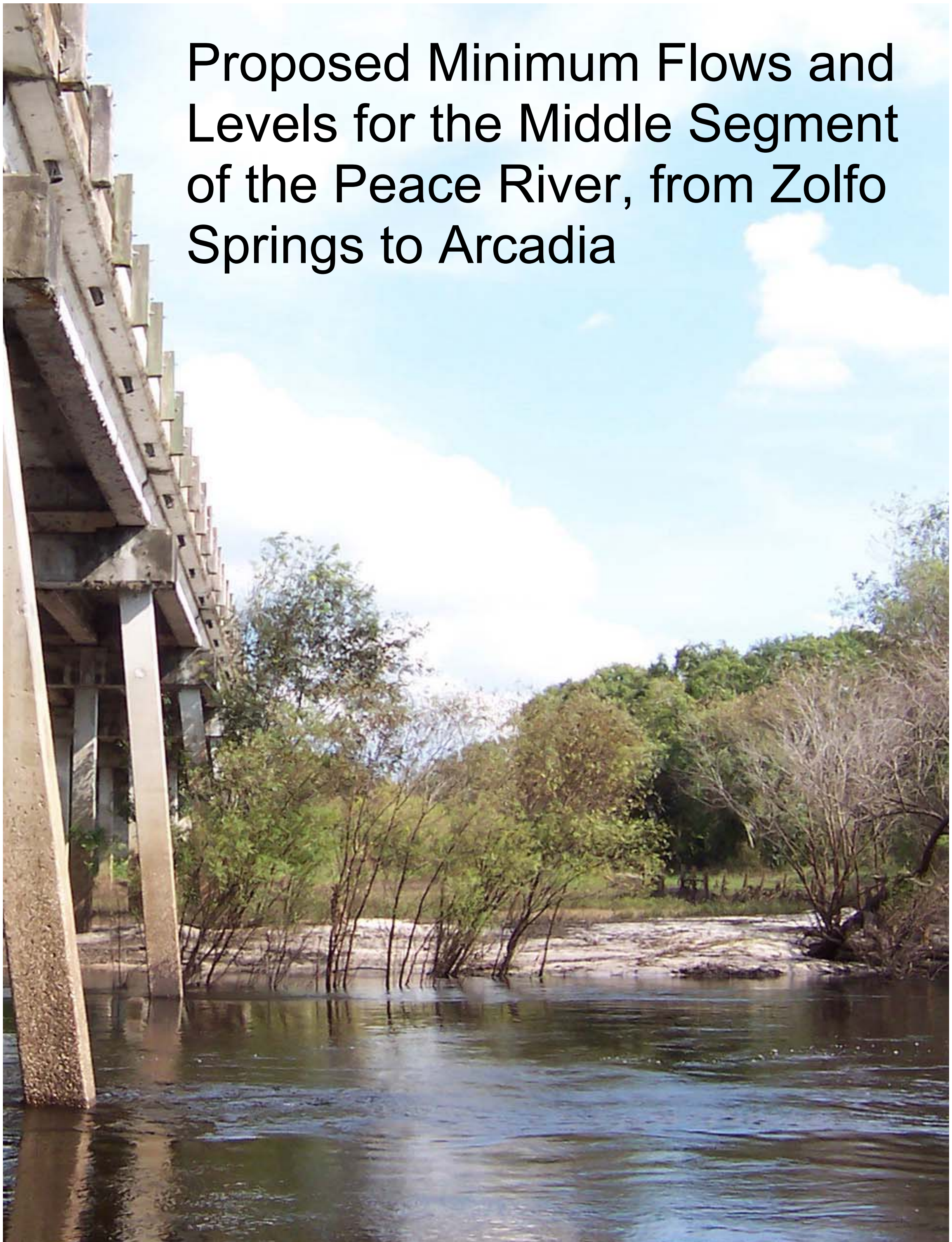
Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia



Southwest Florida
Water Management District

Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia

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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 middle segment of the Peace River, defined as the stretch of the river from the United States Geological Survey Peace River at Zolfo Springs gage downstream to Peace River at Arcadia gage.

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 to what extent 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 middle Peace River which have been ascribed to human causes by some investigators, are largely a function of climatic variation.

For development of MFLs for the middle Peace River, the District identified seasonal blocks corresponding to periods of low, medium and high flows. Short-term minimum flow compliance standards for the Zolfo Springs and Arcadia gage sites were developed for each of these seasonal periods using a "building block" approach. 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. Low flow thresholds, based on fish passage depth and wetted perimeter inflection points are also incorporated into the short-term compliance standards.

The low flow threshold is defined to be a flow that serves to limit withdrawals, with no withdrawals permitted unless the threshold is exceeded. For the Arcadia gage site, the low flow threshold was determined to be 67 cubic feet per second (cfs). For the Zolfo Springs gage site, the low flow threshold was determined to be 45 cfs, a flow previously proposed by the District as a minimum flow at the gage site for the upper segment of the Peace River. A Prescribed Flow Reduction for the low flow period (Block 1, which runs from April 20 through June 24) was based on review of limiting factors developed using the Physical Habitat Simulation Model (PHABSIM) to model potential changes in habitat availability for several fish species and macroinvertebrate diversity. It was determined using PHABSIM that the most restrictive limiting factors were habitat requirements for

the fry of spotted sunfish, and the fry of largemouth bass for the Arcadia gage and Zolfo Springs gage, respectively. Simulated reductions in historic flows greater than 10% resulted in more than a 15% loss of available habitat at sites upstream from the Arcadia and the Zolfo Springs gages. Using this limiting factor, the prescribed flow reduction for both gage sites during the low flow period was defined as 10% reductions in flow, with the exception that withdrawals should not be allowed to reduce the flow to less than 45 cfs at the Zolfo Springs site and 67 cfs at the Arcadia site. In the event that high flows occur during Block 1, a prescribed flow reduction of 8% applies for both gage sites. This percent of flow reduction is to be applied when flows exceed 1,362 cfs and 783 cfs respectively, at the Arcadia and Zolfo Springs sites.

For the high flow season of the year (Block 3, which runs from June 25 to October 27), a prescribed flow reduction was based on review of limiting factors developed using the HEC-RAS floodplain model and Regional and Long Term Positional Hydrographic (RALPH) analyses to evaluate percent of flow reductions associated with changes in the number of days of inundation of floodplain features. It was determined that a stepped flow reduction of 13% and 8% of historic flows, with the step occurring at the 25% exceedance flow (1,362 cfs) resulted in a decrease of 15% or more in the number of days that flows would inundate floodplain features at the Arcadia gage. A stepped flow reduction of 11% and 8% of historic flows, with the step occurring at the 25% exceedance flow (783 cfs) was established at the Zolfo Springs gage. Using these limiting factors, prescribed flow reductions consistent with the stepped flow reductions described above were established, with the exception that withdrawals should not be allowed to reduce the flow to less than 45 and 67 cfs at the Zolfo Springs and Arcadia gage sites, respectively. The 8% flow reduction is also to be applied during Blocks 1 and 2, if flows exceed 1,362 cfs and 783 cfs, respectively, at the Arcadia and Zolfo Springs gage sites. This ensures that high flows are protected for excessive withdrawals, even if they occur during periods typified by low or medium flows.

For the medium flow period (Block 2, which runs from October 28 of one year to April 19 of the next), PHABSIM analyses were used to model flows associated with potential changes in habitat availability for several fish species and macroinvertebrate diversity. In addition, flows associated with inundation of instream woody habitats were evaluated using the HEC-RAS model and RALPH analyses. Using the more conservative of the two resulting flows, it was determined that for both gages PHABSIM would define the percent flow reduction. It was determined that more then 15% of historically available habitat would be lost for specific species life-stages if flows were reduced by more than 18% at Arcadia or more the 10% at Zolfo during the medium flow period. Using these limiting factors, prescribed flow reductions during the medium flow period were defined as 18% and 10% reductions in flow at the Arcadia and Zolfo Springs gage sites, respectively, with the exception that withdrawals would not be allowed to reduce flow at the Arcadia site below 67 cfs or flow at the Zolfo

Springs site below 45 cfs. Based on analyses of high flow reduction during Block 3, a prescribed flow reduction of 8% applies during Block 2 when flows exceed 1,362 cfs or 783 cfs at the Arcadia and Zolfo Springs gage sites, respectively.

Because minimum flows are intended to protect the water resources or ecology of an area, and because climatic variation can influence river flow regimes, we developed long-term compliance standards for the middle Peace River gage sites at Arcadia and Zolfo Springs. The standards are hydrologic statistics that represent flows that may be expected to occur during long-term periods when short term-compliance standards are being met. The long-term compliance standards were generated using gage-specific historic flow records and the short-term compliance standards. For the analyses, the entire flow record for each site was altered by the maximum allowable flow reductions in accordance with the prescribed flow reductions and the low flow thresholds. Hydrologic statistics for the resulting altered flow data sets, including five and ten-year mean and median flows were determined and identified as long-term compliance standards. Because these long-term compliance standards were developed using the short-term compliance standards and the historic flow records, it may be expected that the long-term standards will be met if compliance with short-term standards is achieved

Collectively, the short and long-term compliance standards proposed for the USGS gage sites at Zolfo Springs and Arcadia comprise the District's proposed minimum flows and levels for the middle segment of the Peace River. The standards are intended to prevent significant harm to the water resources or ecology of the river that may result from water use. Since future structural alterations could potentially affect surface water or groundwater flow characteristics within the watershed and additional information pertaining to minimum flows development may become available, the District is committed to revision of the proposed levels, if necessary.

Acknowledgement

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Chapter 1 Minimum Flows and Levels

1.1 Overview and Legislative Direction

The Southwest Florida Water Management District (District or SWFWMD), 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.**” Mere development or adoption of a minimum flow, of course, does not protect a water body from significant harm; however, protection, recovery or regulatory compliance can be gauged once a standard has been established. The District's purpose in establishing MFLs is to create a yardstick against which permitting and/or planning decisions regarding water withdrawals, either surface or groundwater, can be made. Should an amount of withdrawal requested cause “significant harm” then a permit cannot be issued. If, when developing MFLs, it is determined that a system is already significantly harmed as a result of existing withdrawals, then a recovery plan is developed and implemented.

According to state law, minimum flows and levels are to be established based upon the best available information (Section 373.042, F.S), and shall be developed with consideration of “...changes and structural alterations to watersheds, surface waters and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer...” (Section 373.0421, F.S.). Changes, alterations and constraints associated with water withdrawals are not to be considered when developing minimum flows and levels. However, according to the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code), “consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic and wetlands ecology, including:

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

Because minimum flows are used for long-range planning and since the setting of minimum flows can potentially impact (restrict) the use and allocation of water, establishment of minimum flows will not go unnoticed or unchallenged. The science upon which a minimum flow is based, the assumptions made, and the policy used must therefore be clearly defined as each minimum flow is developed.

1.2 Historical Perspective

For freshwater streams and rivers, the development of instream flow legislation can be traced to the work of fisheries biologists. Major advances in instream flow methods have been rather recent, dating back not much more than 35 to 40 years. A survey completed in 1986 (Reiser et al. 1989) indicated that at that time only 15 states had legislation explicitly recognizing that fish and other aquatic resources required a certain level of instream flow for their protection. Nine of the 15 states were western states "where the concept for and impetus behind the preservation of instream flows for fish and wildlife had its origins" (Reiser et al. 1989). Stalnaker et al. (1995) have summarized the minimum flows approach as one of standards development, stating that, "[f]ollowing the large reservoir and water development era of the mid-twentieth century in North America, resource agencies became concerned over the loss of many miles of riverine fish and wildlife resources in the arid western United States. Consequently, several western states began issuing rules for protecting existing stream resources from future depletions caused by accelerated water development. Many assessment methods appeared during the 1960's and early 1970's. These techniques were based on hydrologic analysis of the water supply and hydraulic considerations of critical stream channel segments, coupled with empirical observations of habitat quality and an understanding of riverine fish ecology . . . Application of these methods usually resulted in a single threshold or 'minimum' flow value for a specified stream reach."

1.3 The Flow Regime

The idea that a single minimum flow is not satisfactory for maintaining a river ecosystem was most emphatically stated by Stalnaker (1990) who declared that "minimum flow is a myth". The purpose of his paper was to argue that "multiple flow regimes are needed to maintain biotic and abiotic resources within a river ecosystem" (Hill et al. 1991). The logic is that "maintenance of stream ecosystems rests on streamflow management practices that protect physical processes which, in turn, influence biological systems." Hill et al. (1991) identified four types of flows that should be considered when examining river flow requirements, including:

1) flood flows that determine the boundaries of and shape floodplain and valley features;
2) overbank flows that maintain riparian habitats;

3) in-channel flows that keep immediate streambanks and channels functioning; and
4) in-stream flows that meet critical fish requirements.

As emphasized by Hill et al. (1991), minimum flows methodologies should involve more than a consideration of immediate fish needs or the absolute minimum required to sustain a particular species or population of animals, and should take into consideration “how streamflows affect channels, transport sediments, and influence vegetation.” Although, not always appreciated, it should also be noted “that the full range of natural intra- and inter-annual variation of hydrologic regimes is necessary to [fully] sustain the native biodiversity” (Richter et al. 1996). Successful completion of the life-cycle of many aquatic species is dependant upon a range of flows, and alterations to the flow regime may negatively impact these organisms as a result of changes in physical, chemical and biological factors associated with particular flow conditions.

Recently, South African researchers, as cited by Postel and Richter (2004), listed eight general principles for managing river flows:

1) "A modified flow regime should mimic the natural one, so that the natural timing of different kinds of flows is preserved.
2) A river's natural perenniality or nonperenniality should be retained.
3) Most water should be harvested from a river during wet months; little should be taken during the dry months.
4) The seasonal pattern of higher baseflows in wet season should be retained.
5) Floods should be present during the natural wet season.
6) The duration of floods could be shortened, but within limits.
7) It is better to retain certain floods at full magnitude and to eliminate others entirely than to preserve all or most floods at diminished levels.
8) The first flood (or one of the first) of the wet season should be fully retained."

Common to this list and the flow requirements identified by Hill et al. (1991) is the recognition that in-stream flows and out of bank flows are important and that seasonal variability of flows should be maintained. Based on these concepts, the preconception that minimum flows (and levels) are a single value or the absolute minimum required to maintain ecologic health in most systems has been abandoned in recognition of the important ecologic and hydrologic functions of streams and rivers that are maintained by different ranges of flow. And while the term “minimum flows” is still used, the concept has evolved to one that recognizes the need to maintain a “minimum flow regime”. In Florida, for example, the St. Johns River Water Management District typically develops multiple flows requirements when establishing minimum flows and levels (Chapter 40-C8, F.A.C) and for the Wekiva River noted that, “[s]etting multiple minimum levels and flows, rather than a single minimum level and flow, recognizes that lotic [running water] systems are inherently dynamic” (Hupalo et al. 1994).

1.4 Ecosystem Integrity and Significant Harm

"A goal of ecosystem management is to sustain ecosystem integrity by protecting native biodiversity and the ecological (and evolutionary) processes that create and maintain that diversity. Faced with the complexity inherent in natural systems, achieving that goal will require that resource managers explicitly describe desired ecosystem structure, function, and variability; characterize differences between current and desired conditions; define ecologically meaningful and measurable indicators that can mark progress toward ecosystem management and restoration goals; and incorporate adaptive strategies into resource management plans" (Richter et al. 1996). Although it is clear that multiple flows are needed to maintain the ecological systems that encompass streams, riparian zones and valleys, much of the fundamental research needed to quantify the ecological links between the instream and out of bank resources, because of expense and complexity, remains to be done. This research is needed to develop more refined methodologies, and will require a multi-disciplinary approach involving hydrologists, geomorphologists, aquatic and terrestrial biologists, and botanists (Hill et al. 1991).

To justify adoption of a minimum flow for purposes of maintaining ecologic integrity, it is necessary to demonstrate with site-specific information the ecological effects associated with flow alterations and to also identify thresholds for determining whether these effects constitute significant harm. As described in Florida's legislative requirement to develop minimum flows, the minimum flow is to prevent "significant harm" to the state's rivers and streams. Not only must "significant harm" be defined so that it can be measured, it is also implicit that some deviation from the purely natural or existing long-term hydrologic regime may occur before significant harm occurs. The goal of a minimum flow would, therefore, not be to preserve a hydrologic regime without modification, but rather to establish the threshold(s) at which modifications to the regime begin to affect the aquatic resource and at what level significant harm occurs. If recent changes have already "significantly harmed" the resource, or are expected to do so in the next twenty years, it will be necessary to develop a recovery or prevention plan.

1.5 Summary of the SWFWMD Approach for Developing Minimum Flows

1.5.1 Elements of Minimum Flows

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

1) a goal (e.g., non-degradation or, for the District’s purpose, protection from “significant harm”);
2) identification of the resources of interest to be protected;
3) a unit of measure (e.g., flow in cubic feet per second, habitat in usable area, inundation to a specific elevation for a specified duration);
4) a benchmark period, and
5) a protection standard statistic.

The District's approach for minimum flows development incorporates the five elements listed by Beecher (1990). The goal of an MFL determination is to protect the resource from significant harm due to withdrawals and was broadly defined in the enacting legislation as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." What constitutes "significant harm" was not defined. Impacts on the water resources or ecology are evaluated based on an identified subset of potential resources of interest. Ten potential resources were listed in Section 1.1. They are: recreation in and on the water; fish and wildlife habitats and the passage of fish; estuarine resources; transfer of detrital material; maintenance of freshwater storage and supply; aesthetic and scenic attributes; filtration and absorption of nutrients and other pollutants; water quality and navigation. The approach outlined in this report identifies specific resources of interest and identifies when it is important seasonally to consider these resources.

While the main unit of measure used by the District for defining minimum flows is flow or discharge (in cubic feet per second), it will become evident that several different measures of habitat, along with elevations in feet above the National Geodetic Vertical Datum of 1929 (NGVD 1929) associated with these habitats were employed. Ultimately, however, these different measures of habitat and inundation elevations were related to flows in order to derive the minimum flow recommendations.

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 determine if current flows reflect past conditions. If this is the case, the development of minimum flows and levels becomes a question of what can be allowed in terms of withdrawals before significant harm occurs. If there have been changes to the flow regime of a river, these must be assessed to determine if significant harm has already occurred. If significant harm has occurred, recovery becomes an issue. For development of minimum flows for the upper segment of the Peace River (i.e., the river corridor upstream of the United States Geological Survey Peace River at Zolfo Springs, FL. streamflow gage site), the District used a "reference" period, from 1940 through 1956, to evaluate flow regime changes (SWFWMD 2002). More recently, the District has adopted an approach for establishing benchmark flow periods that involves consideration of the effects of multidecadal climatic oscillations on river flow patterns. The approach, which led to identification of separate benchmark periods for flow records collected prior to and after 1970, was used for development of MFLs for the freshwater segment of the Alafia River (Kelly at al. 2004) and has been utilized for analyses of flows in the middle segment of the Peace River.

Following assessment of historic and current flow regimes and the factors that have affected their development, the District develops protection standard statistics or criteria for preventing significant harm to the water resource. For the upper segment of the Peace River, criteria associated with the fish passage in the river channel and maximization of the wetted perimeter were used to recommend a minimum low flow (SWFWMD 2002). Criteria associated with medium and higher flows that result in the inundation of woody habitats associated with the river channel and vegetative communities on the floodplain were described. These criteria were not, however, used to develop recommended levels, due to an inability to separate water withdrawal impacts on river flow from those associated with structural alterations within the watershed. For the middle segment of the Peace River, the District has used criteria to protect low flows and applied approaches associated with development of medium to high flow criteria per recommendations contained in the peer review of the proposed upper Peace River minimum flows (Gore et al. 2002). These efforts have included collection and analyses of in-stream fish and macroinvertebrate habitat data using the Physical Habitat Simulation (PHABSIM) model, and evaluation of inundation characteristics of floodplain habitats.

1.5.2 A Building Block Approach

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.

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. Resource values associated with low, medium and high flows were identified and evaluated for use in the development of MFLs for each flow range. Low minimum flows, corresponding to maintaining instream flow requirements for fish passage and wetted perimeter were proposed. Medium and high minimum flows were not however, proposed for the river segment, due primarily to an inability to separate the effects of natural and anthropogenic factors on flow declines. Nonetheless, methods were used to evaluate potential ecological changes associated with variation in medium to high flows. The methods focused on the inundation of desirable in-stream habitats and on floodplain wetlands. Implicit in this approach was the concept that the three ranges of flow (low, medium and high) were associated with specific natural system values or functions.

For development of minimum flows and levels for the middle segment of the Peace River, the District has explicitly identified three building blocks in its approach. 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 (e.g., Figure 1-1). 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, the 123 day period that immediately follows the dry season (June 26 to October 26). 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.

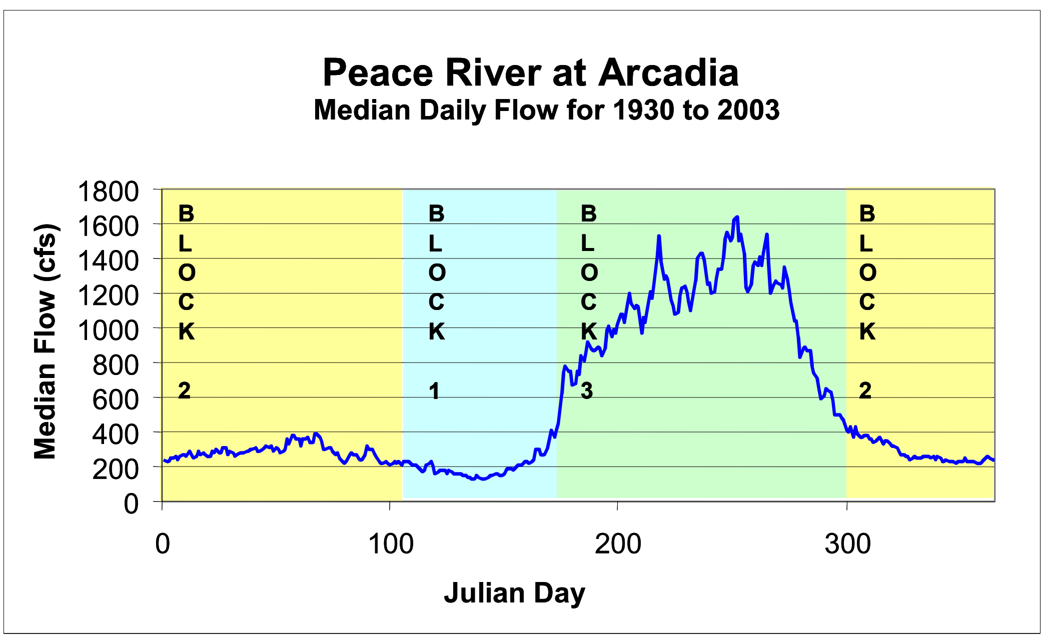


Figure 1-1. Building blocks developed for a building block approach to the development of minimum flows. Blocks corresponding to low (Block 1), medium (Block 2) and high (Block 3) flows are shown along with period of record median daily flows for the USGS Peace River at Arcadia gage.

1.6 Flows and Levels

Although somewhat semantic, there is a distinction between flows, levels and volumes that should be appreciated. All terms apply to the setting of “minimum flows” for flowing waters. The term “flow” may most legitimately equate to water velocity; which is typically measured by a flow meter. A certain velocity of water may be required to physically move particles heavier than water; for example, periodic higher velocities will transport sand from upstream to downstream; higher velocities will move gravel; and still higher velocities will move rubble or even boulders. Flows may also serve as a cue for some organisms; for example, certain fish species search out areas of specific flow for reproduction and may move against flow or into areas of reduced or low flow to spawn. Certain macroinvertebrates drift or release from stream substrates in response to changes in flow. This release and drift among other things allows for colonization of downstream areas. One group of macroinvertebrates, the caddisflies, spin nets in the stream to catch organisms and detritus carried downstream, and their success in gathering/filtering prey is at least partially a function of flow. Other aquatic species have specific morphologies that allow them to inhabit and exploit specialized niches located in flowing water; their bodies may be flattened (dorsally-ventrally compressed) to allow them to live under rocks or in crevices; they may have special holdfast structures such as hooks or even secrete a glue that allows them to attach to submerged objects.

Discharge, on the other hand, refers to the volume of water moving past a point per unit time, and depending on the size of the stream (cross sectional area), similar volumes of water can be moved with quite large differences in the velocity. The volume of water moved through a stream can be particularly important to an estuary. It is the volume of freshwater that mixes with salt water that determines, to a large extent, what the salinity in a fixed area of an estuary will be. This is especially important for organisms that require a certain range of salinity. The volumes of fresh and marine water determine salinity, not the flow rate per se; therefore, volume rather than flow is the important variable to these biota. For the purpose of developing and evaluating minimum flows, the District identifies discharge in cubic feet per second for field-sampling sites and specific streamflow gaging stations.

In some cases, the water level or the elevation of the water above a certain point is the critical issue to dependent biota. For example, the wetland fringing a stream channel is dependent on a certain hydroperiod or seasonal pattern of inundation. On average, the associated wetland requires a certain level and frequency of inundation. Water level and the duration that it is maintained will determine to a large degree the types of vegetation that can occur in an area. Flow and volume are not the critical criteria that need to be met, but rather elevation or level.

There is a distinction between volumes, levels and velocities that should be appreciated. Although levels can be related to flows and volumes in a given stream (stream gaging, in fact, depends on the relationship between stream stage or level and discharge), the relationship varies between streams and as one progresses from upstream to downstream in the same system. Because relationships can be empirically determined between levels, flows and volumes, it is possible to speak in terms of, for example, minimum flows for a particular site (discharge in cubic feet per second); however, one needs to appreciate that individual species and many physical features may be most dependent on a given flow, level or volume or some combination of these three for their continued survival or occurrence. The resultant ecosystem is dependent on all three.

1.7 Content of Remaining Chapters

In this chapter, we have summarized the requirements and rationale for developing minimum flows and levels in general and introduced the need for protection of the flow regime rather than protection of a single minimum flow. The remainder of this document considers the development of minimum flows and levels specific to the middle segment Peace River, which is defined as the river corridor occurring between streamflow gaging stations near Zolfo Springs and Arcadia. In Chapter 2, we provide a short description of the entire river basin and its hydrogeologic setting, and consider historic and current river flows and the factors that have influenced the flow regimes. Identification of at least two benchmark periods of flow, resulting from natural climatic oscillations is noted and seasonal blocks corresponding to low, medium and high flows are identified. Water quality changes related to flow are also summarized in Chapter 2 to enhance understanding of historical flow changes in the watershed. Chapter 3 includes a discussion of the resources of concern and key habitat indicators used for developing minimum flows. Specific methodologies and tools used to develop the minimum flows are outlined in Chapter 4. In Chapter 5, we present results of our analyses and provide flow prescriptions that are used for developing proposed minimum flows for the middle segment of the Peace River. The report concludes with recommendations for evaluating compliance with the proposed minimum flows, based on the proposed short and long-term compliance standards for the middle Peace River.

Chapter 2 Basin Description With Emphasis On Land Use, Hydrology And Water Quality

2.1 Overview

This chapter includes a brief description of the Peace River watershed and is followed by a presentation and discussion of land use, hydrology, and water quality data relevant to the development of MFLs on the middle segment of the Peace River. Land use changes within the basin are evaluated to support the hydrology discussion that follows and to address questions that have been raised regarding the potential impact of land use changes on river flow volumes (Hammett 1995, SDI 2003). Flow trends and their potential causes are discussed for the Peace River and other regional rivers to provide a basis for identifying benchmark periods and seasonal flow blocks that are used for a building block approach to the establishment of minimum flows. Water chemistry changes are discussed to illustrate how land use changes associated with phosphate mining have played a significant role in observed trends in certain water quality parameters, and to demonstrate how these trends are useful in interpreting flow changes over time.

2.2 Watershed Description

2.2.1 Geographic Location

The Peace River basin has a drainage area of approximately 2,345 square miles (Figure 2-1) that includes portions of eastern Sarasota, Manatee, and Hillsborough counties, parts of central and southern Polk County, most of Hardee and DeSoto counties, part of northern Charlotte County, and western portions of Highlands County. The principal drainage system within the basin is the Peace River, which originates at the confluence of Saddle Creek and the Peace Creek/Canal system. Other tributaries include Payne Creek, Charlie Creek, Horse Creek, Joshua Creek, and Shell Creek. The Peace River is a free-flowing system over its entire length, although two of its tributaries, Saddle Creek and Shell Creek have regulated flow.

Figure 2-1. Map of Peace River watershed showing the Peace River main-stem and tributaries, sub-basins and long-term USGS gage site locations.

Saddle Creek and Peace Creek, the two principal tributaries of the Peace River, originate on the southern boundary of Green Swamp in Polk County. An 11.1 mile channelized portion of Peace Creek, known as the Peace Creek Canal, drains 229 square miles. Saddle Creek is approximately 2.8 miles long and drains 144 square miles. There are numerous lakes in the Peace and Saddle Creek sub-basins, and many are linked by systems of canals. In some, there is continual flow between lakes; in others, flow occurs only under high-water conditions. There are fixed or operable control structures on many of the lake outlets (Texas Instruments 1976), including the District's P-11 structure on Saddle Creek, south of Lake Hancock.

The main stem of the Peace River begins just south of Lake Hancock at an elevation of approximately 100 feet above the National Geodetic Vertical Datum of 1929. The river flows southward for about 75 miles through Polk, Hardee, DeSoto and Charlotte Counties and discharges into the northeastern portion of Charlotte Harbor near the City of Punta Gorda. Shell Creek, one of the river's tributaries discharging to the estuarine portion of the river is impounded to form a water supply reservoir at the City of Punta Gorda. Charlotte Harbor is a large bay with a surface area of approximately 142 square miles and an average depth of about 11 feet, which gives a volume of 43.5 billion cubic feet at mean low water (Texas Instruments 1976).

The channel of the Peace River upstream from Arcadia is well defined. Downstream from Arcadia, the river’s flood plain widens, and the channel becomes braided. In some places, the marsh and swampy area bordering the river spans more than a mile. During periods of low flow, the river is tidally affected upstream from Fort Ogden, which is about 10 miles southwest of the United States Geological Survey Peace River at Arcadia gage site. Several areas near the mouth of the Peace River have been channelized for development of waterfront home sites. Sea walls and bulkheads are commonplace (Hammett 1990).

For the purpose of minimum flow development as discussed in this report, the middle Peace River is defined as segment of the river between the USGS Peace River at Zolfo Springs, FL and the Peace River at Arcadia, FL gage sites.

2.2.2 Climate

The climate of west-central Florida is described as humid subtropical. The mean annual temperature for Hillsborough County is 72.2°F, ranging from normal maximums of 91°F in July and August to a typical low of 49° F in January. The average annual rainfall based on a number of rainfall stations in the area is approximately 52 to 53 inches. The Arcadia gage is typical for the area and has a record that extends back to 1908 (see Figure 2-2). Annual rainfall totals of less than forty inches were recorded for ten years during the period of record while the highest three yearly rainfall totals occurred in 1947, 1982 and 1959 (80, 78 and 74 inches, respectively). Approximately 60% of annual precipitation falls during the months of June, July, August and September.

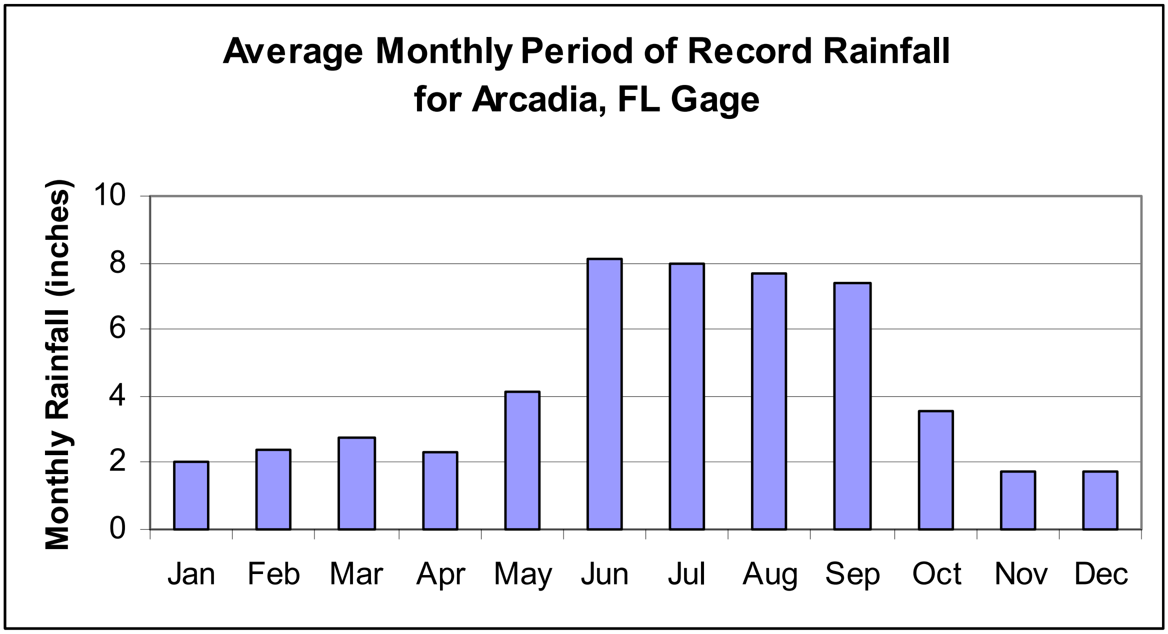


Figure 2-2. Average total monthly rainfall at Arcadia, FL gage for period of record 1908 to 2000.

2.2.3 Physiography (taken from SWFWMD 2001a and 2002)

The physiography of the Peace River watershed ranges from an internally drained lake district with high ridges in Polk County, to a poorly-drained upland that extends into the northern half of Hardee County, to a broad, gently-sloping plain with well-developed surface drainage in southern Hardee and most of DeSoto Counties. White (1970) classified these regions as the Polk Upland, DeSoto Plain and Gulf Coastal Lowlands. Brooks classified the regions as the Bone Valley Uplands, DeSoto Slope and Barrier Island Coastal Strip, and included the Bartow Embayment and Winter Haven Karst in the upland area. The physiographic boundaries generally correspond to paleoshorelines (ancient shorelines). A paleoshoreline at the 100-foot elevation separates the upland regions from the plain, and the 30-foot elevation separates the plain from the low coastal region (Lewelling et al. 1998).

The Bartow Embayment, which extends from above Lake Hancock to directly north of Homeland, is an internally drained, local erosional basin that has been partially infilled with phosphate-rich siliclastic deposits (Brooks 1981). The Winter Haven Karst, lying to the east of the Bartow Embayment, includes numerous lake features. The Polk Upland (White 1970) extends south from Homeland to Zolfo Springs, and it corresponds to the Bone Valley Uplands defined by Brooks (1981). Polk Upland land surface elevations are generally greater than 130 feet above sea level. The area contains flatwoods, wetlands and lakes that occupy a poorly-drained plateau underlain by deeply weathered sand and clayey sand of the Bone Valley Member of the Peace River Formation. Natural drainage upstream of Bowling Green has been altered by phosphate mining activity. The DeSoto Slope (Brooks 1981), or the DeSoto Plain (White 1970), consists of wet prairie, swamp, and flatwoods with a well-developed surface drainage system. The Gulf Coastal Lowlands (White 1970) and the Barrier Islands Coastal Strip (Brooks 1981) are located where the Peace River discharges into the Charlotte Harbor Estuary

2.2.4 Hydrogeology

The Peace River is located within the Southern West-Central Florida Ground-Water Basin, an aquifer system described by Moore et al. (1987). In general, the geology underlying this area consists of a series of clastic sediments underlying carbonate rocks. Three recognized aquifer systems that occur in the region are the Surficial, the Intermediate and the Floridan aquifer systems. At the surface and extending up to several tens of feet thick is the unconfined Surficial Aquifer System. This aquifer system is generally comprised of unconsolidated quartz sand, silt, and clayey sand. Underlying the Surficial Aquifer System is the confined Intermediate Aquifer System, which consists of a series of thin, interbedded limestone and phosphatic clays of typically low permeability. The confined Floridan Aquifer System underlies the Intermediate Aquifer System. The Floridan Aquifer System is composed of a series of limestone and dolomite formations.

The Floridan Aquifer System is further divided into the Upper Floridan and Lower Floridan aquifers which are separated by a middle confining unit consisting of a thick, massive sequence of evaporite materials of extremely low permeability (Miller 1986). The Lower Floridan aquifer is comprised of interbedded dolomite and anhydrite hydraulically isolated from the Upper Floridan aquifer, generally low in permeability, and is brine-saturated. Because of its poor water quality, deep depth, and limited ability to yield water, the Lower Floridan aquifer has only been used for disposal of industrial waste through deep well injection in the Southern West-Central Florida Ground-Water Basin. However, it is a source of potable water in east-central Florida.

2.3 Land Use Changes in the Peace River Watershed

2.3.1 Peace River Watershed

A series of maps, tables and figures were generated for the entire Peace River watershed for three specific years (1972, 1990 and 1999) for purposes of reviewing land use changes that have occurred during the last several decades. The 1972 maps, tables and figures represent land use and land cover generated using the USGS classification system (Anderson et al. 1976). The USGS classification system incorporates a minimum mapping unit of 10 acres for man-made features with a minimum width of 660 feet. The minimum mapping unit for non-urban and natural features is 40 acres for areas with a minimum width of 1320 feet. The 1990 and 1999 maps and data represent land use and land cover information developed using the Florida Department of Transportation's (1999) Florida Land Use, Cover and Forms Classification System (FLUCCS). The FLUCCS system is more detailed than the USGS system, with minimum mapping units of 5 acres for uplands and 0.5 acres for wetlands. Differences in land-use estimates for the three periods may therefore be attributed to analytic precision differences. However, for presentation and discussion purposes, we combined numerous land use types into fairly broad categories, and thereby eliminated much of the error associated with use of the two classification systems.

For our analyses, land use/cover types identified included: urban; uplands (rangeland and upland forests); wetlands (wetland forests and nonforested wetlands); mines; water; citrus; and other agriculture. We examined changes in these use/cover types for the entire watershed and also for ten sub-basins (Figure 2-1), which included: Peace Creek, Saddle Creek, Payne Creek, Peace River at Zolfo Springs (the area draining to the river between the Bartow and Zolfo Springs gages excluding Payne Creek), Charlie Creek, Peace River at Arcadia (the area draining to the river between the Zolfo Springs and Aracdia gages, excluding Charlie Creek), Horse Creek, Joshua Creek, Shell/Prairie Creek, and the Coastal Sub-basin (area below Arcadia gage excluding Joshua, Horse, and Shell/Prairie Creeks). Since this MFL report addresses the middle segment of the Peace River, most of the discussion that follows deals with sub-basins above the Peace River gage at Arcadia, including Peace Creek, Saddle Creek, Payne Creek, Peace River at Zolfo Springs, Charlie Creek and Peace River at Arcadia. The Horse Creek sub-basin, which contributes flow to the river below the Arcadia gage, is considered in some detail because of similarities between it and Charlie Creek.

Land use/cover maps for 1972, and 1999 for the entire Peace River watershed are shown in Figures 2-3 and 2-4. Based on these maps, the Peace River watershed is 2,345 square miles or 1,501,318 acres in size. The upper Peace River, i.e., the area above the Zolfo Springs gage, is 827 square miles as compared with an area of 822 square miles as reported by the USGS. The area above the Arcadia gage is 1361 square miles compared with the 1367 square miles reported by the USGS.

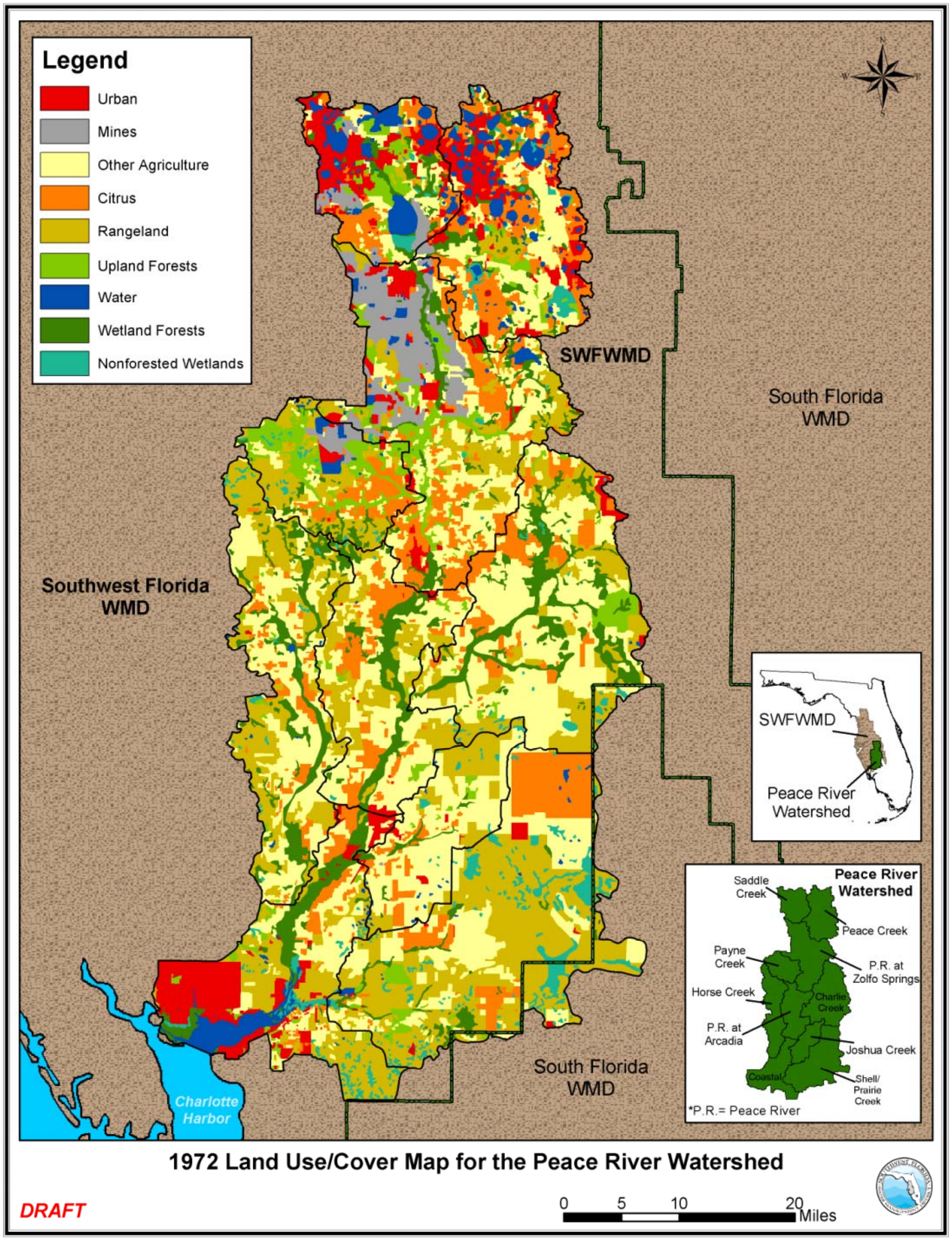


Figure 2-3. 1972 Land use/cover map of the Peace River watershed.

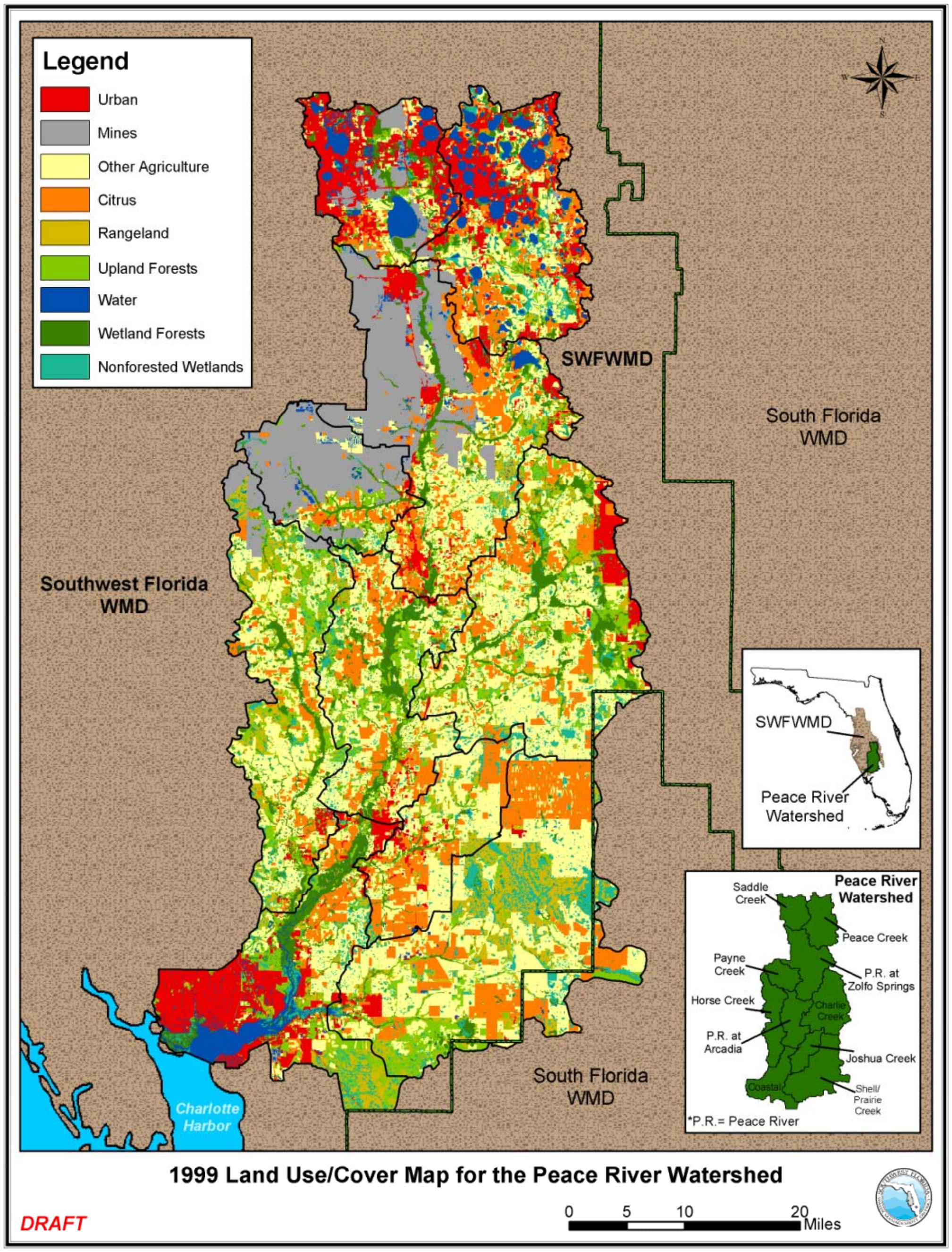


Figure 2-4. 1999 Land use/cover map of the Peace River watershed.

Based on the 1999 map, citrus and other agriculture combined comprised 44% of the land use/cover in the Peace River watershed (Table 2-1, Figure 2-5). Uplands and wetlands account for a combined 32%, while urban and mine land uses were approximately 10% in each case. Open water accounts for less than 5% of the land cover of the basin. Over the 28 year span from 1972 to 1999, the biggest land use/cover change has been with respect to uplands. A total of 299 square miles of uplands, amounting to almost 13% of the watershed, has been converted to other uses. Part of this estimated loss of uplands is probably due to classification of some upland areas as wetlands for the more recent period. This was a result of differences in mapping resolution for the data sets, and not due to an actual increase in wetland area. Mines and urban land use/cover types showed substantial increases between 1972 and 1999.

Of the approximately 230 square miles of mined lands shown on the 1999 land cover map, 90% occur in the Zolfo Springs and Payne Creek sub-basins with much of the remainder occurring in the now heavily urbanized Saddle Creek sub-basin. These mined areas tend to retain initial rainfall volumes and provide surface discharge only after internal storage areas are filled. Current rules of the Department of Environmental Protection require that lands mined after July 1, 1975 must be reclaimed. Fifty-nine percent of lands mined in Florida between July 1, 1975 and December 1, 2000 have been reclaimed. Reclamation techniques have evolved since 1975, and reclaimed lands in the upper Peace River basin reflect a mix of reclamation strategies.

According to the 1999 land cover map, there are approximately 245 square miles of urbanized land in the Peace River watershed. Population centers are located in the uppermost part of the watershed and in the Charlotte Harbor area. One hundred and thirty-five square miles of the 245 square miles (56%) of urbanized area occurs in the upper watershed in the vicinity of Winter Haven, Lakeland, and Bartow; most of the remainder abuts Charlotte Harbor (see Figure 2-4).

Excluding open water associated with Charlotte Harbor, most open water features (e.g., lakes, reservoirs, and mine pits) in the Peace River watershed are found in the upper Peace sub-basin. As discussed elsewhere (SWFWMD 2002), the lakes in the upper Peace Basin can potentially store large quantities of water; however, there is evidence that considerable storage potential has been lost due to lowering of lakes in the area by construction of outlet canals.

The middle segment of the Peace River is comprised of two sub-basins, the Charlie Creek sub-basin and the Peace River at Arcadia sub-basin. The Charlie Creek watershed extends over 334 square miles, and the Peace River at Arcadia sub-basin is 200 square miles in size. Therefore, the middle Peace River basin encompasses 534 square miles, and combined with the area of the upper Peace River (826 square miles), the watershed area that drains past the Arcadia gage is approximately 1360 square miles. The major land use/cover in the 534 square mile middle Peace River watershed is agriculture (15% citrus and 41% other agriculture). Less than 5% of the watershed is urbanized, 19% is uplands and almost 20% is classified as wetlands. Less than 0.1% of this area has been mined.

Table 2-1. Land use and land cover percentages in the Peace River watershed for three time periods, 1972, 1990 and 1999.

Peace River Watershed	1972	1990	1999
Urban	7.0%	9.7%	10.5%
Citrus	14.3%	12.6%	14.5%
Other Agriculture	29.9%	31.7%	29.4%
Uplands	29.0%	18.1%	16.3%
Wetlands	12.7%	15.9%	15.5%
Mines	3.4%	8.4%	9.8%
Water	3.7%	3.6%	4.1%
Total acres	1501318	1501318	1501318

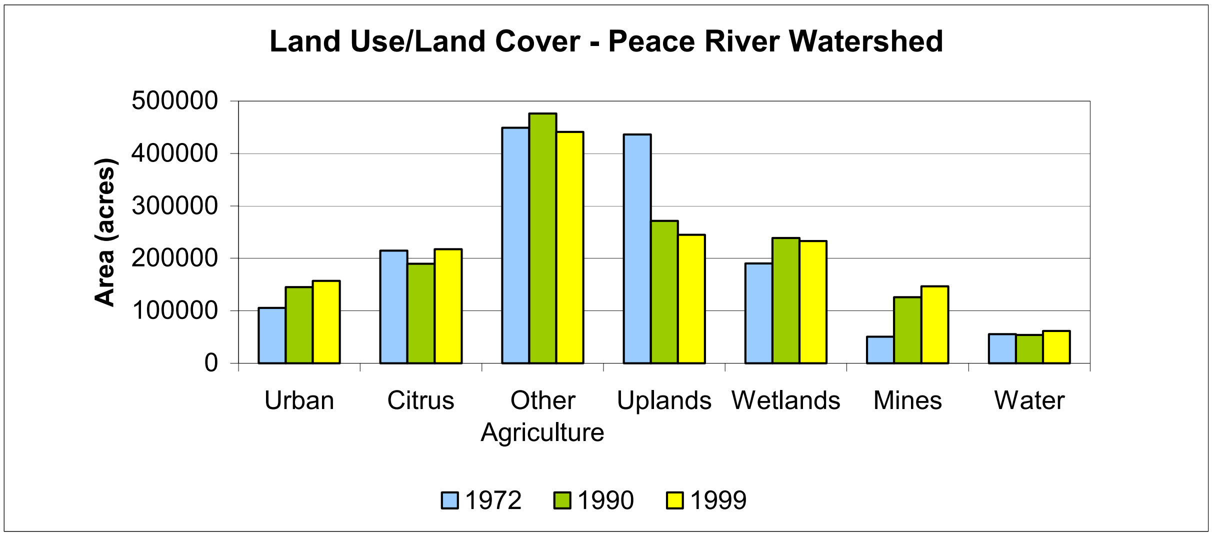


Figure 2-5. Land use/cover acreage in the Peace River watershed in 1972, 1990 and 1999.

2.3.2 Peace Creek Sub-Basin

The Peace Creek sub-basin is 229 square miles in size. Land use/cover within the sub-basin consists predominantly of urban development within the upper portion, and agricultural lands, mainly pasture lands, in the lower portion. Most of the lakes in the Peace River watershed are located in the headwaters of the upper Peace River above the confluence of Saddle Creek and the Peace Creek/Canal system. A total of 152 lakes occur in this headwaters area, with a combined surface area of 32,000 acres. There are 115 lakes in the Peace Creek basin, and they range in size from 2 to 2,162 acres. Drainage features associated with nearly all of the lakes within the watershed been altered. For example, the lakes that comprise the Winter Haven Chain of Lakes historically differed in surface-water elevations over a range of several feet; however, with the construction of interconnecting canals in the 1920s for recreational boating purposes, these lakes now fluctuate at approximately the same elevation under control of a structure on Lake Lulu which discharges ultimately to the Peace Creek/Canal system.

2.3.3 Saddle Creek Sub-Basin

The Saddle Creek sub-basin encompasses approximately 144 square miles. It is proportionally the most urbanized (39%) sub-basin in the watershed. In addition to its urbanized acreage, this sub-basin, like the Peace Creek sub-basin, has a substantial area in open water features (primarily lakes and phosphate mine pits). There are over 14,000 acres in surface water including Lake Hancock, the largest lake in the Peace River watershed.

2.3.4 Peace River at Zolfo Springs Sub-Basin

The Peace River at Zolfo Springs sub-basin is 328 square miles in size. As of 1999, almost half (112 square miles) of the mined area in the Peace River watershed occurred in this sub-basin. Inspection of the 1999 Zolfo Springs land use/cover map shows that most of this mining related acreage occurs in the upper half of the sub-basin (above Ft. Meade) with mined lands occurring on both sides of the Peace River from Bartow south to Ft. Meade. Tributaries of this reach of the river (e.g., Six Mile Creek and Barber Branch) have also been mined, and their basins are now part of water control systems for the mined lands, from which water is periodically released the river (SWFWMD 2002).

2.3.5 Payne Creek Sub-Basin

The Payne Creek sub-basin is 125 square miles in size, and on a percentage basis (64%) the most heavily mined sub-basin in the watershed. It is second only to the nearby South Prong of the Alafia River in terms of the percent of watershed mined for phosphate within the District.

2.3.6 Charlie Creek Sub-Basin

The Charlie Creek sub-basin is one of the larger sub-basins in the watershed with an area of 334 square miles or 213,834 acres. As of 1999 (Table 2-2, Figure 2-6), most of the sub-basin was used for agricultural purposes (14% citrus and 43% other agriculture). Much of the sub-basin is relatively undeveloped (18% uplands, 19% wetlands) with only 5% of the area classified as urban. There are no significant mining activities or surface water features in the watershed. Between the1972 and1999 land use studies (Figures 2-7 to 2-8), the area of the watershed in uplands decreased by 6% while the percentage of the watershed in urban and citrus increased by 4 and 3 percent, respectively.

Table 2-2. Land use/cover and land cover percentages in the Charlie Creek watershed for three time periods, 1972, 1990 and 1999.

Charlie Creek	1972	1990	1999
Urban	1.2%	4.9%	5.4%
Citrus	11.0%	11.7%	13.6%
Other Agriculture	45.4%	45.2%	43.0%
Uplands	24.6%	19.1%	18.4%
Wetlands	17.7%	18.9%	19.1%
Mines	0.0%	0.0%	0.0%
Water	0.1%	0.2%	0.4%
Total acres	213834	213834	213834

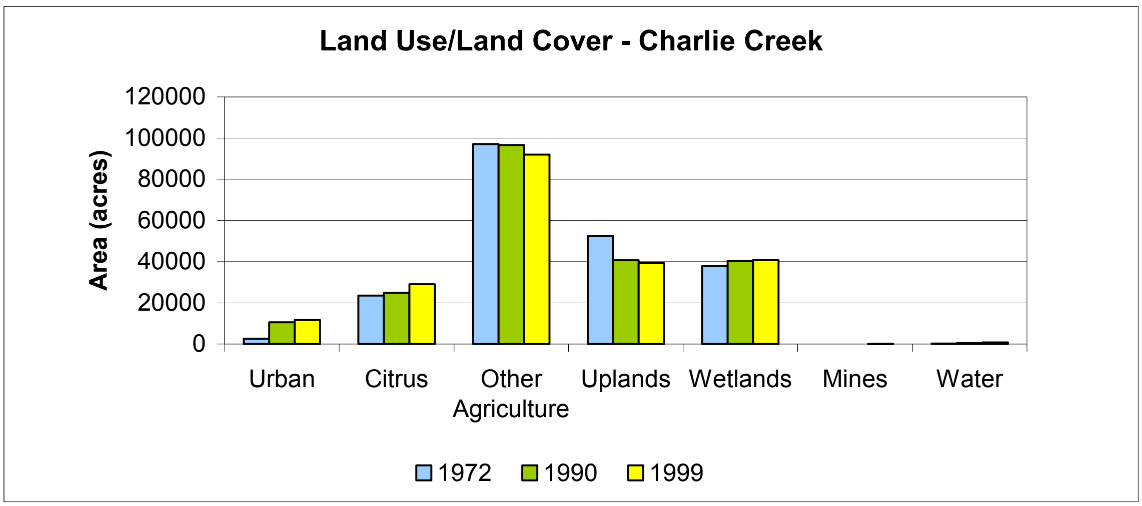


Figure 2-6. Land use/cover acreage in the Charlie Creek sub-basin in 1972, 1990 and 1999.

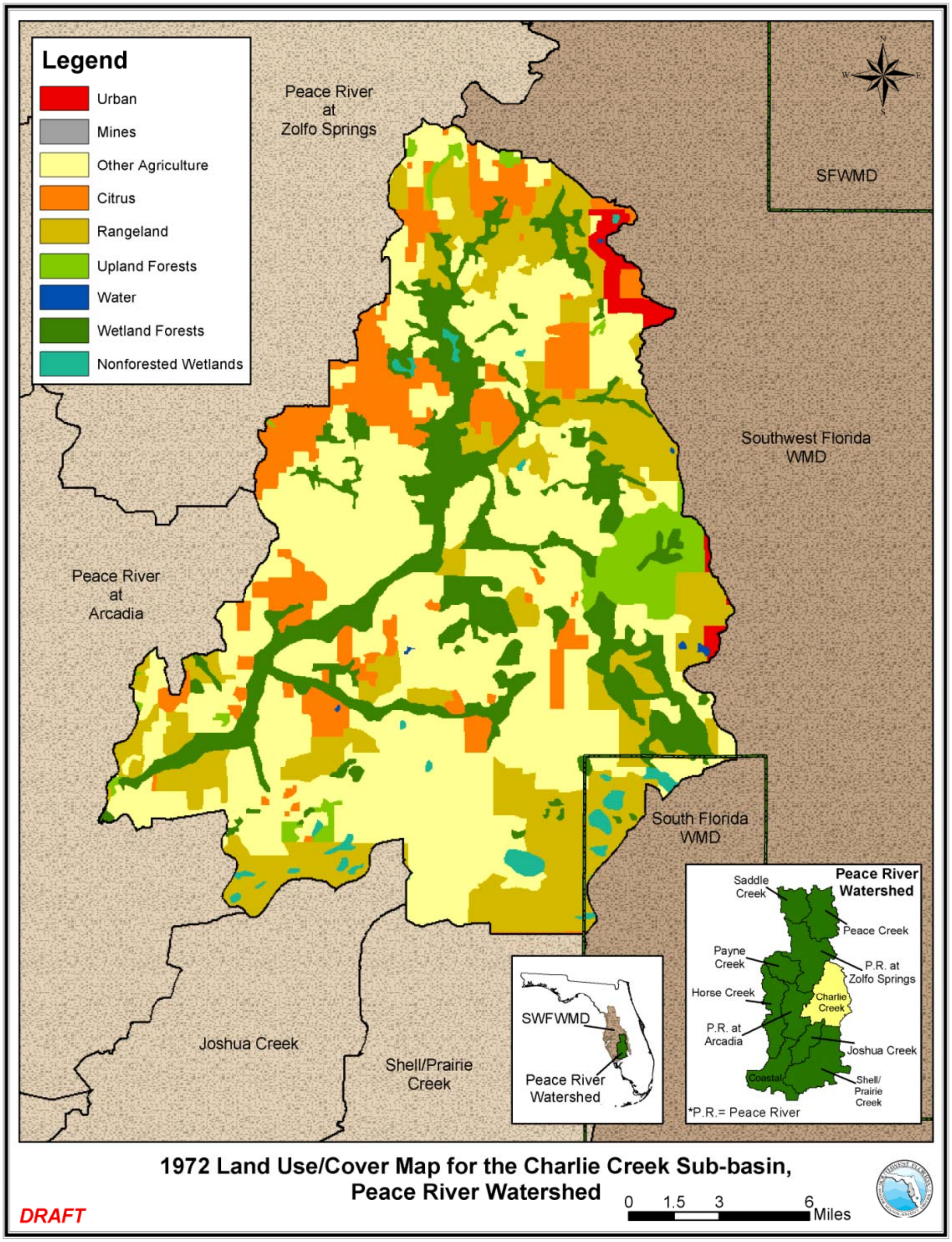


Figure 2-7. 1972 Land use/cover map of the Charlie Creek sub-basin.

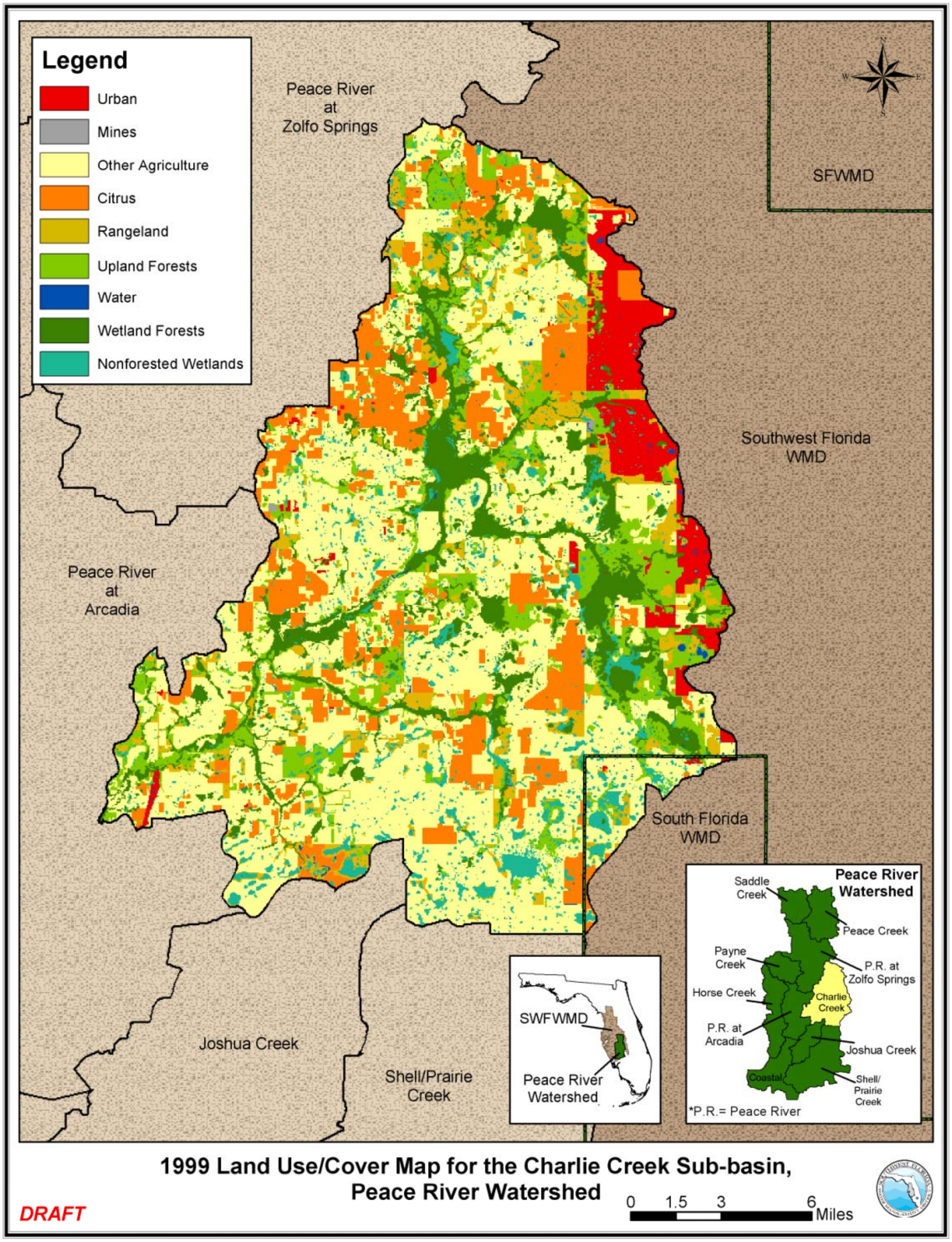


Figure 2-8. 1999 Land use/cover map of the Charlie Creek sub-basin.

2.3.7 Peace River at Arcadia Sub-Basin

The area of the Peace River at Arcadia sub-basin is 200 square miles or 128,135 acres. In 1999 (Table 2-3, Figure 2-9), 56% of the watershed was in agricultural land uses (17% citrus, 39% other agriculture). Twenty-one percent of the watershed was in uplands and 19% in wetlands in 1999. Between the 1972 and 1999 land use surveys (Figures 2-10 to 2-11), land use/cover changed very little in this sub-basin. Between 1972 and 1999 the area of wetlands increased by the same amount that uplands decreased. This may likely be attributed to differences in mapping resolution for the two time periods rather than to an actual increase in wetland area.

Table 2-3. Land use/cover percentages in the Peace River at Arcadia sub-basin for three time periods, 1972, 1990 and 1999.

Peace River at Arcadia	1972	1990	1999
Urban	1.3%	2.6%	3.3%
Citrus	16.8%	14.6%	17.3%
Other Agriculture	42.2%	41.4%	38.8%
Uplands	25.4%	19.4%	18.9%
Wetlands	14.2%	21.6%	21.1%
Mines	0.0%	0.0%	0.1%
Water	0.1%	0.4%	0.5%
Total acres	128135	128135	128135

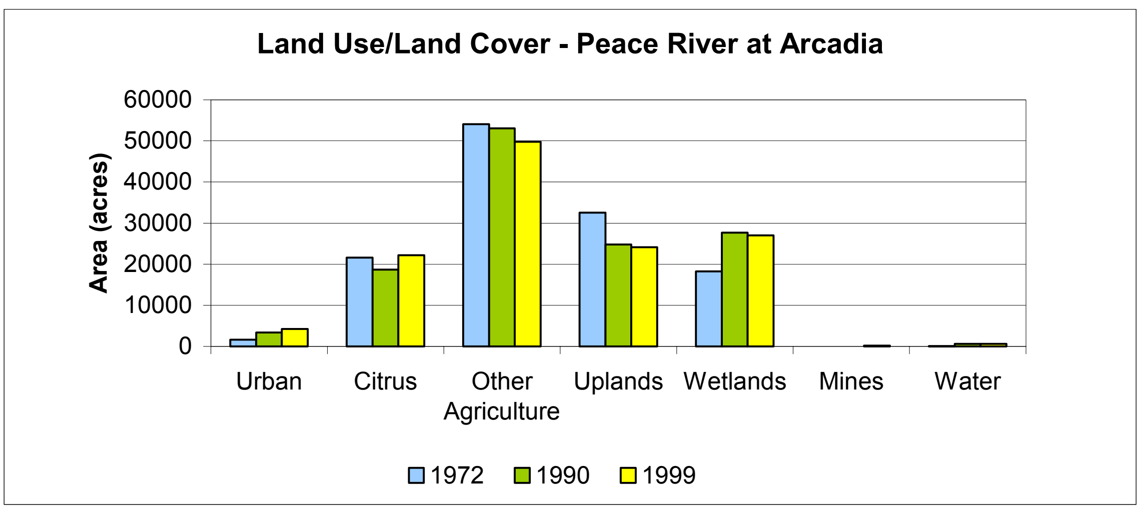


Figure 2-9. Land use/ cover in the Peace River at Arcadia sub-basin in 1972, 1990 and 1999.

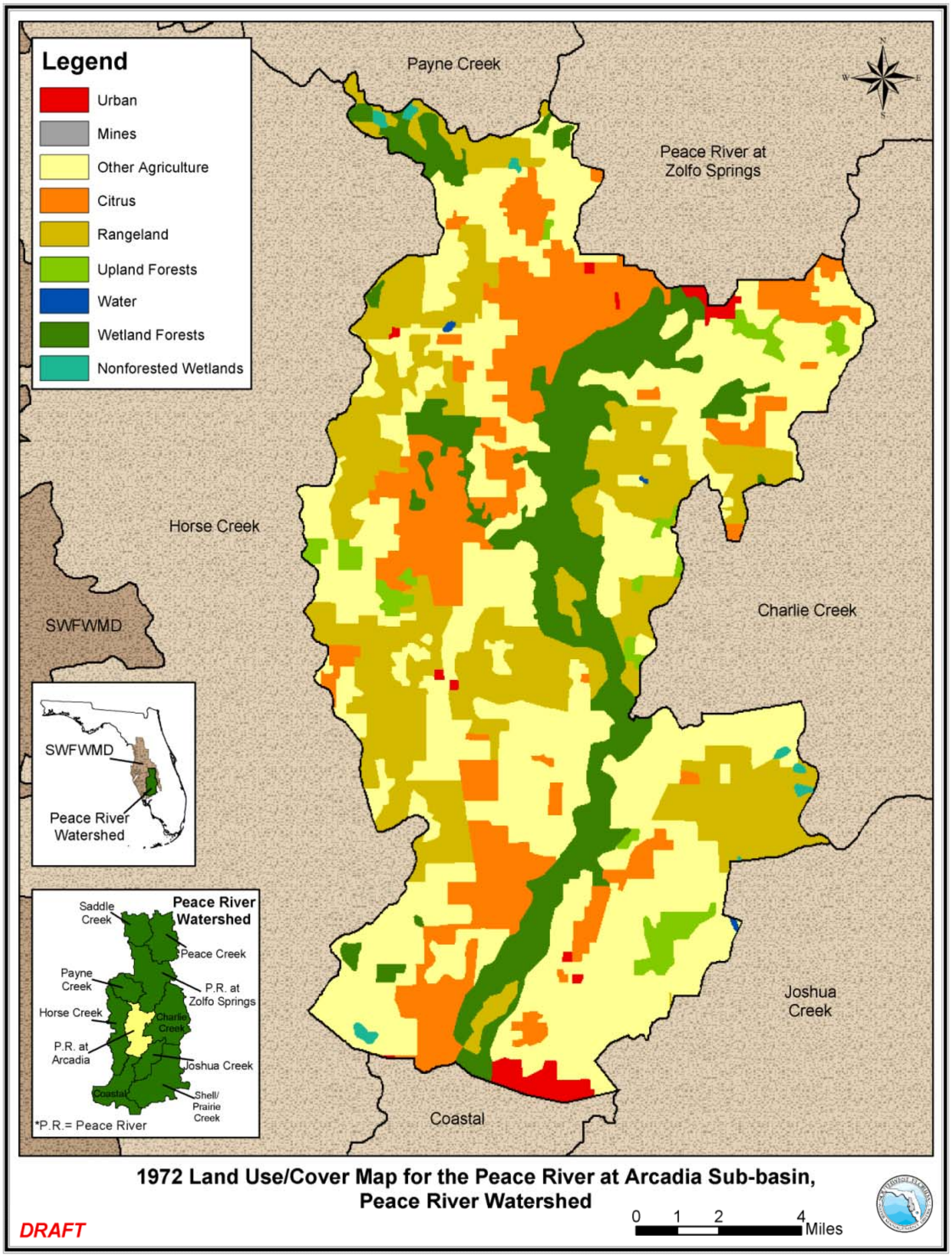


Figure 2-10. 1972 Land use/cover map of the Peace River at Arcadia sub-basin.

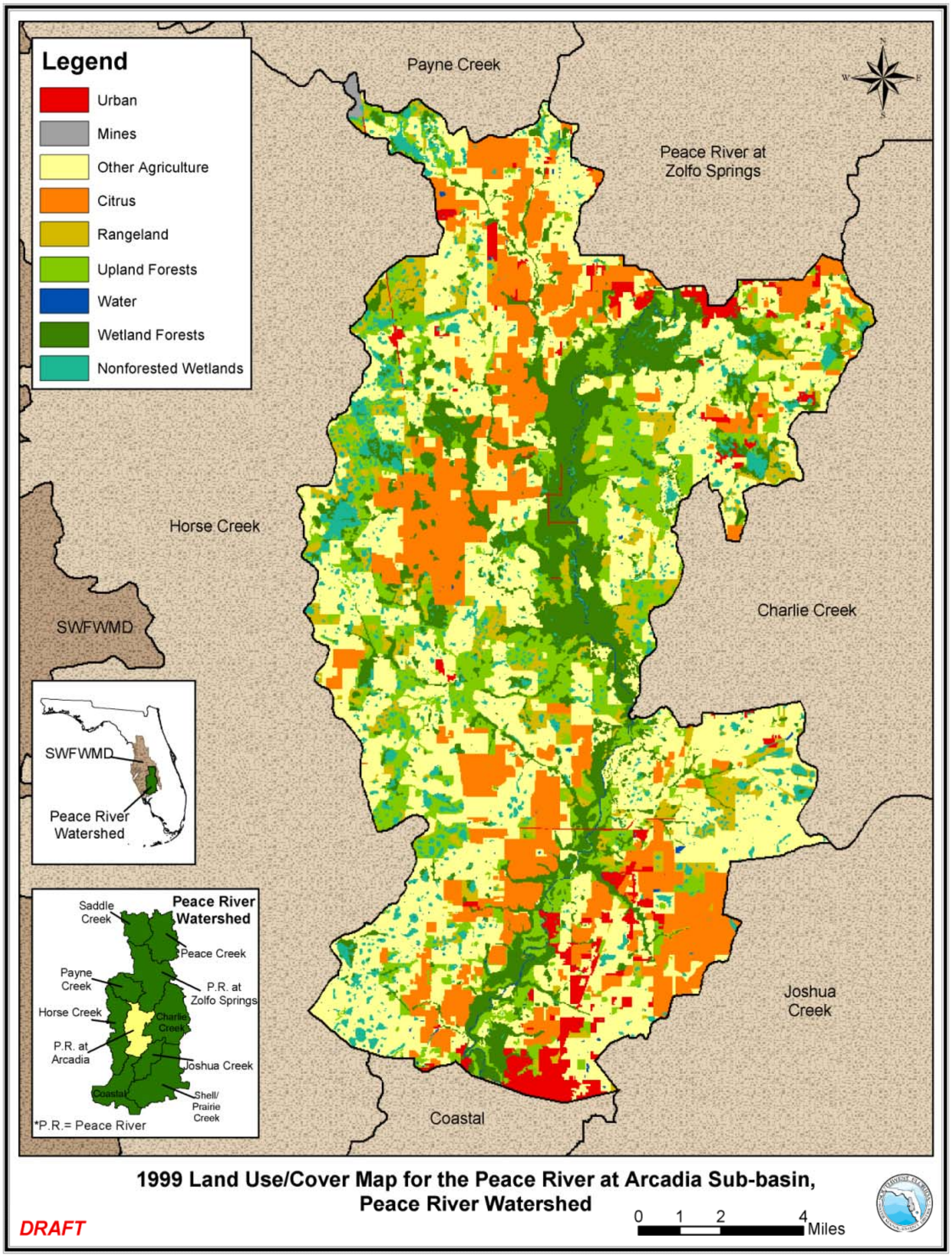


Figure 2-11. 1999 Land use/cover map of the Peace River at Arcadia sub-basin.

2.3.8 Horse Creek Sub-Basin

The Horse Creek sub-basin is not part of the middle Peace River watershed as defined in this report; however, frequent mention will be made of this sub-basin because its flow characteristics and land use/cover are similar to that of Charlie Creek, and there is currently considerable interest in this sub-basin due to the potential for phosphate mining to expand within the basin. The Horse Creek tributary joins the Peace River below the Peace River at Arcadia gage. As of 1999 (Table 2-4, Figure 2-12), 28% of the 246 square mile (157,643 acre) watershed was in uplands and 18% in wetlands. Forty-six percent of the watershed was in agricultural land uses (8% citrus, 38% other agriculture). Prior to 1990 there was little phosphate mining in this watershed (1%; 1,922 acres), but by 1999 (Figures 2-13 and 2-14), 6% (9,400 acres) had been mined; there was a net reduction of 8% in uplands during this time. As of 1999 this sub-basin had the highest percentage of wetlands and uplands (46%) of any sub-basin within the Peace River watershed.

Table 2-4. Land use/cover percentages in the Horse Creek watershed for three time periods, 1972, 1990 and 1999.

Horse Creek	1972	1990	1999
Urban	0.2%	1.6%	1.5%
Citrus	7.5%	6.5%	7.8%
Other Agriculture	38.1%	39.8%	38.5%
Uplands	35.7%	32.3%	27.7%
Wetlands	18.1%	18.6%	18.3%
Mines	0.0%	1.2%	6.0%
Water	0.4%	0.1%	0.3%
Total acres	157643	157643	157643

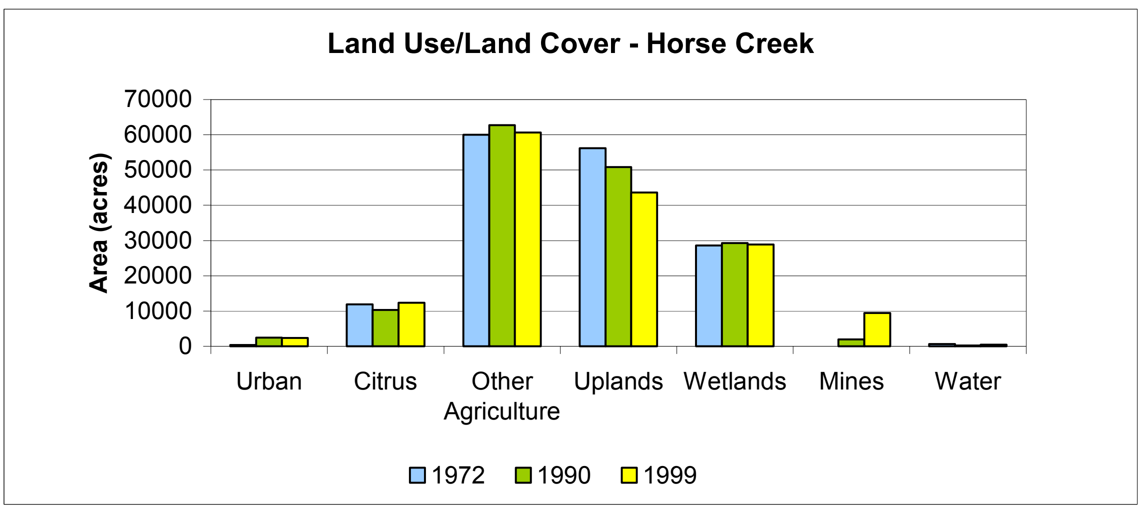


Figure 2-12. Land use/cover in the Horse Creek sub-basin in 1972, 1990 and 1999.

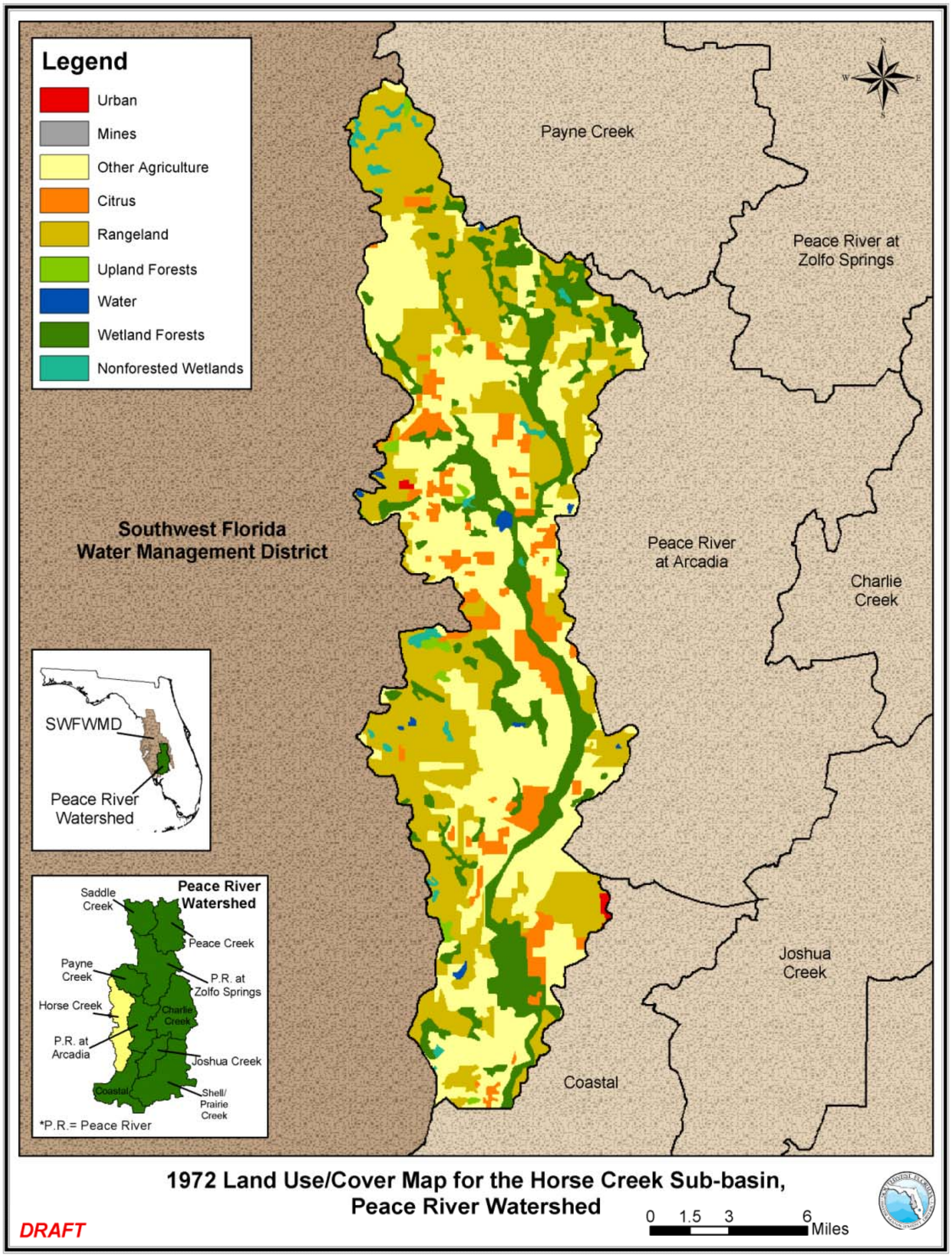


Figure 2-13. 1972 Land use/cover map of the Horse Creek sub-basin.

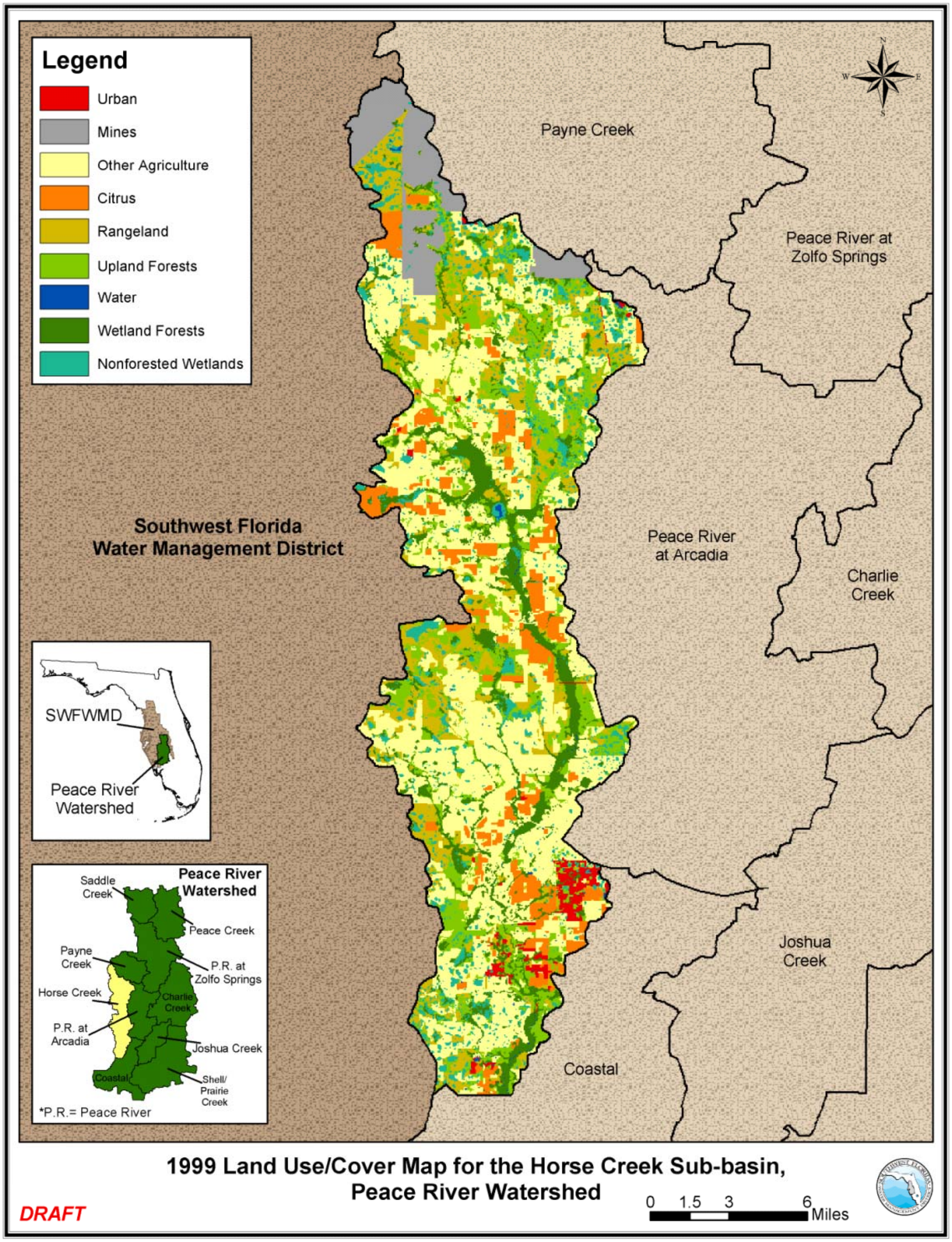


Figure 2-14. 1999 Land use/cover map of the Horse Creek sub-basin.

2.3.9 Joshua Creek Sub-Basin

The Joshua Creek sub-basin is comparable in size to the Payne Creek sub-basin, and at 122 square miles (78,113 acres) is the smallest of the ten Peace River watershed sub-basins. In comparison with the other sub-basins, the Joshua Creek sub-basin had the greatest proportional area in use for agricultural purposes in 1999 (Table 2-5, Figure 2-15). Twenty-nine percent of the sub-basin (35 square miles) was in citrus; 44% in other agricultural land use/cover. The combined acreage in wetlands and uplands was 22%. Between 1972 and 1999 (Figures 2-16 and 2-17), citrus acreage increased substantially, from 9 to 29%of the sub-basin total. Joshua Creek enters the Peace River downstream of the Peace River at Arcadia gage so is not considered part of the middle Peace River.

Table 2-5. Land use/cover percentages in the Joshua Creek watershed for three time periods, 1972, 1990 and 1999.

Joshua Creek	1972	1990	1999
Urban	1.6%	3.7%	4.3%
Citrus	8.8%	20.3%	28.9%
Other Agriculture	59.0%	52.3%	44.1%
Uplands	25.0%	13.2%	11.7%
Wetlands	4.9%	10.3%	10.5%
Mines	0.1%	0.0%	0.0%
Water	0.8%	0.2%	0.6%
Totals	78113	78113	78113

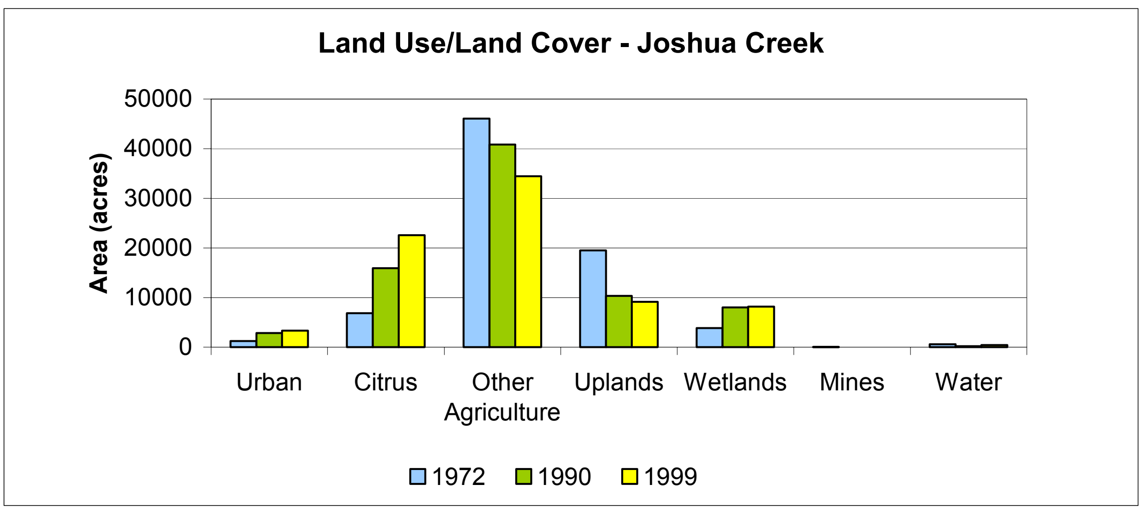


Figure 2-15. Land use/cover in the Joshua Creek sub-basin in 1972, 1990 and 1999.

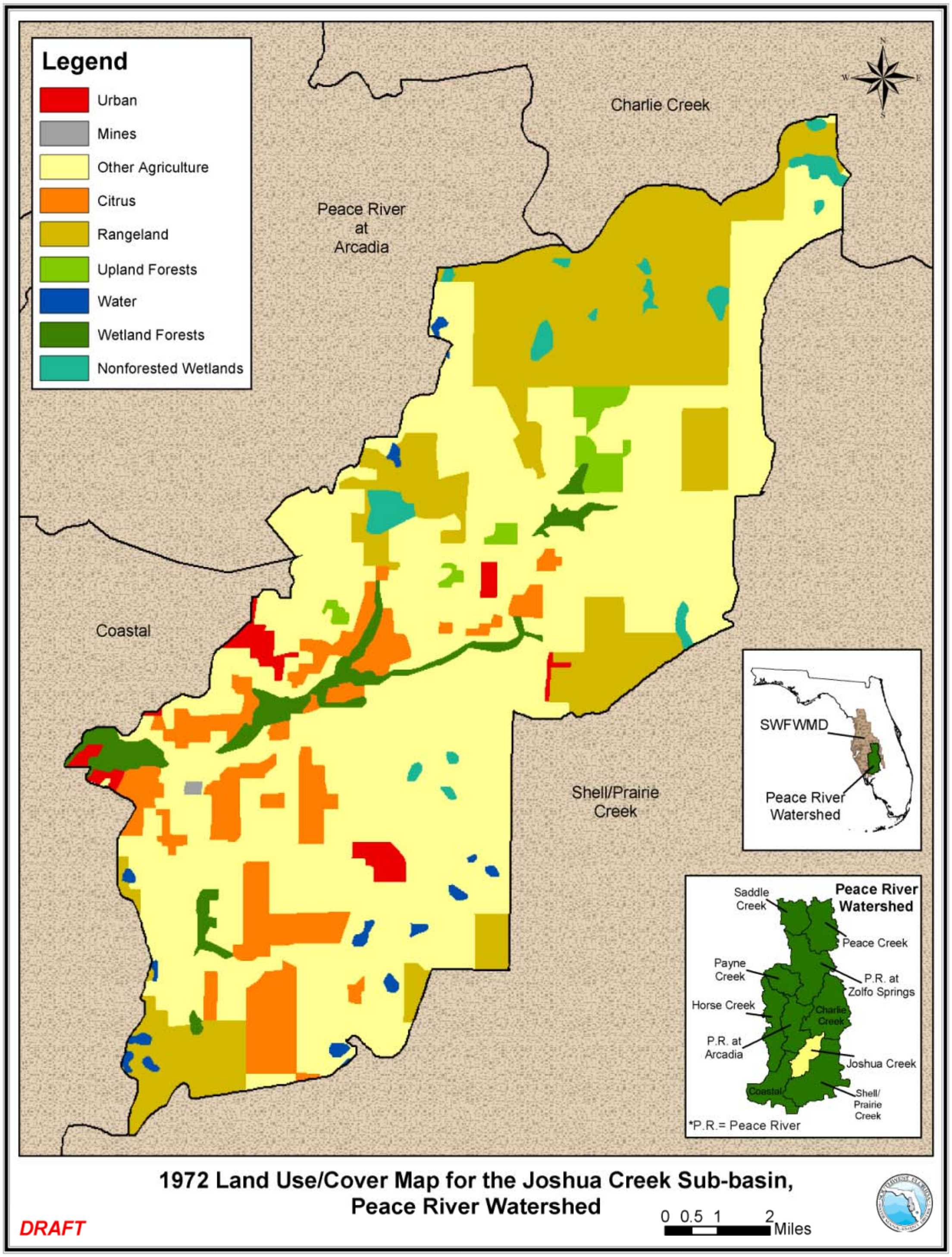


Figure 2-16. 1972 Land use/cover map of the Joshua Creek sub-basin.

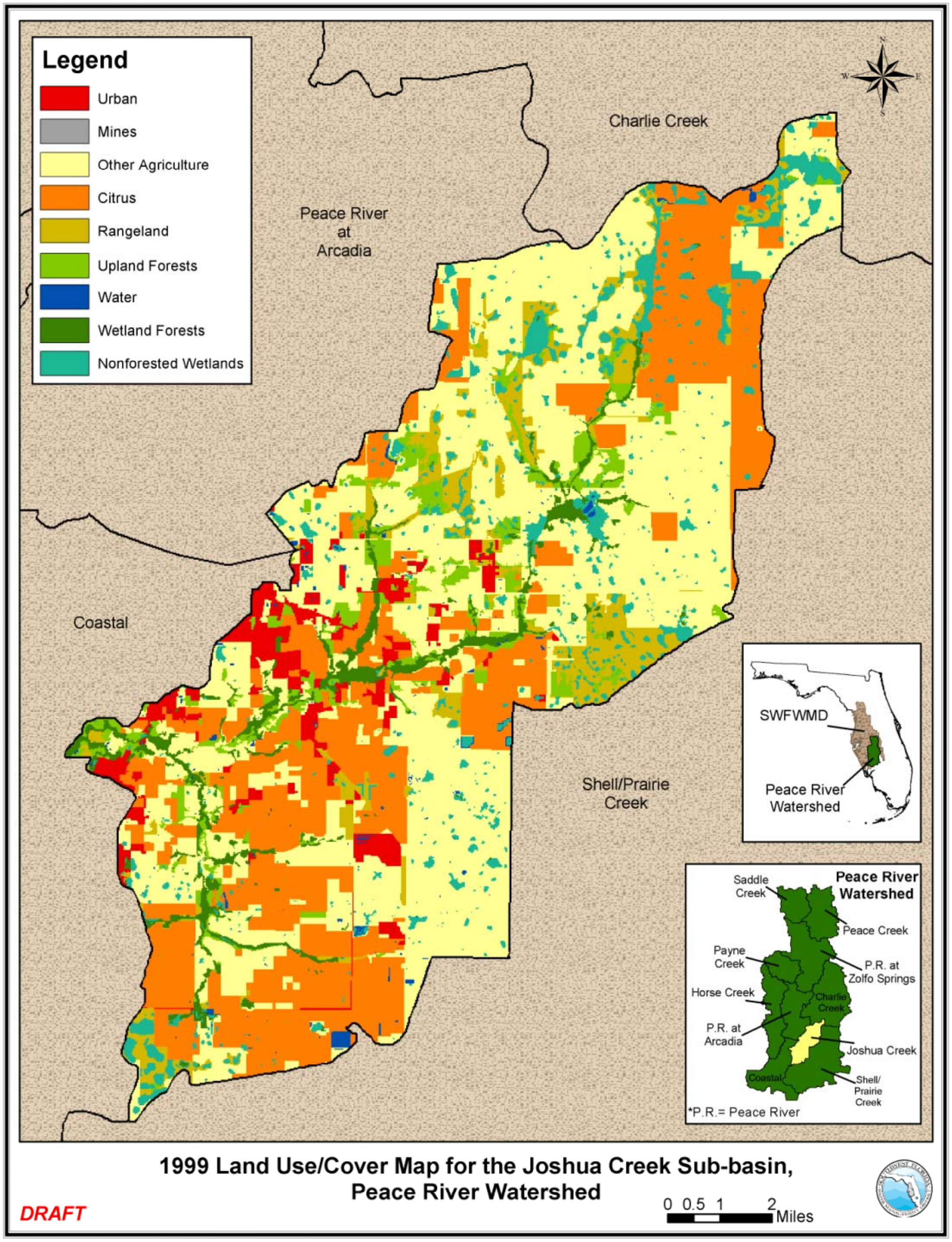


Figure 2-17. 1999 Land use/cover map of the Joshua Creek sub-basin.

2.3.10 Shell and Prairie Creeks Sub-Basin

The Shell/Prairie Creek sub-basin is the largest sub-basin within the Peace River watershed. Like Joshua Creek, it enters the Peace River downstream of the Arcadia gage so is not considered part of the middle Peace River. Agriculture is the dominant land use/cover in this sub-basin. As of 1999, 22% of this watershed was in citrus, and 36% was in other agricultural land uses. Uplands and wetlands comprised a combined 39% of the sub-basin area in 1999. Between 1972 and 1999, approximately 21% of the sub-basin was converted from wetlands and uplands to agricultural uses.

2.3.11 Coastal Sub-Basin

The Coastal sub-basin is approximately 237 square miles in size. It is second only to the Saddle Creek sub-basin in the percentage of urbanized land. Sixty-eight square miles (28.5%) of the sub-basin is in urban land use/cover. Approximately 6% of the sub-basin was converted to urban land use between 1972 and 1999. Most of the increase was offset by a corresponding loss of uplands. There was little net change in the amount of wetland and agricultural acreage during this time.

2.4 Hydrology

2.4.1 Overview

Significant declining trends in flows in the Peace River have been documented or reported by a number of workers (Hammett 1995, Flannery and Barcelo 1998, Kelly 2004); however, the cause(s) for these declines have been the subject of some debate. Although there has been considerable phosphate mining in the Peace River watershed (especially in the upper part of the basin) and substantial groundwater withdrawals from the Floridan Aquifer System, comparison of river flow declines at the USGS Peace River at Arcadia with that of neighboring watersheds suggests a similar causative factor for the declines, especially during the rainy season. Kelly (2004) attributes the flow declines largely to climate, and that is a primary assumption inherent in the minimum flow analyses used for the middle segment of the Peace River.

The effect of the Atlantic Multidecadal Oscillation (AMO; see Enfield et al. 2001) on climate and river flows is considered briefly in this chapter, and its relevance and importance to developing MFLs in general and on the middle Peace River in particular is discussed. We conclude that the AMO is a major factor that must be considered when developing baseline or benchmark periods for evaluating flow reductions and establishing MFLs. The chapter concludes with a discussion of the development of seasonal flow blocks that are utilized for minimum flow development.

2.4.2 Florida River Flow Patterns and the Atlantic Multidecadal Oscillation

> *"It would be reasonable to assume that given a fairly constant climate, the amount of water flowing down a river's course each year would vary evenly about an average value."* (Smith and Stopp 1978)

Smith and Stopp's statement reflects the typical paradigm with respect to the impact of climate on river flow. As a result, little attention has been paid to the potential for a climate change (oscillation) to affect river flows, and thus any change (trend) in flow other than expected annual variability has typically been assumed to be anthropogenic.

While much of Florida has a summer monsoon, the north to northwest portion of the state experiences higher flows in the spring similar to most of the southeast United States. Spatial and temporal differences in flows for southeastern rivers were highlighted by Kelly (2004), who used a graphical approach not routinely used to examine river flow patterns. By constructing plots of median daily flows (in cubic feet per second), seasonal flow patterns were clearly illustrated, and by dividing mean daily flows by the upstream watershed area, flows could be compared between watersheds of varying size. One of the more interesting features evident from this analysis was the existence of a distinctly bimodal flow pattern (Figure 2-18) which characterizes a number of streams in a rather narrow geographic band that extends from the Georgia-Florida border in the northeastern part of the state where the St. Mary's River discharges into the Atlantic Ocean towards the mouth of the Suwannee River in the Big Bend area. Rivers south of this line (most of peninsular Florida) exhibit highest flows in the summer, while those north of the line exhibit highest flows in the spring (Figure 2-18).

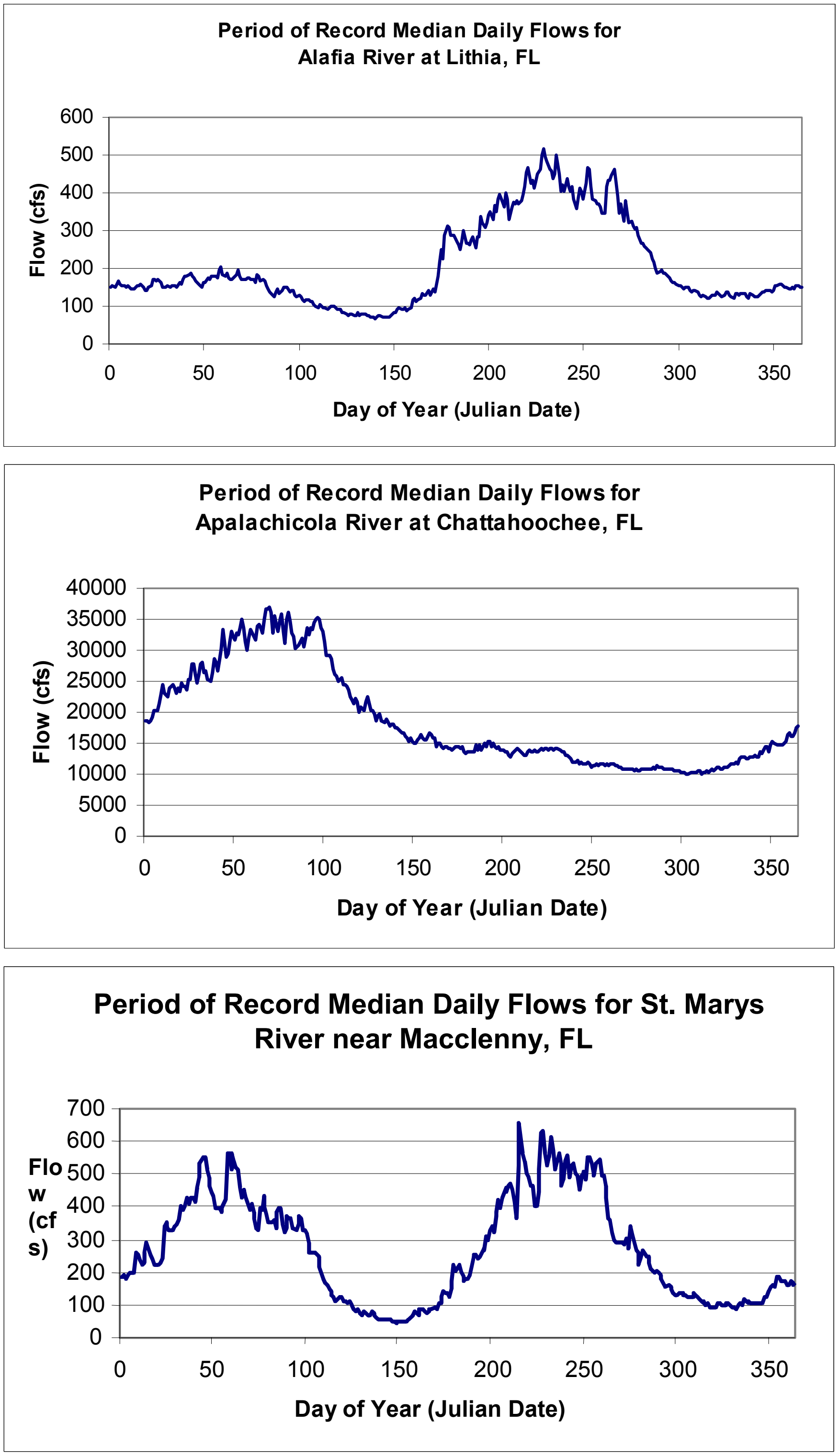


Figure 2-18. Examples of three river flow patterns: the Southern River Pattern (upper panel), the Northern River Pattern (center panel) and Bimodal River Pattern (bottom panel).

2.4.2.1 Multidecadal Periods of High and Low Flows

Citing Enfield et al. (2001), Basso and Schultz (2003) noted that the Atlantic Multidecadal Oscillation (AMO) offered an apparent explanation for observed rainfall deficits throughout central Florida. Although the SWFWMD and others (Hammett 1990, Hickey 1998) have discussed the lack of tropical storm activity and deficit rainfall in recent decades, the mechanism or mechanisms that would account for such differences were unknown. Based on an emerging body of research, climatologists now believe that multidecadal periods of warming and cooling of the North Atlantic Ocean's surface waters ultimately affect precipitation patterns across much of the United States. What is particularly interesting is that unlike most of the continental United States, there is for most of Florida a positive (rather than negative) correlation between rainfall and prolonged periods of North Atlantic Ocean sea surface warming (Enfield et al. 2001). While periods of warmer ocean temperature generally resulted in less rainfall over most of the United States, there are some areas, including peninsular Florida where rainfall was increased.

Since river flows are largely rainfall dependent, variation in rainfall should result in variations in river flows. To be consistent with Enfield et al. (2001) conclusions regarding the AMO and rainfall and with Basso and Schultz (2003) who examined long-term variations in rainfall in west-central Florida, Kelly (2004) reasoned that in Florida, flows would be highest at streamflow gage sites when sea surface temperatures in the North Atlantic are in a warm period (i.e., positively correlated). At the same time most of the continental United States would be expected to be in a period of lower flows. Conversely, the majority of continental gage sites would be expected to exhibit higher flows during AMO cool periods and much of peninsular Florida would be expected to be in a period of low flows.

Based on these hypotheses, Kelly (2004) examined flow records for multidecadal periods corresponding to warming and cooling phases of the AMO for numerous gage sites within the District, the state, and the southeastern United States to discern if increases and decreases in river flows were consistent with AMO phases. He concluded that flow decreases and increases in the northern part of the state and flow increases and decreases in peninsular Florida are consistent with the AMO and the reported relationship with rainfall. When rivers in peninsular Florida were in a multidecadal period of higher flows (1940 to 1969), rivers in the north to northwestern part of the state were in a low flow period. Conversely rivers in peninsular Florida exhibited generally lower flows (1970 to 1999) when rivers in the northern portion of the state exhibited higher flows. Examination of streams with a bimodal flow pattern offered particularly strong supporting evidence for a distinct difference in flows between northern and southern rivers, since differences between pre- and post 1970 flows that occurred during the spring were similar to differences noted for northern river flows while differences in summer flows were similar to flow changes that occurred in southern rivers.

2.4.3 Peace River Flow Trends

2.4.3.1 Gage Sites and Periods of Record

Flow analyses in the Peace River watershed focused on a number of USGS gage sites (Table 2-6; Figure 2-1). Several sites on the mainstem of the river have period of record daily flows extending back to the 1930's, and a number of major tributaries (e.g., Horse, Charlie, Shell) have records that date to 1950. Many of these sites also have a fairly good water quality database which can be helpful in interpreting flow trends. The Peace River at Arcadia, FL gage is especially important in this regard; it has one of the most comprehensive flow and water quality records in the state.

Table 2-6. Stream flow gaging sites in the Peace River watershed.

USGS STATION NUMBER	SITE NAME	PERIOD OF RECORD	DRINAGE AREA (SQ MILES)
2296500	Charlie Creek near Gardner, FL	5/1/1950	330
2297310	Horse Creek near Arcadia, FL	5/1/1950	218
2297100	Joshua Creek near Nocatee, FL	5/1/1950	132
2295420	Payne Creek near Bowling Green, FL	10/1/1963	121
2296750	Peace River at Arcadia, FL	4/1/1931	1367
2294650	Peace River at Bartow, FL	10/1/1939	390
2294898	Peace River at Fort Meade, FL	6/1/1974	480
2295637	Peace River at Zolfo Springs, FL	9/1/1933	826
2298123	Prairie Creek near Fort Odgen, FL	10/1/1963	233
2298202	Shell Creek near Punta Gorda, FL	1/1/1965	373

2.4.3.2 Peace River Flows

The middle Peace River is defined as that segment of the river bounded by the USGS Peace River at Zolfo Springs, FL gage to the north and the Peace River at Arcadia, FL gage to the south. The upper segment of the Peace River (Bartow gage to the Zolfo Springs gage) MFL is discussed in a separate document (SWFWMD 2002), and the lower or estuarine portion of the Peace River (south of the Arcadia gage to Charlotte Harbor) is the subject of a separate MFL determination to be completed in 2006.

It has been demonstrated that low flows in the upper Peace River have been severely impacted due to the regional lowering of the potentiometric surface of the Floridan Aquifer system as a result of significant groundwater withdrawals (Hammett 1990, SWFWMD 2002, Basso 2002). While high flows have declined as well and some of this decline is no doubt attributable to loss of the baseflow component from the aquifer systems, uncertainty remains as to the factor(s) most responsible for medium and high flow declines. Because of this uncertainty, the SWFWMD refrained from proposing minimum mid and high flows on the upper Peace River (SWFWMD 2002).

Natural low flows to the middle Peace River have also certainly declined because Floridan Aquifer water was historically discharged to the upper portion of the river. These declines, however, have not been as great as in the upper river segment simply because of the increasing contributing watershed area as one proceeds downstream and because the Payne Creek watershed apparently discharges more water during low flows than would be anticipated for a watershed of its size based on a comparison with other Peace River sub-basins (Figure 2-19 and 2-20). Nevertheless, a disproportionately greater amount of the baseflow in low flow months historically originated upstream of Zolfo Springs (i.e., from the upper Peace) due to the greater degree of connectivity of this part of the watershed with the underlying Floridan and Intermediate Aquifer systems. .

Based on a comparison of median daily flows in the Peace River at Arcadia with flows from Charlie and Horse Creeks (Figure 2-21), it was concluded that most of the perceived decline in flows at Arcadia must be attributable to natural climatic variation (Kelly 2004). Similarity in flow trends between Charlie Creek, Horse Creek and the Peace River for two multidecadal time periods suggests a similar causative factor is operative in the three watersheds (granted that the Charlie Creek sub-basin is part of the larger Peace River at Arcadia watershed). Since there is no phosphate mining, little urbanization, and little surface water storage (few lakes) in the Charlie Creek sub-basin, it is suggested that the similar causative factor is climatic (i.e., rainfall).

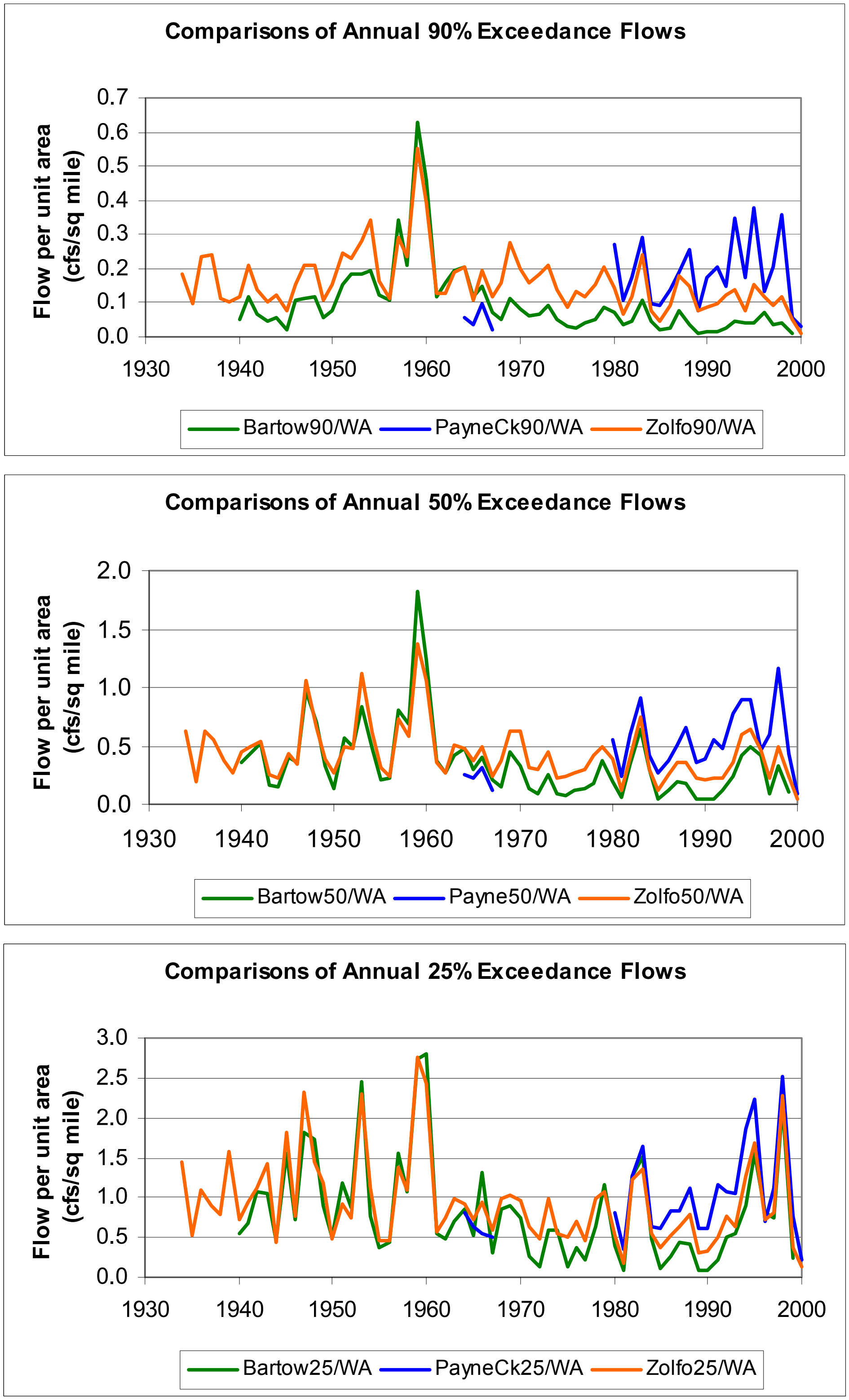


Figure 2-19. Comparison of Payne Creek annual percent exceedance flows with flows at Bartow and Zolfo Springs gages on the Peace River. Upper panel shows the 90% annual exceedance flows, middle panel shows the 50% flows and the lower panel shows the 25% flows. "WA" is "watershed area."

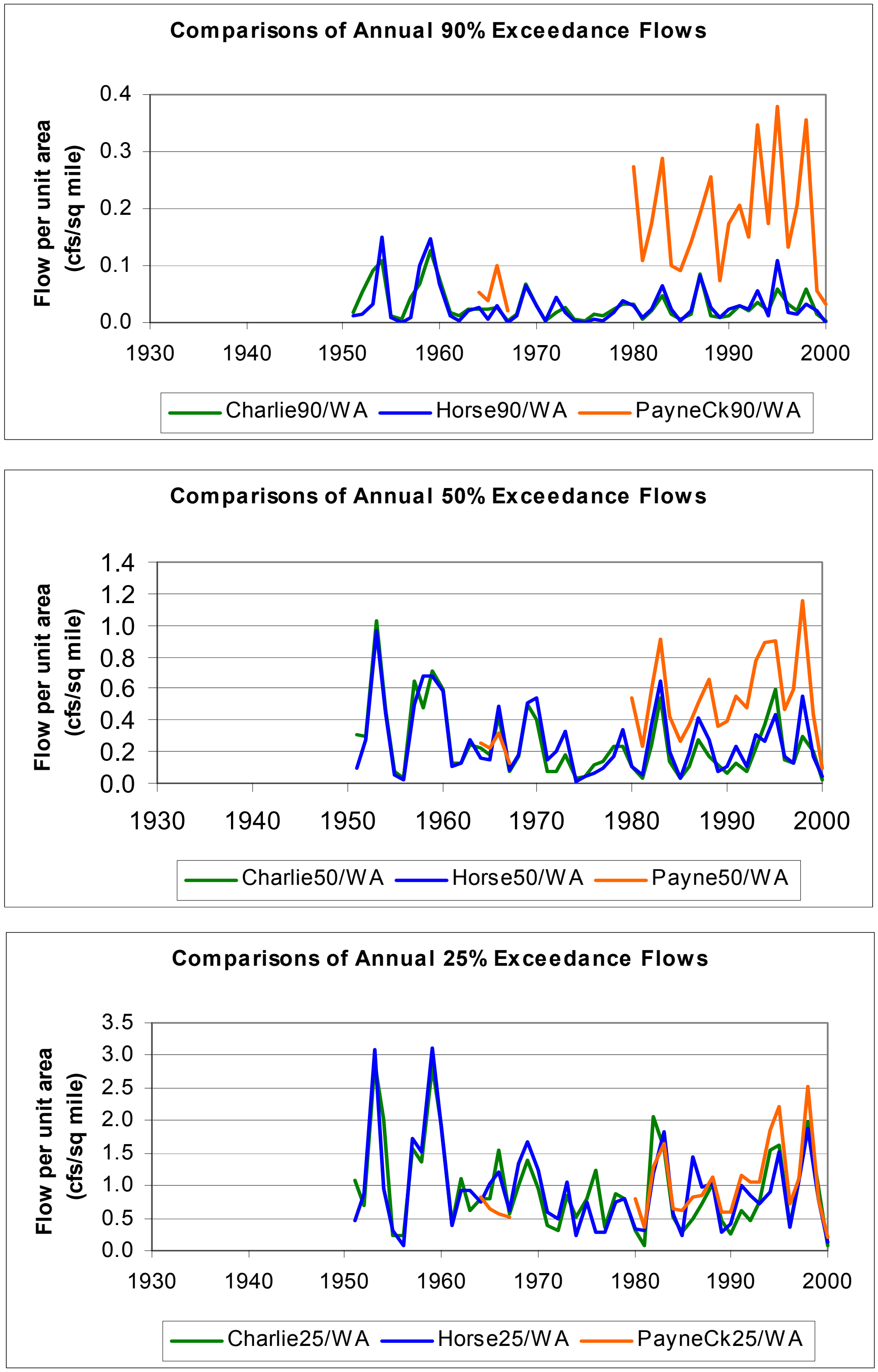
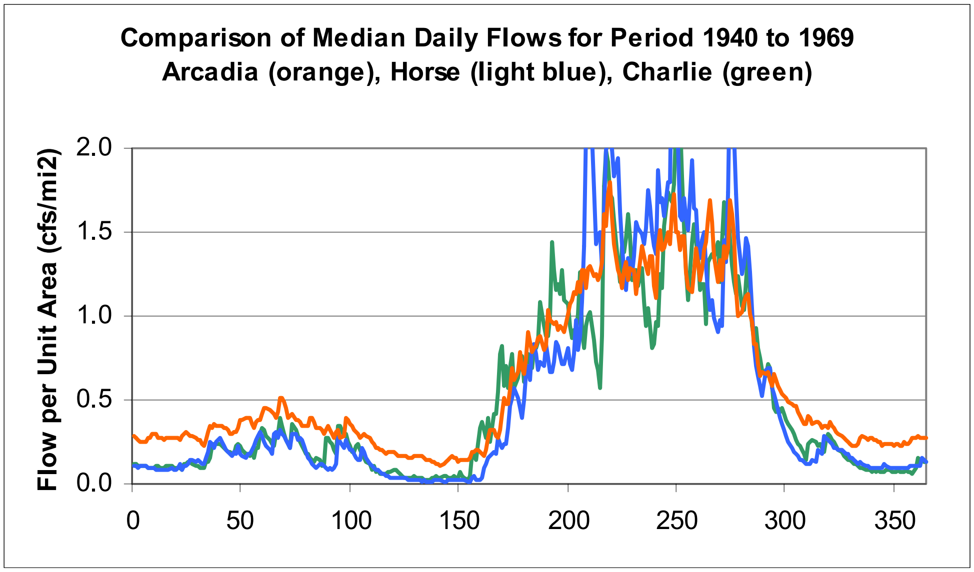


Figure 2-20. Comparison of Payne Creek annual percent exceedance flows with flows at Charlie and Horse Creek gages. Upper panel shows the 90% annual exceedance flows, middle panel shows the 50% flows, and lower panel shows the 25% flows. “WA” is “watershed area.”



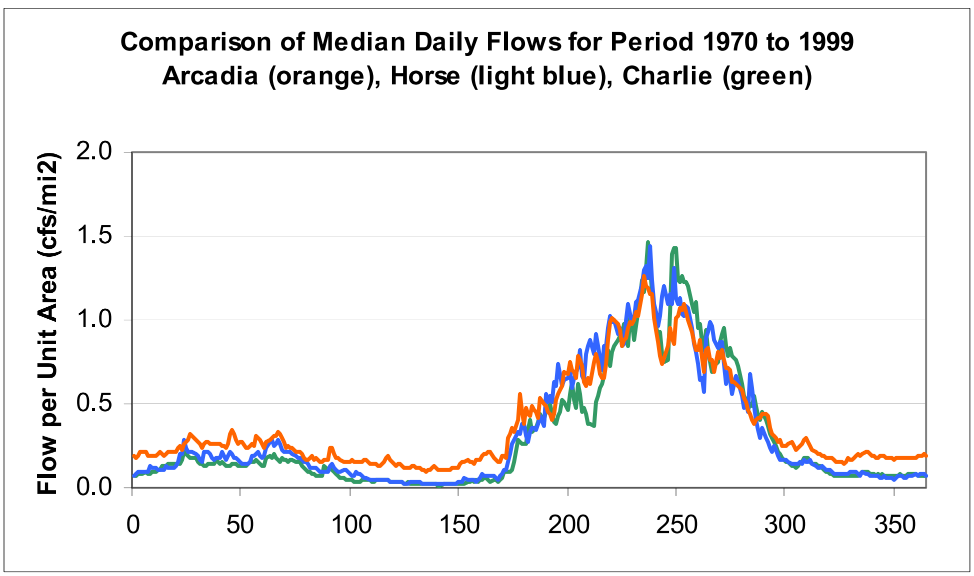


Figure 2-21. Comparison of median daily flows for two time periods for the Peace River at Arcadia, Charlie Creek and Horse Creek (from Kelly 2004).

A report by Hammett (1990) and its implications with respect to anthropogenic impacts on stream flow particularly as measured at the Arcadia gage has led to considerable debate over impacts to Peace River flows (see Garlanger 2002, SWFWMD 2002, SDI 2003). Keeping in mind that Hammett (1990) was examining flow data only through 1985, she stated and then concluded, "If rainfall were the controlling factor, then all streamflow stations in the area would show similar trends, which is not the case." While we concur with the opening phrase of her statement, we cannot agree with the resulting conclusion. Hammett used the Kendall's tau test to evaluate whether or not a site demonstrated a significant declining trend in flow, and applied an alpha level of 0.1 to her analysis. Simply stated if the alpha level at a site was greater than 0.1, then no trend was assumed. Since flows at the Peace River at Arcadia, FL gage met her criterion for significance with its alpha level at exactly 0.1 (see Table 16 in Hammett 1990), a significant trend was indicated. Both Charlie Creek and Horse Creek exhibited relatively low alphas, 0.17 and 0.11, respectively; however, neither site met the criterion for statistical significance, and it was apparently assumed that they did not exhibit similar flow trends. No flow plots similar to the Arcadia plot in Hammett's report were generated for either of these sub-basins. If this had been done a different conclusion may have been reached (see Figure 2-22 which shows a plot similar to Hammett's but also includes overlays for Charlie and Horse Creeks). While one might anticipate flows in the Myakka River or Joshua Creek to exhibit flow trends similar to the Peace River at Arcadia, the fact that they do not compare as favorably as might be expected is attributable more to anthropogenic flow increases in the Myakka River and Joshua Creek rather than to anthropogenic flow decreases in the Peace River. The lack of agreement in flow trends among some sites is the result of anthropogenic factors acting on those sites which do not correspond well to the pattern seen at the Arcadia gage.

Flow variation was also examined for a number of major tributaries to the Peace River. Flow patterns for Horse and Charlie Creeks and the Peace River at Arcadia are remarkably similar when the two periods examined earlier in connection with the AMO are compared (see Figure 2-21). Note that for these comparisons, the earlier record for the Arcadia gage has been shortened to 1951 to 1969, since this is when flow records began on both Charlie and Horse Creeks. This simple visual comparison suggests that variations in flow are largely the result of similar causative factors; no elaborate or complex analysis is needed. One only needs to examine the empirical data to come to this conclusion. All three sites showed a 35% decrease in flows when the 1951 to 1969 period is compared to the 1970 to 1999 period (Figure 2-21).

On its publicized listing of endangered rivers for 2004, American Rivers Inc. listed the Peace River as the eighth most endangered river in America. In a statement released by the organization and reported in the media, they concluded "that most of the flow decline of the middle Peace River is attributable to phosphate mining." Unfortunately this statement was not substantiated. Most of the flow decline in the Peace River at Arcadia (which is the gage obviously referenced) must be attributed to the same factor(s) that contributed to flow declines in Charlie and Horse Creek. We believe that the obvious factor is climate. SDI (2003), representing one of the entities nominating the Peace River for this endangered status, reported that most of the flow decline of the Peace River as measured at the Arcadia gage is attributable to climate (55%) and that mining was responsible for 17% of the decline. While we agree that climate is the major controlling factor and while we cannot attribute a percentage figure to this decline, we conclude that the percent attributable to mining must be similar to the percentage attributable to mining in either the Charlie Creek or Horse Creeks sub-basins, a very low percentage at worst and considerably lower than the 17% referenced by SDI (2003).

There has been considerable discussion relative to anthropogenic effects on flows of the Peace River. The clear implication of a report published by the USGS (Hammett 1990) is that much of the flow decline seen in the Peace River as measured by flow at the Arcadia gage is attributable to factors other than rainfall. It should be appreciated that the conclusions in the Hammett report are based largely on an analysis of mean annual flows. Further, it was stated that if rainfall were the major controlling factor behind flow declines then one should see similar flow patterns in neighboring watersheds, and it was concluded that this was not the case. A re-analysis of flows using the graphical approach presented above; however, strongly suggests that there are very similar flow patterns in neighboring watersheds, leading us to conclude that rainfall patterns account for most of the long-term variation in streamflow measured at the Arcadia gage. Consideration of differences in land use and anthropogenic factors that may affect stream flow in neighboring watersheds helps to explain in some cases why stream flows patterns do not appear similar. Consideration of anthropogenic factors may also explain why some of the neighboring river segments examined by Hammett (1990) did not show flow patterns similar to the flows rat the Arcadia gage.

For example, in recent years, there has been a dramatic increase in dry season flow in Joshua Creek, one of the sites to which Hammett (1990) compared the Arcadia gage flows. The Joshua Creek gage site (located near Nocatee, FL) shows an apparent monotonic increasing trend in low flow beginning in the late 1970s (Figure 2-22, upper panel). It is believed that this increasing flow trend is due largely to agriculturally related runoff of irrigation water as has been documented for other streams in this region. Consistent with the AMO discussion presented earlier, we should not expect to see increasing flow trends during the 1980s and midway into the 1990s; however, rather dramatic increases are apparent, and these increases are of sufficient magnitude to noticeably affect median flows (Figure 2-26, middle panel).

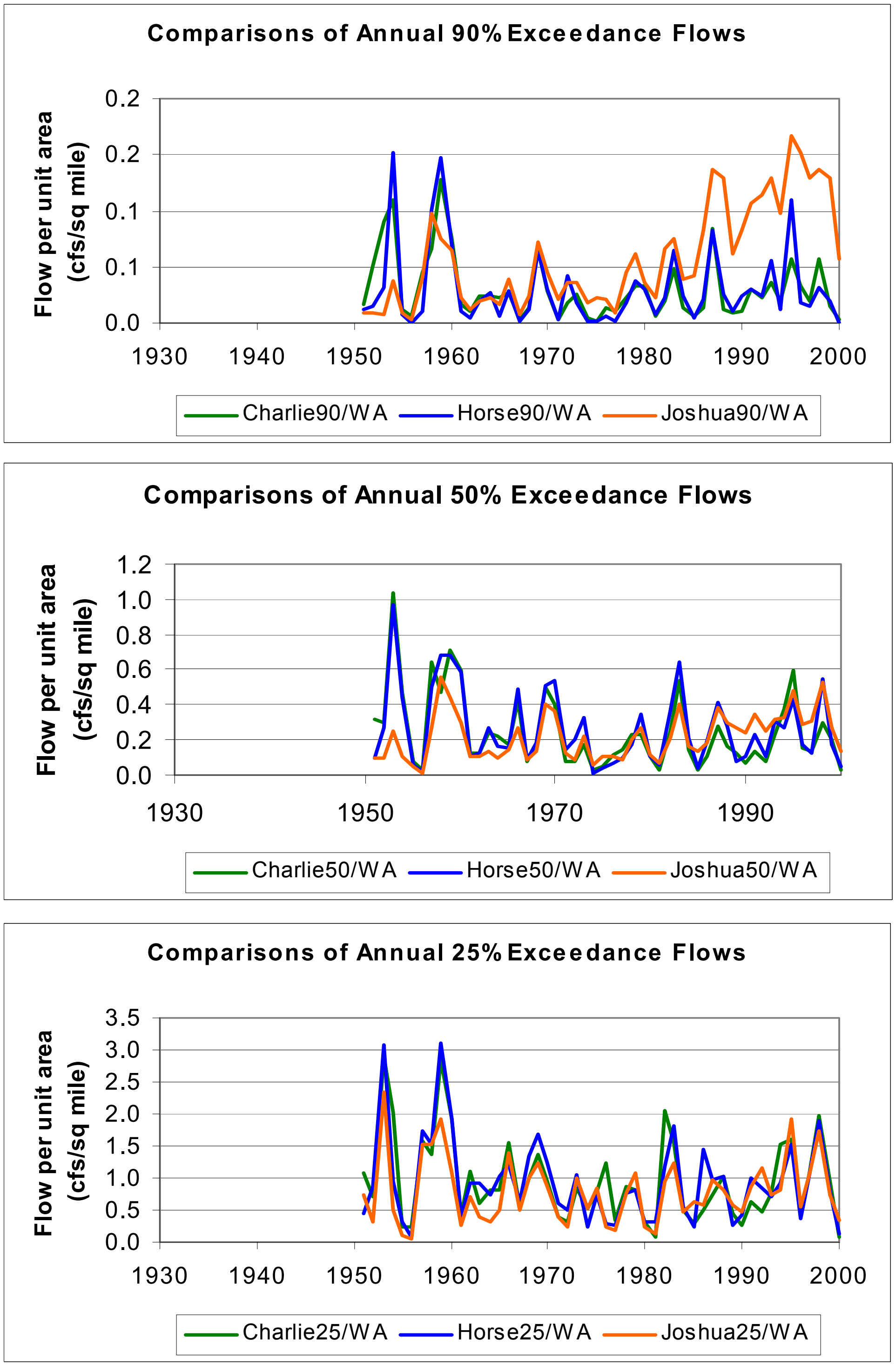


Figure 2-22 Comparison of Joshua Creek annual percent exceedance flows with flows at Charlie and Horse Creek. Upper panel shows the 90% flows, middle panel shows the 50% flows and the lower panel shows the 25% flows.

2.4.3.3 Step Trend in Peace River Flows

Kelly (2004) argued, similarly to McCabe and Wolock (2002), that there was a step change in river flow volumes related to climatic change associated with the Atlantic Multidecalal Oscillation. This is shown graphically for the Peace River at Arcadia, FL gage site in Figure 2-23. The upper panel of the figure shows the results of a Kendall's tau regression of mean annual flows at the site versus time for the period 1940 to 1999. The Kendall's tau p-value was 0.0269 with a slope of –8.825 cfs/yr indicating a statistically significant declining trend. However, using 1970 as a break-point and repeating the analysis for the periods from 1940 to 1969 and 1970 to 1999 (periods corresponding to warm and cool-water phases of the AMO) indicated that there were no significant trends for either period. As can be seen in the middle panel of Figure 2-23, there was not a statistically significant trend in mean annual flows for the period 1940 to 1969; p = 0.8028, slope = –1.947. In the lower panel, Kendall's tau regression for the period 1970 to 1999 also showed no significant trend; p = 0.5680, slope = 3.759. A Mann-Whitney test for flow difference between mean annual flows for the two multidecadal times periods indicated that flows at the Arcadia gage site were significantly greater (p=0.0035) during the earlier period (1940 to 1969) as compared to the more recent period (1970 to 1999). Similar results for the Peace River at Zolfo Springs (Figure 2-24) and other area rivers were also noted (Tables 2-7 and 2-8), providing evidence for a step change in Peace River flows rather than a monotonic trend as suggested by Hammett (1990). To paraphrase slightly McCabe and Wolock (2002), the identification of an abrupt decrease in peninsular Florida streamflow rather than a gradual decreasing trend is important because the implications of a gradual trend is that the trend is likely to continue into the future whereas the interpretation of a step change is that the climate system has shifted to a new regime that will likely remain relatively constant until a new shift or step change occurs.

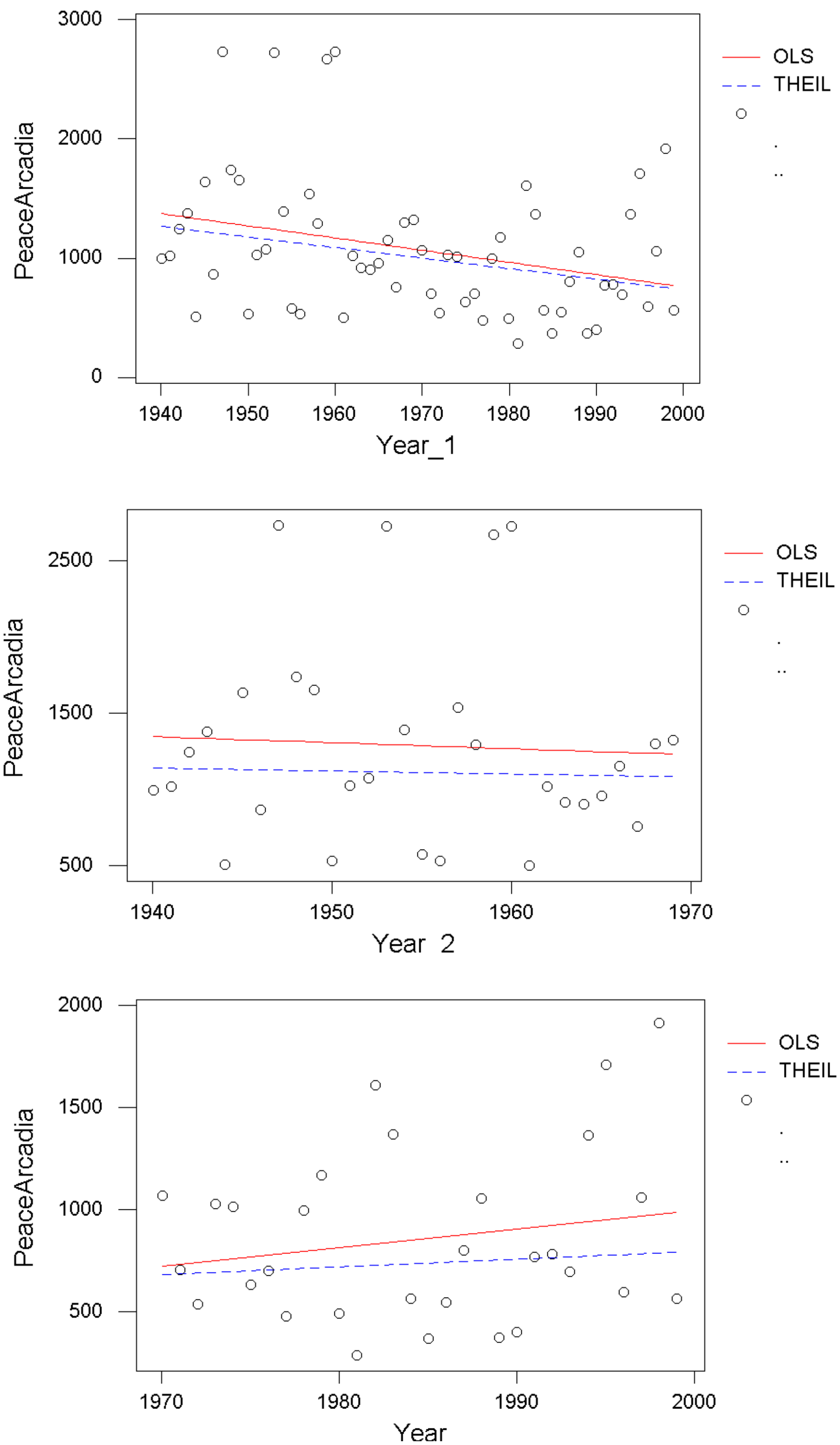


Figure 2-23. Graphical results of Kendall's tau test of mean annual flows for the Peace River at Arcadia for the period 1940 to 1999 (upper panel), 1940 to 1969 (middle panel), and 1970 to 1999 (lower panel). The red line is the Ordinary Least Squares line, and the blue line is the Kendall's tau Thiel line.

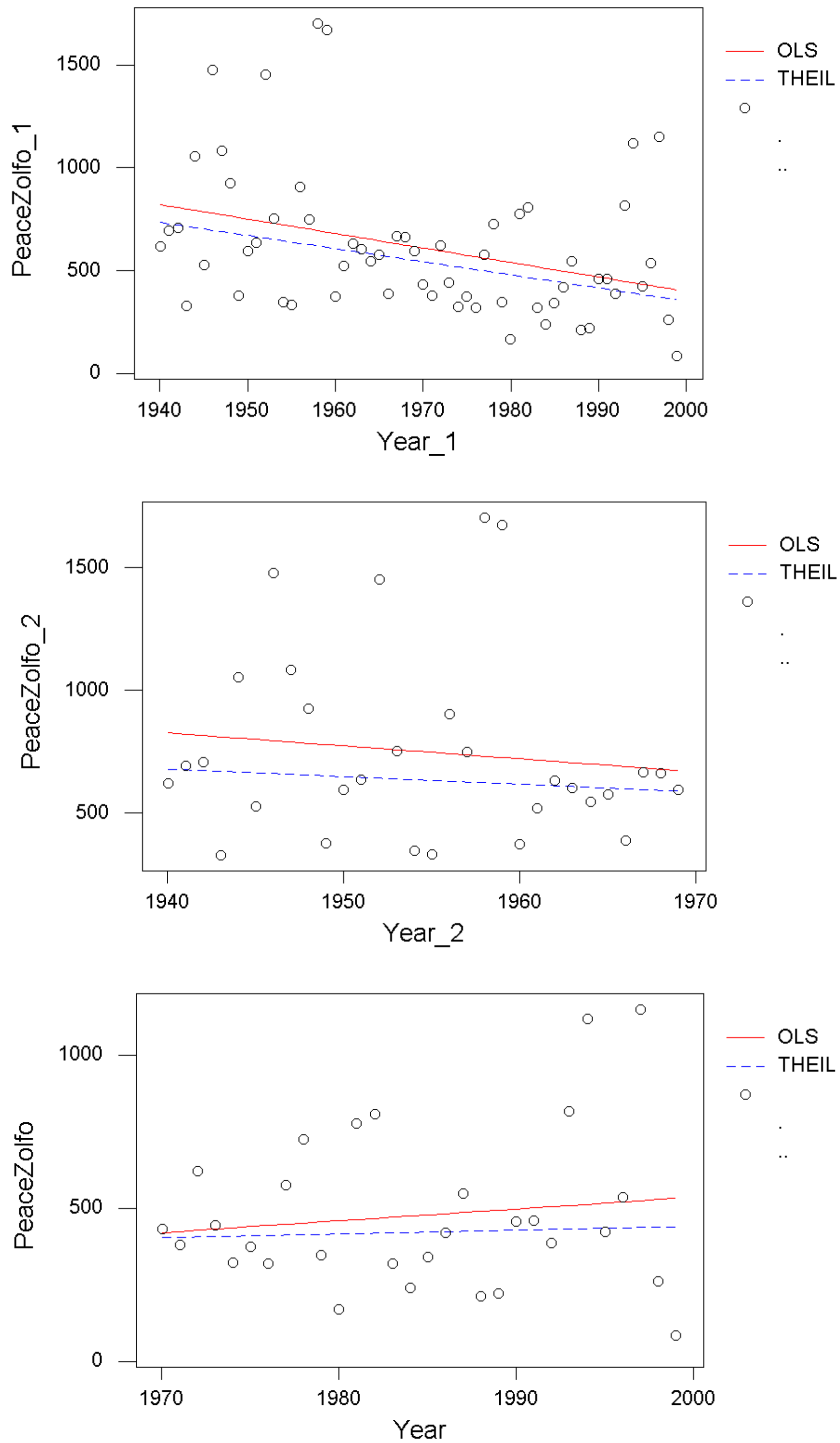


Figure 2-24. Graphical results of Kendall's tau test of mean annual flows for the Peace River at Zolfo Springs for the period 1940 to 1999 (upper panel), 1940 to 1969 (middle panel), and 1970 to 1999 (lower panel). The red line is the Ordinary Least squares line, and the blue line is the Kendall's tau Thiel line.

Table 2-7. Results of Kendall's tau test of mean annual flows (XannQ) for selected gage sites and selected time periods. P values < 0.1 are highlighted in bold; those associated with flow decreases are shaded yellow, those that indicate flow increases are shaded blue. Table is an excerpt from a table in Kelly (2004).

Site Name	1940 to 1999				1940 to 1969				1970 to 1999			
	XAnnQ	MedAnnQ	Slope	p	XAnnQ	MedAnnQ	Slope	p	XAnnQ	MedAnnQ	Slope	p
Alafia River at Lithia	336	309	-2.122	**0.0653**	388	375	3.796	0.3353	284	268	0.1081	1.0000
Hillsborough River near Tampa	454	387	-6.3982	**0.0003**	632	516	3.149	0.6947	276	264	0.1813	0.9147
Hillsborough River at Zephyrhills	248	209	-1.223	**0.0419**	292	247	1.189	0.6427	202	187	1.703	0.4754
Little Manatee River near Wimauma	171	159	-0.331	0.6324	184	178	0.3341	0.9431	158	139	2.318	**0.0867**
Myakka River near Sarasota	251	227	0.4538	0.5966	261	215	1.721	0.5680	241	228	4.405	0.1435
Peace River at Arcadia	1073	1006	-8.825	**0.0268**	1289	1113	-1.947	0.8028	856	738	3.759	0.5680
Peace River at Bartow	228	183	-2.425	**0.0075**	295	241	-1.367	0.6427	161	145	3.335	0.2251
Peace River at Zolfo Springs	614	547	-6.376	**0.0031**	751	636	-3.084	0.4754	477	422	1.231	0.8305
Withlacoochee River at Croom	428	372	-0.5033	**0.0228**	531	431	1	0.7752	325	330	-0.3577	0.9147
Withlacoochee River near Holder	1008	885	-8.9686	**0.0055**	1206	1028	1.153	0.9147	810	742	-9.271	0.3008
Withlacoochee River at Trilby	322	270	-2.5065	**0.0672**	401	340	2.069	0.4537	244	244	1.301	0.8027

XAnnQ = Mean Annual Flow (cfs)
MedAnnQ = Median Annual Flow (cfs)

Table 2-8. Results of Mann-Whitney tests for flow differences between mean annual flows at selected gage sites for two multidecadal time periods (1940 to 1969 and 1970 to 1999). P values of 0.1 or less are highlighted in bold; p values that indicate a flow decrease between periods are shaded yellow. Excerpt of table from Kelly (2004).

Site Name	1940 to 1969 median	n	1970 to 1999 median	n	Test	p
Alafia River at Lithia	374.9	30	268.1	30	Pre>Post	**0.0054**
Hillsborough River at Zephyrhills	247	30	187	30	Pre>Post	**0.0021**
Hillsborough River near Tampa	516	30	264	30	Pre>Post	**0.0000**
Little Manatee River near Wimauma	178	30	139	30	Pre>Post	**0.0954**
Myakka River near Sarasota	215	30	228	30	Pre>Post	0.4094
Peace River at Arcadia	1113	30	738	30	Pre>Post	**0.0035**
Peace River at Bartow	241	30	145	30	Pre>Post	**0.0003**
Peace River at Zolfo Springs	636	30	422	30	Pre>Post	**0.0007**
Withlacoochee River at Croom	431	30	330	30	Pre>Post	**0.0033**
Withlacoochee River at Trilby	339	30	244	30	Pre>Post	**0.0054**
Withlacoochee River near Holder	1038	30	742	30	Pre>Post	**0.0023**

2.4.4 Benchmark Periods

Based on analyses described in the preceding sections of this report, we concluded that there have been no appreciable flow declines in the middle Peace River that cannot be explained by climate. The entire flow records available for the USGS gage sites on the Peace River at Zolfo Springs and Arcadia may therefore be utilized for evaluating river flow patterns in support of minimum flow development. Climate-based differences in flows associated with ocean warming and cooling phases of the AMO suggest, however, that two benchmark periods should be utilized for evaluating minimum flow criteria. A benchmark period from 1940 through 1969 corresponds to the warm phase of the AMO, and is correlated with a multidecadal period of higher rainfall and increased river flows; the period from 1970 through 1999 corresponds to the cool phase of the AMO, and is correlated with a multidecadal period of lower rainfall and lower river flows.

Several approaches could be used to develop minimum flows and levels given that two benchmark flow periods have been identified. If permitting or allowing consumptive water use is conducted on a fixed-quantity basis (e.g., 50 million gallons per day) a conservative approach for protecting the ecology and aquatic resources of river systems would be to use the drier period as the benchmark period, since this would yield the lowest withdrawal recommendation. This approach would prevent significant harm from withdrawals during the low flow benchmark period, and provide greater protection during the period of higher flows. If, however, permits are issued on a percent-of-flow basis (e.g., 10% of the preceding day's flow is available for use), the most conservative approach would be to base permitting on the benchmark period that produces the lower percent-of-flow reduction associated with the criterion or key resource identified for protection from significant harm. This would allow the recommended percent-of-flow reduction to be used in either benchmark period while affording protection to the key resource during both flow periods. A third option would be to adjust either the fixed quantity or percent-of-flow withdrawal restrictions according to the current AMO period or phase. From a water supply perspective, this would probably be the most desirable approach, since it would allow the maximum amount of water to be withdrawn irrespective of the multidecadal phasing of the AMO. This option, however, would be difficult to apply since there is currently no method for determining when a step change to a new climatic regime has occurred, except in hindsight.

Based on the difficulty of determining when a step change in flows has occurred and given that there are several advantages to the "percent-of-flow" approach (e.g., maintenance of the seasonality and distribution of flows in the natural flow regime) over the fixed-quantity approach, we have developed minimum flow criteria that are based on percent-of-flow reductions. For the middle Peace River, these criteria are based on the most restrictive flow reductions associated with analyses involving two benchmark periods, from 1940 through 1969 and from 1970 through 1999.

Although the District has determined that groundwater withdrawals are the primary cause for loss of Floridan (and intermediate) Aquifer baseflow to the Upper Peace River (SWFWMD 2002, Basso 2002) resulting in a Low Minimum Flow (LMF) recommendation that required development and implementation of a "recovery strategy," this is not the case for the middle and consequently lower sections of the Peace River. Hammett (1990) explicitly attributed significant declines in Peace River flow as measured at the Arcadia gage to anthropogenic causes and not climate. Others have attributed much (SDI 2003) if not "most" (American Rivers Inc.) of this flow decline to a single anthropogenic factor (phosphate mining). By re-evaluating Hammett's conclusions, determining that there has been a climatic "step change" in rainfall and thus flow, demonstrating almost identical flow reductions in neighboring watersheds with either minimal (Horse Creek) or no (Charlie Creek) mining impacts, and showing that there have been anthropogenic increases in flow in some sub-basins of the Peace River (e.g, Payne Creek, Joshua Creek, Shell / Prairie Creek), the District has concluded that there have not been appreciable flow declines in the mid to lower Peace River than can not be explained by climate. For these reasons, we believe that the entire flow record for the multidecadal period extending from 1940 to 1969 can be used as a benchmark period for evaluating flow reductions during the wetter (i.e., AMO warm period) climatic oscillation, and that the multidecadal period extending from 1970 to 1999 can be used as a benchmark period for evaluating flow reductions during the drier (i.e., AMO cool period) climatic oscillation.

2.4.5 Seasonal Flow Patterns and the Building Block Approach

For most rivers in the SWFWMD, there is a repetitive annual flow regime that can be described on the basis of three periods. These three periods are characterized by low, medium, and high flows and for the purpose of developing minimum flows and levels, are termed Block 1, Block 2, and Block 3, respectively. To determine when these blocks may be expected to occur seasonally, we evaluated flows record for several regional rivers.

For this analysis, flow records for long-term gage sites including the Alafia River at Lithia, the Hillsborough River at Zephyrhills, the Myakka River near Sarasota, the Peace River at Arcadia, and the Withlacoochee River at Croom were reviewed. The mean annual 75 and 50 percent exceedance flows and average median daily flows for two time periods (1940 to 1969 and 1970 to 1999), corresponding to climatic phases associated with the Atlantic Multidecadal Oscillation were examined. On a seasonal basis, a low flow period, Block 1, was defined as beginning when the average median daily flow for a given time period fell below and stayed below the annual 75% exceedance flow. Block 1 was defined as ending when the high flow period, or Block, 3 began. Block 3 was defined as beginning when the average median daily flow exceeded and stayed above the mean annual 50% exceedance flow. The medium flow period, Block 2, was defined as extending from the end of Block 3 to the beginning of Block 1.

With the exception of the gage site on the Withlacoochee River, there was very little difference in the dates that each defined period began and ended, irrespective of the time period evaluated (Table 2-9). For the Alafia, Hillsborough, Myakka, and Peace Rivers, Block 1 was defined as beginning on Julian day 110 (April 20 in non-leap years) and ending on Julian day 175 (June 24). Block 3 was defined as beginning on Julian day 176 (June 25) and ending on Julian day 300 (October 27). Block 2, the medium flow period, extends from Julian day 301 (October 28) to Julian day 109 (April 19) of the following calendar year. Using these definitions: Blocks 1, 2, and 3 are 65, 176 and 124 days in length, respectively (Table 2-10).

The three flow blocks were utilized for development of minimum flows for the middle Peace River and are evident in a hydrographs of median daily flows for the at the Arcadia gage site (Figure 2-25). Lowest flows, which are typically confined to the river channel, occur during Block 1. Highest flows, which are often sufficient for inundating the river floodplain, occur during Block 3, although high flows may also occur during Block 2. Medium flows occur during Block 2.

Table 2-9. Beginning Julian days for the wet and dry periods (Blocks 1 and 3) and ending date for the Wet period at five different gage stations in the SWFWMD.

	Begin dry (Block 1)	Begin wet (Block 3)	End wet (Block 3)
Alafia at Lithia	106	175	296
Hillsborough at Zephyr Hills	112	176	296
Myakka at Sarasota	115	181	306
Peace at Arcadia	110	174	299
Withlacoochee at Croom	130	208	306
Mean w/o Withlacoochee	110	176	300
Mean with Withlacoochee	114	183	301

Table 2-10. Beginning and ending calendar dates for annual flow Blocks 1, 2, and 3 for the Alafia, Hillsborough, Myakka and Peace Rivers for non-leap years. Calendar dates apply for both non-leap years and leap years.

	Start Date (Julian day)	End Date (Julian Day)	Number of days
Block 1	April 20 (110)	June 24 (175)	65
Block 2	October 28 (301)	April 19 (109)	176
Block 3	June 25 (176)	October 27 (300)	124

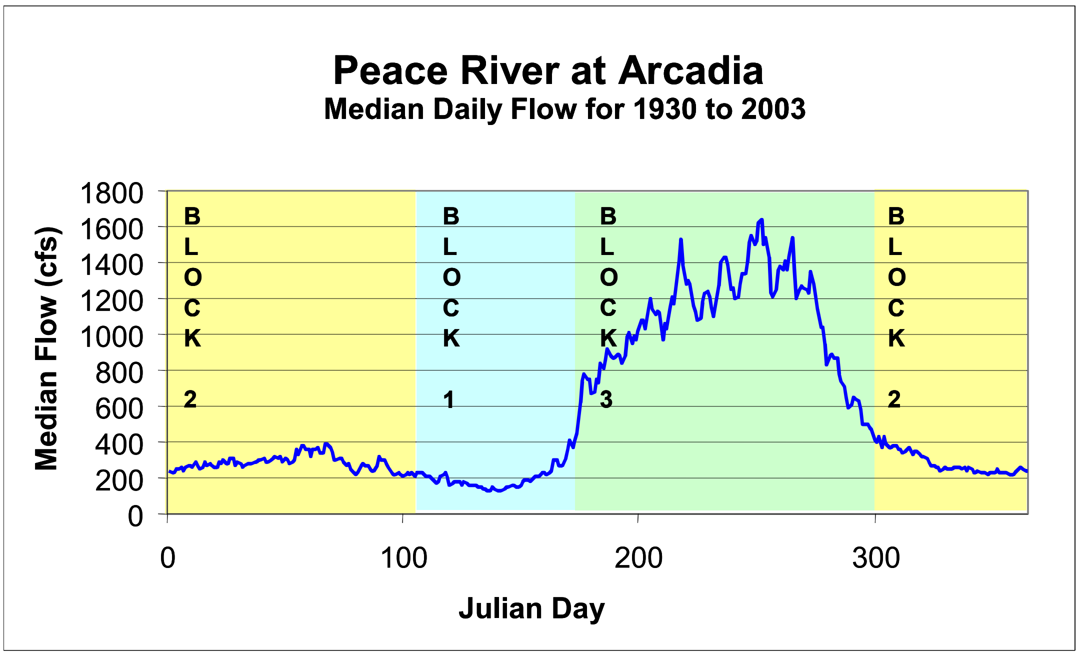


Figure 2-25. Median daily flows for 1930 through 2000 at the USGS Peace River at Arcadia, FL Gage site and seasonal flow blocks (Blocks 1, 2 and 3) for the middle Peace River.

2.5 Water Chemistry

2.5.1 Water Quality Data

Although flow can affect water quality, it is not expected that the adoption and achievement of minimum flows in the Peace River will necessarily lead to substantial changes in water quality. However, it is appropriate to review the water quality of the Peace River to fully appreciate how land use changes have affected the system. The Peace River has experienced high nutrient concentrations and loads rarely encountered in flowing water systems, because of its unique geologic setting and the mining and processing of phosphate ore in its watershed. The examination of water quality data is also useful for understanding the complex nature of flow changes in the Peace River.

Long-term water quality changes were evaluated using USGS data gathered at gage sites on the Peace River (at Bartow, Zolfo Springs and Arcadia) and on selected tributaries of the Peace River (see Appendix WQ). Comparison of water quality data with flow records was made for evaluation of possible relationships between flow and land use. In addition, comparisons were made with gage sites on other river systems, specifically the Alafia River at Lithia, the Myakka River near Sarasota, and the Withlacoochee River near Holder. The Withlacoochee River in contrast to the Alafia and Peace Rivers exhibits relatively good water quality, perhaps the best of any river system within the District. This is in part attributable to land use differences and in part attributable to inherent differences in geologic setting. Because both the Alafia and Peace River watersheds lie in the Bone Valley geologic formation and because significant portions of both watersheds have been mined for phosphate, it was deemed desirable to evaluate water quality on a river system minimally impacted by phosphate mining. Phosphate mining has occurred historically in the Withlacoochee River watershed, specifically in the Dunnellon-Rainbow River area (which is downstream of the Holder gage), and actually predated mining activities on the Peace and Alafia Rivers.

For the following analyses, available water quality data for selected gages were retrieved from the USGS on-line database. While some data are available on a number of water quality parameters, analysis was restricted to those parameters for which it was felt that a sufficient number of observations existed for inspection of trends. The USGS has long-term flow and water quality data for a number of gage sites throughout the District. Flow records at many sites exceed 50 to 60 years, and some of these have water quality records of 40 years or more. Except for special studies of relatively short duration, water quality at most USGS sites was typically monitored on a quarterly basis at best.

Data for each parameter discussed in the following sections of this chapter are typically presented in three plots, including a time-series plot, a plot of the parameter versus flow, and a plot of the residuals obtained from a LOWESS regression of the parameter versus flow. The last plot was used to evaluate if a parameter loading has increased or decreased over time irrespective of flow. The results of a Kendall's tau analysis on the residuals were used to help determine if apparent increasing or decreasing trends in a parameter were statistically significant.

2.5.2 Macronutrients: Phosphorus and Nitrogen

Concentrations of the two major macronutrients, phosphorus and nitrogen, have been monitored for some time at mainstem gage sites. The exact chemical form of the nutrient monitored has changed over time (e.g., total nitrate, dissolved nitrate, nitrite+nitrate, etc.), however, for purposes of the discussion that follows and for trend analysis, values for some constituents were combined to provide a sufficient number of data points for analysis.

2.5.2.1 Phosphorus

Phosphorus has over the years been variously reported by the USGS as total phosphorus, dissolved phosphate, and as ortho-phosphate. For our analyses, it was assumed that dissolved phosphate and ortho-phosphate are essentially equivalent. Although some of the older data were reported as mg/l phosphate, all values were converted and expressed as mg/l phosphorus (P). As similarly described for the Alafia (Kelly et al. 2005) and Upper Peace Rivers (SWFWMD 2002), historic P concentrations in the Peace River were impressive (Figures 2-26 to 2-28). A high of 52 mg/l P was reported for a sample collected on March 20, 1974 at the Bartow gage site; the highest concentration recorded at the Arcadia site was 17 mg/l on March 8, 1963. Considering that background concentrations for a stream in the Bone Valley area should probably be between 0.1 and 0.5 mg/l P, these high values are more than 30 to 100 times higher than should be expected. Although these values represent the extreme, values in excess of 10 and 4 mg/l were frequently measured before 1985 at the Bartow and Arcadia sites, respectively.

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) (Figures 2-26 through 2-29). 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.

Unfortunately, there are no long-term records of in-stream phosphorus concentrations at the gage sites prior to phosphate mining in the Peace River watershed. Therefore, it is difficult to determine if current in-stream concentrations approach those that would have been expected in the absence of mining impacts. While there has been a considerable decrease in loading (perhaps an order of magnitude or more), concentrations of phosphorus are still high when compared to most natural stream systems. Friedemann and Hand (1989) determined the typical ranges of various constituents found in Florida lakes, streams and estuaries. Based on their finding, 90% of all Florida streams exhibited total phosphorus concentrations less than 0.87 mg/l P. Mean total phosphorus concentrations for the Peace River at Bartow and Arcadia for the decade from 1990 to 1999 were 1.16 mg/l P and 0.93 mg/l P, respectively; which place the Peace among the rivers with the highest P concentrations in the state.

Similar trends in instream phosphorus concentrations are also evident in the Alafia River (Kelly et al. 2005). As with the Peace River, these elevated levels were also attributable to past mining practices and discharges from related chemical processing plants. Similarly to the Peace River, dramatic decreases in P concentration also occurred in the Alafia River (Figure 2-30, although they occurred a few years earlier (around 1980) than at Peace River sites). Like the Peace River, other constituents found in association with phosphate also followed similar trends in concentration (e.g., fluoride – Figure 2-31) and similar declines as phosphate mining practices changed.

Both the Alafia and Peace River watersheds lie within the Bone Valley geologic area, and thus elevated phosphorus concentrations might be expected. Trends in phosphorus concentrations of the Withlacoochee River at the USGS Holder gaging site were examined (Figure 2-32). Like the Peace River, the headwaters of the Withlacoochee River lie within the Green Swamp; however, unlike the Alafia and Peace Rivers, phosphate has not been extensively mined in the watershed. As a result, one might expect to find lower naturally occurring instream concentrations of phosphorus. Phosphorus concentrations in the Withlacoochee River (less than 0.04 mg/l), as measured at the Holder gaging site, are more than an order of magnitude lower than concentrations now encountered in the Peace River.

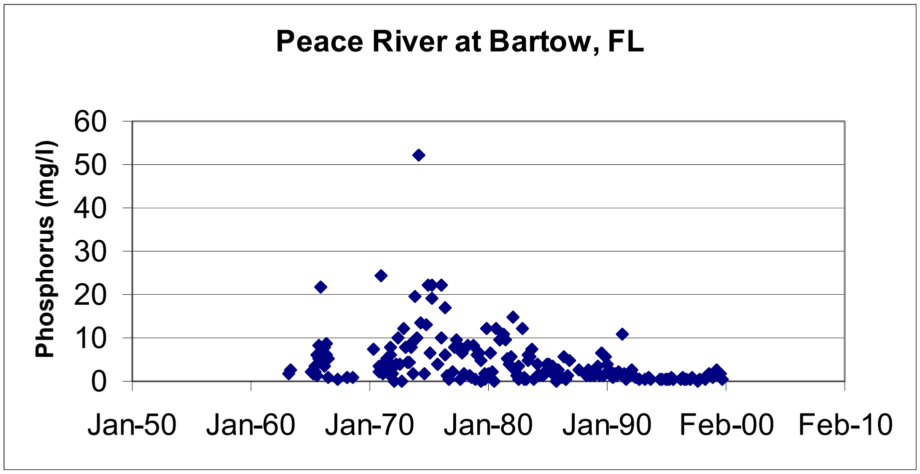
2.5.2.2 Nitrogen

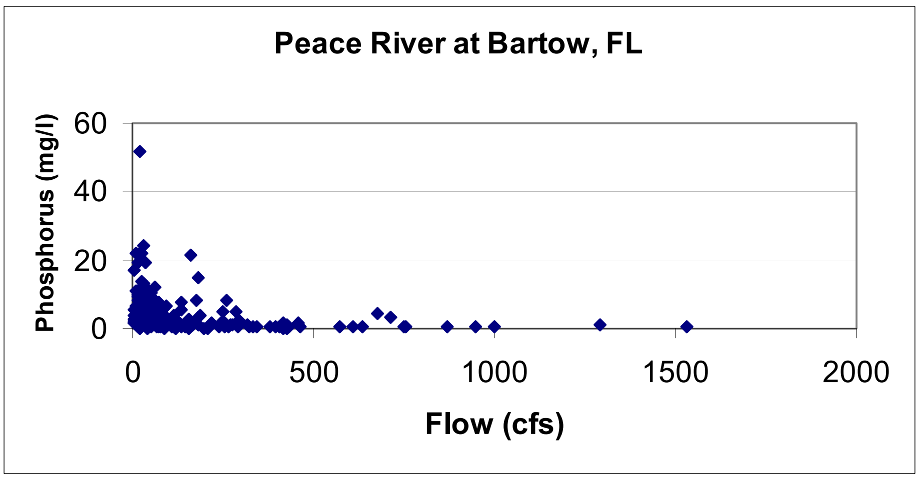
Nitrogen has most often been reported by the USGS as either nitrate or nitrate+nitrite. For our analyses, it was assumed that total nitrate, dissolved nitrate, and nitrate+nitrite are essentially equivalent, unless both were reported. In this case, the highest concentration was used for data analysis. Total Kjeldahl nitrogen, total organic nitrogen, ammonia nitrogen and total nitrogen are not considered here, because considerably fewer observations were generally made for these parameters. All nitrogen concentrations are reported as mg/l N. Nitrate+nitrite concentrations at Bartow, Zolfo Springs, and Arcadia gage sites on the Peace River (Figures 2-33, 2-34 and 2-35) indicate a general decrease in inorganic nitrogen concentrations; historically concentrations of 1.0 mg/l were commonly encountered at all sites, and despite the fact that nitrate+nitrite nitrogen was significantly negatively correlated with discharge at most sites, concentrations were typically higher downstream of Bartow (SWFWMD 2002). Prior to 1984, nitrate+nitrite concentrations at Bartow and Arcadia averaged 0.36 mg/l and 0.90 mg/l, respectively. Mean concentrations during the1990's were 0.18 and 0.63 mg/l at Bartow and Arcadia, respectively. Concentrations at the Bartow site have declined approximately 50% from historic (pre-1984) levels, while concentrations at Arcadia were have declined by approximately 30%. Given the large decrease in inorganic phosphorus concentrations, the apparent decrease in inorganic nitrogen concentrations which have occurred over the last decade or two, and the fact that both nutrients tend to be negatively correlated to flow, it can be inferred that inorganic nutrient loading to downstream areas is now less than that which occurred historically (SWFWMD 2002).

2.5.3 Potassium and Trend Analysis of Selected Chemical Constituents

One of the more interesting and unanticipated findings of the analysis of gage site water quality data on the Peace River (SWFWMD 2002) was an apparent increasing trend in dissolved potassium (Figure 2-36). Statistical analysis revealed that the trend was significant and unrelated to increases or decreases in flow, indicating an increasing rate of loading from the watershed (Tables 2-11 and 2-12). It was speculated that the trend was most likely attributable to increasing fertilizer application within the watershed. An increasing trend in dissolved potassium was also clearly evident for the Myakka River and Alafia Rivers as well (Figures 2-37 and 2-38 and Tables 2-13 and 2-14; Kelly et al. 2005).

Numerous other water quality parameters at Peace River tributary sites showed significant increasing or decreasing trends irrespective of flow. These are not considered in detail, but plots of many of these are included in Appendix WQ. It appears that some of these trends may be related to irrigation with groundwater, since many of the observed increases over time are in constituents that are typically higher in groundwater.





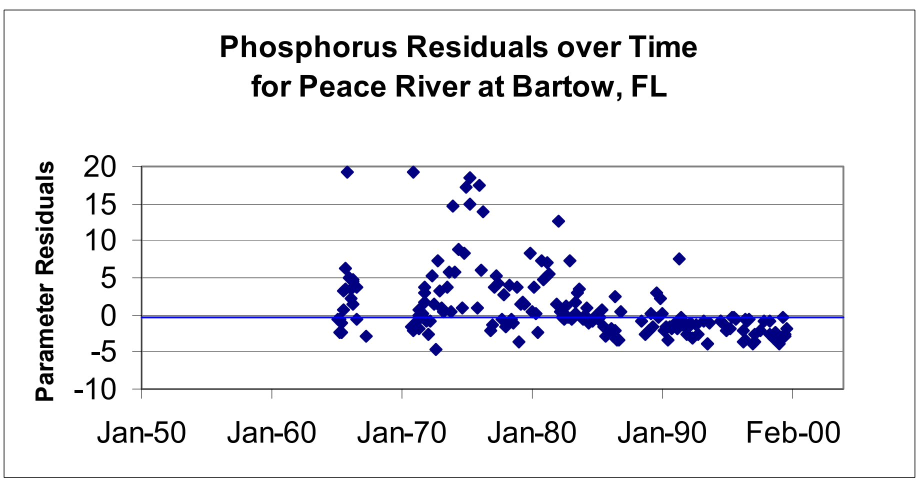
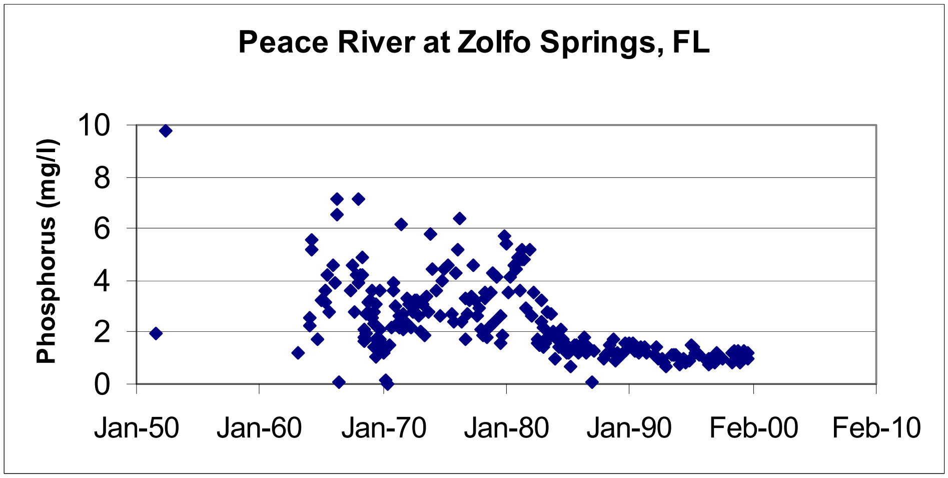
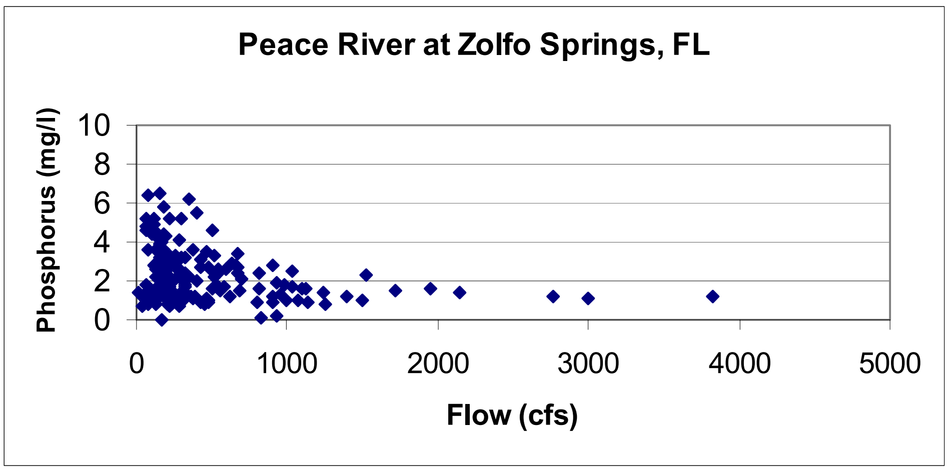


Figure 2-26. Phosphorus concentrations in water samples collected by the USGS at the Peace River at Bartow gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





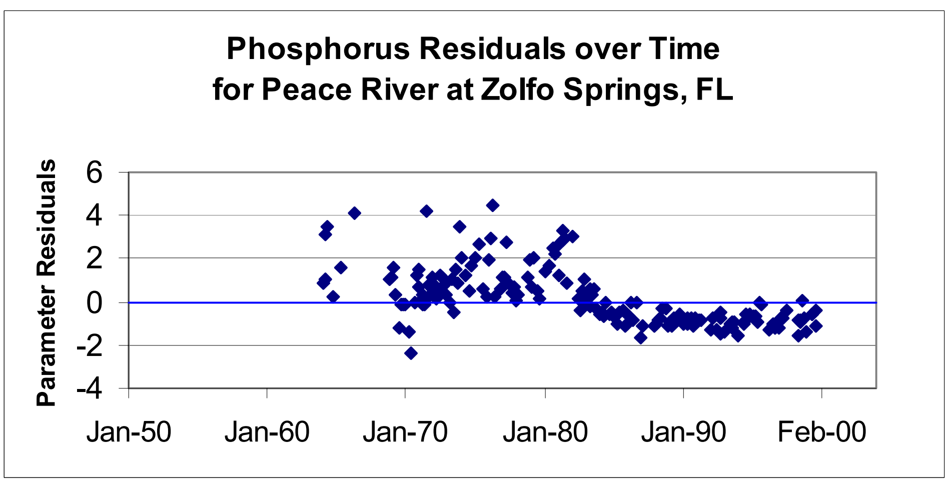
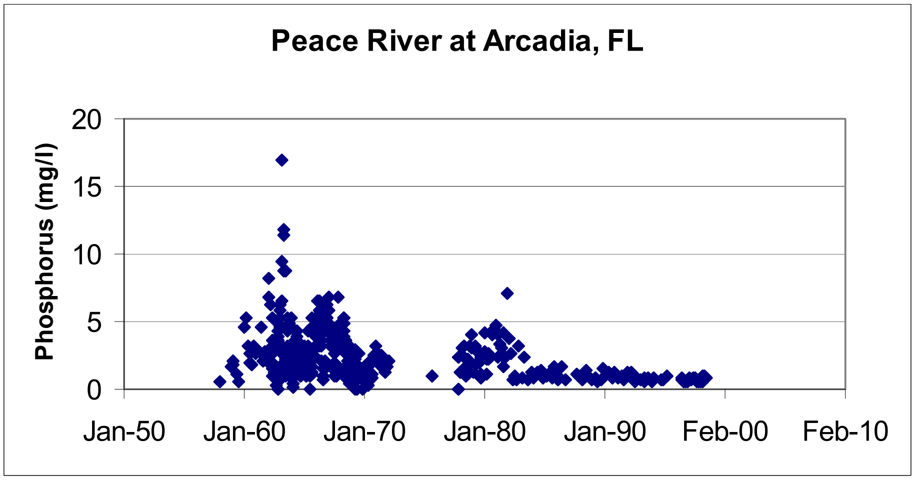
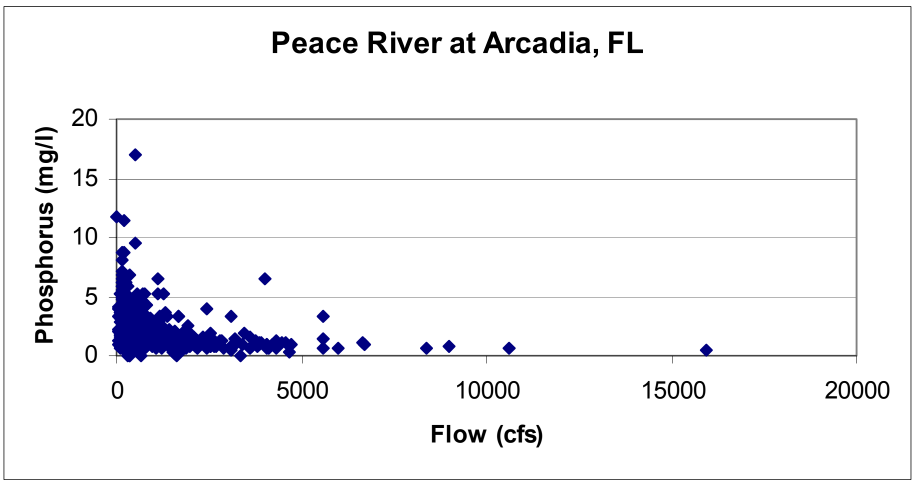


Figure 2-27. Phosphorus concentrations in water samples collected by the USGS at the Peace River at Zolfo Springs gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





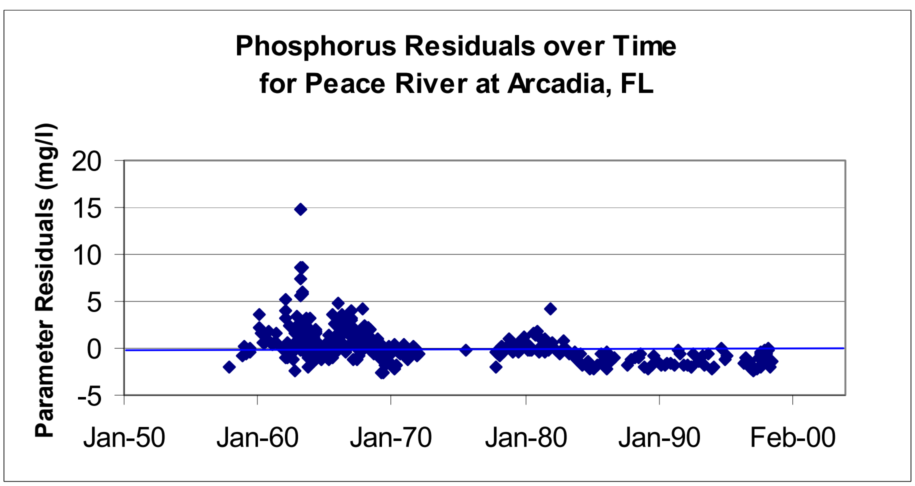


Figure 2-28. Phosphorus concentrations in water samples collected by the USGS at the Peace River at Arcadia gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

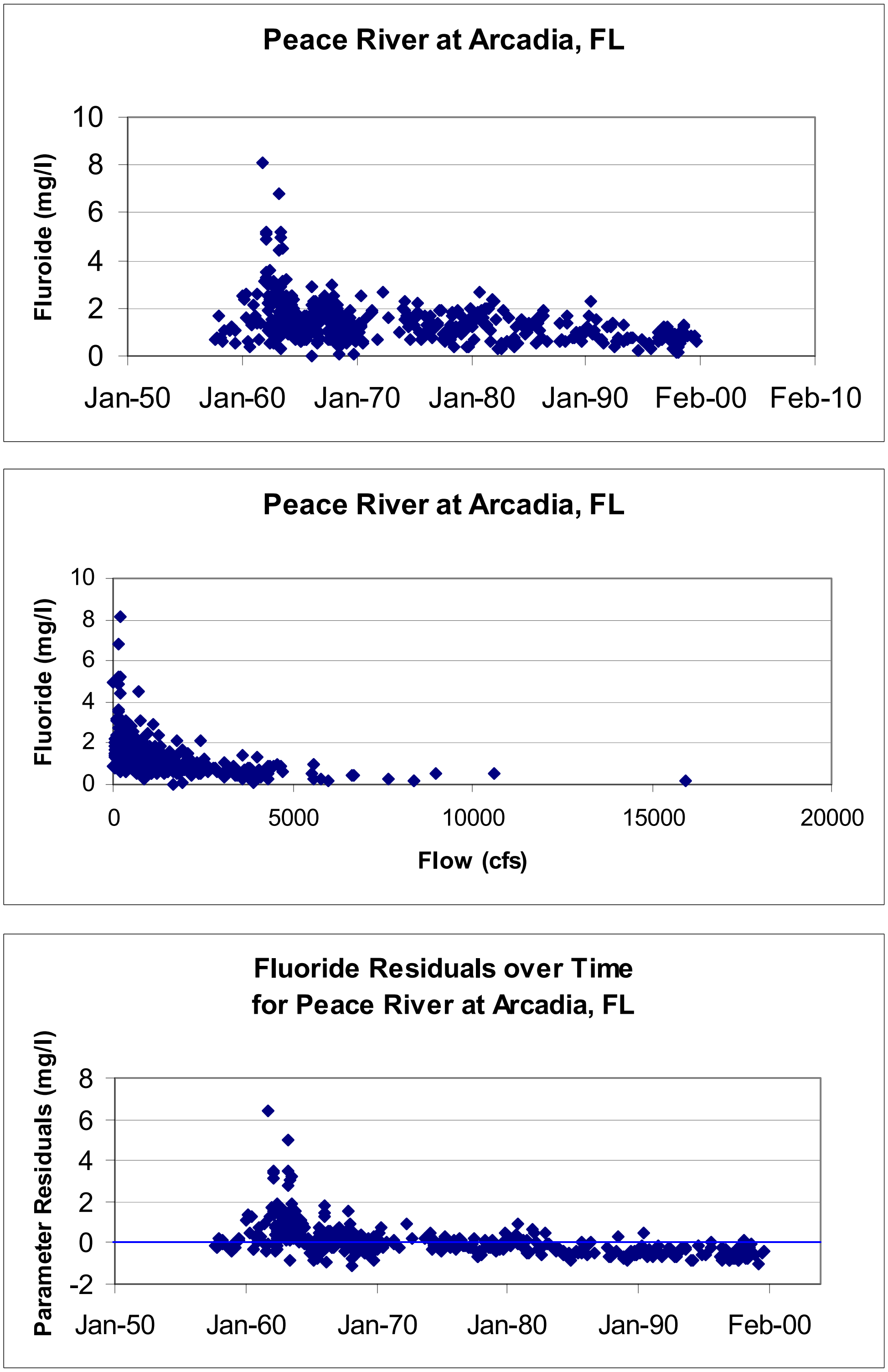


Figure 2-29. Fluoride concentrations in water samples collected by the USGS at the Peace River at Arcadia gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

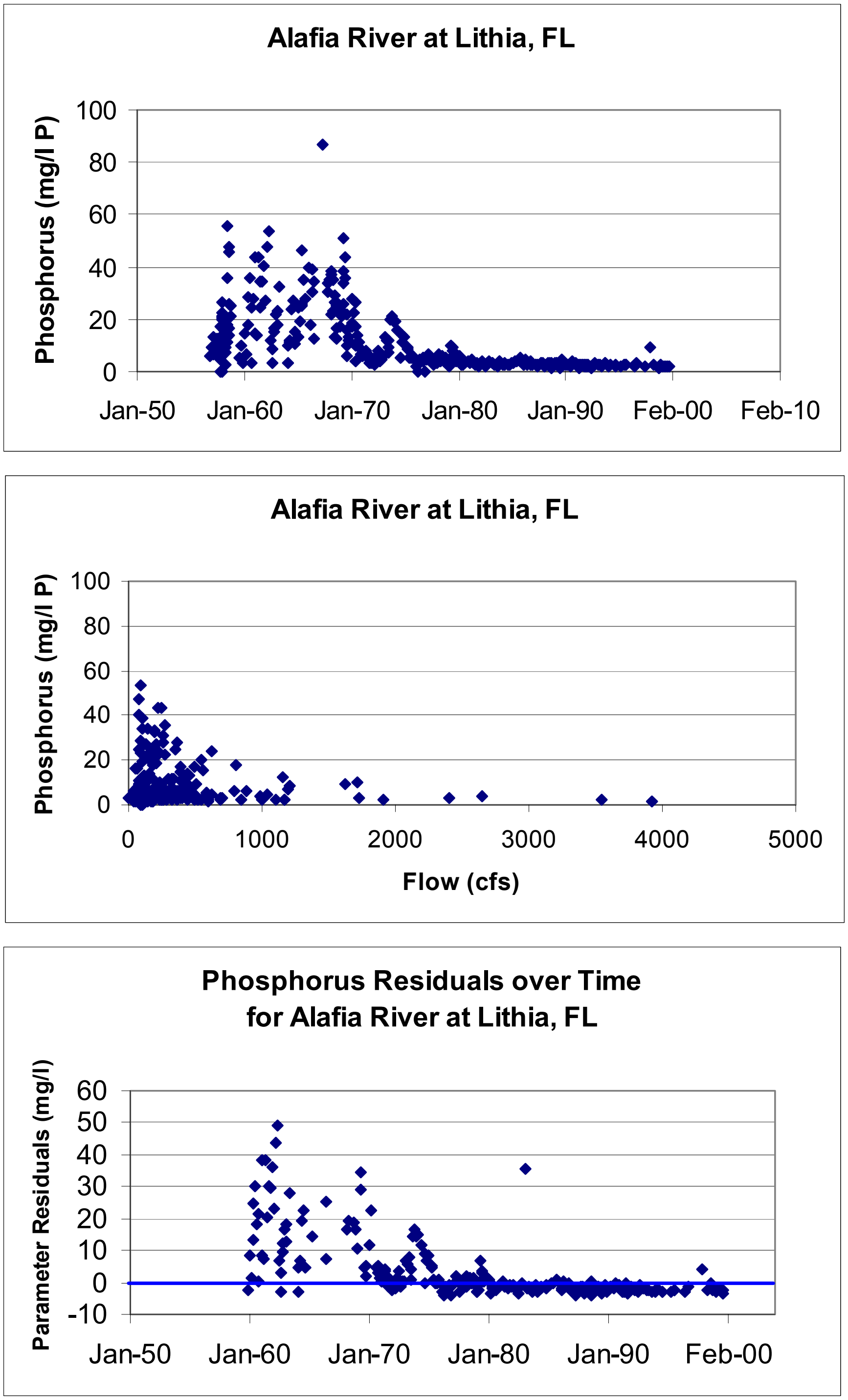
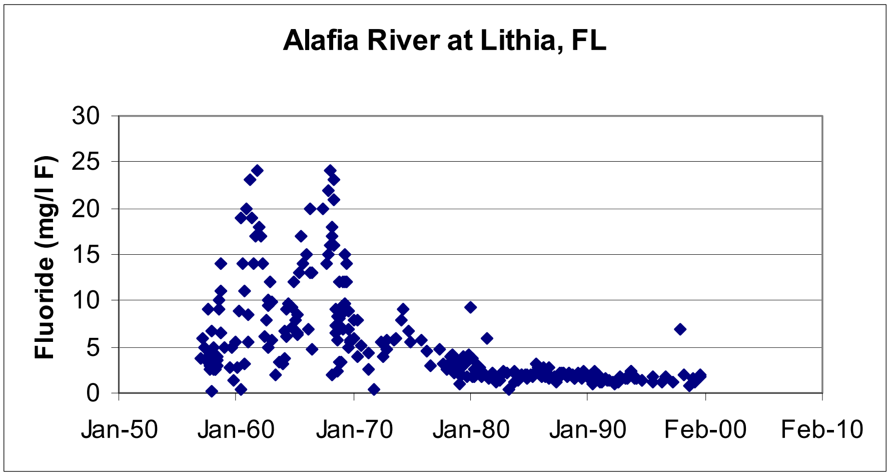
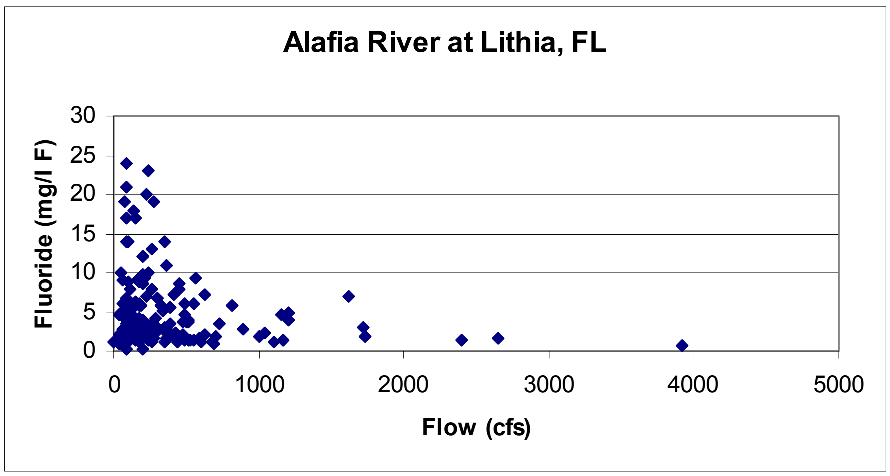


Figure 2-30. Phosphorus concentrations in water samples collected by the USGS at the Alafia River at Lithia gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





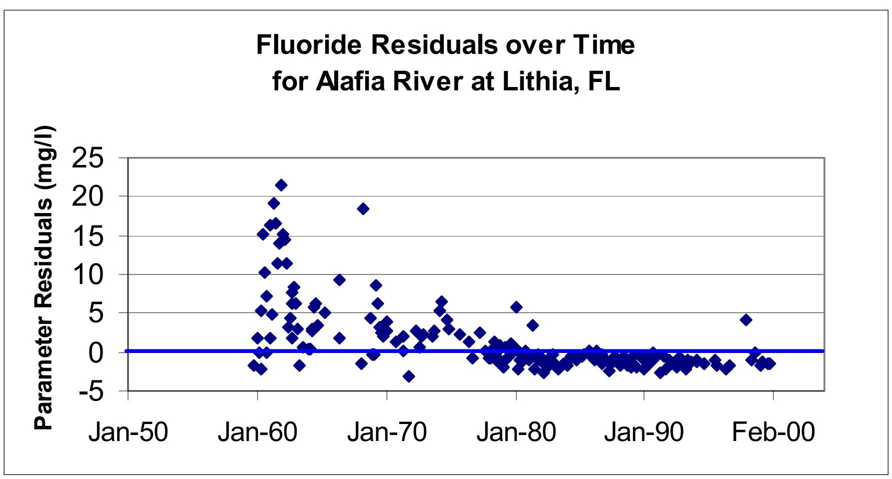
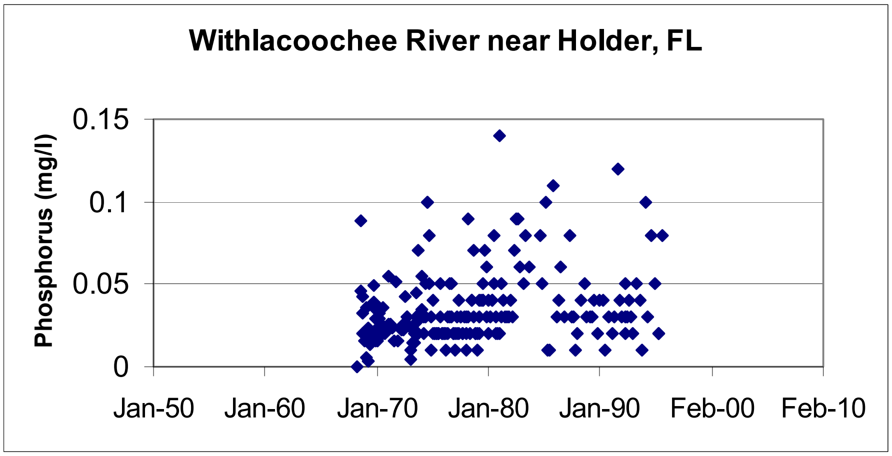
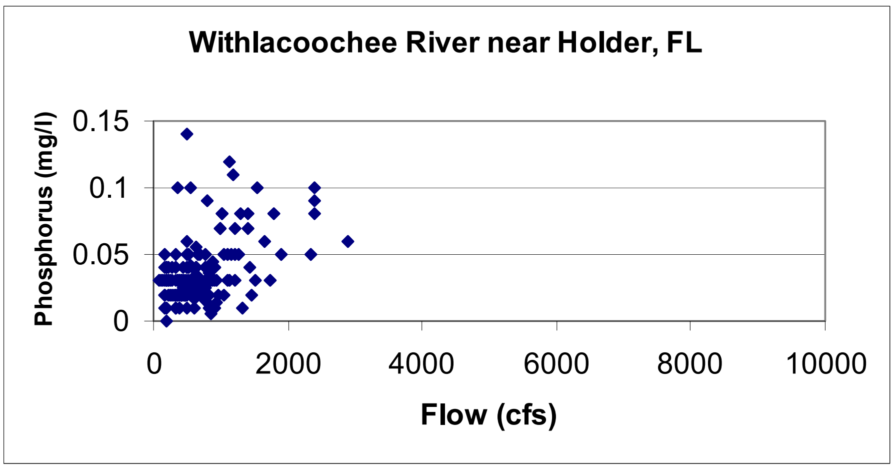


Figure 2-31. Fluoride concentrations in water samples collected by the USGS at the Alafia River at Lithia gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





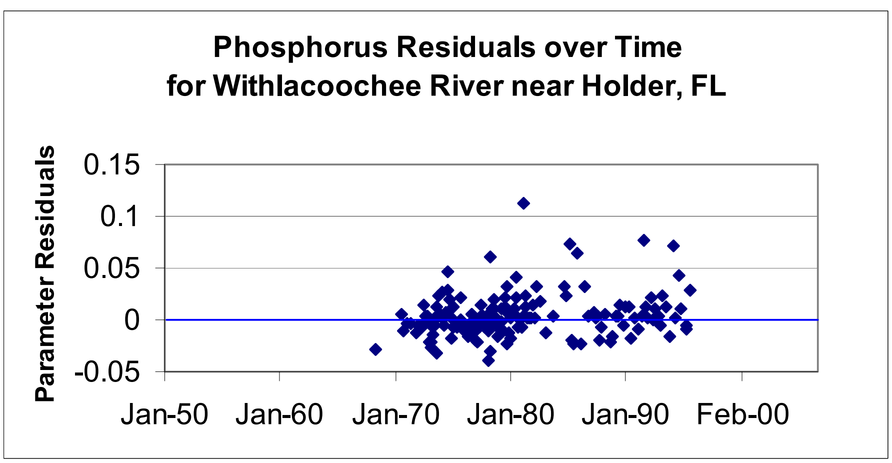
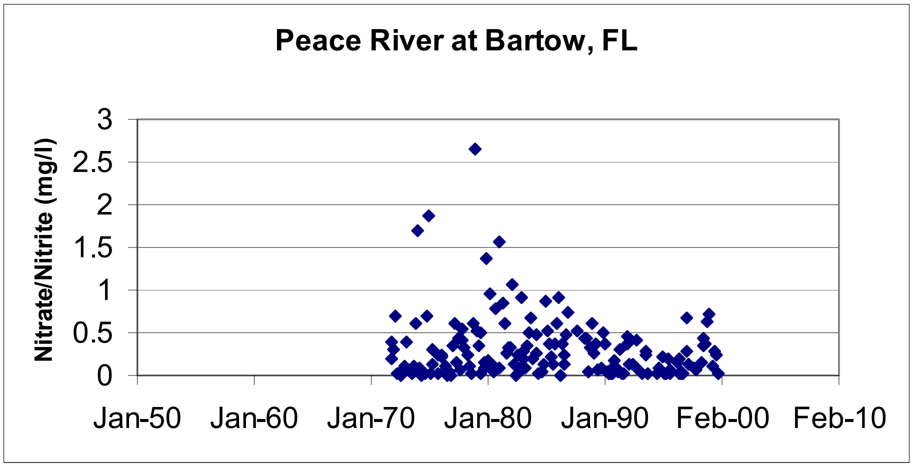
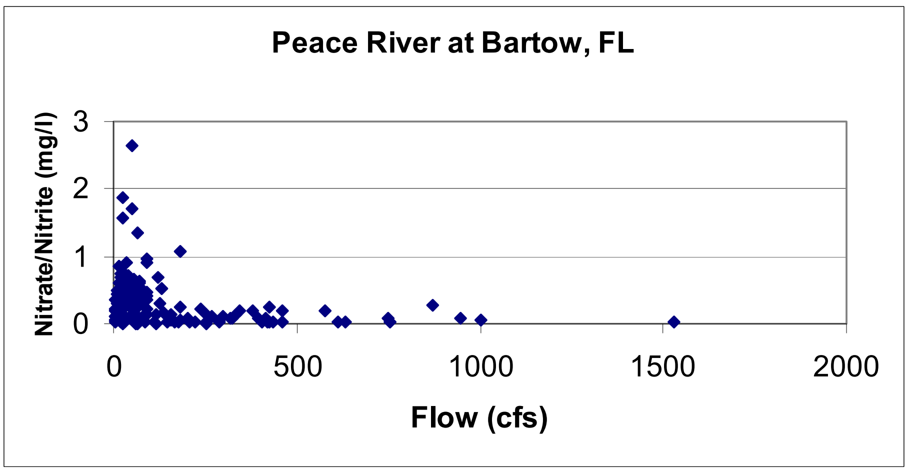


Figure 2-32. Phosphorus concentrations in water samples collected by the USGS at the Withlacoochee River at Holder gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





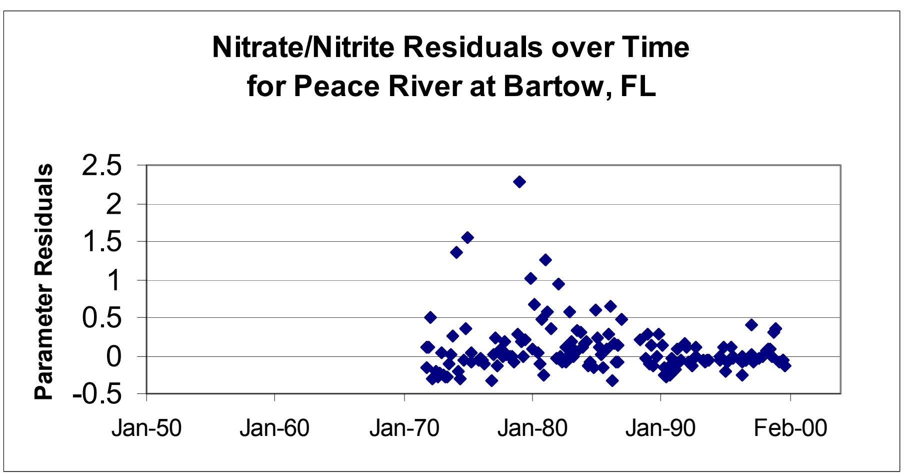
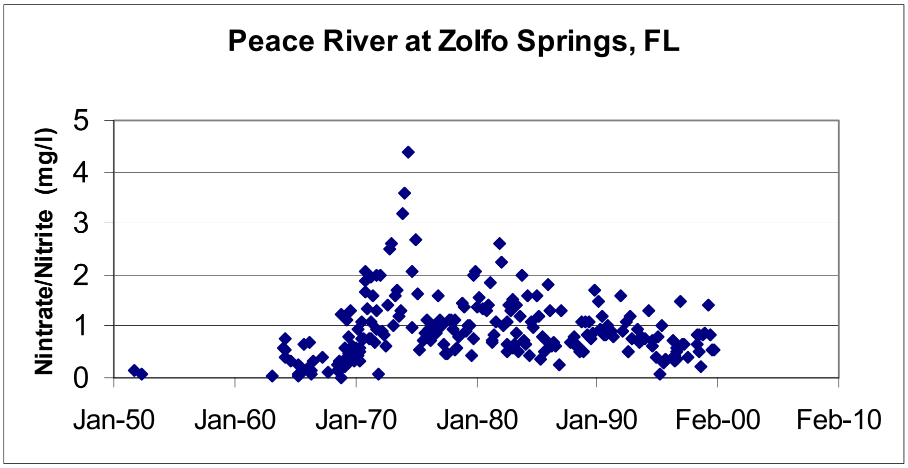
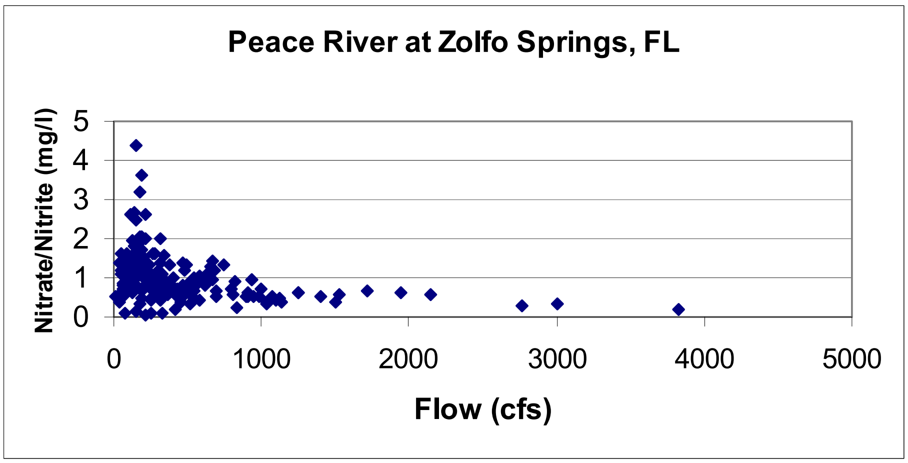


Figure 2-33. Nitrate or Nitrate/Nitrite concentrations in water samples collected by the USGS at the Peace River at Bartow gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





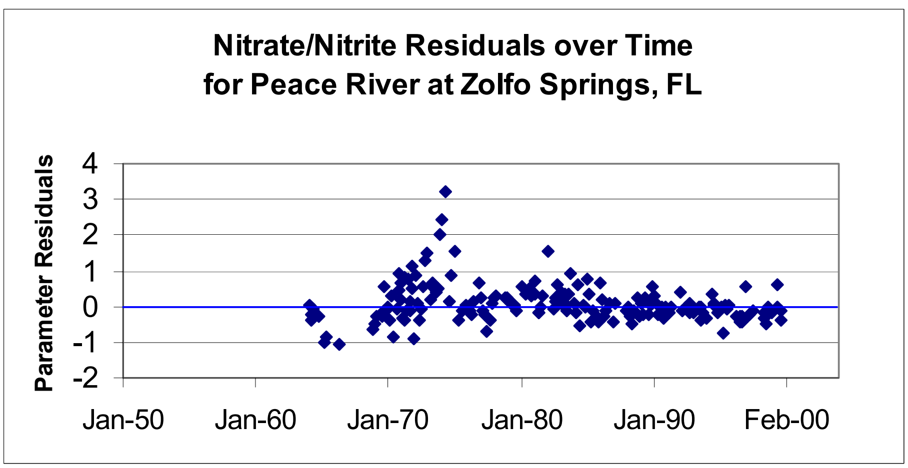


Figure 2-34. Nitrate or Nitrate/Nitrite concentrations in water samples collected by the USGS at the Peace River at Zolfo Springs gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

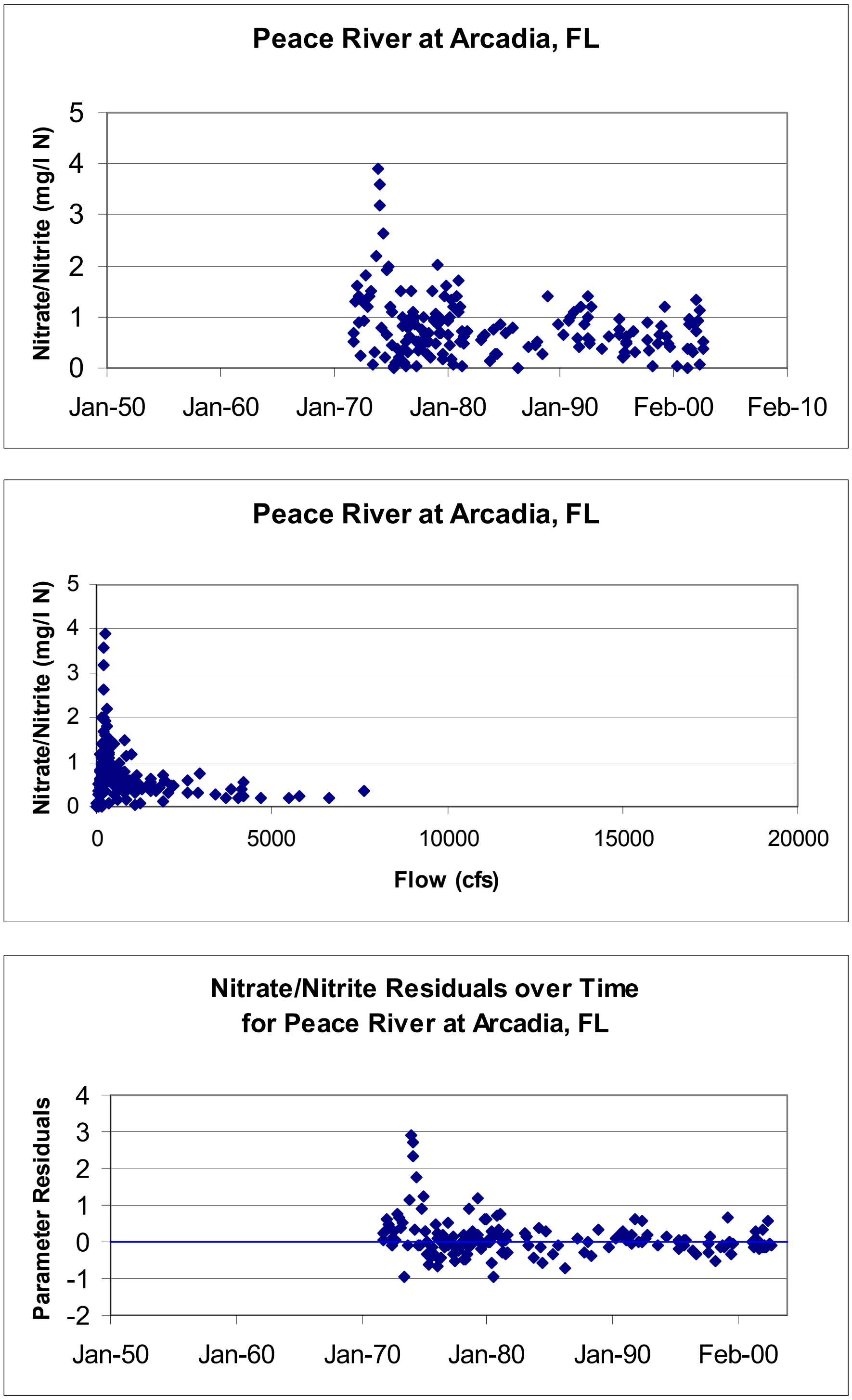
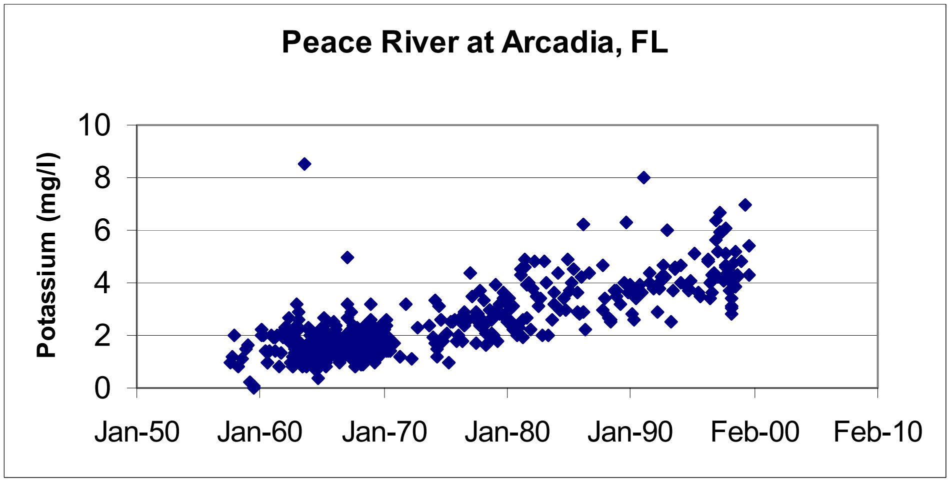
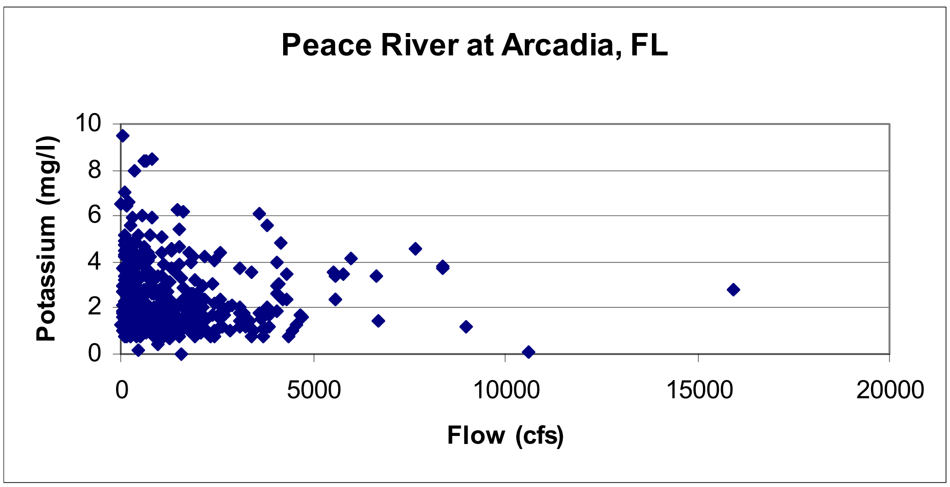


Figure 2-35. Nitrate or Nitrate/Nitrite concentrations in water samples collected by the USGS at the Peace River at Arcadia gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





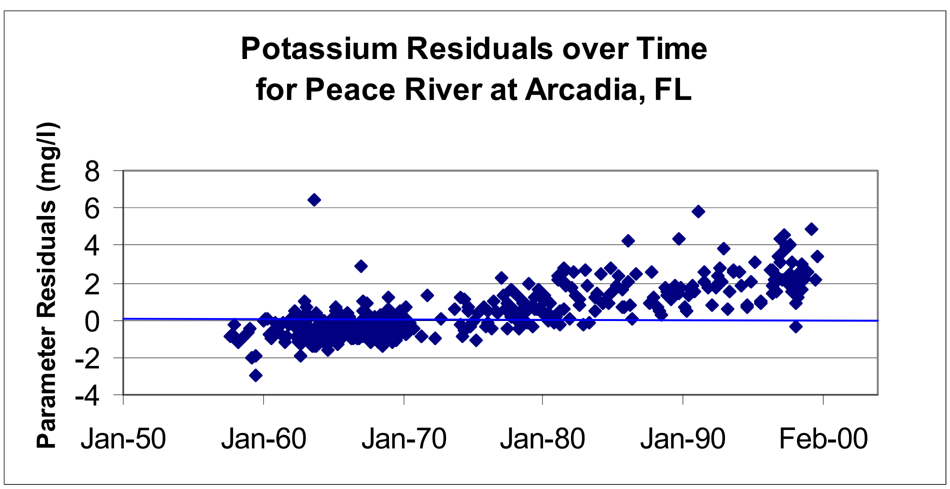
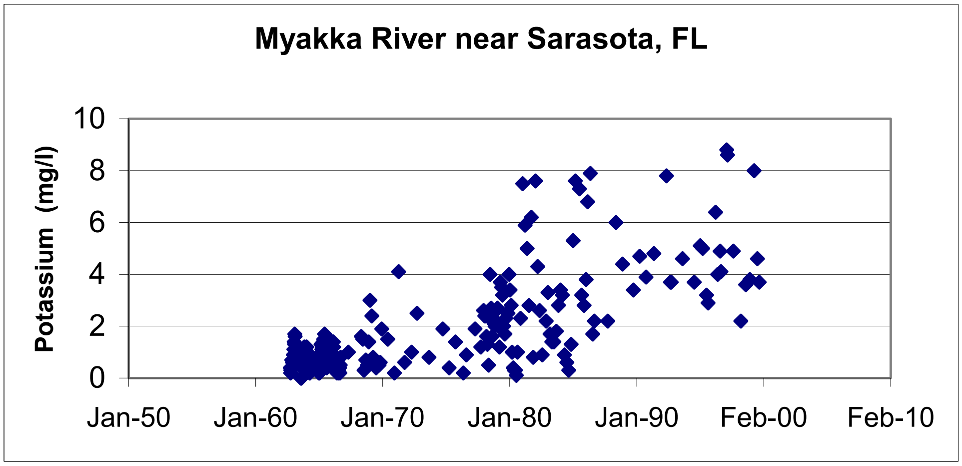
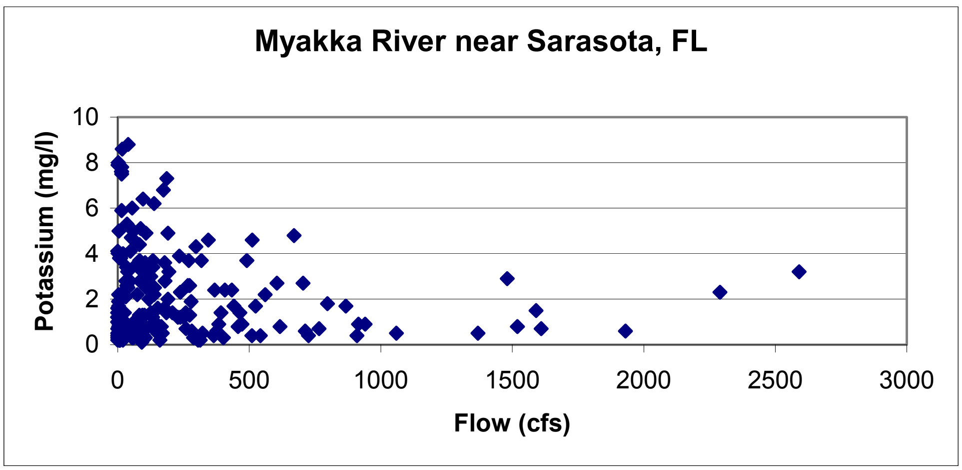


Figure 2-36. Potassium concentrations in water samples collected by the USGS at the Peace River at Arcadia gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





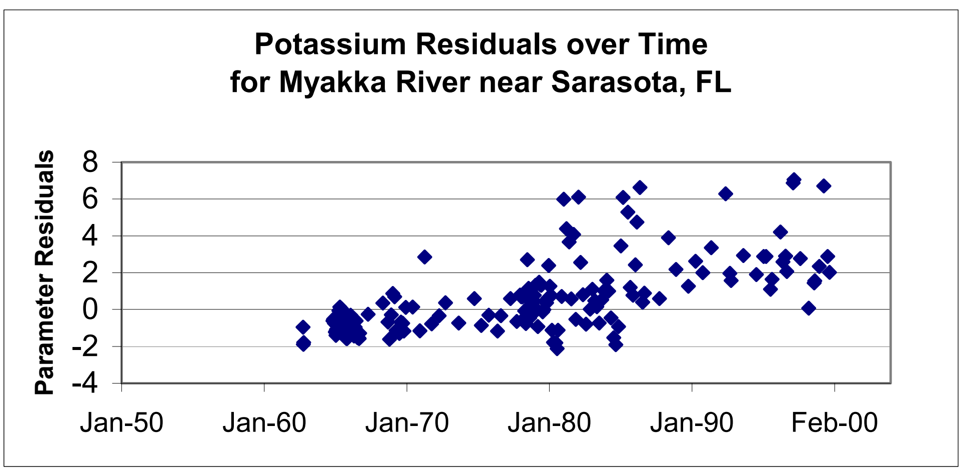


Figure 2-37. Potassium concentrations in water samples collected by the USGS at the Myakka River near Sarasota gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

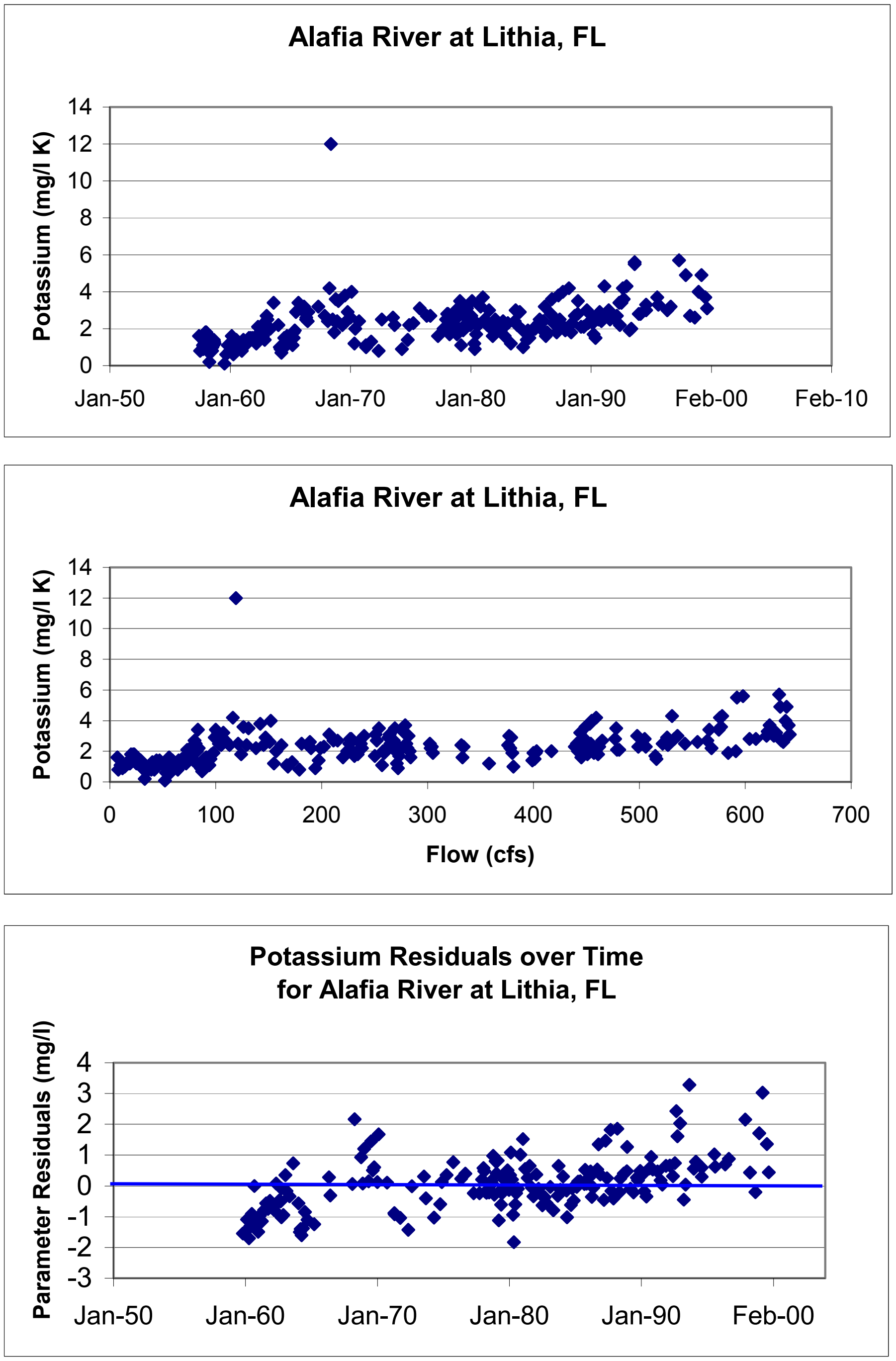


Figure 2-38. Potassium concentrations in water samples collected by the USGS at the Alafia River at Lithia, FL gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

Table 2-11. Results of Kendall's tau analysis on residuals from various parameters regressed against flow for the Peace River at Zolfo Springs gage. Yellow shading indicates a statistically significant decreasing trend, while blue shading indicates a statistically significant decreasing tend.

PEACE RIVER AT ZOLFO SPRINGS

Parameter Residual	Residual Median	n	p Value	intercept	slope
Conductance	-2.1600	194	0.24105	33.38050	0.00087
Dissolved Oxygen	-0.0110	163	0.10035	-2.16677	0.00007
pH	0.0129	172	0.00716	-0.83519	0.00005
NOx	-0.0257	179	0.00926	0.64039	-0.00002
Phosphorus	-0.0960	176	0.00000	6.15835	-0.00021
Hardness	-1.0800	34	0.09685	-70.09360	0.00270
Calcium	0.4600	48	0.25157	8.88164	-0.00032
Chloride	-0.1780	49	0.00000	-14.12370	0.00053
Fluoride	0.0214	49	0.15745	0.77328	-0.00003
Iron	insufficient data (n=18)				
Magnesium	-0.2170	48	0.35994	-2.83899	0.00010
Potassium	-0.0710	47	0.00000	-4.97350	0.00018
Silica	-0.0820	60	0.00394	6.10975	-0.00023
Sodium	0.1820	47	0.00741	-9.13969	0.00035
Sulfate	1.8600	48	0.47157	18.84010	-0.00064

Table 2-12. Results of Kendall's tau analysis on residuals from various parameters regressed against flow for the Peace River at Arcadia gage. Yellow shading indicates a statistically significant decreasing trend, while blue shading indicates a statistically significant decreasing tend.

PEACE RIVER AT ARCADIA

Parameter Residual	Residual Median	n	p Value	intercept	slope
Conductance	-6.0400	642	0.00000	-131.00000	0.00495
Dissolved Oxygen	-0.0791	245	0.57867	0.41129	-0.00002
pH	-0.0064	621	0.95414	-0.00224	0.00000
NOx	0.0059	173	0.01243	0.48939	-0.00002
Phosphorus	-0.0345	495	0.00000	4.00839	-0.00016
Hardness	-3.7300	446	0.00000	-87.03340	0.00341
Calcium	-0.4210	551	0.03372	-3.34403	0.00012
Chloride	-0.2820	560	0.00000	-12.67960	0.00050
Fluoride	-0.0132	570	0.00000	1.83663	-0.00007
Iron	-2.3100	450	0.00000	-153.77200	0.00616
Magnesium	-0.1790	552	0.00000	-8.13830	0.00032
Potassium	-0.1309	548	0.00000	-5.54515	0.00022
Silica	0.1470	563	0.00000	11.16780	-0.00044
Sodium	-0.2390	548	0.00000	-3.74362	0.00014
Sulfate	-1.9490	555	0.00000	-24.41510	0.00090

Table 2-13. Results of Kendall's tau analysis on residuals from various parameters regressed against flow for the Myakka River near Sarasota gage. Yellow shading indicates a statistically significant decreasing trend, while blue shading indicates a statistically significant decreasing tend.

MYAKKA RIVER NEAR SARASOTA

Parameter Residual	Residual Median	n	p Value	intercept	slope
Conductance	-10.0000	248	0.00000	-424.30800	0.01456
Dissolved Oxygen	0.0350	120	0.50922	1.46821	-0.00005
pH	-0.0083	215	0.00416	0.63905	-0.00002
NOx	-0.0069	129	0.06248	0.04895	0.00000
Phosphorus	-0.0171	127	0.00000	-0.73127	0.00003
Calcium	-1.0090	193	0.00000	-36.99860	0.00127
Chloride	-0.3290	198	0.00001	-9.87780	0.00034
Fluoride	0.0045	197	0.00027	0.17920	-0.00001
Hardness	-2.9100	146	0.00000	-187.61700	0.00734
Magnesium	-0.4650	193	0.00000	-19.95630	0.00069
Potassium	-0.2810	193	0.00000	-8.17683	0.00028
Silica	0.0850	192	0.77540	-0.23801	0.00001
Sodium	0.0070	192	0.00000	-7.44218	0.00026
Sulfate	-3.7800	191	0.00000	-135.29300	0.00463

Table 2-14. Results of Kendall's tau analysis on residuals from various parameters regressed against flow for the Alafia River at Lithia gage. Yellow shading indicates a statistically significant decreasing trend, while blue shading indicates a statistically significant decreasing tend.

ALAFIA AT LITHIA

Parameter Residual	Residual Median	n	p Value	intercept	slope
Conductance	-15.5800	250	0.0000	408.3210	-0.01459
Dissolved Oxygen	-0.0570	194	0.5140	0.6278	-0.00002
pH	-0.0043	234	0.0000	-2.7960	0.00010
Nox	-0.0079	186	0.0168	1.0721	-0.00004
Phosphorus	-0.4750	249	0.0000	22.0165	-0.00064
Hardness	-5.7500	118	0.0131	79.6733	-0.00314
Calcium	-0.4370	188	0.0000	41.1177	-0.00132
Magnesium	0.0210	188	0.0295	2.2041	-0.00007
Sodium	-1.0410	187	0.2962	4.4662	-0.00188
Potassium	0.0583	188	0.0000	-3.3258	0.00012
Chloride	-0.0300	195	0.0000	27.9862	-0.00095
Sulfate	-2.6600	188	0.0000	101.0630	-0.00354
Fluoride	-0.3910	191	0.0000	12.6430	-0.00045
Iron	-0.9400	131	0.0000	-156.5600	0.00527

Chapter 3 Goals, Ecological Resources of Concern and Key Habitat Indicators

> *"There is no universally accepted method or combination of methods that is appropriate for establishing instream flow regimes on all rivers or streams. Rather, the combination or adaptation of methods should be determined on a case-by-case basis; . . . In a sense, there are few bad methods – only improper applications of methods. In fact, most . . . assessment tools . . . can afford adequate instream flow protection for all of a river's needs when they are used in conjunction with other techniques in ways that provide reasonable answers to specific questions asked for individual rivers and river segments. Therefore, whether a particular method 'works' is not based on its acceptance by all parties but whether it is based on sound science, basic ecological principles, and documented logic that address a specific need"* (Instream Flow Council 2002).

3.1 Goal – Preventing Significant Harm

The goal of an MFL determination is to protect the resource from significant harm due to withdrawals and was broadly defined in the enacting legislation as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." What constitutes "significant harm" was not defined. The District has identified loss of flows associated with loss of fish passage or loss of maximization of stream bottom habitat as significantly harmful to river ecosytems. Also, based upon consideration of a recommendation of the peer review panel for the upper Peace River MFLs (Gore et al. 2002), we propose that significant harm in many cases can be defined as quantifiable reductions in habitat.

In their peer review report on the upper Peace River, Gore et al. (2002) stated, "[i]n general, instream flow analysts consider a loss of more than 15% habitat, as compared to undisturbed or current conditions, to be a significant impact on that population or assemblage." This recommendation was made in consideration of employing the Physical Habitat Simulation Model (PHABSIM) for analyzing flow, water depth and substrate preferences that define aquatic species habitats. With some exceptions (e.g., loss of fish passage or wetted perimeter inflection point), there are few "bright lines" which can be relied upon to judge when "significant harm" occurs. Rather loss of habitat in many cases occurs incrementally as flows decline, often without a clear inflection point or threshold.

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. Although we recommend a 15% change in habitat availability as a measure of unacceptable loss, it is important to note that percentage changes employed for other instream flow determinations have ranged from 10% to 33%. For example, Dunbar et al. (1998) in reference to the use of PHABSIM noted, "an alternative approach is to select the flow giving 80% habitat exceedance percentile," which is equivalent to a 20% decrease. Jowett (1993) used a guideline of one-third loss (i.e., retention of two-thirds) of existing habitat at naturally occurring low flows, but acknowledged that, "[n]o methodology exists for the selection of a percentage loss of "natural" habitat which would be considered acceptable." The state of Texas utilized a target decrease of less than 20% of the historic average in establishing a MFL for Matagorda Bay (http://www.tpwd.state.tx.us/texaswater/coastal/freashwater/matagorda/matagorda.phtml).

3.2 Resources and Area of Concern

The resources addressed by the District's minimum flows and levels analyses include the surface waters and biological communities associated with the river system, including the river channel and its floodplain. A river system is physiographically complex, with a meandering channel and associated floodplain wetlands. This hydrologic and physical setting provides habitat for a diverse array of plant and animal populations. Because "[a]quatic species have evolved life history strategies primarily in direct response to the natural flow regimes" (Bunn and Arthington 2002), a primary objective of minimum flows and levels analysis is to provide for the hydrologic requirements of biological communities associated with the river system. Human uses of the natural resources are also an important consideration for the establishment of minimum flows and levels. Such uses include fishing, swimming, wildlife observation, aesthetic enjoyment, and boating.

3.3 Resource Management Goals and Key Habitat Indicators

The SWFWMD approach for setting minimum flows and levels is habitat-based. Because river systems include a great variety of aquatic and wetland habitats that support a diversity of biological communities, it is necessary to identify key habitats for consideration, and, when possible, determine the hydrologic requirements for the specific biotic assemblages associated with the habitats. It is assumed that addressing these management goals will also provide for other ecological functions of the river system that are more difficult to quantify, such as organic matter transport and the maintenance of river channel geomorphology.

Resource management goals for the middle Peace River addressed by our minimum flows analysis include:

1) maintenance of minimum water depths in the river channel for fish passage and recreational use;
2) maintenance of water depths above inflection points in the wetted perimeter of the river channel to maximize aquatic habitat with the least amount of flow:
3) protection of in-channel habitat for selected fish species and macroinvertebrate assemblages;
4) inundation of woody habitats including snags and exposed roots in the stream channel; and
5) maintenance of seasonal hydrologic connections between the river channel and floodplain to ensure floodplain structure and function.

These goals are consistent with management goals identified by other researchers as discussed in Chapter 1. The rationale for identifying these goals and the habitats and ecological indicators associated with the goals are addressed in subsequent sections of this chapter. Field and analytical methods used to assess hydrologic requirements associated with the habitats and indicators are presented in Chapter 4, and results of the minimum flows and levels analyses are presented in Chapter 5.

3.3.1 Fish Passage and Recreational Use

Ensuring sufficient flows for the passage or movement of fishes is an important component of the development of minimum flows. Maintenance of these flows is expected to ensure continuous flow within the channel or river segment, allow for recreational navigation (e.g., canoeing), improve aesthetics, and avoid or lessen potential negative effects associated with pool isolation (e.g., high water temperatures, low dissolved oxygen concentrations, localized phytoplankton blooms, and increased predatory pressure resulting from loss of habitat/cover). Tharme and King (1998, as cited by Postel and Richter 2004) in developing a "building block" approach for South African rivers listed the retention of a river's natural perenniality or nonperenniality as one of eight general principles for managing river flows. For many rivers within the District, flows and corresponding water depths adequate for fish passage are currently or were historically maintained by baseflow during the dry season. For example, in the upper Peace River, historical flows were sufficient for maintaining a naturally perennial system and flow was sufficiently high during the low flow season to permit passage of fish along most of the river segment (SWFWMD 2002). Recent flows in the upper Peace River have not, however, been sufficient for fish passage much of the time. Historic flows in other District rivers, such as the Myakka River were probably intermittent, historically, but have increased in recent years. Evaluation of flows sufficient for fish in support of minimum flows development may, therefore, involve consideration of historic or recent flow conditions with respect to perenniality and the likelihood of fish passage being maintained naturally (i.e. in the absence of consumptive water use).

3.3.2 Wetted Perimeter Inflection Point

A useful technique for evaluating the relation between the quantity of stream habitat and the rate of streamflow involves an evaluation of the "wetted perimeter" of the stream bottom. Wetted perimeter is defined as the distance along the stream bed and banks at a cross section where there is contact with water. According to Annear and Conder (1984), wetted perimeter methods for evaluating streamflow requirements assume that a direct relationship between wetted perimeter and fish habitat exists in streams. By plotting the response of wetted perimeter to incremental changes in discharge, an inflection can be identified in the resulting curve where small decreases in flow result in increasingly greater decreases in wetted perimeter. This point on the curve represents a flow at which the water surface recedes from stream banks and fish habitat is lost at an accelerated rate. Stalnaker et al. (1995) describe the wetted perimeter approach as a technique for using "the break" or inflection point in the stream's wetted perimeter versus discharge relation as a surrogate for minimally acceptable habitat. They note that when this approach is applied to riffle (shoal) areas, "the assumption is that minimum flow satisfies the needs for food production, fish passage and spawning."

We view the wetted perimeter approach as an important technique for evaluating minimum flows and levels near the low end of the flow regime. Studies on streams in the southeast have demonstrated that the greatest amount of macroinvertebrate biomass per unit reach of stream occurs on the stream bottom (e.g., Benke et al. 1985). Although production on a unit area basis may be greater on snag and root habitat, the greater area of stream bottom along a reach makes it the most productive habitat under low flow conditions. The wetted perimeter inflection point in the channel provides for large increases in bottom habitat for relatively small increases of flow. This point is defined as the "lowest wetted perimeter inflection point" or LWPIP. It is not assumed that flows associated with the LWPIP meet fish passage needs or address other wetted perimeter inflection points outside the river channel. However, identification of the LWPIP permits evaluation of flows that provide the greatest amount of inundated bottom habitat in the river channel on a per-unit flow basis.

3.3.3 In-Channel Habitats for Fish and Macroinvertebrates

Maintenance of flows greater than those allowing for fish passage and maximization of wetted perimeter are needed to provide aquatic biota with sufficient resources for persistence within a river segment. Feeding, reproductive and cover requirements of riverine species have evolved in response to natural flow regimes and these life history requirements can be used to develop protective minimum flows.

To achieve this goal, Physical Habitat Simulation (PHABSIM) protocols have been added to the District's approach for establishing minimum flows for river systems. PHABSIM is the single most widely used methodology for establishing "minimum flows" on rivers (Postel and Richter 2003), and its use was recommended in the peer review of proposed MFLs for the upper Peace River (Gore et al. 2002). The technique has, however, been criticized, because it is based on the specific requirements of a few select species (typically fish of economic or recreational value), and it is argued that such an approach ignores many ecosystem components. This criticism is overcome in the current District approach for MFLs development, since PHABSIM represents only one of several tools used to evaluate flow requirements. Results of PHABSIM analyses are used to assess flow needs during periods of low to medium flows.

3.3.4 Woody Habitats

Stream ecosystem theory emphasizes the role of instream habitats in maintaining ecosystem integrity. These habitats form a mosaic of geomorphically defined substrate patches (Brussock et al. 1985), each with characteristic disturbance regimes and macroinvertebrate assemblages (Huryn and Wallace 1987). For instance, invertebrate community composition and production in a blackwater river varies greatly among different habitat types, where the habitats are distinguished by substrates of different stability (e.g., sand, mud and woody debris) (Benke et al. 1984, Smock et al. 1985, Smock and Roeding 1986). Ecosystem dynamics are influenced by the relative abundance of these different habitat types. Changes in community composition and function occurring along the river continuum are in part a consequence of the relative abundance of different habitat patches, which are under the control of channel geomorphology and flow. For determining MFLs, we identify key habitats and features that play a significant role in the ecology of a river system using a habitat-based approach that includes a combination of best available data, published research, and site specific field work.

Among the various instream habitats that can be influenced by different flow conditions, woody habitats (snags and exposed roots) are especially important. In low-gradient streams of the southeastern U.S.A. coastal plain, wood is recognized as important habitat (Cudney and Wallace 1980; Benke et al. 1984, Wallace and Benke 1984; Thorp et al. 1990; Benke and Wallace 1990). Wood habitats harbor the most biologically diverse instream fauna and are the most productive habitat on a per unit area basis (Benke et al. 1985). Comparisons of different instream habitats in a southeastern stream indicates that production on snags is at least twice as high as that found in any other habitat (Smock et al. 1985).

Wood provides advantages as habitat, as it is relatively stable and long lived compared to sand substrata, which constantly shift. Even bedrock substrates, though the most stable of all, are susceptible to smothering by shifting sand and silt. Wood is a complex structural habitat with microhabitats (such as interstices that increase surface area) that provide cover for a variety of invertebrates. As an organic substrate, wood is also a food resource for utilization by microbial food chains, which in turn supports colonization and production of macroinvertebrates. As physical impediments to flow, woody structures enhance the formation of leaf packs and larger debris dams. These resulting habitats provide the same functions as woody substrata in addition to enhancing habitat diversity instream. Higher trophic levels such as fish have been shown to also depend on woody structures either for cover, as feeding grounds, or as nesting areas.

Since woody habitats are potentially the most important instream habitat for macroinvertebrate production, inundation of these habitats for sufficient periods is considered critical to secondary production (including fish and other wildlife) and the maintenance of aquatic food webs. Not only is inundation considered important, but sustained inundation prior to colonization by invertebrates is necessary to allow for microbial conditioning and periphyton development. Without this preconditioning, the habitat offered by snags and wood is essentially a substrate for attachment without associated food resources. The development of food resources (microbes) on the substrate is needed by the assemblage of macroinvertebrates that typically inhabit these surfaces. After the proper conditioning period, continuous inundation is required for many species to complete development. The inundated woody substrate (both snags and exposed roots) within the stream channel is viewed as an important riverine habitat and it is assumed that withdrawals or diversions of river flow could significantly decrease the availability of this habitat under medium to high flow conditions.

3.3.5 Hydrologic Connections Between the River Channel and Floodplain

Although not historically addressed in most minimum flow determinations, floodplains have long been recognized as seasonally important riverine habitat. A goal of the SWFWMD's minimum flows and levels approach is to ensure that the hydrologic requirements of biological communities associated with the river floodplain are met during seasonally predictable wet periods. Periodic inundation of riparian floodplains by high flows is closely linked with the overall biological productivity of river ecosystems (Crance 1988, Junk et al. 1989). Many fish and wildlife species associated with rivers utilize both instream and floodplain habitats, and inundation of the river floodplains greatly expands the habitat and food resources available to these organisms (Wharton et al. 1982, Ainsle et al. 1999, Hill and Cichra 2002). Inundation during high flows also provides a subsidy of water and nutrients that supports high rates of primary production in river floodplains (Conner and Day 1979, Brinson et al. 1981). This primary production produces large amounts of organic detritus, which is critical to food webs on the floodplain and within the river channel (Vannote et al. 1980, Gregory et al. 1991). Floodplain inundation also contributes to other physical-chemical processes that can affect biological production, uptake and transformation of macro-nutrients (Kuensler 1989, Walbridge and Lockaby 1994).

Soils in river floodplains exhibit physical and chemical properties that are important to the overall function of the river ecosystem (Wharton et al. 1982, Stanturf and Schenholtz 1998). Anaerobic soil conditions can persist in areas where river flooding or soil saturation is of sufficient depth and duration. The decomposition of organic matter is much slower in anaerobic environments, and mucky or peaty organic soils can develop in saturated or inundated floodplain zones (Tate 1980, Brown et al. 1990). Although these soils may dry out on a seasonal basis, typically long hydroperiods contribute to their high organic content. Plant species that grow on flooded, organic soils are tolerant of anoxic conditions and the physical structure of these soils (Hook and Brown 1973, McKevlin et al. 1998). Such adaptations can be an important selective mechanism that determines plant community composition. Because changes in river hydrology can potentially effect the distribution and characteristics of floodplain soils, soil distributions and their relationship to river hydrology are routinely investigated as part of minimum flows and levels determinations for District rivers.

Compared to instream evaluations of MFL requirements, there has been relatively little work done on river flows necessary for meeting the requirements of floodplain species, communities or functions. Our work on the upper Peace and Alafia Rivers suggests that direct and continuous inundation of floodplain wetlands by river flows is in many cases not sufficient to meet the published inundation needs of the dominant species found in the wetlands. There are probably several reasons for this apparent inconsistency. Some floodplain systems likely include seepage wetlands, dependent on hydrologic processes other than direct inundation from the river. Other wetlands may occur in depressional areas where water is retained after subsidence of river flows.

The District's approach to protection of flows associated with floodplain habitats, communities and functions involves consideration of the frequency and duration of direct connection between the river channel and the floodplain. As part of this process, plant communities and soils are identified across the river floodplain at a number of sites, and periods of inundation/connection with the river are reconstructed on an annual or seasonal basis. These data are used to characterize the frequency and duration of direct connection/ inundation of these communities to or by the river and to develop criteria for minimum flow development.

Figure 3-1 Example of low flow in a riffle or shoal area. Many potential in-stream habitats such as limerock (foreground), snags, sandbars, and exposed roots are not inundated under low flow conditions.

Chapter 4 Technical Approach for Establishing Minimum Flows and Levels for the Middle Peace River

4.1 Overview

Methods used to determine the minimum flow requirements for the middle portion of the Peace River between Zolfo Springs and Arcadia are described in this chapter. The approach outlined for the river involves identification of a Low Flow Threshold and development of prescribed flow reductions for periods of low, medium and high flows (Blocks 1, 2 and 3). The low flow threshold is used to identify a minimum flow condition and is expected to be applicable to river flows throughout the year. The prescribed flow reductions are based on limiting potential changes in aquatic and wetland habitat availability that may be associated with changes in river flow during Blocks 1, 2 and 3.

4.2 Transect Locations and Field Sampling of Instream and Floodplain Habitats

The middle Peace River was designated as the portion of the river from the USGS Peace River at Zolfo Springs, FL gage (02295637) near Highways 64 and 17 with a drainage area of approximately 826 sq. miles to the USGS Peace River at Arcadia, FL gage (02296750) near County Road 676 with a drainage area of approximately 1367 sq. miles (Figure 4-1). Sampling and data collection extended to sites beyond this segment of the river and including stretches of the river north to Wachula and south to a short-term USGS gage (2207100), located west of Nacotee at the confluence of Joshua Creek and the river.
Sampling included characterization of cross-sectional physical, hydrologic and habitat features. Four types of cross-sectional information were collected, including data used for HEC-RAS modeling, Physical Habitat Simulation (PHABSIM) modeling, instream habitat assessment, and floodplain vegetation/soils assessments. HEC-RAS cross-sections were established to develop flow and inundation statistics for the other cross-section sites, based on existing flow records for the gage sites at Zolfo Springs and Arcadia.

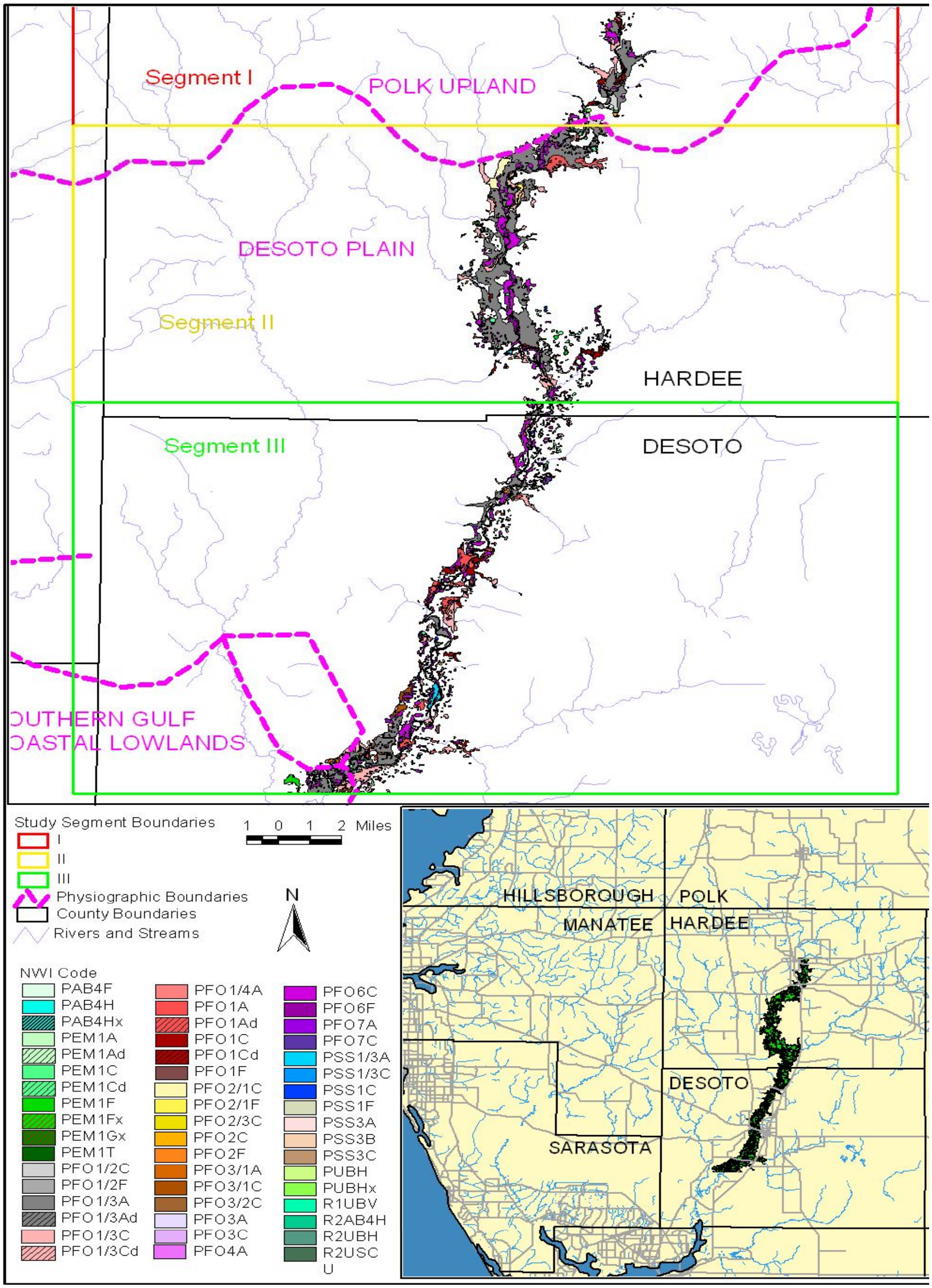


Figure 4-1. Study corridor for the middle Peace River.

4.2.1 HEC-RAS Cross-Sections

Cross-section channel geometry data used to generate a HEC-RAS model for the middle Peace River were adopted from previously established USGS channel cross-sections (Lewelling 2003) for the study area and from additional sites identified by District staff. The locations of the 81 USGS cross-sections, which were developed for describing theoretical flood peak discharges, construction of flood profiles and determining the extent of areal inundation of riverine wetlands are shown in Figure 4-2. Shoals, representing high spots that could restrict flow and result in loss of hydraulic connection, present barriers to fish migration, or hamper recreational canoeing were also identified by District staff in May 2002. Cross-section elevations and channel geometry data were obtained for seven shoals and these data were combined with the USGS cross-section data for development of the HEC-RAS model.

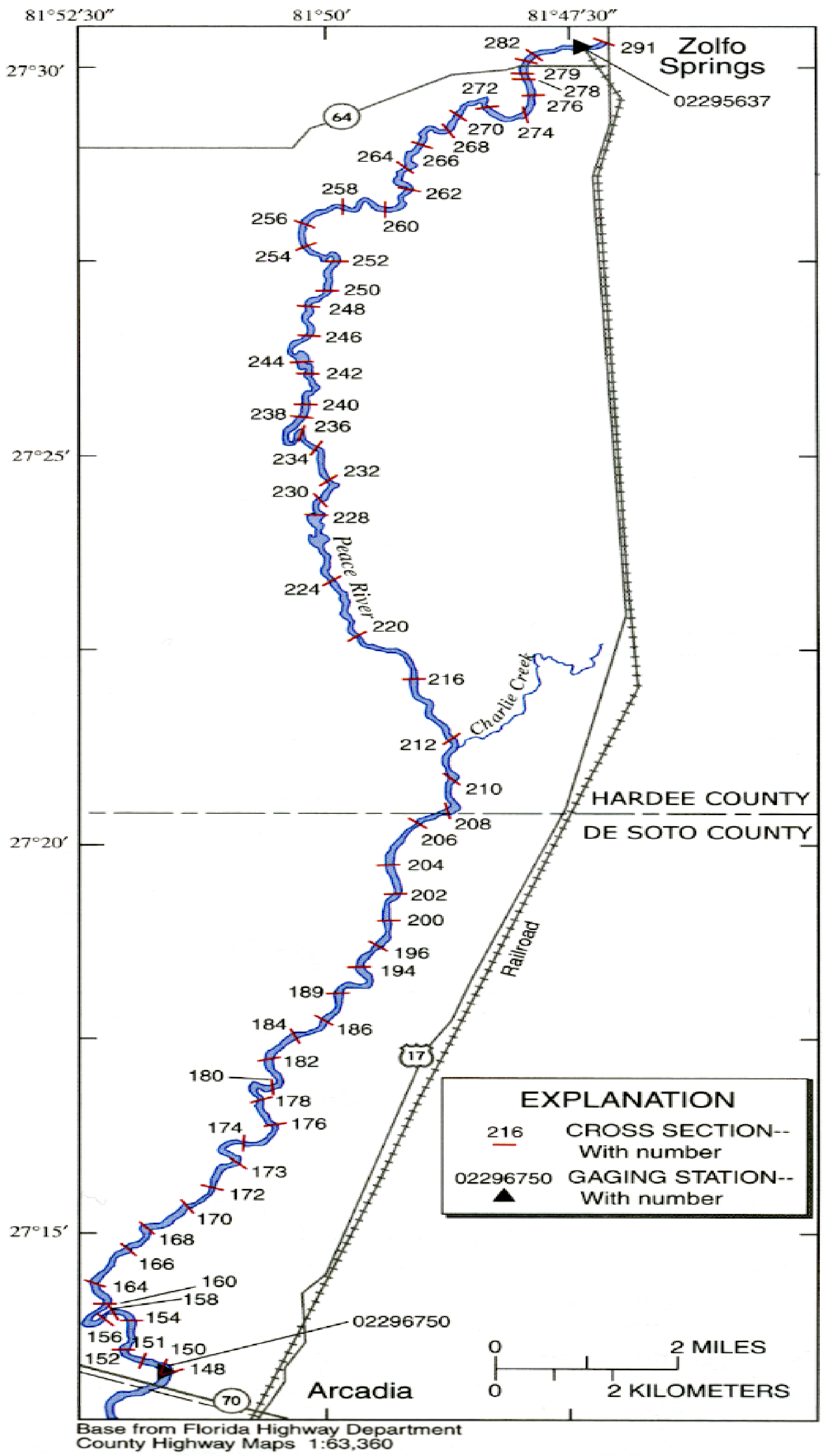


Figure 4-2 Location of USGS cross-sections in the middle Peace River study area that were used for HEC-RAS analyses. Figure reprinted from Lewelling 2003.

4.2.2 PHABSIM Cross-Sections

Physical Habitat Simulation (PHABSIM) cross-sections, designed to quantify specific habitats for fish and macroinvertebrates at differing flow conditions, were established at three of the shoal sites identified on the middle Peace River. The northernmost site was located near Zolfo Springs, about 2000 yards upstream of the USGS gage at the bridge on Highway 17. A centrally located site was situated near Brownsville, about 500 yards downstream of the Brownsville Road bridge. The southernmost site was located about 1500 yards upstream of the USGS gage at Arcadia. The results from the Brownsville site were suspect. The time series analysis resulted in errors and program termination. It has been speculated that this trouble might be related to the distance of the site from the gage station and the distribution of sampled flows being too narrow. Results from the remaining two sites were used preferentially at the Arcadia and Zolfo Springs gage when determining limiting factors.

PHABSIM analysis required acquisition of field data concerning channel habitat composition and hydraulics. At each PHABSIM site, tag lines were used to establish three cross-sections across the channel to the top of bank on either side of the river. The three cross-sections were sited to include a riffle, pool and run sequence. Water velocity was measured with a Marsh-McBirney Model 2000 flow meter at two or four-foot intervals along each cross-section. Stream depth, substrate type and habitat cover were recorded along the cross-sections. Other hydraulic descriptors measured included channel geometry (ground elevations), water surface elevations across the channel and water surface slope determined from points upstream and downstream of the cross-sections. Data were collected under a range of flow conditions (low, medium and high flows) to provide the necessary information needed to run the PHABSIM model for each stream reach.

4.2.3 Instream Habitat Cross-Sections

Cross-sections for assessing instream habitats were examined at four sites on the middle Peace River. Triplicate instream cross-sections, from the top of bank on one side of the channel through the river and up to the top of bank on the opposite channel, were established at each site perpendicular to flow in the channel. One of the three cross-sections at each site was situated along the floodplain vegetation transect line. Replicates were located 50 ft upstream and downstream. A total of 12 instream cross-sections were sampled (4 cross-sections x 3 replicates at each site).

For each instream habitat cross-section, the range in elevation and linear extent (along the cross-section) of the following habitats were determined:

- bottom substrates (which included sand, mud, or bedrock);
- exposed roots;

- snags or deadwood;
- aquatic plants;
- wetland (herbaceous or shrubby) plants; and
- wetland trees.

4.2.4 Floodplain Vegetation Cross Sections

Floodplain cross-sections based on the location of vegetation communities identified from the USGS Gap Analysis Program maps were established to characterize wetlands and soils within the middle Peace River corridor. For cross-section site selection, the river corridor was stratified using criteria described by Berryman and Henigar (2004). Ten representative floodplain vegetation cross-sections were established perpendicular to the river channel within dominant National Wetland Inventory (NWI) vegetation types (Figures 4-3 and 4-4). Cross-sections were established between the 0.5 percent exceedance levels on either side of the river channel, based on previous determinations of the landward extent of floodplain wetlands in the river corridor. Ground elevations were determined at 50-foot intervals along each cross-section. Where changes in elevation were conspicuous, elevations were surveyed more intensively.

To characterize forested vegetation communities along each cross-section, changes in dominant vegetation communities were located and used to delineate boundaries between vegetation zones. At each change in vegetation zone, plant species composition, density, basal area and diameter at breast height (for woody vegetation with a dbh > 1 inch) were recorded. At least five samples located within each vegetation zone were collected using the Point Centered Quarter (PCQ) method (see Cottam and Curtis 1956, as cited in Berryman and Henigar 2004).

Soils were characterized within each vegetation zone as hydric, organic, peat, or mineral by obtaining at least three soil cores. The cores were examined to a depth ranging from 20-60 inches to classify the soils. Special consideration was placed on locating elevations of the upper and lower extent of muck soils (> 8 inches in thickness) at cross-sections where they occurred.

Ground elevation data were used to compare vegetation and soils within and among cross-sections. For some comparisons, vegetation elevations were normalized to the lowest channel elevations at the cross-section to account for differences in absolute elevations among the cross-sections. The HEC-RAS floodplain model (see Section 4.2.1) was used to determine corresponding flows at the Arcadia gage that would be necessary to inundate specific floodplain elevations (e.g., mean vegetation zone and soils elevations).

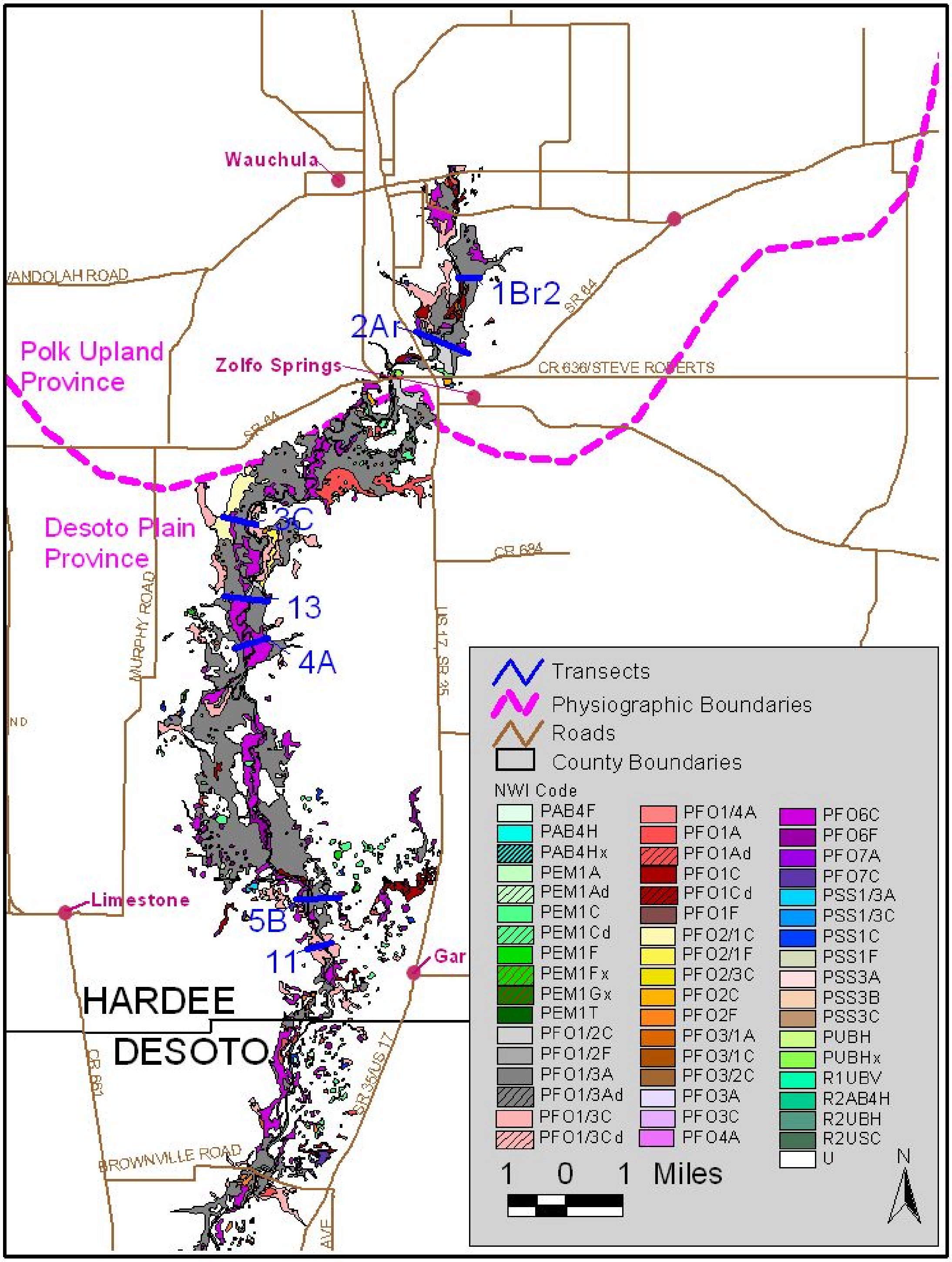


Figure 4-3. Upstream vegetation cross-section locations and NWI classes on the middle Peace River.

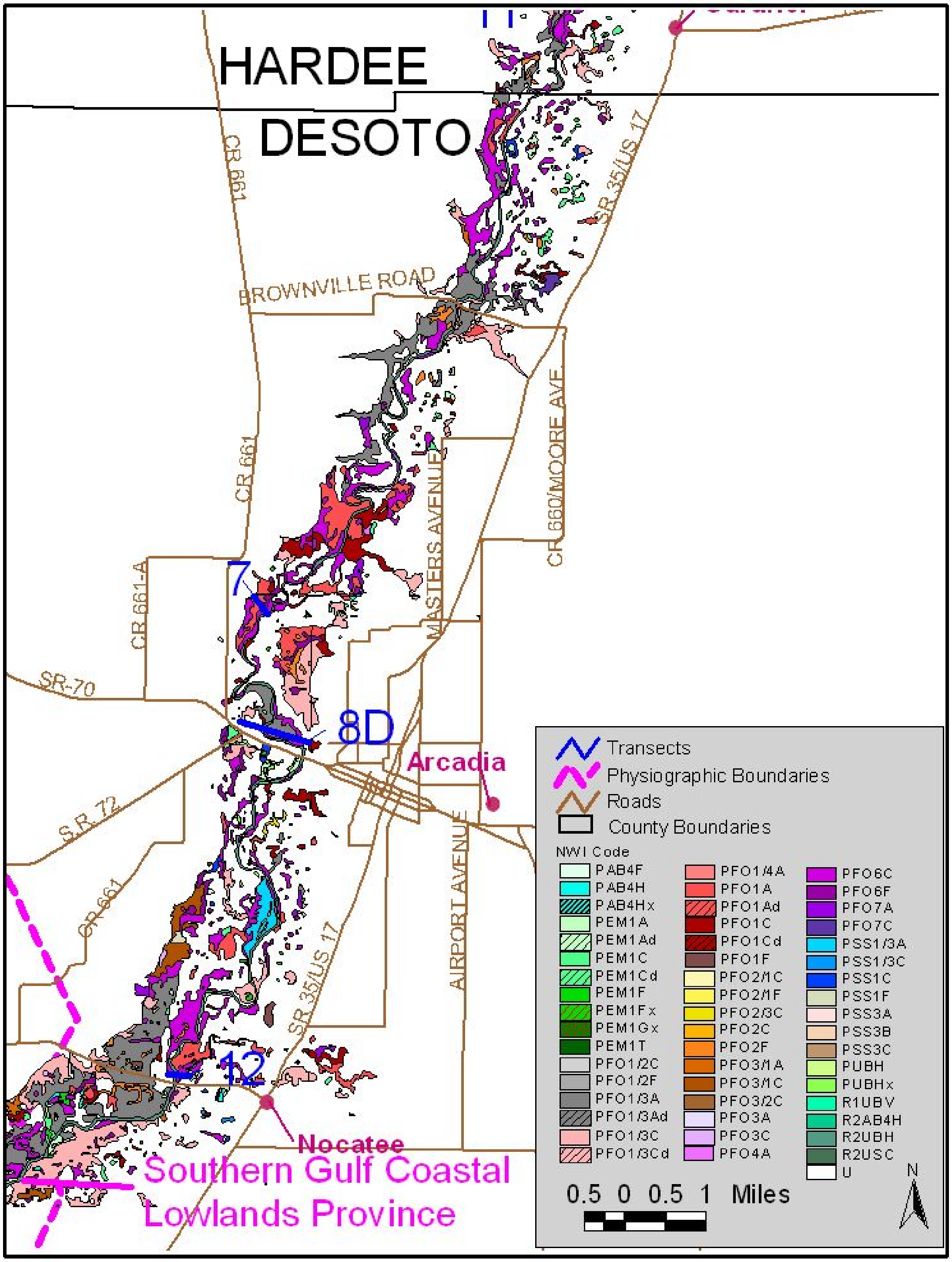


Figure 4-4. Downstream vegetation cross-section locations and NWI classes for the middle Peace River.

4.3 Modeling Approaches

A variety of modeling approaches were used to develop minimum flows and levels for the middle Peace River. HEC-RAS models were developed to characterize flows at all study sites. Physical Habitat Simulation (PHABSIM) modeling was used to characterize potential changes in the availability of fish habitat and macroinvertebrate habitat. Recent and Long-term Positional Hydrographs (RALPH) plots/analyses were used to examine inundation durations for specific habitats or floodplain elevations and to also examine changes in inundation patterns that could be expected with changes to the flow regime.

4.3.1 HEC-RAS Modeling

The HEC-RAS model is a one-dimensional hydraulic model that can be used to analyze river flows. Version 3.1.1 of the HEC-RAS model was released by the U.S. Army Corps of Engineers Hydrologic Engineering Center in November 2002 and supports water surface profile calculations for steady and unsteady flows, including subcritical, supercritical, or mixed flows. Profile computations begin at a cross-section with known or assumed starting condition and proceed upstream for subcritical flow or downstream for supercritical flow. The model resolves the one-dimensional energy equation. Energy losses between two neighboring cross sections are computed by the use of Manning's equation in the case of friction losses and derived from a coefficient multiplied by the change in velocity head for contraction/expansion losses. For areas where the water surface profile changes rapidly (e.g., hydraulic jumps, bridges, river confluences), the momentum equation is used (US Army Corps of Engineers 2002).

We used the HEC-RAS model and available flow records for the USGS Arcadia and Zolfo Springs gages to simulate flows at cross-section sites within the middle Peace River study area. Data required for performing HEC-RAS simulations included geometric data and steady flow data. Geometric data used for our analyses consisted of connectivity data for the river system, cross-section elevation data for 81 USGS cross-sections and 7 shoal sites surveyed by the District, reach length, energy loss coefficients due to friction and channel contraction/expansion, stream junction information, and hydraulic structure data, including information for bridges, culverts, etc. Required steady-flow data included the USGS gage records, boundary conditions, and peak discharge information.

Calculations for subcritical flow begin downstream where a boundary condition is applied. For the middle Peace River, a known water-surface elevation, calculated from a stage-discharge relationship at the Arcadia gage, was used as a downstream boundary condition. The energy equation is then solved between the first and second (most downstream) cross sections. Once this is achieved, the model repeats this process working its way upstream balancing the energy equation (or momentum equation if appropriate) between adjacent cross-sections until the most upstream cross-section is reached.

Model accuracy is evaluated by comparing calculated water-surface elevations at any gage location with a stage-discharge relationship derived from historic data for the location. The model is calibrated by adjusting factors in the model until calculated results closely approximate the observed relationship between stage and flow. While expansion and contraction coefficients can be altered, the major parameter altered during the calibration process is typically Manning's roughness coefficient (n), which describes the degree of flow resistance. Flow resistance is a function of a variety of factors including sediment composition, channel geometry, vegetation density, depth of flow and channel meandering. Generally, the model is considered calibrated when model results are within 0.5 ft of the established stage-discharge relationship at the upstream gage site(s) (Murphy et al. 1978; Lewelling 2003). For the middle Peace River model, the rating curve for the Zolfo Springs gage site was used to calibrate calculations for the river segment between Zolfo Springs and the Arcadia gage site

Accuracy of the step-backwater analysis for the Peace River was determined by comparing model output elevations with the measured water surface elevations at the upstream gage at Zolfo Springs. The HEC-RAS model was considered calibrated when the calculated water surface elevations were within plus or minus 0.5 ft of the measured values. This is in keeping with standard USGS practices where the plus or minus 0.5 ft, is based on the potential error range using the 1-ft aerial contour maps (Lewelling 2004). The U.S. Geological Survey, Water-Resources Investigations Report 78-57 titled Flood Profiles for the Peace River, South-Central Florida was the study from which a majority of the cross-sections used in the HEC-RAS model were obtained (Murphy et al. 1978). This report judged the model to be generally accurate to plus or minus 0.5 foot. Though some of our cross-sections have been surveyed in with a greater accuracy the majority of the modeled cross-sections are from Murphy et al. (1978) and thus the plus or minus 0.5 ft standard to determine calibration was used.

No long-term gage records are available for the middle Peace River between the Arcadia and the Zolfo Springs gage site. To validate the model for this stretch of the river the District intends to study the inundation of wetlands along river corridors where PHABSIM or vegetative transect work has been completed. This is intended to include staff gages in both the wetlands and the river channel. This will allow verification of the rivers connection with the wetland or the partial independence of the wetland hydrology. This will also serve to verify the model by collecting upstream gage heights.

The original USGS middle Peace River HEC-RAS model calculates profiles for a total of 16 steady flow rates. They are the 89, 50, 30, 2, 0.5, 0.1, 89.1, 50.1, 30.1, 2.1, 0.51, 0.11, 20, 20.1, 10, and 10.1 upper percentiles of historical flow data measured in the river. The boundary conditions were specified with known water surface elevations for each flow rates at the downstream boundaries. In other words, rating curves at the downstream boundaries were used as the boundary conditions. To develop minimum flow for the river, it is necessary to characterize the entire flow range, including flows lower and higher than those included in the original model. To accomplish this goal, we added 16 additional steady-state flows to the model. The added flows were 25, 71, 120, 143, 167, 188, 213, 243, 276, 364, 422, 495, 698, 1060, 2150, and 4460 cfs at the Arcadia gage.

The HEC-RAS models were run using all flows to determine stage vs. flow and wetted perimeter vs. flow relationships for each cross-section. These relationships were also used to determine inundation characteristics of various habitats at instream habitat and floodplain vegetation cross-sections. The peer review panel assessing the "Upper Peace River; An Analysis of Minimum Flows and Levels" found HEC-RAS to be an "appropriate tool" for assessing these relationships and determined this to be a "scientifically reasonable approach" (Gore et al. 2002).

4.3.2 Physical Habitat Simulation (PHABSIM) Modeling

It is suggested that the District consider use of procedures which link biological preferences for hydraulic habitats with hydrological and physical data (Gore et al. 2002). Specifically, they endorsed use of the Physical Habitat Simulation (PHABSIM), a component of the Instream Flow Incremental Methodology (Bovee et al. 1998) and its associated software for determining changes in habitat availability associated with changes in flow. Following the recommendations of the reviewers, we used the PHABSIM program to support development of minimum flows for the middle Peace River.

PHABSIM analysis requires acquisition of data concerning channel composition, hydraulics, and habitat suitability or preferences. Required channel composition data includes dimensional data, such as channel geometry and distance between sampled cross-sections, and descriptive data concerning substrate composition and cover characteristics. Hydraulic data requirements include measurement of water surface elevations and discharge at each cross section. These data are gathered under a range of flow conditions to provide for model calibration. Habitat suitability criteria are required for each species of interest. Criteria may be empirically derived for individual species/water bodies or developed using published information.

Hydraulic and physical data are utilized in PHABSIM to predict changes in velocity in individual cells of the channel cross-section as water surface elevation changes. Predictions are made through a short series of back-step calculation using either Manning's equation or Chezy's equation. Predicted velocity values are used in a second program routine (HABTAT) to determine cell-by-cell the amount of weighted usable area (WUA) or habitat available for various organisms at specific life history stages or for spawning activities (Figure 4-5). The WUA/discharge relationship can then be used to evaluate modeled habitat gains and losses with changes in discharge. Once the relationships between hydraulic conditions and WUA are established they are examined in the context of historic flows, and altered flow regimes. This process is accomplished using a time series analysis routine (TSLIB, Milhous et al. 1990) and historic flow records.

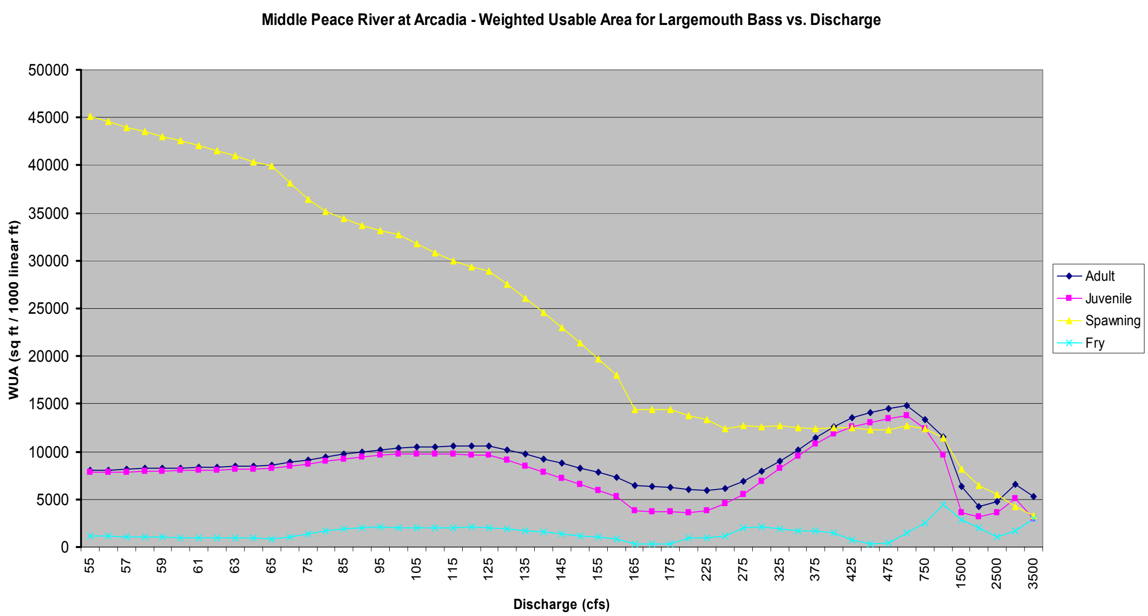


Figure 4-5. Weighted usable area (WUA) versus discharge for three life history stages (fry, juvenile, adult) and spawning activity of largemouth bass at the middle Peace River at Arcadia gage site.

PHABSIM analysis does not prescribe an acceptable amount of habitat loss for any given species or assemblage. Rather, given hydrologic data and biological preferences, it establishes a relationship between hydrology and WUA and allows examination of habitat availability in terms of the historic and altered flow regimes. Determining from this data the amount of loss, or deviation for the optimum, that a system is capable of withstanding is based on professional judgment. Gore et al. (2002) provided guidance regarding this issue, suggesting that "most often, no greater than a 15% loss of available habitat" is acceptable. For the purpose of minimum flows and levels development, we have defined percent-of-flow reductions that result in greater than a 15% reduction in habitat from historic conditions as limiting factors. Figure 4-6 shows an example of habitat gain/loss plots, which display changes in WUA (habitat) relative to flow reductions of 10 to 40%.

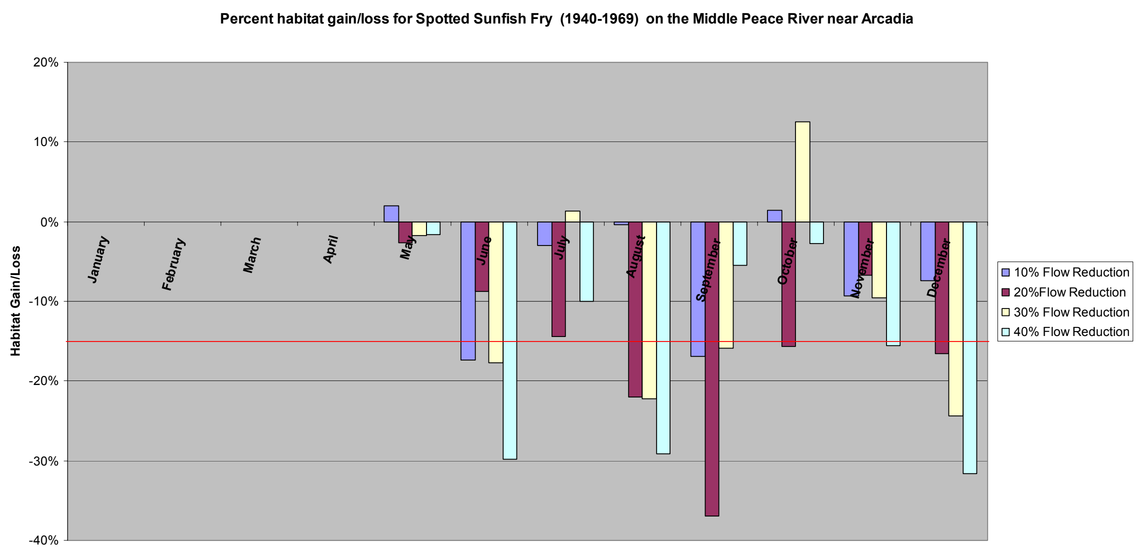


Figure 4-6. Example of a plot of habitat gain/loss relative to flow reductions of 10, 20, 30, and 40%. Habitat loss is shown for spotted sunfish fry at the Arcadia gage site based on historic flow records from 1940 to 1969.

4.3.2.1 Development of Habitat Suitability Curves

Habitat suitability criteria used in the PHABSIM model include continuous variable or univariate curves designed to encompass the entire range of suitable conditions for water depth, water velocity, and substrate/cover type and proximity. There are three types of suitability curves.

Type I curves do not depend upon acquisition of additional field-data but are, instead based on personal experience and professional judgment. Informal development of Type I curves typically involves a roundtable discussion (Scheele 1975); stakeholders and experts meet to discuss habitat suitability information to be used for prediction of habitat availability for specific target organisms. A more formal process, known as the Delphi technique (Zuboy 1981) involves submission of a questionnaire to a large respondent group of experts. Results from this survey process are summarized by presenting a median and interquartile range for each variable. Several iterations of this process must be used in order to stabilize the responses, each expert being asked to justify why his/her answer may be outside the median or interquartile range when presented the results of the data. The Delphi system lacks the rapid feedback of a roundtable discussion, but does remove the potential biases of a roundtable discussion by creating anonymity of expert opinion. The Delphi system does assume that experts are familiar with the creation of habitat suitability criteria and can respond with sufficient detail to allow development of appropriate mathematical models of habitat use.

Type II curves are based upon frequency distributions for use of certain variables (e.g., flow), which are measured at locations utilized by the target species. Curves for numerous species have been published by the U.S. Fish and Wildlife Service or the U.S. Geological Survey and are commonly referred to as the "blue book" criteria.

Type III curves are derived from direct observation of the utilization and/or preference of target organisms for a range of environmental variables (Manly et al. 1993). These curves are weighted by actual distribution of available environmental conditions in the stream (Bovee et al. 1998). Type III curves assume that that the optimal conditions will be "preferred" over all others if individuals are presented equal proportions of less favorable conditions (Johnson 1980).

Based on dominance of the spotted sunfish (*Lepomis punctatus*) in the Peace River and other regional rivers, a habitat suitability curve was created for this species. Since most of the regional experts in fish ecology were unfamiliar with development of habitat suitability criteria, we chose to use a hybrid of the roundtable and Delphi techniques to develop a Type I curve. For this effort, a proposed working model of habitat suitability criteria was provided to fourteen experts for initial evaluation. The proposed suitability curves were based on flow criteria for redbreast sunfish (*Lepomis auritus*) (Aho and Terrell 1986) modified according to published literature on the biology of spotted sunfish. Respondents were given approximately 30 days to review the proposed habitat suitability criteria and to suggest modifications. Six of the fourteen experts provided comments. In accordance with Delphi techniques, the suggested modifications were incorporated into the proposed curves. Suggested modifications that fell outside of the median and 25% interquartile range of responses were not considered unless suitable justification could be provided.

Modified Type II habitat suitability criteria for the largemouth bass (*Micropterus salmoides)* and bluegill sunfish (*Lepomis macrochirus*), two other common species in the Peace River, were established using USFWS/USGS "blue book" criteria (Stuber et al. 1982). Curves for these species have been widely used in PHABSIM applications.

Type III habitat suitability criteria for macroinvertebrate community diversity were established based on suitability curves published by Gore et al. (2001). Modified substrate and cover codes used for criteria development were established through consultation with District and Florida Fish and Wildlife and Conservation

Commission staff. For this effort, emphasis was placed on invertebrate preference for macrophytes, inundated woody snags and exposed root habitats.

4.3.3 Recent and Long-term Positional Hydrograph/Analyses

Recent and Long-term Positional Hydrographs (RALPH) plots and analyses are used to identify the number of days each year during a defined period of record that a specific flow or level (elevation) was equaled or exceeded at individual river cross-sections, including streamflow gaging sites (Figure 4-7). The plots and associated spreadsheets are developed using measured elevations for habitats or other features and HEC-RAS model output. RALPH plots also allow examination of how future changes in flow could affect the number of days of inundation during a particular span of time (Figure 4-8). For the purpose of developing minimum flows and levels, percent-of-flow reductions that result in greater than a 15% reduction in habitat from historic conditions are characterized as limiting factors.

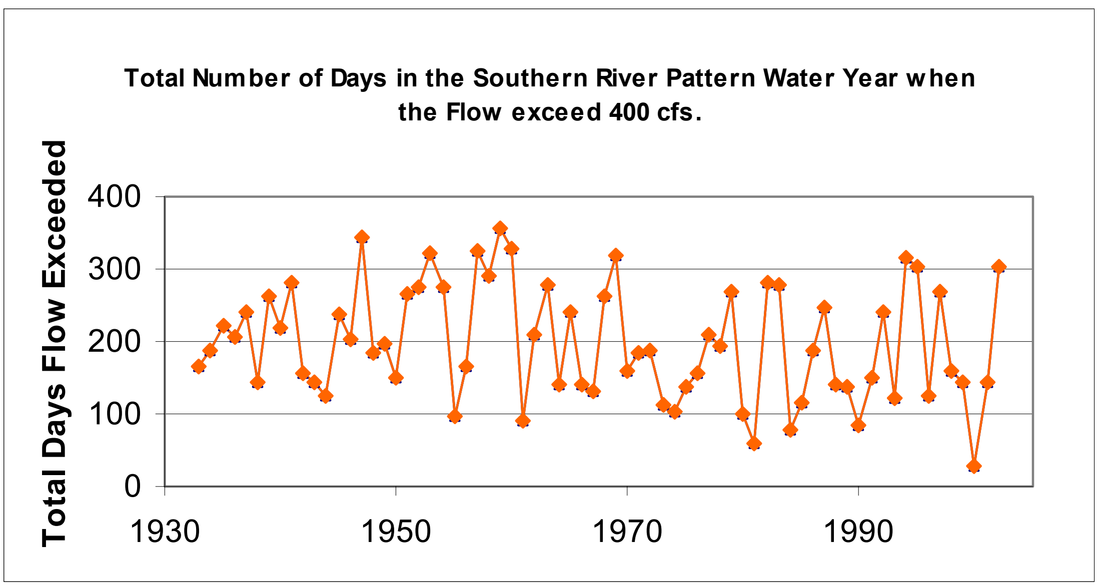


Figure 4-7. RALPH plot of the number of days during the southern river pattern (SRP) water year that 400 cfs is exceeded at the USGS Peace River at Arcadia gage site.

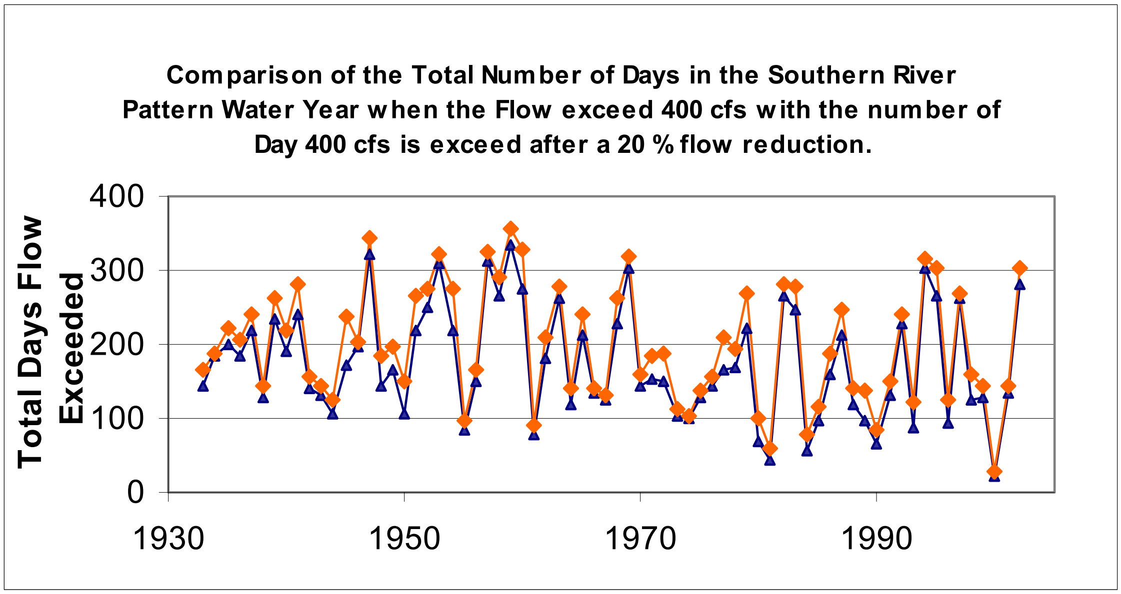


Figure 4-8. RALPH plot of the number of days during the southern river pattern water year that 400 cfs is exceeded at the USGS Peace River at Arcadia gage site (orange line) compared with the number of days that inundation would have occurred if there had been a 20% reduction in river flows (blue line).

4.4 Seasonal Flow and Development of Blocks 1, 2, and 3

For development of minimum flows and levels for the middle segment of the Peace River, we identified three seasonal blocks corresponding to periods of low, medium and high flows. Lowest flows occur during Block 1, a 65 day period that extends from April 20 to June 24 (Julian day 110 to 175). Highest flows occur during Block 3, the 124 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 at other times. The remaining 176 days constitute an intermediate or medium flow period, which is referred to as Block 2.

Table 4-1 Beginning and ending calendar dates (and Julian days) for seasonal flow Blocks 1, 2, and 3 for the middle Peace River.

Block	Start date (Julian day)	End Date (Julian Day)	Number of days
1	April 20 (110)	June 24 (175)	65
2	October 28 (301)	April 19 (109)	176
3	June 25 (176)	October 27 (300)	124

4.5 Low Flow Threshold

Protection of aquatic resources associated with low flows is an important component of the minimum flows and levels implementation. To accomplish this goal, it is necessary to develop a *low flow threshold* which identifies flows that are to be protected in their entirety (*i.e.,* flows that are not available for consumptive-use). To determine this threshold, two low flow standards are developed. One is based on the lowest wetted perimeter inflection point; the other is based on maintaining fish passage along the river corridor. The low flow threshold is established at the higher of the two flow standards. Although flows less than the low flow threshold may be expected to occur throughout the year, they are most likely to occur during Block 1.

4.5.1 Wetted Perimeter Standard

Output from multiple runs of the HEC-RAS model were used to generate a wetted perimeter versus flow plot for each HEC-RAS cross-section of the middle Peace River corridor (see Figure 4-9 and, Appendix WP). Plots were visually examined for inflection points, which identify flow ranges that are associated with relatively large changes in wetted perimeter. The lowest wetted perimeter inflection point (LWPIP) for flows up to 200 cfs was identified for each cross-section. Inflection points for flows higher than 200 cfs were disregarded since the goal was to identify the LWPIP for flows contained within the stream channel. Many cross-section plots displayed no apparent inflection points between the lowest modeled flow and 200 cfs. These cross-sections were located in pool areas, where the water surface elevation may exceed the lowest wetted perimeter inflection point even during low flow periods. For these cross-sections, the LWPIP was established at the lowest modeled flow. Flows associated with the LWPIP at each cross-section were converted to flows at the USGS Peace River at Arcadia, FL gage using relationships from HEC-RAS model output. The LWPIP flows were used to develop a wetted perimeter standard for the Arcadia gage site. A wetted perimeter standard was also developed for the USGS Peace River at Zolfo Springs, FL gage site, based on previously identified LWPIP flows for upper portions of the river (see SWFWMD 2002).

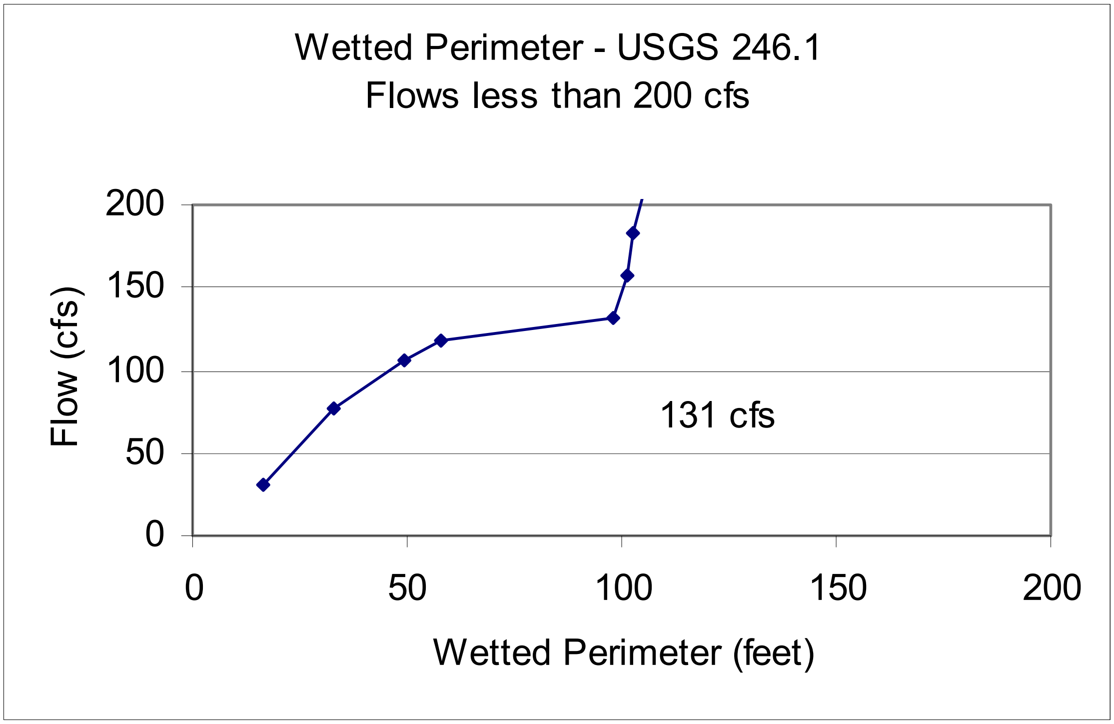


Figure 4-9. Wetted perimeter versus discharge at HEC-RAS transect number 246.1 in the middle Peace River corridor. Wetted perimeter values for modeled flows up to 200 cfs are shown and the Lowest Wetted Perimeter Inflection Point (LWPIP) is identified.

4.5.2 Fish Passage

For development of minimum flows, it is desirable to maintain longitudinal connectivity along a river corridor, to the extent that this connectivity has historically occurred. To secure the benefits associated with connectivity and sustained low flows, a 0.6 ft fish-passage criterion was used to develop a low flow standard for the middle Peace River. The fish passage criterion has been used by the District for development of proposed minimum flows and levels for the upper Peace (SWFWMD 2002) and Alafia (Kelly et al. 2005) Rivers and was found to be acceptable by the panel that reviewed the proposed upper Peace River flows (Gore et al. 2002).

Flows necessary for fish passage at each HEC-RAS cross-section were identified using output from multiple runs of the HEC-RAS model. The flows were determined by adding the 0.6 ft depth fish passage criterion to the elevation of the lowest spot in the channel and determining the flow necessary to achieve the resultant elevations. At many cross-sections, the minimum channel elevation plus 0.6 ft resulted in a water surface elevation lower than the elevation associated with the lowest modeled flow. These cross-sections were located in pool or run areas, where fish passage could occur during periods of little or no flow. For these sites, the flow requirement for fish passage was established at the lowest modeled flow.

Ultimately, regressions between the stage at each cross-section and the flow at the USGS Arcadia gage were used to determine flows at the Arcadia gage that corresponded to the target fish-passage elevation at the cross sections (Figure 4-10). The flow at the Arcadia gage that was sufficient to provide for fish passage at all HEC-RAS cross sections at all sampled cross-sections was used to define the fish passage, low flow standard. A fish passage standard was also developed for the USGS Peace River at Zolfo Springs, FL gage site, based on previously identified fish passage elevations (SWFWMD 2002).

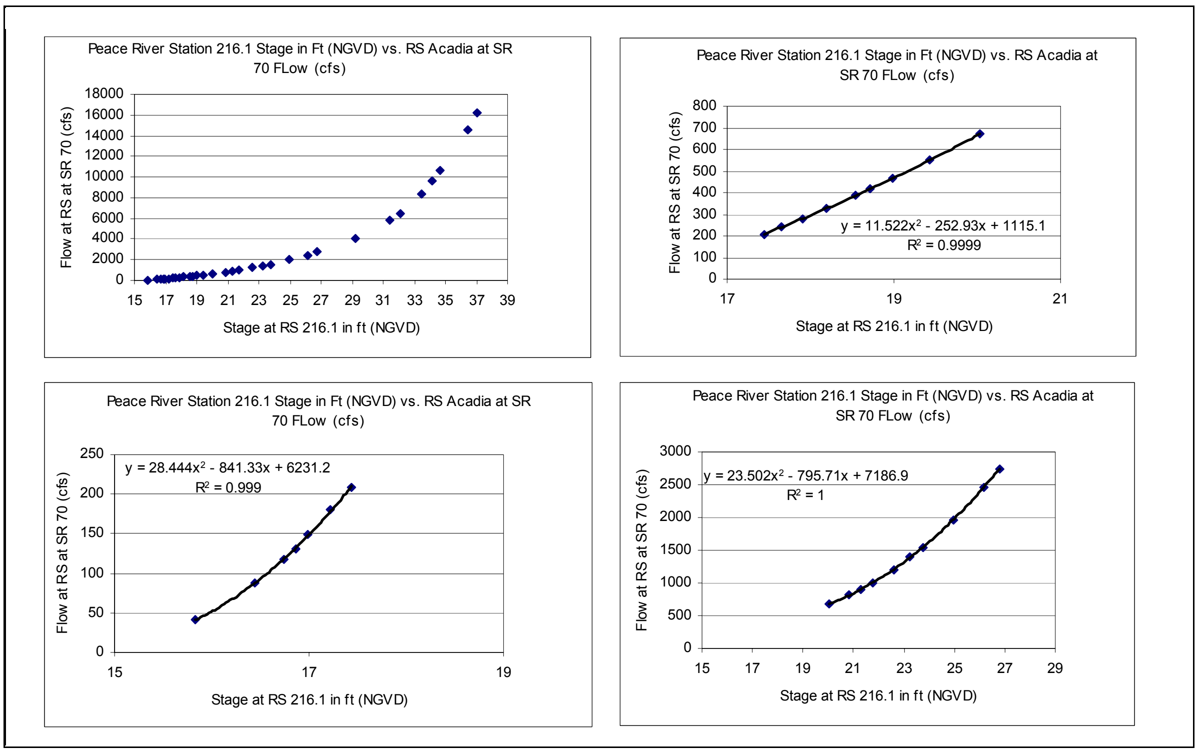


Figure 4-10. Stage flow relationships between HEC-RAS cross-section 216.1 and flow at the USGS Arcadia gage derived from the HEC-RAS model of the middle Peace River. The upper-left plot shows the relationship derived for the entire range of flows evaluated. The other three show relationships used to develop regression equations for selected portions of the flow range.

4.6 Prescribed Flow Reduction for Block 1

When flows exceed the low flow threshold during Block 1, it may be that some portion of the flows can be withdrawn for consumptive use without causing significant harm. To establish these quantities, the availability of aquatic habitat for selected fish species and macroinvertebrate populations for low flow periods can be estimated using the Physical Habitat Simulation Model (PHABSIM).

4.6.1 PHABSIM – Application for Block 1

PHABSIM was used to evaluate potential changes in habitat associated with variation in low flows in the middle Peace River. For the analyses, we used historic time series data from the Arcadia and Zolfo Springs gage sites for two benchmark periods, from 1940 through 1969 and from 1970 through 1999. Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill sunfish and for macroinvertebrate diversity at three sites on the middle Peace River. Flow reductions during Block 1, i.e., from April 20 to June 24 that resulted in no more than a 15% reduction in habitat from historic conditions for either benchmark period were determined to be limiting factors. These factors were used to derive prescribed flow reductions which identify acceptable flow requirements for each gage site during Block 1 when flows exceed the low flow thresholds.

4.7 Prescribed Flow Reduction for Block 2

During Block 2, flows are typically higher than in Block 1 (Figure 4-9), but are still dominated by in-channel events. Minimum flows and levels are established for Block 2 for flows that exceed the low flow threshold using PHABSIM to evaluate potential habitat losses, and through the use of HEC-RAS model output and Recent and Long-term Positional Hydrographs (RALPH) plots and analyses to evaluate potential changes in the inundation of woody habitats. Results from the PHABSIM analysis and woody habitat analyses define limiting factors, the most conservative of which is used to develop a prescribed flow reduction for Block 2.

4.7.1 PHABSIM – Application for Block 2

PHABSIM was used to evaluate potential changes in habitat associated with variation in medium flows. For the analyses, we used historic time series data collected at the Arcadia and Zolfo Springs gages site from 1940 through 1969 and 1970 through 1999. Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill sunfish and macroinvertebrate diversity at three sites in the middle Peace River. Maximum flow reductions that resulted in no more than a 15% reduction in habitat from historic conditions during Block 2, which runs from October 28 to April 19 of the following calendar year, were determined to be limiting factors. These factors were considered for development of prescribed flow reductions that identify acceptable flow requirements for each gage site during Block 2 when flows exceed the low flow thresholds.

4.7.2 Snag and Exposed Root Habitat Analyses – Application for Block 2

Mean elevations of snag and exposed root habitats were determined for the eight instream habitat cross-sections in the middle Peace River corridor. Flows at the cross-section sites and corresponding flows at the Arcadia or Zolfo Springs gages that would result in inundation of the mean habitat elevations at each cross-section were determined using the HEC-RAS model. RALPH plots/analyses were used to determine the number of days that the mean elevations for the snag or root habitat were inundated. Flow records from two benchmark periods (1940 through 1969 and 1970 through 1999) were examined to identify percent-of-flow reductions that would result in no more than a 15% loss of habitat defined as a reduction of no more than 15% of the number of days of inundation from direct river flow for the entire year, after prescribed flow reduction for Blocks 1 and 3 were applied. Loss of days of direct connection with river flows was evaluated for the entire year since woody habitats in the river are expected to be inundated during periods of high flow (Block 3) and may also be inundated by flows occurring during Block 1 in some years. The percent-of-flow reductions derived for Block 2 flows at the two gage sites were considered to be limiting factors and evaluated for development of prescribed flow reductions for Block 2. For the analyses, we used historic time series data from the Arcadia and Zolfo Springs gage sites for two benchmark periods, from 1940 through 1969 and from 1970 through 1999.

4.8 Prescribed Flow Reduction for Block 3

Junk et al. (1989) note that the "driving force responsible for the existence, productivity, and interactions of the major river-floodplain systems is the flood pulse". Floodplain vegetation development and persistence does not, however, necessarily depend wholly on inundation from the river channel. Groundwater seepage, hyporheic inputs, discharge from local tributaries, and precipitation can also lead to floodplain inundation (Mertes 1997). However, because river channel-floodplain connections are important, can be influenced by water use, and may be a function of out-of-bank flows, it is valuable to characterize this connectivity for development of minimum flows and levels.

Highest flows, including out-of-bank flows, are most likely to occur during Block 3, which for the middle Peace River extends from June 25 to October 27. Minimum flows developed for this period are intended to protect ecological resources and values associated with floodplain by maintaining hydrologic connections between the river channel and flood plain and maintaining the natural variability of the flow regime. This goal is accomplished through the

HEC-RAS modeling and use of RALPH plots/analyses to evaluate floodplain feature inundation patterns associated with channel-floodplain connectivity. Based on these analyses, a prescribed flow reduction for Block 3 can be developed.

4.8.1 Floodplain Connection Analyses – Application for Block 3

HEC-RAS model output and RALPH plots/analyses were used to evaluate floodplain inundation patterns associated with river flows at the ten floodplain vegetation cross-sections and associated flows at the Arcadia gage site. Inundation of elevations associated with floodplain features, including vegetation zones and soils was evaluated to establish percent-of-flow reductions that would result in no more than a 15% reduction in the number of days of inundation during Block 3, based on flows during two benchmark periods (1940 through 1969 and 1970 through 1999)   The percent-of-flow reductions were considered to be limiting factors and used for development of prescribed flow reductions for the Arcadia and Zolfo Springs gage sites during Block 3.

Chapter 5 Results and Recommended Minimum Flows

5.1 Overview

Results from modeling and field investigations on the middle Peace River were assessed to develop minimum flow criteria/standards for ensuring that ecological functions associated with various flows and levels are protected from significant harm. Low flow thresholds based on fish passage depth and wetted perimeter inflection points are recommended for two USGS gage sites on the river, along with prescribed flow reductions for Blocks 1, 2, and 3. Based on the low flow thresholds and prescribed flow reductions, short-term and long-term minimum flow compliance standards are identified for establishing minimum flows and levels for the two gage sites on the middle segment of the Peace River.

5.2 Low Flow Thresholds

The low flow threshold defines flows that are to be protected in their entirety (i.e., flows that are not available for consumptive-use) throughout the year. The low flow threshold is established at the higher of two flow standards, which are based on maintaining fish passage and maximizing wetted perimeter for the least amount of flow in the river channel. For the middle Peace River, low flow thresholds were developed for the USGS Peace River at Arcadia, FL and Peace River at Zolfo Springs, FL gage sites.

5.2.1 Fish Passage Standards

Flows necessary to reach a maximum water depth of 0.6 foot to allow for fish passage at each cross-section in the HEC-RAS model of the middle Peace River between the gage site at Arcadia and a short distance upstream of the Zolfo Springs gage site are shown in Figure 5-1. At most cross-sections, the minimum water surface elevation that would allow for fish passage was lower than the elevation associated with the lowest modeled flow. These cross-sections were located in pool or run areas, where fish passage would be possible during low flow periods.

Inspection of the data indicated that local flows equal to or greater than 60 cfs would be sufficient for fish passage at all sampled sites. Flows at cross-sections where local flow requirements are relatively high were examined with respect to corresponding flows at the Arcadia gage (cross-section 148). Cross-section 220 was found to be the limiting site, with a flow of 67 cfs at the Arcadia gage required for meeting the fish passage criterion. A flow of 67 cfs was therefore used to define the fish passage standard for the Arcadia gage site on the middle Peace River. The standard flow is sufficient to maintain constant flow in the river and would minimize problems such as low dissolved oxygen levels that may be associated with low flow or stagnant conditions.

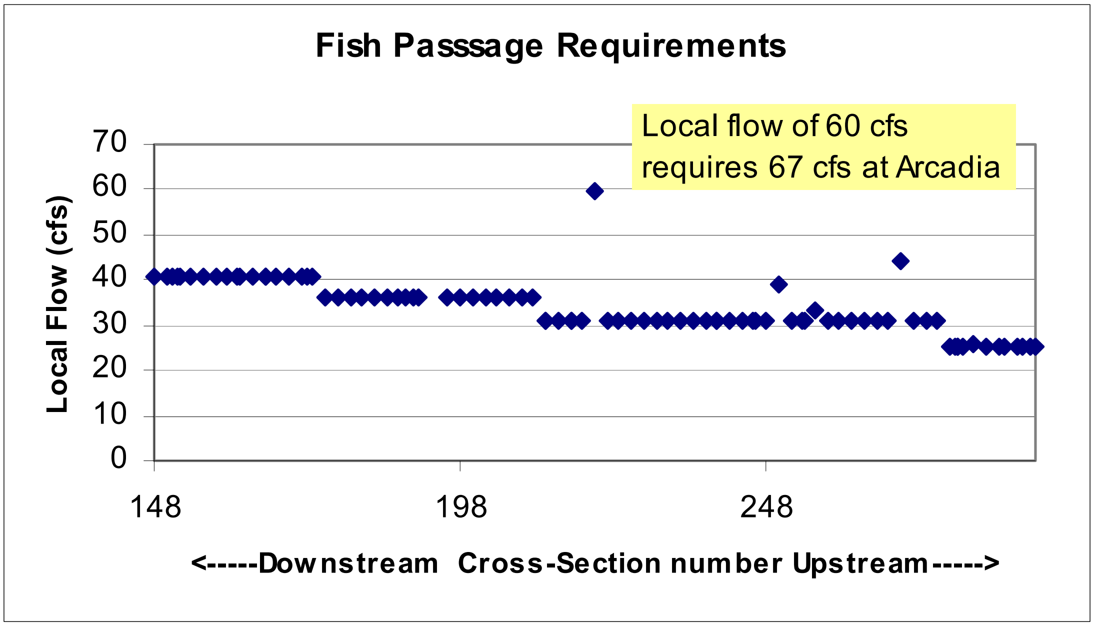


Figure 5-1. Plot of local flow required to inundate the deepest part of the channel at each HEC-RAS cross-section in the middle Peace River to a depth of 0.6 ft. A local flow of 60 cfs at the limiting site (cross-section 220) is the equivalent of 67 cfs at the Arcadia gage.

Flow requirements for fish passage upstream of the Zolfo Springs gage site were determined previously through our work supporting development of proposed minimum flows and levels for the upper Peace River (SWFWMD 2002). Based on data collection and analyses procedures identical to those utilized for the Arcadia gage site, a flow of 45 cfs at the USGS Peace River at Zolfo Springs, FL gage site was identified for ensuring fish passage. For our current analyses, this flow was used to define the fish passage standard for the Zolfo Springs gage site.

5.2.2 Wetted Perimeter Standards

Wetted perimeter plots (wetted perimeter versus local flow) and the lowest wetted perimeter inflection point (LWPIP) were developed for each HEC-RAS cross-section of the middle Peace River between the gage site at Arcadia and a short distance upstream of the Zolfo Springs gage site based on modeled flow runs (see Appendix WP for all plots). The LWPIP was below the lowest modeled flow for all sites except cross-section 246.1 (Figure 5-2). The LWPIP at this site corresponds to a local flow of 131 cfs, while local flows of 41 cfs of less were sufficient for meeting the LWPIP at all other cross-sections. The local flow of 131 cfs at cross-section 246.1 corresponds to a flow of 150 cfs at the Arcadia gage. A flow of 150 cfs at the Arcadia gage would, therefore, be sufficient to meet the local LWPIP flows at all sampled cross-sections.

Examination of the LWPIP flows for the cross-sections suggested that a flow of 150 cfs at the Arcadia gage might be excessive for use as a wetted perimeter standard. Substantial differences between the high local LWPIP flow requirement for cross-section 246.1 and the flow requirements for other cross-sections indicated that cross-section 246.1 is not representative of the river segment. With the exclusion of this site, maximization of channel bottom habitat with the least amount of flow can be achieved throughout the river segment with flow as low as 41 cfs at the Arcadia gage. Review of fish passage depth requirements for cross-section 246.1 indicates that a local flow of less than 31 cfs would be sufficient for movement of fish past the site. This means that at a local flow of 31 cfs, which corresponds to a flow of 41 cfs at the Arcadia gage, fish passage and flow continuity would be maintained at cross-section 246.1. Based on these considerations, the wetted perimeter flow standard for the middle Peace River between the gage sites at Arcadia and Zolfo Springs was established at 41 cfs at the Arcadia gage.

Our previous work supporting the establishment of minimum flows and levels for the upper Peace River indicated that a flow of 26 cfs at the USGS Peace River at Zolfo Springs, FL gage would be sufficient for maximizing wetted perimeter in the river upstream to Ft. Meade. Based on this earlier work, we established the wetted perimeter standard for the Zolfo Springs gage site at 26 cfs.

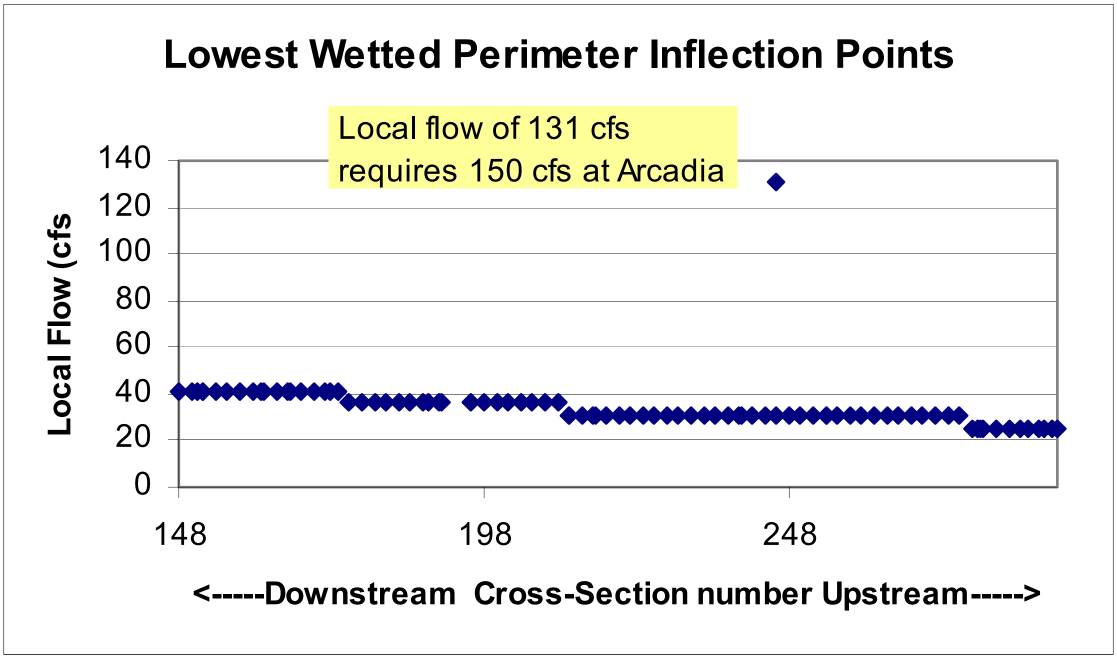


Figure 5-2. Plot of local flow required to inundate the lowest wetted perimeter inflection point at each HEC-RAS cross-section. Local flows are shown for site 148 (the Arcadia gage) to sites slightly upstream of the Zolfo Springs gage.

5.2.3 Low Flow Thresholds

Low flow thresholds of 45 and 67 cfs, respectively, were identified for the middle Peace River at the USGS Zolfo Springs, FL and Peace River at Arcadia, FL gage sites. The low flow thresholds were established at the higher of the fish passage and wetted perimeter standards for both sites and are therefore expected to provide protection for ecological and cultural values associated with both standards. Although flows in the river at the gage sites may be expected to drop below the low flow thresholds naturally, the thresholds are defined to be flows that serve as a limit to withdrawals throughout the year, with no withdrawals permitted from the river unless the threshold flows are exceeded.

5.3 Prescribed Flow Reductions for Block 1

Prescribed flow reductions for Block 1 at the Arcadia and Zolfo Springs gage sites were based on review of limiting factors developed using PHABSIM to model potential changes in habitat availability for several fish species and macroinvertebrate diversity. During Block 1, which runs from April 20 through June 24, the most restrictive limiting factor identified for the PHABSIM cross-section site located near the Arcadia gage site was for spotted sunfish. Based on the 1940 through 1969 benchmark period spotted sunfish in the spawning and fry life stage exhibit a 15% loss of habitat when flows are reduced by 10%. Based on the 1970 to 1999 benchmark, simulated reductions in historic flow greater than 10% resulted in more than 15% loss of available habitat for adult spotted sunfish (Figure 5-3, Figure 5-4, and Appendix PHABSIM). A prescribed flow reduction of 10% was therefore established for Block 1 at the Arcadia gage. A prescribed flow reduction for Block 1 at the Zolfo Springs gage was also defined as a 10% reduction in flows, based on limiting factors associated with habitat availability for spotted sunfish adults and largemouth bass fry (Figure 5-4, Figure 5-6, and Appendix PHABSIM) at the PHABSIM site located upstream of the Zolfo Springs gage site.

Results from PHABSIM analyses for the Brownsville site were not utilized for development of a prescribed flow reduction for Block 1 (or Block 2) due to problems associated with characterization of the stage-flow relationship at the cross-section site. Although flows and habitat data were collected on three dates, data representative of medium flow conditions were not obtained. Coupled with the distance between the site and the Arcadia gage, this data collection issue resulted in loss of confidence in output derived from the time-series component of the PHABSIM model runs.

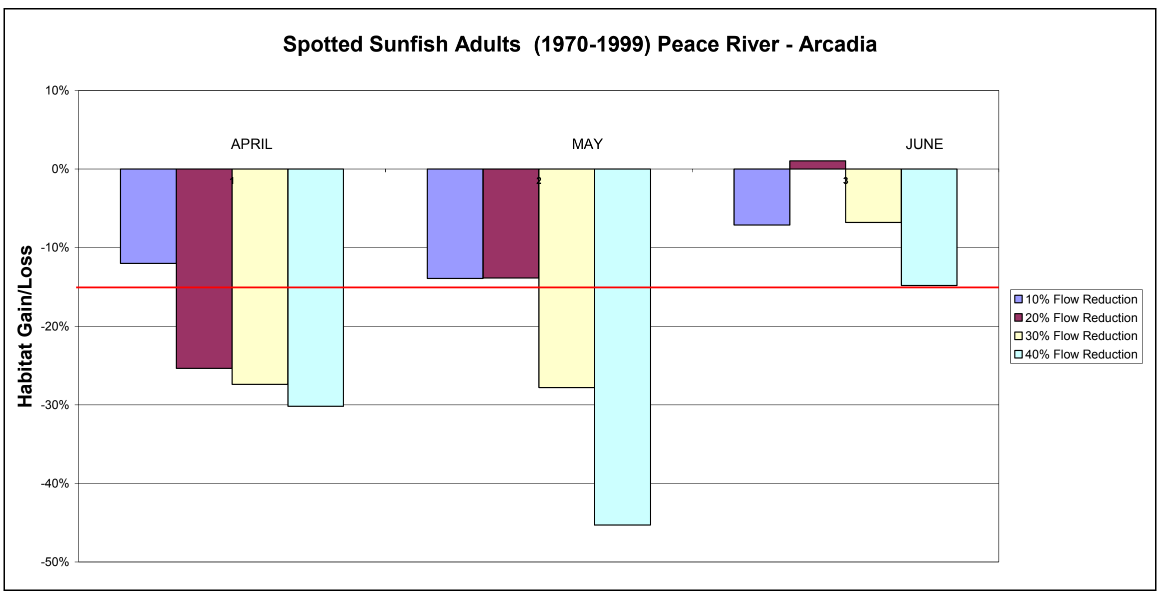
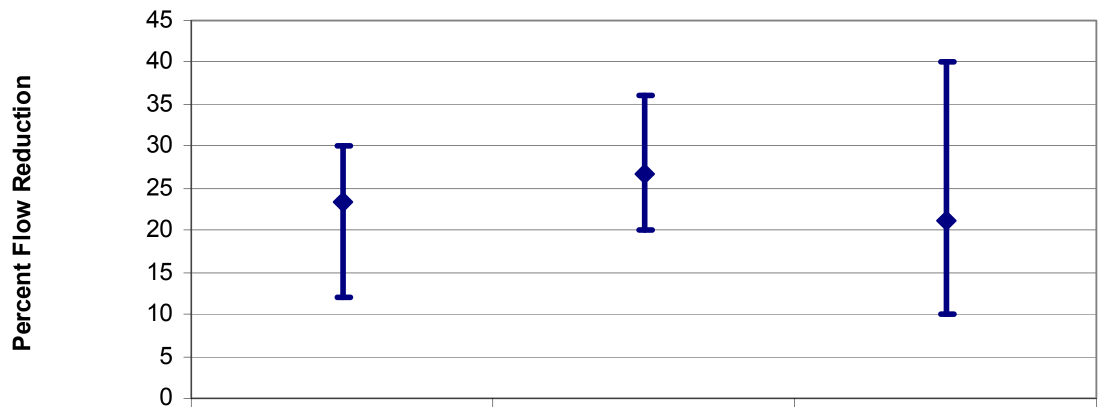


Figure 5-3. Predicted habitat gain/loss for adult spotted sunfish during April, May and June based on the flow record for the Arcadia gage site from 1970 to 1999.



	Apr	May	June
◆ Mean	23	27	21
Minimum	12	20	10
Maximum	30	36	40
N	3	8	6

Figure 5-4. Summary of PHABSIM results for the Arcadia gage. Predicted habitat gain/loss for all species which limited flow reduction to less than 50% during April, May and June based on the flow record for the Arcadia gage site and both benchmark periods.

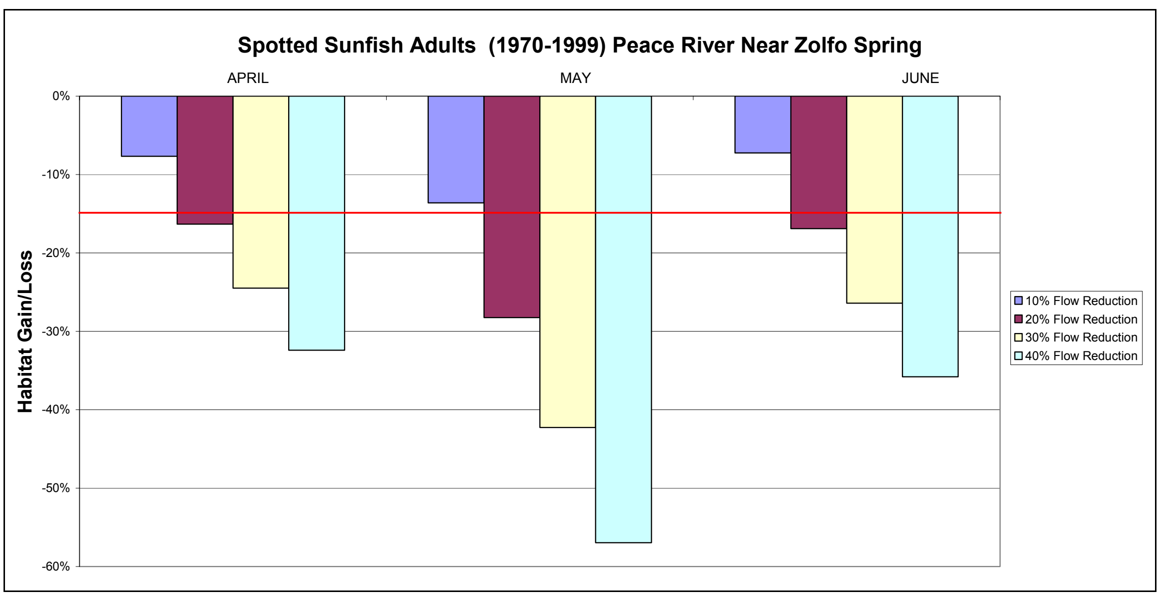
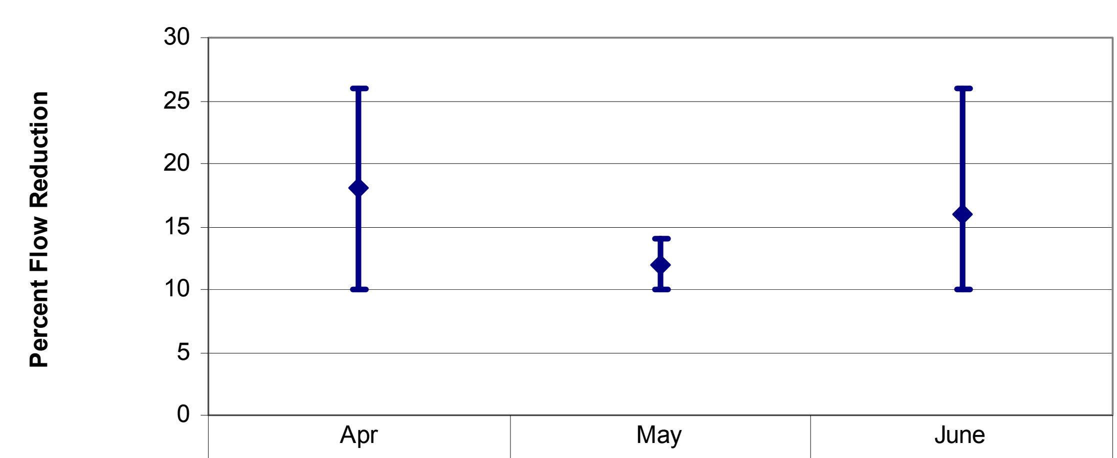


Figure 5-5. Predicted habitat gain/loss for adult spotted sunfish during April, May and June based on the flow record for the Zolfo Springs gage site from 1970 to 1999.



	Apr	May	June
◆ Mean	18	12	16
Minimum	10	10	10
Maximum	26	14	26
N	3	3	4

Figure 5-6. Summary of PHABSIM results for the Zolfo Springs gage. Predicted habitat gain/loss for all species which limited flow reduction to less the 50% during April, May and June based on the flow record for the Zolfo Springs gage site and both benchmark periods.

5.4 Short-Term Compliance Standards for Block 1

Short-Term Compliance Standards represent a flow prescription that can be utilized for evaluating minimum flows compliance on a short-term basis, for example, based on measured daily flows. For Block 1 flows in the middle Peace River, the standards were defined for two USGS gage sites.

For the USGS Peace River at Arcadia, FL gage site, the following Short-Term Compliance Standards are proposed for Block 1, which begins on April 20 and ends on June 24:

1) All flows equal to or below 67 cfs measured at the USGS Peace River at Arcadia, FL gage are protected in their entirety;

2) When flows are greater than 67 and less than 75 cfs all flows above 67 cfs measured at the Arcadia gage are available for use; and

3) A 10% of all flows are available for consumptive use when flows are greater than or equal to75 cfs.

For the USGS Peace River at Zolfo Springs, FL gage site, the following Short-Term Compliance Standards are recommended for Block 1:

1) All flows equal to or below 45 cfs measured at the USGS Peace River at Zolfo Springs, FL gage are protected in their entirety;

2) When flows are greater than 45 and less than 50 cfs all flows above 45 cfs measured at the Zolfo Springs gage are available for use; and

3) A 10% of all flows are available for consumptive use when flows are greater than or equal to 45 cfs.

For both gage sites, the first standard was developed using the respective low flow threshold. The second and third standards were developed to permit compliance with the Block 1 prescribed flow reductions without violation of the respective low flow thresholds.

5.5 Prescribed Flow Reductions for Block 3

The prescribed flow reductions for Block 3 flows at the Arcadia and Zolfo Springs gage sites were based on review of limiting factors developed using the middle Peace River HEC-RAS model and RALPH analyses. Factors assessed included changes in the number of days river flows were sufficient for inundation of identified floodplain features, including river banks, floodplain vegetation zones, floodplain wetted perimeter inflection points and hydric soils. Change in the number of days specific flows occurred was demonstrated to be a good indication of potential changes in inundation patterns for floodplain features, including those that were not identified. During Block 3, which runs from June 25 to October 27 for the Peace River, it was determined that a stepped reduction in historic flows was appropriate and would allow for consumptive uses and habitat protection. During Block 3 when flows are less than the 25% exceedance flow (1362 cfs) a 13% reduction in historic flows can be accommodated without exceeding a 15% loss of days of connection. When flows exceed the 25% exceedance flow (1362 cfs) more than an 8% reduction in historic flows resulted in a decrease of 15% or more in the number of days that flows would inundate floodplain features. Using this limiting condition, the prescribed flow reduction for Block 3 for the Arcadia gage site was defined as 8% reduction in flows when flows exceed 1362 cfs and a 13% reduction in flows when flows are below 1362 cfs provided that no withdrawal results in failure to comply with the low flow threshold. For the Zolfo Springs gage the prescribed flow reduction for Block 3 was defined as 8% reduction in flows when flows exceed 782 cfs and a 18% reduction in flows when flows are below 782 cfs provided that no withdrawal results in failure to comply with the low flow threshold.

5.5.1 Inundation of Floodplain Features

Twelve major vegetation zones or community types were identified at the ten floodplain vegetation cross-section on the middle Peace River. Although there was site-to-site variability, and not all zones were identified at all sites, the vegetation zones were typically distributed along an elevation gradient in the following order: dry hardwood hammock, upland, berm, seepage slope, maple, wet hardwood hammock, river terrace, marsh, cypress, hardwood swamp, river bank and stream (Table 5-1). Based on the linear extent of the vegetation zones relative to the total combined length of the cross-sections, hardwood hammock and river terrace zones accounted for 41 and 25% of the floodplain vegetation (Table 5-2). Two other forested wetland zones, cypress and hardwood swamp accounted for 8 and 6% of the linear extent of the cross-sections. The remaining wetland/aquatic zones accounted for about 11% of the linear cross-sections with upland and dry hardwood hammock zones combined covering about 9% of the total cross-section length.

Table 5-1. Rank order of vegetation zones by mean elevation (from highest to lowest) at ten floodplain vegetation cross-sections on the middle Peace River.

Transect	Relative Mean Elevations from Highest to Lowest For Each Transect							
01BR2					Seepage Slope	Wet Hardwood Hammock	River Terrace	River Bank
02AR	Dry Hardwood Hammock	Seepage Slope	Wet Hardwood Hammock	Hardwood Swamp	Stream	Berm	River Terrace	River Bank
03C					Wet Hardwood Hammock	Berm	River Terrace	Cypress
04A							Wet Hardwood Hammock	River Terrace
05B					River Terrace	Cypress	Berm	Hardwood Swamp
08D				Upland	Berm	Hardwood Swamp	River Bank	River Terrace
7			Seepage Slope	Maple	Wet Hardwood Hammock	Hardwood Swamp	River Terrace	River Bank
11					Wet Hardwood Hammock	River Terrace	Hardwood Swamp	River Bank
12				Berm	River Terrace	Marsh	Hardwood Swamp	River Bank
13						River Terrace	Wet Hardwood Hammock	Cypress

Table 5-2. Linear extent of vegetative zones expressed as a percentage of the total combined length of ten floodplain vegetation cross-sections on the middle Peace River.

Vegetation Zone	Percentage (%)
Dry Hardwood Hammock	2
Upland	7
Berm	2
Seepage Slope	3
Maple	3
Wet Hardwood Hammock	41
River Terrace	25
Marsh	1
Cypress	6
Hardwood Swamp	8
Stream	1
River Bank	1

Hydric soils occurred in all vegetation zones except the highest berms. Seepage slopes and the Maple community were underlain by muck or clay soil and were influenced by seepage, rather than flood disposition and overflow from the river. Vegetation zones closer to the river such as berms, river terraces, hardwood swamps, marsh, and river banks contained stratified soil layers, indicating frequent river flooding. The cypress, hardwood swamps, and stream zones contained relatively thick muck layers, indicating long periods of inundation or ponding (Table 5-3).

Elevation profiles were developed for the ten floodplain vegetation cross-sections (see Appendix RH) to determine flows necessary for inundation of floodplain features (Table 5-4). The mean flow at the Arcadia gage that would result in inundation of the floodplain on one side of the channel at the ten cross-sections was 4,096 cfs. A mean flow of 5,571 cfs would be required to inundate both sides of the floodplain. Mean flows at the Arcadia gage inundate the four dominant vegetation zones (wet hammock, river terrace, cypress, hardwood swamp). Mean flows of 4,331 and 6,952 cfs would be necessary for inundation of the 90th percentile elevations of river terrace and wet hardwood hammocks, respectively. Mucky soils occurring in hardwood and cypress zones would be inundated at flows ranging from 1,288 to 3,807 cfs, with a mean of 2348 cfs.

Table 5-3. Characteristics of soils in vegetation zones at floodplain vegetation cross-sections on the middle Peace River.

Zone	Hydric	Soil Characteristics
Dry Hardwood Hammock*	Yes	Dark surface, fine mineral soils, relatively deep water table.
Upland		No soil samples.
Berm	Higher Berms No	Sandy loam or sandy clay loam in surface layers, coarse sand, deposition and shell fragments below 32 inches.
Seepage Slope*	Yes	Muck or sandy clay loam on surface, natural soil not influenced by depositions from river.
Maple	Yes	Muck in top 6 inches, natural soil, not influenced by stream channelization or flooded depositions.
Wet Hardwood Hammock*	Yes	Fine mineral soils, dark surface soils or sandy redox and mottles, indicating fluctuating water tables, some areas highly calcareous in the lower horizons.
River Terrace	Yes	Stratified layers and mottles, indicating fluctuating water levels and repeated deposition of materials from river, muck presence in swales.
Marsh	Yes	Muck in top 4 inches, coarse sand below 30 inches, depositional area.
Cypress	Yes	More than 6 inches of muck on surface, indicating long periods of inundation.
Hardwood Swamp	Yes	Mucky or loamy surface layers, indicating ponding, also contain stratified layers, indicating repeated deposition of fine materials from river.
Stream	Yes	Muck and/or clay in surface horizons.
River Bank	Yes	Very sandy, sometimes with a thin layer of muck on the surface or in stratified layers.

* Areas with cabbage palm tended to have sandy loam, sandy clay loam, and/or calcareous marl layers in the subsurface horizons.

Table 5-4. Mean (±SD) flows at the Arcadia gage required to inundate selected floodplain features and maximum reductions associated with less than a 15% reduction in the number of days flow is sufficient to inundate the feature. Reductions were based on flow records for 1940 to 1969 and 1970 to 1999.

Floodplain Feature	Mean (±SD) Flow Required for Inundation	Percent-of-Flow Reduction 1940 to 1969	Percent-of-Flow Reduction 1970 to 1999
Lowest Bank Elevation to inundate one side of the river floodplain	4096 (2772)	7%	8%
Lowest Bank Elevation to inundate both sides of river floodplain	5571 (2092)	6%	5%
90th Percentile Elevation of River Terrace Vegetation	4331 (1669)	7%	7%
90th Percentile Elevation of Wet Hardwood Hammock	6952 (2531)	7%	6%
Mean Elevation of River Terrace Vegetation	3976 (2319)	8%	8%
Mean Elevation of Wet Hardwood Hammock	5644 (2152)	7%	6 %
Mean Elevation of Cypress Swamp	2879 (869)	12%	8%
Mean Elevation of Hardwood Swamp	2934 (1214)	12%	7%
Mean elevation of mucky soils	2348 (1105)	13%	10%

Changes in flow at the Arcadia gage during Block 3 that are expected to result in no more than a 15% reduction in the number of days of inundation of the mean elevation of selected floodplain features are listed in Table 5-4. The percent-of-flow changes, which were determined using RALPH analyses and flow data from both benchmark periods, were similar, ranging from 5-10 % for 1970 to 1999 and from 6-13% for 1940 to 1969. This suggested that use of any of these limiting factors could be appropriate for establishing a prescribed flow reduction for Block 3 at the gage site.

To further investigate limiting factors associated with the middle Peace River floodplain, plots of percent-of-flow reductions that would result in a 15% loss of the number of days river flows reached a given flow were produced (Figures 5-7 and 5-8). Plots ranged from 500 to 6,000 cfs at the Arcadia gage site and 400 to 4,000 cfs at the Zolfo Springs gage site. The low end of the plotted flows reflects the approximate 50% exceedance flow for the period of record at the respective gage, a flow that is used to define the beginning of Block 3. The high end of the plotted flow range was selected to exclude rare flow events (approximately the 1 % exceedance) that would be expected to occur for relatively short durations; durations for which 15% changes would be difficult to evaluate. To develop the plots the 1970 to 1999 benchmark period was use because it generally represents a more limiting condition (Table 5-4).

Figures 5-7 and 5-8 indicate that for flows of approximately 2,000 cfs or greater, flow reductions that result in a 15% reduction in the number of days the flow is achieved tend to stabilize around 8% for both the Arcadia and Zolfo Springs gage sites. This percent-of-flow reduction is comparable to the values derived for flows at the Arcadia site that would inundate dominant vegetation zones, mucky soils, and top of bank elevations (Table 5-4). Collectively, these data indicate that up to an 8% reduction in the flows necessary to inundate floodplain features of the middle Peace River, including those we have not identified, will result in a 15% or less reduction in the number of days the features are inundated. However, the plots also show that there are flows which occur during Block 3 which do not require reductions be limited to 8% to avoid a 15% reduction in the number of days a flow is achieved. Using the 25% exceedance of 1,362 cfs at the Arcadia gage as a cutoff we can apply as stepped prescription which allows an 8% reduction in flows when flows exceed 1,362 cfs and a 13% reduction in flows when flows are below 1,362 cfs (Figure 5-7). For the Zolfo Springs gage the prescribed flow reduction for Block 3 for was defined as an 8% reduction in flows when flows exceed 783 cfs and an 18% reduction in flows when flows are below 783 cfs (Figure 5-8). This step is conservative with respect to water supply in order to provide more consistency with the results for Block 2, as discussed below.

Shaw et al (2005) "recommend that staff re-evaluate proposed flow reduction criteria to determine whether all intended resource protection goals would be satisfied during El Nino events or other unusual hydrologic conditions." For this reason the stepped flow reduction, identified for high flows should be applicable throughout the year, unless during Block 1 or Block 2 the criteria for these blocks are more restrictive than the stepped high –flow reduction. In other words when the flow exceeds 783 cfs at Zolfo Springs and 1,362 cfs at Arcadia the amount of water available should be determined as the more restrictive of the Block specific flow reduction or the stepped, high-flow reduction. Foe example, if a flow of greater the 783 cfs were to occur at the Zolfo Springs site during Block 1, the allowable percent –of-flow reduction would be the 8% stepped high-flow reduction rather than the 10% reduction specified for the lower flows during Block 1.

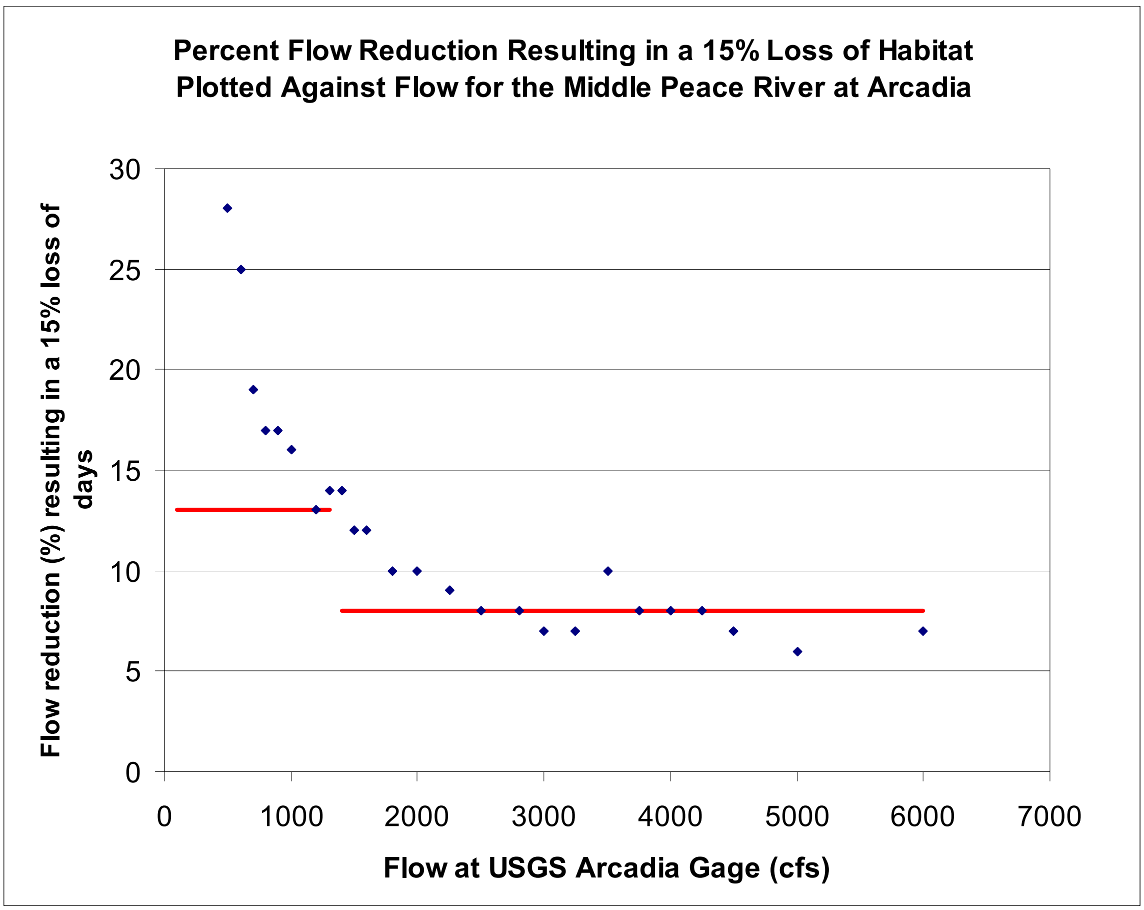


Figure 5-7.   Percent-of-flow reductions that result in a 15% reduction in the number of days flows at the USGS Arcadia gage are achieved, based on flow records from 1970 through 1999

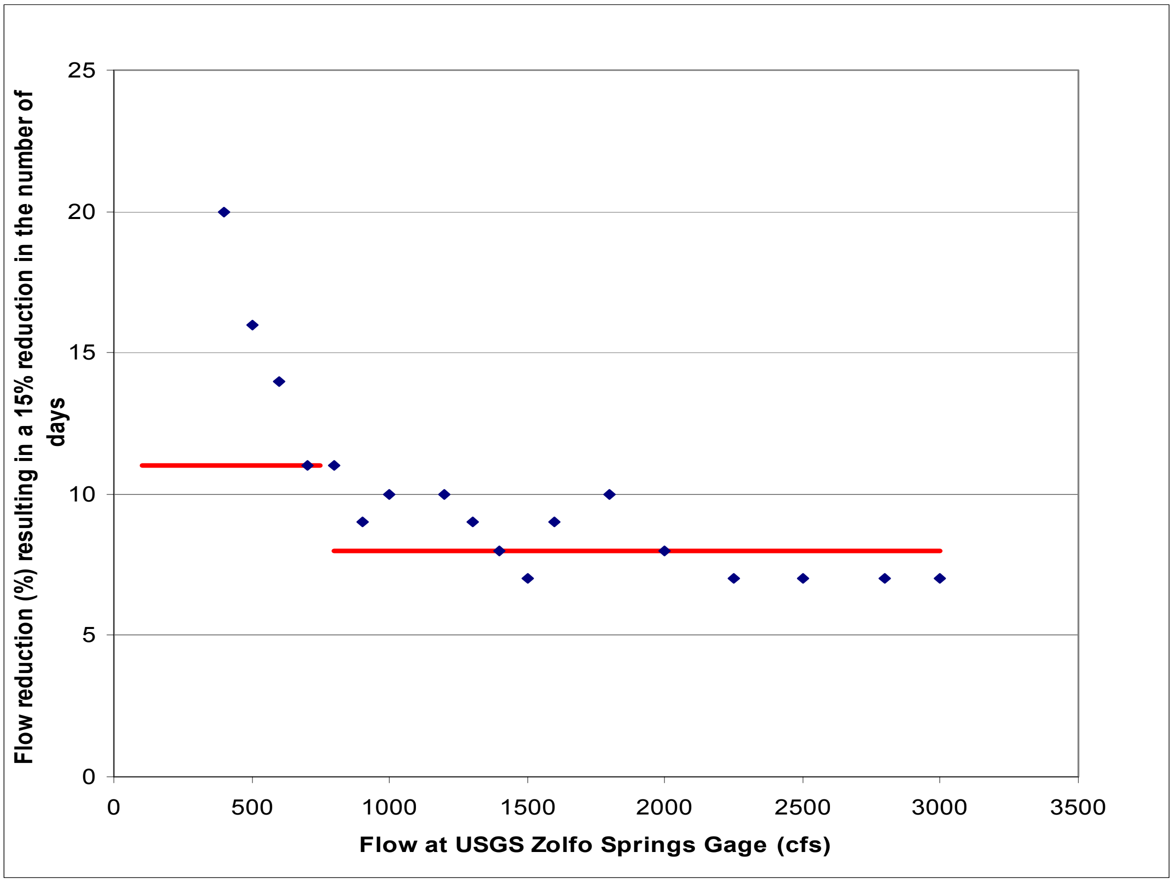


Figure 5-8. Percent-of-flow reductions that result in a 15% reduction in the number of days flows at the USGS Zolfo Springs gage are achieved, based on flow records from 1970 through 1999.

5.6 Short-Term Compliance Standards for Block 3

Short-Term Compliance Standards represent a flow prescription that can be utilized for evaluating minimum flows compliance on a short-term basis, for example, based on measured daily flows. During Block 3, which for the Peace River begins on June 25 and ends on October 27, standards were developed for two gage sites.

For the USGS Peace River at Arcadia, FL gage site, the following Short-Term Compliance Standards are proposed for Block 1:

1) All flows equal to or below 67 cfs measured at the USGS Peace River at Arcadia, FL gage are protected in their entirety;

2) All flows between 67 cfs and 77 cfs measured at the Arcadia gage are available for use; and

3) A 13% reduction of all flows above 77 cfs and below 1,362 cfs measured at the Arcadia gage is available for use; and

4) An 8% reduction of all flows above 1,362 cfs measured at the Arcadia gage is available for use.

For the USGS Peace River at Zolfo Springs, FL gage site, the following Short-Term Compliance Standards are recommended for Block 1:

1) All flows equal to or below 45 cfs measured at the USGS Peace River at Zolfo Springs, FL gage are protected in their entirety;

2) All flows between 45 cfs and 52 cfs measured at the Zolfo Springs gage are available for use;

3) A 11% reduction of all flows above 52 cfs and below 783 cfs measured at the Zolfo Springs gage is available for use; and

4) An 8% reduction of all flows above 783 cfs measured at the Zolfo Springs gage is available for use.

For both sites, the first standard was derived from gage-specific low flow thresholds. The second and third standards were developed to permit compliance with the prescribed flow reductions for Block 3 without violation of the respective low flow thresholds. The fourth standard was developed through RALPH analysis to assure not greater than a 15% loss of days in given flows being achieved.

5.7 Prescribed Flow Reduction for Block 2

Prescribed flow reductions for Block 2 for flows at the Arcadia and Zolfo Springs gage sites were based on review of limiting factors developed using PHABSIM to model potential changes in habitat availability for several fish species and macroinvertebrate diversity, and use of RALPH analyses to specifically evaluate changes in inundation patterns of woody habitats. The prescribed flow reductions were established by calculating the percent-of-flow reduction which would result in no more than a 15% loss of habitat availability during Block 2 or no more than a 15% reduction in the number of days of inundation of exposed root habitat, over the entire year, after prescribed flow reductions for Blocks 1 and 3 were applied. For both sites, PHABSIM analyses yielded the most conservative percent-of-flow reductions. PHABSIM results were therefore used to establish prescribed flow reductions of 18 and 8%, respectively, for the Arcadia and Zolfo Springs gage sites.

5.7.1 Application of PHABSIM – Block 2

PHABSIM analyses were used to model potential changes in habitat availability for several fish species and macroinvertebrate diversity during Block 2, which runs from October 28 through April 19. Results were evaluated for one cross-section site located near the Arcadia gage and a second site upstream of the Zolfo Springs gage. Results for the PHABSIM cross-section site near Brownsville were not evaluated for reasons identified in Section 5.3.

The reductions in historic flow greater than about 18% resulted in more than a 15% loss of available habitat for spotted sunfish adults and spotted sunfish fry (Figure 5-9, Figure 5-10, and Figure 5-11). This percent-of-flow reduction was considered for use in the development of a prescribed flow reduction for Block 2 at the Arcadia gage site. A prescribed flow reduction of 10% was identified for consideration for Block 2 at the Zolfo Springs gage, based on limiting factors associated with habitat availability for spotted sunfish adults (Figure 5-12, and Figure 5-13) at the PHABSIM site located upstream of the Zolfo Springs gage site.

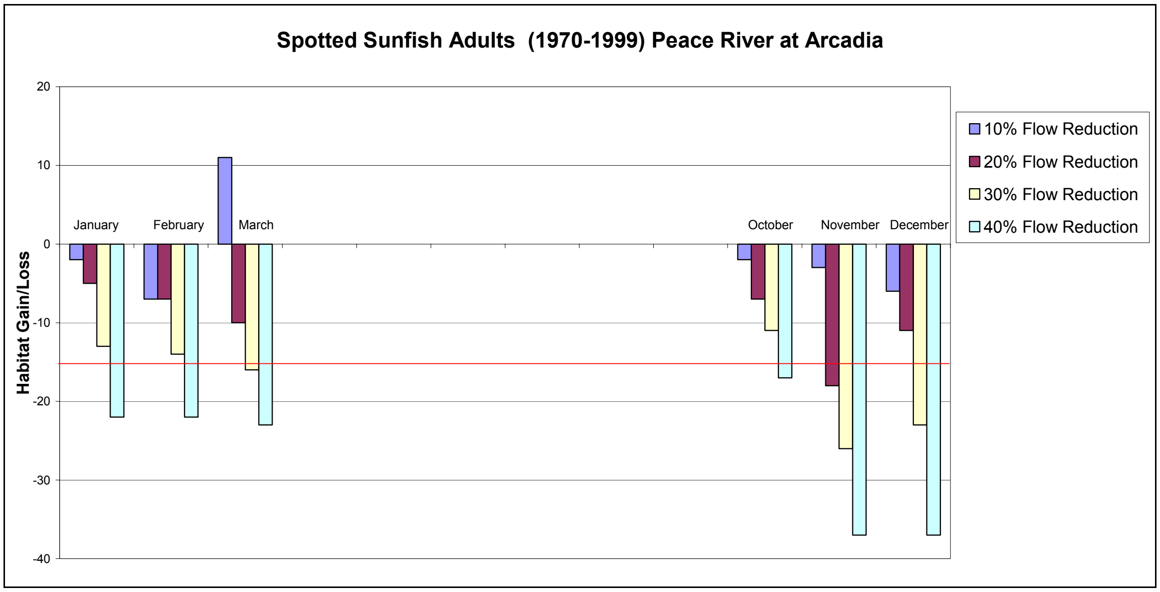


Figure 5-9. Predicted habitat gain/loss for spotted sunfish adults based on the flow record at the Arcadia gage from 1970 to 1999 and flow reductions of 10, 20, 30, and 40 percent.

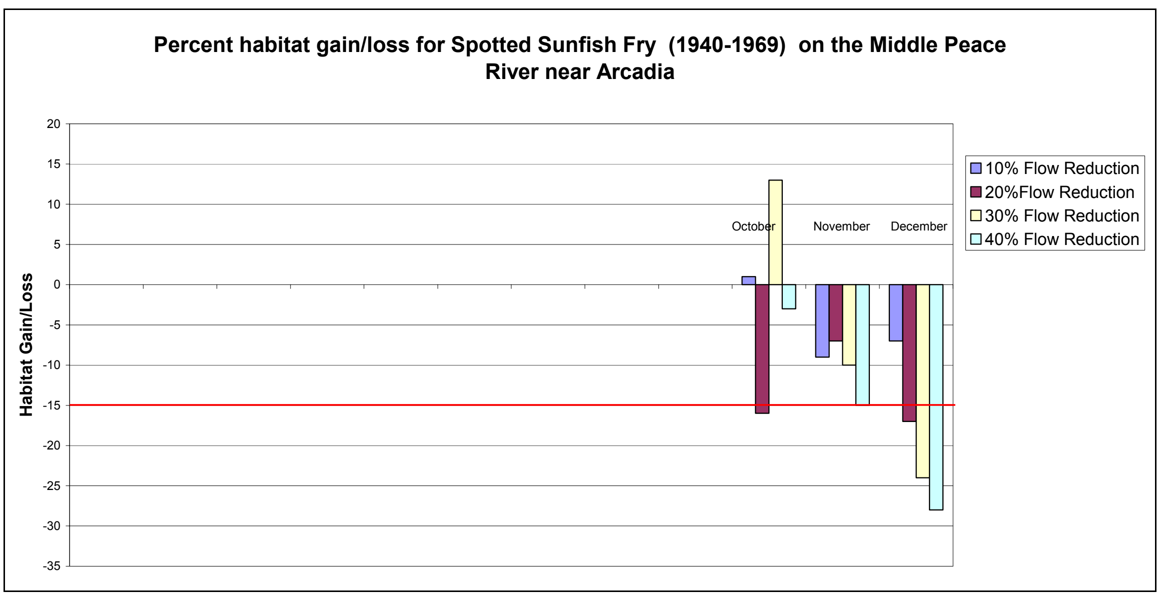
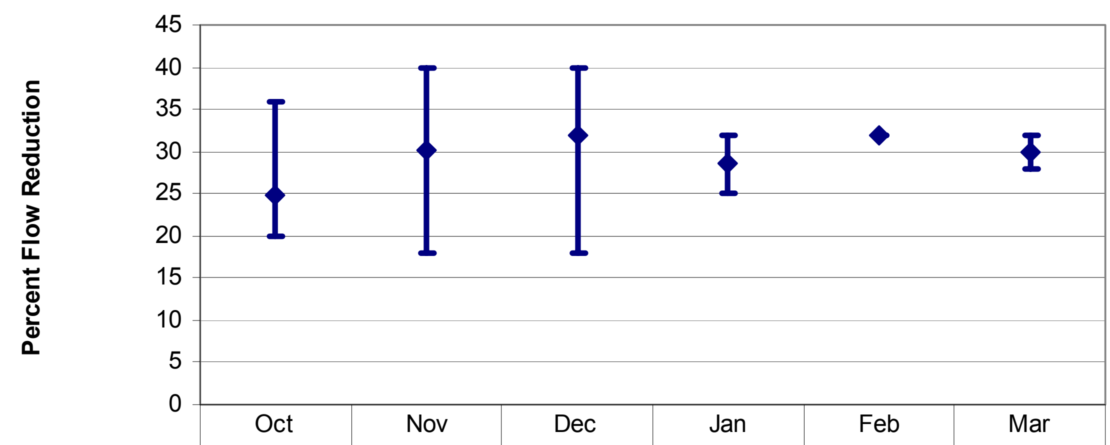


Figure 5-10. Predicted habitat gain/loss for spotted sunfish fry based on the flow record at the Arcadia gage from 1940 to 1969 and flow reductions of 10, 20, 30, and 40 percent.



	Oct	Nov	Dec	Jan	Feb	Mar
◆ Mean	25	30	32	29	32	30
Minimum	20	18	18	25	32	28
Maximum	36	40	40	32	32	32
N	5	4	7	2	2	2

Figure 5-11. Summary of PHABSIM results for Arcadia gage site. Predicted habitat gain/loss for all species which limited flow reduction to less the 50% for October through March based on the flow record for the Arcadia gage site and both benchmark periods.

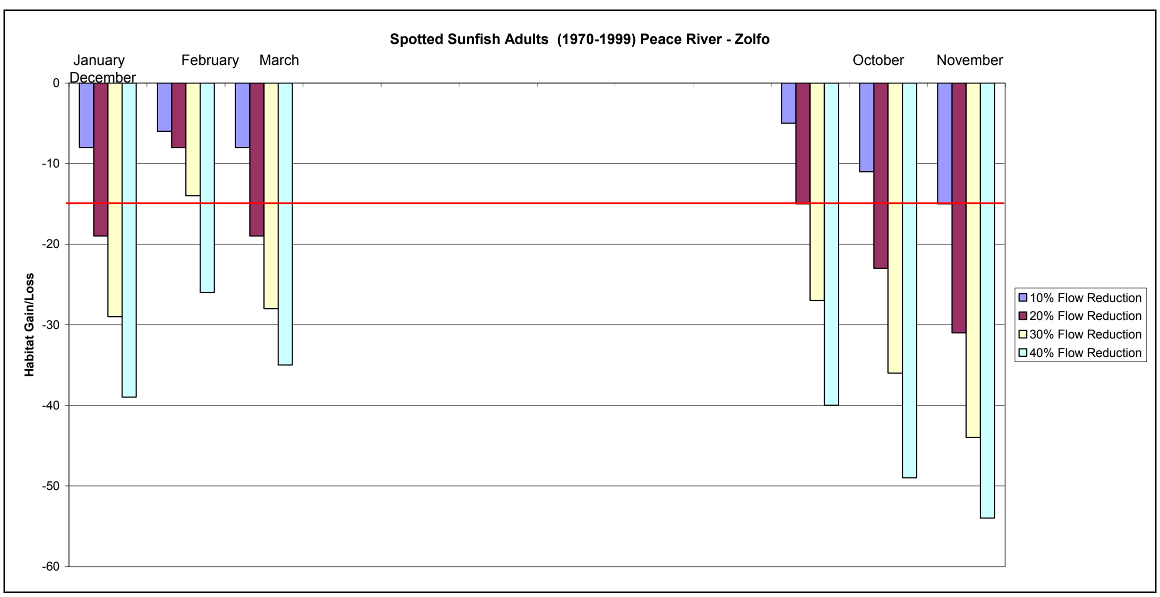
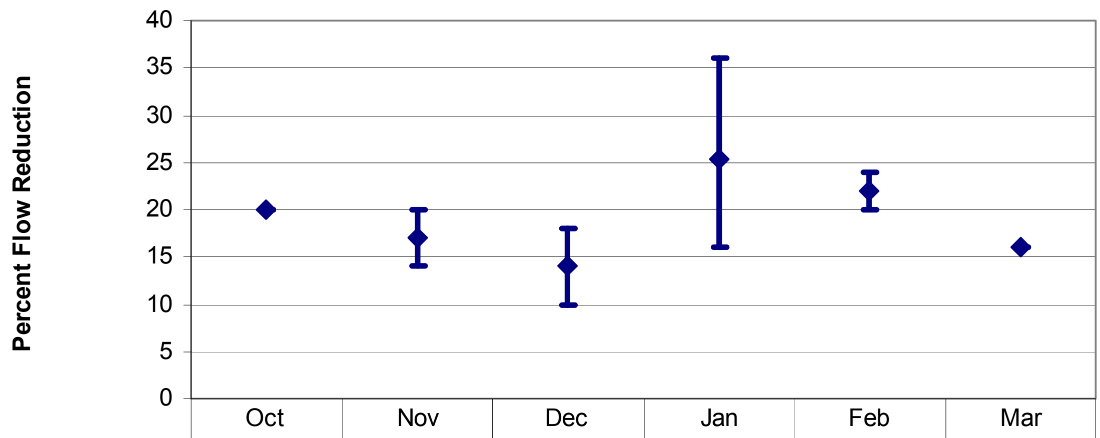


Figure 5-12. Predicted habitat gain/loss for spotted sunfish adults based on the flow record from at the Zolfo Springs gage from 1970 to 1999 and flow reductions of 10, 20, 30, and 40 percent.



	Oct	Nov	Dec	Jan	Feb	Mar
◆ Mean	20	17	14	25	22	16
Minimum	20	14	10	16	20	16
Maximum	20	20	18	36	24	16
N	1	2	2	3	2	1

Figure 5-13. Summary of PHABSIM results for the Zolfo Springs site. Predicted habitat gain/loss for all species which limited flow reduction to less than 50% for October through March based on the flow record for the Zolfo Springs gage site and both benchmark periods.

5.7.2 Instream Habitats

Bottom habitats, including sand, mud and bedrock were the dominant instream habitats, based on the linear extent of the habitat along the four instream habitat cross-sections (Figure 5-14). Wetland tree habitat was also abundant. Exposed roots, snags and wetland plants comprised substantially less of the linear habitat. Relative elevations of the habitats were consistent among the cross-sections (Figures 5-15). Wetland trees were typically situated near the top of the banks with wetland plants and exposed roots occurring at slightly lower elevations. Snags were found in association with the bottom habitats. The occurrence of exposed roots at relatively high elevations is important because inundation of this habitat results in inundation of habitats located at lower elevations. Maintaining a mosaic of aquatic and wetland habitats provides the greatest potential for stream productivity and ecosystem integrity (Pringle et al. 1988).

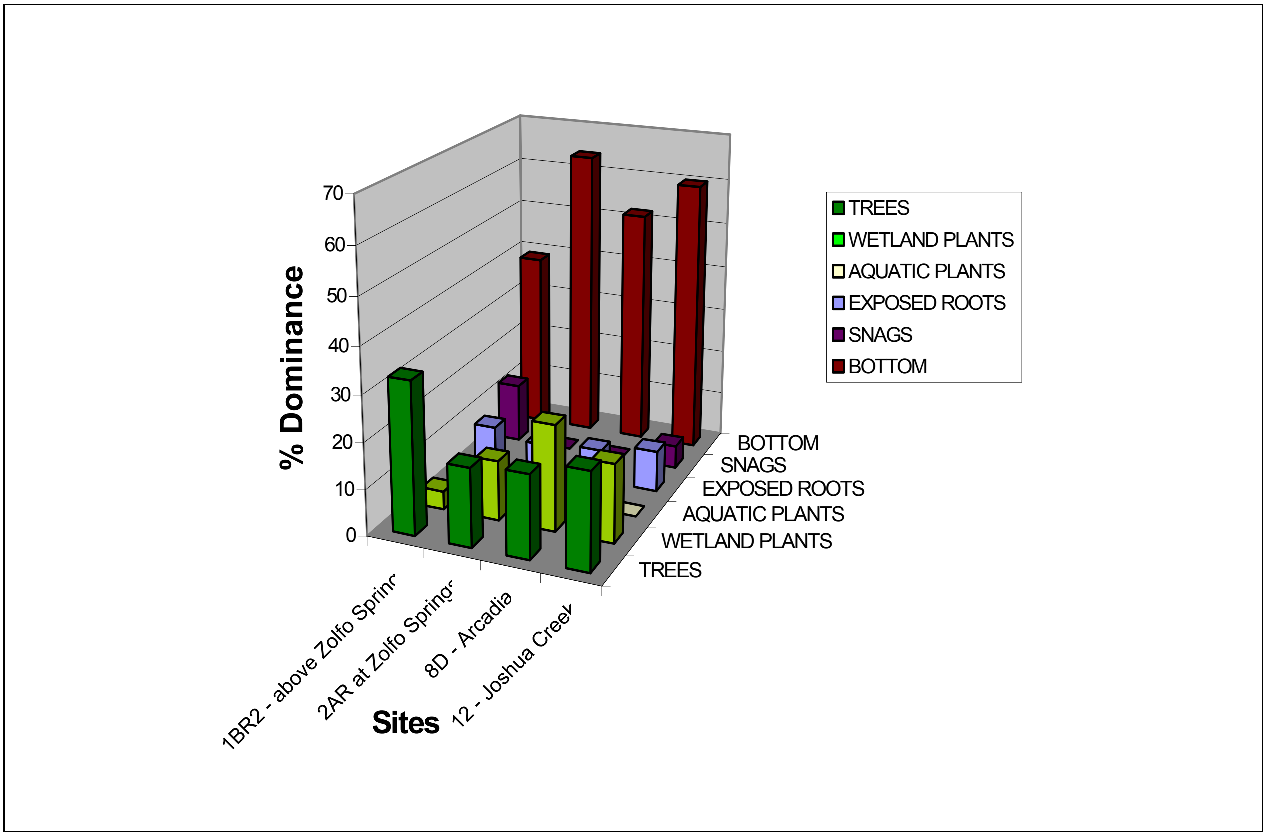


Figure 5-14. Percent dominance of instream habitats based on linear extent of the habitats along four cross-sections in the middle Peace River corridor.

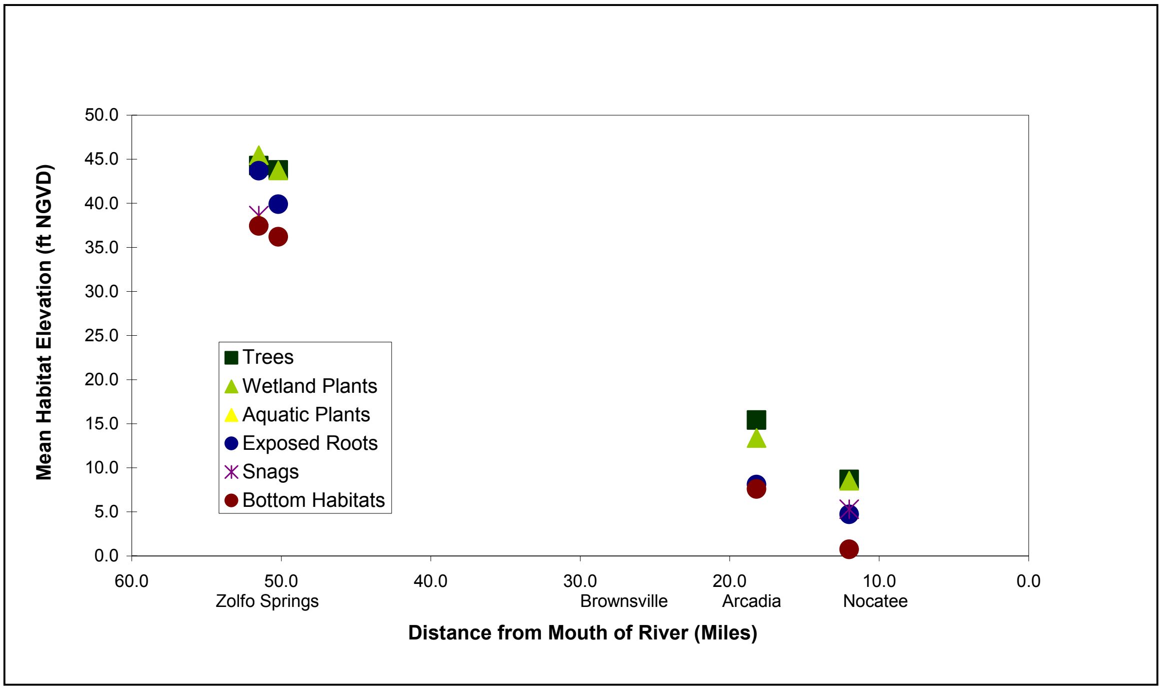


Figure 5-15. Mean instream habitat elevations at four cross-section sites on the middle Peace River.

5.7.3 Flow Relationships with Woody Instream Habitats

Based on the ecological importance of woody habitat, and its potential for use in development of a medium flow standard, inundation patterns were examined for exposed root and snag habitats at the four middle Peace River instream habitat cross-sections (Table 5-5). Flows at the Zolfo Springs gage site that would be required to inundate exposed root habitat at the two sites upstream of the gage were 187 and 1,181 cfs. Snag habitat occurred at one of the sites, but flows required for inundation of the mean snag elevation were lower than the lowest modeled-flow included in the middle Peace River HEC-RAS model. For the sites upstream of the Arcadia gage site, flows of 210 to 562 cfs would be necessary to inundate exposed root habitat and a flow of 725 cfs would be required to inundate snag habitat.

Based on historic flow records for the gages, inundation of woody habitats in the middle Peace River is expected during Block 2, and would therefore also occur during Block 3 when flows are higher. Flows sufficient to inundate the habitat may also occur in Block 1 during some years. Because these important habitats may be inundated during all three seasonal blocks, we determined percent-of-change flow reductions for inundation of the habitats during Block 2 using prescribed flow reductions developed for Blocks 1 and 3. Percent-of-flow reductions during Block 2 were derived for each gage site by calculating the flow reduction that would result in no more than a 15% loss of days of inundation of woody habitat over the entire year, after the flow reductions for Block 1 and Block 3 were applied. Using RALPH plots/analyses and flow records from 1970 through 1999, we decreased the flows in Blocks 1 and 3 by 13% and 8% respectively for the Arcadia gage and 18 and 8% respectively for the Zolfo Springs Gage, and evaluated percent-of-flow reductions for Block 2 which combined with these prescribed flow reductions would not violate the habitat availability criterion. Because the flow requirement at the Zolfo Springs Gage to inundate exposed roots at site 1BR2 is 1,181 cfs which is above the Block 3 step of 783 cfs, a flow reduction of 8% was used for Block 3 rather then low flow step reduction of 18%. The same method was applied to the 1940 to 1960 benchmark. The 1970 through 1999 period resulted in more restrictive criteria and are thus utilized as the more conservative approach. Based on these criteria, percent-of-flow reductions of 31 and 33% were identified for woody habitats at sites upstream of the Arcadia gage and reductions of 26 and 32% were identified for the sites upstream from the Zolfo Springs gage.

Table 5-5. Mean elevation of instream woody habitats (exposed roots and snags) at four instream habitat cross-section sites, corresponding flows at the Zolfo or Arcadia gage site required for inundation of the mean elevations, and maximum percent-of-flow reductions associated with less than a 15% reduction in the number of days flow sufficient to inundate the mean habitat elevations.

Habitat	Site	Mean Elevation (ft NGVD)	Flow at Gage (cfs) Required for Inundation	Gage	Percent-of-Flow Reduction 1940-1969	Percent-of-Flow Reduction 1970-1999
Exposed Root	1BR2	43.7	1,181	Zolfo	34%	26%
Exposed Root	2AR	39.9	187	Zolfo	41%	32%
Exposed Root	8D	8.1	210	Arcadia	41%	31%
Exposed Root	12	4.7	562	Arcadia	34%	33%
Snag	1BR2	38.6	NA[a]	Zolfo	NA[a]	NA[a]
Snag	2AR	NA[b]	NA[b]	Zolfo	NA[b]	NA[b]
Snag	8D	NA[b]	NA[b]	Arcadia	NA[b]	NA[b]
Snag	12	5.3	725	Arcadia	32%	24%

NA[a] Flows required to inundate the habitat were below modeled flows.
NA[b] Snag habitat not found at the cross-section sites.

5.7.4 Selection of the Prescribed Flow Reductions for Block 2

Percent-of-flow reductions associated with PHABSIM modeling and RALPH analyses associated with inundation of woody habitats were compared for identification of prescribed flow reductions. Prescribed flow reductions were established for the Arcadia and Zolfo Springs gage sites based on percent-of-flow reductions derived from PHABSIM analyses. These analyses indicated that up to 18% and 10% reductions in flows would be acceptable for the Arcadia and Zolfo Springs sites, respectively, while analyses of the inundation of woody habitat yielded percent-of-flow reductions around 30%.

5.8 Short-Term Compliance Standards for Block 2

Short-Term Compliance Standards represent a flow prescription that can be utilized for evaluating minimum flows compliance on a short-term basis, for example, based on measured daily flows. During Block 2, which for the Peace River begins on October 28 and ends on April 19 of the subsequent year, the standards were developed for two gage sites.

For the USGS Peace River at Arcadia, FL gage site, the following Short-Term Compliance Standards are proposed for Block 2:

1) All flows equal to or below 67 cfs measured at the USGS Peace River at Arcadia, Fla gage are protected in their entirety;

2) All flows between 67 cfs and 82 cfs measured at the Arcadia gage are available for use; and

3) An 18% reduction of all flows above 82 cfs measured at the Arcadia gage is available for use.

For the USGS Peace River at Zolfo Springs, FL gage site, the following Short-Term Compliance Standards are recommended for Block 2:

1) All flows equal to or below 45 cfs measured at the USGS Peace River at Zolfo Springs, Fla gage are protected in their entirety;

2) All flows between 45 cfs and 50 cfs measured at the Zolfo Springs gage are available for use; and

3) A 10% reduction of all flows above 50 cfs measured at the Zolfo Springs gage is available for use.

For both sites, the first standard was developed using the gage-specific low flow thresholds. The second and third standards were developed to assure that the prescribe flow reductions for Block 2 do not lead to violation of the respective low flow thresholds.

5.9 Compliance Standards and Proposed Minimum Flows for the Middle Peace River at Zolfo Springs and Arcadia

We have developed short-term compliance standards that comprise a flow prescription for preventing significant harm to the middle Peace River. Compliance standards were developed for three blocks that represent periods of low (Block 1), medium (Block 2) and high (Block 3) flows at two USGS gage sites; the Peace River at Zolfo Springs, FL and the Peace River at Arcadia, FL (Figures 5-16 and 5-17; Tables 5-6 and 5-7). During Block 1, which runs from April 20 to June 24, the allowable withdrawal from the middle Peace River that may be withdrawn for consumptive-use is 10% of the daily flow as measured at the USGS Zolfo Springs and Arcadia gages, once flows exceed 50 cfs at the Zolfo Springs gage and 75 cfs at the Arcadia gage. During Block 1, it is also proposed that no withdrawals be allowed when flows at the Zolfo Springs gage are below 45 cfs and that withdrawals when flows at the site are between 45 and 50 cfs not be allowed to lower the flow below 45 cfs. Similarly, during Block 1, it is proposed that withdrawals should not be allowed when flows at the Arcadia gage are below 67 cfs and that withdrawals when flows at the site are between 67 and 75 cfs not be allowed to lower the flow below 67 cfs. During Block 2, which extends from October 28 of one year to April 19 of the next, withdrawals of up to 10 and 18% of the daily flow at the Zolfo Springs and Arcadia gage sites, respectively may be allowed, with the exception that withdrawals should not be allowed to reduce the flow to less than 45 cfs at the Zolfo Springs site and 67 cfs at the Arcadia site. During Block 3, which extends from June 25 to October 27, withdrawals should be limited to a stepped flow reduction of 13% and 8% of flows, with the step occurring at 1,362 cfs at the Arcadia gage. A stepped flow reduction of 11% and 8% of flows, with the step occurring at 783 cfs was established at the Zolfo Springs gage. Proposed Block 3 reduction also must comply with the low flow threshold and assure that withdrawals not reduce the flow to less than 45 and 67 cfs at the Zolfo Springs and Arcadia gage sites, respectively.

Because minimum flows are intended to protect the water resources or ecology of an area, and because climatic variation can influence river flow regimes, we developed long-term compliance standard for the middle Peace River gage sites at Zolfo Springs and Arcadia. The standards are hydrologic statistics that represent flows that may be expected to occur during long-term periods when short term-compliance standards are being met. The long-term compliance standards were generated using gage-specific historic flow records, prescribed flow reductions for the three seasonal blocks and low flow threshold values. For the analyses, the entire flow records for each site were reduced by the maximum allowable flow reductions in accordance with the prescribed flow reduction and the low flow thresholds. Hydrologic statistics for the resulting altered flow data sets, including five and ten-year mean and median flows were calculated. These statistics integrate duration and return frequency components of the flow regime for long-term (five or ten-year) periods, and were used to establish the long-term compliance standards.

For flows in the middle Peace River at the USGS Arcadia gage, long-term compliance standards were established at the minimum five and ten-year mean and median flows (Tables 5-6 and 5-7). Standards were developed for evaluating flows on an annual basis and for the seasonal blocks corresponding to periods of low (Block 1), medium (Block 2) and high (Block 3) flows. Because these long-term compliance standards were developed using the short-term compliance standards and the historic flow records, it may be expected that the long-term standards will be met if compliance with short-term standards is achieved.

Collectively, the short and long-term compliance standards proposed for the USGS gage sites at Zolfo Springs and Arcadia comprise the District's proposed minimum flows and levels for the middle segment of the Peace River. The standards are intended to prevent significant harm to the water resources or ecology of the river that may result from water use. Since future structural alterations could potentially affect surface water or groundwater flow characteristics within the watershed and additional information pertaining to minimum flows development may become available, the District is committed to revision of the proposed levels, if necessary.

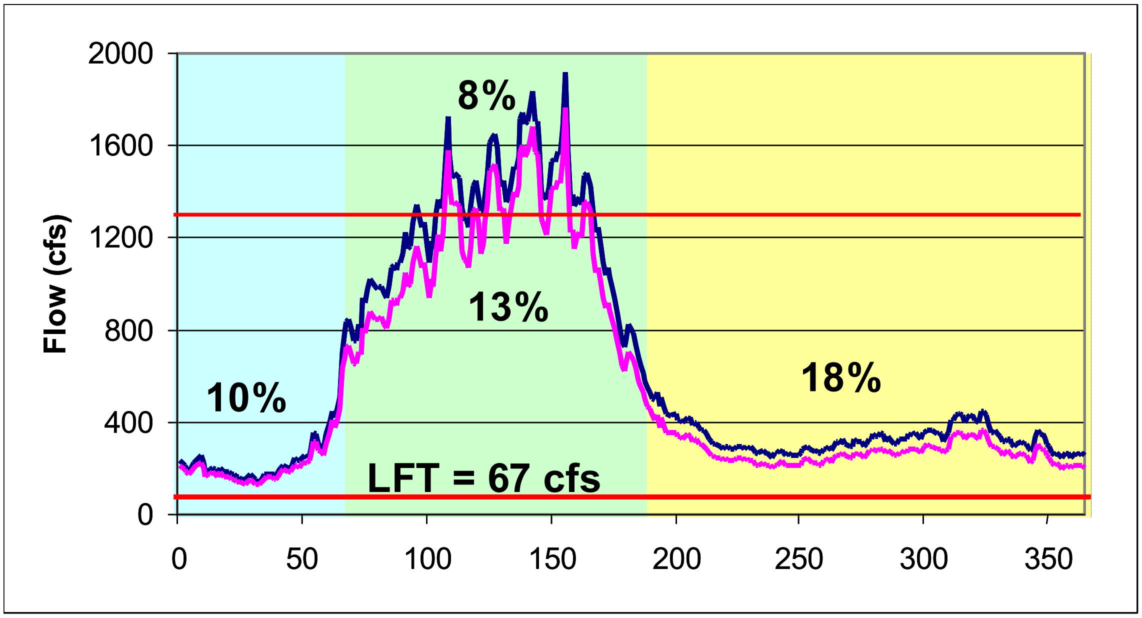


Figure 5-16. Median daily flows for the period of record for each Julian date at the USGS Peace River at Arcadia gage (Blue Line). The low flow threshold and high flow threshold are shown in red and the pink line shows what the hydrograph would look like if the maximum allowable reduction had occurred historically.

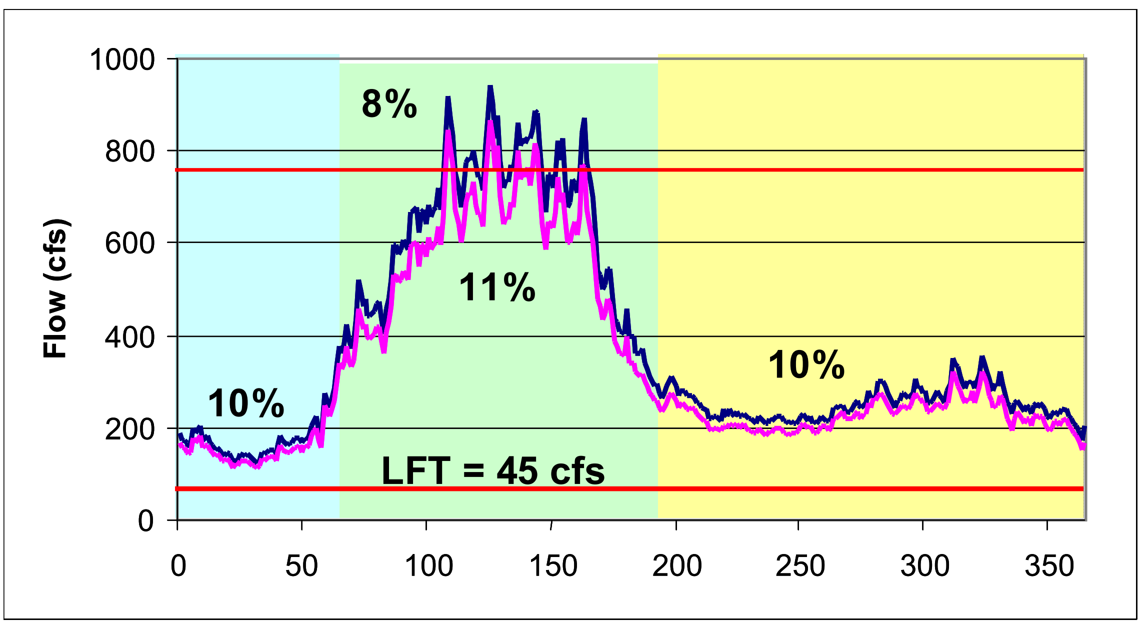


Figure 5-17. Median daily flows for the period of record for each Julian date at the USGS Peace River at Zolfo Springs gage (Blue Line). The low flow threshold and high flow threshold are shown in red and the pink line shows what the hydrograph would look like if the maximum allowable reduction had occurred historically.

Table 5-6. Proposed Minimum Flows for the middle Peace River, including short-term and long-term compliance standards for the USGS Peace River at Zolfo Springs, FL gage site.

Period	Effective Dates	Short-Term Compliance Standards		Long-Term Compliance Standards	
		Flow on Previous Day	**Daily Flow Available for Consumptive Use**	**Hydrologic Statistic**	**Flow (cfs)**
Annually	January 1 to December 31	<45 cfs >45 cfs and <783 cfs >783 cfs	0% of flow Seasonally dependent 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	318 183 308 125
Block 1	April 20 to June 25	<45 cfs >45 cfs and <50 cfs >50 cfs and <783 cfs >783 cfs	0% of flow Flow in excess of 45 cfs 10% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	136 86 90 45
Block 2	October 27 to April 19	<45 cfs >45 cfs and <50 cfs >50 cfs and <783 cfs >783 cfs	0% of flow Flow in excess of 45 cfs 10% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	229 164 206 85
Block 3	June 26 to October 26	<45 cfs >45 cfs and <49 cfs >49 cfs and <783 cfs >783 cfs	0% of flow Flow in excess of 45 cfs 11% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	538 347 255 261

Table 5-7. Proposed Minimum Flows for the middle Peace River, including short-term and long-term compliance standards for the USGS Peace River at Arcadia, FL gage site.

Period	Effective Dates	Short-Term Compliance Standards		Long-Term Compliance Standards	
		Flow on Previous Day	**Daily Flow Available for Consumptive Use**	**Hydrologic Statistic**	**Flow (cfs)**
Annually	January 1 to December 31	<67 cfs >67 cfs and < 1,362 cfs >1,362 cfs	0% of flow Seasonally dependent 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	547 243 534 196
Block 1	April 20 to June 25	<67 cfs >67 cfs and <75 cfs >75 cfs and <1,362 cfs >1,362 cfs	0% of flow Flow in excess of 67 cfs 10% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	219 121 160 64
Block 2	October 27 to April 19	<67 cfs >67 cfs and <82 cfs >82 cfs and <1,362 cfs >1,362 cfs	0% of flow Flow in excess of 67 cfs 18% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	359 182 300 122
Block 3	June 26 to October 26	<67 cfs >67 cfs and <73 cfs >73 cfs and <1,362 cfs >1,362 cfs	0% of flow Flow in excess of 67 cfs 13% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	977 631 790 382

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APPENDIX A – Peer Review

The District is committed to submitting major documents concerning minimum flows and levels to voluntary peer review process. Appendix A is a copy of the peer review report generated by this process for the middle segment of the Peace River.

A Review of

“Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia”

February 18, 2005 Draft by:

Ecological Evaluation Section
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June 2005

EXECUTIVE SUMMARY

This is a summary of the Scientific Peer Review Panel's ("Panel") evaluation of the scientific and technical data, assumptions, and methodologies used by the Southwest Florida Water Management District in the development of its proposed minimum flows and levels (MFLs) for the Middle Peace River from Zolfo Springs to Arcadia ("Report", SWFWMD 2005).

The Peer Review Panel has attempted to provide a critical review of the methods, data, and conclusions of the District. Overall, the Panel endorses the District's approach for setting MFLs in the Middle Peace River, and we find no serious flaws or errors in the methodology or findings documented in the Report. Assumptions of the approach are well documented and are reasonable given the amount and quality of data available. Tools and methods of analysis employed in this effort are appropriately used and utilize best available information. Conclusions in the Report are based on an impressive field data collection effort and sound application of findings from the scientific literature and previous investigations by District staff. The District has done a commendable job of incorporating the suggestions of past peer review, notably that for the Upper Peace River MFLs (Gore et al, 2002), in the proposed MFLs for the Middle Peace, including use of seasonal building blocks and the application of the Instream Flow Incremental Methodology. The District has also continued to apply and refine several concepts that were endorsed by previous peer review panels (Gore et al, 2002; Shaw et al, 2004). The Panel has provided suggestions for relatively minor changes or additions to the Middle Peace River Report that we feel will improve the repeatability of the methods, better justify the conclusions and ensure that resource protection goals are satisfied for overlooked species or unusual flow conditions.

The Panel finds particular merit with and strongly endorses several novel concepts incorporated in the Middle Peace MFLs. These include:

- Identifying ***two separate benchmark periods*** based on different phases of the Atlantic Multidecadal Oscillation (AMO) for identifying the most protective minimum flows
- Applying ***multiple, independent approaches*** to identify the most protective minimum flows in each seasonal block (*e.g.,* fish passage criteria *and* wetted perimeter analyses for Block 1 flows, PHABSIM modeling *and* woody habitat analyses for Block 2 flows, etc.)
- Specifying minimum flows in terms of allowable ***percent flow reductions*** that vary by season and flow conditions

The Panel recommends that the District continue to refine these concepts and that they should routinely be incorporated when setting future MFLs for rivers in

Southwest Florida.

We applaud the District's commitment to periodic reassessment of the MFLs for the Middle Peace River and other water bodies as structural alterations or changes in watershed conditions occur. We strongly recommend, however, that the District begin now to develop the process and methodology by which such reassessment would occur, and we suggest that such a process should be based on an adaptive management framework.

INTRODUCTION

The Southwest Florida Water Management District (SWFWMD) under Florida statutes provides for peer review of methodologies and studies that address the management of water resources within the jurisdiction of the District. The SWFWMD has been directed to establish minimum flows and levels (designated as MFLs) for priority water bodies within its boundaries. This directive is by virtue of SWFWMD's obligation to permit consumptive use of water and a legislative mandate to protect water resources from *significant harm*. According to the Water Resources Act of 1972, *minimum flows* are defined as "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" (Section 373.042 F.S.). A *minimum level* is defined as "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." Statutes provide that MFLs shall be calculated using the *best available* information,

The process of analyzing minimum flows and levels for the Middle Peace River is built upon the analyses previously performed on the Upper Peace River (Southwest Florida Water Management District 2002) and peer reviewed by Gore et al. (2002). Establishment of minimum flows and levels generally is designed to define thresholds at which further withdrawals would produce significant harm to existing water resources and ecological conditions if these thresholds were exceeded in the future.

This review follows the organization of the Charge to the Peer Review Panel and the structure of the draft report. It is the job of the Peer Review Panel to assess the strengths and weaknesses of the overall approach, its conclusions, and recommendations. This review is provided to the District with our encouragement to continue and enhance the scientific basis that is firmly established for the decision-making process by the SWFWMD.

1.0 THE CHARGE

The charge to the Peer Review Panel contains five basic requirements:

1. Review the District's draft document used to develop provisional minimum levels and flows for the Middle Peace River.
2. Review documents and other materials supporting the concepts and data presented in the draft document.
3. Participate in an open (public) meeting at the District's Tampa Service Office for the purpose of discussing directly all issues and concerns regarding the draft report with a goal of developing this report.
4. Provide to the District a written report that includes a review of the data, methodologies, analyses, and conclusions outlined in the draft report.
5. Render follow-up services where required.

We understand that some statutory constraints and conditions affect the District's development of MLFs and that the Governing Board may have also established certain assumptions, conditions and legal and policy interpretations. These *givens* include:

1, the selection of water bodies or aquifers for which minimum levels have initially been set;
2. the determination of the baseline from which "significant harm" is to be determined by the reviewers;
3. the definition of what constitutes "significant harm" to the water resources or ecology of the area;
4. the consideration given to changes and structural alterations to watersheds, surface waters, and aquifers, and the effects and constraints that such changes or alterations have had or placed on the hydrology of a given watershed, surface water, or aquifer; and
5. the adopted method for establishing MFLs for other water bodies and aquifers.

In addition to the draft report and appendices, various types of supplementary data provided by the District also were examined as part of this review.

2.0 RESULTS OF THE PEER REVIEW

MFL Benchmarks and Resource Protection Goals

Benchmarks and the Atlantic Multidecadal Oscillation (AMO)

The report uses the five elements listed by Beecher (1990) as guidelines for developing minimum flows and levels (MFLs). These are a good set of guidelines. One guideline, the use of a benchmark period, needs to be coupled to the growing understanding of climate variability, the AMO, and river flow regimes in Florida. The draft report by Kelly (SWFWMD 2004) does an excellent job in demonstrating how various benchmark periods can yield very different answers with regards to flow regime when the AMO is in different modes. The analyses of AMO and streamflow relationships for Florida (SWFWMD, 2004) was previously peer reviewed and the findings of the draft report were strongly endorsed by the reviewers (Shaw et al, 2004). In Florida, the status of the AMO needs to be considered when MFLs are being set, especially given the strong influence of the AMO on streamflow patterns, and when regulatory and other measures are being considered to sustain adequate flows and levels (Enfield et al. 2001). The District has fully embraced the climate-streamflow issue in developing the MFLs for the Middle Peace by evaluating and identifying limiting flow conditions for two separate benchmark periods (based on different phases of the AMO) for each approach described in the report. Recommended low-flow thresholds and percent flow reduction criteria are based on the most limiting of these benchmark periods to ensure adequate protection during periods when less rainfall and lower streamflow prevail. The peer review panel strongly endorses this approach and recommends that similar approaches should routinely be incorporated when setting MFLs for all rivers in Florida and that knowledge of AMO-streamflow relationships gained by District staff be widely disseminated to water managers throughout Florida and other parts of the eastern United States.

The MFL report for the Middle Peace River includes a convincing argument that observed trends in mid- to high-percentile flows in this segment of the river and its tributaries over the past several decades is largely the result of climate, rather than of land use changes in the watershed as has been previously concluded. These arguments and conclusions were peer reviewed in conjunction with the AMO streamflow report (SWFWMD, 2004), and were determined to be persuasive, soundly based on insights gained in analyzing AMO-streamflow patterns and well supported by data (Shaw et al, 2004). We believe this analysis adequately addresses issues of prior anthropogenic changes to the hydrologic regime of the Middle Peace River.

Building Block Approach

The SWFWMD has employed a building block approach in establishing MFLs on the Middle Peace (Gore et al. 2002, Postel and Richter 2003). The assumptions behind building block methods are based upon simple ecological theory. Organisms and communities occupying a 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 specific flow requirements, the best alternative is to maintain or recreate the hydrologic[SWG1] conditions under which communities had existed prior to disturbance of the flow regime or allocation of instream flows. Building-block models are the "first-best-approximation" of adequate conditions to meet ecological needs. More often than not, resource agencies have hydrographic records for long periods of time, while little or no biological data are available.

Hydrological variability is the critical template for maintaining ecosystem integrity. The use of this natural variability as a guide for ecosystem management has been widely advocated (e.g. Richter et al. 1996). Although variability is a key to ecosystem maintenance, some sort of predictability of variation must be maintained. It must be realized that survival of aquatic communities is contained within the envelope of natural variability (Resh et al. 1988). In addition to the seasonal pattern of flow, such conditions as time, duration and intensity of extreme events, as well as the frequency and predictability of droughts and floods may also be significant environmental cues. Also, the frequency, duration, and intensity of higher and lower flows can affect channel morphology and riparian vegetation, and thus change aquatic habitat. Indeed, the rate of change of these conditions must also be considered (Poff and Ward 1989, Davies et al. 1994, Richter et al. 1996, 1997).

Hydrologic variability is a critical component of the Middle Peace hydrograph, and three blocks are defined from the average long-term annual hydrograph. Block 1 considers the low flow period that occurs during the spring dry season, Block 2 considers the baseflow period during the cooler portion of the year when evapotranspiration rates are often at their lowest levels, and Block 3 considers the high flow period during the summer/fall wet season. This is a valid approach for setting MFLs because it accounts for expected seasonal variability during a typical year. By contrast, MFLs focused solely upon low flow conditions are inadequate for protecting important river and riparian ecosystem functions that occur at other times of the year which are often critical to the viability of aquatic organisms. The building block approach is based upon predictably varying hydrological conditions and is a rigorous and defensible approach for the establishment of protective MFLs for the Middle Peace. It also has the advantage of insuring a flow regime with the range of variability essential to the maintenance of stream structure and function.

However, one potential weakness of using building blocks with fixed beginning and ending dates, as was done for the Middle Peace, is that some important ecosystem functions may receive inadequate protection if an atypical or unusual water year occurs. For example, during strong El Niño cycles, Florida often receives more intense rains and higher streamflows during the winter and spring months, which are assumed to be low flow periods in the Middle Peace River.

Conversely, less than average rainfall and streamflow may occur during the summer. This often results in an annual hydrograph that is seasonally reversed from the pattern assumed by the District's building blocks. It is not clear whether fish and other aquatic organisms in the Peace River utilize available habitat in the same way if high flows occur during the winter as they do if high flows occur in the summer, and additional research on this issue is probably warranted. Nevertheless, we commend District staff for specifying that the proposed low flow threshold should apply year around, not just during Block 1, and we recommend that staff re-evaluate proposed flow reduction criteria to determine whether all intended resource protection goals would be satisfied during El Niño events or other unusual hydrologic conditions.

Preventing Significant Harm – 15% Change in Habitat

The draft report for setting MFLs in the Middle Peace has chosen to use a 15% change in habitat availability as the threshold for defining significant harm. This value was chosen based upon the peer review report by Gore et al. (2002) for the SWFWMD report on setting MFLs for the Upper Peace (SWFWMD 2002). The report notes that percentage changes have ranged from 10-33% in other applications designed to prevent significant harm (Dunbar et al. 1998; Jowett 1998). The peer review panel feels that the 15% threshold selected for preventing significant harm is appropriate and prudent for the Middle Peace. It should be acknowledged, however, that a 15% change in habitat availability based on a reduction in spatial extent of habitat (as was used in the PHABSIM analyses) may not be equivalent to a 15% change in habitat availability based on number of days a particular habitat is inundated (as was applied to the RALPH analyses).

Analytical Tools Used to Develop MFLs

HEC-RAS

The Hydrologic Engineering Centers River Analysis System (HEC-RAS) model is used for estimating one-dimensional steady-state water surface profiles in setting MFLs for the Middle Peace. HEC-RAS is a model developed by the US Army Corps of Engineers Hydrologic Engineering Center and is widely used, having previously replaced the HEC-2 model as the standard program for water surface profile calculations. The newest generation of the model (version 3.1.1) was used with a range of flows from the USGS Arcadia and Zolfo Springs gages to determine stage versus flow and wetted perimeter versus flow for numerous cross sections and shoal sites along the Middle Peace. This model has a history of being used to estimate minimum flows (Gore and Mead 2002).

The HEC-RAS model also was used in establishing MFLs for the Upper Peace (SWFWMD 2002). The concern expressed in the peer review of this report was that the hydraulic model needed to be linked to a biotic habitat model. This has been done in the report for the Middle Peace by use of the Physical Habitat Simulation (PHABSIM) model with key biota from the Middle Peace, and is also used in the fish passage and wetted perimeter analysis and with RALPH analyses of woody habitat and floodplain plant communities. This is an appropriate linking of models and makes for a more robust determination of MFLs.

The peer review panel deems the HEC-RAS model to be an appropriate tool for assessing flow-stage relationships along the Middle Peace. However, a more explicit discussion of the precision and accuracy of HEC-RAS in estimating water depths and sensitivity of depth calculations to changes in flow would be a helpful addition to the report and would improve our understanding of the sources of uncertainty inherent in the minimum flow recommendations. Also useful in a similar vein would be to include more information about how elevations of the USGS cross sections that form much of the basis for HEC-RAS calculations were determined, specifically whether elevations were field surveyed or taken from a digital elevation model and what are the associated standard errors of those data sets.

PHABSIM

The Instream Flow Incremental Methodology (IFIM) (Bovee et al. 1998) and its software, the Physical Habitat Simulation (PHABSIM) requires hydrological data plus the additional effort of determining the physical habitat requirements of target biota. There are five major hydraulic conditions that affect the distribution and ecological success of riverine biota. These are suspended load, bedload movement, turbulence, velocity profile, and substratum interactions (near bed hydraulics). Singly, or in combination, changes in these conditions can alter distribution of biota and disrupt community structure. The interactions of these hydraulic conditions upon the morphology and behavior of the individual organisms govern the distribution of aquatic biota. The IFIM attempts to describe these interactions using a relatively simple modeling technique.

Traditionally, the IFIM technique has focused on habitat availability of target fish species. Gore and Nestler (1988) believe that habitat suitability curves can be thought of as surrogates for basic niches. Statzner et al. (1988) and Gore and Bryant (1990) have demonstrated that different macroinvertebrate life stages also require different hydraulic conditions to achieve completion of life cycles, just as fish species have very different spawning, incubation, and maintenance requirements. Most recently, Gore et al. (2001) demonstrated that inclusion of macroinvertebrate criteria often dramatically altered decisions on flow reservations[SWG2] versus those based upon analysis of fish species alone. By the same token, we recommend that the District evaluate whether additional habitat suitability curves should be developed and PHABSIM analyses be conducted for other species that may be more sensitive to hydrologic change than the three common centrarchid fishes identified in the Middle Peace report.

Changes in velocity distribution and substrate/cover characteristics at regular intervals, combined with stage/discharge relationships, provide the calibration data for PHABSIM. Habitat suitability curves were developed for spotted sunfish (*Lepomis punctatus*), largemouth bass (*Micropterus salmoides*), bluegill sunfish (*Lepomis macrochirus*), and macroinvertebrate community diversity (Gore et al. 2001; Stuber et al. 1982). These are appropriate species for consideration in the Middle Peace and their selection is validated by data presented on fish abundance in the appendix to the MFL report. The need for continued development and refinement of habitat suitability curves for these species and other species of concern remains a necessary long-term goal as noted below, but the peer review panel affirms that the best available information was used in the PHABSIM modeling for the Middle Peace River. This strengthens the specific recommendations for MFLs made in the report.

Over the long term, we recommend that the District focus research on evaluating and potentially developing habitat suitability information on additional species or groups of species that may be more sensitive to changes in the hydrologic regime. Of particular concern would be any listed, imperiled, or endemic species, species tracked by the Florida Natural Areas Inventory (FNAI) (e.g., ironcolor shiner, present in several tributaries of the Middle Peace), freshwater mussels, anadromous or catadromous fishes (e.g., American eel), marine fishes utilizing the freshwater portions of the river, and species with preferences for stream edges or banks that might be the first places to feel the effects of reduced flows. Similarly, it may be useful to develop better habitat suitability information for certain exotic species present in the Peace River (e.g., blue tilapia) to ensure that reduced flows do not *improve* habitat conditions for such species or facilitate their invasion of new habitat.

RALPH Plots

Recent and Long-Term Positional Hydrographs (RALPH) plots and analyses were used in the report to identify the number of days from a defined period of record when flows or levels associated with a specific aquatic habitat or floodplain feature were equaled or exceeded. These analyses were applied at various river cross-sections and enable a quantitative assessment of how flow reductions of a certain magnitude would affect the number of days that certain flow characteristics would be met or exceeded. Examples are given in Figures 4-7 and 4-8 in the report. As a means of analysis and graphical visualization, the panel feels that the RALPH plots are an important enhancement to the presentation of MFLs for the Middle Peace River, and we recommend that the District continue to utilize and refine this tool for future MFL development.

Habitat Criteria and Characterization Methods Used to Develop MFLs

FISH PASSAGE

Fish passage was used to estimate flows sufficient to permit fish movement throughout the Middle Peace River. Flows of this magnitude would also likely permit recreation (i.e. canoeing) and presumably provide adequate water movement to prevent the most extreme adverse effects associated with intermittency (i.e. low dissolved oxygen, high temperature, and stagnation). A fish passage criterion of 0.6 ft was used based in part on size data from large-bodied fishes in Florida streams and minimum fish passage depths used in other instream flow settings elsewhere in the U.S. This criterion has been used to develop previous minimum flow plans (SWFWMD 2002) and has been found acceptable following peer review (Gore et al. 2002).

Flows adequate to maintain the fish passage criterion were estimated at stream cross sections using output from the HEC-RAS model. Water depth at the deepest part of the channel was used to establish the criterion. Fish passage criteria were established for both the Arcadia and Zolfo Springs gages. The peer review panel feels that the continued use of the 0.6 ft standard represents best available information and is reasonable and consistent with overall SWFWMD water allocation policy.

This notwithstanding, fish passage depths in the range of 0.5-0.8 ft were originally derived from requirements of migratory salmonids in cool, well oxygenated waters of the western U.S. The adequacy of these standards for use in Florida's warmwater streams has been questioned by resource managers (HSW, 2004). Although no definitive research has yet been conducted on this issue (Hill and Cichra, 2002), it is the emerging consensus that minimum depth criteria used in Florida need to be re-evaluated to ensure that they adequately prevent negative effects associated with low flows in warmwater ecosystems, including high water temperatures, low dissolved oxygen, algal blooms and increased predatory pressure, in addition to mere physical passage of fish. The peer review panel recommends that the District engage with researchers studying fish passage depths for warmwater streams and actively work to develop minimum fish passage criteria that are more suitable for warmwater aquatic ecosystems and which go beyond the issue of simple physical passage to address other negative impacts of low flows.

It should also be noted that based on size data included in the appendix of the present report, a minimum depth of 0.6 ft is barely adequate for physical passage of several of the largest-bodied gamefish common to the Middle Peace River. Re-evaluation of fish size data and occurrence records for additional species that may be using (or may have historically used) shoal habitat on the Peace River may be warranted to ensure that minimum depth criteria are adequate for all species. For example, several records of gulf sturgeon (*Acipenser oxyrinchus desotoi*) occur in the lower Peace River and Charlotte Harbor, and although no upstream records for this species exist for the Middle Peace, this fish is known to spawn in other Gulf slope rivers in Florida at limestone shoals similar to those on the Peace. The District should evaluate whether minimum depth criteria used for sturgeon in other Florida rivers (e.g., the U.S. Fish and Wildlife Service has proposed a minimum depth of one meter or greater over shoals in the Apalachicola River to protect sturgeon spawning, J. Ziewitz, USFWS, Panama City, personal communication) would be appropriate for use in the Middle Peace as an alternative to the 0.6 ft minimum depth.

As a final note, one of the water resource functions the Middle Peace MFLs are intended to protect is recreational use of the river. This goal is cited in Chapter 3, but the issue is never discussed or developed further anywhere in the report. While the panel feels that 0.6 ft is most likely an adequate depth that will permit canoeing during low flow periods, this issue and discussion of appropriate minimum depth criteria should be further developed. If it is being assumed that recreation is mostly passive (e.g., canoeing) and that the low flow threshold based on fish passage or wetted perimeter analysis will also protect flows and levels for recreation, then the peer review panel recommends that this be explicitly stated and justified in the report. The justification, if possible, should cite figures on boating usage, minimum depths and widths needed for safe and enjoyable passage of canoes or other craft and include analysis demonstrating that those conditions would be satisfied by the proposed low threshold flows. It would also be helpful for evaluating the potential impacts to both recreation and ecological functions to include a plot of the proposed low-flow thresholds versus historic flows to provide context and perspective for the recommendations.

DAYS OF FLOODPLAIN INUNDATION

Low gradient streams, like the Middle Peace River, often have an extensive floodplain. Floodplains support complex and diverse plant communities whose distribution is determined by small changes in microtopography and average length of annual inundation or hydroperiod. Plant communities are often adapted to the average annual flow regime and decline if flood frequency is altered. Extensive floodplains are often critical to aquatic life. During floods river biota migrate into floodplains for foraging and spawning. In addition, periodic flooding stimulates biogeochemical transformations in floodplain soils which benefit both floodplain and riverine productivity.

The District has recognized the critical role of floods in proposing minimum flows for the Middle Peace River. Extensive vegetation and elevation surveys were used to characterize the structure of floodplains in the Middle Peace. HEC-RAS and RALPH plots/analysis were used to determine floodplain inundation patterns based on historical benchmark periods. This information was then used to estimate percent of flow reductions for Block 3 that would result in no more than a 15% reduction in the number of days of inundation. The analysis suggested that a stepped approach to water allocation during Block 3 would meet the established criteria.

The peer review panel feels that consideration of high flows and patterns of floodplain inundation is commendable. The use of a 15% reduction in the number of days of inundation is an appropriate criterion for water allocation and is consistent with the working definition of significant harm used in the report.

However, some modifications to the methodology and its presentation in the report would improve the repeatability of the analyses and our confidence in the results. First, the characterization of floodplain communities is a sometimes confusing mix of geomorphic settings (e.g., berm, river terrace, uplands) and plant communities (e.g., marsh, cypress, hardwood swamp, maple, etc.) that do not appear to conform to any standard scheme for community classification that is widely accepted in Florida; e.g., FNAI natural communities. Some categories would seem to overlap with or represent subsets of others (e.g., maple and hardwood swamp or wet hardwood hammock and perhaps seepage slope). More explanation is needed of the methods used for identifying and characterizing floodplain plant communities, including procedures for determining boundaries between communities, what diagnostic species are used to identify each community, whether the understory or overstory was primary in defining communities, and what system was used for assigning names to different plant communities. At a minimum, plant lists or a table of dominant or diagnostic species for each community should be included in the appendix and referenced in the main body of the report, and plant community names should be changed to conform to more accepted convention.

Second, while the analysis considers inundation to both the mean and 90^{th}-percentile (highest) ground elevations of the dominant wetland plant communities, it fails to consider the need for inundation over and above what would barely cover the ground surface. Not only would inundation to some minimum depth be necessary to permit fish passage into these communities, but is also necessary for maintaining productivity of the floodplain wetlands. We recommend redoing the analyses considering inundation of each community to some minimum depth above the mean ground elevation. The minimum depth selected could be the value selected for fish passage or a typical wet season depth for the type of community being analyzed. There are numerous references in the literature to normal or typical wet season inundation depths for various wetland community types in Florida (e.g., CH2M Hill, 1996; ESE, 1991). While the final flow reduction derived from this modified analysis may not differ appreciably from what is presented in the report, the analysis would be more ecologically defensible and perhaps more protective of wetland functions in the floodplain.

Third, a more thorough discussion of sources of uncertainty and how uncertainty was controlled or dealt with in this analysis, as well as more information on the range of variability of measured elevations, would be helpful additions to the report and would aid in interpreting the results. Including more of the RALPH plots in the main body of the text or at least making reference to such plots included in the Appendix would also improve readers' understanding of the results.

SNAG AND ROOT INUNDATION

Woody substrates (snags and exposed roots) are a critical habitat in most low gradient southeastern streams. Woody substrates are often the most productive habitat (on a unit area basis). Wood also provides shelter for freshwater fishes and basking sites for aquatic herpetofauna. Submerged wood is also important in biogeochemical transformation; as biofilms develop on submerged wood, carbon and nutrient processing are enhanced and overall stream metabolism is increased.

The District estimated the mean elevation of woody substrates using instream habitat cross-sections in the Middle Peace River. Then, an estimate of the average frequency of inundation was determined using the two benchmark periods. Data from the most recent period (1970-1999) was used because it was more conservative (i.e. it was a period of lower stream flow). This was compared with previously prescribed flow reductions in Blocks 1 and 3 to determine the overall effect on woody substrate inundation. These analyses were used to help determine the allowable flow allocation during Block 2 and then estimate flow allocations that would result in no more than 15% reduction in days of inundation over the entire year.

The peer review panel agrees with the District that woody substrates are a critical habitat in the Middle Peace River and that their duration of inundation should be considered in flow allocation strategies. The approach adopted by the District is reasonable and consistent with other recommendations made in the report.

As noted above for floodplain inundation analyses, a more thorough discussion of sources of uncertainty and how uncertainty was controlled or dealt with in this analysis, as well as more information on the range of variability of measured elevations, would be helpful additions to the report and would aid in interpreting the results. Including some more of the RALPH plots in the main body of the text or at least making reference to such plots included in the appendix would also improve readers' understanding of the results.

COMPLIANCE STANDARDS AND PROPOSED MINIMUM FLOWS

The peer review panel strongly endorses the District's proposed minimum flows for the Middle Peace River at Arcadia and Zolfo Springs and finds them to be based on sound science and best available information, subject to our comments and recommendations above. We believe that the use of two separate benchmark periods based on distinct climate regimes and multiple assessment methods and habitat criteria for identifying the limiting flow reductions in each seasonal block gives additional confidence in the District's work and lends credibility to the results. We recommend that a similar methodological framework be adopted for developing all future MFLs. We commend the District for specifying minimum flows in terms of allowable percent flow reductions for different seasonal blocks and a low-flow threshold applicable at all times of the year. This "percent of flow approach" as it is called by instream flow analysts, combined with seasonal building blocks, has been recognized as one of the best ways of protecting multiple functions and values of river systems under a wide range of flow conditions (Postel and Richter, 2003). The proposed short and long term compliance standards proposed in the report are a pragmatic and logical means of implementing the findings of the report in a regulatory context.

We applaud the District's commitment to periodic reassessment of the MFLs for the Middle Peace River and other water bodies as structural alterations or substantial changes in watershed conditions occur. We strongly recommend, however, that the District begin now to develop the process and methodology by which such reassessment would occur. Specifically, we recommend that an adaptive management framework be adopted for evaluating compliance with the MFL, taking corrective action to reduce water withdrawals and triggering MFL reassessments when necessary. Such a framework should include ongoing evaluation of the effectiveness of the MFLs based on long term monitoring of key ecosystem and water resource values the MFL is intended to protect and periodic assessment of whether key assumptions inherent in the MFL development are still satisfied.

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APPENDIX B - Staff Response to Peer Review

Introduction

Overall the peer review committee endorsed the Districts approach to establishing minimum flows and levels on the middle Peace River. Specifically the peer review committee noted that the assumptions of the approach are well documented and are reasonable, the tools and methods of analysis employed are appropriate and utilize best available information, and the conclusions in the report are based on an impressive field data collection effort and sound application of findings from the scientific literature. In short they found "no serious flaws or errors in the methodology or findings documented in the report" (Shaw et al. 2005, Appendix A). The Panel also found particular merit with and strongly endorses several novel concepts including;

- Identifying ***two separate benchmark periods*** based on different phases of the Atlantic Multidecadal Oscillation (AMO) . . .
- Applying ***multiple, independent approaches*** to identify the most protective minimum flow in each seasonal block. . .
- Specifying minimum flows in terms of allowable ***percent flow reductions*** that vary by season and flow conditions.

However, the panel did supply some direction for improving the report.

1. *We recommend that staff re-evaluate proposed flow reduction criteria to determine whether all intended resource protection goals would be satisfied during El Nino events or other unusual hydrologic conditions.*

   The District interpreted this concern as one involving seasonality. The concern seems to be that the protection offered high flow events during Block 3 is not afforded to high flow events which may occur during other Blocks. Specifically, this may be expected during El Nino events when elevated flow events occur outside Block 3. The District addressed this concern by extending the High Flow Threshold from Block 3 to be in effect year-round. While such flows do not occur annually when they do occur outside block 3 they will be protected to the same extent they are during Block 3. This change was incorporated into both the short-term compliance standards and the long-term compliance standards for both gage sites (Tables 5-6 and 5-7).

2. *It should be acknowledged, however, that a 15% change in habitat availability based on a reduction in spatial extent of habitat (as was used*

in PHABSIM analyses) may not be equivalent to a 15% change in habitat availability based on number of days a particular habitat is inundated.

The District acknowledges this and is currently performing a comparison of temporal and spatial loss of habitat. The results are under review but preliminarily indicate that on the Peace River flow reduction required to effect a 15% spatial loss are greater then those required to effect a 15% temporal loss (Munson et al. DRAFT).

3. *A more explicit discussion of the precision and accuracy of HEC-RAS would be a helpful addition to the report. Specifically, what is the expected level of uncertainty? Also what steps are being taken to validate the model?*

   The District has added to Chapter 4 a discussion of the uncertainty in the data used for the model. This was also done prior to the peer review of the Myakka River MFL report. In the peer review report of the Myakka River the peer review panel note that "a more thorough discussion of precision and accuracy issues related to the use of HEC-RAS and the methods of determining cross section elevations is provided in the Myakka Report, perhaps, in response to peer review suggestions for the middle Peace River" (Appendix A). This is the case and a similar discussion has been added to this report.

   To validate the model and help with a study, in part generated by comment 5 below, the District is installing gages at sites in rivers and adjacent wetlands. Data collected from these sites will assist with validation of the HEC-RAS model results.

4. *Over the long term, we recommend that the District focus research on evaluating and potentially developing habitat suitability information on additional species or groups of species that may be more sensitive to change in the hydrologic regime.*

   The District agrees and had, prior to this recommendation, arranged with Dr. James Gore of the University of South Florida to develop additional habitat suitability curves specific to southwest Florida species.

5. *Although no definitive research has yet been conducted on this issue, it is the emerging consensus that minimum depth criteria used in Florida needs to be re-evaluated to ensure that they adequately prevent negative effects associated with low flows in warm water ecosystems.*

   To address this issue the District is identifying locations on rivers where such research can occur, and staff is proposing the deployment of data logging equipment under low flow conditions to collect data necessary to further investigate this issue.

6. *While the panel feels that 0.6 ft is most likely an adequate depth that will permit canoeing during low flow periods, this issue and discussion of appropriate minimum depth criteria should be further developed.*

   The District will continue to review the literature regarding minimum depth requirements for canoeing and other recreational activities, and assimilate this information into future minimum flow analysis and reports.

7. *With respect to floodplain wetland vegetation some modifications to the methodology and its presentation in the report would improve the repeatability of analyses and our confidence in the results.*

   The District acknowledges some inconsistencies in the reporting of floodplain vegetation data. Developing methodologies on multiple rivers in parallel resulted in inconsistencies between consultants in the type of data was gathered. As the most useful and easily replicated procedures become evident the District will streamline and control the process to assure better repeatability in the field.

8. *Also with regard to floodplains, while the analysis considers inundation to both the mean and 90th-percentile (highest) ground elevations of the dominant wetland plant communities, it fails to consider the need for inundation over and above what would barely cover the ground surface.*

   The discussion presented in Chapter 5 was intended to communicate the point that reductions in the continuum of flows that inundate the floodplain features 15% fewer day tended to be similar, regardless of the actual flow values. Figures 5-7 and 5-8 show that for the entire range of high flows that may be expected to inundate the floodplain features, 8% flow reductions would result in those flows occurring 15% fewer days per year. Because the flows included in the figures span the range of flow expected to inundate the entire range of elevations associated with floodplain features, the flows associated with reductions in the number of days specific features are inundates by an inch, or foot or some other depth are depicted. We therefore assert that results from our analysis are representative of flow reduction that would be associated with, for example, inundation of the tenth, fiftieth, and ninetieth elevation percentiles for cypress swamp vegetation or any other feature, at ground elevation, or to a specific depth above ground elevation.