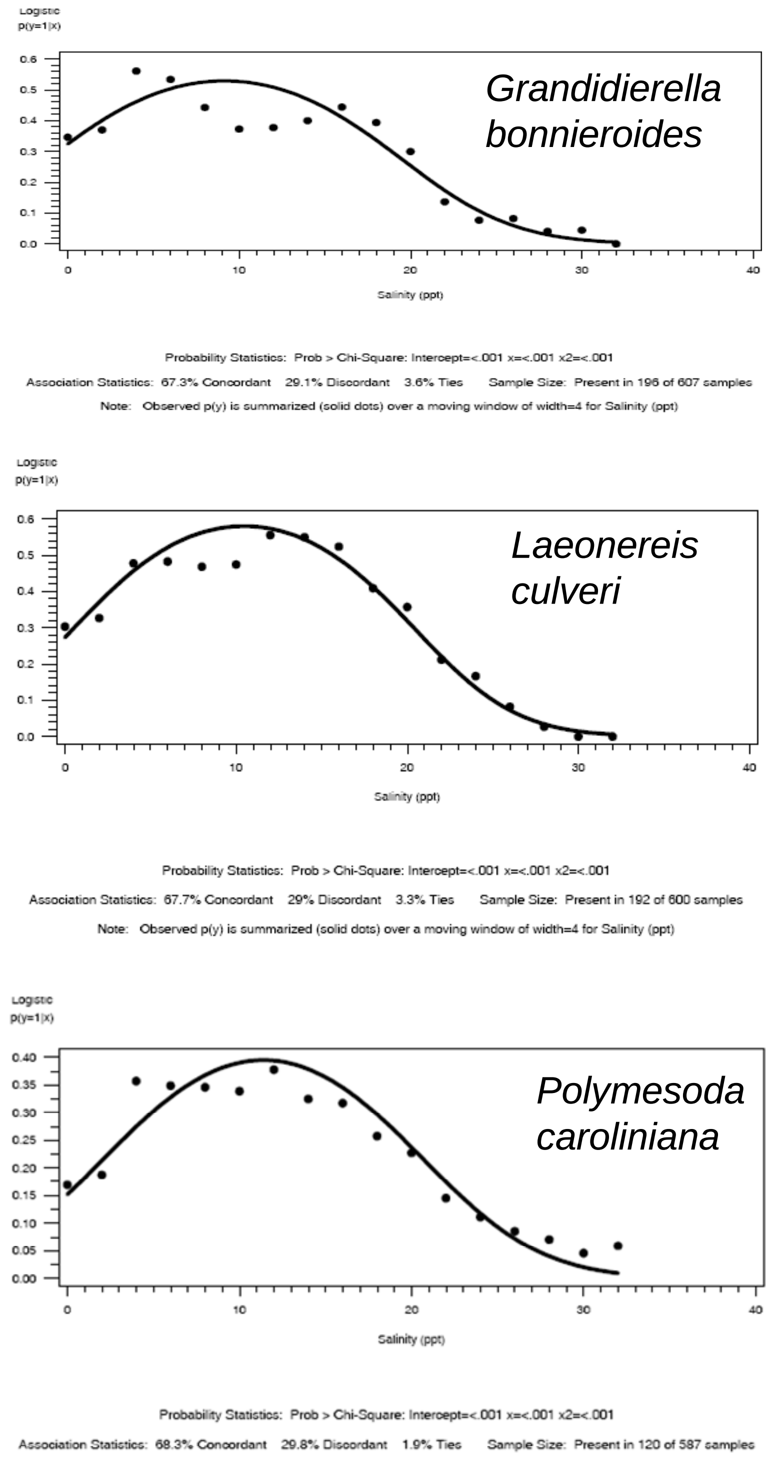
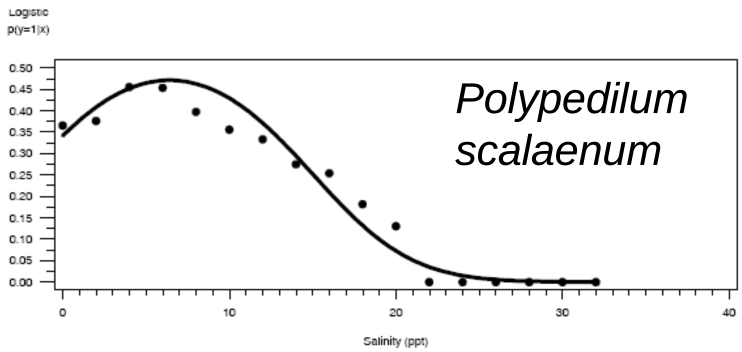


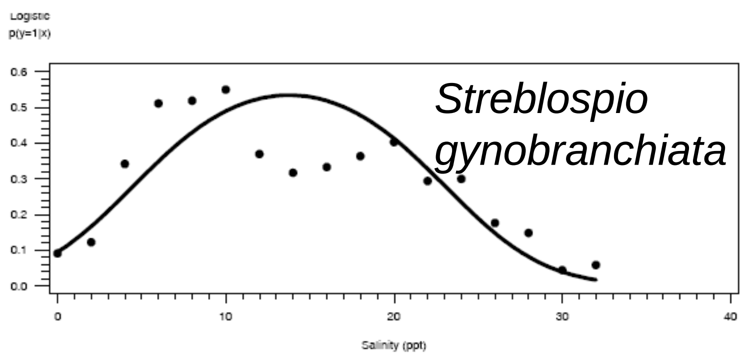
Figure 4-8. **Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Oligohaline-Mesohaline salinity class (cf. Figure 4-4): *Grandidierella bonnieroides, Laeonereis culveri,* and *Polymesoda caroliniana* in Charlotte Harbor tidal rivers, all months.**



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 69.1% Concordant 26.3% Discordant 4.6% Ties Sample Size: Present in 168 of 600 samples

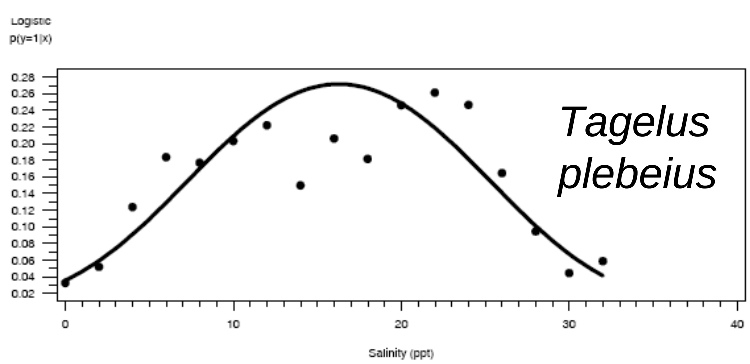
Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 74.8% Concordant 24% Discordant 1.1% Ties Sample Size: Present in 138 of 612 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

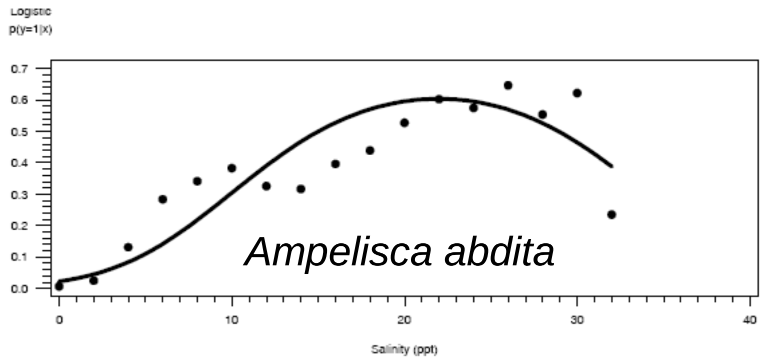


Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 71.9% Concordant 26.6% Discordant 1.5% Ties Sample Size: Present in 68 of 598 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

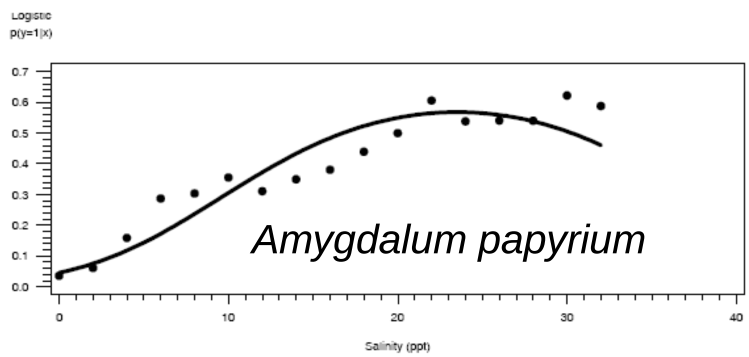
Figure 4-9. Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Oligohaline-Mesohaline salinity class (cf. Figure 4-4): *Polypedilum scalaenum, Streblospio gynobranchiata,* and *Tagelus plebeius* in Charlotte Harbor tidal rivers, all months.



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 85.7% Concordant 13.9% Discordant 0.4% Ties Sample Size: Present in 145 of 613 samples

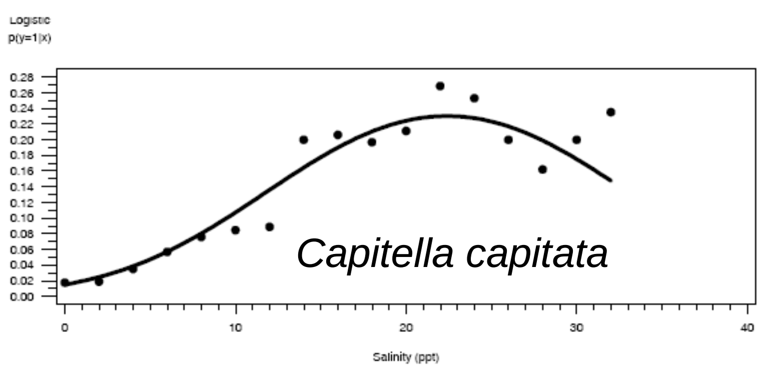
Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 82.5% Concordant 16.7% Discordant 0.8% Ties Sample Size: Present in 148 of 601 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

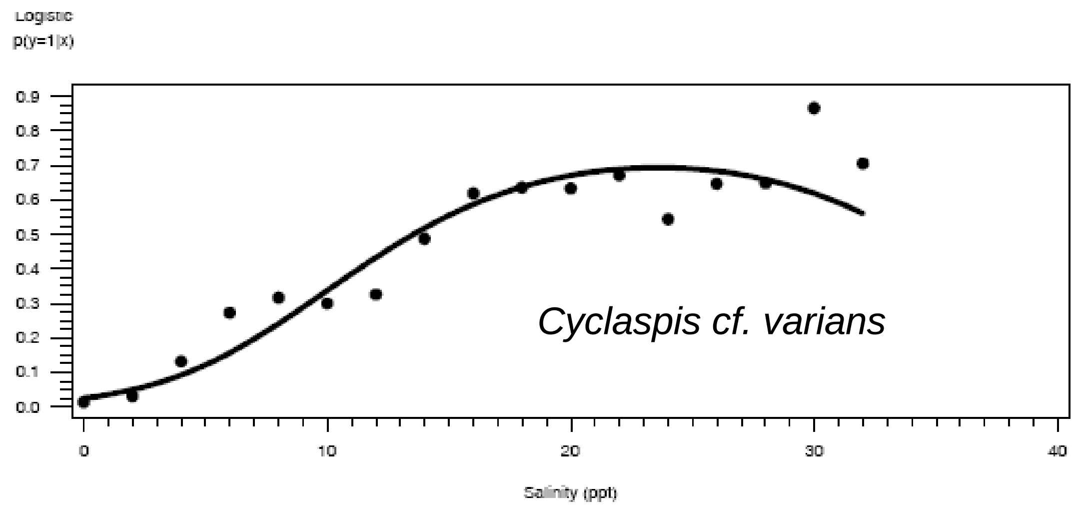


Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=0.003

Association Statistics: 75.9% Concordant 21.1% Discordant 2.9% Ties Sample Size: Present in 56 of 608 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

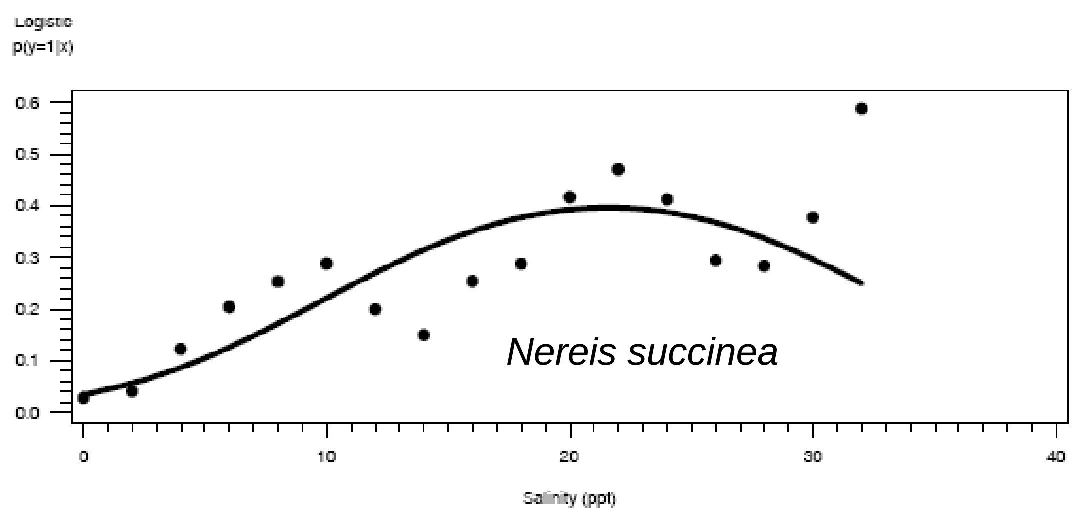
Figure 4-10. Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Mesohaline-Polyhaline salinity class (cf. Figure 4-4): *Ampelisca abdita, Amygdalum papyrium,* and *Capitella capitata* in Charlotte Harbor tidal rivers, all months.



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 87.2% Concordant 12.3% Discordant 0.5% Ties Sample Size: Present in 167 of 612 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001 x2=<.001

Association Statistics: 78.4% Concordant 19.8% Discordant 1.8% Ties Sample Size: Present in 104 of 610 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

Figure 4-11. Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Mesohaline-Polyhaline salinity class (cf. Figure 4-4): *Cyclaspis cf. varians* and *Nereis succinea* in Charlotte Harbor tidal rivers, all months.

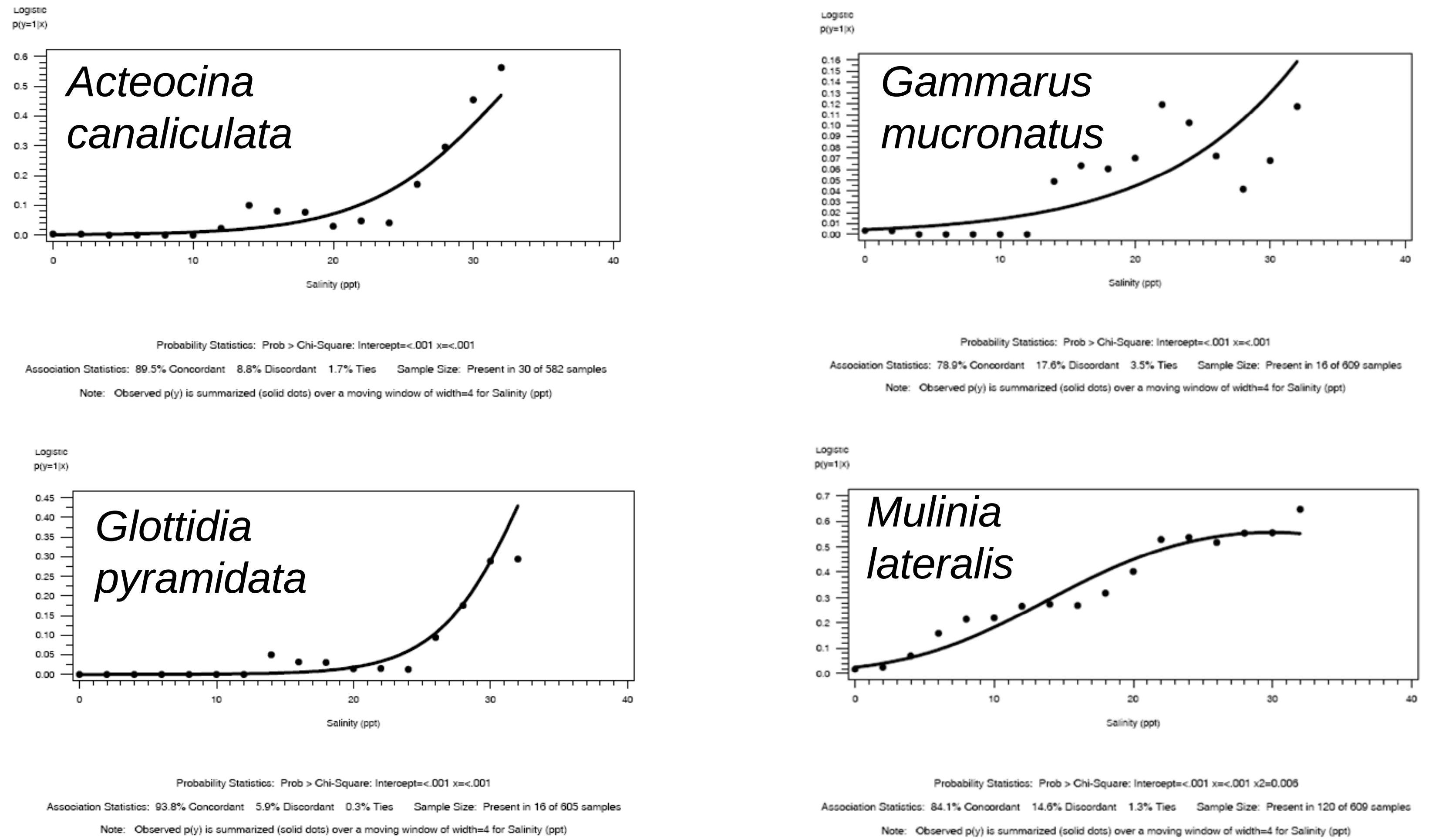
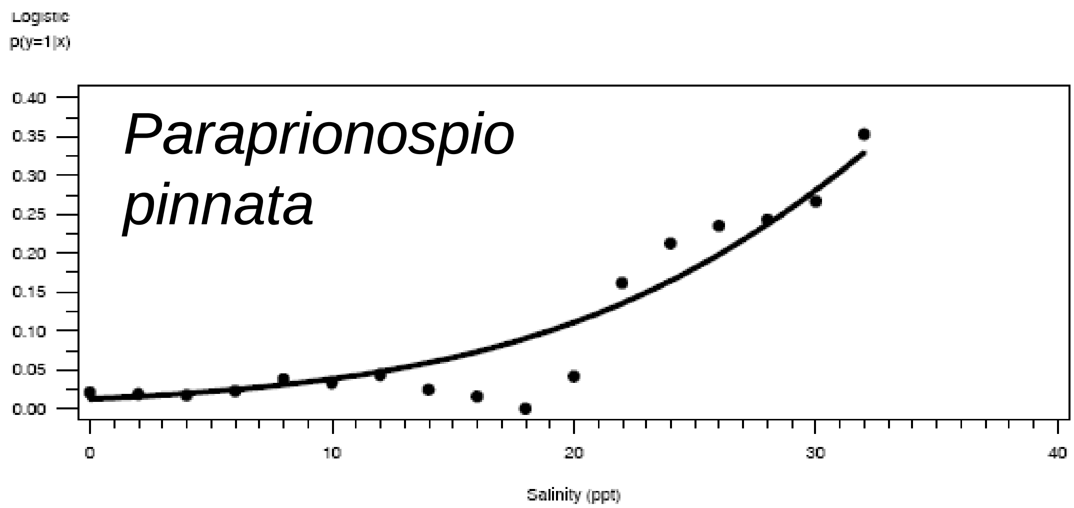


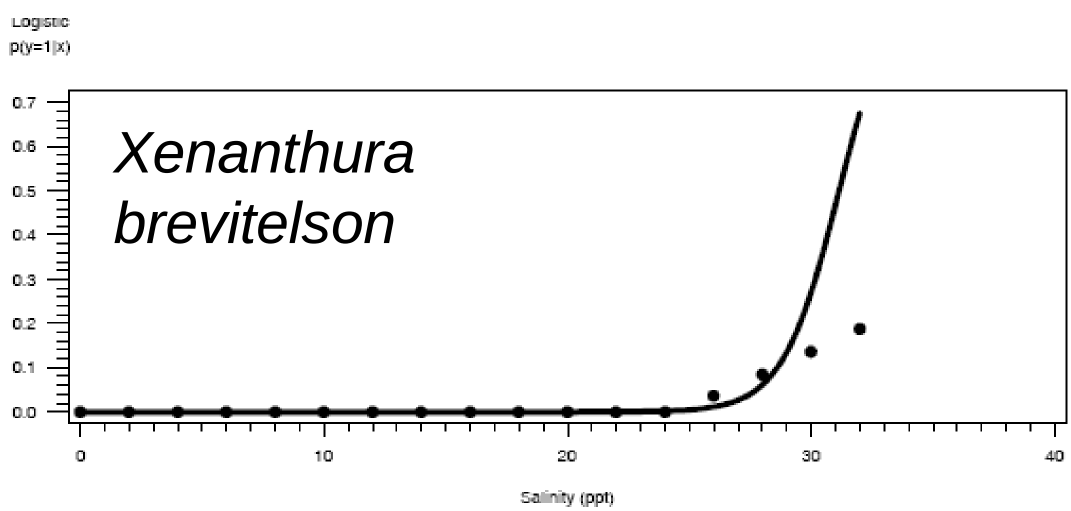
Figure 4-12. Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Euhaline salinity class (cf. Figure 4-4): *Acteocina canaliculata, Gammarus mucronatus, Glottidia pyramidata* and *Mulinia lateralis* in Charlotte Harbor tidal rivers, all months.



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=<.001

Association Statistics: 76.7% Concordant 17.7% Discordant 5.5% Ties Sample Size: Present in 39 of 613 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

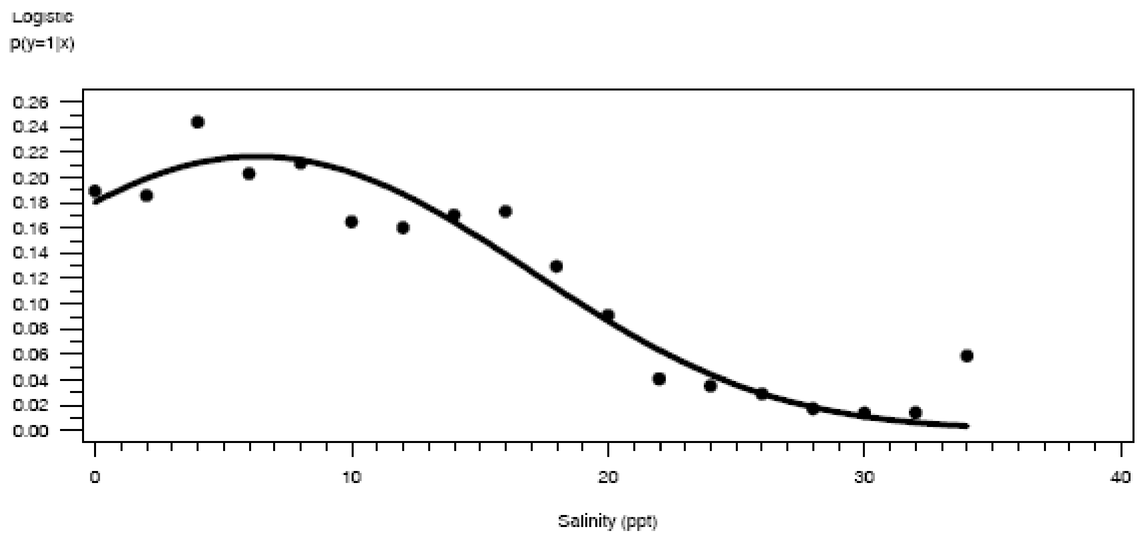


Probability Statistics: Prob > Chi-Square: Intercept=0.005 x=0.008

Association Statistics: 97.7% Concordant 2.2% Discordant 0% Ties Sample Size: Present in 6 of 581 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

Figure 4-13. Estimated probability of occurrence, as a function of salinity, for taxa with optimal salinities in the Euhaline salinity class (cf. Figure 4-4): *Paraprionospio pinnata* and *Xenanthura brevitelson* in Charlotte Harbor tidal rivers, all months.



Probability Statistics: Prob > Chi-Square: Intercept=<.001 x=0.007 x2=<.001

Association Statistics: 61.3% Concordant 31.4% Discordant 7.4% Ties Sample Size: Present in 292 of 1991 samples

Note: Observed p(y) is summarized (solid dots) over a moving window of width=4 for Salinity (ppt)

Figure 4-14. Estimated probability of occurrence, as a function of salinity, of hydrobiid gastropods, a dominant taxon in SC, in Charlotte Harbor tidal rivers, all months.

4.5 Results

The “best available data” to examine relationships between benthic community structure and salinity were limited to one year of sampling in the Lower Peace River and a single sampling event in SC.

Mote Marine Laboratory (2002) divided the LPR into four zones *a priori* based upon historical salinity data. Reanalysis of their data showed that multivariate community structure of the benthos differed between contiguous zones:

- within Zone 1, both Lettuce Lake and Deep Creek were similar to Zone 1 but differed from each other; the benthos within Zone 1 was mainly a freshwater fauna (chironomid larvae and hydrobiid gastropods);

- the fauna in Zone 2 differed from that of Zone 1 as freshwater organisms were replaced by estuarine fauna;

- Zones 2 and 3 also differed as the numbers of *Cyclaspis varians*, *Mulinia lateralis*, and *Amygdalum papyrium* increased in Zone 3 and *Apocorophium lacustre, Grandidierella bonnieroides*, and *Polypedilum scalaneum* decreased;

- Zone 4 differed from Zone 3 as the abundance of *Cyclaspis, Mulinia, Amygdalum*, and *Streblospio gynobranchiata* decreased downstream; *Ampelisca abdita* and *Mysella planulata* abundance increased;

- the benthos associated with the SAV beds near RKM 0 also differed from that of Zone 4; the polychaetes *Capitella capitata* and *Nereis succinea* were more abundant in SAV;

- SC benthos were more similar to that of Zone 2 in the LPR.

These data also showed that the benthos within the LPR was primarily influenced by salinity:

PCA showed that the benthos (based upon presence-absence) could be apportioned among four salinity classes:

- Tidal Freshwater: < 1 ppt
- Oligohaline-Mesohaline: 1 - 18 ppt
- Mesohaline-Polyhaline: 16 - 28 ppt
- Euhaline: $\geq$ 28.0 ppt

Multivariate analysis of community structure, based upon numbers of organisms rather than merely presence absence, showed that there were shifts in the taxa characteristic of each of the salinity classes:

- the Tidal Freshwater salinity class was characterized by the presence of *Corbicula fluminea;*
- the Oligohaline-Mesohaline class was dominated by *Grandidierella bonnieroides*, *Laeonereis culveri*, and *Streblospio gynobranchiata;*
- as salinity increased to the Mesohaline-Polyhaline class, freshwater taxa were no longer ranked.
- the cumacean *Cyclaspis cf. varians*, the amphipod *Ampelisca abdita*, and the bivalves *Amygdalum papyrium* and *Mulinia lateralis* were abundant in both the Mesohaline-Polyhaline and Euhaline salinity classes.

Statistically significant (p<0.05) relationships were found between numbers of taxa, diversity, or total abundance and the abiotic variables within each of the four river zones. However, each of the r^2 values was $\leq$ 0.41:

- the best fitting equation (r^2=0.41) was for the relationship between numbers of individuals, temperature, salinity, the 7-day cumulative flow, and the flow on the date of collection within Zone 2;

- the second best fitting relationship (r^2=0.39) was between numbers of taxa, the 7-day cumulative flow, and the flow on the date of collection within Zone 2 as well.

Exploratory analysis did show that, consistent with the above analyses, that salinity was the single variable that was most correlated with benthic community structure within each of the four zones of the Lower Peace River.

Twenty-four taxa showed statistically significant relationships between salinity and their probability of occurrence within the Charlotte Harbor area.

Reductions in freshwater inflows could facilitate habitat expansion by *Glottidia, Xenanthura, Gammarus mucronatus, Acteocina*, and *Paraprionospio* and diminish available habitat for freshwater species. The distributions of taxa with the wider tolerance ranges (>10 ppt) could be modified, but would be more difficult to detect.

In SC, where the measured salinities averaged 1.3 ppt, dominants included *Polymesoda, Grandidierella*, species with relatively wide salinity tolerance ranges. These species are not likely to be affected by increased salinities. Hydrobiid gastropods are also abundant in SC. Since salinity tolerances may differ by genera and several genera may be represented, responses to altered salinities by this Family is an unknown.

5 Fish Communities of the Lower Peace River and Shell Creek

Flow is an influential component of riverine and estuarine systems, and changes to the flow regime can potentially affect many ecological and environmental variables. Freshwater inflow influences the salinity of a tidal system and this interaction largely determines the distribution of fish in the river. Freshwater flow also influences water quality, namely dissolved oxygen, nutrient loading, and chlorophyll-a.

Salinity is an important factor for fish in tidal rivers, and is influenced by the amount of freshwater inflow entering the system, combined with the effects of the tides. Salinity may affect the distribution and abundance of individual species, and the overall composition of the fish community. Flow is typically negatively correlated with salinity in tidal rivers and generally the salinity gradient is expected to shift upstream and downstream based on flow conditions.

The physiological challenges and stresses associated with variable salinity environments affect the presence, absence and range of fish species. Osmotic limitations restrict the ability of many freshwater species from using habitat in downstream portions that are tidally influenced. Marine species also face osmotic problems, which restrict access to upstream freshwater habitats that are low in salinity. However, numerous euryhaline species exist that have adaptations that allow them to live within a wide range of salinity conditions (Banks *et al.* 1991). Many species, including estuarine-dependent fish, rely on different habitats/salinity zones, during different life stages (Wang and Raney 1971, Peebles 2002, Greenwood *et al.* 2004).

Salinity can impact the overall abundance of certain species and these composite effects influence the fish community as a whole. The success of an individual fish within a species may be affected by the physiological stresses caused by salinity, consequently impacting the overall abundance of that species. While the distribution of a given species is determined by salinity, species able to tolerate saline conditions may still be affected by salinity-related stressors. Species typically have an optimal salinity that is somewhere within the range of salinity that they may be able to inhabit. The salinity in which the eggs, larval, or juvenile forms of certain species develop, may impact their growth and survival rates. It will also affect the availability of prey and where adults of the species congregate and forage (Peterson-Curtis 1997; Baltz *et al.* 1998). The composition of the fish community in a tidal system is likely to change based on the salinity regime. Responses in the fish community are expected to be the composite result of the affects of salinity on all the individual species within the community, as described previously.

Additionally, many fish use the tidal river as nursery habitat. Transport to desirable nursery grounds can be influenced by freshwater flow, in terms of currents that carry larval and juvenile fish (Barbin 1998), and in terms of water quality constituents which serve as olfactory cues for larval fish movement (Benfield and Aldrich 1991).

Freshwater flow also affects dissolved oxygen concentrations by modifying residence times and by physically altering stratification conditions. Increased residence times and stratification may be associated with decreased dissolved oxygen. Alterations in dissolved oxygen conditions may affect the fauna as well (Browder and Moore 1981).

Other physical factors influenced by flow include depth, velocity, substratum, and residence time. Water depth influences two physical factors relevant to fish, habitat availability and structure, and dissolved oxygen. Available habitat expands as water levels increase and additional areas adjacent to the edge of the river become inundated. Accessibility to these habitats also changes with water depth, as increasing depth allows larger sized fish to enter into areas typically restricted only to the smallest fish. As water depth increases, the volume of certain habitats increases as well. Dissolved oxygen also changes with depth. Typically dissolved oxygen is lower in bottom waters than in surface waters due to influx from the atmosphere and possible lack of mixing and stratification in the bottom waters.

Water velocity is a physical force exerted on organisms inhabiting flowing water systems. Velocity affects the size of particles that make up the substrate, as well as nutrient and food delivery to the system. Velocity also affects dissolved oxygen concentrations. During higher flows, dissolved oxygen levels are expected to be higher than during low flow periods. However, under very high flow conditions the river can become stratified with very low dissolved oxygen levels at the bottom.

The magnitude and timing of freshwater inflows affects the amount of nutrients and organic matter that enters a waterway, such that increased productivity may occur some time after a period of increased flows (Kalke and Montagna 1989; Bate *et al*. 2002). Sediment loads to a water body are also increased during high flows. Loadings of contaminants, including metals and organic compounds that bind to smaller particles are often associated with increased sediment loads (Browder and Moore 1981).

Residence time affects the ability of phytoplankton to uptake nutrients, as well as the ability for secondary producers to consume phytoplankton. This extends to other consumers as well. Higher flows are associated with increased nutrient loading. Low flow also allows a longer residence time for chlorophyll and nutrients. During high flow conditions, flushing is more rapid and residence time in the river is reduced (Jassby *et al*. 1995, Flannery *et al*. 2002).

5.1 Lower Peace River

A number of studies have been conducted since 1975 in the Lower Peace River. The following presents summaries of the earliest studies, as gathered from PBS&J (1999b) and more recent studies (1996-present), Peebles (2002) and Greenwood *et al.* (2004).

5.1.1 Earlier Studies, 1975-1996

The first comprehensive study of fish from the Charlotte Harbor area was by Wang and Raney (1971). They used a random trawl sampling program which reported a total of 107 species. Wang and Raney (1971), along with an earlier report by Finucane and Sykes (1966), observed the bay anchovy to be the most abundant species with other common fish including the pinfish, silver perch, sand seatrout, spot, and silver jenny. General fish abundance in the harbor was reported to decrease with decreasing salinity in the wet season (June-September) and decreased with decreasing temperature in the winter (January-February) (Wang and Raney 1971). This study did not comprehensively describe fish distribution and abundance in the lower salinity tributaries (i.e. the LPR and SC).

In 1996 the PRMRWSA initiated the preparation of a document summarizing all data available to date on the Lower Peace River and Upper Charlotte Harbor Estuarine System (PBS&J, 1999b). This document included summaries of fish communities, based on a long-term monitoring program by Environmental Quality Laboratory, Inc. (EQL) from 1975-1989 and sampling conducted by the Fish and Wildlife Research Institute (FWRI) (formerly the Florida Marine Research Institute) from 1989-1995.

5.1.1.1 Environmental Quality Laboratory (EQL)

Objectives

The EQL sampling was initiated through the Hydrobiological Monitoring Program (HBMP) set forth in the original Consumptive Use Permit for the Peace River Regional Water Treatment Plant. The HBMP was designed to describe and assess the responses of various physical, chemical and biological characteristics of the Charlotte Harbor system in response to change in flow in the Peace River (PBS&J 1999a). Fish sampling was a component of the HBMP, with the main goal of determining the relationship between freshwater inflow and trawl susceptible fish. Fraser (1997) published the findings and conclusions of this 13 year study.

Sampling Methods

Results from Wang and Raney (1971) were used to help locate a sampling area considered to be representative of the Upper Charlotte Harbor estuary (e.g., Marker #1 on Figure 5-1). Reciprocal trawl tows (4.9 m otter trawls) were made at the four cardinal points of the compass with Marker #1 at the center of the sampling effort, each tow lasting 5-7 minutes. Trawling began the first hour after twilight and yielded eight samples per date (June 1975-May 1988). *In-situ* physical data profiles were collected with a Hydrolab prior to each evening trawl.

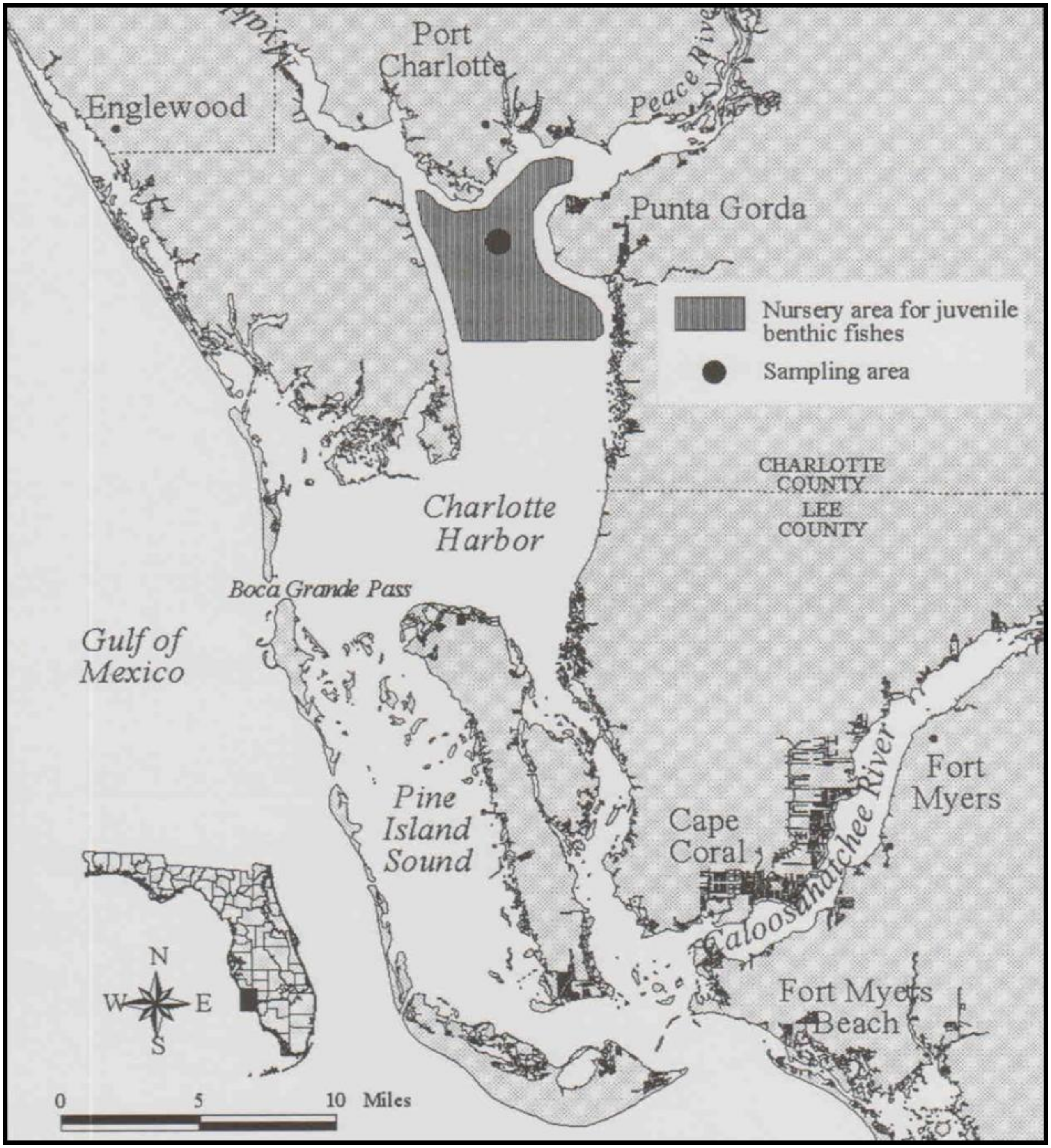


Figure 5-1. **Map from P BS&J (1999) showing the location of EQL Marker #1 (after Fraser,, 1997)**

Analysis Methods

The occurrence and abundance of each species was examined, both with respect to other fish species and community structure indices. The effects of freshwater inflow, temperature, salinity, dissolved oxygen, and other variables were examined. Rainfall data from six gages throughout the study area were obtained from the District. Rainfall totals for the same day and the previous 29 days were added and used to estimate direct rainfall and runoff from ungaged areas. Freshwater inflow from the following gaged stations was used: SC, Horse Creek, Joshua Creek, Peace River at Arcadia, Big Slough, Deer Prairie Creek and the Myakka River. In order to determine which flows were most highly with the physical-chemical data and with fish abundance and distribution, a series of flow lags were investigated (from 1 to 28 days). Calculating flow lags consisted of taking the average over a certain number of days. For example, the 7 day lag flow consisted of taking the average of the flow on and given day and the preceding six days. Cluster, principal components, and regression analyses were used.

Results and Conclusions

Sixty-two species of fish were collected over the course of the study. Size frequency analysis suggested that the habitat around Marker #1 was used primarily by juveniles less than one year old. The 13 most abundant species and the total numbers caught are shown in Table 5-1. Of these 13 species, consistent seasonal groupings (wet vs. dry season) were observed. The wet season group, as evidenced from cluster and principal components analysis, included: sand seatrout *(Cynoscion arenarius)*, gafftopsail catfish *(Bagre marinus),* hardhead catfish *(Arius felis)*, and southern kingfish *(Menticirrhus americanus)*. The wet season group was more abundant in periods of higher flows and temperature and lower salinity and dissolved oxygen. The dry season group regularly consisted of silver perch *(Bairdiella chrysoura)*, blackcheek tonguefish *(Symphurus plagiusa)*, southern kingfish, silver jenny *(Eucinostomus gula)*, bighead searobin *(Prionotus tribulus)*, and pinfish *(Lagodon rhomboides)*. The dry season group was more abundant in periods of lower flow and temperature and higher salinity and dissolved oxygen.

Significant changes in species abundance were correlated with trends in seasonal freshwater flow and water quality. These changes were consistent with the wet season and dry season groupings. Low dissolved oxygen values were observed in September, causing the relative abundance of all species to decline noticeably. This pattern occurred to some degree every wet season. The more abundant species seemed to have higher tolerances for low dissolved oxygen conditions. Generally, it was concluded that the trawl susceptible fish community was slowly changing in response to wet and dry periods and that these responses to variation in freshwater inflow could be on the order of several years in duration. Because of the long duration, combined with natural variation and interactions between species, critical flow levels and thresholds were not identified based on month or season.

Table 5-1. **The 13 most abundant fish species sampled by EQL during the 13 year monitoring period and the total number collected.**

Species	Total Number Collected
Anchoa mitchilli (bay anchovy)	14, 110
Cynoscion arenarius (sand seatrout)	9,795
Leiostomus xanthurus (spot)	4,982
Arius felis (hardhead catfish)	4,335
Menticirrhus americanus (southern kingfish)	2,689
Symphurus plagiusa (blackcheek tonguefish)	1,964
Prionotus scitulus (leopard searobin)	1,908
Trinectes maculatus (hogchoker)	1,548
Eucinostomus gula (silver jenny)	1,465
Lagodon rhomboides (pinfish)	1,427
Bagre marinus (gafftopsail catfish)	897
Prionotus tribulus (bighead searobin)	525
Bairdiella chrysoura (silver perch)	523
Grand Total	46,168

5.1.1.2 FWRI

Objectives

FWRI has conducted fish monitoring in Charlotte Harbor, as a spatial component of the Fisheries Independent Monitoring (FIM) program, since 1989. The objectives are to describe and quantify the annual status and trends of fish communities, independent of recreational and commercial fishing effort, in estuaries throughout Florida.

Sampling Methods

Two methods, fixed stations and variable stations based on a stratified-random design, were used to sample fish in Charlotte Harbor. The stratified random sampling included three bay zones (a fourth was added in 1994 to encompass Pine Island Sound) and two river zones (Figure 5-2). The bay zones were sampled using seines, trawls, gillnets (night only) and drop nets (day only), while the river zones were only sampled with seines and trawls. Stratified random sampling occurred in the spring (March-May) and fall (September-November). The fixed sampling consisted of 15 stations and occurred monthly. Temperature, salinity, dissolved oxygen and other physical-chemical data were typically collected with a Hydrolab.

Analysis Methods

Data summaries are provided periodically by FWRI, but analyses are not carried out in respect to freshwater inflow or water quality parameters for Charlotte Harbor. An assessment of the data from 1990-1994 was presented by PBS&J (1999a) which reported the most abundant species, across all years, and the dominant species, by gear type and year. A more recent study by FWRI biologists that is focused on the Peace River and incorporates data from the FIM program is discussed in a following section of this report.

Results and Conclusions

The seven most abundant species, as derived from the fixed station data, were: sand seatrout, kingfish (*Menticirrhus* spp.), hogchoker, anchovies (*Anchoa* spp.), hardhead catfish, silver perch, and blackcheek tonguefish. Comparisons between the previously described EQL data and the FWRI data showed the bay anchovy being far more abundant in the EQL data, while the relative dominance of sand seatrout and kingfish were similar in both data sources. Station locations differed in the two studies, and reduced dominance of bay anchovy in the FWRI dataset was attributed to the upstream location of one of their stations.

Additionally, while some inter-annual variability in catches is attributable to changes in gear and sampling regime, FWRI reported an increase in fish numbers for 1990-1994. However, specific analyses in relation to freshwater inflow or water quality variables were not provided. Summaries of the top five dominant species from the stratified random sampling regime are provided by gear type and year in Table 5-2 and 5-3.

5.1.2 Recent Studies, 1996-Present

Surveys of fish and zooplankton in the Lower Peace River have been conducted by the University of South Florida, Department of Marine Science (Peebles 2002) for the District and by the Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute (Greenwood *et al.* 2004).

5.1.2.1 USF/DEM

Objectives

Peebles (2002) conducted a 26 month study, beginning in April 1997, of freshwater inflow effects on habitat use by estuarine taxa in the tidal portion of the Peace River and SC. This study was funded by the District and the PRMRWSA in efforts to develop ecological relationships and develop criteria that could be used in establishing MFLs and to improve the overall management of these systems. The main objectives of the project were to establish a descriptive database to serve as a baseline against future ecological change and to develop regressions to model the response of estuarine organisms to variations in freshwater inflows and salinity (Peebles 2002).

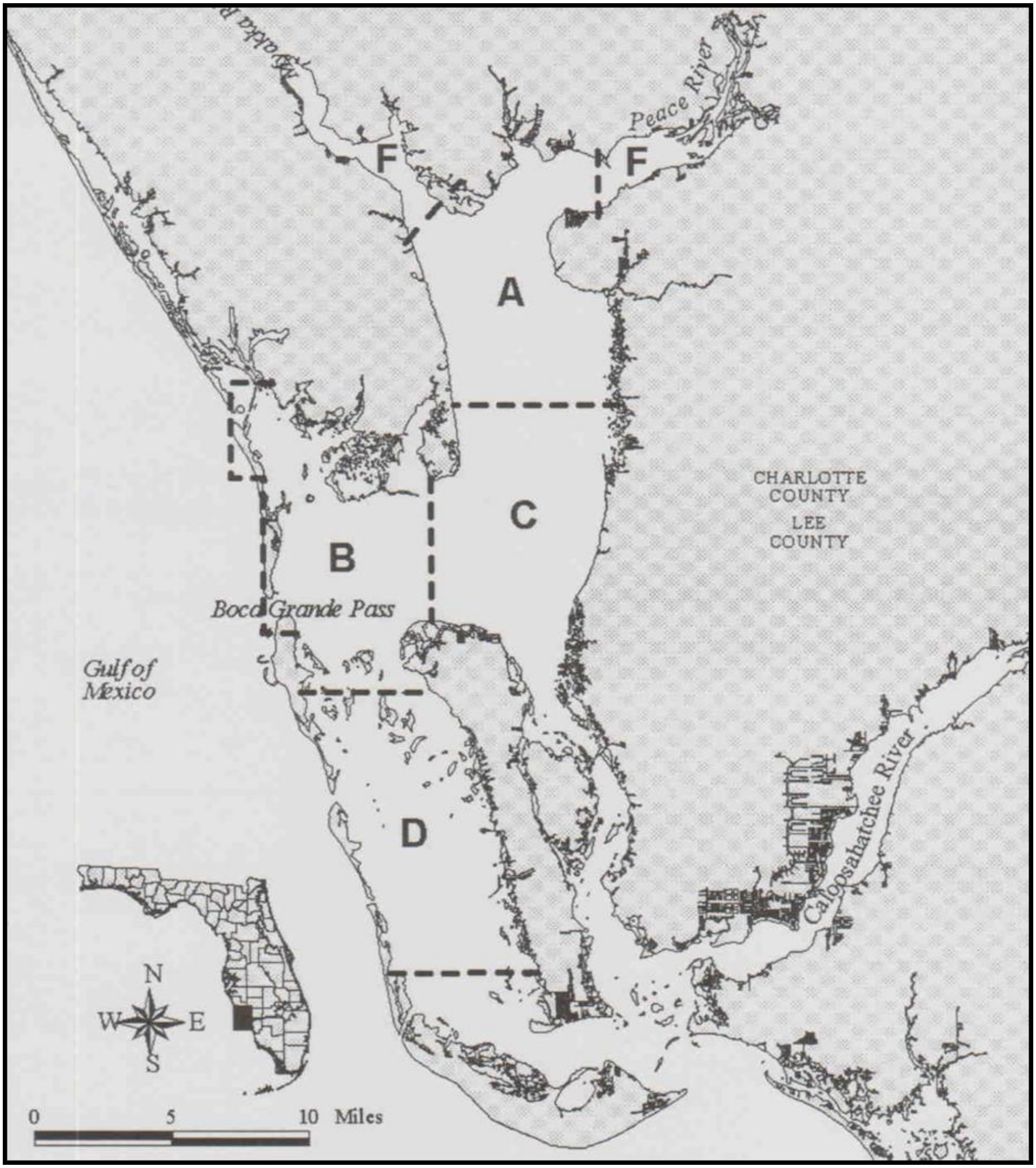


Figure 5-2. Location of FWRI sampling zones in Charlotte Harbor (PBS&J, 1999b).

Table 5-2. Summary table from PBS&J (1999b) showing the top five numerically dominant catch data from the FWRI stratified-random sampling during spring in Charlotte Harbor (1990-1994).

GEAR	1990		1991		1992		1993		1994	
Offshore Seines	1. *L. rhomboides* 2. *L. parva* 3. *Anchos* spp. 4. *B. chrysoura* 5. *O. chrysoptera*	6122 3411 686 471 431 14032	1. *Anchoa* spp. 2. *L. rhomboides* 3. *O. chrysoptera* 4. *B. chrysoura* 5. *Eucinostomus* spp.	9126 3609 1645 897 816 18376	1. *L. rhomboides* 2. *O. chrysoptera* 3. *L. parva* 4. *Anchoa* spp. 5. *D. holbrooki*	46171 10436 3628 1714 1412 66722	1. *L. rhomboides* 2. *O. chrysoptera* 3. *L. parva* 4. *S. scovelli* 5. *M. gulosus*	11079 1293 492 401 363 14728	1. *L. rhomboides* 2. *O. chrysoptera* 3. *Anchoa* spp. 4. *Eucinostomus* spp. 5. *B. chrysoura*	48764 6626 3995 2668 1637 68644
Boat Seines	1. *Anchoa* spp. 2. *Menidia* spp. 3. *L. rhomboides* 4. *T. maculatus* 5. *B. chrysoura*	9337 864 791 221 136 12068	1. *Anchoa* spp. 2. *Menidia* spp. 3. *Eucinostomus* spp. 4. *L. rhomboides* 5. *M. martinica*	8913 1231 881 568 626 13396	1. *Anchoa* spp. 2. *F. majalis* 3. *L. rhomboides* 4. *Menidia* spp. 5. *B. chrysoura*	87664 2216 1744 1691 1341 97467	1. *Anchoa* spp. 2. *Menidia* spp. 3. *T. maculaatus* 4. *B. chrysoura* 5. *Eucinostomus* spp.	830 818 223 86 83 2480	1. *Anchos* spp. 2. *Menidia* spp. 3. *Brevoortia* spp. 4. *Eucinostomus* spp. 5. *T. maculatus*	26743 1436 814 380 368 30086
Beach Seines	1. *Menidia* spp. 2. *L. rhomboides* 3. *F. similis* 4. *Anchoa* spp. 5. *Mugil* spp.	4812 863 712 610 447 8473	1. *Anchoa* spp. 2. *Menidia* spp. 3. *L. rhomboides* 4. *Eucinostomus* spp. 5. *L. parva*	34763 11944 8601 4108 2872 71312	1. *L. rhomboides* 2. *F. carpio* 3. *C. variegatus* 4. *Mugil* spp. 5. *Eucinostomus* spp.	16621 4590 4630 3688 2614 43641	1. *L. rhomboides* 2. *Anchoa* spp. 3. *Menidia* spp. 4. *Eucinostomus* spp. 5. *L. parva*	14928 9700 2618 1896 1327 34481	1. *L. rhomboides* 2. *L. parva* 3. *Menidia* spp. 4. *Eucinostomus* spp. 5. *Anchoa* spp.	32820 12271 11763 7671 6649 81736
Trawls	1. *O. chrysoptera* 2. *L. rhomboides* 3. *P. scitulus* 4. *Penaeus* spp. 5. *C. sapidus*	1678 1212 634 666 400 6731	1. *Penaeus* spp. 2. *T. maculatus* 3. *P. scitulus* 4. *L. rhomboides* 5. *C. sapidus*	2844 668 466 463 374 7281	1. *Anchoa* spp. 2. *P. scitulus* 3. *T. maculatus* 4. *C. sapidus* 5. *C. arenarius*	2429 2206 869 582 247 8269	1. *Anchoa* spp. 2. *O. chrysoptera* 3. *P. scitulus* 4. *L. rhomboides* 5. *C. arenarius*	4694 1829 1224 777 748 12040	1. *Anchoa* spp. 2. *L. rhomboides* 3. *T. maculatus* 4. *P. scitulus* 5. *O. chrysoptera*	8737 1910 1893 1064 1013 19897
Gillnets	1. *A. felis* 2. *B. marinus* 3. *E. saurus* 4. *S. tiburo* 5. *Brevoortia* spp.	469 83 39 29 24 774	1. *A. felis* 2. *Brevoortia* spp. 3. *B. marinus* 4. *C. hippos* 5. *C. arenarius*	176 93 81 66 38 642	1. *Brevoortia* spp. 2. *A. felis* 3. *B. marinus* 4. *C .faber* 5. *E. saurus*	362 93 79 56 41 870	1. *A. felis* 2. *Brevoortia* spp. 3. *B. marinus* 4. *E. saurus* 5. *C. sapidus*	169 91 63 36 14 509	1. *H. jaguana* 2. *A. felis* 3. *O. oglinum* 4. *B. marinus* 5. *E. saurus*	349 191 131 71 63 1076
Dropnets	1. *L. parva* 2. *S. scovelli* 3. *L. rhomboides* 4. *G. robustum* 5. *Penaeus* spp.	148 123 99 69 24 633	1. *L. rhomboides* 2. *S. scovelli* 3. *O. chrysoptera* 4. *Penaeus* spp. 5. *G. robustum*	281 121 88 67 56 807	1. *L. rhomboides* 2. *S. scovelli* 3. *M. gulosus* 4. *G. robustum* 5. *O. chrysoptera*	417 71 62 36 32 732	1. *L. rhomboides* 2. *S. scovelli* 3. *O. chrysoptera* 4. *G. robustum* 5. *M. gulosus*	95 70 70 47 46 355	1. *L. rhomboides* 2. *Anchoa* spp. 3. *G. robustum* 4. *L. parva* 5. *S. scovelli*	841 171 128 107 99 1650

Table 5-3. Summary table from PBS&J (1999b) showing the top five numerically dominant catch data from the FWRI stratified-random sampling during fall in Charlotte Harbor (1990-1994).

GEAR/	1990		1991		1992		1993		1994	
Offshore Seines	1. *Anchoa* spp.	32123	1. Anchoa *spp.*	8314	1. *Eucinostomus* spp.	3761	1. *Eucinostomus* spp.	9980	1. *L. parva*	16984
	2. *Eucinostomus* spp.	3974	*2. Eucinostomus* spp.	4217	2. *Penaeus* spp.	2224	2. *Penaeus* spp.	6536	2. *Anchoa* spp.	8277
	3. *Penaeus* spp.	974	3. *Penaeus* spp.	2035	3. *Anchoa* spp.	2211	3. *Anchoa* spp.	2255	3. *Eucinostomus* spp.	4609
	4. *O. oglinum*	660	4. *B. Chrysoura*	1153	4. *B. chrysoura*	704	4. *L. parva*	990	4. *Penaeus* spp.	1768
	5. *M. martinica*	427	5. *C. nebulosus*	587	5. *C. nebulosus*	428	5. *M. gulosus*	689	5. *L. rhomboides*	503
	Total catch	40251	Total catch	18807	Total catch	12015	Total catch	22903	Total catch	34696
Boat Seines	1. *Anchoa* spp.	28643	1. *Anchoa* spp.	18483	1. *Anchoa* spp.	7603	1. *Menidia* spp.	2662	1. *Anchoa* spp.	10268
	2. *Menidia* spp.	2023	2. *G. holbrooki*	1769	2. *Menidia* spp.	2176	2. *Eucinostomus* spp.	2030	2. *Eucinostomus* spp.	2062
	3. *Eucinostomus* spp.	1669	3. *Menidia* spp.	1060	3. *Eucinostomus* spp.	468	3. *Anchoa* spp.	904	3. *Menidia* spp.	973
	4. *L. parva*	1559	4. *L. parva*	964	4. *F. majalis*	153	4. *Penaeusi* spp.	218	4. *S. ocellatus*	220
	5. *G. holbrooki*	884	5. *Eucinostomus* spp.	860	5. *Penaeus* spp.	114	5. *D. plumieri*	115	5. *M. gulosus*	96
	Total catch	29640	Total catch	25236	Total catch	11193	Total catch	6654	Total catch	13924
Beach Seines	1. *Anchoa* spp.	86643	1. *Anchoa* spp.	6549	1. *Eucinostomus* spp.	16399	1. *Eucinostomus* spp.	10586	1. *L. parva*	19990
	2. *Eucinostomus* spp.	43611	2. *Eucinostomus* spp.	6435	2. *Anchoa* spp.	6630	2. *L. parva*	9948	2. *Eucinostomus* spp.	19076
	3. *Mugil* spp.	28331	3. *F. carpio*	6953	3. *Penaeus* spp.	3448	3. *Penaeus* spp.	4032	3. *Anchoa* spp.	8439
	4. *Menidia* spp.	15216	4. *Menidia* spp.	4791	4. *L. parva*	2581	4. *Menidia* spp.	3229	4. *Penaeus* spp.	4369
	5. *Penaeus*spp.	4891	5. *L. parva*	2816	5. *Menidia* spp.	1938	5. *F. carpio*	2301	5. *F. carpio*	3616
	Total catch	190541	Total catch	35035	Total catch	38888	Total catch	36742	Total catch	63676
Trawls	1. *Anchoa* spp.	8761	1. *P. scitulus*	1214	1. *Anchoa* spp.	3409	1. *T. maculatus*	2449	1. *L. rhomboides*	2833
	2. *C. arenarius*	3759	2. *T. maculatus*	899	2. *L. rhomboides*	2561	2. *P. scitulus*	881	2. *Menticirrhus* spp.	1709
	3. *T. maculatus*	3396	3. *Penaeus* spp.	804	3. *P. scitulua*	1297	3. *C. arenarius*	760	3. *Eucinostomus* spp.	1634
	4. *Penaeus* spp.	2569	4. *L. rhomboides*	699	4. *T. maculatus*	1155	4. *Penaeus* spp.	598	4. *Anchoa* spp.	1626
	5. *L. rhomboides*	2637	5. *O. chrysoptera*	690	5. *Penaeus* spp.	943	5. *Anchoa* spp.	547	5. *Penaeus* spp.	1300
	Total catch	28174	Total catch	7669	Total catch	13009	Total catch	7420	Total catch	14715
Gillnets	1. *A. felis*	168	1. *Brevoortia* spp.	163	1. *Brevoortia* spp.	327	1. *Brevoortia* spp.	240	1. *Brevoortia* spp.	465
	2. *T. falcatus*	98	2. *A. felis*	143	2. *A. felis*	129	2. *A. felis*	121	2. *B. marinus*	204
	3. *B. marinus*	70	3. *Mugil* spp.	79	3. *B. marinus*	62	3. *C. sapidus*	48	3. *A. felis*	146
	4. *Mugil* spp.	47	4. *B. marinus*	44	4. *E. saurus*	30	4. *B. marinus*	48	4. *E. saurus*	129
	5. *C. sapidus*	39	5. *C. sapidus*	32	5. *C. sapidus*	24	5. *E. saurus*	32	5. *L. xanthurus*	62
	Total catch	608	Total catch	658	Total catch	730	Total catch	657	Total catch	1399
Dropnets	1. *Penaeus* spp.	361	1. *Penaeus* spp.	394	1. *Penaeus* spp.	459	1. *Penaeus* spp.	487	1. *Anchoa* spp.	469
	2. *G. robustum*	190	2. *G. robustum*	289	2. *G. robustum*	189	2. *Eucinostomus* spp.	283	2. *Penaeus* spp.	441
	3. *M. gulosus*	126	3. *C. sapidus*	265	3. *M. gulosus*	138	3. *C. sapidus*	184	3. *M. gulosus*	182
	4. *S. scsovelli*	94	4. *M. gulosus*	123	4. *S. scovelli*	113	4. *S. scovelli*	64	4. *G. robustum*	99
	5. *Eucinostomus* spp.	74	5. *Anchoa* spp.	120	5. *C. sapidus*	104	5. *G. robustum*	59	5. *S. scovelli*	66
	Total catch	982	Total catch	1500	Total catch	1168	Total catch	1220	Total catch	1483

Sampling Methods
Sampling consisted of plankton, seine and trawl nets, deployed within seven zones on the mainstem of the Peace River and four zones in SC (Figure 5-3). Two plankton nets were deployed monthly in each zone in the channel during nighttime flood tides. Two seine nets were deployed monthly in each zone along the shoreline during the day under variable tide conditions. One trawl net was deployed monthly in the channel during the day under variable tide conditions. Salinity, water temperature, DO and pH measurements were recorded with each gear deployment. Daily freshwater flows were derived by summing flows at the following gages: Peace at Arcadia, Joshua Creek at Nocotee, Horse Creek near Nocotee, and Shell Creek near Punta Gorda.

Analysis Methods
Isohaline location was used, along with same day inflow, to investigate organism response to flow. Isohaline location was not measured directly, but was determined based on salinity measurements associated with various gear deployments. Organism weighted salinity (i.e., the central tendency for catch-per-unit-effort) and center of CPUE (i.e., the central geographic tendency for CPUE) was calculated. Organism total number was calculated for plankton net catches only, as it was related to water volume within each zone. Inflow response regressions were developed between organism total number and flow and isohaline location and between center of CPUE and flow and isohaline location.

Results and Conclusions
Habitat use patterns were documented and found to be consistent with those observed in other tidal rivers. The habitat use of egg, larval, juvenile and adult stages of estuarine-dependent, estuarine-resident, and freshwater fish were described. Estuarine-dependent fish are spawned at seaward locations and move into tidal rivers as late larval or early juvenile life stages. Estuarine resident fish are present in tidal rivers throughout their entire life cycle. The ingress of estuarine-dependent fish into the Peace River was observed based on salinities associated with certain life stages. The mean salinity at capture for the bay anchovy decreased during development, beginning at 22 psu during the egg stage and decreasing from 21 to 14 psu during the various larval stages, ending at 6 psu as juveniles occupied their estuarine nursery habitat. Similar patterns of were observed for other estuarine-dependent species.

The plankton net fish assemblage was dominated by bay anchovy *(Anchoa mitchilli)*, gobies (primarily *Gobiosoma* spp. and *Microgobius* spp.), menhaden *(Brevoortia* spp*.)*, sand seatrout, rainwater killifish *(Lucania parva)*, silversides (*Menidia* spp.) and the hogchoker *(Trinectes maculatus)*. The plankton net invertebrate assemblage was dominated by larval crabs, arrow worms, copepods, mysids, amphipods, isopods, cumaceans, the larvacean *Oikepleura dioica*, larval and juvenile bivalves, and ctenophores. Shoreline seines were dominated by bay anchovy, menhaden, silversides, mojarras *(Eucinostomus* spp*.),* eastern mosquitofish *(Gambusia holbrooki)*, killifish *(Fundulus* spp*.),* striped mullet *(Mugil cephalus)* and hogchoker. The trawl catch was dominated by bay anchovy, sand seatrout, southern kingfish, hogchoker and blue crab *(Callinectes sapidus)*.

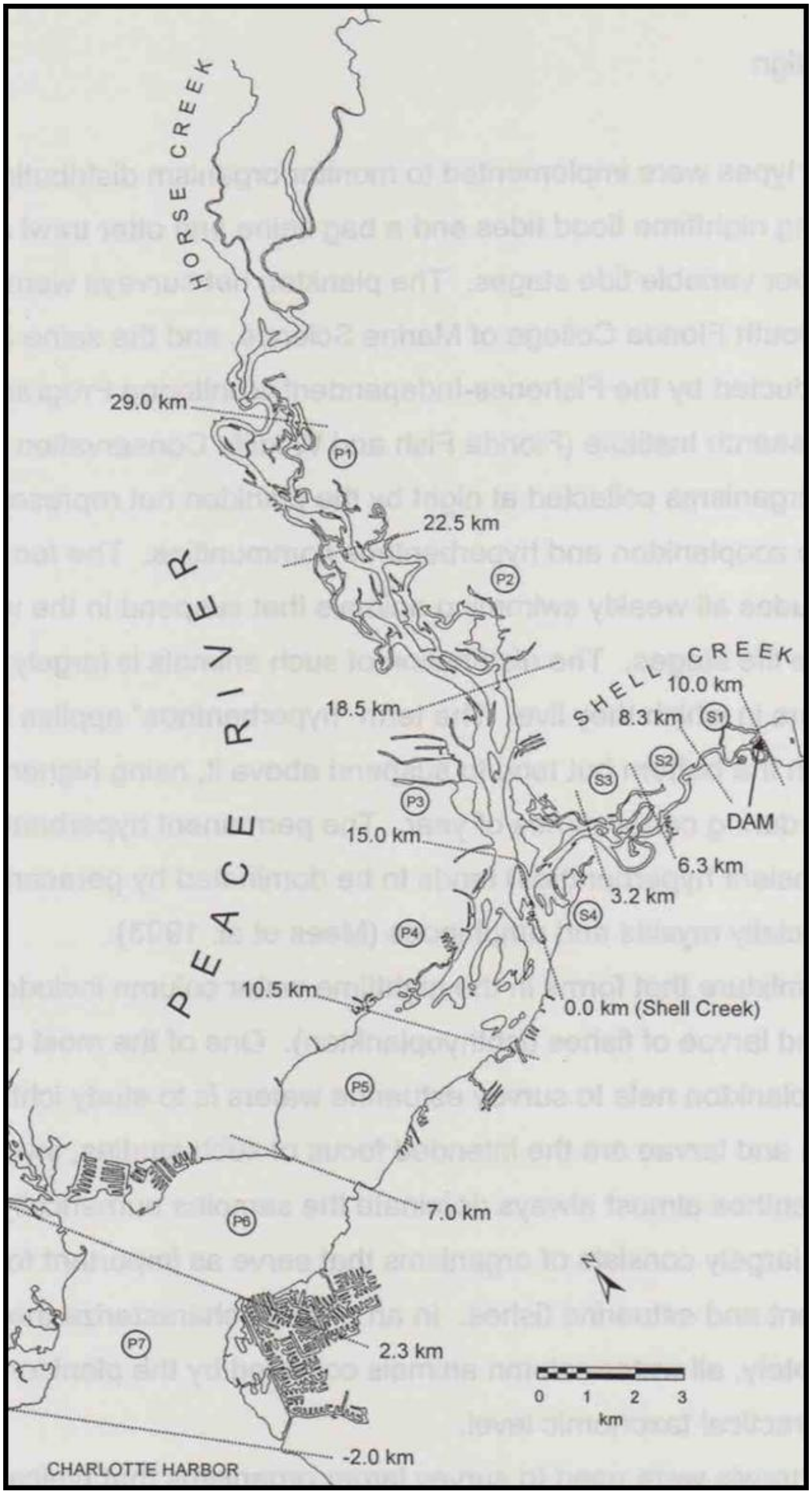


Figure 5-3. Map from Peebles (2002) showing study area with sampling zones numbered based on labels used for plankton samples.

Species determined to be spawning in or very near the tidal Peace River, based on the presence of eggs or early larval stages, were the bay anchovy, silversides, rough silverside *(Membras martinica)*, blennies (primarily *Chasmodes saburrae)*, several species of goby *(Gobiosoma* spp*., Microgobius* spp*., Bathygobius soporator),* sand seatrout, southern kingfish, and skilletfish *(Gobiesox strumosus)*. Live-bearing species, such as the eastern mosquitofish, lined seahorse *(Hippocampus erectus)*, chain pipefish *(Syngnathus louisianae)*, gulf pipefish *(Syngnathus scovelli)* and dusky pipefish *(Syngnathus floridae)*, released young into the tidal Peace River. Seine data indicated that juvenile snook, red drum, and striped mullet occurred commonly in the tidal river although no eggs or larvae were captured.

Estuarine-dependent species documented as congregating in the tidal Peace River as juveniles are the bay anchovy, yellowfin menhaden *(Brevoortia smithi)*, gulf menhaden *(Brevoortia patronus)*, ladyfish *(Elops saurus)*, snook *(Centropomis undecimalis)*, red drum *(Sciaenops ocellatus)*, spotted seatrout *(Cynoscion nebulosus)*, sand seatrout, striped mullet, hogchoker, blue crab and pink shrimp *(Penaeus duorarum)*. Of these species, all were also detected as larvae except for snook, striped mullet, and blue crab.

Seasonality was evident among the fish catches. In the plankton catch, the number of taxa increased during spring, decreased during fall, and was generally highest from April-October. A spring increase was also seen in the seine data, but the fall decrease was not observed, because the older juveniles caught in the seines remained in the river long after the larval recruitment observed in the plankton nets had ended. April to June was considered to be the time period with the most potential for impact due the combined effect of naturally low inflows and increased use of the estuary as nursery habitat. However, because other species (i.e., red drum and menhaden) spawn in the fall, the potential for ecological or economic impacts exists year round.

Over 20 taxa of fish and invertebrates displayed distributional responses to freshwater inflow based on the plankton catch data. Almost all, 94%, of these taxa moved downstream in response to increasing inflow and example regression plots are shown in Figure 5-4. Good indicators of organism position within the tidal river were determined to be same day inflow and the reference isohaline (7 ppt isohaline). While most organisms displayed the same directional response, the distribution of different organisms within the river was staggered and some were located farther upstream than others.

Eighteen taxa in the LPR and ten taxa in SC displayed either positive or negative abundance responses to flow. Positive responses were generally observed for freshwater species that shifted downstream with increasing flow, increasing their total numbers on the river (Figure 5-5). High salinity organisms accounted for the negative responses as these organisms generally left the tidal river during periods of high inflow. Positive responses were also found for sand seatrout juveniles and mysids (opossum shrimp). The majority of estuarine and estuarine dependent taxa had positive responses to high inflow that were delayed 3-6 months. The very high flows of the 1997-1998 El

Nino event was followed by very large peaks of these taxa several months after the event.

Additionally, mysids are an important prey source for many juvenile estuarine-dependent organisms; reducing mysid abundance during low flow periods is expected to reduce the carrying capacity of the LPR and SC for snook, red drum, sand seatrout, spotted seatrout and other species. Inflow-induced movement of important prey groups (i.e., mysids) relative to the fixed structural habitats preferred by certain fish could cause prey distributions to be offset (upstream or downstream) of their fish predators, acting to reduce the carrying capacity of the river for these fish. In the LPR, mysid populations were frequently located upstream from the principal habitat of juvenile red drum. It was suggested that the mysids in SC were favored as an alternative food supply and this contributed to the red drum remaining downstream of the mysid peak in the Lower Peace River. Other species, such as juvenile spotted seatrout and sand seatrout were more spatially in step with their prey in the Lower Peace River, often congregating above the confluence with SC.

5.1.2.2 FWC/FWRI

Objectives

Greenwood *et al.* (2004) conducted a multi-year study from January 1996 to December 2003 to establish relationships between freshwater inflow and biotic populations and communities within Peace River and SC by staff from the Fisheries-Independent Monitoring Program (FIM) of the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FCW/FWR). This is the same sampling program that was described earlier by PBS&J (1999b) but with more recent efforts the FIM program has expanded to include sampling areas in the LPR and SC.

The specific objectives of this project were to: 1) assess the composition of the nekton community (finfish and selected macroinvertebrates) over the period of record, 2) to examine habitat use for selected economically or ecologically important species, 3) to analyze movement and relative abundance of the nekton populations in relation to magnitude of freshwater inflow, and 4) to examine nekton community composition in relation to magnitude of freshwater inflow. Data collected for the SWFWMD by Peebles (2002) was also included in the analysis and provided additional data for 1997-1999.

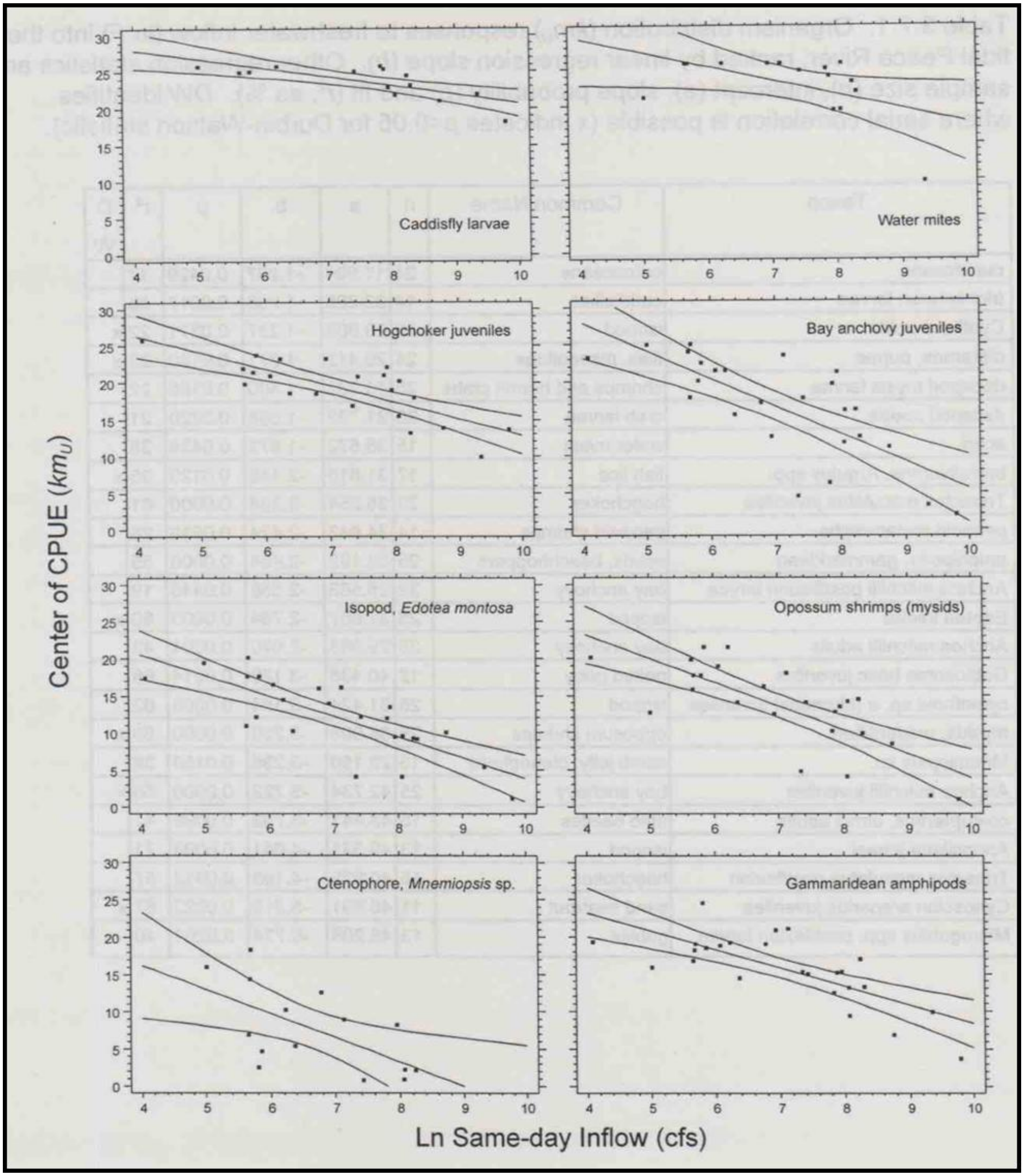


Figure 5-4. **Example regressions of organism location vs. inflow with 95% confidence limits for estimated means, showing general trend of movement downstream with increasing flows (Peebles 2002).**

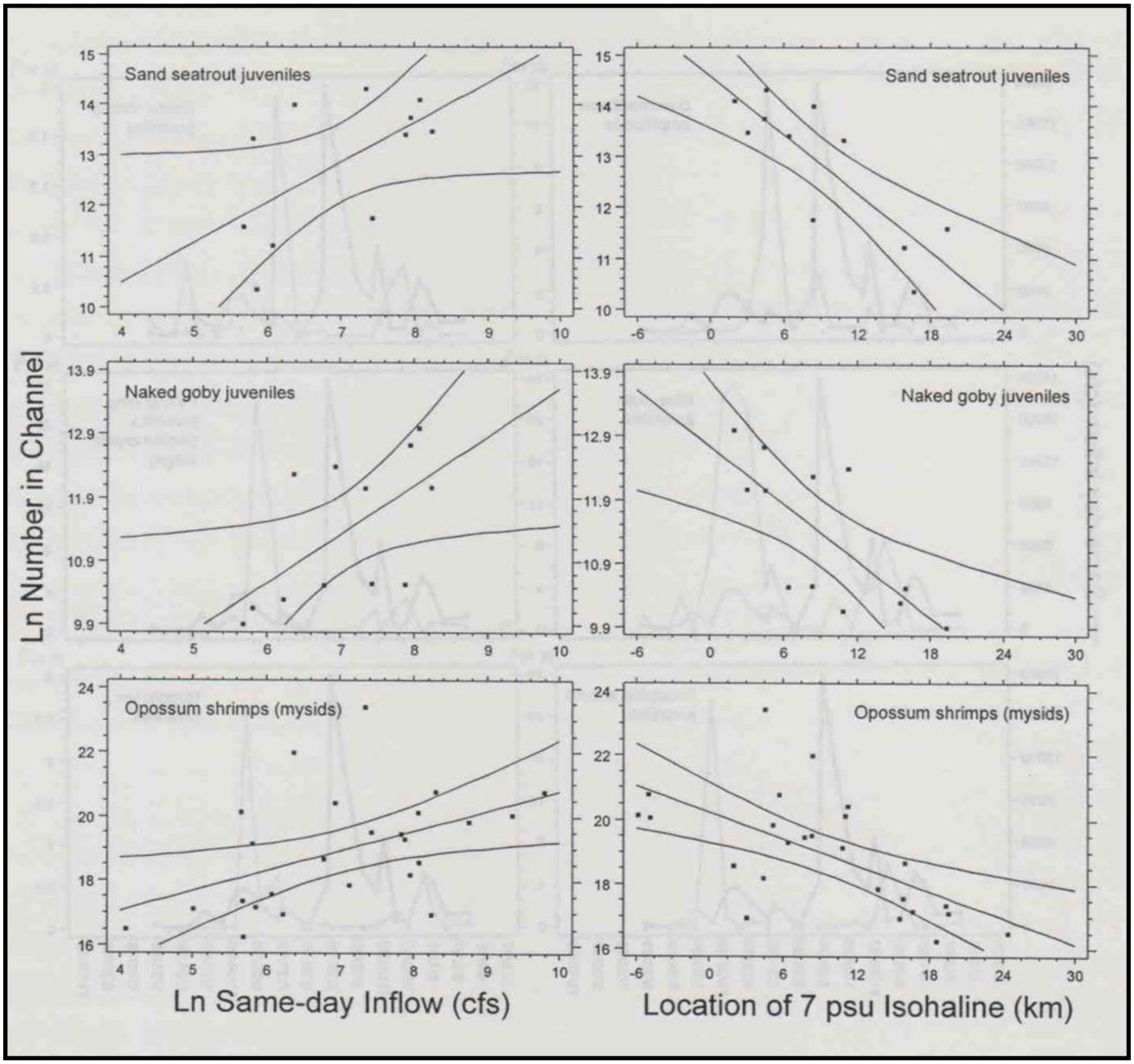


Figure 5-5. **Example regressions of organism number vs. inflow and 7 ppt isohaline location, with 95% confidence limits for estimated means (Peebles 2002).**

Sampling Methods

Sampling consisted of seine and trawl sampling in the main stem of the LPR and SC (Figure 5-6). Nearshore habitats were sampled with a 21.3 m seine set from a boat and channel habitats were sampled with a 6.1 m otter trawl. Stratified random sampling was used to collect the FIM data; the data in the Peebles (2002) study where based on the establishment of seven zones in the LPR and four in SC and consisted of two seines samples and one trawl sample per month (Figure 5-6). A Hydrolab multi-probe was used to record water temperature, salinity, pH and dissolved oxygen with each sample, at the surface and at 1.0-m intervals down to the bottom. Secchi disk readings were taken at the end of each sample.

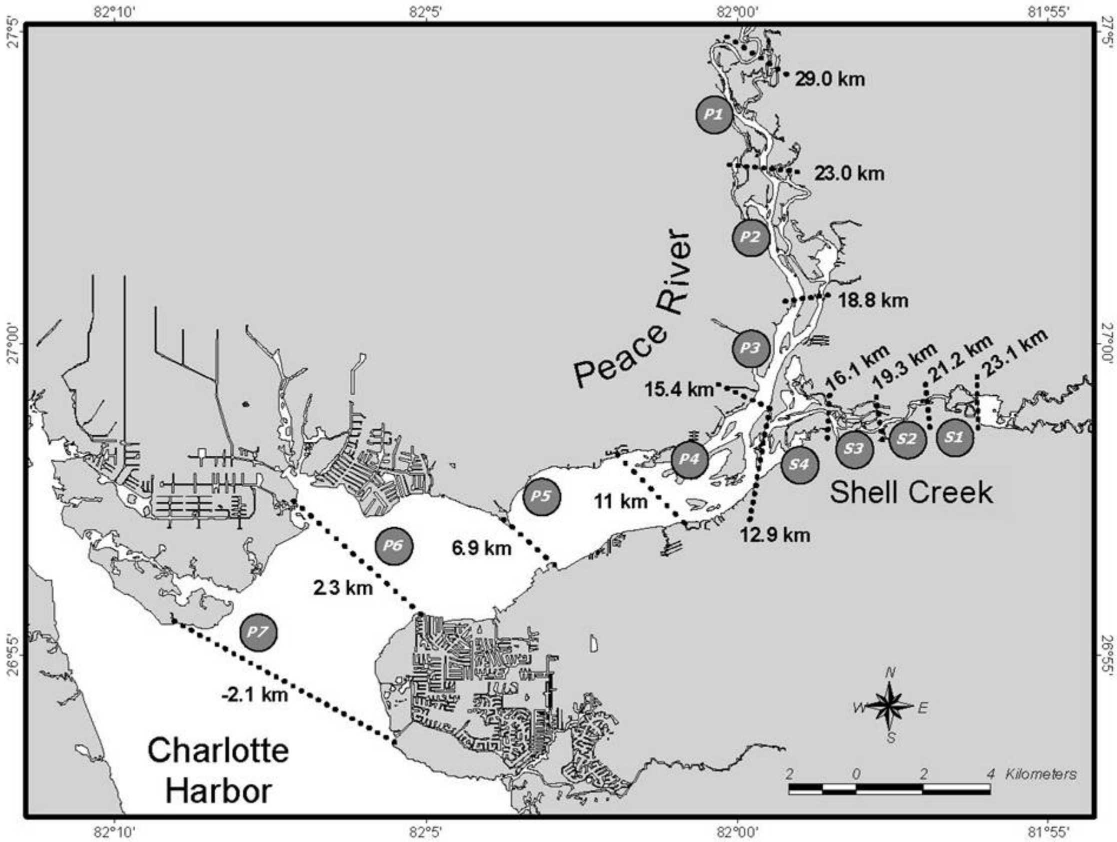


Figure 5-6. Study area of the tidal Peace River and Shell Creek showing the sampling locations of the SWFWMD study data (Peebles 2002) that were incorporated with the FWRI stratified-random sampling program (occurred between river km 6.8 and 15.4) (Greenwood *et al.* 2004).

Analysis Methods

The analysis goal was to regress organism abundance/distribution from a sampling trip, comprised of several individual seine or trawl samples, against the mean daily inflow that corresponded to the sampling trip. Abundance information was summarized separately for seine and trawl data for all species that were either 1) commercially or recreationally important, and/or 2) had an Index of Relative Important (Gilmore, 1988) of greater than 0.3. Plots of monthly length frequency were used to determine the appropriate size classes and time periods within each species (i.e., termed pseudo-species).

Samples were divided into three geographic zones prior to analysis based on different river flow. These groups included data from the following locations: 1) Peace River above the confluence of SC which corresponded to the summed inflow from the USGS gages at Joshua Creek at Nocatee, Horse Creek at Nocatee, and Peace River at Arcadia; 2) SC and the corresponding inflow from Shell Creek near Punta Gorda; and 3) Peace River below the confluence with SC and the corresponding flow was summed from the gages used for the previous two categories. Additionally data were separated into six different salinity classes: limnetic, oligohaline, low mesohaline, high mesohaline, polyhaline and euhaline. Data was presented for the distribution of size classes of major taxa and abundance on a monthly basis.

Linear regressions of center of CPUE (kmu) and freshwater inflow were computed for pseudo-species with IRI values >0.3 to examine the response to variations in river flow (km=the distance from the river mouth; u=the number of animals per 100 m^2). The kmu for each pseudo-species was regressed against mean daily flow for the sampling day and various lags. Lags included flow for the same day plus the previous 6, 13, 29, 44, 59, 89, 179, or 364 days. Linear and non-linear regressions were also developed for CPUE and same day flow, within the period of highest pseudo-species abundance.

Nekton community structure was analyzed using the Bray-Curtis similarity measure.

Results and Conclusions

In the Peace River above the confluence with SC, bay anchovies were the most abundant species and accounted for over 61% of the total catch. Hogchoker was the most frequently occurring species, being found in over 80% of all samples. In the Peace River below the confluence with SC, bay anchovies were still the most abundant species, accounting for 67% of the seine catch and nearly 47% of the trawl catch. Silversides were the most frequently occurring seine species, being found in nearly 73% of all samples and blue crab was the most frequently occurring trawl species, being found in nearly 70% of the samples.

The following ten species were most abundant in the nearshore habitat (based on total numbers caught) and comprised between 90.4%-97% of the total catch in the three segments: bay anchovy, silversides, rainwater killifish, eastern mosquitofish, mojarras, hogchoker, seminole killifish *(Fundulus seminolis)*, sailfin molly *(Poecilia latipinna)*, tidewater mojarra *(Eucinostomus harangulus)*, and striped mullet. Bay anchovies dominated the catch in each segment, with the percentage of the catch comprised of bay anchovies ranging from 59.4%-67%.

The following ten species were most abundant in the channel habitat (based on total numbers caught) and comprised between 96.3-97.7% of the total catch in the three segments: bay anchovy, hogchoker, sand seatrout, pink shrimp, blue crab, southern kingfish, mojarras, silver perch, bighead searobin, and hardhead catfish. The bay anchovy dominated the total catch in both the Peace River below the confluence of SC (46.7%) and in SC (41.8%), while the hogchoker was most abundant in the Peace River above the confluence (39.8%).

Thirty-four taxa were selected for detailed regression analysis on the basis of overall abundance. Regression results were complex and numerous, preventing the summary of individual species results. However, overall the comparisons of freshwater inflow to population center-of-abundance and overall relative abundance showed that many species are likely to move upstream during periods of low flow and reach their maximum abundance at intermediate flows. Longer term inflow lag periods (90-365 days) generated the best fitting regressions indicating the longer lags have a stronger relationship with nekton abundance and distribution than short term inflow patterns. Complex relationships were seen between relative importance of freshwater inflow and the life history stages of species found within the river. Although less common, there were some differences between the relationships observed depending on which of the three segments of the system, or which of the two habitats (shoreline or channel), is being considered.

Community structure in the Peace River and SC were generally separated into assemblages above and below the confluence between the two systems. Relatively little difference was observed between the Peace River above the confluence and SC. However, these two segments differed from the Peace River below the confluence with SC.

Annual cycles were most evident in the Peace River below the confluence and were poorly defined in the other areas. This was thought to relate to the Lower Peace River being used as a nursery area for a number of transient species with fairly well-defined seasonal patterns of recruitment. Patterns observed in community structure in the Peace River above the confluence and SC were more strongly correlated with changes in salinity (as opposed to flow), while changes in community structure below the confluence were equally correlated with both salinity and flow.

5.2 Shell Creek

A number of studies have been conducted since 1975 in the LPR. The following presents summaries of the earliest studies, as gathered from PBS&J (1999b) and more recent studies (1996-present) as gathered from Peebles (2002) and Greenwood *et al.* (2004).

5.2.1 Earlier Studies, 1975-1996

The first comprehensive study of fish from the Charlotte Harbor area was by Wang and Raney (1971), but did not include SC or other lower salinity tributaries. In 1999 a summary document was prepared by PBS&J (1999b) for the PRMRWSA. This document included summaries of fish communities, based on a long-term monitoring program by EQL from 1975-1989 and sampling conducted by the FWRI from 1989-1995. However, sampling from these programs focused solely on the LPRr and Charlotte Harbor and did not extend sampling into SC.

5.2.2 Recent Studies, 1999-Present

Surveys of fish and zooplankton in the LPR and SC have been conducted by the University of South Florida, Department of Marine Science (Peebles 2002) for the District and by the Florida Fish and Wildlife Conservation Commission, FWRI (Greenwood *et al.* 2004).

5.2.2.1 USF/DEM

Objectives

Peebles (2002) conducted a 26 month study, beginning in April 1997, of freshwater inflow effects on habitat use by estuarine taxa in the tidal portion of the Peace River and SC. This study was funded by the District and the PRMRWSA in efforts to develop ecological relationships and develop criteria that could be used in establishing MFLs and to improve the overall management of these systems. The main objectives of the project were to establish a descriptive database to serve as a baseline against future ecological change and to develop regressions to model the response of estuarine organisms to variations in freshwater inflows and salinity (Peebles 2002).

Sampling Methods

Sampling consisted of plankton, seine and trawl nets, deployed within seven zones on the mainstem of the Peace River and four zones in SC (Figure 5-3). Two plankton nets were deployed monthly in each zone in the channel during nighttime flood tides. Two seine nets were deployed monthly in each zone along the shoreline during the day under variable tide conditions. One trawl net was deployed monthly in the channel during the day under variable tide conditions. Salinity, water temperature, DO and pH measurements were recorded with each gear deployment. Daily freshwater flows were derived by summing flows at the following gages: Peace at Arcadia, Joshua Creek at Nocatee, Horse Creek near Nocatee, and Shell Creek near Punta Gorda.

Analysis Methods

Isohaline location was used, along with same day inflow, to investigate organism response to flow. Isohaline location was not measured directly, but was determined based on salinity measurements associated with various gear deployments. Organism weighted salinity (i.e., the central tendency for catch-per-unit-effort) and center of CPUE (i.e., the central geographic tendency for CPUE) was calculated. Organism total number was calculated for plankton net catches only, as it was related to water volume within each zone. Inflow response regressions were developed between organism total number and flow and isohaline location and between center of CPUE and flow and isohaline location.

Results and Conclusions

SC had high inflows during most of the Peebles (2002) study, which caused the numbers of freshwater organisms to increase and numbers of estuarine organisms to decrease. There were no apparent inflow-related trends in the numbers of estuarine and estuarine-dependent organisms within SC, but this may have been due to the lack of low flow conditions during the study period. SC exhibited freshwater conditions during 13 of 25 surveys and the mean salinity during the study period was only 3.0 psu.

Salinities greater than 17 psu were never observed during this study, although earlier work by PBS&J (1999b) reported salinities of greater than 25 psu.

The lifestage specific ingress demonstrated in the Peace River was not observed in SC for two possible reasons. First, larvae of fish such as anchovies, seatrout and other species that broadcast their eggs spawned primarily in the bay-like reaches of the Peace River as opposed to the more river-like areas of SC. Additionally, salinities in SC were generally low during the sampling period which prevented much gradient for ingress to be identified.

The plankton net fish assemblage was dominated by bay anchovy, gobies (primarily *Gobiosoma spp*. and *Microgobius spp.*), menhaden, sand seatrout, rainwater killifish, silversides and the hogchoker. The plankton net invertebrate assemblage was dominated by larval crabs, arrow worms, copepods, mysids, amphipods, isopods, cumaceans, the larvacean *Oikepleura dioica*, larval and juvenile bivalves, and ctenophores. Shoreline seines were dominated by bay anchovy, menhaden, silversides, mojarras, eastern mosquitofish, killifish, striped mullet and hogchoker. The trawl catch was dominated by bay anchovy, sand seatrout, southern kingfish, hogchoker and blue crab.

Species determined to be spawning in or very near the tidal Peace River, based on the presence of eggs or early larval stages, were the bay anchovy, silversides, rough silverside, blennies (primarily *Chasmodes saburrae*), several species of goby *(Gobiosoma* spp*., Microgobius* spp*., Bathygobius soporator)*, sand seatrout, southern kingfish, and skilletfish. Live-bearing species, such as the eastern mosquitofish, lined seahorse, chain pipefish, gulf pipefish and dusky pipefish, released young into the tidal Peace River.

Estuarine dependent species documented as congregating in the tidal Peace River as juveniles are the bay anchovy, yellowfin menhaden, gulf menhaden, ladyfish, snook, red drum, spotted seatrout, sand seatrout, striped mullet, hogchoker, blue crab and pink shrimp. Of these species, all were also detected as larvae except for snook, striped mullet, and blue crab. Seasonality was evident among the fish catches. In the plankton catch, the number of taxa increased during spring, decreased during fall, and was generally highest from April-October. A spring increase was also seen in the seine data, but the fall decrease was not observed because the older juveniles caught in the seines remained in the river long after the larval recruitment observed in the plankton nets had ended. April to June was considered to be the time period with the most potential for impact due the combined effect of naturally low inflows and increased use of the estuary as nursery habitat. However, because other species (i.e., red drum and menhaden) spawn in the fall, the potential for ecological or economic impacts exists year round.

Over 20 taxa of fish and invertebrates displayed distributional responses to freshwater inflow based on the plankton catch data. Almost all, 94%, of these taxa moved downstream in response to increasing inflow and example regression plots are shown in

Figure 5-4. Good indicators of organism position within the tidal river were determined to be same day inflow and the reference isohaline (7 ppt isohaline). While most organisms displayed the same directional response, the distribution of different organisms within the river was staggered and some were located farther upstream than others.

Eighteen taxa in the Lower Peace River and ten taxa in SC displayed either positive or negative abundance responses to flow. Positive responses were generally observed for freshwater species that shifted downstream with increasing flow, increasing their total numbers on the river (Figure 5-5). High salinity organisms accounted for the negative responses as these organisms generally left the tidal river during periods of high inflow. The majority of estuarine and estuarine dependent taxa had positive responses to high inflow that were delayed 3-6 months. The very high flows of the 1997-1998 El Nino event was followed by very large peaks of these taxa several months after the event.

Additionally, mysids are an important prey source for many juvenile estuarine-dependent organisms; reducing mysid abundance during low flow periods is expected to reduce the carrying capacity of the LPR and SC for snook, red drum, sand seatrout, spotted seatrout and other species. Inflow-induced movement of important prey groups (i.e., mysids) relative to the fixed structural habitats preferred by certain fish could cause prey distributions to be offset (upstream or downstream) of their fish predators, acting to reduce the carrying capacity of the river for these fish. In the Lower Peace River, mysid populations were frequently located upstream from the principal habitat of juvenile red drum. It was suggested that the mysids in SC were favored as an alternative food supply and this contributed to the red drum remaining downstream of the mysid peak in the LPR. Other species, such as juvenile spotted seatrout and sand seatrout were more spatially in step with their prey in the LPR, often congregating above the confluence with SC.

5.2.2.2 FWC/FWRI

Objectives

Greenwood *et al.* (2004) conducted a multi-year study from January 1996 to December 2003 to establish relationships between freshwater inflow and biotic populations and communities within Peace River and SC by staff from the FIM of the Florida Fish and Wildlife Conservation Commission's FWRI. The specific objectives of this project were to: 1) assess the composition of the nekton community (finfish and selected macroinvertebrates) over the period of record, 2) to examine habitat use for selected economically or ecologically important species, 3) to analyze movement and relative abundance of the nekton populations in relation to magnitude of freshwater inflow, and 4) to examine nekton community composition in relation to magnitude of freshwater inflow. Data collected for the SWFWMD by Peebles (2002) was also included in the analysis and provided additional data for 1997-1999.

Sampling Methods

Sampling consisted of seine and trawl sampling in the main stem of the LPR and SC (Figure 5-6). Nearshore habitats were sampled with a 21.3 m seine set from a boat and channel habitats were sampled with a 6.1 m otter trawl. Stratified random sampling was used to collect the FIM data; the data in the Peebles (2002) study where based on the establishment of seven zones in the LPR and four in SC and consisted of two seines samples and one trawl sample per month (Figure 5-6). A Hydrolab multi-probe was used to record water temperature, salinity, pH and dissolved oxygen with each sample, at the surface and at 1.0-m intervals down to the bottom. Secchi disk readings were taken at the end of each sample.

Analysis Methods

The analysis goal was to regress organism abundance/distribution from a sampling trip, comprised of several individual seine or trawl samples, against the mean daily inflow that corresponded to the sampling trip. Abundance information was summarized separately for seine and trawl data for all species that were either 1) commercially or recreationally important, and/or 2) had an Index of Relative Important (Gilmore 1988) of greater than 0.3. Plots of monthly length frequency were used to determine the appropriate size classes and time periods within each species (i.e., pseudo-species).

Samples were divided into three geographic regions prior to analysis based on different river flow. These groups included data from the following locations: 1) Peace River above the confluence of SC which corresponded to the summed inflow from the USGS gages at Joshua Creek at Nocatee, Horse Creek at Nocatee, and Peace River at Arcadia; 2) SC and the corresponding inflow from Shell Creek near Punta Gorda; and 3) Peace River below the confluence with SC and the corresponding flow was summed from the gages used for the previous two categories.

Linear regressions of center of CPUE (kmu) and freshwater inflow were computed for pseudo-species with IRI values >0.3 to examine the response to variations in river flow (km=the distance from the river mouth; u=the number of animals per 100 m^2). The kmu for each pseudo-species was regressed against mean daily flow for the sampling day and various lags. Lags included flow for the same day plus the previous 6, 13, 29, 44, 59, 89, 179, or 364 days. Linear and non-linear regressions were also developed for CPUE and same day flow, within the period of highest pseudo-species abundance.

Nekton community structure was analyzed using the Bray-Curtis similarity measure.

Results and Conclusions

In SC, as in the Peace River, bay anchovies were the most abundant taxa, comprising nearly 60% of the total catch. Silversides and the rainwater killifish were the most frequently occurring taxa, being present in over 83% of all samples.

The following ten species were most abundant in the channel habitat (based on total numbers caught) and comprised between 96.3-97.7% of the total catch in the three segments: bay anchovy, hogchoker, sand seatrout, pink shrimp, blue crab, southern kingfish, mojarras, silver perch, bighead searobin, and hardhead catfish. The bay anchovy dominated the total catch in both the Peace River below the confluence of SC (46.7%) and in SC (41.8%), while the hogchoker was most abundant in the Peace River above the confluence (39.8%).

Regression results were complex and numerous, preventing the summary of individual species results. However, overall the comparisons of freshwater inflow to population center-of-abundance and overall relative abundance showed that many species are likely to move upstream during periods of low flow and reach their maximum abundance at intermediate flows. Longer term inflow lag periods (90-365 days) generated the best fitting regressions indicating the longer lags have a stronger relationship with nekton abundance and distribution than short term inflow patterns. Complex relationships were seen between relative importance of freshwater inflow and the life history stages of species found within the river. Although less common, there were some differences between the relationships observed depending on which of the three segments of the system, or which of the two habitats (shoreline or channel), is being considered.

Community structure in the Peace River and SC were generally separated into assemblages above and below the confluence between the two systems. Relatively little difference was observed between the Peace River above the confluence and SC. However, these two segments differed from the Peace River below the confluence with SC. Annual cycles were most evident in the Peace River below the confluence and were poorly defined in the other areas. This was thought to relate to the Lower Peace River being used as a nursery area for a number of transient species with fairly well-defined seasonal patterns of recruitment. Patterns observed in community structure in the Peace River above the confluence were more strongly correlated with changes in salinity (as opposed to flow), while changes in community structure below the confluence were equally correlated with both salinity and flow.

5.3 Fish Community Structure and Distribution in the Lower Peace River

To expand on the existing information, additional analyses were completed for this report using the same dataset used by Greenwood *et al.* (2004). While the same data were used, they were spatially segregated into the four zones used by Mote Marine Laboratory (2002), plus SC. Zones 1 and 2 of the new segregation are above the confluence of SC, while Zones 3 and 4 correspond to the below SC zone used by FWRI.

The spatial variation in the total abundance and number of taxa has been examined and summarized in Figures 5-7 through 5-10. The taxa richness varied spatially as expected; seine data showed the lowest number of species in the higher salinity zones

(Zones 3 and 4) and slightly higher numbers of species in the lower salinity zones (Zones 1, 2 and SC) (Figure 5-7). Trawl data exhibited an opposite pattern, with fewer species in the lower salinity zones (Zones 1, 2, and SC) and the highest number of species in the highest salinity zone (Zone 4) (Figure 5-8).

Since seines samples shoreline habitat and trawls sample deeper channel habitat, these opposing patterns may reflect differing extents of each habitat type present in the various zones. Additionally, shoreline habitat is increasingly important as nursery area in lower salinity zones, it may follow that the greatest number of seine species would occur in the lower salinity zones for this reason. Trawls sample deeper channel habitat which is typically occupied by marine and euryhaline species which tolerate higher salinities and this may account for the greatest number of trawl species being reported in the higher salinity zones.

The total number of taxa caught per seine sample was highest in Zone 2 and SC, where the median number of taxa per sample was 9. Similar numbers of taxa were found in Zone 1 (median number of taxa=8) and Zone 3 (median number of taxa=7). The fewest number of taxa was found in Zone 4 (median number of taxa=6).

The total number of species caught per trawl sample was generally lower than numbers reported for seines, and displayed a similar pattern of higher numbers of taxa in the more saline environments (Figure 5-8). The total number of taxa caught per trawl was lowest in Zone 1 (median=4). Slightly higher numbers of taxa were found in Zone 2 (median=5) and SC (median=4). The median number of taxa per trawl was 6 in Zone 3 and greatest in Zone 4 (median=7).

The total number of fish caught per seine sample varied across zones much more than number of taxa (Figure 5-9). The lowest number of fish per seine occurred in Zone 1 (median=114 individuals/sample) and Zone 4 (median=65 individuals/sample). Slightly higher abundances were found in Zone 2 (median=121 individuals/sample) and Zone 3 (median=90 individuals/sample). The highest number of organisms per seine samples was found in SC (median=311 individuals/sample).

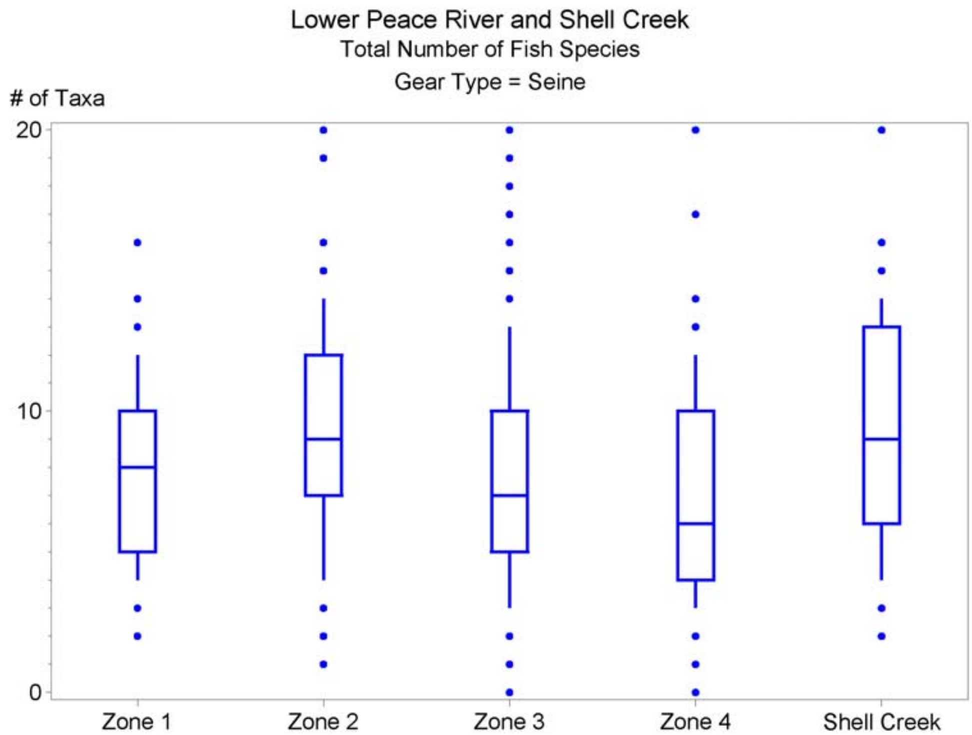


Figure 5-7. Box-and-whisker plots of the taxa richness in seine samples collected in the four LPR zones and SC (Data source: Greenwood *et al.* 2004).

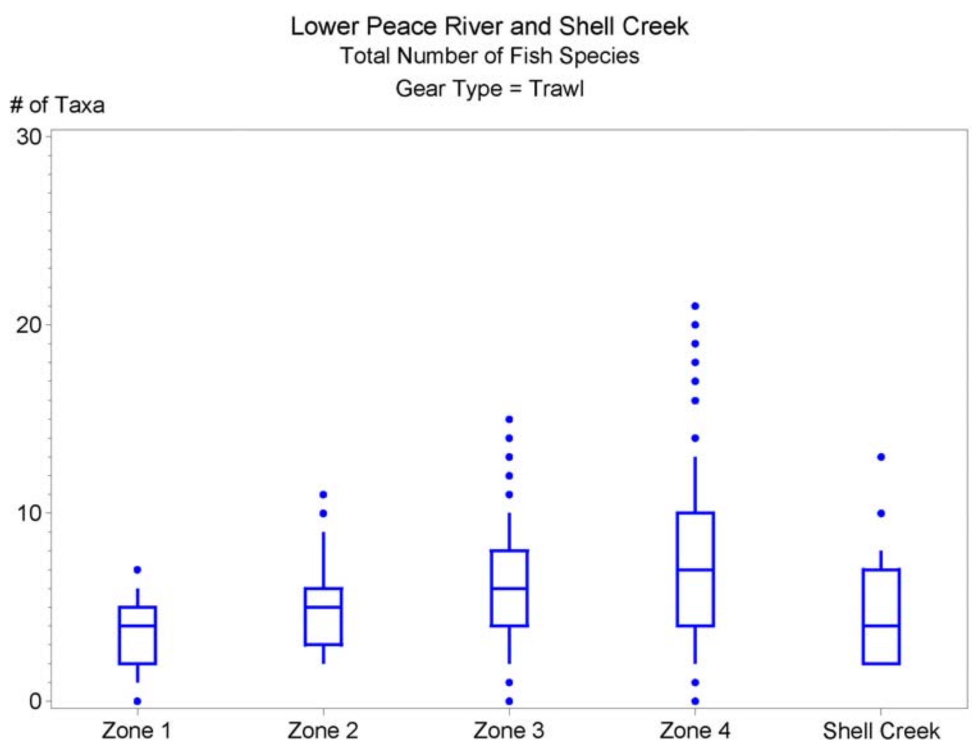


Figure 5-8. Box-and-whisker plots of the taxa richness in trawl samples collected in the four LPR zones and SC (Data source: Greenwood *et al*. 2004).

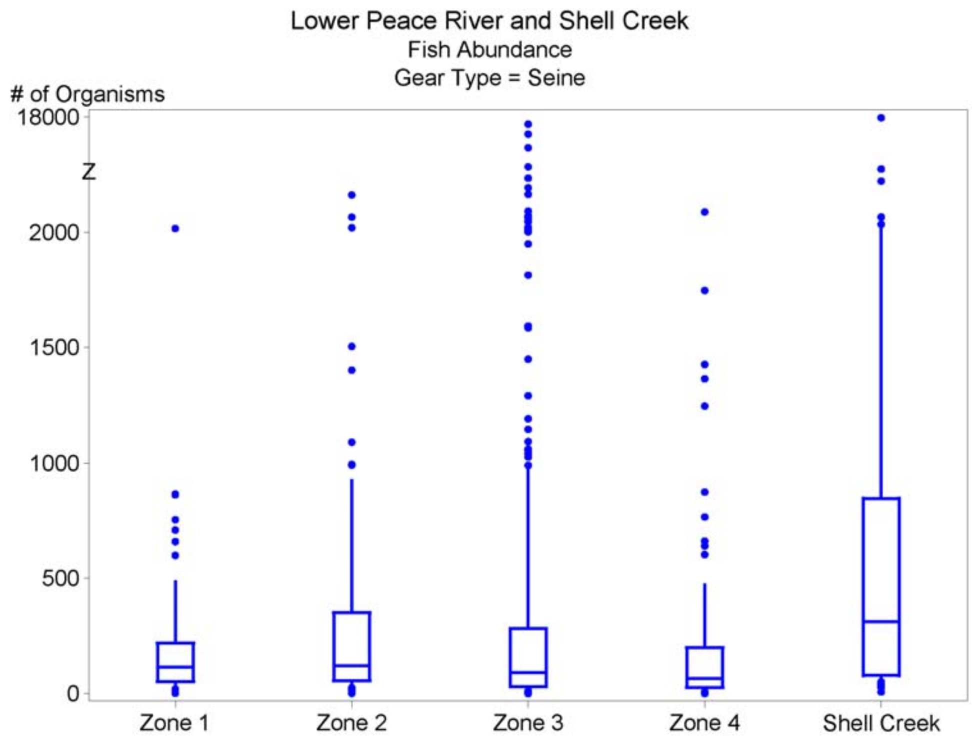


Figure 5-9. **Box-and-whisker plots of the total abundance (individuals/sample) in seine samples collected in the four LPR zones and SC k (Data source: Greenwood *et al.* 2004).**

The total number of organisms caught per trawl sample was more consistent than in the seine data (Figure 5-10). The median number of individuals/sample in Zones 1 through 4 was 30, 33, 39, and 29, respectively. The lowest number of fish per trawl was found in SC where the median was 27.

It should be noted that opposing patterns were seen between the two gear types, indicating differences in the type of habitat available to fish in the different zones. The seine data, which samples shoreline habitat, reported the lowest number of species per sample in Zone 4. The trawl data, which samples deeper water channel habitat, indicated the highest number of species per sample in Zone 4. This would suggest that of all the zones, Zone 4 may exhibit the least amount of shoreline habitat and the most amount of channel habitat. As for total number of organisms, number per seine sample was highest in SC, where as the number per trawl sample was lowest in SC. Additionally, in terms of number of species per sample, Zone 2 and SC were very similar for both gear types.

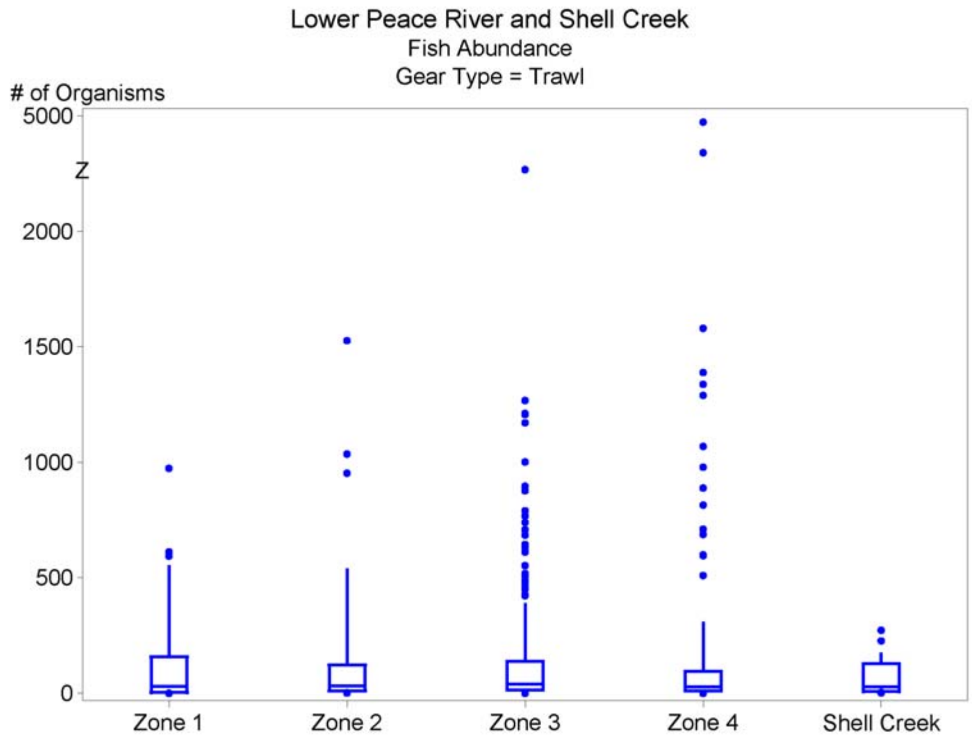


Figure 5-10. **Box-and-whisker plots of the total abundance (individuals/sample) in trawl samples collected in the four LPR zones and SC (Data source: Greenwood *et al.* 2004).**

The taxonomic composition of the fish communities in the LPR and SC is summarized in Tables 5-4 and 5-5. Dominance is calculated as (% Occurrence * % Composition) $^{-0.5}$.

In both seine and trawl samples hogchokers were the most dominant taxon in Zone 1 with Eastern mosquito fish and bay anchovies being relatively abundant. Bay anchovies, sand seatrout, blue crabs, and Atlantic silversides were most dominant in Zone 2. In Zone 3 bay anchovies, sand seatrout, Atlantic silversides, and hogchokers were dominant in both seine and trawl samples. Further downstream in Zone 4 bay anchovies and Atlantic silversides were abundant. Bay anchovies, sand seatrout, blue crabs, and Atlantic silversides were most dominant in SC.

Table 5-4. Dominant fish taxa captured in seine samples from each of the four LPR zones and SC. Data source: FWRI.

Area	Taxon	Common Name	Dominance
Zone 1	*Trinectes maculatus*	Hogchoker	246
Zone 1	*Gambusia holbrooki*	Eastern mosquito fish	230
Zone 1	*Anchoa mitchilli*	Bay anchovy	98
Zone 1	*Fundulus seminolis*	Seminole killifish	90
Zone 1	*Lucania parva*	Rainwater killifish	62
Zone 1	*Menidia* spp.	Atlantic silverside	50
Zone 1	*Poecilia latipinna*	Sailfin molly	7
Zone 1	*Callinectes sapidus*	Blue crab	4
Zone 1	*Gobiosoma bosc*	Naked goby	4
Zone 1	*Microgobius gulosus*	Clown goby	3
Zone 2	*Anchoa mitchilli*	Bay anchovy	278
Zone 2	*Menidia* spp.	Atlantic silverside	137
Zone 2	*Trinectes maculatus*	Hogchoker	58
Zone 2	*Gambusia holbrooki*	Eastern mosquito fish	56
Zone 2	*Lucania parva*	Rainwater killifish	35
Zone 2	*Eucinostomus harengulus*	Tidewater mojarra	27
Zone 2	*Eucinostomus* spp.	Silvery mojarra	22
Zone 2	*Fundulus seminolis*	Seminole killifish	15
Zone 2	*Callinectes sapidus*	Blue crab	5
Zone 2	*Microgobius gulosus*	Clown goby	5
Zone 3	*Anchoa mitchilli*	Bay anchovy	268
Zone 3	*Menidia* spp.	Atlantic silverside	194
Zone 3	*Eucinostomus harengulus*	Tidewater mojarra	35
Zone 3	*Eucinostomus* spp.	Silvery mojarra	22
Zone 3	*Farfantepenaeus duorarum*	Pink shrimp	15
Zone 3	*Mugil cephalus*	Striped mullet	12
Zone 3	*Callinectes sapidus*	Blue crab	7
Zone 3	*Sciaenops ocellatus*	Red drum	6
Zone 3	*Cynoscion arenarius*	Sand seatrout	5
Zone 3	*Lucania parva*	Rainwater killifish	5
Zone 4	*Anchoa mitchilli*	Bay anchovy	109
Zone 4	*Menidia* spp.	Atlantic silverside	101
Zone 4	*Eucinostomus harengulus*	Tidewater mojarra	47
Zone 4	*Eucinostomus gula*	Silver jenny	42
Zone 4	*Eucinostomus* spp.	Silvery mojarra	18
Zone 4	*Callinectes sapidus*	Blue crab	15
Zone 4	*Farfantepenaeus duorarum*	Pink shrimp	15
Zone 4	*Fundulus majalis*	Striped killifish	13
Zone 4	*Mugil cephalus*	Striped mullet	12
Zone 4	*Mugil gyrans*	Fantail mullet	11
Shell Creek	*Anchoa mitchilli*	Bay anchovy	394
Shell Creek	*Lucania parva*	Rainwater killifish	169
Shell Creek	*Menidia* spp.	Atlantic silverside	105
Shell Creek	*Gambusia holbrooki*	Eastern mosquito fish	41
Shell Creek	*Eucinostomus harengulus*	Tidewater mojarra	21
Shell Creek	*Fundulus seminolis*	Seminole killifish	16
Shell Creek	*Trinectes maculatus*	Hogchoker	10
Shell Creek	*Poecilia latipinna*	Sailfin molly	8
Shell Creek	*Gobiosoma bosc*	Naked goby	8
Shell Creek	*Eucinostomus spp.*	Silvery mojarra	6

Table 5-5. Dominant fish taxa captured in trawl samples from each of the four Lower Peace River zones and Shell Creek. Data source: FWRI.

Area	Taxon	Common Name	Dominance
Zone 1	*Trinectes maculatus*	Hogchoker	1572
Zone 1	*Anchoa mitchilli*	Bay anchovy	97
Zone 1	*Callinectes sapidus*	Blue crab	83
Zone 1	*Cynoscion arenarius*	Sand seatrout	70
Zone 1	*Ictalurus punctatus*	Channel catfish	12
Zone 1	*Fundulus seminolis*	Seminole killifish	3
Zone 1	*Ameiurus catus*	White catfish	2
Zone 1	*Notropis petersoni*	Coastal shiner	1
Zone 1	*Gobiosoma bosc*	Naked goby	0
Zone 1	*Eucinostomus* spp.	Silvery mojarra	0
Zone 2	*Cynoscion arenarius*	Sand seatrout	412
Zone 2	*Anchoa mitchilli*	Bay anchovy	353
Zone 2	*Callinectes sapidus*	Blue crab	206
Zone 2	*Trinectes maculatus*	Hogchoker	136
Zone 2	*Menticirrhus americanus*	Southern kingfish	10
Zone 2	*Ameiurus catus*	White catfish	7
Zone 2	*Farfantepenaeus duorarum*	Pink shrimp	6
Zone 2	*Ictalurus punctatus*	Channel catfish	2
Zone 2	*Dasyatis sabina*	Atlantic stingray	1
Zone 2	*Eucinostomus harengulus*	Tidewater mojarra	0
Zone 3	*Anchoa mitchilli*	Bay anchovy	231
Zone 3	*Cynoscion arenarius*	Sand seatrout	209
Zone 3	*Trinectes maculatus*	Hogchoker	169
Zone 3	*Farfantepenaeus duorarum*	Pink shrimp	112
Zone 3	*Callinectes sapidus*	Blue crab	111
Zone 3	*Menticirrhus americanus*	Southern kingfish	39
Zone 3	*Bairdiella chrysoura*	Silver perch	3
Zone 3	*Prionotus tribulus*	Bighead searobin	2
Zone 3	*Symphurus plagiusa*	Blackcheek tonguefish	2
Zone 3	*Eucinostomus harengulus*	Tidewater mojarra	2
Zone 4	*Anchoa mitchilli*	Bay anchovy	203
Zone 4	*Cynoscion arenarius*	Sand seatrout	94
Zone 4	*Farfantepenaeus duorarum*	Pink shrimp	89
Zone 4	*Menticirrhus americanus*	Southern kingfish	51
Zone 4	*Callinectes sapidus*	Blue crab	50
Zone 4	*Trinectes maculatus*	Hogchoker	47
Zone 4	*Prionotus scitulus*	Leopard searobin	13
Zone 4	*Prionotus tribulus*	Bighead searobin	8
Zone 4	*Eucinostomus gula*	Silver jenny	6
Zone 4	*Eucinostomus spp.*	Silvery mojarra	6
Shell Creek	*Trinectes maculatus*	Hogchoker	395
Shell Creek	*Anchoa mitchilli*	Bay anchovy	217
Shell Creek	*Cynoscion arenarius*	Sand seatrout	181
Shell Creek	*Callinectes sapidus*	Blue crab	122
Shell Creek	*Microgobius gulosus*	Clown goby	36
Shell Creek	*Eucinostomus* spp.	Silvery mojarra	29
Shell Creek	*Lucania parva*	Rainwater killifish	25
Shell Creek	*Farfantepenaeus duorarum*	Pink shrimp	13
Shell Creek	*Eucinostomus harengulus*	Tidewater mojarra	4
Shell Creek	*Ictalurus punctatus*	Channel catfish	2

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

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

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

Four salinity classes were identified, separately for seines and trawls, using PCA (Figure 5-11 and 5-12):

Seines:

- Class 1= 1 - 3 ppt,
- Class 2 = 4 - 14 ppt,
- Class 3 = 15 -23 ppt, and
- Class 4 = >24 ppt.

Trawls:

- Class 1= 1 - 2 ppt,
- Class 2 = 3 - 14 ppt,
- Class 3 = 15 -28 ppt, and
- Class 4 = > 29 ppt.

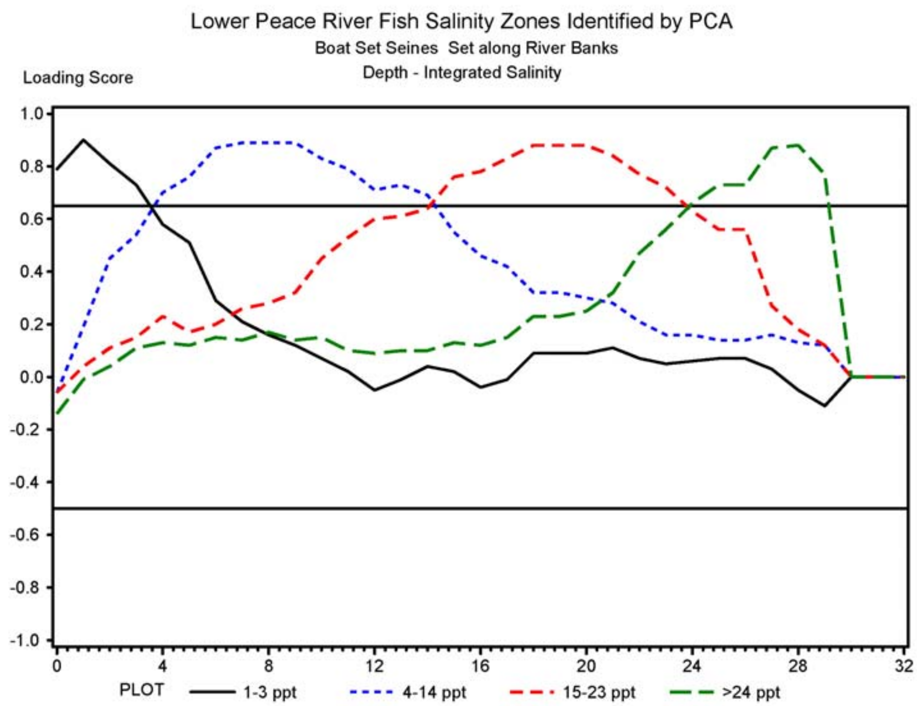


Figure 5-11. Salinity classes identified by Principal Components Analysis for the Lower Peace River, based upon the distribution of fish captured in seine samples. (Data source: FWRI).

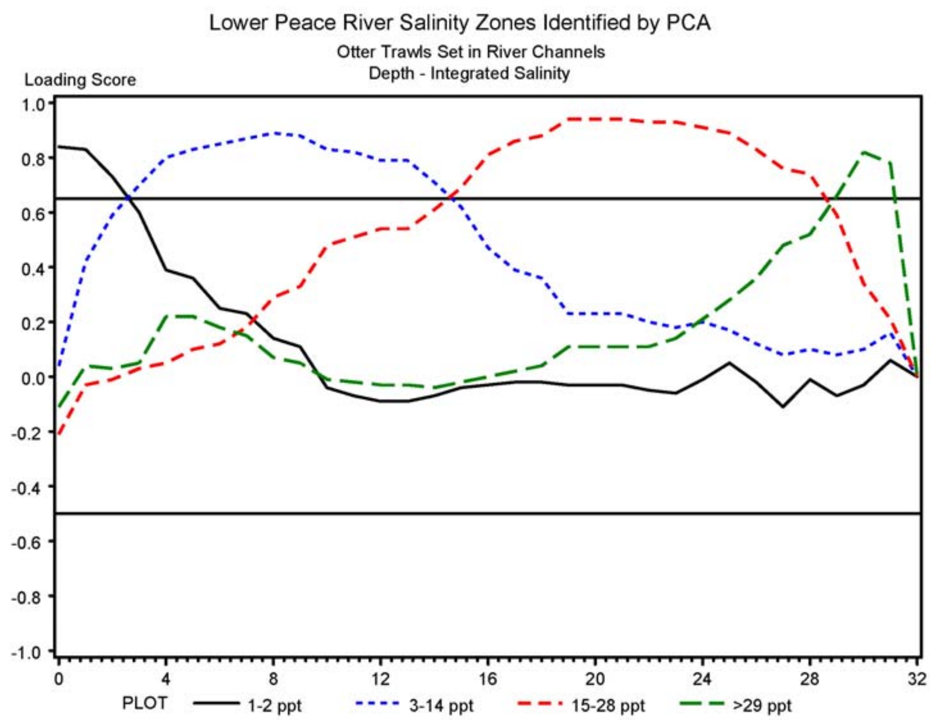


Figure 5-12. Salinity classes identified by Principal Components Analysis for the Lower Peace River, based upon the distribution of fish captured in trawl samples. (Data source: FWRI).

For the seine data, fantail mullet and various species of gobies (naked goby, code goby, clown goby, and frillfin goby) were commonly collected in Classes 1-3 and contributed most to the similarity among the catch in these zones. The absence of gobies, increased presence of blackcheek tongue fish, and the occurrence of southern puffer and rough silverside, were the notable characteristics which separated Class 4. Subtler differences in species composition were seen between Classes 1-3. The most notable differences between Class 1 and 2 were the presence of redear sunfish, a freshwater species, in Class 1 but not 2. Additionally, the following estuarine species were in Class 2 but lacking in Class 1: Gulf pipefish, leopard searobin, redfin needlefish. Class 2 and 3 differed mainly in Class 2 having a much higher occurrence of freshwater-low salinity species than Class 3, namely bluegill, sailfin molly, marsh killifish, Seminole killifish and the least killifish. The main differences between Class 3 and 4 were the presence of silver jenny, sheepshead, sheepshead minnow and striped anchovy in Class 3 and not 4.

For the trawl data, various species of gobies, along with hogchoker and blackcheek tongue fish were commonly collected in Classes 1 and 2. These species were also collected in Class 3, with the additional occurrence of the Atlantic spadefish. Class 4 was comprised of similar species as Class 3, with the absence of gobies and the presence of grass shrimp. The most notable differences between Class 1 and 2 were the occurrence of lower salinity species, namely Seminole killifish and coastal shiner, in Class 1 but not 2. Additionally, the higher salinity species spotted seatrout and big head searobin occurred in Class 2 but not 1. The main differences between Class 2 and 3 were the occurrence of lined sole, striped mojarra, and spotted seatrout in Class 2, but not 3, and the occurrence of sand seatrout in Class 3 but not 2. Class 3 and 4 differed with higher occurrences of a number of species in Class 3 as opposed to 4 (i.e., green goby, naked goby, pinfish, silverperch).

6 RELATIONSHIP BETWEEN FLOW AND WATER QUALITY CONSTITUENTS

The objective of this section is two-fold:

1) to review historical studies of the relationships between flow and water quality constituents in the LPR and SC, and
2) to review observed empirical relationships that describe how freshwater inflow affects responses in salinity, DO, chlorophyll *a*, and other water quality constituents in the LPR and SC.

These empirical relationships can be developed into suitable tools (e.g., regressions) that can be used to examine expected responses in the river to alternative minimum flow levels.

6.1 Historical Studies Relating Flow to Water Quality Constituents

Studies that examine the response of salinity, residence time, and water quality in the estuary to freshwater inflow are briefly summarized in this chapter. Other studies, such as those of streamflow trends in watershed or the general physical or water quality characteristics of the estuary, were reviewed in previous chapters.

6.1.1 Stoker *et al.* (1989)

Stoker *et al.* (1989) addressed hydraulic and salinity characteristics of the tidal reach of the Peace River. The authors concluded that the hydraulic characteristics of the tidal river are influenced primarily by fluctuations in tidal stage. Salinity characteristics in the tidal portion of the Peace River are influenced by freshwater inflows, tide, and the salinity in Charlotte Harbor. They also concluded that wind effects may occasionally become important by affecting the normal tidal patterns. Regression analyses of surface and bottom salinity in the tidal river indicated that gaged flows at Arcadia (02296750) and Horse Creek near Arcadia (02297310) and the daily mean tide were the most significant explanatory variables in predicting the high-tide location of various salinities. The authors concluded that a permanent reduction of streamflow upstream of the tidal portion of the Peace River would cause an upstream migration of the surface isohalines.

6.1.2 Hammett (1990)

Hammett (1990) examined land use, water use, streamflow characteristics, and water-quality characteristics of the Charlotte Harbor inflow area. Water-quality data through 1985 were presented and described. Hammett (1990) performed trend analyses of approximately 50 years of streamflow data and found a statistically significant decreasing trend for the Peace River stations at Bartow (02294650), Zolfo Springs (02295637), and Arcadia (02296750). She speculated that the decrease in flow may have been related to a long-term decline in the potentiometric surface of the Floridan aquifer system, which resulted from ground-water withdrawals. In addition to trend analyses of flow at several locations in the Peace River, trend analyses of water quality constituents at Arcadia (02296750) were also performed. A significant increase was detected in specific conductance at the Arcadia (02296750) gage.

6.1.3 Stoker (1992)

Stoker (1992) investigated salinity variation due to freshwater inflow and tides and the potential changes in salinity due to altered freshwater inflow into Charlotte Harbor. The results of the study indicated that seasonal fluctuations in salinity in Charlotte Harbor occur primarily in response to fluctuations in freshwater inflow from the Peace, Myakka, and Caloosahatchee rivers. Correlation analyses showed that daily minimum, maximum, and mean salinities at several continuous recorders were inversely related to discharge from the rivers, whereas the daily range in salinity was directly related to stream discharge (Stoker 1990).

6.1.4 PBS&J (1999b)

PBS&J (1999b) summarized historical information relevant to the hydrobiological monitoring of the Lower Peace River and Upper Charlotte Harbor. Regressions were developed to predict surface salinity at HBMP stations 10, 12, 14, and 18 based on 28-day mean flow at Arcadia (02296750). At the more upstream stations (18 and 14), the relationship was generally L-shaped, with relatively high salinities at low flows and primarily fresh water at low to moderate flows. As you move downstream, the relationship changes from being strongly curvilinear to being somewhat more linear.

Relationships between bottom dissolved oxygen and 28-day mean flow at Arcadia (02296750) were also discussed and the following observations were made relative to the Lower Peace River:

- Periods of hypoxia at station 10 occur only during periods of high flow.
- Hypoxic conditions are not common in the Lower Peace River upstream of the I-75 bridge. Though dissolved oxygen concentrations near the bottom seem to decline with flow, this relationship may be confounded by higher oxygen consumption during the wet season (June-September).
- High dissolved oxygen concentrations during period of low flow are reflective of two conditions:

    - higher saturation during colder winter months and
    - increases in phytoplankton during the periods of low flow during the spring and fall.

6.1.5 Janicki Environmental, Inc (2001)

Coastal Environmental (1997) used data from the PRMRWSA HBMP to develop regressions to predict the locations of salinity zones as a function of freshwater inflows. Janicki Environmental, Inc (2001) re-evaluated the regressions developed by Coastal

Environmental of salinity and streamflow in the Peace River estuary. There is considerable natural variation in salinity for a given flow condition, but there is a clear and predictable decrease in the overall distribution of salinity values at any given location in the river for an increase in flow. The relationships between salinity at several HBMP fixed stations (11, 13, 14, and 15) were described well by regression models. In addition, the relationships between isohaline locations and river flow fit the regression models well for all the isohaline locations tested (0.5 ppt, 6 ppt, 12 ppt, and 20 ppt). The authors also analyzed the proportion of flow to the lower river comprised of Arcadia (02296750) flow. Peace at Arcadia typically comprises 72% of the flow at the PRMRWSA plant (Peace at Arcadia [02296750] + Joshua Creek at Nocatee [02297100] + Horse Creek near Arcadia [02297310]). Peace at Arcadia typically comprises 56% of the flow in the lower river (Peace at Arcadia [02296750] + Joshua Creek at Nocatee [02297100] + Horse Creek near Arcadia [02297310] + Shell Creek near Punta Gorda [02298202]).

6.1.6 Janicki Environmental, Inc (2003)

Janicki Environmental, Inc (2003) conducted an analysis of status and trends of water quality conditions within the Charlotte Harbor National Estuary Program (CHNEP) study area. The results of rainfall analyses indicated that there were no overall trends in rainfall for the period of record (1950's to 2000), and, therefore, it is unlikely that any changes in water quality data for the Peace River could be attributed to changes in rainfall alone. The results of streamflow trend analyses indicated that there have been statistically significant changes in streamflow for the period of record analyzed.

A statistically significant increase in conductivity was observed in the Lower Peace River between the mouth of the river and just upstream of Arcadia. While there was a significant increase in conductivity in the lower Peace River, there was significant increase in conductivity detected at the mouth of the Peace River or Charlotte Harbor.

6.1.7 PBS&J (2006)

PBS&J (2006) performed analyses in order to evaluate and address whether the biological communities of the SC/LPR estuarine system would be adversely impacted as a result of the proposed "gap" increased permitted freshwater withdrawals. Within the SC reservoir, concentrations of most parameters, including specific conductance, hardness, DO, pH, total dissolved solids, total Kjeldahl nitrogen (TKN), total phosphorus, orthophosphorus, total organic carbon, and alkalinity increased with increasing flows, while color, sulfate, and chloride decreased (PBS&J, 2006).

6.2 Empirical Analyses to Relate Flow to Water Quality in the Lower Peace River

The objective of the empirical analyses was to increase the knowledge of the observed relationships that describe how freshwater inflow affects responses in salinity, DO, chlorophyll *a*, and other water quality constituents in the Lower Peace River. The relationships include the response of water quality constituents at a representative group of HBMP fixed stations (Figure 2.3) with a period of record that extends back to the 1970's. These stations represent a broad range of geographic locations. The inflow is defined as the sum of flows at Peace at Arcadia (02296750), Joshua Creek at Nocatee (02297100), and Horse Creek near Arcadia (02297310), minus the withdrawals at the PRMRWSA plant.

6.2.1 Relationship Between Flow and Salinity

In the Lower Peace River, the general expectations for salinity response to freshwater inflow are well-known based on many years of review of the observed data and knowledge from other similar systems (Stoker *et al.* 1989; Stoker 1992; PBS&J 1999b; Janicki Environmental Inc. 2001). Salinity declines in the lower river in response to increasing freshwater inflow. Due to higher salinity waters being denser than lower salinity waters, salinity concentrations are expected to be lower near the water surface and higher near the water bottom for any particular location in the lower river.

As discussed in Section 3, a high degree of variation in salinity is expected due to freshwater inflows and the influences of tide, wind, and vertical stratification. Salinity can vary significantly over the course of each day as the tide moves upstream and downstream. Lateral variation in salinity is also expected due to the highly braided nature of the river.

Salinity field observations from a representative group of PRMRWSA HBMP fixed monitoring stations were plotted against freshwater inflow to empirically describe the relationship of freshwater inflow to salinity in the Lower Peace River (Figures 6-1 to 6-2). The salinity observations were in agreement with the expectations described above. As expected, salinity was more responsive to freshwater inflow at the most upstream station (Station 18), and least responsive to flow at the most downstream station (Station 10).

In addition to the monthly HBMP fixed station salinity data presented in Figures 6-1 and 6-2, daily mean salinity as a function of flow for two continuous recorders in the LPR are also presented. The Peace River at Harbor Heights continuous recorder (USGS 02297460) is located at rkm 15.5. The Peace River at Peace River Heights continuous recorder (USGS 02297350) is located at rkm 26.7. Mean daily surface and bottom salinity for Peace River at Harbor Heights as a function of LPR flow are presented in Figure 6-3. Mean daily surface and bottom salinity for Peace River at Peace River

Heights as a function of LPR flow are presented in Figure 6-4. As anticipated, the range of salinities at Harbor Heights was greater than that at Peace River Heights.

Salinity field observations from the PRMRWSA HBMP moving stations were plotted against freshwater inflow to empirically describe the relationship of freshwater inflow to isohaline location in the Lower Peace River (Figures 6-5 to 6-8). As expected, the 0 ppt isohaline exhibited the widest range of locations. At very low flows, the 0 ppt isohaline was as high as rkm 38, while at very high flows the 0 ppt isohaline was as low as rkm 3. The location of the 6 ppt isohaline ranged from rkm 1 to rkm 27. The 12 ppt isohaline ranged from rkm 0 at high flows to rkm 24 at the lowest flows. As expected, the 20 ppt isohaline exhibited the smallest range of locations in the LPR, ranging from rkm 0 to rkm 18.

As mentioned in Section 6.1.5, regressions have been developed that relate salinity to freshwater inflow at several fixed locations in the Lower Peace River based on PRMRWSA HBMP fixed station observations. The general form of the regression that predicts salinity as a function of flow is:

$$\hat{S} = \alpha + \beta(mean\,30\,day\;\,flow)$$

A summary of the regression models is presented in the Table 6-1. In addition, regressions have been developed based on PRMRWSA HBMP moving station observations that predict isohaline locations based on freshwater inflows to the system. The general form of the regression that predicts the location of a particular isohaline as a function of flow is:

$$Rkm = \alpha + \beta * \ln(mean\,8\,day\;\,flow)$$

A summary of the regression models is presented in the Table 6-2.

Though there is considerable natural variation in salinity for a given flow condition, there is a clear and predictable decrease in the overall distribution of salinity values at any given location in the river for an increase in flow. The regressions discussed above can be used as a tool to corroborate predictions from other tools such as a hydrodynamic model.

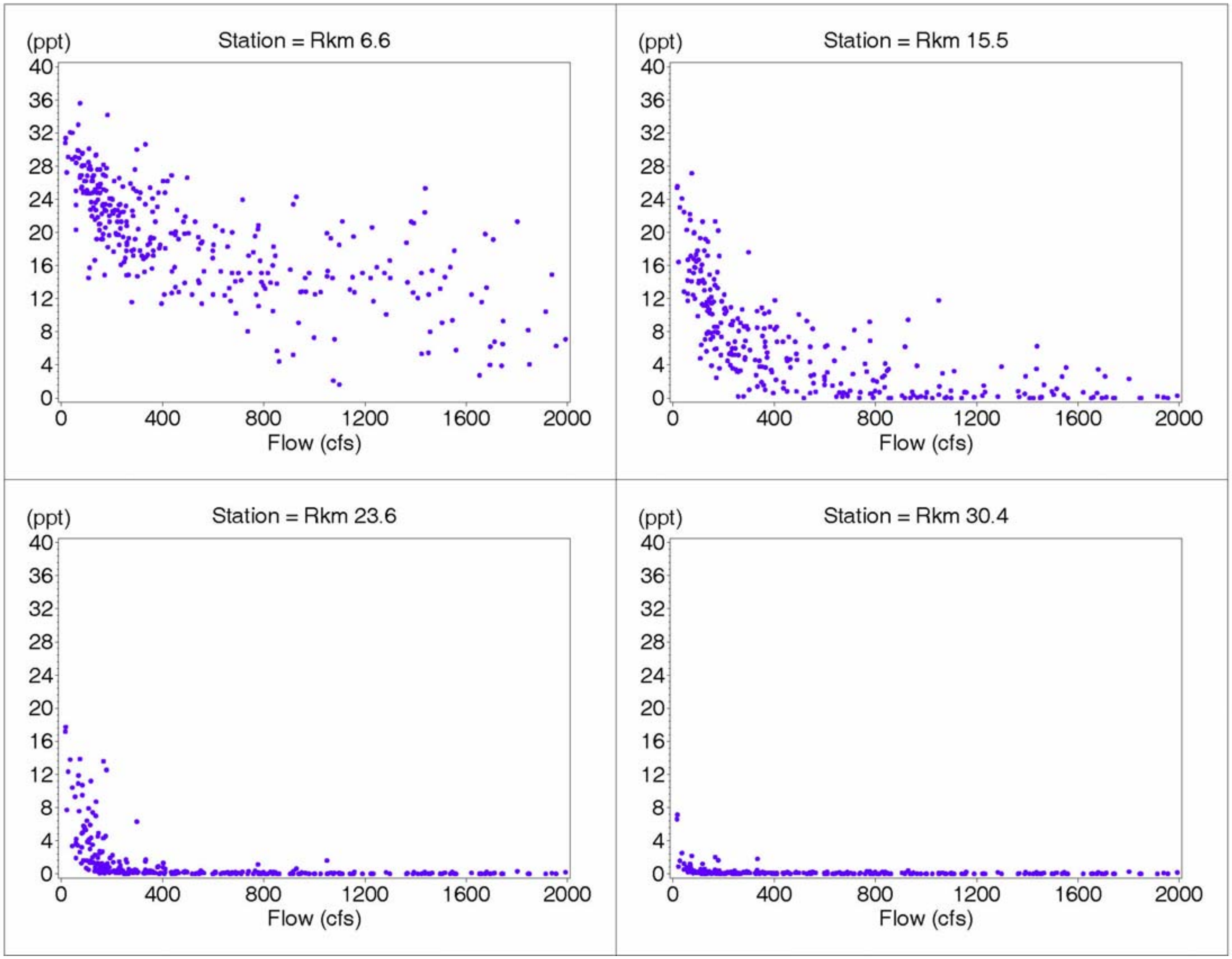


Figure 6-1. **Long-term HBMP surface salinity observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.**

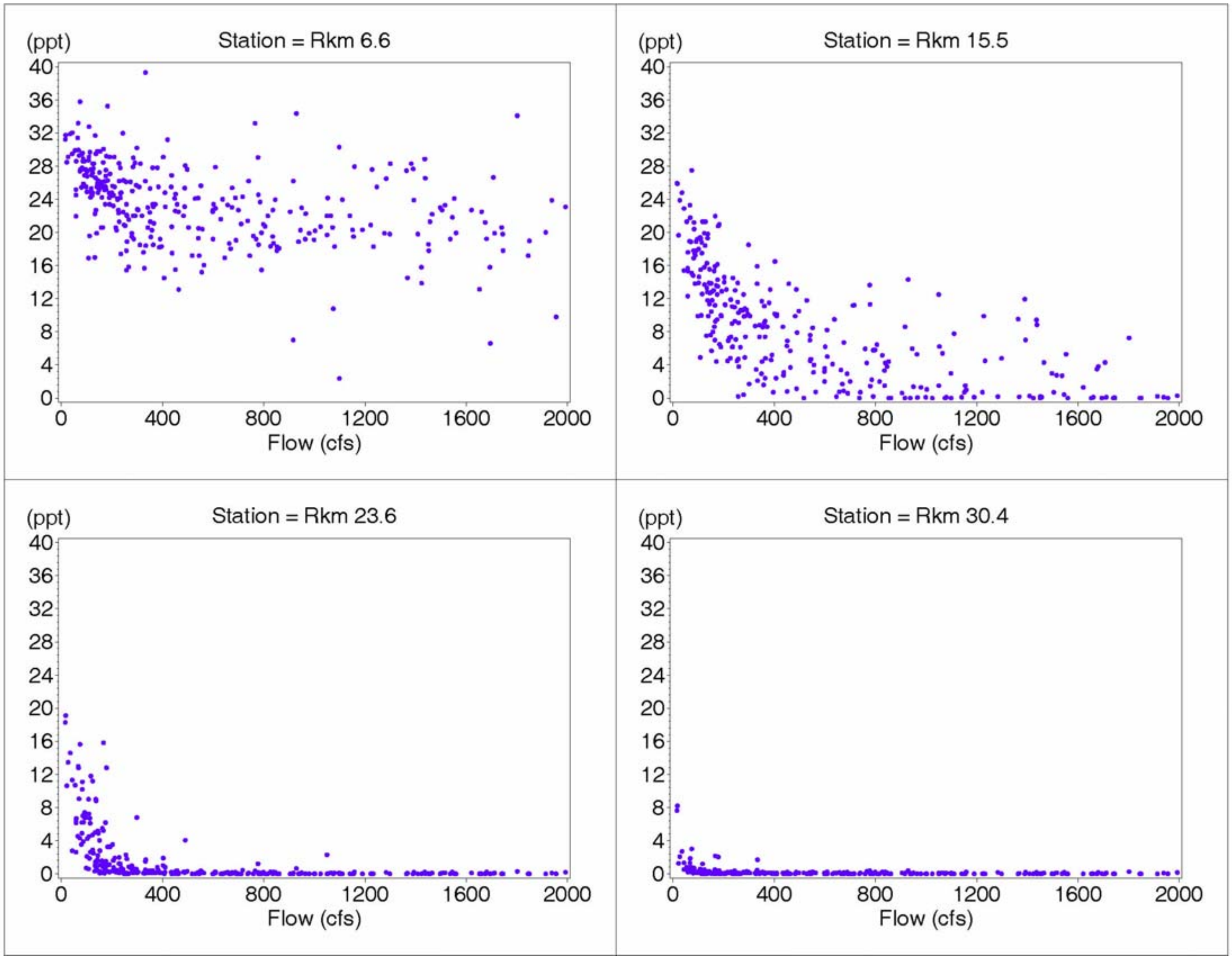


Figure 6-2. **Long-term HBMP bottom salinity observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.**

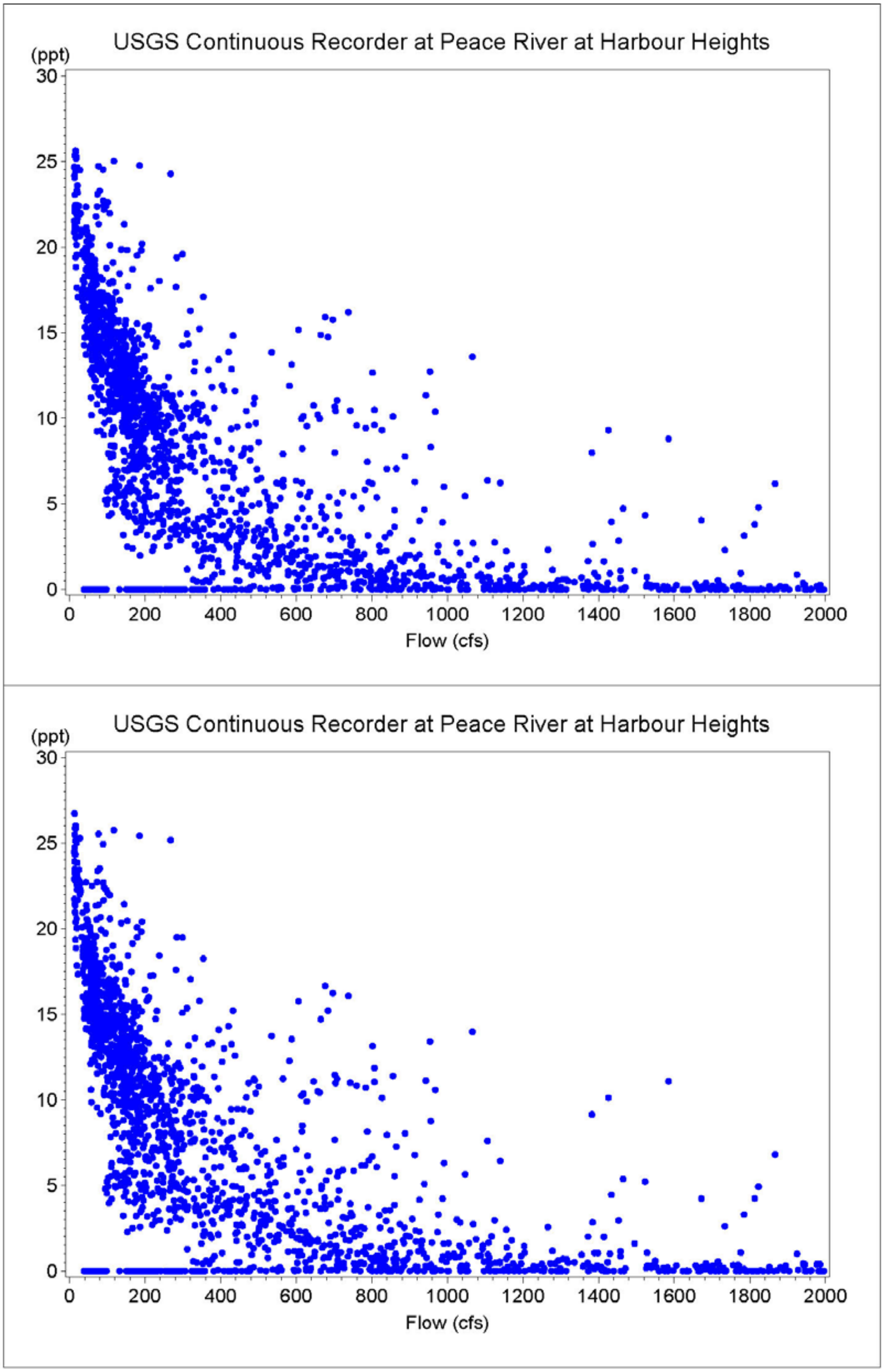


Figure 6-3. Peace River at Harbor Heights continuous recorder (USGS gage 02297460) daily mean surface salinity (upper figure) and bottom salinity (lower figure) as a function of flow in the Lower Peace River.

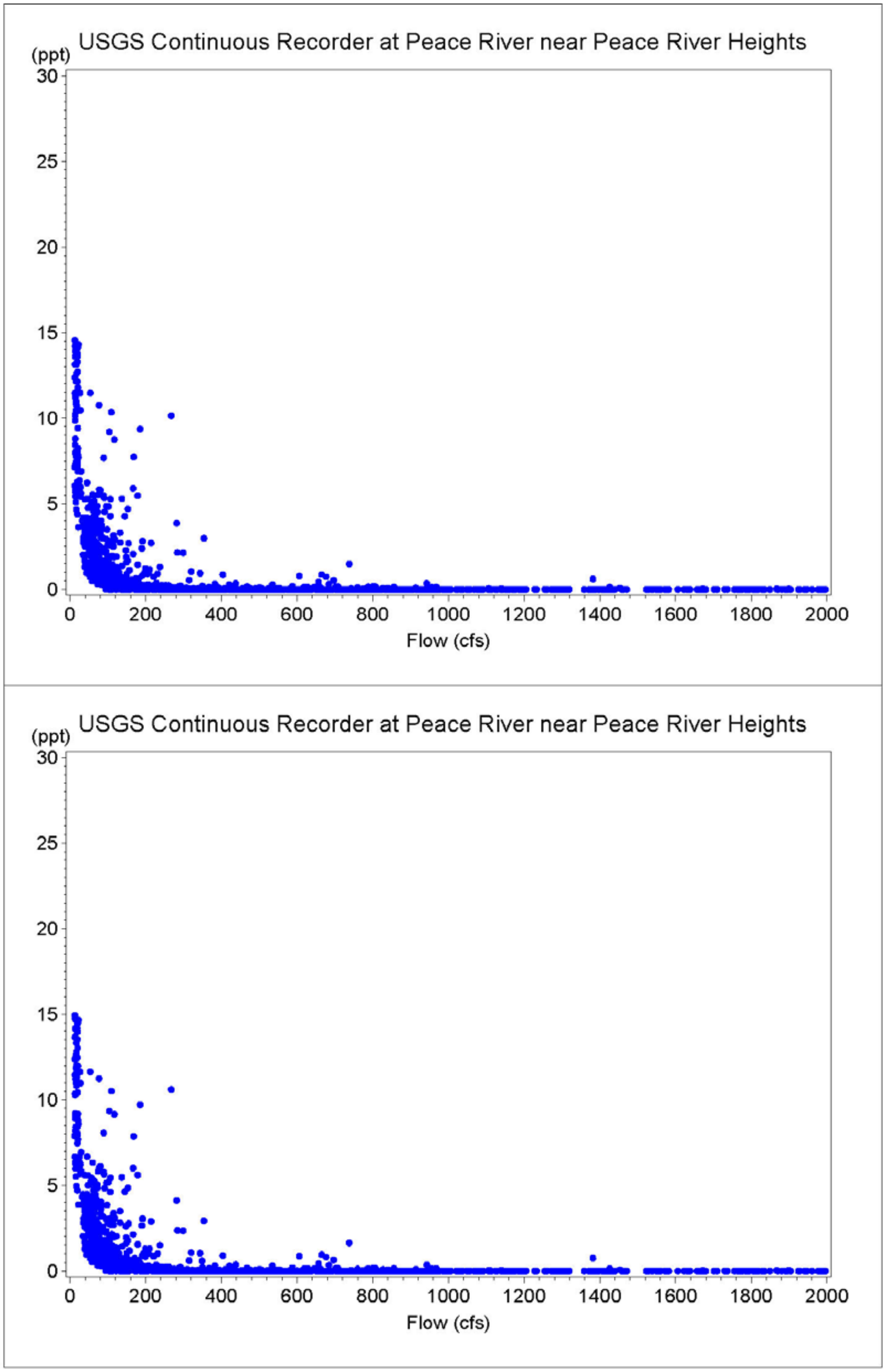


Figure 6-4. **Peace River at Peace River Heights continuous recorder (USGS gage 02297350) daily mean surface salinity (upper figure) and bottom salinity (lower figure) as a function of flow in the Lower Peace River.**

Table 6-1. Summary of fixed station regression models (Source: Janicki Environmental, Inc., 2001).

Station	Depth	Intercept Estimate	Slope Estimate	Prob>F H_0: slope not equal 0	Prob>|t| H_0: slope Not equal 0	R-square Value
9	Surface	56.2857	-5.1052	< 0.0001	< 0 .0001	0.77
9	1 meter	55.3533	-4.9143	< 0.0001	< 0 .0001	0.76
9	2 meter	51.4360	-4.1807	< 0.0001	< 0 .0001	0.71
9	Bottom	44.8194	-2.9656	< 0.0001	< 0 .0001	0.48
10	Surface	55.7390	-5.8103	< 0.0001	< 0 .0001	0.76
10	1 meter	52.8787	-5.1426	< 0.0001	< 0 .0001	0.69
10	2 meter	48.4570	-4.1215	< 0.0001	< 0 .0001	0.58
10	Bottom	46.2886	-3.6889	< 0.0001	< 0 .0001	0.55
11	Surface	50.1617	-5.9070	< 0.0001	< 0 .0001	0.67
11	1 meter	48.9276	-5.5575	< 0.0001	< 0 .0001	0.61
11	2 meter	47.1649	-5.0642	< 0.0001	< 0 .0001	0.57
11	Bottom	43.2533	-4.2843	< 0.0001	< 0 .0001	0.47
12	Surface	39.1579	-5.1913	< 0.0001	< 0 .0001	0.71
12	1 meter	40.3856	-5.3147	< 0.0001	< 0 .0001	0.70
12	2 meter	41.2220	-5.3514	< 0.0001	< 0 .0001	0.69
12	Bottom	42.4495	-5.4786	< 0.0001	< 0 .0001	0.69
13	Surface	35.7949	-5.3488	< 0.0001	< 0 .0001	0.60
13	1 meter	38.8002	-5.7623	< 0.0001	< 0 .0001	0.60
13	2 meter	41.8546	-6.1637	< 0.0001	< 0 .0001	0.65
13	Bottom	39.6592	-5.8482	< 0.0001	< 0 .0001	0.60
14	Surface	39.3733	-7.2944	< 0.0001	< 0 .0001	0.49
14	1 meter	40.5885	-7.4985	< 0.0001	< 0 .0001	0.48
14	2 meter	42.1987	-7.7630	< 0.0001	< 0 .0001	0.48
14	Bottom	45.5255	-7.7268	< 0.0001	< 0 .0001	0.53
15	Surface	20.4275	-3.8658	< 0.0001	< 0 .0001	0.48
15	1 meter	20.7830	-3.9235	< 0.0001	< 0 .0001	0.48
15	2 meter	23.6838	-4.3632	< 0.0001	< 0 .0001	0.58
15	Bottom	21.7795	-4.0964	< 0.0001	< 0 .0001	0.48

Table 6-2. Summary of isohaline location regression models (Source: Janicki Environmental, Inc., 2001).

Isohaline	Intercept Estimate	Slope Estimate	Prob>F H_0: slope not equal 0	Prob>|t| H_0: slope Not equal 0	R-square Value
0 ppt	5.01278	-0.03478	< 0.0001	< 0.0001	0.65
6 ppt	4.95031	-0.03634	< 0.0001	< 0.0001	0.71
12 ppt	4.90144	-0.03448	< 0.0001	< 0.0001	0.63
20 ppt	4.83565	-0.03145	< 0.0001	< 0.0001	0.52

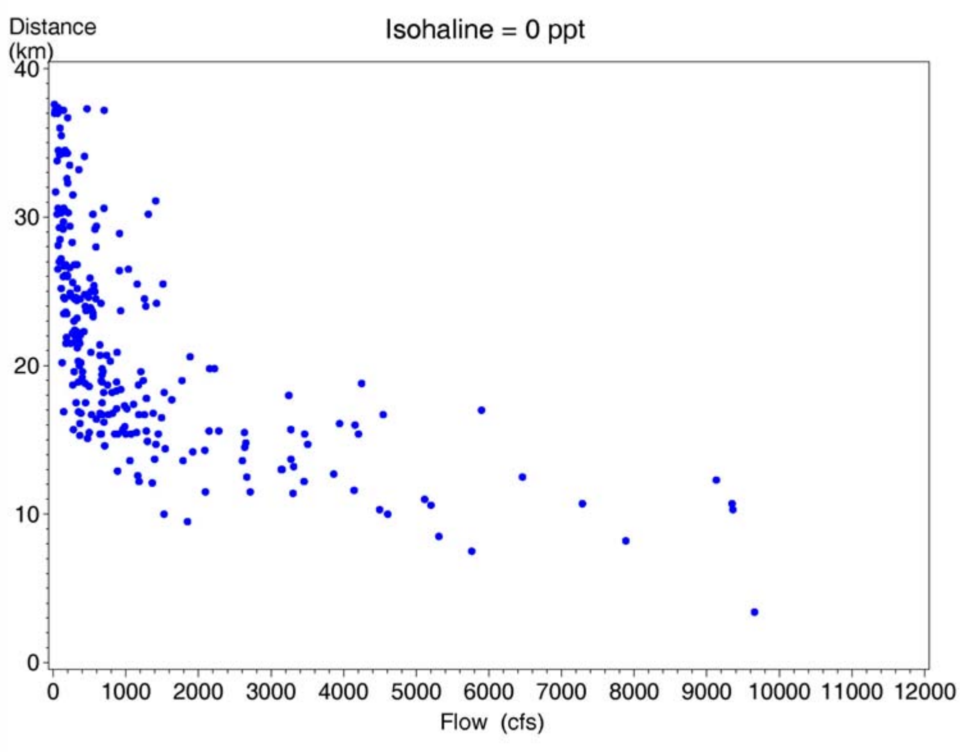


Figure 6-5. Plot of the relationship between HBMP 0 ppt isohaline location as a function of flow in the Lower Peace River.

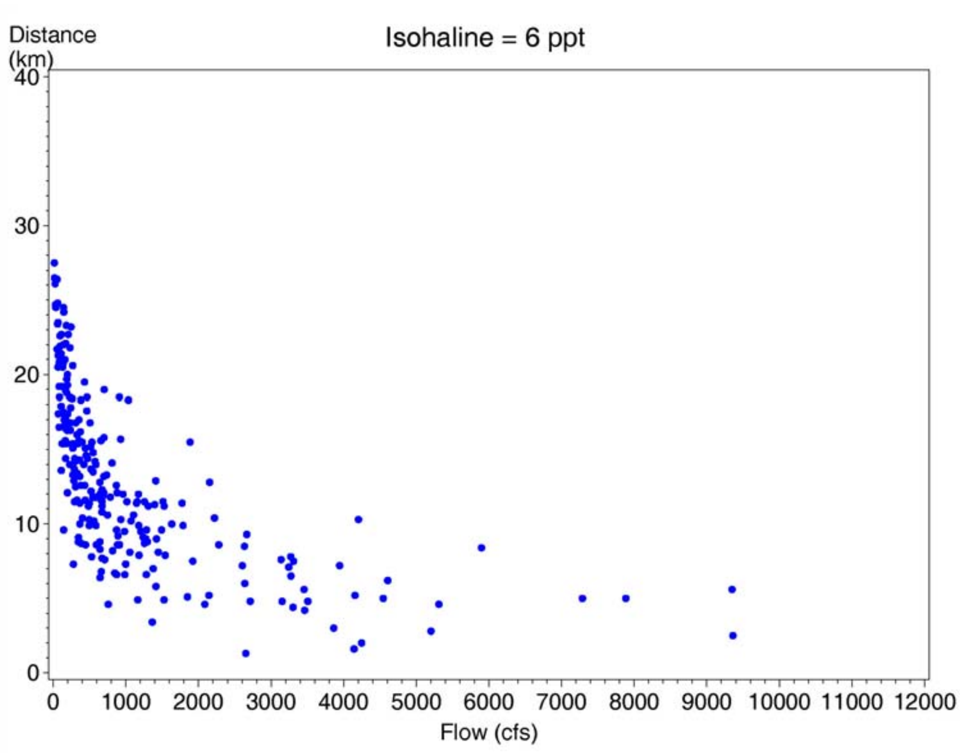


Figure 6-6. Plot of the relationship between HBMP 6 ppt isohaline location as a function of flow in the Lower Peace River.

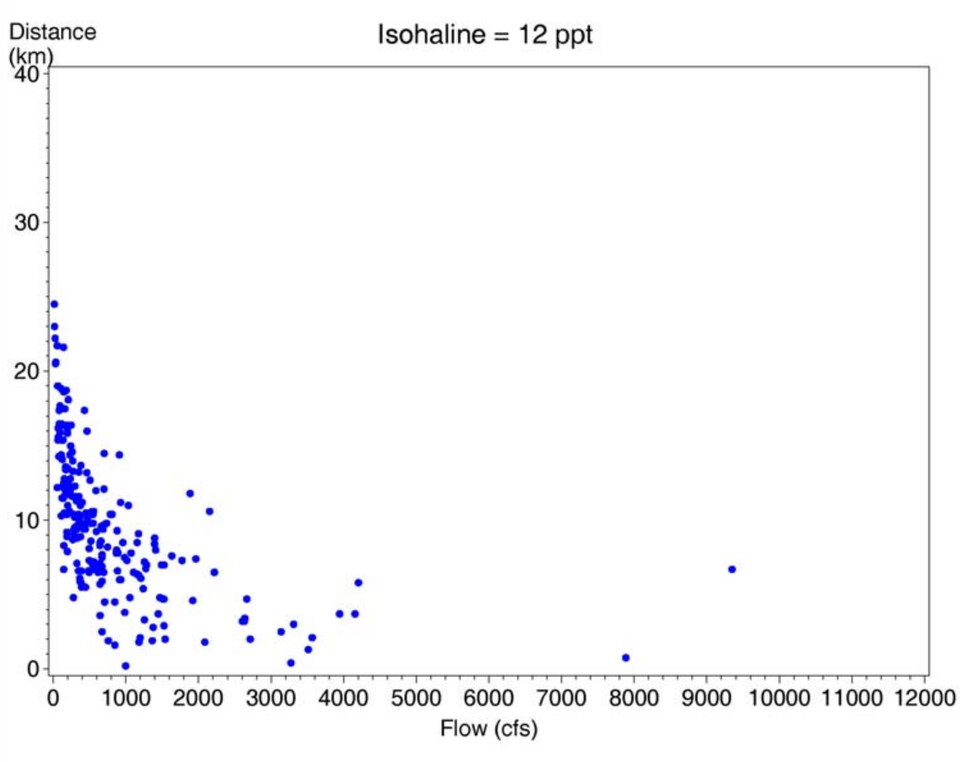


Figure 6-7. **Plot of the relationship between HBMP 12 ppt isohaline location as a function of flow in the Lower Peace River.**

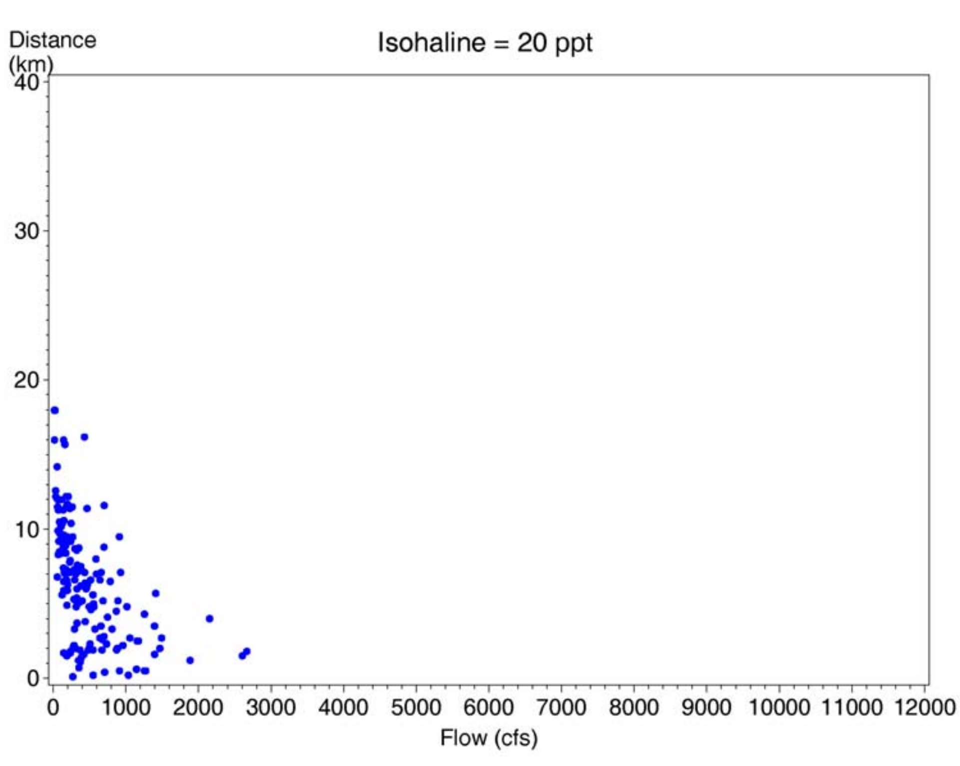


Figure 6-8. **Plot of the relationship between HBMP 20 ppt isohaline location as a function of flow in the Lower Peace River.**

6.2.2 Relationship Between Flow and DO

The spatial and temporal variation in DO has been described in Section 3. The spatial and temporal variations in DO are expected to be relatively high, and are expected to be particularly responsive to location, depth, temperature, salinity, and time of day. A series of empirical analyses were conducted using the PRMRWSA HBMP stations to quantify the expected relationship of dissolved oxygen responses to freshwater inflow. As documented by the PRMRWSA HBMP, hypoxic conditions are not common in the Lower Peace River upstream of the I-75 bridge (PBS&J 1999b). Previous work by Camp, Dresser & McKee (1998) revealed a general pattern of hypoxic conditions in the upper portion of Charlotte Harbor between June and October. Plots of bottom dissolved oxygen and flow are presented in Figure 6-9. Though dissolved oxygen concentrations near the bottom generally decline with flow, this is not a strong relationship due to confounding factors. While general patterns have been documented between dissolved oxygen and freshwater inflows, statistically defensible relationships have yet to be identified. Therefore, appropriate tools relating DO to freshwater inflows the LPR and SC do not currently exist.

6.2.3 Relationship Between Flow and Chlorophyll a

Although chlorophyll *a* concentrations are expected to be highly variable in the Lower Peace River, they are expected to follow a predictable pattern in response to the combined effects of nutrient supply and residence time. Managing nutrient loading is expected to be the primary driver for aquatic eutrophication, and the best understanding of this relationship depends upon knowledge of other factors such as residence time. The relationship between nutrient loading and estuarine responses (such as changes in algal biomass) is mediated significantly by hydrologically-controlled residence times (Rudek *et al.* 1991, Valiela *et al.* 1997, Hubertz and Cahoon 1999, Caffrey *et al.* 2007). As freshwater inflow initially increases from a near zero flow condition, chlorophyll *a* is expected to increase in response to the increased nutrient supply. As inflow rate increases even higher, the increase in nutrient supply becomes offset by the reduction in residence time, and the resulting chlorophyll *a* concentrations will peak. At higher inflow rates, the negative effects of shortening residence time become greater than the positive effects of increasing nutrient supply, and the chlorophyll *a* concentrations decline. The effects are expected to be less responsive downstream than upstream due to physical dilution effects. Chlorophyll *a* concentrations in the Lower Peace River exhibit distinct spring and fall peaks that are influenced by both the timing and volume of freshwater inflows (PBS&J 2004). These peaks generally move downstream as freshwater inflows increase. Plots of the relationship between surface and bottom chlorophyll a and flow are presented in Figures 6-10 and 6-11.

A regression model was developed to predict the location of the chlorophyll *a* maximum based on Peace River flow (Peace at Arcadia + Horse Creek + Joshua Creek) and season. The regression model fit the observed data well, explaining 64 % of the variation in the location of the chlorophyll *a* maximum. This regression can be used to predict the impact of proposed management actions on the location of the chlorophyll *a* maximum.

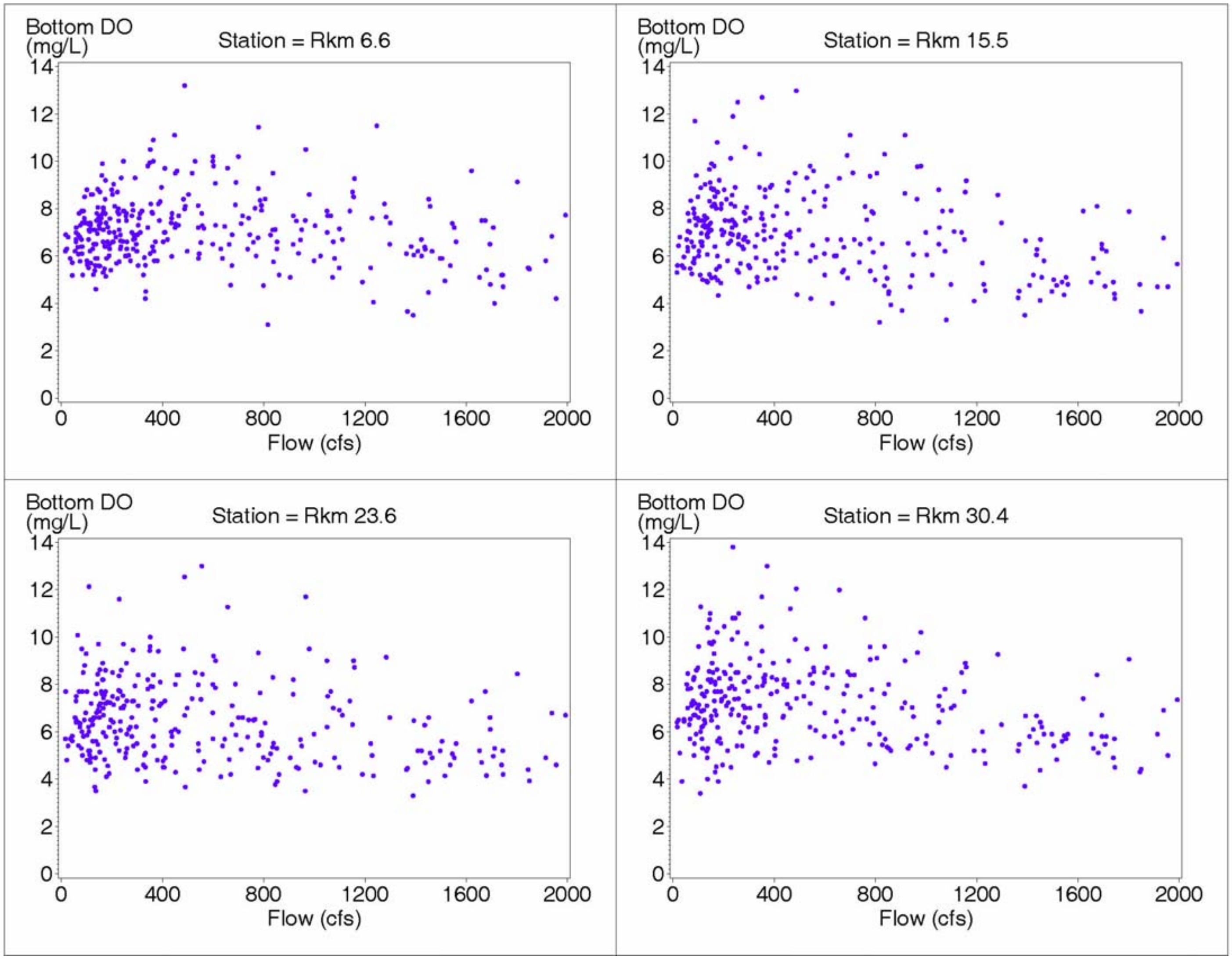


Figure 6-9. **Long-term HBMP bottom dissolved oxygen observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.**

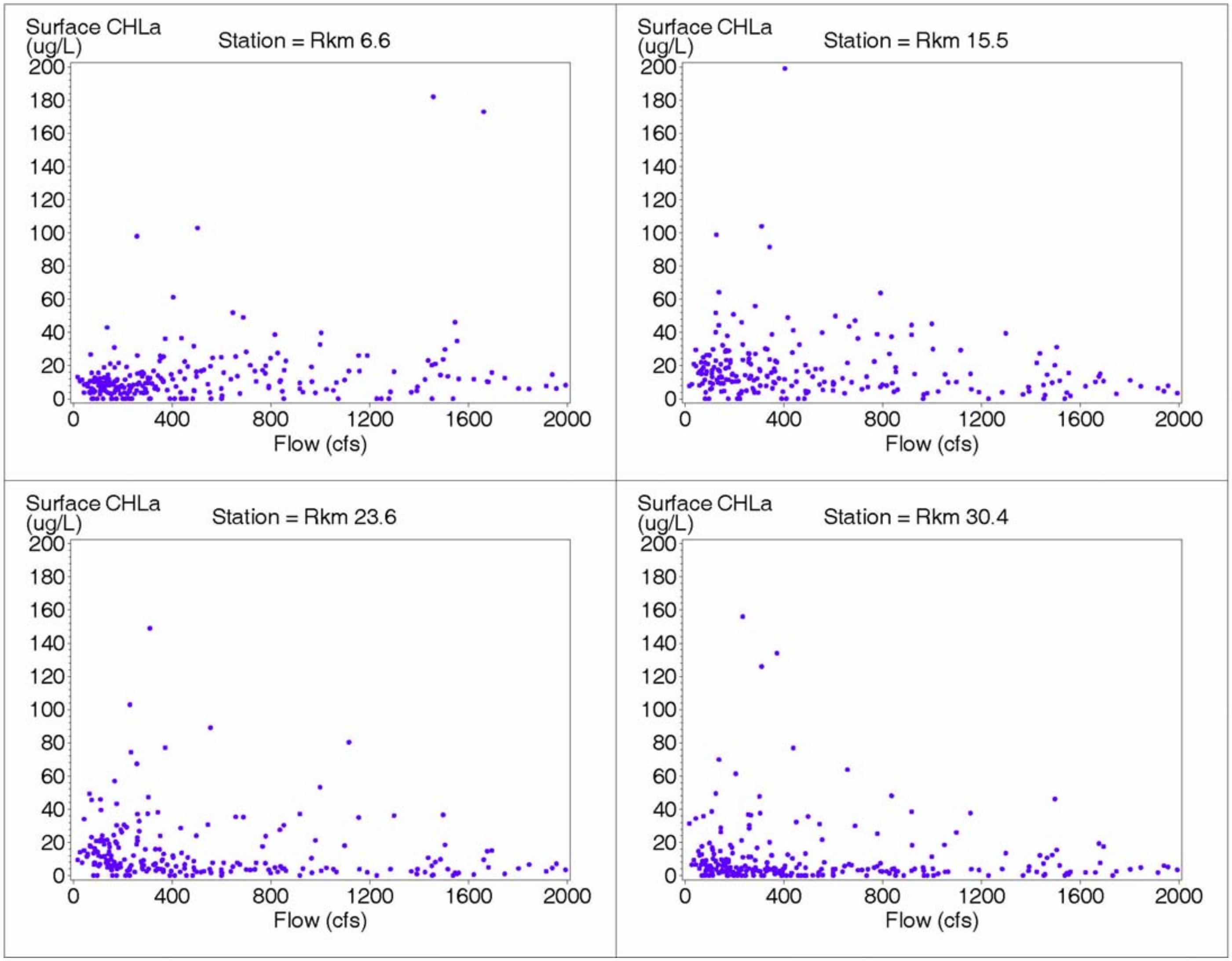


Figure 6-10. **Long-term HBMP surface chlorophyll a observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.**

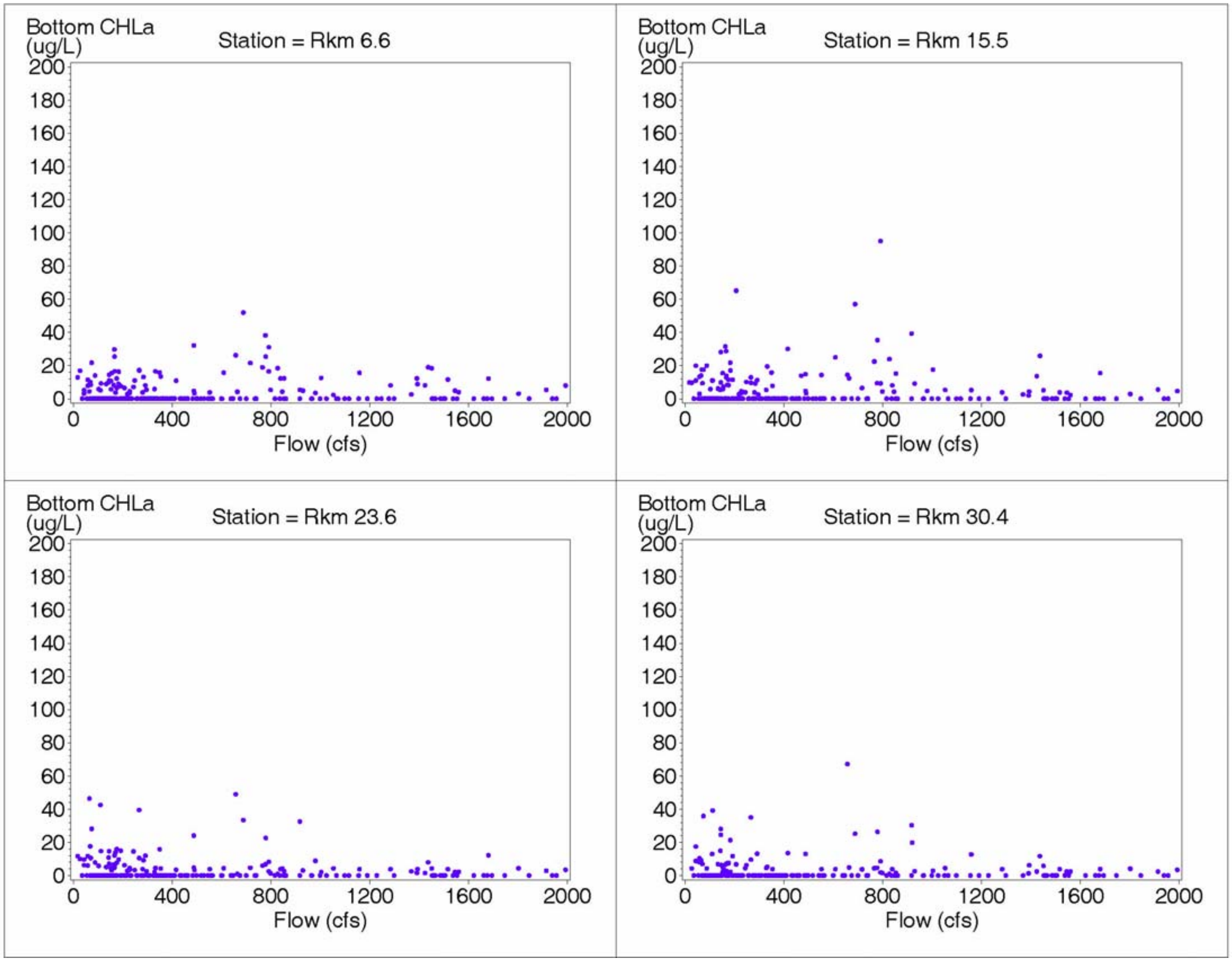


Figure 6-11. Long-term HBMP bottom chlorophyll a observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.

6.2.4 Relationship Between Flow and Nutrients

Total nitrogen field observations from the HBMP were plotted against freshwater inflow to describe responses (Figures 6-12 and 6-13). As anticipated, total nitrogen concentrations did not have a strong relationship to freshwater inflows. Total phosphorous field observations from the HBMP were plotted against freshwater inflow to describe responses (Figures 6-14 and 6-15). Similar to total nitrogen, the total phosphorous concentrations did not have a strong relationship to freshwater inflows. Therefore, appropriate tools relating total nitrogen and total phosphorus to freshwater inflows the LPR and SC do not currently exist.

6.3 Conclusions

Statistically significant relationships between salinity and freshwater inflow have been identified in several previous studies (Stoker *et al.* 1989, Stoker 1992, PBS&J 1999b, Janicki Environmental, Inc. 2001). A statistically significant relationship between the location of the chlorophyll a maximum and freshwater inflow was developed as part of this study. While general patterns have been documented between dissolved oxygen and freshwater inflows, statistically defensible relationships have yet to be defined.

In addition to regression models, hydrodynamic models are also appropriate tools to be used to understand the implications of proposed management actions. A hydrodynamic model has been developed for the Lower Peace River by District staff. This model will be discussed in Section 7.

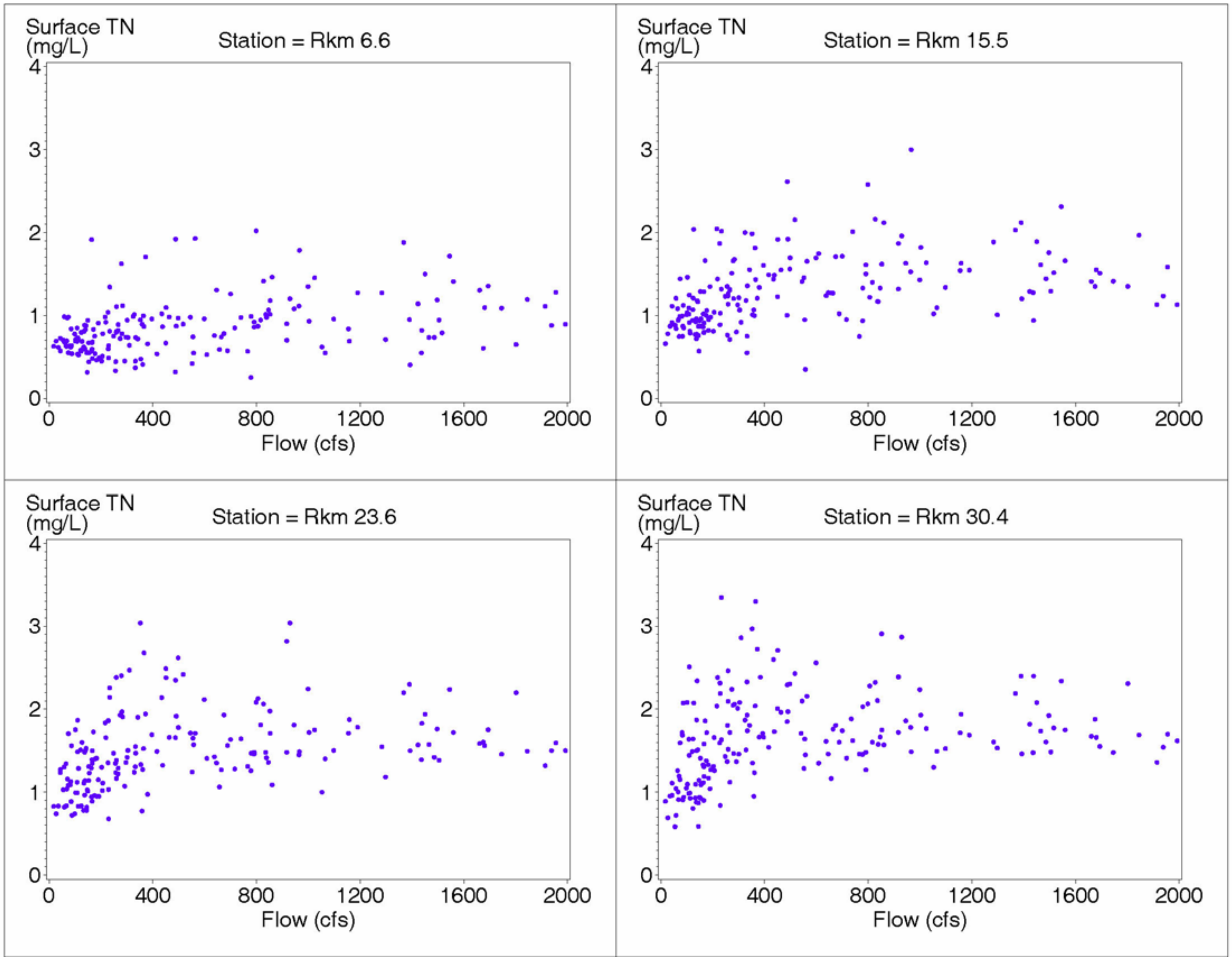


Figure 6-12. Long-term HBMP surface total nitrogen observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.

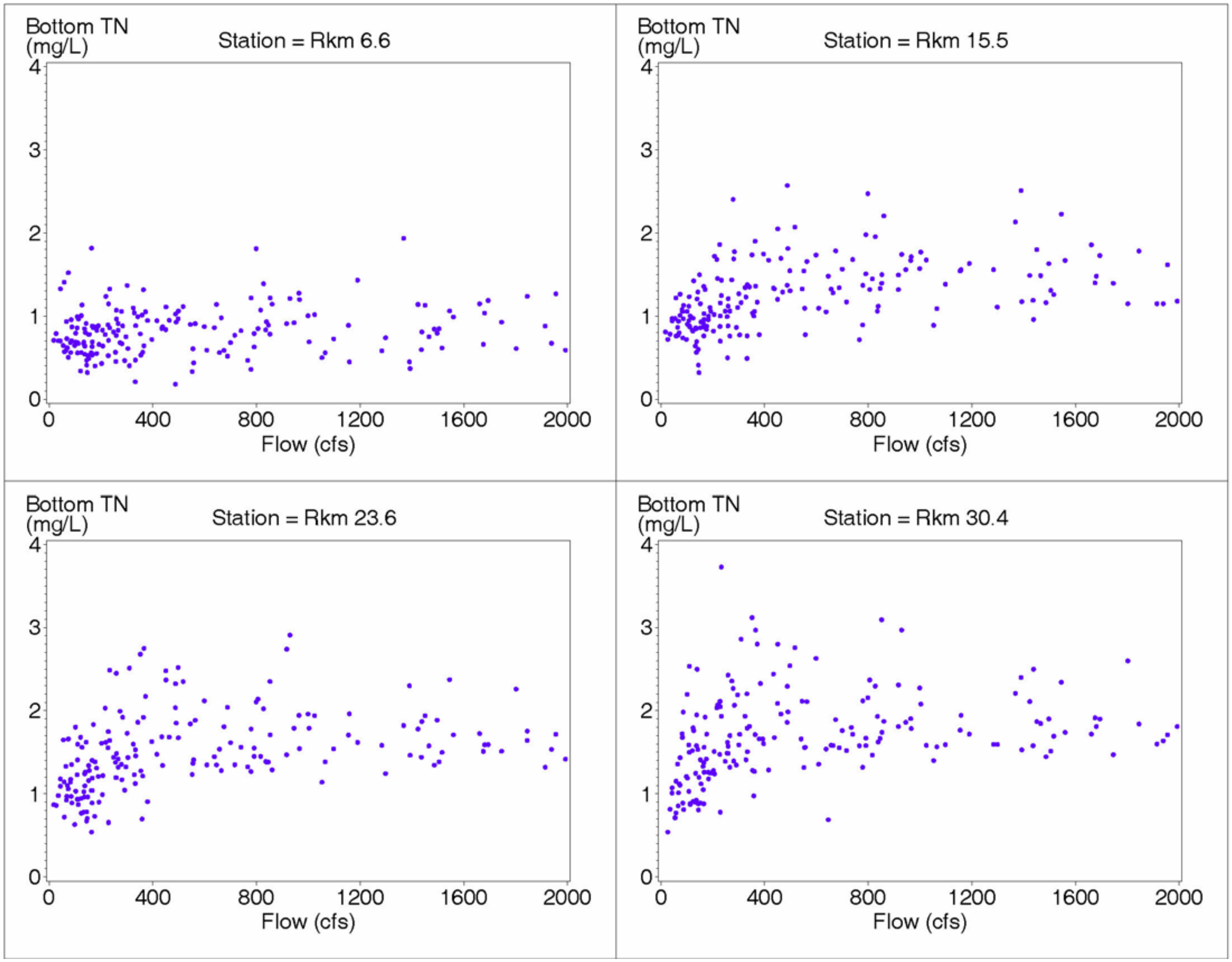


Figure 6-13. **Long-term HBMP bottom total nitrogen observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.**

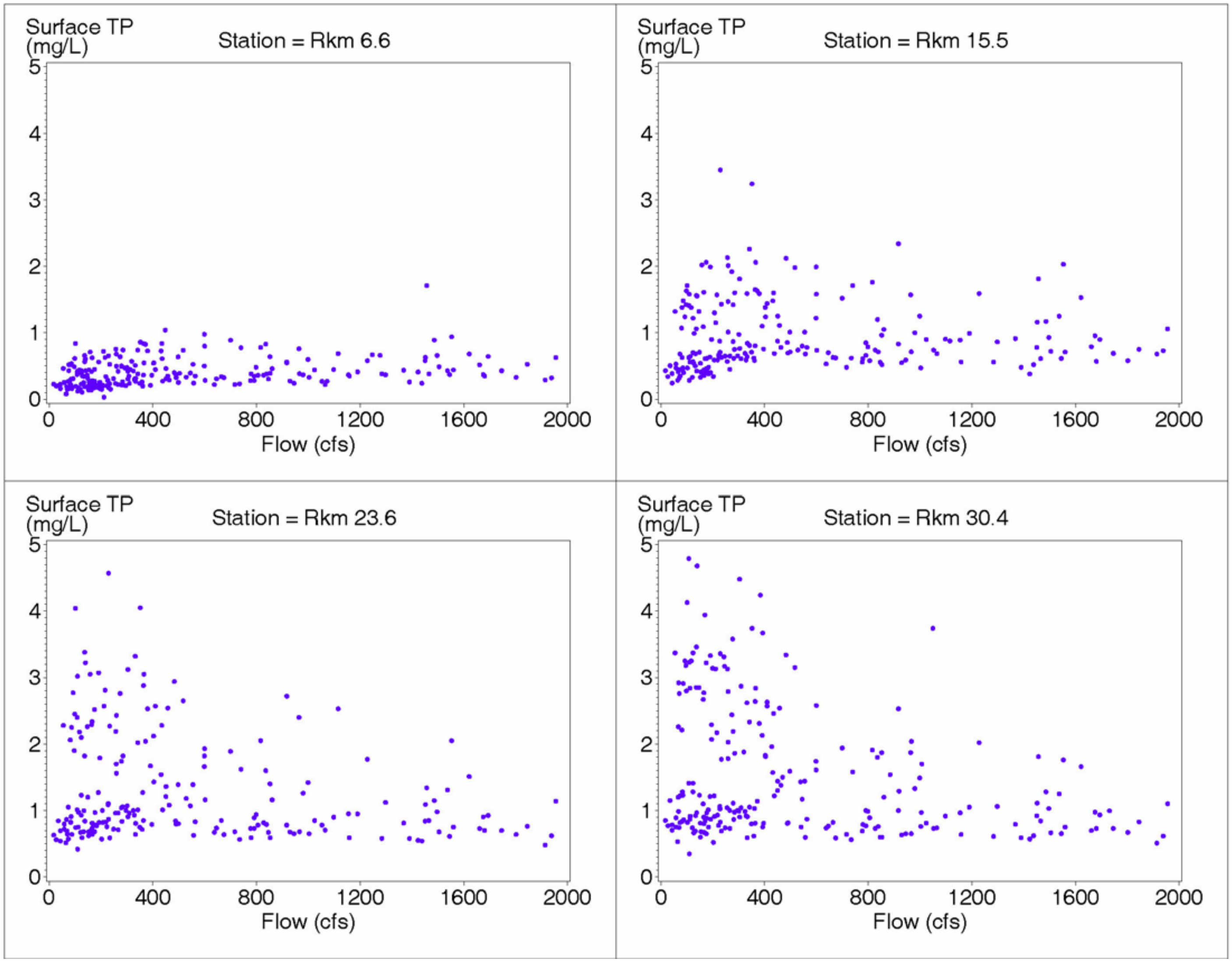


Figure 6-14. **Long-term HBMP surface total phosphorus observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.**

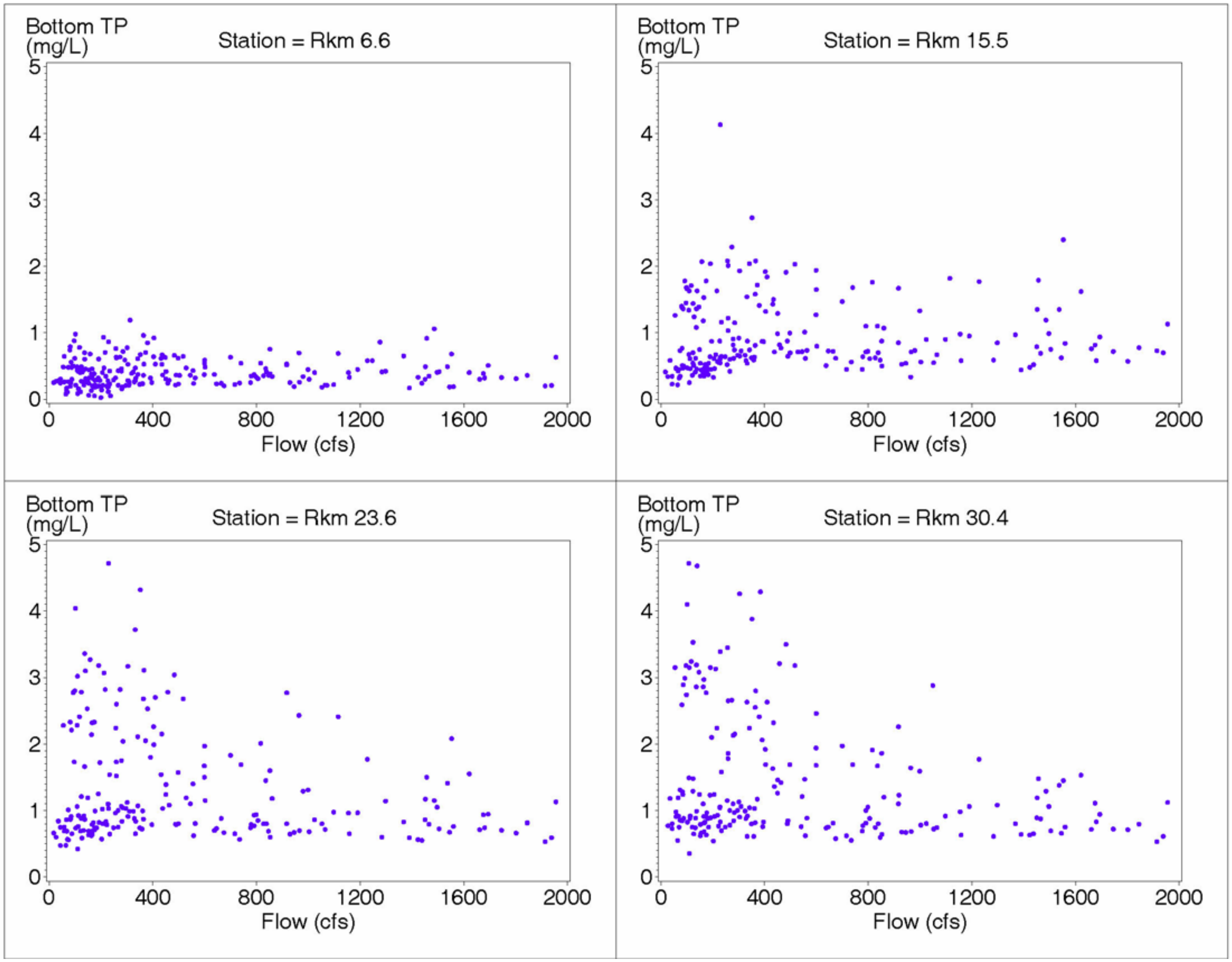


Figure 6-15. Long-term HBMP bottom total phosphorus observations at Stations 10, 12, 14, and 18 (see Figure 2-3 for locations) as a function of flow in the Lower Peace River. Lower Peace River flow was calculated as the sum of Peace at Arcadia (USGS 02296750), Joshua Creek at Nocatee (USGS 02297100), and Horse Creek near Arcadia (USGS 02297310), minus the withdrawals taken out at the PRMRWSA plant.

7 Application of Modeling Tools that Relate Freshwater Inflows to Salinity in Shell Creek and the Lower Peace River

In this section, the following elements to be used in establishing MFLs will be presented for both LPR and SC:

- Definition of biologically-relevant salinities,
- Description of the metrics used to quantify habitat,
- Definition of seasonally specific assessment periods,
- Description of analytical tools used to quantify habitat,
- Definition of the study area,
- Definition of the baseline period for minimum flow evaluation,
- Definition of the modeling period for minimum flow evaluation,
- Definition of the Baseline Scenario,
- Definition of alternative modeling scenarios, and
- Review of the results provided by the analytical tools.

The biologically-relevant salinities, metrics used to quantify the amount of available habitat, and seasonally specific assessment periods are the same for LPR and SC and are discussed in Section 7.1. Because the other elements are specific to each system, these elements will be discussed separately in the following Sections 7.2 and 7.3.

7.1 Definition of Biologically-Relevant Salinities, Habitat Assessment Metrics, and Seasonally-Specific Assessment Periods

This section defines the Biologically-Relevant Salinities, Habitat Assessment Metrics, and Seasonally-Specific Assessment Periods to be used to establish the MFLs in both LPR and SC.

7.1.1 Definition of Biologically-Relevant Salinities

Clearly, establishment of an MFL requires identification of a critical biologically-relevant variable that can be defensibly and quantitatively related to variation in freshwater flows. The results presented in Section 6 indicate that salinity is the most quantifiable and defensible link to variation in freshwater flow. Therefore, the first step in the establishment of an MFL is the definition of biologically-relevant salinities to provide a focus to the analysis of the effect of freshwater flow on LPR and SC.

The following biologically relevant salinities were used in minimum flow development for LPR and SC:

- <2 ppt - this critical salinity is supported by several pieces of evidence – Jassby *et al.* (1995) use the 2 ppt isohaline as an indicator of overall ecosystem productivity in estuaries; fish studies on the LPR and SC showed that many freshwater fish and invertebrates have mean salinity of capture values of less than 2 ppt; analysis of fish community structure in the Lower Peace River (Figures 5-11 and 5-12) reveals break points for distinct groups of these organisms at approximately 2, 5, and 15 ppt; Clewell *et al.* (1999) described glycophytes as having low salinity tolerances with several species being most abundant where median yearly salinities are below 2 ppt; and the Lower Suwannee River MFL was based on "average salinities of high tide waters flooding the swamps should be kept <2 ppt, with briefer periods of higher salinity tolerable." (WRA *et al.* 2005).

- <5 ppt - this critical salinity is also supported by several lines of evidence - oligohaline river habitats with salinities in the range less than 5 ppt have been disproportionately lost throughout the Gulf Coast (Beck *et al.* 2000), and that there is an opportunity to maintain such habitats in LPR and SC given appropriate minimum flows for these systems; analysis of fish community structure in the Lower Peace River (Figures 5-11 and 5-12) reveals break points for distinct groups of these organisms at approximately 2, 5, and 15 ppt; and the Sulphur Springs MFL (SWFWMD 2004) and Lower Hillsborough River MFL reevaluation (SWFWMD 2006) both had the goal of maintaining low salinity (less the 5 ppt) habitat in the Lower Hillsborough River.

- 15 ppt - this critical salinity is also supported by several lines of evidence - analysis of fish community structure in the Lower Peace River (Figures 5-11 and 5-12) reveals transition points for distinct groups of these organisms at approximately 2, 5, and 15 ppt; and analysis of benthic community structure in the lower Peace River and Myakka River also shows salinities in the range of 15-18 ppt are important to maintain the integrity of a healthy mesohaline community type.

7.1.2 Definition of Habitat Assessment Metrics

In order to estimate the amount of available habitat that meets the biologically-relevant salinities discussed above under various flow conditions, the following metrics were used:

- the volume of water in the system less than a given salinity, since the fishes in the LPR and SC generally utilize the entire water column,

- the bottom area in the system less than a given salinity, since the benthic macroinvertebrates inhabit the bottom substrate in the LPR and SC,

- the shoreline length in the system less than a given salinity, since this metric best defines the amount of shoreline vegetation habitat available in the system.

7.1.3 Seasonally-Specific Assessment Periods

Definition of an MFL that maintains biologically-relevant salinities over a range of flow conditions must also consider the expected variation on flows within given portions (hydroperiods) of the year. The peer-review report on proposed MFLs for the upper segment of the Peace River (Gore *et al.* 2002) identified a "building block" approach as "a way to more closely mirror original hydrologic and hydroperiodic conditions in the basin". Development of regulatory flow requirements using this type of approach typically involves description of the natural flow regime, identification of building blocks associated with flow needs for ecosystem specific functions, biological assemblages or populations, and assembly of the blocks to form a flow prescription (Postel and Richter 2003). As noted by the panelists comprising the Upper Peace River MFL review panel, "assumptions behind building block techniques are based upon simple ecological theory; that organisms and communities occupying that river have evolved and adapted their life cycles to flow conditions over a long period of pre-development history (Stanford *et al.* 1996). Thus with limited biological knowledge of flow requirements, the best alternative is to recreate the hydrographic conditions under which communities have existed prior to disturbance of the flow regime." Although in most cases, the District does not expect to recreate pre-disturbance hydrographic conditions through MFL development and implementation, the building block approach is viewed as a reasonable means for ensuring the maintenance of similar, although dampened**,** natural hydrographic conditions (SWFWMD 2005a).

Conceptually, the approach used by the District for development of MFLs for the upper Peace River (SWFWMD 2002) was consistent with the building block approach. Available flow records were summarized and used to describe flow regimes for specific historical periods. For development of minimum flows and levels for the middle segment of the Peace River, the District explicitly identified three building blocks in its approach (SWFWMD 2005a). The blocks correspond to seasonal periods of low, medium and high flows. The three distinct flow periods are evident in hydrographs of median daily flows for the river (Figure 7-1). Lowest flows occur during Block 1, a 66 day period that extends from April 20 to June 25 (Julian day 110 to 176). Highest flows occur during Block 3 (June 26 to October 26), the 123 day period that immediately follows the dry season. This is the period when the floodplain is most likely to be inundated on an annual basis; although high flows can occur in early to mid-March. The remaining 176 days constitute an intermediate or medium flow period, which is referred to as Block 2. For development of minimum flows and levels for LPR and SC, the same Blocks as defined for the middle Peace River have been applied.

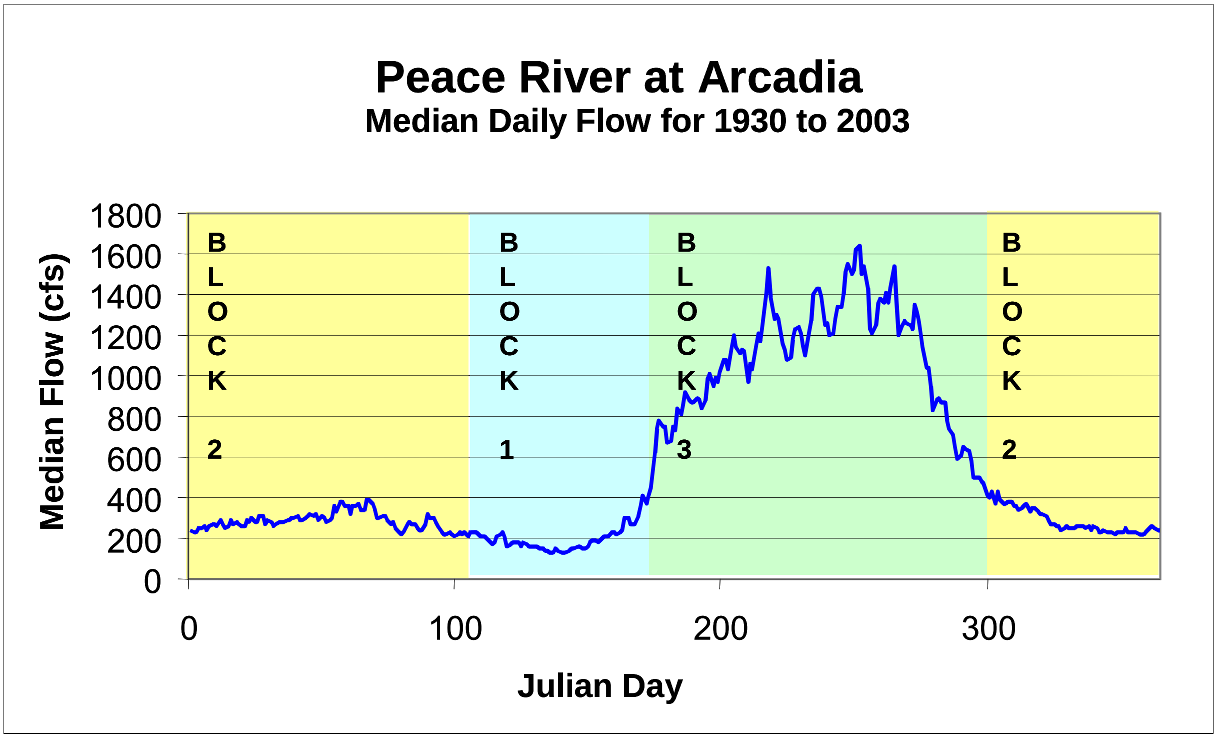


Figure 7-1. **Building blocks developed for a building block approach to the development of minimum flows. Blocks corresponding to low (Block 1), medium (Block 2) and high (Block 3) flows are shown along with period of record median daily flows for the USGS Peace River at Arcadia gage (from: SWFWMD 2005a).**

7.2 Application of Modeling Tools that Relate Freshwater Inflows to Salinity in Shell Creek

In this subsection, the following elements will be met for SC:

- Description of analytical tools used to quantify habitat,
- Definition of the study area,
- Definition of the baseline period for minimum flow evaluation,
- Definition of the modeling period for minimum flow evaluation,
- Definition of the Baseline Scenario,
- Definition of alternative modeling scenarios, and
- Review of the results provided by the analytical tools.

7.2.1 Analytical tool that relates flow to salinity for Shell Creek

The purpose of the analytical tool is to estimate the volume, bottom area, and shoreline length meeting the biologically relevant salinities as a function of flow. To this end, a regression model of SC was developed. The regression model is described in Appendix 7-1. The regression model predicts daily salinity at any point in the study area as a function of flow and other confounding factors. Factors besides flow include the location in the river, season, Peace River flow and salinity in the north-eastern portion of Charlotte Harbor. Because the system is relatively well mixed vertically, the model predicts water column average salinity. The final form of the regression model is as follows:

$$Salinity = \alpha + \beta_1 Month + \beta_2 Q_{SC}^{-0.05} + \beta_3 S_{BM} + \beta_4 Tide + \beta_5 (\ln Q_{PR}) + \beta_6 RK^{1.5} + \beta_7 Q_{SC} RK$$

where:

Salinity	=	Water Column-Average Salinity
Month	=	Calendar Month
Q_{SC}	=	Shell Creek Flow
S_{BM}	=	Salinity in Upper Charlotte Harbor at Black Marker
Tide	=	Tide Height at Boca Grande
Q_{PR}	=	Peace River Flow (Peace at Arcadia + Horse Creek + Joshua Creek)
RK	=	River Kilometer

Salinity observations from fixed station sampling by the Peace River HBMP were used to develop this model. The model was based on data collected from of 1997 through 2004. Although additional HBMP fixed station sampling data were available prior to 1997, the time of data collection was not recorded. Therefore, these data could not be used since there was no way to determine the tide phase at the time of sampling.

The salinity-flow model was statistically significant and accounted for more than 80% of the variation in salinity in SC (p<0.0001, r^2 = 0.82). The parameter estimates, model statistics, and residual analyses are presented in Appendix 7-1.

7.2.2 Shell Creek Study Area

The physical domain of the salinity-flow regression model is shown in Figure 7-2. This area is comprised of the main stem of SC from HBMP Station 7 (rkm 2.35) to the dam (rkm 9.9).

7.2.3 Shell Creek Baseline Period

The Baseline Period is defined as the period from 1966 through 2004. This period reflects the significant year-to-year variation in flows that have occurred historically within SC.

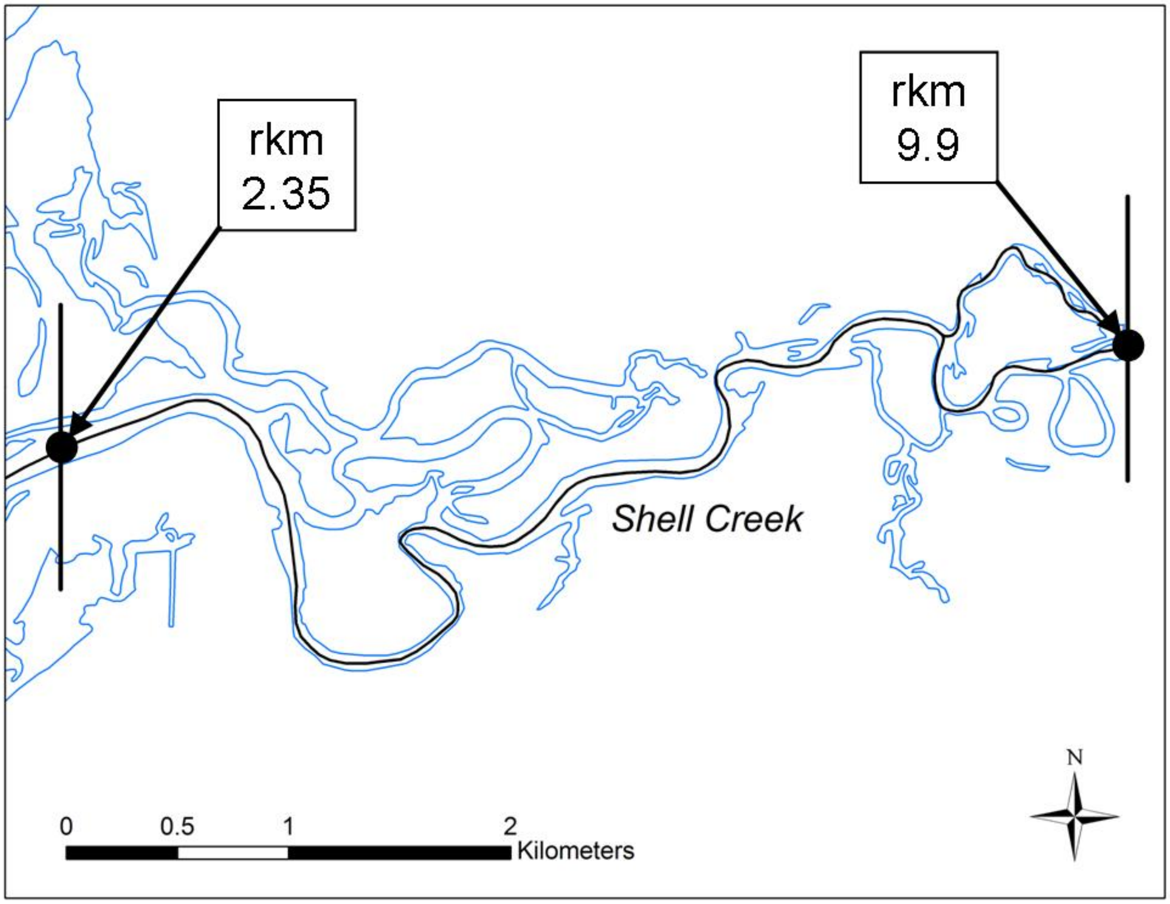


Figure 7-2. **Study area for SC whole river regression. The physical domain of the regression is comprised of the main stem of SC and extends from river km 2.35 to river km 9.9 at the base of the dam. The map includes the centerline (black line) of the main stem of SC.**

7.2.4 Shell Creek Modeling Period

The modeling period, i.e., the period to which the salinity-flow regression model is to be applied, was also defined as the period from 1966 to 2004. Because tide and Black Marker Salinity were not available for the entire period of record, the median tide and Black Marker salinity were calculated by calendar month for the period 1997 to 2004. These median values were then applied to the daily flow record by calendar month and predictions were made for each day between January 1, 1966 and December 31, 2004.

7.2.5 Definition of Baseline and Model Scenarios for Shell Creek

The Baseline Scenario for SC consisted of the observed daily flows at the Shell Creek near Punta Gorda gage (USGS 02298202) plus the withdrawals by the City of Punta Gorda. Additional model runs were made based on a series of percent reductions from the Baseline SC flows. The series of percent flow reductions that defined the Percent Flow Reduction Modeling Scenarios ranged from 1% to 50% in 1% increments.

7.2.6 Approach to the Quantification of Habitat Availability as a Function on Inflow in Shell Creek

Habitat availability is quantified in terms of space and time. The tool used to evaluate temporal persistence and spatial extent of habitat meeting a biologically-relevant salinity is a cumulative distribution function (CDF) plot (for example, see Figure 7-3). CDF plots are an ideal tool as they incorporate the spatial extent and the temporal persistence that a given salinity is met. Plots are drawn of the various scenarios that have been run and comparisons can be made among scenarios.

Since the three habitat metrics (i.e., volume, bottom area, and shoreline length) are highly correlated in the portion of SC that was modeled, only one metric, volume, has been used in the following analyses.

As discussed above, the concept of defining "building blocks" to establish MFLs is to get the "right flow at the right time." If the variability in flow within a block is appreciable, then it is prudent to refine the recommended MFL within a block by accounting for this variability. This is especially important in Block 1, the low flow block, when the quantity of low salinity habitat is normally at its lowest. If Block 1 is considered in its entirety, the same percent reduction in flow would be allowed for any day in Block 1. Therefore, to account for the variability of flow within a block and provide protection for the low salinity habitat when flows are at their lowest, the salinity response to changes in flow under relatively high (i.e., above the median flow for the block) or relatively low (i.e., below the median flow for the block) was examined. If the flow is above the median, a greater percent of the flow can be taken. But if the flow is below the median, a lesser percent of the flow can be taken. The median flows by block in SC are presented in Table 7-1. For the remainder of this document, the flow conditions for SC will be referred to as "under the low flow condition" (below the median flow within a block) or "high flow condition" (above the median flow within a block).

Table 7-1. Median SC baseline flow by block for the period 1966 to 2004. Baseline flow = Shell Creek near Punta Gorda gage (USGS 02298202) plus withdrawals by City of Punta Gorda.

Block	Dates	Baseline Median Flow (cfs)	Baseline Median Flow (mgd)
1	April 20 to June 25	84	54
2	October 27 to April 19	98	63
3	June 26 to October 26	424	274

7.2.7 Results of the Quantification of Habitat Availability as a Function on Inflow in Shell Creek

Examination of the CDF plots in Figures 7-3 through 7-8 lead to the following observations and conclusions for all Blocks:

- Both flow conditions create some portion of SC with a salinity of less than 2 ppt for at least some portion of time within the baseline period.
- Under the high flow condition, the entire volume of SC within the study area is less than 2 ppt at least 10% of the time for all scenarios.
- The low flow condition creates some portion of SC with salinity less than 5 ppt for at least 50% of the baseline period.
- The high flow condition maintains salinity less than 5 ppt in some portion of the SC study area throughout the entire baseline period in all scenarios.

Examination of the CDF plots for Block 1, the following observations can be made:

- Under the low flow condition, water with salinity less than 2 ppt is lacking during at least 90% of the time in all scenarios.
- Under the high flow condition, no portion of SC has a salinity less than 2 ppt 30% of the days for the Baseline Scenario and 45% of the days for the 50% Reduction Scenario.
- The high flow condition maintains salinity less than 5 ppt in some portion of the SC study area throughout the entire baseline period in all scenarios.

Examination of the CDF plots for Block 2 reveals the following:

- Under the high flow condition, some portion of SC with a salinity of less than 2 ppt is maintained at least 90% of the baseline period in all model scenarios.
- Under the Baseline Scenario all of SC has salinity less than 2 ppt 30% of the time under the low flow condition and 90% of the time under the high flow condition.

Examination of the CDF plots for Block 3 reveals the following:

- Under the high flow condition, all of SC has a salinity of less than 2 ppt is maintained at least 90% of the baseline period in all model scenarios.
- Under both flow conditions, all of SC has salinity less than 5 ppt at least 50% of the time in all model scenarios.

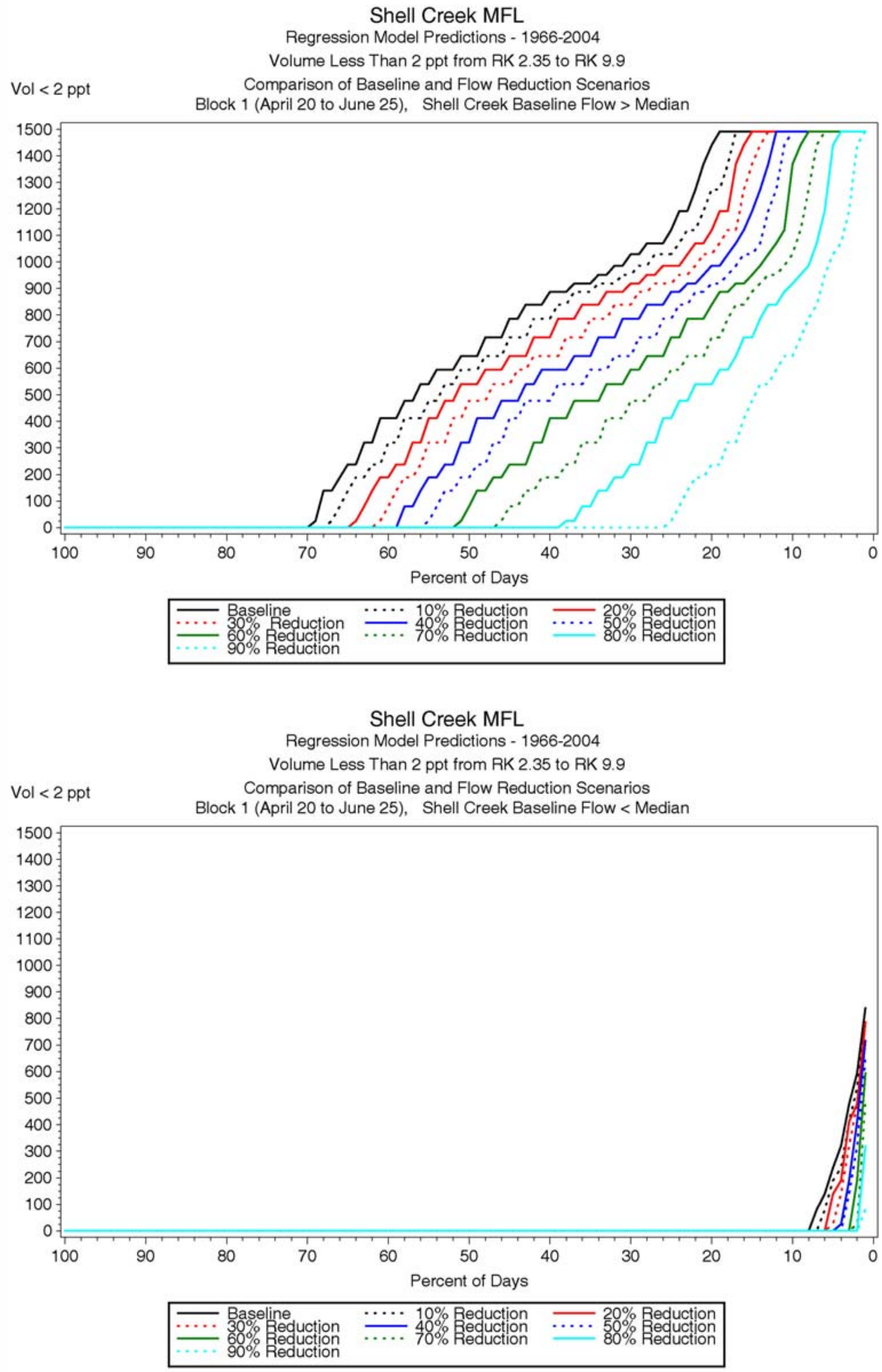
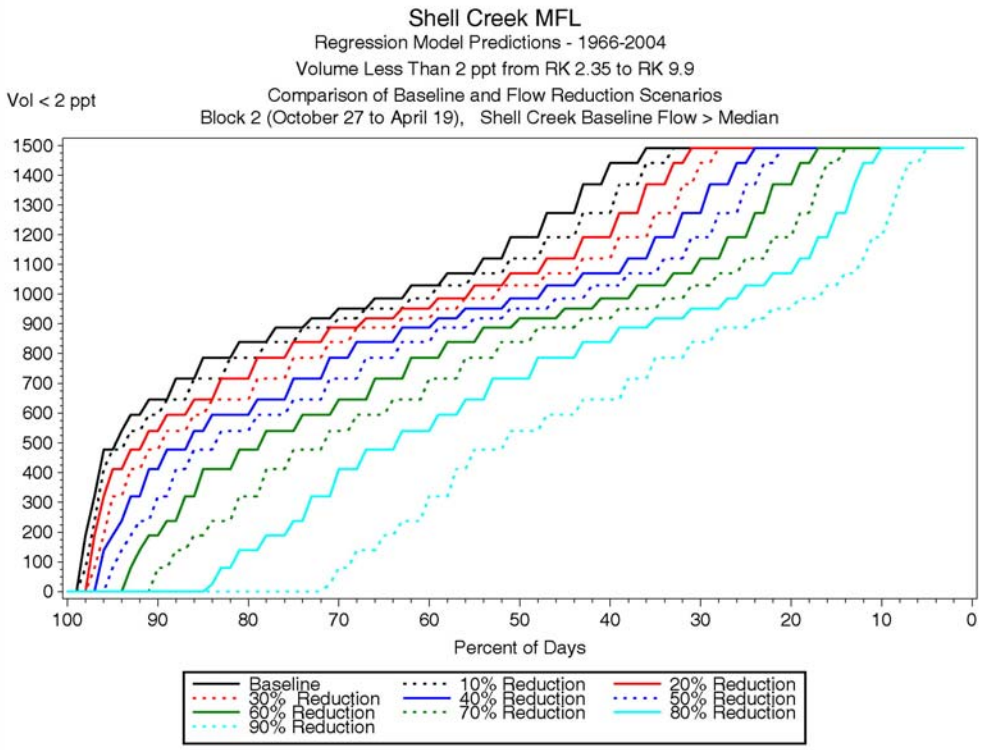


Figure 7-3. CDF plot of water volume from the dam to rkm 2.35 less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



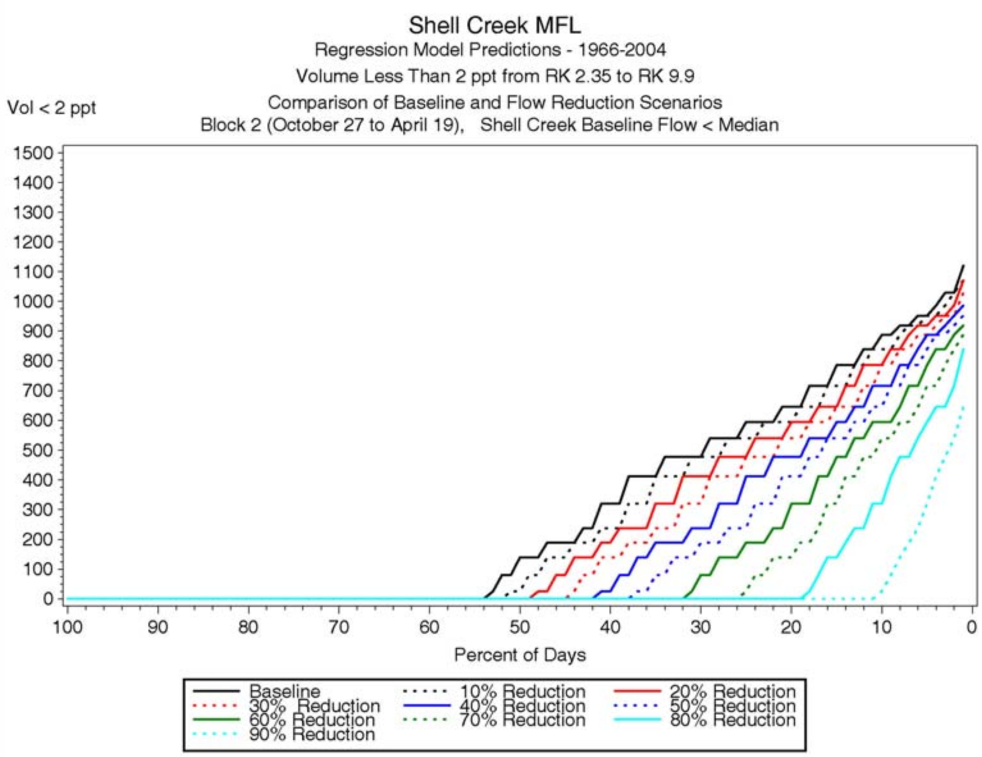


Figure 7-4. CDF plot of water volume from the dam to rkm 2.35 less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).

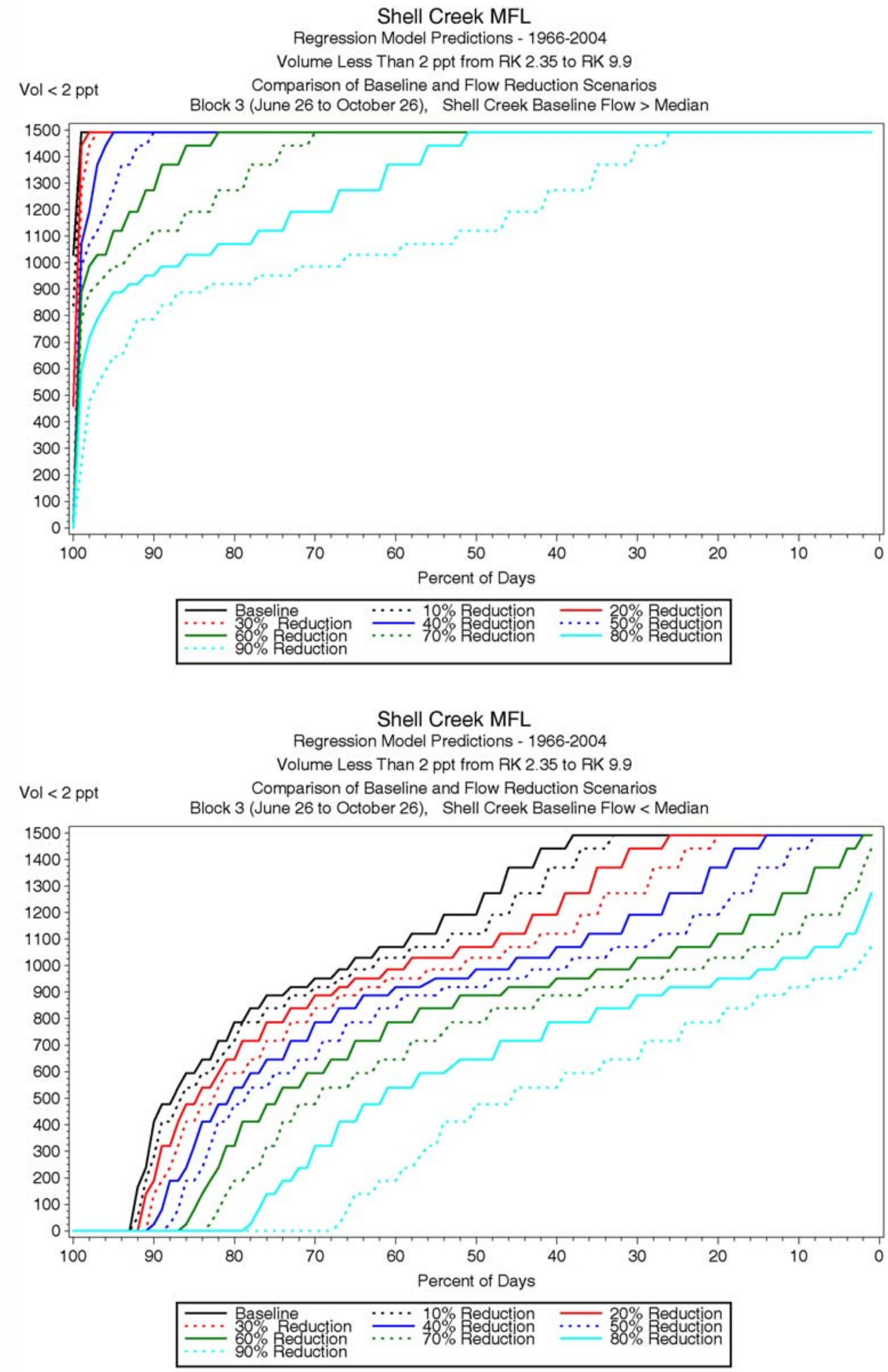


Figure 7-5 **CDF plot of water volume from the dam to rkm 2.35 less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).**

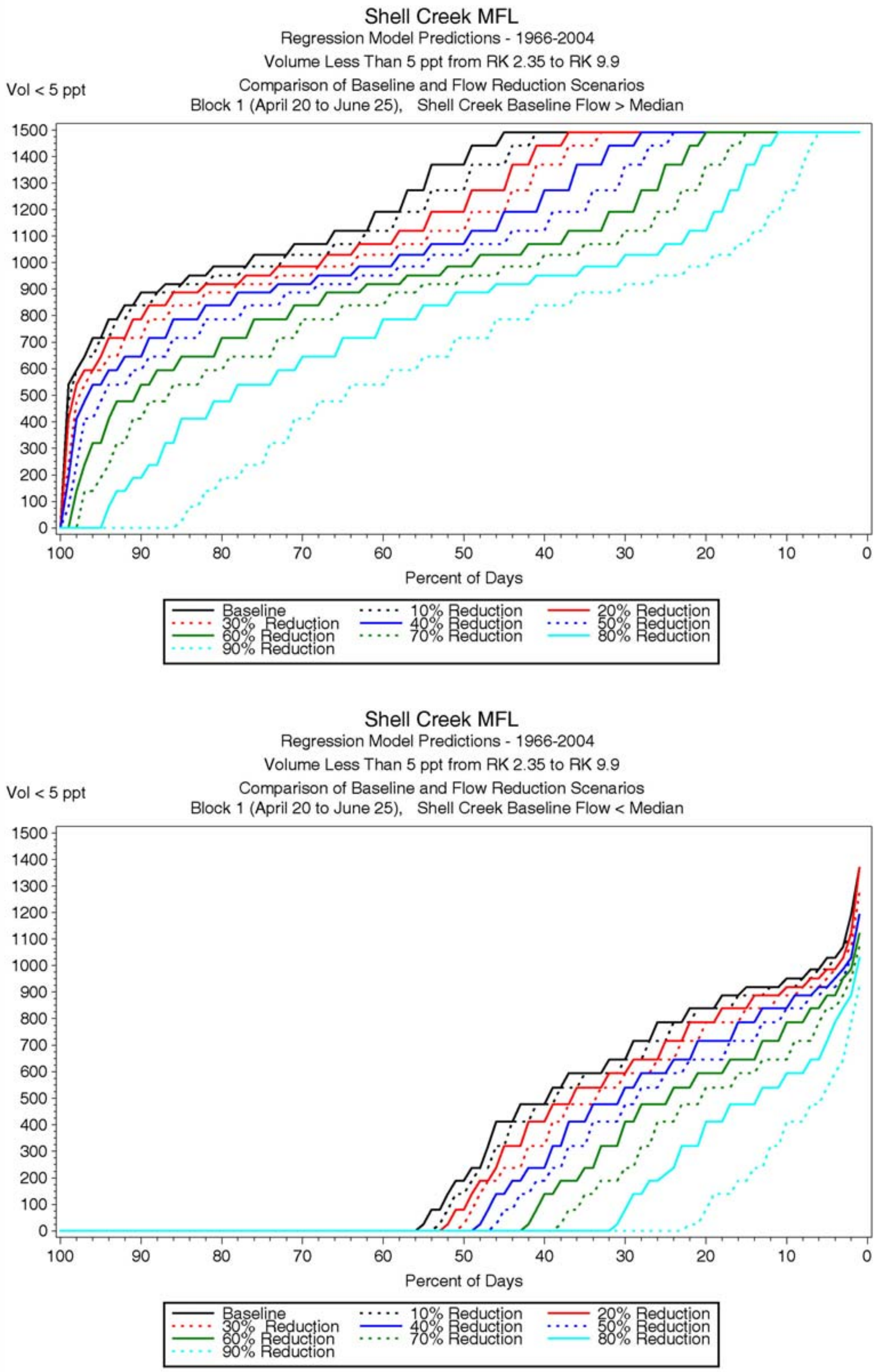


Figure 7-6 CDF plot of water volume from the dam to rkm 2.35 less than 5 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).

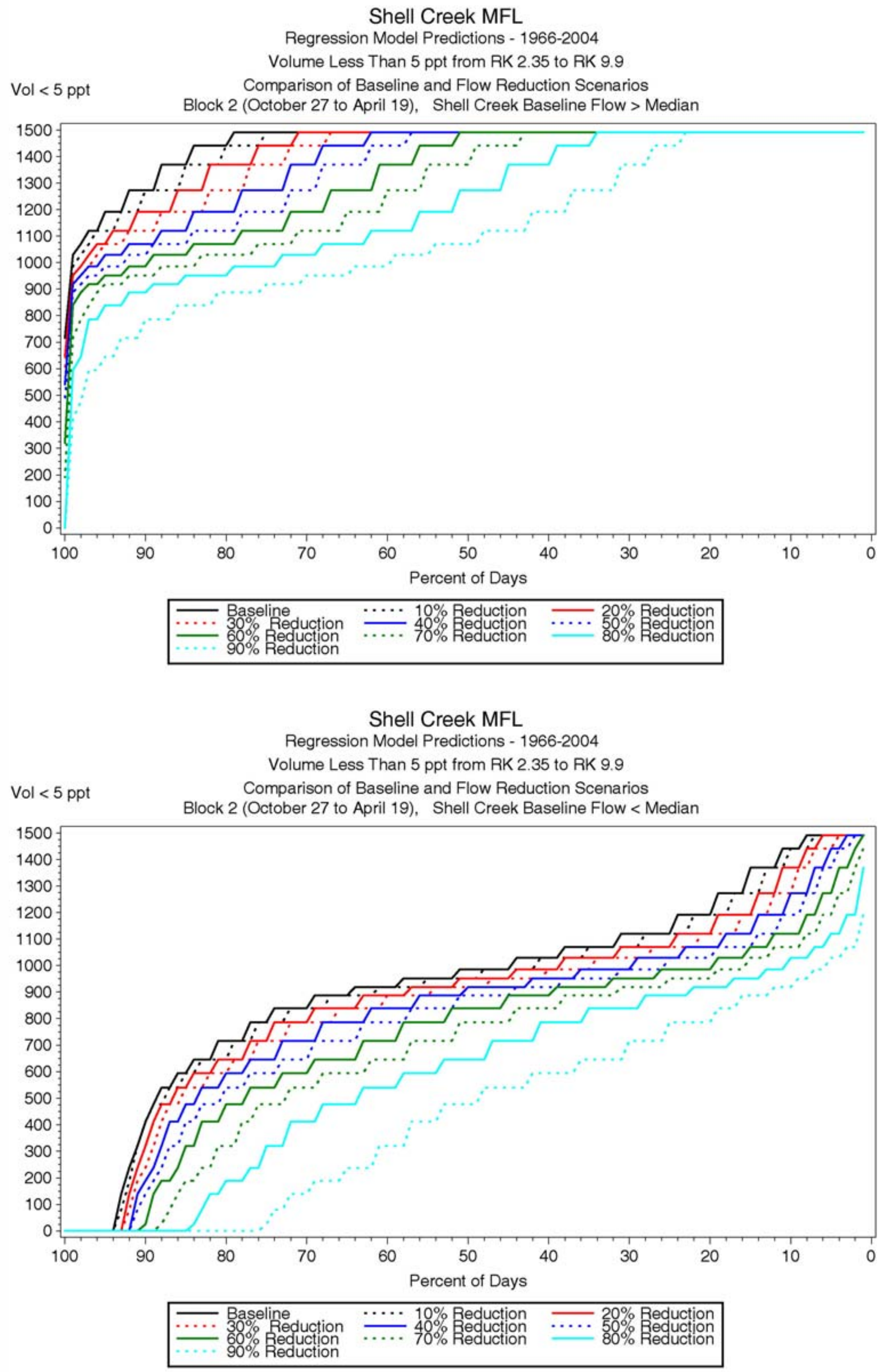


Figure 7-7 **CDF plot of water volume from the dam to rkm 2.35 less than 5 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).**

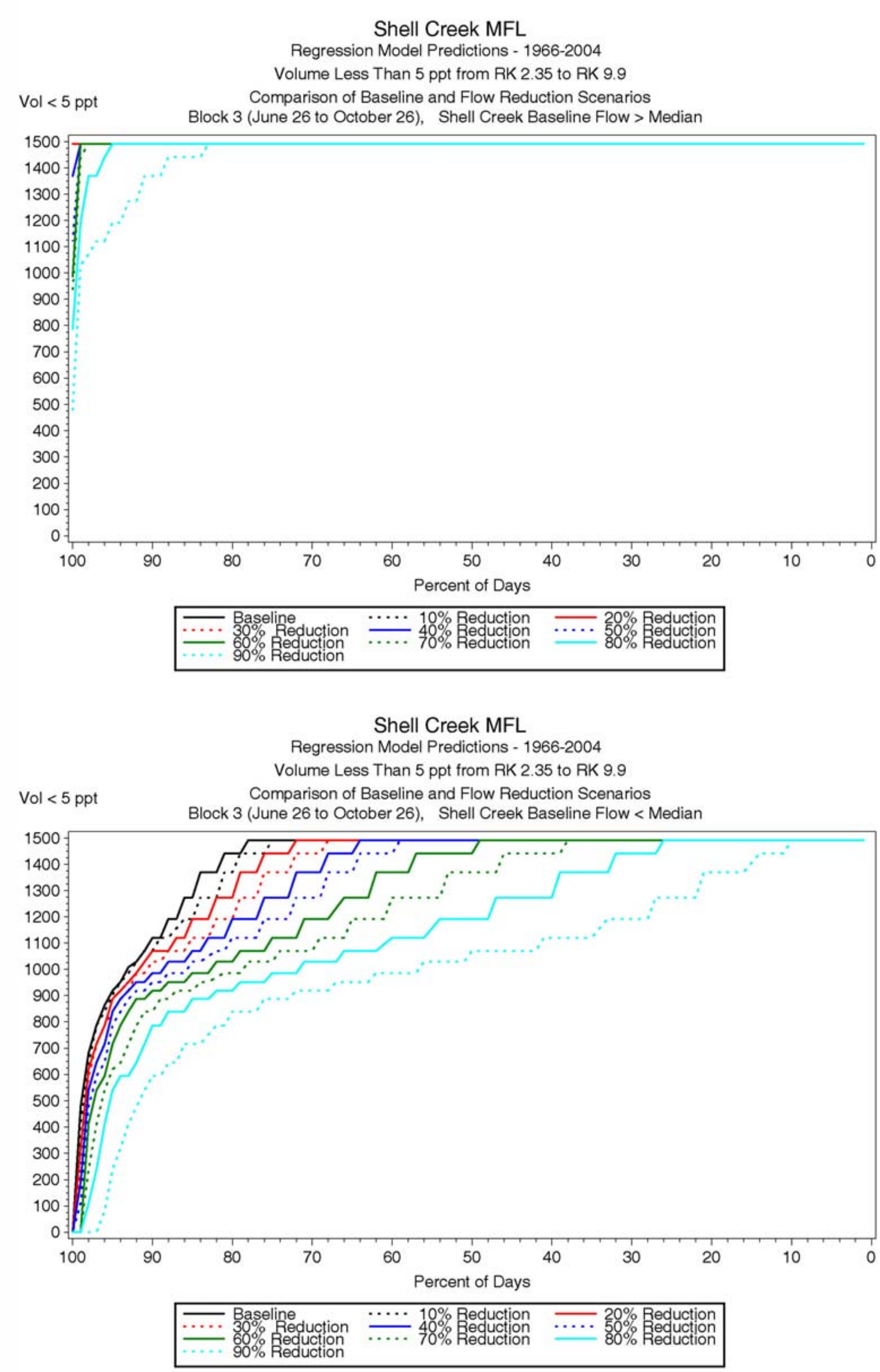


Figure 7-8 **CDF plot of water volume from the dam to rkm 2.35 less than 5 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).**

7.3 Application of Modeling Tools that Relate Freshwater Inflows to Salinity in the Lower Peace River

In this subsection, the following objectives will be met for Lower Peace River:

- Description of analytical tools used to quantify habitat,
- Definition of the study area,
- Definition of the baseline period for minimum flow evaluation,
- Definition of the modeling period for minimum flow evaluation,
- Definition of the Baseline Scenario,
- Definition of alternative modeling scenarios, and
- Review of the results provided by the analytical tools.

7.3.1 Analytical Tool That Relate Flow to Salinity in the Lower Peace River

A hydrodynamic model has been developed by District staff that estimates the response in the Lower Peace River to variations in freshwater inflows (Chen 2004). A description of the model as well as the calibration of the model is provided in Appendix 7-2. The domain of the hydrodynamic model includes the northern portion of Charlotte Harbor, the Myakka River, the tidally influenced portion of SC, the LPR (downstream of Arcadia). The hydrodynamic model cells used for minimum flow development for the LPR are illustrated in Figure 7-9.

7.3.2 Lower Peace River Study Area

The physical domain of the Lower Peace River model is presented in Figure 7-10. The study area extends from the mouth of the river to just upstream of the confluence of Horse Creek.

7.3.3 Lower Peace River Baseline Period

The baseline period is defined as the period from 1985 through 2004. This period represents a wide range of hydrologic conditions including a significant wet period and a significant dry period due to the Atlantic Multidecadal Oscillation (Kelly 2004).

7.3.4 Lower Peace River Modeling Period

Establishment of an MFL for the Lower Peace River requires the hydrodynamic model to provide predicted salinities for a Baseline Scenario and a series of flow scenarios with different percent flow reductions. The hydrodynamic model requires a significant amount of computer time to simulate changes in water levels and salinities in the LPR. As such it is impractical to simulate the entire 20-year baseline period for the series of modeling scenarios that is necessary to support development of an MFL for the LPR. Because of this impracticality it was desirable to identify a shorter time period on the order of 3-5 years that reflects a similar range of hydrologic conditions to that observed over the entire 20-year baseline period.

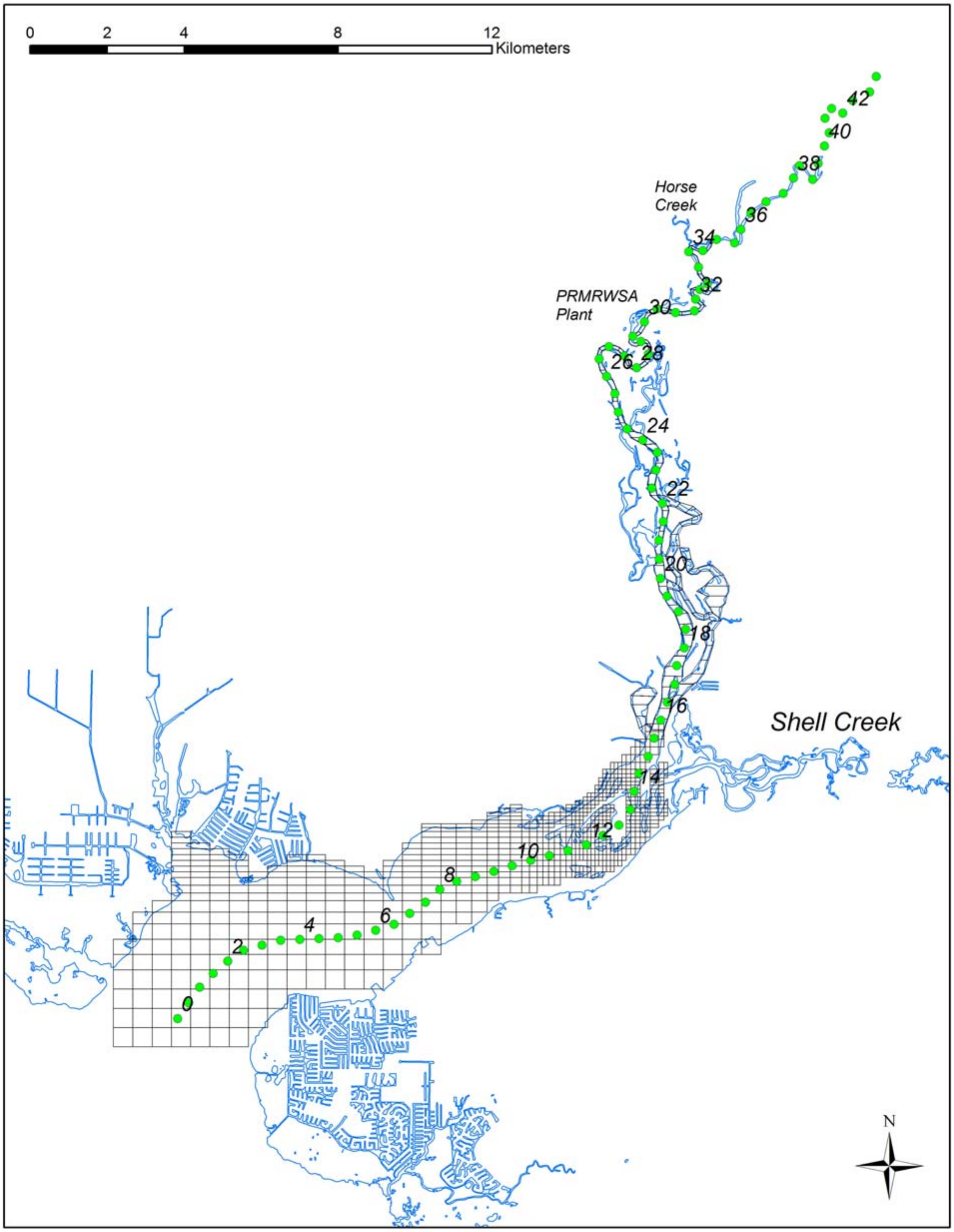


Figure 7-9. **Lower Peace River hydrodynamic model cells used for minimum flow development. The river centerline with river kilometer is also presented.**

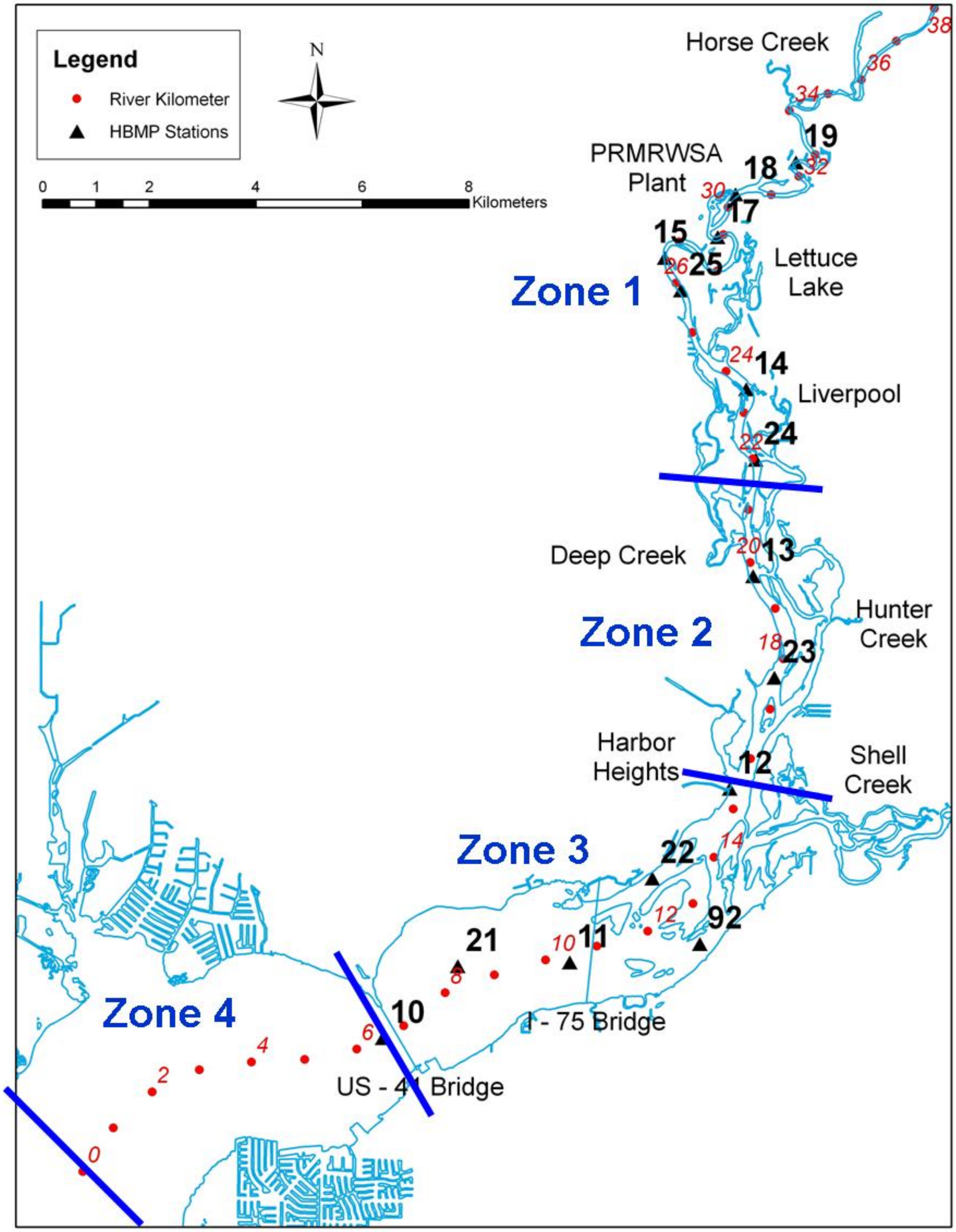


Figure 7-10. **Map of the Lower Peace River study area including salinity zones (in blue) as defined by Mote (2002), PRMRWSA HBMP fixed station sampling sites (black triangles), and the centerline of the river with river kilometers (in red).**

A number of candidate modeling periods was examined. This was accomplished by defining the flow duration curve for the baseline period (1985 to 2004) and comparing the flow duration curves for each candidate modeling period. It was found that a minimum 4-year period is necessary to attain reasonable concordance to the 20-year flow duration curve. Specifically, the flow duration curve for the 1996-1999 period most closely resembled the 1985 to 2004 flow duration curve (Figure 7-11). Therefore, 1996 to 1999 was selected as the period to be used for modeling of the Lower Peace River.

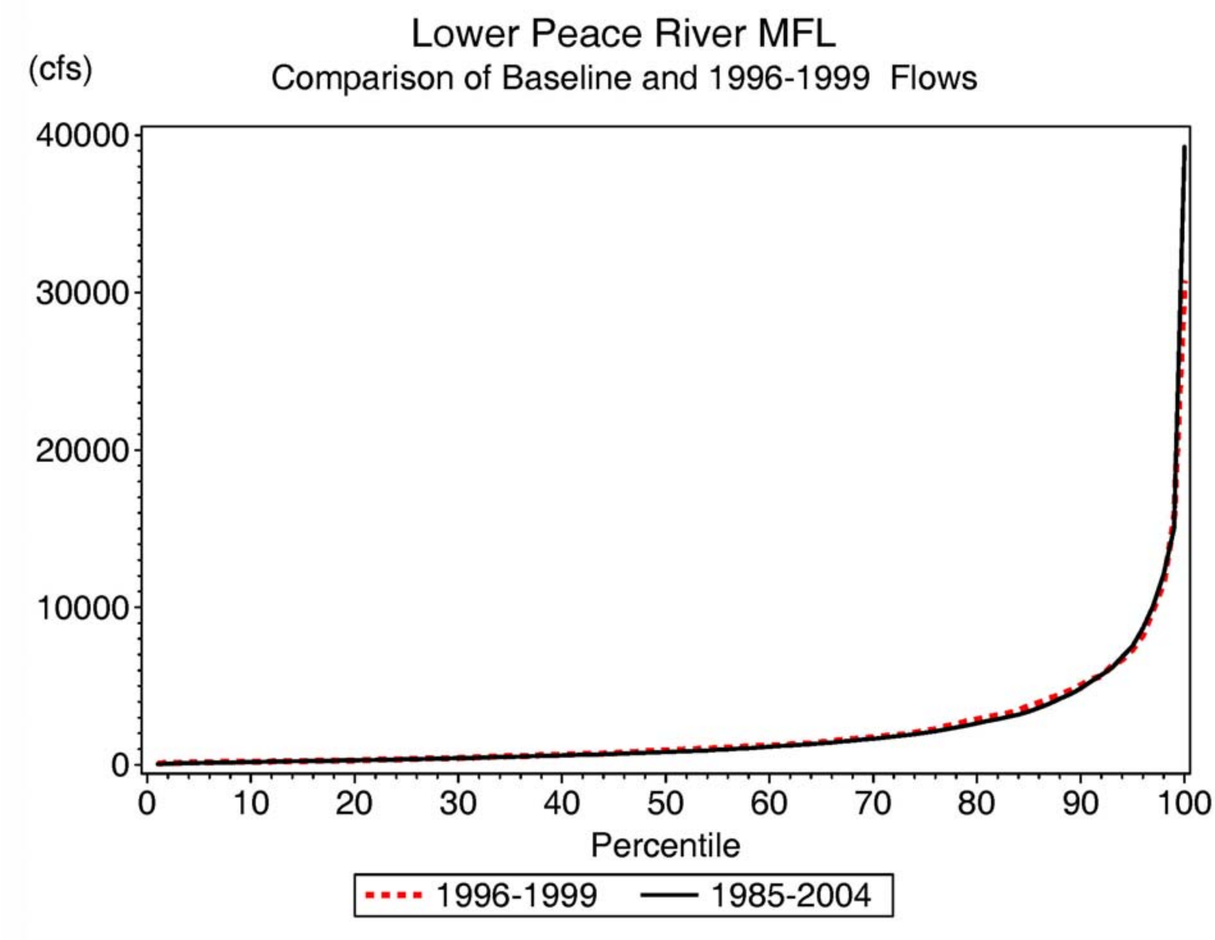


Figure 7-11. Comparison of flow CDF for the Baseline Period (1985-2004) and the Modeling Period (1996-1999).

7.3.5 Definition of Baseline and Model Scenarios for Lower Peace River

As defined above, the LPR flow is the sum of the gaged flows at:

- Peace River at Arcadia (USGS gage 02296750),
- Horse Creek near Arcadia (USGS gage 02297310), and
- Joshua Creek at Nocatee (USGS gage 02297100).

The Baseline Scenario flows were defined as the sum of the LPR gaged flows with the withdrawals by the PRMRWSA plant added back. In order to be conservative, the SC flows used for the LPR Baseline Scenario consisted of the SC flows minus the maximum daily allowable withdrawals as defined in Table 8-1.

The scenarios that were run to support development of the MFL for the Lower Peace River included the following:

- Baseline Scenario,
- 10% Reduction Scenario,
- 20% Reduction Scenario,
- 24% Reduction Scenario,
- 28% Reduction Scenario, and
- 30% Reduction Scenario.

7.3.6 Definition of Low-Flow Cutoff for Lower Peace River

The percent reduction scenarios will be compared to the Baseline Scenario to determine the impact the reductions have relative to the Baseline. Besides the percent reduction in flow, it is necessary to investigate whether there is a critical flow at which further reductions in flow would be detrimental to the system. This concept of a low flow cutoff is currently being applied to the Alafia River minimum flow (SWFWMD 2007c).

Attempts were made to develop empirical models that relate flow to ecological criteria for the Lower Peace River. However, no defensible relationship was found between flow and DO or between flow and chlorophyll *a* in the Lower Peace River. Therefore, it was not possible to establish a low flow cutoff based on these ecological criteria.

The PRMRWSA plant withdraws water from the Lower Peace River for potable water supply. It is important to maintain freshwater at the PRMRWSA withdrawal point because saline water hinders the treatment process for the plant. Therefore, an operational criterion of maintaining freshwater (< 0.5 ppt) at the PRMRWSA plant is an acceptable criterion since no defensible ecological criterion has been developed.

An empirical model has been developed that predicts salinity at the Peace River near Peace River Heights continuous recorder (USGS 02297350) based on flow and gage height at the continuous recorder. The form of the regression is as follows:

$$Salinity = \alpha + \beta_1 \ln(Q) + \beta_2 GH + \beta_3 Q + \beta_4 \ln(Q60) + \beta_5 Q\, GH + \beta_6 Q60$$

where:

Salinity	=	Salinity at Peace River Heights
Q	=	Peace River Flow (Peace at Arcadia + Horse Creek + Joshua Creek)
GH	=	Gage Height at Peace River Heights
$Q60$	=	Average Peace River Flow over that last 60 days

The Peace River near Peace River Heights continuous recorder is at rkm 26.7, while the PRMRWSA plant is at approximately rkm 30. The regression was used to identify the flow (Peace at Arcadia + Horse Creek + Joshua Creek) that results in freshwater conditions (< 0.5 ppt) at the continuous recorder. This analysis yielded a low flow cutoff of 90 cfs in order to maintain freshwater at the continuous recorder. Since the continuous recorder is 3 km downstream of the plant, this number is conservative, because the salinity at the plant will always be less than the salinity at the continuous recorder.

7.3.7 Approach to the Quantification of Habitat Availability as a Function of Inflow in Lower Peace River

Habitat availability is quantified in terms of space and time. In simple terms, we seek to quantify how much habitat is available for how much of the time. The tool used to evaluate temporal persistence and spatial extent of habitat meeting a biologically relevant salinity is a cumulative distribution function (CDF) plot. CDF plots are an ideal tool as they incorporate the spatial extent and the temporal persistence that a given salinity is met. Plots are drawn of the various scenarios that have been run and comparisons can be made between scenarios.

Habitat availability is characterized as those waters that meet the following biologically-relevant salinities:

- 2 ppt,
- 5 ppt, and
- 15 ppt.

The evidence that supports the choice of the three biologically-relevant salinities was discussed in section 7.1.1.

As discussed above, three habitat metrics are assessed to estimate the MFL in the Lower Peace River:

- Volume of water,
- Bottom area, and
- Shoreline length.

Also as discussed above, the MFL for each of three distinct flow periods (blocks) are estimated. These blocks include:

- Block 1 (low flow) from April 20 to June 25,
- Block 2 (moderate flow) from October 27 to April 19, and
- Block 3 (under the high flow condition) from June 26 to October 26.

In addition to examining the extent of the biologically-relevant salinities river-wide, a more spatially-specific assessment of salinity within a portion of the Lower Peace River was also deemed critical. As discussed above, studies have shown that the area of the river approximately located at Zone 3 (Figure 7-15) has a significantly abundant and diverse fish community. Earlier work has shown that this region is characterized by salinities typically in the range of 8-16 ppt (Mote 2002). Therefore, the volume of water meeting the appropriate salinity range in Zone 3 (i.e., volume of water with salinity between 8 and 16 ppt) was also analyzed.

7.3.8 Results of the Quantification of Habitat Availability as a Function on Inflow in the Lower Peace River

The Lower Peace River flow scenarios analyzed were the Baseline and 10%, 20%, 24%, 28%, and 30% flow reduction scenarios. As discussed in Section 7.2.1, the volume, bottom area, and shoreline length for a given salinity criteria are analyzed for the hydrodynamic model scenarios. CDF plots of volume, bottom area, and shoreline length for the stated salinity criteria are presented for the entire Lower Peace River minimum flow study area.

CDF plots of the daily volume of water less than 2 ppt in the Lower Peace River minimum flow study area are presented in Figures 7-12 through 7-14. Examination of these plots reveals the following:

- In Block 1 under the low flow condition, the daily volume of water less than 2 ppt ranged from approximately 0.75 to 5.5 million cubic meters. The daily volume of water less than 2 ppt was between 1 and 12 million cubic meters during Block 1 under the high flow condition.

- The daily volume of water less than 2 ppt was between approximately 1 and 13 million cubic meters in Block 2 under the low flow condition. The daily volume of water less than 2 ppt ranged between roughly 2 and 17 million cubic meters in Block 2 under the high flow condition.

- During Block 3 under the low flow condition, the daily volume of water less than 2 ppt ranged from approximately 1 to 27 million cubic meters. The daily volume of water in Block 3 under the high flow condition was between 2 and 30 million cubic meters.

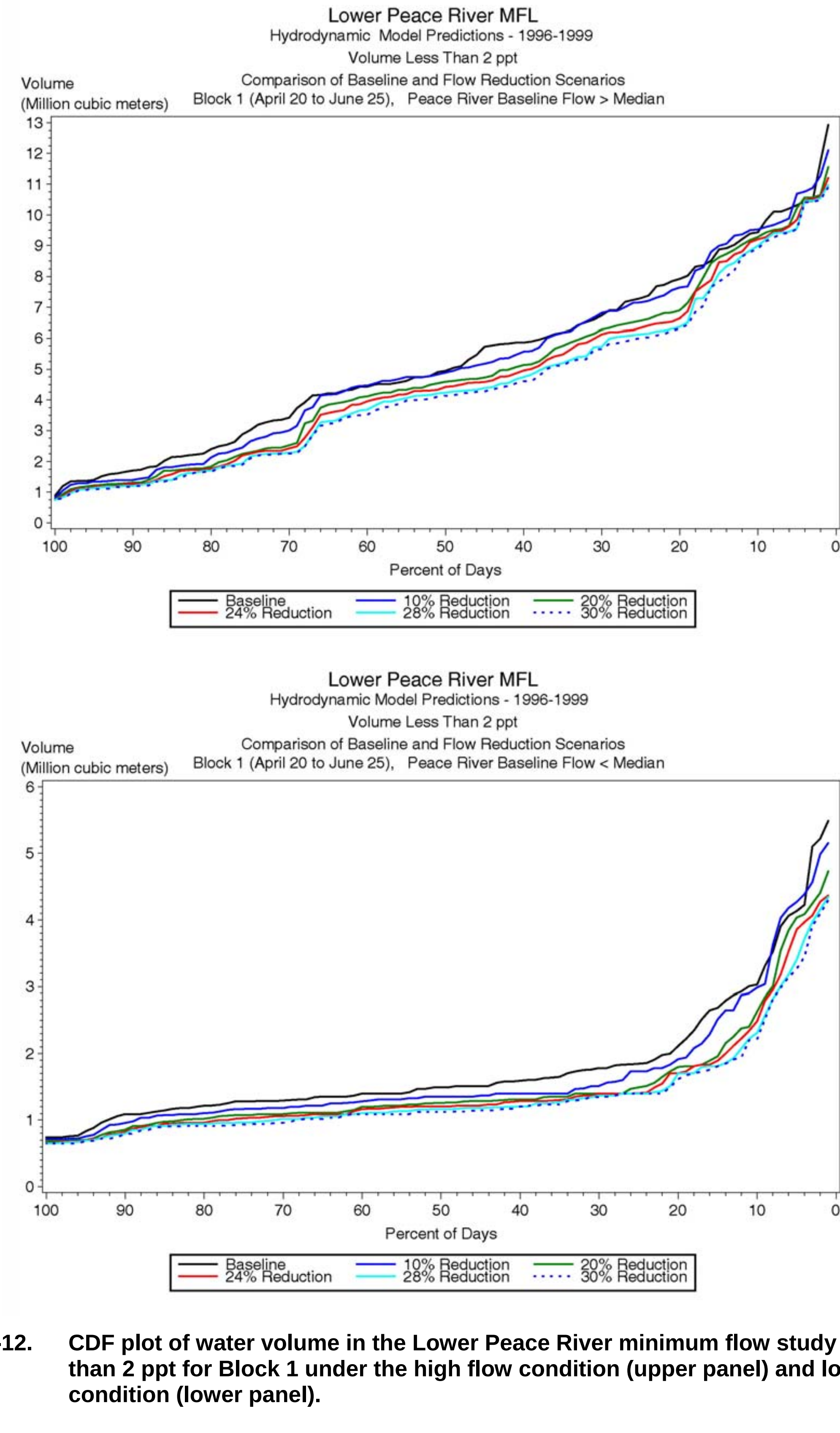
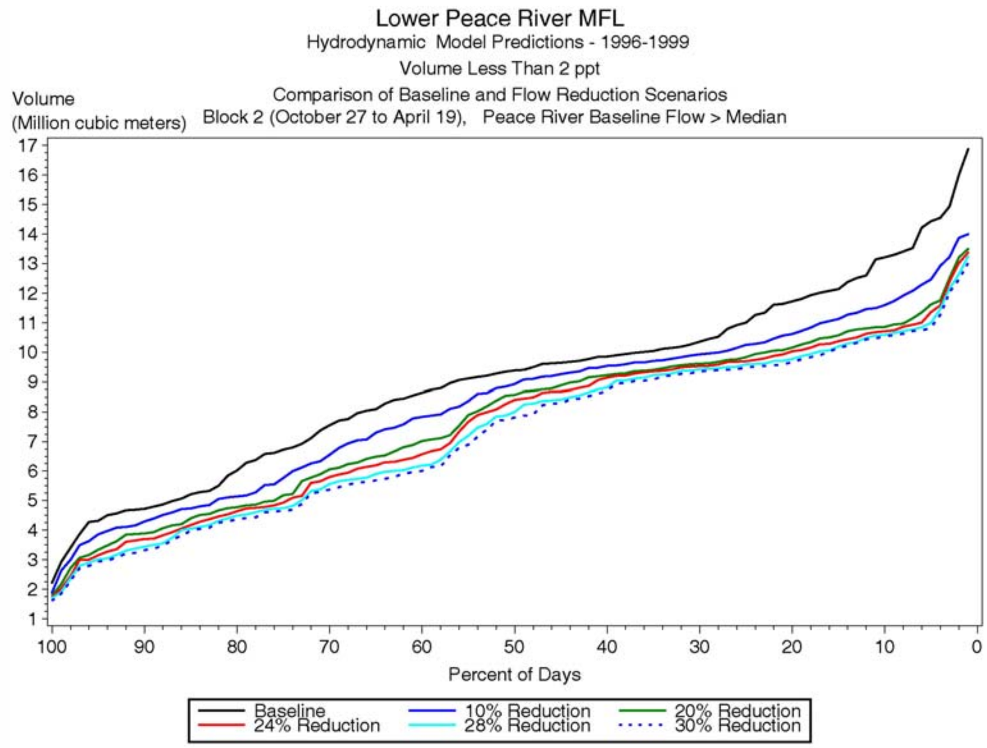


Figure 7-12. CDF plot of water volume in the Lower Peace River minimum flow study area less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



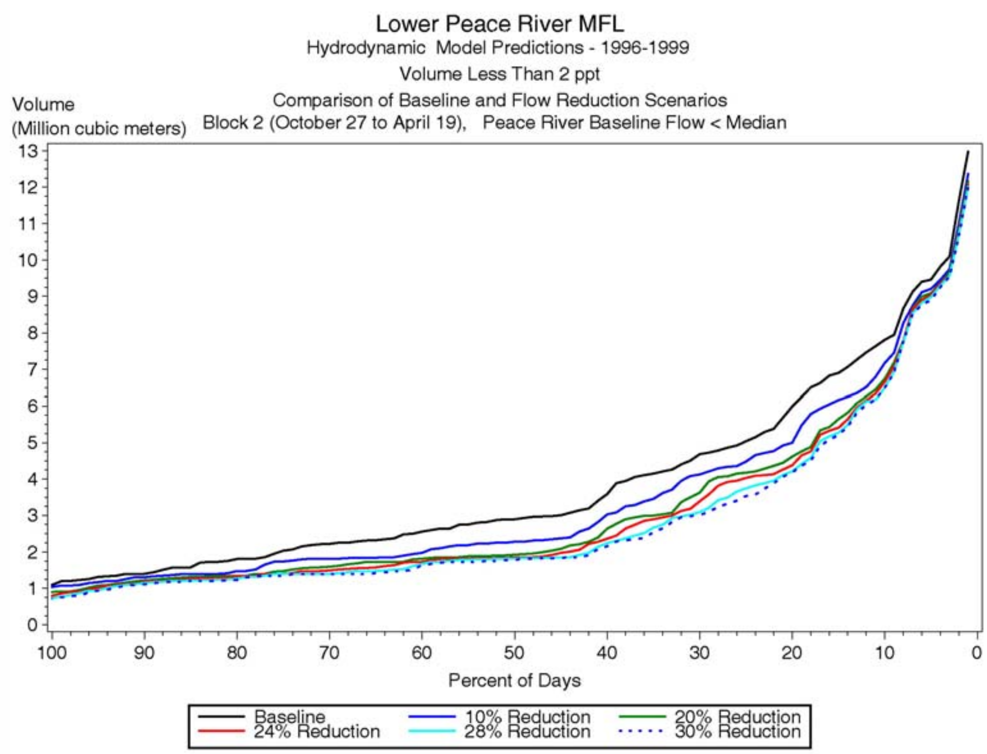
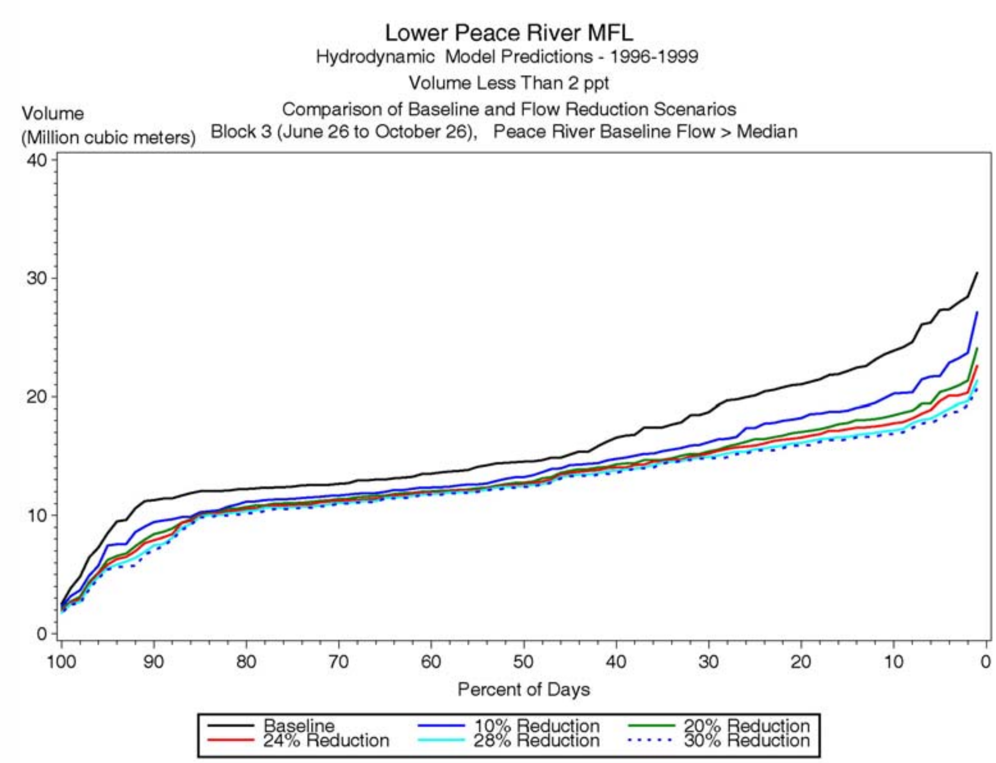


Figure 7-13. CDF plot of water volume in the Lower Peace River minimum flow study area less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).



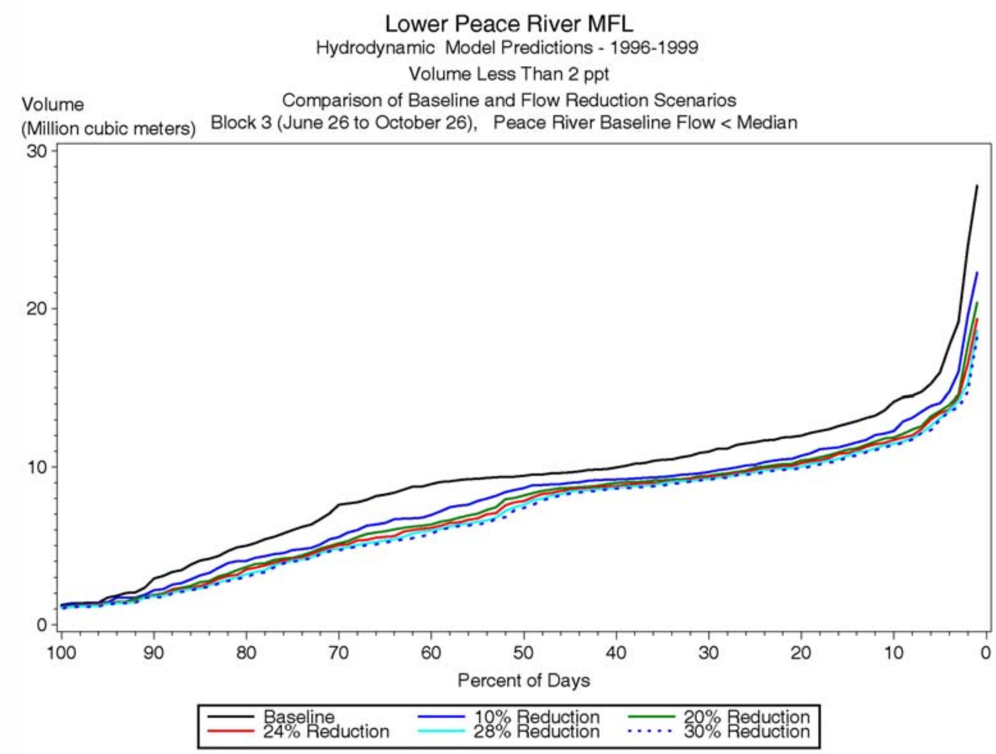


Figure 7-14. CDF plot of water volume in the Lower Peace River minimum flow study area less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).

CDF plots of the daily volume of water less than 5 ppt in the Lower Peace River minimum flow study area are presented in Figures 7-15 through 7-17. Examination of these plots reveals the following:

- In Block 1 under the low flow condition, the daily volume of water less than 5 ppt ranged from approximately 1 to 8 million cubic meters. The daily volume of water less than 5 ppt was between approximately 1 and 14 million cubic meters in Block 1 under the high flow condition.

- The daily volume of water less than 5 ppt was between approximately 1 and 14 million cubic meters in Block 2 under the low flow condition. In Block 2 under the high flow condition, the daily volume of water less than 5 ppt ranged from approximately 3 to 23 million cubic meters.

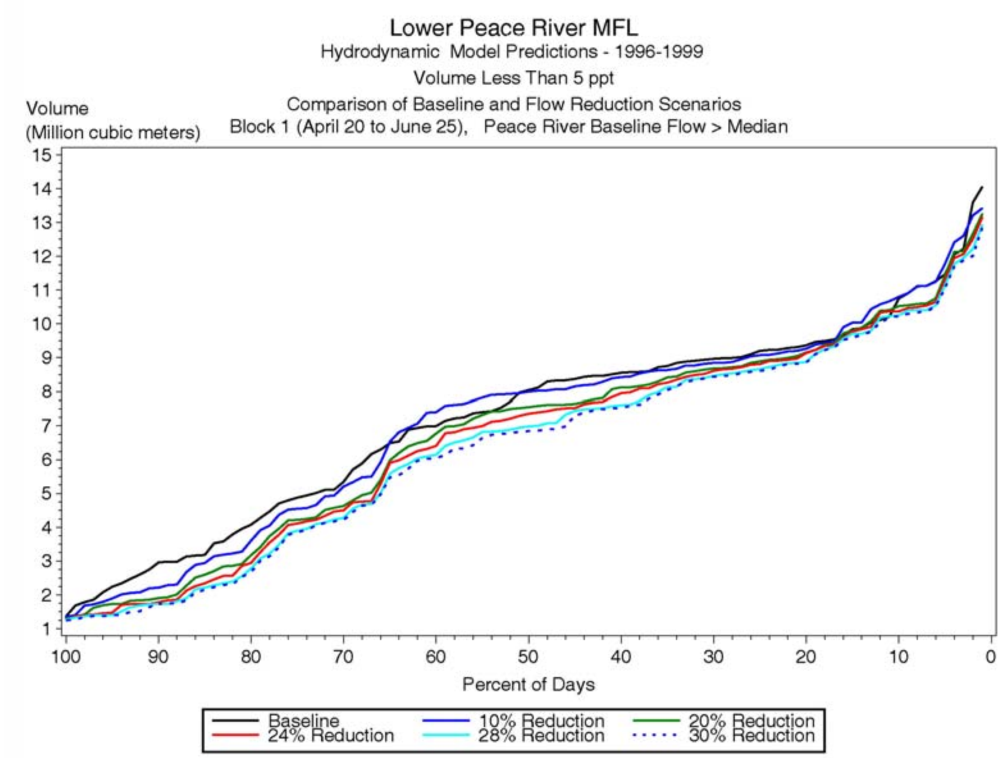
- For Block 3 under both low and high flow conditions, the daily volume of water less than 5 ppt ranged from approximately 2 to 40 million cubic meters.

CDF plots of daily bottom area less than 2 ppt in the Lower Peace River minimum flow study area are presented in Figures 7-18 through 7-20. From these plots, the following observations can be made:

- In Block 1 under the low flow condition, the daily bottom area less than 2 ppt ranged from approximately 50 to 300 hectares. The daily bottom area less than 2 ppt was between 50 and 600 hectares in Block 1 under the high flow condition.

- The daily bottom area less than 2 ppt was between approximately 50 and 600 hectares in Block 2 under the low flow condition. In Block 2 under the high flow condition, the daily bottom area less than 2 ppt ranged from approximately 100 to 750 hectares.

- For Block 3 under the low flow condition, the daily bottom area less than 2 ppt ranged from approximately 80 to 1,100 hectares. In Block 3 under the high flow condition, the daily bottom area less than 2 ppt ranged from approximately 120 to 1100 hectares.



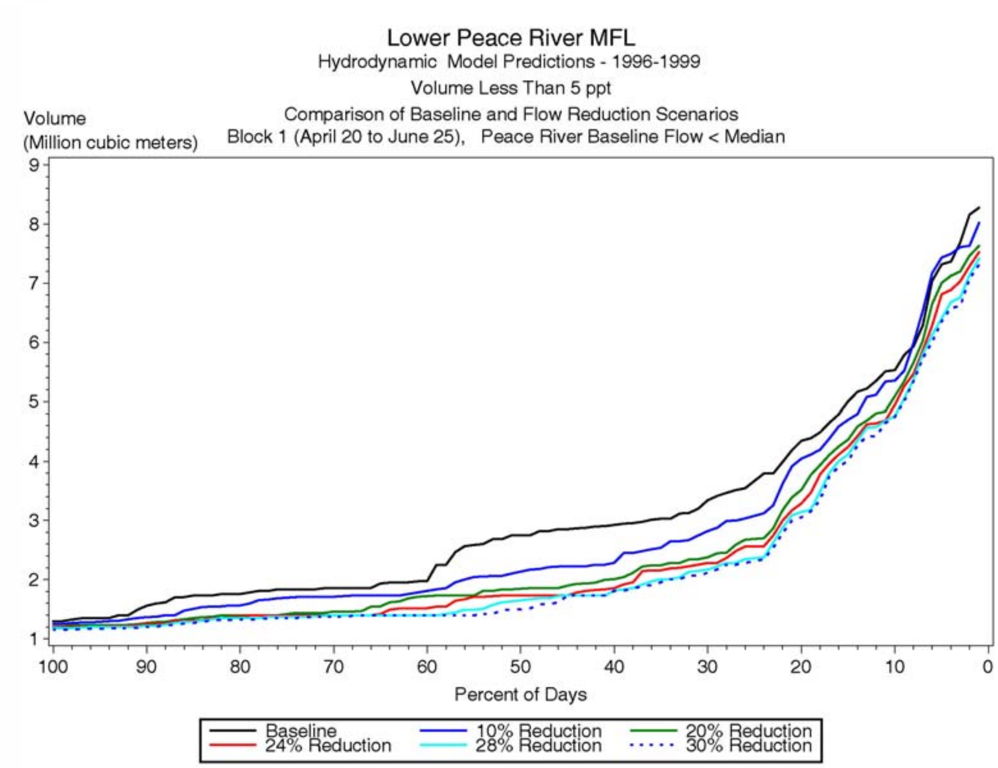


Figure 7-15. CDF plot of water volume in the Lower Peace River minimum flow study area less than 5 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).

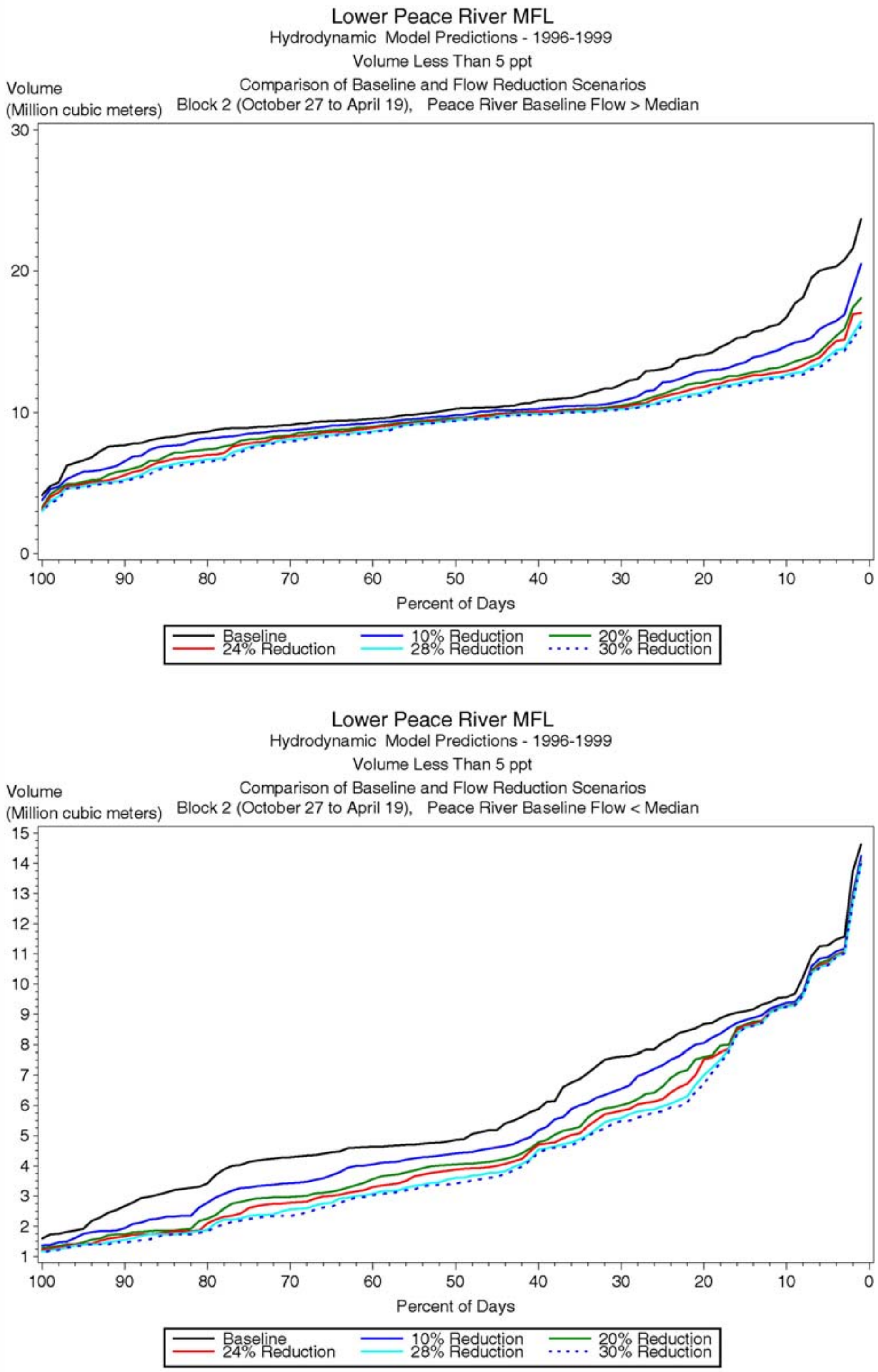
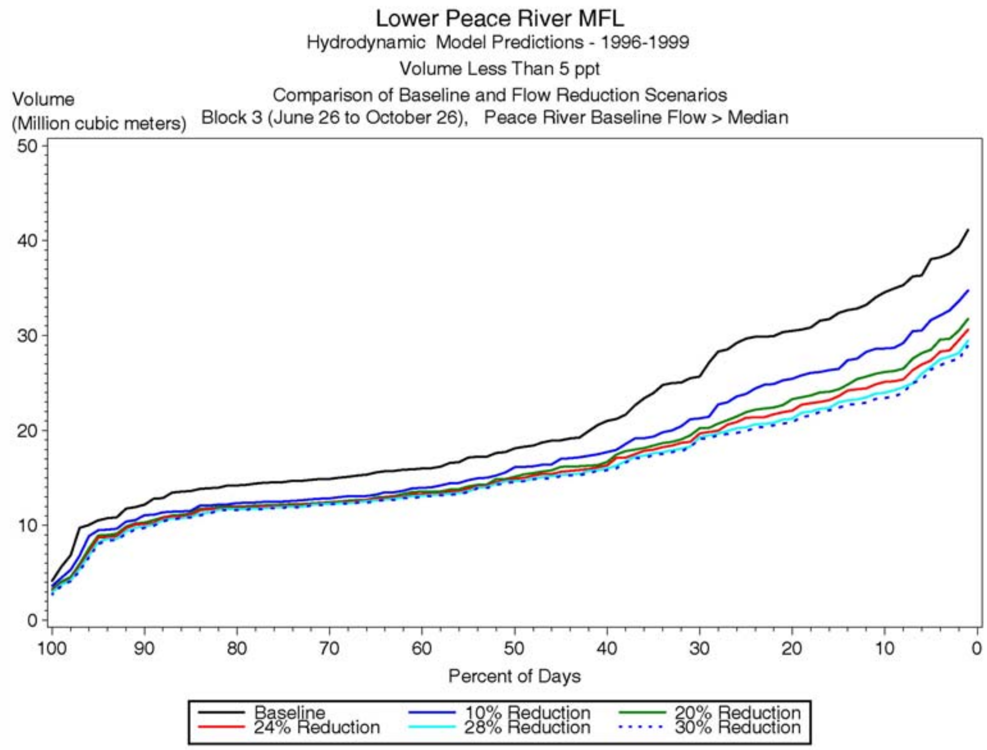


Figure 7-16. CDF plot of water volume in the Lower Peace River minimum flow study area less than 5 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).



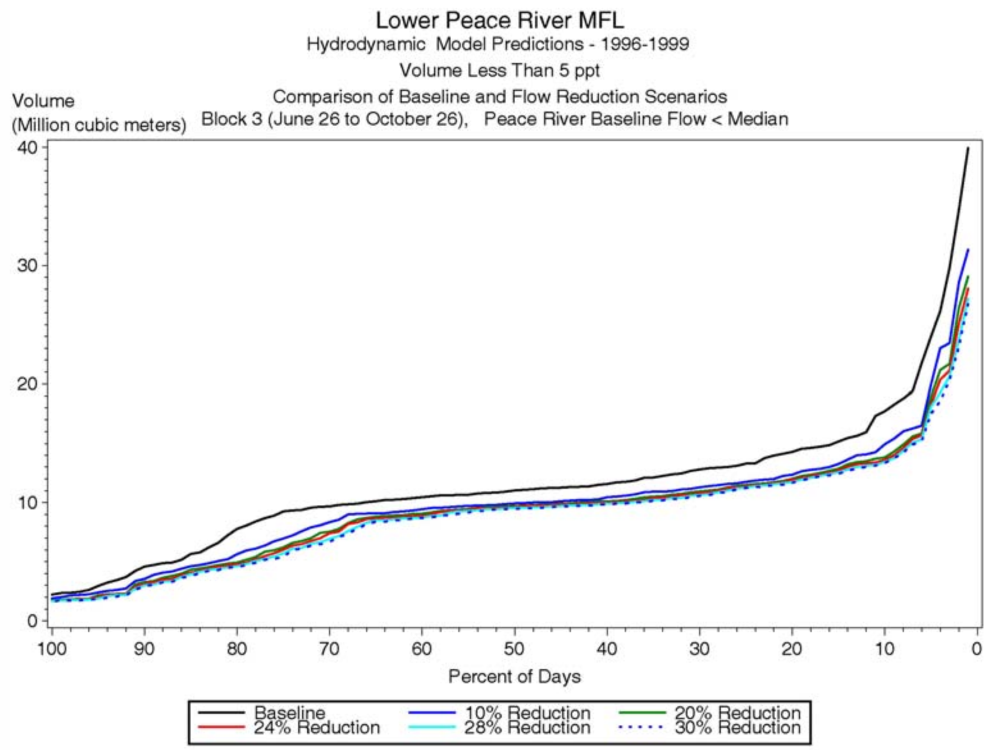
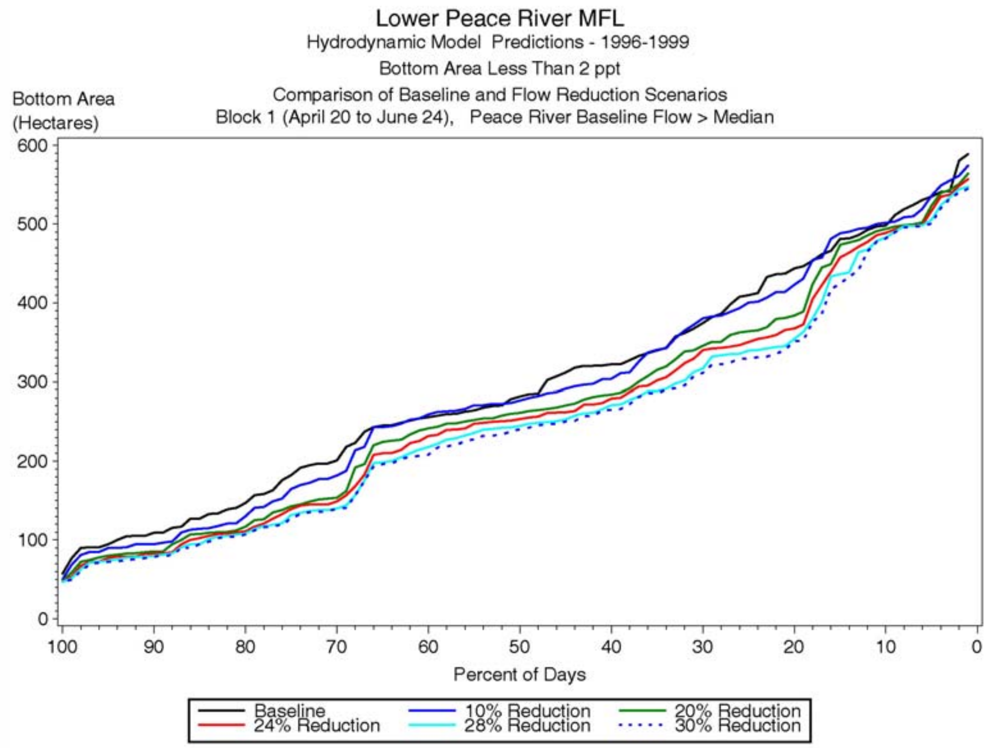


Figure 7-17. CDF plot of water volume in the Lower Peace River minimum flow study area less than 5 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).



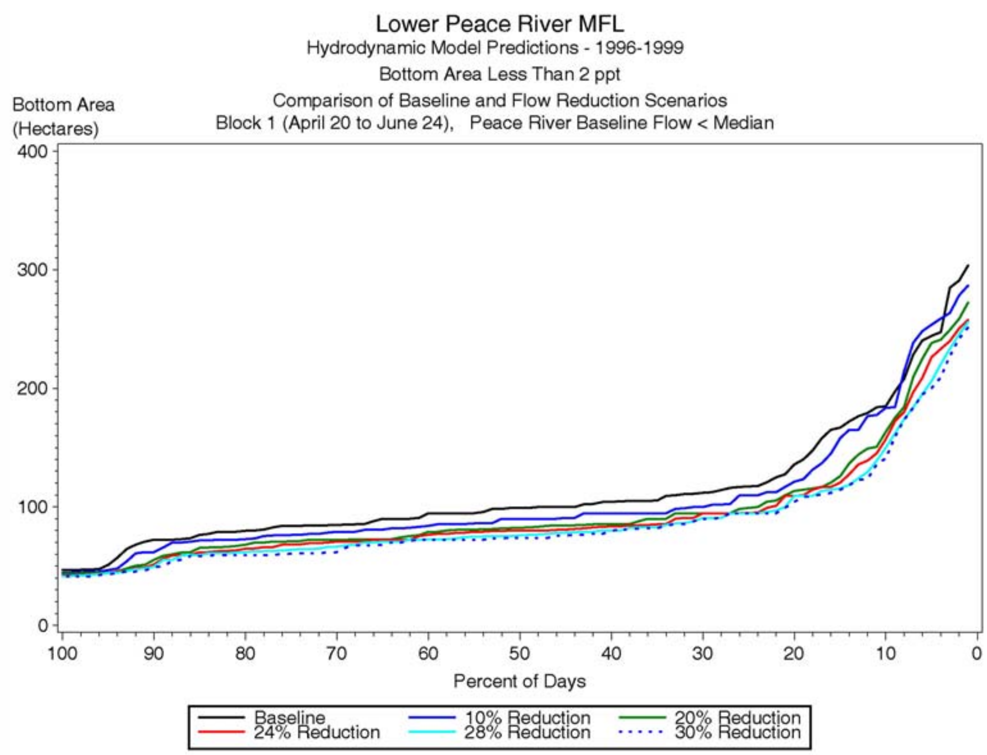
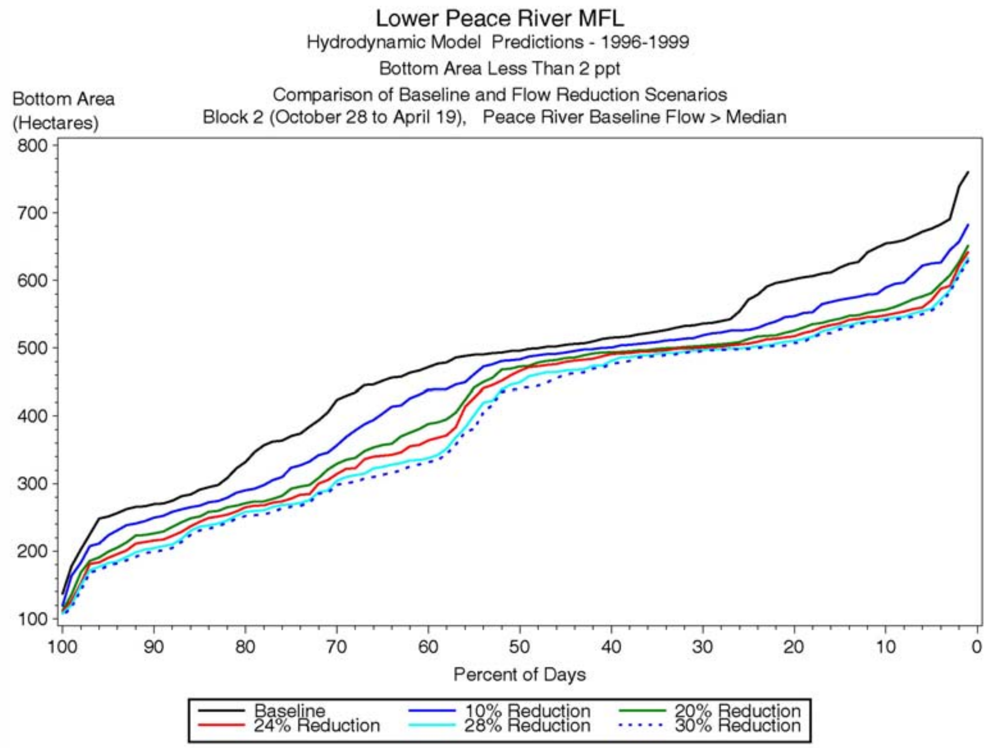


Figure 7-18. CDF plot of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



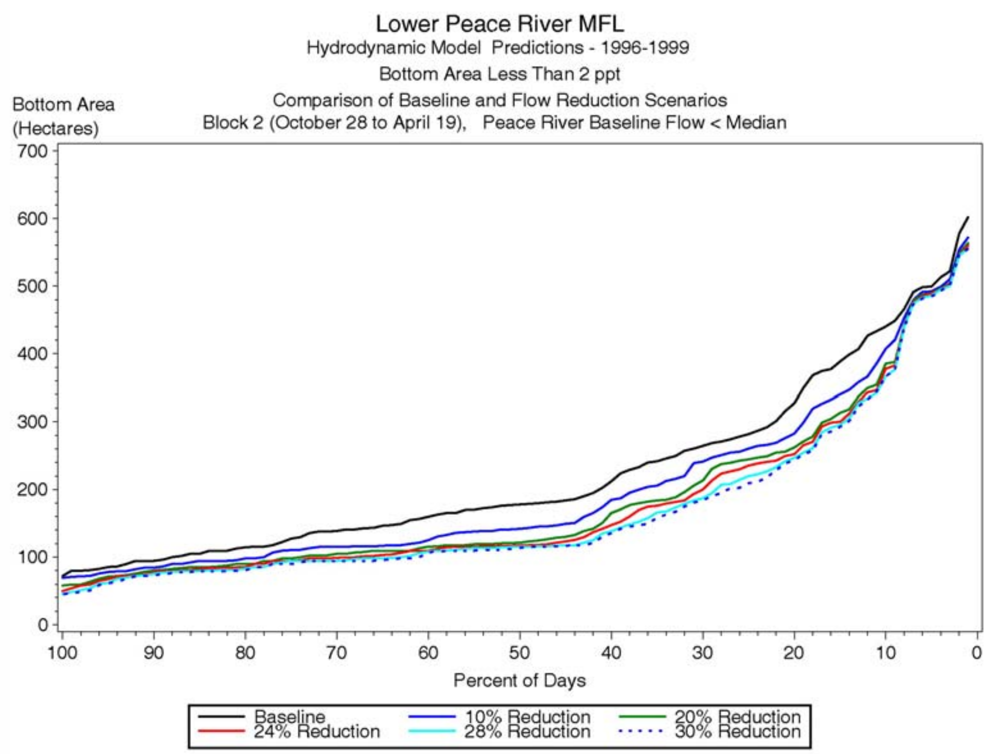
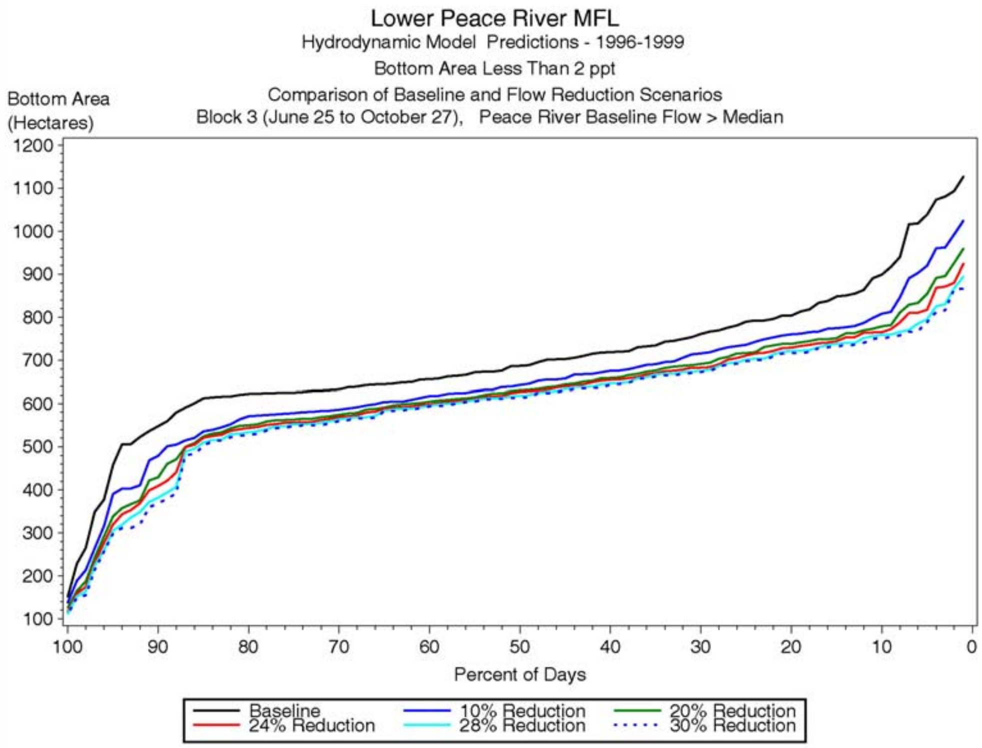


Figure 7-19. CDF plot of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).



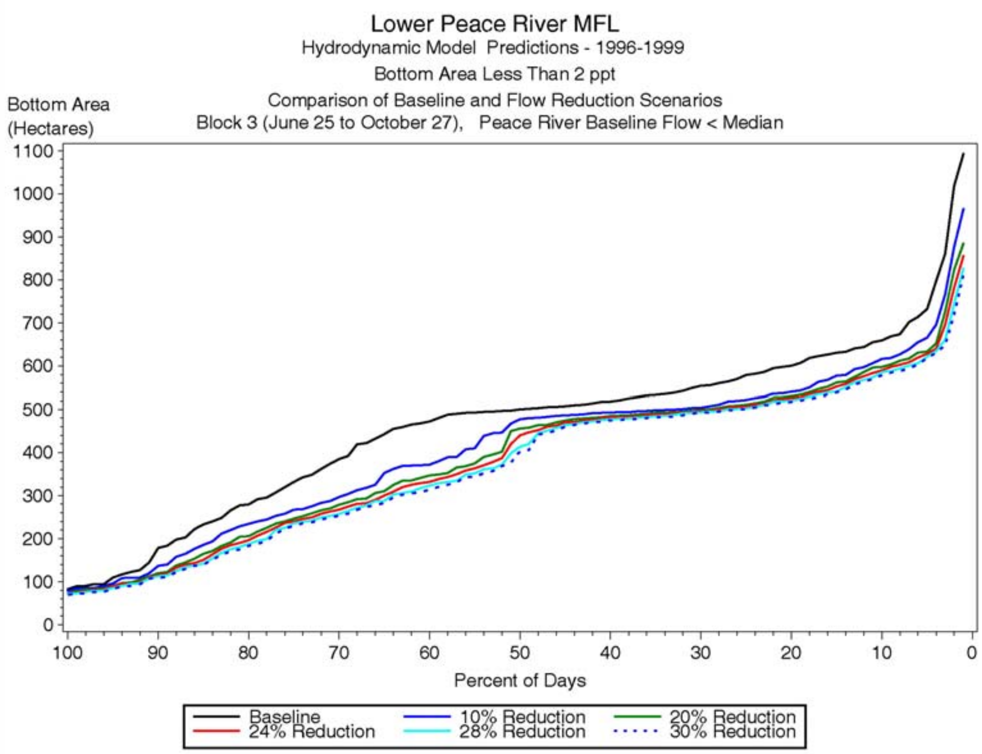


Figure 7-20. CDF plot of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).

CDF plots of daily bottom area less than 5 ppt in the Lower Peace River minimum flow study area are presented in Figures 7-21 through 7-23. From these plots, the following observations can be made:

- In Block 1 under the low flow condition, the daily bottom area less than 5 ppt ranged from approximately 75 to 450 hectares. The daily bottom area less than 5 ppt was between 80 and 650 hectares in Block 1 under the high flow condition.

- The daily bottom area less than 5 ppt was between approximately 80 and 650 hectares in Block 2 under the low flow condition. In Block 2 under the high flow condition, the daily bottom area less than 5 ppt ranged from approximately 200 to 950 hectares.

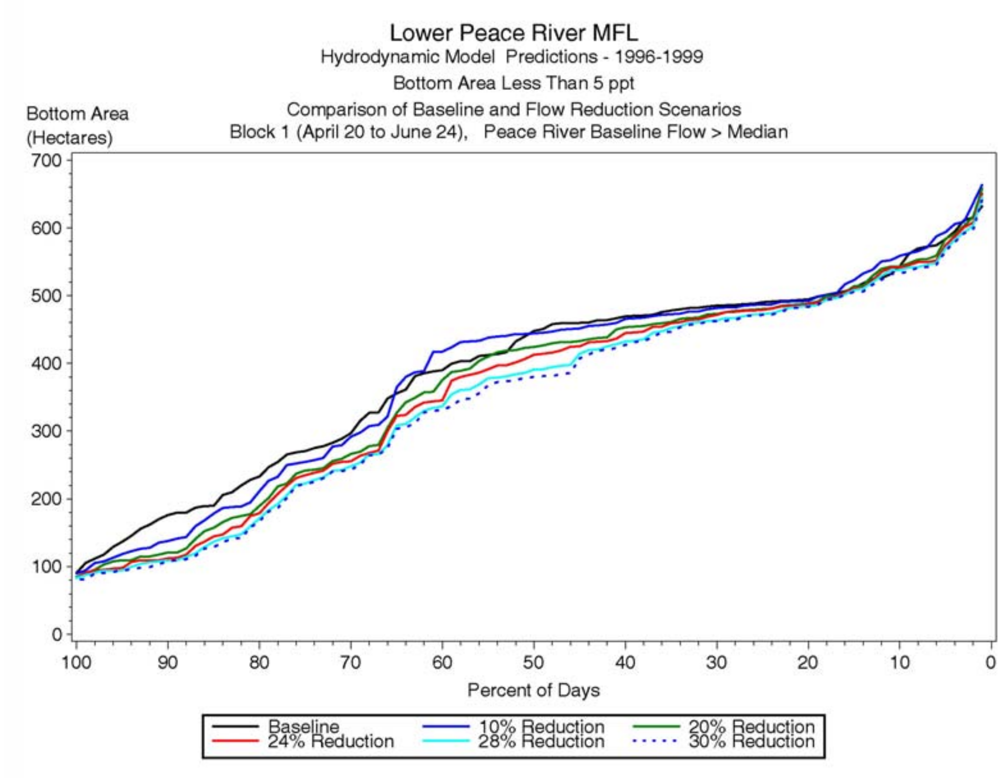
- For Block 3 under the low flow condition, the daily bottom area less than 5 ppt ranged from approximately 100 to 1,300 hectares. In Block 3 under the high flow condition, the daily bottom area less than 5 ppt ranged from approximately 200 to 1350 hectares.

From the CDF plots of daily shoreline length less than 2 ppt in the Lower Peace River minimum flow study area (Figures 7-24 through 7-26), the following conclusions can be drawn:

- In Block 1 under the low flow condition, the daily shoreline length less than 2 ppt ranged from approximately 10 to 55 km. For Block 1 under the high flow condition, the daily shoreline length less than 2 ppt ranged from approximately 10 to 85 km.

- The daily shoreline length less than 2 ppt was between approximately 12 and 85 km in Block 2 under the low flow condition. In Block 2 under the high flow condition, the daily shoreline length less than 2 ppt ranged from approximately 22 to 115 km.

- For Block 3 under the low flow condition, the daily shoreline length less than 2 ppt ranged from approximately 15 to 115 km. In Block 3 under the high flow condition, the daily shoreline length less than 2 ppt ranged from approximately 25 to 120 km.



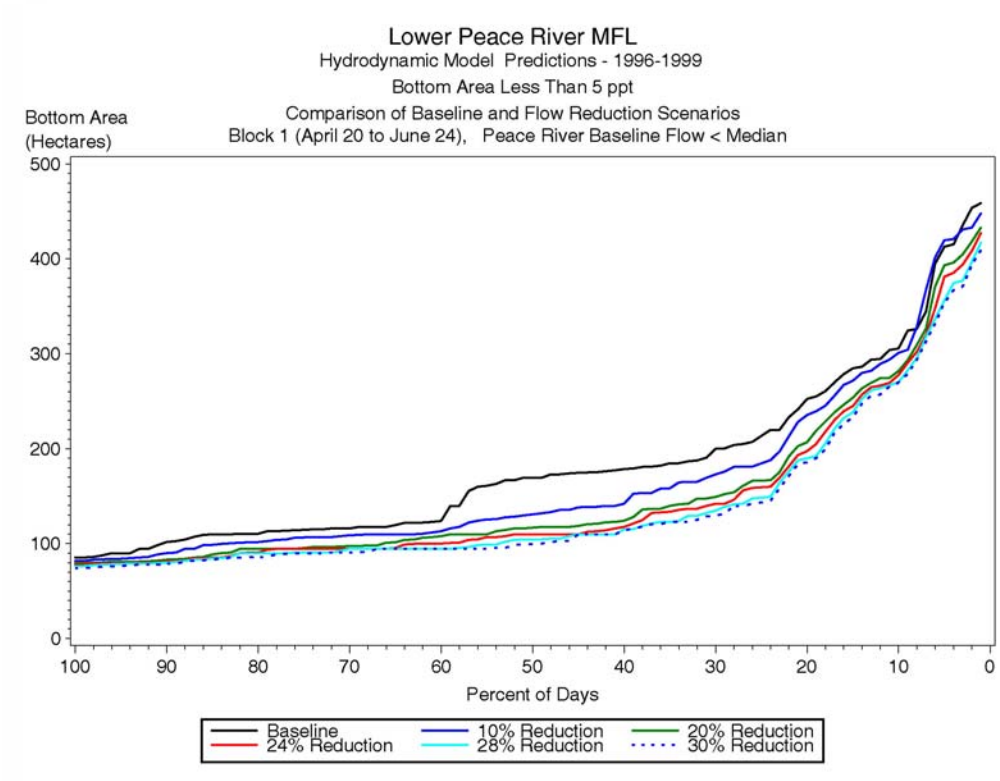
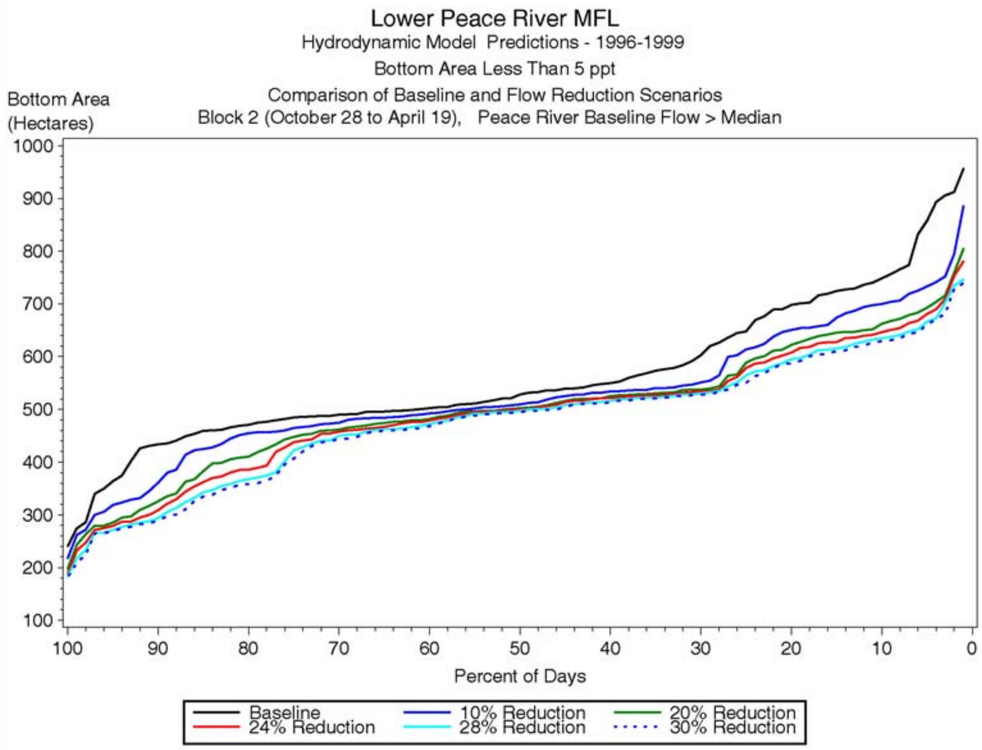


Figure 7-21. **CDF plot of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).**



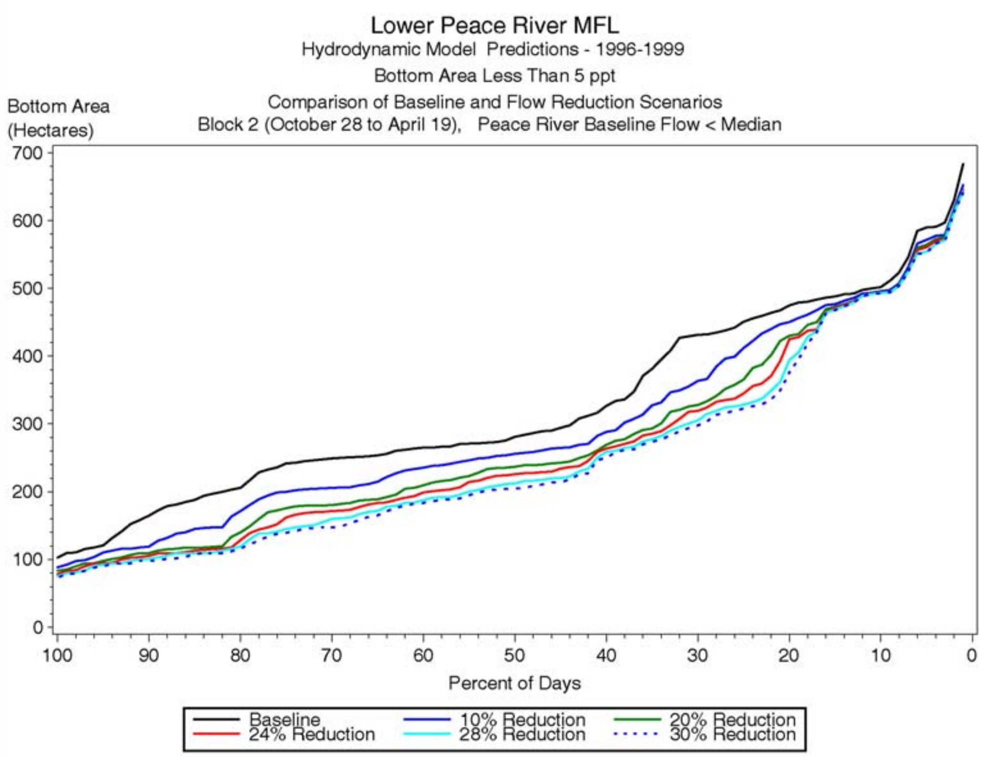


Figure 7-22. CDF plot of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).

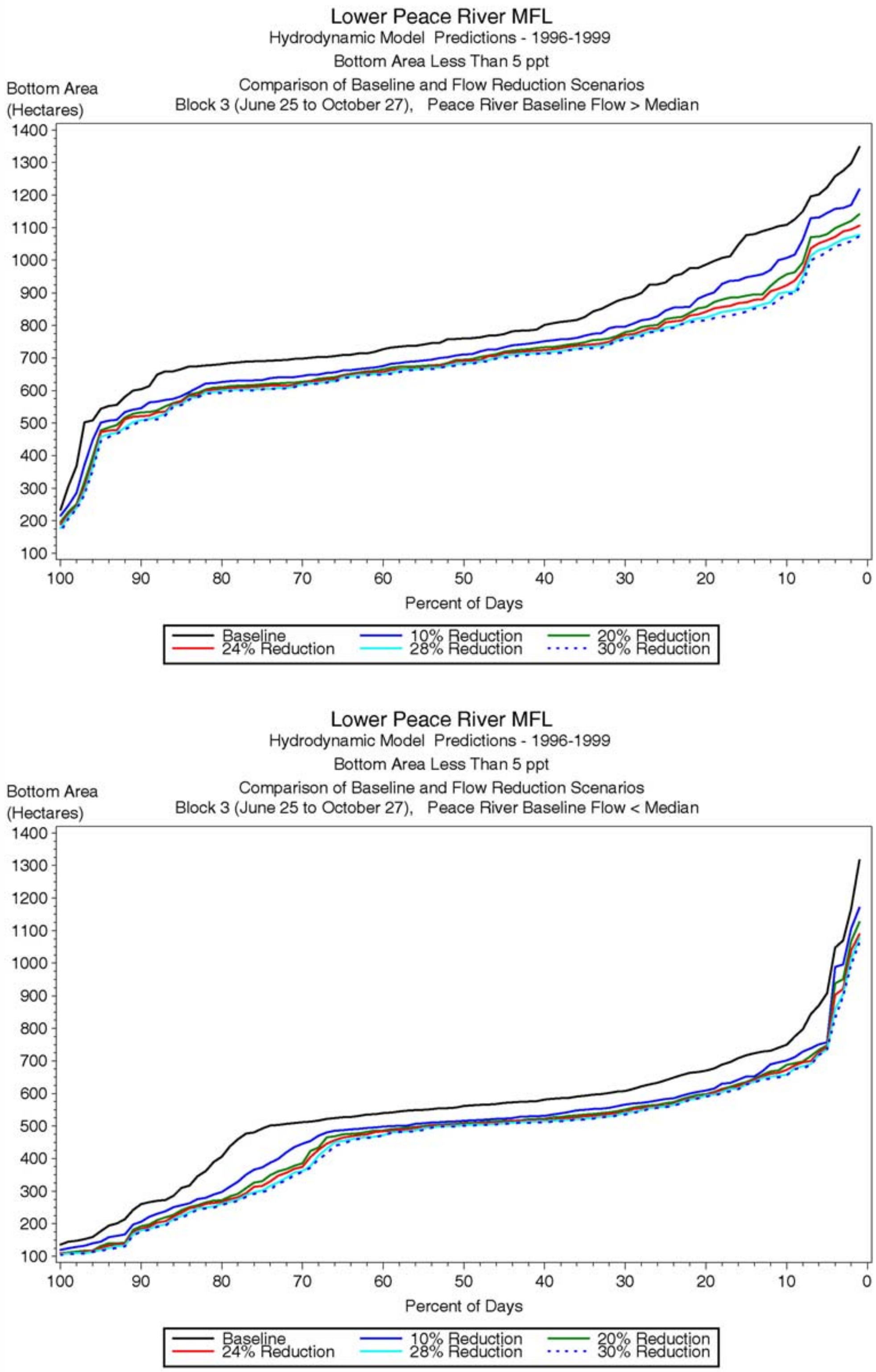


Figure 7-23. CDF plot of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).

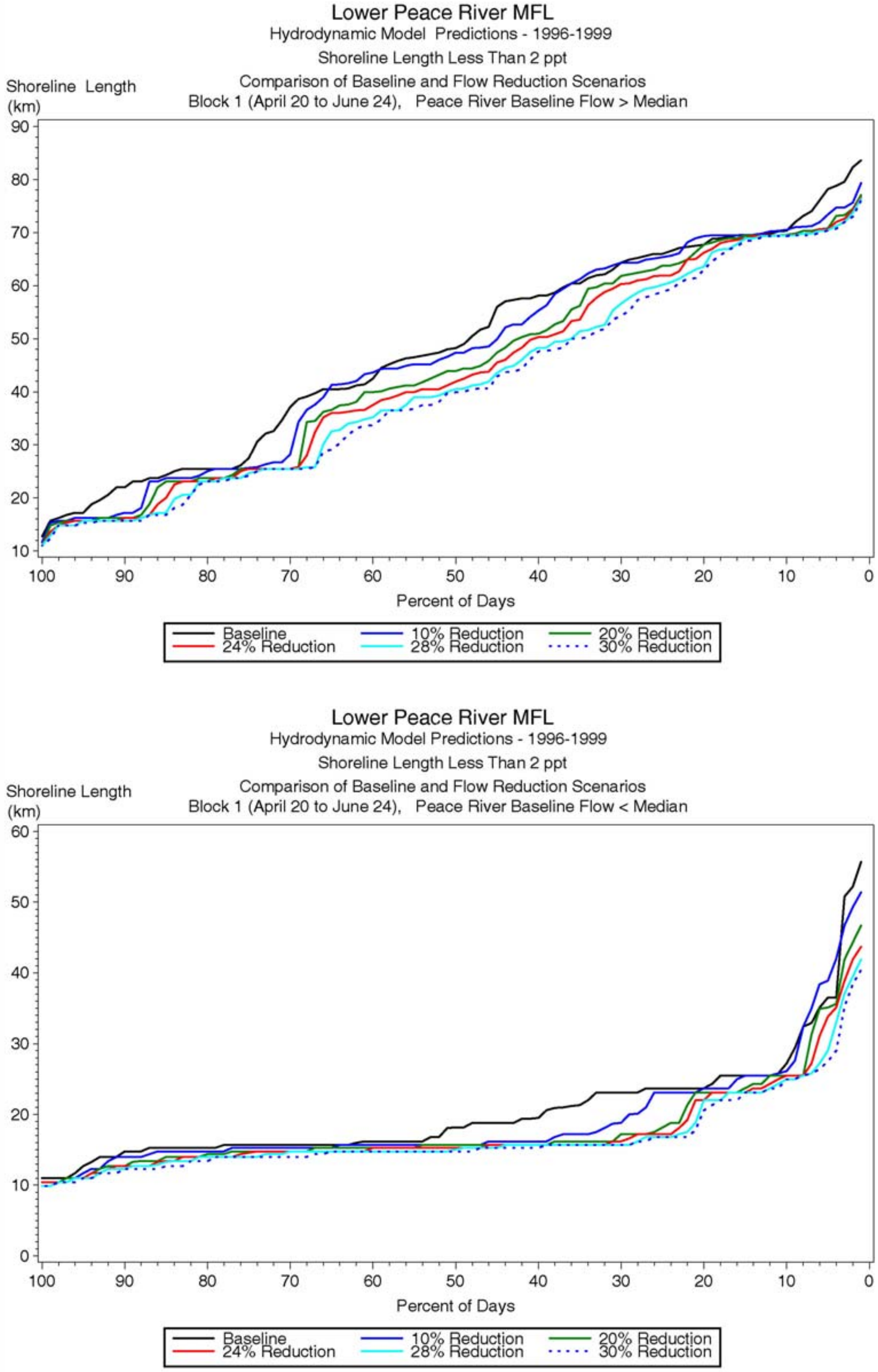
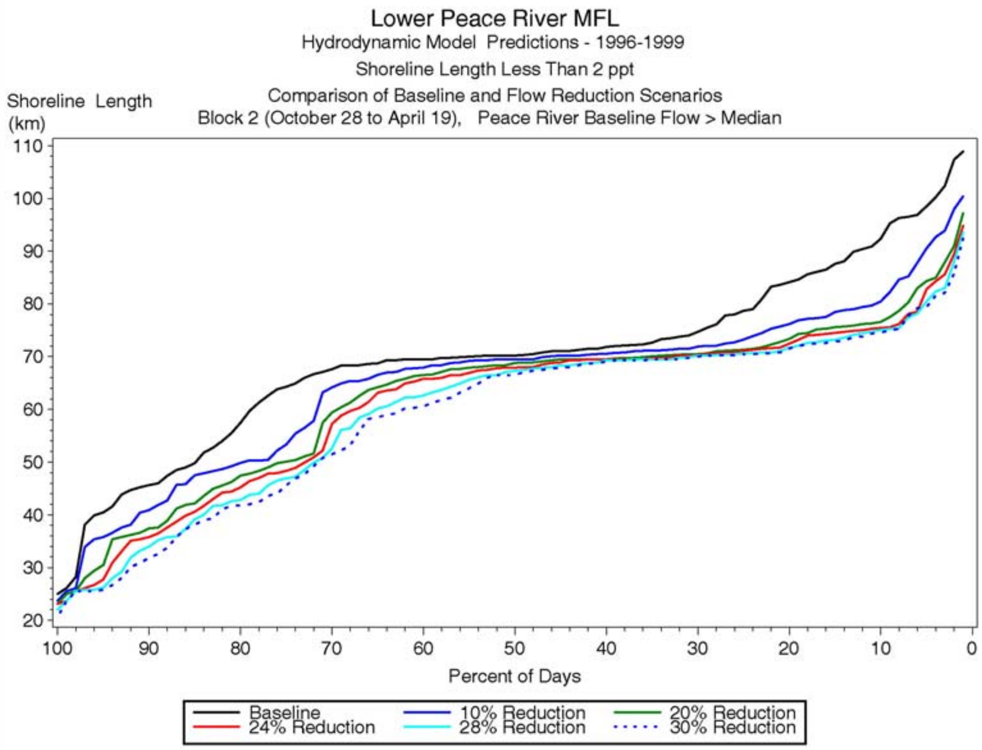


Figure 7-24. CDF plot of shoreline length in the Lower Peace River minimum flow study area less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



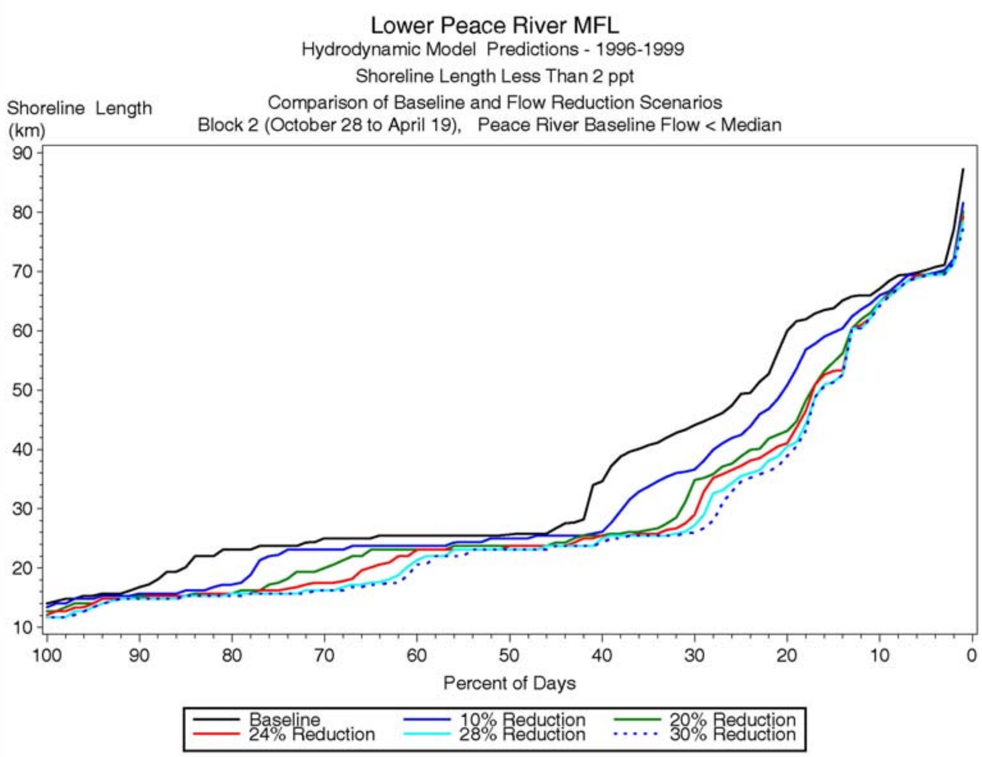
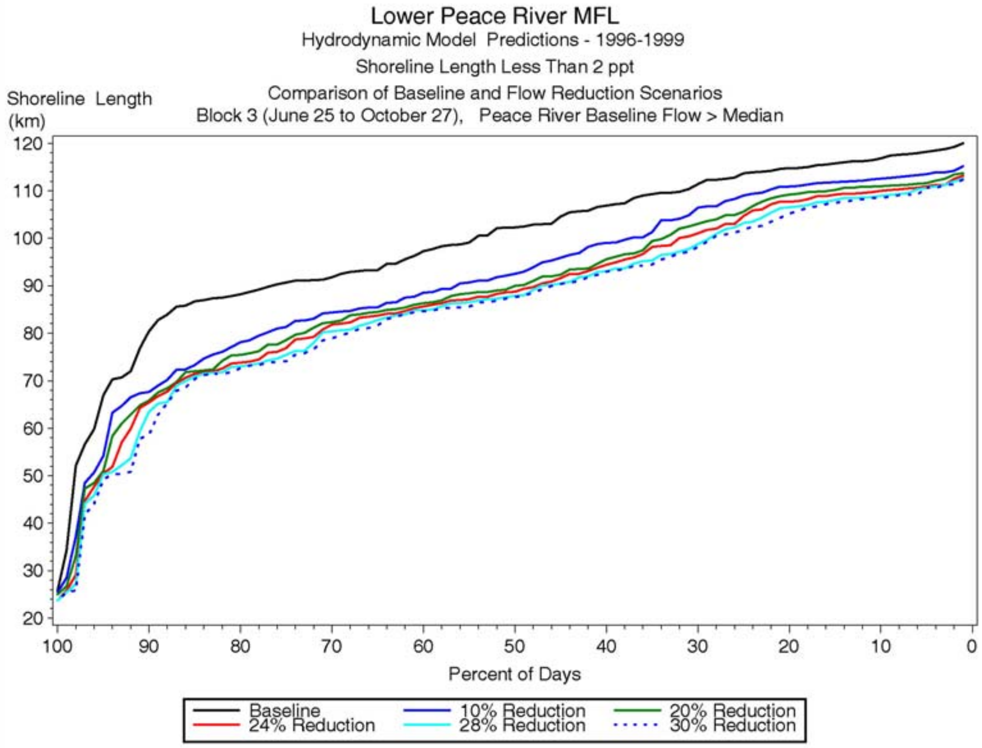


Figure 7-25. **CDF plot of shoreline length in the Lower Peace River minimum flow study area less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).**



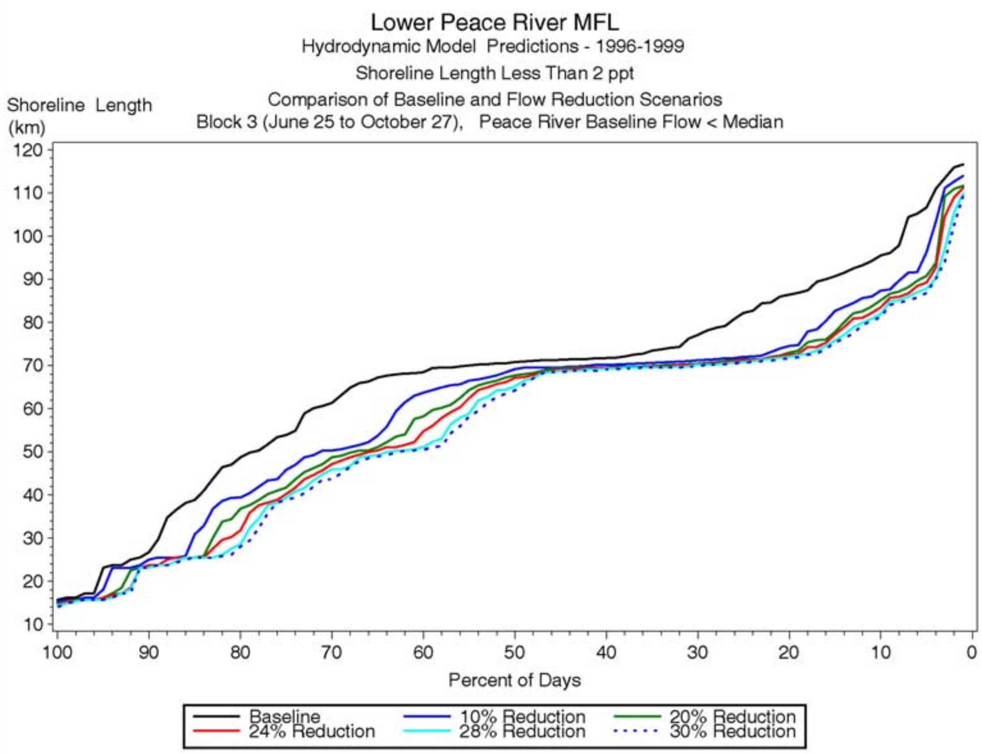


Figure 7-26. **CDF plot of shoreline length in the Lower Peace River minimum flow study area less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).**

From the CDF plots of daily shoreline length less than 5 ppt in the Lower Peace River minimum flow study area (Figures 7-27 through 7-29), the following conclusions can be drawn:

- In Block 1 under the low flow condition, the daily shoreline length less than 5 ppt ranged from approximately 15 to 65 km. For Block 1 under the high flow condition, the daily shoreline length less than 5 ppt ranged from approximately 15 to 95 km.

- The daily shoreline length less than 5 ppt was between approximately 15 and 105 km in Block 2 under the low flow condition. In Block 2 under the high flow condition, the daily shoreline length less than 5 ppt ranged from approximately 25 to 115 km.

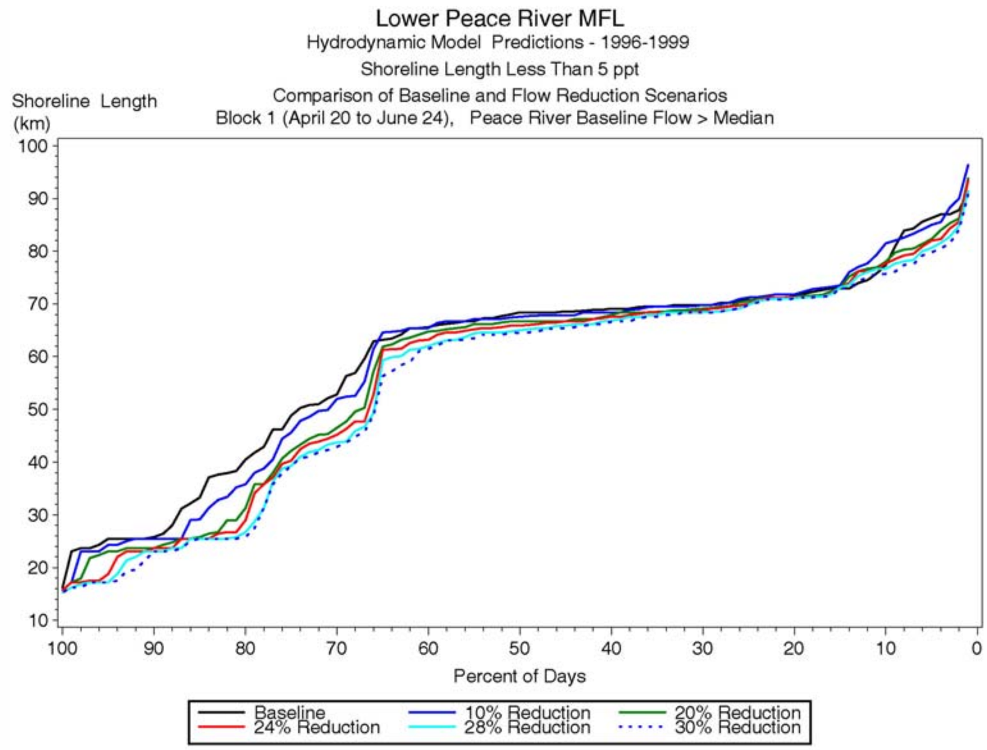
- For Block 3 under the low flow condition, the daily shoreline length less than 5 ppt ranged from approximately 22 to 125 km. In Block 3 under the high flow condition, the daily shoreline length less than 5 ppt ranged from approximately 25 to 130 km.

CDF plots of the daily volume of water in Zone 3 by block and flow condition for the salinity representative of Zone 3 are presented in Figures 7-30 through 7-32. Examination of these plots reveals the following:

- In Zone 3, during Block 1 under the low flow condition, the daily volume of water between 8 and 16 ppt ranged from approximately 0 to 2.7 million cubic meters. The daily volume of water between 8 and 16 ppt ranged from 0 and 17 million cubic meters in Zone 3 during Block 1 under the high flow condition.

- The daily volume of water between 8 and 16 ppt ranged from 0 and 15 million cubic meters in Zone 3 during Block 2 under the low flow condition. For Zone 3, during Block 2 under the high flow condition, the daily volume of water between 8 and 16 ppt ranged from approximately 0 to 20 million cubic meters.

- In Zone 3, during Block 3 under the low flow condition, the daily volume of water between 8 and 16 ppt ranged from approximately 0 to 22 million cubic meters. The daily volume of water between 8 and 16 ppt ranged from 0 and 14.5 million cubic meters in Zone 3 during Block 3 under the high flow condition.



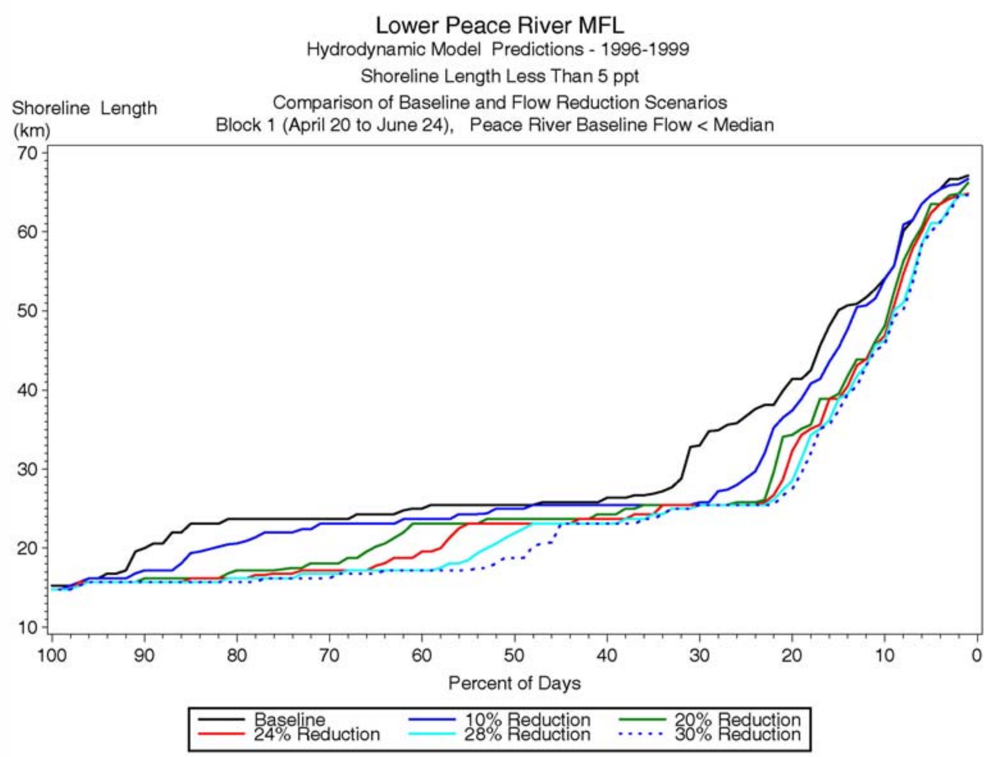
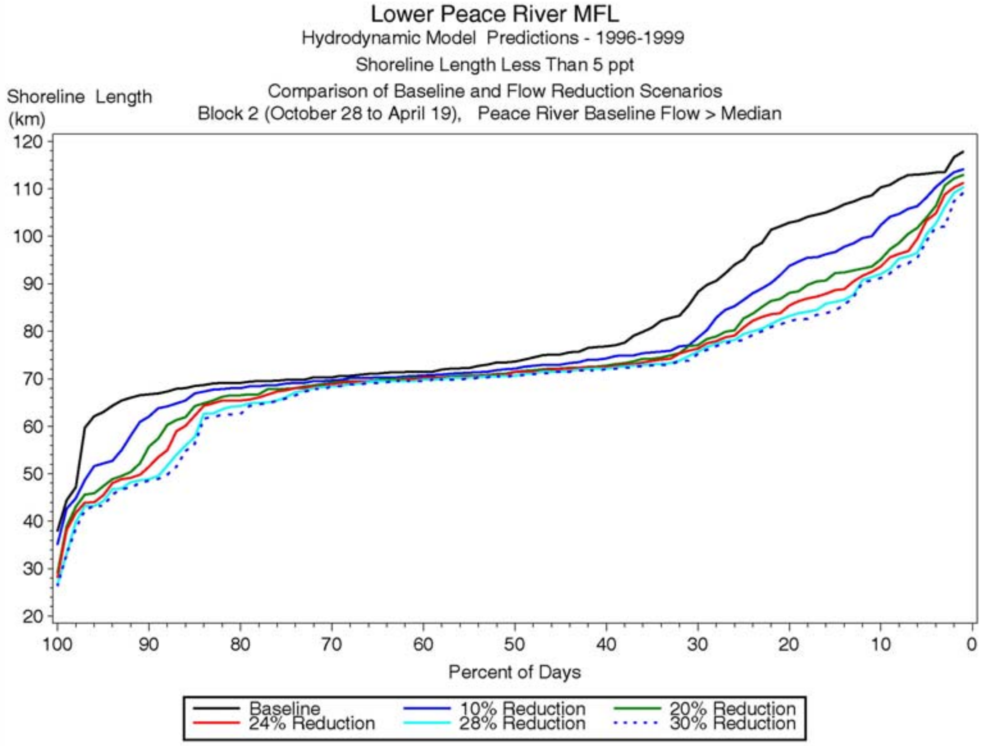


Figure 7-27. CDF plot of shoreline length in the Lower Peace River minimum flow study area less than 5 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



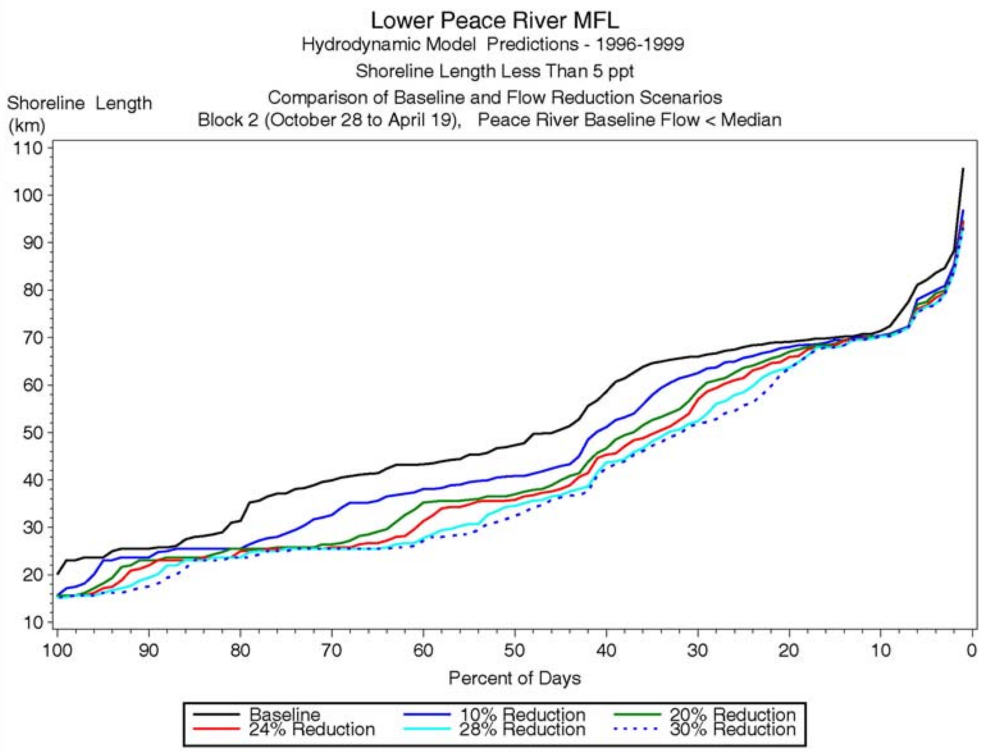
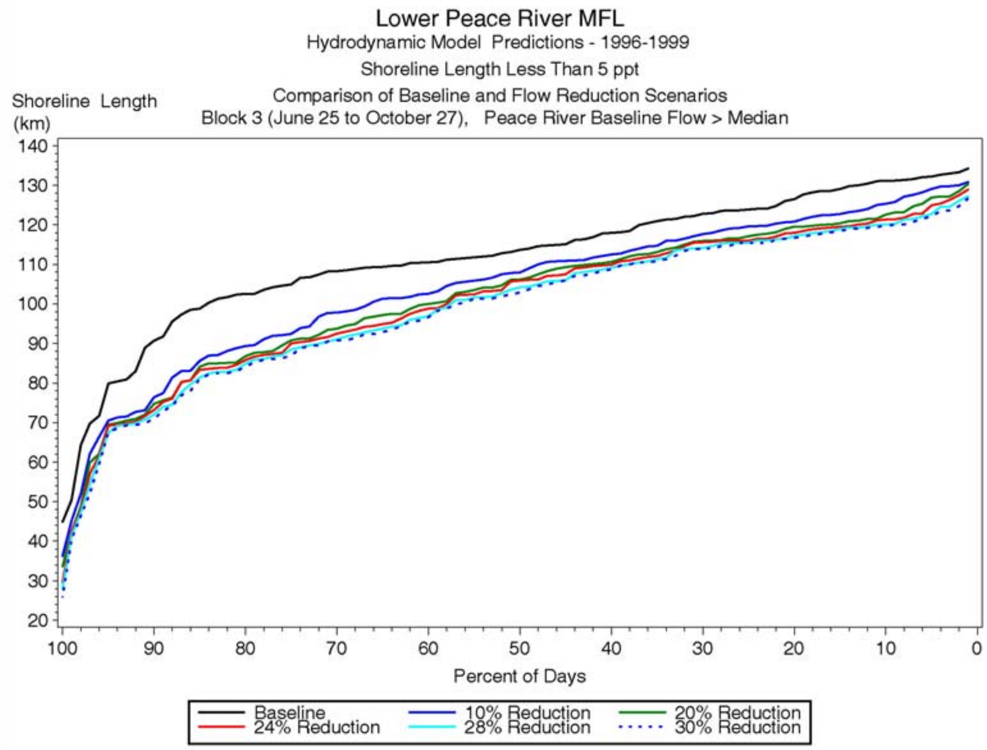


Figure 7-28. CDF plot of shoreline length in the Lower Peace River minimum flow study area less than 5 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).



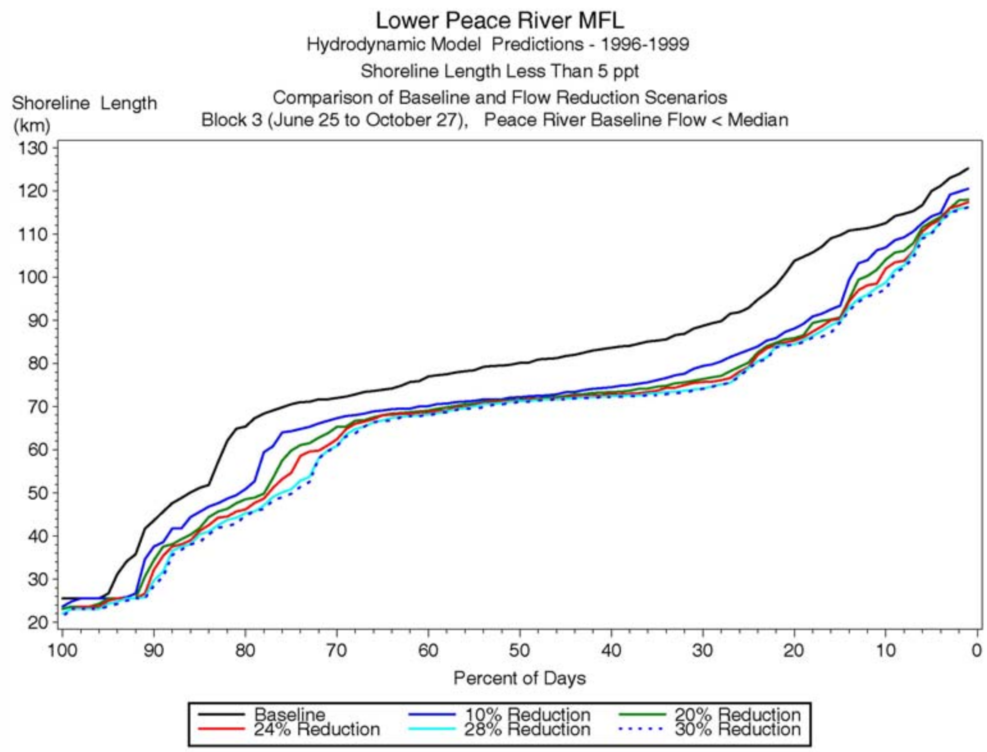
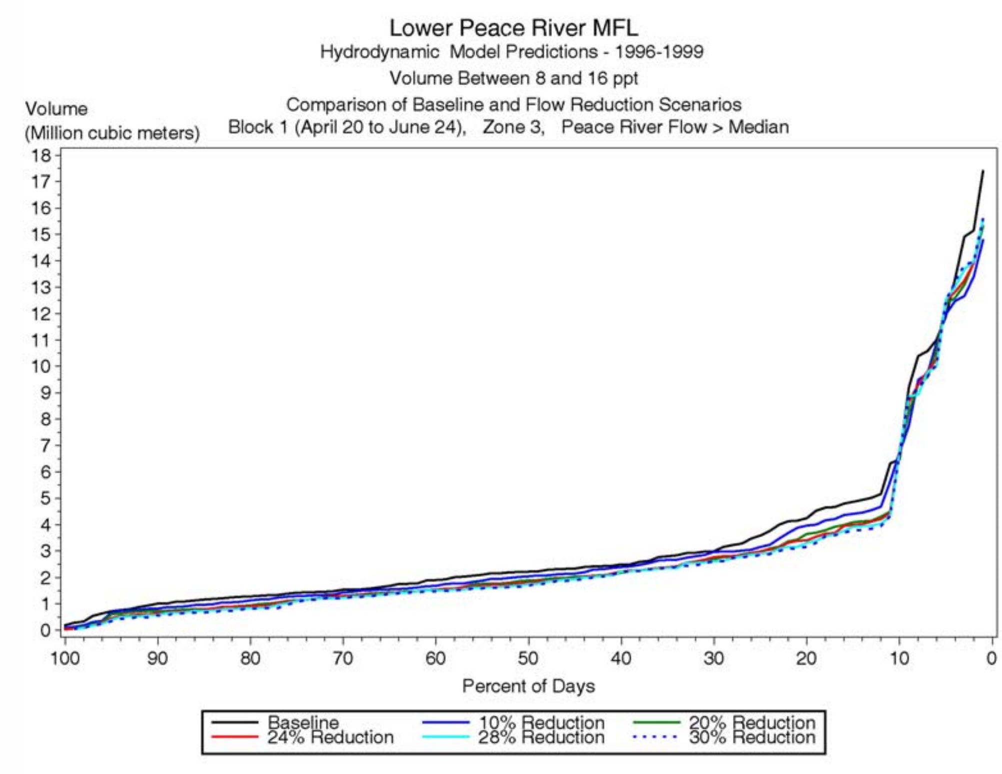


Figure 7-29 CDF plot of shoreline length in the Lower Peace River minimum flow study area less than 5 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).



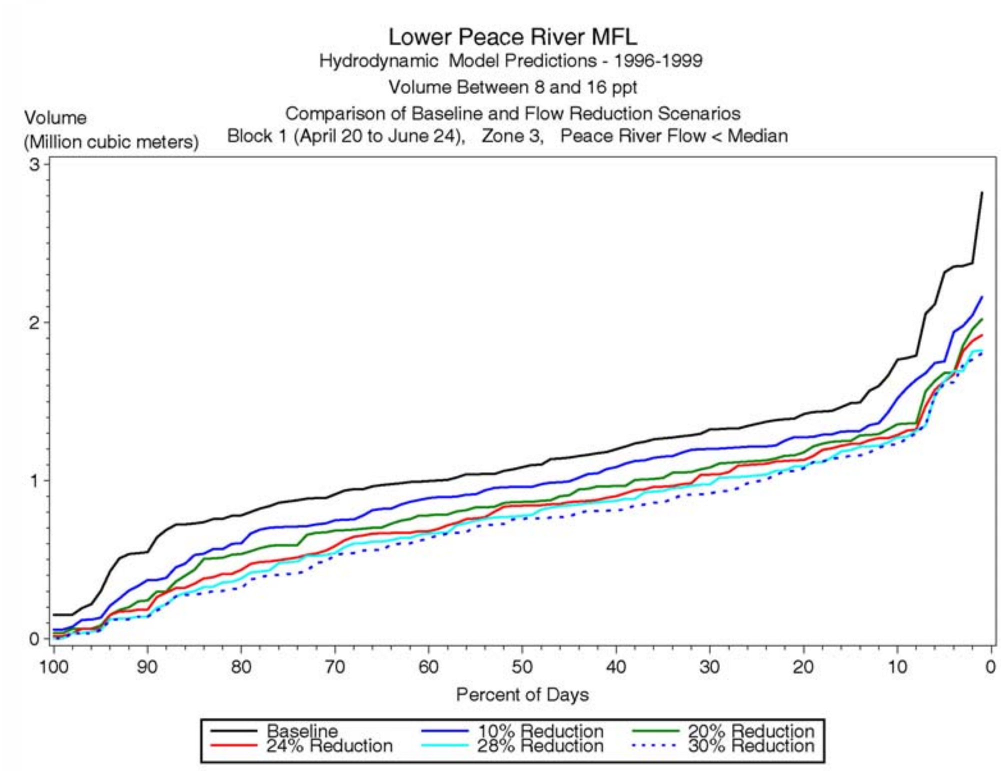


Figure 7-30. CDF plot of water volume in the Lower Peace River minimum flow study area between 8 and 16 ppt in Zone 3 for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).

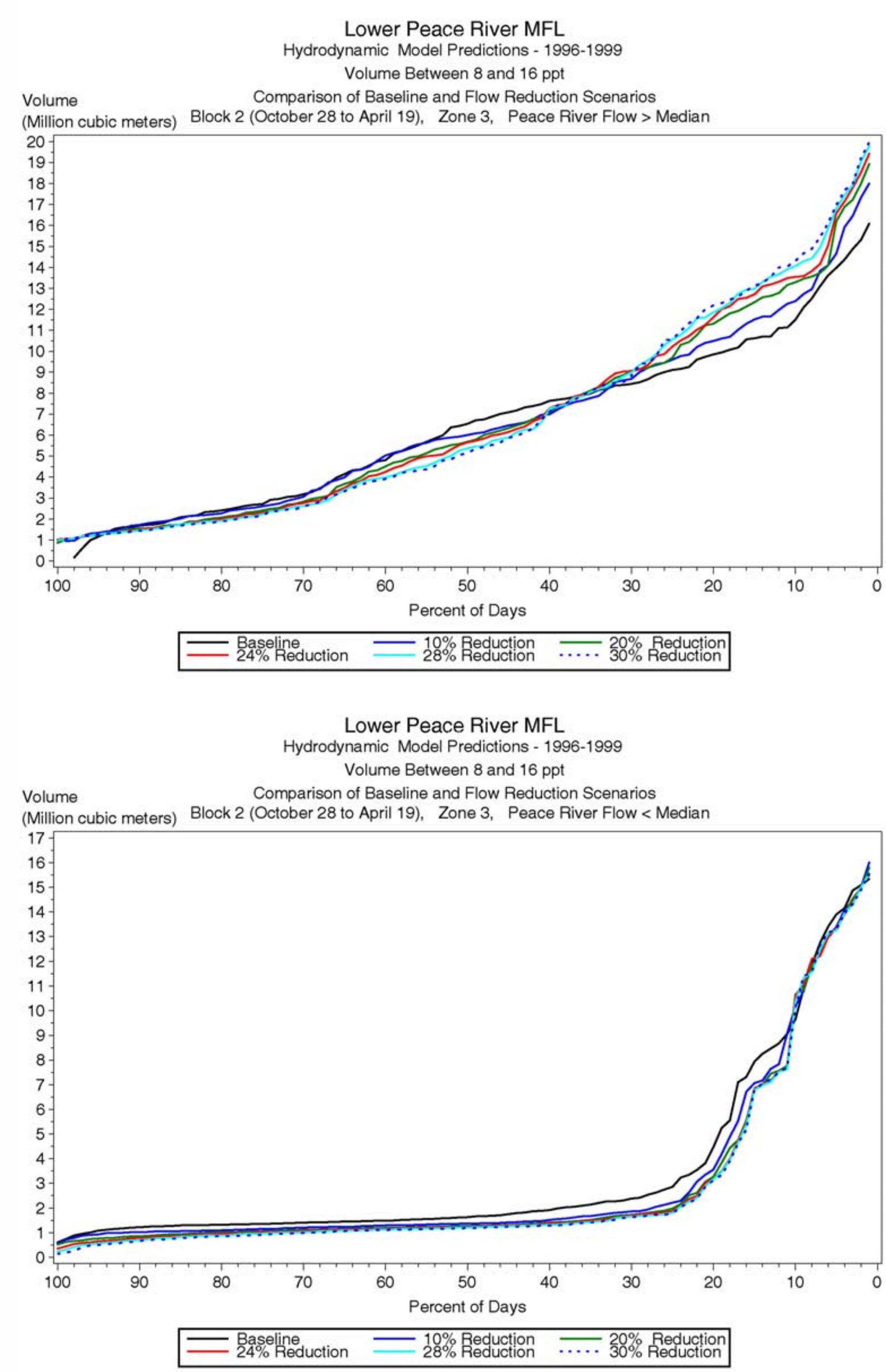


Figure 7-31. CDF plot of water volume in the Lower Peace River minimum flow study area between 8 and 16 ppt in Zone 3 for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).

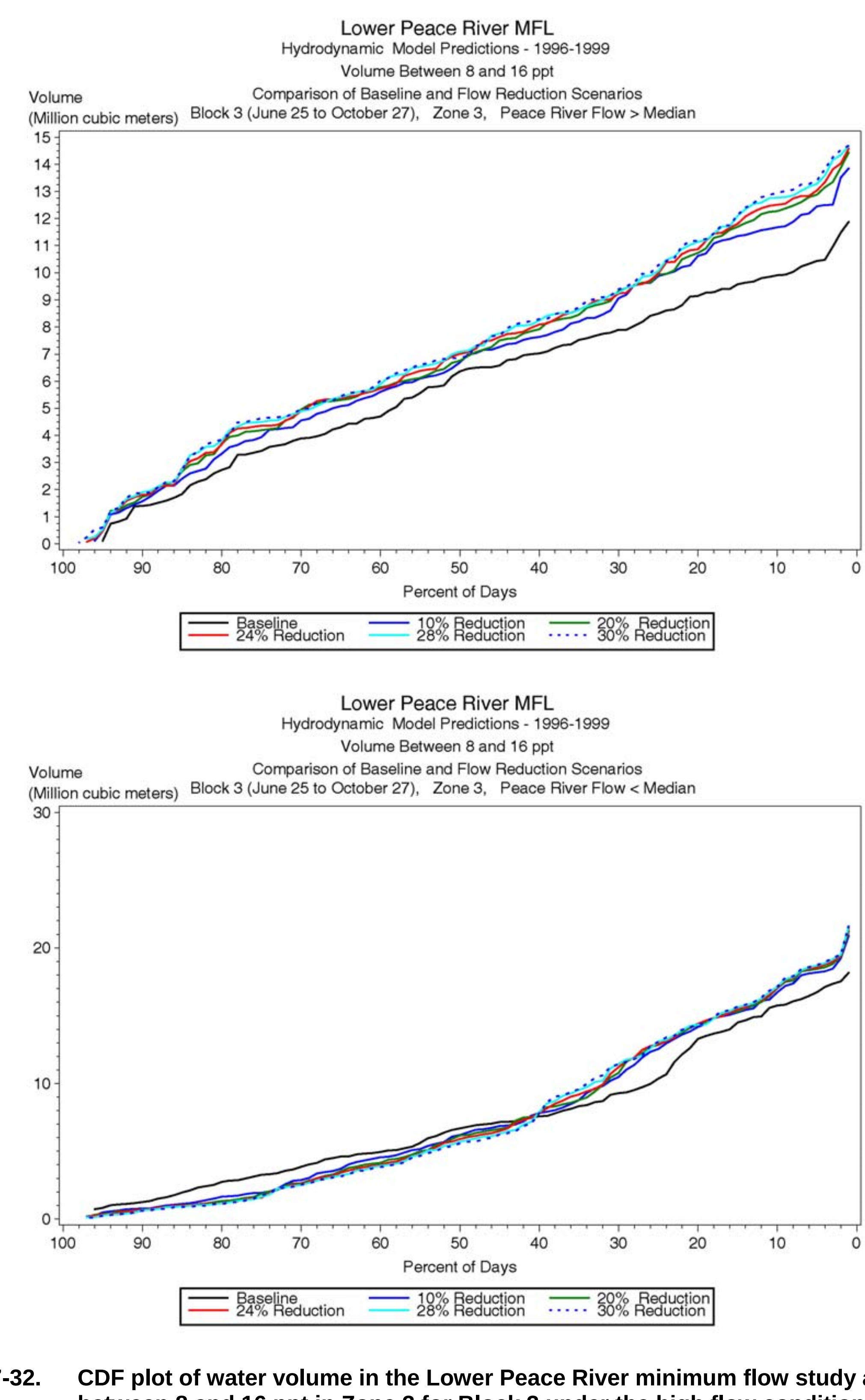


Figure 7-32. **CDF plot of water volume in the Lower Peace River minimum flow study area between 8 and 16 ppt in Zone 3 for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).**

8 DISTRICT RECOMMENDATION FOR SHELL CREEK AND LOWER PEACE RIVER MINIMUM FLOWS

The objectives of this section are:

1. to define the minimum flow criterion to be used in estimating the minimum flows for LPR and SC,
2. to define the method to be used to establish the minimum flows for LPR and SC,
3. to apply the method to results of the analytical tools that relate flow to salinity in LPR and SC,
4. to recommend minimum flows for LPR and SC, and
5. to describe the influence of the proposed minimum flows on other water quality constituents and ecological components in LPR and SC.

8.1 Minimum Flow Criterion

Section 373.042, F. S. defines the minimum flow for a surface watercourse as “the limit at which further withdrawals would be significantly harmful to water resources or ecology of the area”. “Significant” harm has been operationally defined as a 15% loss of available habitat. Based on Gore *et al.* (2002) comments regarding significant impacts of habitat loss, we recommend use of a 15% change in habitat availability as a measure of significant harm for the purpose of MFLs development (SWFWMD 2005a). This definition of significant harm has been used in minimum flow studies for the Middle Peace River (SWFWMD, 2005a), Upper Alafia River (SWFWMD, 2005b), Upper Myakka River (SWFWMD, 2005c), Braden River (SWFWMD 2007a), and Upper Hillsborough River (SWFWMD, 2007b).

The minimum flow criterion for Shell LPR and SC is the flow that results in no more than a 15% reduction in available habitat relative to the Baseline flow condition. To this end, results from Section 7 were summarized in order to define seasonal and flow-specific minimum flows for both systems. These recommended minimum flows have been defined as an allowable percent reduction in flow for each system. Therefore, the proposed minimum flow is the seasonal and flow specific percent flow reduction that maintains at least 85% of the habitat that is available under the Baseline condition.

8.2 Method to Define Minimum Flow

As discussed in Section 3.1, the District applied the percent-of-flow method to determine minimum flows for the LPR and SC. The percent-of-flow method allows water users to take a percentage of streamflow at the time of the withdrawal. The percent-of-flow method has been used for the regulation of water use permits since 1989, when it was first applied to withdrawals from the Lower Peace River.

Habitat availability can be quantified in terms of both space and time. The tool used to evaluate temporal persistence and spatial extent of habitat meeting a biologically-relevant salinity is a cumulative distribution function (CDF) plot. CDF plots are an ideal tool as they incorporate the spatial extent and the temporal persistence that a given salinity is met. Plots are drawn of the various scenarios that have been run and comparisons can be made among scenarios.

The method used to compare alternative scenarios to the baseline condition is presented in Figure 8-1. The habitat available for a given scenario is estimated by calculating the area under the curve from the CDF plots in Section 7. In Figure 8-1a, the blue-hatched area (area under the curve) is the estimate of the habitat available under the baseline condition (HA_B) for the baseline period. Figure 8-1b presents the habitat available under an alternative scenario, Scenario 1 (HA_{S1}), for the same period. To compare the two scenarios, the area between the two curves can be calculated (Figure 8-1c). This difference is the habitat loss from the Baseline Scenario under Scenario 1.

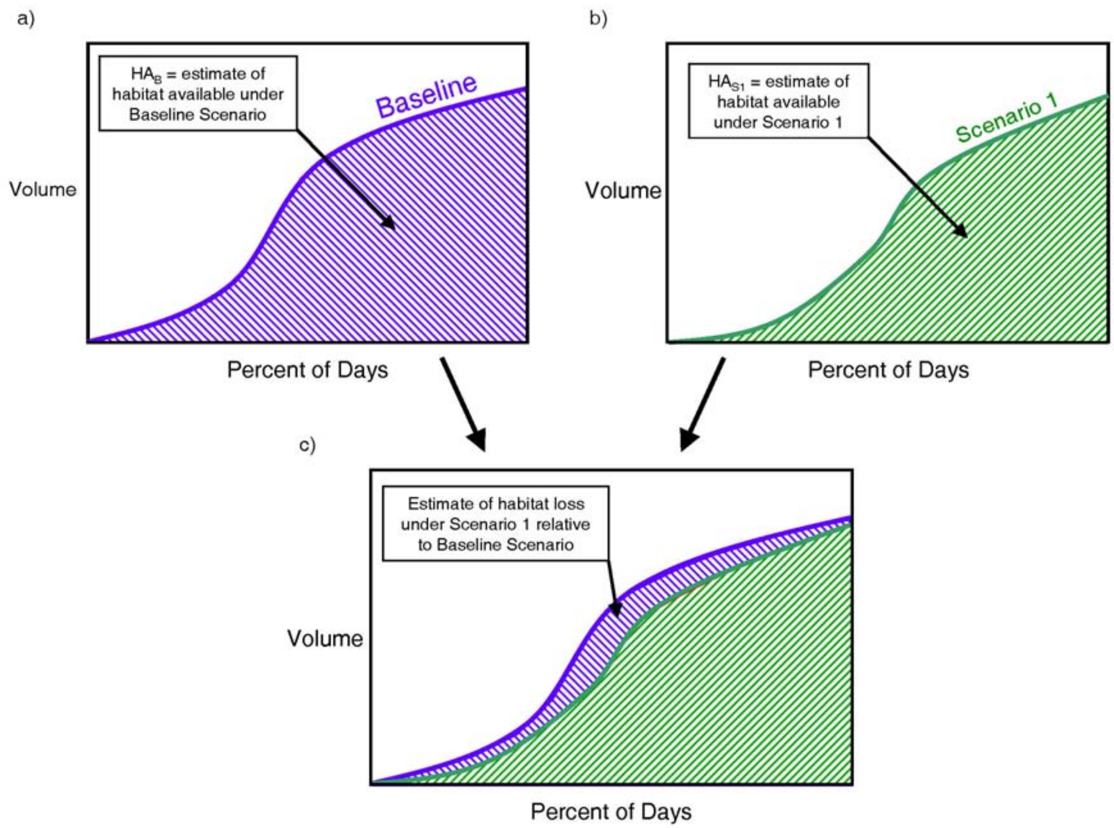


Figure 8-1. **Example of area under curve calculated from a CDF plot. a) represents the area under the curve for the Baseline condition. b) represents the area under the curve for an alternative condition, Scenario 1. c) represents the of water volume for the Baseline flow condition.**

The proposed minimum flow is defined as the flow that maintains at least 85% of the habitat that is available under the Baseline condition. In order to determine which alternative scenario results in no more than a 15% reduction in available habitat relative to the Baseline Scenario (i.e., maintains 85% of habitat available in the Baseline Scenario), the normalized area under the curve (NAUC) has been calculated for each alternative scenario relative to the Baseline Scenario. The formula to calculate the NAUC for a scenario (e.g. Scenario 1) is:

$$NAUC = \frac{(HA)_{S1}}{(HA)_B}$$

By plotting the NAUC for all alternative scenarios for each block and flow condition, the scenario that results in a 15% reduction in available habitat can be identified. A conceptual plot of NAUC for several alternative scenarios is presented in Figure 8-2. The scenarios are plotted on the x-axis while the NAUC for each scenario is on the y-axis. The reference line on the y-axis at 0.85 represents a 15% loss in habitat. From Figure 8-3, it can be seen that the flow which results in a 15% reduction in available habitat is between Scenario B and Scenario C.

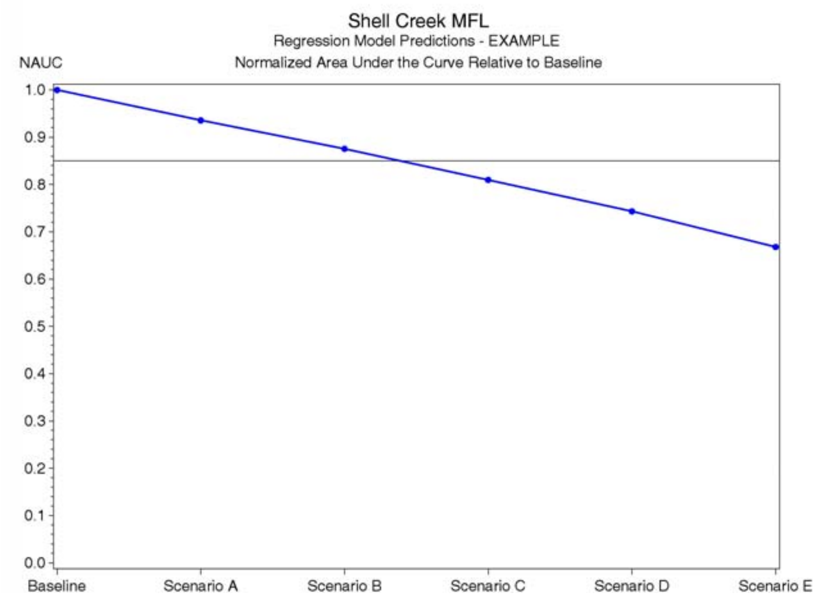


Figure 8-2. Plot of normalized area under the curve from CDF plots of water volume in the minimum flow study area.

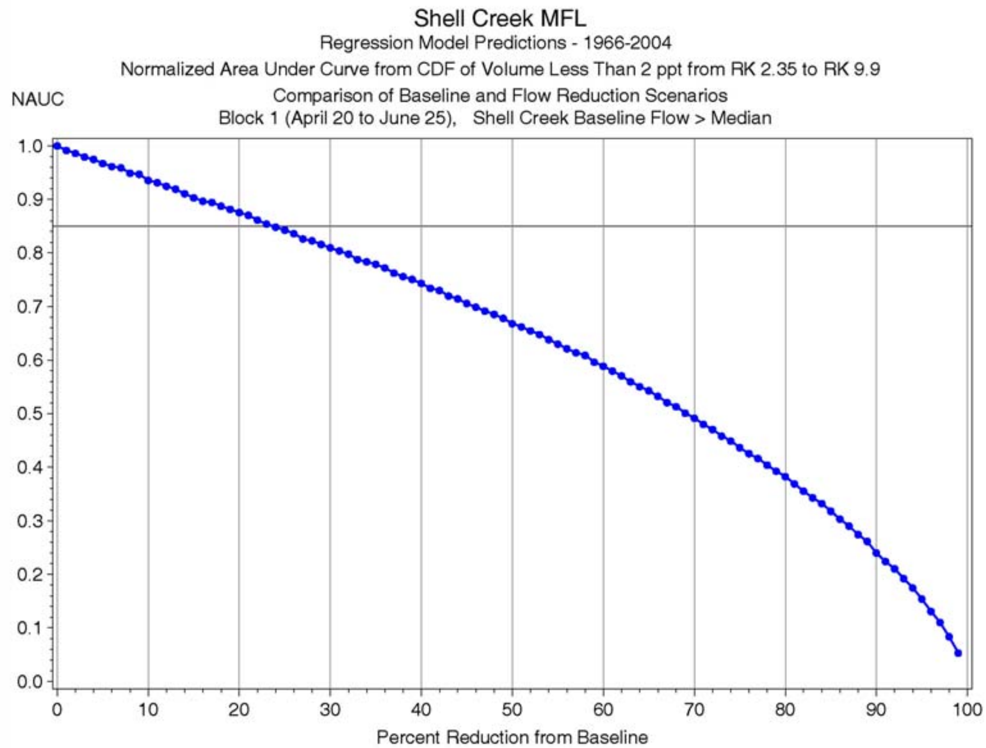
8.3 Application of Method to Define Minimum Flows

The method described in Section 8.1 was applied to all combinations of metrics and biologically-relevant salinities for all blocks and flow conditions. The results of these analyses for LPR and SC are presented in the following subsections.

8.3.1 Shell Creek

Examination of the CDF plots of volume less than 2 ppt and volume less than 5 ppt in SC that were presented in Section 7.2.7 shows that maintenance of habitat less than 2 ppt in SC requires a higher flow than maintenance of habitat less than 5 ppt. Therefore, the method described was applied to the CDF plots for the volume less than 2 ppt.

Plots of the NAUC for each scenario by block and flow condition are presented in Figures 8-3 to 8-5.



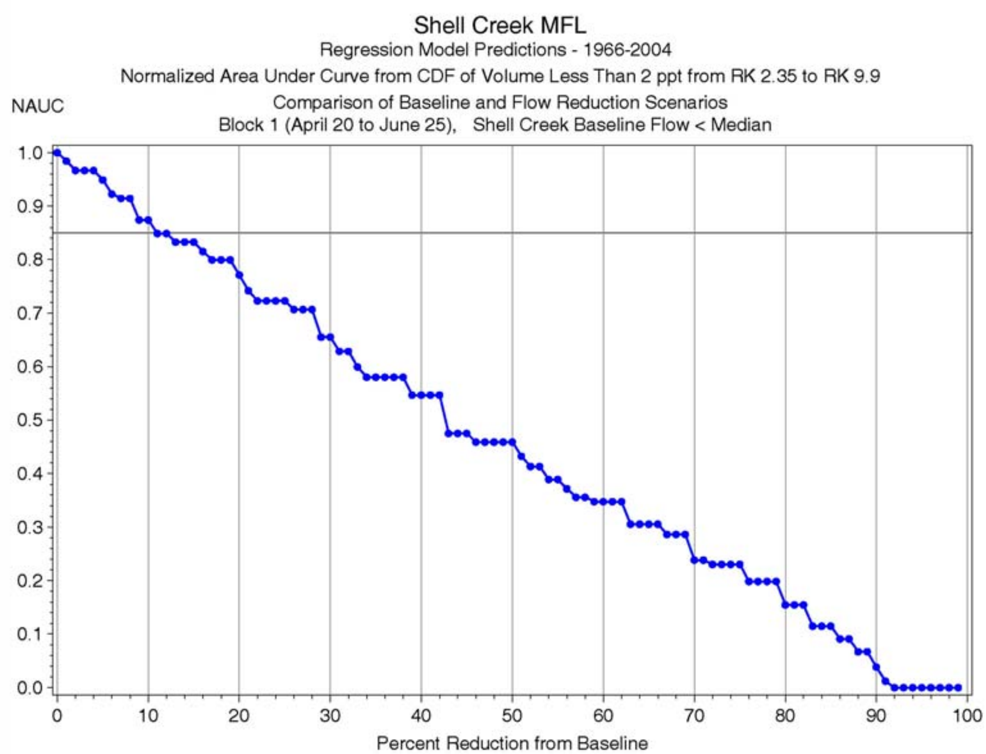
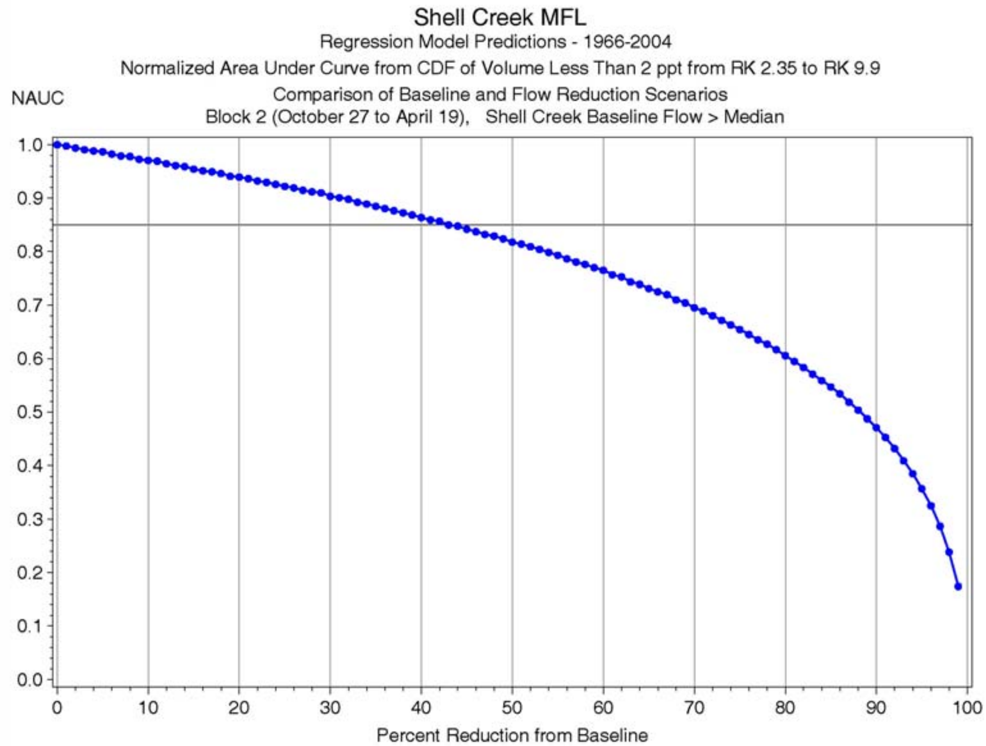


Figure 8-3. Plot of normalized area under the curve from CDF plots of water volume from the dam to rkm 2.35 less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



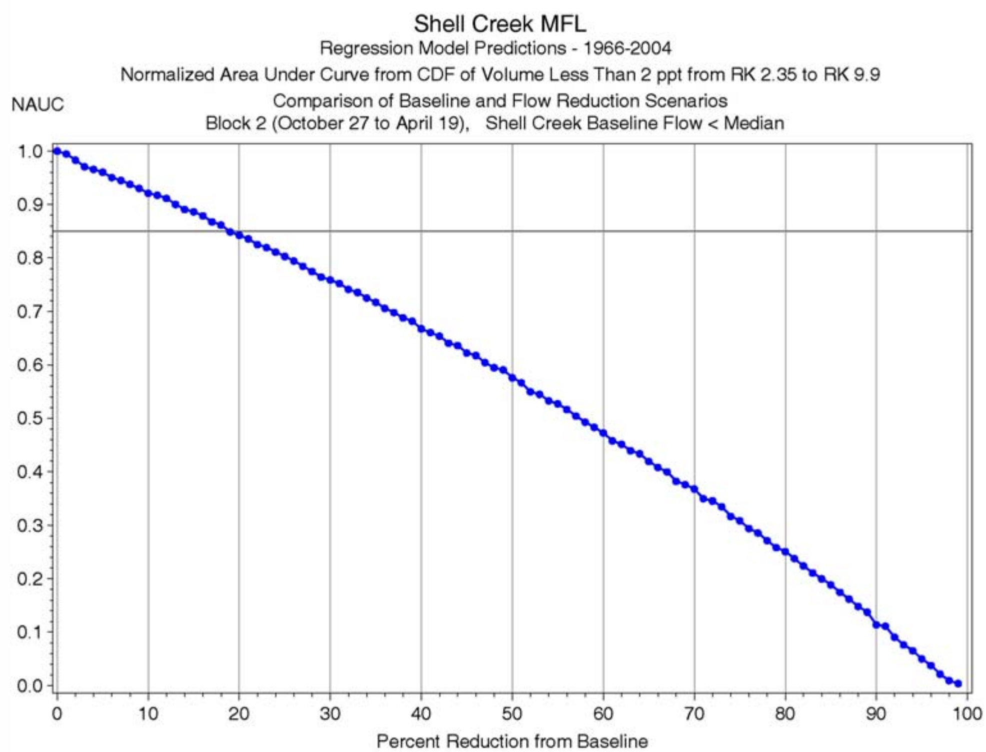


Figure 8-4. Plot of normalized area under the curve from CDF plots of water volume from the dam to rkm 2.35 less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).

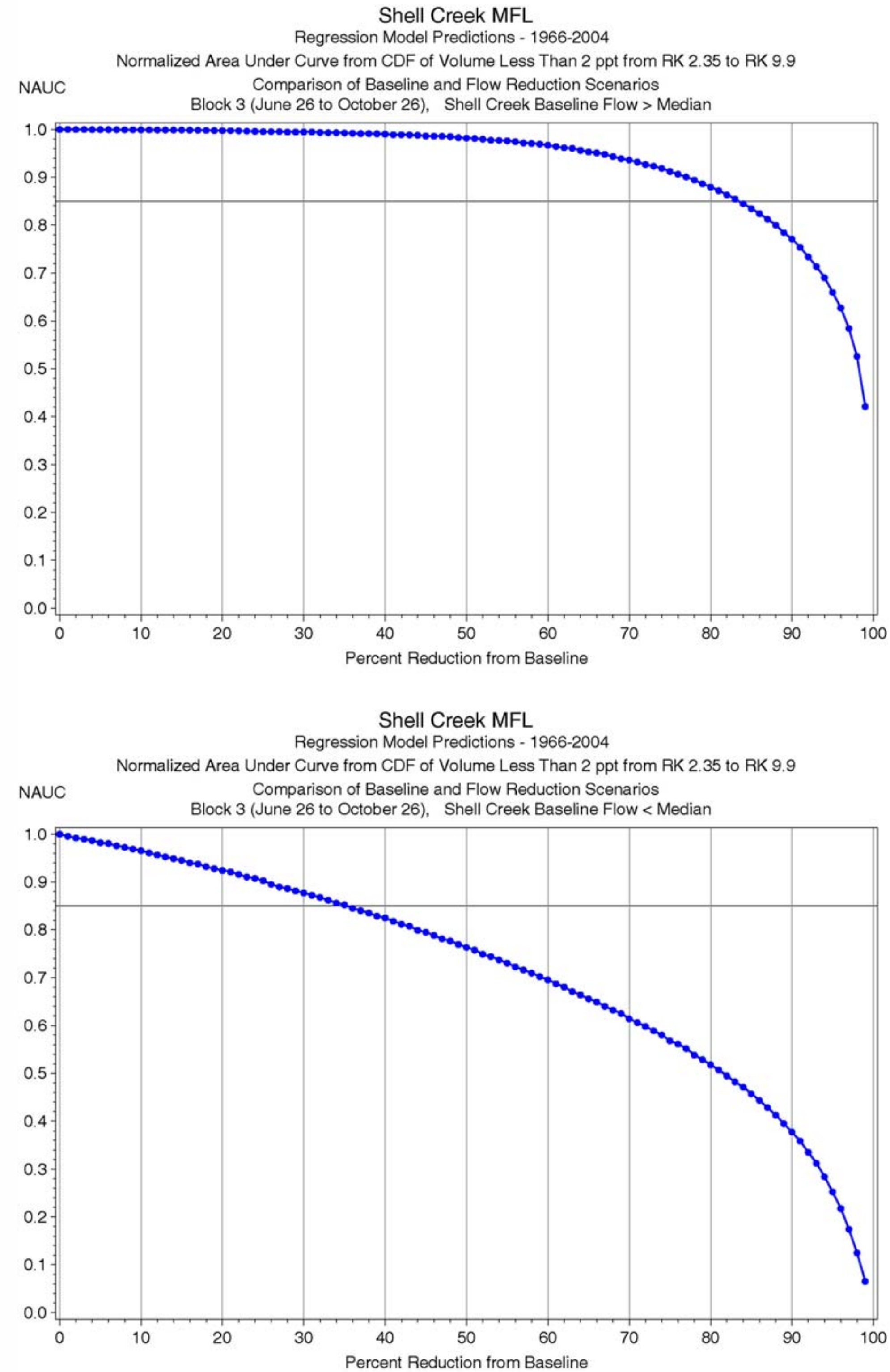


Figure 8-5. **Plot of normalized area under the curve from CDF plots of water volume from the dam to rkm 2.35 less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).**

The percent flow reductions within each block and flow condition that result in protection of 85% of the habitat available under the Baseline Scenario for SC are presented in Table 8-1.

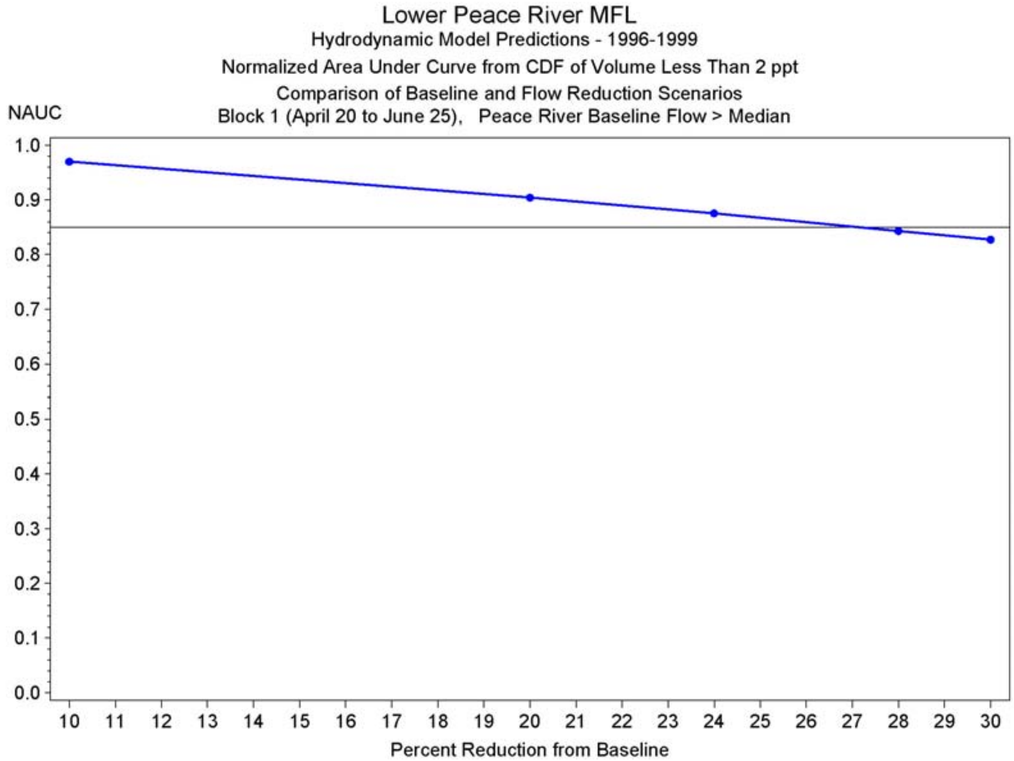
Table 8-1 Summary of allowable percent reduction in flow for SC by block and flow condition.

Block	Allowable Percent Reduction in Flow Under:	
	Low Flow Condition	High Flow Condition
Block 1 (April 20 – June 25)	10%	23%
Block 2 (October 27 – April 19)	18%	42%
Block 3 (June 26 – October 26)	35%	83%

8.3.2 Lower Peace River

Examination of the CDF plots of volume, bottom area, and shoreline length less than 2 ppt and less than 5 ppt for Lower Peace River that were presented in Section 7.3.8 shows that maintenance of habitat less than 2 ppt in the Lower Peace River requires a higher flow than maintenance of habitat less than 5 ppt. Therefore, the method described was applied to the CDF plots for the volume, bottom area, and shoreline length less than 2 ppt.

Plots of the NAUC by block and flow condition for the volume of water, bottom area, and shoreline length less than 2 ppt are presented in Figures 8-6 to 8-8, Figures 8-9 to 8-11, and 8-12 to 8-14, respectively.



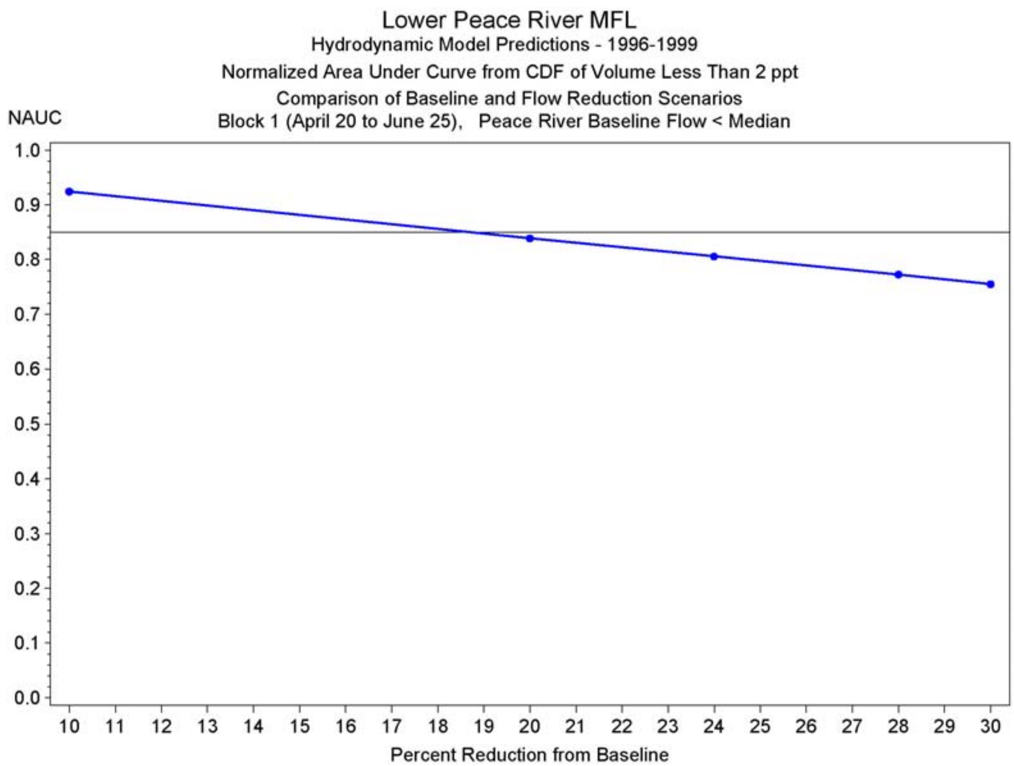


Figure 8-6. **Plot of normalized area under the curve from CDF plots of water volume in the Lower Peace River minimum flow study area less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).**

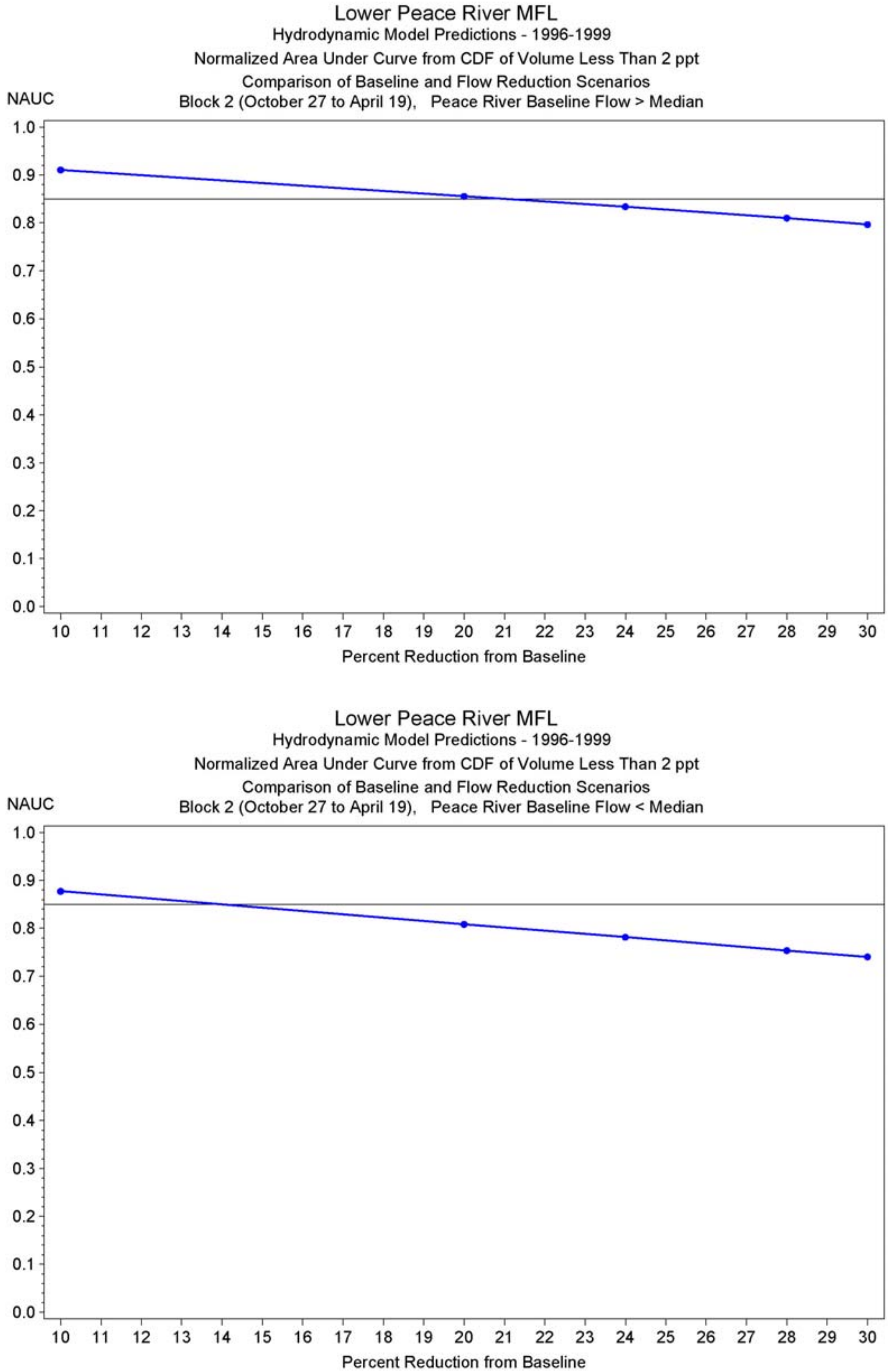
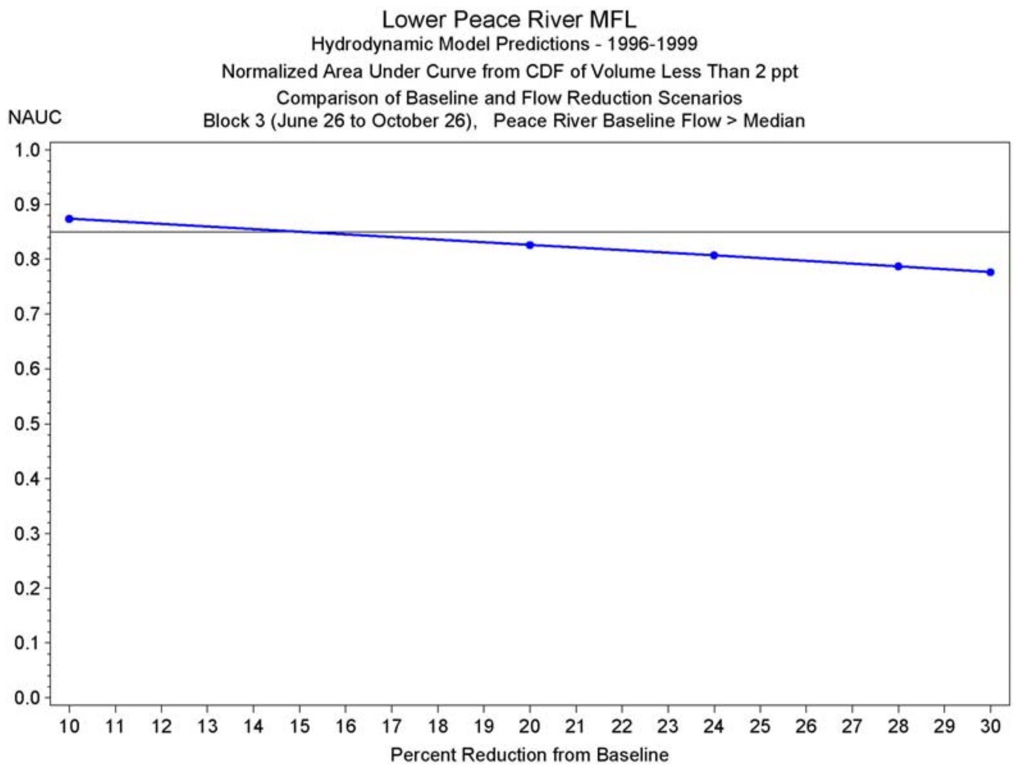


Figure 8-7. **Plot of normalized area under the curve from CDF plots of water volume in the Lower Peace River minimum flow study area less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).**



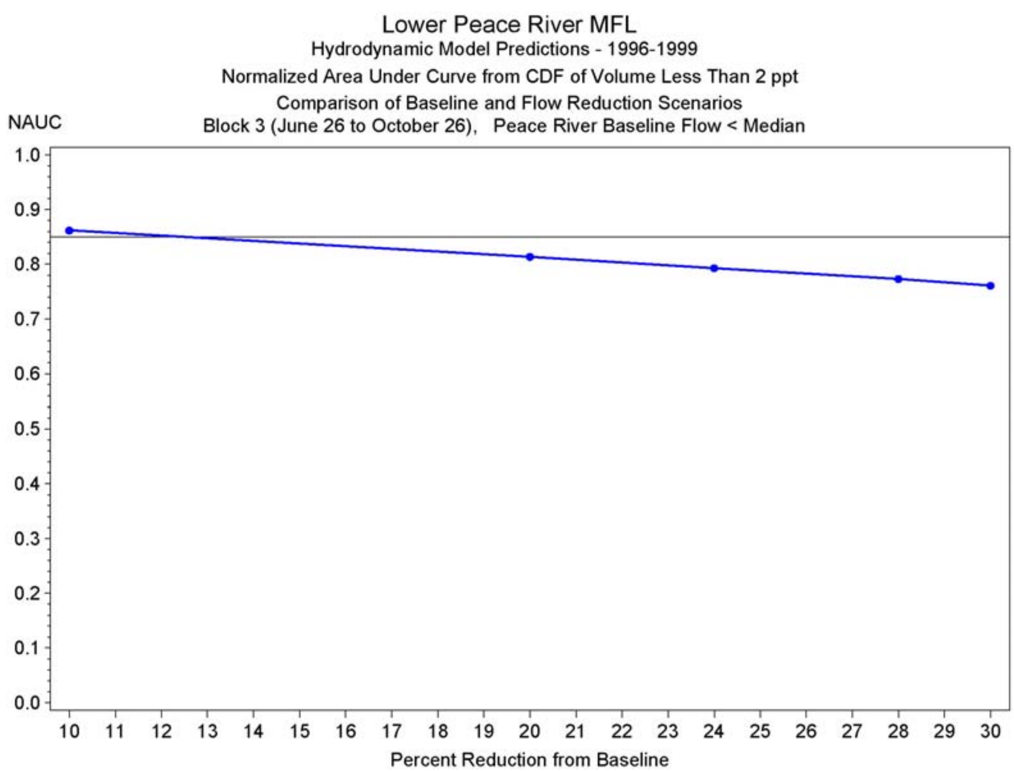
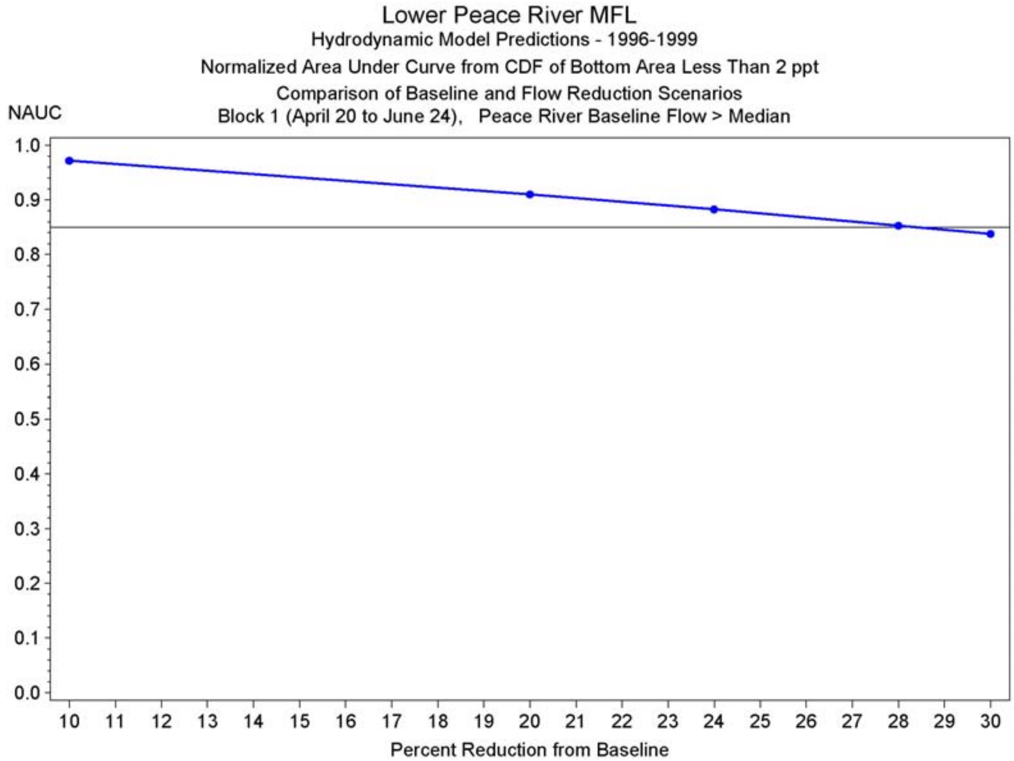


Figure 8-8. Plot of normalized area under the curve from CDF plots of water volume in the Lower Peace River minimum flow study area less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).



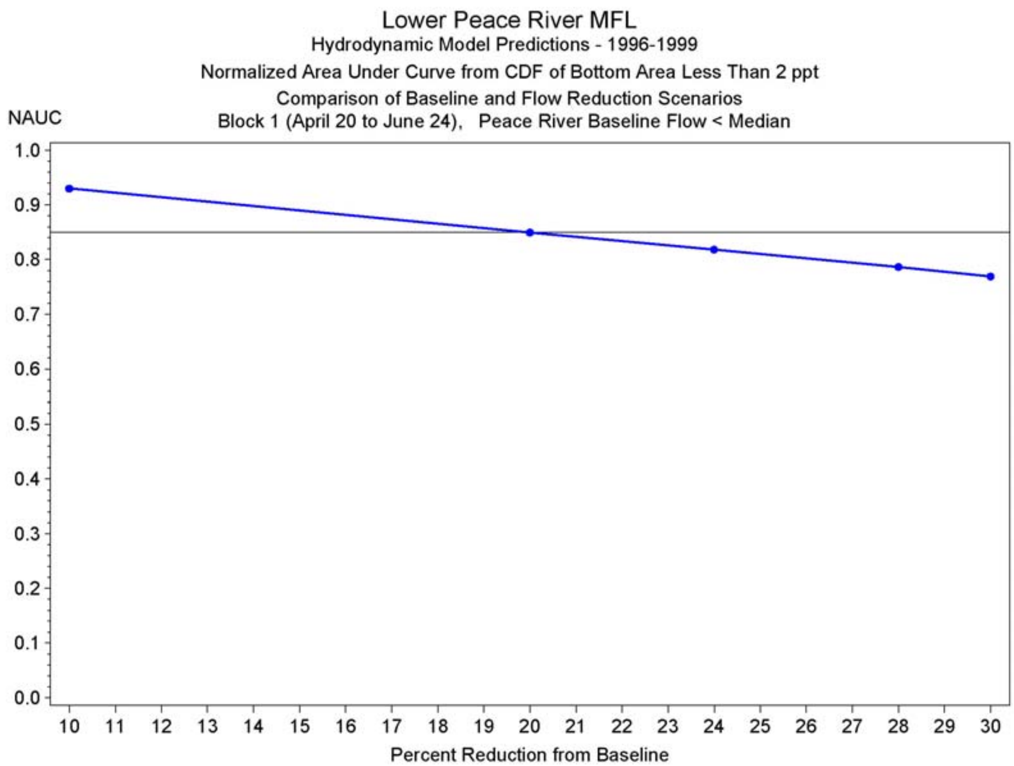
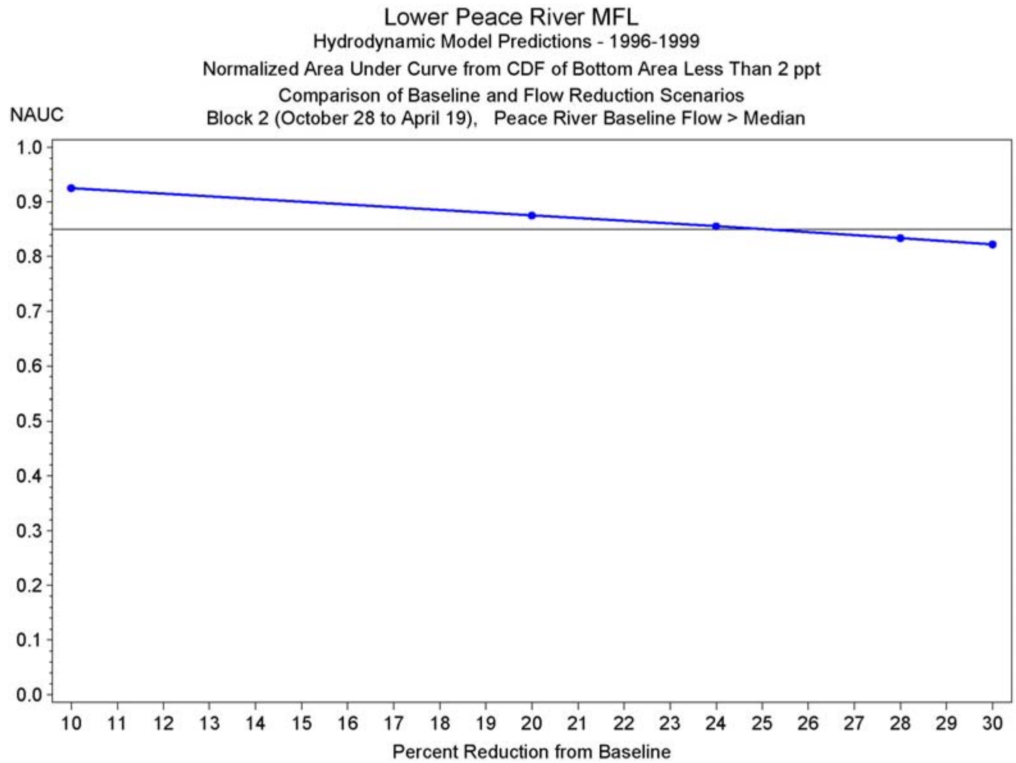


Figure 8-9. Plot of normalized area under the curve from CDF plots of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



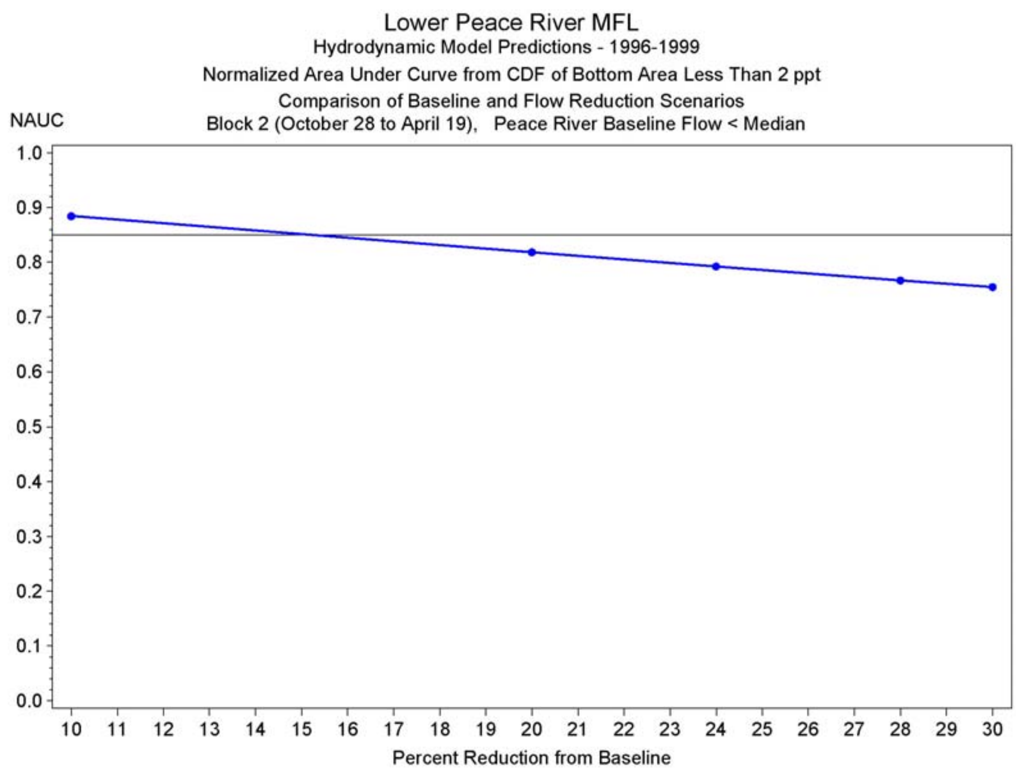
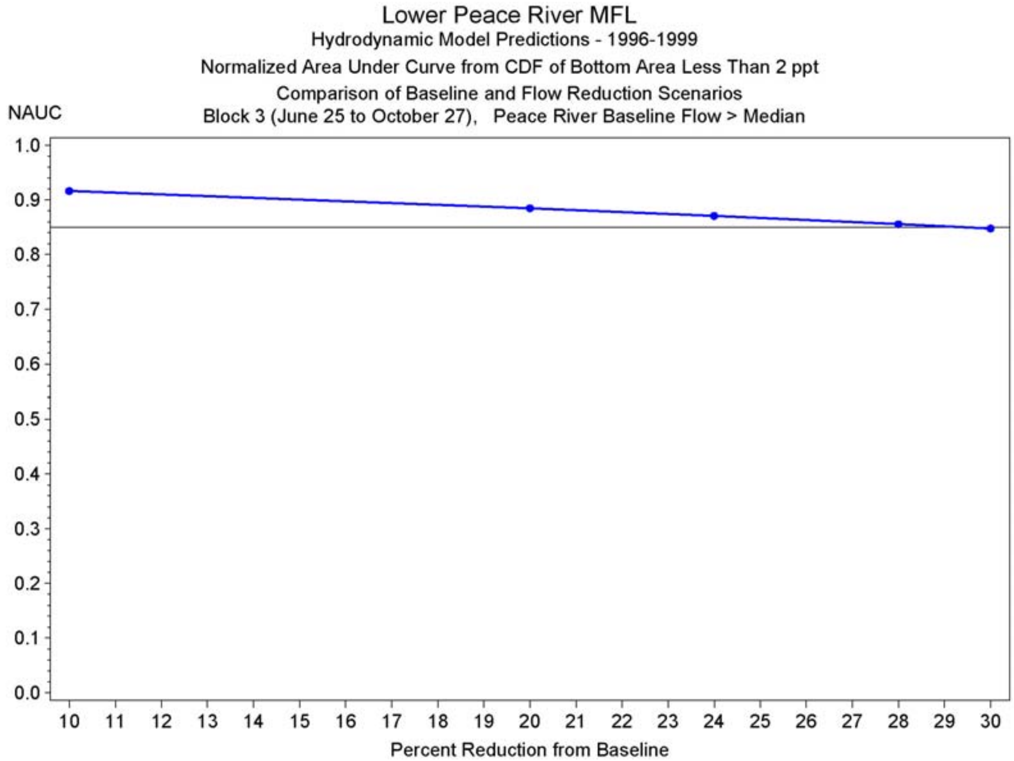


Figure 8-10. **Plot of normalized area under the curve from CDF plots of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).**



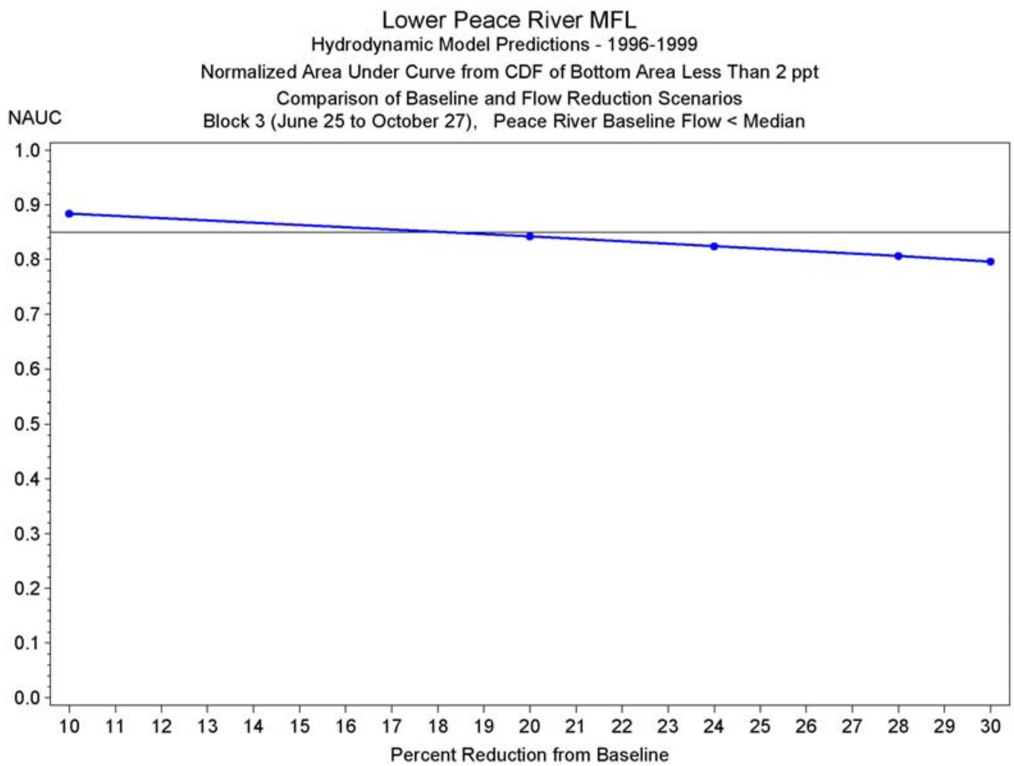


Figure 8-11. Plot of normalized area under the curve from CDF plots of bottom area in the Lower Peace River minimum flow study area less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).

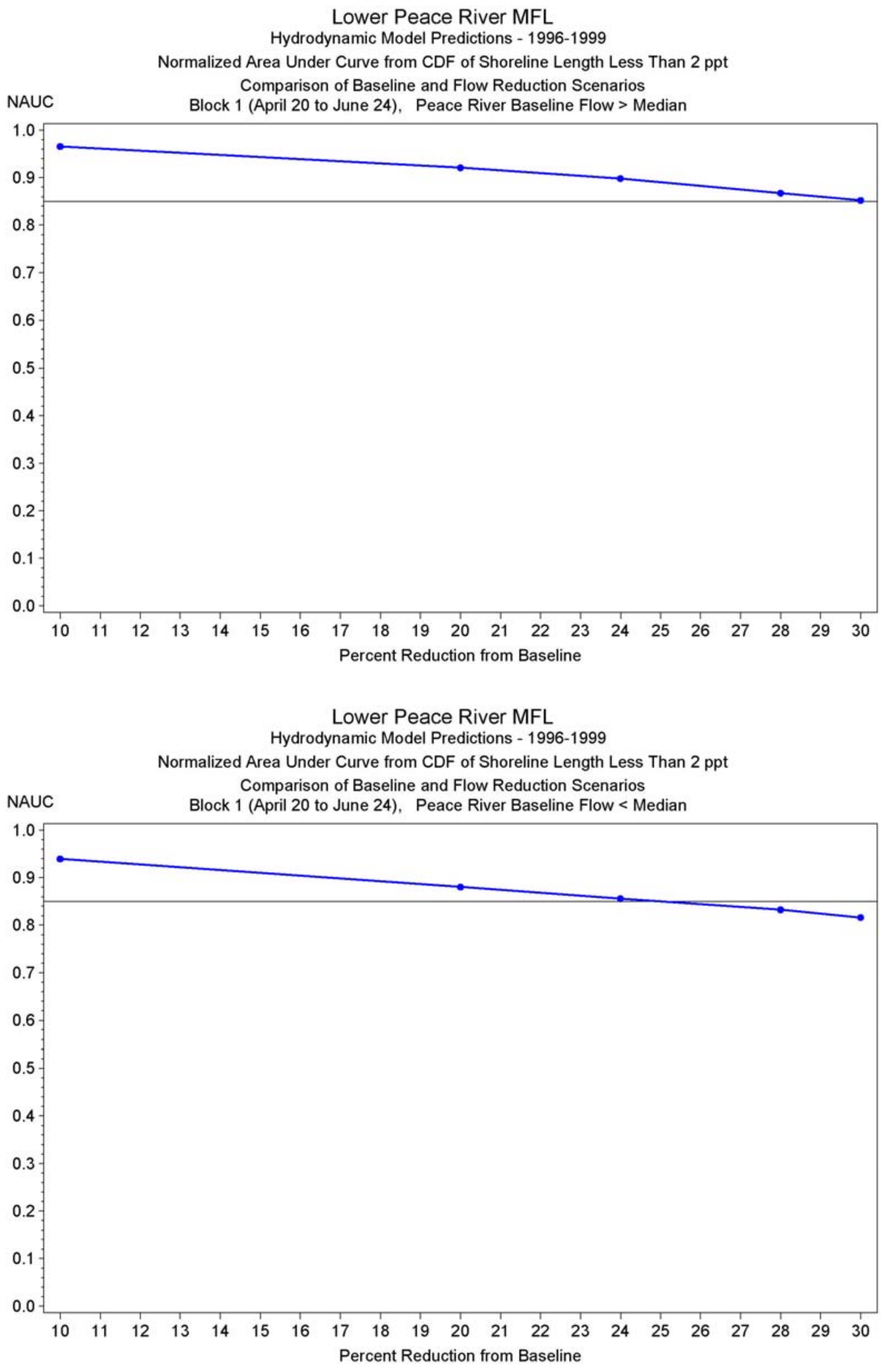
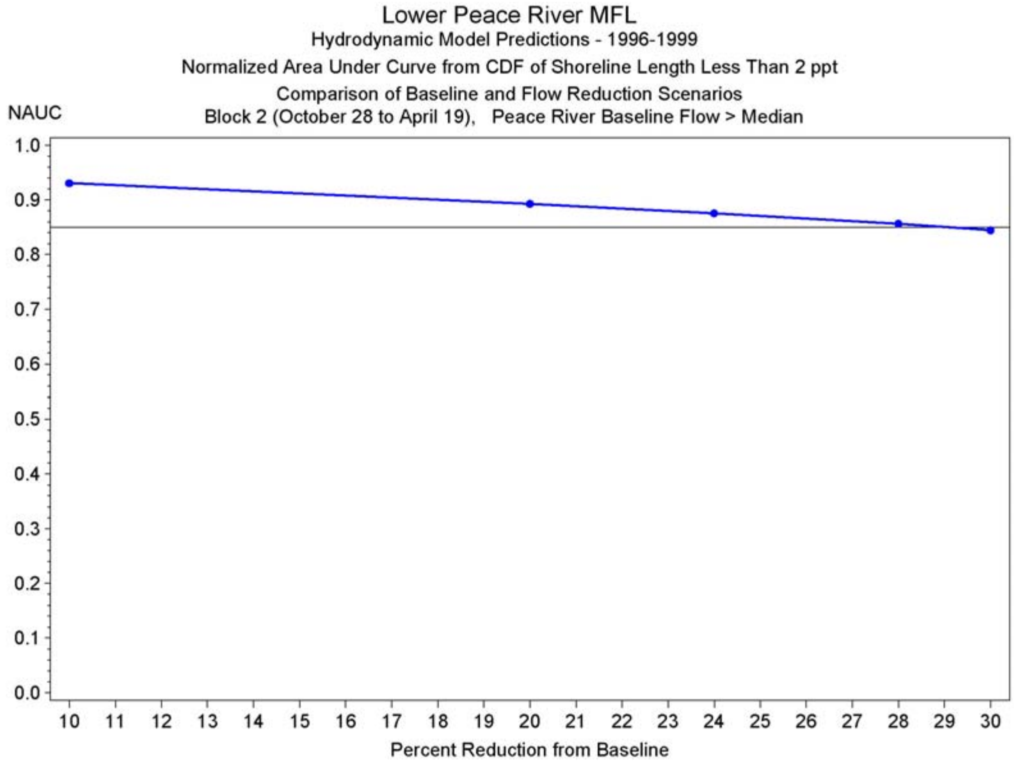


Figure 8-12. **Plot of normalized area under the curve from CDF plots of shoreline length in the Lower Peace River minimum flow study area less than 2 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).**



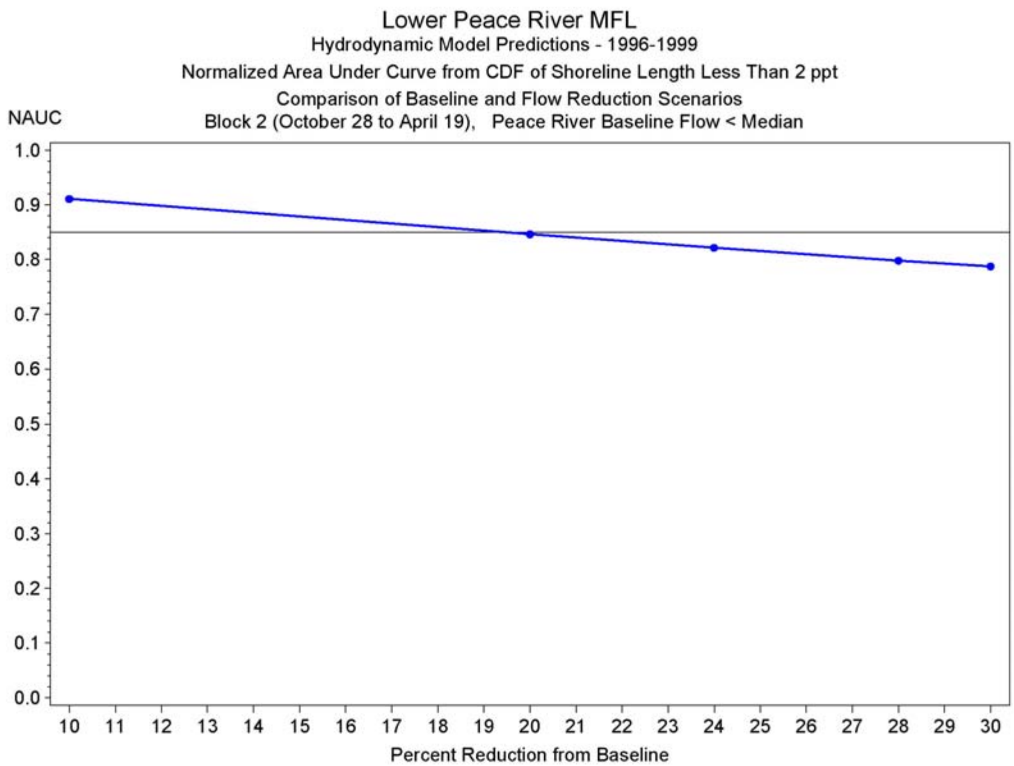
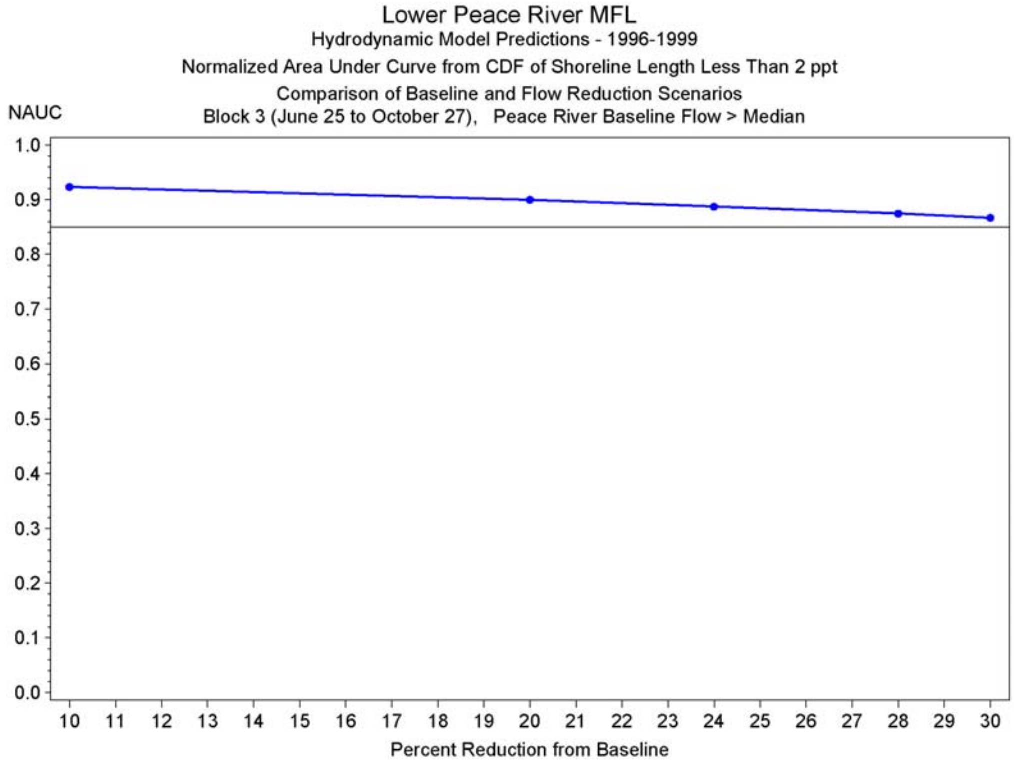


Figure 8-13. Plot of normalized area under the curve from CDF plots of shoreline length in the Lower Peace River minimum flow study area less than 2 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).



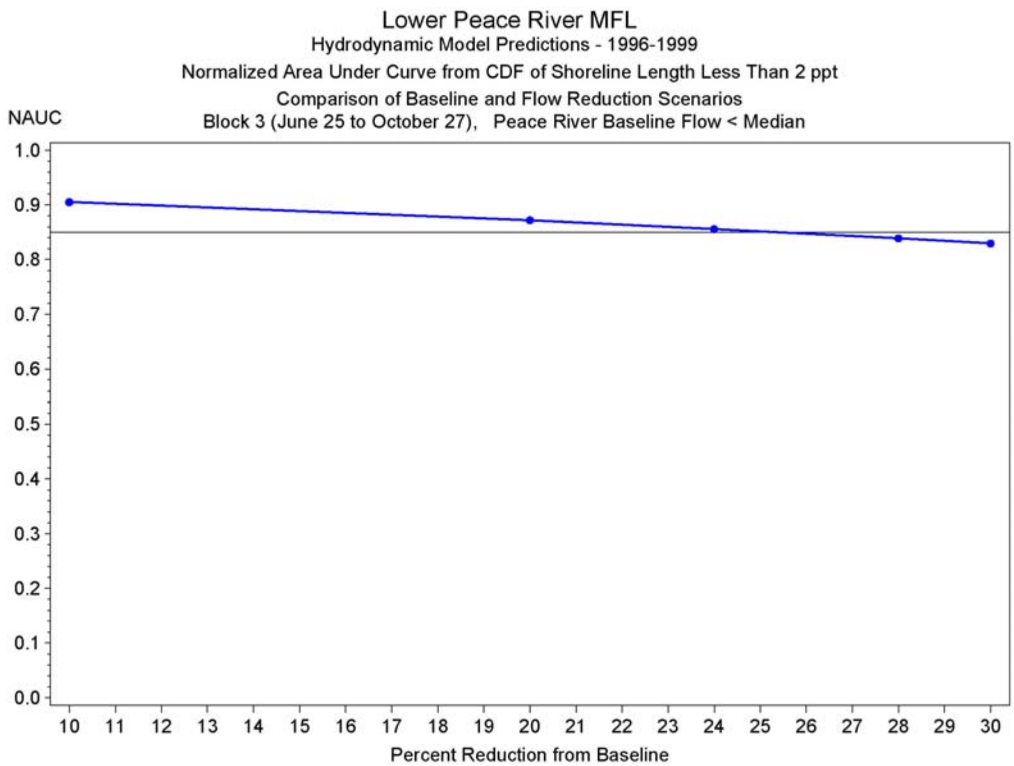


Figure 8-14. Plot of normalized area under the curve from CDF plots of shoreline length in the Lower Peace River minimum flow study area less than 2 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).

Summaries of the allowable percent flow reduction by block and flow condition based on the volume of water, bottom area, and shoreline length less than 2 ppt in the Lower Peace River minimum flow study area are presented in Tables 8-2, 8-3, and 8-4, respectively.

Table 8-2. Summary of allowable percent reduction in flow based on the volume of water less than 2 ppt for Lower Peace River by block and flow condition.

	Allowable Percent Reduction in Flow Under:	
Block	Low Flow Condition	High Flow Condition
Block 1 (April 20 – June 25)	18%	27%
Block 2 (October 27 – April 19)	14%	21%
Block 3 (June 26 – October 26)	12%	15%

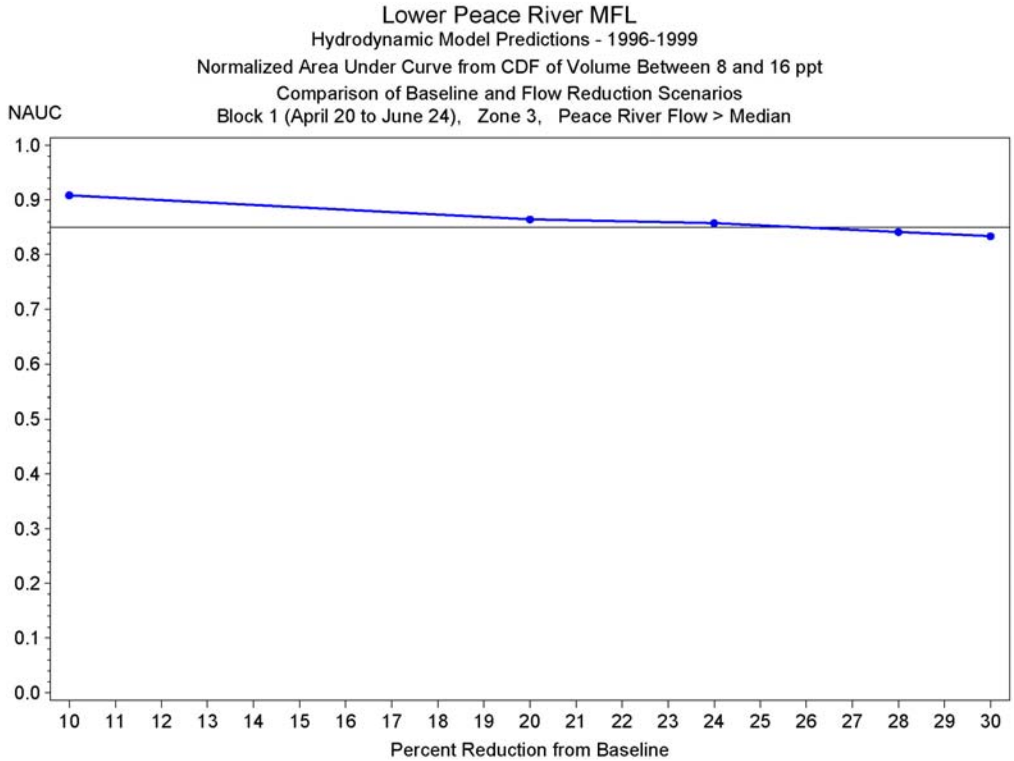
Table 8-3. Summary of allowable percent reduction in flow based on bottom area less than 2 ppt for Lower Peace River by block and flow condition.

	Allowable Percent Reduction in Flow Under:	
Block	Low Flow Condition	High Flow Condition
Block 1 (April 20 – June 25)	20%	28%
Block 2 (October 27 – April 19)	15%	25%
Block 3 (June 26 – October 26)	18%	30%

Table 8-4. Summary of allowable percent reduction in flow based on the shoreline length less than 2 ppt for Lower Peace River by block and flow condition.

	Allowable Percent Reduction in Flow Under:	
Block	Low Flow Condition	High Flow Condition
Block 1 (April 20 – June 25)	25%	30%
Block 2 (October 27 – April 19)	19%	29%
Block 3 (June 26 – October 26)	26%	30%

In addition to examining the river-wide extent of the biologically-relevant salinities a more spatially-specific assessment of salinity within a portion of the Lower Peace River was also deemed critical. As discussed above, studies have shown that the area of the river approximately located at Zone 3 (Figure 7-15) has a significantly abundant and diverse fish community. Earlier work has shown that this region is characterized by salinities typically in the range of 8-16 ppt (Mote 2002). Therefore, the volume of water meeting the appropriate salinity range in Zone 3 (i.e., volume of water with salinity between 8 and 16 ppt) was also analyzed. Plots of the NAUC by block and flow condition for the volume of water between 8 and 16 ppt in Zone 3 are presented in Figures 8-15 to 8-17.



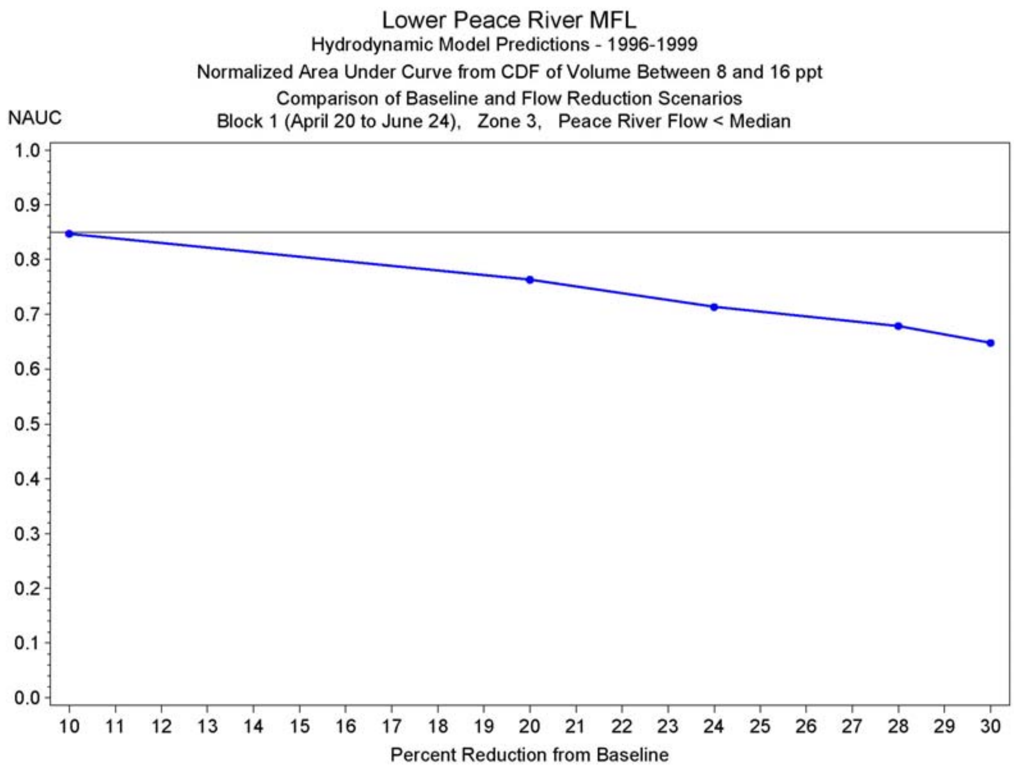
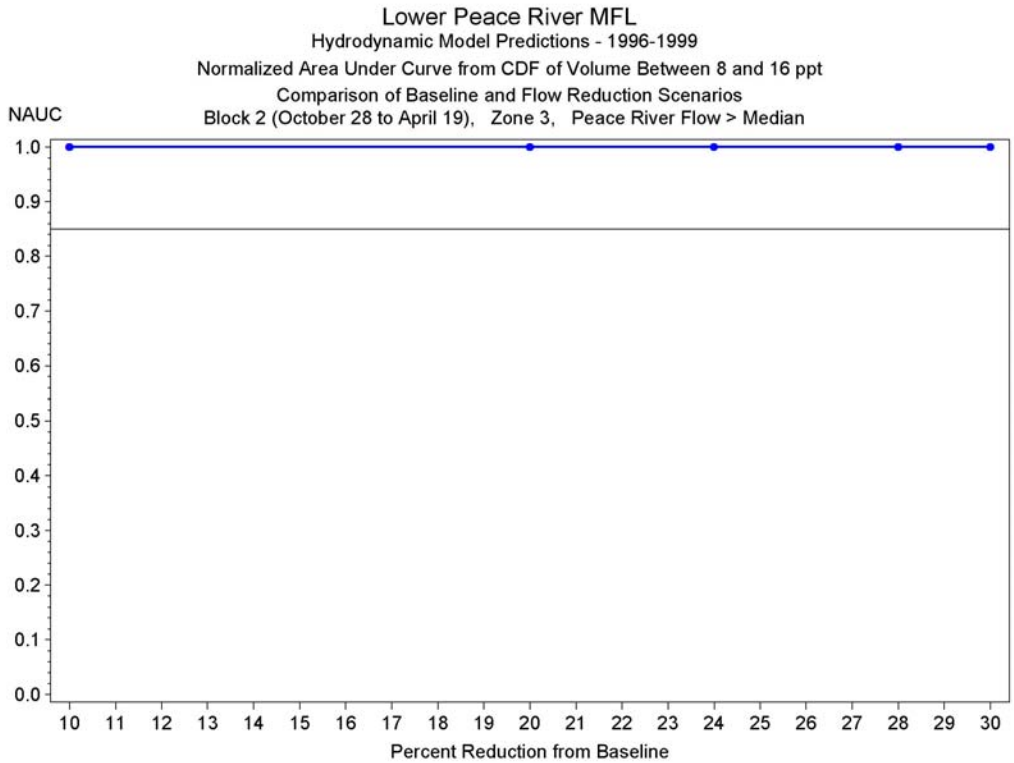


Figure 8-15. Plot of normalized area under the curve from CDF plots of water volume in Lower Peace River Zone 3 between 8 and 16 ppt for Block 1 under the high flow condition (upper panel) and low flow condition (lower panel).



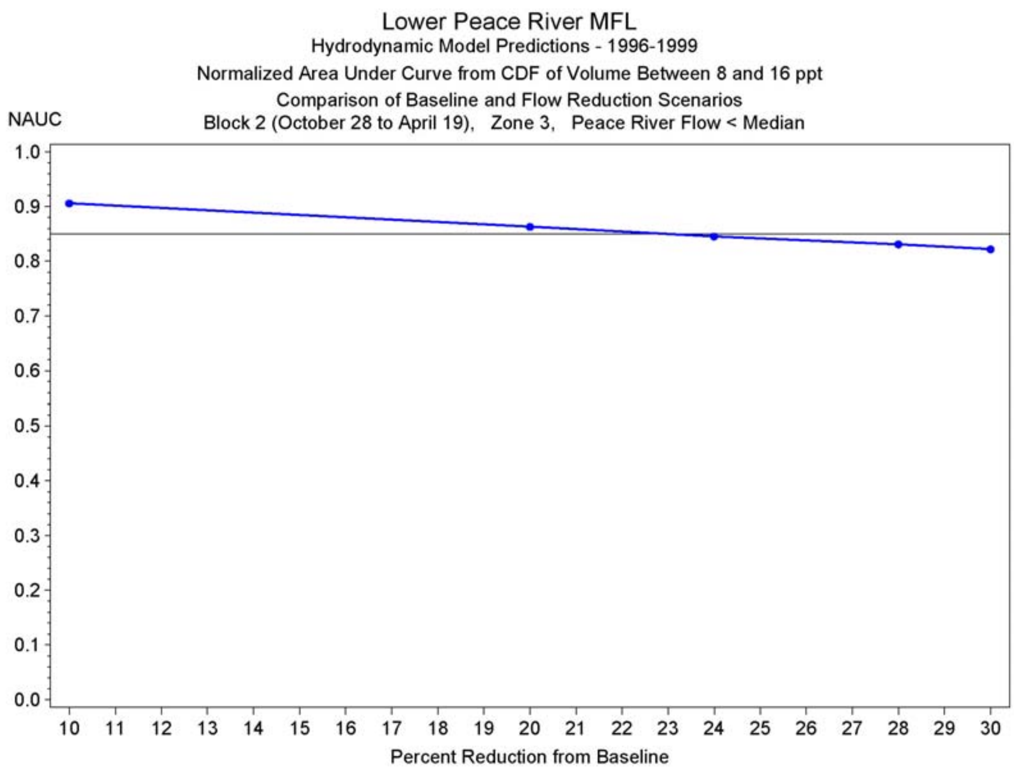


Figure 8-16. Plot of normalized area under the curve from CDF plots of water volume in Lower Peace River Zone 3 between 8 and 16 ppt for Block 2 under the high flow condition (upper panel) and low flow condition (lower panel).

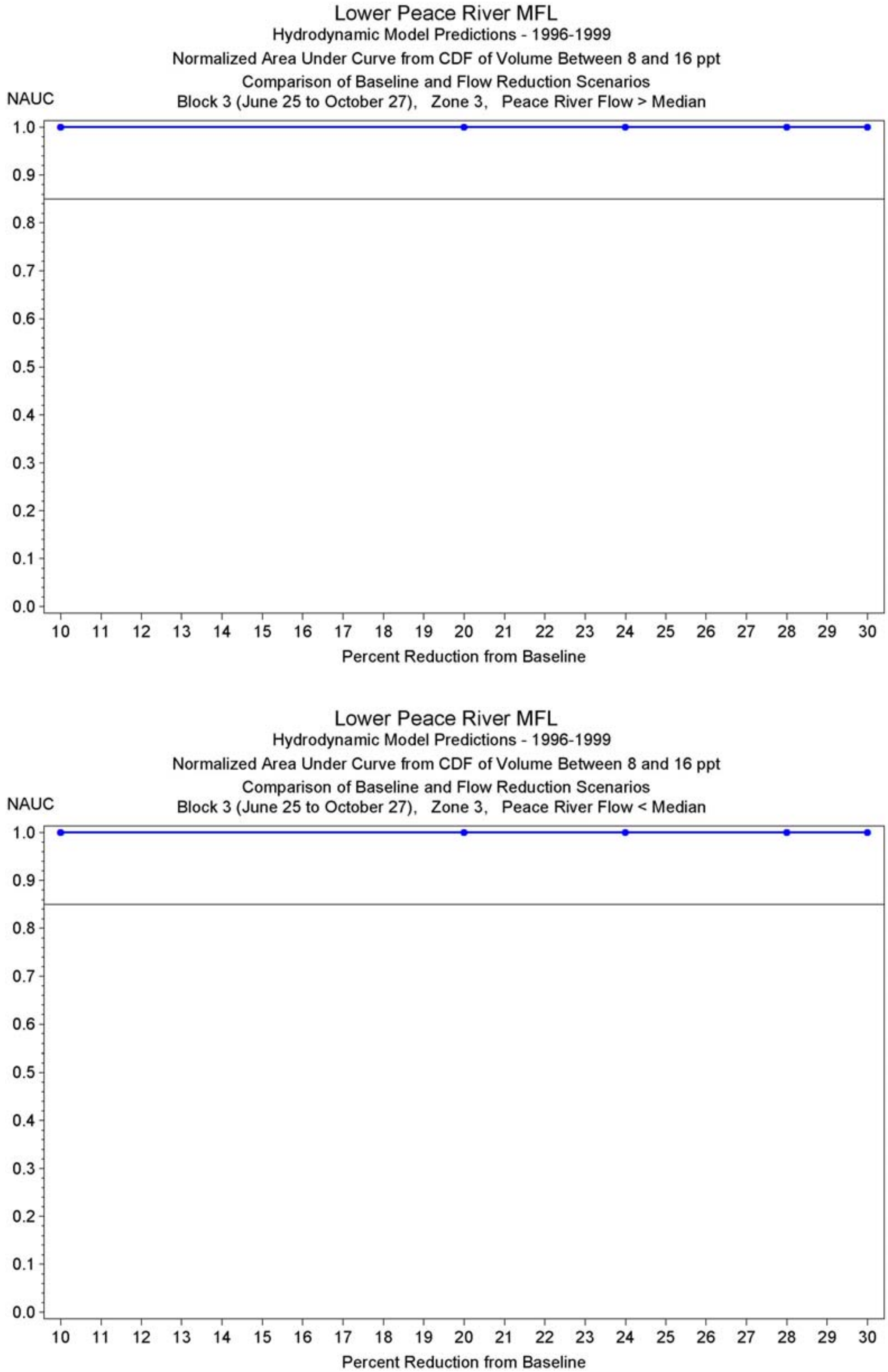


Figure 8-17. **Plot of normalized area under the curve from CDF plots of water volume in Lower Peace River Zone 3 between 8 and 16 ppt for Block 3 under the high flow condition (upper panel) and low flow condition (lower panel).**

The allowable percent flow reduction by block and flow condition based on the volume of water between 8 and 16 ppt in Lower Peace River Zone 3 is presented in Table 8-5.

Table 8-5. Summary of allowable percent reduction in flow based on the volume of water between 8 and 16 ppt for Lower Peace River Zone 3 by block and flow condition.

Block	Allowable Percent Reduction in Flow Under:	
	Low Flow Condition	High Flow Condition
Block 1 (April 20 – June 25)	10%	26%
Block 2 (October 27 – April 19)	23%	30%
Block 3 (June 26 – October 26)	30%	30%

The recommended minimum flow for the Lower Peace River is the lowest percent reduction that satisfies the criterion (no more than 15% loss in habitat available from the Baseline condition) under each block and flow condition based on the allowable percent reductions presented in Tables 8-2 through 8-5. The percent flow reductions within each block and flow condition that result in protection of 85% of the habitat available under the Baseline Scenario for the Lower Peace River are presented in Table 8-6.

Table 8-6. Summary of allowable percent reduction in flow for Lower Peace River by block and flow condition.

Block	Allowable Percent Reduction in Flow Under:	
	Low Flow Condition	High Flow Condition
Block 1 (April 20 – June 25)	10%	26%
Block 2 (October 27 – April 19)	14%	21%
Block 3 (June 26 – October 26)	12%	15%

8.4 Influence of MFL on Water Quality Constituents and Ecological Parameters

As mentioned in Section 7, attempts were made to develop empirical models that relate flow to ecological criteria for the Lower Peace River in order to identify a low flow cutoff. No defensible relationship was found between flow and DO or between flow and chlorophyll *a* in the Lower Peace River. Therefore, it was not possible to define a flow that would preclude low DO values or high chlorophyll *a* values.

However, a statistically significant relationship between the location of the chlorophyll a maximum and freshwater inflow was developed for the Lower Peace River as part of this study. In addition, regressions have been developed to predict the location of the center of abundance of numerous fish and plankton species in the Lower Peace River based on flows.

In order to quantify the impact of the proposed minimum flows, predictions were made using the baseline flows and the proposed minimum flows. The Baseline flow condition consisted of the sum of the gaged flows at Peace River at Arcadia (USGS gage 02296750), Horse Creek near Arcadia (USGS gage 02297310), and Joshua Creek at Nocatee (USGS gage 02297100). For the Proposed MFL Scenario, the maximum allowable daily withdrawals were taken out based on Table 8-6 while maintaining at least 90 cfs after withdrawals for the combined flow (Peace+Johsua+Horse). If the daily combined flow was less than 90 cfs, no withdrawals were taken out. The results of the empirical models are presented in the following sections.

8.4.1 Shell Creek

No empirical relationships between flow and water quality constituents or between flow and ecological parameters were established for SC.

8.4.2 Lower Peace River

As discussed above, two analyses were performed for the Lower Peace River, the location of the chlorophyll *a* maximum and fish and plankton center of abundance. The predicted median location of the chlorophyll a maximum for the period 1996 to 1999 is presented in Table 8-7. The differences between the median location of the chlorophyll a maximum for the Baseline and MFL scenarios were not significant as the differences were within the error of prediction for the estimates.

Table 8-7. Summary of median predicted location (river kilometer) of the chlorophyll *a* maximum for Lower Peace River for the Baseline and MFL scenarios.

	Median Location of the Chlorophyll *a* Maximum Under:			
	Low Flow Condition		High Flow Condition	
Block	Baseline	MFL	Baseline	MFL
Block 1 (April 20 – June 25)	25.5	26.0	21.0	22.5
Block 2 (October 27 – April 19)	24.5	25.0	15.0	16.0
Block 3 (June 26 – October 26)	20.0	20.5	15.5	17.0

The predicted median center of abundance (river kilometer) for selected species is presented in Table 8-8. The differences between the median center of abundance for the Baseline and MFL scenarios were not significant as the differences were well within the error of prediction for the estimates.

Table 8-8 Summary of median predicted location (river kilometer) of the chlorophyll *a* maximum for Lower Peace River for the Baseline and MFL scenarios.

	Median Center of Abundance (rkm)	
Species	Baseline	MFL
Hogchoker juveniles	21.0	21.3
Sand Seatrout juveniles	15.0	15.7
Bay Anchovy juveniles	19.0	19.5
Bay Anchovy adults	11.1	11.5
Amphipods	17.4	17.7
Mysids	15.6	16.0

8.5 Summary of MFL Recommendations

A summary of the MFL recommendations for SC and LPR is presented in this subsection.

8.5.1 Shell Creek

The SC MFL encompasses the portion of SC from HBMP station 7 (rkm 2.35) to the SC dam (rkm 9.9) (Figure 7-2). This portion of SC is relatively shallow (less than 2 m) and the shoreline is primarily buffered by wetlands.

The City of Punta Gorda is permitted to withdraw water from the SC reservoir according to WUP (#200871.06). The current permit allows for an average permitted withdrawal of 5.38 mgd (8.3 cfs) and a maximum peak monthly withdrawal of 6.9 mgd (10.7 cfs).

The criterion used for MFL development in SC was the available habitat less than two ppt in the study area (rkm 2.35 to rkm 9.9). Because the habitat metrics (volume, bottom area, and shoreline length) were highly correlated for SC, only one metric, volume, was used. An empirical model was developed to predict salinity in SC as a function of flow and other appropriate variables.

The empirical model was used to estimate available habitat for the observed flows at the SC dam (baseline scenario) and flow reduction scenarios ranging from 1% to 50% reductions in observed flows by 1% intervals (i.e., baseline, 99% of observed flows at SC dam, 98% of observed flows at SC dam, … , 1% of observed flows at SC dam). The amount of available habitat (volume) less than two ppt was determined for each scenario for the period 1966-2004 for each of the three Blocks and flow conditions (low flow condition [less than median for the Block] and high flow condition [greater than median flow for the Block]). The threshold used to determine the MFL was a 15% reduction in available habitat compared to the baseline.

As mentioned in Section 8.4.1, no empirical relationships between flow and water quality constituents or between flow and ecological parameters have been established for SC. For this reason, no low flow cutoff was used for SC. The recommended MFLs for SC by Block and flow condition are presented in Table 8-9 along with the median flow by Block.

Table 8-9. Summary of allowable percent reduction in flow for SC by block and flow condition, including median flow by Block.

Block	Median Flow (cfs)	Allowable Percent Reduction in Flow:	
		Below Median	Above Median
Block 1 (April 20 – June 25)	84	10%	23%
Block 2 (October 27 – April 19)	98	18%	42%
Block 3 (June 26 – October 26)	424	35%	83%

As stated in Section 1.3, the goal of the percent-of-flow method is to maintain the natural flow regime, albeit with some dampening allowed due to withdrawals. Therefore, the percentages in Table 8-9 should be applied as described in the following example. In SC there is no low flow threshold in effect. If the flow on a given day in Block 1 is 50 cfs (i.e., below the median for Block 1), then the maximum allowable withdrawal would be 50*10% = 5 cfs. If the flow on a given day in Block 1 is 100 cfs (i.e., above the median for Block 1), then the maximum allowable withdrawal would be 10% of 84 cfs plus 23% of the difference between 100 cfs and the median ([84cfs * 10%] + [(100 – 84)* 23%] = 8.4 + 3.7 = 12.1 cfs).

The hydrographs of the SC median daily flows for the Baseline and flow remaining after the maximum allowable withdrawals were taken is presented in Figure 8-18 for the period 1966 to 2004.

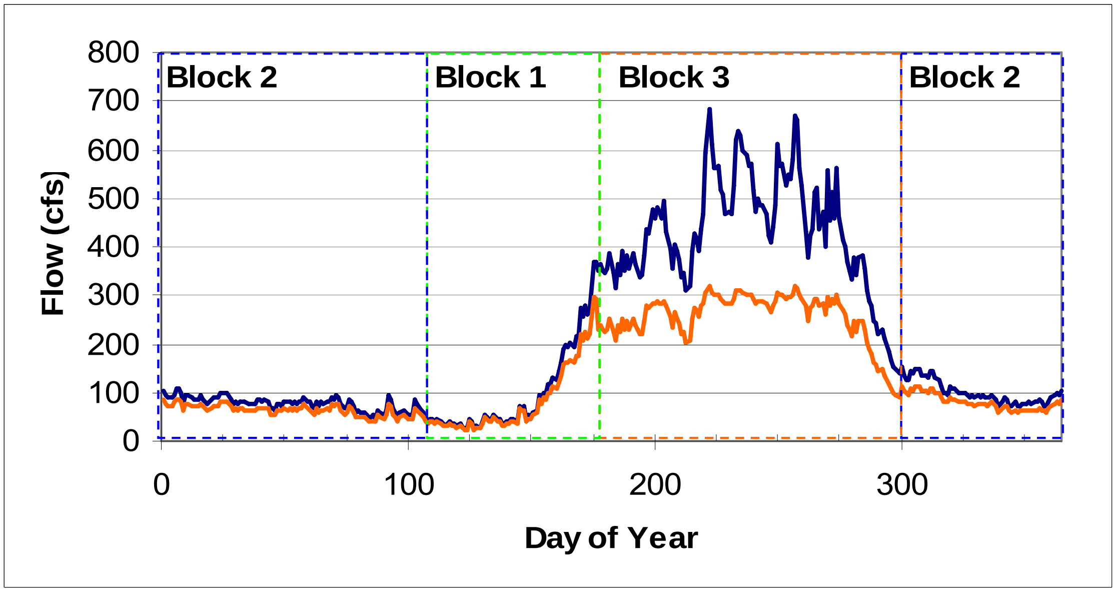


Figure 8-18. **Hydrographs of the median daily SC flows for the Baseline (blue line) and flow remaining after the maximum allowable withdrawals were taken (orange line).**

8.5.2 Lower Peace River

The Peace River watershed is one of the largest in Florida, draining approximately 2,350 square miles. The watershed extends from its headwaters in northern Polk County to the river mouth in Charlotte Harbor. The LPR MFL encompasses the portion of the river from the mouth to Arcadia. There are three major tributaries that flow into the LPR, Joshua Creek, Horse Creek, and SC. The lower portion of the LPR, between the mouth and SC, is broad and strongly influenced by tides. Between the confluence of SC (rkm 15) and the PRMRWSA plant (rkm 30), the system is highly braided. There is one permitted surface water withdrawal on the LPR at the PRMRWSA plant. The PRMRWSA began withdrawing water in 1980. The WUP (#2010420.02) held by the PRMRWSA, as modified on 18 December 1998, permits:

- withdrawals on days when the previous days flow at the USGS Arcadia gage was at least 130 cfs,
- a daily maximum withdrawal of 139 cfs (90 mgd),
- a monthly maximum of 59 cfs (38.1 mgd); and
- an annual average of 51 cfs (32.7 mgd).

The criteria used for MFL development in LPR was the available habitat less than two ppt or less than five ppt. Unlike SC, the habitat metrics (volume, bottom area, and shoreline length) were not highly correlated. Therefore, volume, bottom area, and shoreline length less than two ppt or less than five ppt were all used for the LPR. A hydrodynamic model was developed by District staff to predict salinity in LPR as a function of flow and other variables.

The hydrodynamic model was used to estimate available habitat in the study area (rkm 0 to rkm 58) for the observed flows in the LPR (baseline scenario) and various flow reduction scenarios for the period 1996 to 1999. In order to be conservative, the SC flows were reduced by the maximum allowable amount as recommended in Table 8-9 for all LPR scenarios. For the flow reduction scenarios, the flows at Arcadia, Joshua Creek, and Horse Creek were all reduced according to their relative contribution to the combined flow (Arcadia + Joshua Creek + Horse Creek). Unlike SC, a low flow cutoff for the combined flows at Arcadia, Joshua Creek, and Horse Creek of 90 cfs was used. In other words, if the combined flow (Arcadia + Joshua Creek + Horse Creek) was less than 90 cfs, no water was taken out. Additionally, the combined flow was never allowed to be reduced to less than 90 cfs by withdrawals.

In addition to examining the extent of the biologically-relevant salinities over the entire study area, a more spatially-specific assessment of salinity within a portion of the Lower Peace River was also deemed critical. As discussed above, studies have shown that the area of the river approximately located at Zone 3 (Figure 7-15) has a significantly abundant and diverse fish community. Earlier work has shown that this region is characterized by salinities typically in the range of 8-16 ppt (Mote 2002). Therefore, the volume of water meeting the appropriate salinity range in Zone 3 (i.e., volume of water with salinity between 8 and 16 ppt) was also analyzed.

The amount of available habitat was determined for each scenario for the period 1996-1999 for each of the three Blocks and flow conditions (low flow condition [less than median for the Block] and high flow condition [greater than median flow for the Block]). As with SC, the threshold used to determine the MFL was a 15% reduction in available habitat compared to the baseline. For each Block and flow condition, the most conservative criterion was selected amongst the metrics discussed above for the entire study area or volume between 8 and 16 ppt in Zone 3.

The recommended MFLs for LPR by Block and flow condition are presented in Table 8-10 along with the median flow (Arcadia + Joshua + Horse) by Block.

Table 8-10. Summary of allowable percent reduction in flow for Lower Peace River by block and flow condition, including median flow (Arcadia + Joshua + Horse) by Block.

Block	Median Flow (cfs)	Allowable Percent Reduction in Flow Under:	
		Low Flow Condition	High Flow Condition
Block 1 (April 20 – June 25)	221	10%	26%
Block 2 (October 27 – April 19)	330	14%	21%
Block 3 (June 26 – October 26)	1370	12%	15%

As stated in Section 1.3, the goal of the percent-of-flow method is to maintain the natural flow regime, albeit with some dampening allowed due to withdrawals. In the LPR a low flow threshold of 90 cfs is in effect. Therefore, the combined flow (Arcadia + Joshua Creek + Horse Creek) is never allowed to go below 90 cfs as a result of withdrawals. Therefore, the percentages in Table 8-10 should be applied as described in the following example. For example, if the flow on a given day in Block 1 is 95 cfs (i.e., below the median for Block 1), then the maximum allowable withdrawal would be 95*10% = 9.5 cfs. However, a reduction of 9.5 cfs would cause a flow below the low flow threshold. Therefore, only 5 cfs would be taken thus maintaining the 90 cfs low flow threshold. If the flow on a given day in Block 1 is 300 cfs (i.e., above the median for Block 1), then the maximum allowable withdrawal would be 10% of 221 cfs plus 26% of the difference between 300 cfs and the median ([221cfs * 10%] + [(300 – 221)* 26%] = 22.1 + 20.5 = 42.6 cfs).

The hydrographs of the LPR median daily flows for the Baseline and flow remaining after the maximum allowable withdrawals were taken is presented in Figure 8-19 for the period 1966 to 2004.

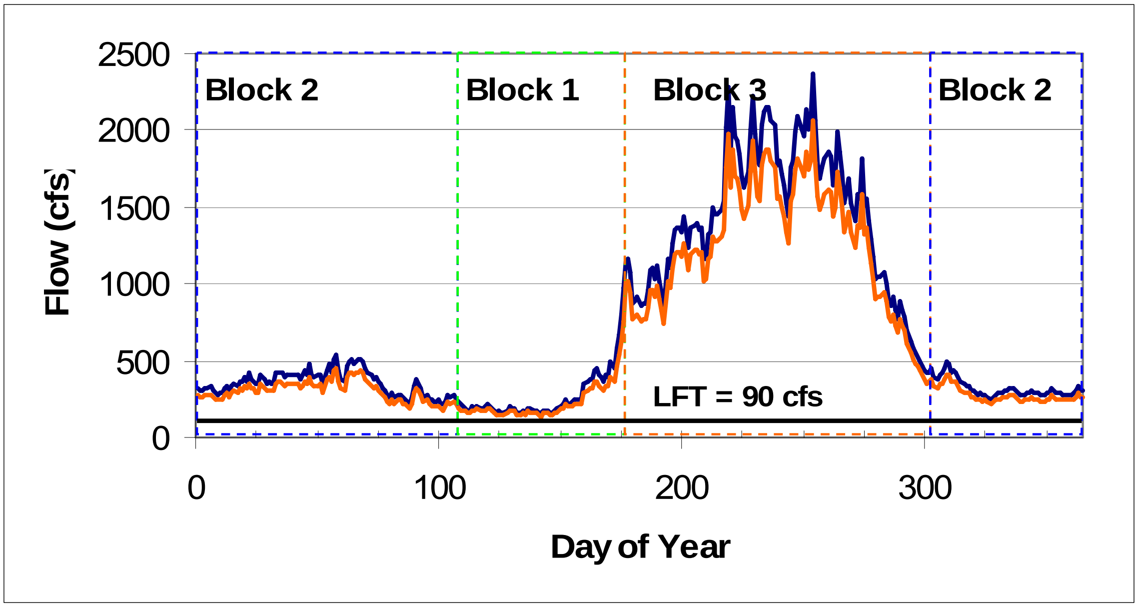


Figure 8-19. Hydrographs of the median daily Lower Peace River flows for the Baseline (blue line) and flow remaining after the maximum allowable withdrawals were taken (orange line).

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