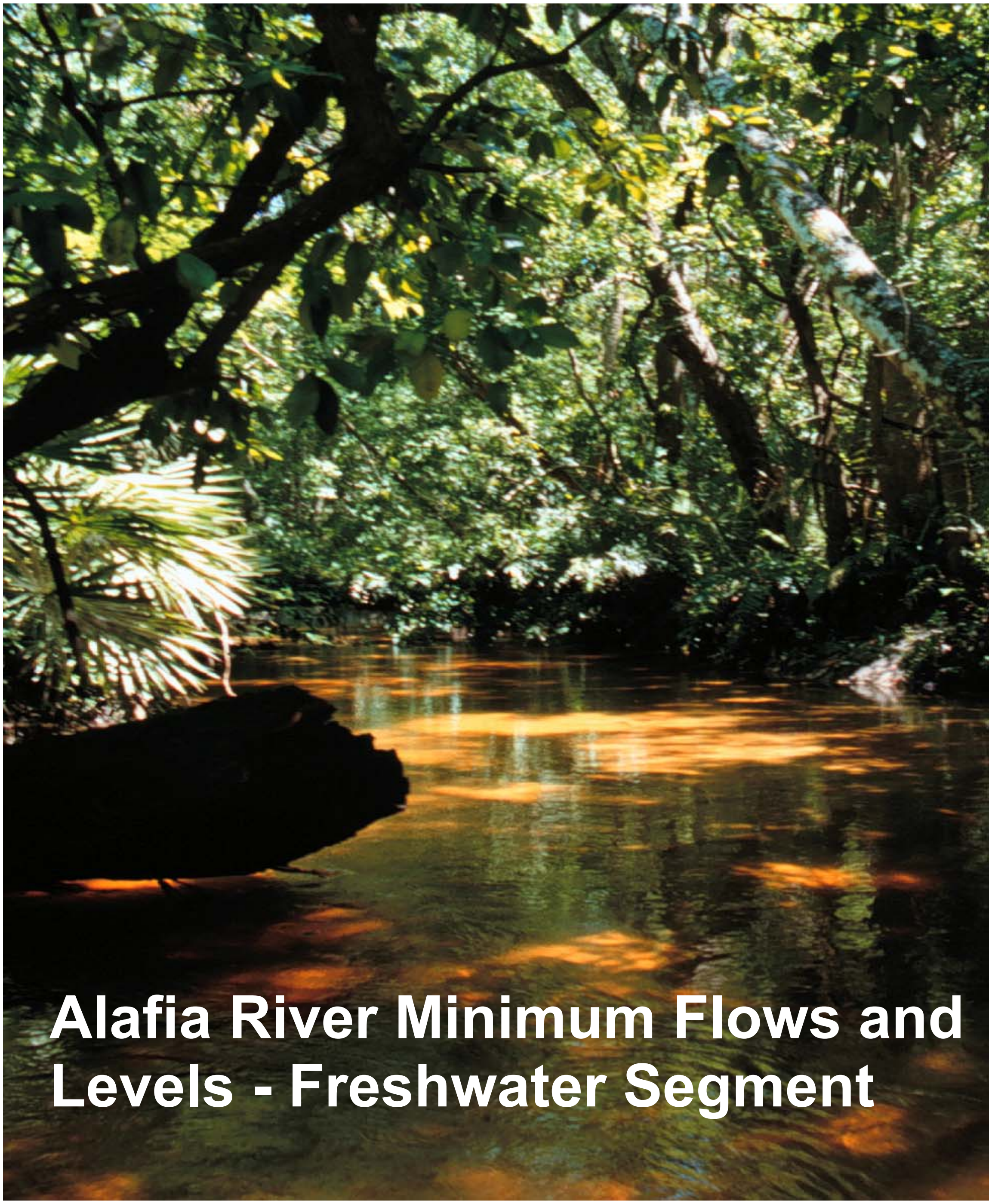

Alafia River Minimum Flows and Levels - Freshwater Segment

Southwest Florida Water Management District

Alafia River Minimum Flows and Levels; Freshwater Segment

November 2005

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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 being proposed for the freshwater segment of the Alafia River and for two springs (Lithia and Buckhorn) that discharge to the river.

Fundamental to the approach used for development of minimum flows and levels is the realization that a flow regime is necessary to protect the ecology of the river system. The initial step in this process requires an understanding of historic and current flow conditions to assess 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 evaluation of flows in the Alafia River. It has also been demonstrated that flow declines in the Alafia River, which have been ascribed to human causes by some investigators, are largely a function of climatic variation.

For development of MFLs for the Alafia River, the District identified seasonal blocks corresponding to periods of low, medium and high flows. Short-term minimum flow compliance standards for the Lithia Springs gage site were developed for each of these 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 Lithia gage site, the low flow threshold was determined to be 59 cubic feet per second (cfs). 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 factor was the fry of largemouth bass for the Lithia gage. Simulated reductions in historic flows greater than 10% resulted in more than a 15% loss of available habitat at sites upstream from the Lithia gage site. Using this limiting factor, the prescribed flow reduction for the Lithia site during the low flow period was defined as a 10% reduction in flow, with the exception that withdrawals should not be allowed to reduce the flow to less than 59 cfs at the Lithia gage site.

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 (374 cfs), resulted in a decrease of 15% or more in the number of days that flows would inundate floodplain features at the Lithia 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 59 cfs at the Lithia gage site.

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 woody habitat would define the percent flow reduction. It was determined that a flow of 255 cfs at the USGS Lithia gage is required for inundation to the mean elevation of exposed root habitat. Using these limiting factors, the prescribed flow reduction during the medium flow period was defined as a 15% reduction in flow at the Lithia gage site, with the exception that withdrawals would not be allowed to reduce flow at the Lithia site below 59 cfs.

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 Alafia River gage site at the Lithia gage. 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 threshold. 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 site at Lithia comprises the District's proposed minimum flows and levels for the Alafia 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, as necessary.

A minimum flow recommendation was developed for Buckhorn Spring based on a PHABSIM analysis of Buckhorn Creek. It was determined that Buckhorn Spring flow should not be reduced by more than 15% to ensure no more than a 15% reduction in fish habitat in Buckhorn Creek. Flows from Lithia Spring were evaluated using a recreational standard (for bathing places) and a PHABSIM analysis of the short spring run between the spring and the Alafia River. The recreational standard would allow considerable reductions in flow before being violated; however, the PHABSIM analysis indicates that no more than a 5% reduction in flow is allowable before a 15% loss of fish habitat in the run occurs. The spring run is small and offers no unique fish habitat that does not exist in the main channel of the Alafia River. Because flow from these two springs may be an important component of downstream estuarine flow requirements, we have refrained from recommending minimum flows for Buckhorn Spring and Lithia Springs until the MFL assessment for the estuarine portion of the river is complete.

Acknowledgement

The authors would like to thank Richard Gant, Jason Hood, Michelle Dachsteiner, Mike Lee, Ryan Horstman, Tiffany Dawson, and Jason Fulton of the Southwest Florida Water Management District for their assistance in data collection. We also thank Lisa Henningsen and Frank Sargent for assistance with land-use maps and data and Michelle Dachsteiner for assistance with data entry, data analysis and the compilation of the Appendix. Doreen Chan contributed to the hydrogeology section. Dr. James Gore of the University of South Florida performed all PHABSIM modeling and consulted frequently on the application of PHABSIM analysis. We also thank the property owners and land managers who facilitated our access to the river, including, Antoinette Tedesco, Parker Keen of Mosaic Corporation, John Schleman and Vicki Rechard of River Hills Golf LLC, Mark Orendorf of Cedarkirk Camp and Conference Center Presbytery of Tampa Bay, and the Staff of Alderman Ford Park and Lithia Springs County Park.

Chapter 1 Minimum Flows and Levels

1.1 Overview

The Southwest Florida Water Management District (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 fisheries biologists. Advances in methodologies 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), any minimum flows methodology should involve more than a consideration of immediate fish needs or the absolute minimum needed to sustain a particular species or population of animals, but 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 seasons 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 flow 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 Ecologic 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 will be necessary to demonstrate with site-specific information the effects that implementation and compliance with the proposed MFLs will have. 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; this also implies that some deviation from the purely natural or existing long-term hydrologic regime must 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, it may be necessary to develop a recovery 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 followed 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 (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 State 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 (Kelly 2004; Shaw et al. 2004). The approach, which led to identification of separate benchmark periods for flow records collected prior to and after 1970, has been utilized for analyses of flows in the Alafia 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 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 Alafia River, the District has applied approaches associated with development of medium to high flow criteria per recommendations 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) system, 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 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". A building block approach to the development of regulatory flow requirements 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 Alafia 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 Alafia River (Figure 1-1). 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 (June 25 to October 27). 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.

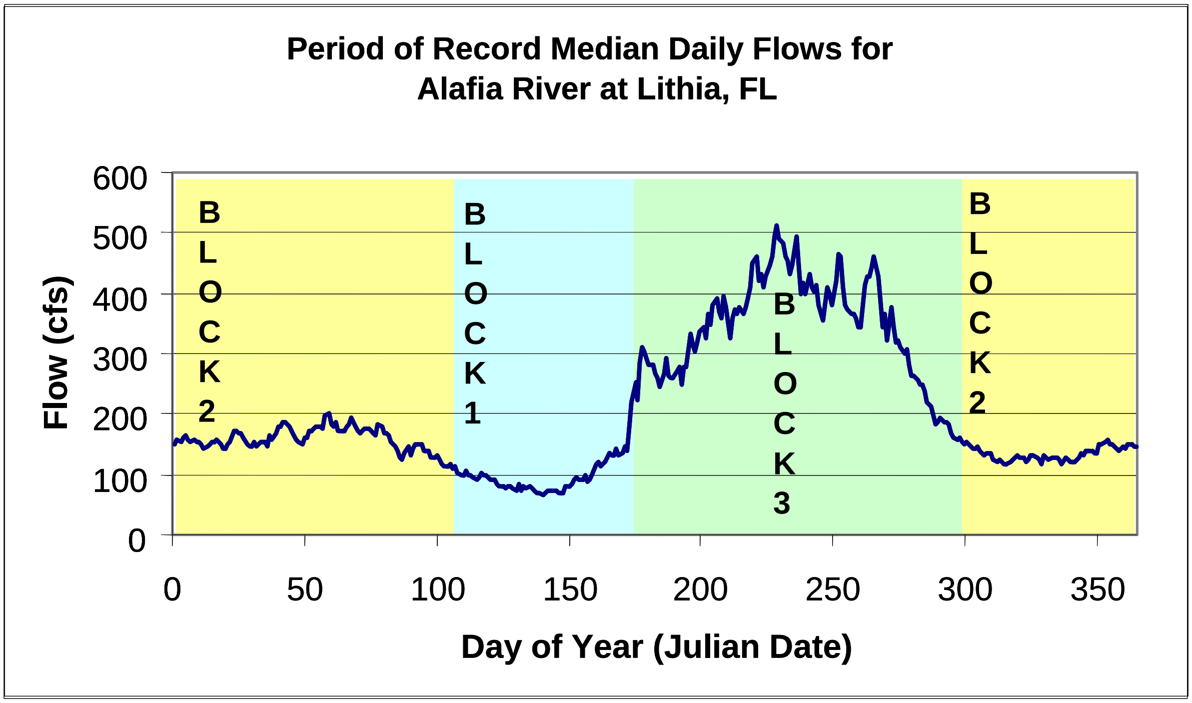


Figure 1-1. Building blocks developed for a building block approach to the development of minimum flows. Blocks corresponding to low (Block 1), medium (Block 2) and high (Block 3) flows are shown along with period of record median daily flows for the Alafia River at Lithia gage.

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 (lotic) 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 high flows will transport sand from upstream to downstream; higher flows will move gravel; and still higher flows 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 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, and depending on the size of the stream (cross sectional area), similar volumes of water can be moved with quite large differences in the rate of flow (velocity). The volume of water moved through a stream can be particularly important to an estuary. It is the volume of freshwater that mixes with salt water that determines what the salinity in a fixed area of an estuary will be. This is especially important for organisms that require a certain range of salinity. The 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 flows 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; 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 the 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 freshwater segment of the Alafia River. In Chapter 2, we provide a description of the 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 naturally occurring 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 Alafia 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 Alafia River.

Chapter 2 Basin Description with Emphasis on Land Use, Hydrology and Water Quality

This chapter includes a brief description of the Alafia 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 freshwater segment of the Alafia River. Land use changes within the basin are discussed to set the stage for a hydrology discussion that follows and to address questions that have been raised regarding the potential impact of land use changes on river flow volumes (see SDI 2003). 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 through time.

With respect to hydrology and trends in flow, a number of important observations and conclusions are made that affect how MFLs are developed not only for the Alafia River but for flowing systems in general. Concern over apparent declining flow trends is an issue not only for the Alafia River, but for essentially all rivers in the SWFWMD for which MFLs will be developed. Before discussing trends in Alafia River flow, some discussion is devoted to river flow patterns and trends throughout the SWFWMD and Florida. This is important, since it is concluded that there is a significant climatic factor that must be considered when developing MFLs. It is argued that some flow trends that should be expected as a result of a natural climate oscillation have been interpreted as primarily anthropogenic (refer to Kelly 2004). In addition, it is demonstrated that there are at least two potential benchmark periods that should be considered when developing MFLs, and that selection of the proper benchmark period is a critical part of the process. A "Building Block" approach to establishing MFLs (as suggested in the peer review of the upper Peace River MFL – Gore et al. 2002) is developed based on the inherent seasonal hydrologic pattern of rivers in the SWFWMD. Further it is argued that the "percent of flow" approach to permitting surface water withdrawals has many desirable attributes. Biological connections with hydrology are addressed in Chapters 4 and 5, and result in MFL recommendations specific to the freshwater segment of the Alafia River.

2.1 Watershed Description

2.1.1 Geographic Location

The Alafia River watershed extends over parts of two counties (Figure 2-1) including much of the eastern and southern portions of Hillsborough County, and a smaller portion of west-central Polk County. It is bounded on the north by the Hillsborough

River watershed, to the east by the Peace River watershed and to the south by the Little Manatee River watershed. The river originates from several creeks that form its two major tributaries, the North and South Prongs. The South Prong drains from Hookers Prairie, while the North Prong rises in a swampy area just to the north of Hookers Prairie (Dames and Moore 1975). The Alafia River proper is formed by the confluence of these two Prongs and flows generally westward into lower Hillsborough Bay. Based on current land use maps, the estimated watershed area is roughly 270,000 acres or 422 square miles. Urbanized areas include parts of Lakeland, Plant City, Mulberry, and the community of Brandon as well as large expanses of rural and undeveloped farm and mined lands.

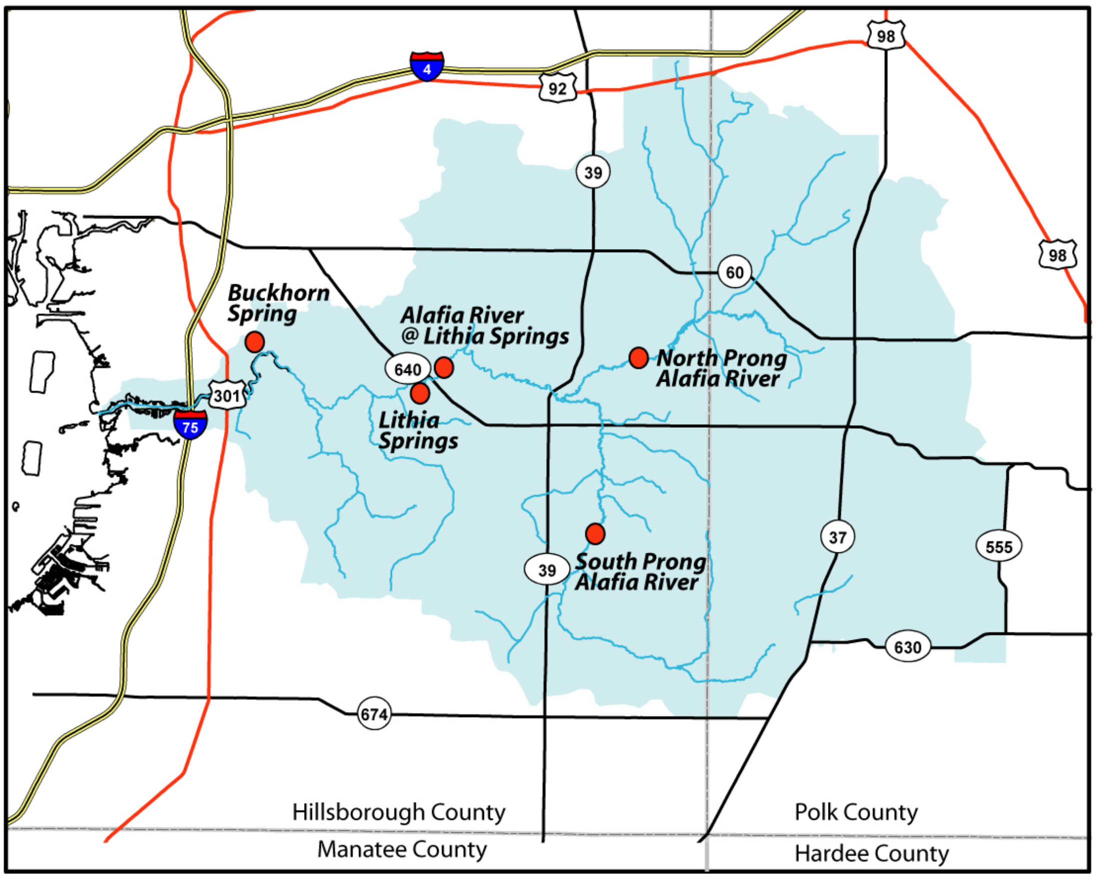


Figure 2-1. Map of Alafia River watershed showing USGS gage site locations and locations of Lithia and Buckhorn Springs.

2.1.2 Climate

The climate of west-central Florida is described as humid subtropical. The mean annual temperature for Hillsborough County is 72.2º F, ranging from normal maximums of 91º F in July and August to a typical low of 49º F in January. The average annual rainfall based on a number of rainfall stations in the area is approximately 52 to 53 inches. The Plant City gage is typical for the area and has a record that extends back to 1901 (Figure 2-2). Annual rainfall totals of less than forty inches were recorded for four years during the period of record while the highest rainfall totals occurred during the back-to-back years of 1959 and 1960 (88.7 and 78.2 inches, respectively). Approximately 60% of annual precipitation falls during the months of June, July, August and September.

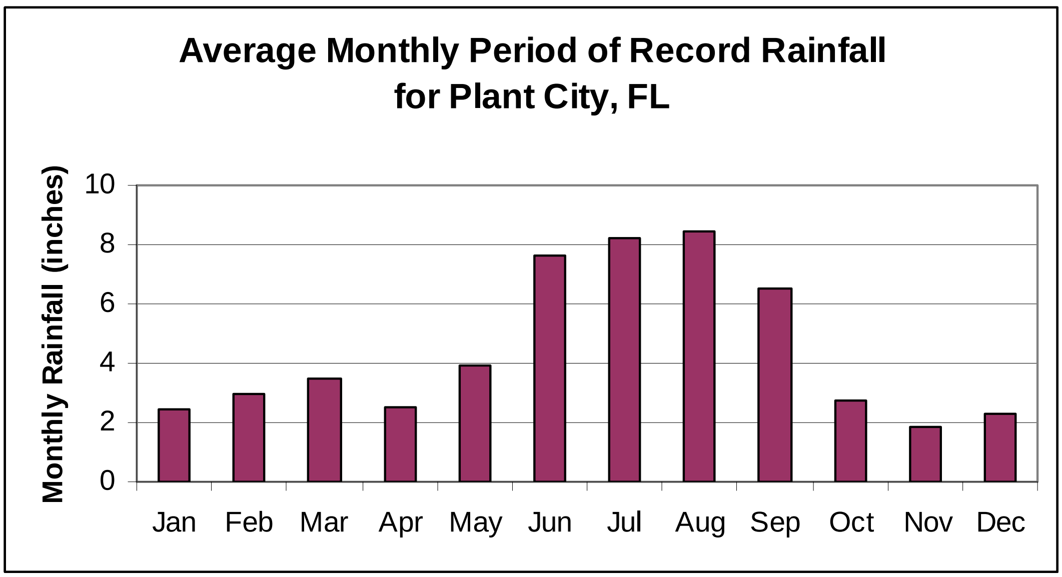


Figure 2-2. Average total monthly rainfall at Plant City, FL gage for period of record 1901 to 2000.

2.1.3 Physiography (excerpted from SWFWMD 2001)

The Alafia River watershed lies within two physiographic provinces; the Gulf Coastal Lowlands, and the Polk Upland (White 1970). The lower portion of the watershed flows over the Gulf Coastal Lowlands province, a relatively flat plain extending eastward with a gentle slope upward to the border with the Polk Upland physiographic province. The northern edge of the watershed drainage basin borders an adjacent area locally known as the Brandon Karst Terrain (BKT), an internally drained basin (SWFWMD 1993). The western edge of the Polk Upland is defined by the presence of the first of several paleo-shoreline scarps associated with the Pleistocene Ice-Age sea level fluctuations. This physiographic feature is known as the Pamlico Scarp or shoreline. Elevations in this part of the Gulf Coast lowlands province range from sea level to 25 feet.

The rest of the Alafia River watershed is situated in the Polk Upland Province. Elevations in the extensive Polk Upland range between 100 and 130 feet; however, in this area of the province the elevations are mostly between 25 and 75 feet within the watershed. Eastward of the Pamlico Scarp the river's banks attain a narrower, steeper profile and some spots are very bluff-like with 20-25 feet of relief from the river's water level. In the vicinity of Riverview and Bell Shoals, the physiography adjacent and south of the river is composed of low sand hills, which in some cases attain 75-80 feet elevation. The Talbot and Penholoway paleo-shorelines pass through this area in a north-south orientation, with their surface features having elevations of 42 and 75 feet, respectively. Moving eastward, further into the Polk Upland province, in the vicinity of the town of Lithia, the river travels over the clay-rich Bone Valley Formation (Pliocene). This is the lithologic unit which is extensively mined for phosphate minerals further into the eastern part of the Alafia River watershed. The river's banks in this region become less steep with many low-relief floodplain or wetland areas surrounding the river. The remainder of the Alafia River watershed and its tributaries drain an area of the Polk Upland where the Pleistocene marine sands (overburden), and the underlying materials of the ore-bearing Bone Valley Formation and Hawthorn Group rocks have been disturbed for phosphate strip-mining in many areas. Much of this area has had its physiography and associated surface water drainage systems modified by this mining activity. This process generally strips the overburden sediments out of the way, mines the ore layer, and then redistributes the overburden sediments through land reclamation or other processes. Outstanding physiographic features in this region include many water-filled, former mine pits and large, bermed clay-settling areas of various rectilinear configurations easily observable on maps and aerials photos. Most all the areas identified as "Open Water" natural systems in the entire eastern half of the basin south of State Road 60 are of phosphate mining origin.

Primary soil groups in the Alafia River watershed include the Myakka-Basinger-Holopaw association, which predominates in the upland areas in the northern and southern portions of the watershed. The Candler-Lake association occurs in the vicinity of the Brandon-Bloomingdale area, while the Winder-Chobee-St. Johns occurs along the main stem of the river including the main tributaries. A significant area of Arents-Haplaquents-Quartzipsamments soils occupies an area surrounding Durant, in the Turkey Creek drainage basin. Soil classification indicates these are considered as manmade soil areas. This area extends from southern Dover through the Medard Park/Reservoir and Lithia area, and to some minor areas on the east side of State Road 39. This coincides with areas of former phosphate mining activities. In the Polk County area of the Alafia River watershed, this disturbed soil type dominates the entire area except for small remnants of flatwoods (Myakka association) near the watershed divide with river systems to the north and east.

2.1.4 Hydrogeology

In general, the geology of the Alafia River/Lithia Springs area consists of a thin layer of late Tertiary and Quaternary clastic sediments, overlying a thick sequence of Tertiary Period carbonate rocks. There are three recognized aquifer systems present in the area. In descending order (from youngest to oldest) they are the unconfined surficial aquifer system (SAS), the confined intermediate aquifer system (IAS) and the confined Floridan aquifer system. The Floridan aquifer is further sub-divided into the Upper (UFA) and Lower (LFA) Floridan by a middle confining unit comprised of low-permeability evaporites. A conceptual hydrogeologic cross section through the major geologic features of the area is presented in Figure 2-3 (modified from SDI 2002)

In areas south of the river, the potential for sinkhole development is diminished by the presence of thick clay layers of the intermediate aquifer system that impede surface water from moving downward into the limestone layers. In areas north of the river, these clay units become thinner and discontinuous, allowing surface water to move vertically. This in turn has resulted in large-scale dissolution of the underlying limestone.

Potentiometric maps of the UFA and hydrochemical analyses indicate that groundwater recharge to the Alafia River and its springs are derived primarily from the local surficial aquifer and from nearby recharge in the Brandon Karst Terrain (BKT) located north of the river. Water from the southern portion of the BKT is the dominant source of water for both Lithia and Buckhorn Springs while the surficial aquifer is the main water source for Green and Boyette Springs (Jones & Upchurch 1993). Fracture trace analyses also indicate the potential presence of direct conduit pathways from the BKT to the springs (Doreen Chan, SWFWMD, personal communication).

2.1.4.1 Surficial Aquifer

The surficial aquifer system (SAS), or water table, is the uppermost unconfined aquifer, composed primarily of unconsolidated sediments deposited during the Holocene and Pleistocene Epochs. Based on available geologic well log descriptions for the area, the surficial aquifer consists mainly of fine- to medium-grained quartz sands grading to clayey sand with depth. The thickness of the aquifer varies from being absent in areas to approximately 50 feet. Aquifer thickness in the study area averages 20 to 25 feet.

Water in the surficial aquifer is recharged primarily by rainfall. Depth to water can range from zero to up to fifty feet below land surface. Fluctuations in water level occur seasonally with higher water levels occurring during the summer rainy months and lowered water levels during the late spring dry season.

2.1.4.2 Intermediate Aquifer System

The intermediate aquifer system (IAS) is generally comprised of siliciclastic sediments, limestone and dolomite beds, collectively known as the Hawthorn Group, that were deposited during the Miocene and Pliocene Epochs. The Hawthorn Group is further subdivided into the Peace River (siliciclastic deposits) and Arcadia Formations (carbonate deposits). Within the District, the thickness of IAS sediments ranges from completely absent in the north to greater than 700 feet in the south. These stratigraphic units generally thicken and dip from north to south.

The IAS consists of three principal components: the upper intermediate confining unit (ICU), an aquifer or water-bearing formation (IA), and the lower intermediate confining unit. In the southern portions of the District, all three units of the IAS are typically present, limiting flow between the overlying surficial aquifer and the underlying Upper Floridan aquifer. However, in areas north of the Alafia River, the IAS begins to thin out, and transitions from an aquifer system (with confining units) to simply a confining unit (the ICU). These areas become more susceptible to sinkhole development as the clay units thin and allow for organic-rich surface water to leak through and dissolve underlying carbonates. The approximate northern limit of the IAS extends in a line from southwest Hillsborough County to north central Polk County, although a thin discontinuous intermediate aquifer may exist locally north of this line (SWFWMD 1993). In areas north of the Alafia River and west of Lithia Springs, the thick confining units have also been compromised by intense karst activity. This area, known also as the Brandon Karst Terrain (BKT) (Upchurch & Littlefield 1988; Jones & Upchurch 1993), provides a direct connection for groundwater flow between the surficial aquifer and the underlying Upper Floridan aquifer (see Figure 2-3).

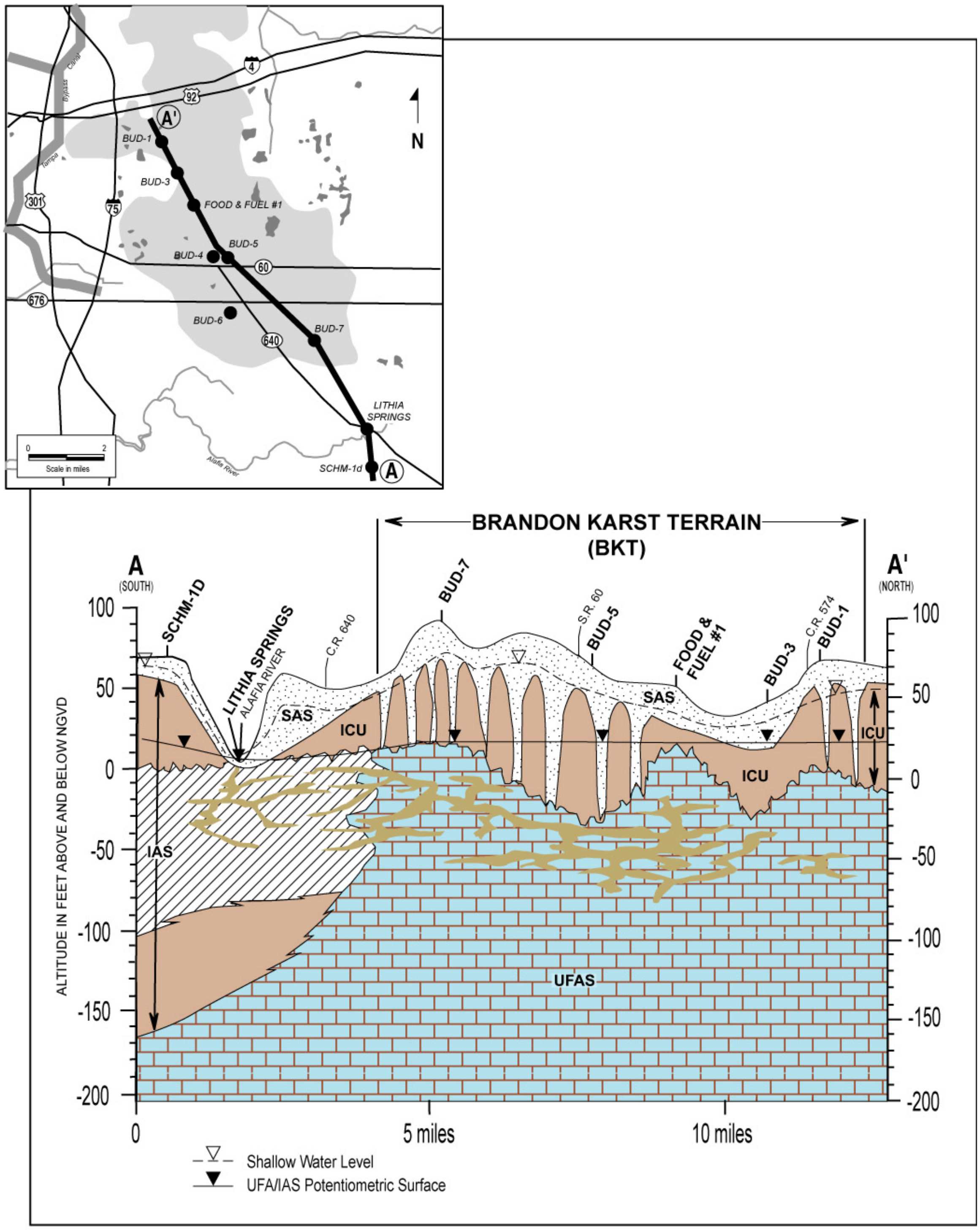


Figure 2-3. Conceptual hydrogeologic cross-section of the Alafia River/Lithia Springs Area. (modified from SDI (2002))

2.1.4.3 Upper Floridan Aquifer System

The Upper Floridan aquifer (UFA) system consists of a thick series of limestone and dolomite units that were deposited during the Eocene, Oligocene and early Miocene Epochs starting 53 million years ago. The UFA includes the Suwannee Limestone, Ocala Limestone, Avon Park Formation and permeable sections of the lower Tampa Member of the Hawthorn Group that are in direct hydraulic connection with the underlying carbonates. Average thickness of the UFA in the area ranges from 1000 to 1200 ft (Miller 1982). The base of the UFA is marked by a regionally extensive unit of low-permeability evaporites, generally referred to as the Middle Confining Unit (MCU) (Ryder 1985). Lithologic logs for the area show that the top of the UFA generally dips southeastward and depth to the top of the UFA (limestone) can range from 30 to 180 feet below land surface (bls).

Within the UFA, there are two principal water-producing zones. These flow zones are typically associated with the Tampa Member and Suwannee Limestone (the upper flow zone), and highly permeable zones within the Avon Park Formation (the lower flow zone). These water-bearing zones are separated by relatively lower permeable portions of the Ocala Limestone. Although the Ocala Limestone is often regarded as a semi-confining unit, there is usually sufficient hydraulic connection across the Ocala such that the Upper Floridan aquifer essentially acts as a single hydrologic unit.

2.1.4.4 Brandon Karst Terrain

The Brandon Karst Terrain (BKT) is an area of approximately 40 square miles, located to the north of the Alafia River and west of Lithia Springs (Figure 2-3). The limestone in this area has been heavily weathered by chemical dissolution and the area is dominated by karst topography including a high density of ancient and modern sinkholes, internal drainage, springs, and significantly increased transmissivities in the limestone.

The BKT was formed in an area where the IAS pinches out and the confining units of the Hawthorn begin to thin. This has allowed large quantities of highly aggressive (acidic) surface waters to leak through and dissolve the underlying limestone to form sinkholes. These sinkholes further facilitated the downward movement of surface-water and dissolution of the underlying limestones to create a well-developed underground drainage system capable of moving large quantities of groundwater through a network of conduits and voids (Jones and Upchurch 1993).

The enhanced underground flow conditions of the BKT is reflected in the reduced gradient or 'flattening' of the potentiometric surface observed in the UFA overlying the BKT. As a result, regional groundwater flow in the southern portion of the terrain is diverted to the south and southeast, towards the springs and the Alafia River. Fracture trace analysis in the BKT area also indicates the presence of at least two major fracture traces that potentially provide for significant groundwater movement directly from the BKT to springs located along the Alafia (Jones and Upchurch 1993). Transmissivity measurements also show considerable variability, which may indicate the presence of large solution features. Average transmissivity values obtained from three aquifer performance test conducted in the BKT area by Terra Environmental (1998) ranged from 20,000 ft^2/day to 1,000,000 ft^2/day.

2.1.4.5 Groundwater Flow and Levels

Observed water levels and United States Geological Survey (USGS) potentiometric surface estimates for the UFA in May and September 2001 are shown for the Alafia River region in Figure 2-4. Observed water levels for the SAS (May 2001) with associated depth-to-water table values are presented in Figure 2-5.

Due to the relatively thin and discontinuous nature of the sediments, groundwater flow in the surficial aquifer is more local in nature rather than regional. Flow direction is variable and is controlled primarily by the surface topography. Water levels from nearby wells and Alafia River stage indicate that the water table gradient slopes toward the river during both the dry and wet periods of the year (May and September), providing baseflow to the river all-year round. Conversely, water levels between the UFA and river stage suggest a seasonal pattern of flow, with potential recharge to the UFA (from the river) during the drier months and potential discharge from UFA (to the river) during the summer months.

Groundwater flow in the IAS and UFA is controlled by the elevation of the potentiometric surface, with water moving from areas of higher elevation (potentiometric "highs") to lower elevation. Where the aquifer intercepts the Gulf of Mexico and Tampa Bay, groundwater is discharged offshore. The regional hydraulic gradient and direction of flow for groundwater is typically westward towards the coast and Tampa Bay. In the study area, groundwater flow is also influenced by the Alafia River and karst features of the BKT. As a result, much of the groundwater flowing through the central and southern portion of the BKT is consistently diverted to the south and southeast, towards the springs and the Alafia River (Figure 2-4). Groundwater contributions from the UFA in areas south of the river appears to be seasonal. Water level contours from the May 2001 potentiometric surface (Figure 2-4) show that during the drier months, groundwater flows south and southwest. As a result, there is no apparent potential for UFA contribution to the river from the south. However, during the summer months water levels increase significantly, such that the groundwater flows in a west to northwest direction south of the river as seen in the September 2001 potentiometric surface.

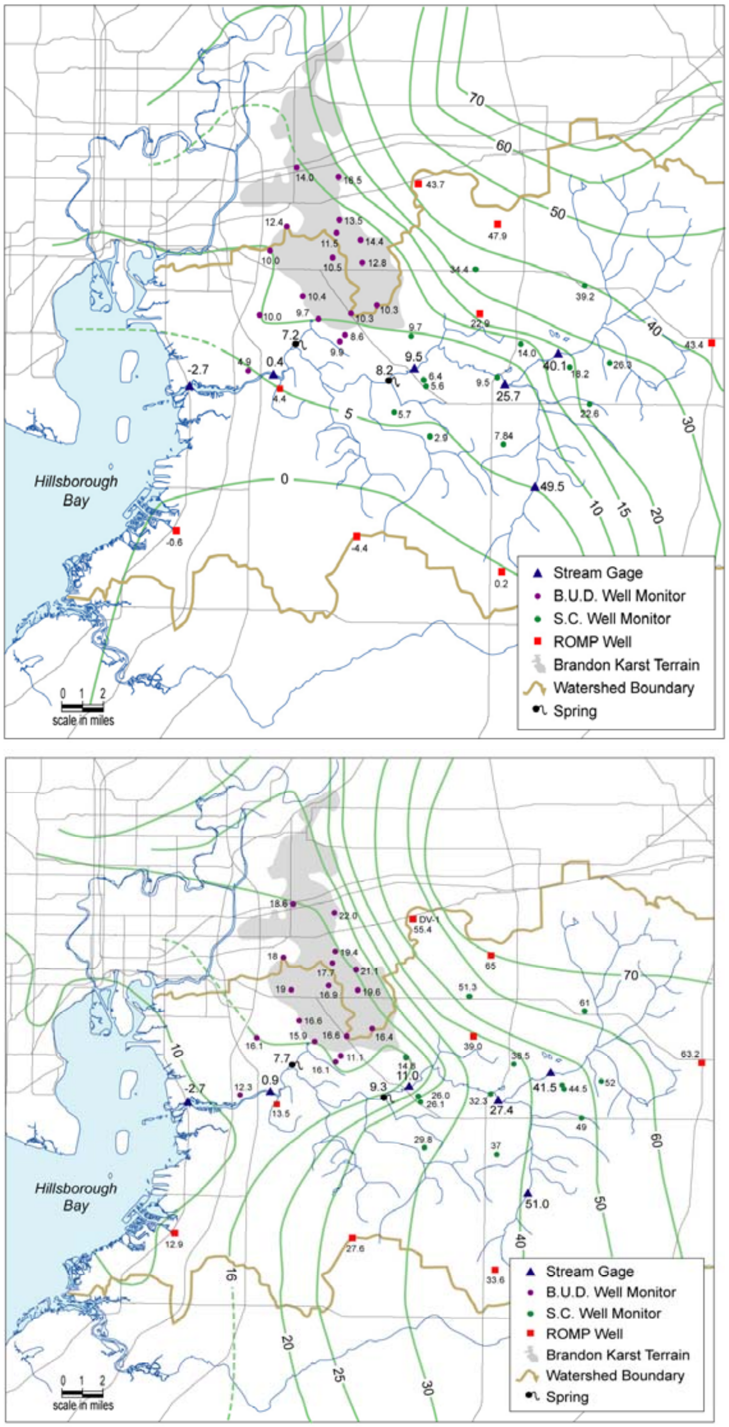


Figure 2-4. May and September 2001 observed water levels and USGS potentiometric surface estimates (feet NGVD) in the Upper Floridan aquifer in the vicinity of the Alafia River.

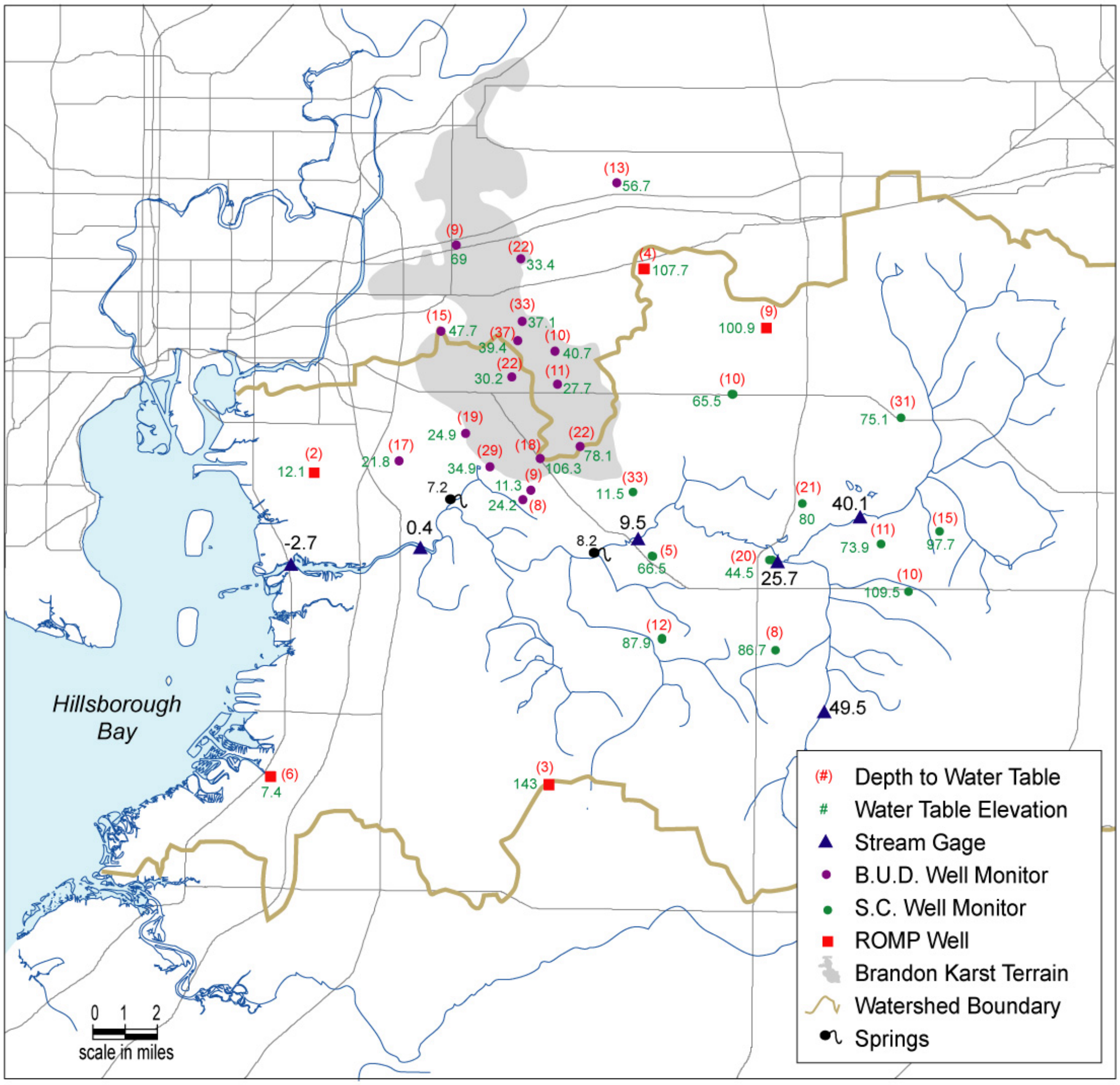


Figure 2-5. May 2001 observed water levels (feet NGVD) and depth to water table (in feet below land surface) in the surficial aquifer in the vicinity of the Alafia River.

Vertical flows (recharge or discharge) to the IAS and UFA are dependent upon the thickness and integrity of the overlying confining units, the permeability of the confining unit sediments, and the water level or head difference between aquifers. When water levels in the surficial aquifer are higher than levels in the underlying aquifer, water moves downward to recharge the UFA/IAS. Conversely, when water levels in the surficial aquifer are lower, water moves upward, or is discharged from the UFA or IAS to the surficial aquifer.

Hydraulic head differences between the UFA and surficial aquifer are highly variable, especially in the BKT, ranging from 2 feet to 90 feet in areas north of the river (Figure 2-6). This variability illustrates the highly karst nature of the BKT with low head differences indicating breaches in the clay confining unit between aquifers. South of the Alafia, head differences are generally larger, ranging from 23 feet to 128 feet, and indicating a greater degree of confinement between the aquifers.

For the most part, water levels in the SAS are consistently higher than levels in the IAS and UFA, indicating a downward flow gradient. Along the coast, this downward gradient is typically reversed with water from the UFA being discharged upward into the overlying aquifers. However, for much of southern coastal Hillsborough County, water levels in the UFA have declined due to groundwater withdrawals. This has resulted in a seasonal reversal of the vertical gradient between the aquifers. During the drier periods of the year (typically the spring months) water levels decrease with depth along the coast and water moves downward from the surficial aquifer. During the remainder of the year, water levels in the UFA are higher and the vertical movement of water resumes in an upward direction.

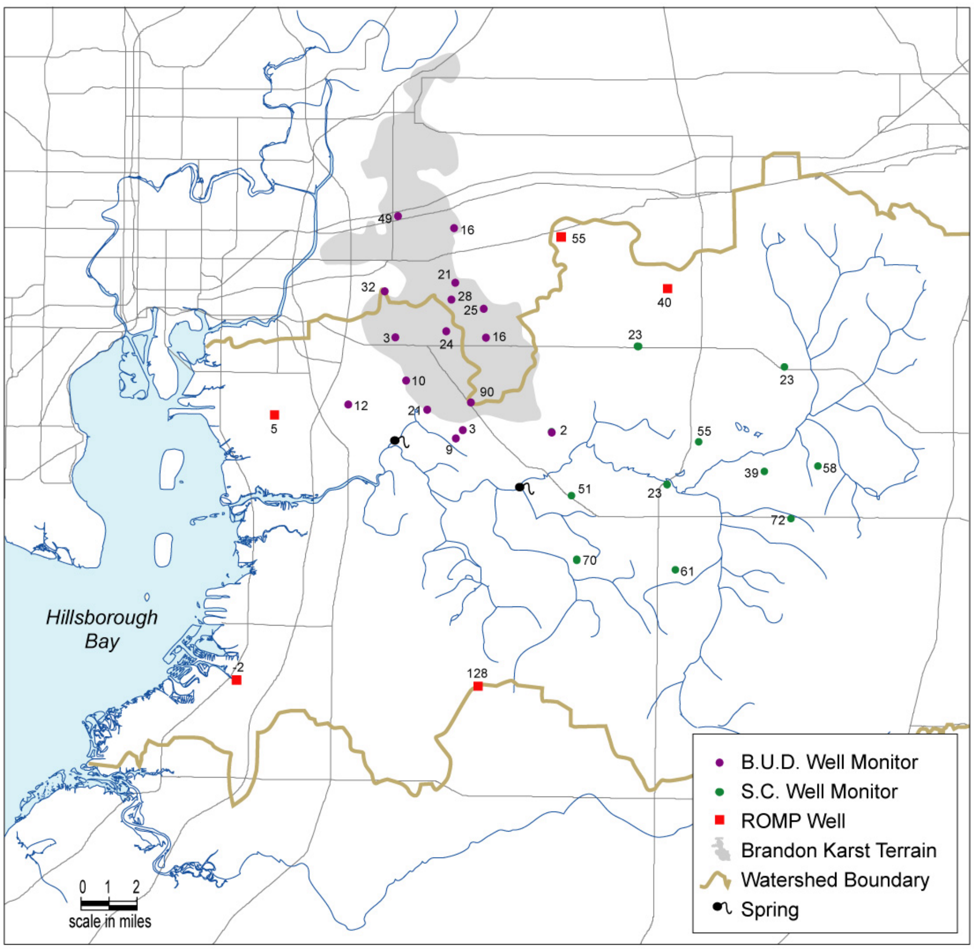


Figure 2-6. Average observed head difference between the surficial aquifer and the Upper Floridan aquifer water levels (feet) in the vicinity of the Alafia River, based on period-of-record data.

2.1.4.6 Springflow and Groundwater Relationship

Previous studies investigating the relationship between groundwater levels and flow from Lithia or Buckhorn Springs include Geraghty & Miller (1984), Jones and Upchurch (1983), Basso (1998), and SDI (1988, 1992, 2002). Results from regression analyses by Geraghty & Miller (1984) included a moderate correlation between springflow at Lithia Springs and water levels from a UFA well located approximately 1.5 miles west of the spring. A strong correlation was also observed between springflow and water levels in a surficial aquifer well located approximately 1.25 miles south of the spring. Regression analysis performed by Basso (1998) using spring flow at Buckhorn and Lithia Springs and water level data from wells (4 SAS, 5 IAS and 12 UFA) located adjacent to and up to five miles from the springs were generally inconclusive. Poor to moderate correlations between springflow and water levels were observed. Coefficient of determination (r^2) values ranged from 0.1 to 0.7 with the furthest monitor well (located approximately 5 miles from Lithia Springs) showing the highest correlation with springflow). Higher r^2 values were obtained using Lithia Springs than Buckhorn Springs. Using hydrochemical and isotope analyses, Jones and Upchurch (1993) determined that springflow from the Lithia and Buckhorn complexes were derived primarily from UFA groundwater recharged from the BKT. Fracture trace analyses indicated the presence of karst conduits that could provide significant pathways for groundwater to move from the BKT to the springs. For the smaller Boyette and Green Springs, the major source of water is derived primarily from the local surficial aquifer.

To further examine relationships between groundwater levels in the BKT area and springflow, we evaluated available data, including water level data from wells constructed and monitored since 2000 for the Brandon Urban Dispersed Wellfield permit. Coefficients of determination (r^2), indicating the strength of linear relationship between springflow and water levels are presented on Figures 2-7 and 2-8 for Lithia and Buckhorn Springs, respectively. For almost all of the UFA wells located within the BKT, a strong correlation ($r^2 > 0.8$) was noted between water level and springflow. Coefficient of determination values were generally higher for well water levels and flow at Lithia springs (greater than 0.9) than at Buckhorn Springs (mostly between 0.7 and 0.9). Strong correlations were observed from wells located just south and southwest of the BKT. Well water levels elsewhere showed only poor to moderate correlation with springflow. Our results corroborate previous findings by Jones and Upchurch (1993) who noted that springflow at Lithia and Buckhorn Springs is derived from recharge in the BKT. Regressions using SAS water level data showed only weak to moderate correlation with springflow. These results are also consistent with observations made by Basso (1998).

Correlation analyses were also performed to determine the relationship between water level data and river stage data. Simultaneous (simple regression) and lagged data (multiple regression) analyses showed weak ($r^2 < 0.2$) to moderate ($r^2 < 0.8$) correlations between the two variables. Simple linear regressions were also performed to assess the relationship between spring flows, spring water levels and river stage in the area. Correlation analyses between discharge quantities at Lithia and Buckhorn Springs indicate there is very little relationship between springflow at the two sites along the river. Neither simultaneous nor lagged water level data showed any significant correlation with spring flow ($r^2 < 0.2$).

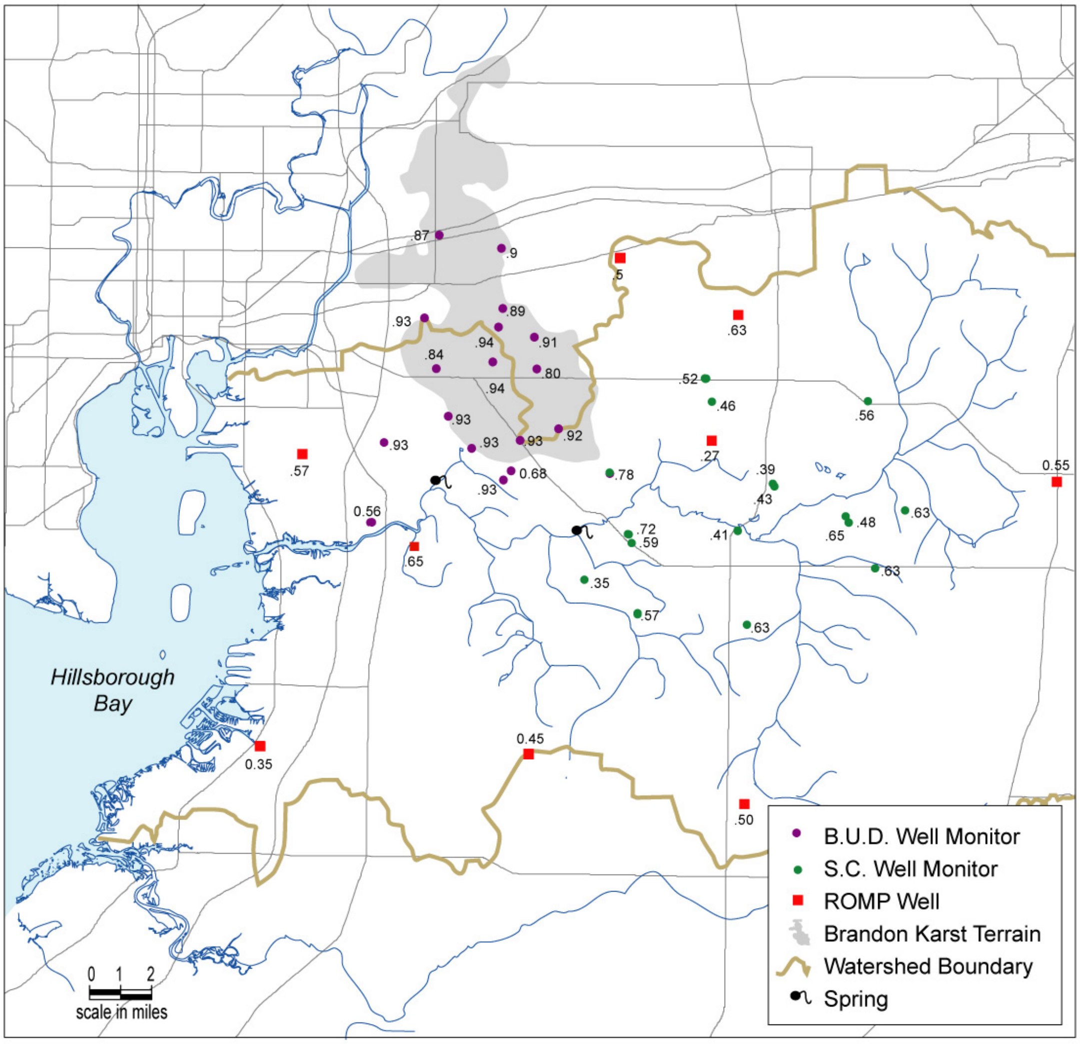


Figure 2-7. Coefficent of determination (r^2) values between nearby well water levels (in feet above NGVD) and discharge at Lithia Springs.

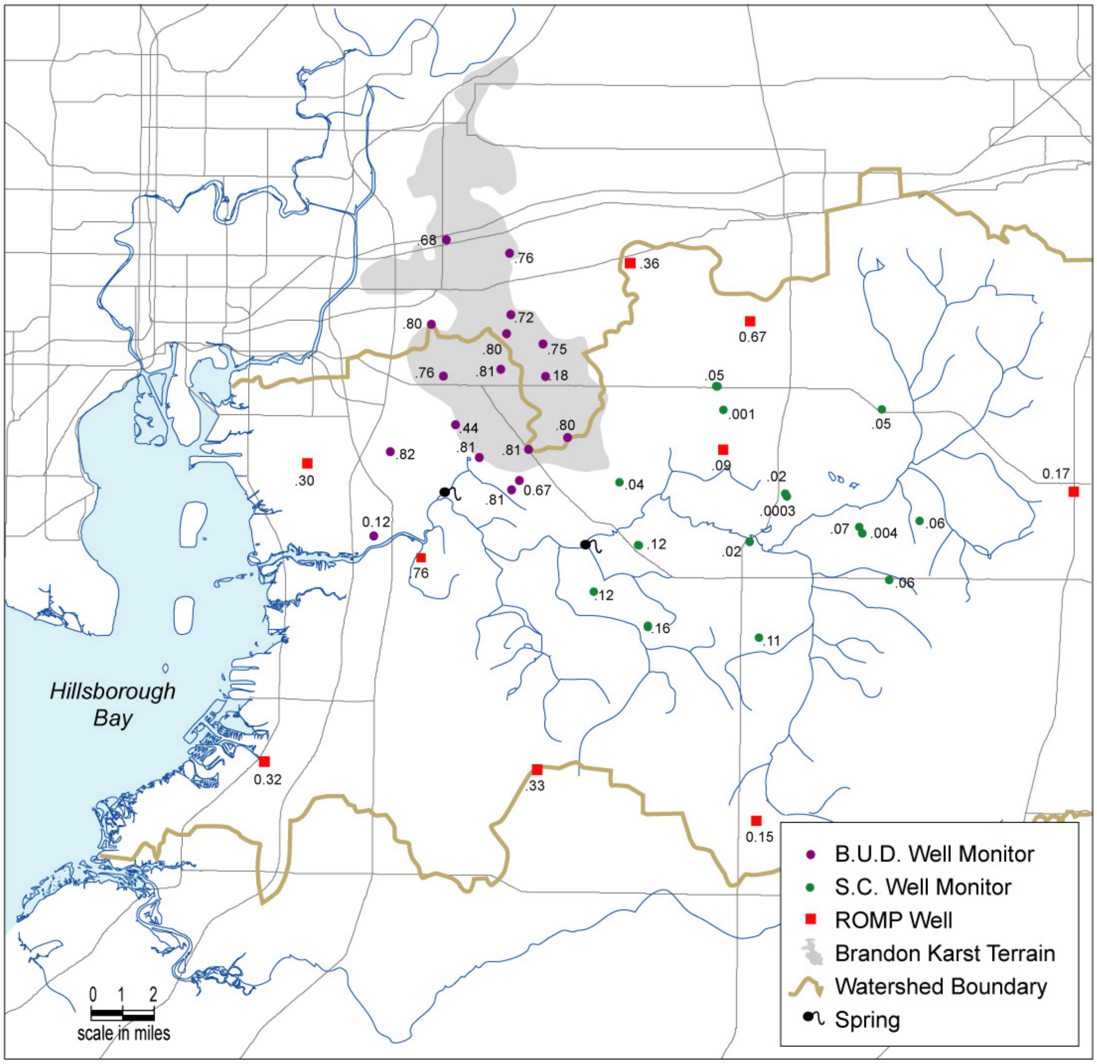


Figure 2-8. Coefficient of determination (r^2) values between nearby well water levels (ft NGVD) and discharge at Buckhorn Springs.

2.2 Land Use Changes in the Alafia River Watershed

A series of maps, tables and figures were generated for the Alafia River watershed for three specific years (1972, 1990 and 1999) for purposes of considering land use changes that have occurred over the last several decades. Not all maps and tables are presented in the text that follows, but all can be found in the appendix. 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 has 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 represent land use and land cover information from the Florida Department of Transportation (FDOT). The FDOT (1999) developed the Florida Land Use, Cover and Forms Classification System (FLUCCS) using the USGS classification system as its basis. Unlike the USGS classification system, the FLUCCS is a hierarchical system with four different levels of classification. Each level contains information of increasing specificity to describe land cover conditions. Minimum mapping units are also smaller. The minimum mapping unit for uplands is 5 acres; for wetlands, the minimum mapping unit is 0.5 acres.

The 1990 and 1999 land use/land cover maps prepared for our analyses appear more detailed than the 1972 maps due to the higher resolution of the latter maps and differences in land use categories. As a result, some of the changes in land use between the USGS and FLUCCS derived maps are likely the result of differences in methodologies rather than actual land use changes. 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. Land use/cover types identified for our analysis included: Urban; Uplands (including rangeland); Wetlands (forested and nonforested); Mines; Water; Citrus; and Other Agriculture.

For purposes of discussion, the Alafia River watershed was divided into several major sub-basins. These sub-basins are: the Alafia Mainbranch, Buckhorn Creek, Bell Creek, Fish Hawk Creek, Lithia Springs, Turkey Creek, North Prong Alafia, and South Prong Alafia. As delineated on land use maps in this report, sub-basins ranged in size from 4,826 acres (Buckhorn Creek; approximately 8 square miles) to 88,303 acres (South Prong Alafia River; approximately 138 square miles). Buckhorn Creek was retained as a separate sub-basin because Buckhorn Springs is the subject of an MFL analysis. As an example of the lumping of sub-basins that was done, the South Prong of the Alafia River is composed of 16 USGS delineated sub-basins most named after a tributary creek (e.g., Gully Branch, Mizelle Creek, etc.). A listing of the smaller sub-basins, which comprise larger sub-basins, is given in Table 2-1**.**

Table 2-1. Major sub-basins within the Alafia River watershed, associated areas and minor USGS sub-basins included in the major sub-basins.

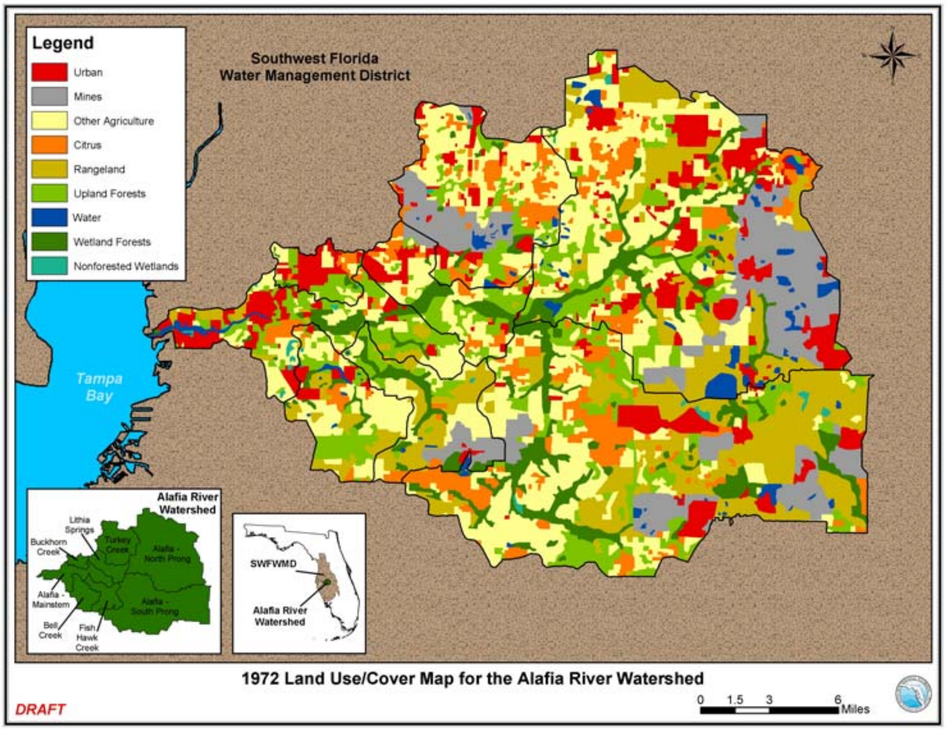
Major Sub-basin	Total Acres	Square Miles	Minor Sub-basins
Alafia Mainbranch	19309	30	ALAFIA MAINBRANCH LITTLE FISHHAWK CREEK RICE CREEK
North Prong Alafia	86202	135	AIRPORT BRANCH BIRD BRANCH ENGLISH CREEK HAMILTON BRANCH HOWELL BRANCH LAKE DRAIN MINED AREA NORTHPRONG ABOVEGAGE AL POLEY CREEK SLOMAN BRANCH THIRTYMILE CREEK
South Prong Alafia	88303	138	SOUTHPRONG ABOVEGAGE AL CHITC BRANCH GULLY BRANCH HALLS BRANCH HOOKERS PRAIRIE HURRAH CREEK LAKE BRANCH LEWIS BRANCH LITHIA_SPRONG_BLOGAGE MCMULLEN BRANCH MINED AREA MIZELLE CREEK OWENS BRANCH SOUTHPRONG ABOVEGAGE AL UNNAMED STREAM WEST BRANCH
Bell Creek	13490	21	BELL CREEK BELL CREEK RESERVOIR BOGGY CREEK PELLEHAM BRANCH
Buckhorn Creek	4826	8	BUCKHORN CREEK
Fish Hawk Creek	14288	22	DOE BRANCH FISHHAWK CREEK FLAT CREEK MINED AREA
Lithia	16281	25	LITHIA_ABOVEGAGE_ALA LITHIA_NPRONG_BLOGAGE MC DONALD BRANCH MCCULLOUGH BRANCH
Turkey Creek	27287	43	MEDARD PARK RUN TURKEY CREEK
TOTALS	269986	422	

Before discussing individual sub-basin land use changes, it is informative to discuss the entire watershed of the Alafia River to get an appreciation of the major land uses/covers and the changes that have occurred during the nearly 30 years for which land use maps are available. Land use / cover maps for 1972 and 1999 for the entire Alafia River watershed are shown in Figure 2-9. Note that for mapping purposes, uplands were divided into two subgroups (rangeland and upland forests) and wetlands were separated into wetland forests and nonforested wetland subgroupings. Subgroupings were not maintained for tabular analyses and plotting of land use changes (Table 2-2, Figure 2-10).

The total area of the Alafia River watershed is 269,986 acres or 422 square miles. From inspection of acreage changes as shown in either Table 2-2 or Figure 2-10, several land use/cover changes are readily apparent. There have been noticeable increases in both urban land area and mined area. As of 1999, almost 18% of the watershed area was urbanized. In 1972, urban land was 11% of the watershed. Even more striking, however, is the increase in mined lands. In 1972, approximately 11% of the watershed had been mined; by 1999 the amount of mined land encompassed approximately 36% of the watershed, equivalent to 105 square miles.

While the area of mined and urbanized lands increased markedly, upland and agricultural land area decreased correspondingly. Total decreases in agricultural land and uplands amounted to approximately 54 and 87 square miles, respectively. Decreases in these two land use categories of 141 square miles were almost offset by the 133 square mile increase in urbanized and mined lands.

Of the eight large sub-basins delineated for this report, only four lie upstream of the Alafia at Lithia gage. These are the North Prong, South Prong, Turkey Creek, and Lithia Springs sub-basins. Based on land use maps prepared for this report the total combined area of these four sub-basins is 218,073 acres or approximately 341 square miles. The USGS reports that the area above the Lithia gage is 335 square miles. Most of the mined land in the Alafia River watershed can be found in these four sub-basins (96%) and most of this is in either the North (32%) or South Prongs (57%).



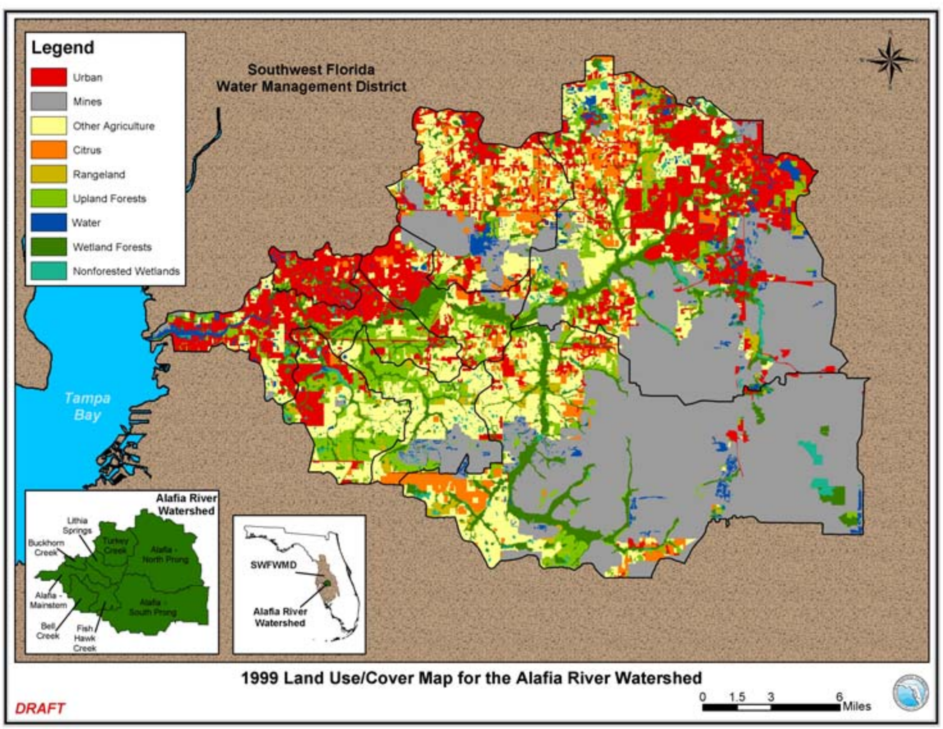


Figure 2-9. 1972 and 1999 Land use/cover maps of the Alafia River watershed, Florida.

Table 2-2. Land use and land cover (by percentage) changes in the Alafia River watershed (269,986 acres) for three time periods, 1972, 1990 and 1999.

Alafia River Watershed	1972	1990	1999
Urban	10.9	13.9	17.6
Citrus	9.1	4.9	4.7
Other Agriculture	26.9	21.8	18.4
Uplands	30.7	12.8	10.1
Wetlands	9.3	12.1	10.7
Mines	10.9	32.8	35.9
Water	2.3	1.8	2.5

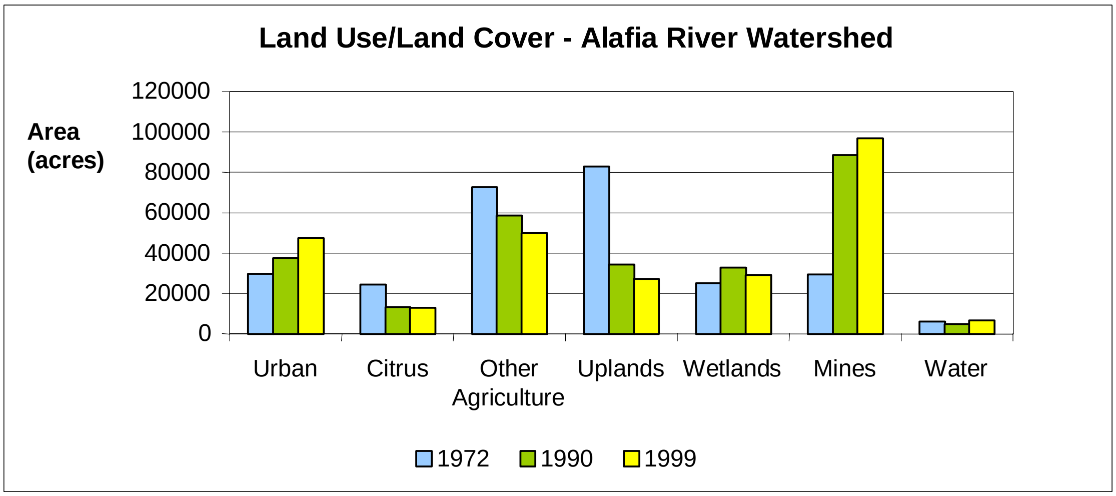
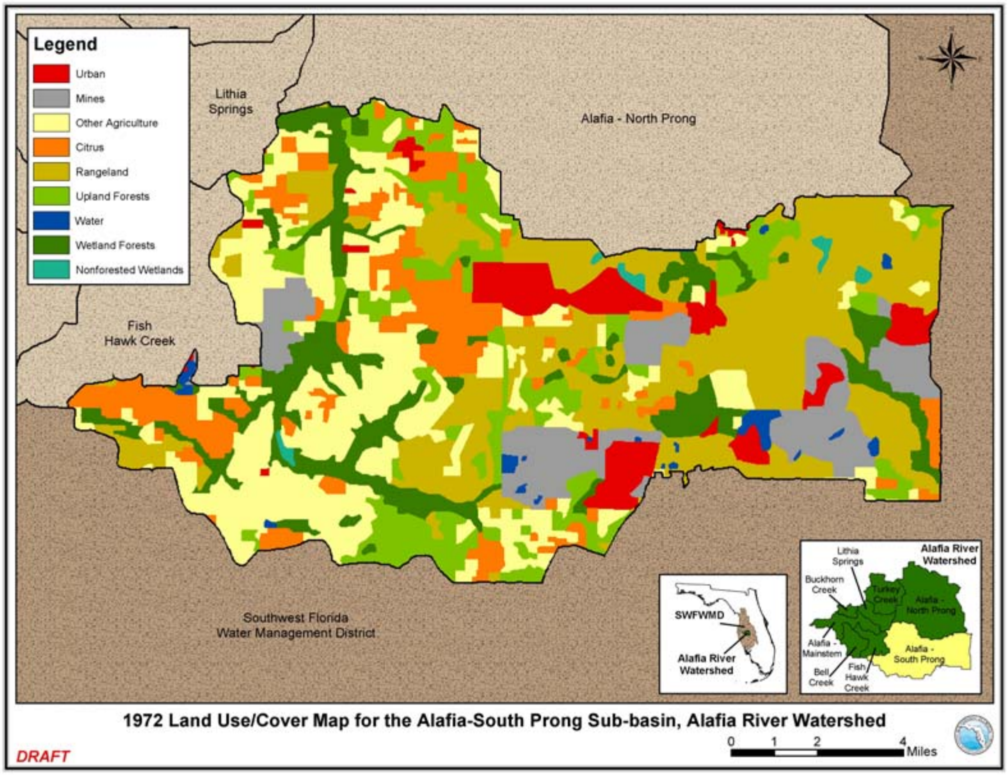


Figure 2-10. Comparison of land use and land cover changes in the Alafia River watershed.

2.2.1 South Prong Sub-Basin

The South Prong sub-basin is the second largest sub-basin delineated for this report. Total area is 88,303 acres (138 square miles). The USGS gage on the South Prong is located some distance upstream so that it captures runoff from 107 square miles or approximately 78% of the sub-basin watershed. The largest increase in mined area between 1972 and 1999 occurred in this sub-basin (see Figure 2-11). During this time, mined acreage increased from 7,824 acres to 55,216 acres, an increase of approximately 74 square miles over a 28-year span. Mined land increases were largely offset by decreases in uplands (45 square miles) and agriculture (22 square miles). The decline in urban land use in the South Prong Sub-Basin was due to change in the resolution of the data sets. Acreage of land use / cover changes are shown in Table 2-3 and Figure 2-12.



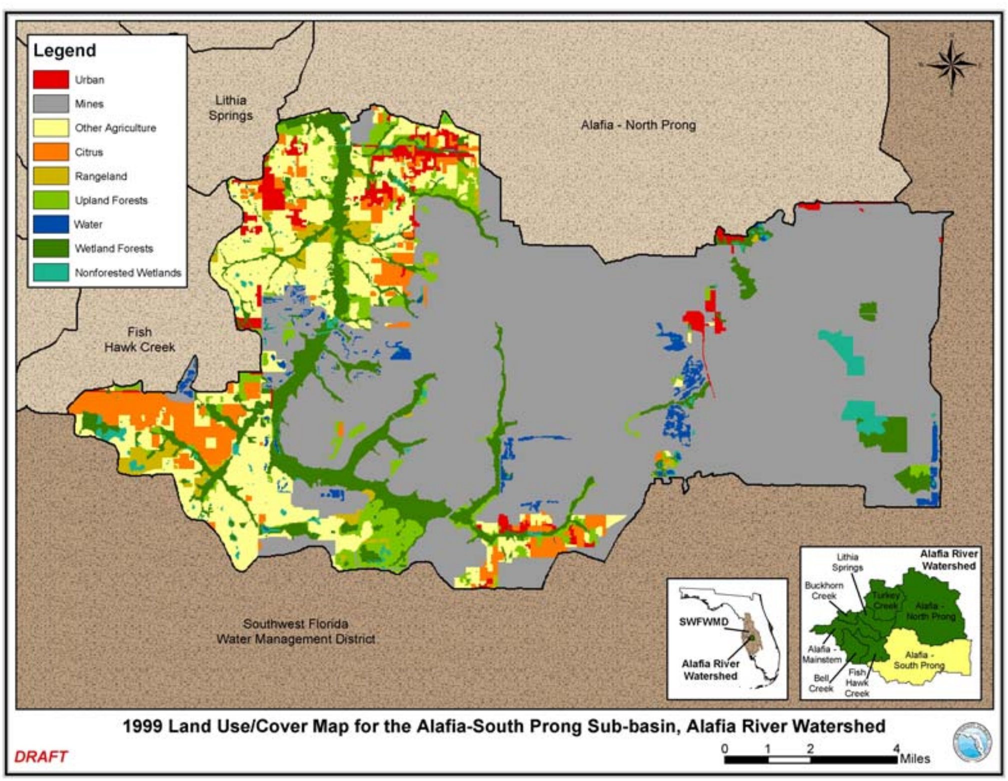


Figure 2-11. 1972 and 1999 Land use / cover maps of the South Prong sub-basin of the Alafia River watershed, Florida.

Table 2-3. Land use and land cover (by percentage) in the South Prong sub-basin of the Alafia River watershed (88,303 acres) for three time periods, 1972, 1990 and 1999.

Alafia - South Prong	1972	1990	1999
Urban	6.3	1.7	2.3
Citrus	11.0	5.0	4.5
Other Agriculture	22.2	14.8	12.8
Uplands	38.3	9.5	5.5
Wetlands	12.4	13.7	10.9
Mines	8.9	54.7	62.5
Water	1.0	0.8	1.5

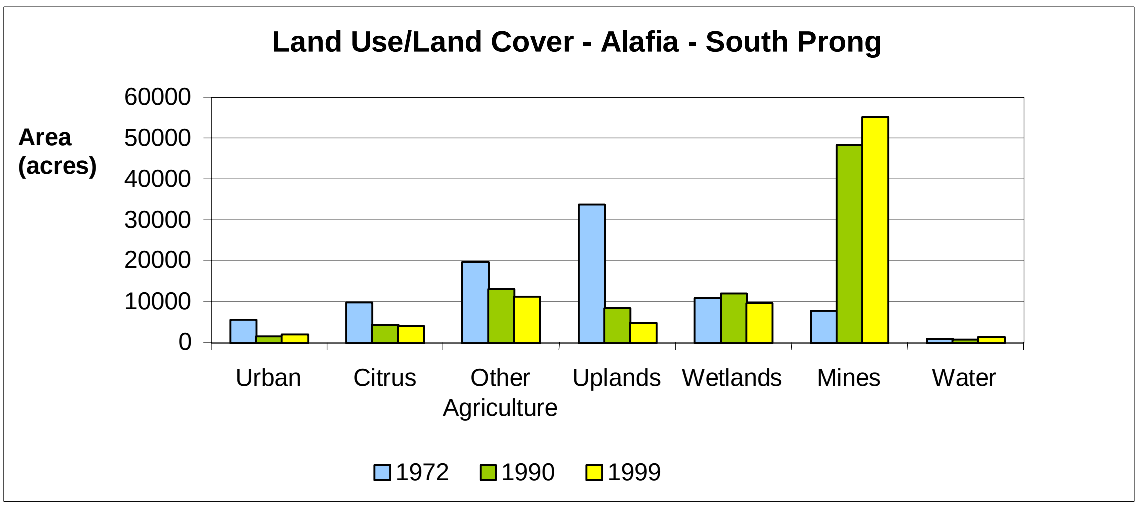
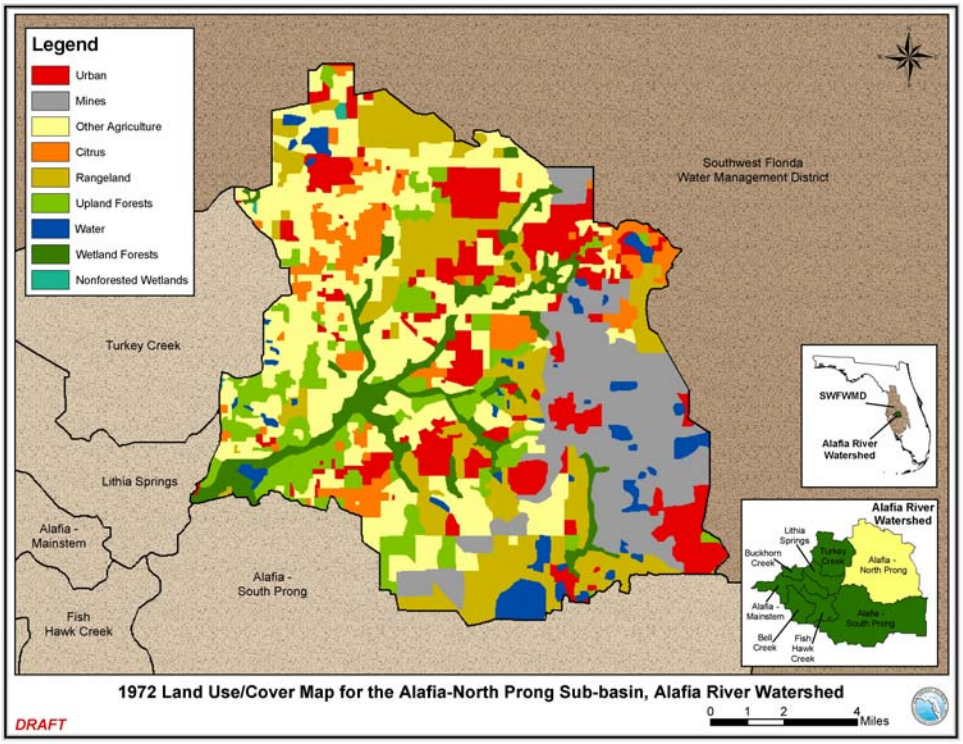


Figure 2-12. Comparison of land use and land cover changes in the South Prong sub-basin of the Alafia River watershed.

2.2.2 North Prong Sub-Basin

The North Prong sub-basin is 141 square miles (90,115 acres) in size. Most of this sub-basin is located upstream of the USGS gage which captures flow off approximately 135 square miles. As with the South Prong, the largest change in land use since 1972 has been in the amount of sub-basin area mined. In 1972, 16 percent of the sub-basin had been mined; by 1999 an additional 17,592 acres or 25 percent of the sub-basin had been mined (Figure 2-13). Although heavily mined (35% of the entire sub-basin), considerably more acreage has been mined in the South Prong of the Alafia River (55,216 acres versus 31,776 acres or 63% versus 35%). As will be discussed, a comparison of flow changes between the North and South Prongs and the Alafia River at Lithia offers some insight into the potential effects of increasing mined lands on river flows.

Mining represented the single largest increase in land use acreage. Urban was second; expanding from 14 percent (12,617 acres) of the watershed in 1972 to 23 percent in 1999. Collectively, urban and mining accounted for 58% of the land use in 1999 or a net conversion between 1972 and 1999 of 29%. During this same time period, the amount of acreage in uplands decreased by 17% while agricultural lands excluding citrus decreased by 12% (Table 2-4, Figure 2-14).



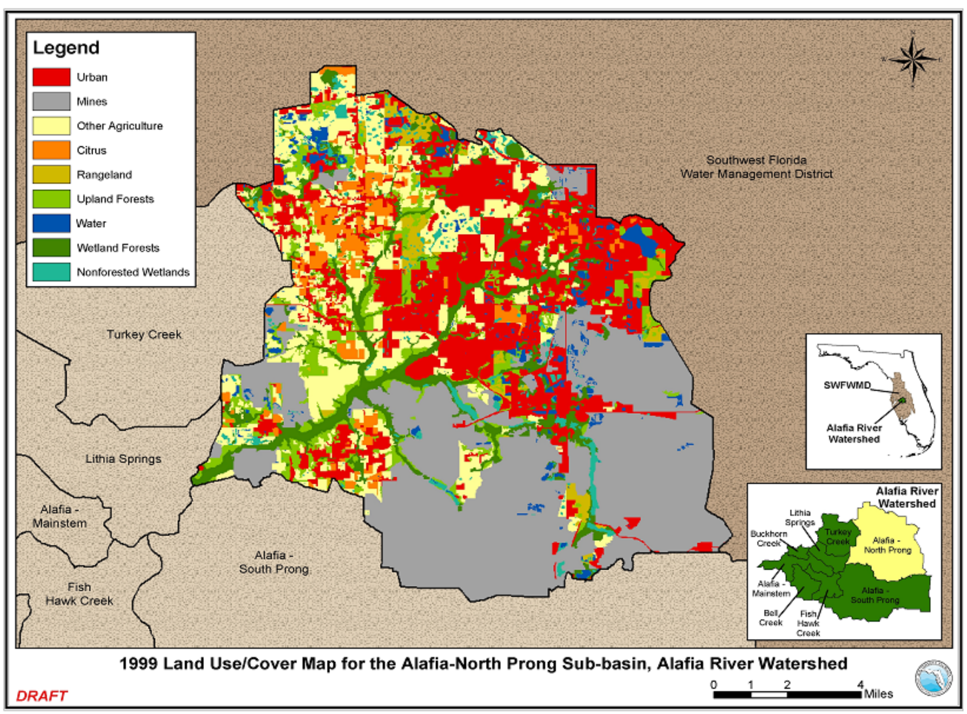


Figure 2-13. 1972 and 1999 Land use / cover maps of the North Prong sub-basin of the Alafia River watershed, Florida.

Table 2-4. Land use and land cover (by percentage) in the North Prong sub-basin of the Alafia River watershed (90,115 acres) for three time periods, 1972, 1990 and 1999.

Alafia - North Prong	1972	1990	1999
Urban	14.0	17.0	23.4
Citrus	6.6	4.1	3.9
Other Agriculture	26.6	21.1	14.8
Uplands	25.8	11.5	9.3
Wetlands	7.2	10.6	10.6
Mines	15.7	33.8	35.3
Water	4.0	2.0	2.7

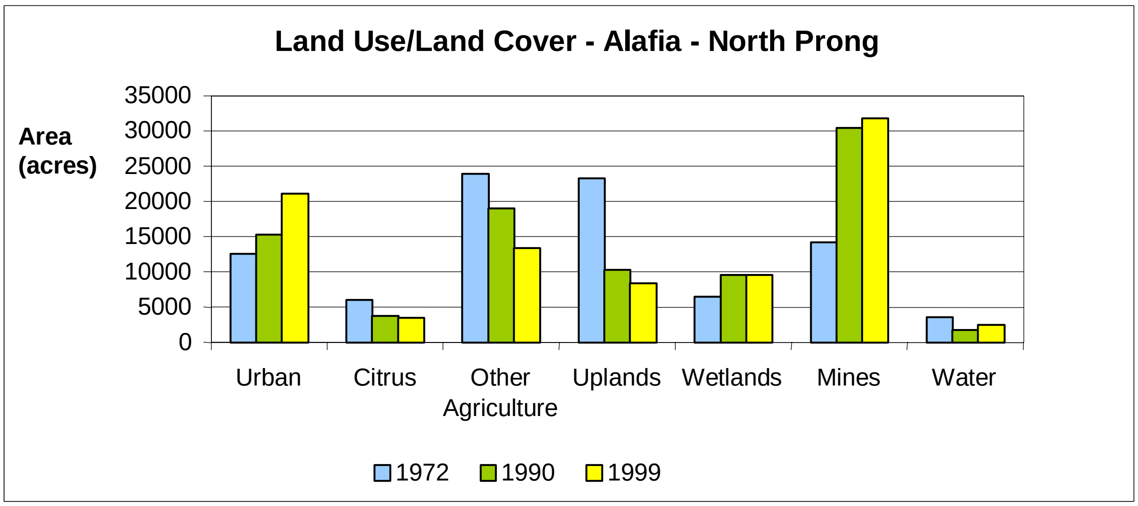


Figure 2-14. Comparison of land use and land cover changes in the North Prong sub-basin of the Alafia River watershed.

2.2.3 Turkey Creek Sub-Basin

The Turkey Creek sub-basin is approximately 43 square miles (27,287 acres) and is composed of the USGS sub-basins of Medard Park Run and Turkey Creek. The single greatest land use change in this sub-basin between 1972 and 1999 was an approximate 10% increase in the amount of urbanized land. Some mining has occurred in this sub-basin (19% mined in 1999), but most of this occurred pre-1972 (18%). Agricultural acreage has decreased in this sub-basin since 1972, with a net decrease amounting to 8% of the watershed area. The area of uplands has likewise decreased by approximately 2,272 acres (8% of the watershed) during this time. Land use maps and tables for this sub-basin are included in the appendix.

2.2.4 Lithia Springs Sub-Basin

The Lithia Springs sub-basin includes both McDonald and McCullough Branches and covers approximately 19 square miles (16,281 acres). This sub-basin has become increasingly more residential, while uplands and agricultural acreage has declined. In 1972, approximately 13 percent of the basin was urbanized; by 1999 this had increased to 34 percent. During this same time, agricultural acreage declined considerably; in 1972, 47% percent of this basin was in agriculture, but by 1999 this had declined to 28%. Uplands decreased from 24% to 13% from 1972 to 1999. Land use maps and tables for this sub-basin are included in the appendix.

2.2.5 Fish Hawk Creek Sub-Basin

The Fish Hawk Creek sub-basin covers approximately 22 square miles (14,288 acres) and includes Doe Branch, Flat Creek and Fish Hawk Creek. Of the eight sub-basins delineated for this report, only the Fish Hawk sub-basin showed a net increase in agricultural lands between 1972 and 1999. Citrus acreage declined from 540 acres in 1972 to 328 acres by 1999, but other agricultural uses increased from 3,332 acres to 4,972 acres. Most of this increase in agricultural lands occurred in the pastureland/cropland category. Mining has occurred in this sub-basin; 1,301 acres were mined between 1972 and 1999, adding to the 1,966 acres, which had already been mined. Although residential development has been occurring at an increased rate since 1999, only 2% of this sub-basin was urbanized in 1999. The predominant land use in 1999 was agriculture (37% which includes a small amount of citrus). Although considerable uplands were lost between 1972 and 1999, uplands was still the second most common land use in 1999 (26%). A total of 23% of this sub-basin was mined by 1999. Land use maps and tables for this sub-basin are included in the appendix.

2.2.6 Buckhorn Creek Sub-Basin

The Buckhorn Creek sub-basin is the smallest sub-basin delineated for this report (4,826 acres). Since Buckhorn Springs is the subject of a specific MFL determination, it was deemed desirable to characterize this sub-basin's land use separately. The amount of land in residential use has increased substantially since 1972. In 1972, approximately 38% of its eight square miles had been urbanized. By 1999, the amount of urbanized land had increased to 75%. The percent of land in agriculture has decreased from a combined 30% (citrus and other) to 7%, and upland and wetlands have decreased from a combined 32% to 15%. Land use maps and tables for this sub-basin are included in the appendix.

2.2.7 Bell Creek Sub-Basin

The Bell Creek sub-basin is 21 square miles (13,490) in area, and is composed of the Bell Creek, Bell Creek Reservoir, Boggy Creek and Pelleham Branch sub-basins. In 1972, 46% of this watershed was in uplands or wetlands and 45% was in agricultural uses. The amount of urbanized land increased from 7% to 20% of the sub-basin total between 1972 and 1999, while agricultural usage declined from 45% to 37%. The total acreage in uplands and wetlands has declined slightly from 46% to 42% between 1972 and 1999, with much of the increase in urbanized areas apparently offset by decreases in agricultural lands. Land use maps and tables for this sub-basin are included in the appendix.

2.2.8 Alafia Mainstem Sub-Basin

The Alafia Mainstem is defined as that portion of the Alafia River below the confluence of the North and South Prongs which receives direct runoff or runoff from Little Fishhawk Creek or Rice Creek. Its drainage area is 30 square miles (19,309 acres) and accounts for slightly more than 7% of the entire Alafia River watershed. Since 1972, the amount of urbanized land in this sub-basin has increased from 21% to 42%, and agricultural land use in the sub-basin's watershed has declined from a total of 31% to 20%. Uplands and wetlands that totaled 45% of the watershed in 1972 had decreased to 30% of the sub-basin total by 1999. Land use maps and tables for this sub-basin are included in the appendix.

2.3 Hydrology

The assessment of minimum flow and levels for the freshwater segment of the Alafia River was supported by analyses of long-term streamflow records that date to the 1930s. Significant declining trends in flow have been documented or reported by a number of workers (Stoker et al. 1996, Hickey 1998, SDI 2003, Kelly 2004); however, the cause(s) of these declines has been the subject of some debate. Kelly (2004) attributed flow declines in the Alafia River largely to climate, and that is a primary assumption inherent in the minimum flow analyses to follow.

Although there has been considerable phosphate mining in the Alafia watershed (especially in the watersheds of the North and South Prongs) and substantial groundwater withdrawals from the Floridan aquifer, comparison of river flow declines with neighboring watersheds suggests a similar causative factor for flow declines. Our analyses indicate that flow declines attributed by Stoker et al. (1996) to groundwater withdrawals, and by SDI (2003) to increasing area of mined land are due to another factor, namely the removal or reduction of discharges from the phosphate mining industry. These flow declines actually represent an increase in water use efficiency by the mining industry such that the large volumes of groundwater historically used for ore extraction and processing have been substantially reduced. In response to work done by SDI (2003), we have compared discharge volumes from the watersheds of the South and North Prongs of the Alafia River to demonstrate that similar amounts of water are being discharged from both basins and thus increasing area of mined lands has not lead to substantial nor quantifiable reductions in flow.

Kelly (2004) concluded that the Atlantic Multidecadal Oscillation (AMO; see Enfield et al. 2001) has an important controlling effect on river flow volumes throughout southwest Florida, and is a major factor that must be considered when developing minimum flows and levels (Shaw et al. 2004). This phenomenon is shown to affect the baseline or benchmark period against which flow reductions and MFLs should be judged.

2.3.1 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 2-15) 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 2-15).

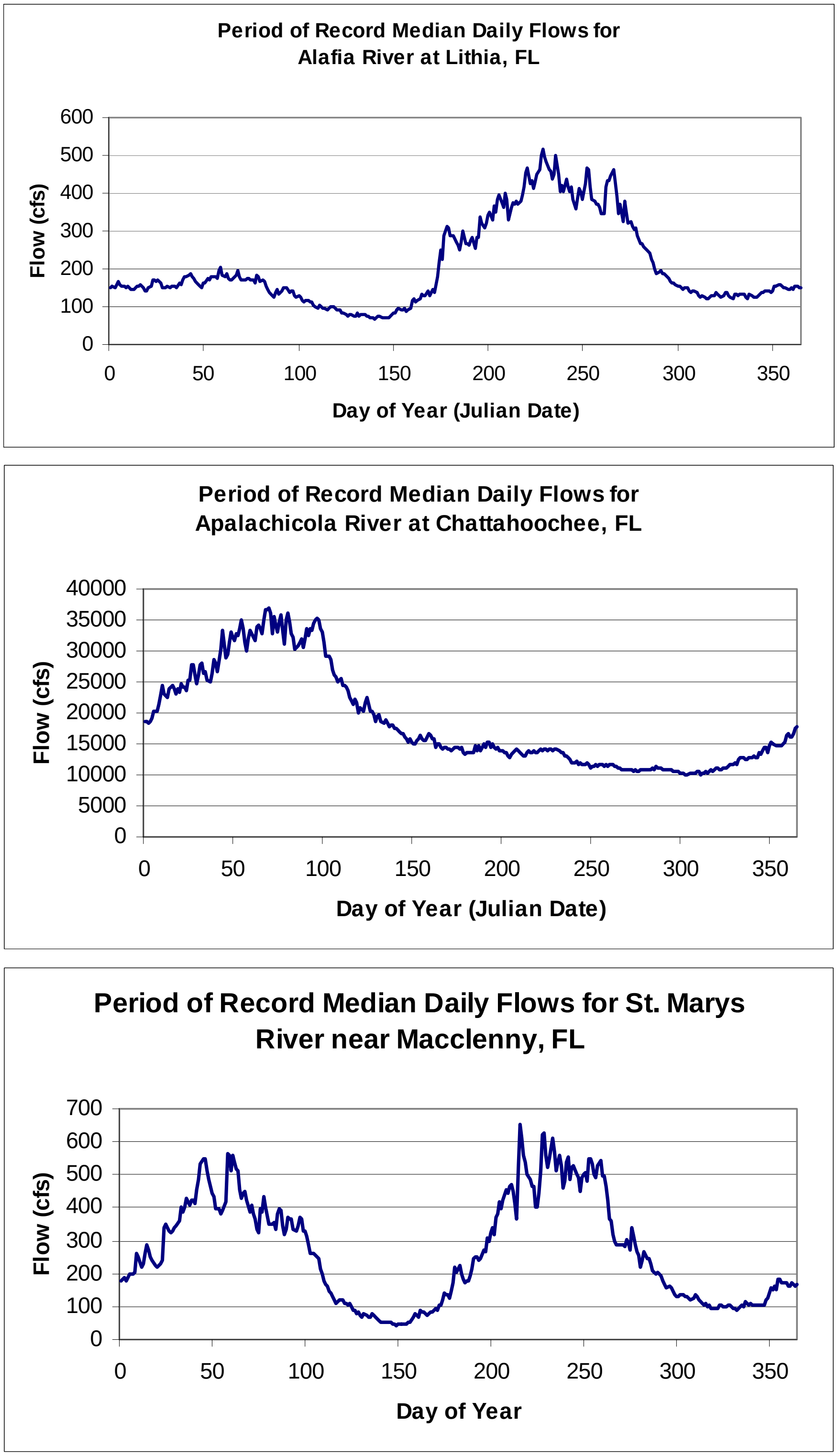


Figure 2-15. Examples of three river flow patterns: the Southern River Pattern (upper panel), the Northern River Pattern (center panel) and Bimodal River Pattern (bottom panel).

2.3.1.1 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, most of Florida has a positive (rather than negative) correlation between rainfall and prolonged periods of North Atlantic Ocean sea surface warming (Einfeld 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 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.'s (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.

2.3.1.2 Flow Trends – testing for a monotonic trend and a step trend

While several authors have examined temporal stream flow patterns in anticipation of monotonic trends, the AMO suggests that a step trend rather than a monotonic trend should be expected in rainfall and river flows. Kelly (2004) demonstrated that many of the observed decreasing flow trends reported for rivers in the SWFWMD are consistent with a step trend. He found that, while a Kendall's tau test of pre and post periods (1940 to 1969 and 1970 to 1999) suggested no trends in flow in many cases, a Mann-Whitney test of the two periods indicated a significant difference in flows between the two periods. Supporting results specific to the Alafia River are presented later in this chapter. It should be noted that prior to any consideration of the AMO as a causal mechanism for a step change in rainfall and consequently river flows, several authors (see especially Hickey 1998) suggested that a rather abrupt change in rainfall patterns had occurred.

While most workers realize that there can be extreme annual variation in flow, most also believe that this variation is more or less random. As a result when flow declines occur, the tendency has been to look for an anthropogenic explanation for these flow trends. Olsen et al. (1999) in examining flood frequency estimation for the upper Mississippi and lower Missouri Rivers observed that, "the annual maximum peak floods are considered to be a sample of random, independent and identically distributed (iid) events Thus one implicitly assumes that climatic trends or cycles are not affecting the distribution of flood flows in a significant way." Olsen et al. (1999) eventually conclude that "current interest in climate change and its potential impacts on hydrology in general and on floods in particular calls into question the iid assumption." Although Olsen et al. (1999) were interested in flood flow, their comments are applicable to flow variation in general. Further, in the words of McCabe and Wolock (2002), "the identification of an abrupt increase [or decrease] in streamflow rather than a gradual increasing [decreasing] trend is important because the implications of a step change are different from those of a gradual trend. The interpretation 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."

2.3.2 Benchmark period

According to Beecher (1990), an instream flow standard should include certain elements, one of which is the establishment of a benchmark period. The benchmark period is selected as the measuring stick against which acceptable flow reductions will be compared. A major impediment to the establishment of MFLs in the SWFWMD has been the difficulty of identifying and establishing a benchmark period for available flow records. This has apparently not posed a significant problem for most working on minimum flow issues; in many instances a 20 to 30-year period of record has generally been deemed acceptable (Richter et al. 1996). Identification of a benchmark period has not been recognized as a problem in much of the United States for two possible reasons:

1. it is generally assumed that except for anthropogenic factors, river flows are the consequence of a sequence of random independently and identically distributed random variables (Olsen et al. 1999); and

2. while river flows in peninsular Florida have declined when two multidecadal periods are examined (Kelly 2004), they have increased in most of the United States.

The traditional method of selecting a benchmark period would be to simply identify a sufficient period of the historic record believed to have been minimally impacted by humans. Since many of the rivers in the SWFWMD have periods of record extending back 50 years or more, this approach would typically lead to selection of a flow period in the 1940s, 50s or 60s. In general, except where major structural alterations have occurred (e.g., construction of a dam), one would expect man's impact in the 1940s, 50s and 60s to be less than from 1970 onward. This period would predate Florida's major population growth, high agricultural use of groundwater, and most large-scale water supply development projects. However, as has recently been demonstrated, the period from 1940 thru 1960 represents a period when peninsular Florida was experiencing a multidecadal period of higher rainfall and consequently river flows (Enfield 2001, Basso and Schultz 2003, Kelly 2004). It is believed that even without the intervention of man, that flows in many stream and river systems would show a decline of 20 to 40% when two multidecadal periods are compared (i.e., 1940 to 1969 and 1970 to 1999).

Unless cognizant of this multidecadal climate oscillation, the danger in using a flow record pre-1970 as a benchmark for setting MFLs on rivers in the SWFWMD is that it would likely be assumed that these declines are somehow related to human factors. In this case, there is the potential for setting unrealistically high MFLs. Not only would this affect society's ability to use a portion of the flow, but could lead to the development of unneeded recovery strategies.

Conversely, since most of the United States including the panhandle of Florida, has actually seen higher rainfall over the last thirty years (refer to Enfield et al. 2001 and McCabe and Wolock 2002), anthropogenic impacts leading to flow reductions could go unnoticed or at least underestimated if the multidecadal climate oscillation is not considered. This, in turn, could lead to the setting of MFLs or their equivalent at excessively high levels. Under this scenario, the return to a lower rainfall oscillation could cause MFLs to be violated naturally, even in the absence of water withdrawals. In many cases, where the flow record for a river does not span move than a few decades and includes a presumed period of pre-impact flow data, potential problems with natural streamflow variation may not even be noticed.

Peninsular Florida in comparison to most of the United States is almost singularly unique when it comes to evaluating declining flow trends. The combination of a multidecadal climate related flow decline and the requirement to develop MFLs with the need to establish a benchmark period necessitated a full evaluation of this relationship (refer to Kelly 2004). With the exception of the work of Enfield et al. (2001) supported by the South Florida Water Management District, we are aware of no other minimum flow related study that acknowledges multidecadal differences in rainfall and flow and seeks to factor these differences into water management decisions or minimum flows determinations.

It would probably be difficult to argue that rivers with human caused flow reductions of 30 to 40% could tolerate even greater anthropogenic reductions without causing significant harm. For example, considerable attention has been focused on the Peace River at Arcadia and development of MFLs. There is a documented decline in flows of at least 30% over the last 30 years when compared with the preceding 30 years (e.g., Hammett 1990, SDI 2003). Some have attributed this flow decline largely to anthropogenic factors with the resultant expectation that no further human caused flow declines could be tolerated without significant affects on the river system and the downstream estuary. However, if it can be demonstrated that the observed flow declines are largely climate related, different expectations are warranted. MFLs legislation implicitly assumes that some anthropogenic flow reduction (e.g., withdrawals) can occur before significant harm occurs.

Recent work related to the AMO and Florida river flow patterns suggest that at least two benchmark periods exist in the absence of human influences. One benchmark period would be related to a multidecadal period coincident with the Atlantic sea surface warming (increased rainfall in peninsular Florida) and one related to a multidecadal period of Atlantic sea surface cooling (decreased rainfall in peninsular Florida). When developing MFLs for the upper Peace River (see SWFWMD 2002), it was noted that there was a substantial change in the number of days that a given flow was exceeded prior to and after 1970; similar differences were noted for other water bodies (e.g., Alafia River, middle Peace

River, Myakka River, Withlacoochee River). This, in large part, prompted an evaluation of multidecadal differences in flow patterns.

As a result of findings in, "Florida River Flow Patterns and the Atlantic Multidecadal Oscillation" (Kelly 2004), the District has identified two benchmark periods. One benchmark period corresponds to the warm phase of the AMO, and is correlated with a multidecadal period of higher rainfall and thus increased river flows, and one corresponds to the cool phase of the AMO, and is correlated with a multidecadal period of lower rainfall and thus climatically lower river flows.

One of several approaches could be used in developing MFLs given that two and not one benchmark period exists. If permitting or allowing consumptive water use (i.e., withdrawals) on a volume basis (a fixed withdrawal; e.g., 50 mgd) rather than on a percent of flow approach (e.g., 10% of the preceding day's flow), the more conservative approach toward ecology and aquatic resources of a system would be to use the drier period as the benchmark period, since this would yield the lowest withdrawal recommendation. This approach would protect from significant harm during the low flow period, and provide even greater protection during the higher flow period. If, however, permitting on a "percent of flow" approach, the more conservative approach would be to base permitting on the benchmark period that produces the lower percent recommendation. This would allow the recommended percent to be used in either benchmark period and would allow the actual volume withdrawn to increase when flow enters the higher flow period. While it might seem intuitive that the lower flow period would always produce a lower recommended percent of flow reduction, this does not have to be the case.

A third option would be to adjust either the permitted volume or percent of flow recommendation according to the AMO period that one happens to be in. 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 consistent with multidecadal climatic conditions. 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. Given the difficulty of determining when a step change has occurred and given that there are several advantages to the "percent of flow" approach (e.g., maintenance of the shape and seasonality of the natural hydrograph) over the fixed quantity approach, we have proposed flow reductions that would yield the lowest recommended percent withdrawal regardless of the benchmark period used. We in essence use two benchmark periods in developing our MFLs recommendations.

Although some (e.g., Stoker et al. 1995, SDI 2003) have reported that Alafia River flows have declined due to anthropogenic factors, we have demonstrated that much of the reported flow decline is attributable to either a natural climatic oscillation (step change) or to removal or reduction of mine related discharges. For this reason, we believe that the entire flow record for the mutidecadal 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. Because the flows of the Alafia River were actually augmented during the 70's (and for at least part of the 60's), the appropriate benchmark for the cooler (drier) AMO oscillation is a subset of the multidecadal period that extends from 1970 to 1999. It is most appropriate (especially during the lower flow part of the year, late April through mid-June) to use the period 1980 to 1999, as the benchmark against which flow reductions should be compared for the low flow (AMO cool) period. Despite assertions by others (Stoker et al. 1995, SDI 2003), there have not been measurable anthropogenic declines in Alafia River flows. In fact, seasonal low flows (April-June) during the multidecadal "low flow" period were often equal to or greater than the corresponding flows during the multidecadal "high flow" period.

2.3.3 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 flow records 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 2-5). 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 2-6).

The three flow blocks were utilized for development of minimum flows for the Alafia River and are evident in a hydrograph of median daily flows for the Lithia gage site (Figure 2-16). 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 2-5. 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 Zephyrhills	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 2-6. 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

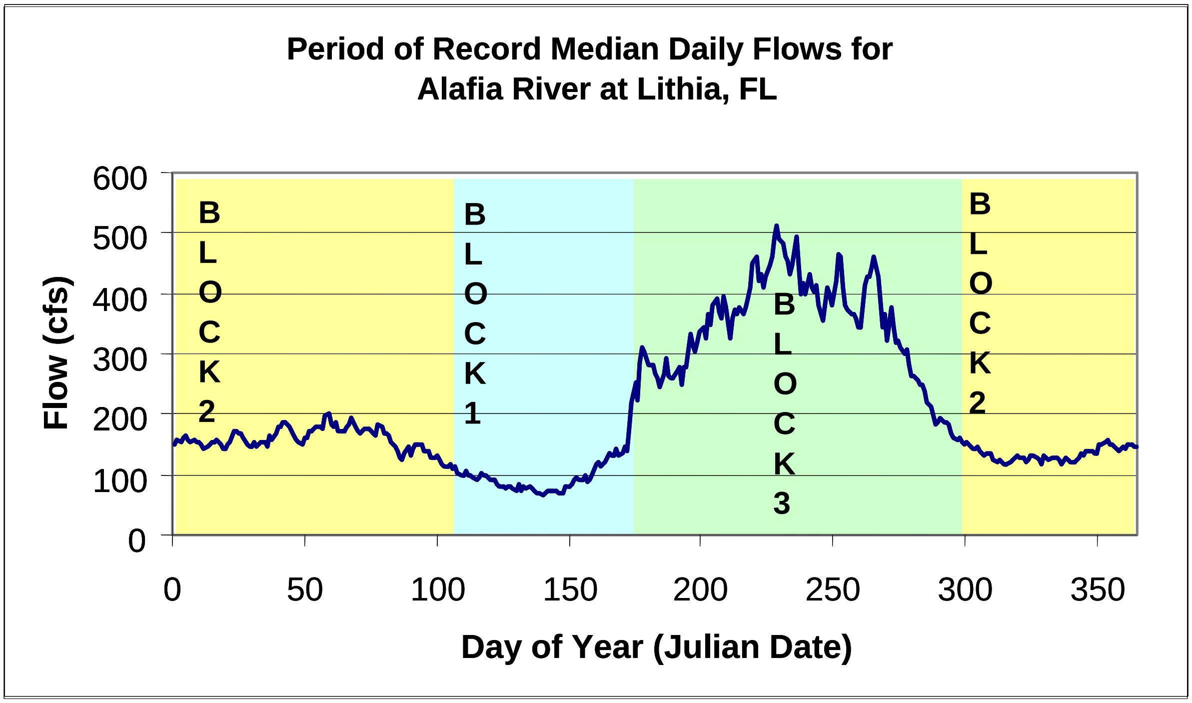


Figure 2-16. Building blocks developed for a building block approach to the development of minimum flows. Blocks corresponding to low (Block 1), medium (Block 2) and high (Block 3) flows are shown along with period of record median daily flows for the Alafia River at Lithia.

2.3.4 Alafia River Flow Trends

2.3.4.1 Gage Sites and Periods of Record

Flow analyses in the Alafia River watershed focused on three USGS gage sites, one located on the main stem of the Alafia River and one each on the two major tributaries to the Alafia River, the North and South Prongs (Table 2-7).

Table 2-7. Long-term USGS gage sites located within the Alafia River Watershed.

USGS Station	Site	Period of Record	Basin Drainage
0230150	Alafia River at Lithia,	1-Oct-32	335 sq
0230100	North Prong Alafia River at	1-May-50	135 sq
0230130	South Prong Alafia River near	1-Jan-63	107 sq

The Alafia at Lithia gage (USGS # 02301500) is located approximately 16 miles upstream from the river mouth of the Alafia River. Continuous flow measurements have been made at this site since October 1, 1932. The single highest daily flow of 40,800 cfs was recorded on September 7, 1933. This flow greatly exceeded the third highest daily flow, 19,800 cfs, which occurred in connection with Hurricane Donna on September 12, 1960 (the second highest flow occurred September 6, 1933 and was 32,900 cfs). Daily flows in excess of 1000 cfs are rare occurring less than 6% of the time on a daily basis. Of the almost 26,000 daily flow measurements made as of September 30, 2003, fewer than 100 were below 10 cfs. The lowest daily flow of 4.1 cfs was recorded on June 5, 2000. Mean daily flow for the period of record is 335 cfs with a median of 174 cfs.

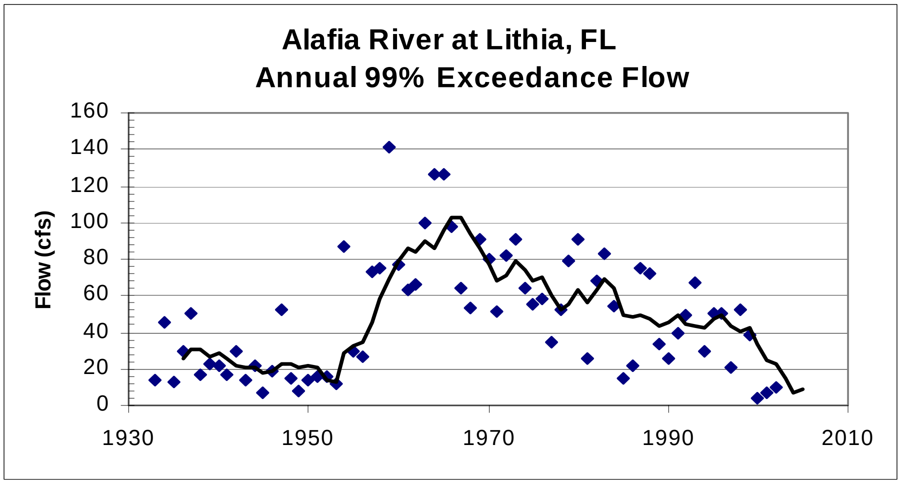
The North Prong gage at Keysville, FL (USGS # 0230100) is approximately 29 miles upstream from the mouth of the Alafia River and 4 miles upstream of its confluence with the South Prong. Flow has been measured at this site since May 1, 1950; however, there is a break in the record that extends from October 1, 1992 to July 1, 1995. The period of record at this site is considerably shorter than that at the Lithia gage, as a result the period of record high flow was recorded on September 11, 1960 at 8,200 cfs. The second highest flow was recorded the following day (Sept. 12, 1960), but it is interesting to note that the third highest flow occurred early in 1960 (March 17, 1960) presumably in connection with an El Nino event. While the fourth highest flow on record occurred on July 30, 1960, it is likewise interesting to note that the fifth highest daily flow (of 18,508 observations) occurred on March 20, 1959. Although flows below 10 cfs were recorded during the 2000 drought, the lowest recorded flow was on May 17, 1952 at 3.9 cfs. The period of record mean daily flow is 153 cfs and the median daily flow is 90 cfs.

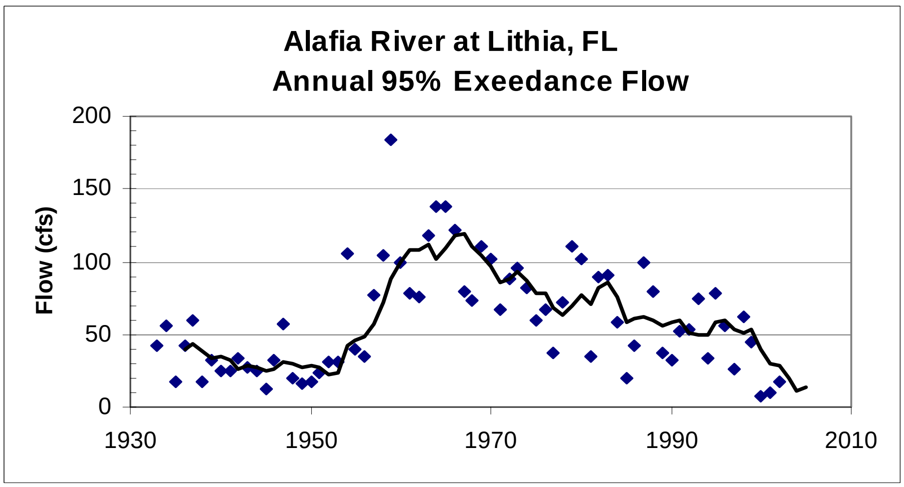
The South Prong gage near Lithia (USGS # 2301300) was established on January 1, 1963, and is located 7.6 miles upstream of the confluence with the North Prong. Although spanning 40 years, the flow record is considerably shorter at this site than at either the Lithia or North Prong site. The single highest flow recorded at this site was 2,430 cfs on August 14, 1967; the second highest flow at 2,110 cfs was recorded on June 22, 2003. Flows of zero cfs were recorded in May and June of 2000 and 2001, the period of record drought. During the period of record (ending Sep. 20, 2003) the mean and median daily flows were 101 and 57 cfs, respectively.

2.3.4.2 Alafia River Flows

Annual percent exceedance flows were determined for each year in the period of record at gage sites located on the mainstem near Lithia, on the South Prong of the Alafia near Lithia, and on the North Prong of the Alafia at Keysville. The South Prong gage measures discharge from a 107 square mile watershed, and the North Prong gage measures discharge from a 135 square mile watershed. The Lithia gage measures discharge from an area of 335 square miles. Because the Lithia gage is located downstream of the confluence of the North and South Prongs, its watershed encompasses the combined area of the gaged North and South Prongs (i.e., 242 square miles) plus an additional 93 square miles. Based on relative watershed size, the gaged area of the South Prong should contribute approximately 32% of the flow as measured at the Lithia gage, and the gaged area of the North Prong should contribute 40% of the flow as measured at the Lithia gage.

Selected percent exceedance flows for the period of record at the Alafia, North Prong and South Prong gages are shown in Figures 2-17 to 2-19. Apparent at the Alafia gage at Lithia is a substantial increase in low to median flows (99% to 50% exceedance flows) beginning around 1960. Both Stoker et al. (1995) and Hickey (1998) noted this increase in flow; Hickey (1998) postulated that the increases could be attributed to phosphate mining related discharges. Inspection of USGS water quality data collected at the Lithia gage on an approximate quarterly basis validates this supposition (see Figure 2-20). Exceptionally high phosphorus concentrations and elevated fluoride concentrations are obviously mine related, since fluoride is found in association with apatite, the phosphate ore that is mined. What is evident from water quality data is a substantial decrease in both phosphorus and fluoride concentrations in the late 1970s. Although low flows decreased considerably since the 1960s and 1970s, they have not decreased below the levels seen in the earlier part of the record (1940s). Since rainfall was generally higher in this earlier period, one would expect flows during this earlier period to exceed or at least match those of the 1960s-1970s, but this is not the case. While Stoker et al. (1995) attributed the flow decline to a lowering of the potentiometric surface, Hickey (1998) was correct in attributing this decline to climate and curtailment of mining related discharges. This is also confirmed by decreases in parameter concentrations that are associated with groundwater inputs (e.g., calcium and sulfate).





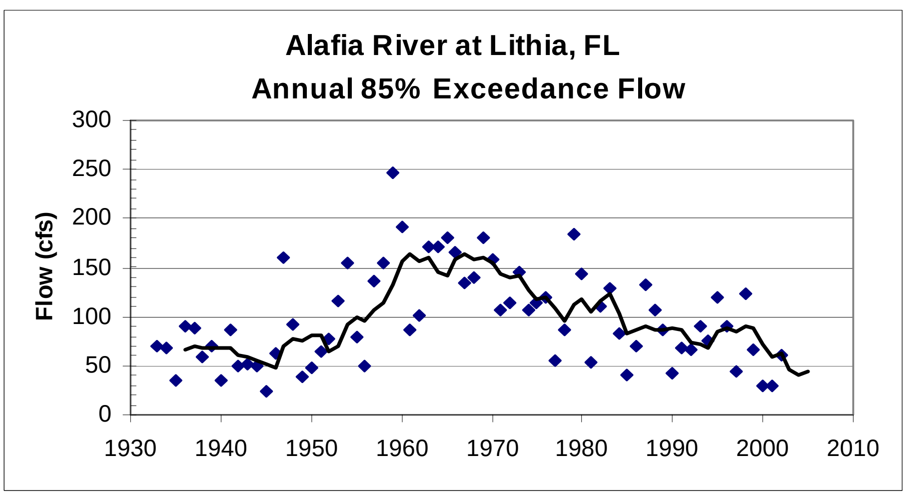
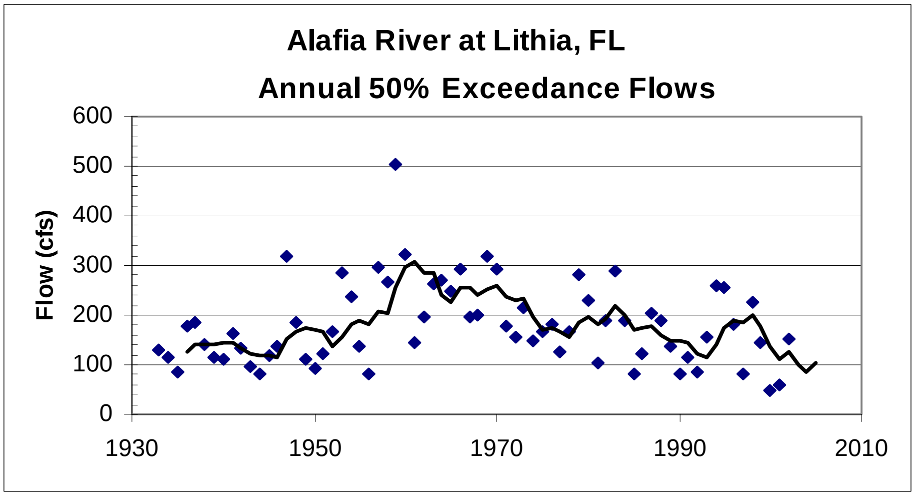
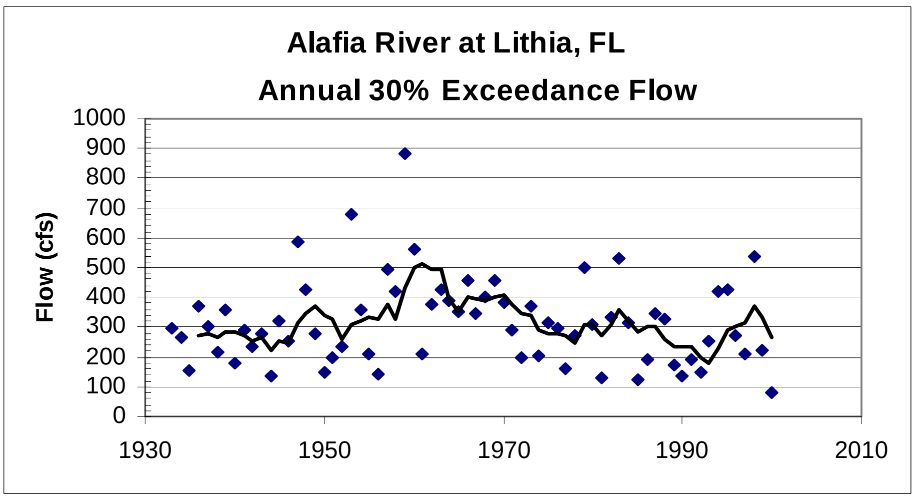


Figure 2-17. Annual percent exceedance flows (points) for the Alafia River at Lithia gage displayed with a 5-yr running average (line).





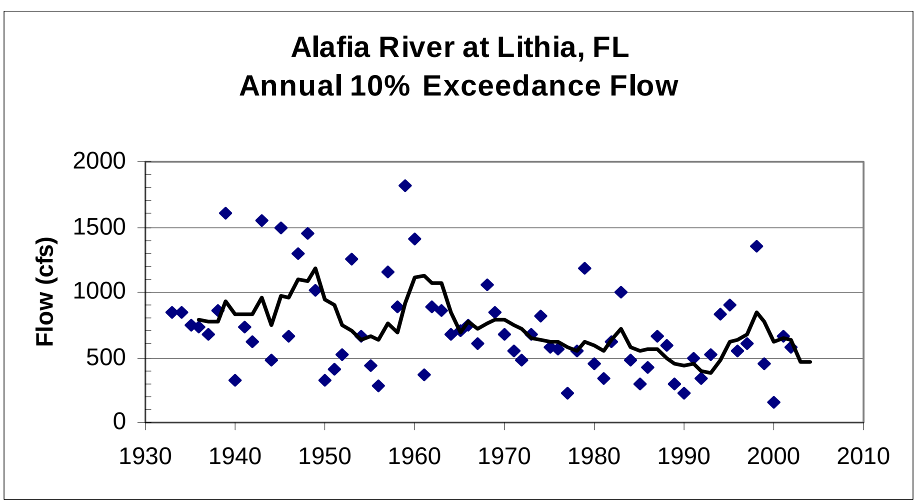
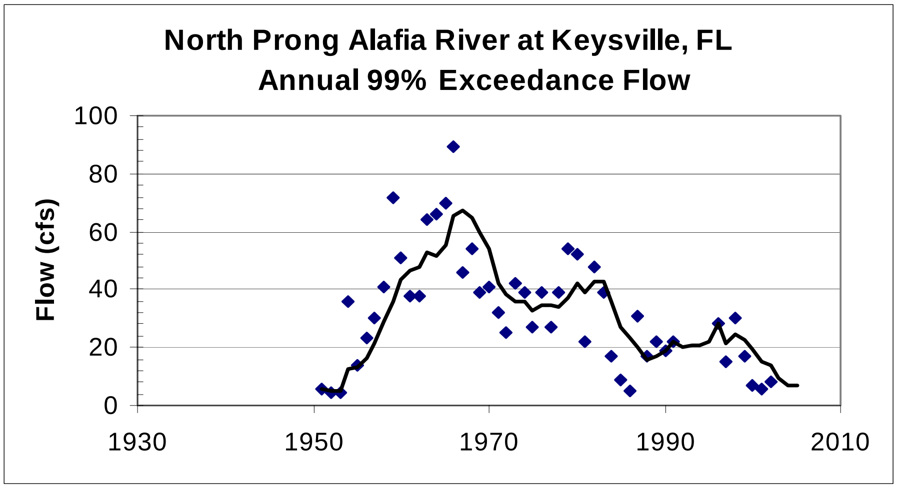
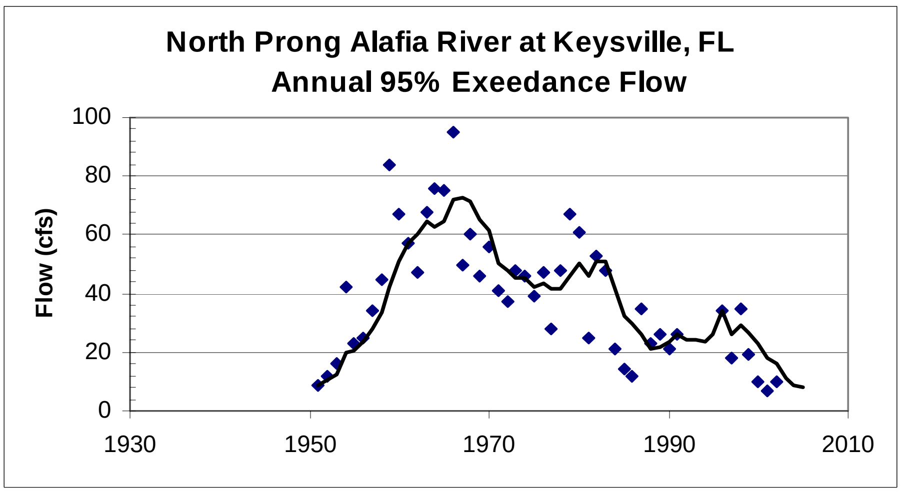


Figure 2-17. (continued). Annual percent exceedance flows (points) for the Alafia River at Lithia gage displayed with a 5-yr running average (line).





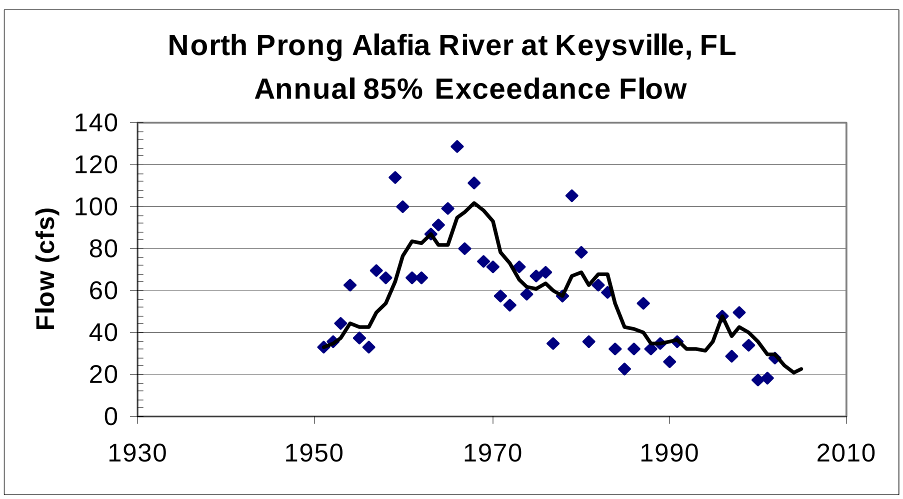
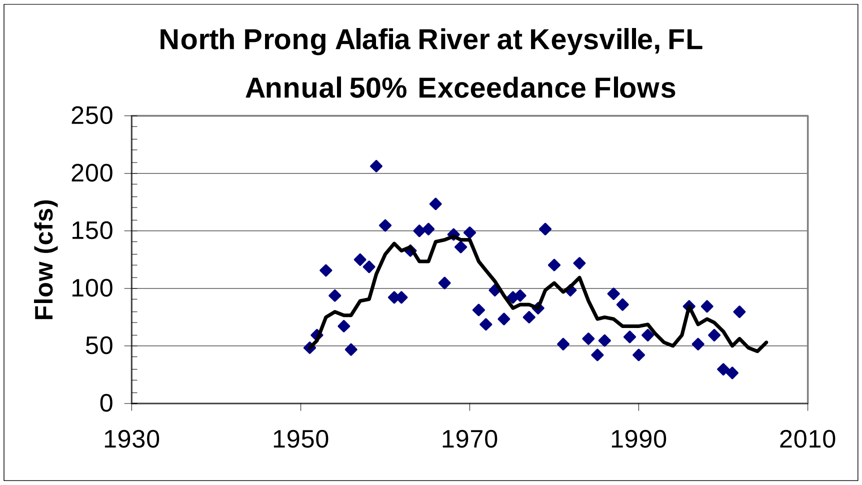
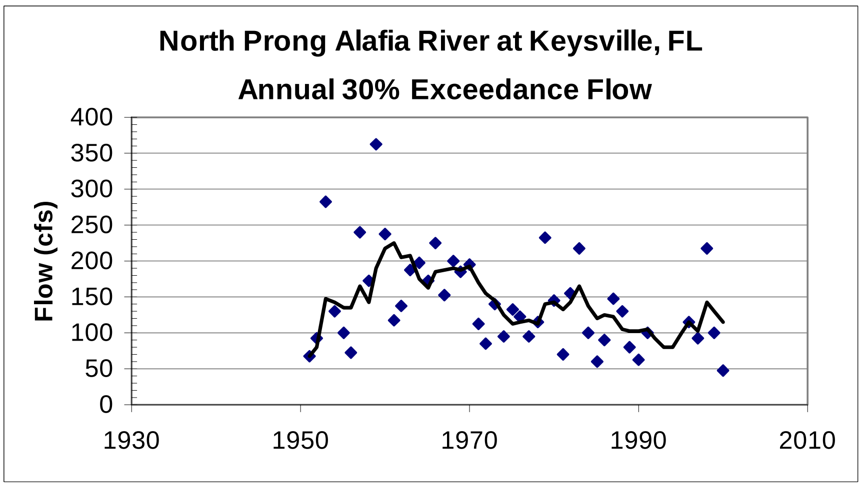


Figure 2-18. Annual percent exceedance flows (points) for the North Prong of the Alafia River gage displayed with a 5-yr running average (line).





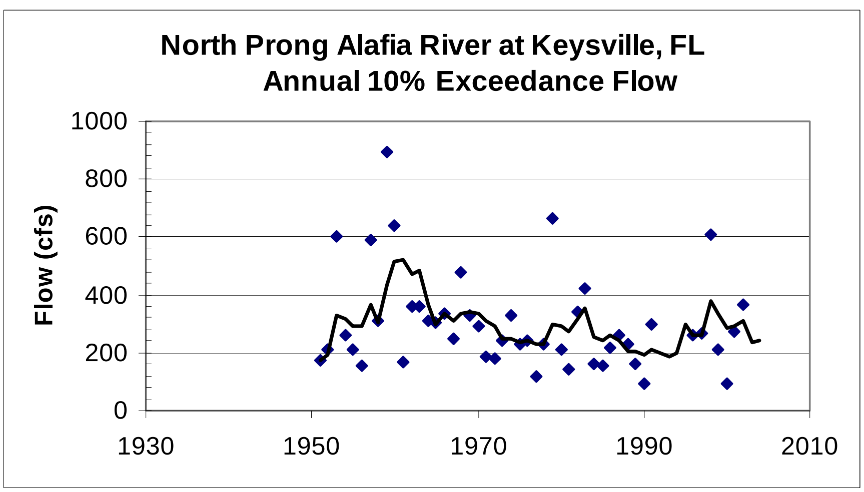
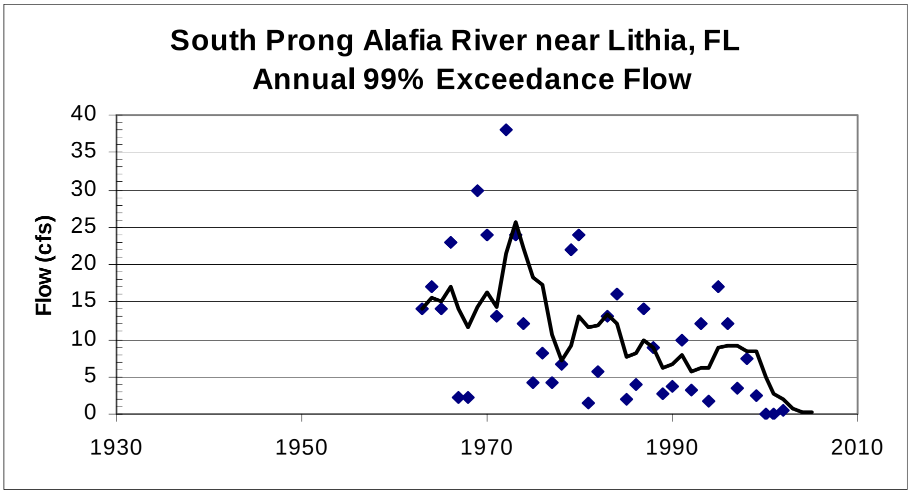
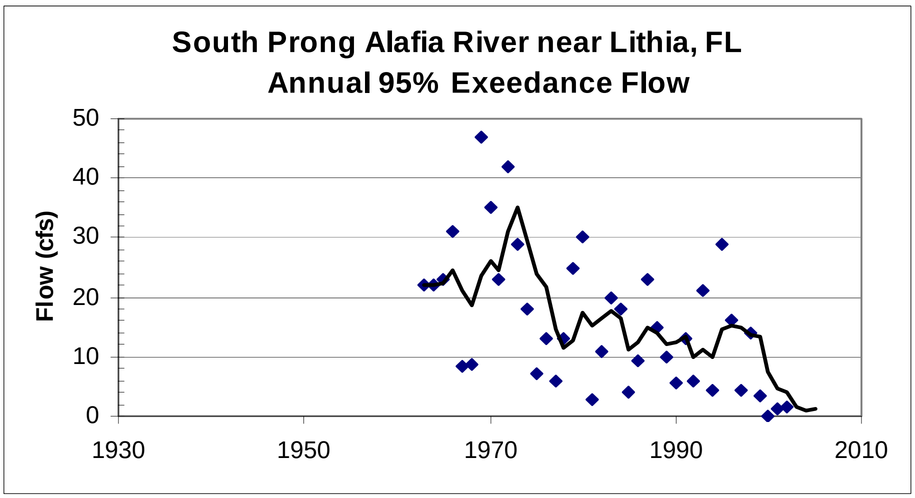


Figure 2-18 (continued). Annual percent exceedance flows (points) for the North Prong of the Alafia River gage displayed with a 5-yr running average (line).





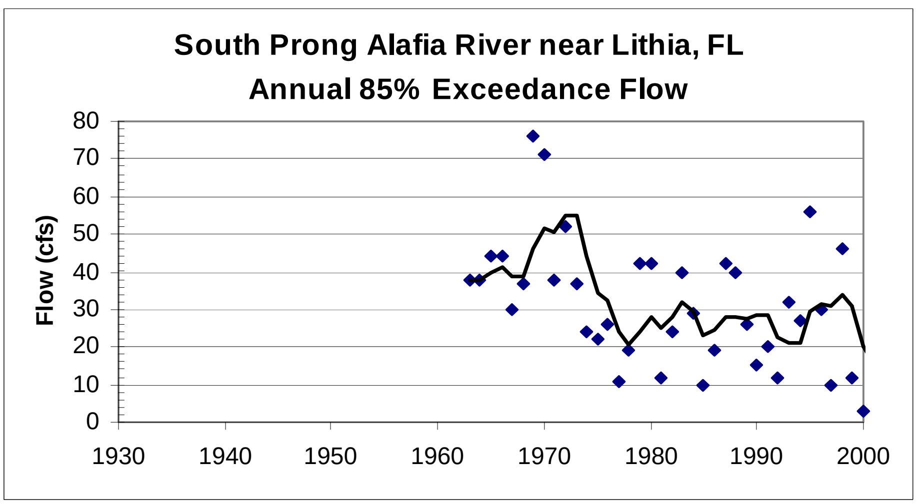
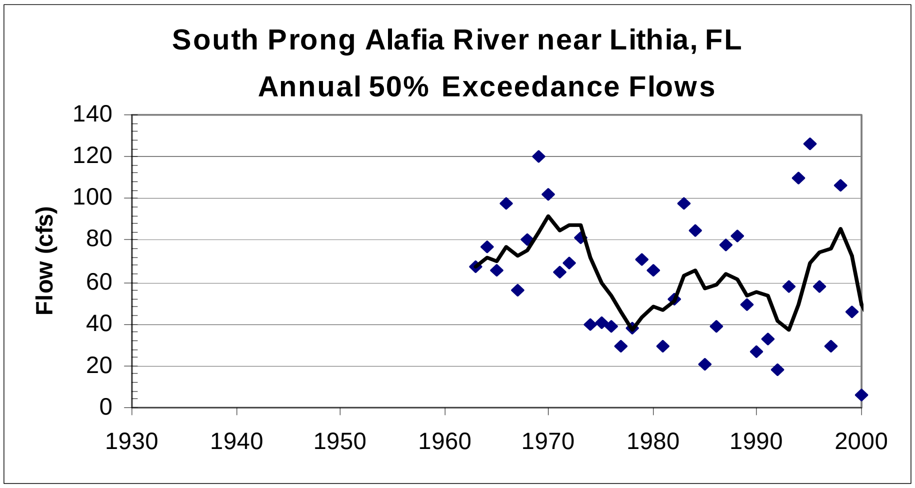
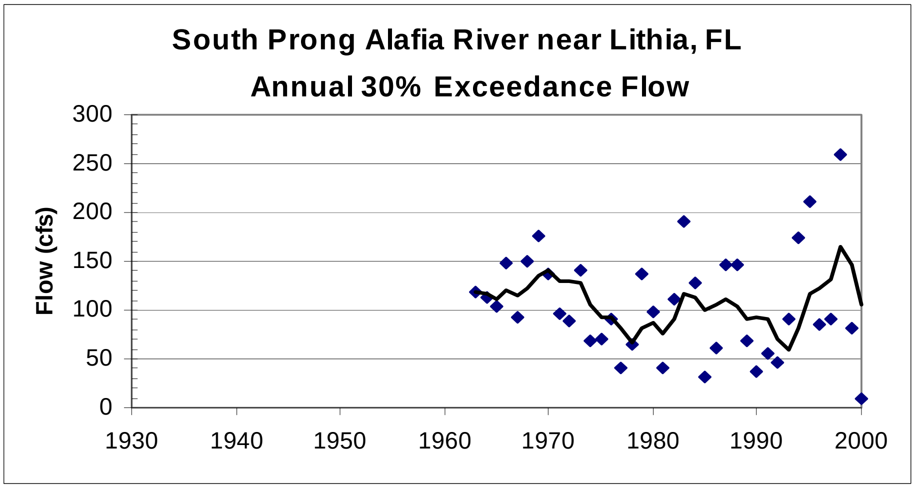


Figure 2-19. Annual percent exceedance flows (points) for the South Prong of the Alafia River gage displayed with 5-yr running average (line).





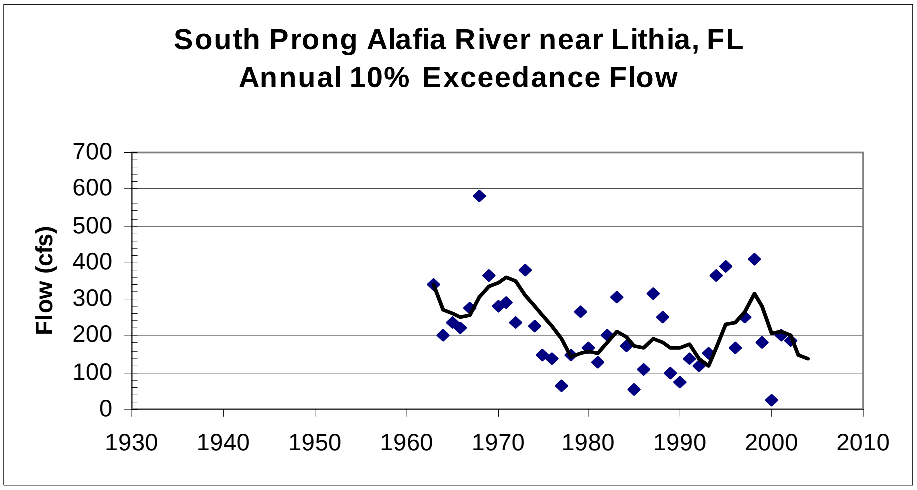


Figure 2-19. (continued). Annual percent exceedance flows (points) for the South Prong of the Alafia River gage displayed with 5-yr running average (line).

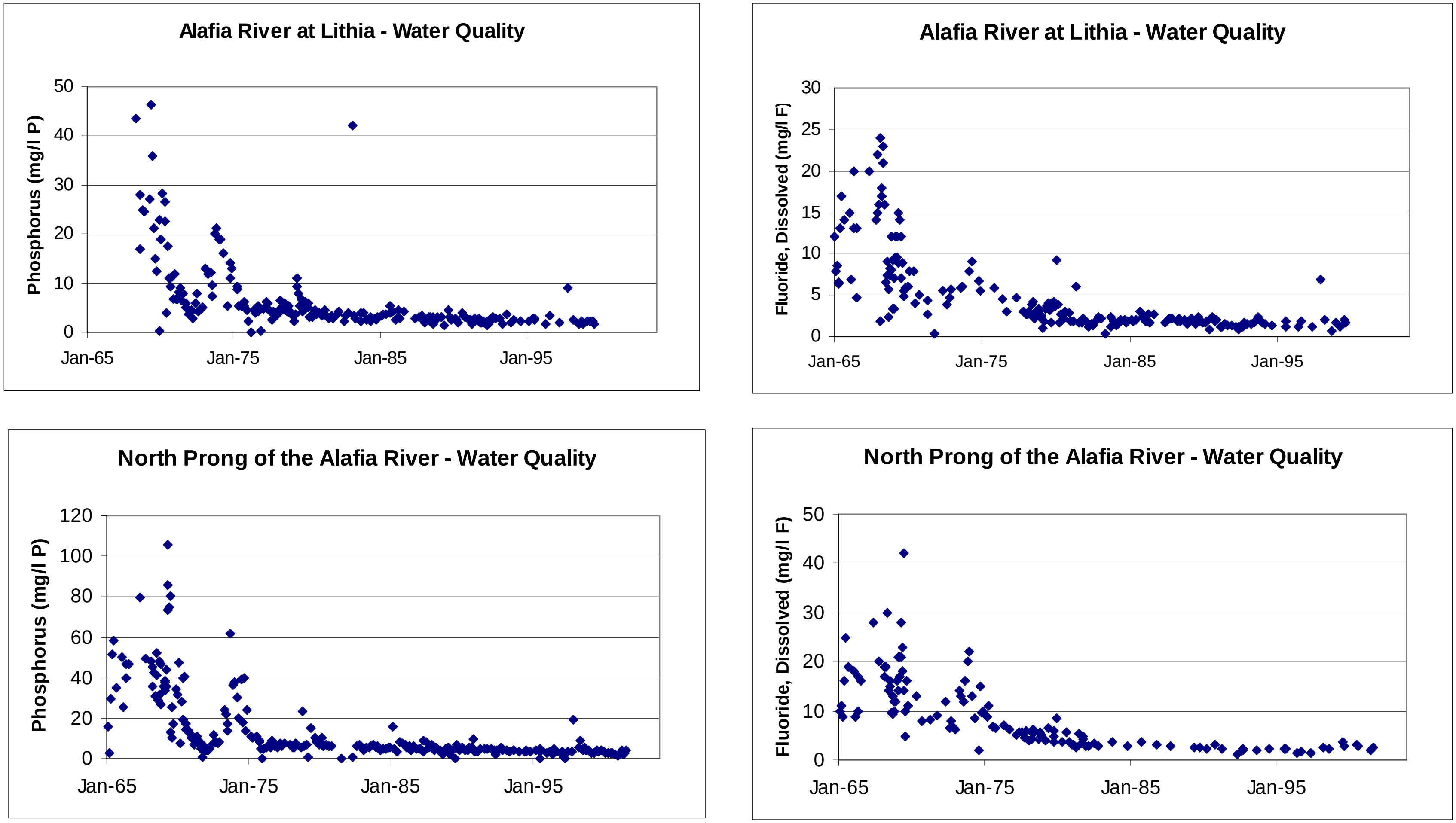
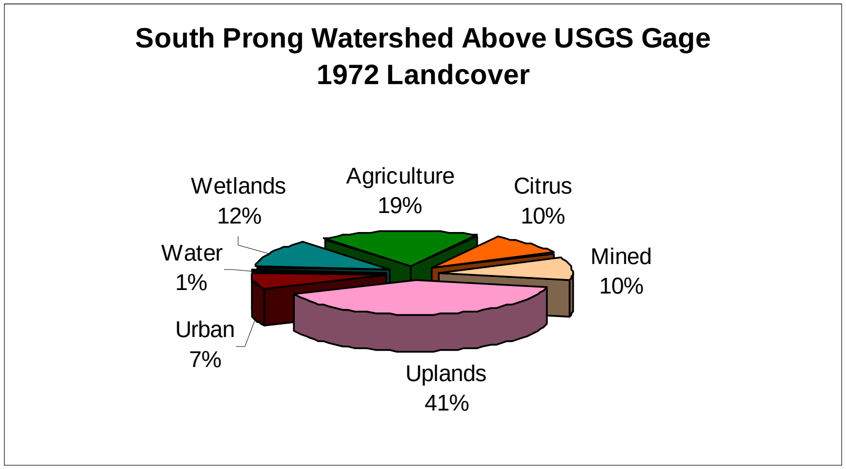
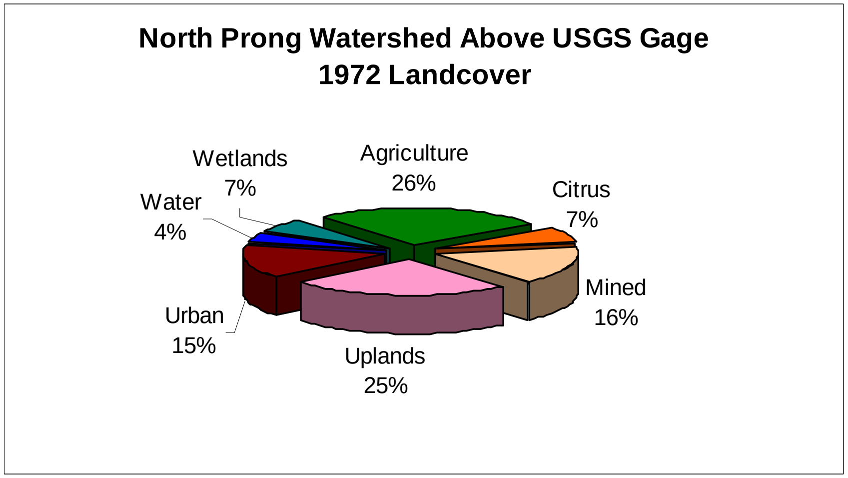


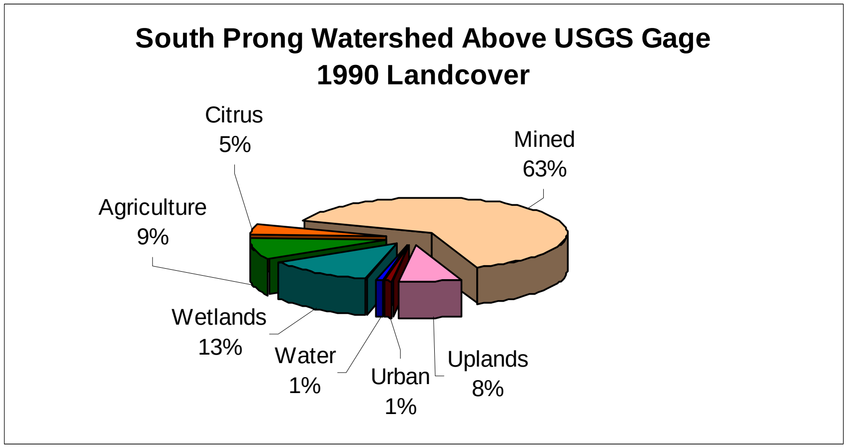
Figure 2-20. Phosphorus and fluoride concentrations in the Alafia River and the North and South Prongs.

Although Hickey (1998) concluded that climate was largely responsible for the decreasing trend, he did note that at the Alafia River at Lithia stream flow decreased about 44 cfs in the period between January 1962 to December 1981. He speculated that these flow declines were the result of mining, but were related to a substantial decrease in water being discharged rather than landscape changes that resulted in hydrologic alterations. Decreases in discharge were accomplished through increased water use efficiency and a decrease in ground water usage. Inspection of water quality data for the river suggests that Hickey (1998) is correct, and flow declines are related to improved efficiency rather than a diminishment of flows resulting from landscape alterations due to mining. In developing a relationship for the expressed purpose of predicting the impact of increasing area of phosphate mined land on stream flow, SDI (2003) assumed that the trend of decreasing stream flow in the South Prong of the Alafia River was related to increasing area of land mined. This assumption was made because mining was essentially the only land use that changed during the time interval investigated.

While SDI (2003) assumed that the flow decline was attributable to increases in land area mined for phosphate, this is not the case. Using logic similar to SDI (2003), there should be a steady monotonic decreasing trend in flow with increasing mined area. While mined area in the South Prong above the USGS gage increased substantially between 1972 and 1999 (from 9 to 72%) based on land use maps for this time period (see Figure 2-21), flow remained fairly stable (Kendall's tau was run on mean annual flows for the period 1970 to 1999, and the slope of the Thiel line was –0.1918 with a p value of 0.8028; indicating no trend; see Figure 2-22).







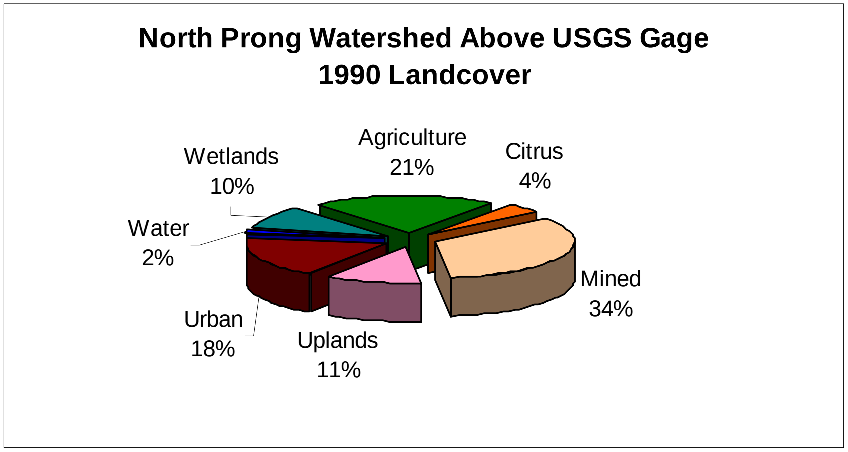


Figure 2-21. Land use in the watershed upstream of USGS gage sites on the South and North Prongs of the Alafia River based on mapping conducted in 1972, 1990 and 1999.

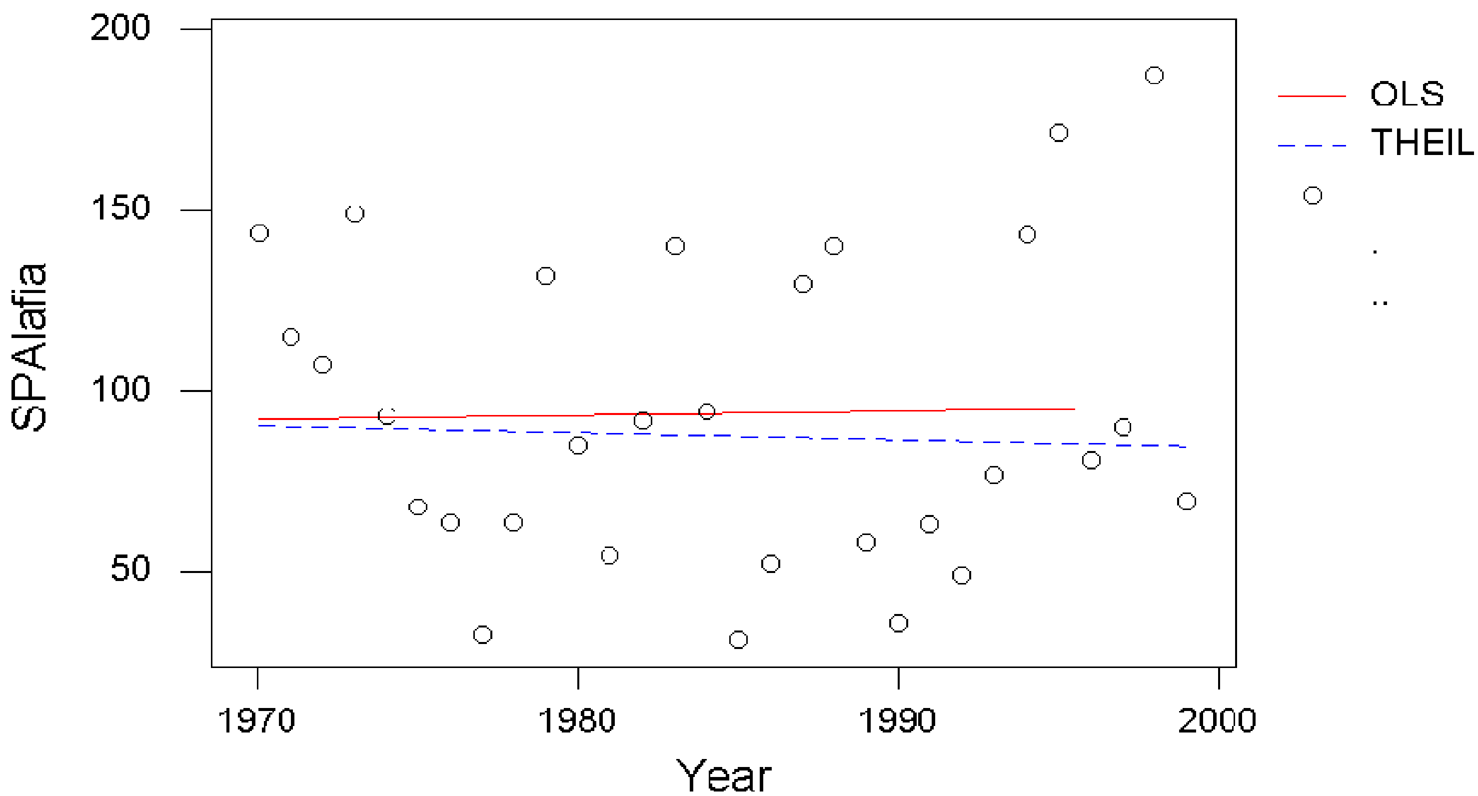


Figure 2-22. Graphical results of Kendall's tau test for trend in mean annual flows for the South Prong of the Alafia River for the period 1970 to 1999. Both the OLS and Thiel best fit lines are shown. The slope of the Thiel line is -0.1918 with a p value of 0.8028.

Comparisons of land use changes and flows in the North and South Prongs of the Alafia River provides an additional means for evaluating the impact of mining on flow in the Alafia River. Although not as extensive as in the South Prong, phosphate mining has also occurred in this sub-basin (see Table 2-8). Between 1972 and 1999, nineteen percent (19%) of the North Prong watershed was mined; during this same time 63% of the South Prong watershed was mined. Using the logic applied by SDI (2003), one would expect to see a substantially greater reduction in flow in the South Prong due to mining than the reduction that would have occurred in the North Prong since the amount of watershed mined was more than three times greater.

Table 2-8. Percent of area mined above three USGS gages in the Alafia River watershed.

	Percent of Watershed Mined		
Year	*North Prong*	*South Prong*	*Lithia minus NP&SP*
1972	**16**	**10**	**10**
1990	**34**	**63**	**16**
1999	**35**	**72**	**18**
Increase (1972 to 1999)	**19**	**62**	**8**
Area (sq miles)	**135**	**107**	**93**

Note: USGS lists area above South Prong gage as 107 sq miles;
SWFWMD determined the area based on 1999 landuse map to be 112 sq miles

Inspection of percent exceedance flows and comparison of decadal flow plots for these two sub-basins suggest that mine-related discharges were greater in the North Prong than the South Prong; however, water quality and flow data suggest that low flows were increased in both systems. Percent exceedance flow plots indicate similar temporal declines in mine-related discharges in both systems; flow data indicate that mine related discharges were essentially eliminated from both the North and South Prongs by the late 1970s or early 1980s. Decadal by decadal comparisons of flow between the two sub-basins (Figure 2-23 verifies that both sub-basins have discharged remarkably similar flows (cfs/square mile) over the last several decades. These flows are essentially identical despite the fact that more than three times the area has been mined in the South Prong as in the North Prong. If flows decline as percent of mined area increases, one would expect to see monotonic flow declines in both sub-basin watersheds, and one would also expect to see a much greater rate of decline in South Prong flows relative to North Prong flows. The logic in selecting the South Prong as a good candidate for demonstrating mining impacts related to increased area of mined land was sound, in that, given the relatively larger increase in mined area since 1963 and the relative lack of other land use changes, one should expect to see a flow impact if increasing area of lands mined does in fact lead to decreases in stream flow. However, this was not the case. The remarkably similar discharges evident between the two watersheds despite relatively large differences in percent of land disturbed by mining suggests that these watersheds have tolerated considerable land disturbance without appreciable changes in flow as measured at USGS gage sites. Inspection of these decadal plots further suggests that the timing and seasonality of flows was not appreciably affected either. As a final check various annual percent exceedance flows per unit area (cfs/square mile) are compared in Figure 2-24. With the possible exception of the lowest flows plotted (annual 90% exceedance flows), examination of these plots suggests that mining may have lead to slightly increased flow. Again, if SDI (2003) is correct, one should expect to see a substantially greater reduction in flow when the South Prong is compared to the North Prong, this is not the case.

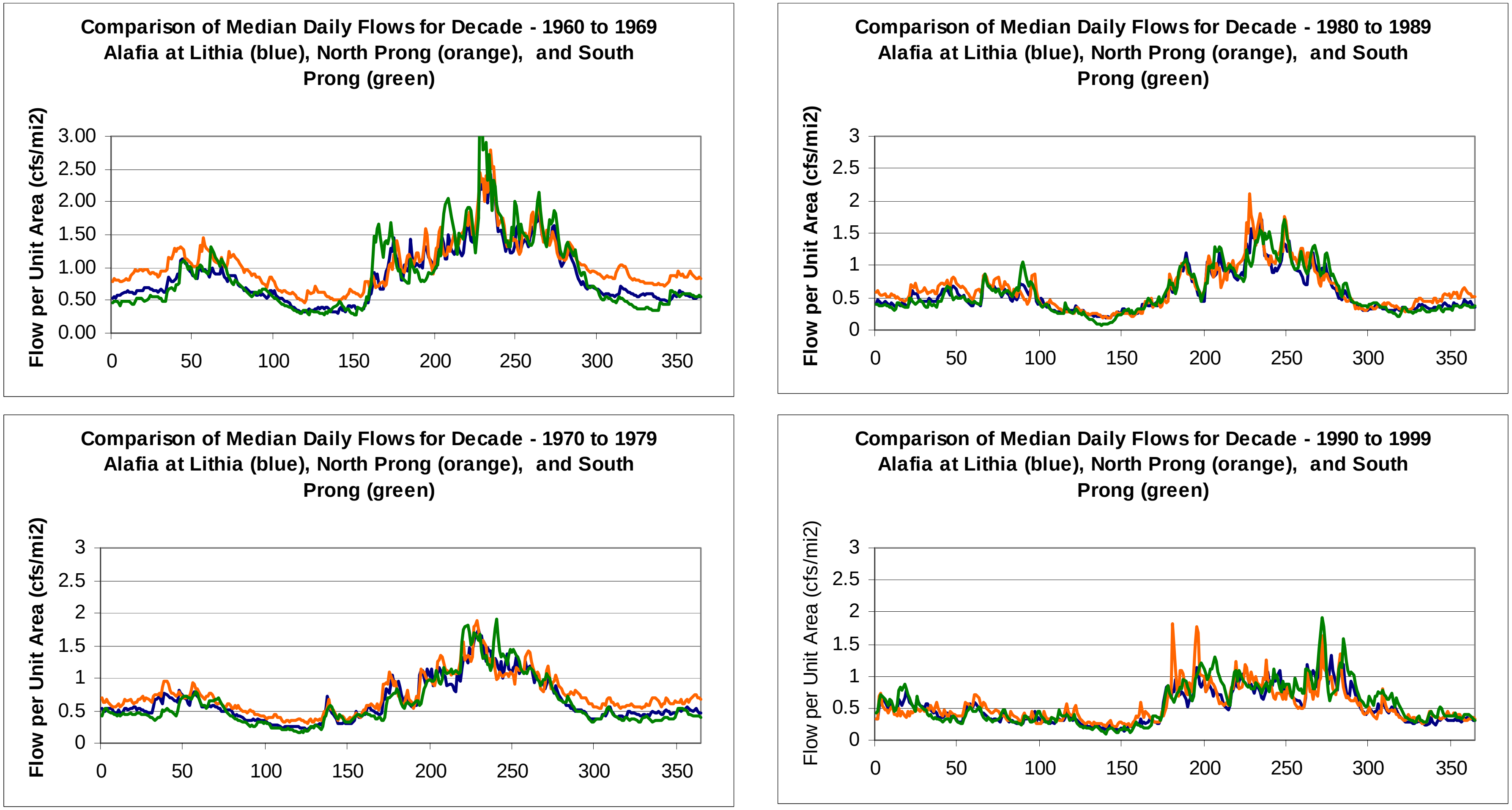
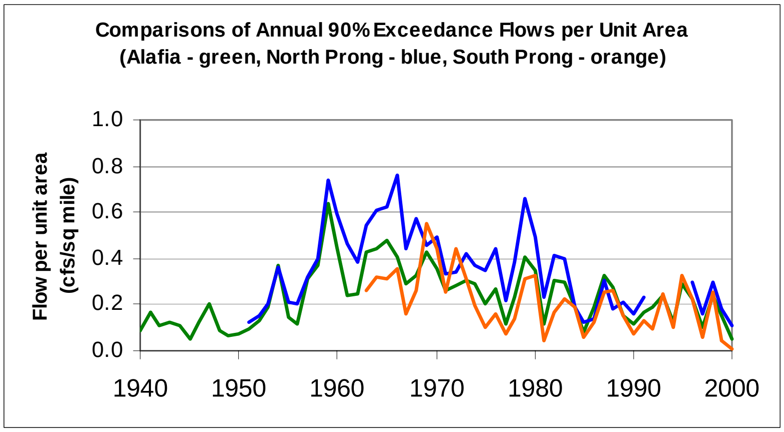
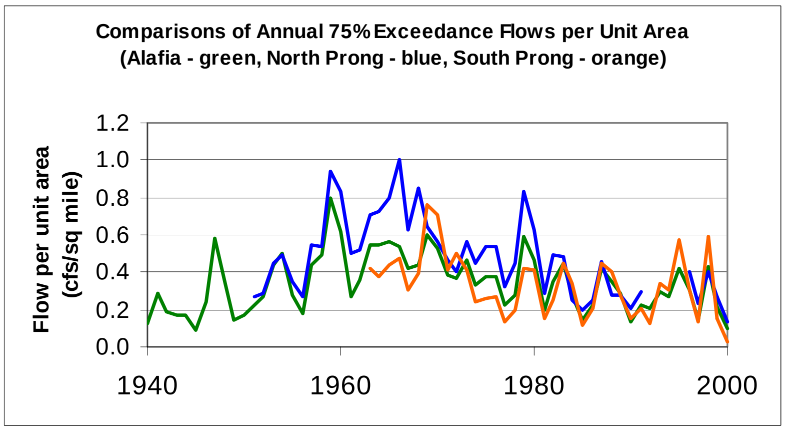


Figure 2-23. Plots comparing decadal median daily flows normalized by watershed area for the Alafia River at Lithia and the North and South Prongs.





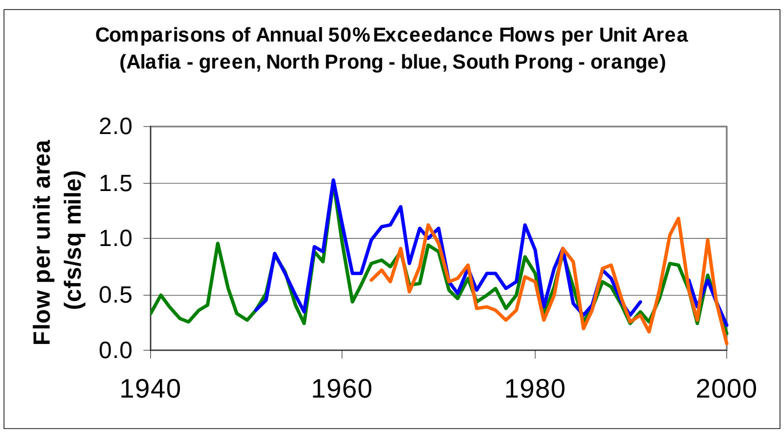
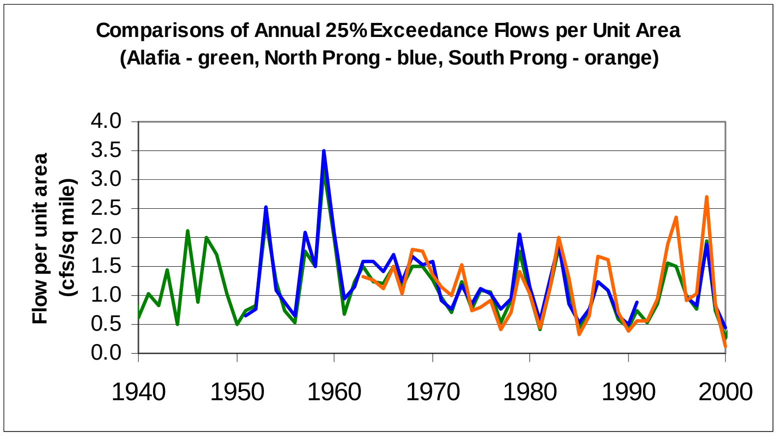


Figure 2-24. Comparison of selected annual percent exceedance flows normalized by watershed area for the Alafia River at Lithia and the North and South Prongs.



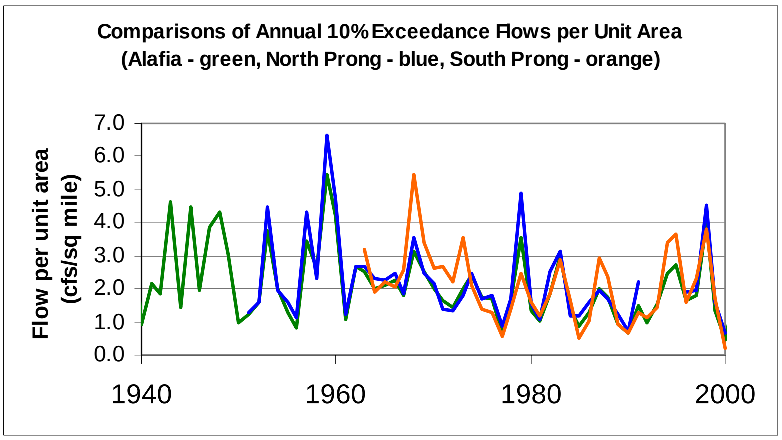


Figure 2-24 (continued). Comparison of selected annual percent exceedance flows normalized by watershed area for the Alafia River at Lithia and the North and South Prongs.

2.3.4.3 Lithia Springs and Buckhorn Springs

2.3.4.3.1 *Site Description (taken largely from Champion and Starks 2001, and Jones and Upchurch 1993)*

The Lithia/Buckhorn Springs group lies in central Hillsborough County, three miles south of Brandon along the Alafia River (Figure 2-1). The group is comprised of two second-magnitude springs and a number of smaller third-magnitude springs. "Discharge at Lithia Springs exhibits significant seasonality, reaching a minimum at the end of the dry season in May and peaking in October, after the end of the summer wet season. This pattern indicates that the lag time between seasonal changes in rainfall and the response of the spring system is minimal. The pattern also indicates that the circulation of ground water in the Floridan aquifer is open and vigorous and the springs are recharged by precipitation falling in close proximity (5-10 mile radius) of the springs" (Champion and Starks 2001).

Lithia Springs is located in a county operated park, and actually consists of two springs, each of which feeds a short run before emptying into the Alafia River. The larger spring is referred to as Lithia Springs Major. The park is open for swimming in the spring pool (Figure 2-25), camping, canoeing (in the river), and picnicking. The vent for Lithia Springs Major lies in 10-15 feet of water, underneath an outcropping of limestone. A large steel grate covers the opening of the vent. The spring pool is somewhat oval with a diameter of 75 to 100 feet. Lithia Springs Major is the subject of an MFL determination as described in Chapters 4 and 5 of this report.

Figure 2-25. Lithia Springs Major bathing area being utilized for recreation.

Buckhorn Springs complex is located on private property, about four miles west of Lithia Springs. The complex is composed of four principal springs and many smaller, less significant vents located near Buckhorn Creek. Buckhorn Springs Main is by the far the largest of the four springs and is the subject of an MFL determination. Its average discharge was reported by Jones and Upchurch (1993) to be 14 cfs with the three smaller springs discharging an estimated 3.6 cfs total. The springs are on private property (Cargill, Inc.). The District has issued a water use permit to Cargill, Inc. for use of a portion of the spring discharge as an industrial water supply. A pumping platform has been constructed directly over the Buckhorn Springs Main (Figure 2-26), and water is pumped from the spring to a phosphate processing facility located on US 41. The spring pool empties directly into Buckhorn Creek which discharges into the Alafia River approximately 0.4 miles downstream.

Figure 2-26. Photographs showing pumping platform located above Buckhorn Springs Main (upper photo) and Buckhorn Creek downstream of the spring vent (lower photo).

2.3.4.3.2 *Discharge from Lithia Springs Major and Buckhorn Springs Main*

Discharge from Lithia and Buckhorn Springs is measured manually; daily values like those for the USGS gage sites on the Alafia River are, therefore, not available. Fortunately, Tampa Bay Water measures discharge at both locations on a regular basis (weekly and sometimes more often). For this report, daily flow records were constructed by interpolating between available flow values and adjusting measured flows by including reported withdrawal volumes. Withdrawals at both spring sites are reported as monthly totals; within each month, monthly totals are distributed evenly between days of the month.

In comparison to USGS maintained gage sites on the Alafia River and its major tributaries, the flow records for Lithia Springs Major and Buckhorn Springs Main are relatively short. The Buckhorn Springs record begins in 1987 with a four-year gap extending from January 1997 to August 2000. The Lithia Springs Major record begins in March 1983 and extends to present. The Lithia Springs Major record can be extended somewhat by using periodic flow measurements made by the USGS. USGS measurements have been made on about a quarterly basis since 1966 with infrequent measurements (much less than one per year) in prior years.

Lithia Springs Major Discharge

The reconstructed daily flow from Lithia Springs Major (referred to hereafter simply as Lithia Springs) is shown in Figure 2-27. Discharge from Lithia and Buckhorn Springs is not well correlated with Floridan aquifer well levels. Various workers have therefore concluded that the springs are connected to a local conduit that is not directly influenced by the regional potentiometric surface (Jones and Upchurch 1993, Basso 1998, SDI 2002). A poor relationship between stage and discharge has also been reported for Lithia Springs (see Figure 2-28). Close inspection of the data, however, indicates that there is a good relationship (R^2=0.???) between stage and discharge (as should be expected) when flows in the Alafia River are low (Figure 2-28). The correct interpretation of the stage to discharge relationship observed for Lithia Springs is that once the stage of the Alafia River increases beyond a certain point, the river essentially controls stage in the Lithia Springs run and in the pool. The data suggest that there is a fairly well defined relationship between stage and discharge at Lithia Springs until the Alafia River discharge as measured at the Lithia gage exceeds approximately 70 cfs. The stage at Lithia Springs is under control of the river for much of the year.

The daily flows for Lithia Springs are shown in Figure 2-27. Despite the extreme low flows encountered during the period of record drought in 2000, a Kendall's tau test on daily flows since 1983 indicates a statistically significant increasing trend in flows for Lithia Springs ($p = 0.0000$; slope = 0.00245, Figure 2-29).

Since 1984, the mean annual flow of Lithia Springs corrected for withdrawals has been 32 cfs, with annual means ranging between 19 to 50 cfs.

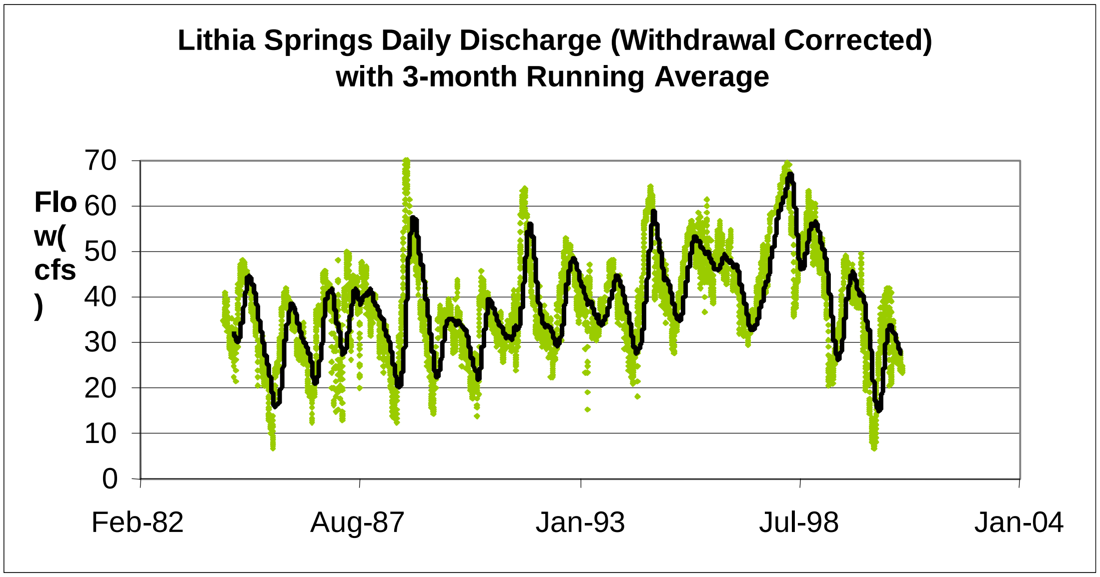
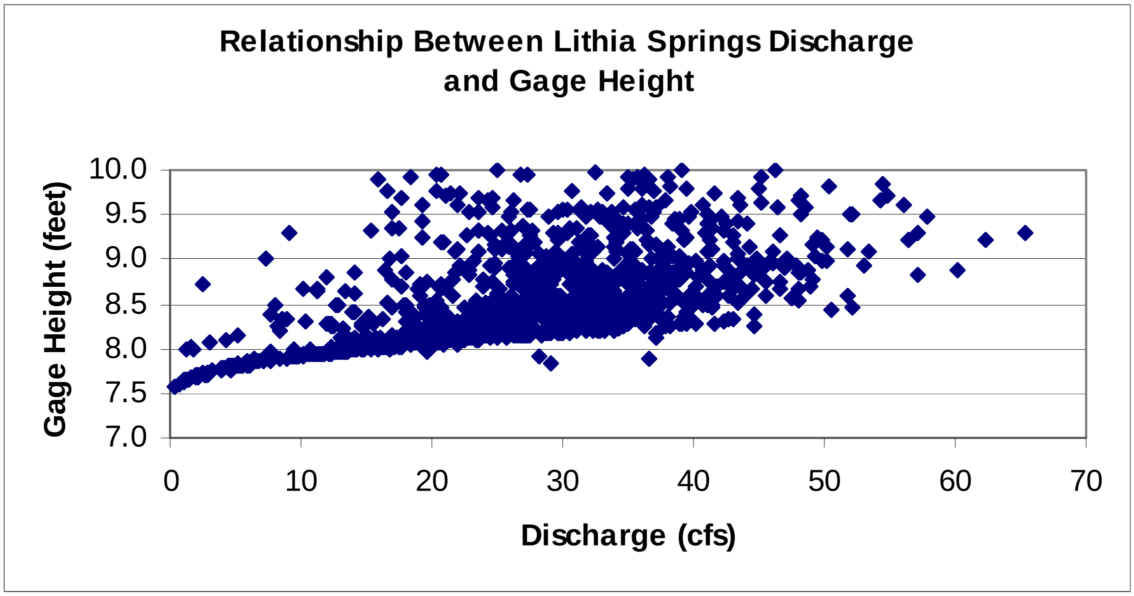


Figure 2-27. Daily flow record for Lithia Springs Major corrected for withdrawals.



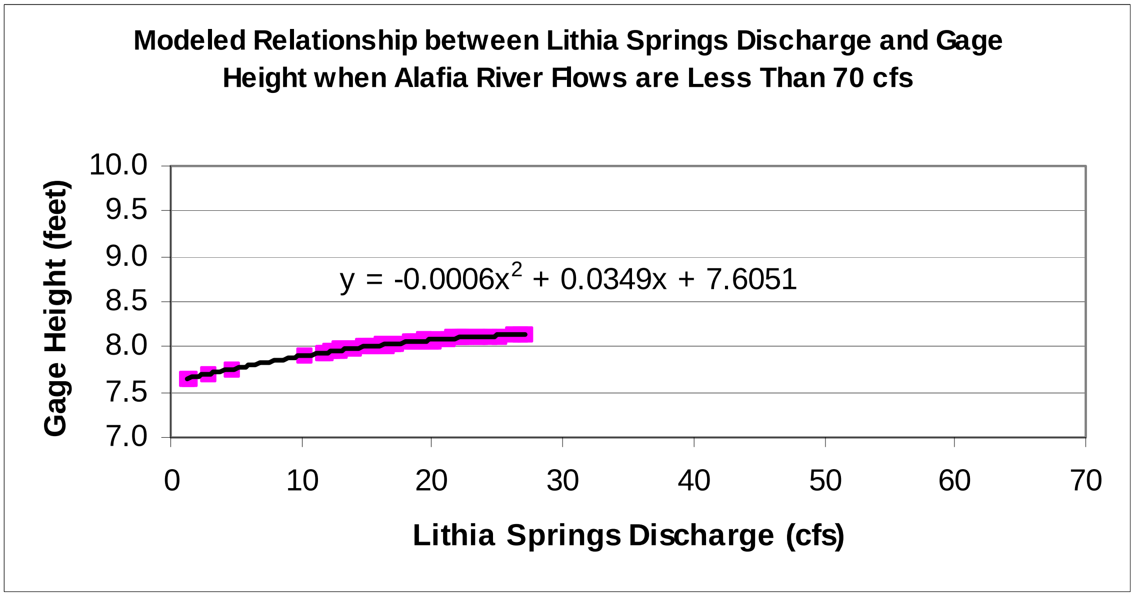


Figure 2-28. Relationships between Lithia Springs Major discharge and stage. Upper panel shows gage height (water surface elevation in feet above NGVD) versus discharge for all available data. Lower panel shows gage height versus discharge when flows in the Alafia River are 70 cubic feet per second or less.

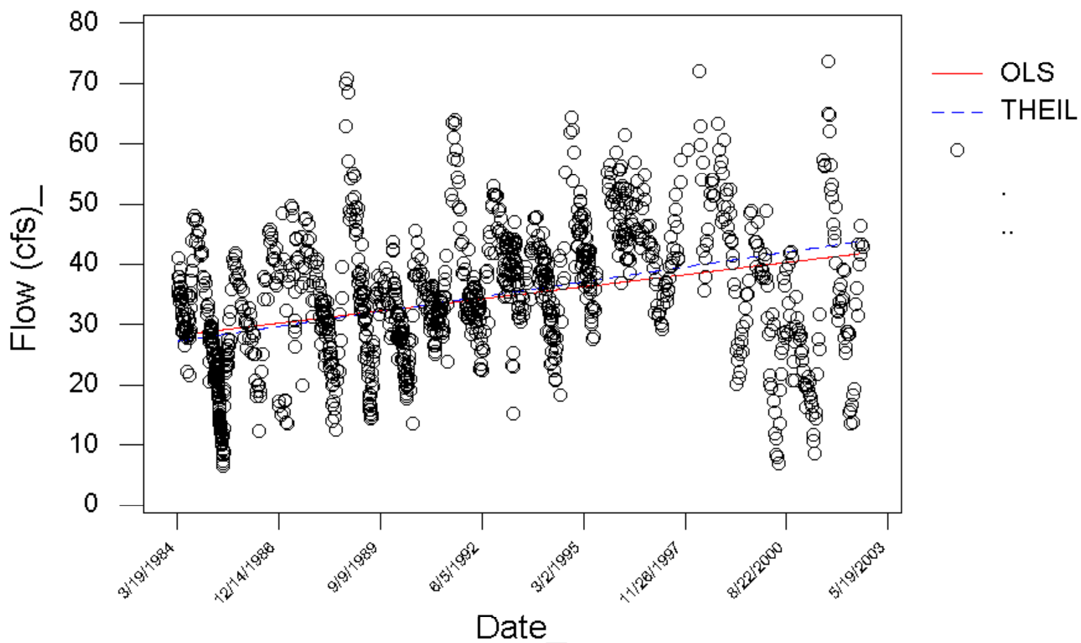


Figure 2-29. Graphical results of Kendall's tau for trend in daily flow (corrected for withdrawals) for Lithia Springs Major for period 1983 to 2002. The slope of the Thiel line is 0.00245 with a p-value of 0.0000.

Buckhorn Springs Main Discharge

Buckhorn Springs Main daily discharge corrected for withdrawals is shown in Figure 2-30. Again, despite the period of record drought, a Kendall's tau test of the daily flows against time indicates a significant increasing trend in flow for Buckhorn Springs (Figure 2-31; p=0.0000; slope = 0.00047). Since 1987, the mean annual flow of Buckhorn Springs corrected for withdrawals has been 13 cfs, with all mean annual flows ranging from 10 to 15 cfs. In contrast to Lithia Springs, Buckhorn Springs flow varies over a relatively narrow range.

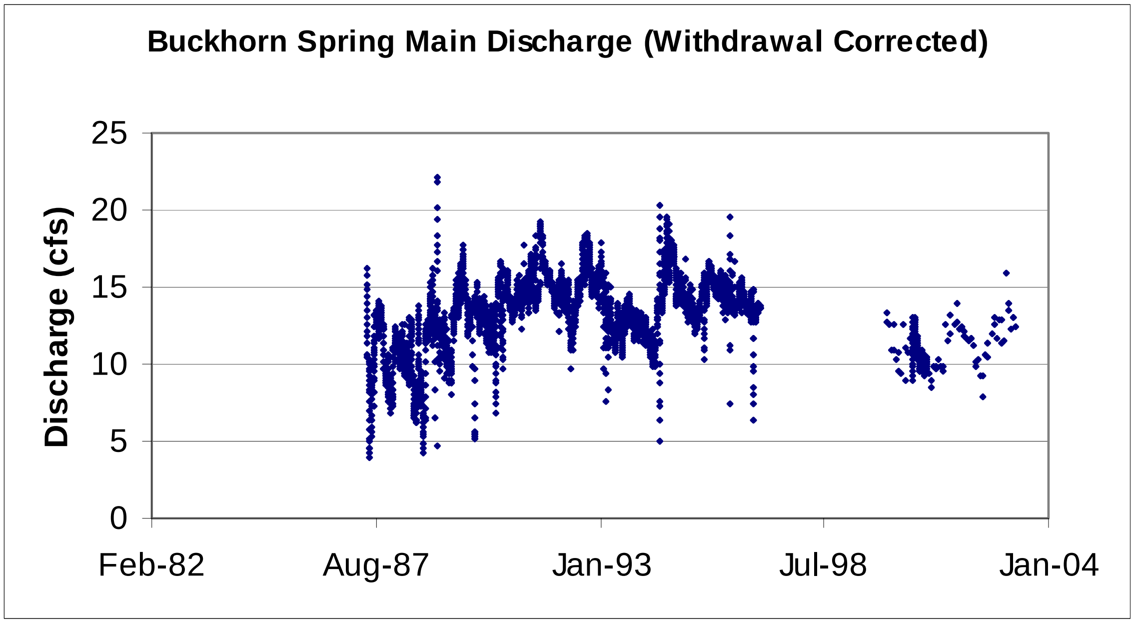


Figure 2-30. Daily flow records for Buckhorn Springs Main corrected for withdrawals.

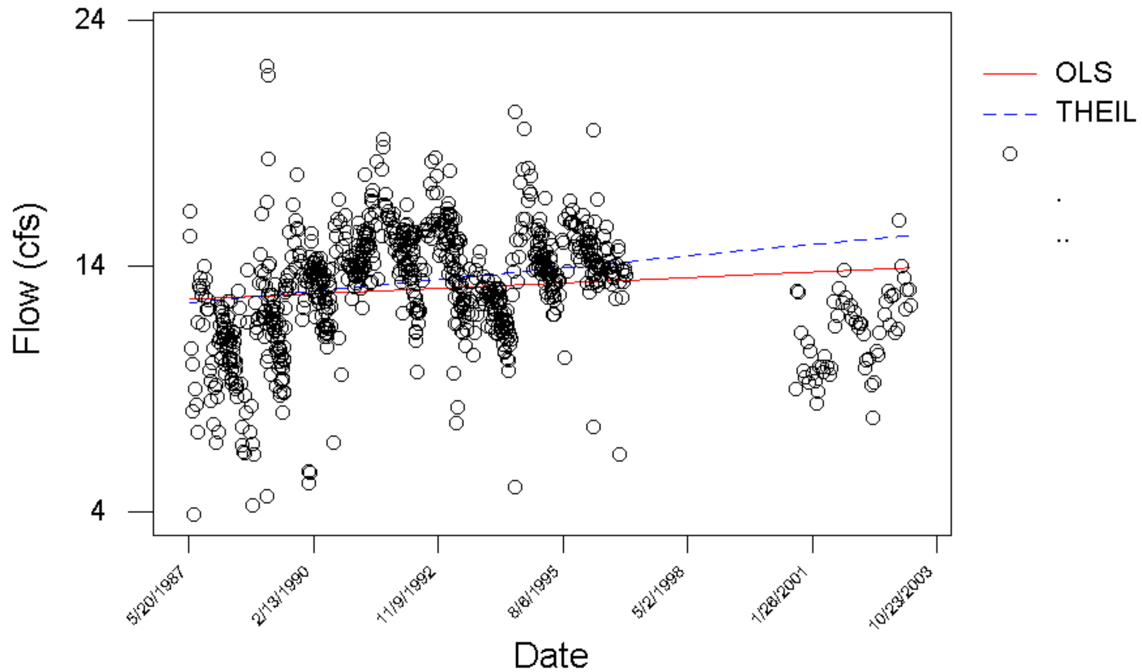


Figure 2-31. Graphical results of Kendall's tau for trend in daily flow (corrected for withdrawals) for Buckhorn Springs Main for period 1987 to 2002. The slope of the Thiel line is 0.00047 with a p-value of 0.0000.

2.4 Water Chemistry

Although flow can affect water quality, it is not expected that the adoption and achievement of minimum flows will necessarily lead to substantial changes in Alafia River water quality; however, it is appropriate to review the water quality of the Alafia River to fully appreciate how land use changes have affected the river. The Alafia 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. Examination of water quality data is useful for understanding the complex nature of flow changes in the Alafia River.

Long-term water quality changes were evaluated using USGS data gathered at gage sites on the Alafia River proper (near Lithia) and on the North and South Prongs of the Alafia River. Comparison of water quality data with flow records was made for evaluation of relationships between flow and land use. In addition, comparisons were made with sites on other river systems, specifically the Peace River at Arcadia, 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 Withlacocchee 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, all 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 are typically presented in three plots. One plot is a simple time-series plot, which is followed by a plot of the parameter versus flow. The third plot typically presented is a plot of the residuals obtained from a LOWESS regression of the parameter versus flow. The last plot is 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 was used to help determine if apparent increasing or decreasing trends in a parameter were statistically significant.

2.4.1 Macronutrients: Phosphorus and Nitrogen

Concentrations of the two major macronutrients, phosphorus and nitrogen, have been monitored for some time at the Lithia gage site and somewhat less frequently at the North and South Prong 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.

2.4.1.1 Phosphorus

Phosphorus concentrations have been reported by the USGS as total phosphorus, dissolved phosphate, and as ortho-phosphate. For purposes of this discussion, 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 Peace River (SWFWMD 2002), historic P concentrations in the Alafia River and its major tributaries (North and South Prongs) were impressive (see Figures 2-32, 2-33). A record high of 105 mg/l P was reported for a sample collected on the North Prong on April 28, 1969. Considering that background concentrations for a tributary in the Bone Valley area should probably be between 0.1 and 0.5 mg/l P, this high value is 200 to 1000 times higher than should be expected. Although 105 mg/l P is the extreme, values in excess of 20 mg/l were frequently found before 1975 in the North Prong. While considerably improved over past conditions, P concentrations in the neighborhood of 5 mg/l still occur in the North Prong of the Alafia. Fewer measurements have been taken from the South Prong, but it appears that concentrations have never been as high as those on the North Prong. However, concentrations above 1.5 mg/l should not be considered natural for this system. Because the North and South Prongs contribute approximately 81% of the flow (and a combined 72% of the watershed above the gage) as measured at the Lithia gage, it should be expected that concentrations of most constituents should be reflected in concentrations of water samples taken at Lithia. While concentrations greater than 4 mg/l P have not been recorded since 1990, P concentrations have not yet reached levels that would be considered background. It can be concluded, however, that P concentrations and consequently the load of this nutrient has diminished considerably since the mid-1970s. The high historical (pre-1970) P concentrations were attributed to water discharged from phosphate mining operations or their associated chemical plants.

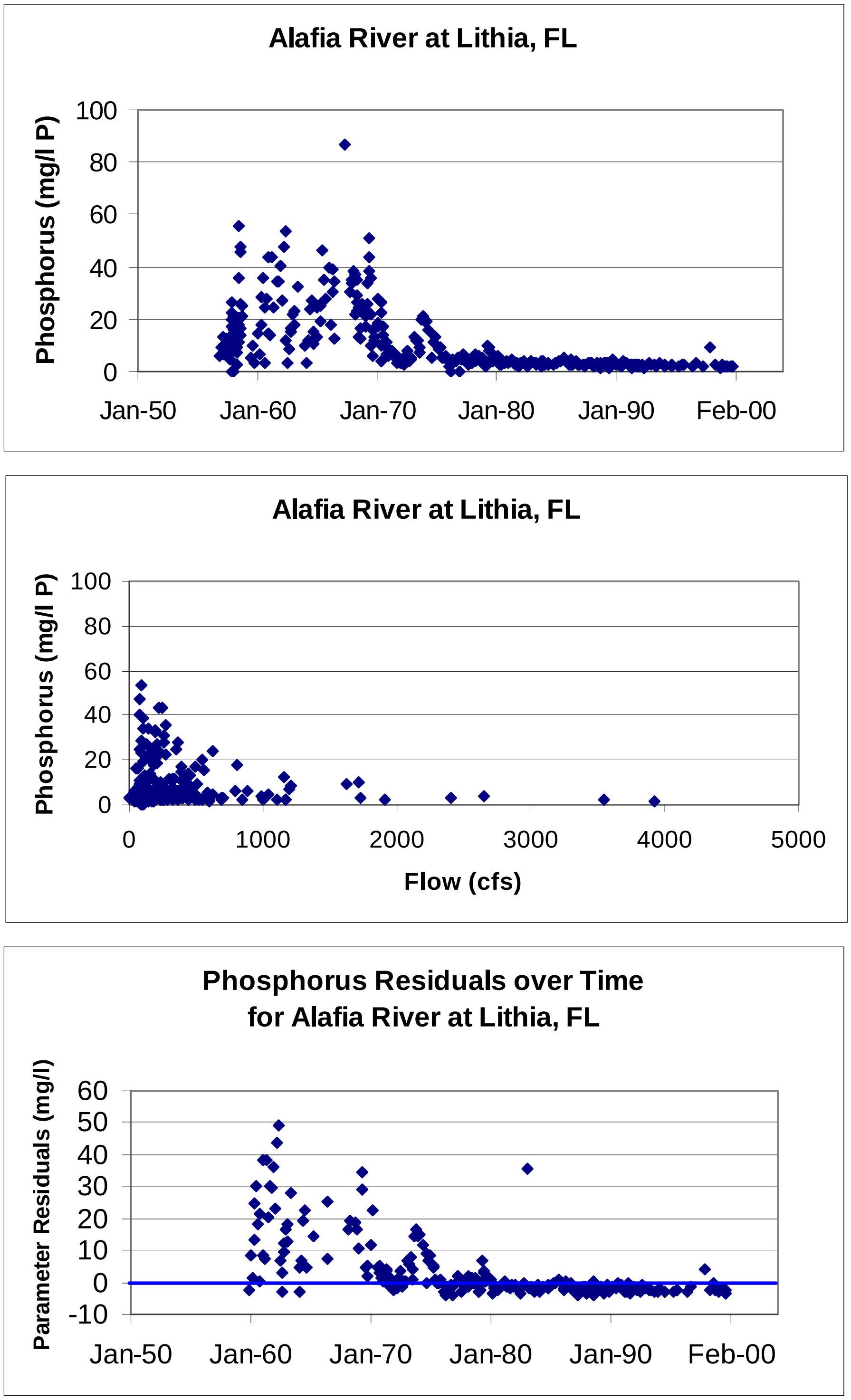


Figure 2-32. Phosphorus concentrations in water samples collected by the USGS at the Alafia River at Lithia gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

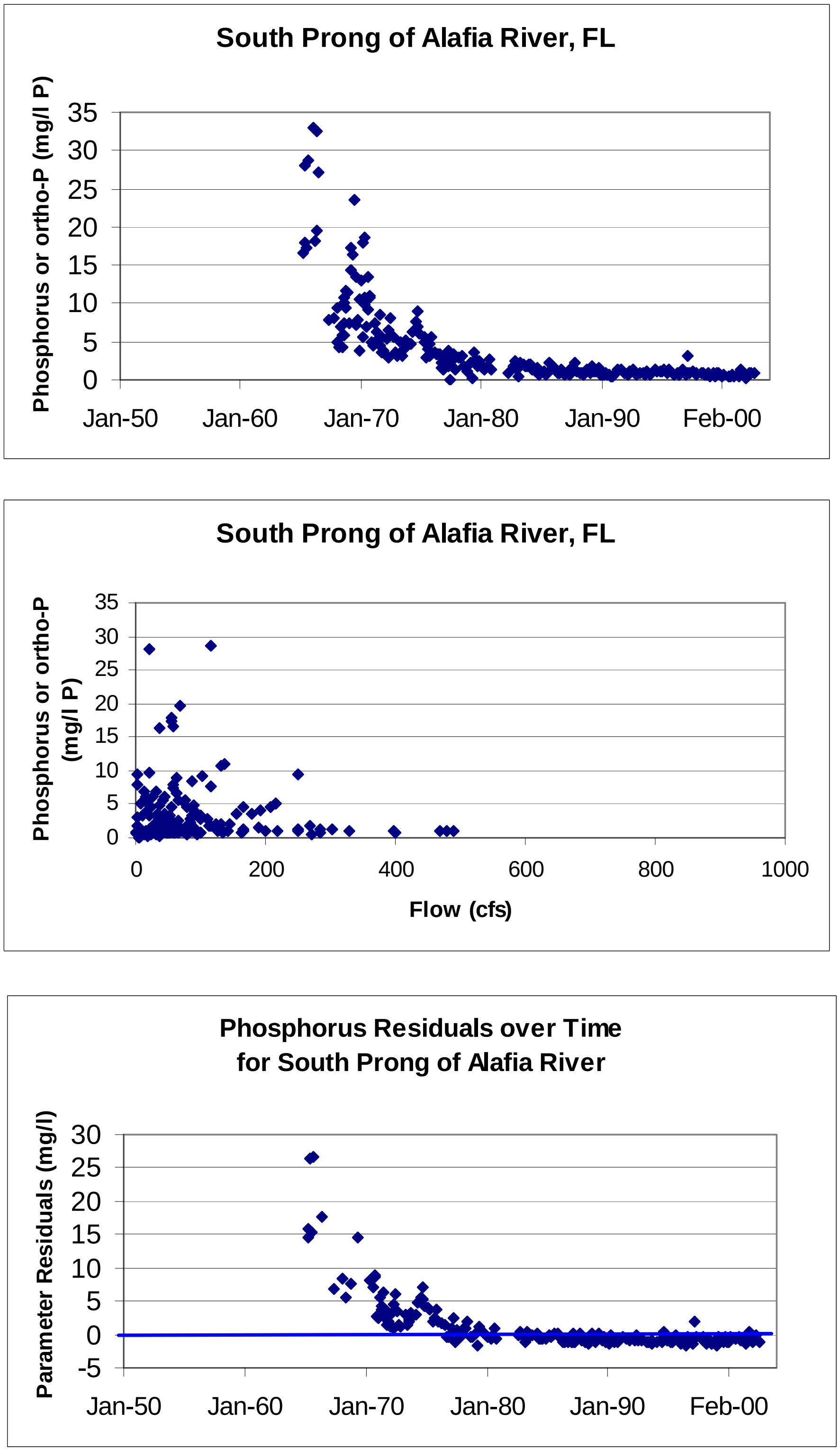
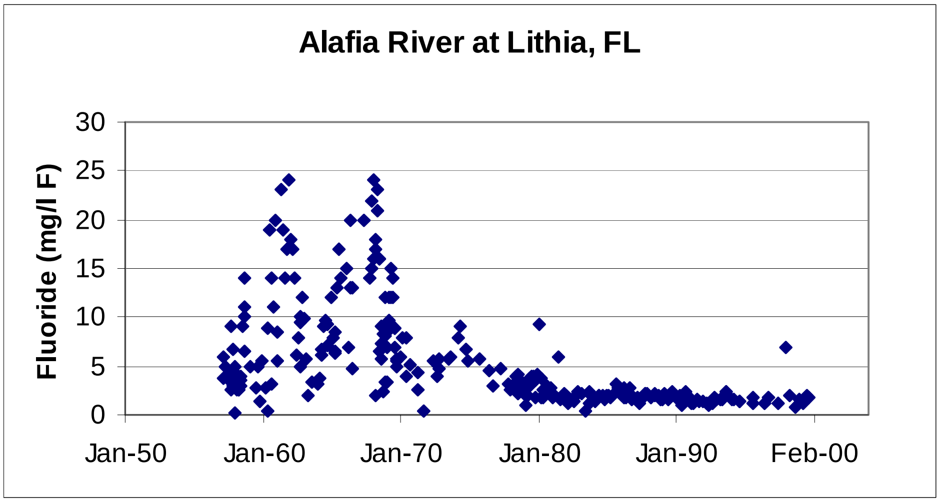


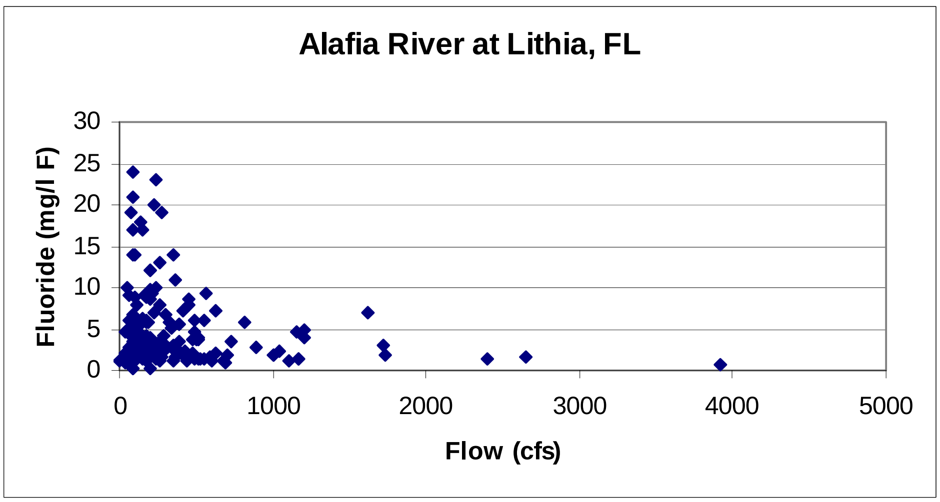
Figure 2-33. Phosphorus concentrations in water samples collected by the USGS at the South Prong Alafia River near Lithia, FL. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

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 by agriculture or from residential areas), there can be little doubt that the elevated concentrations seen in the Alafia 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. Most of this mining (89%) has occurred in the sub-basins of the North and South Prongs. Supporting data are seen in elevated concentrations of a number of other chemical constituents, for example fluoride (an element commonly found in association with phosphate). Beginning in the mid-1970's, there is a rather sudden decline in phosphorus and other chemical constituents found in association with phosphate ore (e.g., fluoride, silica). This decline is graphically apparent (see Figure 2-34). Concomitant declines in fluoride and phosphorus are evidence of a change in mining practices that lead to dramatic reductions in phosphorus (and other constituent) loading to the Alafia River system around 1975-1980.

Unfortunately, there are no long-term records of in-stream phosphorus concentrations at the three gage sites prior to phosphate mining in the watershed (this is true of the upper Peace River also – see SWFWMD 2002). It is therefore difficult to determine if current in-stream concentrations approach those that would have been expected absent mining impacts. While there has been a considerable decrease in loading (perhaps an order of magnitude or more), concentrations of phosphorus (the majority of which is in the most biologically available form, phosphate) 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, 95% of all Florida streams exhibited total phosphorus concentrations less than 1.99 mg/l P. The 1990 to 1999 decade mean for the Alafia River at Lithia is 2.54 mg/l P (the median is 2.40) which despite large decreases in concentration still places it among the rivers with the highest P concentrations in the state.

Similar trends in instream phosphorus concentrations are also evident in the Peace River (SWFWMD 2002). As with the Alafia River, these elevated levels were also attributable to past mining practices and discharges from related chemical processing plants. Similarly to the Alafia River, dramatic decreases in P concentration also occurred in the Peace River (Figure 2-35, although they occurred a few years later (around the mid-1980s) than at Lithia. Like the Alafia River, other constituents found in association with phosphate also followed similar trends in concentration (e.g., fluoride – see Appendix) and similar declines as phosphate mining practices changed.





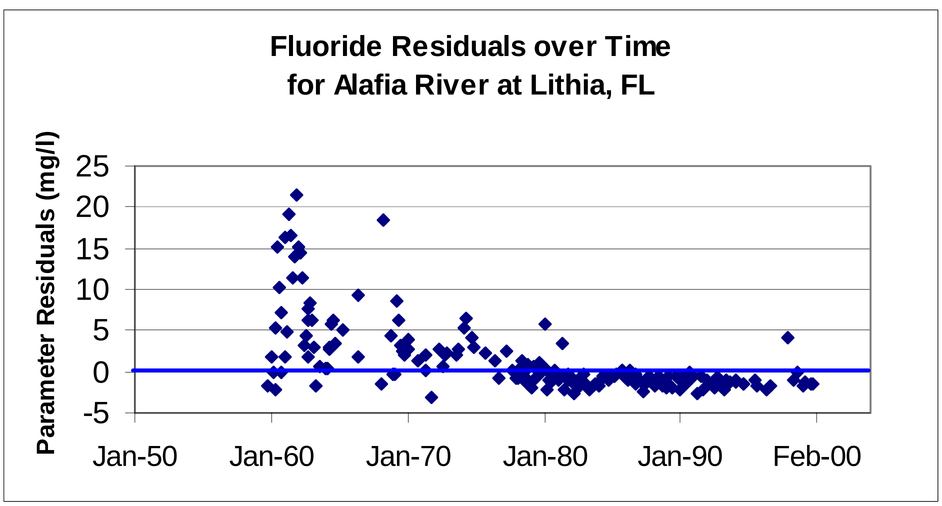
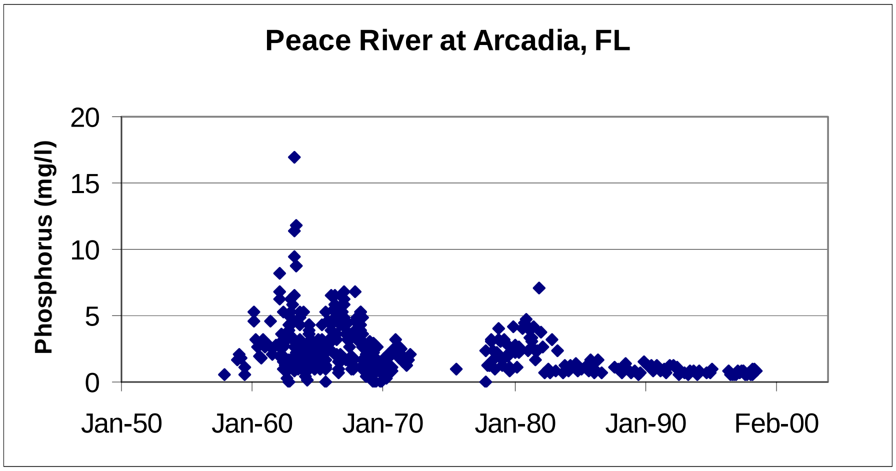
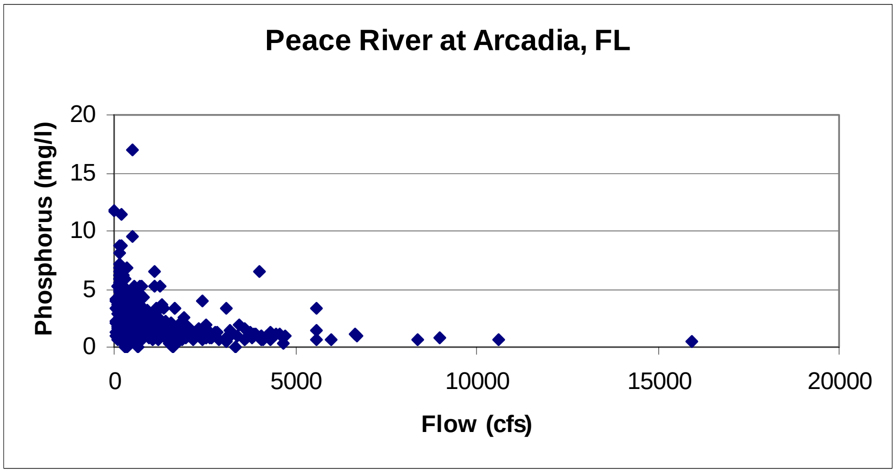


Figure 2-34. Fluoride concentrations in water samples collected by the USGS at the Alafia River at Lithia, FL. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





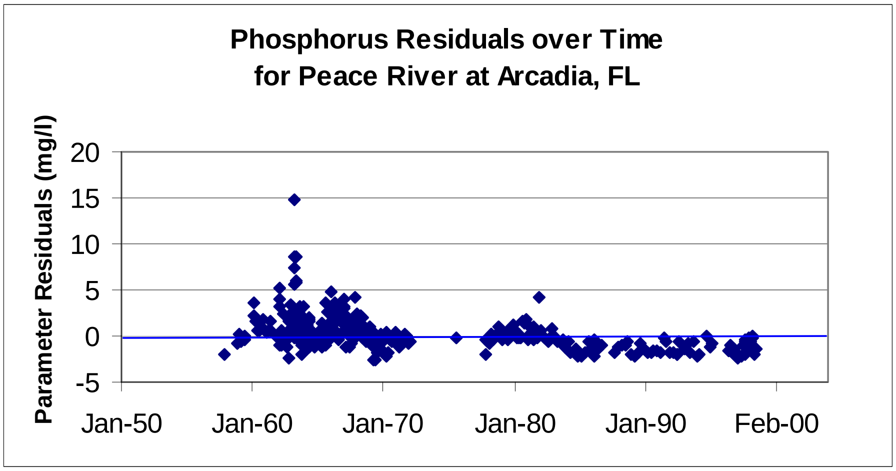
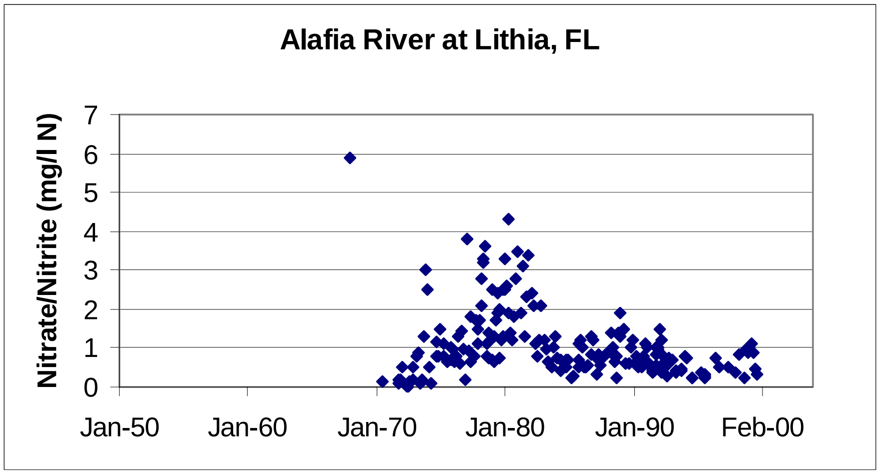


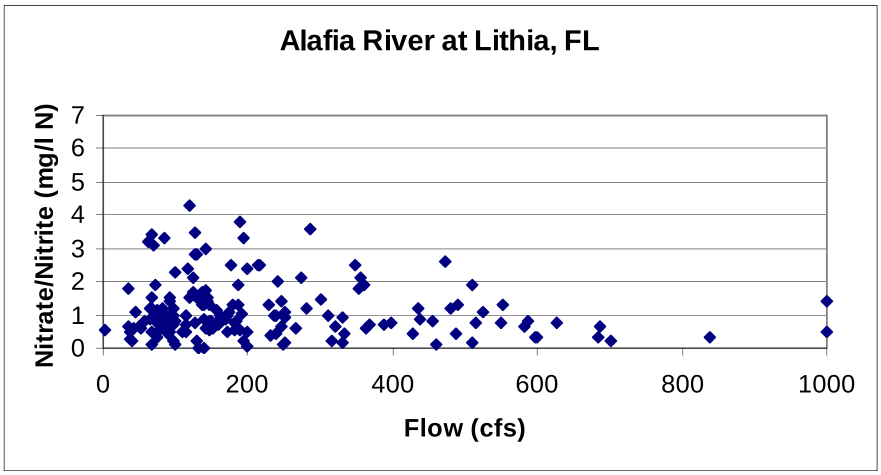
Figure 2-35. Phosphorus concentrations in water samples collected by the USGS at the Peace River at Arcadia, FL gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

2.4.1.2 Nitrogen

Nitrogen concentrations are most often reported by the USGS as the readily bio-available forms; nitrate or nitrate+nitrite. For purposes of this discussion, 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 (also a readily bio-available form) 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.

Although there was not a significant correlation between nitrogen and phosphorus concentrations, the temporal pattern exhibited by nitrogen suggests that elevated concentrations seen in the 1970s thru the mid-1980s may be mining related, since apparently amines or ammonia may be used in the processing/extraction of the ore. The data show a rather dramatic decline in concentrations around 1983 (see Figure 2-36), although the 1990 to 1999 mean concentration of nitrate+nitrite nitrogen of 0.68 mg/l N is still ten times higher than the 1956 to 1959 mean concentration of 0.06 mg/l N. Analogous to phosphorus, there has been a substantial decline in inorganic nitrogen concentrations; however, current concentrations and loadings may still be an order of magnitude higher than would be expected naturally. It appears that historically nitrogen concentrations in the Alafia River were as low as those encountered in the Withlacoochee River (Figure 2-37), where mean nitrate concentration is 0.12 mg/l N.





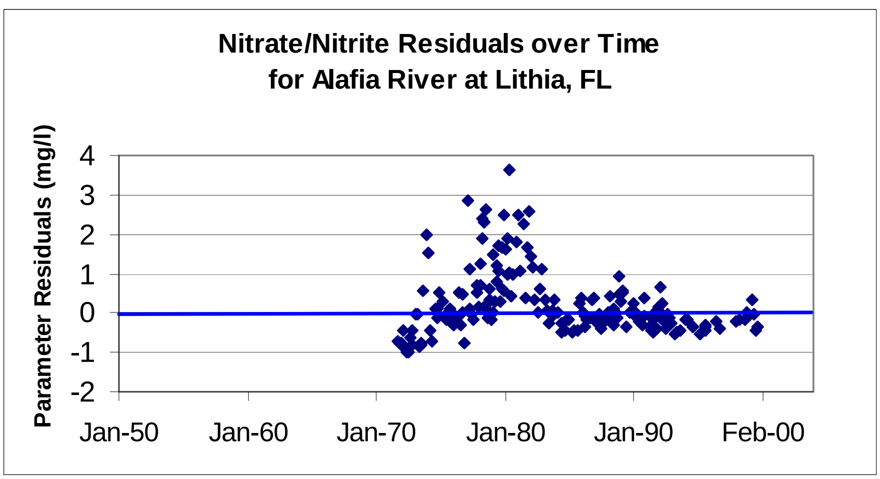
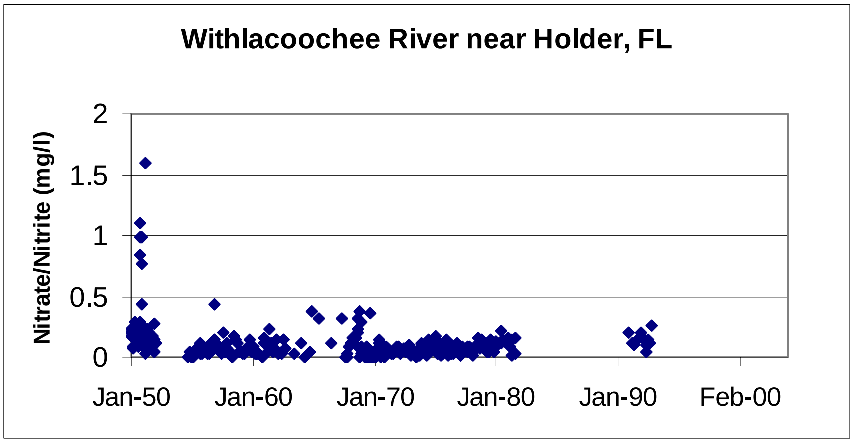
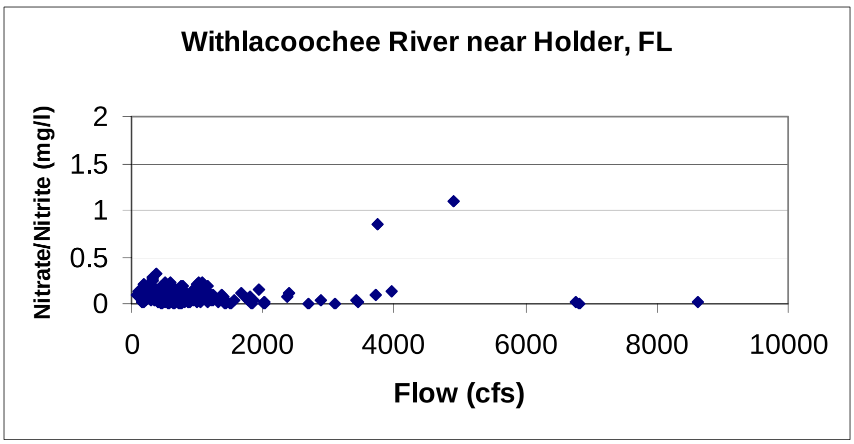


Figure 2-36. Nitrate or nitrate/nitrite concentrations in water samples collected by the USGS at the Alafia River at Lithia, FL gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





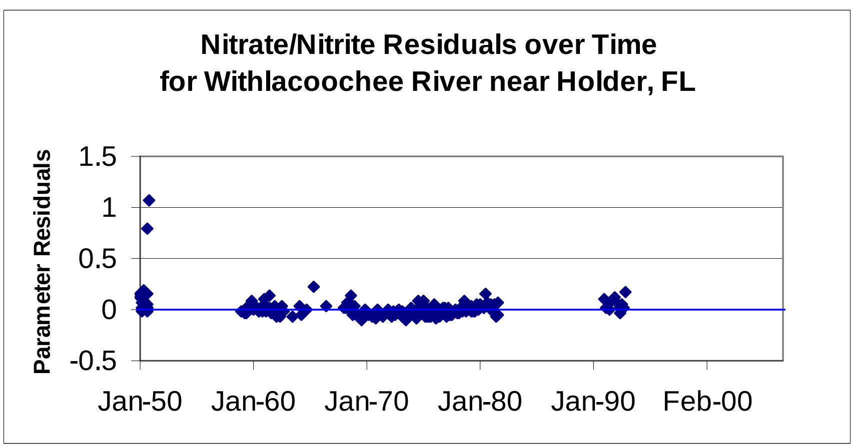


Figure 2-37. Nitrate or nitrate/nitrite nitrogen concentrations in water samples collected by the USGS at the Withlacoochee River at Holder, FL gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

2.4.2 Potassium and Trend Analysis of Selected Chemical Constituents

One of the more interesting and unanticipated finding of the analysis of gage site water quality data on the Peace River (SWFWMD 2002) was an apparent increasing trend in dissolved potassium. 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. It was speculated that the trend was most likely attributable to increasing fertilizer application within the watershed and thus may have some value as an indicator of increasing agricultural activity within the watershed.

An increasing trend in dissolved potassium is also clearly evident for the Alafia River (Figure 2-38). To determine if the trend is statistically significant and unrelated to flow, potassium concentration was regressed against flow and the residuals were tested against time using the Kendall's tau test. This non-parametric test revealed a positive and highly significant trend of increasing concentration and hence load (p value = 0.0000, slope = 0.00012). Other parameters, including conductance, pH, nitrate, phosphorus, calcium, potassium, sulfate, fluoride were also regressed against flow and their residuals determined. Specific conductance, phosphorus, fluoride, and other parameters believed associated with groundwater all showed statistically significant declining trends (Table 2-9). These trends are consistent with the reduction or elimination of discharges associated with mining when groundwater use by the industry was especially high. As the discharge of pumped ground water is reduced, one can expect reductions in those parameters typically associated with an increased ground water contribution. In addition, since the withdrawn ground water is used in the processing of the mined ore, its phosphorus concentration would be expected to increase. When the release of this process water is reduced or eliminated, P concentrations should be expected to decline, as should concentrations of those parameters associated with phosphate such as fluoride. As can be seen from Table 2-9, the pH of the river has increased. It is believed that this is attributable to the reduction or elimination of discharged phosphate mining related process water with its lowered pH. Results of Kendall's tau analysis on selected parameters from the Withlacoochee and Myakka Rivers are included for comparison (Tables 2-10, 2-11). Very few parameters (silica on the Withlacoochee, at Holder and pH and fluoride in the Myakka near Sarasota) showed statistically significant ($p < 0.05$) declines in loading; but numerous parameters (conductance, calcium, chloride, hardness, magnesium, potassium, sodium and sulfate) in the Myakka River have shown significant increased loading. This increased loading is most likely related to a significant increase in agricultural irrigation with groundwater. The Myakka River (Table 2-11 and related Appendix figures) offers an interesting contrast to the Alafia River where decreased loading of a number of parameters is likely due to the elimination or curtailment of mining related groundwater discharges.

2.4.3 Summary

Significant improvements in water quality have occurred during the past 20 to 25 years in the Alafia River. Most improvement is attributable to the reduction or elimination of phosphate mining/processing related discharges. Increasing trends in potassium (potentially related to fertilization) and nitrate have been observed. Although recent nitrite+nitrate nitrogen concentrations are substantially less than they have been in the past, concentrations are still elevated above what is believed to be natural.

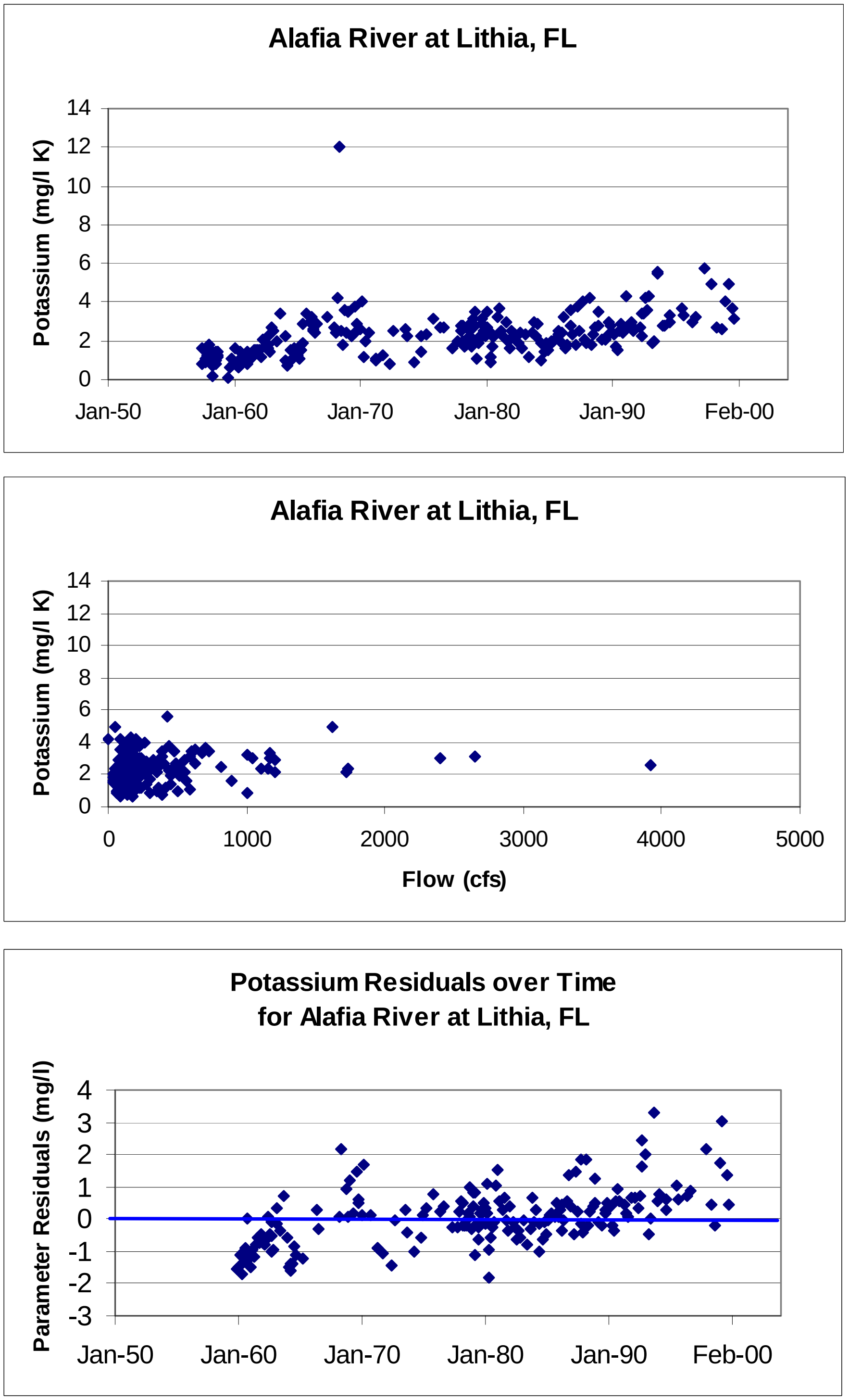


Figure 2-38. Potassium concentrations in water samples collected by the USGS at the Alafia River at Lithia, FL gage. Upper plot is time series plot; middle plot is concentration versus flow, and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.

Table 2-9. Results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant decreasing trend; blue shading indicates a statistically significant increasing trend.

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

Table 2-10. Results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant decreasing trend; blue shading indicates a statistically significant increasing trend.

WITHLACOOCHEE RIVER AT HOLDER

Parameter Residual	Residual Median	n	p Value	intercept	slope
Conductance	-2.8100	269	0.67368	-8.56307	0.00020
Dissolved Oxygen	-0.0530	170	0.23039	1.51387	-0.00005
pH	-0.0124	249	0.39982	0.09717	0.00000
NOx	-0.0006	205	0.30559	0.03173	-0.00001
Phosphorus	0.0008	168	0.00289	-0.04168	0.00000
Hardness	-1.9200	185	0.23975	8.70238	0.00270
Calcium	-0.4120	214	0.62894	0.76156	-0.00004
Chloride	0.0870	228	0.00000	-2.76800	0.00010
Fluoride	-0.0287	207	0.43782	-0.03258	0.00000
Iron	-2.6000	155	0.00000	-118.59200	0.00431
Magnesium	-0.0256	214	0.38274	0.17967	0.00001
Potassium	0.0023	204	0.03940	-0.17603	0.00001
Silica	-0.0700	223	0.02427	2.19811	-0.00008
Sodium	-0.0356	208	0.00087	-0.93858	0.00003
Sulfate	-1.6400	208	0.82802	-0.90412	-0.00003

Table 2-11. Results of Kendall's tau analysis on residuals (from various parameters regressed against flow) versus time. Yellow shading indicates a statistically significant decreasing trend; blue shading indicates a statistically significant increasing trend.

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

Chapter 3 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." The District has identified loss of flows associated with fish passage and maximization of stream bottom habitat with the least amount of flow as significantly harmful to river ecosystems. 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 then 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 Alafia 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, Figure 3-1) 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 (Cufney 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 as compared to sand substrata. 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. Organisms in 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 1976, 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 MFL 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 are likely to 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 riffle or shoal area. Many potential in-stream habitats such as limestone (foreground), snags, sandbars, and exposed roots are not inundated in this stream reach under low flow conditions.

Chapter 4 Technical Approach for Establishing Minimum Flows and Levels for the Alafia River, Lithia Springs Major and Buckhorn Springs Main

4.1 Overview

Methods used to determine the minimum flow requirements for the freshwater portion of the Alafia River and associated springs are described in this chapter. The approach outlined for the river involved 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 was used to identify a minimum flow condition for Block 1, but 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. Methods used for the springs involved development of prescribed flow reductions based on habitat availability assessments and evaluation of recreational-use requirements.

4.2 Transect Locations and Field Sampling of Instream and Floodplain Habitats

The Alafia River study corridor extends approximately 16 miles from Buckhorn Springs near Riverview, Florida, upstream to Aldermans Ford Park (along County Road 39) near the confluence of the North and South Prongs of the Alafia River (Figure 4-1).

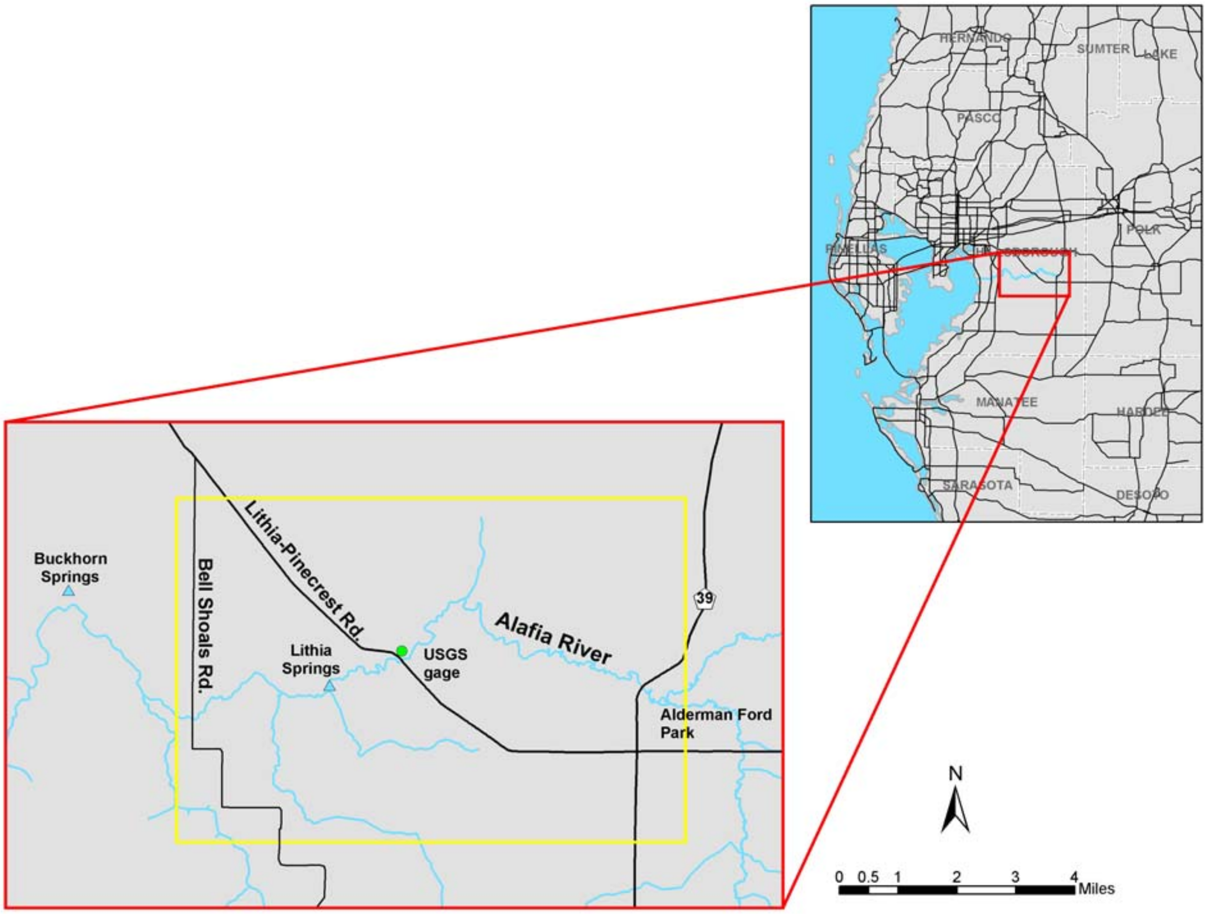


Figure 4-1. Study corridor for the Alafia River.

Sampling sites within the study corridor were situated along the freshwater section of the Alafia River that begins near Bell Shoals Road and extends upstream. Sampling was also conducted in Buckhorn Creek and the Lithia Springs Major spring run. Buckhorn Creek, which conveys discharge from Buckhorn Springs Main to the mainstem of the Alafia River is the only sampled site that is tidally influenced by backwater from Tampa Bay.

Sampling included characterization of cross-sectional physical, hydrological and biological features and semi-quantitative sampling of macroinvertebrate and fish assemblages. 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 flow records from the existing USGS Lithia gage site. Macroinvertebrate and fish assemblages were sampled to characterize these groups within the river system.

4.2.1 HEC-RAS Cross-Sections

Cross section channel geometry data used to generate a HEC-RAS model for the Alafia River corridor were obtained from previously established USGS channel cross sections (Robertson 1978, Lewelling 2003) and from additional sites identified by District staff. USGS cross-sections (Figure 4-2) were developed for describing theoretical flood peak discharges, construction of flood profiles, and determining the extent of floodplain wetland inundation. 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 identified by District staff in June 2001 (Figure 4-3). Cross-section elevations and channel geometry data were obtained for a subsample of the eleven identified shoals (Nos. 1, 9 and 11) and these data were combined with the USGS cross section data for development of HEC-RAS models.

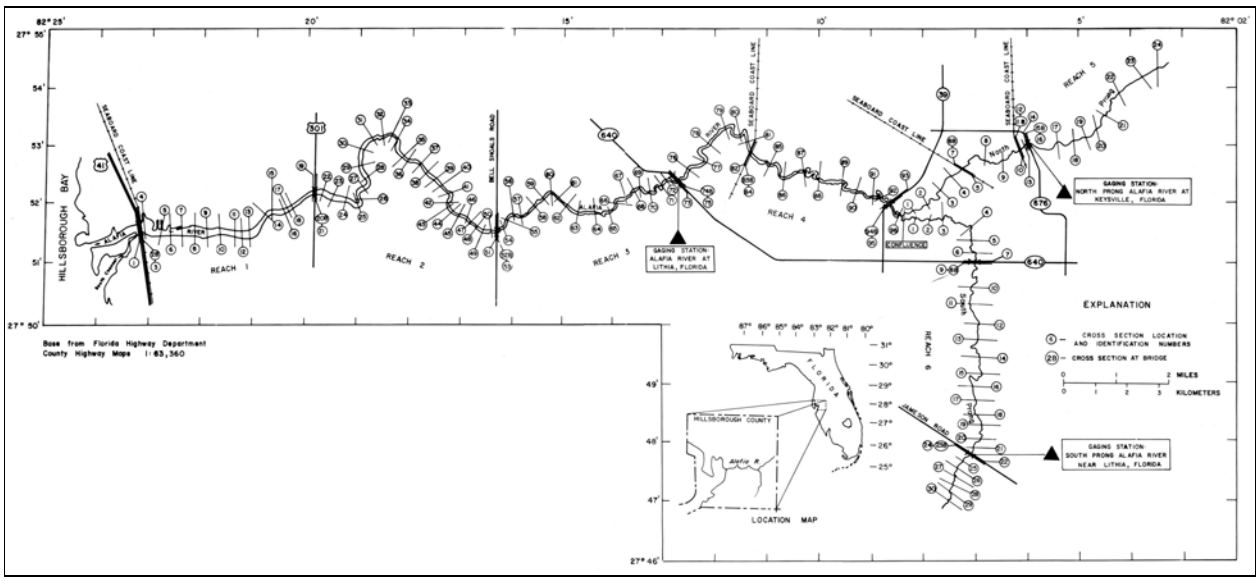


Figure 4-2. Location of USGS transects on the Alafia River used for HEC-RAS analyses. Figure reprinted from Robertson (1978).

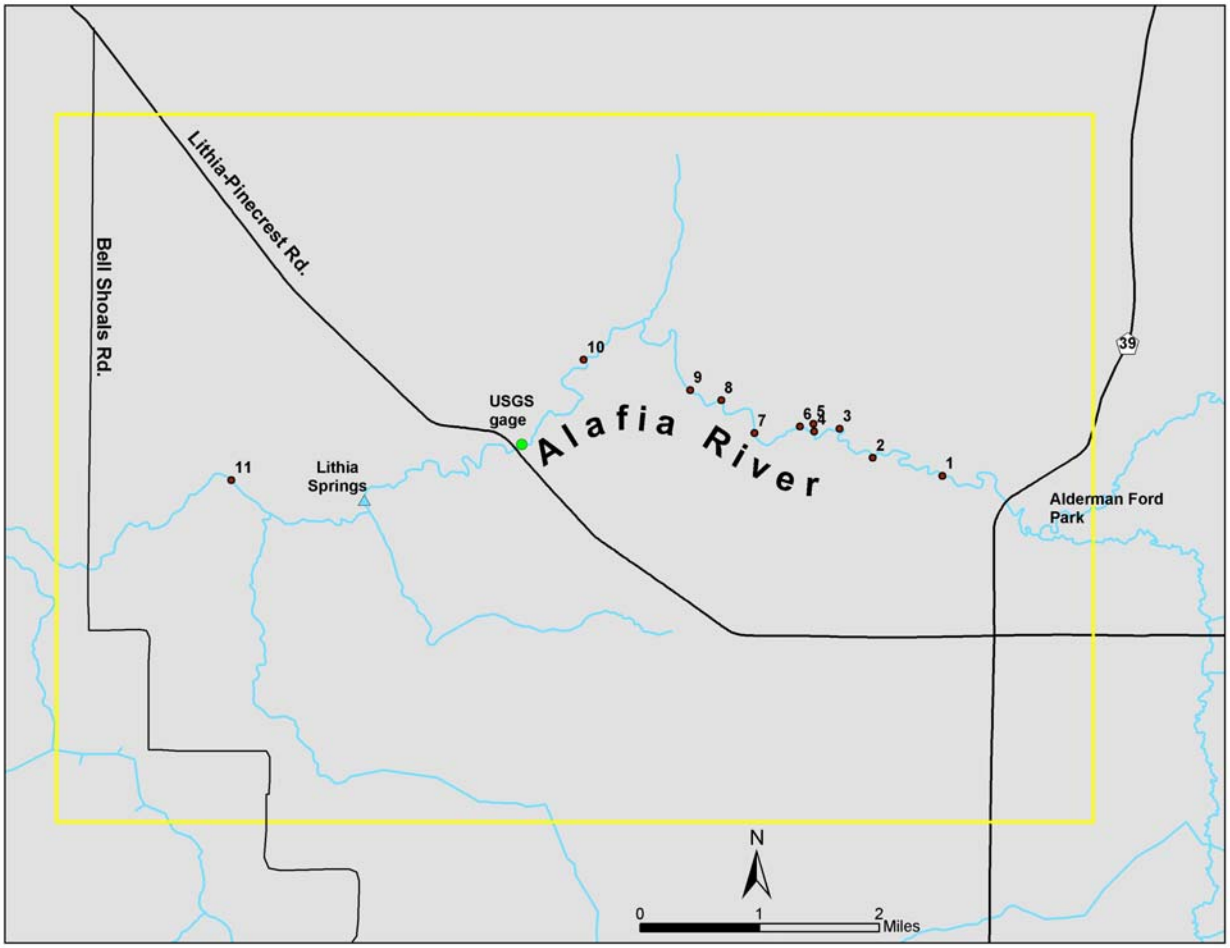


Figure 4-3. Location of eleven shoals identified on the Alafia River.

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 two sites on the Alafia River, at one site in Buckhorn Creek and at one site in the Lithia Springs Major run. Alafia River cross-sections were situated at an upstream site, near Aldermans Ford Park and at a downstream site, near the USGS Lithia gage at the bridge on Lithia Pinecrest Road**.** The upstream site was representative of shallow portions of the river and was bounded by low banks. The downstream site was located in the more incised portion of the river. The cross-sections in Buckhorn Creek were located about 100 yards downstream from Buckhorn Springs Main and the Lithia Springs cross-sections were located in the short spring run between Lithia Springs Major and the Alafia River.

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 (sand, bedrock, mud, snags, exposed roots, snags, aquatic and terrestrial vegetation) and habitat cover (present or absent) were recorded along the cross-sections. Other measured hydraulic descriptors 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 eight sites in the Alafia River corridor. 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 24 instream cross sections were sampled (8 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 was comprised by a combination of either sand, mud, or bedrock);
- exposed roots;
- snags or deadwood;
- wetland plants; and
- wetland trees.

4.2.4 Floodplain Vegetation Cross Sections

Floodplain cross-sections (transects) based on the location of vegetation communities identified from USGS Gap Analysis Program (GAP) maps were established to characterize wetlands and soils within the Alafia River corridor. For cross-section site selection, the river corridor was stratified into upstream and downstream reaches based on differences in dominant vegetation types. Eight representative floodplain vegetation cross-sections; four each in the downstream and upstream reaches of the river were established perpendicular to the river channel in dominant vegetation types (Figures 4-4 and 4-5). Cross-sections were established between the 0.5 percent exceedance levels on the north and south sides 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.

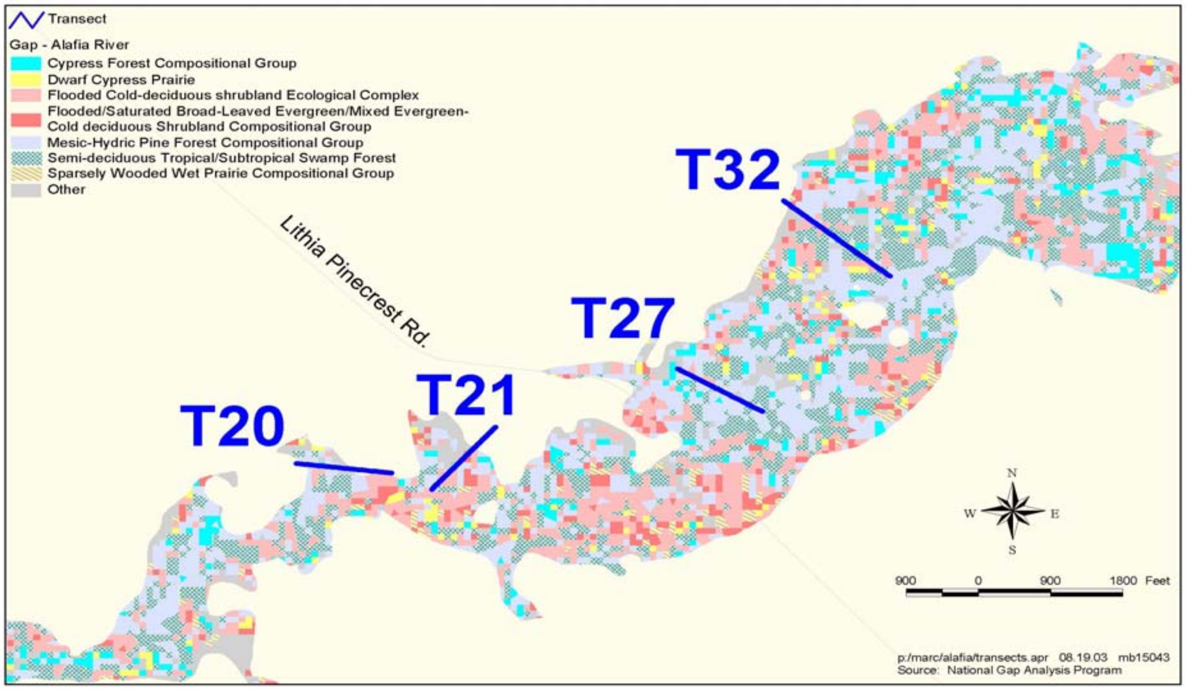


Figure 4-4. Downstream vegetation cross section (transect) locations and GAP classes on the Alafia River.

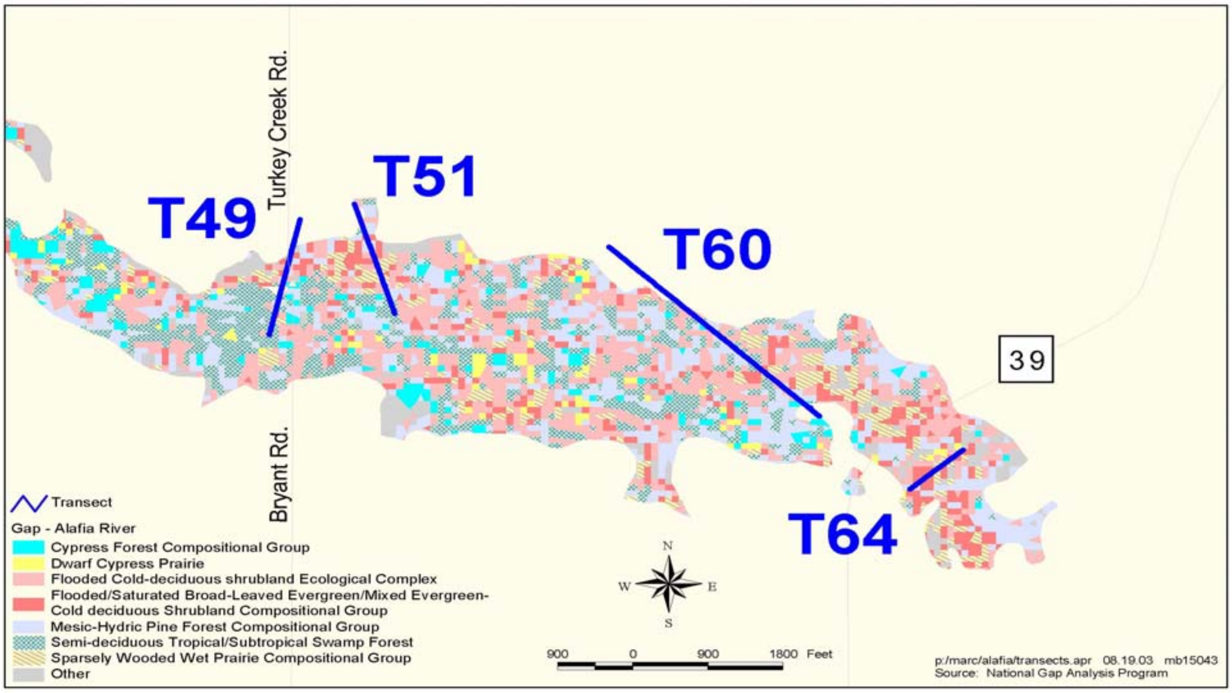


Figure 4-5. Upstream vegetation cross-section (transect) locations and GAP classes for the Alafia River

To characterize forested vegetation communities along each cross-section, changes in dominant vegetation communities, or classes were located and used to delineate boundaries between vegetation classes. At each change in dominant vegetation class, plant species composition, density, basal area and diameter at breast height (for woody vegetation with a dbh > 1 inch) were recorded. Distance to the center of the river channel was also measured for each vegetation class.

Soils along the floodplain vegetation cross-sections were evaluated for the presence of hydric or flooding indicators, as well as saturation and/or inundation condition. At least three soil cores were examined to a minimum depth of 20 inches within each vegetation class at each cross-section. Soils were classified as upland (non-hydric), hydric or non-hydric with the presence of flooding indicators.

Ground elevation data were used to compare vegetation, soils and distance data 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. Floodplain wetted perimeter (linear extent of vegetation classes along the ground surface plotted against elevation change) was calculated to identify vegetation classes in which small changes in elevation (or river stage) would result in large changes in the amount of habitat exposed or inundated. The HEC-RAS floodplain model was used to determine local cross-section flows and corresponding flows at the

USGS Lithia gage that would be necessary to inundate specific floodplain elevations (e.g., mean vegetation class and soils elevations).

4.2.5 Aquatic Invertebrate Community Assessment

Descriptors of aquatic invertebrate community structure, including absolute abundance, relative abundance, Shannon diversity, and evenness of distribution were determined to evaluate the importance of various habitats in the Alafia River corridor.

Invertebrates were sampled at a site in the river near Site 64 at Alderman Ford Park, in the Lithia Springs Major run and Buckhorn Creek. Prior to the initial sampling event, the areal extent of discrete habitats (both instream and on the stream bank) along each transect was computed and mapped. A minimum of four habitats was sampled at each site during sampling events. Three pseudoreplicate samples were collected from each of the sampled habitats. Habitats sampled were bedrock, sand, mud (backwaters), snags, leaf packs/mats, filamentous algal mats, floating vegetation and rooted aquatic vegetation.

Collection methods and gear types were habitat specific with the ability to quantify abundance and biomass estimates on an areal basis (number of organisms per square meter). Qualitative collections were taken in each habitat as a method to ensure that quantitative methods provide an accurate indicator of species richness. Bottom sediments were sampled using a petite ponar dredge, an Eckman dredge, or a Hess Stream sampler (Merritt et al. 1996). Bedrock and aquatic macrophytes were sampled using a modified Hess stream sampler (Warren et al. 2000) while floating vegetation was sampled using a quantitative dip net method (Warren et al. 2000). Snags were examined by enclosing portions of submerged limbs or trunks in heavy-duty plastic bags and sawing off the enclosed sample portion (Warren et al. 2000). Leaf packs and filamentous algal mats were sampled using a traditional or modified Hess stream sampler. Upon collection, all samples were rinsed in 600 micron mesh sieve buckets to remove excess water. Samples were preserved in the field with 95 percent ethanol and placed, separately, into suitable containers for transport to the laboratory.

All samples were processed in the Florida Fish and Wildlife Conservation Commission (FFWCC) aquatic invertebrate laboratory at the University of Florida, Gainesville. Prior to processing, samples were sieved (600 micron mesh) to remove excess ethanol. Small sample portions were then placed in petri dishes, covered with water, and processed by technicians using stereoscopic dissecting microscopes with magnifications to 40X. Organisms from samples were removed, identified to major taxonomic groups, and enumerated to each identified taxon. Organisms were identified to the species level, whenever possible. Immature or damaged specimens were identified to the lowest level possible, given the condition of the organism. To facilitate identification, Oligochaeta, Chironomidae, and Ceratopogonidae were slide-mounted in CMC-10, then examined at up to 100X magnification with a phase-contrast compound microscope.

4.2.6 Fish Community Assessment and Fish Diet Analyses

Fish were collected using habitat-specific backpack electrofishing from dominant habitats in the Alafia River corridor. The sampled area was the main stem of the Alafia River, approximately 50 yards downstream from Vegetation Transect 64, located within Alderman Ford Park. Three habitat types (woody debris, overhanging root wads, and bare sand/bedrock) were selected for sampling, based on identification of dominant habitats. On each sample date, electrofishing was conducted in three sampling reaches, each containing all three habitat types, resulting in nine total habitat sites per sampling trip. Sampling was conducted during January and March 2004 via electrofishing. Fish were collected by investigators wading downstream through each habitat. Total electrofishing time(s) was recorded for each habitat. Upon collection, fish samples were placed in bags and returned to the laboratory for sample processing.

At the laboratory, fish were identified to species using fish keys and individual fish were measured for total length (TL, mm) and weight (nearest 0.01 g). Electrofishing catch-per-minute (CPM) was used as an index of fish abundance for each habitat unit. Species-specific CPM values were used as an index of relative abundance for each species at each habitat type for comparison of richness and community composition across habitats.

Redbreast sunfish, *Lepomis auritus,* were separated from other species and diet contents were assessed for individuals collected from woody debris and overhanging root wad habitats. Fish stomachs were removed and diet contents separated under a dissecting microscope. Prey items were identified to Order or Family depending on the taxa. Items were counted and weighed to the nearest 0.0001 g using an Ohaus AR 2140 balance. Prey item frequency of occurrence and mean composition by number and weight were estimated for both habitat types.

4.3 Modeling Approaches

A variety of modeling approaches were used to develop minimum flows and levels for the Alafia River corridor. 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 diversity. Recent and Long-term Positional Hydrograph (RALPH) analysis was 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 solves the one-dimensional energy equation. Energy losses between two neighboring cross sections are computed by Manning's equation in the case of frictional 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 jump, 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 Lithia gage to simulate flows at cross-section sites within the Alafia River corridor. Data required for performing HEC-RAS simulations included geometric data and steady flow data. Geometric data consisted of connectivity data for the river system, cross-section elevation data, 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 flow regime and boundary conditions.

Calculations for subcritical flow begin downstream where a boundary condition is applied. For the Alafia River corridor, a known water-surface elevation, calculated from a stage-discharge relationship at the USGS Lithia 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 locations with a stage-discharge relationship derived from historic data at that location. The model is calibrated by adjusting factors in the model until the 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).

The HEC-RAS model for the Alafia River was originally set-up and run by the U.S. Geological Survey (USGS) and was transferred to the Southwest Florida Water Management District. The modeled area included the North and South Prongs of the river and the USGS Lithia gage. In 2003, the District conducted surveys at additional cross sections in the Alafia River to obtain additional input data for the model.

The original USGS Alafia River HEC-RAS model calculates profiles for a total of 16 steady flow rates. These rates represent the 89.1, 89, 50.1, 50, 30.1, 30, 20.1, 20, 10.1, 10, 2.1, 2, 0.51, 0.5, 0.11, and 0.1 upper percentiles of the historical flow data for the river. Boundary conditions were specified with known water surface elevations (rating curves) for each flow rate at the downstream boundary (USGS Lithia Gage).

The smallest (lowest) flow in the original USGS Alafia River HEC-RAS model was the 89.1 upper percentile (or 10.9 percentile) flow. To establish minimum flows for the river, it was necessary to evaluate conditions associated with smaller flows. For this purpose, 23 additional low steady flow rates were added to the calculations for the river segment. The 23 additional flows added to the calculation were 8, 16, 25, 33, 39, 48, 57, 65, 81, 91, 104, 112, 138, 205, 248, 298, 399, 505, 666, 885, 1280, 1820 and 2850 cfs at the USGS Lithia gage.

Because some of the cross-sections generated by the SWFWMD surveys were designed to examine in-stream habitat, they failed to extend significantly into the floodplain. This resulted in the highest surveyed elevation in the cross-section being considerably lower than the water surface elevations associated with some of the modeled flows. To eliminate errors in model output that would be associated with use of the truncated cross-sectional data, a second model that excluded the truncated cross-sections was generated. The original model was termed the channel model and was used to analyze flows for elevations confined within the banks. The second model was termed the floodplain model and was applied when analyzing out of bank flows.

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

In "A Review of 'Upper Peace River: An Analysis of Minimum Flows and Levels'" Gore et al. (2002) suggests that the District consider use of procedures which link biological preferences for hydraulic habitats with hydrological and physical data. Specifically, the authors 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, the SWFWMD used the PHABSIM program for development of minimum flows for the Alafia River and associated springs.

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 calculations 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 stages (Figure 4-6). 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 was accomplished by conducting a time series analysis routine (TSLIB, Milhous et al. 1990) using historic flow records.

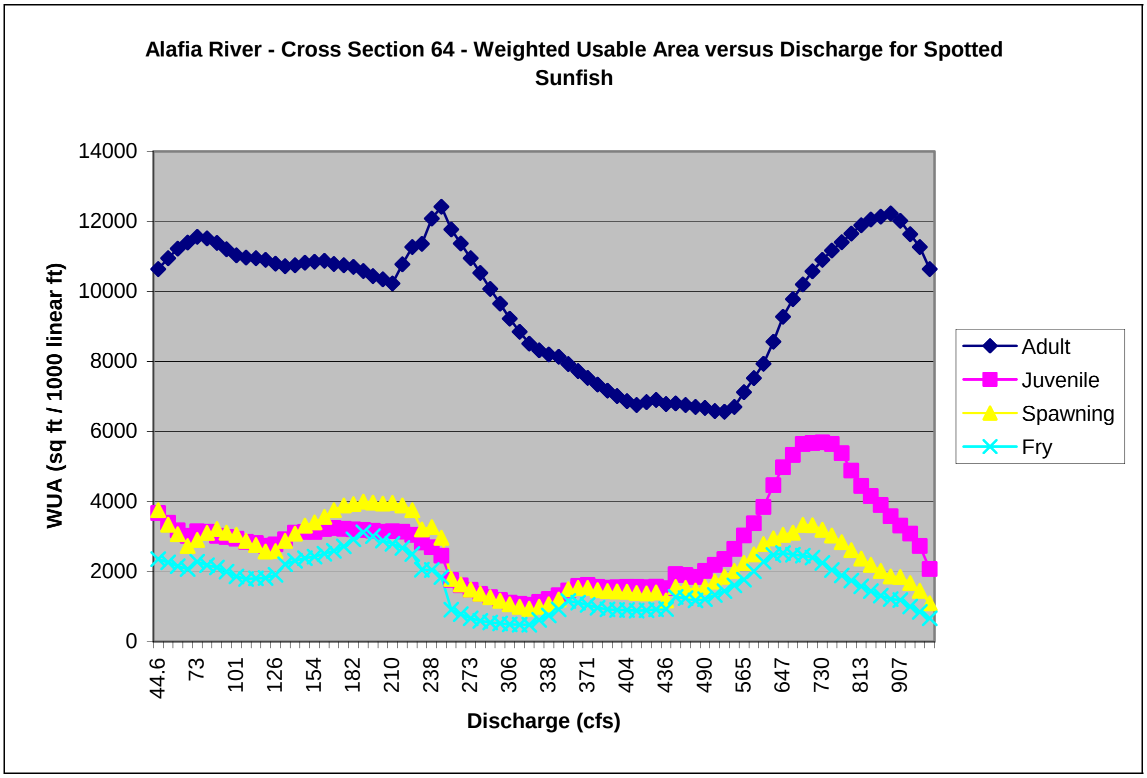


Figure 4-6. Weighted usable area (WUA) versus discharge for spotted sunfish in the Alafia River at PHABSIM cross-section 64.

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 flow regimes. Determining from this data the amount of loss, or deviation for the optimum, that a system is capable of withstanding is left up to profession 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 4-7 shows an example of habitat gain/loss plots, which display changes in WUA (habitat) relative to flow reductions of 10 to 40%.

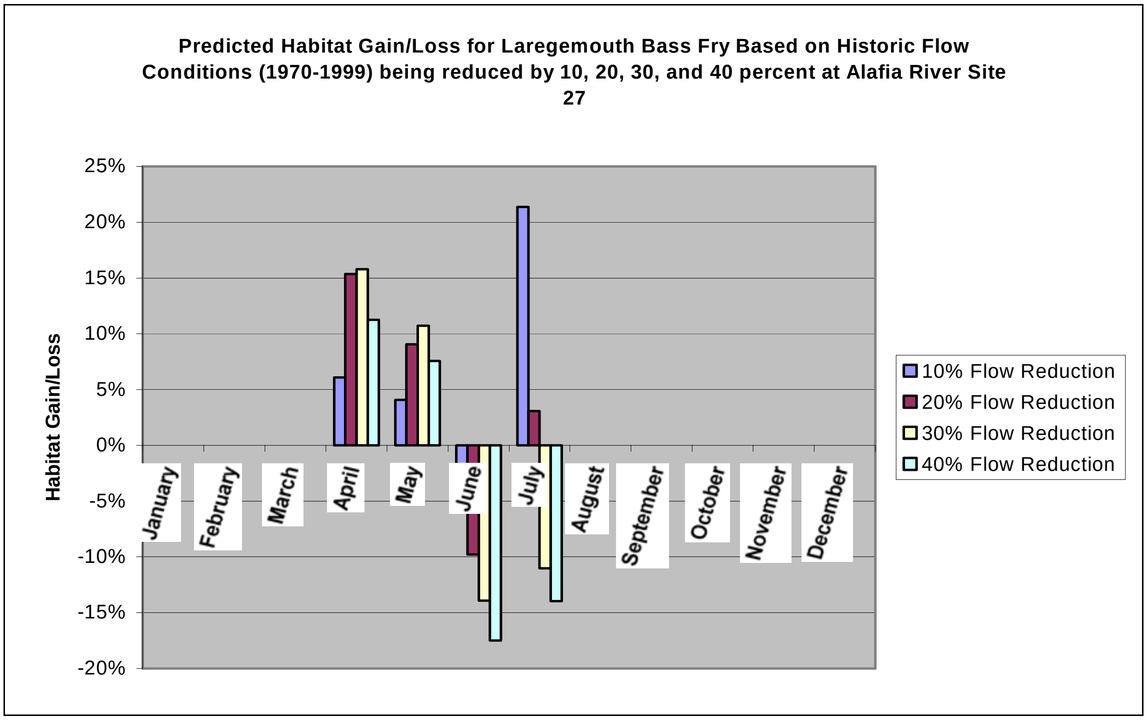


Figure 4-7 Example of a plot of habitat gain/loss relative to flow reductions of 10, 20, 30, and 40%. Data were obtained from time series analysis and the flow reductions are relative to the historic flows recorded at the USGS Lithia Gage site from 1970-1999.

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 depend, instead upon personal experience and professional opinion. 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, know as the Delphi method (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 method 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 method 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 a certain variables (e.g., flow), which are measured at locations used 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 the optimal conditions will be “preferred” over all others if individuals are presented equal proportions of less favorable conditions (Johnson 1980).

In attempting to determine species dominance in the Alafia River fish community composition and abundance were assessed in three prominent habitats (submersed root wads, snag habitats and bare sand/bedrock). Results yielded a total of 15 fish species during January and March of 2004. A total of 8-12 fish species were collected from root wad and snag habitats on both sampling dates, and only 1-2 species were collected from bare sand/bedrock habitats. No rare, threatened or endangered species were observed. Based on electrofishing catch rates (CPM=catch per minute), redbreast sunfish, spotted sunfish *L. punctatus*, coastal shiner *Notropis petersoni*, and sailfin shiner *Pteronotropis hypselopterus* were the most abundant fish taxa in both exposed roots and woody debris (snag) habitats (see Appendix IH).

Diet analysis conducted for redbreast sunfish *Lepomis auritus* collected from the overhanging root wad and woody debris habitats indicated that chironomid larvae and pupae comprised 50-100% of the fishes forage items. Invertebrate community structure in the Alafia River, Buckhorn Creek and the Lithia Springs reveals that snag habitats support relatively high numbers of invertebrate taxa, further emphasizing the importance of these habitats for the river ecosystem. Invertebrate assemblages in the river and spring runs were similar; no rare, threatened or endangered species were observed (see Appendix IH).

Based on dominance of the spotted sunfish (*Lepomis punctatus*) in the Alafia 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 (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 *Lepomis macrochirus*, two other common species in the Alafia 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 SWFWMD and Florida Fish and Wildlife Conservation Commission personnel. For this effort, emphasis was placed on invertebrate preference for macrophytes, inundated woody debris and root wad habitats.

4.3.3 Recent and Long-term Positional Hydrographs

Recent and Long-term Positional Hydrograph (RALPH) analyses are used to illustrate the number of days 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 4-8). The plots 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 4-9). 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.

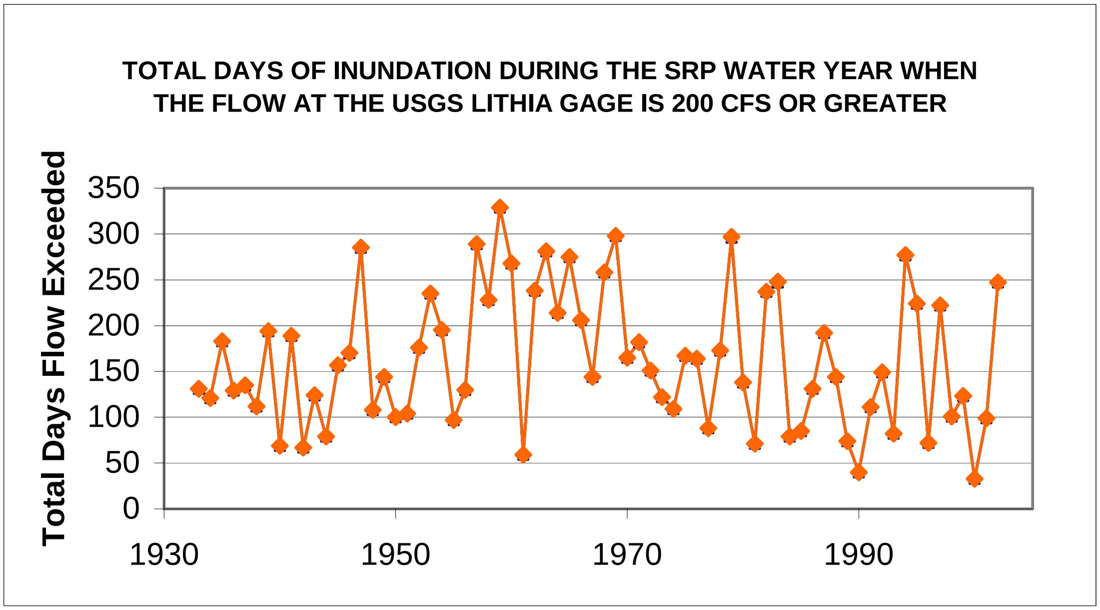


Figure 4-8. RALPH plot of the number of days during the southern river pattern water year (SRPWY) that 200 cfs is exceeded at the USGS Lithia gage on the Alafia River.

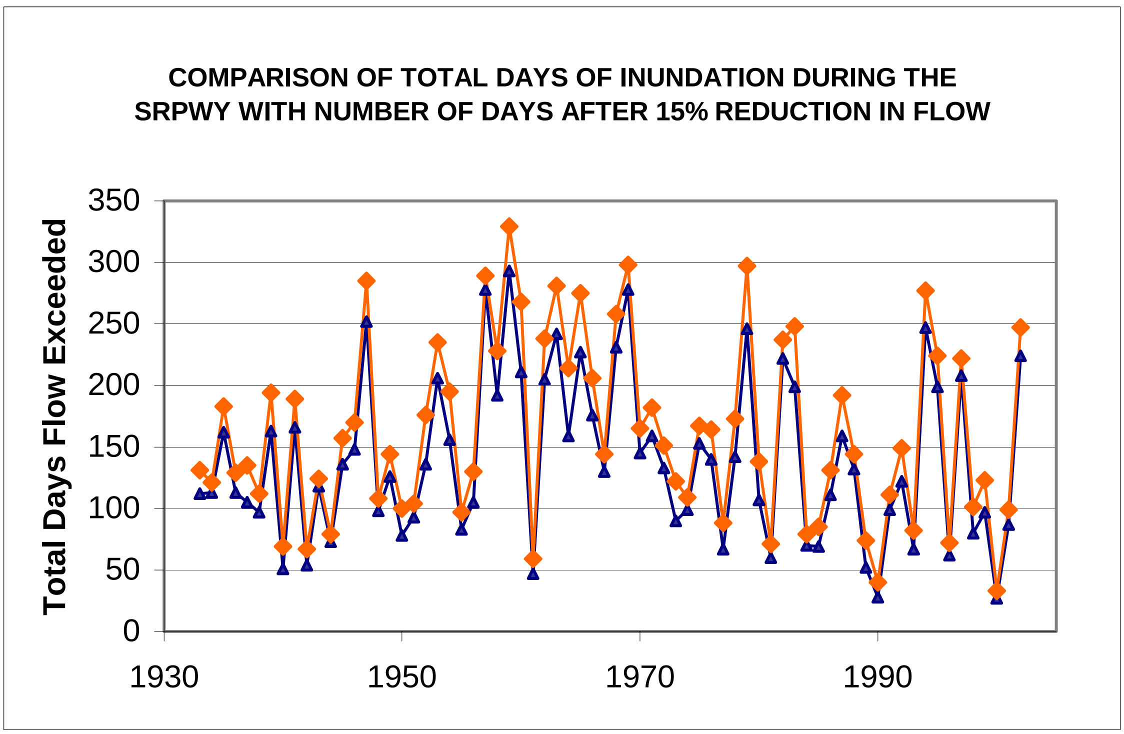


Figure 4-9. RALPH plot of the number of days during the southern river pattern water year (SRPWY) that 200 cfs is exceeded at the USGS Lithia gage (orange line) compared with the number of days that inundation would have occurred if there had been a 15% reduction in river flows (blue line).

4.4 Seasonal Flow and Development of Blocks 1, 2, and 3 for the Alafia River and Other District Rivers

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, flow records for several regional rivers were evaluated.

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) were determined. Records from the two time periods were reviewed to evaluate potential effects of Atlantic Multidecadal Oscillation phases on river flows. The 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 mean median daily flow exceeded and stayed above the mean annual 50% exceedance flow and ending when the flow fell below the 50% exceedance. The medium flow period, Block 2, was defined as extending from the end of Block 3 to the beginning of Block 1 (Figure 4-10).

With the exception of the gage site on the Withlacoochee River, there was little difference in the dates that each defined period began and ended, irrespective of the time period evaluated (Table 4-1). For the Alafia, Hillsborough, Myakka, and Peace Rivers, Block 1 was defined as beginning on Julian day 110 (April 20 on non-leap years) and ending on Julian day 176 (June 25). Block 3 was defined as beginning on Julian day 177 (June 26) and ending on Julian day 299 (October 26). Block 2, the medium flow period, extends form Julian day 300 (October 27) to Julian day 109 (April 19) of the following calendar year. Using these definitions: Blocks 1, 2, and 3 are 66, 175 and 123 days in length, respectively (Table 4-2). Blocks 1 and 3 began approximately 20-30 days later at the Withlacoochee River gage site; it will be necessary to generate a separate set of flow blocks for establishing minimum flows for the Withlacoochee River.

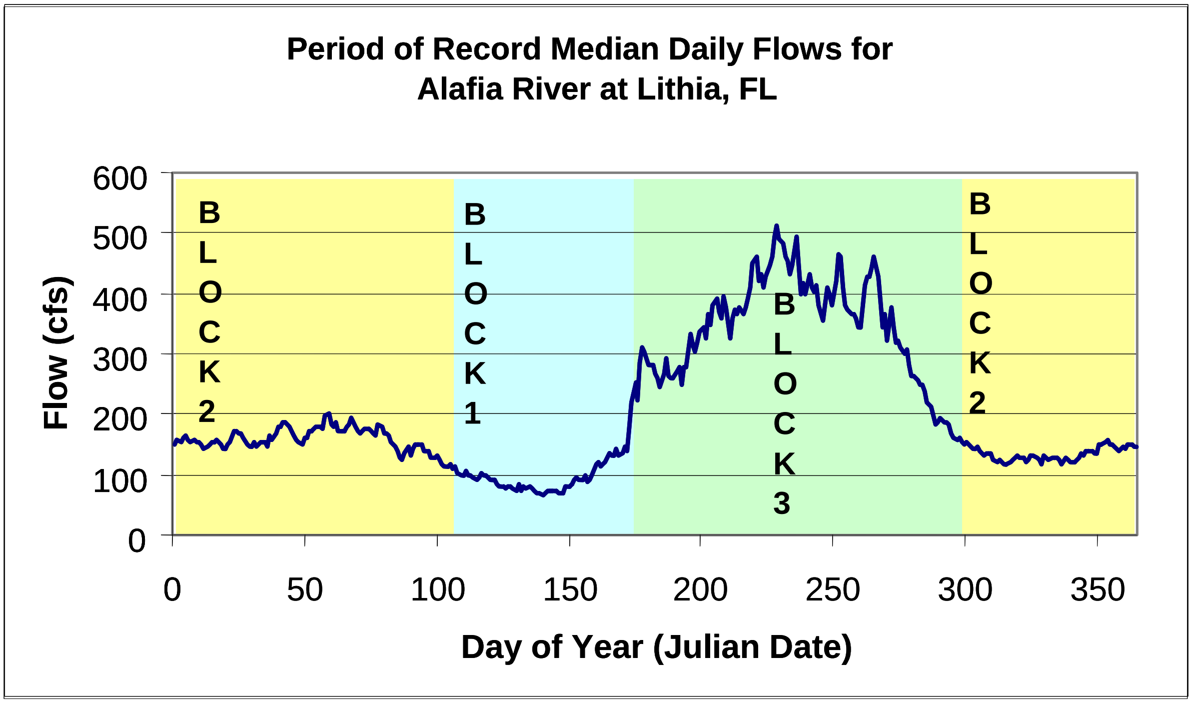


Figure 4-10. Approximate representations of flow blocks (Blocks 1, 2 and 3) projected onto a plot of median daily flows (Julian day) recorded between 1970 and 1999 at the USGS Lithia Gage at the Alafia River.

Table 4-1. Beginning Julian Dates 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 Zephyrhills	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	177	300
Mean with Withlacoochee	114	183	301

Table 4-2. Beginning and ending dates for annual flow Blocks 1, 2, and 3 for the Alafia, Hillsborough, Myakka and Peace Rivers for non-leap years.

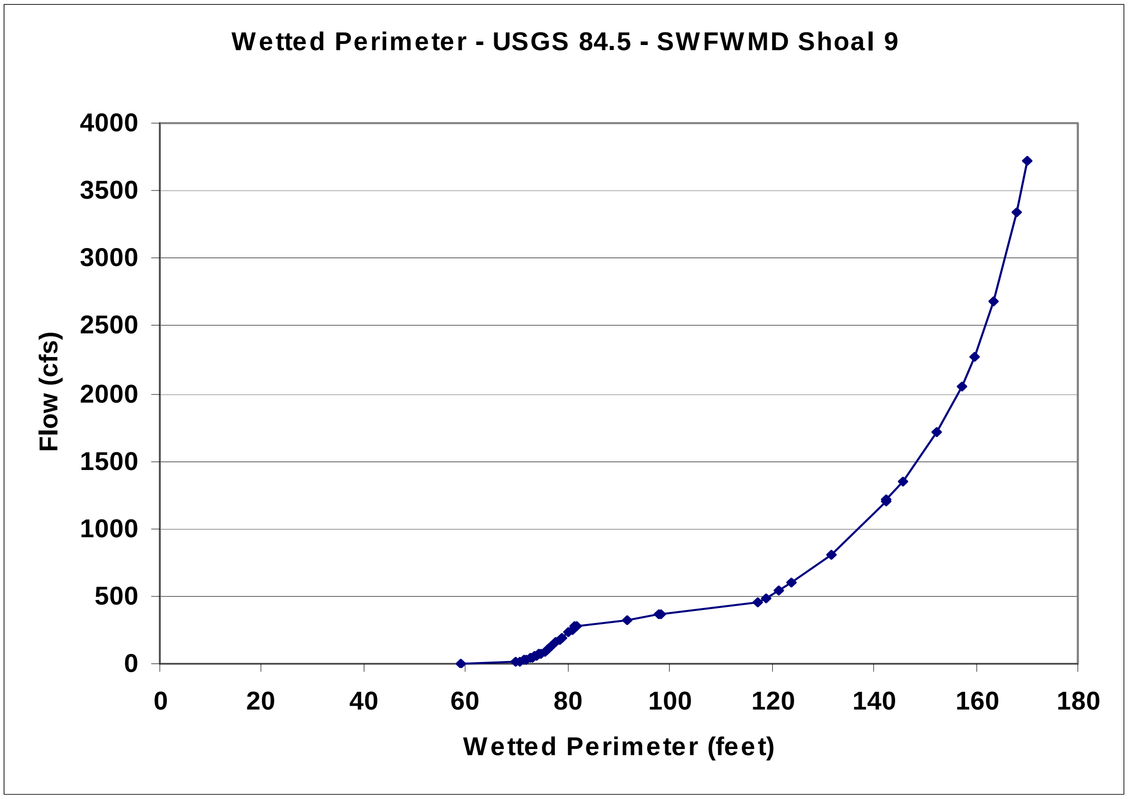
	Start Date (Julian day)	End Date (Julian Day)	Number of Days
Block 1	April 20 (110)	June 25 (176)	66
Block 2	October 27 (300)	April 19 (109)	175
Block 3	June 26 (177)	October 26 (299)	123

4.5 Low Flow Threshold for the Alafia

As part of the protection of the flow regime, minimum flows and levels are intended to protect aquatic resources associated with low flows. 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 (Figure 4-10).

4.5.1 Wetted Perimeter Standard

Output from multiple runs of the HEC-RAS channel model were used to generate a wetted perimeter versus flow plot for each HEC-RAS cross-section of the Alafia River corridor (see Figure 4-11 as an example, 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 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 Lithia Gage using empirical relationships from HEC-RAS channel model output. Flow at the USGS Lithia gage that was sufficient to inundate the LWPIP at all sampled cross-sections was used to define the wetted perimeter low flow standard for the Alafia River corridor.



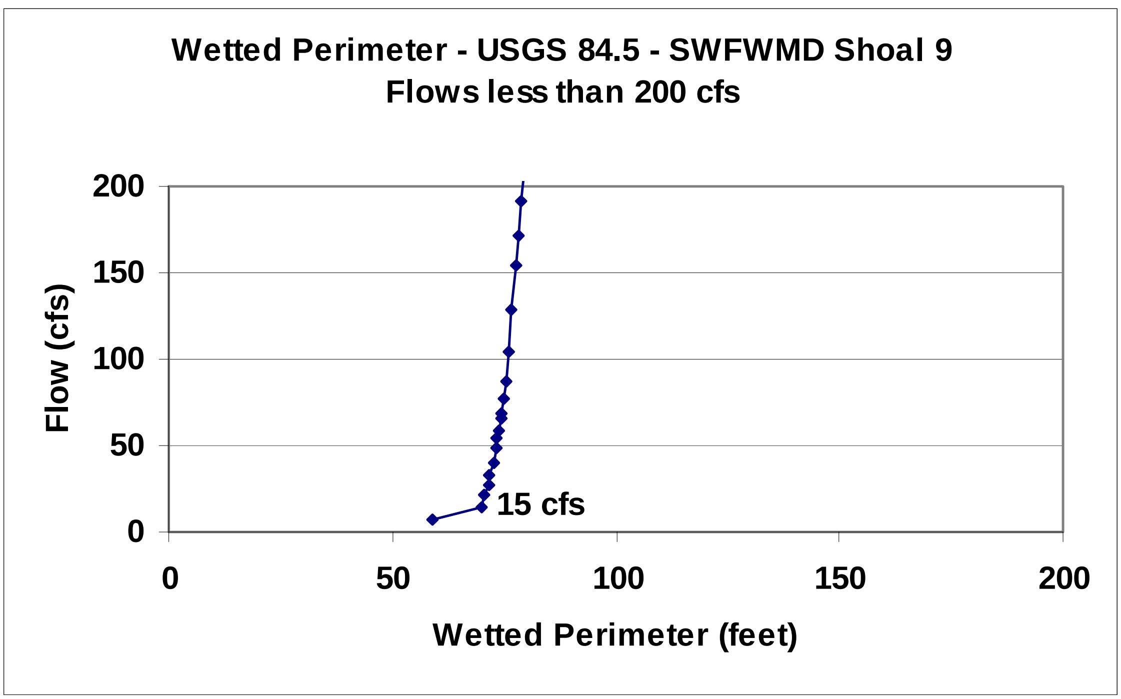


Figure 4-11. Discharge at HEC-RAS transect number 84.5 (Shoal 9). Wetted perimeter values for the entire range of modeled flows are shown in the upper plot; values for modeled flows up to 200 cfs are shown in the lower plot.

4.5.2 Fish Passage Standard

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 Alafia River corridor. The fish passage criterion was used by the District for development of proposed minimum flows and levels for the Upper Peace River (SWFWMD 2002) and was found to be acceptable by the panel that reviewed the proposed 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 channel 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, even during periods of little or no flow.

Ultimately, linear regressions between the stage at each cross-section and the flow at the USGS Lithia gage were used to determine flows at the Lithia gage that corresponded to the target fish-passage elevation at the cross sections (Figure 4-12 as an example). The flow at the Lithia 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 for the Alafia River corridor.

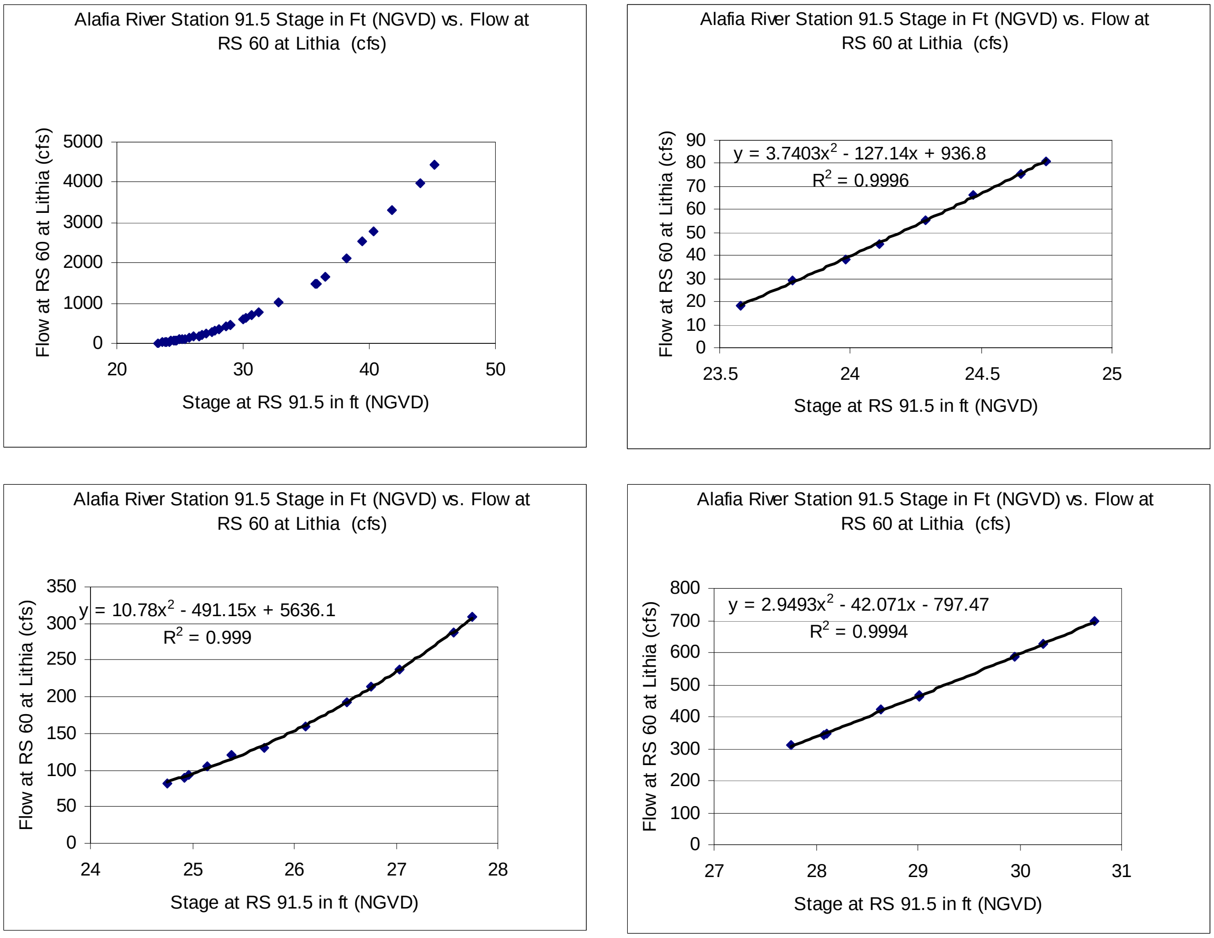


Figure 4-12. Stage flow relationships between HEC-RAS cross-section 91.5 and flow at RS 60 cross-section (USGS Lithia gage) derived from the HEC-RAS model of the Alafia River corridor. The upper-right plot shows the relationship derived for the entire range of flows evaluated. The other three show relationships 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 this low flow period can be estimated using the Physical Habitat Simulation (PHABSIM) analysis.

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 Alafia River. For the analyses, we used historic time series data from the USGS Lithia gage site for periods defined for Block 1, i.e*.,* data collected from April 20 to June 25. Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill and for macroinvertebrates at two sites in the Alafia River corridor. Flow reductions that resulted in no more than a 15% reduction in habitat from historic conditions were determined to be limiting factors. These factors were used to derive a prescribed flow reduction (PFR1) which identifies acceptable flow requirements during Block 1 when flows exceed the low flow threshold

4.7 Prescribed Flow Reduction for Block 2

During Block 2, flows are typically higher than in Block 1 (Figure 4-10) 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 channel model output and Recent and Long-term Positional Hydrographs or RALPH plots to evaluate potential changes in the inundation of woody habitats. Results from the PHABSIM analysis and for woody habitat analyses define limiting factors that are used to develop a prescribed flow reduction (PFR2) 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 from the USGS Lithia gage site for Block 2 periods, i.e*.,* data from October 27 of one calendar year to April 19 of the next year. Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill and macroinvertebrate community diversity at two sites in the Alafia River corridor. Maximum flow reductions that resulted in no more than a 15% reduction in habitat from historic conditions were determined to be limiting values. These values were used to derive a prescribed flow reduction (PFR2) that identifies acceptable flow requirements during Block 2 when flows exceed the low flow threshold.

4.7.2 Snag and Exposed Root Habitat Analyses for Block 2

Mean elevations of snag and exposed root habitats were determined for the eight instream habitat cross-sections in the Alafia River corridor. Flows at the cross-section sites and corresponding flows at the USGS Lithia gage that would result in inundation of the mean habitat elevations at each cross-section were determined using the HEC-RAS channel model. RALPH plots were used to determine the number of days that the mean elevations for the snag or root habitat were inundated. Flow records between 1980 and 1999 were examined to identify percent-of-change 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. Ordinarily, the dry period associated with the multidecadal trends identified would be used. However, low flow augmentation between 1970 and 1980 inflate the flow values found and should not be expected in the future. These percent-of-flow reductions were considered to be limiting factors and used for development of a prescribed flow reduction (PFR2) for Block 2.

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, 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 (Figure 4-10), which for the Alafia River extends from June 26 to October 26. 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 analysis to evaluate floodplain feature inundation patterns associated with channel-floodplain connectivity. Based on these analyses, a prescribed flow reduction for Block 3 (PFR3) can be developed.

4.8.1 Floodplain Connection Analyses for Block 3

HEC-RAS model output and RALPH analysis were used to evaluate floodplain inundation patterns associated with river flows at the eight floodplain vegetation cross-sections. Inundation of elevations associated with floodplain features, including vegetation classes and soils, were evaluated to establish percent-of-flow reductions that would result in more than a 15% reduction in the number of days of inundation during Block 3. Analyses of similar decreases in the number of days a range of flows at the USGS Lithia gage were exceeded was also used to identify a percent-of-flow reduction for the block. These percent-of-flow reductions were considered to be limiting factors and used for development of a prescribed flow reduction (PFR3) for Block 3.

4.9 Prescribed Flow Reductions for Lithia Springs Major and Buckhorn Springs Main

Because the range of flows or discharge from Lithia Springs Major and Buckhorn Springs Main is substantially less than that of the Alafia River (e.g., see Figures 2-18, 2-28 and 2-31), prescribed flow reductions were evaluated for application on a year-round basis rather than for seasonal blocks. To develop prescribed flow reductions for both springs, changes in the availability of aquatic habitat for selected fish species and macroinvertebrate populations were evaluated using the Physical Habitat Simulation Model (PHABSIM). Flow requirements for recreational swimming at Lithia Springs Major were also considered to determine whether this factor could be used to identify a prescribed flow reduction.

4.9.1.1 PHABSIM – Application for Lithia Springs Major and Buckhorn Springs Main (Buckhorn Creek)

PHABSIM was used to evaluate potential habitat changes associated with variation in flow in the Lithia Springs Major run and in Buckhorn Creek, downstream from Buckhorn Springs Main. Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill and for macroinvertebrate community diversity. Maximum flow reductions that resulted in no more than a 15% reduction in habitat from historic conditions were determined to be limiting factors. These factors were used for consideration in the development of prescribed flow reductions for the springs.

For the Lithia Springs Major run, PHABSIM data were collected at three cross-sections at a single site between April and July of 2004. Reconstructed flows from 1983 through 2002 (see Section 2.3.4.3.2) were used for the time series component of the analysis. For the sampled site on Buckhorn Creek, field-data were collected at thee PHABSIM cross-sections in July and August of 2004. Because the Alafia River controls water level in Buckhorn Creek when river stage rises, due to flow events or tidal influences, sampling was conducted with consideration of the local tide schedule. Reconstructed low flows from Buckhorn Springs Main from 1988 through 2002 (see Section 2.3.4.3.2) were used for the time series component of the analysis. A second time series analysis was also performed for Buckhorn Springs using the flow record for Buckhorn Creek.

4.9.1.2 Recreational Use Assessment - Application for Lithia Springs Major

Recreation, in the form of swimming and wading, is a primary use of Lithia Springs Major. The spring pool is considered the main attraction at Lithia Springs Park, and is designated as a swimming area by Hillsborough County (see Figure 4-13). Lithia Springs Major is permitted by the Florida Department of Health as a "bathing place" and as such is subject to use-criteria as described in Chapter 64E-9, F.A.C. These rules stipulate that the bathing load, i.e., the maximum number allowed in the bathing area at one time shall be based on a requirement of 100 ft^2 for each bather. Based on an estimated swimming area of 1 acre, the Lithia Springs Major pool can therefore accommodate 436 bathers. Department rules also require that a "flow through" defined as a minimum of 500 gallons per anticipated bather per 24 hours for bathing places less than two acres in size. Discharge necessary to meet flow criteria for a bathing load of 436 individuals in the pool would therefore be 218,000 gallons per day or 0.3 cfs.

To investigate flow requirements necessary to meet actual use of Lithia Spring as a bathing place, we obtained park attendance records for the period from June 2001 through June 2003. Because park records only included the number of visitors and campers and not the number of swimmers, District staff surveyed the park on several days in July 2003 to determine the number of visitors that were actually swimmers in order to establish a ratio of park visitors to those swimming at the spring pool. Estimated numbers of swimmers, and the requirement of a minimum of 500 gallons per individual for a 24-hour period were used to evaluate the relationship between spring flow and recreational use. This information was used to identify a possible limiting factor for development of a prescribed flow reduction for the spring.

Figure 4-13. Photo of Lithia Spring Major pool being utilized for recreation.

Chapter 5 Results and Recommended Minimum Flows

5.1 Overview

Results from modeling and field investigations on the Alafia 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 the Lithia gage site, 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 Lithia gage sites on the Alafia River. A flow prescription for Buckhorn Springs Main was also developed and used to establish a short-term compliance standard for a gage site in Buckhorn Creek, downstream from the spring pool. Deferment for the development of a prescribed flow reduction and compliance standard for Lithia Springs Major was recommended, pending review of minimum flows and levels requirements for the estuarine segment of the Alafia River.

5.2 Low Flow Threshold for the Alafia River

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. A low flow threshold was developed for the USGS Alafia River at Lithia, FL gage site.

5.2.1 Fish Passage Standard

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 channel model 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 these data indicated that local flows equal to or greater than 47.1 cfs would be sufficient for fish passage at the sampled sites. Flows at the three cross-sections where low flow requirements are the highest were examined with respect to corresponding flows at the USGS Lithia gage (cross-section #60). Cross-section 90.5 (Shoal #1) was found to be the limiting site, with a flow of 59 cfs at the USGS Lithia gage required for meeting the fish passage criterion. A flow of 59 cfs at the USGS Lithia gage was therefore used to define the fish passage standard for the Alafia River corridor. 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.

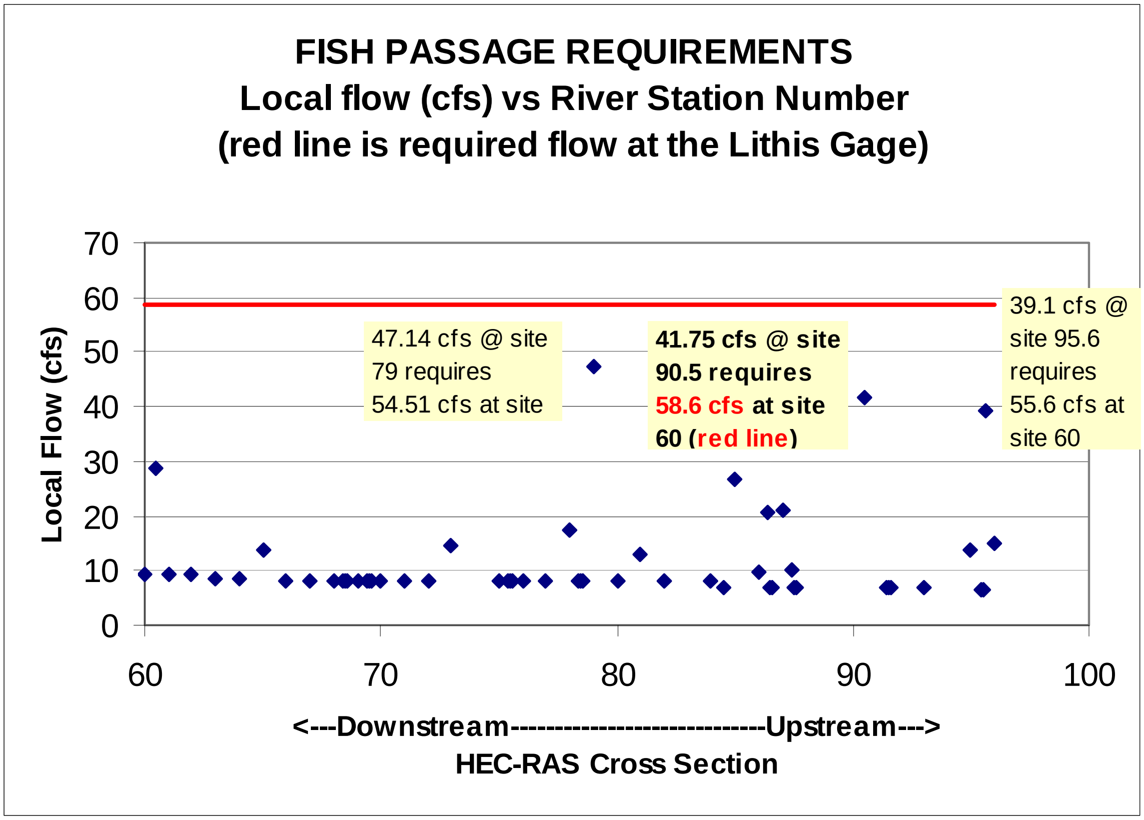


Figure 5-1. Plot of local flow required to inundate the deepest part of the channel at each HEC-RAS cross-section to a depth of 0.6 ft. A local flow of 41.75 cfs at the limiting site (cross-section 60) is the equivalent of 59 cfs at the Lithia gage.

5.2.2 Wetted Perimeter Standard

Wetted perimeter plots (wetted perimeter versus local flow) and the lowest wetted perimeter inflection point (LWPIP) were developed for each HEC-RAS cross-section based on all modeled flow runs (see Appendix WP for all plots). Flows necessary to inundate the LWPIP at each cross-section are shown in Figure 5-2. Inspection of the LWPIP flows indicated that a local flow equal to or greater than 25 cfs would inundate the LWPIP at all cross sections included in the HEC-RAS channel model. Review of flows at the USGS Lithia gage, which correspond to the local flows/stages, indicated that a flow of 29 cfs at the gage site would be sufficient to inundate the LWPIP at all sampled cross-sections. The wetted perimeter standard for the Alafia River corridor was therefore established at 29 cfs at the USGS Lithia gage.

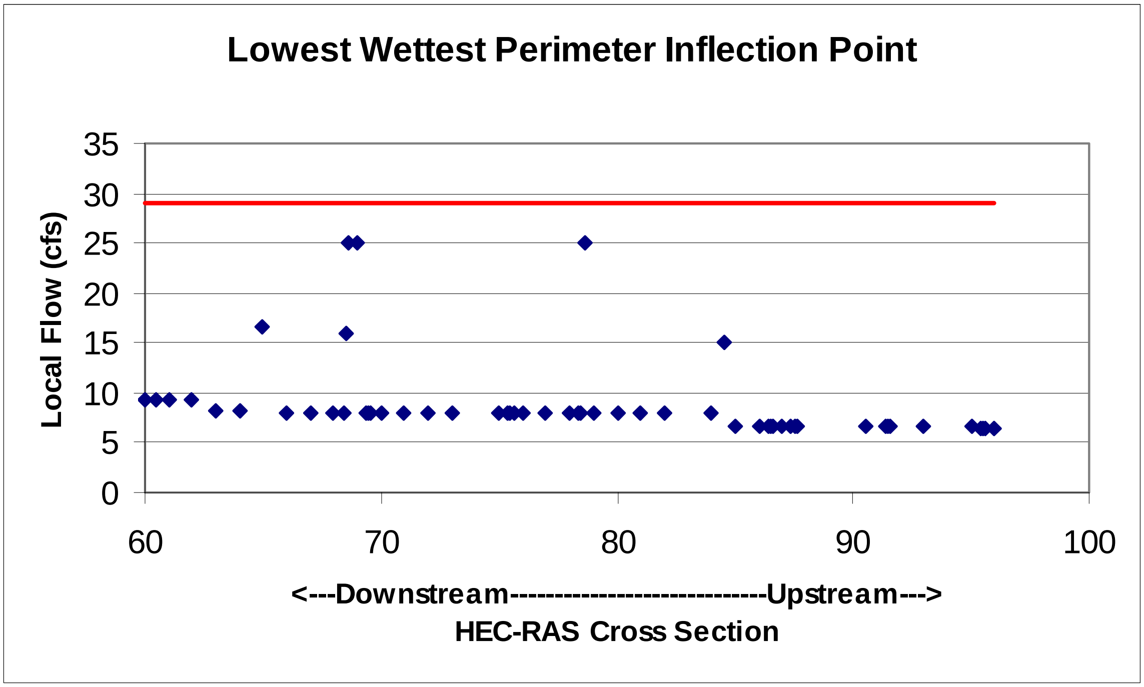


Figure 5-2. Plot of local flow required to inundate the lowest wetted perimeter inflection point at each HEC-RAS cross-section.

5.2.3 Low Flow Threshold

A low flow threshold of 59 cfs at the USGS Lithia gage was established for the Alafia River. The low flow threshold was established at the higher of the fish passage and wetted perimeter standards and is therefore expected to provide protection for ecological and cultural values associated with both standards. Although flows in the river may be expected to drop below the low flow threshold naturally, the threshold is defined to be a flow that serves as a limit to withdrawals, with no withdrawals permitted from the river unless the low flow threshold is exceeded.

5.3 Prescribed Flow Reduction for Block 1

The Prescribed Flow Reduction for Block 1 (PFR1) was 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 two PHABSIM transect sites on the Alafia River was for the fry of largemouth bass (Figure 5-3). Simulated reductions in historic flow greater than 10% resulted in more than 15% loss of available habitat for the early life-history stage of this species. Using this limiting factor, the Prescribed Flow Reduction for Block 1 (PFR1) was defined as a 10% reduction in flows.

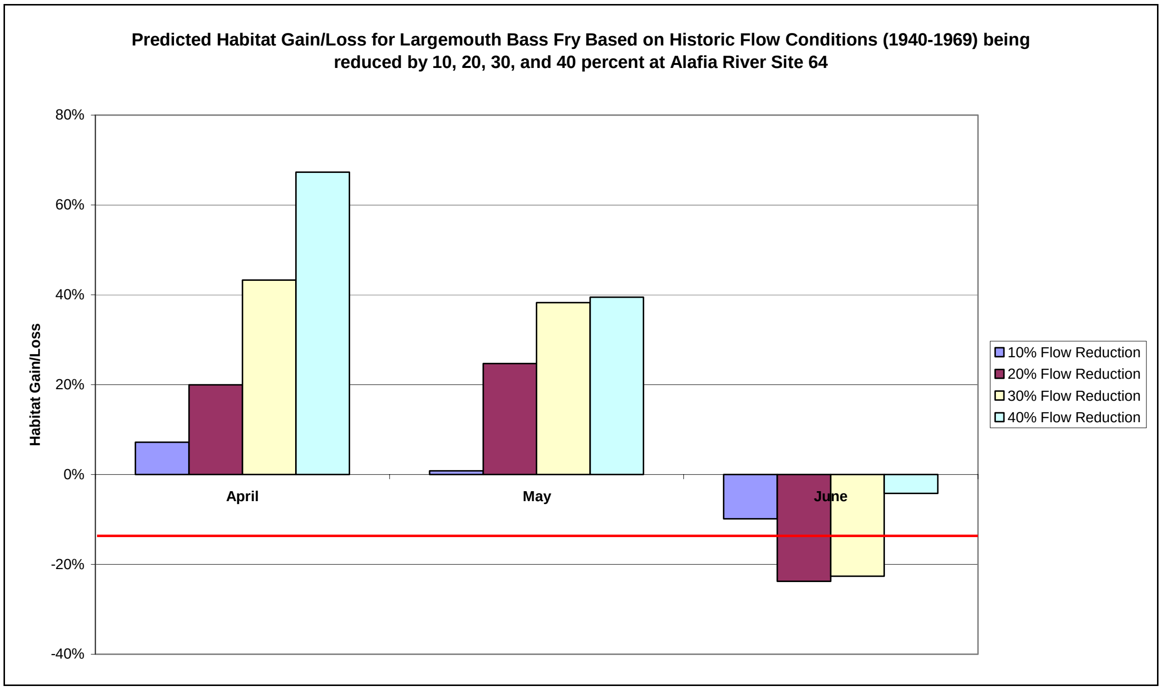


Figure 5-3. Plot of predicted habitat gain/loss for largemouth bass fry based on the flow record from 1940 to 1969 and flow reductions of 10, 20, 30, and 40 percent.

5.3.1 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 Alafia River are defined for the flows at the USGS Lithia gage.

For the USGS Lithia 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 59 cfs measured at the USGS Lithia Gage are protected in their entirety;

2) When flows are between 59 cfs and 66 cfs measured at the USGS Lithia Gage all flows above 59 cfs are available for use; and

3) A 10% reduction of all flows above 66 cfs measured at the USGS Lithia Gage is available for consumptive use.

The first standard was developed using the 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.

5.4 Prescribed Flow Reduction for Block 3

The prescribed flow reductions for Block 3 flows at the Lithia gage site was based on review of limiting factors developed using the Alafia 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 Alafia 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 (374 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 (374 cfs), more than an 8% reduction in historic flows resulted in a decrease of 15% of more in the number of days that flows would inundated floodplain features. Using this limiting condition, the prescribed flow reduction for Block 3 for the Lithia gage site was defined as 8% reduction in flows when flows exceed 374 cfs and a 13% reduction in flows when flows are below 374 cfs provided that no withdrawal results in failure to comply with the low flow threshold.

5.4.1 Inundation of Floodplain Features

Floodplain profiles as shown for cross section (transect) 49 in Figure 5-4, were developed for the eight floodplain vegetation cross-sections (see Appendix RH). Distances across the floodplain (cross-section or transect lengths) ranged from

973 to 3091 ft. Local (cross-section site) flows needed to overflow the river's banks ranged from 566 to 2445 cfs (see Appendix RH for channel bank and other floodplain feature elevations and associated flows). Mean flow at the Lithia gage corresponding to the flow necessary for exceeding the elevation of the lowest bank on either side of the river averaged 1160 cfs; flows at the gage that would be sufficient for the river to overflow both banks averaged 2269 cfs (Table 5-1).

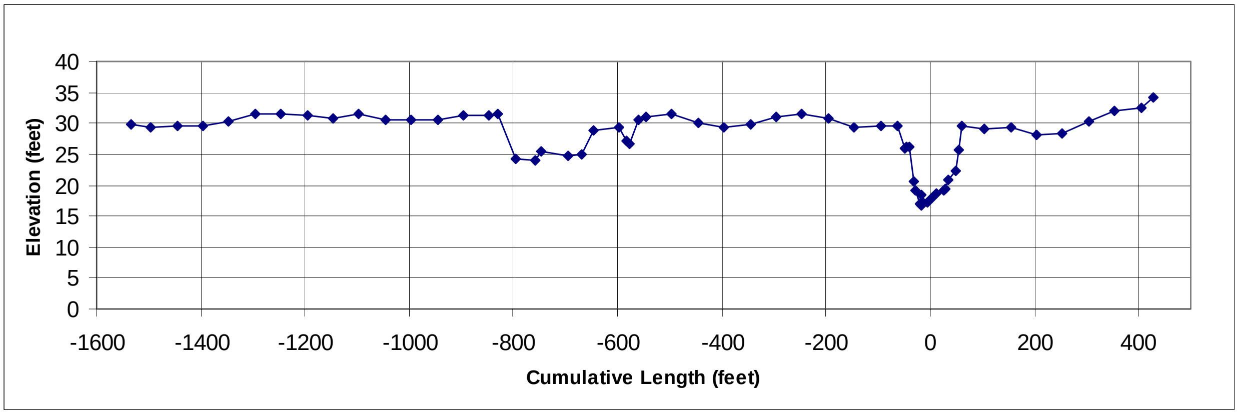


Figure 5-4. Elevation profile for floodplain vegetation cross-section (transect) 49. Distances (cumulative length) are shown centered on the middle of the river channel.

Six vegetation classes were identified at the floodplain vegetation cross-section sites and their mean elevations at each transect are indicated in Figure 5-5. Detailed descriptions of the vegetation classes, which include Cypress/Palm Swamp, Cypress Swamp, Hardwood Swamp, Wet Hardwood Hammock, Dry Palm Bank and Dry Hardwood Hammock, are provided in PBS&J (2004). Mean elevations of vegetation classes were not related to location along the river channel and there were no apparent differences between "upstream" or "downstream" vegetation classes in the study. Consequently, elevation data were normalized to channel elevations at each transect for further comparisons.

Normalized mean elevations for Cypress Palm Swamps, Cypress Swamps and Hardwood Swamps did not differ, but the swamp classes were found at lower elevations than the Wet Hardwood Hammocks (Wilcoxon Signed Rank, $S=-13$, $p<0.05$) and the Dry Hardwood Hammocks (Wilcoxon Signed Rank, $S=-18$, $p<0.05$). Wet Hardwood Hammocks occurred at lower elevations than Dry Hardwood Hammock (Wilcoxon Signed Rank, $S=-13$, $p<0.05$). Dry Palm Bank vegetation occupied higher elevations but was mainly associated along berms by the river channel. Order from low to high elevation is Swamp (Cypress, Cypress/Palm, Hardwood), Wet Hardwood Hammock, Dry Palm Bank and Dry Hardwood Hammock.

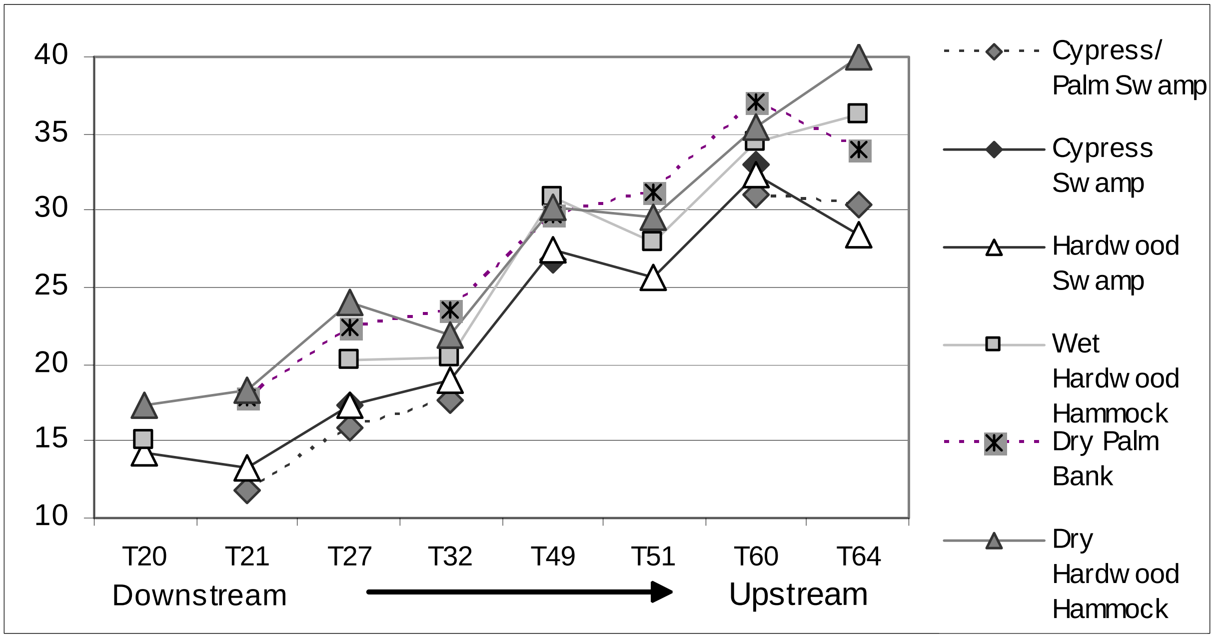


Figure 5-5. Mean elevations of six vegetation classes at eight Alafia River floodplain cross-sections (transects).

Inundation of the highest floodplain vegetation class would require local (cross-section site) flows of 2878 cfs or more (flows for only two cross-sections could be calculated, elevations for other sites were higher than could be modeled with the HEC-RES floodplain model; see Appendix RH). Corresponding flows of 3334 cfs or higher at the USGS Lithia gage would be required to inundate the highest floodplain vegetation classes (Table 5-1). Inundation of the mean elevation associated with the floodplain swamp classes (Cypress/Palm Swamp, Cypress Swamp, Hardwood Swamp) would occur when local flows range from 412 to 1478 cfs. Corresponding flows at the USGS Lithia gage would range from 529 to 1843 cfs, with a mean of 981 cfs (Table 5-1). To inundate the highest swamp class at each cross-section, flows ranging from 731 to 3233 (mean = 1480 cfs) would be required at the Lithia gage (Table 5-1).

Floodplain wetted perimeter plots (patterned after the wetted perimeter plots used for identification of the Lowest Wetted Perimeter Inflection Point) were developed for each floodplain vegetation cross-section (see Appendix RH). The plots were developed to show the linear extent of inundated floodplain (wetted perimeter) associated with measured floodplain elevations, including the mean elevations of the floodplain vegetation classes. For example, Figure 5-6 shows a floodplain wetted perimeter plot for floodplain vegetation cross-section (transect) 51. Based on the plot, an average of 350 linear feet of floodplain would be inundated when the river is staged at the mean elevation of the Wet Hardwood Hammock vegetation class. Flows necessary to inundate the first major slope change at each transect were evaluated using the HEC-RAS model. Local flows of 419 to 1015 cfs would be necessary to inundate the lowest major inflection point associated with maximizing floodplain inundation cfs (see Appendix RH). Corresponding flows at the USGS Lithia gage would range from 485 to 1239 cfs, with a mean of 786 cfs (Table 5-1).

Table 5-1. Mean (SD) flows at the USGS Lithia gage required to inundate selected floodplain features and the maximum percentage flow reductions that would result in no more than a 15% reduction in the number of days the features are inundated.

Critical Floodplain Feature/Criteria	Mean (SD) Flow at Lithia gage (cfs)	Maxiumum Flow Reduction at the Lithia gage (%)
Low Bank Elevation	1160 (603)	5
Low Bank Elevation for inundation of both sides of river floodplain	2269 (652)	5
Highest floodplain vegetation class	3551 (307)	5
Mean elevation of swamp classes	981 (414)	7
Highest swamp class	1480 (778)	9
Floodplain wetted perimeter inflection point	786 (297)	9
Mean elevation of hydric soils	1016 (381)	8
Highest elevation of hydric soils	2043 (1270)	7

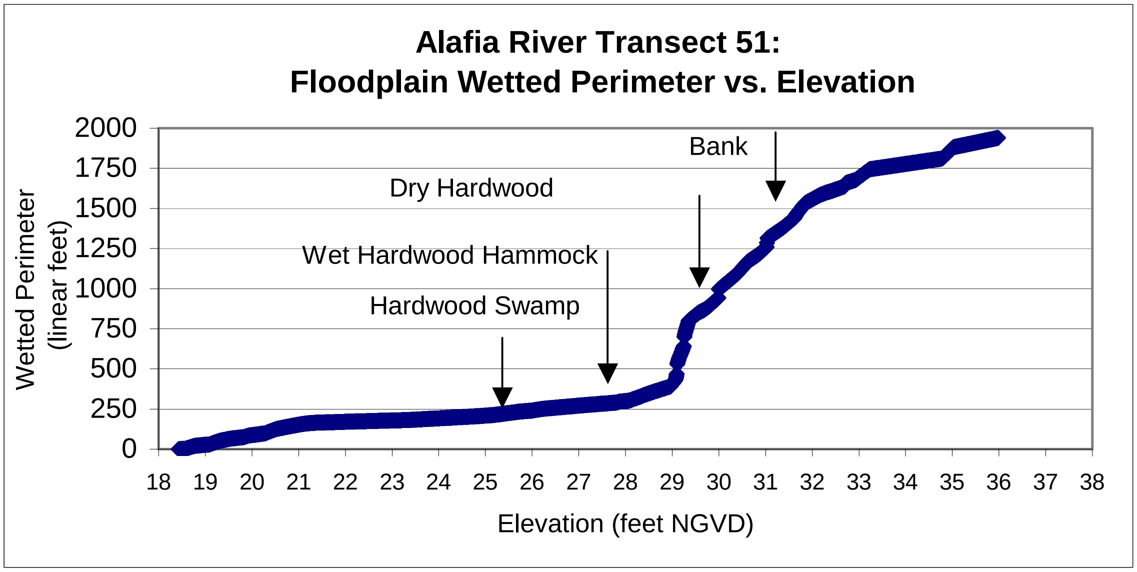


Figure 5-6. Floodplain wetted perimeter versus elevation at floodplain vegetation cross-section 51 (transect 51). Arrows indicate mean elevations for floodplain vegetation classes at the site.

Hydric soils were identified at five of the eight floodplain vegetation cross-section sites (Figure 5-7). Where they occurred, hydric soils were found at significantly lower elevations than nonhydric (upland and non-hydric soils with flooding indicators) soils (Wilcoxon Sign Rank; $S = 18$; $p < 0.01$). Based on output from the HEC-RAS floodplain model, local flows of 404 to 1361 cfs would be necessary to inundate the mean hydric soil elevations (Appendix RH). Corresponding flows at the USGS Lithia gage would range from 520 to 1576 cfs, with a mean of 1016 cfs (Table 5-1). To inundate the highest-occurring hydric soils, flows of 526 to 4004 cfs (mean = 2043 cfs) would be required at the USGS Lithia gage site (Table 5-1).

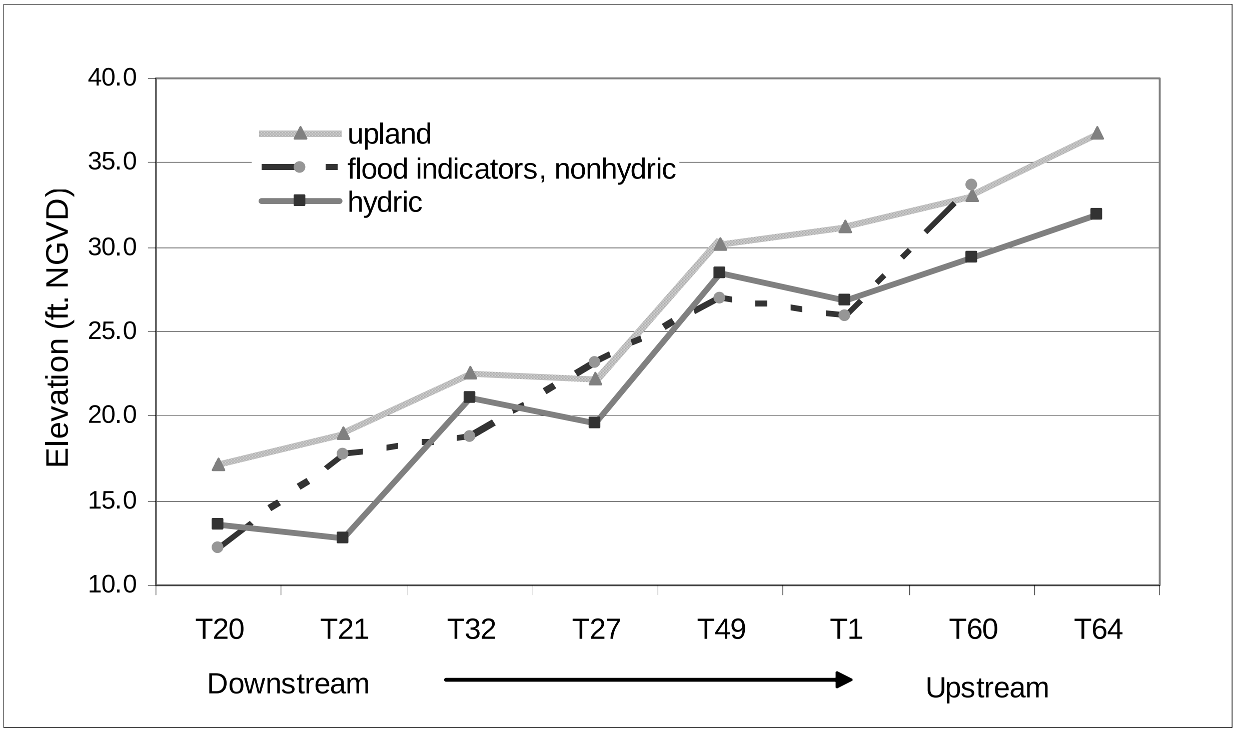


Figure 5-7. Elevations of hydric and nonhydric (upland and non-hydric soils with flooding indicators) soils at the eight floodplain vegetation cross-sections.

Changes in flow at the USGS Lithia gage during Block 3 that are expected to result in no more than a 15% reduction in the number of days of inundation of selected floodplain features are listed in Table 5-1. The range of percent-of-flow changes, which were determined using RALPH analysis, indicate that a 5-9% flow reduction associated with these limiting factors would be appropriate for establishing a Prescribed Flow Reduction for Block 3 (PFR3).

To further investigate limiting factors associated with the Alafia River floodplain, a plot of percent-of-flow reductions that would result in a 15% loss of the number of days river flows reached a given flow was produced (Figure 5-8). The low end of the plotted range reflects the approximate 50% exceedance flow for the period of record, 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 used because it generally represents a more limiting condition.

Figure 5-8 indicates that for flows of approximately 500 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%. 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 5-1). Collectively, these data indicate that up to an 8% reduction in the flows necessary to inundate floodplain features of the Alafia 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 that reductions be limited to 8% to avoid a 15% reduction in the number of days a flow is achieved. Using the 25% exceedance of 374 cfs at the Lithia gage as a cutoff, we can apply a stepped prescription, which allows an 8% reduction in flows when flows exceed 374 cfs and a 13% reduction in flows when flows are below 374 cfs (Figure 5-8). While other multiple steps could be made or an algorithm applied to determine the percent flow reduction allowed, the single step provides a conservative means assuring that unidentified factors are likely to be protected and that water, not needed to protect from significant harm, is available for consumptive use.

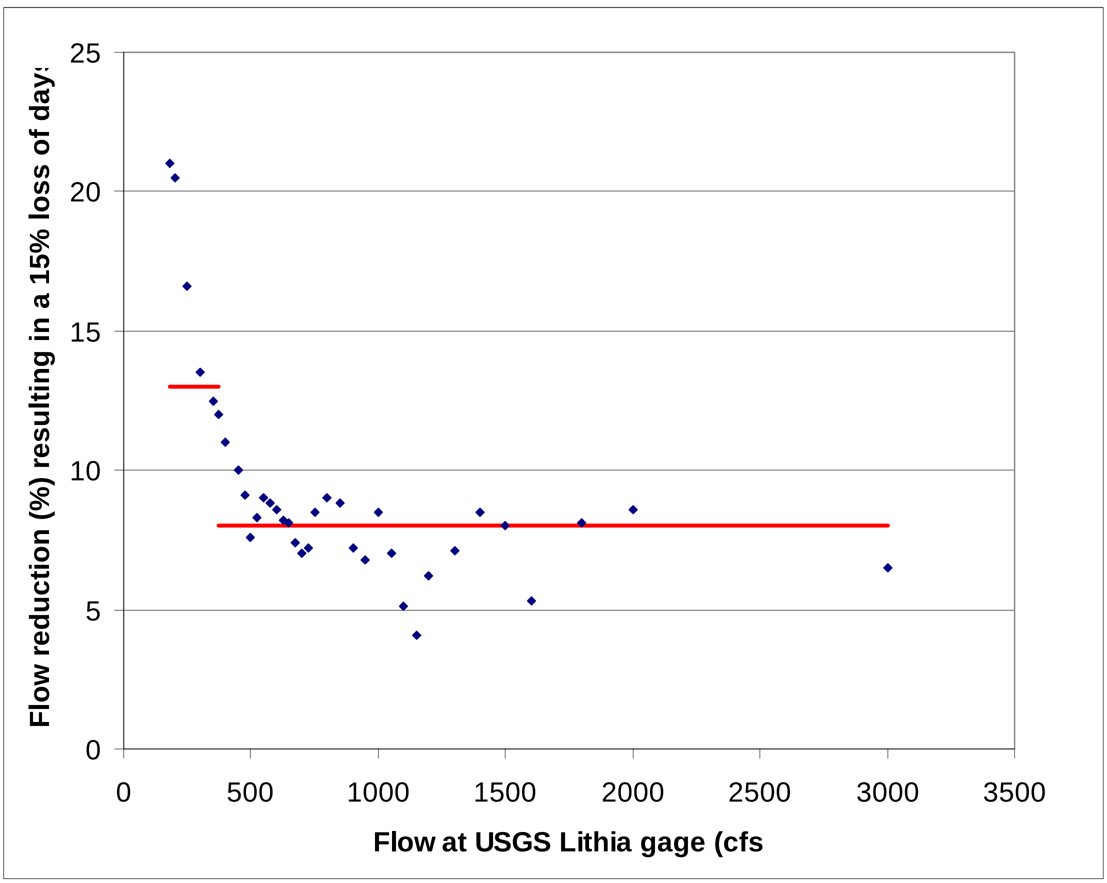


Figure 5-8. Percent-of-flow reductions that result in a 15% reduction in the number of days flows at the USGS Lithia gage are achieved.

5.4.2 Short-Term Compliance Standards for the Alafia River - 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 begins on June 25 and ends on October 27, the following Short-Term Compliance Standards apply:

1) All flows equal to or below 59 cfs measured at the USGS Alafia River at Lithia, FL gage are protected in their entirety;

2) All flows between 59 cfs and 64.2 cfs measured at the Lithia gage are available for use; and

3) A 13% reduction of all flows above 64.2 cfs and below 374 cfs measured at the Lithia gage is available for use; and

4) An 8% reduction of all flows above 374 cfs measured at the Lithia gage is available for use.

The first standard was derived from the low flow threshold. The second and third standards were developed to permit compliance with the prescribed flow reductions for Block 3 without violation of the low flow thresholds. The fourth standard was developed through RALPH analysis to assure no greater than a 15% loss of days for a given flow being achieved.

5.5 Prescribed Flow Reduction for the Alafia River - Block 2

The Prescribed Flow Reduction for Block 2 (PFR2) was 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 analysis to specifically evaluate changes in inundation patterns of woody habitats. The prescribed flow reduction was 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 number of days of inundation of exposed root habitat, over the entire year, after prescribed flow reductions for Block 1 and Block 3 were applied. For the Alafia River, a 15% reduction in number of days of inundation of exposed root habitat, over the entire year, was the limiting factor and yielded a prescribed flow reduction for Block 2 of 19% of the flow at the Lithia gage site.

5.5.1 Application of PHABSIM for 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 two locations in the Alafia River near SWFWMD cross-section locations 27 and 64. The reductions in historic flow greater than about 34% resulted in more than a 15% loss of available habitat for largemouth bass adults (Figure 5-9). This percent-of-flow reduction was considered for use in the development of a prescribed flow reduction for Block 2 at the Lithia gage site.

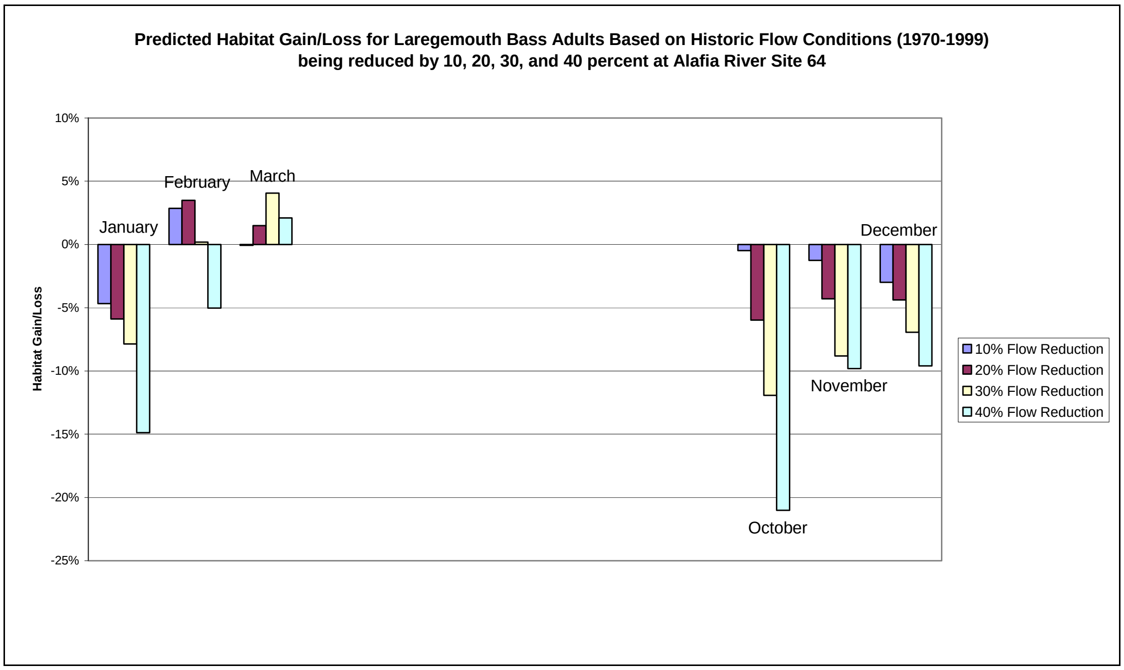


Figure 5-9. Predicted habitat gain/loss for adult large mouthbass based on the flow record from 1970 to 1999 and flow reductions of 10, 20, 30, and 40 percent.

5.5.2 Instream Habitats

Bottom habitats, including sand, mud and bedrock, were dominant, based on the linear extent of the habitat along the cross-sections (Figure 5-10). 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 (Figure 5-11). 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.

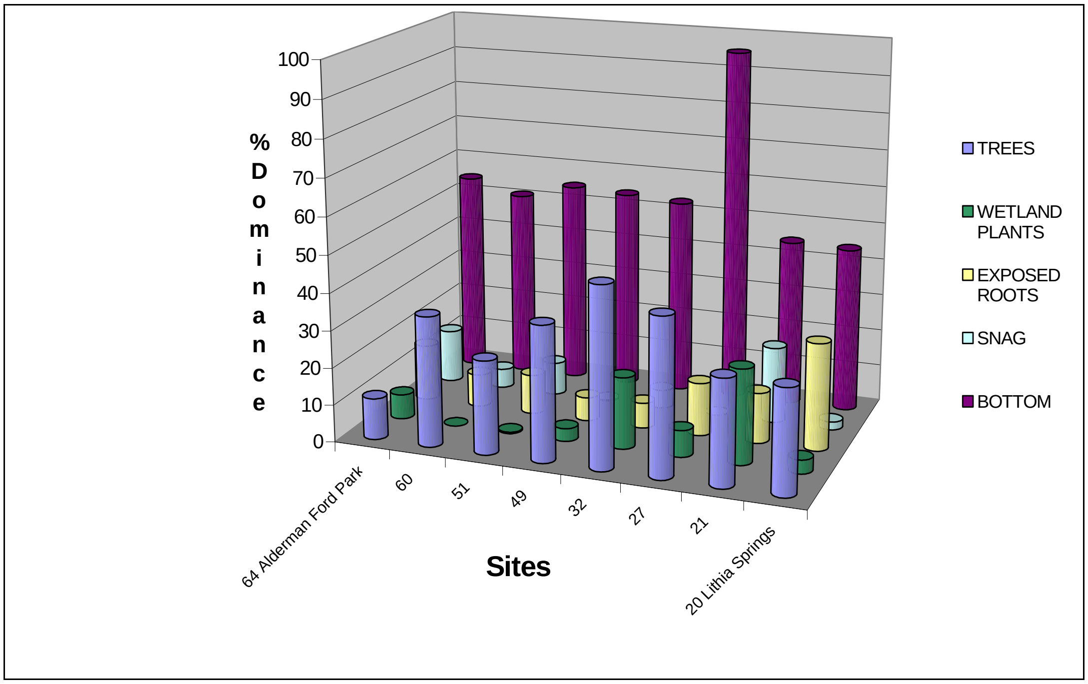


Figure 5-10. Percent dominance of instream habitats based on linear extent of habitats along eight cross-sections in the Alafia River corridor.

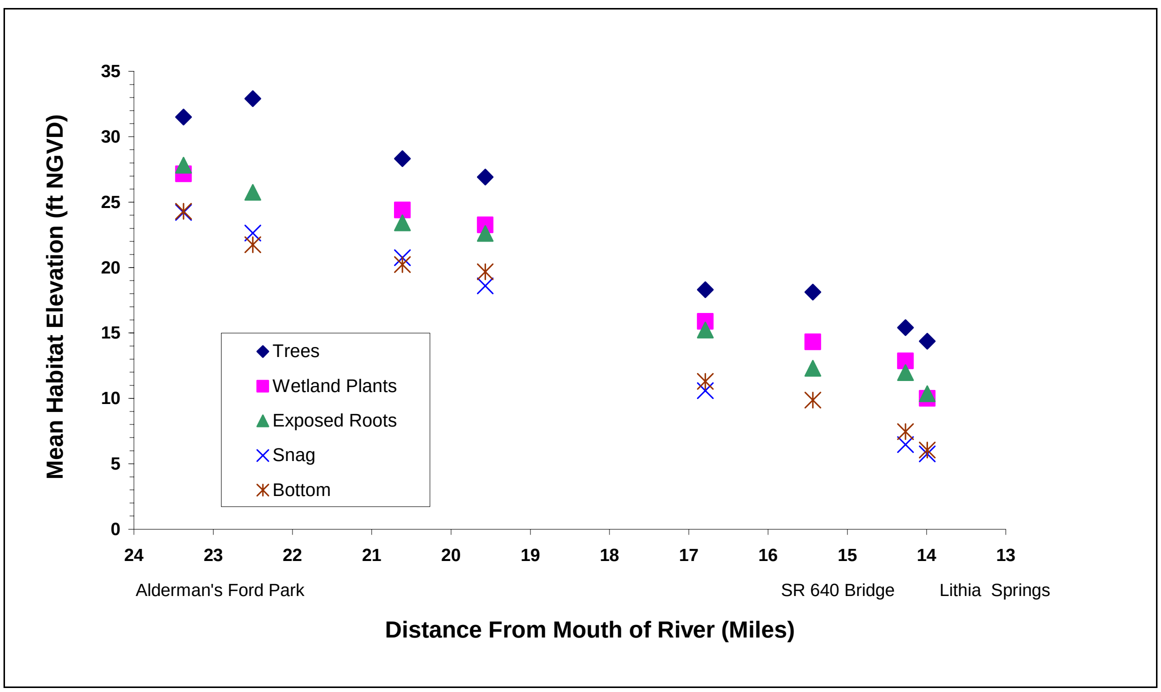


Figure 5-11. Mean elevations of instream habitat at eight cross-section sites on the Alafia River.

5.5.3 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 eight cross-sections in the Alafia River. Modeled local (cross-section site) flows needed to inundate snag habitats ranged from 5 to 67 cfs (Table 5-2). Corresponding flows at the USGS Lithia gage were also variable, ranging from 5 to 85 cfs, with a mean of 27 cfs. Flows required to inundate exposed root habitats were higher (Table 5-3). Local flow requirements ranged from 89 to 537 cfs. Corresponding flows at the USGS Lithia gage site ranged from 118 to 526 cfs, with a mean of 255 cfs.

Table 5-2. Mean elevation, local (cross-section) flows and corresponding flows at the USGS Lithia gage for inundation of snag woody habitats at eight instream habitat cross-sections in the Alafia River for the period from 1933 to 2000. Maximum percent-of-flow reductions at the gage site that result in no more than a 15% decreases in the number of days the habitats are also listed.

Cross-Section	Mean Elevation (ft NGVD)	Local Flow (cfs)	Corresponding Flow at USGS Lithia Gage (cfs)
64	24.2	19.3	38.7
60	22.6	NA*	0.8
51	20.7	NA*	10.4
49	18.6	67.3	85.1
32	10.6	NA*	NA*
27	none	none	none
21	6.5	22.9	22.9
20	5.8	5.0	5.0

Table 5-3. Mean elevation, local (cross-section) flows and corresponding flows at the USGS Lithia gage for inundation of exposed root woody habitats at eight instream habitat cross-sections in the Alafia River for the period from 1933 to 2000. Maximum percent-of-flow reductions at the gage site that result in no more than a 15% decreases in the number of days the habitats are also listed.

Cross-Section	Mean Elevation (ft NGVD)	Local Flow (cfs)	Corresponding Flow at USG Lithia Gage (cfs)
64	27.8	232.	297
60	25.8	112.1	136
51	23.4	89.3	118
49	22.6	202.0	243
32	15.2	145.1	163
27	12.3	160.8	183
21	11.5	536.7	526
20	10.4	319.1	375

The flows required for inundating snag habitats at most of the instream cross-sections are less than the low flow threshold (LFT) of 59 cfs. Snag habitat may, therefore, be expected to be inundated under all but the lowest flow conditions. Because the LFT is protective of these low flows, we did not further evaluate use of snag habitat for developing a Prescribed Flow Reduction for Block 2.

A flow of 255 cfs at the USGS Lithia gage is required for inundation of the mean elevation of exposed root habitat. Based on the historic gage record, inundation of this habitat 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 this important habitat may be inundated during all three seasonal blocks, we determined a percent-of-change flow reduction for inundation of the habitat during Block 2 using prescribed flow reductions developed for Blocks 1 and 3. Percent-of-flow reduction during Block 2 was derived by calculating the flow reduction, which results in no more than a 15% loss of days of inundation of the habitat, over the entire year, after the flow reductions for Block 1 and Block 3 were applied. Using RALPH analysis and flow records from 1970 through 1999, we decreased the flows in Blocks 1 and 3 by 10% and 13% respectively, 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 Lithia Gage to inundate mean exposed root elevation is 255 cfs, which is below the Block 3 step of 374 cfs, a flow reduction of 13% was used for Block 3 rather than higher flow step reduction of 8%. The same method was applied to the 1940 to 1969 benchmark. The 1970 through 1999 period resulted in a more restrictive criterion and are thus is utilized as the more conservative approach. Based on this criterion, a percent-of-flow reduction of 15% was identified for exposed root habitat.

5.5.4 Selection of the Prescribed Flow Reductions for Block 2

Percent-of-flow reduction associated with PHABSIM modeling and RALPH analyses associated with inundation of woody habitats were compared for identification of a prescribed flow reduction. A prescribed flow reduction was established for the USGS Lithia gage site based on percent-of-flow reductions derived from woody habitat. These analyses indicated that up to 15% reduction in flows would be acceptable for the Lithia gage site, while PHABSIM analysis yielded percent-of-flow reductions around 34%.

5.5.5 Short-Term Compliance Standards for Block 2

Short-Term Compliance Standards represent a flow prescription that can be utilized for evaluating minimum flow compliance on a short-term basis, for example, based on measured daily flows. During Block 2, which for the Alafia

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 Alafia River at Lithia, FL gage site, the following Short-Term Compliance Standards are proposed for Block 2:

1) All flows equal to or below 59 cfs measured at the Alafia River at Lithia, FL gage are protected in their entirety;

2) All flows between 59 cfs and 69 cfs measured at the Lithia gage are available for use; and

3) A 15% reduction of all flows above 69 cfs measured at the Lithia gage is available for use.

The first standard was developed using the gage-specific low flow thresholds. The second and third standards were developed to assure that the prescribed flow reduction for Block 2 does not lead to violation of the low flow threshold.

5.6 Prescribed Flow Reduction for Lithia Springs Major

Potential changes in habitat availability in the Lithia Springs Major run were evaluated for development of a prescribed flow reduction for the spring. Flow requirements for maintaining recreational swimming at the spring pool were also evaluated. A prescribed flow reduction and short-term compliance standard were not, however, developed. It was recommended that this process be deferred until analyses for developing minimum flows and levels for the estuarine segment of the Alafia River are completed.

5.6.1 Prescribed Flow Reduction for Lithia Springs Major - PHABSIM Results

PHABSIM analyses were used to model potential changes in habitat availability for several fish species and macroinvertebrate diversity in the Lithia Springs Major run. Simulated reductions in flow greater than 5% indicated that habitat availability for various life history stages and spawning activities of spotted sunfish, largemouth bass and bluegill would be reduced by more that 15% (Figure 5-12, Table 5-4). Based on these limiting factors, a prescribed flow reduction of 5% was identified for consideration in the establishment of a minimum flow for the spring.

Use of this potential prescribed flow reduction for development of a short-term compliance standard for the spring was, however, complicated by several issues.

First, PHABSIM model output for the spring run may not be accurate for periods when flow in the river exceeded 70 cfs at the USGS Lithia gage. During these periods, flow/stage relationships in the spring run are influenced by spring discharge and river stage or flow. Second, the extent of aquatic habitat in the Lithia Springs Major run is not great in comparison to the availability of similar habitat in the Alafia River system. Finally, based on fish and invertebrate sampling conducted for the minimum flow assessment, no uncommon, rare, threatened or endangered species were identified in the spring run. For these reasons, we did not recommend development of a short-term compliance standard based on the 5% prescribed flow reduction for Lithia Springs Main identified from our PHABSIM analyses.

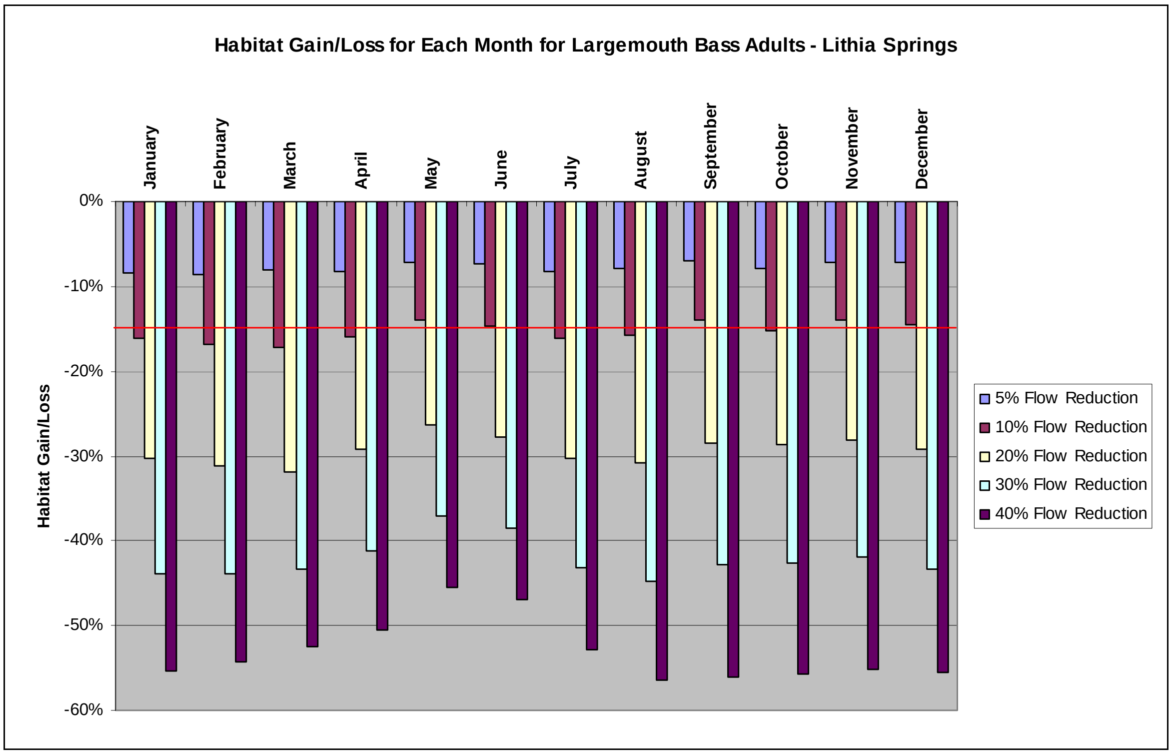


Figure 5-12. Habitat Gain/Loss for adult largemouth bass associated with modeled flow reductions of 5-40% in the Lithia Springs Major run. Similar plots for other largemouth bass life history stages and other species are included in Appendix PHABSIM.

Table 5-4. Maximum monthly percent-of-flow reductions associated with less than a 15% reduction in habitat for various life history stages or activities of several fish species in the Lithia Springs Major run.

Month	Percent-Of-Flow Reduction	Fish Species Life History Stage or Activity
January	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults, juveniles; Bluegill adults
February	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults, juveniles; Bluegill adults
March	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults, juveniles; Bluegill adults
April	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults, juveniles; Bluegill adults, spawning
May	5%	Spotted sunfish adults, juveniles, fry, spawning; Bluegill adults, spawning
June	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults, Bluegill adults, spawning
July	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults, juveniles; Bluegill adults, spawning
August	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults, juveniles; Bluegill adults, spawning
September	5%	Spotted sunfish adults, juveniles, fry, spawning; Bluegill adults, spawning
October	5%	Spotted sunfish adults, juveniles, fry, spawning; Largemouth bass adults; Bluegill adults
November	5%	Spotted sunfish adults, juveniles, fry, spawning; Bluegill adults
December	5%	Spotted sunfish adults, juveniles, fry, spawning; Bluegill adults

5.6.2 Prescribed Flow Reduction for Lithia Springs Major – Recreational Use Assessment Results

Based on Department of Health "bathing load" criteria, a flow of 218,000 gallons per day, or ~0.3 cfs, is necessary to support use of the Lithia Springs Major as a "bathing place" for the maximum number of individuals (436) that should be in the pool at any one time. Surveys conducted by District staff for several days in July 2003, indicate that an average of 16% of the park visitors who entered the park actually swam in the spring pool, although on one day, the percentage of park visitors utilizing the pool was 30%. Assuming that 16% of the 2,570 individuals visiting the park on the single busiest day between June 2001 and June 2003 entered the pool, the minimum necessary spring flow needed to support this use in accordance with state standards would be 205,500 gallons per day, or ~0.3 cfs. Assuming that 30% of the park visitors chose to swim on that day, a minimum discharge of 385,500 million gallons of water per day, or ~0.5 cfs would be required. The minimum flow necessary to support the traditional and long-standing recreational use of the spring as a bathing place is therefore apparently less than 1 cfs. This information was identified as a possible limiting factor for consideration in the development of minimum flows and levels for Lithia Spring Major. Based on this limiting factor, a prescribed flow reduction that permits consumptive-use of spring flows in excess of 1 cfs was identified for consideration in the establishment of a minimum flow for Lithia Springs Major.

Use of this prescribed flow reduction for development of a short-term compliance standard for Lithia Springs Major was not considered appropriate for several reasons. First, although a flow of 1 cfs from the spring may be sufficient for meeting Department of Health requirements for public bathing places, allowing withdrawal of all flows in excess of 1 cfs would likely result in adverse impacts to recreational values. Flows as low as 1 cfs are uncommon at the site (see Figure 2-28), and would be associated with increased incursions of colored river water into the typical clear spring run and pool, which would lead to decreased availability of the pool for swimming and diminished aesthetic values. Second, although the extent of aquatic habitat in the Lithia Springs Major run is not great in comparison to habitat available in the Alafia River system, PHABSIM results indicated that percent-of-flow reductions in excess of 15% may be expected to result in more than a 15% loss of habitats in the spring run. Allowing spring flow to be reduced to 1 cfs, a flow that represents a 97% decrease from the mean annual daily flow for the spring, would therefore be expected to significantly impact spring run habitat. For these reasons, we do not recommend use of the prescribed flow reduction based on use of the pool as a bathing place for development of a prescribed flow reduction or short-term compliance standard.

5.6.3 Short-Term Compliance Standard for Lithia Springs Major

PHABSIM and recreational use assessment results were inconclusive with regard to identification of prescribed flow reduction and short-term compliance standard for flows from Lithia Springs Major. Results from PHABSIM analyses indicate that up to a 5% reduction in flow would be protective of habitat in the spring run. Interpretation of results was, however, confounded by influence of the Alafia River on flows and levels in the spring run. A recreational use assessment indicated that even with substantial reductions in flow, the spring pool could still meet State criteria for public bathing places. The analyses did not, however, address potential recreational use impacts associated with the effect of significantly reduced flow on water chemistry/quality in the run and pool. For these reasons, results from the PHABSIM and recreational use assessment were judged to be insufficient for developing a prescribed flow reduction and short-term compliance standard for Lithia Springs Major.

Minimum flow requirements for the estuarine portion of the Alafia River are currently being evaluated by the District. Because compliance with minimum flows and levels for the estuary may be contingent on flow or discharge from Lithia Springs Major, we recommend that establishment of a minimum flow for the springs be deferred until analyses for the estuarine segment of the Alafia River are completed. The report for the estuarine portion of the Alafia River will include recommendations for minimum flows for Lithia Springs Major.

5.7 Prescribed Flow Reduction and Short-Term Compliance Standard for Buckhorn Springs Main

Potential changes in habitat availability in Buckhorn Creek associated with variation in Buckhorn Springs Main flow were used to develop a prescribed flow reduction for the spring. The prescribed flow reduction was used to develop a short-term compliance standard, which constitutes a proposed minimum flow for Buckhorn Springs Main.

5.7.1 Prescribed Flow Reduction for Buckhorn Springs Main - PHABSIM Results

PHABSIM analyses were used to model potential changes in habitat availability for several fish species and macroinvertebrate diversity in Buckhorn Creek, downstream from Buckhorn Springs Main. Two different flow records were used when running two separate time series analyses. The first record used was for Buckhorn Springs flow only. This record was created by taking the difference between two gages, one just upstream and one just downstream of Buckhorn Springs. The record was then corrected for reported withdrawals to create a record of Buckhorn Spring discharges in the absence of withdrawals. Simulated reductions in flow of more than 15% indicated that habitat availability for largemouth bass adults and various life history stages and spawning activities of spotted sunfish would be reduced by more that 15% (Figure 5-13, Table 5-5).

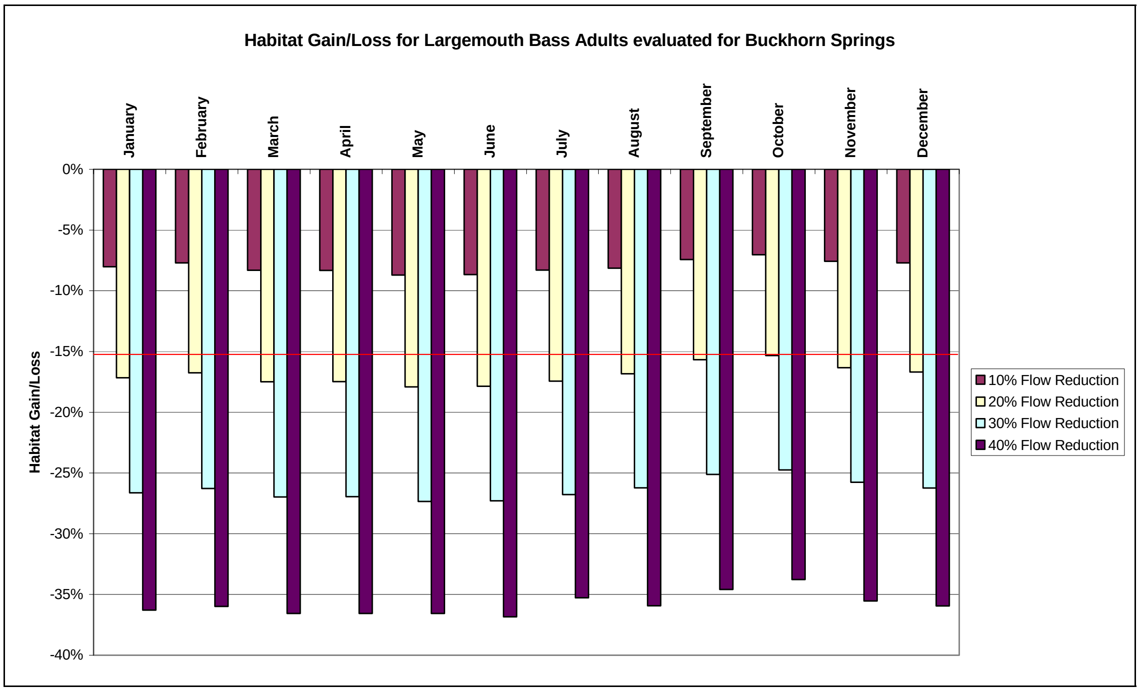


Figure 5-13. Habitat Gain/Loss for adult largemouth bass associated with modeled flow reductions of 10-40% in Buckhorn Creek, based on Buckhorn Spring flows, downstream of Buckhorn Springs Main. Similar plots for other largemouth bass life history stages and other species are included in Appendix PHABSIM.

Table 5-5. Maximum monthly percent-of-flow reductions associated with less than a 15% reduction in habitat for various life history stages or activities of several fish species in Buckhorn Creek, based on Buckhorn Spring flows, downstream from Buckhorn Springs Main.

Month	Percent-Of-Flow Reduction	Fish Species Life History Stage or Activity
January	15%	Spotted sunfish juveniles; Largemouth bass adults
February	15%	Spotted sunfish juveniles; Largemouth bass adults
March	15%	Spotted sunfish juveniles; Largemouth bass adults
April	15%	Spotted sunfish juveniles, spawning; Largemouth bass adults
May	15%	Spotted sunfish juveniles, fry, spawning; Largemouth bass adults
June	15%	Spotted sunfish juveniles, fry, spawning; Largemouth bass adults
July	15%	Spotted sunfish juveniles, spawning; Largemouth bass adults
August	15%	Spotted sunfish juveniles, spawning; Largemouth bass adults
September	20%	Spotted sunfish juveniles; Largemouth bass adults
October	20%	Spotted sunfish juveniles; Largemouth bass adults
November	20%	Spotted sunfish juveniles, spawning; Largemouth bass adults
December	20%	Spotted sunfish juveniles; Largemouth bass adults

The second flow record used was for Buckhorn Creek flow only. This record was created by taking the gage record just downstream of Buckhorn Springs and correcting the flow for reported withdrawals. Simulated reductions in flow of more than 5% from July through October and 10% for the rest of the year, except of 20% in March, indicated that habitat availability for largemouth bass adults and various life history stages of spotted sunfish would be reduced by more that 15% (Figure 5-14, Table 5-6).

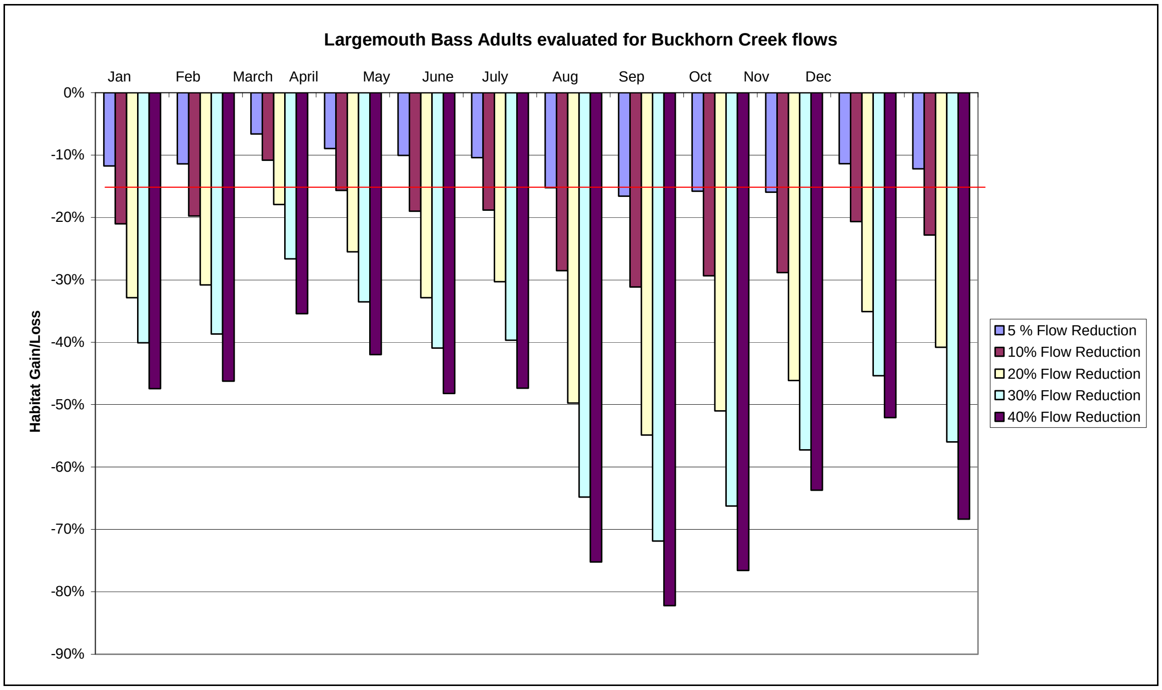


Figure 5-14. Habitat Gain/Loss for adult largemouth bass associated with modeled flow reductions of 10-40% in Buckhorn Creek, based on Buckhorn Creek flows, downstream of Buckhorn Springs Main. Similar plots for other largemouth bass life history stages and other species are included in Appendix PHABSIM.

Table 5-6. Maximum monthly percent-of-flow reductions associated with less than a 15% reduction in habitat for various life history stages or activities of several fish species in Buckhorn Creek, based on Buckhorn Creek Flows, downstream from Buckhorn Springs Main.

Month	Percent-Of-Flow Reduction	Fish Species Life History Stage or Activity
January	10%	Juvenile Spotted Sunfish, Adult Largemouth Bass
February	10%	Juvenile Spotted Sunfish, Adult Largemouth Bass
March	20%	Adult, Juvenile Spotted Sunfish, Adult Largemouth Bass
April	10%	Juvenile Spotted Sunfish, Adult Largemouth Bass
May	10%	Juvenile Spotted Sunfish, Adult Largemouth Bass
June	10%	Juvenile Spotted Sunfish, Adult Largemouth Bass
July	5%	Juvenile Spotted Sunfish, Adult Largemouth Bass
August	5%	Juvenile Spotted Sunfish, Adult Largemouth Bass
September	5%	Juvenile Spotted Sunfish, Adult Largemouth Bass
October	5%	Juvenile Spotted Sunfish, Adult Largemouth Bass
November	10%	Juvenile Spotted Sunfish, Adult Largemouth Bass
December	10%	Juvenile Spotted Sunfish, Adult Largemouth Bass

5.8 Short-Term Compliance Standard for Buckhorn Springs Main

For the Buckhorn Creek/Buckhorn Springs Main system, PHABSIM analyses yielded a prescribed flow reduction of 15% for all months when run using Buckhorn Spring flow data, corrected for withdrawals. When using Buckhorn Creek flow data, corrected for withdrawals, the prescribed flow reduction was 5% for July through October, and 10% for the rest of the year except March when a 20% reduction is appropriate. Buckhorn Spring Main accounts for a clear majority of the flow in Buckhorn Creek a large majority of the time. Both flow records generate answers that are similar. A 15% reduction in spring flow compared to a 10% reduction in creek flow does not differ greatly.

Minimum flow requirements for the estuarine portion of the Alafia River are currently being evaluated by the District. Because compliance with minimum flows and levels for the estuary may be contingent on flow or discharge from Buckhorn Spring, we recommend that establishment of a minimum flow for the spring be deferred until analyses for the estuarine segment of the Alafia River are completed. The report for the estuarine portion of the Alafia River will include recommendations for minimum flows for Buckhorn Spring and will consider the PHABSIM analysis already performed.

5.9 Compliance Standards and Proposed Minimum Flows for the Freshwater Segment of the Alafia River

We have developed short-term compliance standards that comprise a flow prescription for preventing significant harm to the Alafia 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 Alafia River, FL gage sites (Tables 5-6). During Block 1, which runs from April 20 to June 24, the allowable withdrawal from the Alafia River that may be withdrawn for consumptive-use is 10% of the daily flow as measured at the USGS Lithia gage, once flows exceed 66 cfs. During Block 1, it is also proposed that no withdrawals be allowed when flows at the Lithia gage are below 59 cfs and that withdrawals when flows at the site are between 59 and 66 cfs not be allowed to lower the flow below 59 cfs. During Block 2, which extends from October 28 of one year to April 19 of the next, withdrawals of up to 15% of the daily flow at the Lithia gage may be allowed, with the exception that withdrawals should not be allowed to reduce the flow to less than 59 cfs. 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 from 13% to 8% occuring at 374 cfs at the Lithia gage. Proposed Block 3 reduction also must comply with the low flow threshold and assure that withdrawals not reduce the flow to less than 59 cfs at the Lithia gage.

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 Alafia River gage site at Lithia. 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 record was altered by the maximum allowable flow reduction in accordance with the prescribed flow reductions and the low flow threshold. Hydrologic statistics for the resulting altered flow data set, 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 Alafia River at the USGS Lithia gage, long-term compliance standards were established at the minimum five and ten-year mean and median flows (Tables 5-6). 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 Lithia comprise the District's proposed minimum flows and levels for the Alafia 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, as necessary.

Table 5-7. Proposed Minimum Flows for the Alafia River, including short-term and long-term compliance standards, for the Alafia River at the Lithia, FL USGS 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	<59 cfs	0% of flow	10-Yr Mean	192
	December 31	>59 cfs and <374 cfs	Seasonally dependent	10-Yr Median	101
		>374 cfs	8% of flow	5-Yr Mean	163
				5-Yr Median	86
Block 1	April 20 to	<59 cfs	0% of flow	10-Yr Mean	85
	June 24	>59 cfs and <66 cfs	Flow in excess of 59 cfs	10-Yr Median	35
		>66 cfs and <374 cfs	10% of flow	5-Yr Mean	53
		>374 cfs	8% of flow	5-Yr Median	27
Block 2	October 28 to	<59 cfs	0% of flow	10-Yr Mean	137
	April 19	>59 cfs and <69 cfs	Flow in excess of 59 cfs	10-Yr Median	82
		>69 cfs and <374 cfs	15% of flow	5-Yr Mean	110
		>374 cfs	8% of flow	5-Yr Median	66
Block 3	June 25 to	<59 cfs	0% of flow	10-Yr Mean	318
	October 27	>59 cfs and <64 cfs	Flow in excess of 59 cfs	10-Yr Median	179
		>64 cfs and <374 cfs	13% of flow	5-Yr Mean	276
		>374 cfs	8% of flow	5-Yr Median	163

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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 Alafia River, Lithia Springs, and Buckhorn Spring.

A Review of

“Alafia River Minimum Flows and Levels Freshwater Segment including Lithia and Buckhorn Springs”

March 21, 2005 Draft

and

“Proposed Minimum Flows and Levels for the Upper Segment of the Myakka River, from Myakka City to SR72”

August 10, 2005 Draft

by

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Resource Conservation and Development Department
Southwest Florida Water Management District

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September 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 (District) in the development of two proposed minimum flows and levels (MFLs): the Alafia River freshwater segment including Lithia and Buckhorn Springs ("Alafia Report," SWFWMD 2005b) and the Myakka River upper segment from Myakka City to SR 72 ("Myakka Report", SWFWMD 2005c).

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 Alafia and Myakka rivers, and we find no serious flaws or errors in the methodology or findings documented in the reports. 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 reports 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, including those for the Upper and Middle Peace River MFLs (Gore et al. 2002, Shaw et al. 2005), 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 reports for the Alafia and Myakka rivers 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 concepts incorporated in the Alafia and Myakka River MFLs. These include:

- Identifying ***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
- 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.

The draft report for setting MFLs for the Alafia River includes the first effort by the SWFWMD to set MFLs for major springs in a basin, Lithia and Buckhorn springs. The panel expressed concern regarding the District's decision to use for these springs only one of the methods employed to develop allowable flow reductions for the rivers and to set a single flow reduction for the entire year instead of for the three seasonal blocks that were used for the rivers. The panel recognizes the logic of using an annual standard, but noted that there is substantial interannual variability in the discharge from both springs and that there may be merit in reducing permitted withdrawals from the springs in times of lower discharge. The panel suggests that thought be given to more restrictive withdrawals when the springs are discharging at less that 20% of long-term annual means. Although the panel supports the extension of PHABSIM and other riverine instream flow methods to spring systems, we recommend that the District research and consider alternative approaches for setting MFLs in Lithia and other major Floridan Aquifer springs that focus on the unique aquatic habitat provided by these systems. The review team supports the decision by the District to defer setting a prescribed flow reduction for Lithia Springs until MFLs for the Alafia estuary are developed.

The sole modification made to the District's basic MFL approach to deal with the issue of agricultural flow augmentation in the Myakka River was to employ a single benchmark period instead of two periods as was done for the Alafia River. The panel supports this modification and believes it to be reasonable and consistent with the District's overall approach. However, it should be noted that this approach does little to prevent flows from being augmented above natural background levels, nor does it correct the current flow augmentation problem in the watershed. Setting MFLs also may require that historic minimum flows be retained in intact rivers or returned in rivers with significant flow augmentation.

We applaud the District's commitment to periodic reassessment of the MFLs for the Alafia and Myakka rivers 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 Alafia and Myakka rivers is built upon the analyses previously performed on the Upper Peace River (SWFWMD 2002), peer reviewed by Gore et al. (2002), and more recently, on the Middle Peace River (SWFWMD, 2005a), peer reviewed by Shaw et al. (2005). The Alafia and Myakka MFL methodologies incorporate many of the recommendations of these earlier peer reviews, as well as key improvements developed by District staff. 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 to enhance the scientific basis that is firmly established for the decision-making process by the SWFWMD. Combined comments and recommendations are given for the basic approach for analyzing and setting MFLs in both rivers, followed by separate comments on aspects unique to each river; i.e., approaches for setting MFLs for springs in the Alafia River and for dealing with agricultural flow augmentation that occurs in the Myakka River. Extensive editorial comments and suggestions to improve the draft reports on the Alafia and Myakka rivers are provided in the Appendices.

1.0 THE CHARGE

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

1. Review the District's draft documents used to develop provisional minimum levels and flows for the Alafia and Myakka rivers.
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

2.1 Common Approach for Setting MFLs for Alafia and Myakka Rivers

MFL Benchmarks and Resource Protection Goals

Benchmarks and the Atlantic Multidecadal Oscillation (AMO)

The reports use 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 analysis 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 Alafia and Myakka rivers 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. In addition, knowledge of AMO-streamflow relationships gained by District staff should be widely disseminated to water managers throughout Florida and other parts of the eastern United States.

For the Alafia, the report provides convincing evidence (using water quality data and comparison of median daily flow hydrographs from different sub-basins on a flow per unit watershed area basis) that flow increases in low to median flows around 1960 were caused by increases in mining related discharges. Subsequent decreases in the same range of flows in the 1970s were attributed to a combination of curtailment of mining discharges and climate. This is similar to arguments made regarding the hydrologic effects of climate vs. mining in the middle Peace River basin (SWFWMD 2005a). One minor omission in the discussion of flow trends is a statement regarding whether increasing trends detected in the discharge of Lithia and Buckhorn springs are consistent with the expected effects of the AMO.

In the Myakka Report, convincing evidence is presented that dry season (low to median) and mean annual flows on the Myakka River have increased substantially since the late 1970s and that this trend is not caused by climate but instead by increases in discharge (irrigation return flows and runoff) from agricultural operations near the headwaters. Additional studies of agricultural flow augmentation in the Flatford Swamp area are cited to support this inference. The District's decision to determine minimum flows and levels in the Myakka River based only on the 1940-69 benchmark period (the period unaffected by agricultural flow augmentation) is reasonable and prudent given the inability to precisely quantify flow augmentation effects and separate them from effects caused by AMO-induced climate cycles. For a water body that naturally experiences no-flow conditions during the dry season, we consider this approach adequately protective even though the benchmark period selected represents the wetter phase of the AMO for southern rivers like the Myakka.

Building Block Approach

The SWFWMD has employed a building block approach in establishing MFLs for the Alafia and Myakka rivers (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, Bunn and Arthington 2002). Thus, with limited biological knowledge of specific flow requirements, the best alternative is to maintain or recreate the hydrological 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, Bunn and Arthington 2002). 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).

Hydrological variability is a critical component of the flow regime, 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, and 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 Alafia and Myakka rivers. It also has the advantage of insuring a flow regime with the range of variability essential to the maintenance of stream and river structure and function.

One potential weakness of using building blocks with fixed beginning and ending dates that was identified in the peer review for the Middle Peace River is that some important ecosystem functions may receive inadequate protection if an atypical or unusual water year occurs (Shaw et al. 2005). For example, during strong El Niño cycles, Florida often receives more intense rains and higher stream flows during the winter and spring months, which are assumed to be low-flow periods according to the building block concept. Conversely, less than average rainfall and stream flow may occur during the summer. This can result in an annual hydrograph that is seasonally reversed from the pattern assumed by the District's building blocks. In response to this concern, District staff have modified the building block approach so that the low flow threshold applies throughout the year instead of only during the low flow period (Block 1). This improvement is incorporated in the building block approach for both the Alafia River and Myakka River MFLs.

Preventing Significant Harm – 15% Change in Habitat

The draft Alafia and Myakka reports continue the District's practice of using a 15% change in habitat availability as the threshold for defining significant harm. This value was originally chosen based on the peer review report by Gore et al. (2002) for MFLs for the Upper Peace River (SWFWMD 2002) and, strictly speaking, applied to common professional practice when interpreting the results of PHABSIM analyses. The application of the 15% change threshold was expanded somewhat in the District's report on the Middle Peace River MFLs to define significant harm as either a 15% change in the area of available habitat (spatial change) or a 15% change in the number of days habitat is accessible to fish and other aquatic organisms (temporal change) (SWFWMD 2005a). This expanded interpretation also is used for the Alafia River and Myakka River MFLs. 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 temporal availability of habitat, and it is recommended that this issue be more fully investigated in the future. Nevertheless, the peer review panel for the Middle Peace found that use of the 15% threshold is reasonable and prudent (Shaw et al. 2005), especially given the absence of clear guidance in statute or in the scientific literature on levels of change that would constitute significant harm. We acknowledge that percentage changes reported in the literature have ranged from 10-33% in other applications designed to prevent significant harm. The present panel affirms the use of the 15% threshold in the Alafia and Myakka rivers for similar reasons. However, over the long term, it is critical that this presumption be further investigated and validated and/or refined through the collection of additional site-specific data as part of a larger adaptive management program.

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 Alafia and Myakka rivers. 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 stream flow gages to determine stage versus flow and wetted perimeter versus flow for numerous cross sections on the Alafia and Myakka rivers. 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 the Upper Peace report was that the hydraulic model needed to be linked to a biotic habitat model. This has been done with subsequent riverine MFLs, including the Alafia and Myakka, by use of the Physical Habitat Simulation (PHABSIM) model with key biota from these rivers, 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 in the Alafia and Myakka rivers. Some problems were encountered when applying the model to cross-sections that did not extend sufficiently far into the floodplain to handle wet season flows, but it appears that these issues were handled appropriately. 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 report. We recommend that similar discussion be added to the Alafia Report. We support the District's intent to further validate the accuracy of models and the effectiveness of its MFLs by investigating inundation of floodplain wetlands along river corridors where MFLs have been established.

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 but appropriate 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. Recently, Gore et al. (2001) demonstrated that inclusion of macroinvertebrate criteria often dramatically altered decisions on flow allocations 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 hydrological change than the three common centrarchid fishes identified in the Middle Peace report. These other species might include key invertebrates in the rivers of the District.

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 (*Lepomis macrochirus*), and macroinvertebrate community diversity (Gore et al. 2001, Stuber et al. 1982). These are appropriate species for consideration in rivers of the southern Florida peninsula and their selection is validated by data presented on fish abundance in the appendices to the MFL reports. Helpful information on the methods used for aquatic invertebrate and fish community assessment was included in Chapter 4 of the Alafia report, but was absent from the Myakka report. It is not clear whether such assessments were only conducted for the Alafia or whether the same assessments were carried out for the Myakka but the information was left out of the Myakka 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 Alafia and Myakka rivers. 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 hydrological regimes. 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 both the Alafia and upper Myakka rivers), wading birds and fish 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 these rivers (e.g., blue tilapia (*Oreochromis aureus*)) to ensure that reduced flows do not *improve* habitat conditions for such species or facilitate their invasion of new habitat. Additional species of concern in the Alafia and Myakka rivers that may not be directly amenable to the PHABSIM approach include several species of rare plants inhabiting the floodplain (FNAI Element Occurrence Database, 2005).

RALPH PLOTS AND ANALYSES

Recent and Long-Term Positional Hydrographs (RALPH) plots and analyses were used in the reports 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 the reports. 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 riverine systems, 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 Alafia and Myakka rivers. Flows of this magnitude would also likely permit recreation (i.e., canoeing). 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 by peer reviewers (Gore et al. 2002).

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 Engineering, Inc. 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.

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. 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. However, the use of river stages estimated using HEC-RAS, which the authors of the Myakka Report acknowledge as having a calibration accuracy of ± 0.5 ft., in combination with a fish passage criterion of 0.6 ft and linear regressions between modeled stages and flows, raises questions regarding the level of uncertainty that exists in the derived low-flow prescriptions.

As a final note, one of the water resource functions that the low-flow prescriptions are intended to protect is recreational use of the river. This goal is alluded to in Section 3.3.1 of both reports, but the issue is never discussed or developed further. Apparently, the assumption is made that fish passage criteria serve as surrogates for recreational use. 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 this should 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 flow thresholds.

DAYS OF FLOODPLAIN INUNDATION

Low gradient rivers, like the Alafia and (especially) the Myakka, have extensive floodplains. 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 many forms of aquatic life. River biota migrate onto floodplains for foraging and spawning during floods. 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 Alafia and Myakka rivers. Extensive vegetation and elevation surveys were used to characterize the structure and floristic composition of floodplains. 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 floodplain 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 throughout the report.

Inclusion of information on the methods used for identifying and characterizing floodplain plant communities and soils in the Alafia and Myakka reports is helpful and represents a significant improvement in the readability of these reports and interpretation of results. We commend District staff for incorporating these and other changes, which were recommended in previous peer reviews, in these reports.

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 also is important in biogeochemical transformation because 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 Alafia and Myakka rivers. Then, an estimate of the average frequency of inundation was determined using the two benchmark periods. Data from the most recent period (1970-1999) were used because it was more conservative (i.e., it was during 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 a 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 Alafia and Myakka rivers 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.

COMPLIANCE STANDARDS AND PROPOSED MINIMUM FLOWS

The peer review panel endorses the District's proposed minimum flows for the Alafia and Myakka rivers and finds them to be based on sound science and best available information, subject to our comments and recommendations above. We believe that the consideration of two separate benchmark periods based on distinct climate regimes (at least for the Alafia) 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 pragmatic and logical means of implementing the findings of the report in a regulatory context.

The review panel does have a concern about the wording of the second short-term compliance standards for Block 2 and Block 3 of the draft Alafia River report. The wording for the short-term compliance standard for Block 1 reads "When flows are between 59 cfs and 66 cfs measured at the USGS Lithia Gage, all flows above 59 cfs are available for use." The wording for Block 2 states "All flows between 59 cfs and 64.2 cfs measured at the Lithia gage are available for use." The wording for Block 3 states "All flows between 59 cfs and 69 cfs measured at the Lithia gage are available for use." We believe that the present wording for the second short-term compliance standard for Block 2 and 3 could be construed to mean that all water can be extracted from the river when flows are between the stated ranges for Block 2 and Block 3. The wording for Block 1 is clearer. The panel suggests that the wording for Block 2 read "When flows are between 59 and 64.2 cfs measured at the USGS Lithia Gage, all flows above 59 cfs are available for use." Similarly, wording for Block 3 should read "When flows are between 59 cfs and 69 cfs measured at the USGS Lithia Gage, all flows above 59 cfs are available for use." This way of stating the standard would preclude confusion as to whether all the flow or only part of the flow is available for reduction in these windows of river discharge. We also applaud the District's commitment to periodic reassessment of the MFLs for the Alafia and Myakka rivers 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 MFLs, 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 MFLs are intended to protect and periodic assessment of whether key assumptions inherent in the MFL development are still satisfied.

2.2 Minimum Flows and Levels for Lithia and Buckhorn Springs

The draft report for setting MFLs for the Alafia River includes the first effort by the SWFWMD to set MFLs for major springs in a basin. In both cases, the head springs themselves are highly altered from natural conditions, with Lithia Springs serving as a recreational swimming facility and Buckhorn Springs as a water supply pumping facility. Consequently, the MFL approach for these systems focused on protecting the ecological resources of the spring runs (including Buckhorn Creek). Of the various methods employed for developing minimum flow prescriptions for the Alafia and other rivers (e.g., fish passage, snag and root inundation, wetted perimeter, PHABSIM), the decision was made, presumably on the basis of data availability, to apply only the PHABSIM methodology to the spring runs. The use of multiple corroborative methods for setting MFLs in streams is a strength of the District's overall approach, and the panel suggests that additional and more careful explanation is needed in the report to better justify employing only one of these methods to the spring systems, especially given the fact that the PHABSIM results for Lithia Springs are ultimately discounted.

Allowable prescribed flow reductions are to be set on an annual basis for Lithia Springs and Buckhorn Springs Main rather than for three designated blocks with different hydrological characteristics, as is done for the rivers. The review team recognizes the logic of using an annual standard, but there is substantial interannual variability in the discharge from both springs and there may be merit in reducing permitted withdrawals from the springs in times of lower discharge. For example, the range of daily discharges from Lithia Springs Major is 7 to 70 cfs and from 4 to 22 cfs for Buckhorn Springs Main during the period of available record. The review team suggests that thought be given to more restrictive withdrawals when the springs are discharging at less that 20% of long-term annual means. For springs with more constant flow regimes, there would be less of a need for a low discharge threshold at which to reduce withdrawals and a set annual percentage could be applied.

The decision was made to not develop a prescribed flow reduction for Lithia Springs Major at this time. This decision was based on the ongoing MFLs being developed by the District for the estuarine portion of the Alafia River. MFLs for the estuary may be partially dependent on flows from Lithia Springs, and the review team supports the decision by the District to defer setting a prescribed flow reduction until the issue of setting MFLs for the Alafia estuary is resolved.

The panel also recommends that the District research and consider alternative approaches for setting MFLs in Lithia and other major Floridan Aquifer springs. Although we generally support the extension of PHABSIM and other methods for setting minimum flows in rivers to spring systems like Lithia, it should be recognized that springs are unique aquatic ecosystems that are quite different from the blackwater systems that otherwise prevail in Florida. For example, Odum's classic study of Silver Springs identified unique characteristics of the aquatic habitat of springs, including high water clarity and light penetration, high mass turnover rates and flow velocities and steady-state production, some of which might be affected by changes in spring flow (Odum, 1957). This unique environment, while perhaps not supporting a large number of rare or spring obligate species, may in fact provide physiological refuge or serve important habitat needs of more common species that goes beyond a simple stage-habitat relationship. One factor to consider in setting MFLs for springs is the frequency of incursion of riverine conditions (i.e., more highly colored water with different chemical, temperature and other properties) into portions of the spring and spring run habitat as spring flows are reduced. St. Johns Water Management District used the frequency and extent of incursions of cold river water into portions of the spring run utilized as winter habitat for manatee to assess its proposed MFL for Volusia Blue Spring. An analogous approach could be developed for springs in the SWFWMD, focusing on fish or invertebrate habitat, or in cases where ecological values are minimal, focusing on impacts to recreational use, water quality or aesthetics. It is not clear whether the manatee should be considered in setting an MFL for Lithia Springs. The report includes no discussion of whether this species presently or historically utilized the spring, despite the fact that a known manatee aggregation occurs at the TECO Big Bend power plant a short distance downstream.

Another possible factor to consider for springs that are heavily utilized for recreation is the relationship between depth of flow in the spring run and extent of trampling of submerged aquatic vegetation. Observations of springs in north Florida suggest that as water levels decline, damage to vegetation (and associated fauna such as snails) becomes more extensive as swimmers become waders and move into areas of the spring run previously too deep for wading. Such relationships are, for example, built into the limits on recreational use implemented at Ichetucknee Springs.

The percentage of maximum reduction of discharge for Buckhorn Springs Main is proposed as no more than a 15% reduction of mean daily flow from the average from the previous month (corrected for withdrawals). PHABSIM analyses were used to assess habitat changes from various flow reductions, and the analyses suggested a 15% flow reduction on average was most appropriate to meet a less than 15% reduction in habitat for various life history stages for dominant fish species in Buckhorn Creek downstream of the main spring. This is consistent with the criteria used in setting minimum flows and levels for rivers administered by the SWFWMD, and the review panel agrees that this is an appropriate target to use to meet the criteria of no significant harm to the spring and creek. Again, there is significant month-to-month variability in spring discharge, and a reduced or no reduction policy might be considered for times when spring discharge is at the lower one or two deciles of mean annual long-term discharge.

2.3 Approach for Addressing Flow Augmentation in the Myakka River

The sole modification made to the District's basic MFL approach to deal with the issue of agricultural flow augmentation in the Myakka River was to employ a single benchmark period instead of two periods as was done for the Alafia River and Middle Peace River MFLs. As noted above, the panel supports this modification and believes it to be reasonable and consistent with the District's overall approach. However, it should be noted that this modified MFL approach, focusing as it does on *low* flow thresholds and prescriptions for flow *reductions,* does little if anything to prevent flows from being *augmented* above natural background levels, nor does it correct the current flow augmentation problem in the watershed.

Flow augmentation and a change from intermittent to perennial flow conditions can affect wetland and riparian plant communities. For example, wetland hardwoods in the area around Flatford Swamp on the Myakka may be showing increased mortality due to increased duration of flooding from flow augmentation. Bunn and Arthington (2002) point out that the loss of wet-dry cycles can reduce growth and survival of native aquatic macrophytes and set the stage for increased invasion of non-native species. Setting MFLs also may require that historic minimum flows be retained in intact rivers or returned in rivers with significant flow augmentation.

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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 freshwater segment of the Alafia 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" (Cichra 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. *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 Alafia River flow reduction required to effect a 15% spatial loss are greater then those required to effect a 15% temporal loss (Munson and Delfino in review).

2. *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 Alafiaa River MFL report. In the peer review report of the Alafia 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 Alafia 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.

3. *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.

4. *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.

5. *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.

APPENDIX C – Letter from the Tampa Bay Estuary Program with attachments

The following letter contains comments from the Tampa Bay Estuary Program with attachments. Appendix D documents the District response to the issues raised in this letter.

TAMPA BAY Estuary Program

July 8, 2005

Ms. Janet Kovach
Governing Board Member
Southwest Florida Water Management District
2379 Broad Street
Brooksville, FL 34609

RE: Findings and recommendations on the draft Minimum Flow Determinations for the Upper Alafia River and the Tampa Bypass Canal from the Tampa Bay Estuary Program Technical Advisory Committee

Dear Ms Kovach:

In your capacity as the SWFWMD representative on the Tampa Bay Estuary Program Policy Board, we wish to convey the results of a recent review of the above draft reports by members of the TBEP Technical Advisory Committee. The TAC and TBEP staff recognizes the considerable time and effort District staff has devoted to their comprehensive evaluation of potential minimum flow options for the freshwater portion of the Alafia River and for the Palm River/Tampa Bypass Canal. We appreciate the District staff's willingness to invite the TBEP TAC to review technical aspects of MFL determinations for rivers within the Tampa Bay watershed. SWFWMD staff members Dr. Marty Kelly and Mike Heyl provided a presentation on the technical aspects of the draft MFLs for the upstream Alafia River and for the TBC to the TBEP TAC at a workshop held on May 20, 2005. Like the Sulfur Springs MFL workshop held last October, presentations were thorough and professional. Response to questions and requests for additional information posed by the workshop attendees were also provided in a very timely manner.

TBEP partners have adopted a number of long-term goals for the restoration and protection of Tampa Bay. One of those goals is to restore the historic balance of estuarine wetland habitat by restoring a minimum of 20 acres of low-salinity wetland habitat (<10 parts per thousand or ppt) each year. Low-salinity habitat is critical for many estuarine-dependent species of fish and other organisms. A related goal is to protect shallow freshwater wetlands important to estuarine wading birds which fish these wetlands to provide food for their salt-intolerant young.

In February 2004, the TBEP Policy Board approved an updated action to "Establish and maintain minimum seasonal freshwater flows in rivers". The initial step in this process is to convene a workshop to assess potential effects of proposed MFL determinations on existing and potential low-salinity habitat in the Tampa Bay area. The May 20th workshop was the second in a series of workshops for tributaries of Tampa Bay for which MFLs will be established.

TAMPA BAY ESTUARY PROGRAM
Mail Station I-1/NEP · 100 8th Avenue S.E. · St. Petersburg, FL 33701 · (727) 893-2765 · FAX (727) 893-2767 · SUNCOM 513-9497

Based on the District's presentation, draft MFL Reports, and responses to additional questions from the TAC workshop, the TBEP TAC submits the following findings and recommendations.

Additional comments submitted by workshop participants are included as attachments to this letter.

The TBEP TAC requests that its findings and recommendations, including attachments, be considered by the SWFWMD Governing Board and forwarded to the SWFWMD MFL Independent Peer Review Panels for the Alafia River and for the Tampa Bypass Canal, for their consideration.

Findings and Recommendations: Upper Alafia River

Participants in the workshop applaud the integrated physical and biological analyses and approach to developing MFLs for the upper Alafia River. The biological analyses are complex and comprehensive, and there is value in the percentage reduction approach used in the SWFWMD staff analyses in protecting flows at all river stages.

The TBEP TAC recommends consideration of the following issues:

1. Encourage the watershed approach by addressing both the upper and estuarine sections of the Alafia River in setting MFLs. The MFL for the upper Alafia River should not compromise the MFL determination for the estuarine section of the river.

2. Consider how recommended MFLs could affect duration and depth of inundation of offstream freshwater wetlands that may only be connected via surface water to the river during very high flows. These freshwater wetlands can be critical feeding habitat for estuarine-dependent wading birds and other organisms, and have been identified by Audubon and TBEP as important "at-risk" habitats.

3. It would be helpful to include an analysis of measured rainfall during the AMO warm and cool phases, and during the benchmark periods used in this draft report. How has measured rainfall varied over time? Is there a relationship between rainfall and flow, and has that relationship changed over time or between the two benchmark periods? How might the other factors affecting flow (e.g., changes in land use, groundwater use, phosphate industry water management practices) change the outcome of the District's analysis? See the rainfall/flow regression approach developed for SWFWMD by Coastal Environmental for the long-term gages on the Peace River for examples of changing relationships for rainfall and river flow for different time periods, which could yield useful information for developing MFLs.

The participants also expressed a concern that the cumulative effects of water withdrawals on downstream waters (i.e., Hillsborough Bay) may not be addressed in the MFL process. At a TBEP Freshwater Inflow workshop held in 2001, the general consensus by the participants, also expressed by Janet Llewellyn at FDEP, was that impacts of freshwater flow reductions would most likely first be observed in the tidal rivers rather than the larger bay systems, and that MFLs that protect these tidal rivers also provide a level of protection for the bay. However, TBEP staff agrees with the workshop participants that cumulative effects of water withdrawals on the bay should be revisited, and proposes to do that through the TAC later this year.

Findings and Recommendations: Tampa Bypass Canal

Overall, workshop participants appreciated the good effort of District staff on a difficult and highly modified system. However, there is concern that a recommendation of no MFL for the TBC will be interpreted as a de facto MFL of zero flow. Although there may be environmental protection provided through the Water Use Permit process, the absence of an adopted MFL remains a source of concern.

1. Consider the biological effects (especially predation on larval and juvenile fishes and invertebrates) of incursion of marine organisms (medusae, including jellyfish) at the base of the dam during very low or zero discharge. See data presented by Ernst Peebles at the HBMP meeting on May 18th.

2. Consider the possible impacts of very low or zero discharge on hydrologic residence times, which may affect living resources in a variety of ways (e.g., via changing phytoplankton and DO dynamics).

3. The finding that flow explains only about 15% of the variability in biological data was used by SWFWMD staff to support their recommendation not to define MFLs for the TBC. An explanatory value of 15% (shown to be associated with a flow of around 66 cfs) can be considered fairly good for biological data.

4. Conduct analysis of metrics (i.e., fish abundance, etc) on a segment basis, in addition to the entire length lumped together from S-160 to the 22nd Street Causeway. The combining of segments of McKay Bay with the linear Canal into one reporting unit may mask relationships between flow and biological response in the different parts of the system. Possible segmentation may be from S-160 downstream to the sill, from the sill downstream to the mouth of the Bypass Canal, and from the Bypass Canal mouth downstream to the 22nd Street Causeway.

5. Estimate the center of abundance of organisms analyzed under different flow rates. What amount of movement of the center of abundance would be considered "significant harm"?

Relevant recommendations from the Sulfur Springs workshop

In addition to recommendations made during the May 20th workshops, recommendations made by the TBEP TAC at the Sulfur Springs workshop directly address the Tampa Bypass Canal and are included here.

1. The TBEP Technical Advisory Committee recommends that MFLs for Sulphur Springs, Lower Hillsborough River, and the Tampa Bypass Canal be evaluated as an interconnected system prior to adoption. Specifically, the TAC recommends the following:

a. The District should continue the independent peer reviews of the MFLs for each of these three flowing water bodies.

b. Once the draft MFLs for Sulphur Springs, the Lower Hillsborough River and the Tampa Bypass Canal have been individually peer reviewed, the District should fund an independent peer review of the MFLs for the three water bodies as components of an integrated watershed. This would take into account the water bodies being part of the same watershed with the ability to transfer water among them. A watershed-based approach to setting MFLs may provide additional opportunities for habitat restoration and protection, manatee protection, and effective water management. For example, there may be an enhanced potential for oligohaline habitat restoration in the TBC which could be realized if additional fresh water was directed to the TBC, particularly along the sides of the canal downstream of Structure 160.

c. TBEP should reconvene the Hillsborough River/TBC Advisory Group and TAC, giving members the opportunity to evaluate the three proposed MFLs concurrently. Their comments should be forwarded to the independent peer review panel.

d. The District should adopt MFLs for Sulphur Springs, Lower Hillsborough River and TBC concurrently, taking into account Advisory Group and peer review evaluations.

Thank you for your consideration of the TBEP TAC findings and recommendations regarding the draft Upper Alafia River and Tampa Bypass Canal MFLs. If you have questions or comments about the TAC comments, please contact me at 727-893-2765 or hgreening@tbep.org.

Sincerely,

Holly Greening

Holly Greening
TBEP Senior Scientist

cc: SWFWMD Governing Board members
David L. Moore, SWFWMD Executive Director
Dr. Marty Kelly, SWFWMD
Lizanne Garcia, TBEP Management Board member representing SWFWMD
Deborah Getzhoff, TBEP Policy Board chair
TBEP TAC members and workshop participants (electronic copies)

Attachments:

Additional comments from the E. Sherwood, Environmental Protection Commission of Hillsborough County

Additional comments from A. Hodgson, Audubon of Florida's Florida Coastal Islands Sanctuaries Program

Attachment A

June 15th, 2005

Mrs. Holly Greening, Senior Scientist
TBEP Technical Advisory Committee
Tampa Bay Estuary Program
100 8th Ave. SE
St. Petersburg, FL 33701

Re: Proposed Minimum Flows for the Upper Alafia River & Palm River/Tampa Bypass Canal

Dear Mrs. Greening:

Thank you and the District for allowing us the opportunity to comment on the proposed minimum flows for the Upper Alafia River and Palm River/TBC during the public workshop held on May 20th, 2005. As you requested, attached are additional comments and concerns regarding the proposed minimum flows for these two waterbodies.

If you would like to discuss these issues in more detail, please call us at (813) 627-2600.

Sincerely,

Ed Sherwood

1) Upper Alafia River Hydrology

Sect. 2.3 of the draft report proposes that causal relationships exist between multi-decadal trends in the gaged flow of the Alafia River (measured at the Lithia gage) and rainfall patterns that vary in response to changes in sea surface temperature (SST) associated with the Atlantic Multidecadal Oscillation (AMO).

The proposed multi-decadal relationship between the AMO, rainfall, and river flow are not analyzed in detail in the report itself. Instead, the reader is referred to a group of other documents (e.g., Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004) for a more detailed explanation. Basso and Schultz (2003) explain the proposed relationship as follows:

> *"A new study by scientists from the National Oceanic and Atmospheric Administration (NOAA) the University of Miami, and the South Florida Water Management District found statistically significant differences in rainfall between the pre-1970 period versus the last 30 years... Their research attributed this shift in the rainfall regime to the Atlantic Multidecadal Oscillation (AMO), a naturally occurring variation in North Atlantic Ocean temperatures that occurs every 20 to 50 years.*
>
> *Enfield and others (2001) indicate that warmer than average sea surface temperature periods of the AMO lead to increased wet season rainfall while cooler than average ocean temperatures decrease summer rainfall on the Florida peninsula. During warmer ocean temperature periods, global atmospheric circulation patterns shift to a more predominant southeasterly flow across the Florida peninsula, which leads to increased afternoon convective-activity and higher wet season rainfall. During cooler ocean temperature intervals, the upper atmospheric pattern is interrupted more frequently by mid-latitude disturbances, which generally results in less wet season rainfall."*

A quick examination of the Enfield et al. (2001), Basso and Schultz (2003), Kelly (2004), and draft Alafia River MFL documents leads to the following questions:

Question 1A. If other researchers wish to analyze multi-decadal variations in rainfall and river flow patterns in west-central Florida, which time periods should they designate as "warmer Atlantic SST/higher rainfall" and which should they designate as "cooler Atlantic SST/lower rainfall"?

The Enfield et al. (2001) report states that warmer SST conditions existed from 1860 through 1880, 1940 – 1960, and began once again in 1995. They indicate that cooler SSTs were present from 1905 – 1925 and from 1970 – 1990.

Basso and Schultz (2003) define the warmer SST periods as1869 – 1893, 1926 through 1969, and post 1995. They indicate that cooler SST conditions were present during 1894 – 1925 and 1970 – 1994.

The Kelly (2004) report includes a graphic (Fig. 11) showing a cooler SST period extending from the early 1900s to 1928, a warmer SST period from 1928 – 1965, and a cooler SST period from 1965 – 1996. However, the statistical analyses of rainfall and river flow patterns provided in the Kelly (2004) report are based on two other time periods: 1940 – 1969 (described in the report as a "high flow" period), and 1970 – 1999 (described as a "low flow" period).

Given the great year-to-year variability that is present in annual rainfall and river flow data, it appears possible that the choice of starting and ending dates of these analyses may affect the statistical conclusions that are drawn from them. To avoid this potential source of confusion – which might also impact resource management decisions – it would be helpful if a consistent set of starting and ending dates could be agreed upon.

Question 1B. Does annual rainfall show statistically significant differences between the "high flow" and "low flow" periods described in the draft MFL report?

The draft Alafia River MFL report builds on an approach described by Kelly (2004), who examined hydrographs of median daily flows during two benchmark periods: a 1940 – 1969 ("high flow") period and a 1970 – 1999 ("low flow") period. Several statements are made in Sect. 2.3 of the draft report which suggest that annual rainfall was significantly higher during the 1940 – 1969 period than during the 1970 – 1999 period, not only in the Alafia River watershed but throughout west-central and southern Florida. The suggestion is made most clearly on p. 2-33:

> *"…the period from 1940 thru 1960 represents a period when peninsular Florida was experiencing a multidecadal period of higher rainfall and consequently river flows (Enfield 2001, Basso and Schultz 2003, Kelly 2004). It is believed that even without the intervention of man, that flows in many stream and river systems would show a decline of 20 to 40% when two multidecadal periods are compared (i.e., 1940 to1969 and 1970 to 1999.)"*

This suggestion can be examined by analyzing annual rainfall records from the 11 "Comprehensive Watershed Management" (CWM) basins that fall within the Southwest Florida Water Management District. A summary of those data, for the periods 1940 – 1969 and 1970 – 1999, is provided in the following table and figures.

Table 1. Statistical comparisons (Wilcoxon rank-sum test) of annual rainfall in 11 CWM basins during the two multi-decadal periods (1940 – 1969 and 1970 – 1999) discussed in the draft Alafia River CWM report. (Data source = SWFWMD)

CWM Basin	Mean Annual Rainfall (in.) 1940 – 1969	Mean Annual Rainfall (in.) 1970 – 1999	p-value 1940-1969 rainfall greater than 1970-1999 rainfall*	p-value 1940-1969 rainfall greater or less than 1970-1999 rainfall**
Springs Coast	56.4	55.0	0.29984	0.59968
Tampa Bay/Anclote River	53.7	52.0	0.27962	0.55923
Withlacoochee River	55.0	53.4	0.23439	0.46879
Hillsborough River	54.5	53.4	0.37529	0.75058
Lake Wales Ridge	54.2	50.8	**0.07683**	0.15367
Manatee River	56.1	52.5	**0.09288**	0.18577
Peace River	54.3	51.3	**0.07472**	0.14945
Alafia River	53.4	50.5	0.16276	0.32552
Southern Coastal	55.7	50.2	**0.01757**	**0.03514**
Myakka River	54.1	54.7	0.42669[a]	0.85338
Little Manatee River	55.6	51.2	**0.04963**	**0.09926**

* one-tailed test
** two-tailed test
[a] testing for1970 – 1999 rainfall > 1940 – 1969 rainfall

Figure 1. Box-and-whisker plots of annual rainfall records from two time periods (1940 – 1969 and 1970 – 1999). (Data source = SWFWMD).

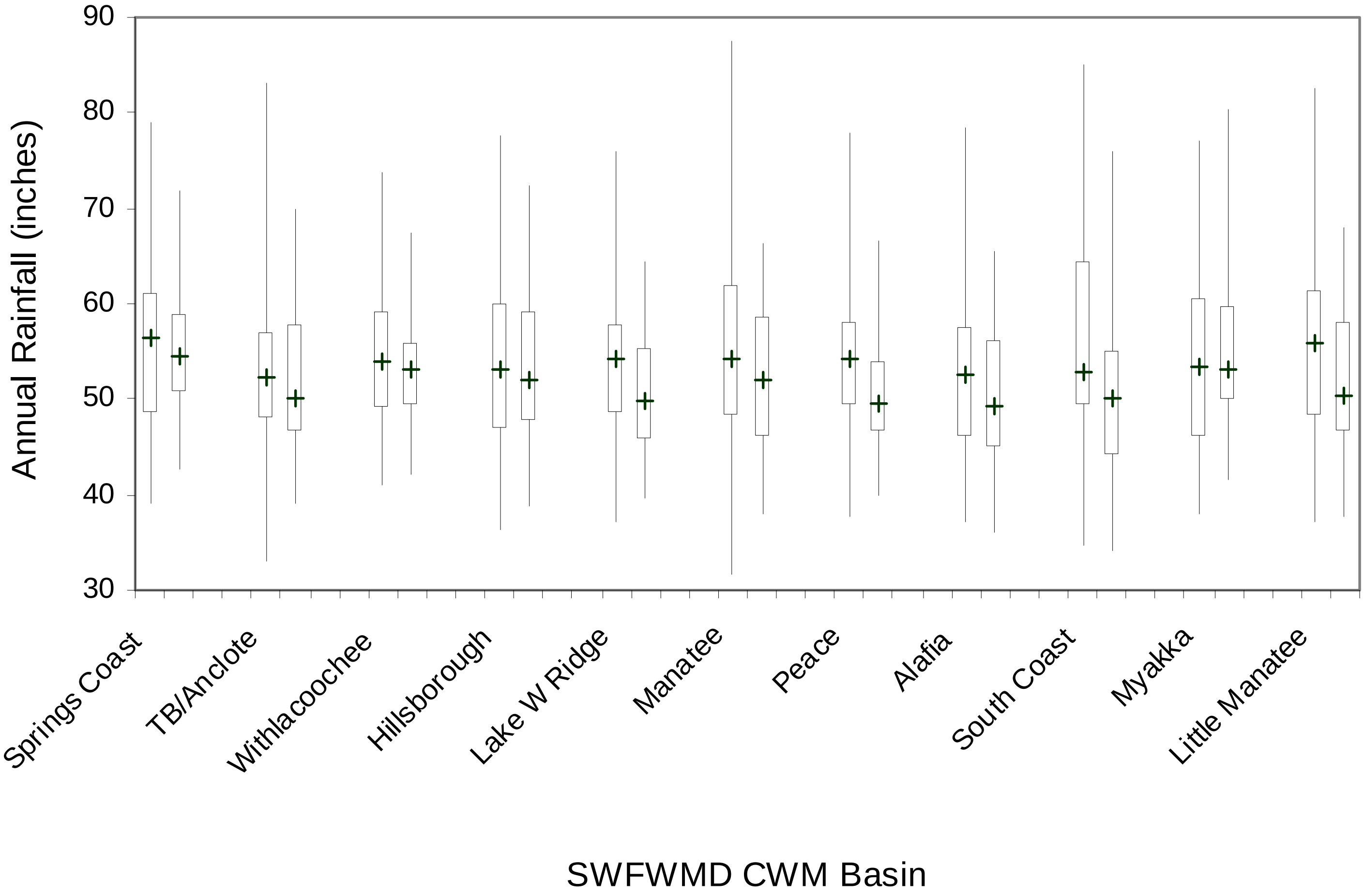
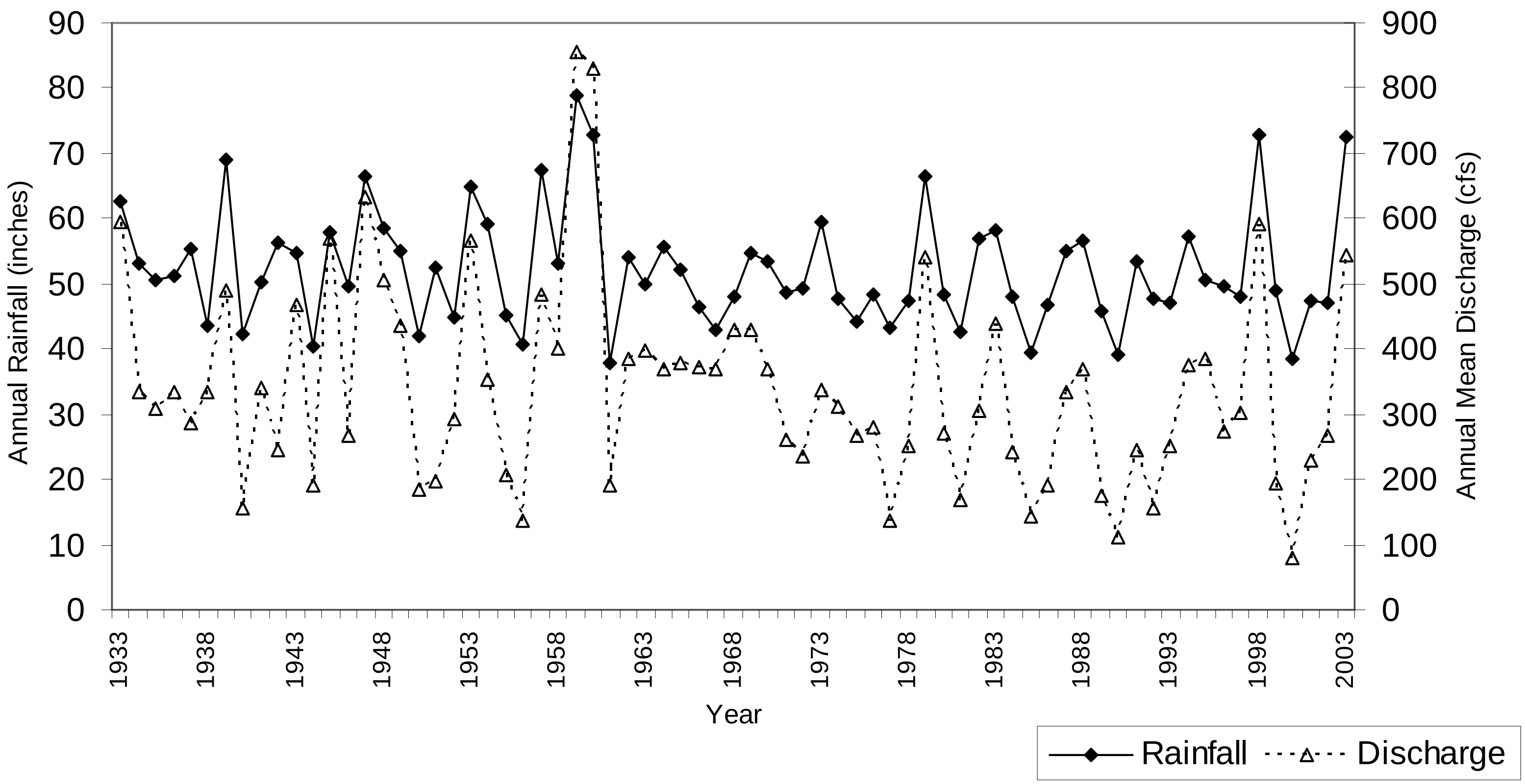


Figure 2. Annual rainfall (basin-wide) and annual mean discharge (at the Lithia gage) in the Alafia River watershed for the period 1933 through 2003. (Data sources: SWFWMD, USGS)



As shown in Table 1, a nonparametric statistical comparison using the Wilcoxon rank-sum test indicates that clearly-significant (two-tailed $p<0.05$) differences in annual rainfall between the two time periods occurred in only one CWM basin (the Southern Coastal basin). A marginally-significant ($p<0.10$) difference is also evident, in the Little Manatee River basin, when using the two-tailed test.

A one-tailed test, which was used by Kelly (2004) based on an assumption that rainfall should be consistently higher during the 1940-1969 period than in the 1970-1999 period, indicates clearly significant ($p<0.05$) differences in two watersheds (Southern Coastal and Little Manatee River) and marginally-significant ($p<0.10$) differences in an additional three basins (Lake Wales Ridge, Manatee River and Peace River).

In the majority of CWM basins – including the Alafia River watershed – the statistical results indicate that annual rainfall amounts did not differ significantly between the two time periods.

In addition to these nonparametric analyses, ANOVA models were also constructed to evaluate the hypothesis that annual rainfall values varied consistently between the two time periods. The significance levels of these models were generally consistent with those of the nonparametric tests. In addition, the R^2 values generated by the ANOVAs were quite small (most less than 5%), indicating that the "two time period" conceptual model explains a relatively small proportion of the variation in annual rainfall levels.

Box and whisker plots (Figure 1), which show the minimum, 25th percentile, median, 75th percentile, and maximum annual rainfall amounts reported for each CWM basin in each of the two time periods, can be used to examine the data visually. These plots indicate that annual rainfall amounts varied a great deal from year to year, and although median values were consistently higher during the 1940 – 1969 period than during the 1970 – 1999 period, years of very low and very high rainfall occurred during each period. Based on visual inspection of Figure 1, the more consistent difference between the two periods appears to be higher year-to-year *variability* in annual rainfall that occurred during the 1940 – 1969 period.

One factor that may explain a portion of the observed variability in annual rainfall may be the El Niño/Southern Oscillation (ENSO) phenomenon. In their seminal paper on the hydrologic implications of the AMO, Enfield et al. (2001) noted that rainfall in south-central Florida tends to be high in the El Niño portion of the ENSO cycle, and low during the La Niña portion, regardless of AMO conditions.

Given these rainfall patterns, it is not clear whether the statement made on p. 2-33 of the draft report:

“*It is believed that even without the intervention of man, that flows in many stream and river systems would show a decline of 20 to 40% when the two multidecadal periods are compared*”

is supported by the available data. A plot of the long-term annual rainfall and annual flow data is shown in Figure 2.

2) Upper Alafia River Water Budgets

Sect. 2.3 of the draft report also proposes that causal relationships exist between long-term trends in the gaged flow of the Alafia River (measured at the Lithia gage) and changes in the water management practices used by the phosphate industry. The proposed relationship is described as followed in the draft report:

“Although there has been considerable phosphate mining in the Alafia watershed (especially in the watersheds of the North and South Prongs) and substantial groundwater withdrawals from the Floridan aquifer, comparison of river flow declines with neighboring watersheds suggests a similar causative factor for flow declines. Our analyses indicate that flow declines attributed by Stoker et al (1996) to groundwater withdrawals, and by SDI (2003) to increasing area of mined land are due to another factor, namely the removal or reduction of discharges from the phosphate mining industry.” (p. 2-28)

“. . . the flows of the Alafia River were actually augmented during the 70's (and for at least part of the 60's)” (p. 2-36)

“. . . flow data indicate that mine related discharges were essentially eliminated from both the North and South Prongs by the late 1970s or early 1980s.” (p. 2-52)

“Decreases in discharge were accomplished through increased water use efficiency and a decrease in ground water usage.” (p. 2-49)

Consideration of these statements and a quick review of the Stoker et al. (1996) report leads to the following questions:

Question 2A. **The changes in mining practices that are alluded to in the draft report apparently occurred during the 1960s and 1970s and had significant influence on the hydrology of the Alafia River. However, the report provides no information on or estimates of the quantities of water that were discharged to the river during the “augmentation” phase, the quantities of groundwater that were used during this phase, or the effects of these groundwater withdrawals on surface water hydrology. Should a detailed analysis of these factors – including quantitative water budgets for the Alafia River during the period prior to, during, and following the period of apparent**

"augmentation" – be performed as part of the Alafia River MFL process, in order to better understand the changes in surface water flows that may have occurred during this period?

Question 2B. A statement made on p. 2-28 of the draft report – that long-term flow trends in the Alafia River are primarily due to changes in water management practices by the phosphate industry – appears to conflict with statements made on p. 2-33 (and elsewhere) of the report, which imply that the long-term trends were caused primarily by multi-decadal changes in rainfall associated with the AMO. Should a more comprehensive comparison of these factors, including the development of quantitative water budgets, be performed as part of the Alafia River MFL process in order to better understand the relative contributions of each of these factors to the long-term flow changes that have occurred in the river?

3) Implications of No MFL Established for the Palm River/Tampa Bypass Canal

It is unclear to us how the existing Water Use Permits held by Tampa Bay Water and the City of Tampa will be affected by the establishment of no minimum flow over S-160 into the Palm River. Under the conditions of each WUP, once a MFL is established for a waterbody (or effectively no MFL established, in this case), a re-evaluation of permitted quantities and withdrawal schedules may be necessary.

Question 3. Given the conditions set forth in the Tampa Bay Water WUP (see Table 2-5 of the report) where flow over S-160 is a determining factor in withdrawal quantity, will the establishment of no MFL for the Palm River/Tampa Bypass Canal effectively negate this permit requirement for future application of renewal?

ATTACHMENT B

From: Ann Hodgson [abhodgson@earthlink.net]
Subject: Florida Coastal Islands Sanctuaries Program - Comments - Draft Alafia River Minimum Flows and Levels Freshwater Segment including Lithia and Buckhorn Springs

Audubon of Florida's Florida Coastal Islands Sanctuaries Program has reviewed the draft Alafia River Minimum Flows and Levels Freshwater Segment including Lithia and Buckhorn Springs [Kelly, M., A. Munson, J. Morales, and D. Leeper. 2005. Draft Alafia River Minimum Flows and Levels Freshwater Segment including Lithia and Buckhorn Springs. Ecologic Evaluation Section, Resource Conservation and Development Department, Southwest Florida Water Management District, Brooksville, FL]. Our programmatic concerns include managment of colonial nesting waterbirds, bird species generally, the habitats, landscapes, and forage species on which they are dependent. We compliment the authors and the Southwest Florida Water Management District (SWFWMD) on preparing a technically expansive analysis of potential MFL's for the Alafia River. Particularly, we note that this study is the first (to our knowledge) MFL report to include physical habitat simulation modelling (PHABSIM) (Bovee et al. 1998) integrated with HECRAS modelling, and we believe this multi-disciplinary approach will be appropriate for future studies. Our comments focus primarily on two areas: (1) maintenance of landscape level ecological integrity for riverflow-dependent species, including associated stream edge habitats, and permanent and intermittent floodplain wetlands; and (2) maintenance of an optimal 'forage fish' component for piscivorous birds. Our specific comments follow.

Extent of analysis.
Figure 4-1 shows the 'Alafia River study corridor' (yellow box), Figure 4-2 shows transects extending to U.S. 41, the text references 'Buckhorn Springs eastward to Aldermans Ford Park, and the report title is '... Freshwater Segment...', which we would assume includes the entire Alafia River from the headwaters westward to the mean high tide (or greater) upstream extent of the salinity prism. Estuarine-dependent organisms occur upstream to a temporally variable location east of U.S. 41 extending to approximately U.S. 301, or further. Similarly, freshwater-dependent species occur downstream until they reach the limits of their species-specific salinity tolerances. The analysis corridor should be additionally defined by geographic coordinates and a revised map. It would be helpful to portray the modeled extent of the estuarine effect because some bird species, while freshwater dependent, are more plastic than others, and others use freshwater during various lifestages, but not entirely (see the Tampa Bay

Estuary Program 'Restoring the Balance' document (Lewis and Robison 1995)).

Maintenance of landscape level ecological integrity for riverflow-dependent species.

Many avian and fish species occurring in the Tampa Bay region have concommitant dependencies on estuarine and freshwater resources. While the proposed net change in freshwater discharge was incrementally small, it would be helpful to include an analysis of prospective change, if any, in the upstream extent of the salinity prism. Modal centrality of some estuarine organisms presumably will vary depending on shifts in salinity. We concur with the reported emphasis on the within-stream functional analysis of large woody debris. We suggest additional analysis related to the decrease in stream edge available foraging habitat (see the great blue heron habitat suitability model, and others). We also suggest some analysis of the off-stream, but still connected, smaller freshwater wetlands that are very important for foraging, aquatic invertebrate production (e.g., Orthoptera, crayfish, and others), and terrestrial invertebrate and vertebrate productivity.

Maintenance of 'forage fish' for piscivorous birds.

In these comments we use the term 'forage fish' specifically in reference to fishes (and invertebrates such as crayfish) providing forage for piscivorous birds. The USGS has published a list of 157 habitat suitability models (http://www.nwrc.usgs.gov/wdb/pub/hsi/hsiindex.htm). In addition to the fish species (red-breasted sunfish, spotted sunfish, coastal shiner, sailfin shiner, bluegill and largemouth bass) used to determine incremental instream flows (Kelly et al. 2005), we are concerned with the maintenance of endemic (preferably) and introduced fishes generally <20 cm TL (see the belted kingfisher, roseate spoonbill, great blue heron, white ibis, wood duck, and other habitat suitability models). While many of these small endemic fishes may not be affected by the fish passage criterion, most are highly dependent on peripheral aquatic vegetation, complex backwater eddies, and permanent and intermittent floodplain wetlands to complete their life cycles. We suspect bias in the enumeration of fishes caught during 'backpack electrofishing from dominant habitats in the Alafia River corridor' (Kelly et al. 2005, p. 4-9). This author's experience is that many forage fishes are not adequately identified, or enumerated when the focus is on the dominant recreational fish species. A table of fish species observed during electroshocking and their morphometric data would be useful. We recommend expanding the analysis to include an examination of forage fish maintenance related to the various state-listed avian species, and a few other riverine-dependent birds known to occur along this segment of the Alafia River as an impromptu guild for the wading birds, ducks, kingfishers, etc. that have a high dependence on small fishes and large aquatic invertebrates in their diet.

Literature Cited.

We noted no references to colonial nesting waterbirds and other bird species anticipated to be distributed along and dependent on the freshwater segment of the Alafia River. We may be able to help the analysis by providing some additional useful references for consideration, as the nesting survey season is coming to a close.

Thank you very much for the opportunity to provide these comments. We look forward to continuing to assist the SWFWMD in developing proposed minimum flows and levels that will provide consumptive use of water while comprehensively protecting Florida's wildlife species.

APPENDIX D – District's response to the Tampa Bay Estuary Program's letter presented in Appendix C

August 25, 2005

Ms. Holly Greening
TBEP Senior Scientist
Tampa Bay Estuary Program
100 8th Avenue S.E.
St. Petersburg, Florida 33701

Subject: Tampa Bay Estuary Program Letter Dated July 8, 2005 with Findings and Recommendations on the Draft Minimum Flow Determinations for the Upper Alafia River and Tampa Bypass Canal

Dear Ms. Greening:

Your letter to Ms. Janet Kovach, Governing Board Member and SWFWMD representative on the Tampa Bay Estuary Program (TBEP) Policy Board, has been directed to staff for purposes of preparing a response. The District sincerely appreciates the TBEP's willingness to conduct Minimum Flows and Levels (MFL) workshops so that staff can present their proposed MFLs to a technical audience for local peer review. We have prepared a response to your letter both to address as best we can the TBEP's comments and those attachments submitted by others, and so that staff can provide its response to the appropriate peer review panel. Your letter was forwarded to the Alafia River peer review panel on July 28, and will be forwarded to the Tampa Bypass Canal (TBC) peer review panel along with this response.

We will begin by addressing TBEP comments relative to the proposed freshwater Alafia River MFLs.

With respect to issue 1 as referenced in your letter, we are developing MFL criteria for both the freshwater segment and estuarine portions of the river. The District has consistently maintained and continues to do so, that when criteria are developed for both a freshwater and estuarine river segment, the more protective MFLs will apply, as appropriate. It is important to the District that the freshwater and estuarine resources of a river are protected from significant harm, and it is, therefore, necessary to consider both and develop MFLs accordingly. We view both potential sets of standards as necessary and as complimentary, and do not propose that one would "compromise" the other.

With respect to issue 2, we feel that the currently proposed MFLs do, in fact, effectively address the duration and depth of inundation of off-stream freshwater wetlands that may be connected via surface water to the river during very high flows. As proposed, the upper Alafia River MFLs assume that the actual days of connection between the river and these off-stream wetlands should be reduced by no more than 15 percent before significant harm occurs. Analysis of these flows indicates that if higher flows are reduced by no more than 8 percent once flows exceed 374 cubic feet per second (cfs) then the number of days that any flow (and consequently the depth of inundation dictated by any given flow) is reached above 374 cfs will not be reduced by more than 15 percent. Interesting, very similar results were found both for the upper Myakka and middle Peace Rivers.

With respect to issue 3, a number of points raised in your letter have been explicitly addressed in companion reports referenced in the MFL document, namely the analysis of river flows patterns and the Atlantic Multidecadal Oscillation (AMO) (Kelly 2004) and rainfall trends as discussed by Basso and Schultz (2003), and are addressed in our response to the Environmental Protection Commission Hillsborough County (EPCHC) attachment to your letter. One of the major difficulties associated with the development of rainfall/flow regressions for the Alafia is the lack of historic rainfall data for the Alafia River basin. As noted below, pre-1970 rainfall estimates throughout the District rely entirely on NOAA rainfall gage sites (those sites analyzed by Basso and Schultz in their 2003 report). In the case of the Peace River, NOAA has historically (pre-1970) monitored and continues to monitor rainfall at 7 to 9 locations in the Peace River watershed. However, prior to 1970, there was not a single rainfall gage, NOAA or otherwise, in the Alafia River basin that could be used for the type of analysis performed by Coastal Environmental for the Peace River basin; this explains why Stoker et al. (1996) and others have typically used rain gages such as the Plant City gage (located in the Hillsborough River basin) in assessing rainfall within the Alafia River basin. In addition, most workers who have looked at rainfall/runoff relationships have used total annual rainfall and mean annual flow in their analyses. It should be noted that mean annual flow is a high flow statistic that is largely determined by rainy season (June – September) rainfall. Extrapolating rainfall totals from one area to another is especially difficult and tenuous for summer (wet season) rainfall, and this is important because flow data as well as papers dealing with the AMO suggest that the greatest impacts of the AMO are associated with changes in summer rainfall.

As an example, see the monthly rainfall correlations developed between two neighboring NOAA gages for the period 1940 to 1999 depicted in Figure 1. Monthly correlations between the Plant City gage (Hillsborough River basin) and the Lakeland gage (Peace River basin) are relatively good for the non-rainy season months (January $R^2 = 0.7955$, February $R^2 = 0.8738$, March $R^2 = 0.8836$, etc.), but quite poor for rainy season months (July $R^2 = 0.1840$, August $R^2 = 0.1981$). We believe that the lack of within basin rainfall gages especially pre-1970 would make the type of analysis

performed on the Peace River basin impractical for the Alafia. Ultimately data limitations affect the degree of analysis that can be conducted. The issue is one of appropriate geographic scale; the type of rainfall analysis performed by Basso and Schultz (2003) and repeated to some extent by Kelly (2004), in our opinion, addresses the affect of climate on rainfall from a regional perspective.

With respect to the two attachments: EPCHC – Mr. Ed Sherwood and Florida Coastal Sanctuaries Program – Dr. Ann Hodgson appended to your letter, some response is warranted.

Since the letter by Mr. Sherwood (EPCHC) posed specific questions and comments, it is appropriate to respond to these in the order presented.

The approach to minimum flows and levels taken by the District on freshwater stream segments in particular relies heavily on the development of benchmark periods and is discussed in the MFL document. As EPCHC noted "the proposed multi-decadal relationship between the AMO, rainfall, and river flow are not analyzed in detail in the report itself. Instead, the reader is referred to a group of other documents (e.g., Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004) for a more detailed explanation." It should be noted that the analysis performed by Kelly (2004) was based on the other two works cited (Enfield et al. 2001 and Basso and Schultz 2003), and was designed to deal specifically with the idea that two climatically distinct benchmark periods may exist due to mutidecadal differences in rainfall. These reports looked at rainfall patterns and concluded that the AMO had a significant affect on rainfall throughout the District (Basso and Schultz 2003) and over a much broader geographic area (Enfield et al. 2001). The District realized that climatic patterns are not limited by watershed boundaries and that the assessment of climatic affects on rainfall and river flows must be developed with a broader perspective, and would of necessity involve analysis of river flow patterns (trends) for many rivers within and outside District boundaries. The argument developed by Kelly (2004) could not be developed by examining the hydrology of a single system (e.g., Alafia River), and rather than repeat this argument in detail in every MFL document, and due to the critical nature of the argument, the District developed a separate report (Florida River Flow Patterns and the AMO; Kelly 2004) and submitted if for independent scientific peer review (Shaw et al. 2004). More than a quick examination of the relevant literature is needed to fully appreciate the importance of the AMO in affecting rainfall and ultimately river flow patterns.

In reviewing the cited documents, EPCHC explicitly asked, "If other researchers wish to analyze multi-decadal variations in rainfall and river flow patterns in west-central Florida, which time periods should they designate as 'warmer Atlantic SST/higher rainfall' and which should they designate as 'cooler Atlantic SST/lower rainfall'?" It is correctly noted that the choice of starting and ending dates of these analyses may affect the conclusions that are drawn from them. While it would be helpful if a consistent set of starting and ending dates could be agreed upon, a considerable volume of work is now being done on the AMO by many researchers, and it is likely that the selection of beginning and ending dates will continue to vary somewhat. The beginning and ending dates are generally selected based on visual inspection of a graphic similar to that presented in Kelly (2004; Fig. 11). Kelly (2004) selected his starting and ending dates with additional criteria in mind. Since comparisons were being made with river flow data and because river flow data are not as extensive temporally as rainfall data, Kelly chose 1940 as a starting date simply because this allowed a reasonable number of river gage sites with comparable temporal records to be used in his analyses. He also believed it was desirable to have an equal number of values (years) in the data sets that corresponded to the AMO warm and cool phases, and this is why a 30-year time period was selected for each phase. In addition it was felt that inclusion of years that spanned warm and cool periods (i.e., at the beginning and end of multidecadal periods) would be conservative in a statistical sense. Having said all this, staff have contacted Dr. Enfield, and note that he is currently proposing to use the time periods 1936 to 1960 and 1968 to 1992 as representative of the AMO warm and cool phases, respectively, in research he is currently proposing to NOAA. This selection provides two 25-year periods for comparison and effectively avoids selecting a clear breakpoint between the two AMO phases. This does not mean that other researchers will not continue to select periods (based on professional judgment) that do not exactly correspond to one another.

The EPCHC also raise the question, "Does annual rainfall show statistically significant differences between the 'high flow' and 'low flow' periods described in the draft MFL report?" and eventually conclude based on analyses presented in their attachment that, "it is not clear whether the statement made on p. 2-33 of the draft report . . . is supported by the available data." We disagree with this conclusion and believe that the data used by EPCHC (although obtained from the District) are inappropriate for the analysis performed. EPCHC's data analysis was performed "by analyzing annual rainfall records from the 11 'Comprehensive Watershed Management' (CWM) basins that fall within the Southwest Florida Water Management District." The CWM basin rainfall records are actually basin estimates based on individual rain gages scattered throughout the District. Many of these gages are the same NOAA gages examined by Basso and Schultz (2003) and Kelly (2004), and it may be appropriate to ask why different conclusions were obtained by the District and EPCHC. The answer lies in the way that CWM basin rainfall estimates were generated. Quite simply, while the CWM estimates for any given year for a given CWM basin are probably the best that could be generated for a given year, each year's basin estimate was not always generated in a similar manner and, as a result, they are not comparable across years. We have attached a brief description (entitled, "Annual Summary Rainfall Estimates") as to how basin estimates were derived, which was supplied by Granville Kinsman, manager of the District's Data Collection Section. It should be noted that prior to 1970, all basin estimates were based on a relatively small number of NOAA gages (30 to 40) scattered throughout the District. Even between 1940 to 1970, the number of gages used in each

year's estimate was not consistent, since the number of gages increased over the time period and gages were deleted from analysis in any year that a complete 365-day record was not obtained. Since there was not a single NOAA gage located within the Alafia River Basin during this time period (1940 to 1970), basin estimates pre-1970 were generated using gages located wholly outside the basin. In fact, there was not a NOAA gage located in the watershed until the mid-1990s. After 1970, the District began to use a number of non-NOAA gages since this greatly expanded the number of sites on which basin estimates could be derived; this was in addition to existing NOAA sites.

To avoid problems associated with analysis of CWM rainfall data sets, it may be appropriate to examine individual gage sites and look for trends/patterns at long-term NOAA sites as was done by Basso and Schultz (2003). Another alternative, if a composite number is preferred, is to make sure that estimates are generated using the same gages each year; however, if older estimates (pre-1970) are needed (and they would be necessary for examining the climatic signature) and one wants to increase the sample size of gage sites, then predictive relationships between gages would need to be developed to extend the record back in time. However, looking for statistical relationships in this type of synthesized data may not be appropriate and would not seem to be preferable to analysis of empirical data. Establishment of highly predictive equations for extrapolating historic conditions becomes especially problematic, since the relationships between individual gages are not especially strong for high rainfall months (very weak in many cases as shown in Figure 1). This, of course, speaks to the highly localized nature of the convective type storms encountered in the summer months in contrast to the large frontal storms that bring rain in the other months.

Staff did, however, generate (using the 20 sites employed by Kelly, 2004) a composite District-wide (rather than CWM basin) mean rainfall record just to see if the result would be statistically significant or not if a composite rather than individual sites were analyzed. The District-wide yearly means were generated using a straight mean (sites were not weighted using Thiessen polygons) for this analysis. The results are shown in Table 1. A one-tailed test was used and is appropriate for this analysis (although this appears to be questioned by EPCHC), since what is being tested is the idea that rainfall in peninsular Florida increases (decreases) during AMO warm (cool) periods as proposed by Enfield et al. (2001). Please note that depending on whether you are looking at means or medians the difference between the two periods is 4.6 to 5 inches, and while this amounts to about a 10 percent difference in rainfall between the two periods this could lead to considerable differences in flow, since most of the rivers in the water management district typically discharge on average 6 to16 inches of water per year.

In consideration of the water budget for upper Alafia River, the EPCHC questions the assertion that declines in low flows are related to removal of phosphate mining related discharges or are confused by District statements related to flow declines being related

to either changes in water management practices by the phosphate industry or climate. We maintain, and perhaps it is not clear in the report, that two types of decline have occurred relative to flows in the upper Alafia River basin. The greatest flow declines as discussed in considerable detail in Kelly (2004) between AMO warm and cool periods are related to rainfall differences that occur as a "step change" between these two periods. We concur with Hickey (1998) and in an analogous manner with McCabe and Wolock (2002) that an abrupt change in river flows occurred around 1970, and believe that this change is related to the AMO and rainfall as proposed by Enfield et al. (2001). However, the hydrology of the Alafia River is somewhat unique (but not totally unlike the upper Peace River; see SWFWMD 2002) in that during part of the record, low flows were essentially augmented by mine related discharges. These discharges were gradually removed (this appears as more of a monotonic trend in the flow record). This explains the observation by Stoker et al. (1996; page 65), that at the Alafia at Lithia gage, "Although annual-mean and annual high flows have decreased, the 7- and 30-day low flows increased from about 1957 to 1966 and then decreased from about 1967 to 1992."

Stoker et al. (1996) also reported that "cumulative annual total rainfall at Plant City [although outside the watershed, it is the closest long-term gage] was plotted against the cumulative annual-mean discharge at site A-3 [Alafia at Lithia gage]. If the change in streamflow characteristics was due only to a change in rainfall patterns, the resulting [double mass] plot would be a straight line. . . The change in slope after about 1980 indicates a decrease in discharge relative to rainfall." Hickey (1998) also relied heavily on double-mass plots in his analysis; however, he came to a different conclusion. "Although Hickey (1998) concluded that climate was largely responsible for the decreasing trend, he did note that at the Alafia River at Lithia stream flow decreased about 44 cfs in the period between January 1962 to December 1981. He speculated that these flow declines were the result of mining, [and] were related to a substantial decrease in water being discharged rather than landscape changes that resulted in hydrologic alterations" (Kelly et al. 2005, page 2-49). Our analysis of water quality data validates Hickey's conclusion. The plot of dissolved fluoride in our document or Stocker et al. (1996; Figure 21 page 31) shows a dramatic decline in concentration around 1980; the time by which we assert that mining related discharges were greatly curtailed. It should be noted, while much more quantitative numbers may be desirable, Hickey (1998) as quoted above did indicate that mining related discharges were on the order of 44 cfs (28 mgd) for the twenty year period extending through the 60's and 70's.

To clarify, we do maintain that substantial flow declines in the Alafia River are consistent with a step change in climate related to the AMO. In addition, removal of phosphate mining related discharges resulted in an apparent monotonic decreasing trend in flows that is particularly evident under low flow conditions. The beginning and ending of this flow augmentation period is clearly discernable in the historic flow and water quality records for the Alafia at Lithia gage site.

Our comments regarding Attachment B (from Dr. Ann Hodgson, Florida Coastal Islands Sanctuaries Program) are considerably shorter. As noted Dr. Hodgson's comments are focused on riverflow and wetland dependent avian species or their forage. Firstly, the Alafia River MFL is being developed in two parts, an upper freshwater segment (the current subject) and an estuarine segment. Dr. Hodgson's concerns relative to the movement of the salinity prism will be explicitly addressed as the MFL for the estuarine segment is developed. There were, however, several comments with respect to our PHABSIM related analyses, and isolated wetlands that we will attempt to address. We explicitly recognize the importance of floodplain wetlands to the ecology of the river system (pages 3-6 to 3-7 of our report) and have made a concerted effort to address the maintenance of these systems. In the short term, we feel that our approach that limits reduction in number of days of connection to no more than 15 percent will be protective of this resource and those organisms dependent on them; however, as part of our adaptive management approach we are committed to examining in greater detail the effects that direct river connection plays in maintaining wetland hydrology. It will, however, probably take several years to adequately assess and understand this relationship in sufficient enough detail before it may be more adequately addressed in our MFL methodology. We have discussed to some extent our plans for this monitoring effort with Dr. Hodgson.

With respect to a bias in the sampling and/or enumeration of fishes, we relied exclusively on the Florida Fish and Wildlife Conservation Commission database as cited. While their sampling techniques and gear may well be directed toward the dominant recreational fish species; our selection of fish species for PHABSIM analyses was based on a consideration of the numerically most abundant species for which habitat suitability curves were available. The only exception, as we noted, was with the spotted sunfish, which appears to be one of the most abundant species in the state. For this species, it was necessary to develop a habitat suitability curve using a modified Delphi method as described in our report. Others including the peer review panel for the middle Peace River MFL (Shaw et al. 2005) have suggested inclusion of other species and the refinement or development of habitat suitability curves specific to Florida. We concur, and will be working with Dr. Jim Gore (University of South Florida) to accomplish this goal over the next several years. Staff appreciates the suggestion of incorporating a habitat suitability curve for a relevant wading bird species in our PHABSIM analysis, and we have discussed this with Dr. Gore as well. While there are habitat suitability indexes available for a number of species, these indexes alone do not provide the detailed flow, water depth and substrate information needed to develop habitat suitability curves; however, staff anticipates exploring further with Dr. Gore the idea of developing the necessary criteria for a representative wading bird species. At present, however, we have not nor do we plan on selecting "target species" in the sense that we would seek to optimize one species' habitat over another. Currently we select the most restrictive percent reduction scenario consistent with a 15 percent reduction in available habitat regardless of species or life stage as the criterion on which to base an

MFL recommendation. If too many species are added to the analysis, it is likely that we would have to develop a criterion based on an averaging of the results or prioritization of the species. As an interesting aside, the peer review panel mentioned that it might be desirable to develop a curve for an exotic species (e.g., blue tilapia) so that the species might be selected against. We concur that selection of additional species and development of Florida habitat suitability curves could be a desired enhancement to our methodology.

Findings and Recommendations: Tampa Bypass Canal

(Response to commentary in first paragraph) The District recognizes that some individuals may interpret the District’s position on the TBC MFL as a de facto zero cfs MFL, but in the absence of a stronger relationship between inflow and the water resources, the District’s position is that setting an MFL at this time is not justifiable.

1) The DISTRICT acknowledges the many problems of impounded estuaries. The predation noted is the result of physical constraints imposed by a confined channel, devoid of protective habitat that terminates in a flood control structure. Peebles (2004) reports that a flow of >100 cfs displaces the medusa downstream and away from the control structure. Such flows are essentially the median baseline discharge (97 cfs) from S-160 and are well beyond what might be considered as low flow. Peebles and others have also questioned whether the attractiveness of a freshwater source truncated by a physical barrier is beneficial or detrimental to estuarine-dependent species. The management conundrum for impounded flood control projects is whether there is justifiable benefit to the ecological resources associated with a minimum flow that may increase predation.

2) Residence times were calculated from the hydrodynamic model and summarized (see page 3-40) for a range of flows. Additional details can be found in Luther and Meyers (2005) available from the District. Chlorophyll (as surrogate for phytoplankton) was not explicitly evaluated because of a prior TBC task force determination that salinity and dissolved oxygen were the primary water quality parameters critical to setting an MFL. The relationship between dissolved oxygen and flow was evaluated and reported (Section 3.8). Surface DO (expressed as percent saturation) was poorly related to flow and lagged flow terms, suggesting that residence time is not an important factor. For some segments, flow was not a significant predictor of percent saturation (at p=0.05). The evaluations were conducted on segments and any relationship between residence time and chlorophyll would be expected to show up in the DO to flow evaluations.

3) The DISTRICT readily acknowledges that biological data is highly variable and that organism abundance is the result of many environmental and ecological forcing functions. The DISTRICT also understands that low correlations are typical for many types of biological data. However, the MFL statutes pertain to management of flows,

which in the case of the TBC account for approximately 15 percent of significant fish and invertebrate abundances. Thus, 85 percent of the resource response is unrelated to the establishment of an MFL. The DISTRICT does not feel it is prudent to establish an MFL at this time based on those conditions.

TBEP comment on the correlation coefficient issue references a flow of 66 cfs. It should be noted the evaluation was not based on a single flow, but included a range of flows and lag flows associated with the fish and invertebrate sampling effort. Over the course of the 2000-2003 sampling, gaged and ungaged flows ranged from 6 to 4,600 cfs. (Actual sample date flows ranged from 6 to 870 cfs). The confusion appears to be rooted in a 15 percent reduction in abundance when the 20-year median flows are reduced from 92 cfs to 66 cfs.

4) The suggested re-evaluation of abundance based on segmentation cannot be related to inflows at the same time because the location of the organisms changes with inflow. Thus, at inflow ‘X’ the organisms might be found in a downstream segment. Increasing

the inflow may result in those same organisms moving upstream (or downstream depending upon the taxa response) into the next segment.

5) The center of abundance is discussed on page 3-14 in the draft MFL report and the regression results presented as Table 3-7. Unfortunately, the equation was not identified in the Table 3-7 header. The header should have included the following line: *$km_U = m*(\text{lag flow}) + b$; where flow is expressed in cfs and km_U is center of abundance expressed as river kilometer.*

With respect to HCEPC's question regarding future permitting and the effect of an MFL on permitting, a permitted quantity cannot cause an MFL to be violated. Permits are now written with this condition, and would require a re-evaluation of a permit should a violation of an MFL result.

In response to TBEP recommendations made at the Sulphur Springs workshop relevant to the TBC, Sulphur Springs and Lower Hillsborough River regarding the treatment of these MFLs concurrently, we do not anticipate that a fourth document will be generated requiring peer review. However, we do not intend to adopt MFLs until all three peer reviews are complete. Once the peer review committee completes their evaluation of the last MFL document (Lower Hillsborough River), we will seek their suggestions and opinions regarding the appropriateness of addressing these systems collectively and, if recommended, how this might be accomplished.

In closing, we hope the responses furnished provide some additional clarification to questions raised by the TBEP and members of the Technical Advisory Committee. The District would again like to thank the TBEP for its willingness to conduct workshops and

review work done on MFL determinations for rivers within the Tampa Bay watershed, and look forward to your continued participation and review of ongoing MFL efforts. We realize that this is a fairly detailed response, and would be happy to discuss further if you have questions or comments. I can be reached directly at 352-796-7211, extension 4235.

Sincerely,

Martin H. Kelly
Manager, Ecologic Evaluation Section
Resource Conservation and Development Department

MHK/brm
cc: SWFWMD Governing Board members
David L. Moore, SWFWMD Executive Director
Deborah Getzhoff, TBEP Policy Board chair

Mark Hammond, Director, Resource Management Department, SWFWMD
Lizanne Garcia, TBEP Management Board Member representing SWFWMD
Mike Heyl, Senior Environmental Scientist, SWFWMD
Suspense Log #22445-05

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Table 1. Mann-Whitney Statistical Analysis of Difference in Period Rainfall	
	District Average Based on 20 NOAA Sites
Mean 1936 to 1960	55.2
Median 1936 to 1960	53.9
Min 1936 to 1960	40.6
Max 1936 to 1960	77.3
Mean 1968 to 1992	50.6
Median 1968 to 1992	48.9
Min 1968 to 1992	40.7
Max 1968 to 1992	64.9
Difference in X's	4.6
Difference in Medians	5.0
p	0.025

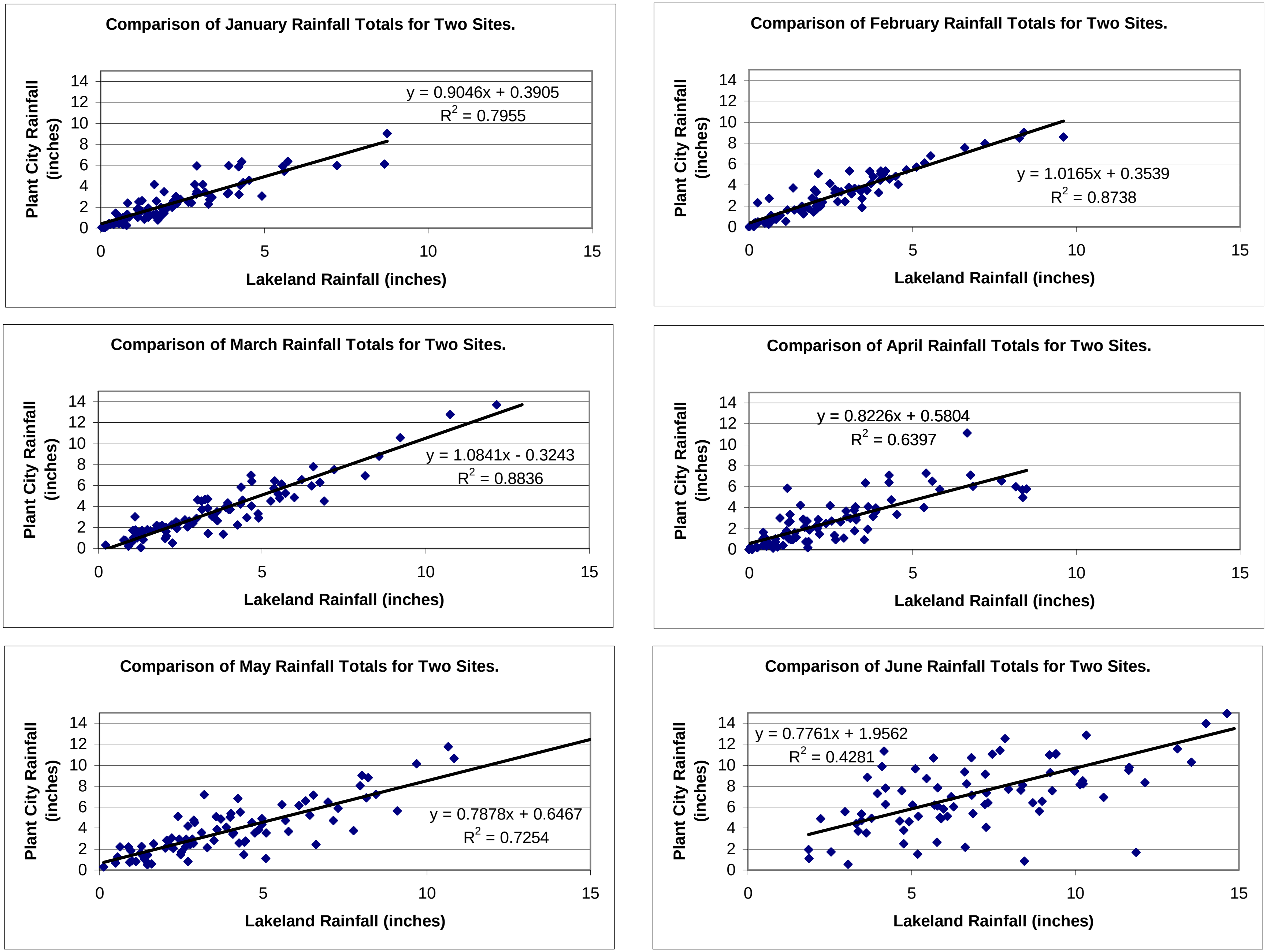
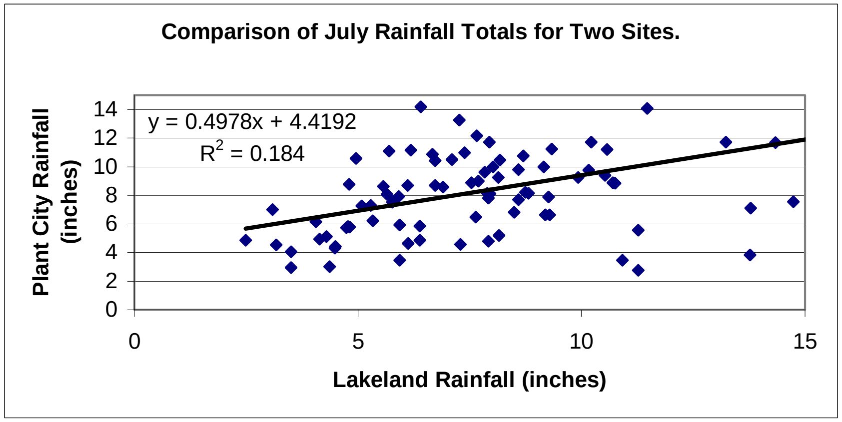
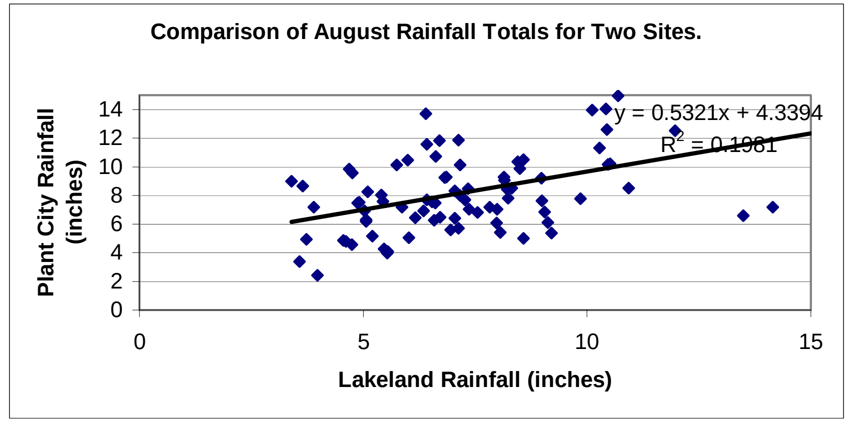
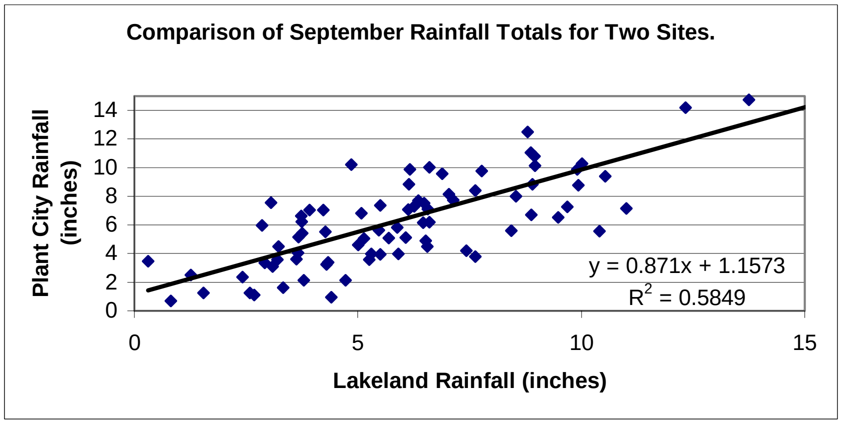
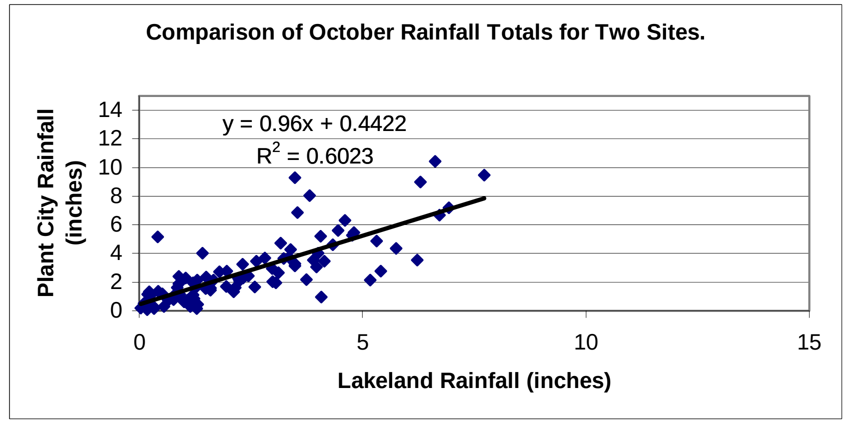


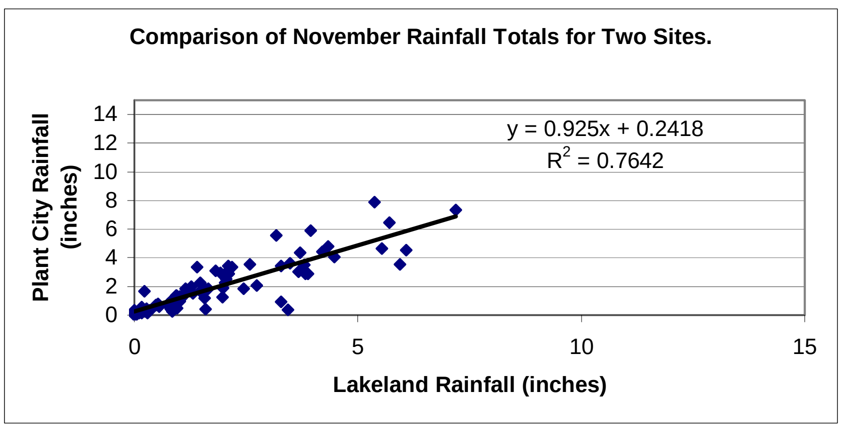
Figure 1. Comparison of total monthly rainfall between two NOAA rainfall sites (Lakeland and Plant City) for the period 1940 to 1999.











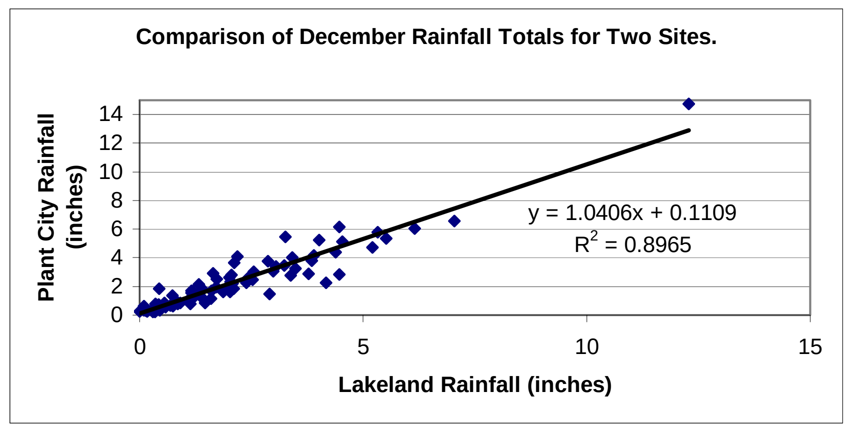


Figure 1. Continued -- Comparison of total monthly rainfall between two NOAA rainfall sites (Lakeland and Plant City) for the period 1940 to 1999.

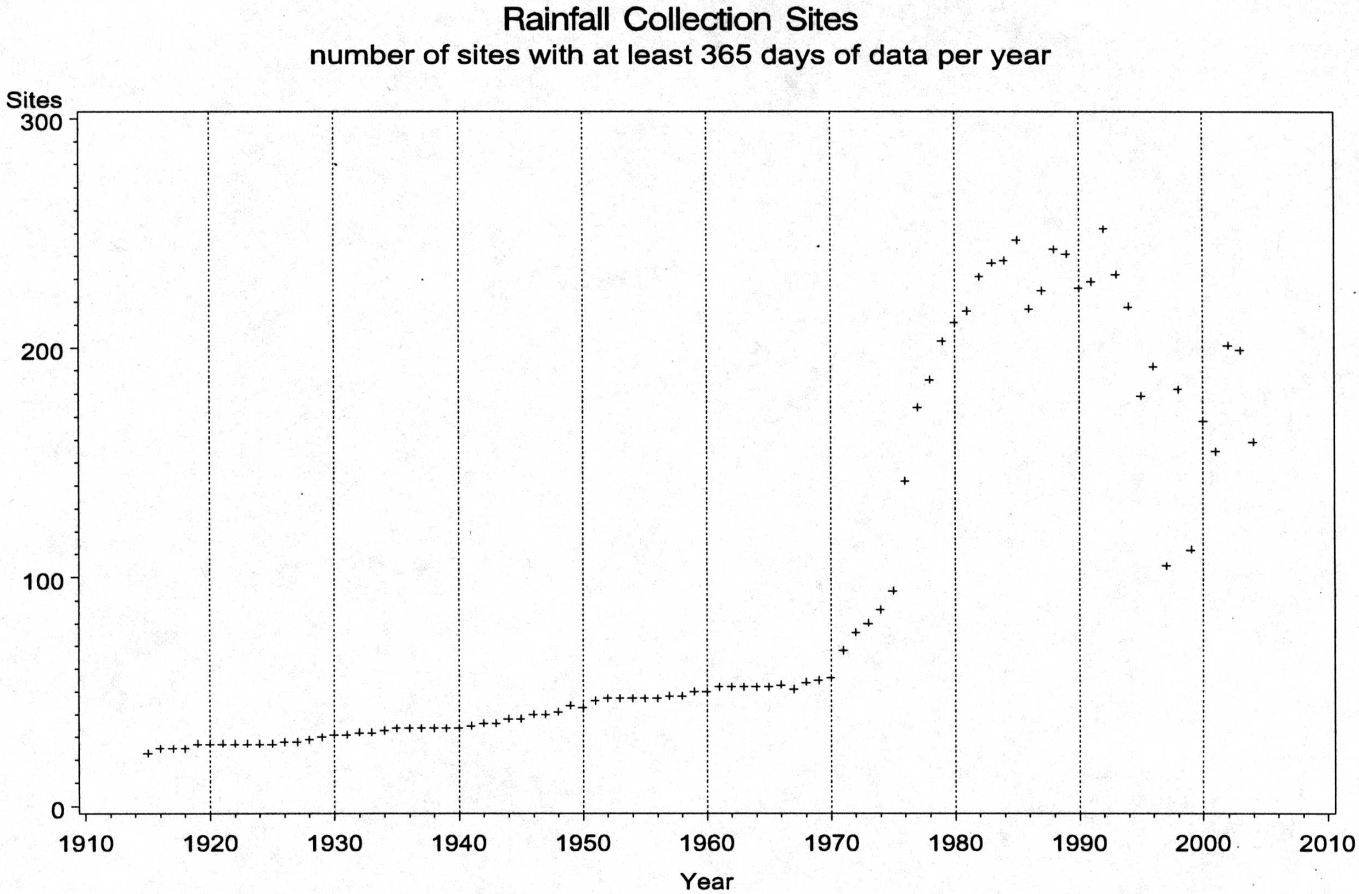
Annual Summary Rainfall Estimates

To aid the management of water resources in the Southwest Florida Water Management District, a number of reports are produced at daily, weekly, monthly, and annual intervals that characterize present-day rainfall over the District in relation to historical rainfall amounts. District staff has drawn upon all of the available data to develop estimates of historical rainfall occurring within political and geographical 'basins.' For the period between 1915 and 1970, most rainfall data were from observer sites and data recorder sites, operated and/or maintained by the National Oceanic and Atmospheric Administration (NOAA). After 1970, the District also became active in its rainfall data collection efforts, greatly increasing the number of monitored rainfall sites within the 16-county region. The District's SCADA system for near-real-time electronic data collection also became an important tool for collecting rainfall data beginning in 1989. Thus, the number of rainfall sites used for the calculation of rainfall summary statistics between 1915 and 2000 varied greatly from year to year throughout the period of record, depending upon the number of available sites with complete data in a given year (see figure).

To estimate rainfall totals for the District's geographical and political basins, data were screened to ensure that they were complete for each year of the period of record. Any years with fewer than 365 days of data were not included in the data set. Selected data were then used to construct Thiessen polygons, a method in which polygons are constructed around each rainfall site, such that the area within the polygon is closer to the central rainfall site than to any other rainfall site. Rainfall anywhere within the polygon area is assumed to be the same as the rainfall at the site central to the polygon. Using a geographical information system (GIS), the polygons were intersected with basins so that each basin contained only the area of each polygon that fell within the basin. The sum of the polygon area and rainfall products for all of the polygons within the basin, divided by the basin total area, yielded an area-weighted estimate of rainfall within the basin. Thiessen polygons were recalculated for each year based on the number of sites with completed data that were available. Thus, the final estimates of annual rainfall were always based upon the best available data for each subject year.

Since December 1999, the geographical and political basin rainfall totals have been calculated from data acquired from OneRain, Inc. OneRain obtains digital rainfall data from the NexRad weather radar. By comparing these rainfall data with District supplied SCADA rainfall data, the company is able to calibrate the radar data to estimate rainfall amounts over the SWFWMD. Daily rainfall estimates derived from the calibrated radar data are provided to the District in a 2-kilometer square grid resolution. Each grid cell is then associated with a region, drainage basin, or other geographical unit, and the rainfall totals are calculated.

When the data from these two sources are combined, they provide a complete record for the period from 1915 to the present. These data are used primarily for comparisons, so the statistics used are typically the means, medians, interquartile ranges, period-of-record minima and maxima, and percentiles.



Rainfall Collection Sites
number of sites with at least 365 days of data per year
Sites
300
200
100
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year