Proposed Minimum Flows and Levels for the Upper Segment of the Hillsborough River, from Crystal Springs to Morris Bridge, and Crystal Springs

Southwest Florida Water Management District

December, 2007

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

Adam Munson
Marty Kelly
Jonathan Morales
Doug Leeper

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Executive Summary

The Southwest Florida Water Management District, by virtue of its responsibility to permit the consumptive use of water and a legislative mandate to protect water resources from “significant harm," has been directed to establish minimum flows and levels (MFLs) for streams and rivers within its boundaries (Section 373.042, Florida Statutes). As currently defined by statute, "the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." In this report, minimum flows are proposed for the fresh water segment of the upper Hillsborough River, defined as the stretch of the river from the United States Geological Survey (USGS) Green Swamp near the Withlacoochee-Hillsborough Overflow at US 98, downstream to the USGS gage at Morris Bridge Road.

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 Hillsborough River.

For development of MFLs for the Hillsborough River, the District identified seasonal blocks corresponding to periods of low, medium and high flows. Short-term minimum flow compliance standards for the Morris Bridge gage site were developed for each of these seasonal periods using a "building block" approach. The compliance standards include prescribed flow reductions based on limiting potential changes in aquatic and wetland habitat availability that may be associated with seasonal changes in flow. A low-flow threshold, based on fish passage depth and wetted-perimeter inflection points is also incorporated into the short-term compliance standards. For the Hillsborough River gage site, the low flow threshold (LFT) was determined to be 52 cubic feet per second.

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 Hillsborough River gage site, the low-flow threshold was determined to be 52 cubic feet per second. 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 evaluate flow related changes in habitat availability for several fish species and macroinvertebrate diversity. It was determined using PHABSIM that the most restrictive limiting factor was the loss of habitat for adult spotted sunfish. Based on the 1970 through 1999 benchmark period, adult spotted sunfish exhibit a 15% loss of habitat when flows are reduced by 10%. This determination was based on three PHABSIM sites on the Hillsborough River and a flow record modified to account for flow declines from water-use.

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 stepped flow reductions of 13% and 8% of historic flows, with the step occurring at the 15% exceedance flow (470 cfs), resulted in a decrease of 15% or more in the number of days that flows would inundate floodplain features as measured at the Morris Bridge gage.

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 PHABSIM would define the percent flow reduction. It was determined that more than 15% of historically available habitat would be lost for specific species life-stages if flows were reduced by more than 11% as measured at the Morris Bridge gage during the medium-flow period.

There has been a noticeable decline in flows at Crystal Springs over the period of record. For development of minimum flows, 50% of the flow decline was considered to be anthropogenic. For Crystal Springs the contribution of the spring flow to the Hillsborough River was examined. It was determined that during the low-flow time of the year Crystal Springs flow comprised a majority of the flow in the river. To protect the river during these periods, it was determined that reductions in spring flow should not cause an increase of more than 15% in the number of days that river flow falls below the low flow threshold of 52 cfs. Analysis determined that more than a 16 percent decrease in median or mean annual flows from Crystal Springs would result in greater than a 15 percent increase in the number of days that the LFT was unmet at Morris Bridge.

Because minimum flows are intended to protect the water resources or ecology of an area, and because climatic variation can influence river flow regimes, we developed long-term compliance standards for the Hillsborough River gage site near Morris Bridge. 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. 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 historic flow records corrected for withdrawals, it may be expected that the long-term standards will be met if compliance with short-term standards is achieved. It should be noted that because the flow record was corrected to estimate natural flows that the compliance standards are constructed in accordance with the natural flow regime

Collectively, the short and long-term compliance standards proposed for the USGS gage site near Morris Bridge comprise the District's proposed minimum flows and levels for the Hillsborough 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.

Acknowledgement

The authors would like to thank Richard Gant, Jason Hood, and Michelle Dachsteiner 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. 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, Robert Thomas, owner of Crystal Springs Preserve and Two Rivers Ranch, Karen Pate, Director of Crystal Springs Preserve, Johnny Nix, Supervisor of Two Rivers Ranch, and Paul Allen, Assistant Park Manger of Hillsborough State Park. For providing us with resources and guidance, especially in the 17 runs area, we thank Joseph and Jean Faulk of the Canoe Escape. For fieldwork, we appreciate the contribution of all student interns including Tiffany Dawson, Ryan Horstman, and Margaret Gilchrist.

1 Minimum Flows and Levels

1.1 Overview and Legislative Direction

The Southwest Florida Water Management District (District or SWFWMD), by virtue of its responsibility to permit the consumptive use of water and a legislative mandate to protect water resources from "significant harm", has been directed to establish minimum flows and levels (MFLs) for streams and rivers within its boundaries (Section 373.042, Florida Statutes). As currently defined by statute, "**the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.**" Mere development or adoption of a minimum flow, of course, does not protect a water body from significant harm; however, protection, recovery or regulatory compliance can be gauged once a standard has been established. The District's purpose in establishing MFLs is to create a yardstick against which permitting and/or planning decisions regarding water withdrawals, either surface or groundwater, can be made. Should an amount of withdrawal requested cause "significant harm," then a permit cannot be issued. If it is determined that a system is either not in compliance, or expected not to be in compliance during the next 20 years, as a result of 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 recent work by fisheries biologists, dating back not much more than 35 to 40 years. Florida has had minimum flow and levels incorporated into its Water Resource Act since its enactment in 1972. However, it was not until 1997 that the role of minimum flows and levels were clearly defined by the state (Munson et al. 2005). 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 1960s and early 1970s. 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 "multiple flow regimes are needed to maintain biotic and abiotic resources within a river ecosystem" (Hill et al. 1991). The logic is that "maintenance of stream ecosystems rests on streamflow management practices that protect physical processes which, in turn, influence biological systems." Hill et al. (1991) identified four types of flows that should be considered when examining river flow requirements, including:

1) flood flows that determine the boundaries of and shape floodplain and valley features;
2) overbank flows that maintain riparian habitats;
3) in-channel flows that keep immediate streambanks and channels functioning; and
4) in-stream flows that meet critical fish requirements.

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

Recently, South African researchers, as cited by Postel and Richter (2003), listed eight general principles for managing river flows:

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

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

In 2005, changes that acknowledge the importance of retaining the hydrologic regime were made to the Florida Administrative Code. Specifically, Chapter 62-40.473(2) directs that "minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime". This is to protect the variation in water flows and levels which water bodies experience and that contribute to significant functions of the ecosystem, described in 62-40.473(1), F.S.C.

1.4 Ecosystem Integrity and Significant Harm

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

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

1.5 Summary of the SWFWMD Approach for Developing Minimum Flows

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

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

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

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

Fundamental to the approach used for development of minimum flows and levels is the realization that a flow regime is necessary to protect the ecology of the river system. The initial step in this process requires an understanding of historic and current flow conditions to determine if current flows reflect past conditions. If this is the case, the development of minimum flows and levels becomes a question of what can be allowed in terms of withdrawals before significant harm occurs. If there have been changes to the flow regime of a river, these must be assessed to determine if significant harm has already occurred. If significant harm has occurred, recovery becomes an issue. For development of minimum flows for the upper 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. The approach, which led to identification of separate benchmark periods for flow records collected prior to and after 1970, was used for development of MFLs for the freshwater segment of the Alafia River, middle Peace River, and the Myakka River (Kelly et al. 2005a, Kelly et al. 2005b, Kelly et al. 2005c), and has been utilized for analyses of flows in the upper portion of the Hillsborough River.

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

1.5.1 A Building Block Approach

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

Conceptually, the approach used by the District for development of MFLs for the upper Peace River (SWFWMD 2002) was consistent with the building block approach. Available flow records were summarized and used to describe flow regimes for specific historical periods. Resource values associated with low, medium and high flows were identified and evaluated for use in the development of MFLs for each flow range. Low minimum flows, corresponding to maintaining instream flow requirements for fish passage and wetted perimeter were proposed. Medium and high minimum flows were not, however, proposed for the river segment, due primarily to an inability to separate the effects of natural and anthropogenic factors on flow declines. Nonetheless, methods were used to evaluate potential ecological changes associated with variation in medium to high flows. The methods focused on the inundation of desirable in-stream habitats and on floodplain wetlands. Implicit in this approach was the concept that the three ranges of flow (low, medium and high) were associated with specific natural system values or functions.

For development of minimum flows and levels for the upper HIllsborough River, the District has explicitly identified three building blocks in its approach. The blocks correspond to seasonal periods of low, medium and high flows. The three distinct flow periods are evident in hydrographs of median daily flows for the river (e.g., Figure 1-1). Lowest flows occur during Block 1, a 66-day period that extends from April 20 to June 25 (Julian day 110 to 176). Highest flows occur during Block 3, the 123-day period that immediately follows the dry season (June 26 to October 26). This is the period when the floodplain is most likely to be inundated on an annual basis; although high flows can occur in early to mid-March. The remaining 176 days constitute an intermediate or medium flow period, which is referred to as Block 2.

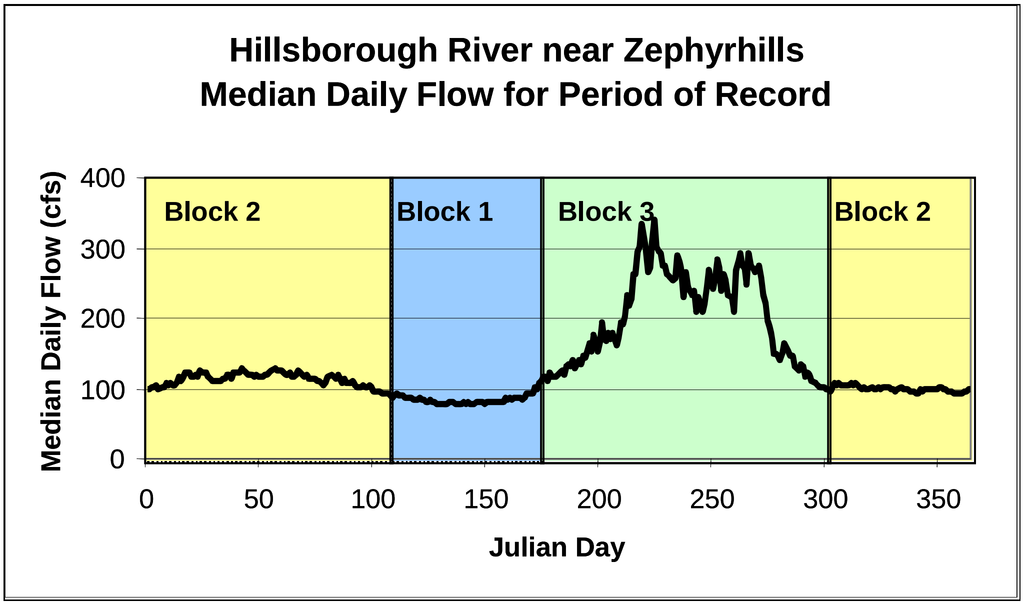


Figure 1-1. Median daily flows for the USGS Hillsborough River near Zephyrhills, FL gage site and seasonal flow blocks (Blocks 1, 2 and 3) for the upper Hillsborough River.

1.6 Flows and Levels

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

Discharge, on the other hand, refers to the volume of water moving past a point per unit time, and depending on the size of the stream (cross sectional area), similar volumes of water can be moved with quite large differences in the velocity. The volume of water moved through a stream can be particularly important to an estuary. It is the volume of freshwater that mixes with salt water that determines, to a large extent, what the salinity in a fixed area of an estuary will be. This is especially important for organisms that require a certain range of salinity. The volumes of fresh and marine water determine salinity, not the flow rate per se; therefore, volume rather than flow is the important variable to this 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 water surface elevation or level.

There is a distinction between volumes, levels and velocities that should be appreciated. Although levels can be related to flows and volumes in a given stream (stream gaging, in fact, depends on the relationship between stream stage or level and discharge), the relationship varies between streams and as one progresses from upstream to downstream in the same system. Because relationships can be empirically determined between levels, flows and volumes, it is possible to speak in terms of, for example, minimum flows for a particular site (discharge in cubic feet per second); however, one needs to appreciate that individual species and many physical features may be most dependent on a given flow, level or volume or some combination of 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 upper Hillsborough River, which is defined as the river corridor above the Morris Bridge USGS gage site. In Chapter 2, we provide a short description of the entire river basin and its hydrogeologic setting, and consider historic and current river flows and the factors that have influenced the flow regimes. Identification of two benchmark periods of flow, resulting from natural climatic oscillations is noted and seasonal blocks corresponding to low, medium and high flows are identified. Water quality changes related to flow are also summarized in Chapter 2 to enhance understanding of historical flow changes in the watershed. Chapter 3 includes a discussion of the resources of concern and key habitat indicators used for developing minimum flows. Specific methodologies and tools used to develop the minimum flows are outlined in Chapter 4. In Chapter 5, we present results of our analyses and provide flow prescriptions that are used for developing proposed minimum flows for the upper Hillsborough River. The report concludes with recommendations for evaluating compliance with the proposed minimum flows, based on the short and long-term compliance standards for the upper HIllsborough River**.**

2 BASIN DESCRIPTION WITH EMPHASIS ON LAND USE, HYDROLOGY AND WATER QUALITY

2.1 Overview

This chapter includes a brief description of the Hillsborough 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 upper (freshwater) segment of the Hillsborough River above the reservoir created by the City of Tampa's dam. Land use changes within the basin are evaluated to support the hydrology discussion that follows and to address questions that have been raised regarding the potential impact of land use changes on river flow volumes. Flow trends and their potential causes are discussed for the Hillsborough River and other regional rivers to provide a basis for identifying benchmark periods and seasonal flow blocks that are used for a building block approach in the establishment of minimum flows. Water chemistry changes are presented to illustrate how land use changes may have affected observed trends in certain water quality parameters, and to demonstrate how these trends are useful in interpreting flow changes over time.

2.2 Watershed Description (material in this section was taken largely from *Hillsborough River Watershed Management Plan*, SWFWMD 2000)

2.2.1 Geographic Location

The Hillsborough River begins in the Green Swamp area of Pasco and Polk counties; as do three other major rivers in Florida: the Withlacoochee, Peace and Oklawaha. The Green Swamp region of central Florida consists of an estimated 870 square miles of low-lying flatlands and swamps flanked by several topographic ridges. In this region of flat topography, seasonal rainfall accumulates over the landscape forming extensive headwater swamps. After leaving the swamps, the Hillsborough River, with an estimated drainage area of 675 square miles as determined from SWFWMD land use maps (or 650 square miles as reported by USGS), flows 54 miles southwesterly into Hillsborough Bay. Annual mean discharge for the Hillsborough River near Tampa for the period 1939 to 2004 was 446 cubic feet per second (cfs). The Hillsborough River watershed (Figure 2-1) extends over parts of three counties, including much of the northeastern quarter of Hillsborough County, a large area of central Pasco County, and a small portion of northwestern Polk County. It is bounded to the north by the Withlacoochee River watershed, to the east by the Peace River watershed, to the south by the Alafia River watershed, and to the west by the North Coastal and Tampa Bay watersheds. It incorporates parts of

Tampa, Lakeland, Dade City, Plant City, the community of Land O' Lakes, and all of the municipalities of Zephyrhills and Temple Terrace. The watershed ends at the Tampa Bypass Canal (TBC) basin. The TBC basin is not within the USGS boundaries of the Hillsborough River watershed, but is highly influenced by it (refer to TBC Minimum Flows and Levels Report, SWFWMD 2005).

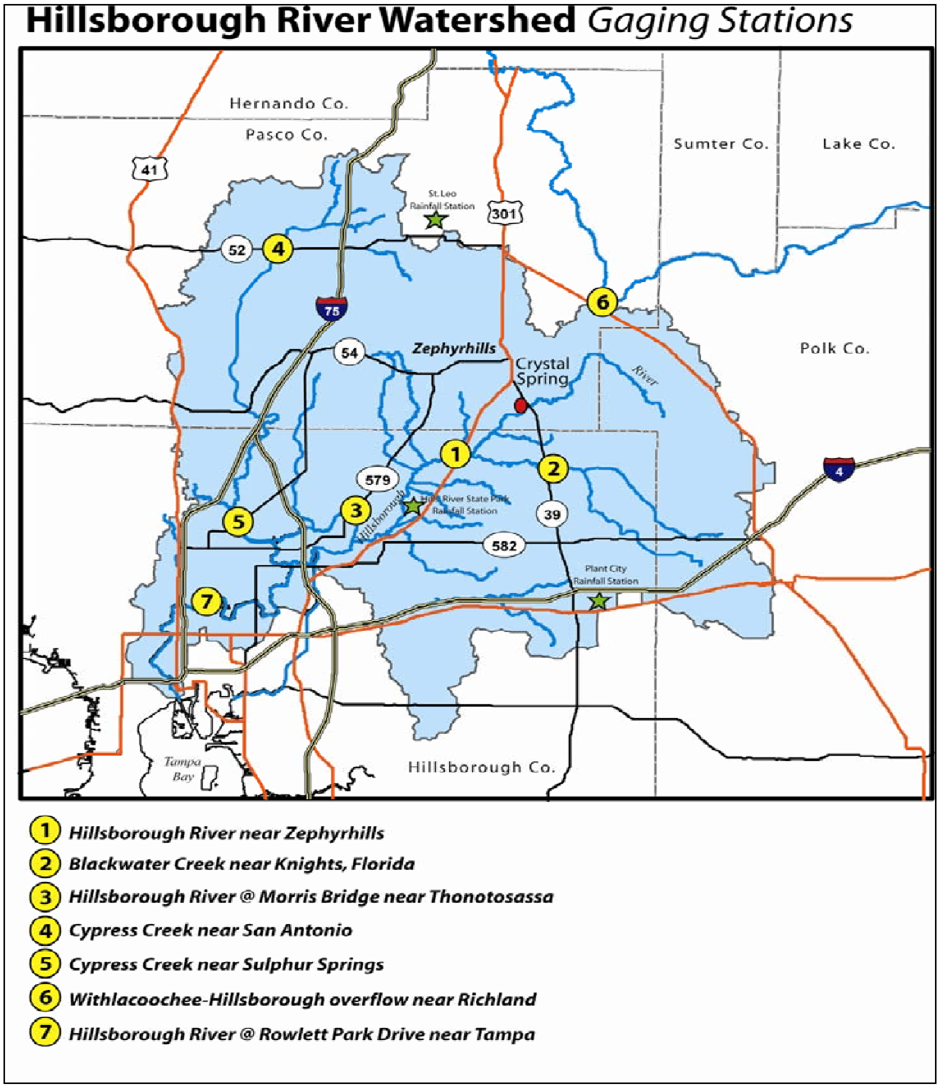


Figure 2-1. Map of the Hillsborough River watershed showing the Hillsborough River main-stem and tributaries, and long-term USGS gage site locations.

2.2.2 Climate

There are three National Weather Service stations in the Hillsborough River watershed: Saint Leo near the northern region of the watershed; Hillsborough River State Park near the center of the watershed; and Plant City to the southeast. The Tampa International Airport National Weather Station is just outside the southwest region of the watershed, but is included in this description of climate patterns to better represent the entire watershed. Data from the period 1948 to 2004 are available for all stations. The climate of west central Florida is classified as humid subtropical. The mean normal yearly temperature for the four National Weather Service Stations is 72.2 F, generally ranging from a normal maximum temperature of 91 F in July and August, to a normal minimum temperature of 49 F in January. In general, temperatures at the Tampa Airport station are 2 to 3 degrees cooler during summer months and 2 to 3 degrees warmer during the winter months than the inland stations, and probably reflect the station's proximity to Tampa Bay and the Gulf of Mexico.

Evapotranspiration for a larger area which encompasses the Hillsborough River watershed is approximately 39 inches per year (SWFWMD 1994). Greatest evapotranspiration rates occur in May and June, and nearly 60 percent of the total yearly evapotranspiration occurs during the six-month period between May and October.

The average annual precipitation for the four National Weather Service Stations is 52.4 inches. In a typical year, approximately 60 percent of the annual precipitation is produced by convective thunderstorms during the four-month period between June through September. Periods of extremely heavy precipitation associated with the passage of tropical low pressure systems may occur during summer and early fall. Normal monthly rainfall within the Hillsborough River watershed is greatest in August (8.2 inches) and least in November (1.8 inches) (Figure 2-2).

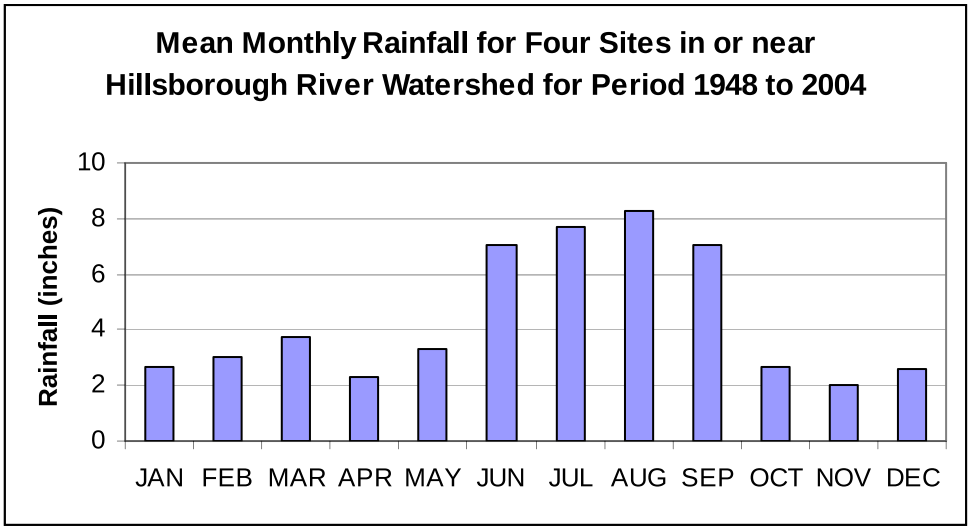


Figure 2-2. Average total monthly rainfall for four NOAA rainfall sites located in or near the Hillsborough River watershed for period 1948 to 2004.

2.2.3 Physiography

The Hillsborough River watershed lies within four physiographic provinces; the Brooksville Ridge, the Gulf Coastal Lowlands, the Zephyrhills Gap, and the Polk Upland (White 1970). The Brooksville Ridge extends from northern Hernando County into eastern Pasco County. The southern portion of the ridge extends into the Hillsborough River watershed. The entire ridge overlies a clay unit up to 30 feet thick, with partial hydraulic connection to the underlying upper Floridan aquifer by way of solution features and fractures (SWFWMD 1996). The Brooksville Ridge has the most irregular topography to be found in peninsular Florida (White 1970). There are few persistent valleys and little surface drainage. The highest elevations in the Hillsborough River watershed are in this physiographic province, with some elevations as high as 300 feet above NGVD. The Gulf Coastal Lowlands province lies to the west of the Brooksville Ridge, and includes the area of Big Cypress Swamp, as well as the extensive lakes region in northwest Hillsborough County and south-central Pasco County. Soils are sandy, with little organic material (SWFWMD 1996). Elevations are generally between 20 and 100 feet.

The Zephyrhills Gap lies to the south of the Brooksville Ridge and east of the Gulf Coastal Lowlands. It encompasses the greatest proportion of the Hillsborough River watershed, and includes nearly the entire main river channel. The Zephyrhills Gap is an erosional watershed with sluggish surface drainage and many karst features (SWFWMD 1996). A thin layer of sand and clay overlies karst limestone, and springs and sinkholes are common. Elevations range from

10 to 140 feet, with poorly drained swamps and marshes in the lower elevations and pine flatwoods in the higher elevations. The southernmost portion of the Hillsborough River watershed is situated in the Polk Upland Province. Elevations in the Polk Upland are typically between 100 and 130 feet, however, elevations are mostly between 20 and 50 feet within the watershed, dipping toward the valley of the Hillsborough River (White1970). Primary soil groups in the Hillsborough River watershed include the Myakka-Basinger-Holopaw association, and the Pomona-EauGallie-Sellers group of soils in Pasco County which predominates in the northern and eastern portions of the watershed. The Candler-Lake association occurs in the vicinity of Lake Thonotosassa, and the Winder-Chobee-St. Johns occurs along the main stem of the non-urbanized upper river. A sequence of urban soils (fill and disturbed soils) occur along the lower reaches of the river in the urban and suburban areas associated with the cities of Tampa and Temple Terrace.

2.2.4 Hydrogeology

The hydrogeologic flow system of the Hillsborough River watershed is comprised of five principal hydrogeologic units: 1) the surficial aquifer; 2) semi-confining beds and the intermediate aquifer; 3) the Upper Floridan aquifer; 4) the middle confining unit; and 5) the Lower Floridan aquifer. The surficial aquifer consists of unconsolidated sands and sandy clays of Miocene, Pleistocene, and recent origin which generally range in thickness from 20 feet to 50 feet (Wolansky and Thompson 1987). The semi-confining beds and intermediate aquifer separate the surficial aquifer from the underlying Upper Floridan aquifer. The semi-confining unit is composed of silt, sandy clay, and clay of the Hawthorn Group that somewhat retards the movement of water (SWFWMD 1996). The intermediate aquifer consists of limestone and dolomite beds of the Hawthorn Formation and upper portions of the Tampa Limestone. Within much of the Hillsborough River watershed, the intermediate aquifer is locally discontinuous or absent. Where the intermediate aquifer does not have adequate thickness or permeability to serve as a water-bearing unit, it may act as a confining unit for the Upper Floridan aquifer (Wolansky and Thompson 1987). The Floridan aquifer is the primary artesian aquifer throughout Florida and much of the southeastern United States. It consists of two transmissive zones, the Upper Floridan aquifer and the Lower Floridan aquifer, which are separated by a middle confining unit. The Floridan aquifer consists of the limestone and dolomite beds of Eocene to Miocene age which have an average thickness of approximately 1100 feet in the Hillsborough Valley area (Wolansky and Thompson 1987).
Flow in both the upper and lower reaches of the Hillsborough River is augmented by groundwater discharges from springs. Crystal Springs, located near the city of Zephyrhills, discharges an average 40 to 60 cfs (cubic feet per second) in the upper watershed (discussion to follow), while Sulphur Springs in the Tampa area discharges an average (period of 1991 to 2002) of 34 cfs to the lower river (SWFWMD 2004). In addition to named springs, monitoring of the surficial aquifer indicates that localized areas with increased ionic content occur in the

vicinity of some portions of the Hillsborough River, apparently as a result of upward leakage of highly mineralized water from deep in the Floridan aquifer (Jones et al., 1990). The deep groundwater likely migrates through areas of high permeability (probable fracture systems) to mix with the overlying Upper Floridan and surficial aquifers (Jones et al., 1990). In general, the areas of upward leakage coincide with the location of the Hillsborough River Tampa Bypass Canal and the Alafia and Little Manatee rivers, suggesting that the surface above the apparent fracture systems provides a preferential zone for surface water flow (Jones et al., 1990).

2.3 Land Use Changes in the Hillsborough River Watershed

2.3.1 Hillsborough River Watershed

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

For our analyses, land use/cover types identified included: urban; uplands (rangeland and upland forests); wetlands (wetland forests and non-forested wetlands); mines; water; citrus; and other agriculture. We examined changes in these use/cover types for the entire watershed and also for 4 major sub-basins. Before discussing individual sub-basin land use changes, it is informative to discuss the entire watershed of the Hillsborough 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 Hillsborough River watershed are shown in Figures 2-3 and 2-4. Based on these maps, the Hillsborough River watershed is 675 square miles or 432,176 acres in size.

Because we combine several agricultural land use types for our analysis, temporal changes in land use from 1972 to 1999 may not reflect the shift which has occurred from less intensive types of agricultural land use to those requiring greater amounts of water. It should be noted, however, that of the major land use categories, the amount of land converted to urban uses has shown the single greatest increase.

In many instances, within sub-basins, what appears to be a substantial decrease in uplands and increase in wetlands is actually an artifact of the disparity in resolution of features denoted in 1972 and 1999 mapping. While it appears that the amount of wetlands has increased in most sub-basins, this is probably not the case. Because many wetlands are small in size and interspersed within upland areas, they were not delineated under the relatively coarser resolution employed in the 1972 mapping. Actual increases in wetlands (resulting in a concomitant decrease in uplands) were the consequence of increased resolution rather than the conversion of, for example, uplands to wetlands. In many cases what appear to be substantial declines in uplands should also more appropriately be interpreted as an improvement in map resolution. However, decreases in uplands have occurred in some sub-basins. It is helpful when interpreting these data to view the sum of the wetlands and uplands as natural area, and the decline in this total as a measure of conversion to some other more intensive land use (e.g., agriculture, mining, urban).

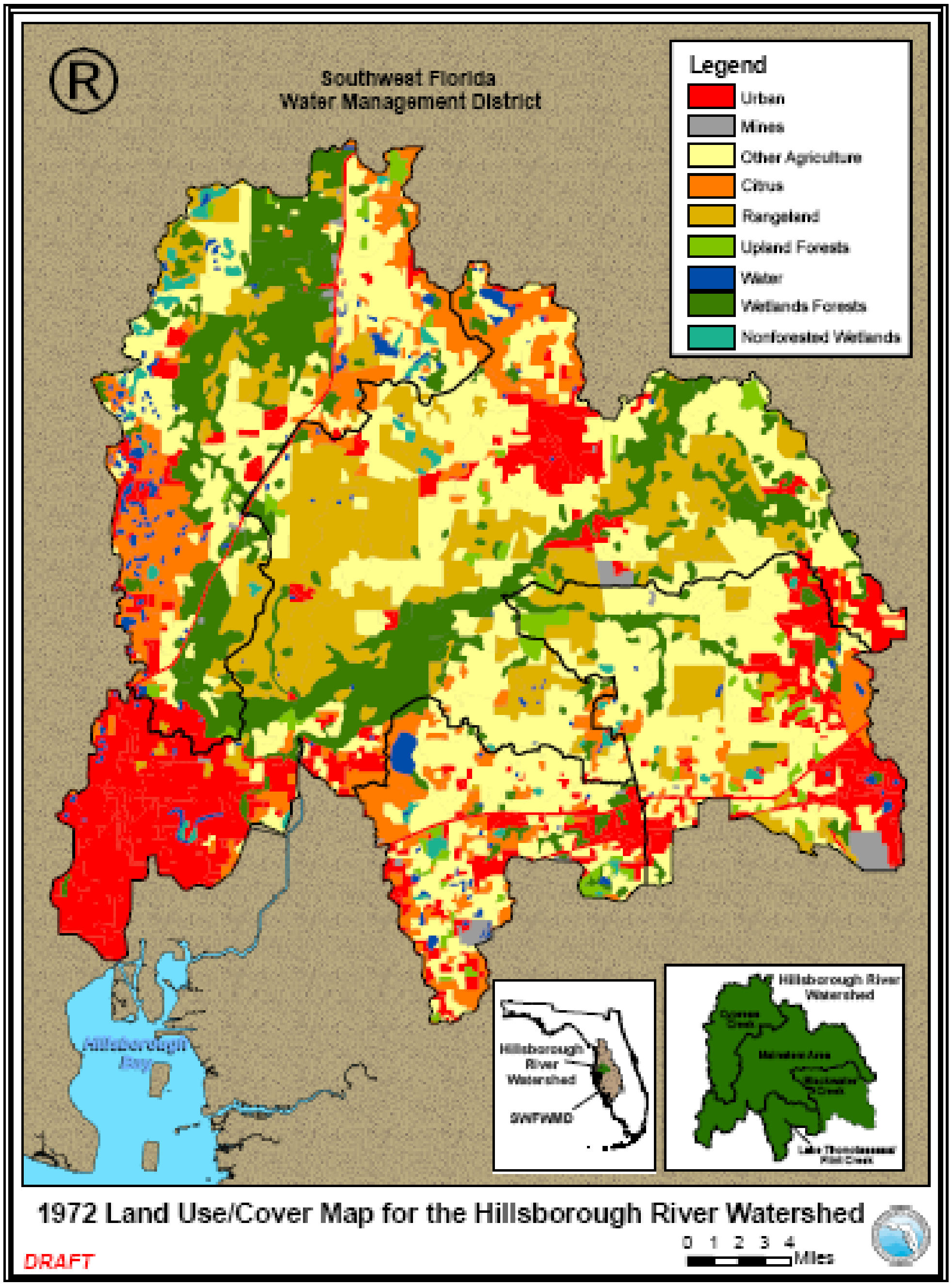


Figure 2-3. 1972 land use/cover map of the Hillsborough River watershed.

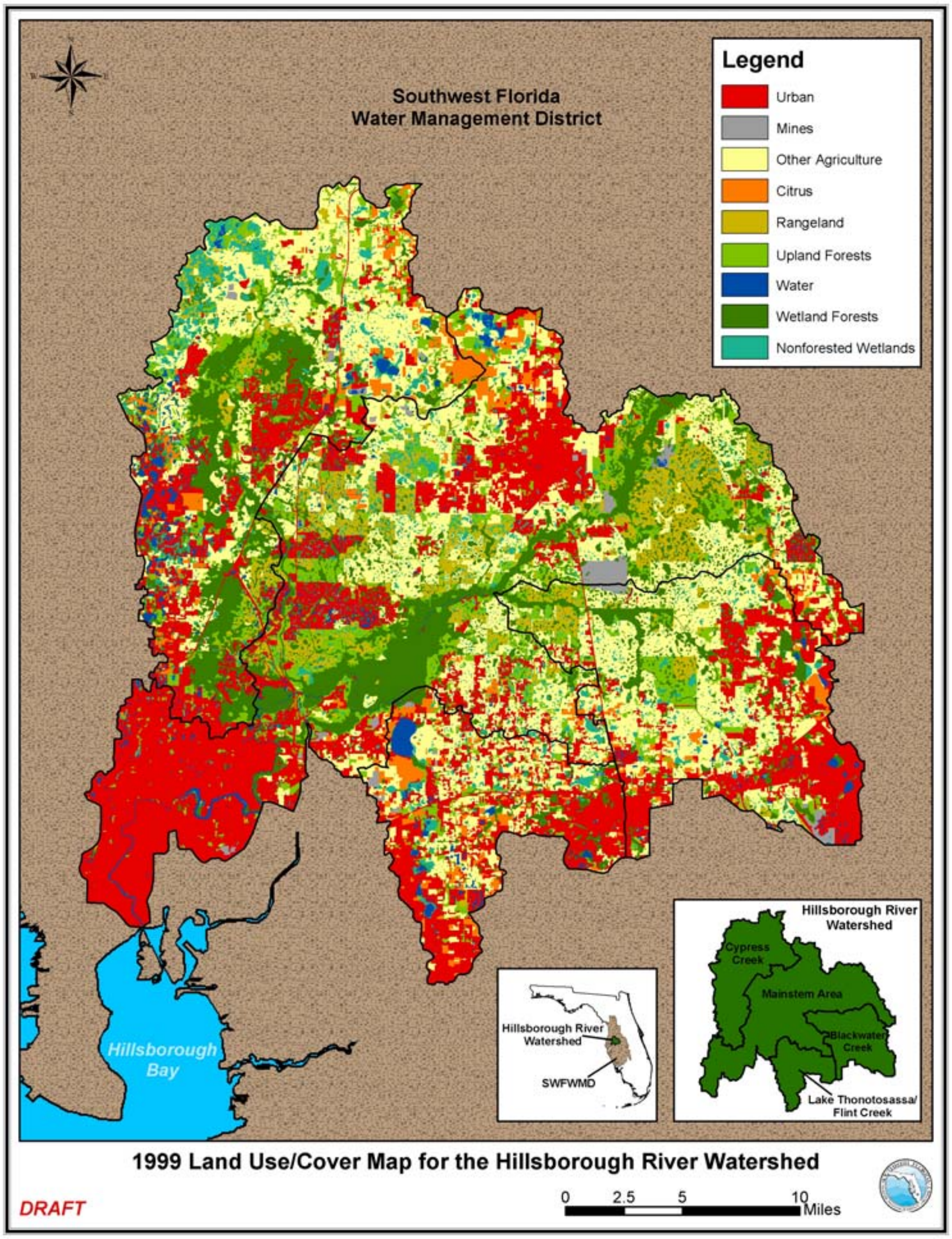


Figure 2-4. 1999 land use/cover map of the Hillsborough River watershed.

Based on the 1999 map, a significant amount of the watershed remains in fairly natural cover; uplands and wetlands comprise approximately 38% of the watershed (Table 2-1, Figure 2-5). On a percentage basis, considerably more of this watershed remains in a relatively undisturbed state as contrasted with either the Peace or Alafia watersheds, where the combined acreage in uplands and wetlands, is 32% and 20%, respectively (Kelly et al. 2005a, 2005b). Of the four major river watersheds studied thus far for MFL purposes, only the Myakka River watershed exceeds the Hillsborough River in natural cover (see Table 2-2). Unlike the neighboring Peace and Alafia watersheds, only a small portion of the Hillsborough River watershed has been mined (1%). Agriculture represents a significant land use in the Hillsborough River watershed (30%); however, the amount of acreage in citrus is small (4%). As of 1999, 29% of the watershed was in urban land use. The amount of urbanization exceeds considerably, on a percentage basis, that in the Peace (11%), Myakka (14%), and Alafia River (18%) watersheds.

Table 2-1. Land use and land cover percentages in the 432,176-acre (675 square miles) Hillsborough River watershed for three time periods: 1972, 1990 and 1999.

Hillsborough River Watershed	1972	1990	1999
Urban	18.28	25.99	28.78
Citrus	10.53	3.07	3.76
Other Agriculture	32.61	29.11	26.35
Uplands	18.56	16.67	16.02
Wetlands	17.80	22.34	21.64
Mines	0.76	0.84	0.89
Water	1.46	1.98	2.56

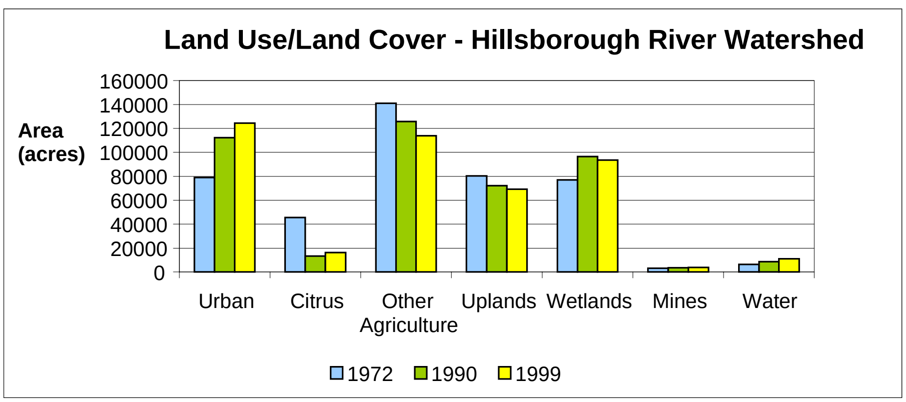


Figure 2-5. Land use/cover acreage in the Hillsborough River watershed in 1972, 1990 and 1999.

Table 2-2. 1999 land use and land cover percentages in the Hillsborough, Myakka, Alafia and Peace River Basins.

	Hillsborough	Myakka	Alafia	Peace
Urban	29	14	18	11
Citrus	4	2	5	15
Other Agriculture	26	26	18	29
Uplands	16	34	10	16
Wetlands	22	21	11	16
Mines	1	1	36	10
Water	3	3	3	4
Total Acres	432176	382764	269986	1501318
Square Miles	675	598	422	2346

2.3.2 Mainstem Area

The predominant land use along the mainstem of the Hillsborough River is urban, which in 1999 accounted for 31.6% of the sub-basin land use (Table 2-3, Figures 2-6, 2-7, and 2-8). Essentially all of the watershed along the City of Tampa's Reservoir and downstream is urbanized. The amount of land in natural cover (uplands and wetlands) has remained surprisingly constant between 1972 and 1999, with the increase in urbanized area essentially offset by decreases in agricultural land.

Table 2-3. Land use/cover and land cover percentages in the 202,873-acre (317 square miles) Hillsborough Mainstem sub-basin for three time periods: 1972, 1990 and 1999.

Mainstem Area	1972	1990	1999
Urban	22.5	29.6	31.6
Citrus	6.4	1.6	2.2
Other Agriculture	28.1	23.7	22.1
Uplands	26.0	20.6	19.4
Wetlands	16.1	22.2	21.7
Mines	0.3	1.0	1.1
Water	0.6	1.3	1.9

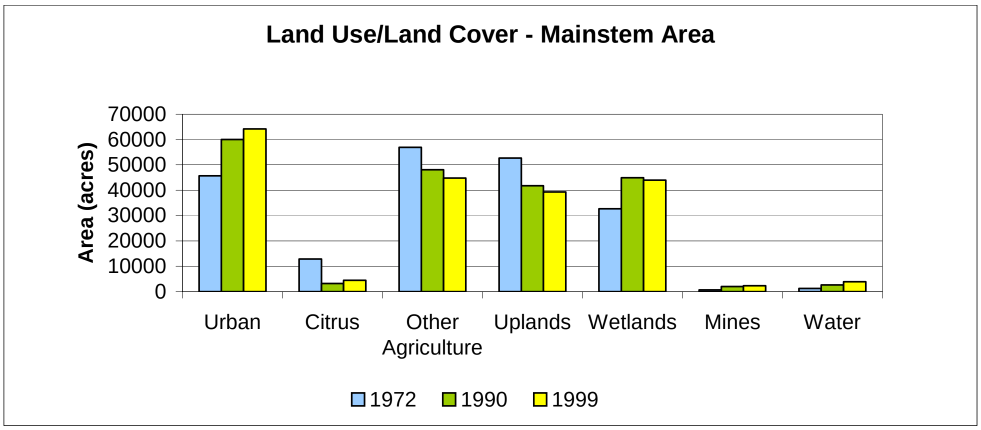


Figure 2-6. Land use/cover acreage in the Hillsborough Mainstem sub-basin in 1972, 1990 and 1999.

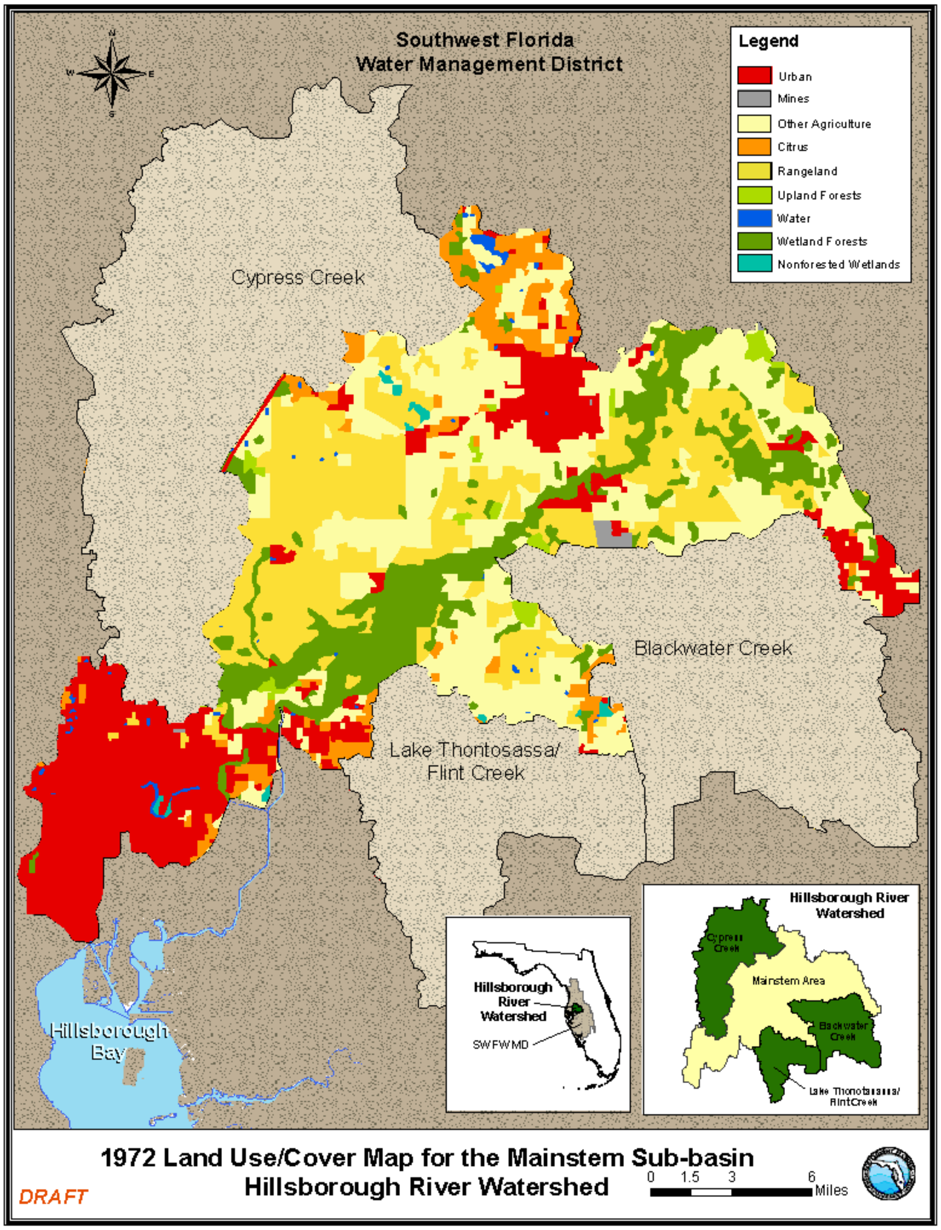


Figure 2-7. 1972 Land use/cover map of the Hillsborough Mainstem sub-basin.

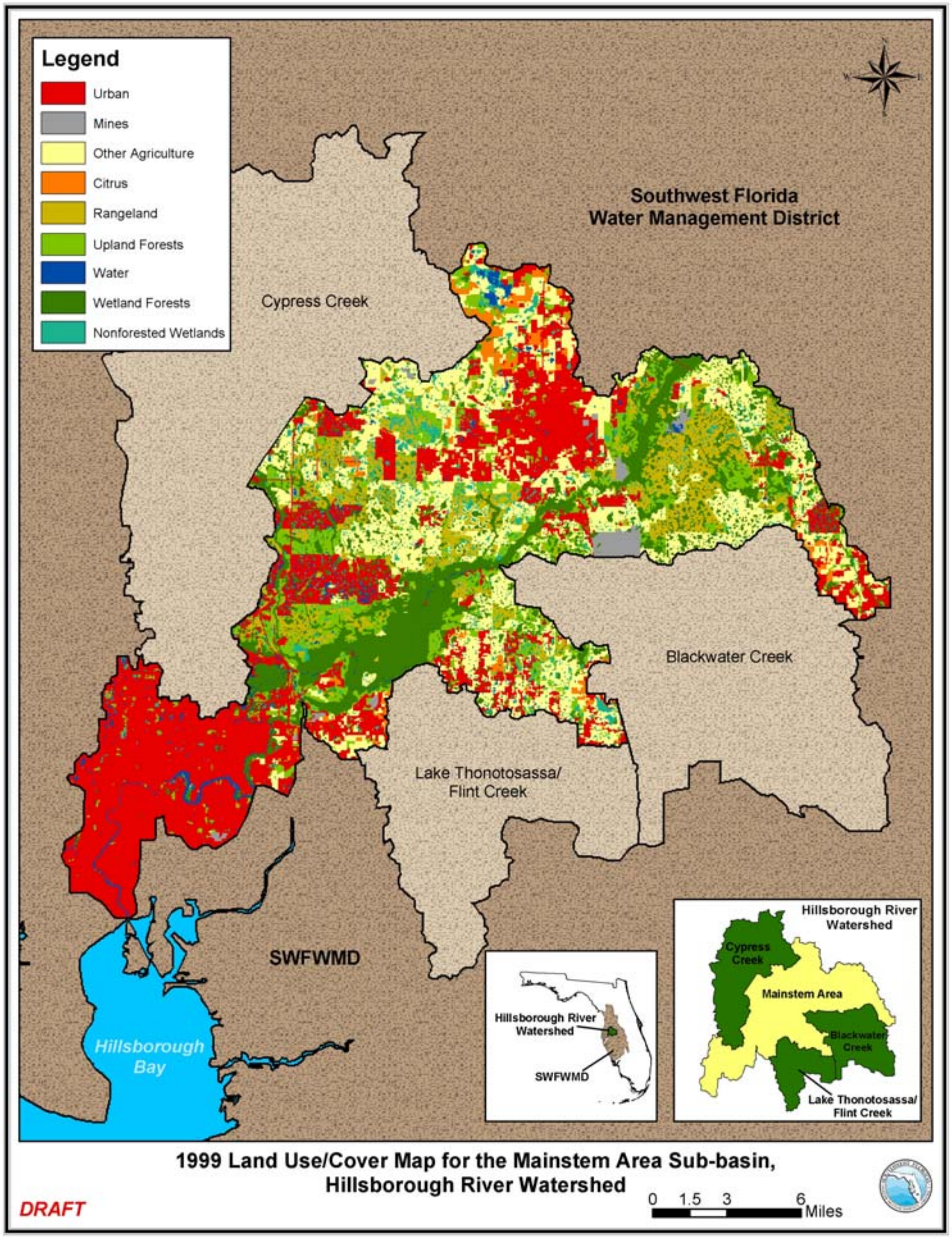


Figure 2-8. 1999 Land use/cover map of the Hillsborough Mainstem sub-basin.

2.3.3 Blackwater Creek Sub-Basin

Land use in the Blackwater Creek sub-basin is also dominated by agricultural uses (Table 2-4, Figure 2-9). Approximately 38.6% of this sub-basin's land use is agriculture; however, between 1972 and 1990, this land use decreased from a high of 50.9%. What appears to be an increase in total acres of wetlands may be attributable to the increase in mapping resolution between 1972 and 1990, and lands formerly classified as agricultural may have decreased as wetland acreage was better defined (Figures 2-10 and 2-11). Again it is believed that the increase in urbanized area occurred largely at the expense of agricultural lands as the combined amount of land cover in wetlands and uplands changed little.

Table 2-4. Land use/cover percentages in the 72,430-acre (113 square miles) Blackwater Creek sub-basin for three time periods: 1972, 1990 and 1999.

Blackwater Creek	1972	1990	1999
Urban	21.4	23.9	28.7
Citrus	5.8	3.7	2.7
Other Agriculture	45.1	40.4	35.9
Uplands	17.2	11.3	13.3
Wetlands	8.2	18.0	16.9
Mines	1.9	1.5	1.1
Water	0.6	1.2	1.6

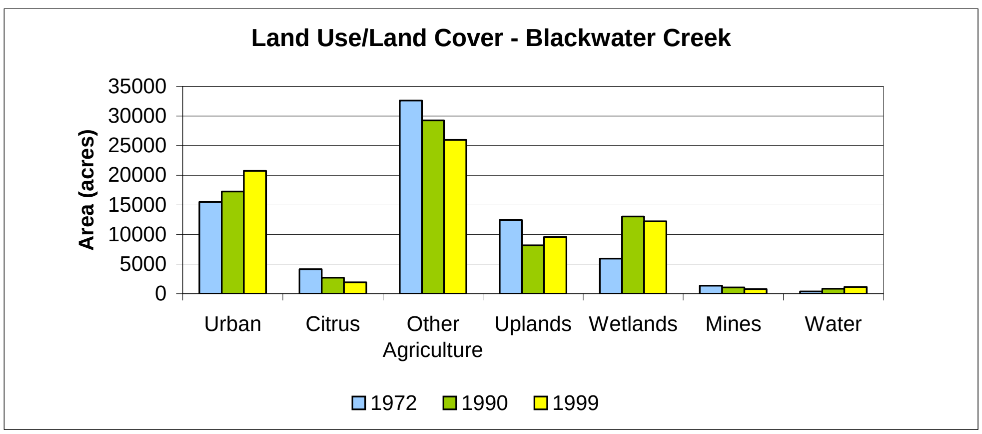


Figure 2-9. Land use/cover in the Blackwater Creek sub-basin in 1972, 1990 and 1999.

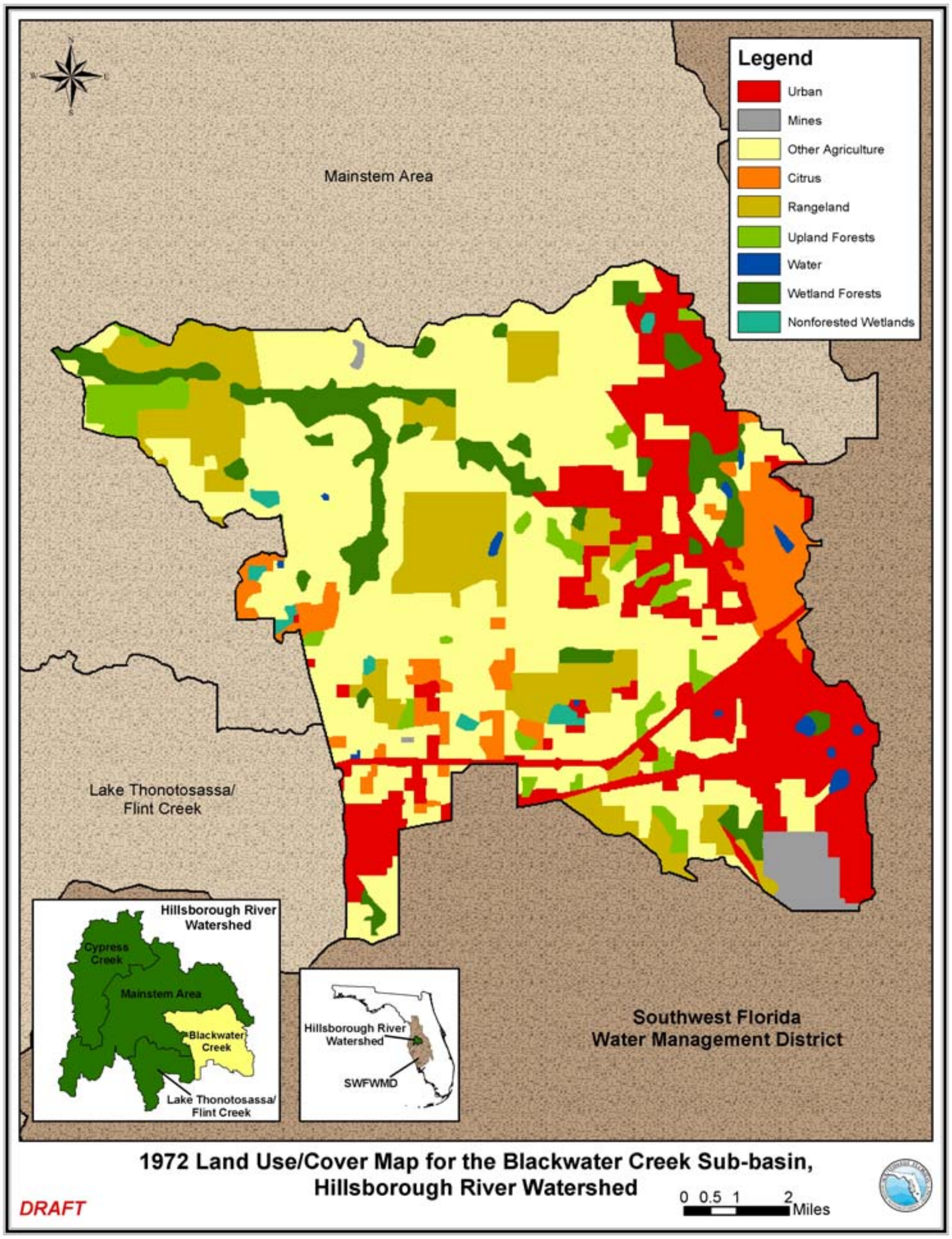


Figure 2-10. 1972 Land use/cover map of the Blackwater Creek sub-basin.

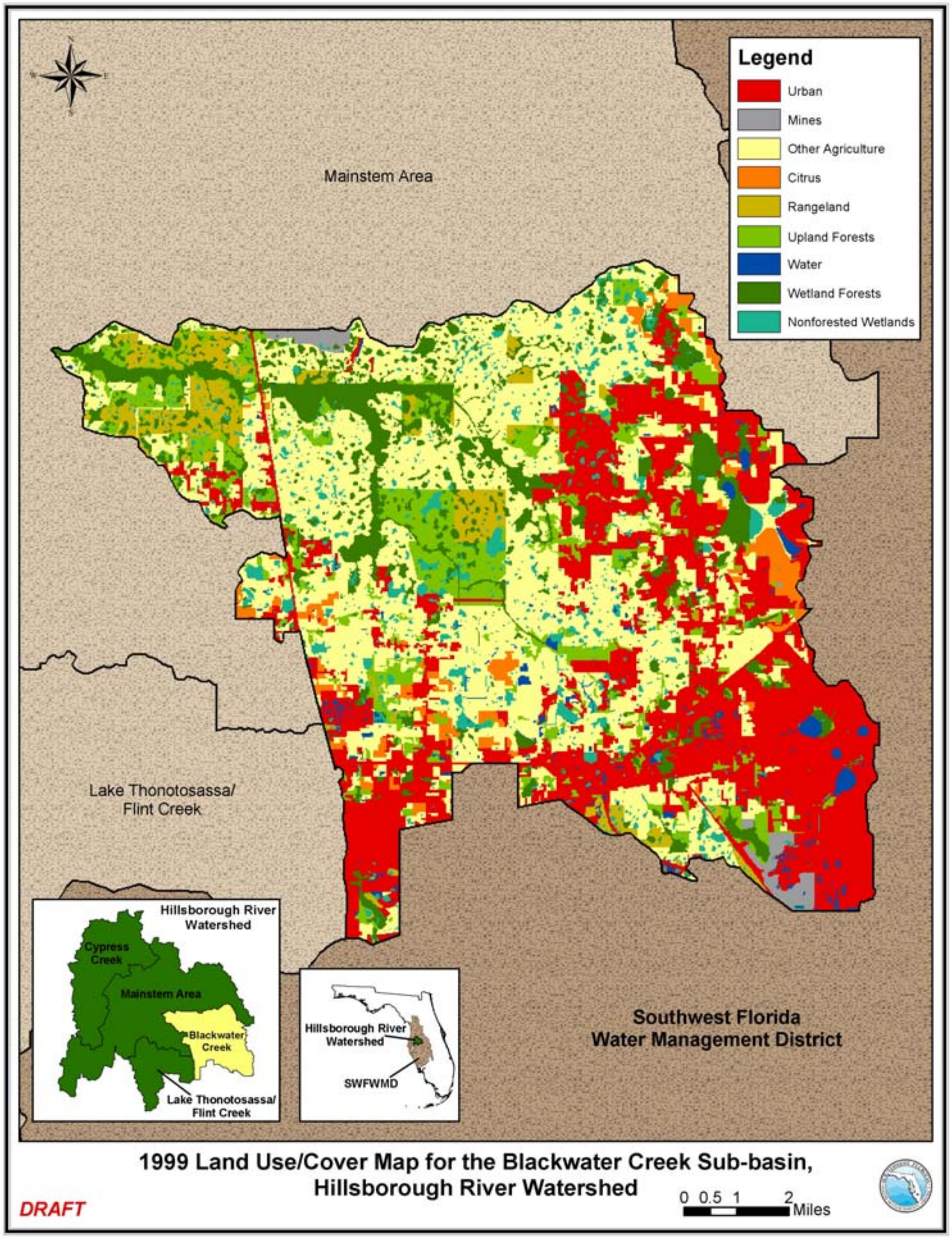


Figure 2-11. 1999 Land use/cover map of the Blackwater Creek sub-basin.

2.3.4 Lake Thonotosassa/Flint Creek Sub-Basin

The single predominant land use in this 71 square mile sub-basin is urban (Table 2-5, Figure 2-12). This is the most urbanized sub-basin in the watershed, with the degree of urbanization increasing substantially between 1972 and 1990 (from 19.5% to 39.4%). Citrus was a significant land use in this sub-basin in 1972 (20.7%), but had declined considerably by 1999 (9.3%). Other types of agriculture declined as well; in 1972, greater than 65% of the watershed was in some sort of agricultural land use, but by 1999, the combined acreage had declined to approximately 35% (Figures 2-13 and 2-14). Again, most of the decline in agricultural land is attributable to conversion to urban land use. It is interesting to note that this sub-basin, which contains the largest lake in Hillsborough County (Lake Thonotosassa), has the least amount of land in natural cover (17%).

Table 2-5. Land use/cover percentages in the 45,674-acre (71 square miles) Lake Thonotosassa/Flint Creek sub-basin for three time periods: 1972, 1990 and 1999.

Lake Thonotosassa/ Flint Creek	1972	1990	1999
Urban	19.5	39.4	40.8
Citrus	20.7	8.2	9.3
Other Agriculture	44.2	29.4	26.8
Uplands	3.8	6.5	6.9
Wetlands	6.9	11.4	10.8
Mines	1.6	1.0	0.9
Water	3.3	4.0	4.6

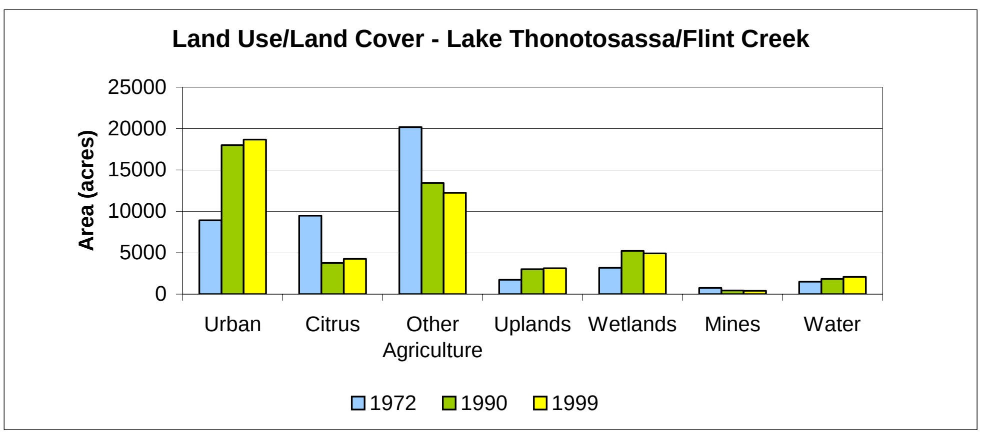


Figure 2-12. Land use/ cover in the Lake Thonotosassa/Flint Creek sub-basin in 1972, 1990 and 1999.

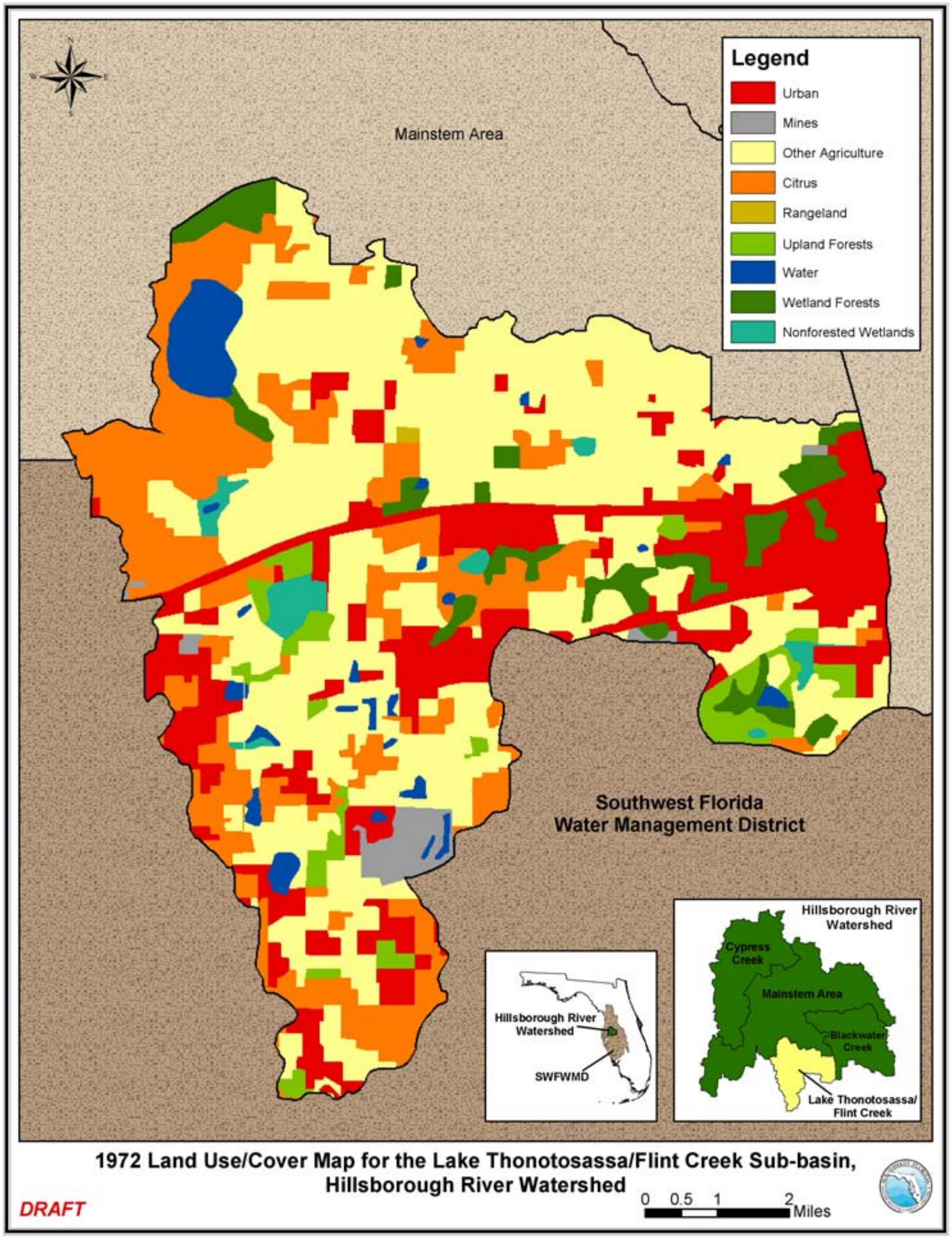


Figure 2-13. 1972 Land use/cover map of the Lake Thonotosassa/Flint Creek sub-basin.

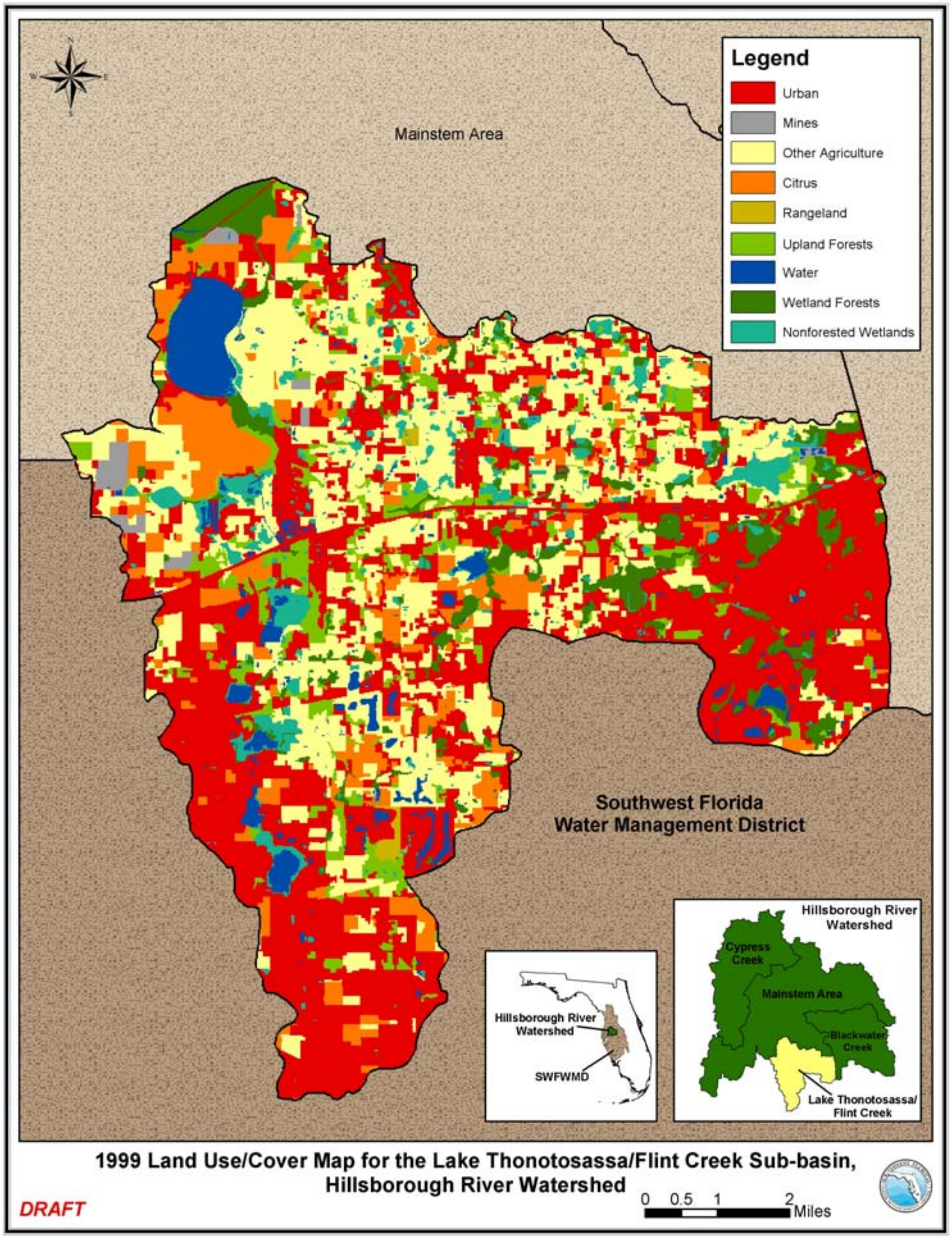


Figure 2-14. 1999 Land use/cover map of the Lake Thonotosassa/Flint Creek sub-basin.

2.3.5 Cypress Creek Sub-Basin

Although the Cypress Creek sub-basin is the least urbanized sub-basin of those delineated for this report, there was a comparatively large increase in urbanized area between 1972 and 1999, with the percentage of the sub-basin in this land use increasing from 7.9% to 18.7%. This increase appears to have been almost totally at the expense of a decrease in citrus acreage, which went from 17.1% of the sub-basin watershed in 1972 to 5% in 1999 (Table 2-6, Figures 2-15, 2-16, and 2-17). There appears to have been little change in other land use types during this time. It should be noted, however, that there has been significant wellfield development in this sub-basin.

Table 2-6. Land use/cover percentages in the 111,199-acre (174 square miles) Cypress Creek sub-basin for three time periods: 1972, 1990 and 1999.

Cypress Creek	1972	1990	1999
Urban	7.9	15.2	18.7
Citrus	17.1	3.2	5.0
Other Agriculture	28.1	31.5	27.8
Uplands	12.0	17.2	15.5
Wetlands	31.6	30.0	29.2
Mines	0.4	0.1	0.3
Water	2.8	2.9	3.5

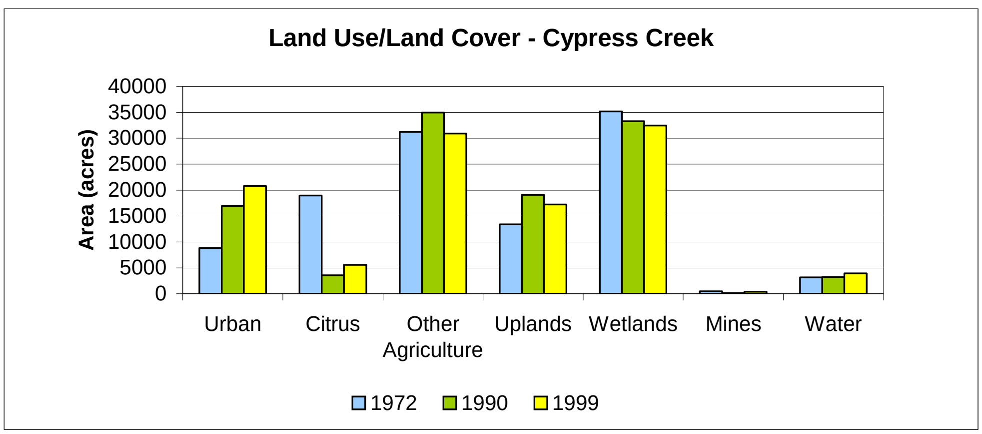


Figure 2-15. Land use/cover in the Cypress Creek sub-basin in 1972, 1990 and 1999.

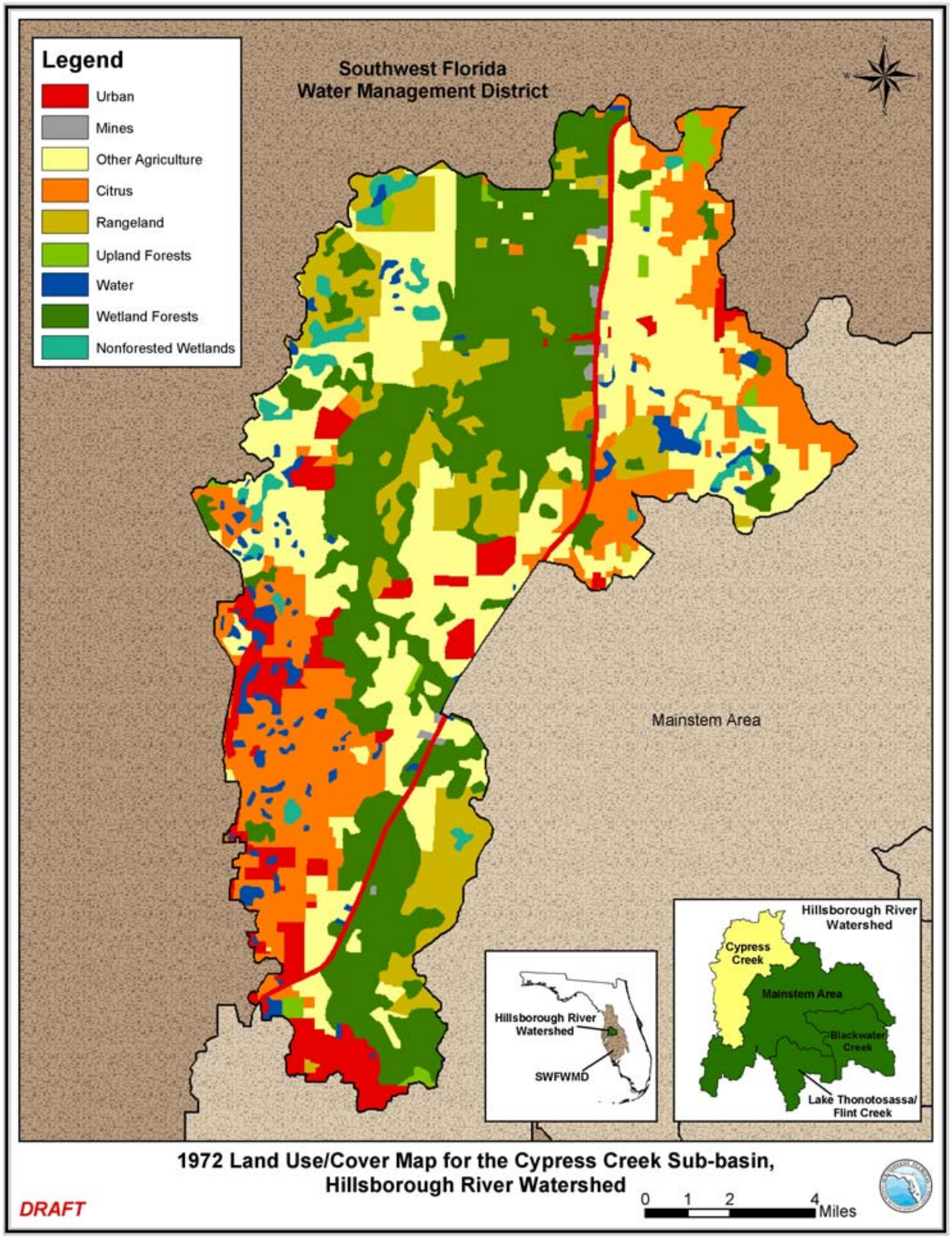


Figure 2-16. 1972 Land use/cover map of the Cypress Creek sub-basin.

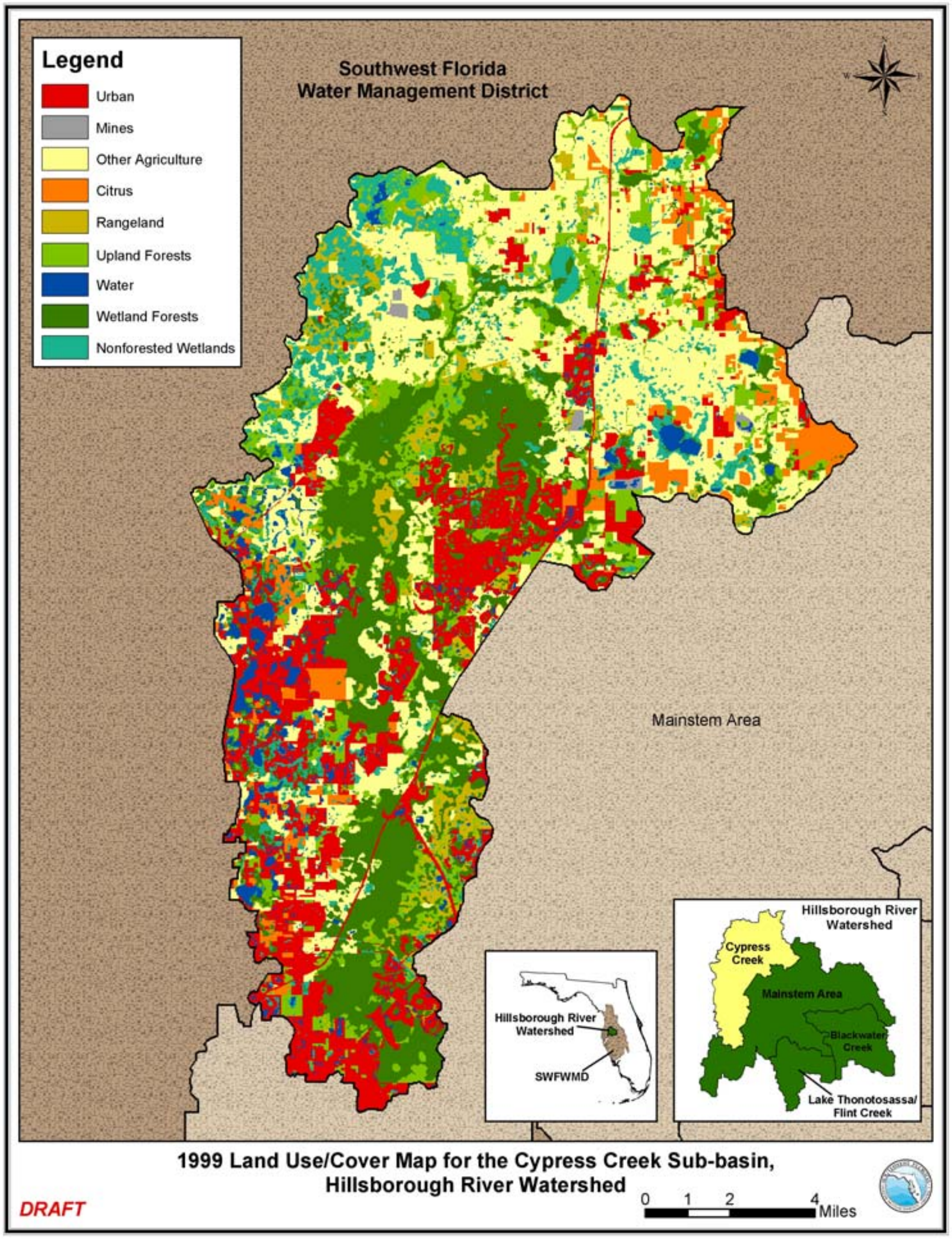


Figure 2-17. 1999 Land use/cover map of the Cypress Creek sub-basin.

2.4 *Hydrology*

2.4.1 Overview

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

2.4.2 Florida River Flow Patterns and the Atlantic Multidecadal Oscillation

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

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

While much of Florida has a summer rainy season, 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. By constructing plots of median daily flows (in cubic feet per second), seasonal flow patterns were clearly illustrated, and by dividing mean daily flows by the upstream watershed area, flows could be compared between watersheds of varying size. One of the more interesting features evident from this analysis was the existence of a distinctly bimodal flow pattern (Figure 2-18, bottom panel) 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 (Figure 2-18, top panel), while those north of the line exhibit highest flows in the spring (Figure 2-18, middle panel).

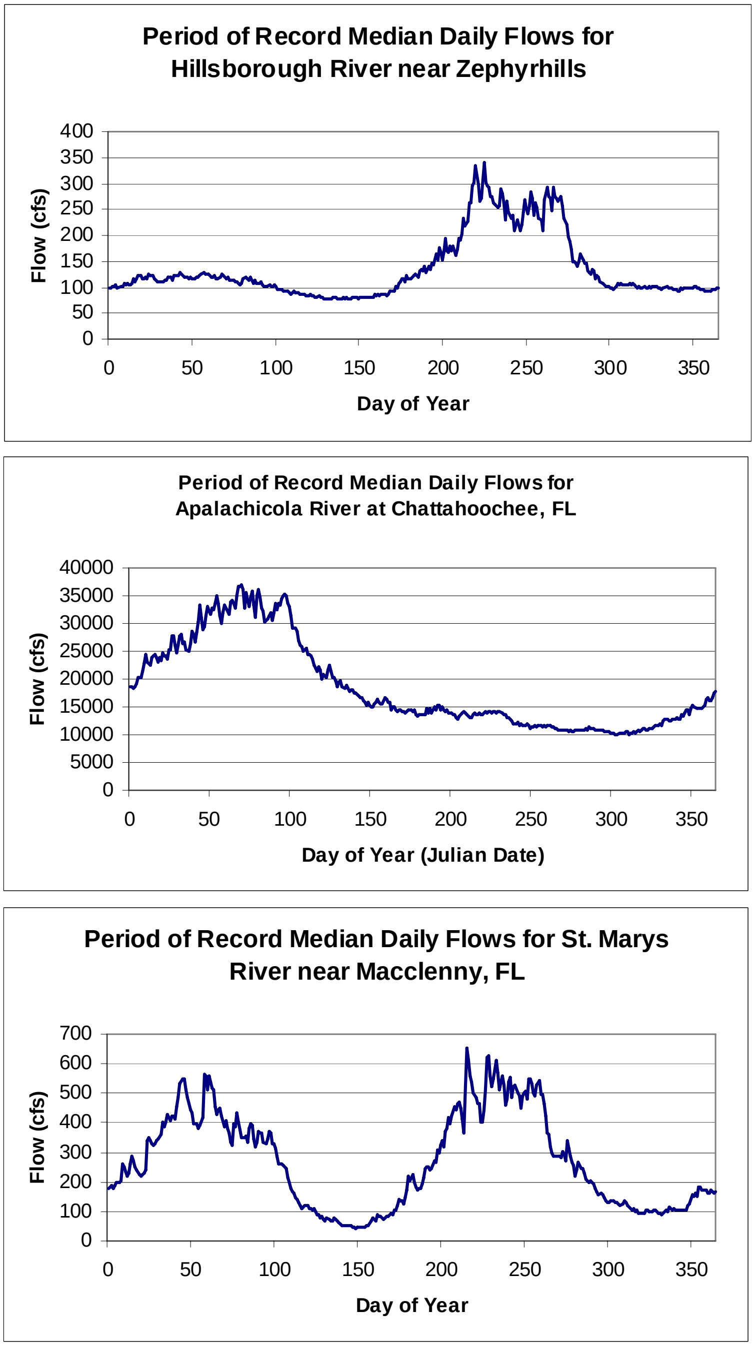


Figure 2-18. Examples of three river flow patterns: the Southern River Pattern (upper panel), the Northern River Pattern (center panel) and Bimodal River Pattern (bottom panel).

2.4.2.1 Multidecadal Periods of High and Low Flows

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

Unlike earlier District MFL reports dealing with river flows (e.g., Kelly 2004, Kelly et al. 2005a, 2005b, 2005c), flow comparisons in this report on the upper Hillsborough River reflect an acknowledgement of a shift from an AMO cool period (1970 to 1994) to an AMO warm period that apparently occurred in the mid-1990s. Previous reports simply divided flows into a pre and post-1970 data set; however, since almost 10 years of flow and rainfall data are now available for many sites during the "new" AMO warmer phase (1995 to 2005), data have in some cases been investigated in consideration of this shift. As a result, it is generally expected that rainfall and flows should reflect this transition, and both should increase relative to the AMO cool phase (1970 to 1994).

2.4.3 Upper Hillsborough River Flow Trends

2.4.3.1 Gage Sites and Periods of Record

Flow analyses in the upper Hillsborough River watershed focused on two USGS gage sites on the mainstem of the river and sites on two major tributaries (Figure 2-19). The two mainstem sites are referenced by the USGS as the Hillsborough River near Zephyrhills gage and the Hillsborough River at Morris Bridge gage. The Hillsborough River near Zephyrhills gage has the longer flow record of the two, extending from October 1939 to present. The USGS gage near Morris Bridge has a much shorter period of record. Flows at this site were monitored for a short time beginning in February 1963 to September 30, 1966, and have been monitored daily from October 1, 1977 to present. Flow records for both Cypress and Blackwater Creeks were considered, as well, during the development of the upper Hillsborough River MFL.

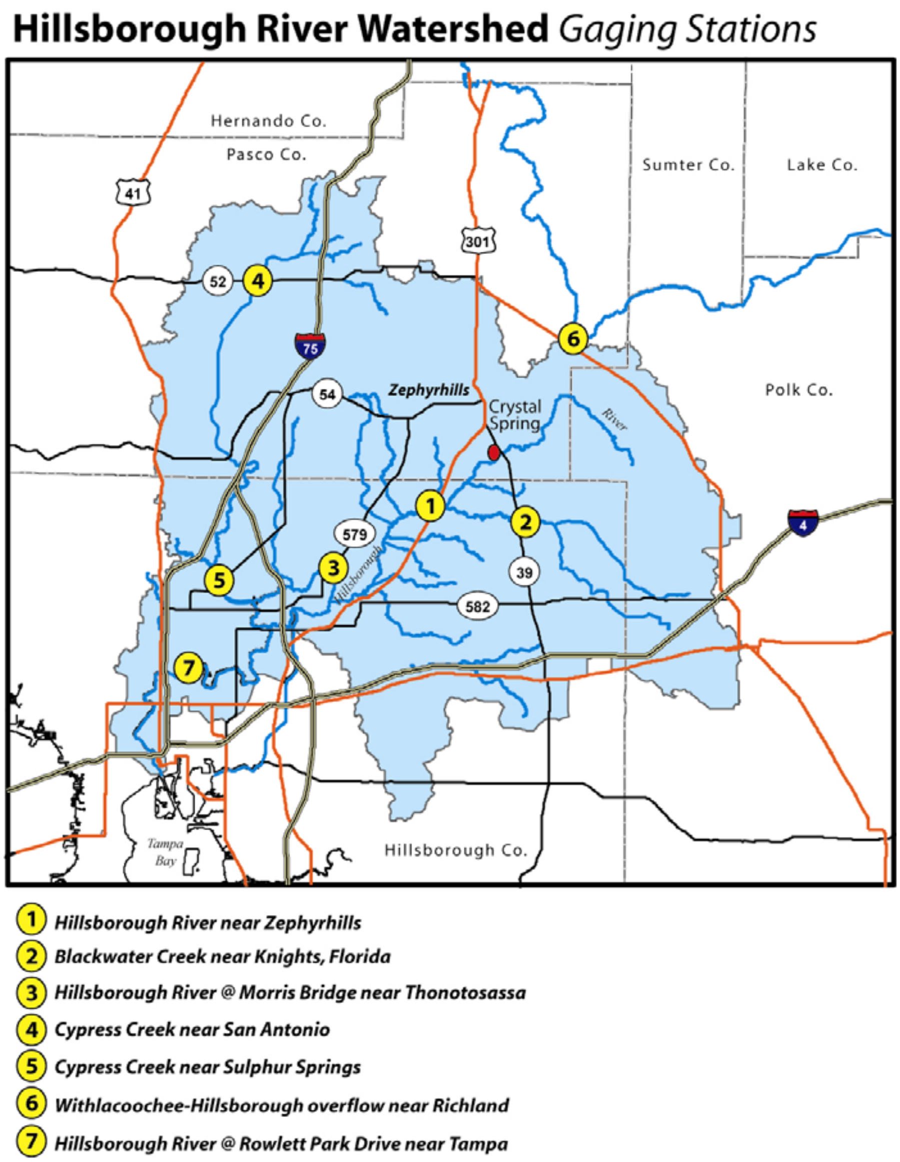


Figure 2-19. Map of Hillsborough River watershed showing the Hillsborough River main-stem and tributaries, and long-term USGS gage site locations.

2.4.3.2 Hillsborough River Flows

MFL work on the upper Hillsborough River was conducted on the river segment beginning upstream of Crystal Springs and extending just beyond the Morris Bridge gage. Despite the shorter period of record at the Morris Bridge site, there is good agreement between flows measured at this site and the site near

Zephyrhills. Figure 2-20 compares mean daily flows for the two sites. As can be appreciated, flow volumes at the Morris Bridge are slightly greater due to the additional watershed area that occurs between the Morris Bridge and Zephyrhills gage; however, the flow volumes are almost identical during the drier months since virtually all the baseflow is contributed by springs upstream of the Zephyrhills gage.

Zephyrhills flow is such a good predictor of Morris Bridge flow, that mean monthly historical flows at Morris Bridge were predicted for use in PHABSIM analyses (explained later in this report) based on its relationship to Zephyrhills flow. Figure 2-21 is an example of predictive equations developed based on monthly mean flows for the period of record beginning in 1974. These relationships were used to predict historic mean monthly flows at Morris Bridge in order to evaluate PHABSIM results for the wetter AMO period – 1940 to 1969. This allowed PHABSIM flow reductions to be assessed for both benchmark periods. Relationships were developed with and without monthly flows spanning the winter of 1997-1998. There was an El Nino during this time which delivered unprecedented rainfall that resulted in river flows which greatly exceeded the typical range. Flows for this period were excluded from data sets used to develop the relationships between the Zephyrhills and Morris Bridge gage sites. All the monthly relationships are shown in the Technical Appendices.

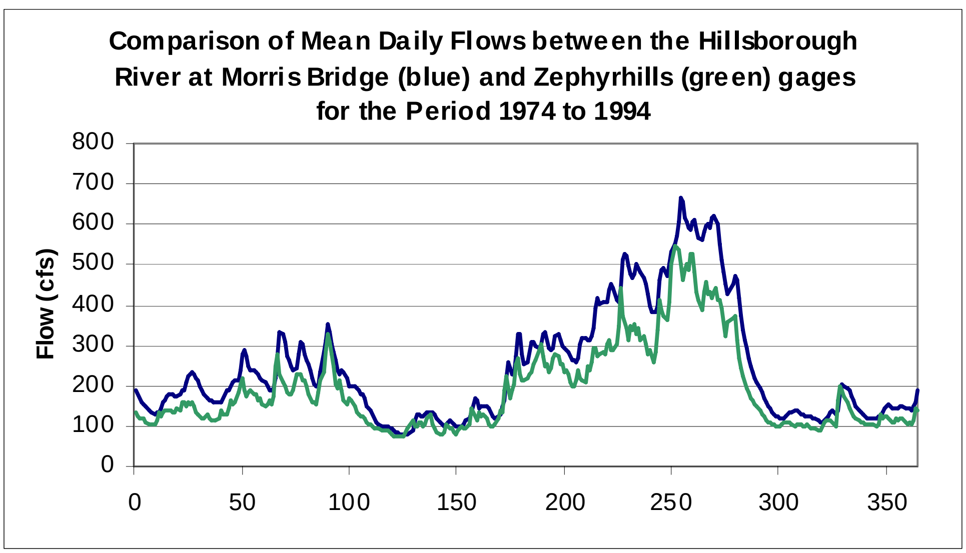
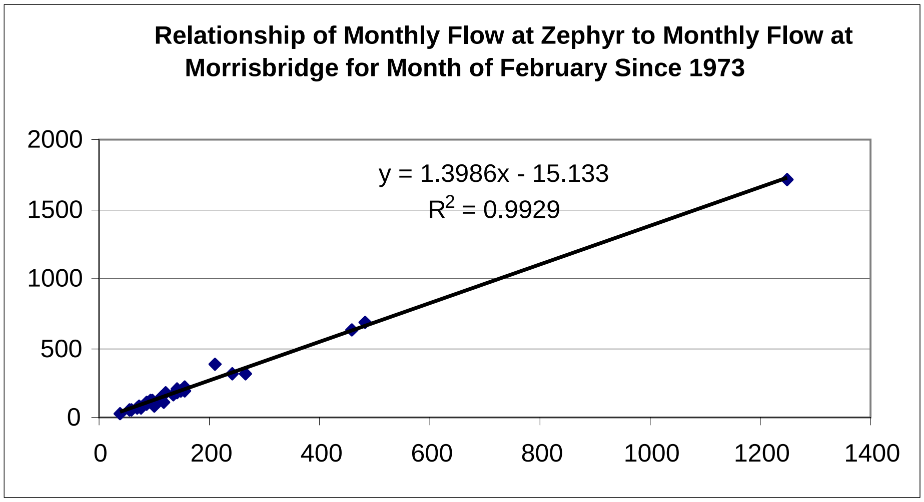


Figure 2-20. Comparison of Mean Daily Flows between the Hillsborough River at Morris Bridge gage with the Zephyrhills gage for the period 1974 to 1994.



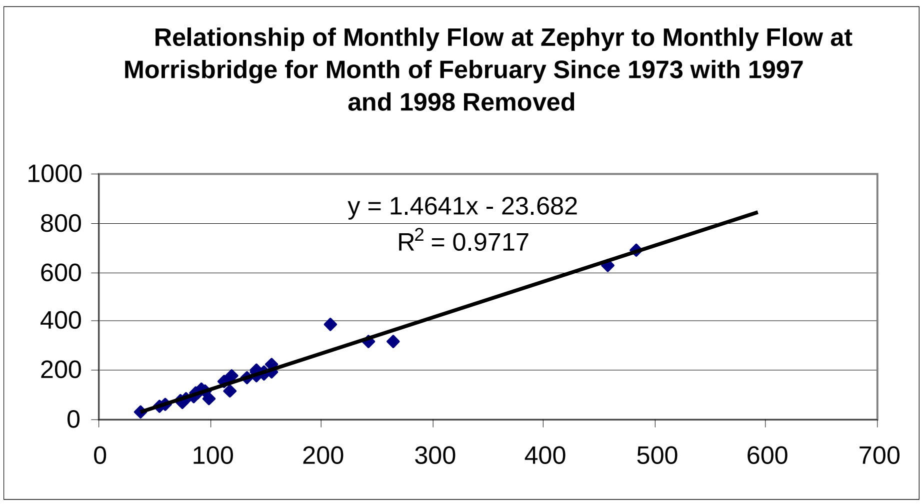


Figure 2-21. Example of relationship between flows at Zephyrhills gage and Morris Bridge gage. The relationship was developed with and without 1997-1998 flows due to the uncharacteristically high flows encountered in some months during these years as a result of an El Nino event.

- **Most of the baseflow is from the upper watershed that is not part of the Blackwater Creek watershed**

The upper Hillsborough River, above the confluence with Blackwater Creek, receives considerably more baseflow than any other river segment. Blackwater Creek flow differs from Zephyrhills gage flow in two significant respects. Most of the baseflow as measured at the Zephyrhills gage is attributable to spring discharges outside of the Blackwater Creek watershed, but in the upper reaches of the Hillsborough River. This is demonstrated graphically by simply substracting a flow (0.25 cfs/square mile) roughly equivalent to Crystal Springs flow from each daily flow record at the Zephyrhills gage and then comparing to Blackwater Creek flows as shown in Figure 2-22. In addition, while high flows appear somewhat similar (Block 3 flows as explained later), there is more flow, volume wise, contributed by that portion of the upper Hillsborough River watershed that is not in the Blackwater Creek watershed. Figure 2-22 was based on the period 1970 to 1994; Figure 2-23 shows a similar plot comparing the period 1951 to 1969 at the two gage sites. Please note that the vertical scales are different for the two time periods; however, this plot also shows that a greater volume of water (per unit area) is contributed by that part of the watershed not measured by the Blackwater Creek gage. This suggests that more water is stored and continues to be released from the non-Blackwater Creek portion of the watershed during and immediately following the summer rainy season. Simply stated, the yield from the uppermost part of the watershed is greater than from the Blackwater Creek watershed even in the absence of spring flow.

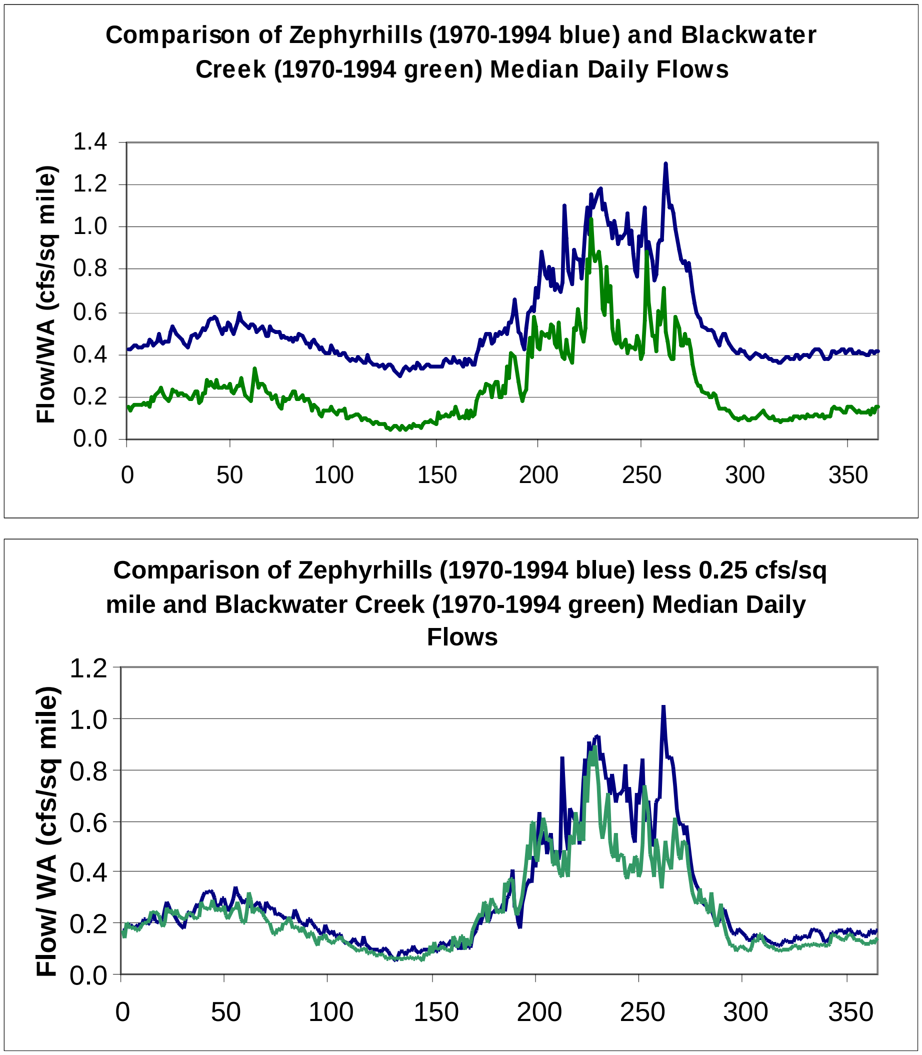
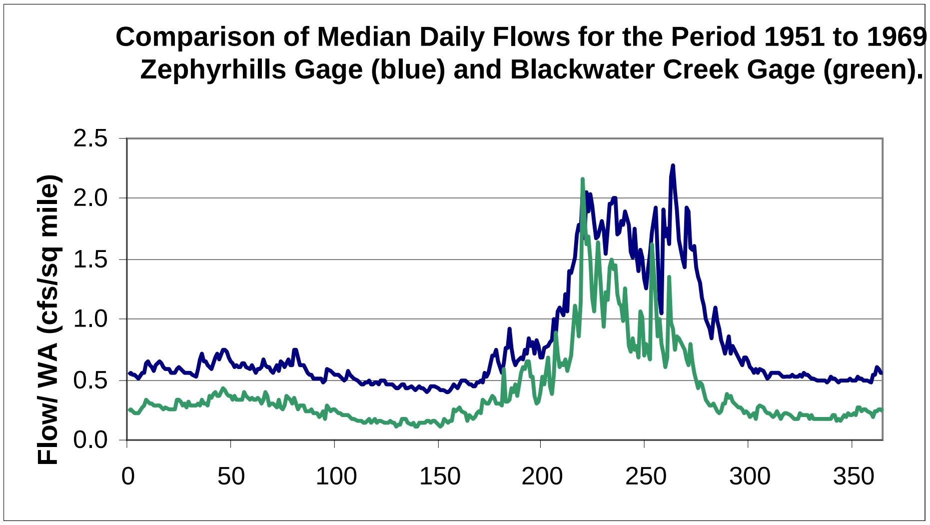


Figure 2-22. Comparison of median daily flows at the Hillsborough River near Zephyrhills site with the Blackwater Creek gage site for the period 1970 to 1994. Upper panel is actual flow record, while bottom panel shows Zephyrhills gage flow with an assumed 0.25 cfs/sq mile artisian baseflow component removed from each day's flow reading.



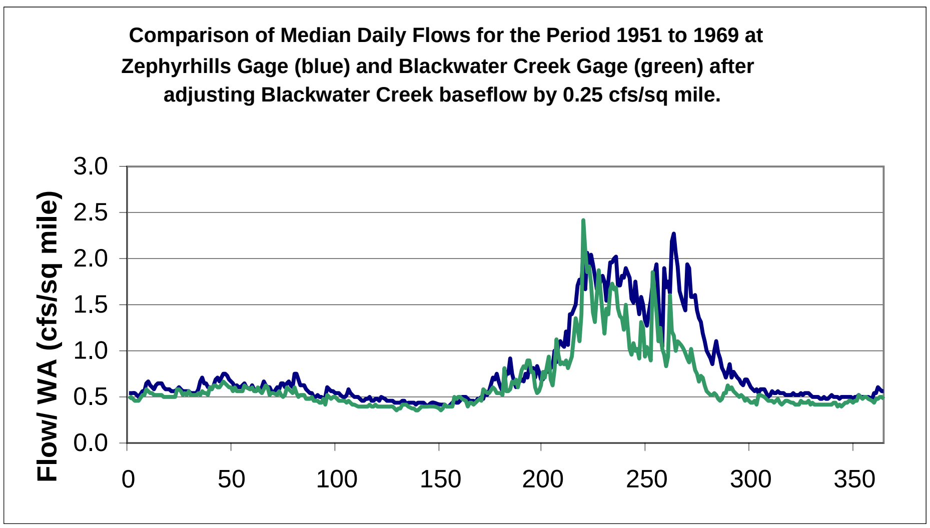
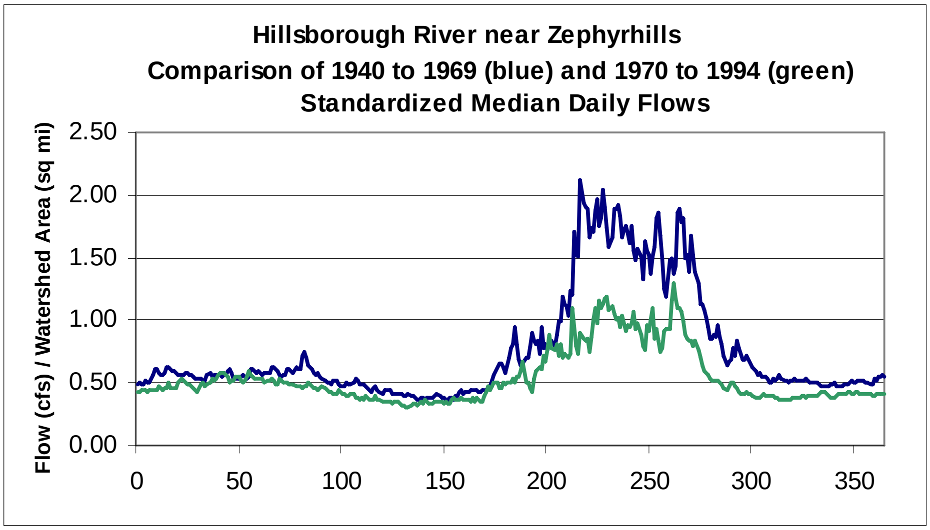


Figure 2-23. Comparison of median daily flows at the Hillsborough River near Zephyrhills site with the Blackwater Creek gage site for the period 1951 to 1969. Upper panel is actual flow record, while bottom panel shows Zephyrhills gage flow with an assumed 0.25 cfs/sq mile artisian baseflow component removed from each day's flow reading.

There is a marked difference in flows at the Zephyrhills gage between the warm (wet) and cool (dry) AMO periods considered (Figure 2-24). While there is a difference in flows throughout the annual cycle, the greatest flow difference occurs during the rainy season (Block 3). At the Zephyrhills gage, the difference in mean annual flow between the AMO warm (1940 to 1969) and cool (1970 to 1994) periods is 36% based on a comparison of mean daily flows; the difference is 29% based on a comparison of median daily flows for the same two time periods.



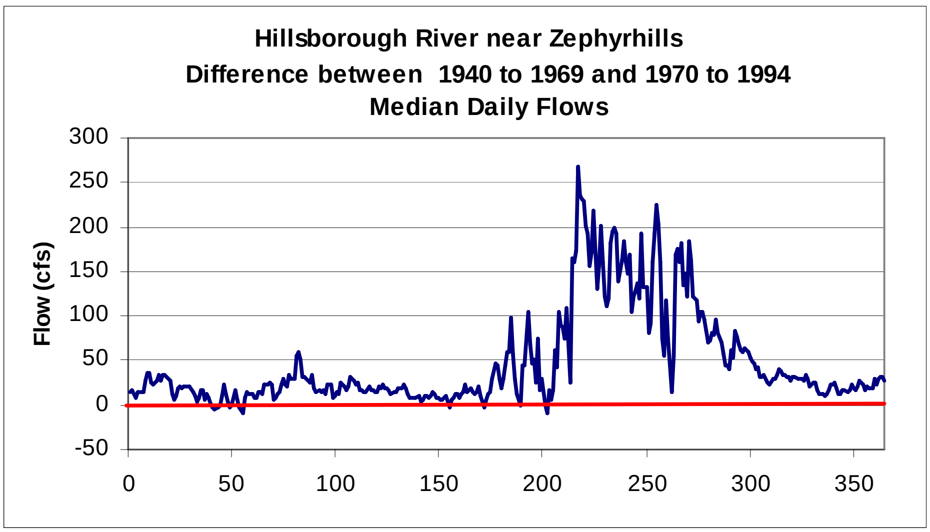


Figure 2-24. Comparison of median daily flows for the Hillsborough River near Zephyrhills for two time periods (1940 to 1969 and 1970 to 1994).

A similar comparison between AMO warm (wet) and cool (dry) periods for Blackwater Creek yields differences (declines) between the wet and dry periods for the mean and median daily flows of 39% and 40%, respectively. The greater percentage reduction in the median daily flow for Blackwater Creek relative to the Zephyrhills gage probably reflects a greater climatic affect on median flows in Blackwater Creek and/or the removal of discharges from the system. Although the percentage reduction is larger in Blackwater Creek, the actual flow differences are small, since there is relatively little baseflow captured at this gage compared to the relatively large baseflow at the Zephyrhills gage.

Reductions in flow during the rainy season (Block 3) are comparable on a percentage basis at the two gages, 38% (Zephyrhills; Table 2-7) and 41% (Blackwater Creek; Table 2-8). Most of this difference is likely related to climatic differences between AMO wet and dry periods. The differences in flow have been expressed as inches across the watershed (see Table 2-9). The reader will note that there is an approximately 6.5-inch difference at the Zephyrhills gage based on a comparison of mean daily flows for the two AMO periods (18.03 inches minus 11.56 inches) and approximately a 4.8-inch difference at the Blackwater Creek gage (12.35 inches minus 7.56 inches). These differences approximate or exceed the average 5-inch difference in rainfall reported for the Plant City gage (1940 to 1969 average minus 1970 to 1994 average; see Table 2-10), and fall several inches short of the period differences at the St. Leo and Hillsborough River State Park rain gages.

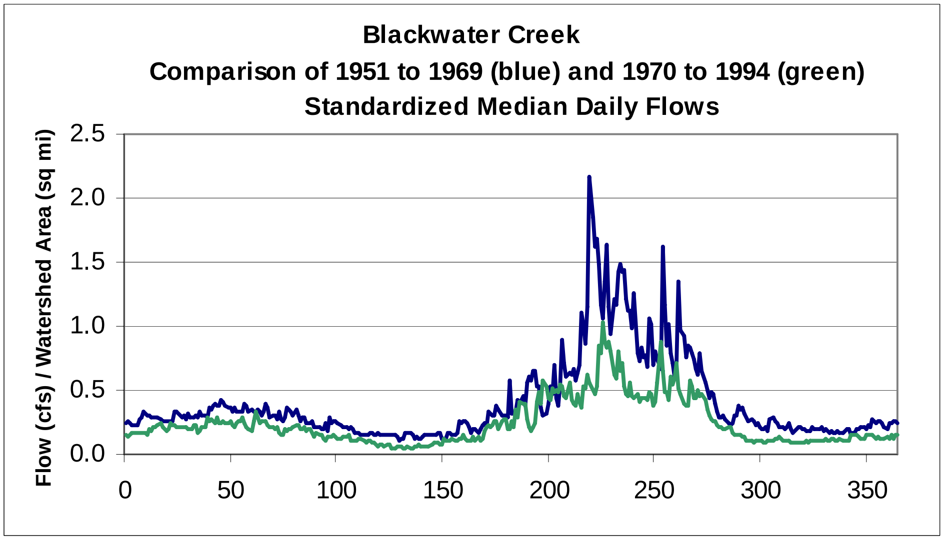
Based on a simple mass balance, it would appear that rainfall differences alone cannot account for flow differences. However, there is a question regarding how much significance should be attached to a 1 to 3 inch difference in such a rough mass balance; although admittedly a real 1 to 3 inch difference can translate to a rather large quantity of water over a 110 or 220 square mile watershed (1 inch over 110 square miles is approximately 5 mgd, and 3 inches over 220 square miles is equivalent to approximately 31 mgd). The Zephyrhills watershed area is 220 square miles compared with the watershed above the Blackwater Creek gage which is 110 square miles. This means that Zephyrhills flows are the sum of flows from the Blackwater Creek watershed plus an additional 110 square miles. The Zephyrhills gage captures most, if not all, the Floridian aquifer flow to the upper river as well. In order to approximate runoff from the 110 square miles not captured by the Blackwater Creek gage, the Blackwater Creek flows (BWCQ) were subtracted from the Zephyrhills flows (ZHGQ) over the common period of record (beginning in 1951). Additionally, 60 cfs was subtracted from each day's flow to remove the Floridian aquifer baseflow component. It is also known that under high flow conditions, the Hillsborough River actually receives some over flow (OF) from what would normally be considered part of the neighboring upper Withlacoochee River's watershed. These flows have been measured since 1960, and this high flow, because it represents an increase in watershed area on a temporary basis, was also subtracted from the Zephyrhills flow. This should give an estimate of flows from off the uppermost 110 square miles of the watershed. These flows were then converted to inches, and several comparisons made as shown in Table 2-9. The net result of all these manipulations is an estimate of mean annual flow for part of an AMO warm (wet) period (1960 to 1969) of 17.96

inches and for the AMO cool (dry) period (1970 to 1994) of 8.69 inches; a difference of 9.27 inches. If we can ignore the overflow term (which apparently we should not), we can extend the period of record back to 1951, and the difference between the AMO wet and dry periods is greater than 13 inches (24.21 inches -10.64 inches). It might be tempting to ascribe this apparent decrease to anthropogenic factors, since the rainfall deficit cannot account for the apparent flow deficit; however, we now have 10 years of record for the most recent AMO wet period (1995 to 2005) that can be examined as well. Using this time period, the mean annual inches of runoff was determined to be 15.43 inches (for ZHGQ-60cfs-BWCQ-OF). This 15.43 inches represents an increase of almost 6.75 inches between the AMO dry and wet periods; however, rain gage records indicate an increase in mean total rainfall of only 1.6 (Hillsborough River State Park) to 4 inches (Plant City) depending on the rain gage used. There are no known discharges to or withdrawals from this upper part of the watershed that can help account for these differences. These data only serve to demonstrate the difficulty in attempting to precisely balance the water budget for the upper Hillsborough and may reflect an inability to accurately measure either summer rainfall and/or high flows in this part of the watershed or the inherent weaknesses in averaging a complex process like runoff over a large watershed.

In order to proceed with the development of minimum flows and levels; however, some assumptions regarding flow will need to be made. Based on the past work related to the AMO and Florida river flow patterns (Kelly 2004) and some discussion to follow, and the apparent increase in mean annual flows over the last 10 years corresponding to an apparent shift to a wetter AMO period beginning in 1995, we assume that high flows have not changed in the upper Hillsborough River over that which might be expected due to climatic differences. We do assume, however, that Floridian aquifer baseflow has been affected by groundwater withdrawals. PHABSIM modeling was done assuming that 50 and 75% of an apparent flow decline of approximately 15 cfs at Crystal Springs is potentially due to anthropogenic groundwater withdrawals within the springshed of the upper Hillsborough River (see discussion in Section 2-5).

Table 2-7. Comparison of changes in median and mean daily flows for the Hillsborough River near Zephyrhills gage for two time periods (1940 to 1969 and 1970 to 1994). Changes are expressed for the entire annual cycle and for three seasonal flow "blocks" as discussed in the text.

Hillsborough River near Zephyrhills					
	Block 1	Block 2	Block 3	Year	
Mean of 40 to 69 Daily Median Flow/WA:	0.42	0.55	1.24	0.76	
Mean 40 to 69 Daily Median Flow (inches)	1.06	3.56	5.69	10.30	10.30
Percentage of annual flow	10.24	34.52	55.24	100.00	
Mean of 70 to 99 Daily Median Flow/WA:	0.36	0.45	0.76	0.54	
Mean 70 to 94 Daily Median Flow (inches)	0.91	2.93	3.50	7.34	7.34
Percentage of annual flow	12.35	39.92	47.73	100.00	
Mean of 40 to 69 Daily Mean Flow/WA:	0.68	0.93	2.24	1.33	
Mean of 40 to 69 Mean Daily Flow in inches	1.69	6.06	10.28	18.03	18.03
Percentage of annual flow	9.39	33.63	56.98	100.00	
Mean of 70 to 94 Daily Mean Flow/WA:	0.48	0.69	1.28	0.85	
Mean of 70 to 94 Mean Daily Flow in inches	1.20	4.48	5.88	11.56	11.56
Percentage of annual flow	10.38	38.72	50.89	100.00	
Percent Change between periods	Block 1	Block 2	Block 3	Year	
40 to 69 versus 70 to 94 Median Daily Flows	14.10699	17.61346	38.43797	28.75778	
40 to 69 versus 70 to 94 Mean Daily Flows	29.13372	26.18243	42.74688	35.89827	



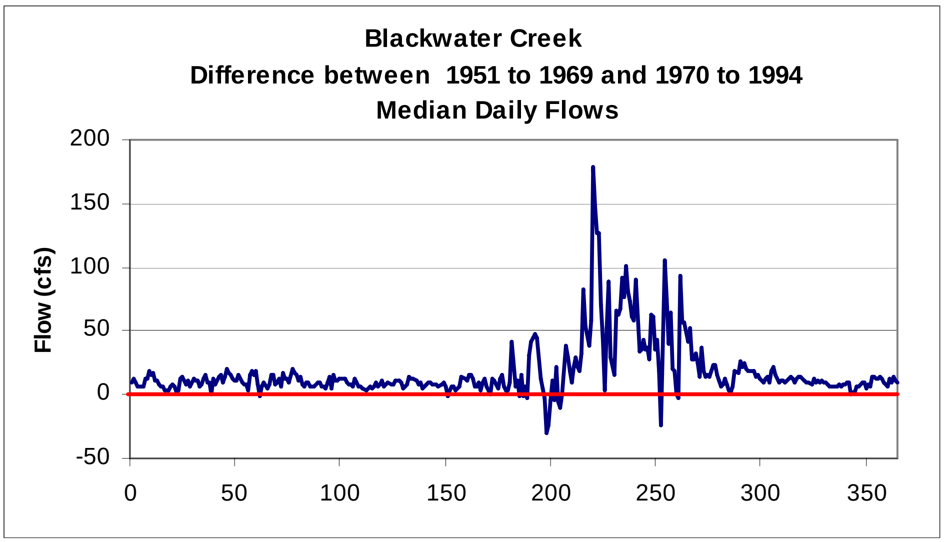


Figure 2-25. Comparison of median daily flows for the Hillsborough River near Zephyrhills for two time periods (1940 to 1969 and 1970 to 1994).

Table 2-8. Comparison of changes in mean and median daily flow for the Blackwater Creek gage for two time periods (1951 to 1969 and 1970 to 1994). Changes are expressed for the entire annual cycle and for three seasonal flow "blocks" as discussed in the text.

# USGS 02302500 BLACKWATER CREEK NEAR KNIGHTS FL					
	Block 1	Block 2	Block 3	Year	
Mean of 40 to 69 Daily Median Flow/WA:	0.18	0.26	0.72	0.40	
Mean 40 to 69 Daily Median Flow (inches)	0.44	1.70	3.31	5.46	5.46
Percentage of annual flow	8.08	31.20	60.72	100.00	
Mean of 70 to 99 Daily Median Flow/WA:	0.10	0.17	0.42	0.24	
Mean 70 to 94 Daily Median Flow (inches)	0.25	1.09	1.94	3.28	3.28
Percentage of annual flow	7.73	33.31	58.96	100.00	
Mean of 40 to 69 Daily Mean Flow/WA:	0.53	0.61	1.55	0.91	
Mean of 40 to 69 Mean Daily Flow in inches	1.31	3.95	7.09	12.35	12.35
Percentage of annual flow	10.62	31.98	57.40	100.00	
Mean of 70 to 94 Daily Mean Flow/WA:	0.26	0.38	0.96	0.56	
Mean of 70 to 94 Mean Daily Flow in inches	0.66	2.49	4.42	7.56	7.56
Percentage of annual flow	8.72	32.89	58.38	100.00	
Percent Change between periods	Block 1	Block 2	Block 3	Year	
40 to 69 versus 70 to 94 Median Daily Flows	42.40	35.73	41.54	39.80	
40 to 69 versus 70 to 94 Mean Daily Flows	49.68	36.99	37.70	38.74	

Table 2-9. Approximate runoff in inches from the watershed above the Zephyrhills (ZHGQ) and Blackwater Creek (BWCQ) gages and for the area above the Zephyrhills gage not in the Blackwater Creek watershed after correcting for an estimated 60 cfs of Floridian aquifer baseflow and for the periodic overflow (OF) of water from the Withlacoochee River watershed. Numbers in blue represent the difference obtained by subtracting the lower number from the number above.

Period	Zephyrhills Gage (ZHGQ) 220 sq miles		Blackwater Creek Gage (BWCQ) 110 sq miles		ZHGQ-60cfs-BWCQ 110 sq miles		ZHGQ-60cfs-BWCQ-OF 110 sq miles	
1940 to 1969	18.03							
1951 to 1969	18.35		12.35		24.21			
1960 to 1969	17.31		11		22.14		17.96	
		5.75		3.44		11.50		9.27
1970 to 1994	11.56		7.56		10.64		8.69	
		-4.2		-4.12		-8.61		-6.74
1995 to 2005	15.76		11.68		19.25		15.43	

Table 2-10. Comparison of mean annual rainfall at three gage sites in the Hillsborough River watershed for different time periods.

Period	Mean ZHQ	Median ZHQ	Minimum ZHQ	Maximum ZHQ	StLeoRainfall	PCRainfall	HRSPRainfall
1940 to 2005	246	126	64	2424	55.5	53.8	54.0
1940 to 1969	292	144	71	2893	56.3	55.8	55.0
1951 to 1969	297	155	76	2680	54.5	56.2	55.8
1960 to 1969	279	138	78	2857	54.2	54.0	56.2
1970 to 1994	187	108	58	1634	54.4	50.9	52.8
1995 to 2005	257	116	55	2941	56.1	54.8	54.4

The Kendall's tau test (Table 2-11) has often been used to test for monotonic trends in flow as described in Kelly (2004) and reiterated later in this report. This analytical approach was repeated here for various percent exceedence flows for the Zephyrhills gage. Periods tested were based on the complete period of record and on periods consistent with warm (wet) and cool (dry) AMO periods (1940 to 1969 – wet; 1970 to 1994 – dry; 1995 to 2004 – wet). These results were interpreted in consideration of Mann-Whitney test results shown in Table 2-12. The Mann-Whitney confirmed a step-trend consistent with changes in the AMO as described in Kelly (2004). Taken together these results generally indicate a step change in flows from one AMO period to another with one important exception. The exception is a decrease in low flows (best approximated by 95% exceedance flow). These results may be an indication of an anthropogenic decrease presumably due to groundwater withdrawals. It is interesting to note, as well, that the difference in medians at the 95 to 75% exceedance flows between periods (see Table 2-11) is on the order of 12 to 15 cfs. These results further support the observation of a 15 cfs decrease in Floridian aquifer baseflow that is at least in part attributable to an anthropogenic rather than climatic factor. Median and mean monthly flows at the Zephyrhills gage are compared graphically for the multidecadal time periods tested in Figure 2-26.

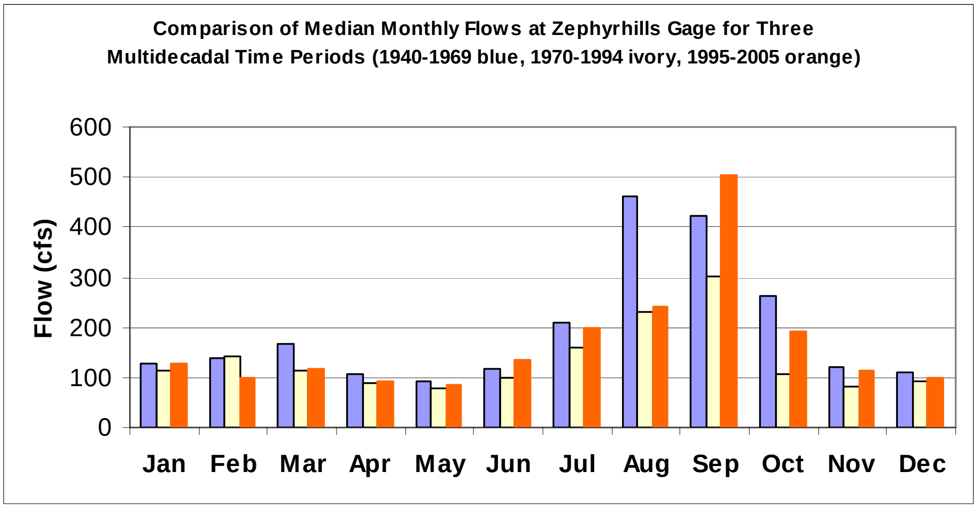
Table 2-11. Results of Kendall's tau analysis of various percent exceedance flows for the Hillsborough River near Zephyrhills gage for different time periods. Values shaded in yellow represent statistically significant (p<0.1) decreasing trends and those shaded in blue represent statistically significant increasing trends.

Kendall Tau Analysis of Zephyrhills % Exceedance Flow Data

Period Tested	% Exceedance	Mean	Median	corr_val	p_value	intercept	slope
1939 to 2004							
	95	70	70	-0.2098	0.0129	607.455	-0.2727
	90	75	75	-0.1706	0.0432	568.125	-0.2500
	75	89	85	-0.1608	0.0568	587.794	-0.2549
	50	126	121	-0.1226	0.1469	748.114	-0.3182
	30	209	186	-0.1128	0.1822	1425.86	-0.6286
	10	258	215	-0.1040	0.2192	1895.28	-0.8519
1939 to 1969							
	95	78	75	0.2598	0.0456	-1321.57	0.7143
	90	83	79	0.2966	0.0222	-1484.6	0.8000
	75	98	95	0.2575	0.0475	-1493.53	0.8125
	50	144	127	0.1963	0.1337	-0.481481	0.8889
	30	251	194	0.0598	0.6555	-1543.33	0.8889
	10	660	548	0.0161	0.9148	-2441.74	1.5294
1970 to 1994							
	95	64	62	-0.3000	0.0373	1658.61	-0.8056
	90	69	70	-0.2100	0.1470	1391.33	-0.6667
	75	82	80	-0.1633	0.2619	982.911	-0.4556
	50	108	103	0.0133	0.9441	-29.1333	0.0667
	30	162	141	-0.0234	0.8885	768.633	-0.3167
	10	385	370	-0.0200	0.9070	1640.51	-0.6410
1995 to 2004							
	95	63	60	0.1091	0.6962	-2340	1.2000
	90	68	66	0.0545	0.8763	-2134	1.1000
	75	81	82	0.0909	0.7555	-1473.56	0.7778
	50	116	121	0.0727	0.8148	-2323.44	1.2222
	30	203	189	-0.0364	0.9378	1300.11	-0.5556
	10	574	543	0.0182	1.0000	-3012.56	1.7778

Table 2-12. Mann-Whitney test for significant differences in median flows between various time periods.

Mann-Whitney Test of Zephyrhills % Exceedance Flow Data				
	1939 to 1969	**greater than**	**1970 to 1994**	Significance level
95% Exceed	median = 75		median = 62	0.0012
90% Exceed	median = 79		median = 70	0.0029
75% Exceed	median = 95		median = 80	0.0049
50% Exceed	median = 127		median = 103	0.0033
30% Exceed	median = 194		median = 141	0.0084
10% Exceed	median = 548		median = 370	0.0094
	1939 to 1969	**not equal**	**1995 to 2004**	
95% Exceed	median = 74.5		median = 60	0.0852
90% Exceed	median =79		median = 66	0.1224
75% Exceed	median = 94.5		median = 82	0.1334
50% Exceed	median = 127		median = 121	0.2895
30% Exceed	median = 194		median = 189	0.5464
10% Exceed	median = 548		median = 543	0.8368



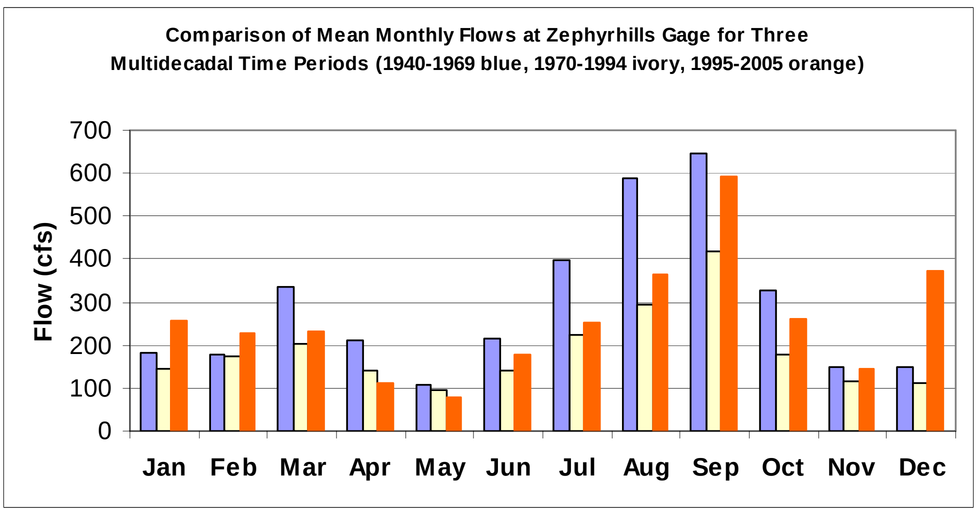


Figure 2-26. Comparison of median and mean monthly flows as measured at the Hillsborough River near Zephyrhills gage for three multidecadal time periods.

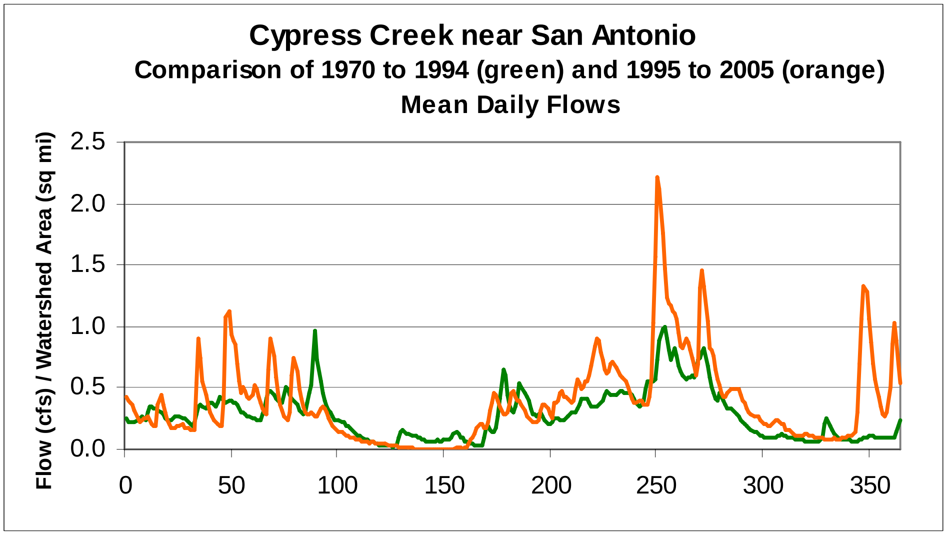
2.4.3.3 Cypress Creek Flows

The MFLs for the upper Hillsborough River are being set at the Morris Bridge gage, and as a result do not capture Cypress Creek flows; however, it is presumed that Cypress Creek flows will benefit from the recovery strategy already in place for the Northern Tampa Bay area as wellfield withdrawals are reduced to 90 mgd by 2010. In addition, it was not possible to evaluate Cypress

Creek flows relative to AMO periods, since flow records at the Cypress Creek near San Antonio and at the Cypress Creek near Sulphur Springs gages did not begin until the mid-1960's. Nevertheless, Cypress Creek flows were examined in an effort to better understand flows in the upper watershed.

Although the previous AMO wet cycle (1940 to 1969) could not be evaluated due to insufficient data, the most recent wet cycle which presumably began in 1995 is contrasted with the 1970 to 1994 dry period. This comparison for the Cypress Creek gage site near San Antonio is summarized in Figure 2-27 and Table 2-13. Based on AMO period medians, there has been essentially no change in median flows of this watershed, although mean annual flow in the more recent period has increased by approximately 1.5 inches. Similar results were observed for the Cypress Creek gage site near Sulphur Springs (Figure 2-28; Table 2-14). Again there was little change between period median daily flows (3% increase), but a two-inch increase (32%) in mean daily flows. These results indicate an increase in wet season flows between the dry to wet AMO periods, but no change in flows for the remainder of the year.

Figure 2-29 presents a slightly different approach by evaluating median daily flows on a decadal rather than a multidecadal basis. Two decades have been highlighted in these two figures; the decade of the 1990s and the partial decade of 2000-2005. While it is difficult to draw conclusions on such a small part of the data set, it is concluded that the flows were greatly diminished at both gage sites during most of the 1990s particularly at the upper gage site, where the median daily flow was near zero for most of the year. Two observations can be made. First, the median daily flows for the partial decade of 2000-2005 during the rainy season equaled or exceeded those of the decades of the 70s and 80s, a considerable improvement over the 90s. Second that the median daily flows for the first several months of the calendar year during the 2000-2005 are still depressed relative to flows that occurred in the 60s, 70s and 80s.



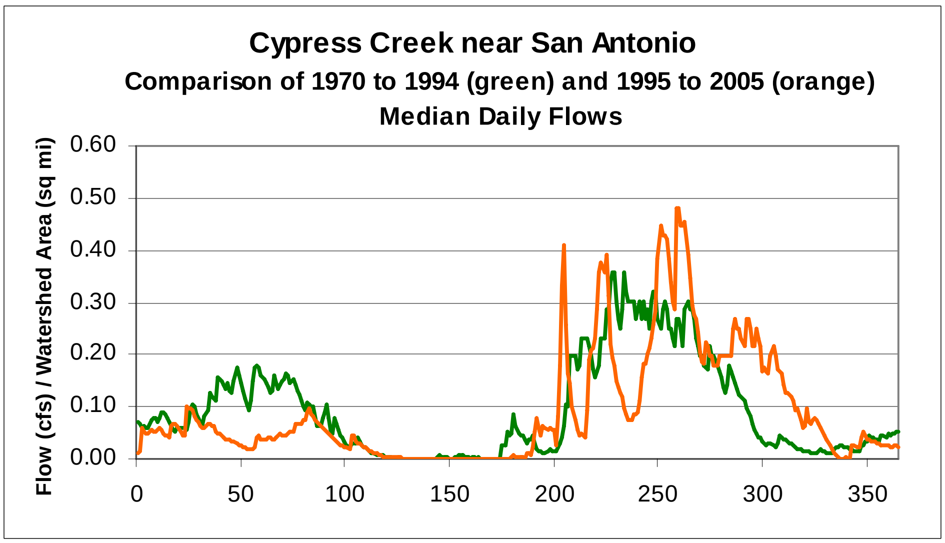
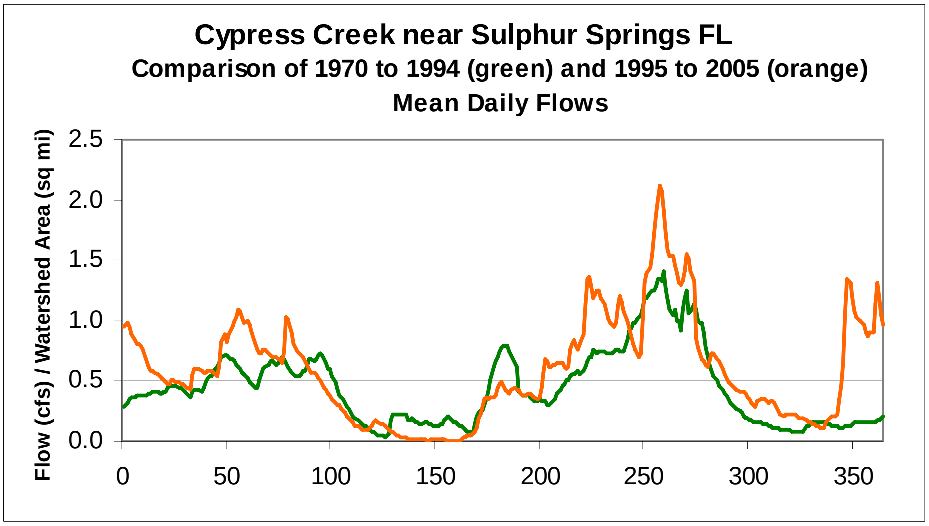


Figure 2-27. Comparison of mean and median daily flows for two time periods – 1970 to 1994 (green) and 1995 to 2005 (orange) for the Cypress Creek near San Antonio gage site.

Table 2-13. Comparison of changes in mean and median daily flow for the Cypress Creek at San Antonio gage for two time periods (1970 to 1994 and 1995 to 2005). Changes are expressed for the entire annual cycle and for three seasonal flow "blocks" as discussed in the text.

# USGS 02303400 CYPRESS CREEK NEAR SAN ANTONIO FL					
	Block 1	Block 2	Block 3	Year	
Mean of 1970 to 1994 Daily Median Flow/WA:	0.00	0.07	0.17	0.09	
Mean 1970 to 1994 Daily Median Flow (inches)	0.01	0.46	0.80	1.27	1.27
Percentage of annual flow	0.79	36.54	62.68	100.00	
Mean of 1995 to 2005 Daily Median Flow/WA:	0.00	0.06	0.19	0.09	
Mean 1995 to 2005 Daily Median Flow (inches)	0.01	0.36	0.87	1.23	1.23
Percentage of annual flow	0.44	29.35	70.21	100.00	
Mean of 1970 to 1994 Daily Mean Flow/WA:	0.09	0.24	0.44	0.28	
Mean of 1970 to 1994 Mean Daily Flow in inches	0.22	1.58	2.00	3.79	3.79
Percentage of annual flow	5.70	41.66	52.64	100.00	
Mean of 1995 to 2005 Daily Mean Flow/WA:	0.07	0.34	0.61	0.38	
Mean of 1995 to 2005 Mean Daily Flow in inches	0.17	2.21	2.79	5.18	5.18
Percentage of annual flow	3.38	42.76	53.86	100.00	
Percent Change between periods		Block 1	Block 2	Block 3	Year
1940 to 1969 versus 1970 to 1994 Median Daily Flows		45.67819	21.9994	-8.74414	2.916466
1940 to 1969 versus 1970 to 1994 Mean Daily Flows		19.159	-40.05367	-39.63616	36.45818



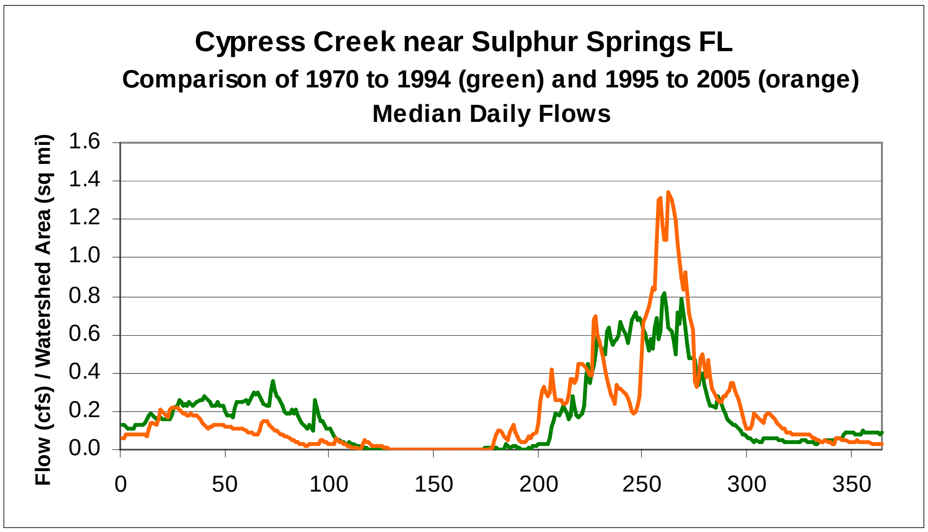
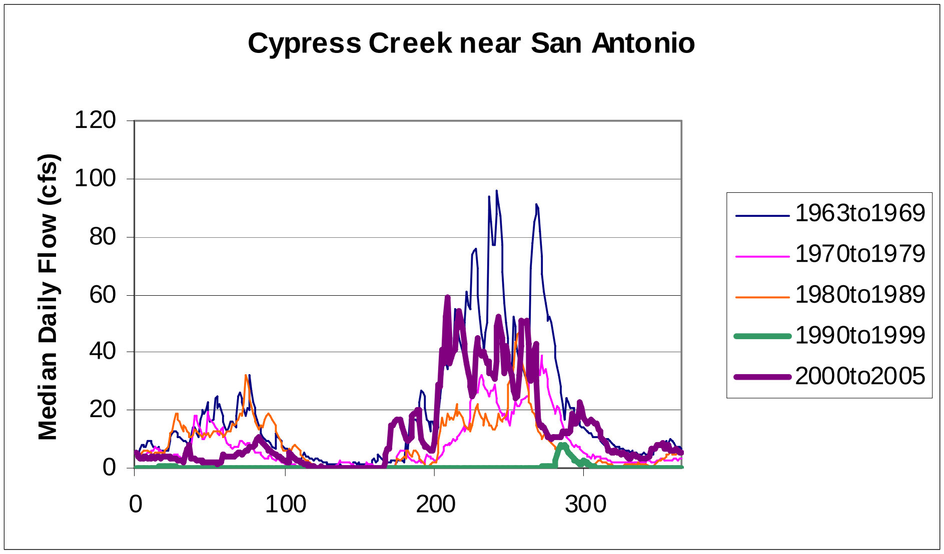


Figure 2-28. Comparison of mean and median daily flows for two time periods – 1970 to 1994 (green) and 1995 to 2005 (orange) for the Cypress Creek near Sulphur Springs gage site.

Table 2-14. Comparison of changes in mean and median daily flow for the Cypress Creek near Sulphur Springs gage for two time periods (1970 to 1994 and 1995 to 2005). Changes are expressed for the entire annual cycle and for three seasonal flow "blocks" as discussed in the text.

# USGS 02303800 CYPRESS CREEK NEAR SULPHUR SPRINGS FL					
	Block 1	Block 2	Block 3	Year	
Mean of 1970 to 1994 Daily Median Flow/WA:	0.00	0.14	0.33	0.18	
Mean 1970 to 1994 Daily Median Flow (inches)	0.01	0.92	1.50	2.43	2.43
Percentage of annual flow	0.36	37.81	61.82	100.00	
Mean of 1995 to 2005 Daily Median Flow/WA:	0.01	0.09	0.41	0.18	
Mean 1995 to 2005 Daily Median Flow (inches)	0.01	0.62	1.88	2.51	2.51
Percentage of annual flow	0.58	24.51	74.91	100.00	
Mean of 1970 to 1994 Daily Mean Flow/WA:	0.16	0.37	0.71	0.45	
Mean of 1970 to 1994 Mean Daily Flow in inches	0.39	2.42	3.25	6.06	6.06
Percentage of annual flow	6.49	39.92	53.59	100.00	
Mean of 1995 to 2005 Daily Mean Flow/WA:	0.08	0.59	0.87	0.59	
Mean of 1995 to 2005 Mean Daily Flow in inches	0.20	3.84	3.98	8.02	8.02
Percentage of annual flow	2.45	47.93	49.63	100.00	
Percent Change between periods	Block 1	Block 2	Block 3	Year	
1940 to 1969 versus 1970 to 1994 Median Daily Flows	-64.05675	33.00699	-25.23164	-3.350594	
1940 to 1969 versus 1970 to 1994 Mean Daily Flows	50.04785	-58.81543	-22.51164	-32.29902	



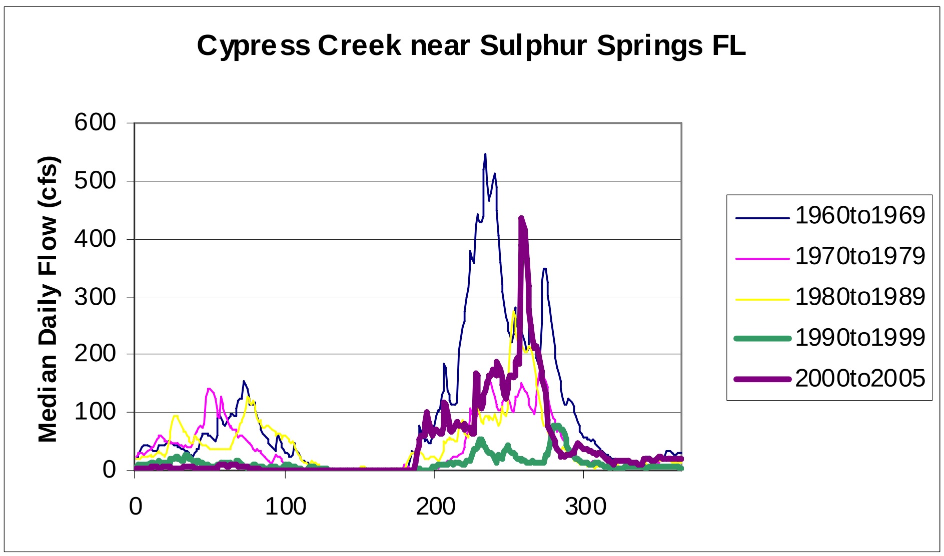


Figure 2-29. Comparison of decadal median daily flows for two gage sites on Cypress Creek.

2.4.3.4 Step Trend in River Flows

Kelly (2004) argued, similarly to McCabe and Wolock (2002), that there was a step change in river flow volumes related to climatic change associated with the Atlantic Multidecadal Oscillation (AMO). This is shown graphically for the Peace River at Arcadia, FL gage site in Figure 2-30. The upper panel of the figure shows the results of a Kendall's tau regression of mean annual flows at the site versus time for the period 1940 to 1999. The Kendall's tau p-value was 0.0269 with a slope of –8.825 cfs/yr indicating a statistically significant declining trend. However, using 1970 as a break-point and repeating the analysis for the periods from 1940 to 1969 and 1970 to 1999 (periods corresponding to warm and cool-water phases of the AMO) indicated that there were no significant trends for either period. As can be seen in the middle panel of Figure 2-30, there was not a statistically significant trend in mean annual flows for the period 1940 to 1969; p = 0.8028, slope = –1.947. In the lower panel, Kendall's tau regression for the period 1970 to 1999 also showed no significant trend; p = 0.5680, slope = 3.759. A Mann-Whitney test for differences between mean annual flows for the two multidecadal times periods indicated that flows at the Arcadia gage site were significantly greater (p=0.0035) during the earlier period (1940 to 1969) as compared to the more recent period (1970 to 1999). Similar results were found for other area rivers and are noted (Tables 2-15 and 2-16), providing evidence for a step change in Peace River flows rather than a monotonic trend as suggested by Hammett (1990). To paraphrase slightly McCabe and Wolock (2002), the identification of an abrupt decrease in peninsular Florida streamflow rather than a gradual decreasing trend is important because the implications of a gradual trend is that the trend is likely to continue into the future whereas the interpretation of a step change is that the climate system has shifted to a new regime that will likely remain relatively constant until a new shift or step change occurs.

A similar sort of analysis using annual flow data was repeated for the Hillsborough River near Zephyrhills gage similar to that done for numerous rivers analyzed previously (Kelly 2004), except that time periods were defined using slightly different breakpoints for AMO phases. There was an apparent shift from an AMO cool period to a warm period beginning in about 1995, and since approximately 10 years worth of data were available for the most recent AMO phase, data were analyzed using the following AMO periods: 1939 to 1969, 1970 to 1994, and 1995 to 2004. Kendall's tau results are presented in Table 2-17, and Mann-Whitney results are presented in Table 2-18. For the period 1939 thru 2004, the Kendall's tau test is no longer statistically significant at p = 0.1000, although a declining trend is indicated with p=0.1534; the trend is significant for the period 1939 to 1994, however (p=0.0179). There are no trends indicated within any AMO phase tested (1939 to 1969, p=0.3954; 1970 to 1994, p=0.9814; 1995 to 2004, p=0.5915 – Table 2-17). The Mann-Whitney test was significant, however, when the 1970 to 1994 period was tested against the 1939 to 1969 period (p=0.0008) and when the 1970 to 1994 period was tested against the 1995 to 2004 period (p=0.0855) (Table 2-18). These results are consistent with a step trend between AMO periods rather than a monotonic increasing of decreasing trend in flow.

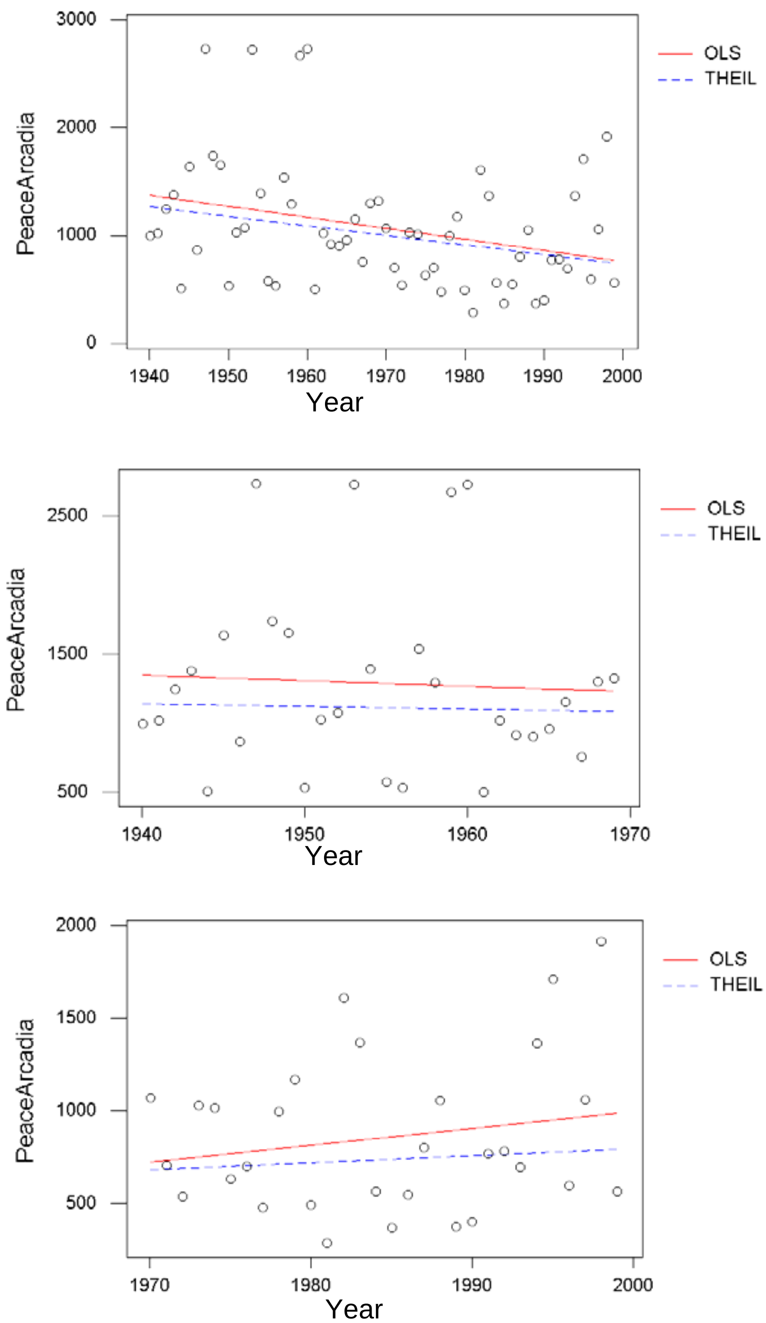


Figure 2-30. Graphical results of Kendall's tau test of mean annual flows for the Peace River at Arcadia for the period 1940 to 1999 (upper panel), 1940 to 1969 (middle panel), and 1970 to 1999 (lower panel). The red line is the Ordinary Least Squares line, and the blue line is the Kendall's tau Thiel line

Table 2-15. Results of Kendall's tau test of mean annual flows (XannQ) for selected gage sites and selected time periods. P values < 0.1 are highlighted in bold; those associated with flow decreases are shaded yellow, those that indicate flow increases are shaded blue. Table is an excerpt from a table in Kelly (2004).

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

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

Table 2-16. Results of Mann-Whitney tests for flow differences between mean annual flows at selected gage sites for two multidecadal time periods (1940 to 1969 and 1970 to 1999). P values of 0.1 or less are highlighted in bold; p values that indicate a flow decrease between periods are shaded yellow.

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

Excerpt from Kelly (2004).

Table 2-17. Kendall tau analysis of annual flow data for the Hillsborough River near Zephyrhills gage for selected time periods. P values less than 0.1 are considered statistically significant and are shaded in yellow.

Period Tested	Mean	Median	corr_val	p_value	intercept	slope
1939 to 2004	246	209	-0.1207	0.1534	1914.37	-0.8648
1939 to 1994	242	206	-0.2182	0.0179	3205.49	-1.5252
1939 to 1969	287	231	0.1097	0.3954	-3068.16	1.6884
1970 to 1994	187	187	-0.0067	0.9814	308.586	-0.0615
1995 to 2004	265	279	0.1556	0.5915	-21177	10.7310

Table 2-18. Results of Mann-Whitney test for flow differences between annual flows for the Hillsborough River near Zephyrhills gage for three time periods coinciding with different breakpoints between phases of the Atlantic Multidecadal Oscillation. P values less than 0.1 are considered statistically significant and are shaded in yellow.

			Significance level
1970 to 1994 median = 186.7	less than	1939 to 1969 median = 230.9	0.0008
1995 to 2004 median = 279.7	not equal	1939 to 1969 median = 230.9	0.9395
1970 to 1994 median = 186.7	less than	1995 to 2004 median = 279.7	0.0855

2.4.4 Benchmark Periods

Climate-based differences in flows associated with ocean warming and cooling phases of the AMO suggest that two benchmark periods should be utilized for evaluating minimum flow criteria. A benchmark period from 1940 through 1969 corresponds to a warm phase of the AMO, and is correlated with a multidecadal period of higher rainfall and increased river flows; the period from 1970 through 1999 corresponds to a cool phase of the AMO, and is correlated with a multidecadal period of lower rainfall and lower river flows.

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

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

2.4.5 Seasonal Flow Patterns and the Building Block Approach

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

For this analysis, flow records for long-term gage sites including the Myakka River near Sarasota, the Alafia River at Lithia, the Hillsborough River at Zephyrhills, the Peace River at Arcadia, and the Withlacoochee River at Croom were reviewed. The mean annual 75 and 50 % 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.

While, it is possible to use data from each river it was determined that it was important to verify that these flow patterns were regionally consistent and therefore more easily linked to climatic conditions. 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 2-19). 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 2-20).

The three flow blocks were utilized for development of minimum flows for the upper Myakka River and are evident in hydrographs of median daily flows for the USGS gage near Zephyrhills (Figure 2-31). 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 2-19. 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 2-20. 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

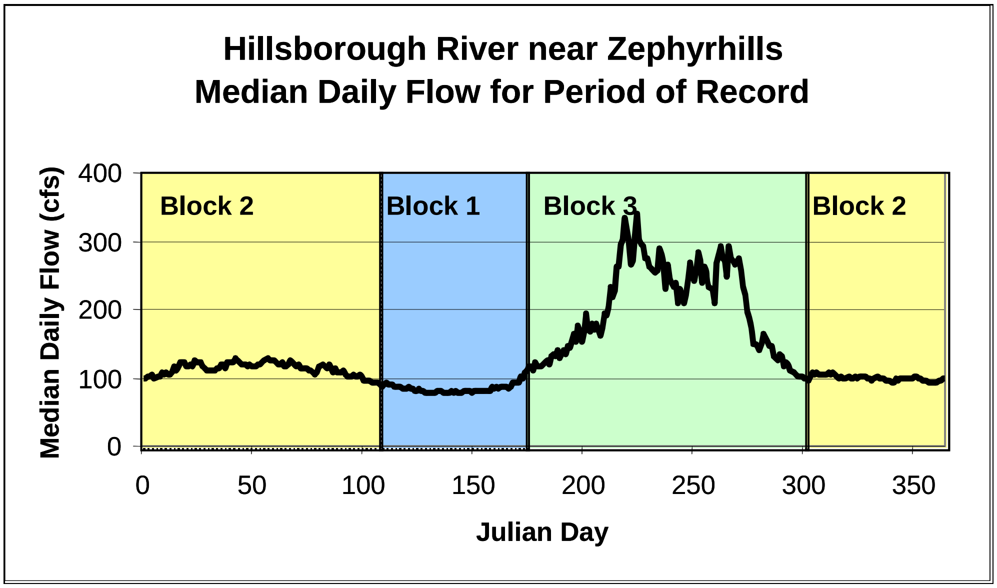


Figure 2-31. Median daily flows for 1937 through 2003 at the USGS Hillsborough River near Zephyrhills, FL Gage site and seasonal flow blocks (Blocks 1, 2 and 3) for the upper Hillsborough River.

2.5 Crystal Springs site description (taken largely from Champion and Starks 2001)

The Crystal Springs group (hereafter referred to as Crystal Springs) lies in southeastern Pasco County along the Hillsborough River. The group is comprised of a single second magnitude spring that has historically discharged 36 mgd to the Hillsborough River, and three additional springs that contribute an additional 4 mgd to the total discharge of the group. The main spring contributes a significant portion of the main river's flow, especially during the dry season.

Crystal Springs was modified in the 1940s by damming the spring run upstream of its confluence with the Hillsborough River (Figure 2-32). This modification created a spring pool that quickly became a recreational attraction. The main spring remained a popular swimming area for visitors and residents until the property was closed to the public in April 1996. A privately owned educational park is operated on the lands adjacent to the main spring. A portion of the flow from the spring is sold as bottled water.

Figure 2-32. Crystal Springs in north Hillsborough County. A dam crosses the spring run just upstream of the confluence with the Hillsborough River. **(photo M. Lopez, SWFWMD)**

2.6 Crystal Spring Flow and Assumed Anthropogenic Declines due to Withdrawals

2.6.1 Historic flow data

Crystal Springs flow is important to the upper Hillsborough River (UHR) system. This spring provides much of the base flow to the river during typical low flow months (normally Block 1; April-June). Although there are numerous small spring vents that feed the upper river in addition to Crystal Spring, flow measurements suggest that most of the Floridan groundwater contribution to the UHR is from Crystal Springs, itself. A plot of the flow data available from the USGS water quality site (i.e., flow on days when water quality samples were taken) is presented in Figure 2-33. The data suggest a monotonic decreasing trend in stream flow beginning in the early to mid-1960s.

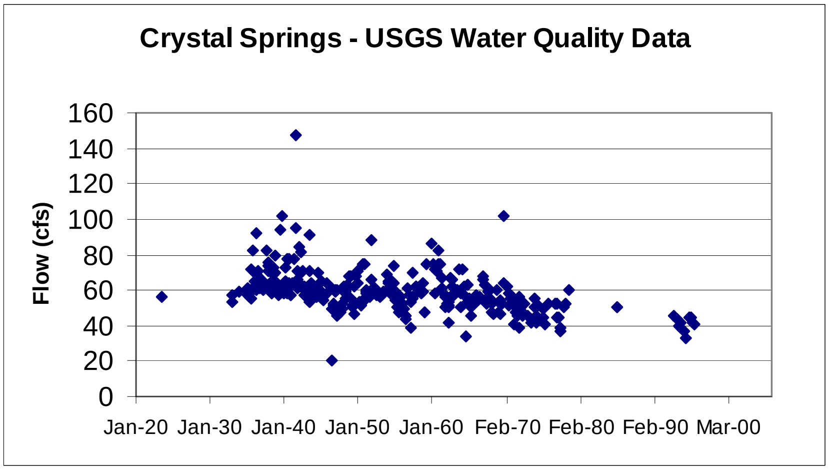


Figure 2-33. Flow data for Crystal Springs taken in conjunction with USGS water quality samples.

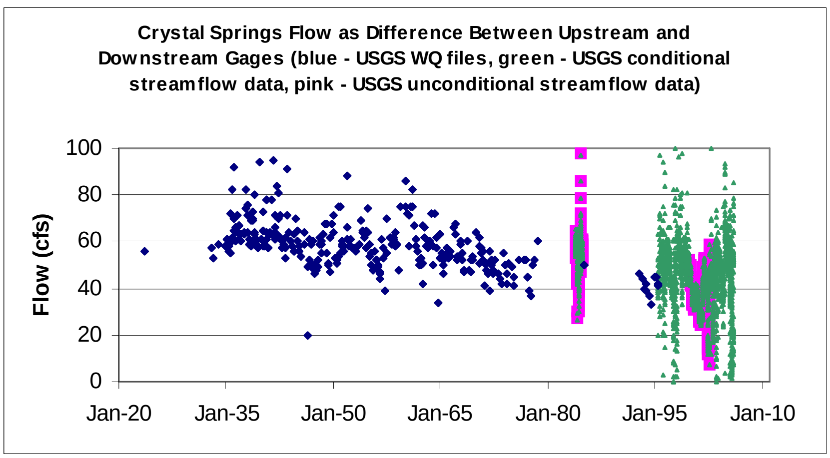


Figure 2-34. Comparison of Crystal Springs flow based on three different data sets: data from USGS water quality database (blue diamond, same data as presented in Figure 2-33); USGS conditional provisional data (green triangle); and USGS non-provisional data (pink square).

Examination of discharge data presented in the USGS's water quality file shows considerably less variability in spring measurements as compared with either conditional or non-conditional data available from the USGS's stream flow files. Since there is no defined spring run below Crystal Springs, discharge measurements are made upstream and downstream of the spring confluence with the Hillsborough River. As a result, Crystal Springs' flow is not measured directly, but is determined as the difference between downstream and upstream readings. Attempts have been made to develop a stage discharge relationship at the two gaging sites so that daily measurements of flow can be made; but when the difference is taken between the two measurements, the results can vary appreciably (see Figure 2-34, pink squares and green triangles). The USGS has indicated that at flows above 400 cfs at the upstream gage, results become unreliable because all the flow is not captured at the two gage sites.

The method of discharge calculation for Crystal Spring is inherently more uncertain than other methods such as gaged measurements from a single channel immediately downstream of a spring vent or from correlations with a nearby Upper Floridan aquifer well, which is what the USGS uses to calculate discharge for Weeki Wachee, Rainbow, and Silver Springs.

A review of the USGS flow data indicates that prior to 1965 there is a high degree of variability in the discharge measurements. An inspection of USGS data from 1937-1964 indicated that when measured stream flow at the station above Crystal Spring was compared with the datum elevation, there was a significant deviation of recorded flow when the datum elevation exceeded 15 ft – with values varying by as much as 80 cfs with the same datum elevation. Upstream river flow graphed against calculated spring flow shows a high degree of variability when spring discharge is above 55 cfs. A plot of Crystal Springs discharge record shows about 75 percent of all measured discharge was above 55 cfs prior to 1965. Post-1965, recorded discharge above 55 cfs makes up just 15 percent of the values. An examination of the USGS comments from the 1937-1964 period shows that discharge was measured at over *20 different locations* from the gaged sites. In addition, several comments in 1948 indicated that all previous river flow measurements included multi-channel flow but thereafter they did not. There were also two datum elevation changes that occurred in 1937 and 1964 which suggests new rating curves and perhaps relocation of the stream flow measuring stations.

Although not shown in the above graphic, there are days using the difference method and daily flow estimates where the resultant flow is a negative number. We conclude that flow data for Crystal Springs is not as reliable as at most USGS sites, and have questions about the accuracy of the water quality associated flow record. Assuming that the center of concentration of data points is fairly representative of spring flow, it appears that for the period of record flow from Crystal Springs has declined from a median of about 60 cfs to 45 cfs based on recent measurements; this equates to approximately a 25% flow decline.

As an aside, considering the difficulty of measuring flow from Crystal Springs, and the fact that there is a direct withdrawal for potable use, a more direct measurement of spring flow is needed.

2.6.2 Examining the Historic Flow Record Based on Comparisons with Other Systems

The daily flow record for Crystal Springs based on rating curves developed upstream and downstream of the springs is not considered adequate for assessing spring flow trends. Flow analysis for minimum flow development was based on differences between actual measured flow upstream and downstream of the main spring head. Ultimately, District staff relied on field notes taken by the USGS prior to 1970 to generate the flow record that was analyzed. Data sheets used and the flow records developed are included in the appendices (Median Daily Flows – MDQ Section).

Figure 2-35 shows a plot of the mean and median annual flow for Crystal Springs based on the set of direct flow measurements collected from 1935 to present. It is generally expected that for springs, the mean and median flow should be essentially equal. This was not the case in the early part of the flow record for Crystal Springs, and suggests that there may be problems with flow measurements collected prior to 1945 or 1950. In addition, it is known that structural alterations and changes were made to the system in the mid-1940's (e.g., construction of a structure around the spring pool, and possible dynamiting of the vent) that could have affected spring flow.

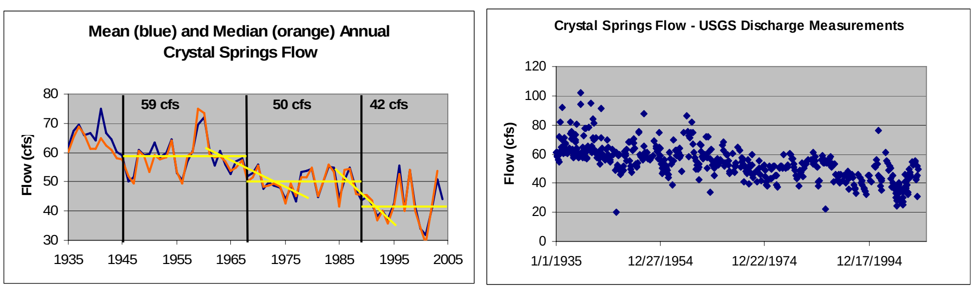


Figure 2-35. (a) Comparison of mean and median annual flow from Crystal Springs for the period of record based on USGS flow measurements made upstream and downstream of the confluence of the main spring and the river. Horizontal yellow lines indicate the mean/median flow for the period bracketed by vertical black lines. The diagonal yellow lines were drawn to highlight two periods of relatively steep flow decline. (b) Crystal Springs raw data used to generate annual mean and medians in panel (a).

2.6.3 Comparisons of Spring Flows using Simple Linear Regression Analysis

Since comparable periods of record data were available for Silver River, Rainbow River, Weeki Wachee River and Crystal Springs, a number of simple regressions were run, on the hypothesis that climatic variability was similar over the area, flows between springs should trend the same and that mean annual flows would be correlated. It was also assumed that as anthropogenic factors began to exert a greater influence over flows, the correlation between flows would weaken or diminish over time relative to any anthropogenic affect. In other words, some degree of correlation between flows was expected, and it was expected that the degree of correlation would lessen over time due to disproportionately increasing anthropogenic stresses on each system. A large number of regressions were examined in an exploratory manner in an effort to find a period in the early record that produced fairly good regressions based on inspection of coefficient of determination (R^2) values. For example, for the period 1935 to 1955 there was essentially no correlation between Crystal Springs flow and any of the other three springs examined (Weeki Wachee, Rainbow and Silver) (Figure 2-36). It is interesting to note, that for this period, the earliest available, none of the correlations between Crystal Springs and the other springs produced an R^2 greater than 0.04, and in every case the slope of the regression was negative. This period (1935 to 1955) includes the period when structural changes were made at Crystal Springs, and it is believed that the lack of correlation may be attributable to structural alterations at Crystal Springs around 1945.

For the period 1945 to 1965, regressions between Crystal Springs flow and the other springs improved; although the R^2 values were relatively low (ranging from 0.15 with Rainbow to 0.34 with Weeki Wachee) (Figure 2-37). The period 1935 to 1965 (Figure 2-38) is shown for completeness; however, the r^2 values were even lower than for the period 1945 to 1965. The period 1945 to 1965 would seem to be a relatively good period to expect fairly high correlations between the springs since groundwater withdrawals in the springshed were probably minimal for most of the period. It was in the 1960s, however, that groundwater withdrawals for citrus irrigation began to increase dramatically (Weber and Perry 2006); further, it has been proposed by some that phosphate withdrawals to the south may have led to declines in the potentiometric surface.

Regressions for the period 1965 to 1995 (Figure 2-39) are informative for at least one reason. During this time, groundwater usage increased significantly, especially in the springshed of Crystal Springs. With respect to Crystal Springs flow, it has been argued that citrus irrigation accounted for a significant impact in the early half of this record (i.e.,1965 to1995), while well field withdrawals had a significant and perhaps greater impact during the second half of this record (Weber and Perry 2006). Interestingly, simple regression analysis for this period indicates a higher degree of correlation between annual flows from the various springs examined as compared to earlier periods. This improved correlation is difficult to reconcile with presumably increased localized anthropogenic effects that should cause a disproportionate impact based on the proximity of anthropogenic withdrawals. The fact that mean annual flows at all the springs are apparently better correlated in the recent record despite presumed localized effects suggests a strong regional factor has been affecting discharge at the springs examined.

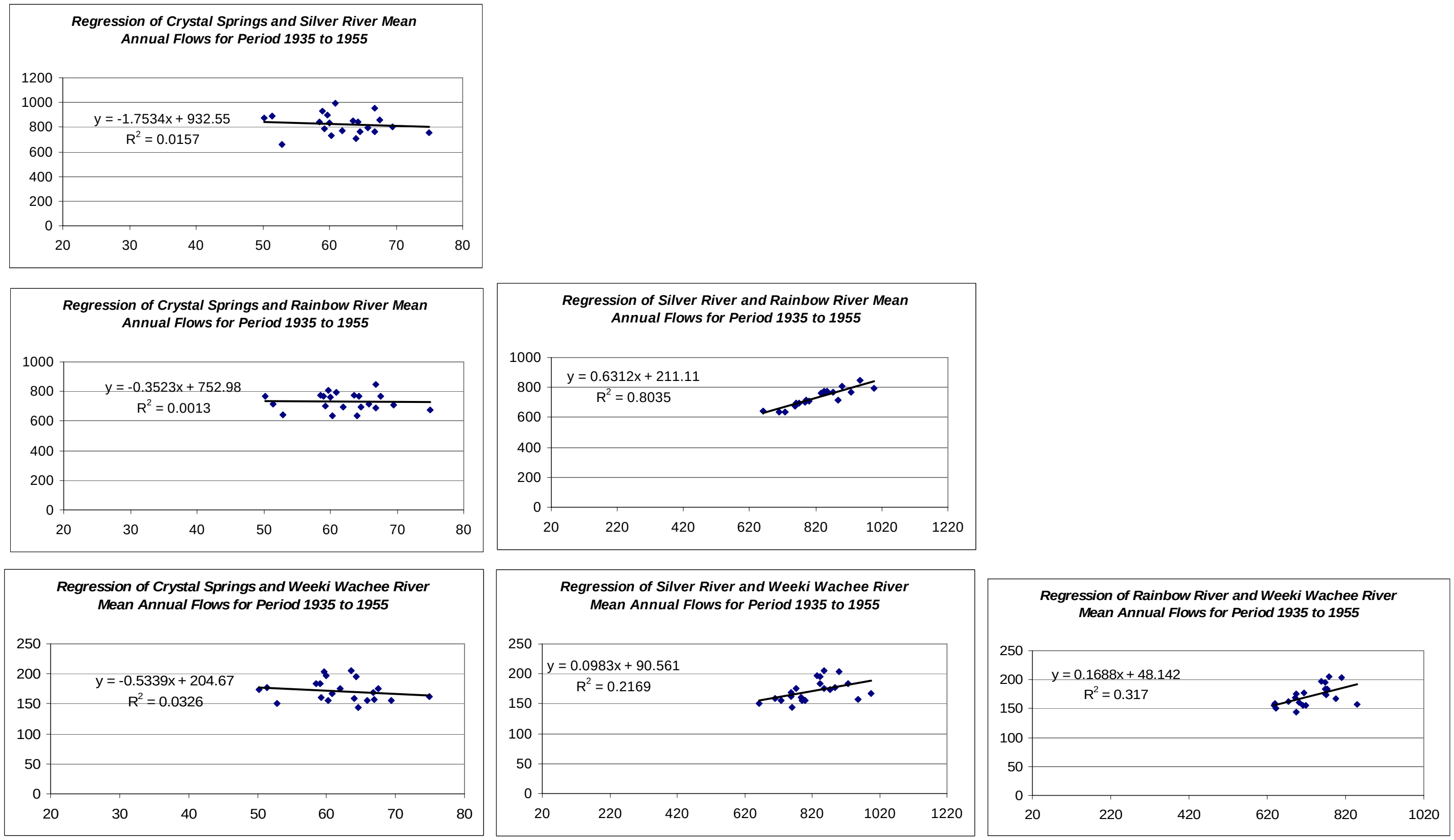


Figure 2-36. Simple regression analysis of mean annual flow for period 1935 to 1955 between various spring systems: Crystal Springs, Silver River, Rainbow River and Weeki Wachee River.

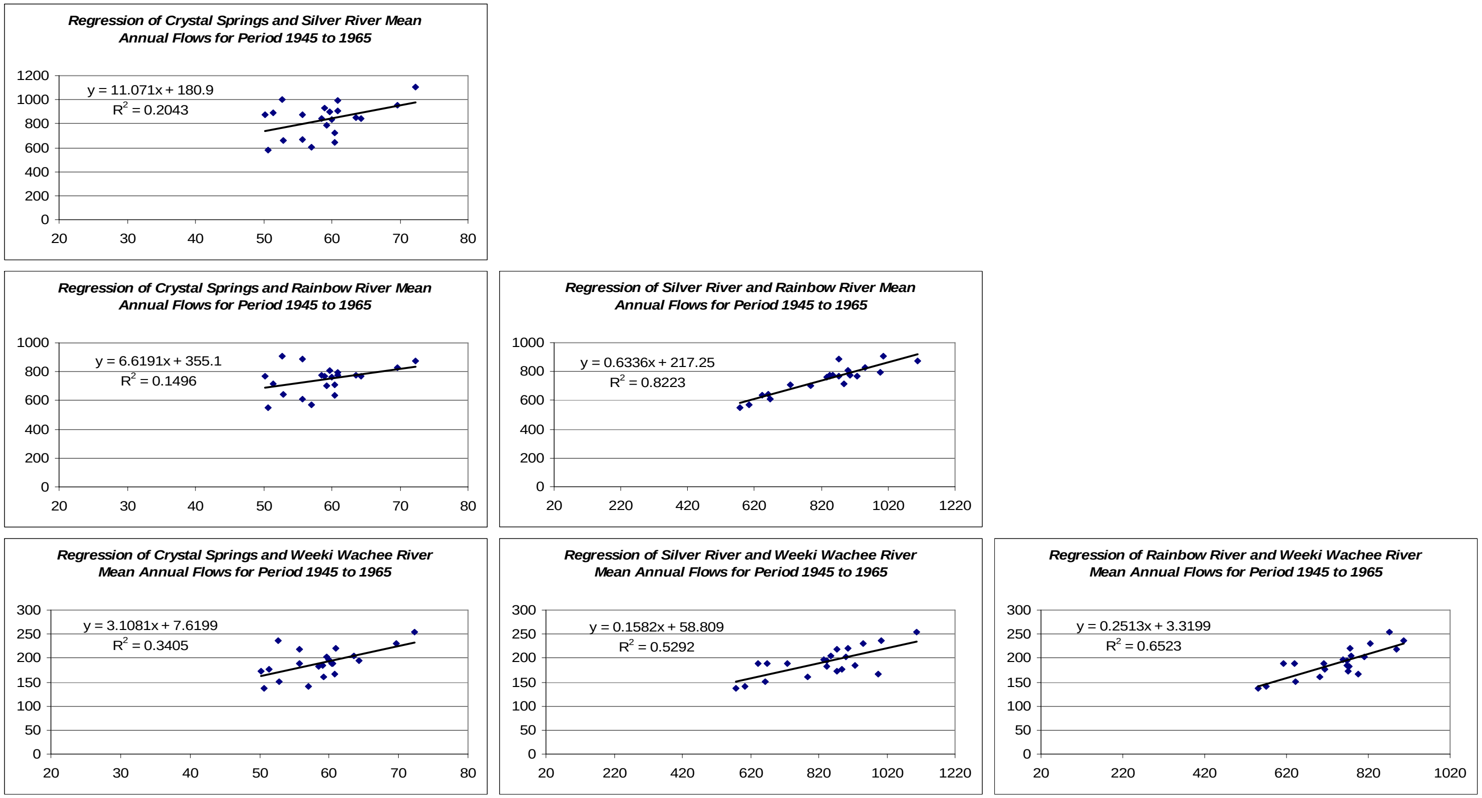


Figure 2-37. Simple regression analysis of mean annual flow for period 1945 to 1965 between various spring systems: Crystal Springs, Silver River, Rainbow River and Weeki Wachee River.

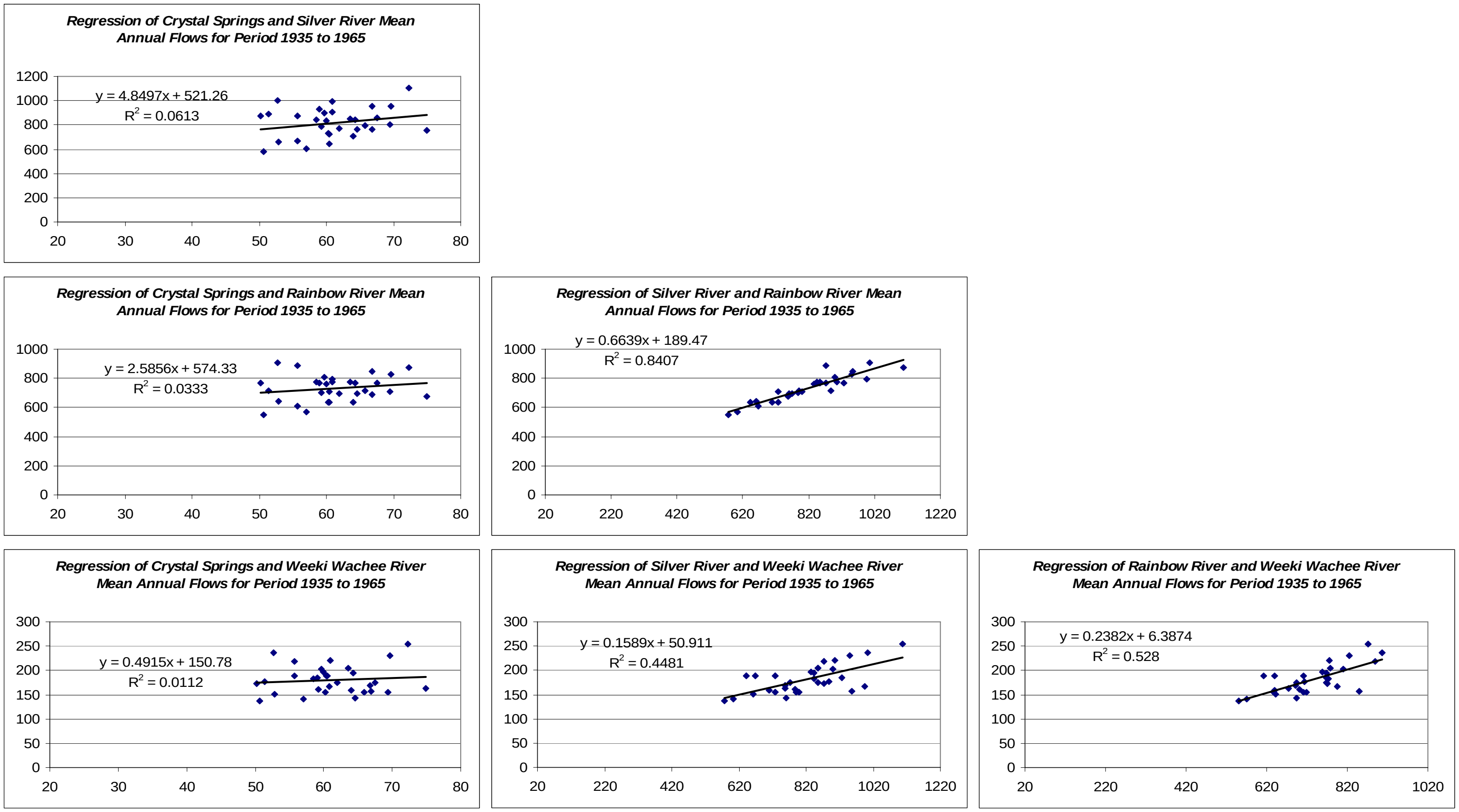


Figure 2-38. Simple regression analysis of mean annual flow for period 1935 to 1965 between various spring systems: Crystal Springs, Silver River, Rainbow River and Weeki Wachee River.

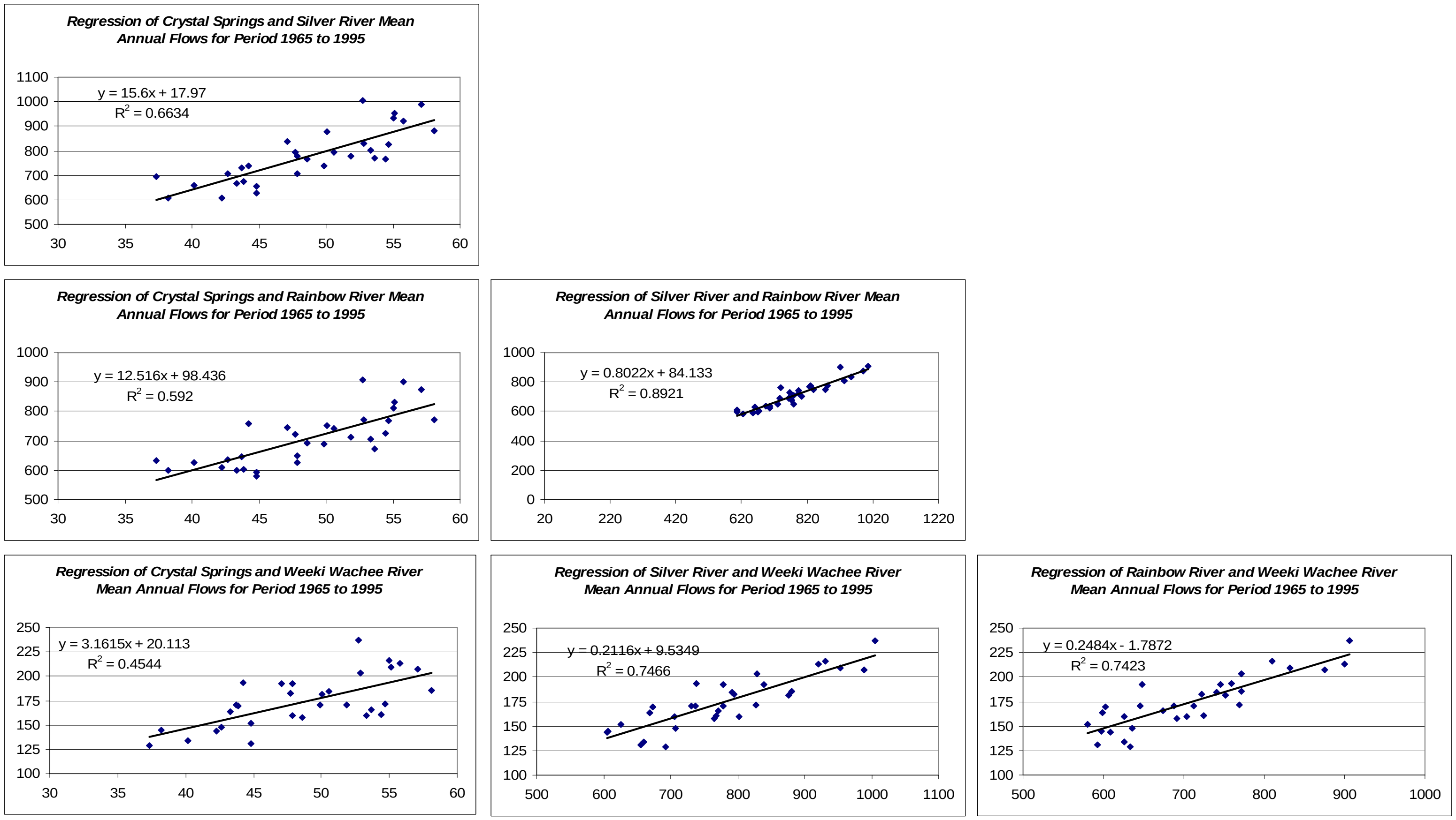


Figure 2-39. Simple regression analysis of mean annual flow for period 1965 to 1995 between various spring systems: Crystal Springs, Silver River, Rainbow River and Weeki Wachee River.

2.6.4 Estimating the Anthropogenic Percentage of Flow Declines

Crystal Springs' flow has declined over the period of record as shown in Figures 2-33 through 2-35. It is likely that some of this flow decline is anthropogenic and some is climatic. It is important to the development of MFL recommendations that we be able to estimate the amount of the flow decline that is due to anthropogenic withdrawals and the amount that is attributable to climatic variability. Weber and Perry (2001, 2006) using a number of parametric and non-parametric techniques concluded that, " the primary factor causing the spring low and baseflow declines is lowered groundwater levels caused by over-abstraction." Although Weber and Perry (2006) attributed springflow decline "primarily" to groundwater withdrawals, they did not provide a quantifiable estimate of this flow decline. In order to estimate habitat loss due to flow declines from withdrawals, it is necessary to quantify this decline. Several other approaches were used to derive a quantifiable estimate of this anthropogenic effect. Three approaches will be briefly discussed, and an estimate of flow decline using each approach will be presented. These approaches provide estimates of the percent of flow decline that is attributable to anthropogenic withdrawals that range from approximately 30 to 75%. This rather large range is at least in part attributable to the assumptions used with each approach. As will be further discussed, a 50% anthropogenic assumption was ultimately used as the basis of MFL recommendations. The three approaches used can be described as 1) modeling (using an integrated surface/groundwater model), 2) a "wavelet" filtering statistical technique, and 3) a rather simple statistical technique based on "z-score" analysis.

The mean annual flow at Crystal Springs for the period 1945 to 1965 was 58.8 cfs compared with a 1995 to 2004 mean annual flow of 43.6 cfs. The difference in flow is 15.2 cfs and corresponds to a 25.9% decline between the two periods. The anthropogenic estimate of flow decline based on the modeling approach is 4.1 to 5 cfs (approximately 30%); the estimate of flow decline based on "wavelet filtering" is 5.4 to 6.1 cfs (approximately 38%); and the estimate of flow decline based on "z-score" analyses ranged from 3.2 to 12.9 cfs (36% to 76%; Tables 2-21 and 2-22) dependent on the standardization period used.

Differences between the results of z-score and wavelet analyses are in large measure due to a major assumption made in the wavelet analyses that essentially excluded the empirical data for the period 1953 to 1963. Z-score analysis, done excluding a similar period of data (i.e., standardizing to 1965 to 1975), yielded similar results to the wavelet analysis; but standardizing to a period similar to the excluded data, yielded the highest percentage decline attributable to anthropogenic effects (i.e., 76%). The assumption regarding the reliability (suitability) of the empirical data for the period 1953 to 1963 is critical to both the wavelet analysis and z-score analysis. If these data are truly suspect, this would mean that historic flows from Crystal Springs were not 59 or 60 cfs as has been reported, but more likely 51 or 52 cfs. If the data are accurate, there was an approximate 8 to 9 cfs flow decline during this period, which could be attributed to groundwater withdrawals related largely to phosphate mining to the south (Weber, personal communication; "Phosphate industry and other pumpage in relatively close proximity to the spring increased dramatically beginning in the 1950's. Phosphate pumpage peaked about 1970 at ~300 mgd, while total Polk county withdrawals peaked about 1978 at ~400 mgd (Weber & Perry, 2006). A USGS study shows that the effects of these withdrawals encompassed Crystal Springs and the surrounding area (Stewart et al. 1971). This report indicates 5 feet or greater reduction in aquifer potentiometric levels south of Crystal Spring and 0-5 feet influence more than 20 miles north of the spring for the period 1964-69. In a follow-up USGS report, Mills and Laughlin (1976) show an additional 5 feet and greater aquifer level decline south of Crystal Springs during the period 1969 to 1975, and it can be inferred that impacts similar to those shown in Stewart et al. (1971) occurred in the area of the spring and northward.").

2.6.4.1 Standardization of Flow Records using Z-score Analysis

When examining river flows with the intent of evaluating flow declines related to climate or anthropogenic effects, it can be informative to use a paired watersheds approach since this type of analysis may be used to account for or factor-out any climatic affects. If it can be assumed that flows in one watershed are relatively free of anthropogenic impacts throughout the record, particularly in comparison to another, one watershed can be used to assess changes in the other if either of assumptions are made. If, for example, two tributaries are located in close proximity to one another in a similar hydrogeologic setting and both have comparably long flow records, changes in one can be assessed relative to the other.

A paired-watershed approach was used by Kelly et al. (2004) to evaluate climatic versus anthropogenic effects in the Peace River basin. Horse Creek and Charlie Creek , both tributaries to the Peace River, were used for the analysis. Both have flow records that began in 1950, and land-use in their watersheds is similar and has changed very little over the past few decades in comparison to other nearby watersheds. Concerns that phosphate mining might affect flows in Horse Creek were assessed looking for differences in flow off these two watersheds (i.e., yield) as the landuse in one (Horse Creek) changed with respect to the other. In order to make comparisons between two watersheds, a good predictable relationship needs to exist between historic flows, and it needs to be assumed that rainfall patterns are essentially the same across the two watersheds. The comparison is facilitated by dividing flows at a particular gage site by the upstream watershed area so that flows can be expressed on a unit area basis (e.g., cfs / square mile). If landuse changes considerably in one watershed with respect to the other, the affect of this change on hydrology can be assessed by comparing differences in yield between the two watersheds. If landuse affects hydrology, then one should expect a change in the relationship between flows based on a comparison to their historic relationship. If landuse changes have not caused a significant change in yield between the two watersheds, then it can be concluded that the landuse change in question has not appreciably affected hydrology.

We have used a similar approach to compare spring flows using a z-score standardization technique. A z-score is simply the difference between a measured value (e.g., a discharge record) and the sample mean (e.g., mean discharge for a defined period) divided by the sample standard deviation (e.g., the SD of flow measurements for a defined period). Converting spring flows (or river flows, or water well elevations) to z-scores allows a direct comparison between spring flows when the size of the springshed is not known. If it can be assumed that climate variability is essentially the same over two springsheds and if a good historic flow record is available, it might be expected that in the absence of anthropogenic effects in two springsheds, historic flows should be correlated. For example, flows for Crystal Springs, Silver River, Weeki Wachee River, and Rainbow River were converted to z-scores using the mean and standard deviations of each for the period 1935 to 1965 (Figure 2-40; z-score = [actual flow – period mean]/period standard deviation). The data were then plotted for the entire period of record with the assumption that the relationship between z-scores for the standardization period (1935 to 1965 in this case) should be maintained for other periods as long as other effects (e.g., anthropogenic withdrawals) did not vary among the period examined. As can be seen in Figure 2-42, z-scores for Crystal Springs deviate appreciably from the other springs around 1965 and stay well below the other trend lines. This variability could be taken as an anthropogenic effect except that it is known that Crystal Springs mean annual flows did not correlate well with the other springs for the standardization period used in this example (see Figure 36 to 39). Attempting to resolve this issue, a number of different standardization periods were evaluated. Silver and Rainbow Rivers showed similar z-score trends regardless of the standardization period used, and Weeki Wachee River showed fairly good agreement except when the earliest part of the record was used for standardization.

Z-score analysis was used in an attempt to quantify anthropogenic effects on spring flow. If it can be assumed that rainfall has behaved similarly across the springsheds examined, then anthropogenic factors acting disproportionately between one springshed and another should show up as departures between plotted z-sores. Referring to Table 2-21, the following example is used to explain the approach. The mean annual flow at Crystal Springs for the standardization period 1945 to 1965 was 58.8 cfs compared with a 1995 to 2004 mean annual flow of 43.6 cfs. The difference in flow is 15.2 cfs and corresponds to a 25.9% decline between the two periods; however, since rainfall between the two periods was different, some of the decline is climate related and some is not (i.e., is anthropogenic). For the values computed in Table 2-21, we assumed that Rainbow River flows were not significantly anthropogenically affected during either period (1945 to 1965 and 1995 to 2004) and that any flow difference between the two periods was related to climate[1]. In other words, the average z-score difference for Rainbow River between the two periods (1945 to 1965 versus 1995 to 2004) is assumed to be directly related to climatic (i.e., rainfall) differences between the two periods. Assuming similar climatic conditions over both springsheds, any further deviation in Crystal Springs z-scores above that exhibited by Rainbow River is taken as a measure of the anthropogenic impact on Crystal Springs flow. The average deviation of Crystal Springs z-scores from the z-scores for Rainbow River for the period 1995 to 2004 was determined by simply taking the average of the differences between the annual z-scores. This average difference, expressed as a z-score, was converted back into a flow value (cfs) by multiplying the average z-score difference by the standard deviation of Crystal Springs flow for the standardization period (i.e., 1945 to 1965). In this case, the computed flow decline attributed to an anthropogenic effect was 9.5 cfs (i.e., the average z-score difference of 1.663 for the period 1995-2004 multiplied by the Crystal Springs standard deviation for the standardization period of 1945 to 1965, which was 5.7 cfs). Since the actual difference in mean annual flows at Crystal Springs for the period 1945 to 1965 minus the mean annual flow for the period 1995 to 2004 (58.8 cfs – 43.6 cfs) was 15.2 cfs, then the anthropogenic effect amounted to 62.6% of the flow decline (9.5 cfs/15.2 cfs).

The difficultly in assessing Crystal Springs flow is in finding a period for standardization which can be considered reliable and relatively free of anthropogenic impacts. In the following analysis, we have evaluated several different standardization periods, and in an attempt to quantify the magnitude of potential anthropogenic changes between springsheds, we examined the deviation (average z-score departure in standard deviations) from a site assumed to be unanthropogenically impacted (either Rainbow River or the Sharpes Ferry Monitoring Well (which is located about 3 miles east of Silver Springs). When using Rainbow River as the standard (see Table 2-22), we compared deviations between the different standardization periods and the period 1995 to 2004. Deviations are expressed as both (1) a change in flow (cfs) with positive numbers

[1] Rainbow Springs Basin, located in eastern Levy and western Marion Counties, contains widely dispersed withdrawals of relatively low extraction. The basin is internally drained with little or no surface water runoff. The total spring basin area is approximately 640 square miles. Water budget analysis indicates average annual recharge of 15 in/yr over the Rainbow Springs Basin based on the period-of-record mean flow for Rainbow Springs of 708 cfs. Currently, about 20 mgd of groundwater is withdrawn in this basin. The amount of groundwater withdrawn equates to about 0.7 in/yr over the basin or about 4 percent of annual recharge. In addition, the USGS Mega Model predicts long term lowering in the unconfined Upper Floridan aquifer of about 0.3 feet in the Rainbow Springs Basin. This value represents a small amount of anthropogenic impact that is generally below measurement detection in regional monitor well data. Based on this the spring basin is believed to be relatively unimpacted by current withdrawals in the area.

reflecting a decrease greater than would be expected in the absence of any anthropogenic effect and (2) a percent change in flow from the standardization period mean. Had there been no anthropogenic effect and assuming no climatic differences between springsheds, we would have expected to see little or no deviation in flow between the two periods (standardization period and the period 1995 to 2004). This analysis was repeated using Sharpes Ferry Well as the control site; however, the standardization period was compared to the period 1995 to 2002 (instead of 2004) because the Sharpes Ferry Well site was abandoned after 2002 (Figure 2-45 to 2-48; Tale 2-23).

Considering both sets of analyses (Rainbow River and Sharpes Ferry as control sites), anthropogenic effects appear to account for approximately 40-75% of the flow decline at Crystal Springs, depending on the standardization period selected.

Table 2-21. Z-scores computed for two time periods (1945 to 1965 and 1995 to 2004) for mean annual flows at Crystal Springs and Rainbow River. The Z-score difference in 1995 to 2004 periods was used to estimate the anthropogenic decline at Crystal Springs, assuming that there was minimal anthropogenic effect on Rainbow River flows in both time periods.

Year	Crystal X Annual Q	Z-Score	Rainbow X Annual Q	Z-Score	Z-Score Difference
1945	59.3	0.0777	700.9	-0.4431	-0.5208
1946	50.2	-1.5086	770.7	0.2677	1.7763
1947	51.4	-1.2870	713.8	-0.3119	0.9751
1948	60.9	0.3587	794.1	0.5067	0.1480
1949	59.0	0.0367	767.2	0.2326	0.1958
1950	59.6	0.1435	810.6	0.6741	0.5305
1951	63.5	0.8220	777.0	0.3322	-0.4898
1952	58.5	-0.0623	772.8	0.2892	0.3515
1953	60.0	0.1998	759.2	0.1511	-0.0487
1954	64.4	0.9665	768.2	0.2428	-0.7237
1955	52.9	-1.0400	641.9	-1.0443	-0.0044
1956	50.6	-1.4260	551.5	-1.9652	-0.5393
1957	57.0	-0.3193	571.4	-1.7620	-1.4428
1958	60.5	0.2852	710.7	-0.3436	-0.6288
1959	69.6	1.8865	825.9	0.8300	-1.0565
1960	72.3	2.3427	872.2	1.3018	-1.0410
1961	60.9	0.3637	776.6	0.3278	-0.0358
1962	55.7	-0.5411	611.7	-1.3523	-0.8112
1963	60.5	0.2914	639.0	-1.0738	-1.3652
1964	55.8	-0.5331	890.3	1.4864	2.0194
1965	52.8	-1.0574	906.8	1.6541	2.7115
Mean	58.8	0.0	744.4	0.0	0.0
Standard Deviation	5.7	1.0	98.2	1.0	1.1
1995	42.7	-2.8156	635.7	-1.1077	1.7079
1996	55.5	-0.5779	709.4	-0.3562	0.2217
1997	40.4	-3.2108	727.4	-0.1734	3.0374
1998	54.2	-0.8046	867.2	1.2514	2.0560
1999	41.4	-3.0414	625.0	-1.2164	1.8250
2000	33.8	-4.3567	518.3	-2.3032	2.0535
2001	31.9	-4.6999	522.7	-2.2585	2.4414
2002	41.1	-3.0959	531.9	-2.1654	0.9305
2003	50.9	-1.3771	682.0	-0.6357	0.7414
2004	43.9	-2.5992	647.8	-0.9838	1.6154
Mean	43.6	-2.7	646.7	-1.0	1.6630
Standard Deviation	7.9	1.4	108.5	1.1	0.8

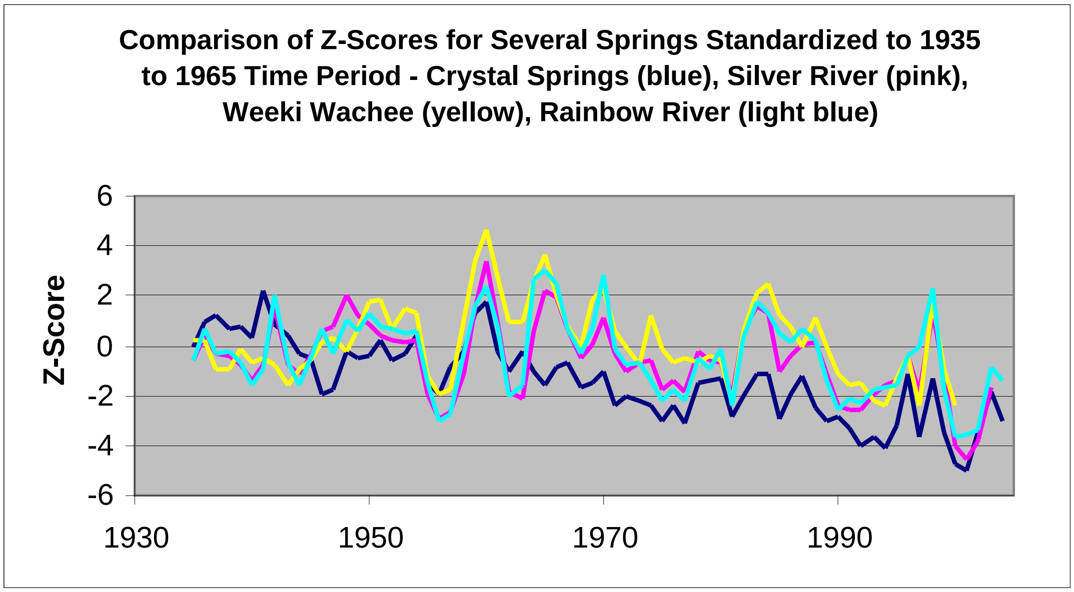


Figure 2-40. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Rainbow River (light blue) standardized to the 1935 to 1965 time period.

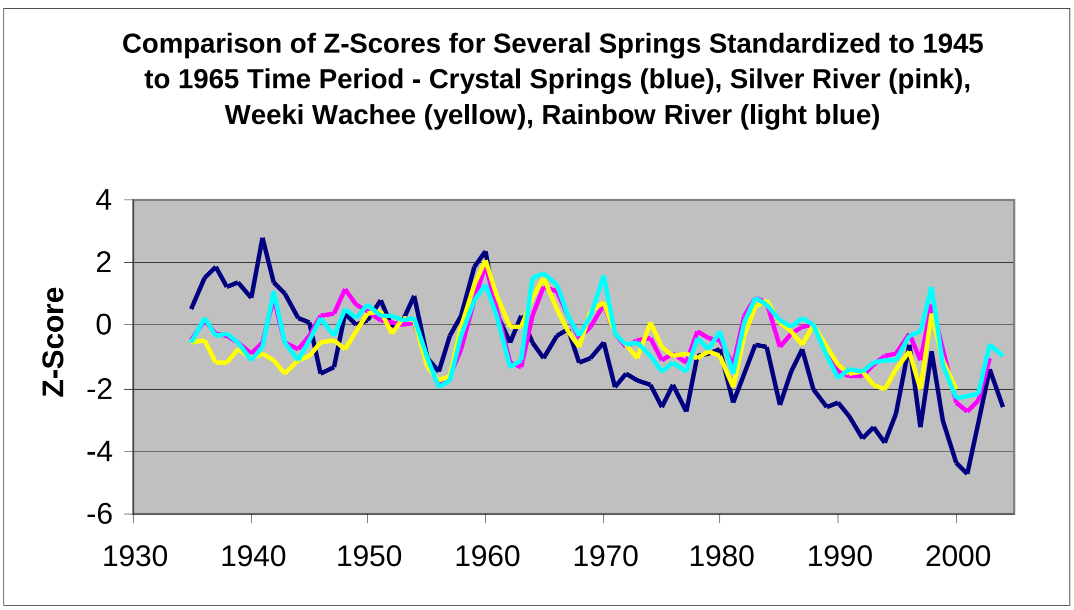


Figure 2-41. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Rainbow River (light blue) standardized to the 1945 to 1965 time period.

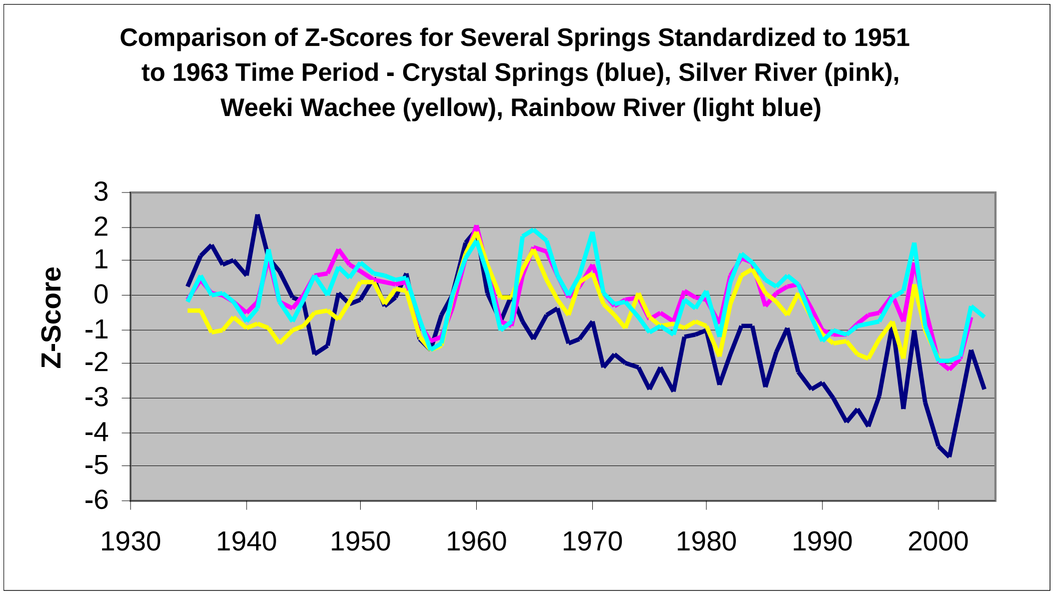


Figure 2-42. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Rainbow River (light blue) standardized to the 1951 to 1963 time period.

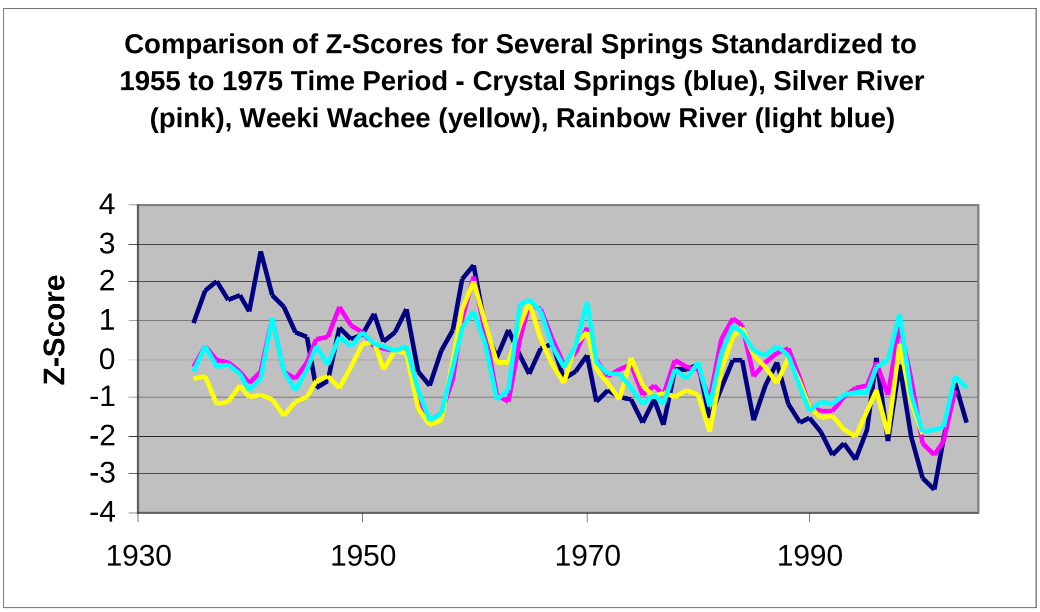


Figure 2-43. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Rainbow River (light blue) standardized to the 1955 to 1975 time period.

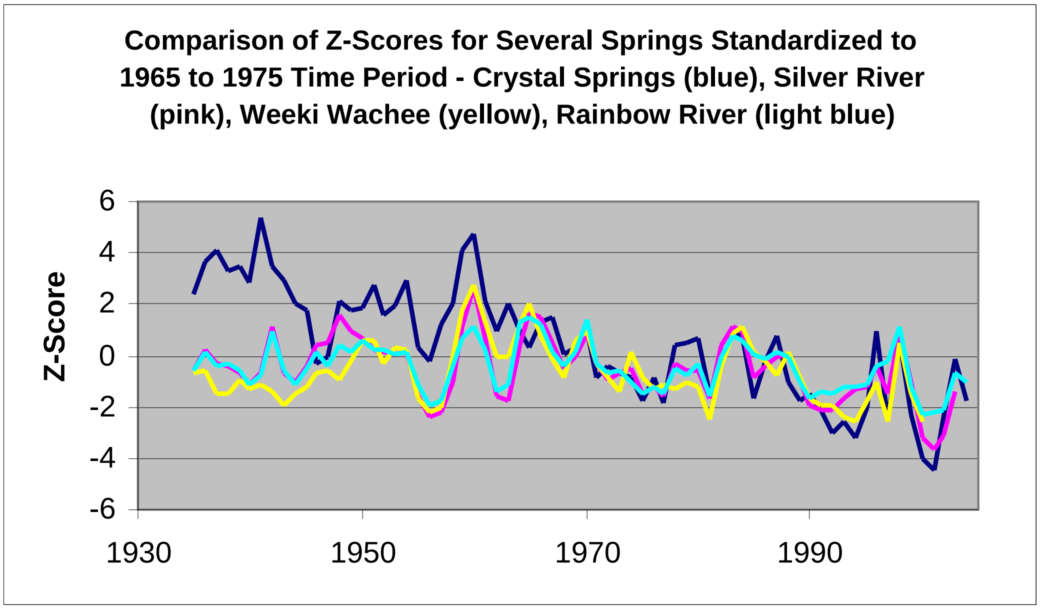


Figure 2-44. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Rainbow River (light blue) standardized to the 1965 to 1975 time period.

Table 2-22. Change in flow at three major springs for the period 1995 to 2004 relative to Rainbow River flow using various standardization periods.

Standardization Period	Crystal Spring	Silver River	Weeki Wachee River
1935 to 1965			
Mean Annual Flow (cfs)	61.2	818.1	180.9
Difference in Flow Relative to 1995 to 2004	17.6	156.7	23.7
% in Flow Relative to 1995 to 2004	28.8	19.2	13.1
Change in Flow due to Anthropogenic Effects	11.6	38.0	-4.5
% Change in Flow due to Anthropogenic Effects	18.9	4.6	-2.5
% of Change Ascribed to Anthropogenic Effects	65.7	24.0	-18.9
1945 to 1965			
Mean Annual Flow (cfs)	58.8	832.0	190.4
Difference in Flow Relative to 1995 to 2004	15.2	170.6	33.2
% in Flow Relative to 1995 to 2004	25.9	20.5	17.4
Change in Flow due to Anthropogenic Effects	9.5	30.7	2.8
% Change in Flow due to Anthropogenic Effects	16.2	3.7	1.5
% of Change Ascribed to Anthropogenic Effects	62.6	18.0	8.5
1951 to 1963			
Mean Annual Flow (cfs)	60.5	786.4	190.7
Difference in Flow Relative to 1995 to 2004	16.9	125.0	33.5
% in Flow Relative to 1995 to 2004	27.9	15.9	17.6
Change in Flow due to Anthropogenic Effects	12.9	21.8	11.1
% Change in Flow due to Anthropogenic Effects	21.3	2.8	5.8
% of Change Ascribed to Anthropogenic Effects	76.3	17.4	33.2
1955 to 1975			
Mean Annual Flow (cfs)	55.3	803.2	190.8
Difference in Flow Relative to 1995 to 2004	11.7	141.8	33.6
% in Flow Relative to 1995 to 2004	21.2	17.7	17.6
Change in Flow due to Anthropogenic Effects	6.5	33.2	9.9
% Change in Flow due to Anthropogenic Effects	11.8	4.1	5.2
% of Change Ascribed to Anthropogenic Effects	55.5	23.4	29.4
1965 to 1975			
Mean Annual Flow (cfs)	51.5	831.9	189.9
Difference in Flow Relative to 1995 to 2004	7.9	170.5	32.7
% in Flow Relative to 1995 to 2004	15.3	20.5	17.2
Change in Flow due to Anthropogenic Effects	3.3	60.7	8.3
% Change in Flow due to Anthropogenic Effects	6.5	7.3	4.4
% of Change Ascribed to Anthropogenic Effects	42.3	35.6	25.3
1995 to 2004			
Mean Annual Flow (cfs)	43.6	661.4	157.2

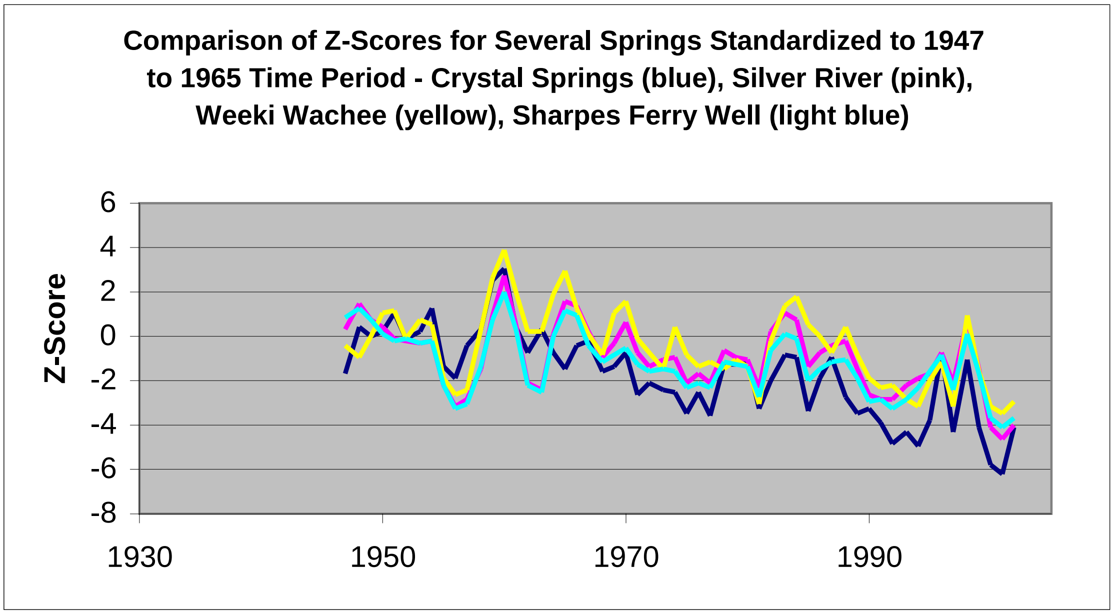


Figure 2-45. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Sharpes Ferry Well (light blue) standardized to the 1947 to 1965 time period.

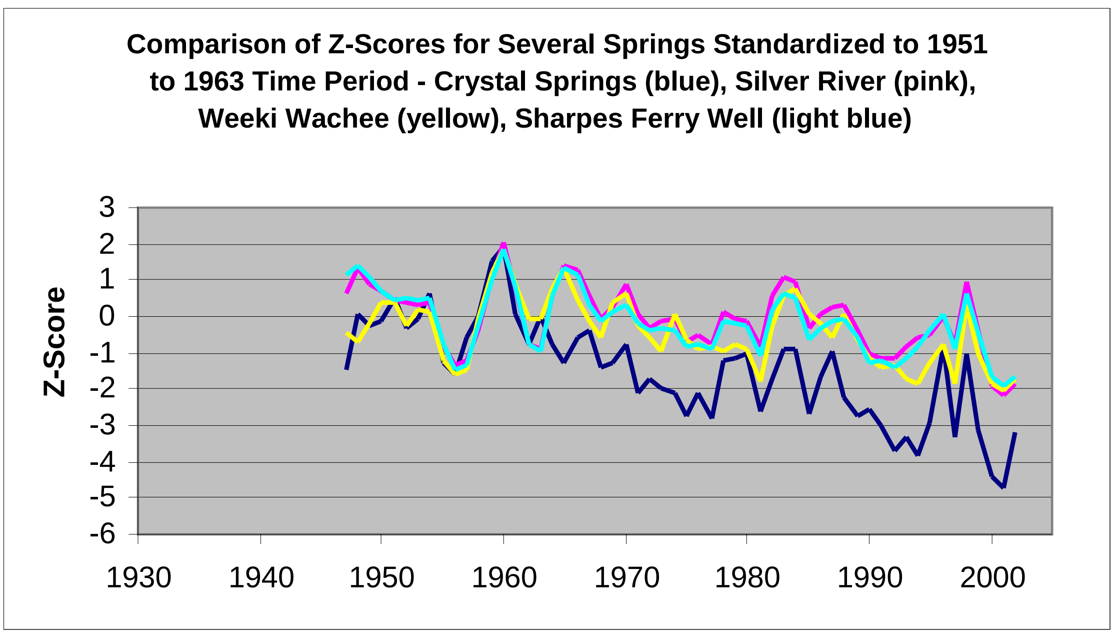


Figure 2-46. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Sharpes Ferry Well (light blue) standardized to the 1951 to 1963 time period.

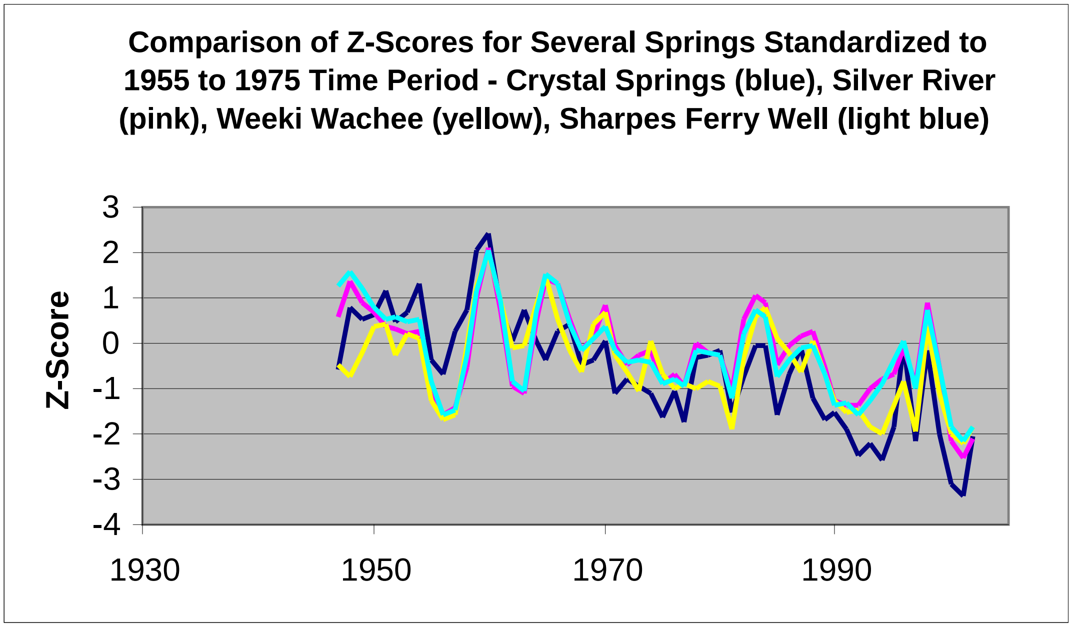


Figure 2-47. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Sharpes Ferry Well (light blue) standardized to the 1955 to 1975 time period.

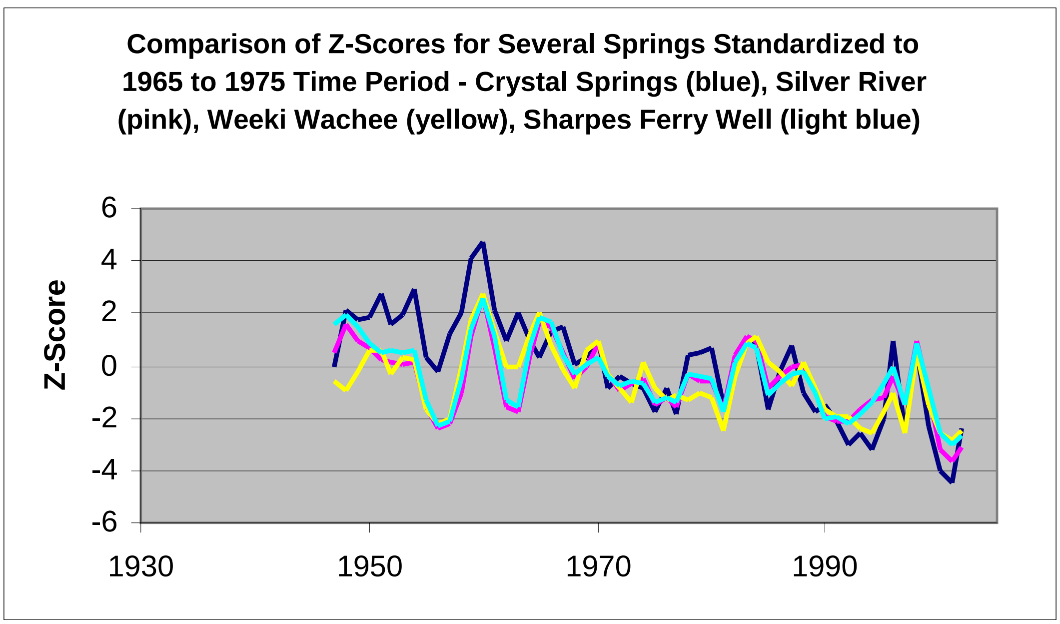


Figure 2-48. Comparison of z-scores for Crystal Springs (dark blue), Silver River (pink), Weeki Wachee (yellow), and Sharpes Ferry Well (light blue) standardized to the 1965 to 1975 time period.

Table 2-23. Change in flow at three major springs for the period 1995 to 2002 relative to ground water elevation in Sharpes Ferry Floridan Aquifer monitoring well.

Standardization Period	Crystal Spring	Silver River	Weeki Wachee River
1947 to 1965			
Mean Annual Flow (cfs)	59.2	832.2	192.9
Difference in Flow Relative to 1995 to 2002 (cfs)	16.6	173.9	45.0
% Change in Flow Relative to 1995 to 2002	28.1	20.9	23.3
Change in Flow due to Anthropogenic Effects (cfs)	10.1	4.9	9.4
% Change in Flow due to Anthropogenic Effects	17.1	0.6	4.8
% Change in Total Flow Change Ascribable to Anthropogenic Effects	60.9	2.8	20.8
1951 to 1963			
Mean Annual Flow (cfs)	60.5	786.4	190.7
Difference in Flow Relative to 1995 to 2002 (cfs)	17.9	128.1	42.8
% Change in Flow Relative to 1995 to 2002	29.6	16.3	22.5
Change in Flow due to Anthropogenic Effects (cfs)	13.1	6.2	16.3
% Change in Flow due to Anthropogenic Effects	21.7	0.8	8.5
% Change in Total Flow Change Ascribable to Anthropogenic Effects	73.3	4.9	38.0
1955 to 1975			
Mean Annual Flow (cfs)	55.3	803.2	190.8
Difference in Flow Relative to 1995 to 2002 (cfs)	12.7	144.9	42.9
% Change in Flow Relative to 1995 to 2002	23.0	18.0	22.5
Change in Flow due to Anthropogenic Effects (cfs)	6.8	21.7	15.9
% Change in Flow due to Anthropogenic Effects	12.2	2.7	8.3
% Change in Total Flow Change Ascribable to Anthropogenic Effects	53.1	15.0	37.1
1965 to 1975			
Mean Annual Flow (cfs)	51.5	831.9	189.9
Difference in Flow Relative to 1995 to 2002 (cfs)	8.9	173.6	42.0
% Change in Flow Relative to 1995 to 2002	17.3	20.9	22.1
Change in Flow due to Anthropogenic Effects (cfs)	3.2	36.7	11.5
% Change in Flow due to Anthropogenic Effects	6.1	4.4	6.0
% Change in Total Flow Change Ascribable to Anthropogenic Effects	35.6	21.1	27.3
1995 to 2002			
Mean Annual Flow (cfs)	42.6	658.3	147.9

2.6.4.2 Flow Analysis using Wavelet Filtration (adapted from R. Schultz)

The flow data for Crystal Springs is time-series data and is most commonly represented in the time-domain. Flow data can also be examined in the frequency domain, where the proportion of the flows occurring at different frequencies is the concern. Classic frequency-domain analysis is performed using Fourier transforms where the original data are represented by a series of linear combinations of sinusoidal functions, each of which represents a particular frequency observed in the data. Wavelet analysis offers an advantage over Fourier transforms by varying frequencies and identifying where they occur in time. That is to say that in wavelet analysis amplitude and frequency can vary.

One way to consider wavelet analysis or wavelet transforms is as a method for passing the data through a series of frequency or bandwidth filters. The data are broken down into components that represent the high frequency, mid- frequency, and low frequency portions. Since the Crystal Springs data are annual in nature, the high frequency portion would represent the behavior of the flow with durations of one or two years. The midrange would be on the order of three to six years, and the low range would be anything that occurs over a longer time frame.

One of the basic applications of wavelet transforms is to “de-noise” data. There are several methods available for accomplishing this. In the case of the Crystal Springs data the premise is that the anthropogenic impacts of primary interest are not short term but rather long term. Short-term fluctuations in the data would be relegated to noise that would potentially obscure the behavior of interest. Indeed, this was found to be the case as shown in Figure 2-49.

The upper portion of the figure clearly shows a persistent decline over the period examined which is 1948 through 2003. The choice of period was dictated in part by the transformation process where it is desirable that the number of data points be a power of 2, because of potential boundary effects.

The lower portion of the figure is the calculated wavelet transform of the data. The top line “crys.vec” represents the reconstruction of the original data from the wavelets. The other lines, “d1”, “d2”, “d3”, and “s3”, are the components of the wavelet transforms referred to as “crystals”. The d1 crystal represents the highest frequency data, while the d3 and s3 crystals represent the lowest frequency. For all the d crystal plots, the vertical scale is the same in order to visualize the relative strength of the data at different frequencies. The vertical scale of the s3 crystal is different because so much of the data are represented here that it would overwhelm the other plots. Examination of the transformed data shows that there is little or no evidence of the downward trend in either the d1 or d2 crystals, however, in the d3 and s3 crystals the downward trend is quite noticeable.

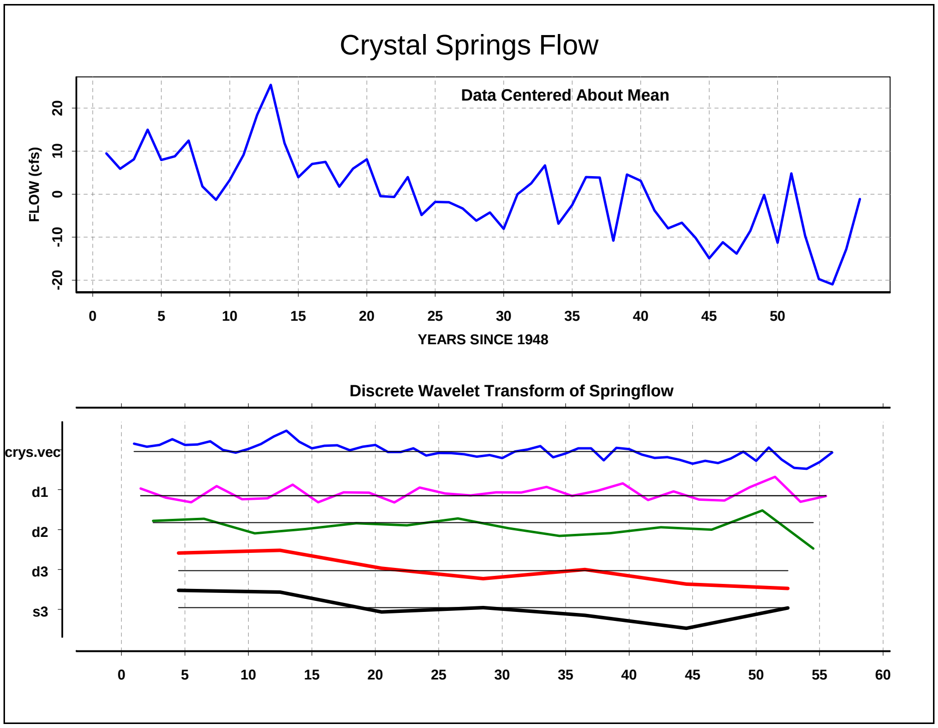


Figure 2-49. Wavelet transform of Crystal Springs flow.

Having identified the wavelet crystals of interest in the flow data, the same process was followed for rainfall from the two weather stations closest to Crystal Springs, the Plant City and St. Leo stations. Additionally, groundwater elevations from the Sharpes Ferry well were also transformed. Sharpes Ferry was chosen both for its period of record and for the fact that it is generally agreed that there are no anthropogenic impacts at the well.

There is an apparent 25-year cycle within the data. (Figure 2-50) It is most apparent in the s3 crystal of the transformed St. Leo rainfall data. Such a multi-decadal cycle has often been mentioned, but the wavelet transforms makes it much more apparent. Also, differences in the intensity of this cycle during the period of 1948 to 2003 are discernable. Further, in the previous figure of the wavelet transform of Crystal Springs flow, the same oscillation is apparent in the s3 crystal. This may indicate that flow at the spring does respond to long-term climate cycles.

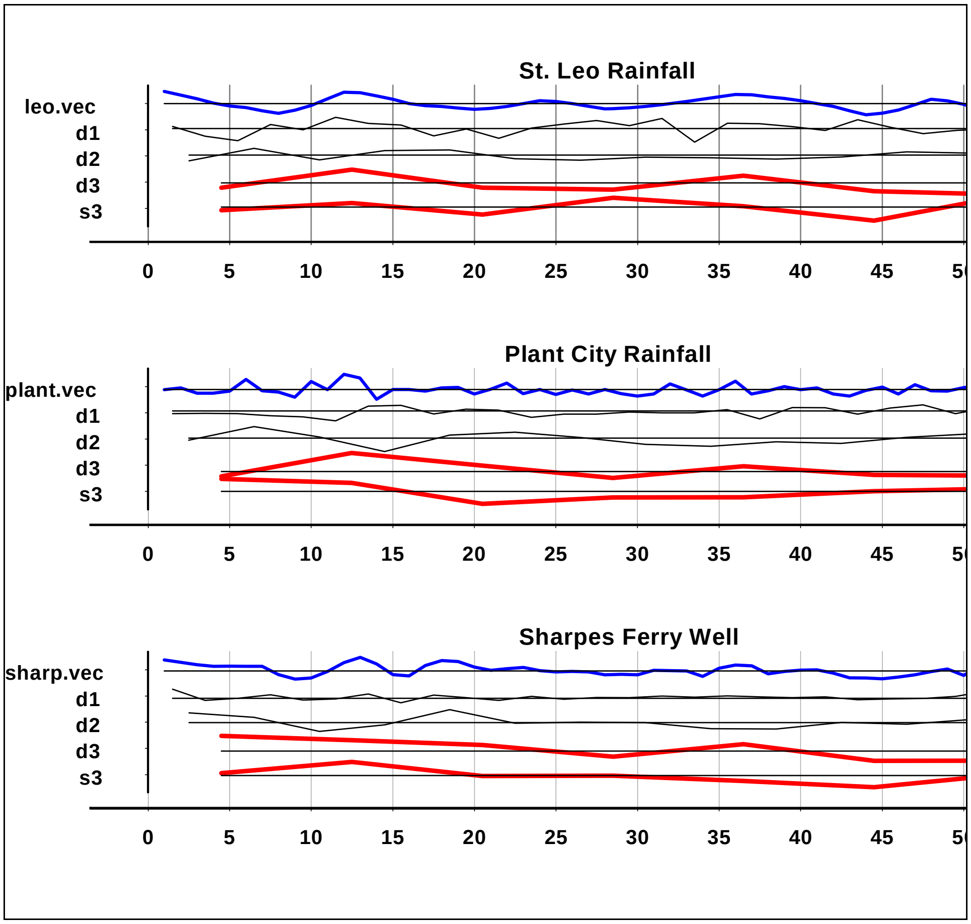


Figure 2-50. Wavelet Transforms of Rainfall and Groundwater.

Having identified the d1 and d2 crystals as noise in the Crystal Springs flow data, only the d3 and s3 crystals were extracted from the transformed data and then untransformed back into the time domain. This was done for all the data, including the rainfall and groundwater data, so as to remain consistent (Figure 2-51).

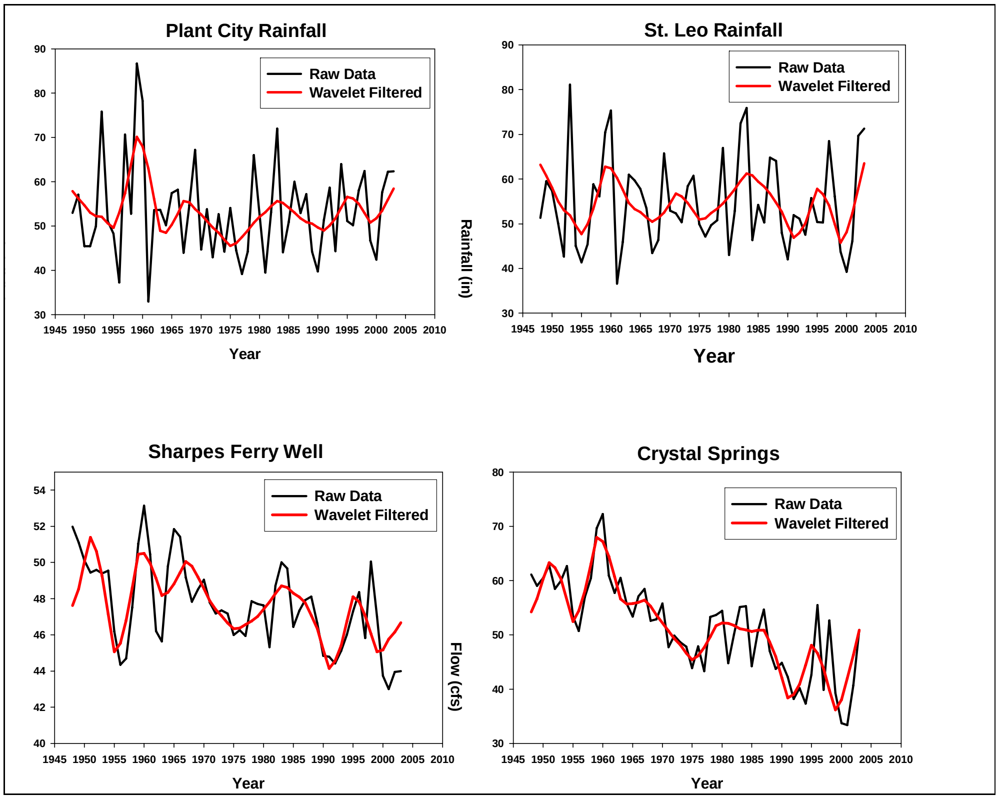


Figure 2-51. Filtered Wavelet Data, where the noise from crystals d1 and d2 have been removed, versus Original Raw Data.

As part of the data exploration process, a plot was constructed of the cumulative flow versus time (Figure 2-52). A break in the slope is visible on this chart which occurs approximately in 1970. So long as the relationship between flow and time is constant, the line should be straight. Breaks in the line slope indicate the possibility that there have been changes in the method of data collection or physical changes that have changed the data.

Two correlation matrices were constructed using the wavelet-filtered data from Crystal Springs, St. Leo and Plant City rainfall, and Sharpes Ferry well. Included also were wavelet-filtered data from Rainbow River and Silver Springs. The first correlation matrix was for the period of 1948 to 1969 and the second was for the period of 1970 to 2003. The results are shown in Table 2-24.

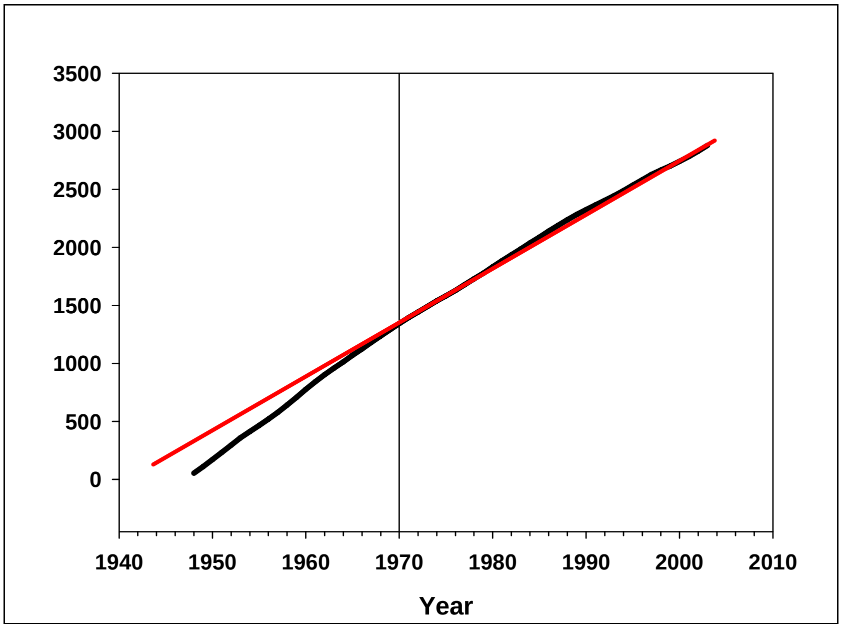


Figure 2-52. Cumulative Crystal Springs Flow versus Time.

Table 2-24. Correlation matrix for the period of 1948 to 1969 and the period of 1970 to 2003.

1948 -1969	Crystal	Rainbow	Silver	Sharpes	Plant City	St. Leo
Crystal	1					
Rainbow	.38	1				
Silver	.58	.95	1			
Sharpes	.65	.94	.98	1		
Plant City	.73	.13	.40	.37	1	
St. Leo	.61	.21	.41	.40	.75	1

1970-2003	Crystal	Rainbow	Silver	Sharpes	Plant City	St. Leo
Crystal	1					
Rainbow	.78	1				
Silver	.89	.95	1			
Sharpes	.87	.95	.98	1		
Plant City	.23	.49	.36	.42	1	
St. Leo	.84	.80	.84	.83	.63	1

Rainbow River and Silver Springs correlate well in both time periods. They also correlate well with Crystal Springs in the later time period. However, the correlation between Crystal Springs and the two other springs is noticeably poorer in the first time period. A similar relationship is seen between Crystal Springs and the Sharpes Ferry well.

Further information on the pre-1970 discrepancy can be found in scatter plots of the data. Figure 2-53 shows the relationship between flow at Crystal Springs and groundwater elevations measured in Sharpes Ferry well. It is apparent that there are two separate populations of data. One population consists of the data from 1953 to 1963 and the other population contains all the other data.

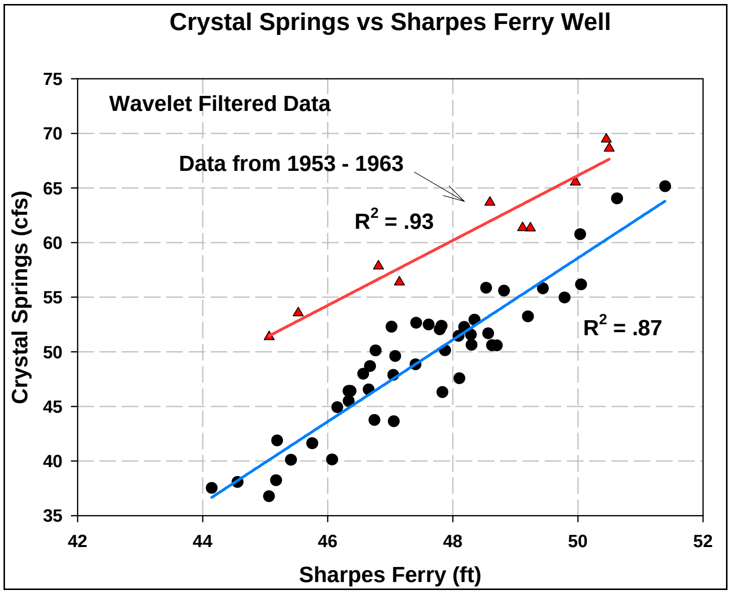


Figure 2-53. Crystal Springs Flow versus Groundwater Elevation

In comparing Crystal Springs flow with flow from Rainbow and Silver Springs, this relationship persists. The period of 1953 through 1963 appears anomalous. Figure 2-54 shows the relationship between Silver Springs and Rainbow Springs. As would be expected the relationship is quite good with an R-squared value of 0.93. However, Figures 2-55 and 2-56 compare Crystal to both Silver Springs and Rainbow Springs and shows the dual populations.

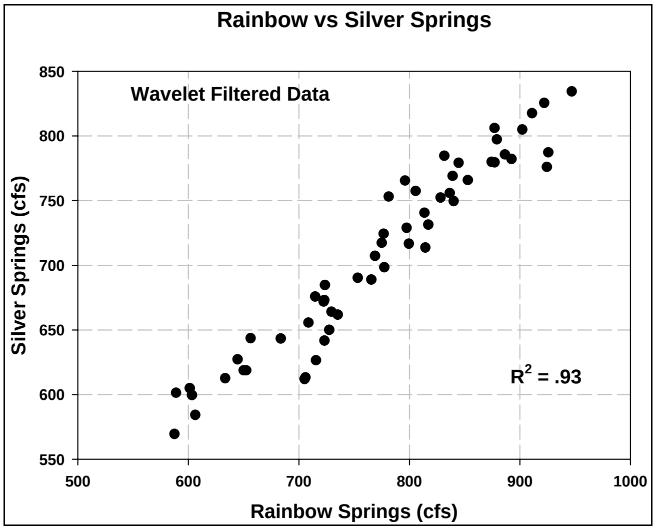


Figure 2-54. Silver Springs vs. Rainbow Springs.

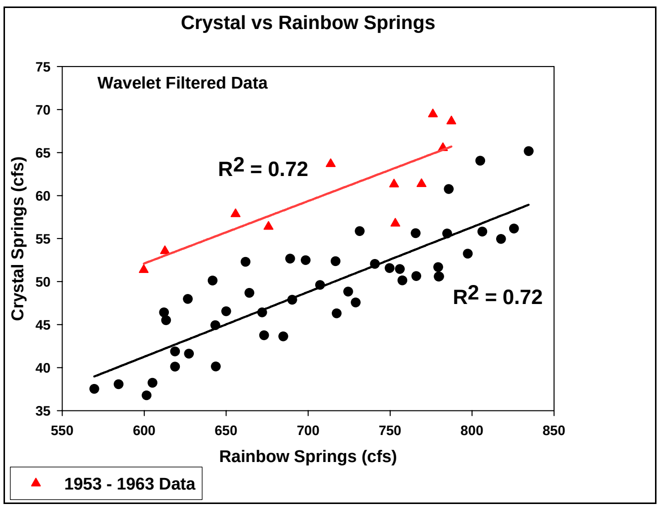


Figure 2-55. Crystal Springs vs. Rainbow Springs.

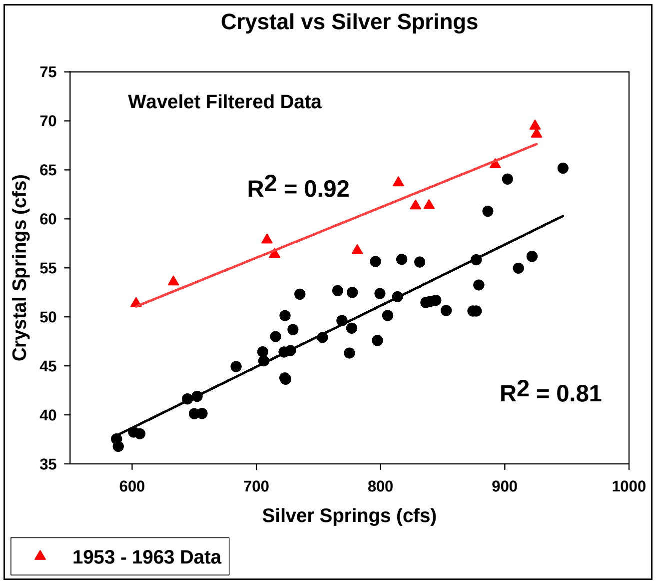


Figure 2-56. Crystal Springs vs. Silver Springs.

The conclusion from examining these graphs is that the flow data from Crystal Springs is in error for the period 1953 through 1963.

In order to correct the data the regression model of Crystal Springs flow as a function of Sharpes Ferry well was used. The model was run with the suspect data excluded to determine the parameter coefficients. These coefficients were then used to predict replacement values for the period of 1953 through 1963 which were then substituted back into the original data set. It is emphasized that all other data were used as reported and that the regression model was only used to adjust the flow values for 1953 through 1963.

Having made the adjustment to the flow data, the correlation matrices and scatter plots were constructed using the adjusted flow data. Table 2-25 presents the correlation matrices of the data with the Crystal Springs flow adjusted as described. There is a marked improvement in the correlations of Crystal Springs with both Rainbow and Silver springs. The correlations between the springs are now approximately the same both pre- and post-1970. The correlation between Crystal Springs and Sharpes Ferry well also improves in the pre-1970 data. Naturally, this is a consequence of using the well to calculate flow for the adjustment period. However, the correlation between well levels and flow are now approximately the same for the pre- and post-1970 periods.

Table 2-25. Correlation Matrices Using Adjusted Crystal Springs Flow.

1948-1969	Crystal	Adjusted Crystal	Rainbow	Silver	Sharpes	Plant City	St. Leo
Crystal	1						
Adjusted Crystal	.64	1					
Rainbow	**.38**	**.84**	1				
Silver	**.58**	**.88**	.95	1			
Sharpes	**.65**	**.85**	.94	.98	1		
Plant City	.73	.51	.13	.40	.37	1	
St. Leo	.61	.55	.21	.41	.40	.75	1

1970-2003	Crystal	Adjusted Crystal	Rainbow	Silver	Sharpes	Plant City	St. Leo
Crystal	1						
Adjusted Crystal	.95	1					
Rainbow	.78	.78	1				
Silver	.89	.89	.95	1			
Sharpes	.87	.87	.95	.98	1		
Plant City	.23	.23	.49	.36	.42	1	
St. Leo	.84	.84	.80	.84	.83	.63	1

Figure 2-57 illustrates the relationship between the adjusted Crystal Springs flow and the Sharpes Ferry well. With the adjusted data, the scatter plot more closely resembles those of Sharpes Ferry with Rainbow and Silver Springs. The overall R-squared value is also more in line with that of the other springs.

In Figures 2-58 and 2-59, the before adjustment and after adjustment scatter plots of Crystal Springs versus Rainbow and Silver Springs are shown. In both cases there is a noticeable improvement in the R-squared values after adjustment.

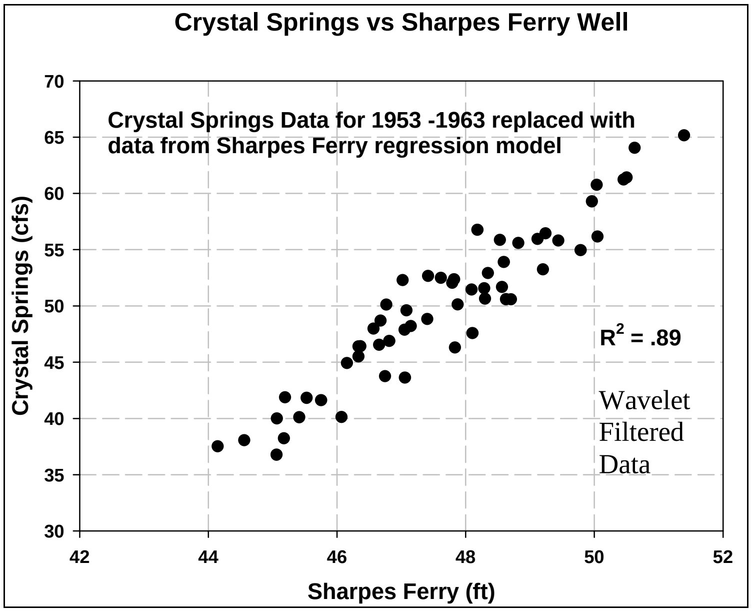


Figure 2-57. Crystal Springs data for 1953 to 1963 adjusted with data from Sharpes Ferry regression model.

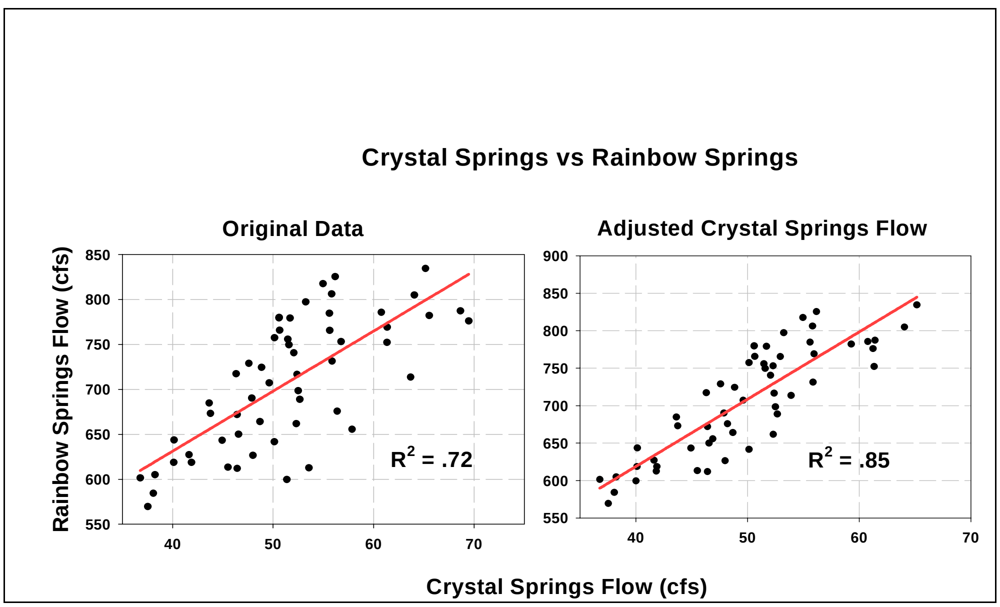


Figure 2-58. Adjusted versus non-adjusted Crystal Springs versus Rainbow Springs (Wavelet filtered data).

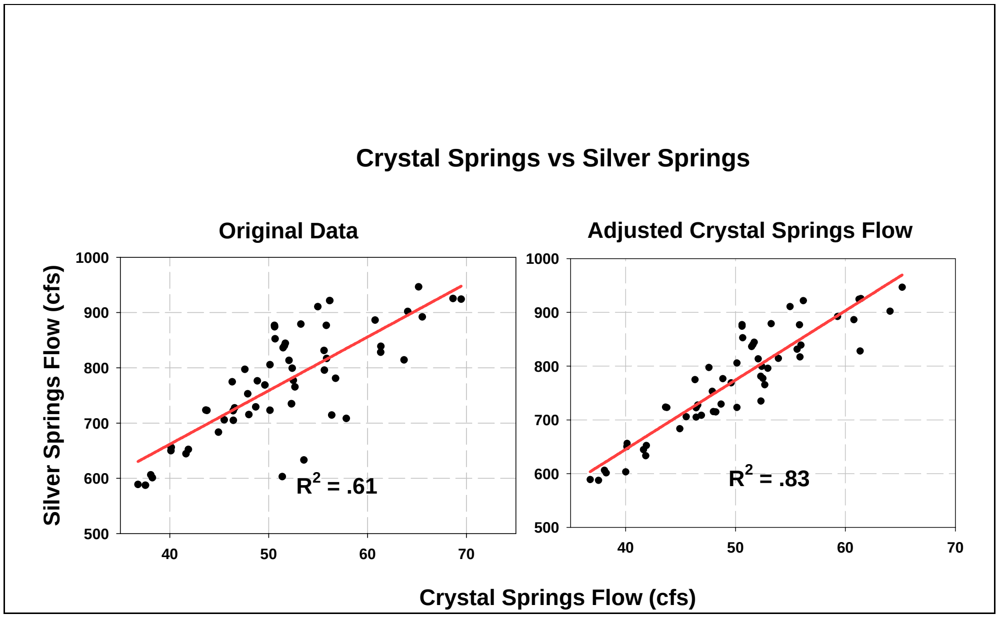


Figure 2-59. Adjusted versus non-adjusted Crystal Springs versus Silver Springs (Wavelet filtered data).

The next stage of the analysis was to determine the quantity of flow decline that could not be explained by either rainfall or relatively un-impacted groundwater levels. This analysis was conducted using the "adjusted", wavelet filtered, Crystal Springs flow along with the similarly filtered data for Sharpes Ferry well and rainfall from either St. Leo or Plant City weather stations.

The procedure followed was to construct a multiple linear regression model of the following form:

Flow = β_1 + β_2*GW Elevation + β_3*Rainfall + β_4*Impact

Where: GW Elevation = Sharpes Ferry well data
Rainfall = either St. Leo or Plant City rainfall
Impact = binary variable:
Impact = 0 = no impact
Impact = 1 = impact

The model in this form allows for the intercept to change while maintaining the same slope. There would be one intercept for no significant impact and another one for the time period of occurring impacts. In this case, since flow is being modeled, the parameter coefficient for impact (β_4) is equal to the quantity of spring flow that is not explained by either rainfall or groundwater levels. The key to using a model of this form is to determine at what time the impacts begin to be noticeable. It is assumed that impacts, once begun, continue to the present time.

While it is possible to establish the beginning year of impact subjectively, a process that would find that year objectively was desired. The method chosen was to run the regression model multiple times, each time moving the year with impacts towards the future. In other words, the first run would have the impact variable set to 1 for all 56 years. The second run would have the impact variable turned on beginning in year two and extending 55 years, and so on. The assumption being that the model with the best fit would be the one where the impact variable is turned on in the correct year.

This procedure was carried out once with St. Leo rainfall and again with Plant City rainfall. The results are quite similar. Using Plant City rainfall, the best model has -6.1 cfs of impact beginning in 1990. Using St. Leo rainfall, the best model has -5.4 cfs of impact also beginning in 1990. Both models have R-squared values of 0.92. Figure 2-60 shows the results for the model using St. Leo rainfall. Additionally, the upper and lower 95% confidence interval for the model is presented as a dashed line. Note that virtually all of the actual flow behavior is within the models confidence interval.

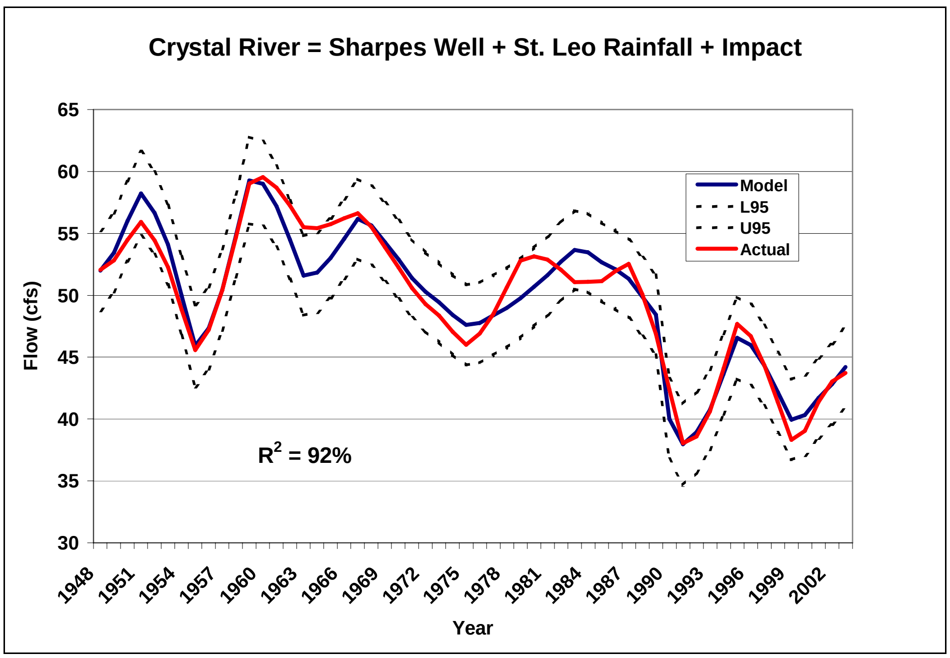


Figure 2-60. Multiple regression model for Crystal Springs Flow using wavelet filtered data.

Figure 2-61 shows the effect of moving the year of beginning impacts forward on the model fit as represented by the R-squared value. It is interesting to note that in the models the impact term began to be statistically significant (alpha = 0.05) in approximately 1966. An argument could be made that the beginning of statistical significance would also mark the beginnings of impacts to the spring system. Based upon the parameter coefficients for the impact parameter over the period of 1966 to 1990, the average impact would have been on the order of 3 cfs using either rain station.

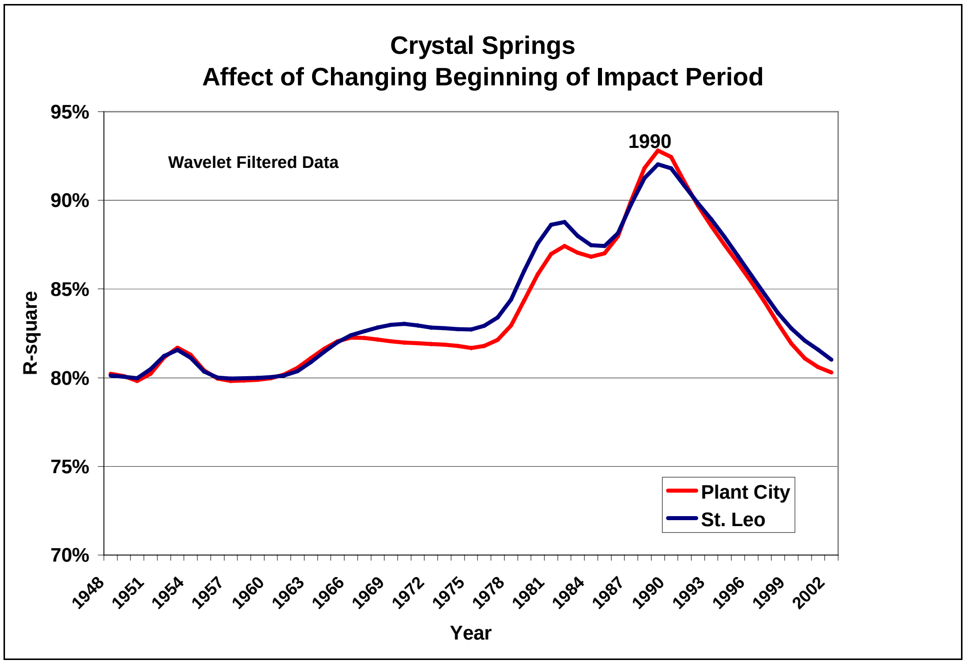


Figure 2-61. R-squared values based on changing the year in which impacts are assumed to have begun.

In general, the impact parameter coefficients follow the pattern exhibited by the R-square value shown in the chart with the maximum values occurring where the models are best.

One of the advantages of this approach is that it is possible to assign confidence intervals to the estimated impact values. The results for the final two models are presented in Table 2-26, assuming an alpha of 0.05.

Table 2-26. Estimated Impacts to Crystal Springs.

Model	Mean	Lower 95%	Upper 95%
St. Leo	-5.4 cfs	-6.7 cfs	-4.2 cfs
Plant City	-6.1 cfs	-7.4 cfs	-4.9 cfs

In summary, Crystal Springs has exhibited a pronounced decline in flow over the period examined. The problem was to arrive at an estimate of how much of this decline could be attributed to natural causes and how much could be attributed to anthropogenic causes.

Wavelet transformation was used to identify those portions of the frequency domain that exhibited declines. These frequencies were then isolated and untransformed back into the time domain. The effect was to effectively "de-noise" the data.

Using the wavelet filtered data for Crystal, Rainbow, and Silver Springs, groundwater elevation data from Sharpes Ferry well, and rainfall data from St. Leo and Plant City rainfall stations, basic data exploration was accomplished. It was found that Crystal Springs flow data from pre-1970 was not consistent with post-1970 data. Further data exploration isolated flow data from the period of 1953 through 1963 as the cause of the inconsistency. The data for this period was subsequently adjusted using a regression relationship between spring flow and groundwater levels.

Following data adjustment, a multiple linear regression model was constructed using a binary variable to account for spring flow impacts. An iterative modeling approach was used to determine when significant impacts began. Although there is some evidence to indicate that impacts began in approximately 1966, the best model results have the significant impacts beginning in 1990. Flow decline is calculated to be between 5.4 and 6.1 cfs.

2.6.4.3 Predicted Impact to Crystal Springs based on Numerical Model Results (Contributed by R. Basso, personal communication)

A number of regional groundwater flow models have included the Hillsborough River watershed and simulated Crystal Springs discharge. Ryder (1982) simulated the entire extent of the Southwest Florida Water Management District. In 1993, the District completed the Northern Tampa Bay groundwater flow model that covered a 2,000 square mile area of Hillsborough, Pinellas, Pasco, and Hernando Counties. In 2002, the USGS simulated the entire Florida peninsula in their Mega Model of regional groundwater flow (Sepulveda 2002). The most recent and advanced simulation of the Hillsborough River watershed and surrounding area is the Integrated Northern Tampa Bay Model (INTBM). The construction and calibration of this model was part of a cooperative effort between the SWFWMD and Tampa Bay Water, a regional water utility that operates 11 major wellfields in the area. The INTBM covers a 4,000 square-mile area of the Northern Tampa Bay region (Figure 2-62).

An integrated model represents the most advanced simulation tool available to the scientific community in water resources investigations. It combines the traditional ground-water flow model with a surface water model and contains an interprocessor code that links both systems. One of the many advantages of an integrated model is that it simulates the entire hydrologic system. It represents the “state-of-art” tool in assessing changes due to rainfall, drainage alterations, and withdrawals.

The model code used to run the INTBM simulation is called the Integrated Hydrologic Model (IHM) which combines the HSPF surface water code and the MODFLOW ground-water code using interprocessor software. During the INTBM development phase, several new enhancements were made to move the code toward a more physically-based simulation. The most important of these enhancements was the partitioning of the surface into seven major land use segments: urban, irrigated land, grass/pasture, forested, open water, wetlands, and mining/other. For each land segment, parameters were applied in the HSPF model consistent with the land cover, depth-to-water table, and slope. Recharge and ET potential were then passed to each underlying MODFLOW grid cell based on an area weighted-average of land segment processes above it. Other new software improvements included a new ET algorithm/hierarchy plus allowing the model code to transiently vary specific yield and vadose zone storages.

The INTBM contains 172 subbasin delineations in HSPF (Figure 2-63). There is also an extensive data input time series of 15-minute rainfall from 300 stations for the period 1989-1998, a well pumping database that is independent of integration time step (1-7 days), a methodology to incorporate irrigation flux into the model simulation, construction of an approximate 150,000 river cell package that allows simulation of hydrography from major rivers to small isolated wetlands, and GIS-based definition of land cover/topography. An empirical estimation of ET was also developed to constrain model derived ET based on land use and depth-to-water table relationships.

The MODFLOW gridded domain of the INTBM contains 207 rows by 183 columns of variable spacing ranging from 0.25 to one mile. The groundwater portion is comprised of three layers: a surficial aquifer (layer 1), an intermediate confining unit or aquifer (layer 2), and the Upper Floridan aquifer (layer 3). The model simulates leakage between layers in a quasi-3D manner through a leakance coefficient term.

The INTBM is a regional model and has been calibrated to meet global metrics. The model is calibrated using a daily integration step for a transient 10-year period from 1989-1998. Model-wide mean error for all wells in both the surficial (SAS) and Upper Floridan aquifers (UFA) is less than 0.2 feet. Mean absolute error was less than two feet for both the SAS and UFA. Total stream flow and spring flow mean error averaged for the model domain is each less than 10 percent.

Two model scenarios were run with the INTBM. The first scenario consisted of simulating the impacts from groundwater withdrawn only within the Upper Hillsborough River Basin. The area of withdrawals totaled 69 mgd and is shown in Figure 2-64. The second scenario included almost the entire Hillsborough River Basin by adding groundwater withdrawals in the Cypress Creek and Trout Creek subbasins. This area of withdrawals totaled 117 mgd and is shown in Figure 2-65.

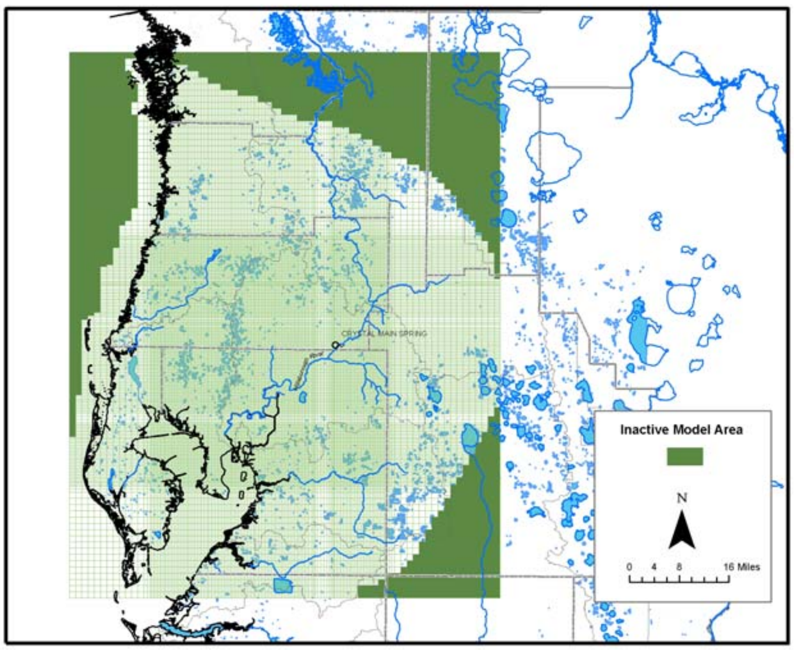


Figure 2-62. **Groundwater grid used in the INTB model.**

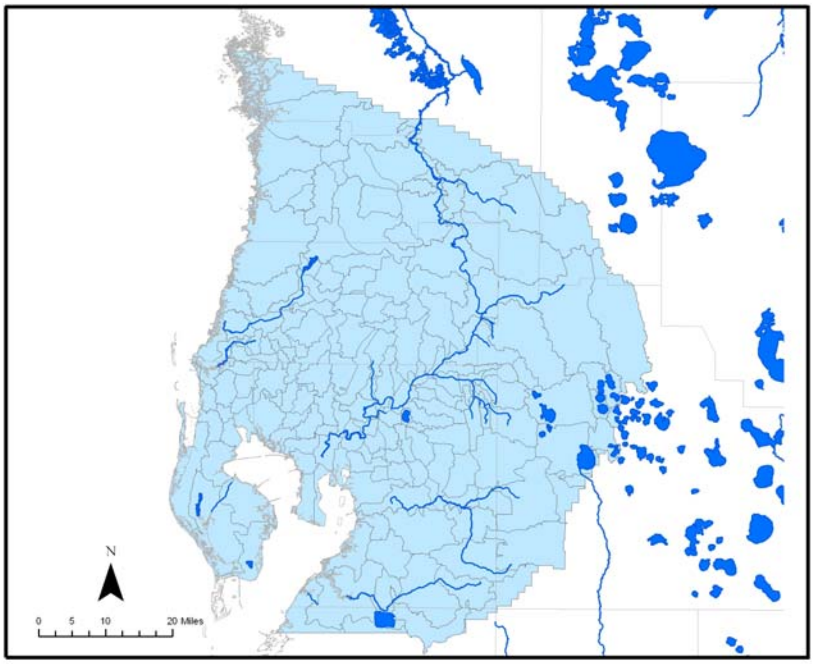


Figure 2-63. HSPF subbasins in the INTBM.

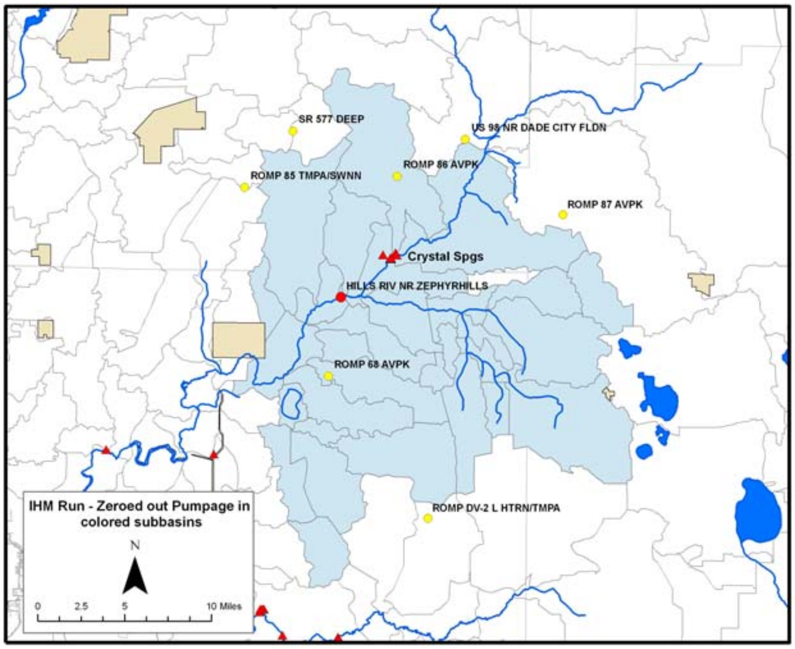


Figure 2-64. INTBM scenario 1 where impacts to the hydrologic system were simulated due to groundwater withdrawals of 69 mgd (1989-1998 average) in the shaded area.

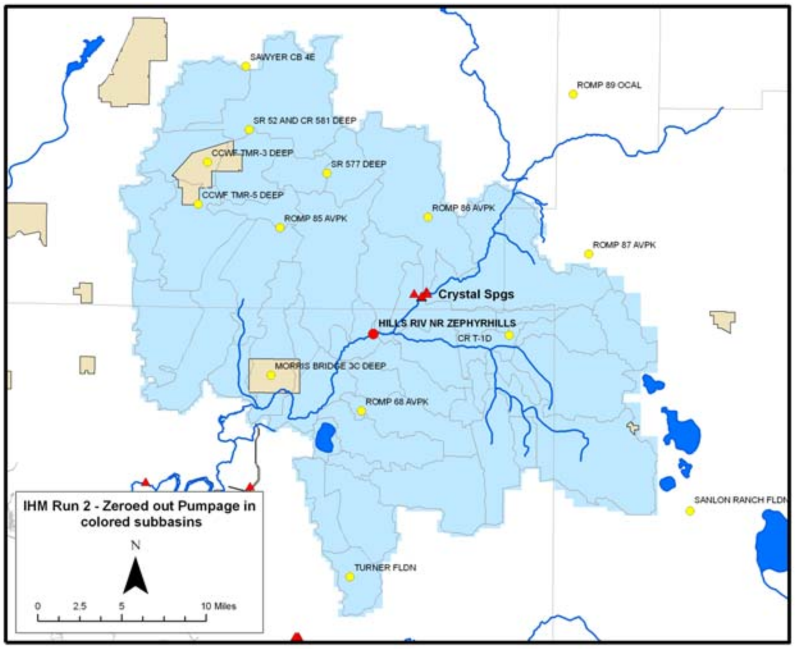


Figure 2-65. INTBM scenario 2 where impacts to the hydrologic system were simulated due to groundwater withdrawals of 117 mgd (1989-1998 average) in the shaded area.

The results of the first INTBM scenario showed that Crystal Springs discharge was reduced by 4.1 cfs or nine percent as an average over the 10-year period from 1989-1998 due to groundwater withdrawals of 69 mgd in the Upper Hillsborough Basin (Figure 2-66). The second scenario indicated that Crystal Springs discharge was reduced by 5 cfs (10.9 %) with 117 mgd of pumping in the Hillsborough River watershed averaged over the 10-year period. It is interesting to note that the addition of the western watershed major wellfield withdrawals for Cypress Creek, Cypress Bridge, and Morris Bridge only represented about 20 percent (0.9 cfs) of the total impact to spring flow. The vast majority of spring discharge reduction was due to pumping within the Upper Hillsborough Basin itself.

In addition to predicted reduction in spring flow, the INTBM can also simulate impacts to river flow. In the two scenarios above, stream flow at Hillsborough River near Zephyrhills station was predicted to decline 21.6 cfs or 8.5 percent as an average over the 10-year period due to 69 mgd of groundwater withdrawn in the Upper Hillsborough Basin (Figure 2-67). When the western wellfield withdrawals were added in Scenario 2, predicted decline in stream flow was only reduced by a little more than one cfs to 22.7 cfs (8.9%). Again, similar to the spring flow predictions, most of the groundwater impact at the Zephyrhills station is due to withdrawals in the Upper Hillsborough Basin.

Predicted decline in Upper Floridan aquifer heads as an average over the 10-year period for scenario 2 is shown at selected well locations in Figure 2-68. The largest head decline or drawdown is 16.6 feet at the TMR 3 well location near the center of Cypress Creek wellfield. At the SR 577 well, predicted mean head decline is 2.7 feet. Generally, predicted drawdown in the Upper Hillsborough Basin ranged from 0.8 to 1.6 feet. These results are generally consistent with simulated results from the NTB regional groundwater flow model (SWFWMD 1993).

Weber and Perry (2006) indicated that regional groundwater withdrawals outside of the Hillsborough watershed could potentially impact Upper Floridan aquifer head within the basin and Crystal Springs discharge. To estimate these effects, the USGS Mega Model (Sepulveda 2002) was simulated with and without current pumping (1993-94 withdrawals) to note drawdown and potential impacts to Crystal Springs flow (Figure 2-69). Based on the impacts of groundwater withdrawals over the entire Florida peninsula, predicted reduction in Crystal Springs discharge was four cfs during a steady-state simulation. The model results suggest that impacts to Crystal Springs discharge are minimal outside the immediate Hillsborough River watershed.

The effect of withdrawals from the SWCFGWB and to the west of Hillsborough River watershed are negligible according to the mega model results. In addition, these results are supported by the INTBM in that even the large wellfields on the western side of the watershed (i.e., Cypress Creek, Cypress Bridge, and Morris

Bridge) affected Crystal Spring flow by less than one cfs. As for the SWCFGWB, it is clear that the high density of withdrawals associated with early phosphate mining and later agriculture have led to regional decline in the UFA of several tens of feet over portions of Polk and Hillsborough counties. The results of the numerical models and UFA water level analysis are consistent with the conceptualization of the hydrogeologic system in most of the Hillsborough River watershed - that aquifer level changes from withdrawals would be localized because of vertical leakage from the overlying surficial aquifer.

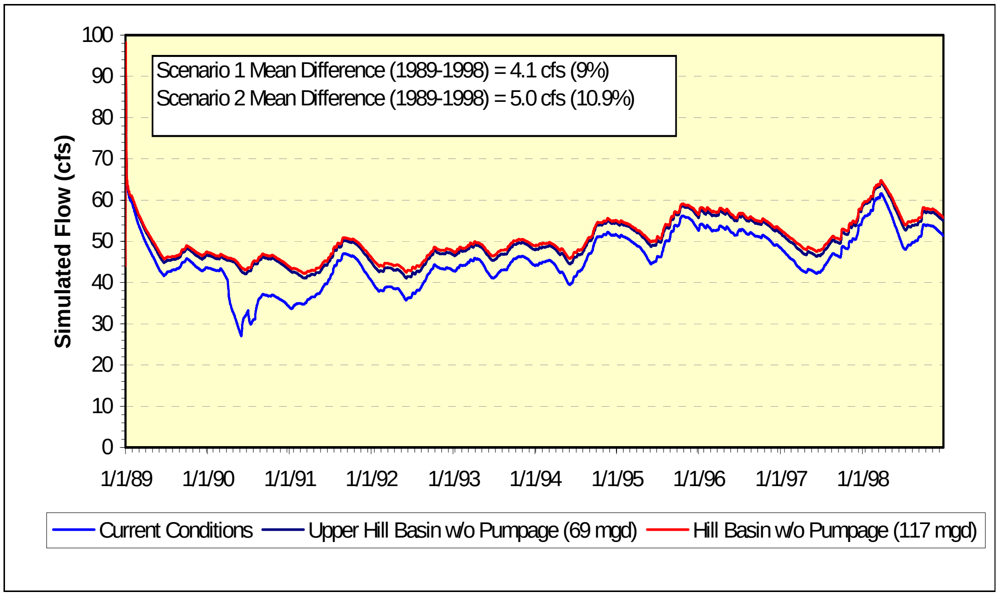


Figure 2-66. **Impacts to Crystal Springs due to 69 mgd and 117 mgd of groundwater withdrawals within the Hillsborough River watershed.**

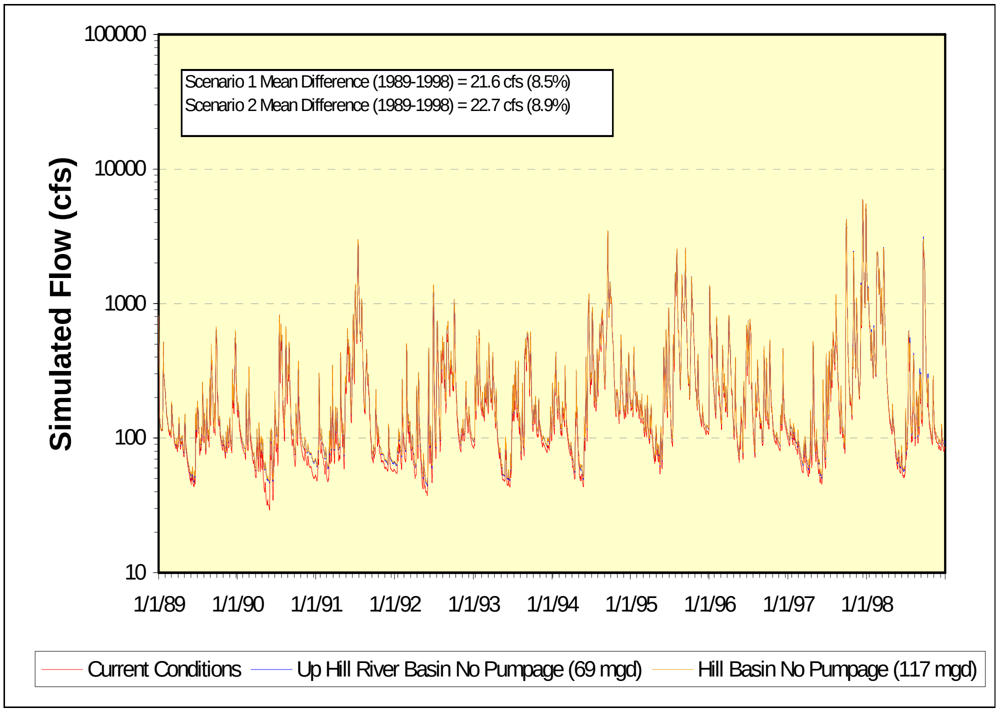


Figure 2-67. **Impacts to Hillsborough River stream flow at the Zephyrhills station due to 69 mgd and 117 mgd of groundwater withdrawals within the Hillsborough River watershed.**

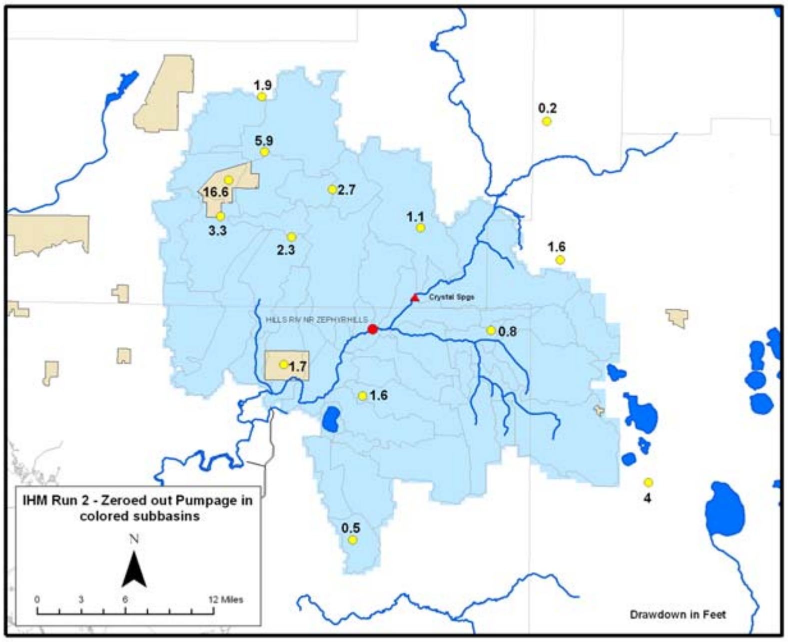


Figure 2-68. **Predicted decline in the Upper Floridan aquifer at selected locations due to 117 mgd of groundwater withdrawals within the Hillsborough River watershed.**

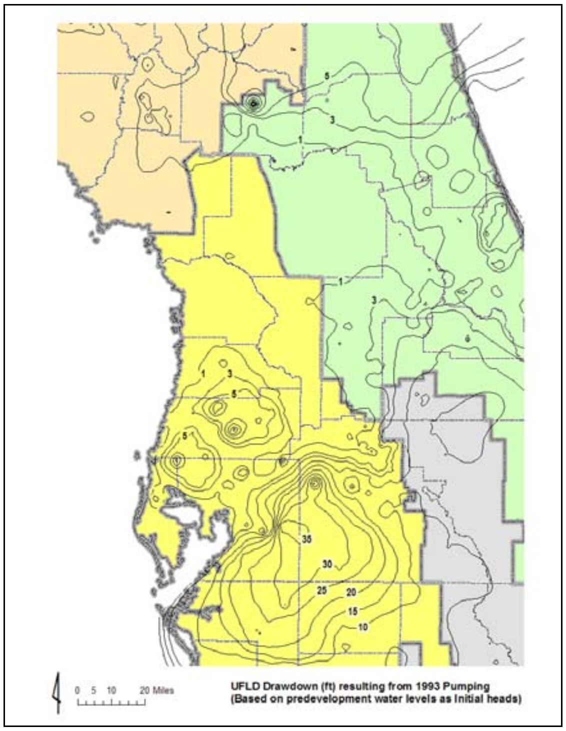


Figure 2-69. Predicted decline in the Upper Floridan aquifer due to groundwater withdrawals over the Florida peninsula.

In the Hillsborough River watershed, major groundwater withdrawals are located at the periphery of the basin with relatively low magnitude dispersed withdrawals found in the Upper Hillsborough/Lower Withlacoochee Basins, close to or within the source region of Crystal Springs flow (R. Basso, Personal Communication).

2.6.5 Construction of an Non-Anthropogenically Impacted Flow Record for Minimum Flow Purposes

- *As noted above, the flow from Crystal Springs has historically been calculated as the difference between two flow measurements. The upstream measurement has been estimated to be 1,500 ft above the main vent while the downstream station is approximately 3,000 ft below the main vent (Basso, personal communication).* ***Therefore, when discussing Crystal Springs flow, this report is actually referring to the flow captured within an approximately 4,500 ft reach of the river.*** *That reach captures the main vent as well as several smaller springs located within 2,000 ft of the main vent as well as the intervening watershed.*

The flow records for Crystal Springs have been extensively examined in preparation for developing a minimum flow recommendation. There are significant differences or inconsistencies in the flow record, which make developing a minimum flow recommendation particularly difficult. For MFL purposes, we must assume that a certain percent decrease in spring flow has occurred over the last several decades. However, this resultant assumption can be questioned from several perspectives and thus will add a level of uncertainty to any minimum flow recommendation. Once the amount of decline in spring flow from historic levels has been estimated, the next major question relevant to MFL development is, "How much of this decline is ascribable to anthropogenic versus climatic factors, and how much of the anthropogenic effect is due to withdrawals." We have utilized the z-score analysis and necessary assumptions presented in previous sections of this report to derive an estimate of the anthropogenic effect.

The actual permitted direct withdrawal by Crystal Springs Corp. is small relative to the apparent decline regardless of the assumptions made. The apparent decline in Crystal Springs flow is in the range of 10 to 15 cfs (6.5 to 9.7 mgd). Crystal Springs Corp. is permitted to withdraw 0.756 mgd (WUP No. 9132, Crystal Springs Reserve Inc.), and thus could account for no more than 10% of the decline. For the period studied, actual withdrawals from the spring were considerably less than 0.5 mgd.

There are few springs in Florida with a flow record sufficient to assess differences between AMO periods (refer to Kelly 2004). Assuming that groundwater withdrawal impacts on Silver Springs have been relatively small, the Silver Spring flow record was examined to determine how much of a flow decline there was between AMO warm and cool phases in order to approximate potential decreases due to climatic factors for comparison with projections made based on the z-score analysis. Silver Springs, although located in the St. Johns River WMD, is the nearest spring to Crystal Springs with a daily flow record that includes substantial portions of both AMO periods. Using either the mean or median difference in flow between the AMO periods of 1940-69 versus 1970-94 at Silver Springs, the percent reduction in flow between the two periods amounts to approximately 8% (Figure 2-70). This 8% decline estimate is undoubtedly affected by some anthropogenic withdrawals, so it could be considered an overestimate of the climatic effect. Assuming that an 8% decline in flow should be expected at Crystal Springs based on climatic variation due to the AMO, it should be expected that any decline in excess of 8% might be anthropogenic. If for example, we anticipate an 8% climatic decline, but a 25% decline in flow has occurred, then a 17% decline might be attributable to anthropogenic factors (e.g., withdrawals, structural alterations, etc.). This would in turn mean that the decline could be partitioned into an amount due to climate (8% decline/25 or 32%) and an amount due to anthropogenic factors (17% decline/25% decline, or 68%).

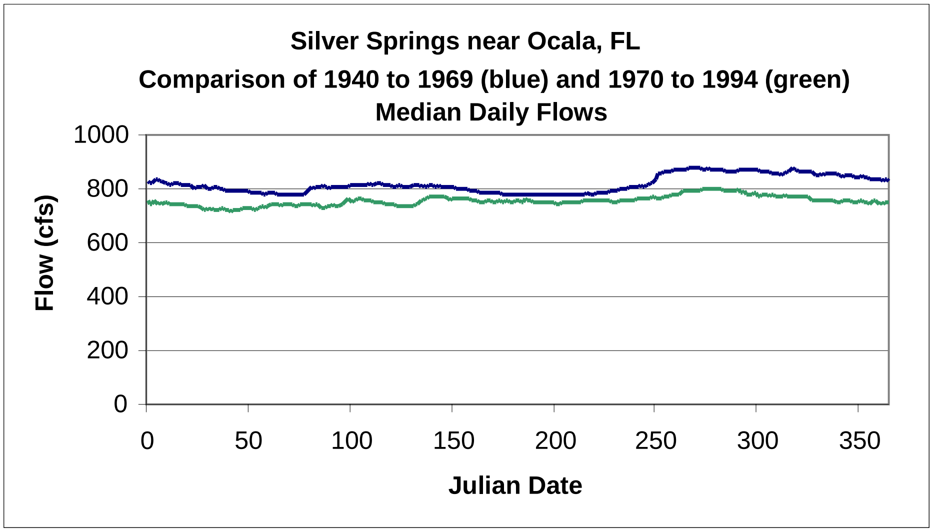


Figure 2-70. Plot comparing median daily flows for two AMO periods; the average difference in mean and median daily flows between the two periods amounted to 8.7 and 7.6%, respectively.

Because of the uncertainty related to the degree of decline in spring flow and the relative proportion of the decline that could be attributed to climate, withdrawals and other anthropogenic factors, several different scenarios were evaluated when modeling flow reductions for purposes of evaluating a minimum flow.

Three iterations of PHABSIM analyses were made assuming that spring flows had declined from a mean/median of approximately 60 cfs. Three projections with respect to withdrawal impacts on Crystal Springs' flow were made with this assumption:

1. ***no impact due to withdrawals*** – this allowed us to use the flow record without correcting for groundwater withdrawals – and would give the maximum percent reduction in flows assuming flows had not yet been impacted;

2. ***a 50% impact due to withdrawals*** - essentially half (50%) of the presumed lost was assumed to be due to withdrawals and was added back into the flow record to determine how much water could be withdrawn from the "natural flow" before significant harm occurred;

3. ***a 75% impact due to withdrawals*** – essentially 25% of the decline in flow was assumed to be natural (related to climate variability) while the

remaining decline is attributed to groundwater withdrawals from the springshed.

Table 2-27 shows how the Crystal Springs flow record was corrected by assuming a 50% and 75% groundwater withdrawal effect on spring flow decline, which is also corrected, for withdrawals by Crystal Springs Corp. beginning in 1990. The correction was applied by decade assuming that the mean and median annual flow should be 60 cfs for the AMO wet period. For example, since the average of the mean and median annual flow for Crystal Springs for the decade of the 1950s was 58.5 cfs, it was assumed that flows had declined by 1.5 cfs. Since 50% of 1.5 cfs is 0.75 cfs, 0.75 cfs was added to each day's flow at Zephyrhills for the decade of the 1950s. If one assumes that 75% of the decline is due to withdrawals, then 1.125 cfs would be added to the measured flows for each day in the decade of the 1950's to account for withdrawals. The median and mean flow for Crystal Springs was 43 and 44 cfs, respectively for the decade of the 1990s. Again assuming that flows should be 60 cfs, 50% and 75% of the difference (60 cfs – 43.5 cfs = 16.5 cfs) was added to each day's flow to simulate a withdrawal impact amounting to 50 and 75%. In addition the mean daily withdrawal by Crystal Springs Corp. was added back into the flow record beginning in 1990. For example, in 1991, the average daily withdrawal was approximately 80,000 gallons/day or 0.12 cfs. For 2000, the average daily withdrawal was approximately 280,000 gallons/day or 0.43 cfs.

Table 2-27. Values used to correct flow records at Zephyrhills and Morris Bridge gage sites assuming a 50 or 75% impact on spring flow decline due to withdrawals.

Decade/Year	Crystal Springs Flow Mean (cfs)	Median (cfs)	Difference from 60 cfs average	50% Correction (cfs)	75% Correction (cfs)	Crystal Springs Mean Daily Withdrawal (cfs)
1920s	56	56				
1930s	66	63				
1940s	64	62				
1950s	59	58	1.5	0.8	1.1	
1960s	58	56	3.0	1.5	2.3	
1970s	49	50	10.5	5.3	7.9	
1980s	51	53	8.0	4.0	6.0	
1990	44	43	16.5	8.3	12.4	0.12
1991	44	43	16.5	8.3	12.4	0.12
1992	44	43	16.5	8.3	12.4	0.12
1993	44	43	16.5	8.3	12.4	0.15
1994	44	43	16.5	8.3	12.4	0.19
1995	44	43	16.5	8.3	12.4	0.23
1996	44	43	16.5	8.3	12.4	0.28
1997	44	43	16.5	8.3	12.4	0.31
1998	44	43	16.5	8.3	12.4	0.36
1999	44	43	16.5	8.3	12.4	0.43
2000	38	37	22.5	11.3	16.9	0.43
2001	38	37	22.5	11.3	16.9	0.45
2002	38	37	22.5	11.3	16.9	0.45
2003	38	37	22.5	11.3	16.9	0.50
2004	38	37	22.5	11.3	16.9	0.57
2005	38	37	22.5	11.3	16.9	0.65

With the exception of Block 1 flows, these various assumptions had little effect on proposed minimum flows for most of the year, simply because Crystal Springs supplies a comparatively smaller portion of the flow in Blocks 2 and 3. The minimum flow recommendations to follow will be based on assuming that historic mean/median daily flow was 60 cfs and that 50% of the decline experienced between approximately 1960 to present is attributable to anthropogenic factors.

2.7 Water Chemistry

2.7.1 Water Quality Data

Although flow can affect water quality, it is not expected that the adoption and achievement of minimum flows in the Hillsborough River will necessarily lead to substantial changes in water quality. However, it is appropriate to review the water quality of the Hillsborough River to fully appreciate how land use changes may have affected the system.

Long-term water quality changes were evaluated using USGS data gathered at gage sites on the Hillsborough River and several of its tributaries (see Appendix WQ). Comparison of water quality data with flow records was made for evaluation of possible relationships between flow and land use. In addition, comparisons were made with gage sites on other river systems. Crystal Springs water quality will be summarized at the end of this section rather than including it within the general discussion of the Hillsborough River. This is because paired flow measurements were not often made, and it is not possible to relate concentrations to changes in flow in any quantifiable way. However, interesting changes in Crystal Springs water quality have apparently occurred and these are worth reviewing if only in a qualified way.

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

Data for each parameter discussed in the following sections of this chapter are typically presented in three plots: a time-series plot, a plot of the parameter versus flow, and a plot of the residuals obtained from a LOWESS regression of the parameter versus flow (Figures 2-71 through 2-76). The last plot was used to evaluate if a parameter's loading has increased or decreased over time irrespective of flow. The results of a Kendall's tau analysis on the residuals were used to help determine if apparent increasing or decreasing trends in a parameter were statistically significant.

2.7.2 Macronutrients: Phosphorus and Nitrogen

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

2.7.2.1 Phosphorus

Phosphorus has over the years been variously reported by the USGS as total phosphorus, dissolved phosphate, and as ortho-phosphate. For our analyses, it was assumed that dissolved phosphate and ortho-phosphate are essentially equivalent. Although some of the older data were reported as mg/l phosphate, all values were converted and expressed as mg/l phosphorus (P).

Friedemann and Hand (1989) determined the typical ranges of various constituents found in Florida lakes, streams and estuaries. Based on their finding, 90% of all Florida streams exhibited total phosphorus concentrations less than 0.87 mg/l P. Phosphorus concentrations at the Zephyrhills gage were noticeably higher between 1970 to about 1982, and values above 1.0 mg/l P were only detected during this time (Figure 2-71). It is believed that these elevated concentrations were at least in part attributable to the phosphate mining industry, since fluoride concentrations (see Figure 2-76) were also slightly elevated during this time. These results are consistent with similar observations in the Peace (SWFWMD 2000, Kelly et al. 2005a) and Alafia Rivers (Kelly et al. 2005b). It is believed that these elevated concentrations are associated with the processing of the ore rather than extraction. It should be noted that all the systems referenced (Peace, Alafia and Hillsborough) showed a substantial reduction in phosphorus (and fluoride and sulfate) concentrations in the early to mid-1980s, and reflects, as has been previously noted, a considerable decrease in water use by the mining industry (Kelly et al. 2005a).

2.7.2.2 Nitrogen

Nitrogen has most often been reported by the USGS as either nitrate or nitrate+nitrite. For our analyses, it was assumed that total nitrate, dissolved nitrate, and nitrate+nitrite are essentially equivalent, unless both were reported. In this case, the highest concentration was used for data analysis. Total Kjeldahl nitrogen, total organic nitrogen, ammonia nitrogen and total nitrogen are not considered here, because considerably fewer observations were generally made for these parameters.

Although not as apparent in the time series plot, there has been a noticeable change in NOx concentration over time (Figure 2-72). The residual plot is easier to read and suggests that NOx concentrations increased from about 1975 to 1988 irrespective of flow, but have leveled off since then. The leveling off is somewhat surprising, since NOx concentrations have continued to climb in water being discharged from Crystal Springs. NOx concentrations at Zephyrhills are now typically in the range of 0.5 to 1.5 mg/l, while concentrations in Crystal Springs water has continued to climb over its period of record and now appear to be averaging approximately 2.5 mg/l (concentrations were typically less than 1.0 mg/l prior to 1972). It should be noted, however, that nitrate concentrations at Crystal Springs are still well below the drinking water quality standard of 10 mg/l N.

2.7.3 Potassium and Trend Analysis of Selected Chemical Constituents

One of the more interesting and unanticipated findings of the analysis of gage site water quality data on the Peace River (SWFWMD 2002) was an apparent increasing trend in dissolved potassium (Figure 2-73). 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. While this trend was also observed in the Myakka and Alafia River watersheds, potassium concentrations have not shown a similar trend at mainstem sites on the Hillsborough River (Figure 2-74). The residual plot does suggest an increasing trend from the 1950s to early 1970s; however, concentrations do not appear to have increased since that time. This suggests that if loadings in other watersheds are due to increased fertilizer application in the watershed, this has not, in general, occurred upstream of Zephyrhills. This may be attributable to the declining acreage of agricultural land in this watershed. The apparent increasing trend in conductance (figure 2-75) may be related primarily to the increasing trend seen at crystal springs (Figure 2-77) since conductance generally decreases as flow increases.

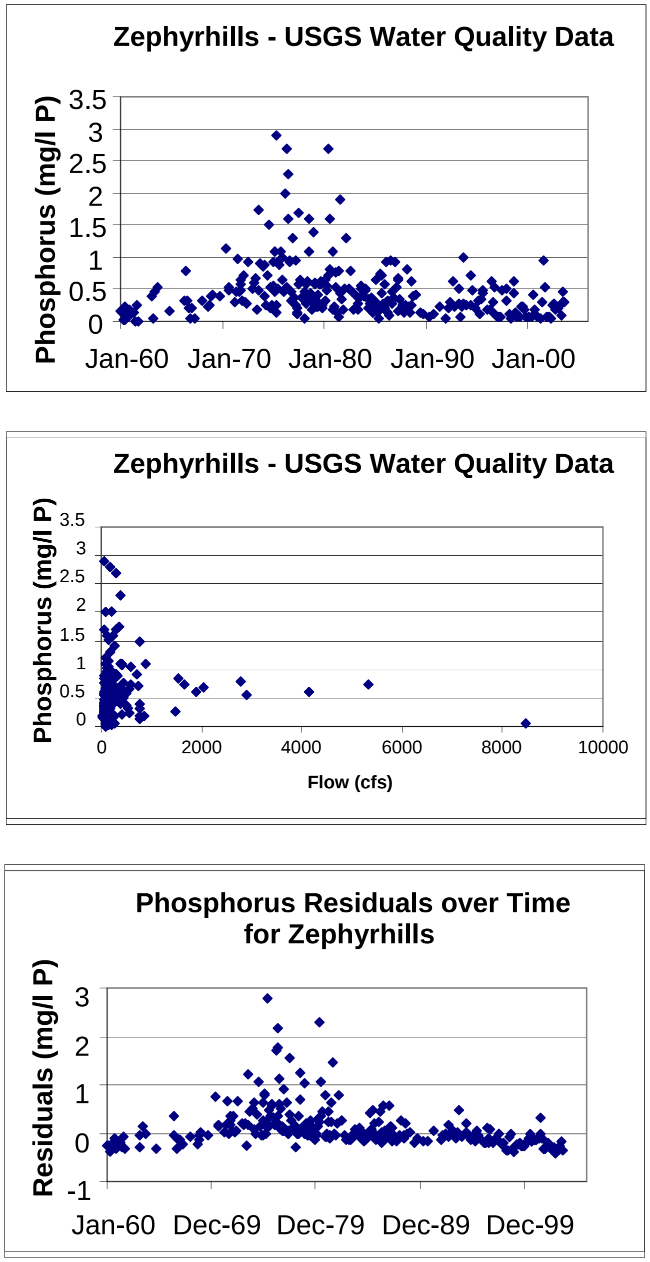
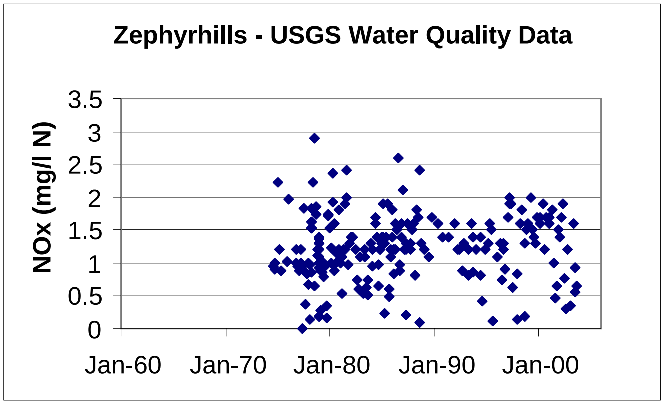
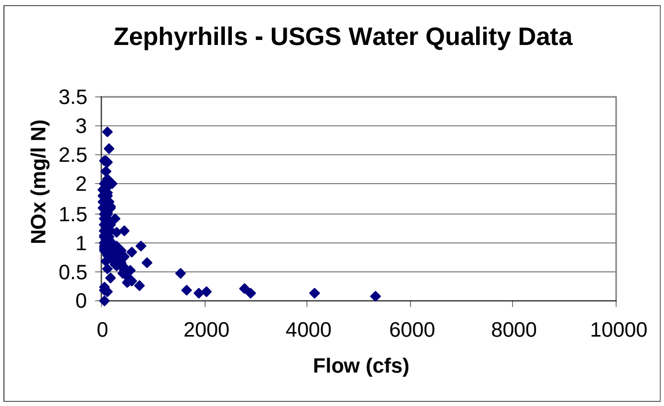


Figure 2-71. Phosphorus concentrations in water samples collected by the USGS at the Hillsborough River near Zephyrhills gage. Upper plot is time series plot; middle plot is concentration versus flow; and the bottom plot is time series plot of residuals of phosphorus concentration regressed against flow.





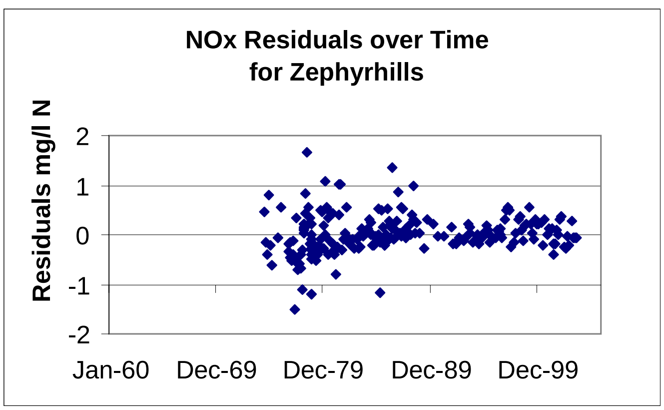


Figure 2-72. Nitrate or nitrate/nitrite concentrations in water samples collected by the USGS at the Hillsborough River near Zephyrhills gage. Upper plot is time series plot; middle plot is concentration versus flow; and the bottom plot is time series plot of residuals of nitrate/nitrite concentration regressed against flow.

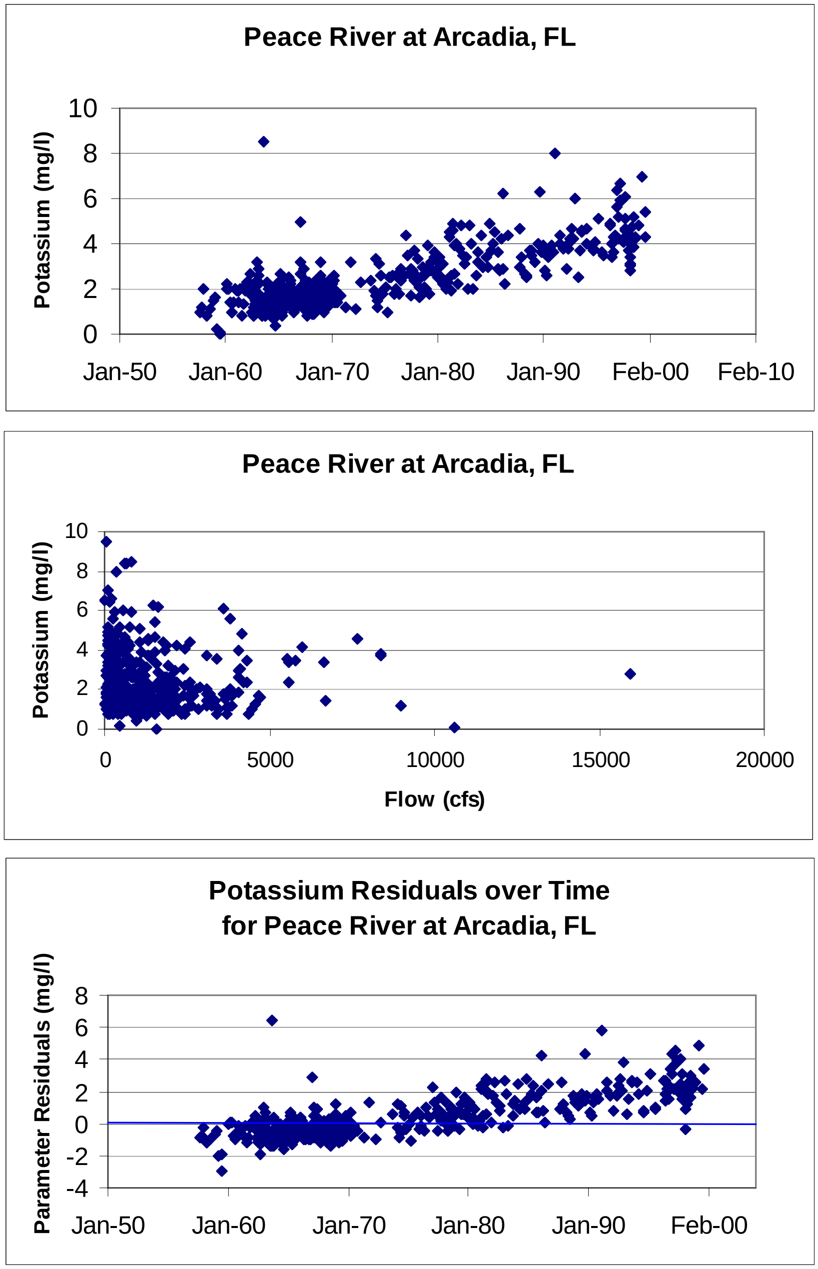


Figure 2-73. Potassium concentrations in water samples collected by the USGS at the Peace River at Arcadia gage. Upper plot is time series plot; middle plot is concentration versus flow; and the bottom plot is time series plot of residuals of potassium concentration regressed against flow.

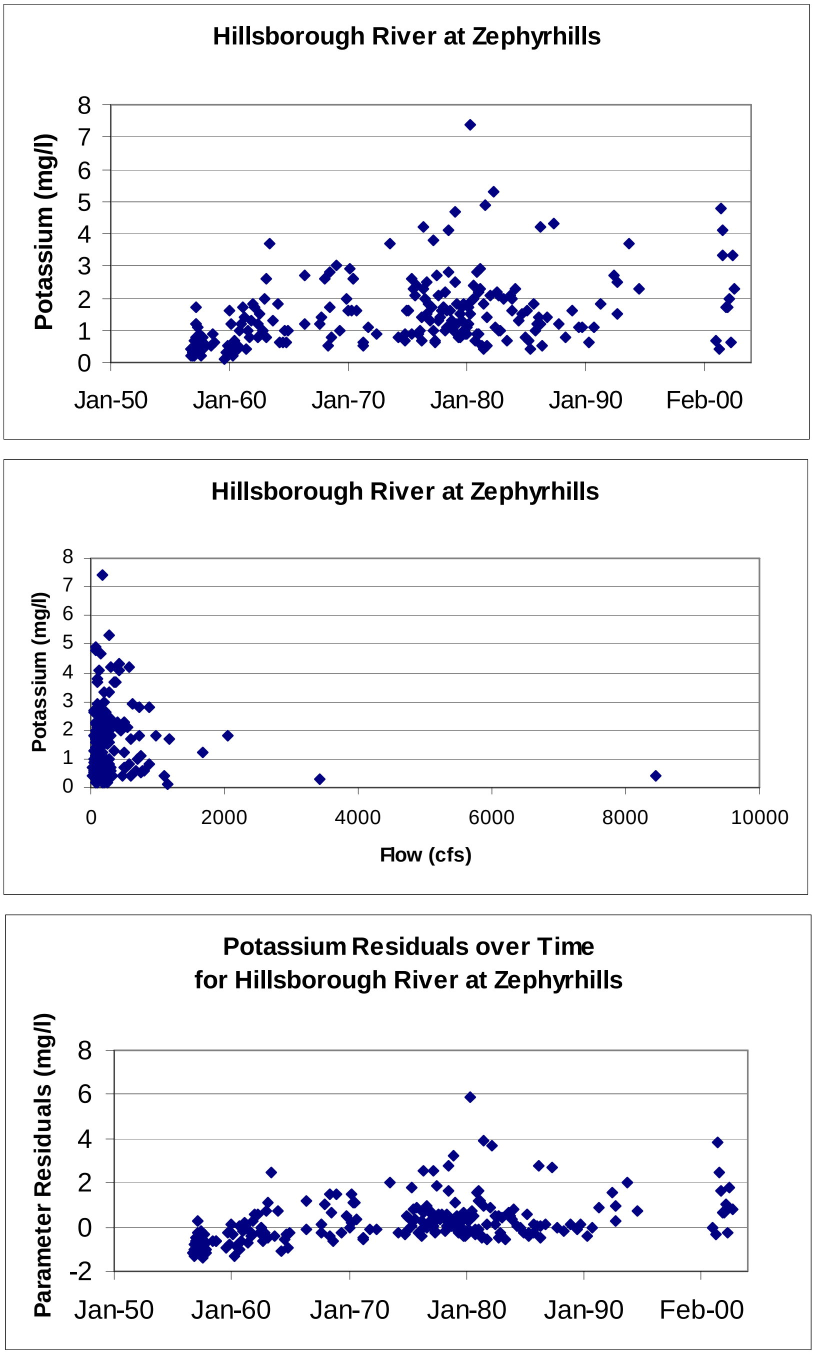
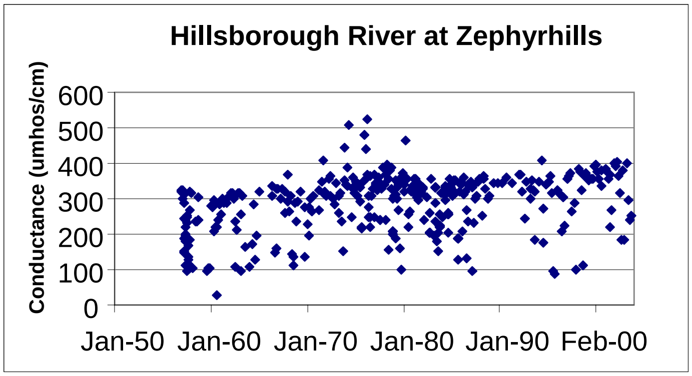
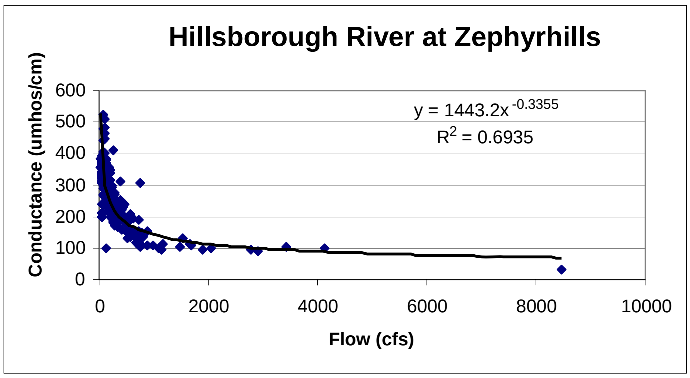


Figure 2-74. Potassium concentrations in water samples collected by the USGS at the Hillsborough River near Zephyrhills gage. Upper plot is time series plot; middle plot is concentration versus flow; and the bottom plot is time series plot of residuals of potassium concentration regressed against flow.





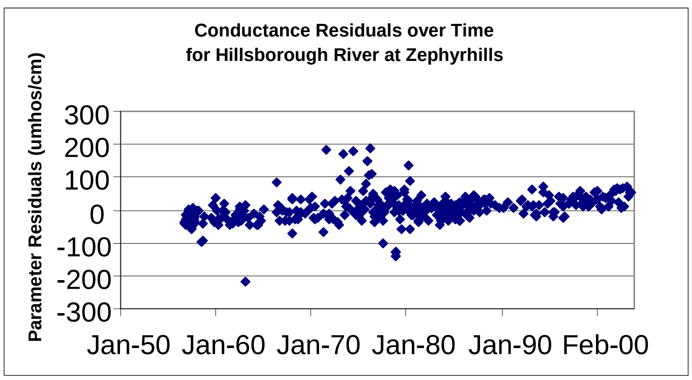
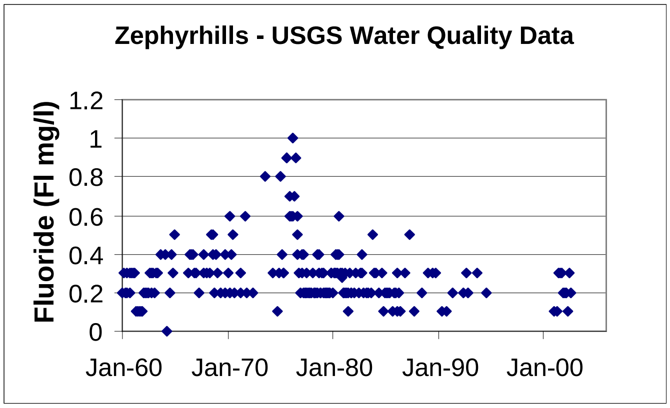
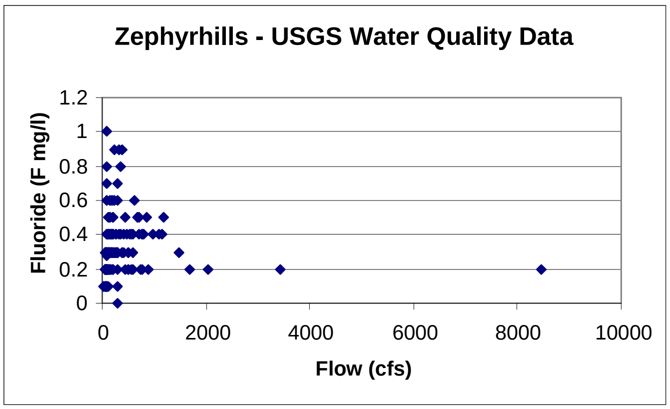


Figure 2-75. Conductance in water samples collected by the USGS at the Hillsborough River near Zephyrhills gage. Upper plot is time series plot; middle plot is conductance versus flow; and the bottom plot is time series plot of residuals of conductance regressed against flow.





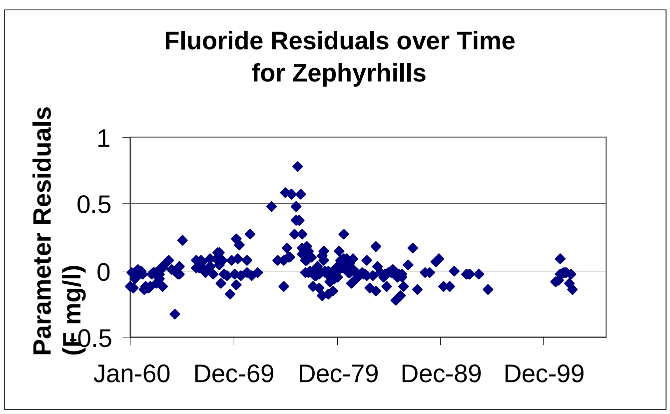


Figure 2-76. Fluoride concentrations in water samples collected by the USGS at the Hillsborough River near Zephyrhills gage. Upper plot is time series plot; middle plot is concentration versus flow; and the bottom plot is time series plot of residuals of fluoride concentrations regressed against flow.

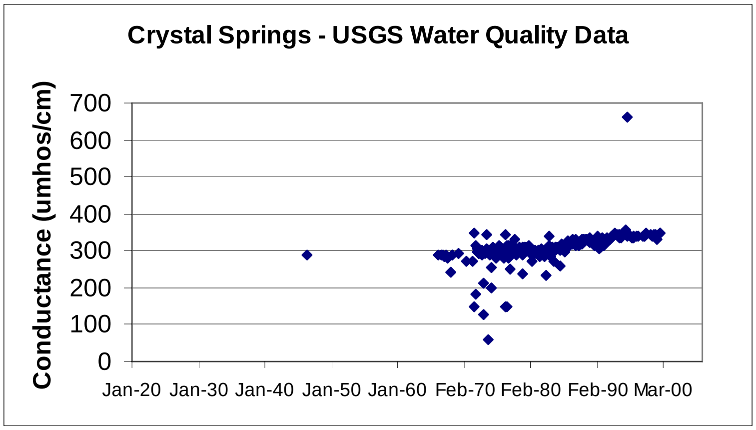
2.7.4 Crystal Springs Water Quality and Water Quality Changes in Numerous Spring Systems

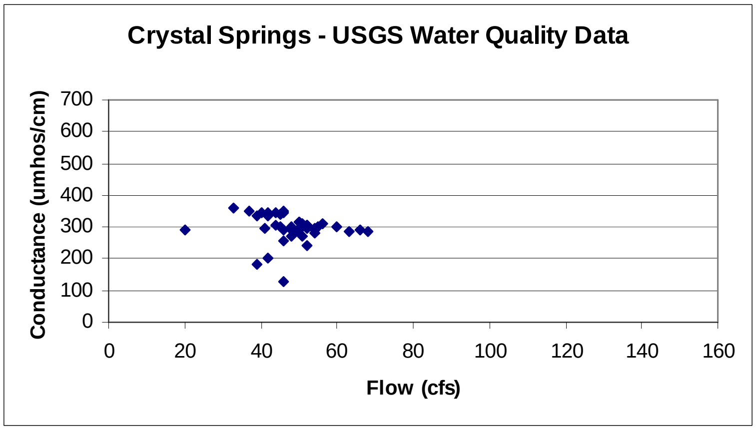
An increasing trend in NOx concentrations has been demonstrated for many springs in Florida, and is attributable to various anthropogenic factors (e.g., septic tank leakage, fertilizer application) and has previously been documented for Crystal Springs. The nitrate-nitrite nitrogen concentration in Crystal Springs water is >2.5 mg/l. The trend is monotonic, and appears to be continuing upward.

While flow data for Crystal Springs collected at the time of water quality sampling indicates a decrease in flow over the period of record, several parameters show an increasing trend that does not appear to be directly related to this flow decline. A number of parameters were investigated for Crystal Springs and a number of other springs in the state (Figures 2-77 through 2-87). Trends (generally what appear to be monotonic increases over time) appear to have occurred at a number of spring sites scattered throughout the state and are not unique to Crystal Springs. Increases in these parameters may not necessarily be related to flow declines, since similar increases can be seen in a spring with an increasing flow trend (e.g., Miami Springs, although it has been noted that Miami Springs may have a decreasing flow trend (see peer review report (Chapter 8) – Figure 2-81).

For whatever reason(s) many springs show, in addition to an increasing trend in nitrate nitrogen, a monotonic increasing trend in conductance. Although nitrate should cause some increase in conductance, the increasing trend at many sites followed the increasing trend in nitrate by several years. Weeki Wachee Spring, for example, has demonstrated an increasing trend in nitrate or NOx nitrogen since the early 1970s when concentrations were quite low (Figure 2-86). What is interesting in the Weeki Wachee data is a steeper rate of nitrate increase (a noticeable inflection) that coincides with a rather distinct inflection in conductance that began in the mid-1980s. Rainbow Springs in Marion County (Figure 2-83) is an interesting contrast to most of the springs examined. Flows and conductance have remained relatively stable (what appears to be outliers in some of the plots are explained by the fact that samples were taken at a different location and thus reflect the water quality of a different vent - Mumma 1996). Water quality plots for Rainbow River do reveal an increasing trend in nitrate-nitrite nitrogen, but other parameters (e.g., conductance, calcium, chloride) observed to have increased at other spring sites show no trend at Rainbow Springs. In contrast to this major first magnitude spring (i.e., Rainbow River), Silver Springs (Figure 2-87) with a similar discharge shows an apparent decreasing flow trend (although this may be related to a change in how this stream is now rated), while conductance, nitrate-nitrite nitrogen, and calcium (among others) reveal what appear to be distinct increasing monotonic trends.

Although changes in water chemistry are not particularly large, most springs examined showed a distinct change in water quality. This means that in many systems where springs are at least seasonally important (a major source of baseflow), the chemistry of the baseflow has and apparently continues to change. What ecological consequences in spring runs and streams, if any, that may result from changes in groundwater chemistry are not known. One also has to wonder what the ecological ramifications of such water quality changes might be on our larger spring-fed systems such as Rainbow River and Silver River, where spring flow is essentially all the flow in these rivers. More research is needed on spring systems with long chemistry records. This research needs to be done collectively on as large a data set as possible (statewide), since it may be that these water quality changes are at least regional in scale. Two major questions to address are: 1) why are these changes occurring, in other words, a cause/effect relationship needs to be understood, and 2) what are the ecological consequences of these changes on biologic communities.





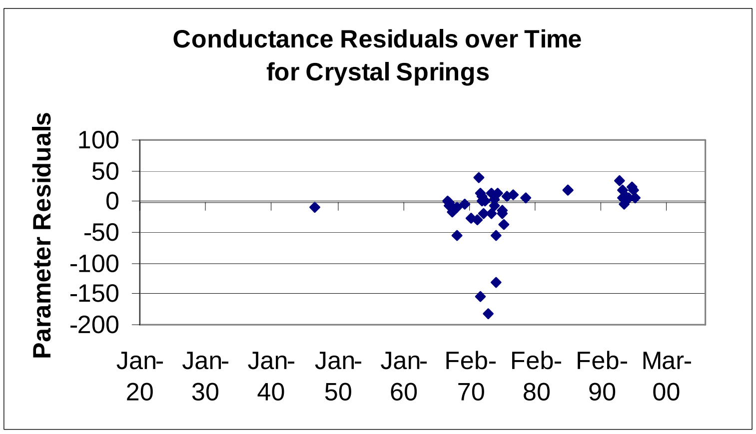
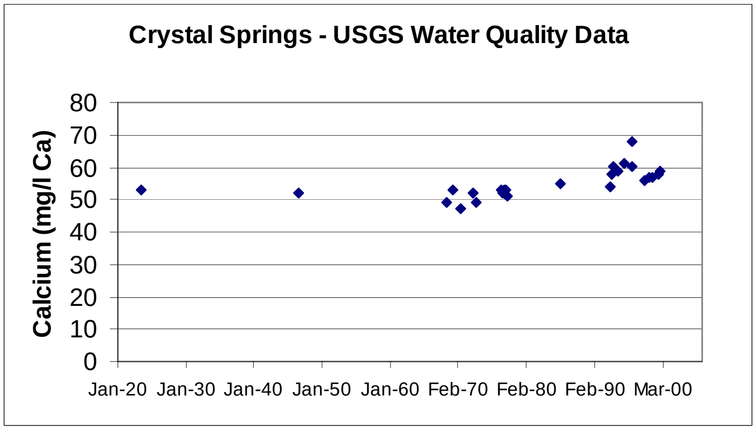
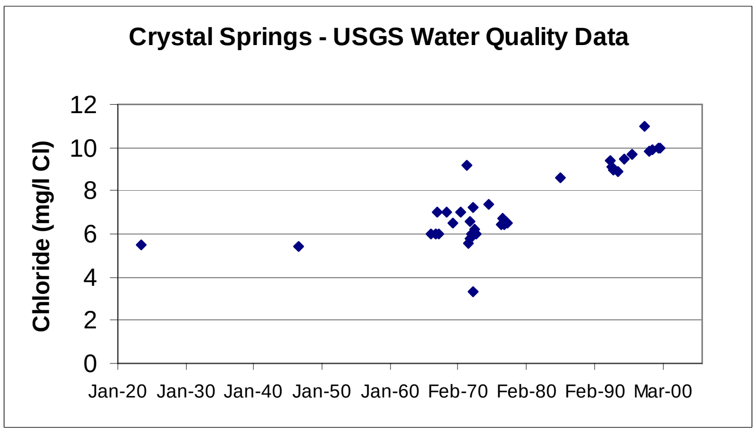


Figure 2-77. Conductance in water samples collected by the USGS at Crystal Springs. Upper plot is time series plot; middle plot is conductance versus flow; and the bottom plot is time series plot of residuals of conductance regressed against flow.





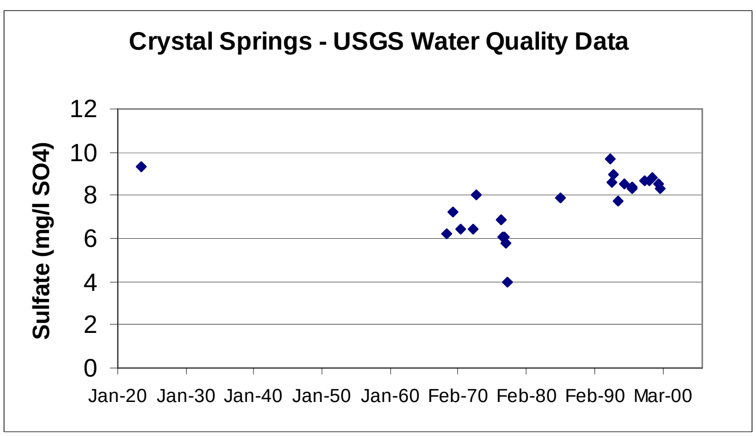


Figure 2-78. Time series plots of sulfate, chloride, and calcium concentrations in water samples collected by the USGS at Crystal Springs.

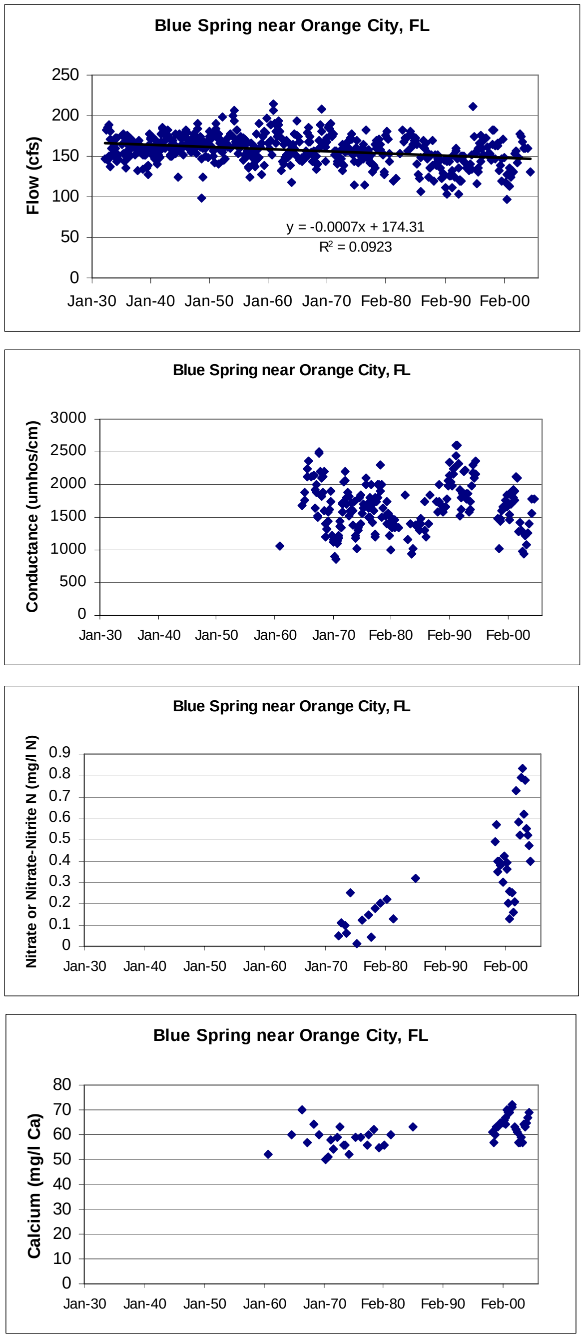


Figure 2-79. Time series plots of flow and selected water quality parameters at Blue Springs.

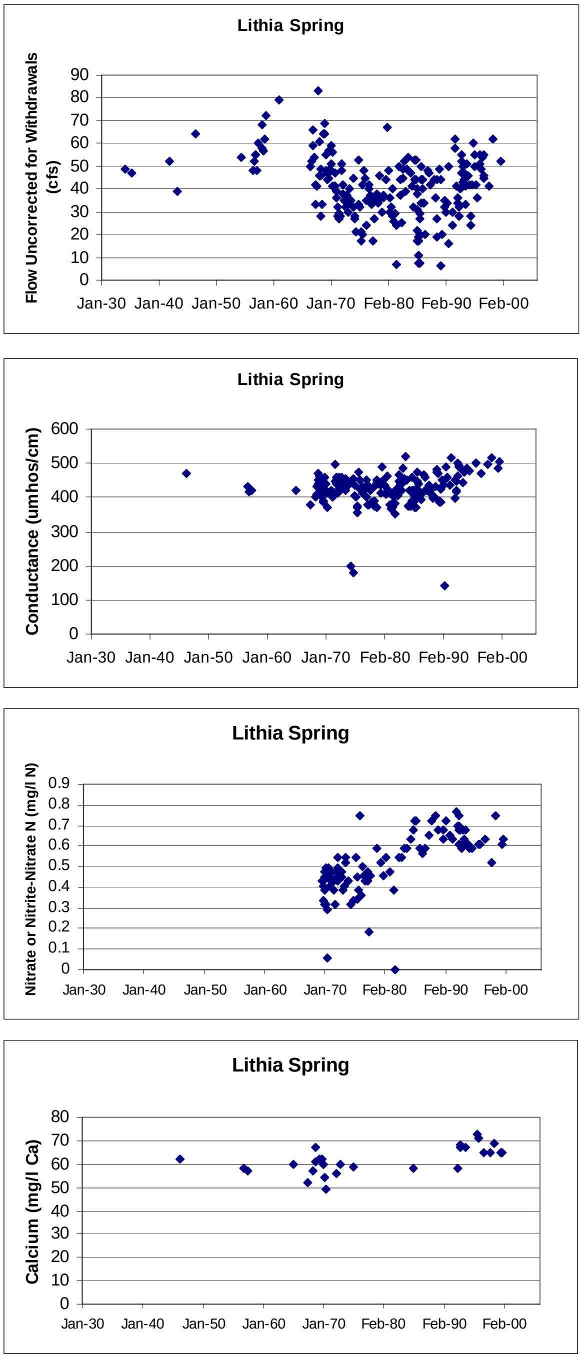


Figure 2-80. Time series plot s of flow and selected water quality parameters at Lithia Springs.

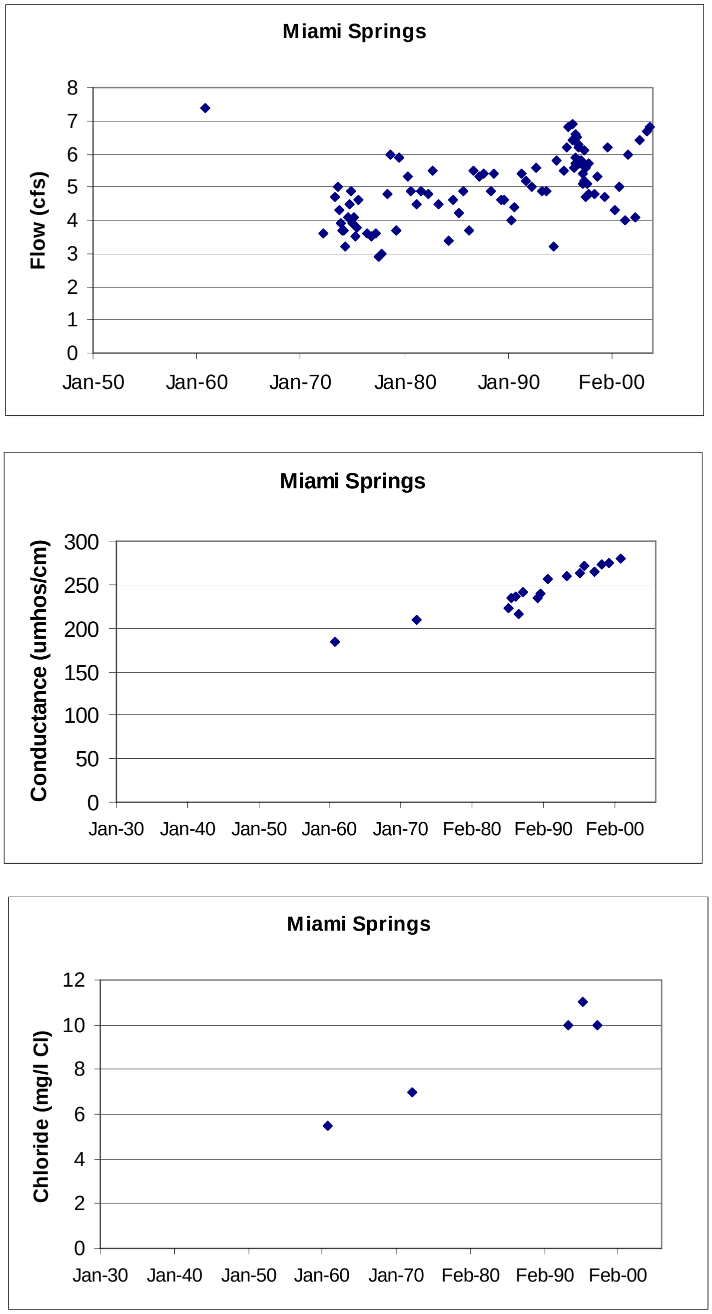
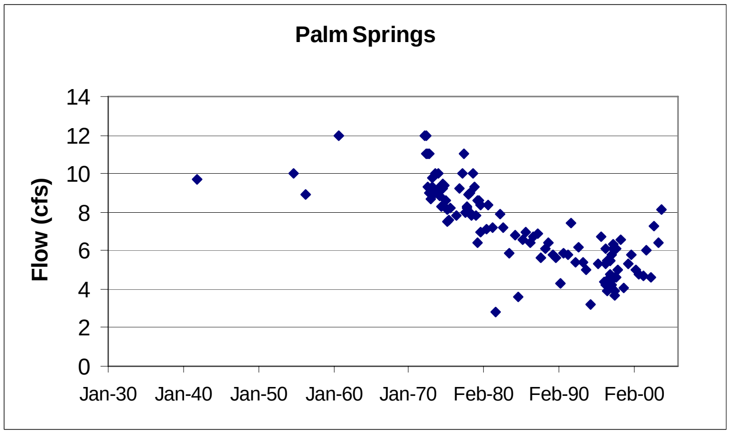
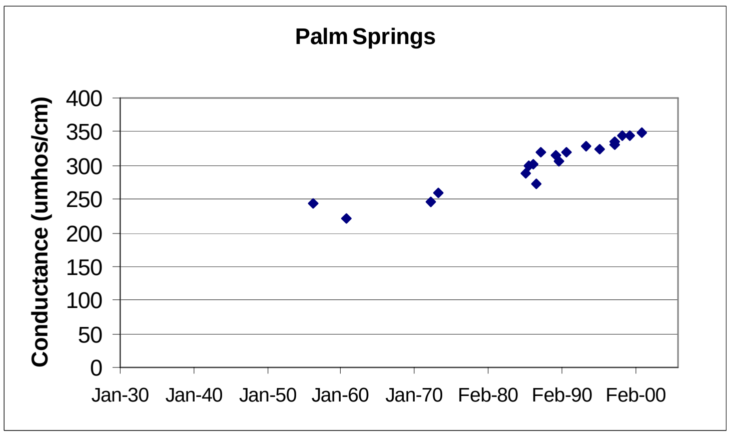


Figure 2-81. Time series plot s of flow and selected water quality parameters at Miami Springs.





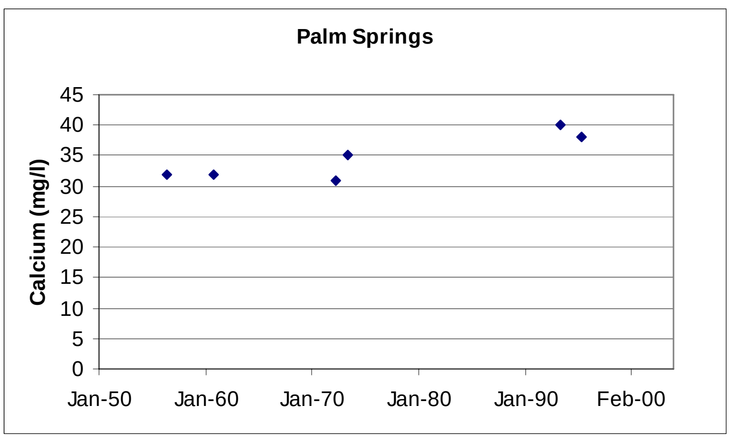


Figure 2-82. Time series plot s of flow and selected water quality parameters at Palm Springs.

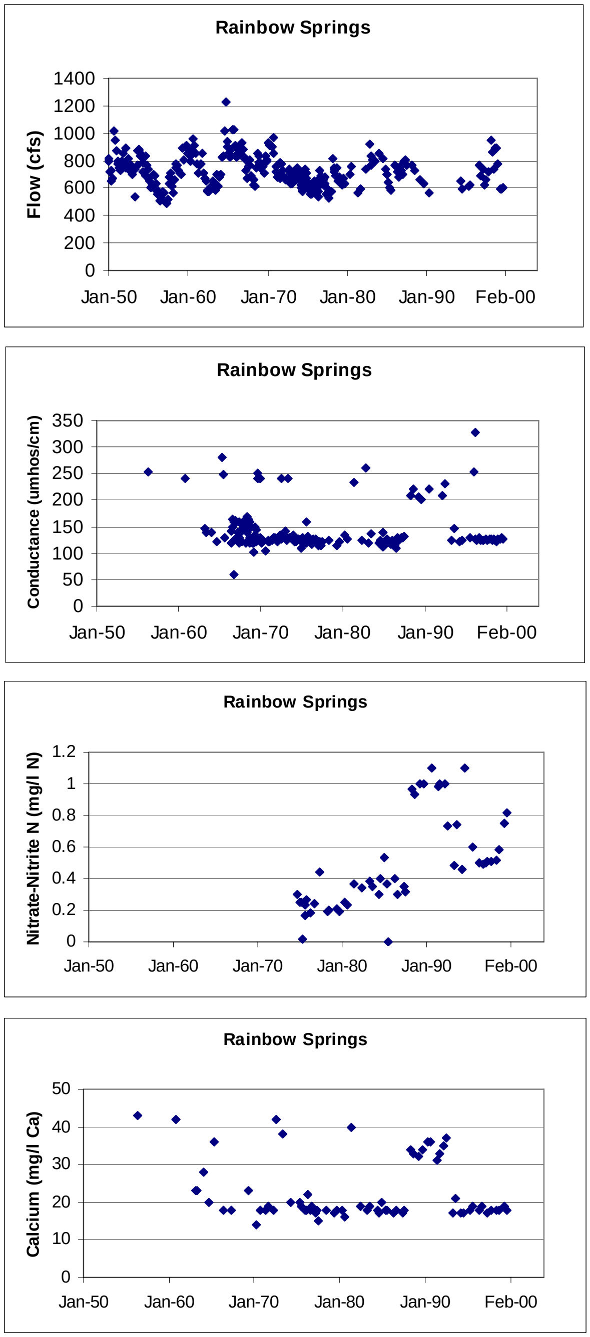


Figure 2-83. Time series plot ss of flow and selected water quality parameters at Rainbow Spring.

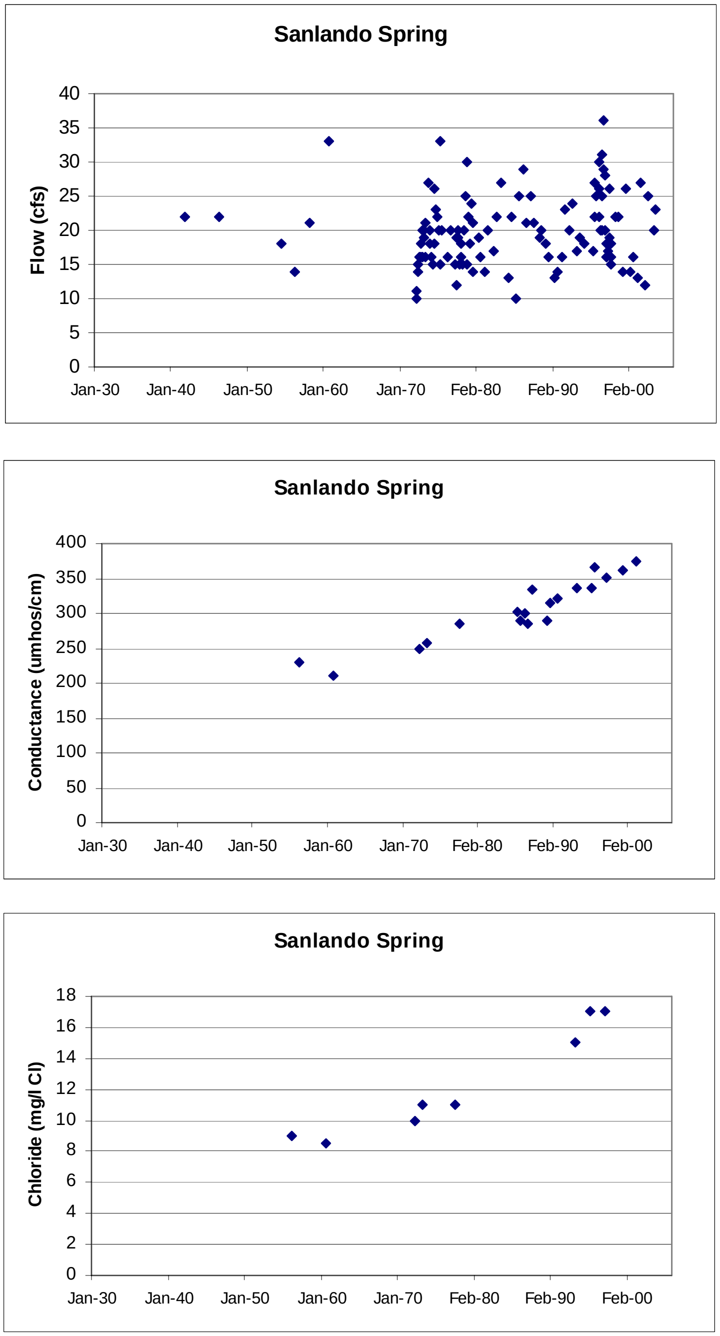
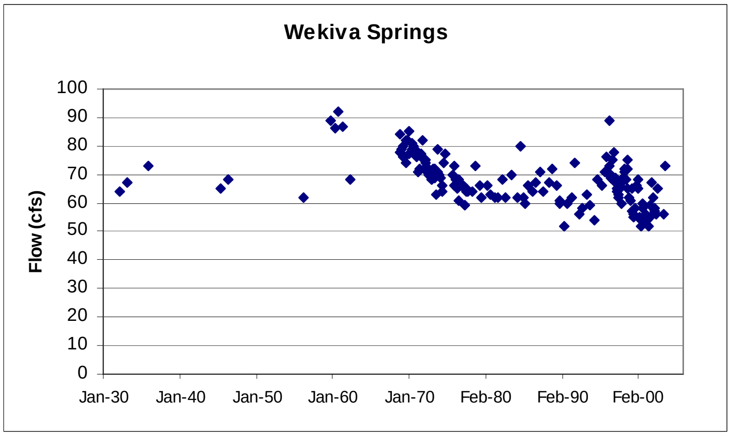
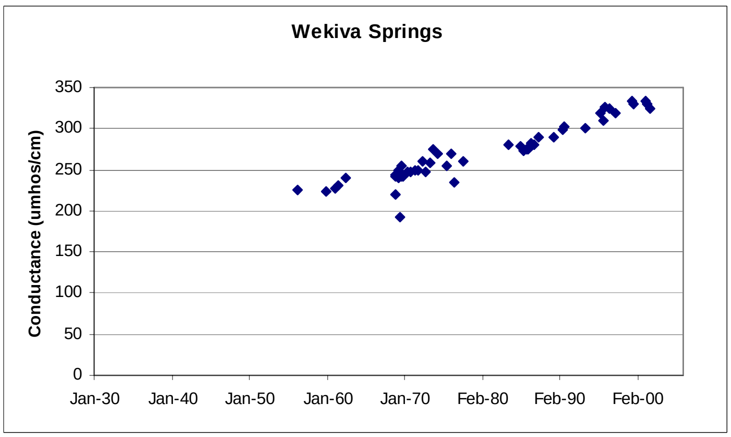


Figure 2-84. Time series plots of flow and selected water quality parameters at Sanlando Springs.





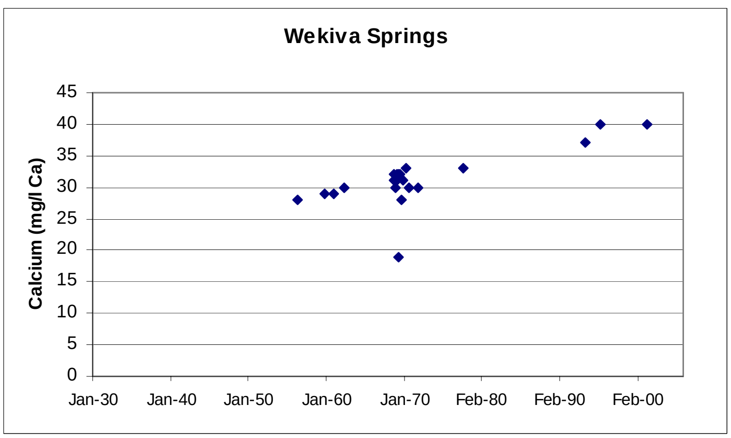


Figure 2-85. Time series plot s of flow and selected water quality parameters at Wekiva Spring.

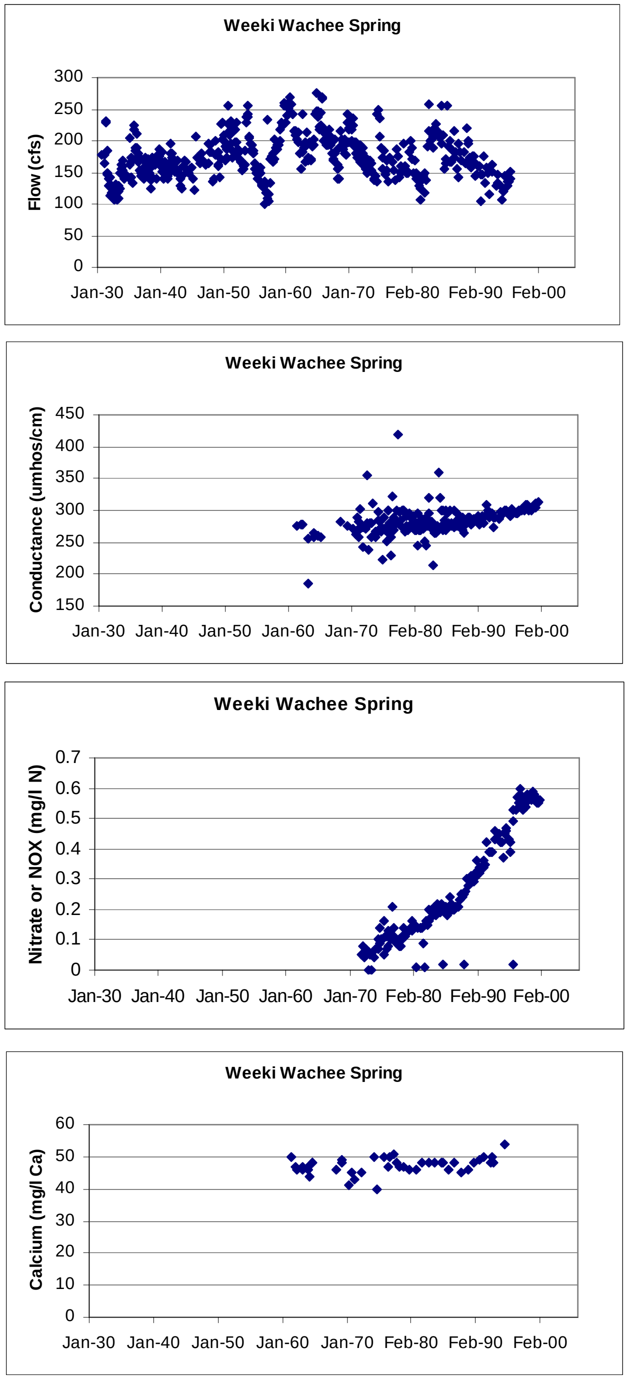


Figure 2-86. Time series plots of flow and selected water quality parameters at Weeki Wachee Springs.

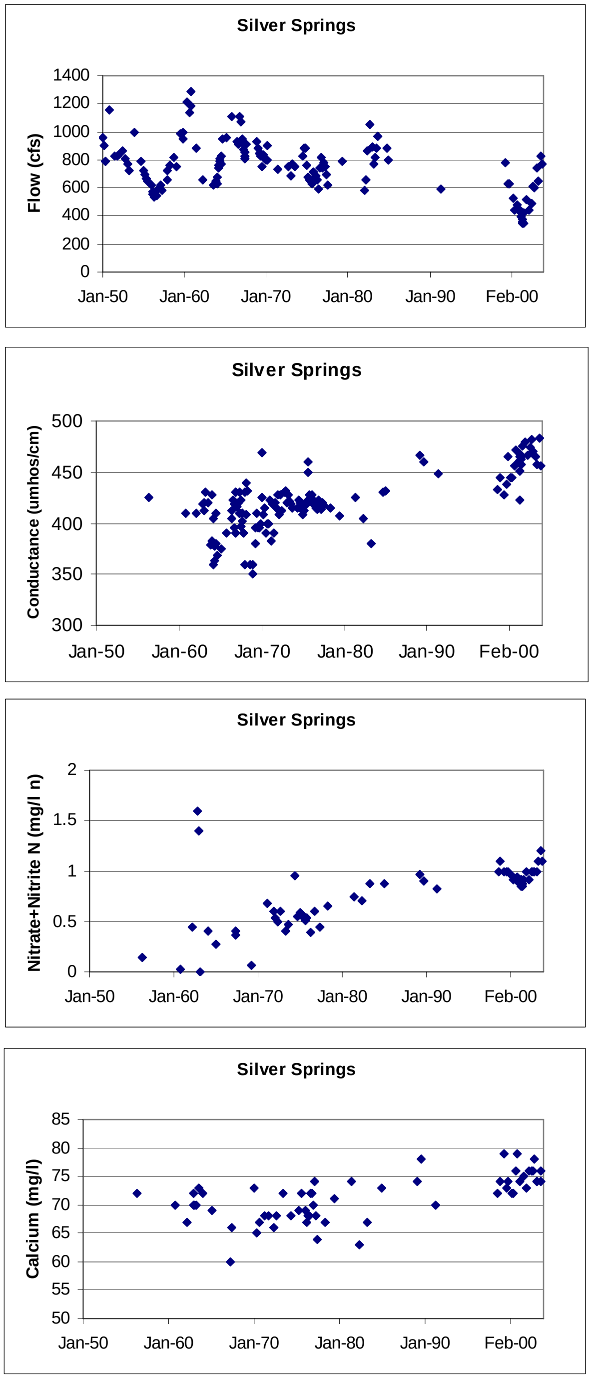


Figure 2-87. Time series plots of flow and selected water quality parameters at Silver Springs.

3 Goals, Ecological Resources of Concern and Key Habitat Indicators

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

3.1 Goal – Preventing Significant Harm

The goal of an MFL determination is to protect the resource from significant harm due to withdrawals and was broadly defined in the enacting legislation as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." What constitutes "significant harm" was not defined. The District has identified loss of flows associated with 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), significant harm in many cases can be defined as quantifiable reductions in habitat.

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

Based on Gore et al. (2002) comments regarding significant impacts of habitat loss, we recommend use of a 15% change in habitat availability as a measure of significant harm for the purpose of MFLs development. Although we recommend a 15% change in habitat availability as a measure of unacceptable loss, it is important to note that percentage changes employed for other instream flow determinations have ranged from 10% to 33%. For example, Dunbar et al. (1998) in reference to the use of PHABSIM noted, "an alternative approach is to select the flow giving 80% habitat exceedance percentile," which is equivalent to a 20% decrease. Jowett (1993) used a guideline of one-third loss (i.e., retention of two-thirds) of existing habitat at naturally occurring low flows, but acknowledged that, "[n]o methodology exists for the selection of a percentage loss of "natural" habitat which would be considered acceptable." The state of Texas utilized a target decrease of less than 20% of the historic average in mandating flows into Matagorda Bay.

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 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 Hillsborough 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 persistence of 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 2003) 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 (Figure 3-1). 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 there is a direct relationship between wetted perimeter and fish habitat. 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. By plotting the response of wetted perimeter to incremental changes in discharge, an inflection can be identified in the resulting curve where small decreases in flow result in increasingly greater decreases in wetted perimeter. This point on the curve represents a flow at which the water surface recedes from stream banks and fish habitat is lost at an accelerated rate. Stalnaker et al. (1995) describe the wetted perimeter approach as a technique for using "the break" or inflection point in the stream's wetted perimeter versus discharge relation as a surrogate for minimally acceptable habitat. They note that when this approach is applied to riffle (shoal) areas, "the assumption is that minimum flow satisfies the needs for food production, fish passage and spawning."

We view the wetted perimeter approach as an important technique for evaluating minimum flows and levels near the low end of the flow regime. 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 are included in the District's approach for establishing minimum flows for river systems. PHABSIM provides a means to quantify changes in habitat that are associated with changes in stream flow. 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 and site-specific field work.

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

Wood provides advantages as habitat, as it is relatively stable and long lived compared to sand substrata, which constantly shift (Edwards and Meyer 1987). 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

A goal of the SWFWMD's minimum flows and levels approach is to ensure that the hydrologic requirements of biological communities associated with the river floodplain are met during seasonally predictable wet periods. Periodic inundation of riparian floodplains by high flows is closely linked with the overall biological productivity of river ecosystems (Crance 1988, Junk et al., 1989). Many fish and wildlife species associated with rivers utilize both instream and floodplain habitats, and inundation of the river floodplains greatly expands the habitat and food resources available to these organisms (Wharton et al. 1982, Ainsle et al. 1999, Hill and Cichra 2002). Inundation during high flows also provides a subsidy of water and nutrients that supports high rates of primary production in river floodplains (Conner and Day 1979, Brinson et al. 1981). This primary production produces large amounts of organic detritus, which is critical to food webs on the floodplain and within the river channel (Vannote et al. 1980, Gregory et al. 1991). Floodplain inundation also contributes to other physical-chemical processes that can affect biological production, uptake and transformation of macro-nutrients (Kuensler 1989, Walbridge and Lockaby 1994).

Soils in river floodplains exhibit physical and chemical properties that are important to the overall function of the river ecosystem (Wharton et al. 1982, Stanturf and Schenholtz 1998). Anaerobic soil conditions can persist in areas where river flooding or soil saturation is of sufficient depth and duration. The decomposition of organic matter is much slower in anaerobic environments, and mucky or peaty organic soils can develop in saturated or inundated floodplain zones (Tate 1980, Brown 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 affect the distribution and characteristics of floodplain soils, soil distributions and their relationship to river hydrology are routinely investigated as part of minimum flows and levels determinations for District rivers.

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

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

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

4 Technical Approach for Establishing Minimum Flows and Levels for the Upper Hillsborough River

4.1 Overview

Methods used to determine the minimum flow requirements for the freshwater portion of the upper Hillsborough River above the USGS gage site at Morris Bridge are described in this chapter. The approach outlined for the river involves identification of a low-flow threshold and development of prescribed flow reductions for periods of low, medium and high flows (Blocks 1, 2 and 3). The low-flow threshold is used to identify a minimum flow condition and is expected to be applicable to river flows throughout the year. The prescribed flow reductions are based on limiting potential changes in aquatic and wetland habitat availability that may be associated with changes in river flow during Blocks 1, 2 and 3.

4.2 Transect Locations and Field Sampling of Instream and Floodplain Habitats

The upper Hillsborough River was designated as the portion of the river that extends from the Green Swamp near the Withlacoochee-Hillsborough Overflow at US 98 to the USGS gage at Morris Bridge Road. The entire drainage area is approximately 375 sq. miles (Figure 4-1). Sampling included characterization of cross-sectional physical, hydrologic and habitat features. Four types of cross-sectional information were collected, including data used for HEC-RAS modeling, Physical Habitat Simulation (PHABSIM) modeling, instream habitat assessment, and floodplain vegetation/soils assessments. HEC-RAS cross-sections were established to develop flow and inundation statistics for the other cross-section sites based on existing flow records for the USGS gage sites at Zephyrhills and Morris Bridge Road. During transect selection attempts were made to include all shoals and hydrologic control points as cross sections in the models.

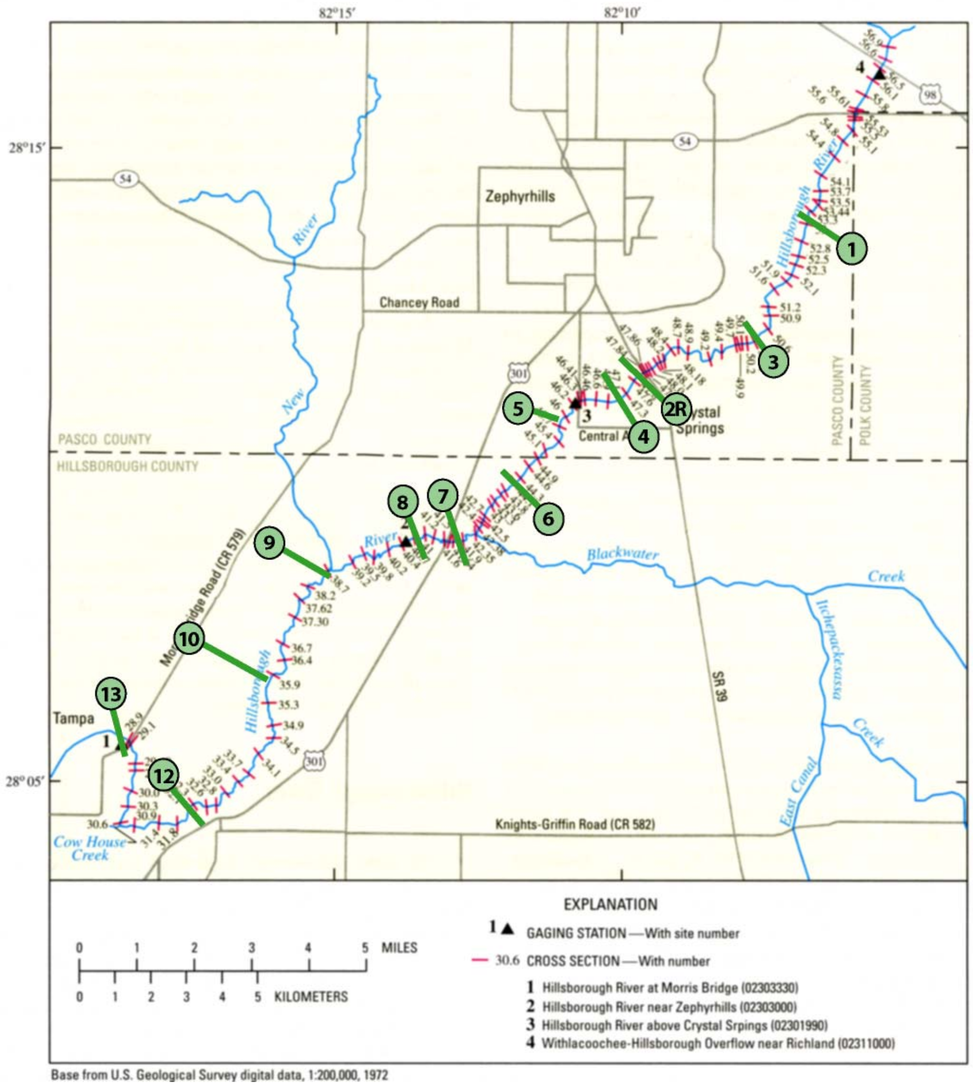


Figure 4-1. Study corridor for the upper Hillsborough River. USGS cross-sections are in red and additional SWFWMD vegetative cross-sections are shown in green. PHABSIM sites were located at or near vegetative cross-sections 12, 8 and 7. Figure was adapted from Lewelling (2004).

4.2.1 HEC-RAS Cross-Sections

Cross-section channel geometry data, used to generate a HEC-RAS model for the upper Hillsborough River, were adopted from previously established USGS channel cross-sections (Lewelling 2004) for the study area and from additional sites identified by District staff. The locations of 111 USGS cross-sections and 12 vegetative sites surveyed by the District and utilized in the HEC-RAS model are shown in Figure 4-1. Shoals, representing high spots that could restrict flow and result in loss of hydraulic connection, present barriers to fish migration, or hamper recreational canoeing were also identified by District staff in April 2003.

4.2.2 PHABSIM Cross-Sections

Physical Habitat Simulation (PHABSIM) cross-sections, designed to quantify specific habitats for fish and macroinvertebrates at differing flow conditions, were established at three sites identified on the upper Hillsborough River (see Figure 4-1). Two of the sites were situated at dominant limestone outcrops that signified major control points for flow downstream. The upper limestone site characterized river conditions with substantial spring flow from Crystal Springs and is referred to as site 7R because it was located slightly upstream of vegetative cross-section 7. The lower limestone PHABSIM site contained more tannic water originating from Blackwater Creek and is referred to as the Hillsborough River State Park site (also synonymous to vegetative cross-section 8). These sites were located upstream of the USGS gage near Zephyrhills. The third PHABSIM site, called the Sergeant Parks site, is situated further downstream (near vegetative cross-section 12) and located north of the USGS gage near Morris Bridge. This site consisted of a sandy shoal colonized by floating and emergent vegetation that accorded some distinct flow constriction at low flows. This site is representative of the wider section of the river, with adjacent broad floodplains and low bank heights, in contrast with the upper two PHABSIM sites where flow is confined in-channel due to higher bank heights and narrower stream widths.

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. Water velocity was measured with a Marsh-McBirney Model 2000 flow meter and/or a Sontek Flow Tracker Handheld Acoustic Doppler Velocimeter (ADV) at two or four-foot intervals along each cross-section. Stream depth, substrate type and habitat/cover were recorded along the cross-sections. Other hydraulic descriptors measured included channel geometry (ground elevations), water surface elevations across the channel, and water surface slope determined from points upstream and downstream of the cross-sections. Data were collected under a range of flow conditions (low, medium and high flows) to provide the necessary information needed to run the PHABSIM model for each stream reach.

4.2.3 Instream Habitat Cross-Sections

Cross-sections, for assessing instream habitats were examined at nine sites on the upper Hillsborough River (Figure 4-1). 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 27 instream cross-sections were sampled (9 cross-section sites x 3 cross-sections at each site).

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

- bottom substrates (which included sand, mud, or bedrock);
- exposed roots;
- snags or deadwood;
- aquatic plants;
- wetland (herbaceous or shrubby) plants; and
- wetland trees.

4.2.4 Floodplain Vegetation Cross Sections

For selection of vegetative cross-section sites, the river corridor was stratified using criteria described by Berryman and Henigar (2005). Twelve representative floodplain vegetation cross-sections were established perpendicular to the river channel within dominant National Wetland Inventory (NWI) vegetation types (Figures 4-1 and 4-2). Cross-sections were established between the 0.5 percent exceedance levels on either side of the river channel based on previous determinations of the landward extent of floodplain wetlands in the river corridor. Ground elevations were determined at 100-foot intervals along each cross-section. Where changes in elevation were conspicuous, elevations were surveyed more intensively.

To characterize forested vegetation communities along each cross-section, changes in dominant vegetation communities were located and used to delineate boundaries between vegetation zones. Trees were used to define vegetation communities rather than shrubs and herbaceous species, because relatively long-lived tree species are better integrators of long-term hydrologic conditions. At each change in vegetation zone, plant species composition, density, basal area and diameter at breast height (for woody vegetation with a dbh greater than 1 inch) were recorded. At least five sampling units located within each vegetation zone were evaluated for using the Point Centered Quarter (PCQ) method (see Cottam and Curtis 1956, as cited in Berryman and Henigar 2005).

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 zone at each cross section. Soils were classified as upland (non-hydric), hydric or non-hydric with the presence of flooding indicators. Special consideration was placed on locating elevations of the upper and lower extent of muck soils (> 12 inches in thickness) at cross-sections where they occurred.

Key physical indicators of historic inundation were also identified, including: cypress buttress inflection elevations; cypress knees; lichen and/or moss lines; stain lines; scarps and lenticels. The number of physical indicators of historic inundation varied by cross-section.

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

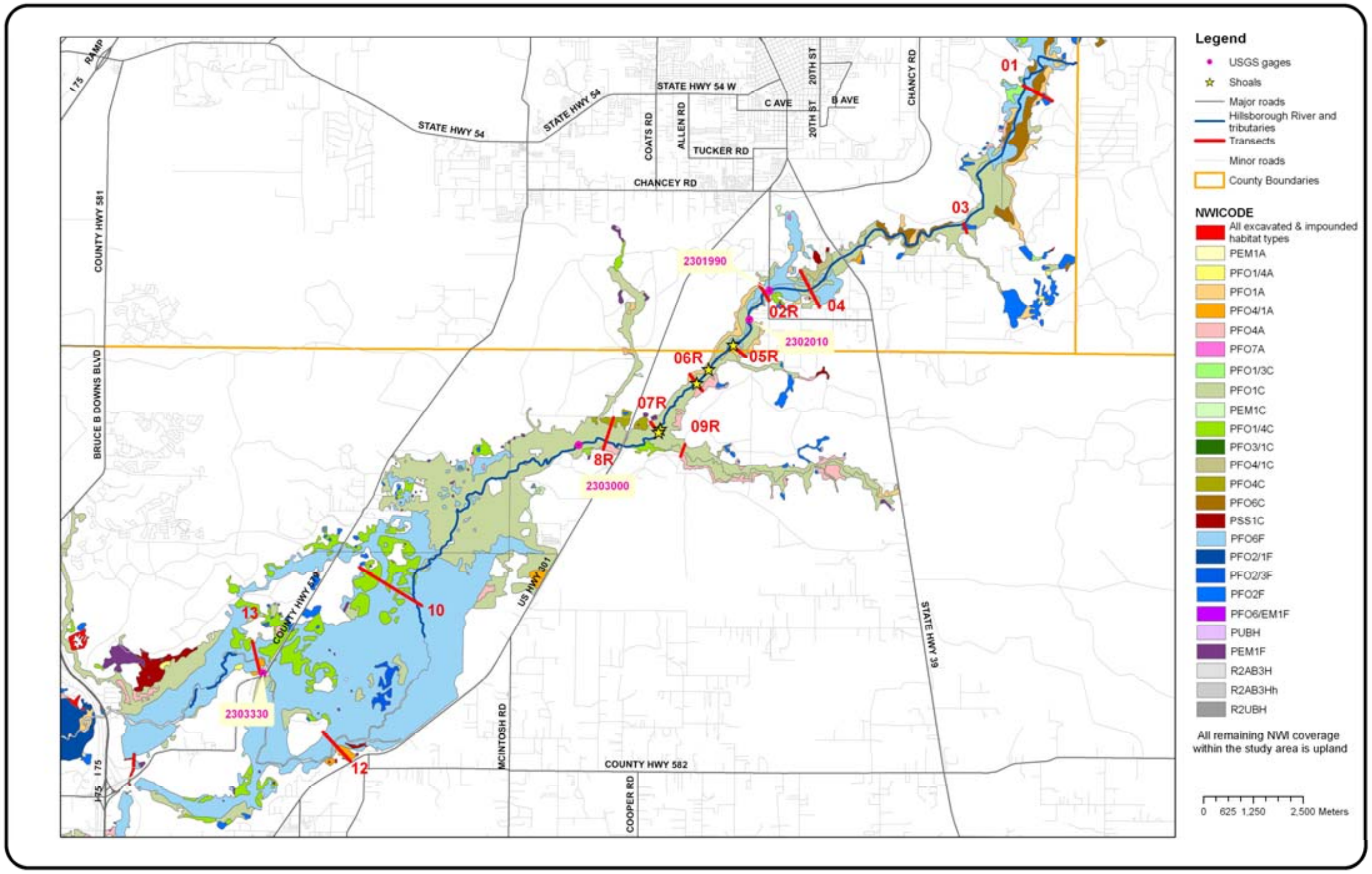


Figure 4-2. Upstream vegetation cross-section locations and NWI classes on the upper Hillsborough River (reprinted from Berryman and Henigar 2005).

4.3 Modeling Approaches

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

4.3.1 HEC-RAS Modeling

The HEC-RAS model is a one-dimensional hydraulic model that can be used to analyze river flows. Version 3.1.3 of the HEC-RAS model was released by the U.S. Army Corps of Engineers Hydrologic Engineering Center in May of 2005 and supports water surface profile calculations for steady and unsteady flows, including subcritical, supercritical, or mixed flows. Profile computations begin at a cross-section with known or assumed starting condition and proceed upstream for subcritical flow or downstream for supercritical flow. The model resolves the one-dimensional energy equation. Energy losses between two neighboring cross sections are computed by the use of Manning's equation in the case of friction losses and derived from a coefficient multiplied by the change in velocity head for contraction/expansion losses. For areas where the water surface profile changes rapidly (e.g., hydraulic jumps, bridges, river confluences), the momentum equation is used (US Army Corps of Engineers 2001).

The HEC-RAS model and available flow records for the USGS gages at Morris Bridge, near Zephyrhills, above Crystal Springs, and near Richland were used to simulate flows at cross-section sites within the Hillsborough River study area. Data required for performing HEC-RAS simulations included geometric data and steady flow data. Geometric data used for our analyses consisted of connectivity data for the river system, cross-section elevation data for 111 USGS cross-sections, and 9 of the 12 vegetative sites surveyed by the District, reach length, energy loss coefficients due to friction and channel contraction/expansion, stream junction information, and hydraulic structure data, including information for bridges, culverts, etc. (Figure 4-1). Required steady-flow data included the USGS gage records, boundary conditions, and peak discharge information.

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

Model accuracy is evaluated by comparing calculated water-surface elevations at any gage location with a stage-discharge relationship derived from historic data for the location. The model is calibrated by adjusting factors in the model until calculated results closely approximate the observed relationship between stage and flow. While expansion and contraction coefficients can be altered, the major parameter altered during the calibration process is typically Manning's roughness coefficient (n), which describes the degree of flow resistance. Flow resistance is a function of a variety of factors including sediment composition, channel geometry, vegetation density, depth of flow and channel meandering. For the Hillsborough River model, the rating curves for the Hillsborough River near Zephyrhills, Hillsborough River above Crystal Springs, and the Withlacoochee-Hillsborough overflow near Richland gage sites were used to calibrate calculations for the river segment between the Morris Bridge gage and the Withlacoochee-Hillsborough overflow near Richland gage site.

The upper Hillsborough River HEC-RAS model calculates profiles for a total of 29 steady flow rates derived from historical flow data measured in the river. The boundary conditions were specified with known water surface elevations for each flow rate at the downstream boundaries. In other words, rating curves (obtained from USGS) at the downstream boundaries were used as the boundary conditions.

Accuracy of the step-backwater analysis for the Hillsborough River was determined by comparing the modeled water surface elevations with rated water-surface elevations at three upstream gage sites: Zephyrhills, Crystal Springs, and Withlacoochee-Hillsborough Overflow. The HEC-RAS model was considered calibrated when the calculated water surface elevations were within plus or minus 0.5 ft. This is in keeping with standard USGS practices where the plus or minus 0.5 ft, is based on the potential error range using the 1-ft aerial contour maps (Lewelling 2004). The U.S. Geological Survey, Scientific Investigations Report 2004-5133 titled "Extent of Areal Inundation of Riverine Wetlands Along Five River Systems in the Upper Hillsborough River Watershed, West-Central Florida" was the study from which the initial HEC-RAS model was obtained though some cross sections specific to the MFL study were added to the model (Lewelling 2004). The greatest error associated with the model is likely to be the accuracy of the cross-sectional data.

To validate the model the District intends to study the inundation of wetlands along river corridors where MFL studies have occurred. This is intended to include staff gages in both the wetlands and the river channel. This will allow verification of the rivers connection with the wetland or the partial independence of the wetland hydrology. This will also serve to verify the model by collecting upstream gage heights.

The HEC-RAS model was run using all flows to determine stage vs. flow and wetted perimeter versus 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 their review of the Districts minimum flow methods, Gore et al. (2002) suggested that the District consider use of procedures that link biological preferences for hydraulic habitats with hydrological and physical data. Specifically, Gore et al. (2002) 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 this recommendation, the PHABSIM system was used to support development of minimum flows for the upper Hillsborough River.

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

Hydraulic and physical data are utilized in PHABSIM to predict changes in velocity in individual cells of the channel cross-section as water surface elevation changes. Predictions are made through a 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 history stages or for spawning activities (Figure 4-3). The WUA/discharge relationship can then be used to evaluate modeled habitat gains and losses with changes in discharge. Once the relationships between hydraulic conditions and WUA are established, they are examined in the context of historic flows, and altered flow regimes. This process is accomplished using a time series analysis routine (TSLIB, Milhous et al. 1990) and historic flow records.

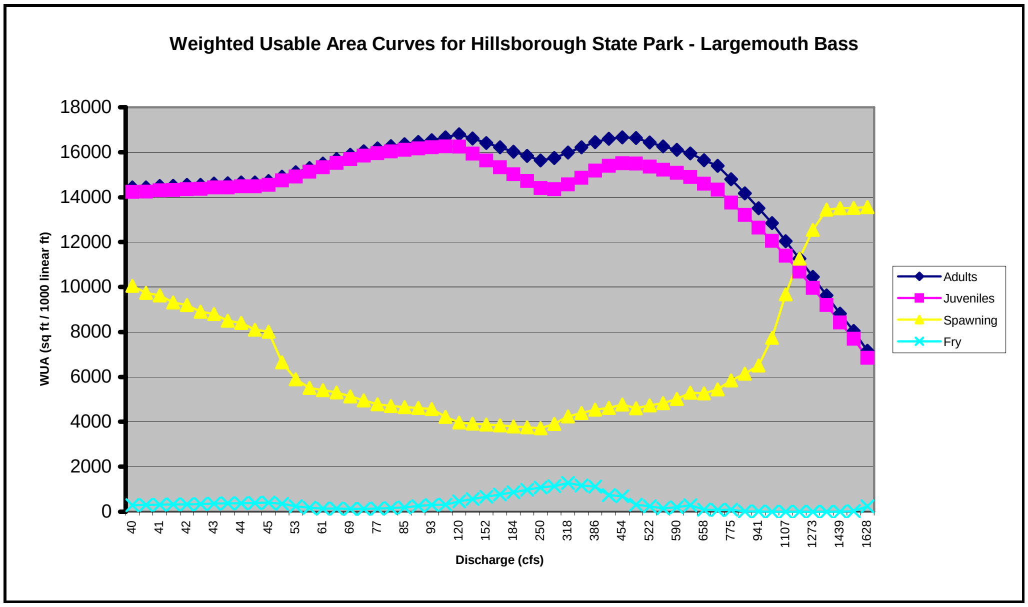


Figure 4-3. Weighted usable area (WUA) versus discharge for three life history stages (fry, juvenile, adult) and spawning activity of largemouth bass at Hillsborough River State Park.

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

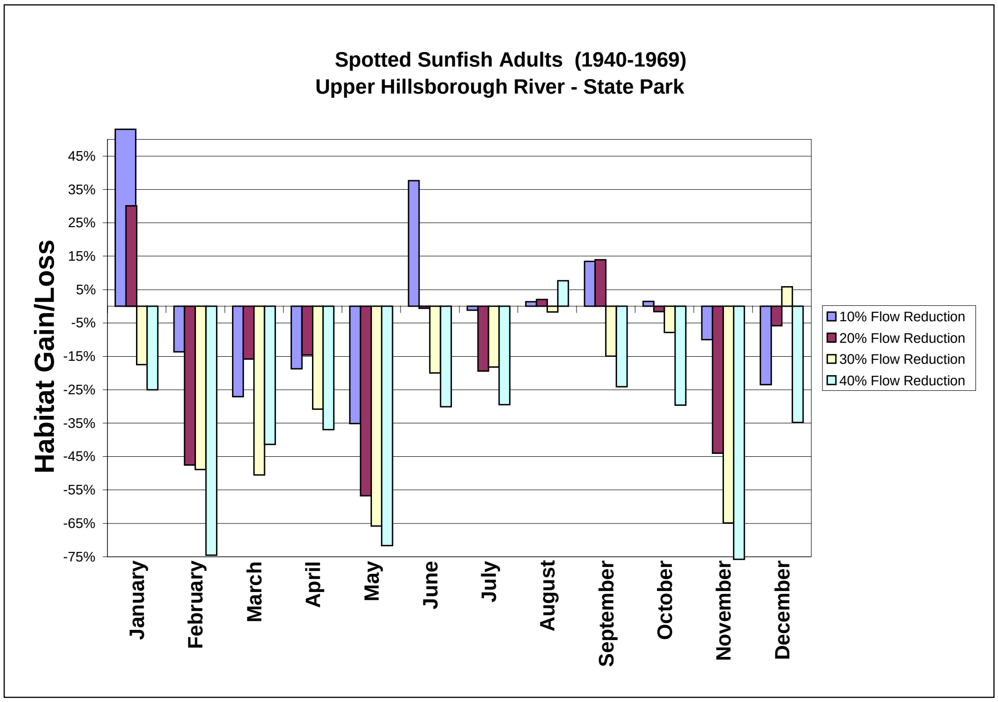


Figure 4-4. Example plot of habitat gain/loss relative to flow reductions of 10, 20, 30, and 40 %. Habitat loss is shown for spotted sunfish adults in the Hillsborough River State Park based on historic flow records from 1940 to 1969.

4.3.2.1 Development of Habitat Suitability Curves

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

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

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

Based on dominance of the spotted sunfish (*Lepomis punctatus*) in rivers within the SWFWMD, 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, a hybrid of the roundtable and Delphi techniques was used to develop a Type I curve. For this effort, a proposed working model of habitat suitability criteria was provided to 14 experts for initial evaluation. The proposed suitability curves were based on flow criteria for redbreast sunfish (*Lepomis auritus*) (Aho and Terrell 1986) modified according to published literature on the biology of spotted sunfish. Respondents were given approximately 30 days to review the proposed habitat suitability criteria and to suggest modifications. Six of the 14 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 fish species in the Hillsborough River, were established using USFWS/USGS “blue book” criteria (Stuber et al. 1982). Curves for these species have been widely used in PHABSIM applications.

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

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

Per recommendation of the peer review panel for the middle Peace River, the District, over the long-term, intends to evaluate and develop additional habitat suitability curves for species of interest. For example curves could be refined for the spotted sunfish, new curves could be developed for species representative of feeding guilds, wading birds, and listed species.

4.3.3 Recent and Long-term Positional Hydrograph/Analyses

Recent and Long-term Positional Hydrographs (RALPH) analysis is used to identify 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 4-5). The plots and associated spreadsheets are developed using measured elevations for habitats or other features, HEC-RAS model output and available flow records. 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 4-6). 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.

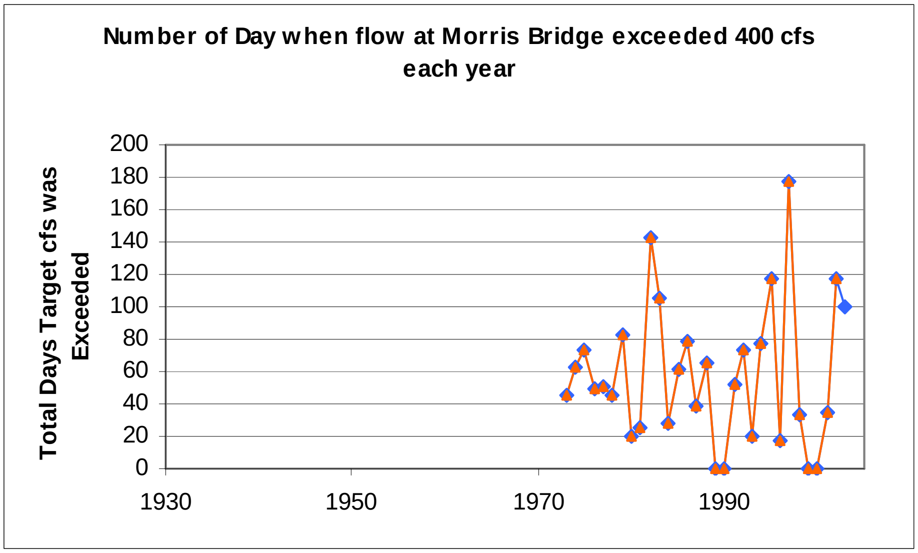


Figure 4-5. RALPH plot of the number of days during the southern river pattern (SRP) water year that 400 cfs is exceeded at the USGS Hillsborough River near Morris Bridge gage site.

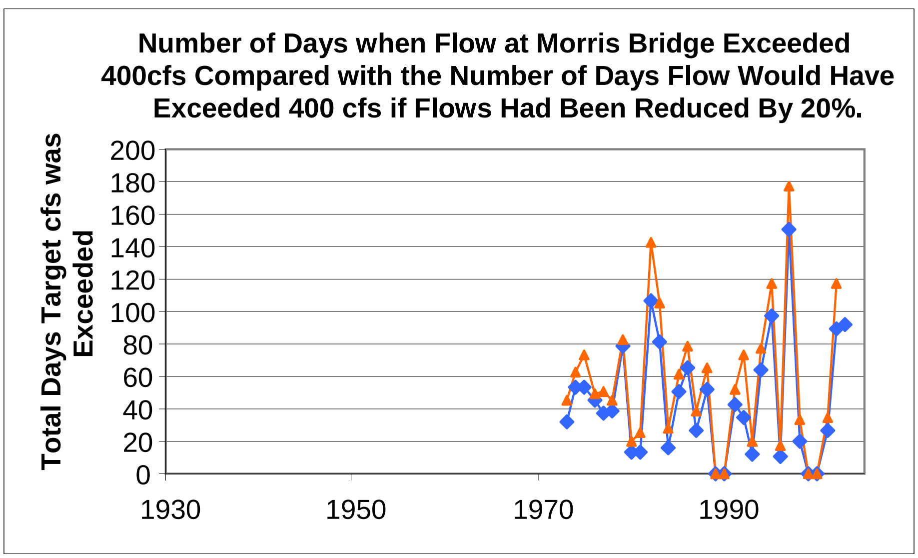


Figure 4-6. RALPH plot of the number of days during the southern river pattern water year that 400 cfs is exceeded at the USGS Hillsborough River near Morris Bridge gage site (orange line) compared with the number of days that inundation would have occurred if there had been a 20% reduction in river flows (blue line).

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

For development of minimum flows and levels for the Hillsborough River, we identified three seasonal blocks corresponding to periods of low, medium, and high flows. Lowest flows occur during Block 1, a 65-day period that extends from April 20 to June 24 (Julian day 110 to 175). Highest flows occur during Block 3, the 124-day period that immediately follows the dry season. This is the period when the floodplain is most likely to be inundated on an annual basis; although high flows can occur at other times. The remaining 176 days constitute an intermediate or medium flow period, which is referred to as Block 2 (Table 4-1).

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

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

4.5 Low Flow Threshold

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

4.5.1 Wetted Perimeter

Output from multiple runs of the HEC-RAS model was used to generate a wetted perimeter versus flow plot for each HEC-RAS cross-section of the Hillsborough River corridor (see Figure 4-7 for an example and Appendix WP for all plots). Plots were visually examined for inflection points, which identify flow ranges that are associated with relatively large changes in wetted perimeter. The lowest wetted perimeter inflection point (LWPIP) for flows up to 200 cfs was identified for each cross-section. Inflection points for flows higher than 200 cfs were disregarded since the goal was to identify the LWPIP for flows contained within the stream channel. Many cross-section plots displayed no apparent inflection points between the lowest modeled flow and 200 cfs. These cross-sections were located in pool areas, where the water surface elevation may exceed the lowest wetted perimeter inflection point even during low-flow periods. For these cross-sections, the LWPIP was established at the lowest modeled flow. Flows associated with the LWPIP at each cross-section were converted to flows at the USGS Hillsborough River near Morris Bridge, FL gage using relationships from HEC-RAS model. The LWPIP flows were used to develop a wetted-perimeter standard for the gage site.

Ultimately, regressions between the stage at each cross-section and the flow at the USGS Morris Bridge gage were used to determine flows at the gage that corresponded to the target wetted perimeter elevation at the cross sections (Figure 4-8). The flow at the Morris Bridge gage that was sufficient to provide for wetted-perimeter at all HEC-RAS cross sections at all sampled cross-sections was used to define the wetted perimeter standard.

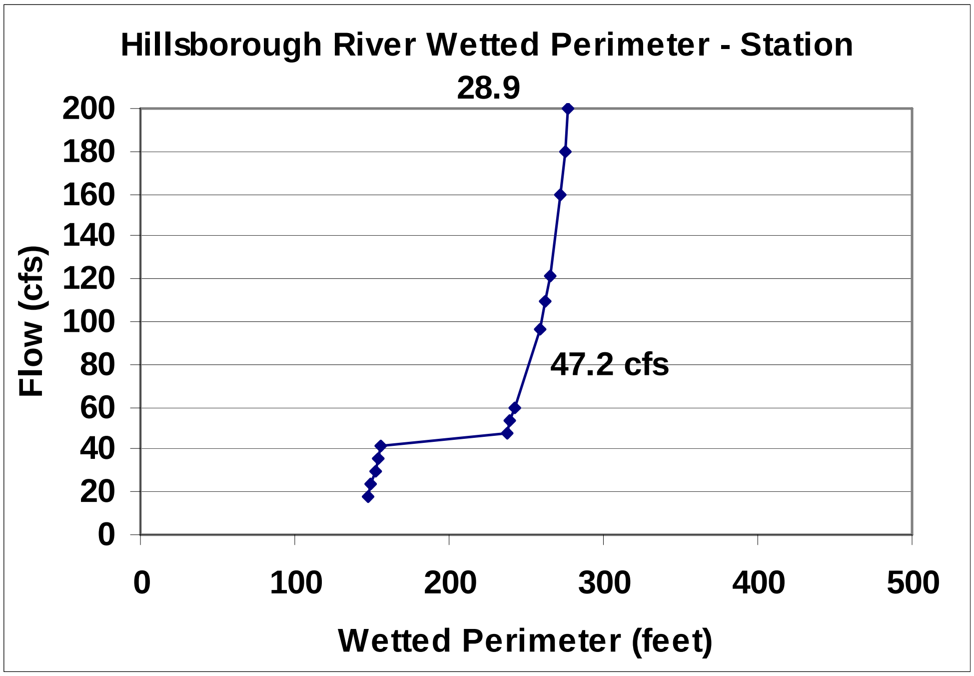


Figure 4-7. Wetted perimeter versus discharge at HEC-RAS transect number 28.9 in the Hillsborough River corridor. Wetted perimeter values for modeled flows up to 200 cfs are shown and the Lowest Wetted Perimeter Inflection Point (LWPIP) is identified.

4.5.2 Fish Passage

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

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

Ultimately, regressions between the stage at each cross-section and the flow at the USGS Morris Bridge gage were used to determine flows at the gage that corresponded to the target fish-passage elevation at the cross sections (Figure 4-8). The flow at the Morris Bridge 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 standard.

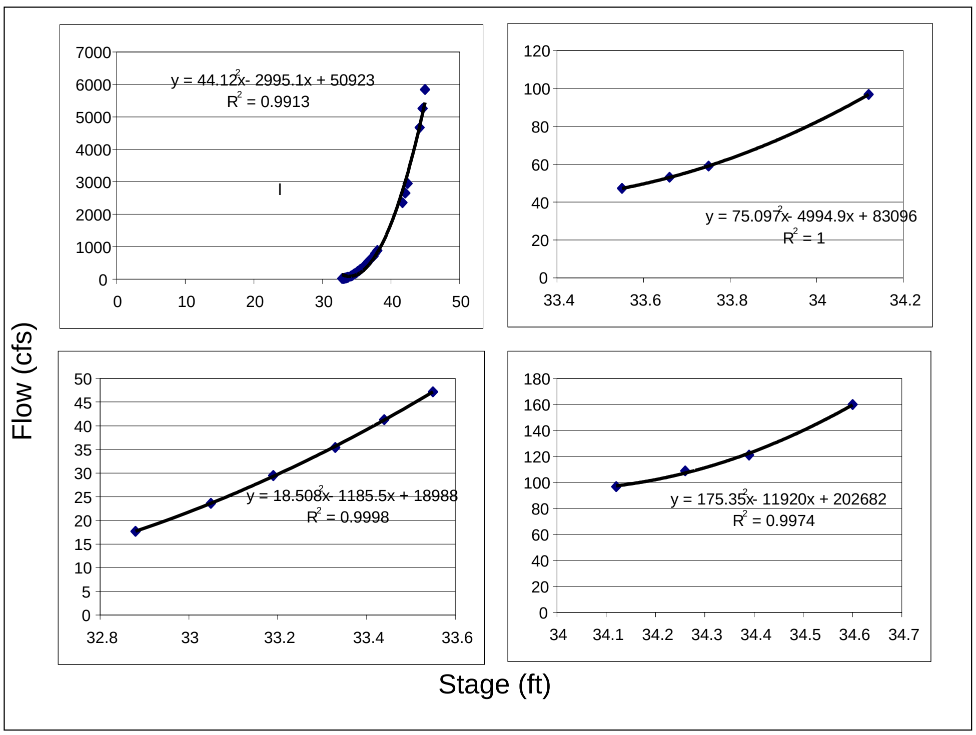


Figure 4-8. Stage flow relationships between HEC-RAS cross-section 40.4 and flow at the USGS Morris Bridge gage derived from the HEC-RAS model of the Hillsborough River. The upper-left plot shows the relationship derived for the entire range of flows evaluated. The other three show relationships used to develop regression equations for selected portions of the flow range.

4.6 Prescribed Flow Reduction for Block 1

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

4.6.1 PHABSIM – Application for Block 1

PHABSIM was used to evaluate potential changes in habitat associated with variation in low flows in the Hillsborough River. For the analyses, historic time series data from the Morris Bridge and Zephyrhills gage sites were used to model changes in habitat at three representative sites. For the Zephyrhills gage two benchmark periods were utilized from 1940-1969 and from 1970-1995. The Morris Bridge record did not extend back to the earlier period so a series of regression equations relating Morris Bridge flow to Zephyrhills flow was used to derive a historic flow record for Morris Bridge (see Chapter 2). This record was used to allow both benchmark periods to be examined at the Sargent Park site, which utilizes the Morris Bridge record.

During Block 1, flows tend to be lowest during the year, and any reduction in base flow provided by ground water would have its most pronounced effects on river flows. For the purposes of evaluating habitat loss from historic conditions, it was necessary to make decisions about likely historic conditions. As discussed in Chapter 2, there has been a decline in river flows in the Hillsborough River. While a reduction in river flows between multidecadal periods is consistent with the AMO (Kelly 2004), aquifer baseflow decline appears to exceed AMO expectations. However, it is unclear precisely how much of this decline can be attributed to climatic (and rainfall) oscillations attributable to the AMO and how much can be attributed to anthropogenic impacts from activities such as groundwater pumping from regional well fields.

For PHABSIM analysis of the Hillsborough River, three flow records were used. In addition to the unaltered flow record, two modified flow records were used. In one, decreased flows are attributed equally to anthropogenic and climatic effects. The other attributed 75% of declines to anthropogenic effects (see Chapter 2). For the purposes of this report, we will refer to the three flow records as the unaltered, the 50% anthropogenic and the 75% anthropogenic records or assumptions. PHABSIM results for all three scenarios are given in Chapter 5, and their development is described in detail in Chapter 2.

Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill, and for macroinvertebrate diversity at three sites on the Hillsborough River. Flow reductions during Block 1, (i.e., from April 20 to

June 24) that resulted in no more than a 15% reduction in habitat from historic conditions for either benchmark period were determined to be limiting factors. These factors were used to derive prescribed flow reductions, which identify acceptable flow requirements for the Zephyrhills and Morris Bridge gage sites during Block 1 when flows exceed the low- flow thresholds.

4.7 Prescribed Flow Reduction for Block 2

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

4.7.1 PHABSIM – Application for Block 2

PHABSIM was used to evaluate potential changes in habitat associated with variation in medium flows. For the analyses, historic time series data from the Morris Bridge and Zephyrhills gage, sites were used. For the Zephyrhills gage two benchmark periods were utilized from 1940-1969 and from 1970-1995. The Morris Bridge record did not extend back to the earlier period so a regression equation relating Morris Bridge flow to Zephyrhills flow was used to derive a historic flow record for Morris Bridge (see Chapter 2). This record was used to allow both benchmark periods to be examined at the Sergeant Park site, which utilizes the Morris Bridge record, rather then the Zephyrhills records of the time-series analysis. As with Block 1, three flow records, including an unaltered, a 50% anthropogenic assumption and a 75% anthropogenic assumption were used.

Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill, and macroinvertebrate diversity at three sites on the Hillsborough River. Maximum flow reductions that resulted in no more than a 15% reduction in habitat from historic conditions during Block 2, which runs from October 28 of one year to April 19 of the following calendar year, were determined to be limiting factors. These factors were used to derive prescribed flow reductions, which identify acceptable flow requirements for the Zephyrhills and Morris Bridge gage sites during Block 2 when flows exceed the low-flow thresholds.

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

Mean elevations of snag and exposed root habitats were determined for nine instream habitat cross-section sites in the Hillsborough River corridor. Flows at the cross-section sites and corresponding flows at the Morris Bridge and Zephyrhills gage that would result in inundation of the mean habitat elevations at each cross-section were determined using the HEC-RAS model. RALPH plots/analyses were used to determine the number of days that the mean elevations for the snag or root habitat were inundated. Flow records from two benchmark periods (1940 through 1969 and 1970 through 1995) were examined to identify percent-of-flow reductions that would result in no more than a 15% loss of habitat defined as a reduction of no more than 15% of the number of days of inundation from direct river flow for the entire year, after prescribed flow reductions for Blocks 1 and 3 were applied. Although we acknowledge that a 15% change in habitat availability based on a reduction in spatial extent of habitat may not be equivalent to a 15% change in habitat availability based on number of days a particular habitat is inundated, the peer review panel for the middle Peace River MFL felt, “that the 15% threshold selected for preventing significant harm is appropriate” (Shaw et al. 2005). Loss of days of direct connection with river flows was evaluated for the entire year since woody habitats in the river are expected to be inundated during periods of high flow (Block 3) and may also be inundated by flows occurring during Block 1 in some years. The percent-of-flow reductions derived for Block 2 flows at the gage site were considered to be limiting factors and evaluated for development of prescribed flow reductions for Block 2 for the Hillsborough River near Morris Bridge gage site when flows exceed the low-flow threshold.

4.8 Prescribed Flow Reduction for Block 3

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

Highest flows, including out-of-bank flows, are most likely to occur during Block 3, which for the Hillsborough River extends from June 25 to October 27.

Minimum flows developed for this period are intended to protect ecological resources and values associated with the floodplain by maintaining hydrologic connections between the river channel and the floodplain and maintaining the natural variability of the flow regime. This goal is accomplished through HEC-RAS modeling and use of RALPH plots/analyses to evaluate floodplain feature inundation patterns associated with channel-floodplain connectivity. Based on these analyses, a prescribed flow reduction for Block 3 can be developed.

4.8.1 Floodplain Connection Analyses – Application for Block 3

HEC-RAS model output and RALPH plots/analyses were used to evaluate floodplain inundation patterns associated with river flows at the 10-floodplain vegetation cross-sections and associated flows at the Morris Bridge gage site. Inundation of elevations associated with floodplain features, including vegetation zones and soils, was evaluated to establish percent-of-flow reductions that would result in no more than a 15% reduction in the number of days of inundation during Block 3, based on flows during two benchmark periods (1940 through 1969 and 1970 through 1995). The percent-of-flow reductions were considered to be limiting factors and used for development of prescribed flow reductions for the Morris Bridge gage site during Block 3. The relationship between 15% change in spatial extent of habitat is not necessarily equivalent to a 15% change in habitat availability based on the number of days a particular habitat is inundated (Munson and Delfino 2007). However, the peer review panel for the middle Peace River MFL felt "that the 15% threshold selected for preventing significant harm is appropriate" (Shaw et al. 2005).

5 Results and Recommended Minimum Flows

5.1 Overview

Results from modeling and field investigations on the Hillsborough 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. A low-flow threshold based on historic flows is recommended for the USGS Hillsborough River at Morris Bridge gage site, along with prescribed flow reductions for Blocks 1, 2, and 3. Based on the low-flow threshold and prescribed flow reductions, short-term and long-term minimum flow compliance standards are identified for establishing minimum flows and levels for the Hillsborough River.

5.2 Low-Flow Threshold

The low-flow threshold defines flows that are to be protected throughout the year. The low-flow threshold is established at the higher of two flow criteria, which are based on maintaining fish passage and maximizing wetted perimeter for the least amount of flow in the river channel. The low flow must also be historically appropriate. For the Hillsborough River, the low-flow threshold was developed for the USGS Hillsborough River at Morris Bridge gage site.

5.2.1 Fish Passage Criteria

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

Inspection of the data indicated that flows equal to or greater than 52 cfs at the Morris Bridge gage would be sufficient for fish passage at all sampled sites. A flow of 52 cfs at the Morris Bridge gage corresponds to a flow of approximately 51 cfs at the Zephyrhills gage. A flow of 52 cfs was used to define the fish passage criteria for the Morris Bridge gage site on the Hillsborough River.

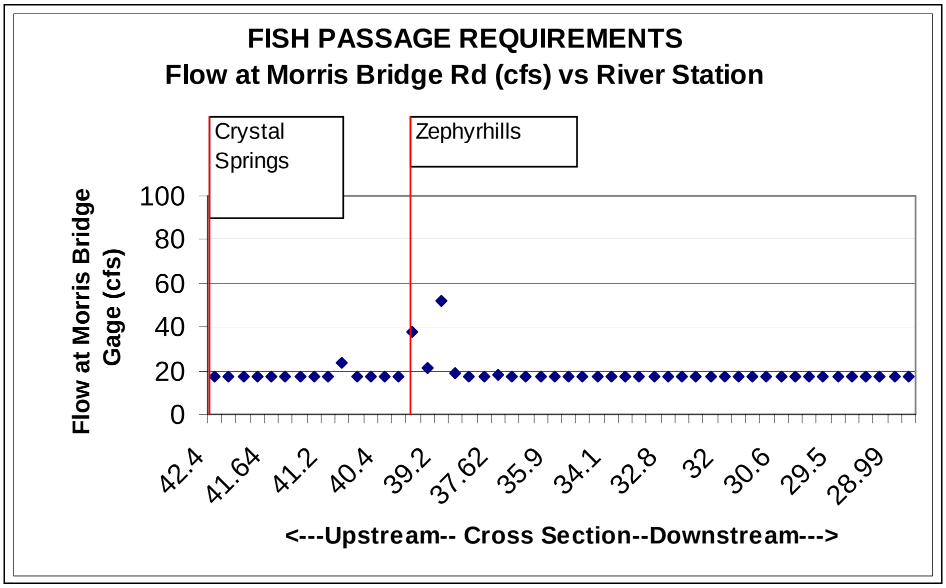


Figure 5-1. Plot of flow required at the Hillsborough River at Morris Bridge gage to inundate the deepest part of the channel at each HEC-RAS cross-section in the Hillsborough River to a depth of 0.6 ft.

5.2.2 Wetted Perimeter Criteria

Wetted perimeter plots (wetted perimeter versus local flow) and the lowest wetted perimeter inflection point (LWPIP) were developed for each HEC-RAS cross-section of the Hillsborough River between Crystal Springs and Morris Bridge gage site based on modeled flow runs (see Appendix WP for all plots). The LWPIP was below the lowest modeled flow for most sites (Figure 5-2). The only flow required to inundate an inflection point was 47.2 cfs, at the Morris Bridge gage site. This site was coincidently the most downstream cross-section in the model.

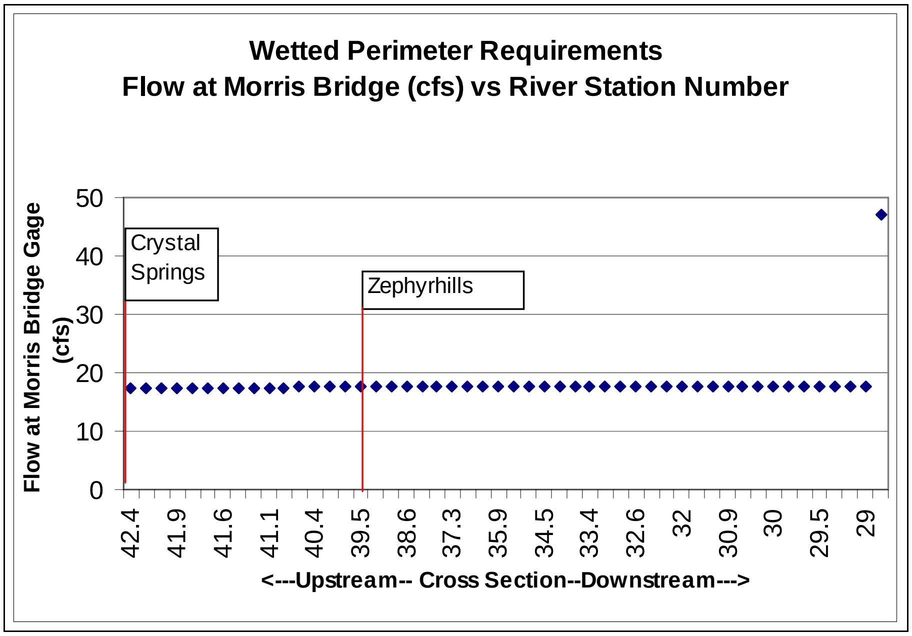


Figure 5-2. Plot of local flow required to inundate the lowest wetted perimeter inflection point at each HEC-RAS cross-section. Flows are shown for the Morris Bridge gage site.

5.2.3 Low-Flow Threshold

A low-flow threshold of 52 cfs at the USGS Morris Bridge gage was established for the Hillsborough River. This is equivalent to a flow of 51 cfs at the Zephyrhills gage. The low-flow threshold was established at the higher of the fish passage and wetted perimeter criteria and is, therefore, expected to provide protection for ecological and cultural values associated with both criteria. Flows in the river may be expected to drop below the low-flow threshold naturally. Identification of this threshold is meant to delineate a low-flow below which the river is most sensitive to further loss of flow.

5.3 Prescribed Flow Reduction for Block 1

A prescribed flow reduction for Block 1 at the Hillsborough River at Morris Bridge gage site was based on review of limiting factors developed using PHABSIM to model potential changes in habitat availability for several fish species and macroinvertebrate diversity. Three PHABSIM sites were established on the Hillsborough River. They were Site 7R located upstream of Blackwater Creek and downstream of Crystal Springs, a site located at Hillsborough River State Park, and one located at Sergeant Park. At each of these three sites, three separate flow records were utilized in the time-series analysis. These are the gage record, the 50% anthropogenic assumption and the 75% anthropogenic assumption as described in Chapters 4 and 2. This results in nine potential protection standards during Block 1 as shown in Table 5-1.

The State Park site provided the fewest constraints of the three sites, constricted entirely by spotted sunfish adults and predominately in the month of May. The next most restrictive factor for this site results in a reduction of approximately 18%. The Sergeant Park site shows more consistency in the months of April, May and June but is based primarily on one species-life-stage, which is Largemouth Bass fry. Site 7R is the most robust where, restrictions are based on both Spotted Sunfish adults and Largemouth Bass juveniles.

It is necessary to consider which of the three flow records is most appropriate based on the merits of the flow records, not the results of the analysis. Further, whichever flow record is most appropriate should be utilized for all PHABSIM results. It would be inconsistent to use one for Block 1 restrictions and another for Block 2. Therefore, it is necessary to select a flow record and apply a percent based on a single flow record and apply that flow record consistently in both Blocks 1 and 2.

For determination of MFLs, the 50% assumption was used. Therefore during Block 1, which runs from April 20 through June 24, the most restrictive limiting factors identified for the PHABSIM cross-section sites were habitat suitability for adult spotted sunfish. Based on the 1940 through 1969 benchmark period, adult spotted sunfish exhibit a 15% loss of habitat when flows are reduced by 8% at the Hillsborough River State Park. Site 7R was only slightly less restrictive and was also based on adult spotted sunfish. The Sergeant Park site's restrictions were based on largemouth bass fry. (Figure 5-3, Figure 5-4, and Appendix PHABSIM). Examining the percent flow reductions allowed at different sites during Block 1 and averaging them resulted in a prescribed flow reduction of 10% for Block 1 at the Hillsborough River near Morris Bridge gage.

Table 5-1. Recommended percent flow reductions for Block 1 based on PHABSIM at each of three sites using three different flow records.

	Gage Flow	50% assumption	75% assumption
7R	10	10	12(12)
Hills. State Park	15	8	4(6)
Sergeant Park	10	12	14

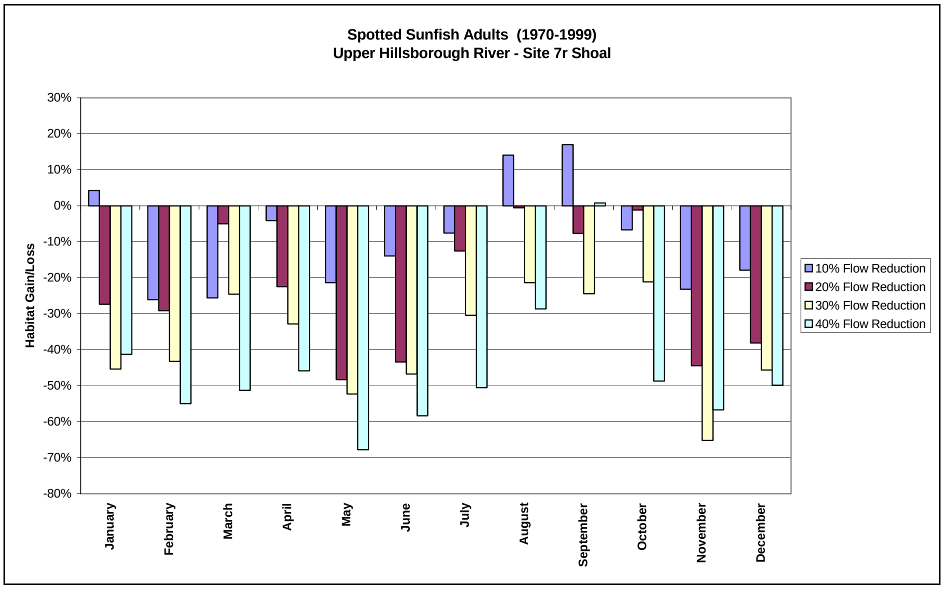
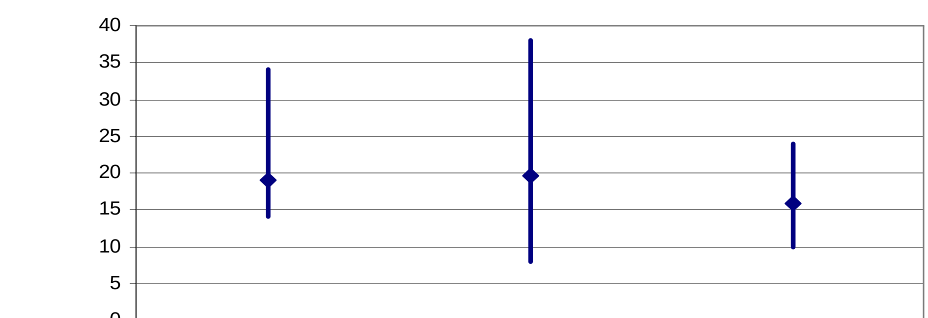


Figure 5-3. Predicted habitat gain/loss for adult spotted sunfish during April, May and June at site 7R based on the flow record for the 50% flow assumption for the Hillsborough River near Zephyrhills gage site from 1970 to 1999.



	Apr	May	June
◆ Mean	19	20	16
Minimum	14	8	10
Maximum	34	38	24
N	12	10	12

Figure 5-4. Summary of PHABSIM results for the Hillsborough River site 7R. Predicted habitat gain/loss for all species which limited flow reduction to less then 50% during April, May and June based on the 50% assumption flow record for the Hillsborough River near Zephyrhills gage site and both benchmark periods.

5.4 Short-Term Compliance Standards for Block 1

Short-Term Compliance Standards represent a flow prescription that can be utilized for evaluating minimum flows compliance on a short-term basis, for example, based on measured daily flows. For the USGS Hillsborough River near Morris Bridge gage site, the following Short-Term Compliance Standards are proposed for Block 1, which begins on April 20 and ends on June 24:

1) The low-flow threshold is 52 cfs;

2) A 10% reduction of natural flows measured at the USGS Hillsborough River near Morris Bridge gage is available for consumptive use when flows are above 52 cfs and below 470 cfs.

3) An 8% reduction of natural flows measured at the USGS Hillsborough River near Morris Bridge gage is available for consumptive use when flows are above 470 cfs (as discussed in section 5.5).

The second standard was developed to permit compliance with the Block 1 prescribed flow reduction without violation of the low-flow threshold. The third standard was developed for protection of the highest flow events as described in the Block 3 discussion below.

5.5 Prescribed Flow Reductions for Block 3

The prescribed flow reductions for Block 3 flows at the Upper Hillsborough River near Zephyrhills and/or Morris Bridge gage sites were based on review of limiting factors developed using the Upper Hillsborough River HEC-RAS model and RALPH analyses. Factors assessed included changes in the number of days that 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 assumed to be a good indicator 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 Upper Hillsborough 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 15% exceedance flow (470 cfs), a 13% reduction in historic flows can be accommodated without exceeding a 15% loss of days of connection. When flows exceed the 15% exceedance flow (470 cfs) more than an 8% reduction in historic flows resulted in a decrease of 15% or more in the number of days that flows would inundate floodplain features. Using these limiting conditions, the prescribed flow reduction for Block 3 for the Upper Hillsborough River at Morris Bridge gage site was defined as an 8% reduction in flows when flows exceed 470 cfs and a 13% reduction in flows when flows are below 470 cfs, provided that no withdrawal results in failure to comply with the low-flow threshold.

5.5.1 Inundation of Floodplain Features

Floodplain profiles, as shown for cross section (transect) 6 in Figure 5-5, were developed for the twelve floodplain vegetation cross sections (see Appendix RH). Distances across the floodplain (cross section or transect lengths) ranged from 894 to 5800 ft. Local (cross-section site) flows, needed to overflow the river's banks, ranged from 181 to 5293 cfs (see Appendix RH for channel bank and other floodplain feature elevations and associated flows). Mean flow at the Zephyrhills and/or Morris Bridge gage corresponded to the flow necessary for exceeding the elevation of the lowest bank on either side of the river and averaged 1317 cfs; flows at the gage that would be sufficient for the river to overflow both banks averaged 2014 cfs (Table 5-5).

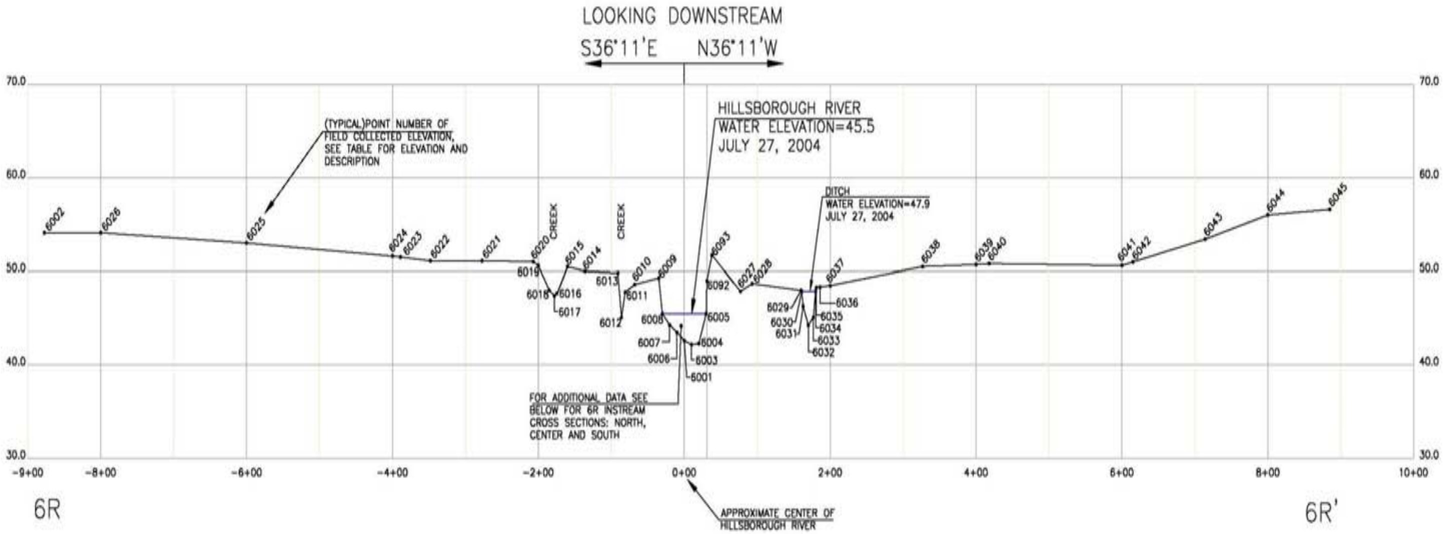


Figure 5-5. **Elevation profile for floodplain vegetation cross-section (transect) 6R. Distances (cumulative length) are shown centered on the middle of the river channel.**

Two major vegetation habitat types (Bottomland Forest and Floodplain Swamp) were identified along twelve transects on the Hillsborough River. Although there were some variations within habitats, their descriptions corresponded closely to the Florida Natural Areas Inventory definitions for these two wetland types (FNAI 2005). Overall, Bottomland Forest covers the greatest distance along the fifteen transects, approximately 71% of the floodplain length sampled, with Floodplain Swamp covering somewhat less area: (Table 5-2). Bottomland Forests generally occurred along the upper edges of the Hillsborough River floodplain. Floodplain Swamps occurred as backwater or oxbow areas in between low ridges of Bottomland Forest. No Floodplain Swamp habitat was present in Transects 6R, 7R, and 8R. The river in the middle portion of the study area (below SR39 and into Hillsborough River State Park) was relatively incised with steep banks. Additional floodplain characteristics of the upper Hillsborough River are further discussed in Berryman and Henigar (2005).

Table 5-2. Percent habitat length along each transect on the upper Hillsborough River.

Transect	% Bottomland Forest	% Floodplain Swamp
01	50.00	50.00
02R	60.00	40.00
03	40.00	60.00
04	75.00	25.00
05R	62.50	37.50
06R	100.00	0.00
07R	100.00	0.00
08R	100.00	0.00
09R	88.89	11.11
10	70.59	29.41
12	42.86	57.14
13	56.25	43.75
ALL	70.51	29.49

Dominant trees, shrubs and groundcover between the two vegetation classes are indicated in Table 5-2. The Bottomland Forest habitat, contained a wide variety of tree species, but laurel oak (*Quercus laurifolia*) of all sizes were usually the most common tree species, with sweetgum (*Liquidambar styraciflua*) and ironwood (*Carpinus caroliniana*) very common at the higher elevations. Floodplain Swamps were often dominated by pop ash (*Fraxinus caroliniana*) which occurred as large tall trees on most transects but also occurred as small multi-trunked shrubby trees. Relatively young bald cypress (*Taxodium distichum*) was dominant in some places and scarce in others, probably as a result of past logging. Additional information detailing tree species lists, absolute densities (number of trees/hectare), tree importance values as well as similar vegetation descriptions in the shrub and groundcover stratum is included in Appendix RH.

Table 5-3. Dominant vegetation for each habitat type along transects on the Hillsborough River.

Habitat Type	Dominant Trees	Dominant Shrubs	Dominant Groundcover
Bottomland Forest	Large *Quarcus laurifolia* usually dormant with many *Liquidambar styraciflua* and small *Carpinus caroliniana*, scattered *Sabal palmetto, Ulmus americana* and *Celtis laevigafa*, and occasional *Quercus virginiana*	Scattered *Sabal palmetto* with some dense patches.	Dense groundcover, especially in open areas, mostly *Smilax bona-nox*, ferns, grasses and sedges (usually *Chasmanthium nitidum* and *Rhynchospora miliacea*).
Floodplain Swamp	*Fraxinus caroliniana* and/or *Taxodium distichum* dominant with *Gleditsia aquatica, Ulmus americana, Acer rubrum* and *Quercus laurifolia*, especially near the edges	Few shrubs, mostly *Cephalanthus occidentalis*, with *Sabal palmetto* near the edge.	Dense groundcover, mostly *Panicum gymnocarpum, Saururus cernuus*, and *Thelyptenis interrupta*, sparser in the wettest areas.

Elevation surveys showed a consistent pattern of Floodplain Swamp samples occurring at lower elevations along each transect in depressional areas adjacent to the river or in river oxbow areas, while the samples classified as Bottomland Forest occurred at higher elevations on terraces or ridges. Figure 5-6 depicts the elevations of the two habitat types identified in each transect using box plots, while Table 5-4 presents summary statistics of the elevations of the two habitat types by transect. For all transects, the median Floodplain Swamp elevations were consistently at lower elevations than the median Bottomland Forest elevations. Some individual sample points from the Floodplain Swamp occasionally occurred at higher elevations than those from the Bottomland Forest at the same transect (e.g., Transects 1, 02R, 4, 05R, and 13) (See Figure 5-6). The overall median relative difference in median elevations between the two habitat types across all transects was 1.6 feet, with a range from 2.6 feet to 0.3 feet, suggesting that the communities would differ in historical hydrologic inundation regimes, with the Floodplain Swamp areas experiencing prolonged and more frequent inundation.

Summarized median, maximum and minimum elevations of hydric and mucky soils greater and less than 1 foot found among the twelve transects are listed on Figure 5-6. Based on output from the HEC-RAS floodplain model, mean flows measured from the USGS Zephyrhills and/or Morris Bridge gage would range from 753 to 1681 cfs in order to inundate the median hydric and mucky soil elevations. For mucky soil layers, that are either greater than 1 foot to those less than one foot, flows needed to inundate the mean elevations are 722 and 1141 cfs (Table 5-6). In addition to soils and vegetation zones, hydrologic indicators of high flow events were measured such as lichen and stain lines, bottom of moss and cypress buttresses. These features as they occurred among the transects are listed in Appendix RH. As high flow indicators, HEC-RAS model output also show them to require the highest flows for inundation with mean flows ranging from 2074 to 3613 cfs (see Table 5-5).

Transect	Bottomland Forest									Floodplain Swamp								
	Hydric			Muck > 1 foot			Muck < 1 foot			Hydric			Muck > 1 foot			Muck < 1 foot		
	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
01	75.4	76.1	76.8	No Samples with Muck						74.8	75.0	75.1	No Samples with Muck >1'			74.8	74.8	74.8
02R	53.0	53.8	54.5	53.0	53.0	53.0	54.5	54.5	54.5	52.5	53.1	53.6	52.5	53.0	53.6	<1'		
03	No Hydric Soils			No Samples with Muck						68.9	68.9	68.9	No Samples with Muck >1'			68.9	68.9	68.9
04	58.2	58.2	58.2	No Samples with Muck >1'			58.2	58.2	58.2	56.7	56.7	56.7	No Samples with Muck >1'			56.7	56.7	56.7
05R	55.6	55.6	55.6	No Samples with Muck						55.4	55.4	55.4	No Samples with Muck >1'			55.4	55.4	55.4
06R	48.6	49.3	50.8	No Samples with Muck >1'			48.8	48.8	48.8	No Floodplain Forest								
07R	45.9	45.9	45.9	No Samples with Muck >1'			45.9	45.9	45.9	No Floodplain Forest								
08R	42.2	43.0	43.8	No Samples with Muck						No Floodplain Forest								
09R	39.2	39.4	39.6	No Samples with Muck						38.4	38.4	38.4	No Samples with Muck					
10	33.0	33.7	34.4	No Samples with Muck >1'			33.0	33.7	34.4	31.9	32.0	32.0	32.0	32.0	32.0	31.9	31.9	31.9
12	No Hydric Soils			No Samples with Muck						29.2	29.2	29.2	29.2	29.2	29.2	No Samples with Muck <1'		
13	27.2	27.9	28.3	No Samples with Muck >1'			27.2	27.8	28.3	26.0	26.9	27.3	No Samples with Muck >1'			26	26.9	27.3

Figure 5-6. **Median, maximum and minimum elevations (NGVD) of hydric and muck soils greater and less than 1 foot along the Upper Hillsborough River.**

Inundation of the median elevation encompassed by Bottomland Forest vegetation community would require flows ranging from 25 to 5447 cfs as measured from the USGS Zephyrhills and/or Morris Bridge gage with an overall mean of 2030 cfs (see Table 5-7 and Appendix RH). Inundation of the median elevation associated with the Floodplain Swamp would occur when flows at the USGS Zephyrhills and/or Morris Bridge gage would range from 291 cfs to 1270 cfs with an overall mean of 661 cfs (Appendix RH).

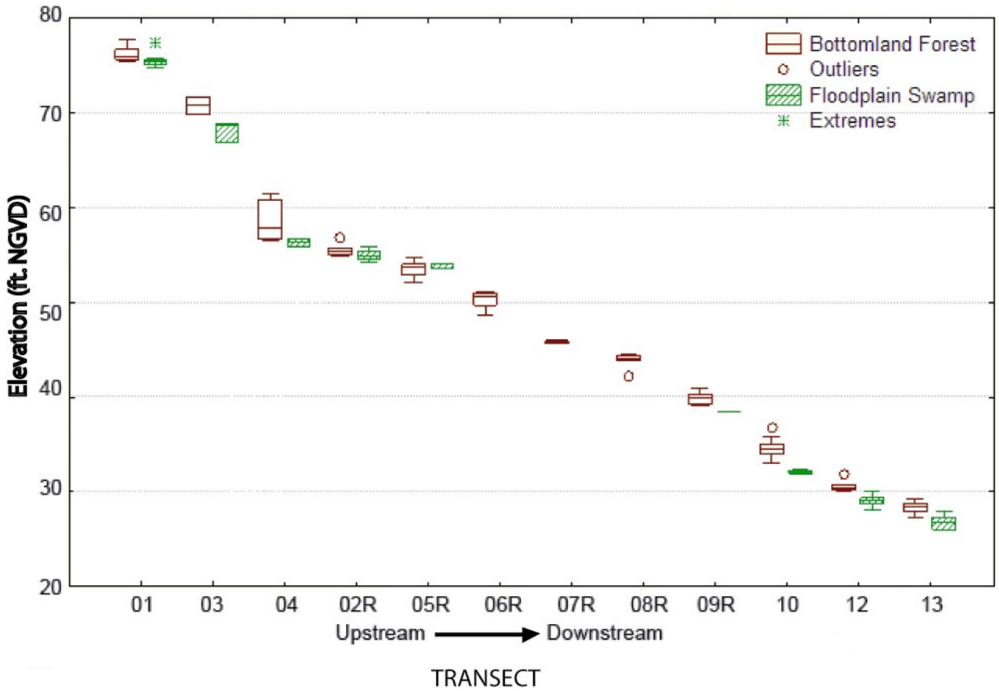


Figure 5-7. **Boxplot of elevations by vegetation type at 12 transects; showing median; Box: 25%-75%; Whisker: Non-Outlier Range.**

Table 5-4. **Range of elevations (NVGD 29 Feet) of each vegetation type in each transect in the Hillsborough River floodplain.**

Transect	Bottomland Forest				Floodplain Swamp				Grand Total			
	Min	Mean	Median	Max	Min	Mean	Median	Max	Min	Mean	Median	Max
01	75.4	76.24	75.95	77.7	74.8	75.45	75.35	77.4	74.8	75.85	75.6	77.7
02R	52.6	53.25	53.15	54.5	51.9	52.68	52.6	53.6	51.9	53.02	52.85	54.5
03	69.8	70.75	70.75	71.7	66.9	68.13	68.6	68.9	66.9	69.18	68.9	71.7
04	56.5	58.53	57.9	61.4	55.9	56.30	56.3	56.7	55.9	57.98	57.15	61.4
05R	53.9	55.30	55.9	56.5	55.4	55.73	55.6	55.9	53.9	55.46	55.7	56.5
06R	48.6	50.22	50.55	51.1					48.6	50.22	50.55	51.1
07R	45.6	45.80	45.8	46					45.6	45.80	45.8	46
08R	42.2	43.80	44	44.6					42.2	43.80	44	44.6
09R	39.1	39.85	39.85	40.9	38.4	38.40	38.4	38.4	38.4	39.69	39.6	40.9
10	33	34.61	34.55	36.7	31.8	32.04	32	32.3	31.8	33.85	34.4	36.7
12	30	30.62	30.45	31.8	28.1	29.05	29.1	30	28.1	29.72	29.7	31.8
13	27.2	28.41	28.4	29.3	25.9	26.77	26.8	28	25.9	27.69	27.8	29.3

Table 5-5 provides a summary of soil characteristics for each habitat type while detailed soil data in the various vegetation transects such as soil horizon names and depths; color; texture; presence of muck, mottles, stratified layers, or other hydric indicators; water table at the time of sampling; and other comments describing the soils are presented in Appendix RH. Most of the soil samples contained hydric soils. However, 21% of the soil samples collected in the Bottomland Forest habitat contained non-hydric soils. The non-hydric soil samples were mostly near the edges of the floodplain, although two were on slightly higher ridges within the floodplain. As shown in Table 5-6, the non-hydric soils typically contained sandy soils with deep water tables. The majority of the soil samples in the Bottomland Forest contained hydric characteristics, usually a thin layer of muck or mucky texture on the soil surface, indicating some ponding. The B-horizon tended to be close to the surface, which would indicate that the water table stays relatively high for prolonged periods.

The soil samples from Floodplain Swamps were all hydric, with finer textured soils. Almost all contained at least a few inches of muck at the surface. The depth of muck varied substantially, but was deeper than one foot in over one-fourth of the samples, indicating prolonged periods of inundation or ponding. Stratified layers were only present in a few of the Bottomland Forest and Floodplain Swamp samples, indicating little deposition of materials from the river.

Table 5-5. Characteristics of soils for each habitat type along twelve transects on the Hillsborough River.

Habitat Type	Hydric	Soil Characteristics
Bottomland Forest	No	Fine sand over limestone or a relatively deep B horizon and water table.
Bottomland Forest	Yes	Fine mineral soils with layers of muck in the upper 2-3" or dark surface soils, indicating ponding, B horizons relatively close to the surface, indicating high water tables, few stratified layers, indicating little deposition of fine materials from river.
Floodplain Swamp	Yes	Mucky surface layers, sometimes very deep, indicating prolonged periods of ponding, few stratified layers, indicating little deposition of fine materials from river.

Table 5-6. Mean (+SD) flows at the Zephyrhills and/or Morris Bridge gage required to inundate selected floodplain features and maximum reductions associated with less than a 15% reduction in the number of days flow is sufficient to inundate the feature. Reductions were based on flow records for 1940 to 1969 and 1970 to 1999.

Floodplain Feature	Number of floodplain transects containing feature (N)	Mean Flow (+SD) Required for Inundation	Percent-of-Flow Reduction 1940 to 1969	Percent-of-Flow Reduction 1970 to 1999
Lowest Bank Elevation to inundate one side of the river floodplain	12	1317 (1048)	11%	9%
Lowest Bank Elevation to inundate both sides of river floodplain	10	2014 (1715)	9%	7%
Median Elevation of Bottomland Forest	12	2030 (1719)	8%	7%
Median Elevation of Floodplain Swamp	9	661 (350)	14%	12%
Elevation of Hydric Soils in Bottomland Forest	10	1681 (993)	9%	7%
Elevation of Hydric Soils in Floodplain Swamp	9	753 (470)	13%	11%
Elevation of Mucky Soils >1 foot in Floodplain of Swamp and Bottomland Forest	3	722 (275)	11%	10%
Elevation of Mucky Soils <1 foot in Floodplain Swamp and Bottomland Forest	13	1141 (1030)	12%	11%
Hydrologic Indicators on Floodplain Swamp Communities	6	2074 (769)	8%	6%
Hydrologic Indicators on Bottomland Forest Communities	3	3613 (2331)	6%	5%

Changes in flow at the Zephyrhills and/or Morris Bridge gage during Block 3 that are expected to result in no more than a 15% reduction in the number of days of inundation of the mean elevation of selected floodplain features are listed in Table 5-6. The percent-of-flow changes, which were determined, using RALPH analyses, ranged from 5 -12% for 1970 to 1999 and from 6 -14% for 1940 to 1969. Examination suggests that higher flows might require slightly more restrictive standards than some of the indicators associated with low flows in the table.

To further investigate limiting factors associated with the Upper Hillsborough River floodplain, a RALPH analysis 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 for the Zephyrhills and Morris Bridge gages (Figures 5-7 and 5-8). Plots ranged from 100 to 2,000 cfs at the Hillsborough River near Zephyrhills and Morris Bridge gage site. The low end of the plotted flows reflects the approximate 50% exceedance flow for the period of record (121 cfs), 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 period of 1973 to 2000 was used for the Morris Bridge site because it approximated as closely as possible the 1970 to 1999 benchmark period. The Zephyrhills gage results from 1940-1969 strongly resembled the Morris bridge results. The Zephyrhills gage results from 1970 to 1999 benchmark period resulted in slightly lower numbers, likely due to decreased flows during this period (Chapter 2).

Figure 5-8 indicates that for flows of approximately 1000 cfs or greater, flow reductions, that result in a 15% reduction in the number of days the flow is achieved, tend to stabilize around 8% for the Morris Bridge gage site. This percent-of-flow reduction is comparable to the values derived for flows at the Zephyrhills and/or Morris Bridge site, from 1970-1999, that would inundate dominant vegetation zones, mucky soils, and top of bank elevations (Table 5-6). Collectively, these data indicate that up to a 8% reduction in the flows necessary to inundate floodplain features of the upper Hillsborough River, including those we have not identified, will result in a 15% or less reduction in the number of days the features are inundated. However, the plots also show that there are flows which occur during Block 3 which do not require reductions be limited to 8% to avoid a 15% reduction in the number of days a flow is achieved. Using the 15% exceedance of approximately 470 cfs at the Morris Bridge gage as a cutoff, we can apply a stepped prescription, which allows an 8% reduction in flows when flows exceed 470 cfs, and a 13% reduction in flows when flows are below 470 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. Unidentified factors could include either unidentified vegetative zones or inundation to various depths of zones, which have been identified.

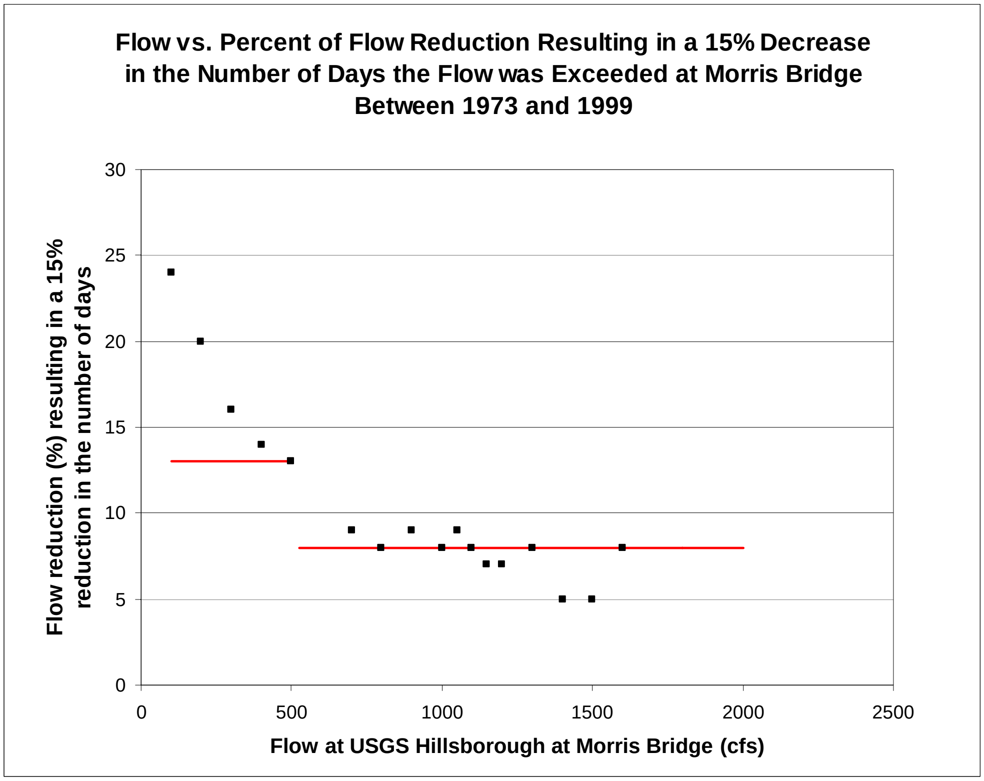


Figure 5-8. Percent-of-flow reductions that result in a 15% reduction in the number of days flows at the USGS Upper Hillsborough River near the Morris Bridge gage are achieved, based on flow records from 1973 through 1999.

5.6 Short-Term Compliance Standards for Block 3

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

For the USGS Hillsborough River near Morris Bridge, FL gage site, the following Short-Term Compliance Standards are proposed for Block 3:

1) The low flow threshold is 52 cfs;

2) A 13% reduction of natural flows between 52 cfs and 470 cfs measured at the Hillsborough River near Morris Bridge gage are available for use, provided that the low flow threshold is not violated; and

3) An 8% reduction of natural flows above 470 cfs measured at the Hillsborough River near Morris Bridge gage is available for use.

The two standards were developed through RALPH analysis to assure not greater than a 15% loss of days of a given flow is being achieved.

5.7 Prescribed Flow Reduction for Block 2

A prescribed flow reduction for Block 2 flows at the Upper Hillsborough River near Zephyrhills and/or Morris Bridge gage site 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 analyses to specifically evaluate changes in inundation patterns of woody habitats. The prescribed flow reductions were established by calculating the percent-of-flow reduction, which would result in no more than a 15% loss of habitat availability during Block 2, or no more than a 15% reduction in the number of days of inundation of exposed root habitat over the entire year, after prescribed flow reductions for Blocks 1 and 3 were applied. PHABSIM analyses yielded the most protective percent-of-flow reductions. PHABSIM results were therefore used to establish a prescribed flow reduction of 12% for the Morris Bridge gage site.

5.7.1 Application of PHABSIM – Block 2

PHABSIM analyses were used to model potential changes in habitat availability for several fish species and macroinvertebrate diversity during Block 2, which runs from October 28 through April 19. As with the Block 1 analysis, the use of three sites and three flow records results in a matrix. It was determined that the 50% altered flow record would be the choice for PHABSIM analysis. Utilization of this record results in the determination that a reduction in historic flow greater than 11% resulted in more than a 15% loss of available habitat. This was determined by averaging the three results for the three PHABSIM sites on the mainstem of the Hillsborough River. For all three sites, habitat for spotted sunfish adults was the most restrictive and the 1970- 1999 was the more restrictive benchmark period (Figure 5-9, and Figure 5-10). This percent-of-flow reduction was considered for use in the development of a prescribed flow reduction for Block 2 at the Morris Bridge gage site.

Table 5-7. Recommended flow reductions based on PHABSIM at each of three sites for three different flow records.

	Gage Flow	50% assumption	75(65)% assumption
7R	10	10	10(6 or 12)
Hills. State Park	8	8	8(10)
Sergeant Park	14	16	14

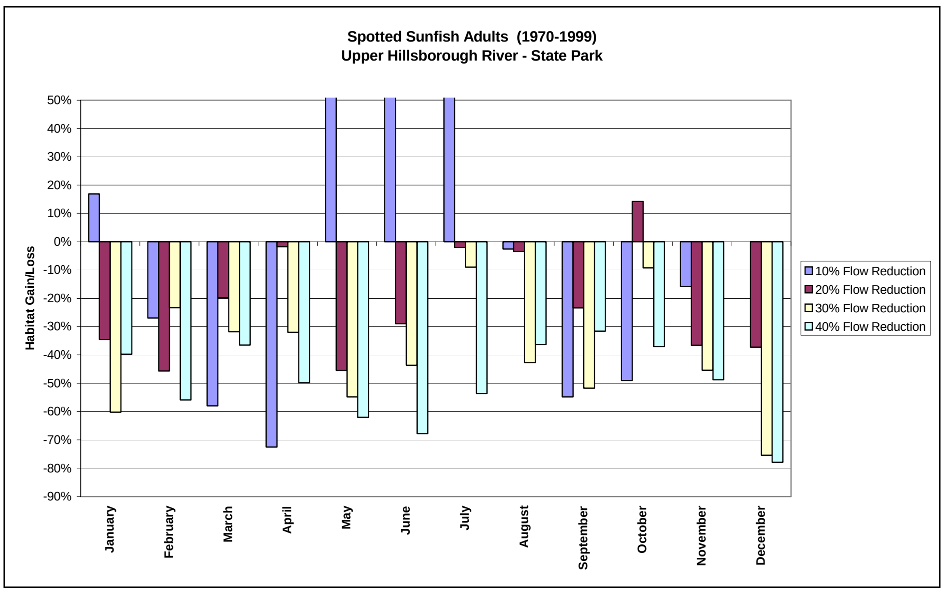
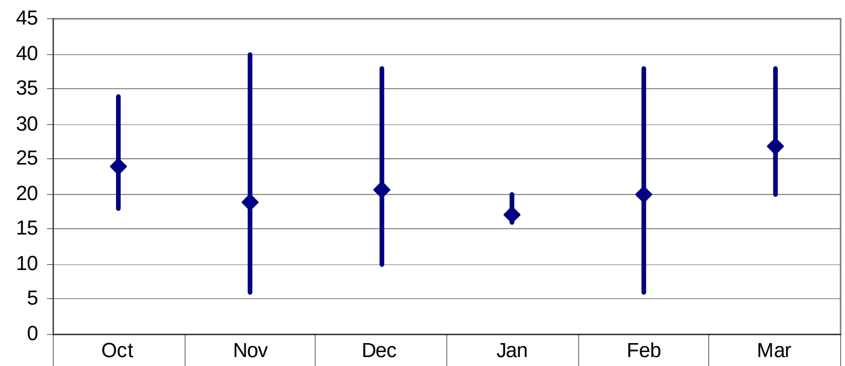


Figure 5-9. Predicted habitat gain/loss for spotted sunfish adults based on the flow record at the Zephyrhills gage from 1970 to 1999 and flow reductions of 10, 20, 30, and 40 percent.



	Oct	Nov	Dec	Jan	Feb	Mar
◆ Mean	24	19	21	17	20	27
Minimum	18	6	10	16	6	20
Maximum	34	40	38	20	38	38
N	8	7	7	6	7	7

Figure 5-10. Summary of PHABSIM results for the Hillsborough River at site 7R. Predicted habitat gain/loss for all species which limited flow reduction to less than 50% for October through March based on the flow record for the Zephyrhills gage and both benchmark periods.

5.7.2 Instream Habitats

Instream habitats shown below comprise data for twelve transects and have been shown to provide a bigger picture of the variety of instream habitats on the upper Hillsborough River. However, for purposes of instream modeling using HEC-RAS needed to develop MFL recommendations, only nine transects were used because they occurred upstream of the lowest long-term gage providing discharge data for the upper Hillsborough River (i.e., Morris Bridge gage).

Bottom habitats, such as bedrock, sand and mud were the dominant instream habitats, based on the linear extent of the habitat along the nine instream habitat cross-sections upstream of the Morris Bridge gage (Figure 5-11). Exposed roots, snags and wetland trees, though ubiquitous in all the cross-sections, were less abundant in terms of linear habitat. Aquatic plant habitat appeared to be more abundant especially in the lower sections of the river near the Morris Bridge gage. Relative elevations of the habitats were consistent among the cross-sections (Figures 5-12). 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 found at lower elevations. Maintaining a mosaic of aquatic and wetland habitats provides the greatest potential for stream productivity and ecosystem integrity (Pringle et al. 1988).

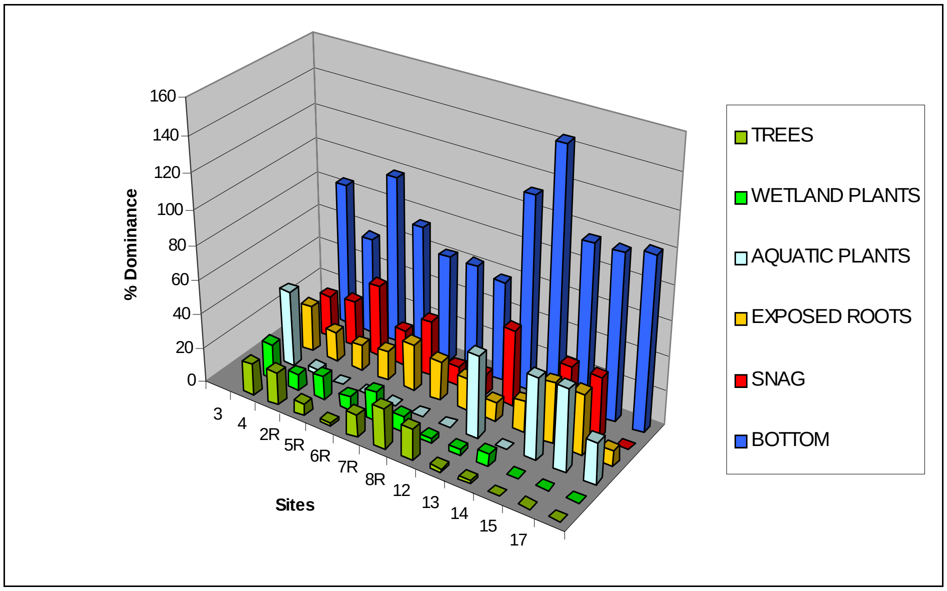


Figure 5-11. Percent dominance of instream habitats based on linear extent of the habitats along twelve cross-sections in the Upper Hillsborough River corridor. Instream modeling through HEC-RAS, however, was confined to 9 transects (between Transects 3 and 13 only).

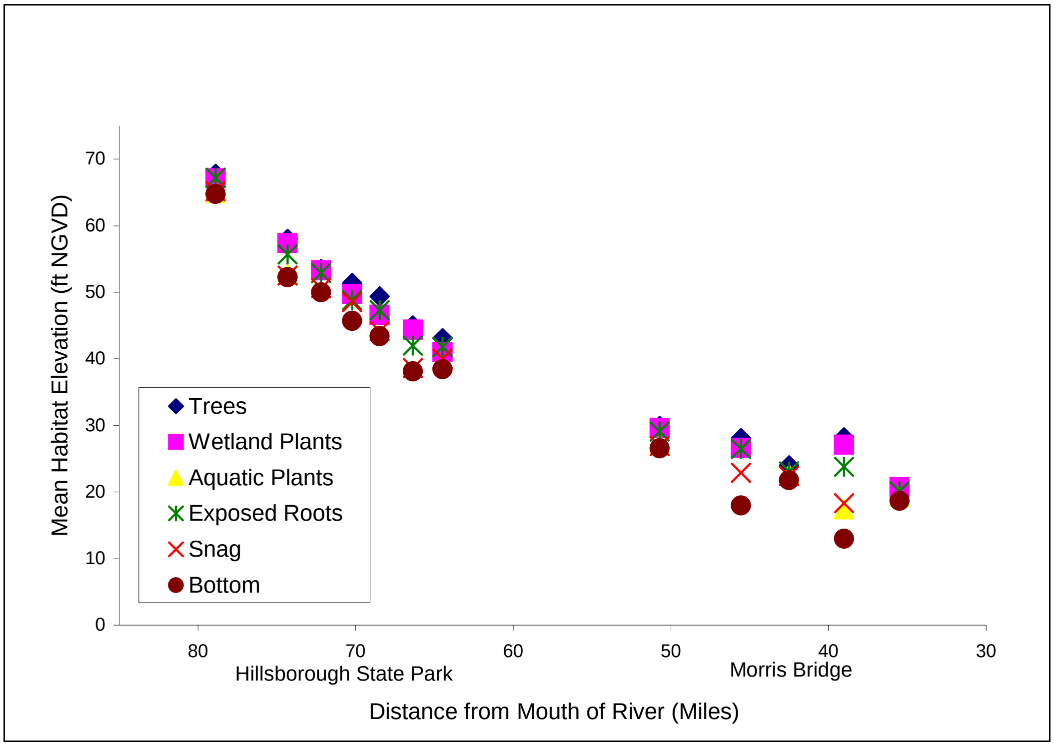


Figure 5-12. Mean instream habitat elevations at twelve cross-section sites on the Upper Hillsborough River. Instream modeling through HEC-RAS, however, was confined to 9 transects (between Transects 3 and 13 only).

5.7.3 Flow Relationships with Woody Instream Habitats

Based on the ecological importance of woody habitat, and its potential for use in development of a medium-flow standard, inundation patterns were examined for exposed root and snag habitats at the nine Upper Hillsborough River instream habitat cross-sections (Table 5-8). Flows at the Zephyrhills and/or Morris Bridge gage site that would be required to inundate exposed root habitat at the sites upstream of the gage ranged from 196 to 1922 cfs. Snag habitat also occurred at nine of the sites, but flows required for inundation of the mean snag elevation were lower than the lowest modeled-flow at three sites. Six of the nine sites required flows of 74 and 1088 cfs for inundation of snag communities.

Based on the historic flow records for the gages, inundation of woody habitats in the Upper Hillsborough River is expected during Block 2, and would, therefore, also occur during Block 3 when flows are higher. Flows sufficient to inundate this habitat may also occur in Block 1 during some years. Because these important habitats may be inundated during all three seasonal blocks, we determined percent-of-change flow reductions for inundation of the habitats during Block 2 using prescribed flow reductions developed for Blocks 1 and 3. Percent-of-flow reductions during Block 2 were derived for each gage site by calculating the flow reduction that would result in no more than a 15% loss of days of inundation of woody habitat over the entire year, after the flow reductions for Block 1 and Block 3 were applied. Using RALPH plots/analyses and flow records from 1970 through 1999, we decreased the flows in Blocks 1 by 10%, and the flows in Block 3 by 8% for flows over 470 cfs and by 13% for flows under 470 cfs, and evaluated percent-of-flow reductions for Block 2 which when combined with these prescribed flow reductions would not violate the habitat availability criterion. The same method was applied to the 1940 to 1969 benchmark. The 1970 through 1999 period resulted in more restrictive criteria and are thus utilized as the more conservative approach. Based on these criteria, percent-of-flow reductions of 6 to 35% were identified for woody habitats at sites upstream of the Zephyrhills and/or Morris Bridge gage. The mean flow required to inundate the mean elevation of exposed roots is 488 cfs. At this flow, an 18% decrease in flow is required to generate a 15% decrease in the number of days of inundation.

Table 5-8. Mean elevation of instream woody habitats (exposed roots and snags) at nine instream habitat cross-section sites, corresponding flows at the Upper Hillsborough River near Zephyrhills and Morris Bridge gage sites required for inundation of the mean elevations, and maximum percent-of-flow reductions associated with less than a 15% reduction in the number of days flow is sufficient to inundate the mean habitat elevations.

Habitat	Site	Mean Elevation (± S.D.) (ft NGVD)	Flow at Gage (cfs) Required for Inundation	Gage	Percent-of-Flow Reduction 1940-1969	Percent-of-Flow Reduction 1970-1999
Exposed Root	3	67.2	428	Zephyrhills	18%	6%
Exposed Root	4	55.7	227	Zephyrhills	25%	12%
Exposed Root	2R	52.9	948	Zephyrhills	NA[c]	NA[c]
Exposed Root	5R	48.8	242	Zephyrhills	27%	12%
Exposed Root	6R	47.3	196	Zephyrhills	24%	12%
Exposed Root	7R	42.0	1142	Zephyrhills	NA[c]	NA[c]
Exposed Root	8R	41.8	1922	Zephyrhills	NA[c]	NA[c]
Exposed Root	12	29.1	423	Morris Bridge	NA[b]	18%
Exposed Root	13	26.5	301	Morris Bridge	13%	9%
Mean Ex. Root			488		NA[a]	NA[a]
Snag	3	65.2	127	Zephyrhills	12%	9%
Snag	4	52.5	NA[a]	Zephyrhills	26%	12%
Snag	2R	50.6	90	Zephyrhills	NA[a]	NA[a]
Snag	5R	48.5	224	Zephyrhills	20%	12%
Snag	6R	44.2	NA[a]	Zephyrhills	NA[a]	NA[a]
Snag	7R	38.6	348	Zephyrhills	20%	12%
Snag	8R	40.0	1088	Zephyrhills	NA[c]	NA[c]
Snag	12	26.9	74	Morris Bridge	NA[b]	19%
Snag	13	22.9	NA[a]	Morris Bridge	NA[a], NA[b]	NA[a]

NA[a] Flows required to inundate the habitat were below modeled flows.
NA[b] Flow Record is not available.
NA[c] The flow occurs infrequently enough in Block 2 that greater than a 15% reduction can be achieved.

5.7.4 Selection of the Prescribed Flow Reductions for Block 2

Percent-of-flow reductions associated with PHABSIM modeling and RALPH analyses associated with inundation of woody habitats were compared for identification of prescribed flow reductions. Prescribed flow reductions were established for the Hillsborough River at Morris Bridge gage site based on percent-of-flow reductions derived from PHABSIM analyses. These analyses indicated that up to an 11% reduction in flow would be appropriate for the Morris Bridge gage site, while analyses of the inundation of woody habitat yielded less restrictive percent-of-flow reductions. The more conservative standard is applied as the short-term compliance standard during Block 2.

5.8 Short-Term Compliance Standards for Block 2

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

For the USGS Hillsborough River near Morris Bridge gage site, the following Short-Term Compliance Standard is proposed for Block 2:

1) The low flow threshold is 52 cfs;

2) A 11% reduction of natural flows measured at the USGS Hillsborough River at Morris Bridge gage is available for consumptive use when flows are below 470 cfs and above 52 cfs.

3) An 8% reduction of all flows measured at the USGS Hillsborough River at Morris Bridge gage is available for consumptive use when flows are above 470 cfs.

The second standard was developed to assure that the prescribed flow reduction for Block 2 does not lead to a violation of the more conservative of the Block 2 standards, in this case, the PHABSIM standard. The third standard is to make sure that the highest flows are protected as developed for Block 3, regardless of the timing of the events.

5.9 Compliance Standards and Proposed Minimum Flows for the Hillsborough River near Morris Bridge

We have developed short-term compliance standards that comprise a flow prescription for preventing significant harm to the Hillsborough River. Compliance standards were developed for three blocks that represent periods of low (Block 1), medium (Block 2) and high (Block 3) flows at the Hillsborough River near Morris Bridge USGS gage sites (Table 5-9). During Block 1, which runs from April 20 to June 24, the allowable withdrawal from the Hillsborough River for consumptive-use is 10% of the natural daily flow as measured at the

USGS Hillsborough River near Morris Bridge gage. During Block 2, which extends from October 28 of one year to April 19 of the next year, withdrawals of up to 11% of the natural daily flow at the Morris Bridge gage site may be allowed. 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 natural flows, with the step occurring at 470 cfs as measured at the Hillsborough River at Morris Bridge gage (Figure 5-13).

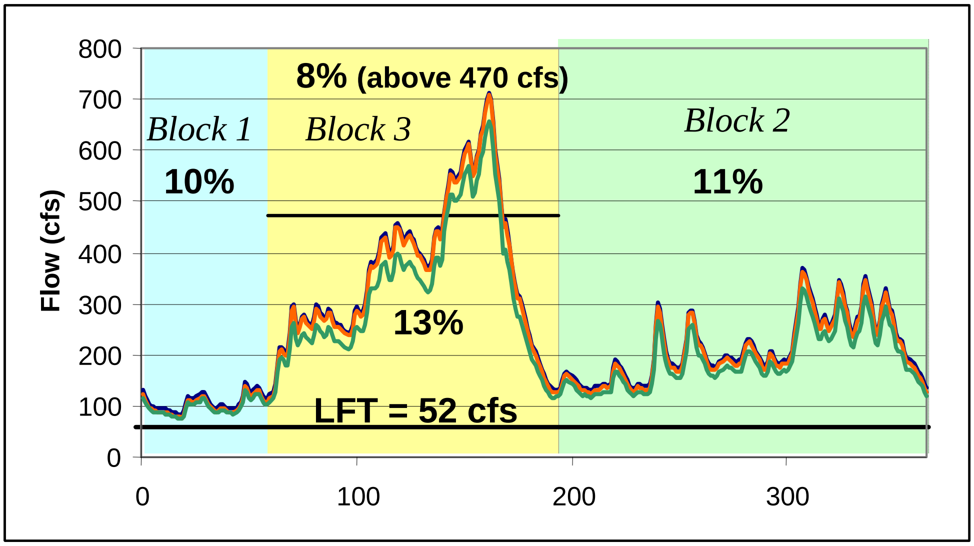


Figure 5-13. Median daily flow plotted for each day of the southern river pattern water year with short-term compliance standards for Blocks 1, 2, and 3. The blue line is the calculated natural flow corrected for withdrawals. The green line represents the natural flow reduced by the maximum allowable. The orange line is the current median calculated from the period of record at the Morris Bridge gage site.

Because climatic variation can influence river flow regimes, long-term compliance standards for the Hillsborough River at Morris Bridge gage site were developed. 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. However, it is also important that the long-term compliance standards be generated from flow records, which represent a period devoid of significant anthropogenic impacts. As discussed in Chapter 2, it is believed that the long-term flow trends for the Hillsborough River are not entirely consistent with expected changes related to the AMO (Figure 2-27). Specifically, low flow declines in the Hillsborough River exceed declines that might be anticipated in peninsular Florida due solely from climate cycles associated with the AMO. It appears that Floridan aquifer baseflow has declined by 15 cfs in the upper river and some of this decline should be attributed to be anthropogenic sources. As discussed in Chapter 2, the difficulty of developing an accurate water budget resulted in the construction of two "natural flow scenarios". Ultimately the 50%

anthropogenic reduction scenario was selected as the scenario upon which minimum flow recommendations were made.

Long-term compliance standards were generated using this corrected flow record and prescribed flow reductions and the low flow threshold for the three seasonal blocks. Hydrologic statistics for the resulting altered flow data sets, including five and ten-year mean and median flows, were calculated. The resulting 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 Hillsborough River at the USGS Morris Bridge gage, long-term compliance standards were established at the minimum five and ten-year mean and median flows (Table 5-8). 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 presumed historic flow records, it may be expected that the long-term standards will be met if compliance with short-term standards is applied to the river's natural flow.

Collectively, the short and long-term compliance standards proposed for the USGS gage site at Morris Bridge comprise the District's proposed minimum flows and levels for the upper Hillsborough 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 5-9. Proposed Minimum Flows for the Hillsborough River, including short-term and long-term compliance standards for the USGS Hillsborough River near Morris Bridge, FL gage site.

Period	Effective Dates	Short-Term Compliance Standards		Long-Term Compliance Standards	
		Flow on Previous Day	**Daily Flow Available for Consumptive Use**	**Hydrologic Statistic**	**Flow (cfs)**
Annually	January 1 to December 31	<52 cfs >52 cfs and <470 cfs >470 cfs	0% of flow* Seasonally dependent (see below)	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	190 96 149 74
Block 1	April 20 to June 24	<52 cfs >52 cfs and <470 cfs >470 cfs	0% of flow* 10% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	74 62 57 52
Block 2	October 28 to April 19	<52 cfs >52 cfs and <470 cfs >470 cfs	0% of flow* 11% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	153 89 105 72
Block 3	June 25 to October 27	<52 cfs >52 cfs and <470 cfs >470 cfs	0% of flow* 13% of flow 8% of flow	10-Yr Mean 10-Yr Median 5-Yr Mean 5-Yr Median	287 150 235 107

***0% based on surface water withdrawals; see discussion on Crystal Springs for groundwater restrictions.**

5.10 Meeting the MFLs

5.10.1 Hillsborough River MFLs

Compliance with the MFL is achieved when the actual flow statistics exceed those defined in the compliance standards presented in Table 5-5. The standards in Table 5-9 were derived using the 50% anthropogenic scenario discussed above. Because compliance standards need to be constructed from natural flows, the selection of the 50% scenario is a crucial component of MFL determination. Using recent non-provisional data from USGS the long-term standards listed in Table 5-9 are being met as of the end of the 2005 southern river pattern water year. The 5 and 10-year means and medians for all blocks had been met consistently over the POR until 2001. In 2001, the Block 1 compliance standards were not met. In 2002, Block 1 compliance standards were still not met. Although improvement was seen in 2003 and 2004, it was not until 2005 that all standards were again met (Table 5-10). This corresponds with the drought of record, which took place in 2001.

Table 5-10. Morris Bridge flows subtracted from Morris Bridge compliance standards listed in Table 5-9. Negative flows indicated by parentheses occur when flow statistics are not exceeding compliance standards.

SRP Year	1999	2000	2001	2002	2003	2004	2005
10yr Mean	79	75	71	89	115	126	112
10yr Median	4	4	4	4	48	30	28
5yr Mean	177	107	117	49	78	155	198
5yr Median	33	14	(3)	(3)	(3)	71	71
Block 1							
10yr Mean	18	15	0	(1)	19	23	32
10yr Median	4	3	(2)	(2)	(2)	7	10
5yr Mean	32	19	(0)	(4)	37	49	80
5yr Median	24	10	3	(6)	(6)	(6)	44
Block 2							
10yr Mean	95	93	93	132	138	131	117
10yr Median	2	2	2	2	10	10	10
5yr Mean	266	213	213	69	79	93	117
5yr Median	23	1	(3)	(3)	(3)	30	49
Block 3							
10yr Mean	105	97	92	92	149	188	164
10yr Median	76	76	30	30	76	76	76
5yr Mean	155	31	68	76	124	324	400
5yr Median	82	47	65	65	65	236	236

5.11 Crystal Springs Minimum Flow

The low-flow cutoff for the upper Hillsborough River based on a consideration of fish passage and wetted perimeter flows, was determined to be 52 cfs at the Morris Bridge gage site. Much of the Floridan aquifer baseflow in the upper Hillsborough River is contributed by the discharge of Crystal Springs. Under lowest flow conditions, essentially all the flow of the upper river is contributed by Crystal Springs. The long-term mean/median spring flow for Crystal Springs is believed to be approximately 60 cfs under the AMO warm phase (1925-1969; above normal rainfall conditions) and may be expected to be 10% or 6 cfs lower under the AMO cool phase (i.e., about 54 cfs). It would not be appropriate to require that Crystal Springs mean/median flow be maintained at 52 cfs, since this would essentially allow no deviation in spring flow from the anticipated natural condition. Consistent with the District's application of a 15% reduction in available habitat, it is proposed that Crystal Springs mean/median flow should not be allowed to drop below a flow that would cause the number of days that 52 cfs is achieved to decline by more than 15%. Using RALPH Plot analyses of the Zephyrhills gage, it is projected that a 16% and 24% decrease in the Block 1 "natural flow" would cause more than a 15% decline in the average number of days that flow would drop below 52 cfs during the AMO cool phase and the AMO warm phase, respectively. Assuming a natural spring flow of 54 cfs during the cool phase and 60 cfs during the warm phase and an allowable reduction of 16% and 24% in the mean/median natural flow, then the mean/median annual flow of Crystal Springs would be expected to equal or exceed 46 cfs (54 cfs x 0.86 and 60 cfs x 0.76). It is now projected that the mean/median flow of Crystal Springs is approximately 39 to 42 cfs based on a 5 and 10-yr running mean of the mean annual flow. The current discharge from Crystal Springs is between 4 and 7 cfs (2.5 to 4 mgd) below the proposed significant harm threshold.

The recommended minimum flow for the Crystal Springs complex is 46 cfs based on a 5-year running mean/median. Several assumptions were made with respect to Crystal Springs flow. Regardless of these assumptions, Crystal Springs flow appears to be below its allowable minimum flow; however, lack of a good daily flow record requires that annual mean and median flows are computed from only a few observations for each year. Since a recovery plan is in place for the Northern Tampa Bay area, it is expected the mean/median annual flow from Crystal Springs should increase. No further recovery strategy is warranted, until the effect of the existing strategy can be fully evaluated.

The northern Tampa Bay recovery strategy is documented in 40D-80.073 F.A.C. While this rule does not mention Crystal Springs specifically, it does specify recovery levels to be obtained in groundwater wells throughout the northern Tampa Bay area. One anticipated effect of raising the well levels will be to increase flows from artesian springs (i.e. Crystal Springs) in the area. Further, 40D-80.073(8) F.A.C. requires the evaluation of the recovery strategy in 2010 including analysis of all information and reports submitted regarding minimum flows and levels for the priority water bodies in the area. If deemed necessary by the evaluation of the initial recovery strategy, the Rule (40D-80.073, F.A.C.) may be revised to incorporate a second phase as necessary.

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7 Glossary of Terms

Algae – Mostly single celled, colonial, or multi-celled plants containing chlorophyll and lacking roots, stems and leaves.

Atlantic Multidecadal Oscillation (AMO) – A natural multidecadal cyclic variation in large-scale atmospheric flow and ocean currents in the North Atlantic Ocean that combine to alternately increase and decrease Atlantic sea surface temperatures. The cool and warm phases last for 25-45 years at a time, with a difference of about 1°F (0.6°C) between extremes.

Aquifer – An underground geologic formation that contains sufficient saturated permeable material to yield significant quantities of water to wells or springs.

Base Flow – Is flow in a channel sustained by ground-water discharge in the absence of direct runoff.

Benchmark Period – A fixed, more or less permanent reference point in time expressed as a period of years where flows are thought to reflect conditions in the absences of withdrawals.

Benthic – Associated with the bottom of a body of water.

Biotic – Of or pertaining to the living components of an ecosystem.

Block 1 – A time period in which recorded flows are at their lowest annually, defined as beginning when the average median daily flow falls below and stays below the annual 75% exceedance flow.

Block 2 – A time period in which recorded flows are at their medium level annually. Usually seen when mean annual exceedance flows range between 50-75% exceedance flows.

Block 3 – A time period in which recorded flows are at their highest annually, defined as beginning when the average median daily flow exceeds and stays above the mean annual 50% exceedance flow.

Braden River Water Pattern Year – An annualized median daily flow hydrograph specific to the Braden River where the first day flow starts at the beginning of Block 1 and run through Block 3 and ends on the last day of Block 2.

cfs – Cubic feet per second is a measure of streamflow or discharge.

Confined Aquifer – A term used to describe an aquifer containing water between relatively impermeable boundaries. The water level in a well tapping a confined aquifer stands above the top of the confined aquifer and can be higher or lower than the water table that may be present in the material above it.

Cross section – A plane across the stream channel perpendicular to the direction of water flow.

Diameter at Breast Height (DBH) – The width of a plant stem as measured at 4.5 ft. above the ground surface.

Discharge – The rate of streamflow or the volume of water flowing at a location within a specified time interval. Usually expressed as cubic meters per second (cms) or cubic feet per second (cfs).

Diversity – That attribute of a biotic (or abiotic) system describing the richness of plant or animal species or complexity of habitat.

Ecosystem – Any complex of living organisms interacting with non-living chemical and physical components that form and function as a natural environmental unit.

Emergent Plant – A rooted herbaceous plant species that has parts extending above a water surface.

Exceedance – That probability of at least a minimal expectation being met, often measured in terms of annual probability of occurrence.

Exposed Roots – Living root associated with riparian vegetation (shrubs and trees) exposed along stream banks that provide structural habitat to instream biota.

Fish Passage – Refers to a flow depth that is deep enough to allow for fish to migrate upstream and downstream in the river. The District has routinely used $6/10^{th}$ of one foot as the depth that allows for passage of most fish.

Floodplain – 1. The area along waterways that is subject to periodic inundation by out-of-bank flows. 2. Land beyond a stream channel that forms the perimeter for the maximum probability flood.

Floodplain Wetted Perimeter –The cross-sectional distance along the stream bed, its banks and adjacent floodplains that is in contact with water seen during flooding events where stream banks are breached by high water flow.

Flow Regime – The variable pattern (magnitude and frequency) of high and low flows exhibited by rivers and streams that are critical to the integrity of river ecosystems.

Gage Height – The water surface elevation referenced to the gage datum. Gage height is often used interchangeably with the more general term "stage". Although gage height is more appropriate when used with a reading of a gage.

Groundwater – In general, all subsurface water that is distinct from surface water, specifically, that part which is in the saturated zone of a defined aquifer.

Habitat – The physical and biological surroundings in which an organism or population (living and non-living) lives; includes life requirements such as food or shelter.

Habitat Suitability Curves – An input to the PHABSIM model where continuous variable or univariate curves designed to encompass the expected range of suitable conditions for water depth, water velocity and substrate/cover type unique to a given target species at a specific life stage is exhibited.

HEC-RAS – The model acronym for Hydraulic Engineering Center-River Analysis System. It is a water-surface profile model for river simulation. In this report it is utilized to evaluate steady, one-dimensional, gradually varied flow.

High Flow Step –.The high flow step is designed to assure that when out-of-bank flows occur they are protected by criterion specific to high flow conditions, rather then by criterion developed to protect in-channel features. The high flow step is therefore, a flow, often the 15% exceedance flow, above which the more restrictive of the seasonally specific percent-of-flow reduction is used, or the high flow percent-of-reduction, developed to protect floodplain inundation during block three.

Hydric Soils – Any one of a class of soils usually formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part that favor the growth and regeneration of hydrophytic vegetation.

Hydrophytic Vegetation – The sum total of macrophytic plant life growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content.

Hypertrophied Lenticels – An exaggerated (oversized) pore on the surface of stems of woody plants through which gases are exchanged between the plant and the atmosphere. The enlarged lenticels serve as a mechanism for increasing oxygen to plant roots during periods of inundation and/or saturated soils.

Instream Habitats – A specific type of area bounded within a stream's banks and its' associated (i.e., biological, chemical, or physical) characteristics used by an aquatic organism, population or community.

Inundation – A condition in which water from any source temporarily or permanently covers a land surface.

Invertebrate – All animals without a vertebral column or backbone; for example, aquatic insects.

Julian Day – Is the term for a day corresponding to the Julian calendar in which days are numbered consecutively. In the context of this report days are number from 1 to 356 (or 366) each year.

Life Stage – A qualitative age classification of an organism into categories related to body morphology and reproductive potential, such as spawning, larva or fry, juvenile, and adult.

Long-term Compliance Standards – Represents a flow prescription that can be utilized for evaluating minimum flows compliance on a long-term basis, for instance, based on measured daily flows expressed over 5 or 10 years.

Long-term Inundation Analyses – Process used to identify the number of days during a defined period of record that a specific flow or level (elevation) was equaled or exceeded at a specified location.

Low Flow Threshold (LFT) – The lowest flow that serves to limit withdrawals.

Main stem – The main channel of the river as opposed to tributary streams and smaller rivers that feed into it.

Macroinvertebrates – Any of the various fauna characterized without a backbone that can be seen without magnification.

Mean Annual Flows – The arithmetic mean of the individual daily mean discharges for the year noted.

Median Daily Flow – The middle flow value in a sequence of daily flow values, having as many above and below a certain daily flow value. If there is an even number of flow values, the median is the average of the two middle flow values.

Minimum Flows – The point(s) or level(s) on a watercourse at which further withdrawals would be significantly harmful to the water resources or ecology of the area.

Muck Soils – Type of organic soil consisting mainly of highly decomposed remains of plant material and other organisms.

National Wetlands Inventory (NWI) – A research program of the U.S. Fish and Wildlife Service aimed at producing and providing information on the characteristics, extent and status of U.S. wetlands, deep water habitats and other wildlife habitats.

Natural Flow – A flow condition where variation in discharge (or river stage) exists in the absence of any human alteration or would occur under completely unregulated conditions; that is not subjected to reservoirs, diversions, or other human works, over a specific time period.

Non-hydric Soil – A soil that has developed under predominantly aerobic soil conditions.

Percent Dominance – A quantitative descriptor of habitat, expressed as a percent, of the relative size or cover of instream habitats in a cross-sectional transect.

Percent-of-Flow Reductions – The percent-of-flow approach is a means of regulation in which a percent of the previous days natural flow is allocated as available for use.

Period of Record – The length of time for which data for a variable has been collected on a regular and continuous basis.

Physical Habitat Simulation Model (PHABSIM) – 1. A specific model designed to calculate an index to the amount of microhabitat available for different faunal life stages at different flow levels. PHABSIM has two major analytical components: stream hydraulics and life stage-specific habitat requirements. 2. This extensive set of programs is designed to predict the micro-habitat (depth, velocities, and channel indices) conditions in rivers as a function of streamflow, and the relative suitability of those conditions to aquatic life.

Pool – Part of a stream with reduced velocity, often with water deeper than the surrounding areas, which is usable by fish for resting and cover.

Prescribed Flow Reduction – A set of minimum flow rules tailored to seasonal blocks that summarize the extent of allowable flow reductions based on ecological criteria and maximum extent of loss allowed before significant harm takes place.

Recharge – Process by which water is added to the zone of saturation as recharge of an aquifer.

Riffle – A relatively shallow reach of stream in which the water flows swiftly and the water surface is broken into waves by obstructions that are completely or partially submersed. In this report riffle is synonymous with the term shoal.

Riparian Vegetation – Vegetation that is dependent upon an excess of moisture during a portion of the growing season on a site that is perceptively moister than the surrounding areas.

Riparian Zone – The transitional zone or area between a body of water and the adjacent upland identified by soil characteristics and distinctive vegetation that requires an excess of water. It includes wetlands and those portions of floodplains that support riparian vegetation.

Run – A portion of a stream with low surface turbulence that approximates uniform flow, and in which the slope of the water surface is roughly parallel to the overall gradient of the stream reach.

Seasonal Blocks – Any one of three time periods where flow conditions among Southwest Florida rivers or streams exhibit similar frequency, duration and magnitude in flow patterns that typically are linked to prevailing annual precipitation patterns. Currently differentiated into low (Block 1), medium (Block 2) and high (Block 3) flows.

Short-Term Compliance Standard – Represents a block-specific flow prescription that can be utilized for evaluating minimum flows compliance on a short-term basis, for instance, based on measured daily flows. Short-term compliance standards are typically defined as a percent of the previous days natural flow.

Snags – Dead or decaying woody debris material found lying along stream banks or in the channel and serve as structural habitats for instream biota.

Stage – The distance of the water surface in a river above a known datum.

Substrate – The material on the bottom of the stream channel, such as rock, sand, mud or vegetation.

Thalweg – A longitudinal profile of the lowest elevations of a sequential series of cross-sections.

Transect – A line on the ground along which observations are made at some interval.

Tributary – A stream that feeds, joins or flows into a larger stream (at any point along its course or into a lake).

Upland – Any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils and/or hydrologic characteristics associated with wetlands.

Watershed – The total topographic region or area bounded peripherally by a divide and draining ultimately to a particular watercourse or body of water; also called catchment area, drainage area, and basin.

Weighted Usable Area (WUA) – A component of PHABSIM which is an indicator of the net suitability of use of a given stream reach by a certain life stage of a certain species.

Wetlands – Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas.

Wetland Soils – A soil that has characteristics developed in a reducing atmosphere, which exists when periods of prolonged soil saturation results in anaerobic conditions.

Wetland Vegetation – The sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present.

Wetted Perimeter – The cross-sectional distance along the stream bed and banks that is in contact with water.
Wetted Perimeter Inflection Point – A point on a curve relating wetted perimeter vs. discharge at which the slope of the line changes from convex to concave or vice versa.

Woody Habitats – Any of the various living (e.g., exposed roots) or dead/decaying (e.g., snags) substrata composed of wood, usually originating from riparian vegetation that serve as habitation for various instream biota.

8 Appendix A – Peer Review Report

A Review of

"Proposed Minimum Flows and Levels for the Upper Segment of the Hillsborough River, from Crystal Springs to Morris Bridge, and Crystal Springs"

January 30, 2007 Peer Review Draft

by

Ecological Evaluation Section
Resource Conservation and Development Department
Southwest Florida Water Management District

Prepared by:
Peer Review Panel:

Charles E. Cichra, Ph.D.
Clifford N. Dahm, Ph.D.
Allan Locke, Ph.D.
Douglas T. Shaw, Ph.D.
Mark Stewart, Ph.D.

July 2007

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 proposed minimum flows and levels (MFLs) for the upper Hillsborough River and Crystal Springs.

The Panel continues to endorse the District's overall approach for setting MFLs in riverine ecosystems and finds particularly merit in the use of seasonal building blocks, multiple benchmark periods based on multi-decadal climate variability, the use of multiple analysis tools for protecting both low and high flow regimes and the expression of MFLs as percent flow reductions. Overall, the Panel finds the methodologies used are appropriate, even innovative. District staff members have clearly spent a great deal of time and effort trying to arrive at a scientifically reasonable set of recommendations and have largely succeeded.

However, the Panel continues to believe that the adequacy of the low-flow threshold and the use of a de facto significant harm criterion based on a 15% reduction in habitat availability has not been rigorously demonstrated and will remain presumptive until such time as the District commits to the monitoring and assessment necessary to determine whether these criteria are truly protective of the resource. We are concerned that the District to date has taken no visible steps to reduce the uncertainty and subjectivity associated with these criteria and urge them to move forward quickly to develop and implement an adaptive management framework that that will facilitate such assessments. In a similar vein, since the report concludes that "no further recovery strategy is warranted until the effect of the [Northern Tampa Bay] strategy can be fully evaluated" the Panel recommends that the draft MFL report be modified to include a thorough discussion of the methods that will be used to evaluate recovery and enable District staff to make informed decisions regarding the need for actions specifically focused on Crystal Springs.

The Panel is concerned about the discarding of ten years of U.S. Geological Survey streamflow data in the hydrologic analysis without convincing justification for doing so, and recommends that the wavelet analysis be re-run using the original "uncorrected" data. We also recommend an extensive re-write of several key sections of Chapter 2 to improve clarity and make the District's reasoning regarding findings and data interpretations more transparent to the reader.

We are puzzled by the assumption that 50% of the flow decline apparent in the flow of Crystal Springs is attributable to anthropogenic sources (i.e., groundwater extraction) without compelling justification, especially when the weight of evidence presented in the report suggests a percentage between 60 and 70%. Likewise, the formulation of the MFL for Crystal Springs as the mean spring flow that would cause the number of days that the low-flow threshold for the river is achieved to decline by no more than 15 percent appears contrary to the logic used to set the MFL for the river. For both issues the Panel recommends that District staff re-evaluate these elements of the report and/or provide more explanation and discussion of the decisions made.

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 upper Hillsborough River is built upon the analyses previously performed on the Upper Peace River (SWFWMD 2002), peer reviewed by Gore et al. (2002), the Middle Peace River (SWFWMD, 2005a), peer reviewed by Shaw et al. (2005) and the Alafia and Myakka Rivers (SWFWMD, 2005b, c) peer reviewed by Cichra et al. (2005). The upper Hillsborough 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. Extensive editorial comments and errata for the upper Hillsborough River MFL are provided as an Appendix.

THE CHARGE

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

1. Review the District's draft document used to develop provisional minimum levels and flows for the upper Hillsborough River and Crystal Springs.
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.

Comment [CD1]: Remove bank line after item 3.

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.

RESULTS OF THE PEER REVIEW

The general methodology employed in the setting of riverine MFLs by the SWFWMD has been reviewed in some detail and strongly endorsed by past peer reviews (e.g., Gore et al. 2002, Shaw et al. 2005, and Cichra et al. 2005). The efficacy of the approach has been well received in past peer reviews. Thus in this peer review the Panel has chosen to focus on new elements unique to the upper Hillsborough River and Crystal Springs MFLs, new insights on the District's approach and increased elaboration or emphasis on key findings from past peer reviews.

MFL Benchmarks and Resource Protection Goals

Benchmarks and the Atlantic Multidecadal Oscillation (AMO)

The Panel continues to endorse and applaud the District's use of multiple benchmark periods for setting MFLs based on multi-decadal climate variability. Although the role of the Atlantic Multi-decadal Oscillation (AMO) in influencing various ecological and climate phenomena (e.g., tropical storm frequency) continues to be debated, the District's thorough analysis of climate-streamflow relationships in Florida (SWFWMD 2004) provides a firm foundation for applying these concepts to the development of MFLs for Florida's rivers. As with previous riverine MFLs beginning with those for the Middle Peace River (SWFWMD 2005a), the District has fully embraced the climate-streamflow issue in developing the MFLs for the upper Hillsborough River by evaluating and identifying limiting flow conditions for two separate benchmark periods based on different climate phases. Recommended low-flow thresholds and percent flow reduction criteria are based on the most conservative of these benchmark periods to ensure adequate protection during periods when less rainfall and lower streamflow prevail. The analysis of stream and spring flows in Chapter 2 of the draft report also does a good job of placing the hydrology of these systems in the context of climate variability and clearly illustrates how such variability is revealed in the data as thresholds or step changes. 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. To our knowledge, SWFWMD is the only water management entity to have adopted such a sophisticated and forward thinking approach for incorporating climate variability into instream flow determinations.

The Panel feels that the Upper Hillsborough River MFL report clearly demonstrates that there are "lower-flow" and "higher-flow" periods that persist for decades, and previous peer reviewed work by the District made a strong case that such long-term variability is linked to different phases of the AMO (SWFWMD, 2004; Shaw et al, 2004) . The decision to use the lower-flow period to set MFLs is appropriate, as this is conservative, and means that it is not necessary to try to predict the current or future climate cycle. However, the AMO label is not necessary to the analysis or the determination of the MFLs considered here, and pinning the MFL determination on a particular climate cycle potentially leaves the MFL determination open to challenge. We suggest simply referencing earlier District documents that propose the AMO link, and not making a big deal of it here. The hypothesized link with AMO has explanatory power, but no real predictive power. Although we are suggesting de-emphasizing the narrative connection with AMO, the panel strongly believes the idea of multidecadal variations in streamflow is valid.

Comment [CD2]: I read over this short document on weakening Walker Cell circulation. This certainly plays a major role in the tropical Pacific and links with ENSO activity that has teleconnections worldwide, but it not a multidecadal sea surface temperature shift like the AMO and PDO that would have effects on regional precipitation and streamflow. I remain satified with the link between the AMO and Florida river flows.

Another important issue involving benchmarks that is unique to the upper Hillsborough MFL is the selection of flow records to use for the analysis and related assumptions about the degree of alteration that is believed to have occurred. In Section 5.3, page 5-4, it is stated, *"It is necessary to consider which of the three flow records is most appropriate based on the merits of the flow records,…"* Once the most appropriate flow record is chosen, then the flow recommendation becomes a reduction of that chosen flow record. Choosing the benchmark condition is a point of great debate. If the goal is to have "no significant harm", then choosing a "natural" benchmark or an already altered benchmark, in terms of flows, will yield two different results. Will both results achieve "no significant harm?" One would think this would not be the case. Therefore, choosing the benchmark becomes a very significant decision point as it directly impacts the flow recommendation. Using the 1970-1995 period as a 'low-flow' benchmark would seem to be conservative, although there are probably anthropogenic influences on the flows during this period. The 1940-1969 period appears to be a high-flow period, and using it as a benchmark for uninfluenced flows would be conservative, as this would assume higher flows prior to anthropogenic influence.

In Section 5.7.1, on page 5-17, it is stated, *"It was determined that the 50% altered flow record would be the choice for PHABSIM analysis."* It is not clear to the Panel why this is the chosen starting point, in terms of flow, upon which the 15% habitat reduction metric is applied. Based on our review of the information presented in chapter 2, it appears that the weight of the evidence presented suggests that the anthropogenic effects at Crystal Springs represent as much 60-70% of the observed decline, rather than 50%. For example, on page 2-104, comparison with Silver Springs suggests a 68% anthropogenic effect at Crystal Spring, a similar result to that obtained with the z-score analysis. In fact, it seems that there are more results >60% than <60%, and that methods that analyze discharge directly give higher percents, suggesting a 60-75% anthropogenic effect at Crystal Springs. Comparison of spring flows gives 62-68% (z-score), 53-60% (wavelet 5-6 cfs in 1990 plus 3 cfs in 1965, but without the higher discharges of 1953-1963 included), and 68% (comparison of 'wet' and 'dry' cycles at Crystal and Silver Springs). Based on this evidence, the Panel strongly recommends the District consider using an anthropogenic effect of >60%, rather than 50%. Absent this, a more transparent explanation of the District's reasoning here is essential. Otherwise, the decision to use 50% appears subjective.

Seasonal Building Blocks

The SWFWMD has continued to employ a seasonal building block approach (e.g., Postel and Richter 2003) in establishing MFLs for the upper Hillsborough River. 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.

Seasonal 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. In response to previous peer review comments (e.g., Shaw et al. 2005) the District now applies the low-flow threshold developed for block 1 year around, recognizing that low flow conditions can occur at any time. 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 upper Hillsborough River. 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. Seasonal building blocks also remain a useful conceptual device for communicating MFLs to the public.

The Panel continues to endorse the District's approach. We note with interest, however, that the District study team encountered some difficulties in *a priori* assigning specific tools for specific flow blocks, and adequately addressed these difficulties. Nevertheless, as the District's methodology for setting riverine MFLs has evolved, the need for pre-defined seasonal blocks has become less clear. The Panel wonders whether applying all of the tools used to set MFLs described in the draft report to all weeks of the year and using the approach that has been employed in this and prior studies of basing compliance standards on the most conservative, or protective, factor would eliminate the need to pre-assign flow blocks.

Resource Protection Goals

Chapter 3 clearly lays out the goals, ecological resources of concern, and key habitat indicators for setting MFLs on the upper Hillsborough River. This discussion is appropriately drawn from past MFLs developed by the District and citations from a wide array of ecological literature. Emphasis here, as in other riverine MFLs in the SWFWMD, is on fish and invertebrate habitat and hydrologic connectivity, both upstream-downstream and laterally between channel and floodplain.

Though these characteristics of the river ecosystem are clearly important, they are but a subset of the factors specifically listed in Florida Statutes that should be considered when setting MFLs (62-40.473 *F.A.C.*). The list (reproduced in Chapter 1 of the draft report) includes recreation, fish and wildlife habitat and fish passage, estuarine resources, transfer of detrital material, maintenance of freshwater storage and supply, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, sediment loads, water quality and navigation. The draft report includes a clear and well justified argument for preserving ecologically meaningful elements of the flow regime, and at least some mention is made of setting low flow thresholds to protect passive recreation uses such as canoeing. However, the report never completely addresses how the proposed MFL or the District's approach addresses any of the other factors listed above or why only certain factors were selected for this water body. (Note that in at least one other water management district in Florida, draft MFLs are developed based on one or a few resource protection goals, then a separate assessment is conducted to evaluate how well the draft flows and levels address the protection needs of other factors such as recreation, water quality and sediment loads).

The Panel suggests that for the upper Hillsborough and other rivers of Florida there may be other important processes from the list that merit consideration by the District in setting MFLs. For example, should there be concern for maintaining a minimum dissolved oxygen level or sustaining temperature below some threshold? Such factors may be especially important in relation to setting the low-flow threshold, which is presently based solely on a presumptive fish passage criterion and an analysis of wetted perimeter.

Preventing Significant Harm – 15% Change in Habitat Availability

The draft report describes the metrics used to define *"the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area"* as stated in Florida statutes. The authors note that "significant harm" was not defined in statute. The District chose to interpret significant harm as: "the loss of flows associated with fish passage and maximization of stream bottom habitat with the least amount of flow and quantifiable reductions in habitat." Overall, this is a reasonable approach from an ecological perspective and likely satisfies the intent of the statute.

The authors state that, *"[in] 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."* The authors further note, in our opinion, correctly, that *"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 flow decline, often without a clear inflection point or threshold."* Nevertheless, the 15% habitat loss criterion remains one of the least rigorous, most subjective aspects of the District's approach to setting MFLs. Justification for this threshold is based on common professional practice in interpreting the results of PHABSIM analyses (Gore at al. 2002), a review of relevant literature where reported percentage changes ranged from 10 to 33% and on previous peer reviews that found the 15% threshold to be "reasonable and prudent, especially given the absence of clear guidance in the statute or in the scientific literature on levels of change that would constitute significant harm…" (e.g., Shaw et al. 2005).

The draft upper Hillsborough report continues the District's practice of using a 15% change in habitat availability as the threshold for defining significant harm and now applies this threshold broadly to include both spatial and temporal loss of habitat or connectivity. The draft report also applies the criteria in a slightly different way to the proposed MFL for Crystal Springs by setting the minimum springflow such that there is no more than a 15% increase in the number of days that the low-flow threshold for the river is violated.

The Panel again acknowledges that the use of this criterion is rational and pragmatic, but also recognizes that the specific value of 15% is subjective and has only modest validation or support from the primary literature. Arguments can and likely will be made for both lower and higher percentages of habitat loss to be used for defining significant ecological harm. Other work has been done, in addition to the literature that is already cited, and the Panel believes it would be prudent to expand the literature review to gather as much additional supporting documentation as possible. Where lower or higher percentages have been used elsewhere, it would be illuminating to understand the rationale for these decisions (e.g., lower percentages used where imperiled or more sensitive species are concerned, higher percentages for more degraded systems, etc.).

More importantly, however, is the need for the District to commit the resources necessary to validate the presumption that a 15% decrease in spatial or temporal habitat availability or a 15% increase in violations of the low-flow threshold does not cause significant harm. The District would appear to be in an excellent position to implement monitoring, natural experiments and other analyses necessary to evaluate the effectiveness of this threshold and establish a framework for adaptive management. Several riverine MFLs have now been developed and adopted by the District using the same or similar criteria, and the infrastructure for field work used to develop these MFLs is still in place. The present drought conditions that prevail over most of Florida as this peer review is written would seem to make for ideal conditions for testing and evaluating assumptions regarding minimum flows. Several previous peer reviews have called on the District to collect additional site-specific data to validate and refine assumptions used in the development of MFLs (Cichra et al. 2005; Gore et al. 2002; Shaw et al. 2005), and the District has committed to periodic re-evaluation of its MFLs as structural changes or changes in the watershed warrant. Despite this, we have seen little evidence so far that the District is moving rapidly to implement the needed monitoring or assessment. The Panel strongly believes that without such follow-up, the 15% threshold remains a presumptive criterion vulnerable to legal and scientific challenge.

Analytical Tools Used to Develop MFLs

PHABSIM

Previous peer review reports have discussed at length and affirmed the District's use of the Instream Flow Incremental Methodology (IFIM) and the related PHABSIM software (Cichra et al. 2005; Gore et al. 2002; Shaw et al. 2005). The District likewise employs this methodology to the upper Hillsborough River, using habitat suitability curves for the same suite of three common *Centrarchid* fish species plus invertebrates that were used in developing MFLs for the Middle Peace, Myakka and Alafia Rivers. Overall, the District's use of the methodology and its description of the development of habitat suitability curves are consistent with standard practice and follow the recommendations of previous peer review.

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 reported fish abundance data for these rivers. However, the Panel notes that both bluegill and largemouth bass are habitat generalists and are not especially sensitive to changes in hydrologic regime. As such they may be rather poor choices for use in establishing MFLs, despite the merits of the IFIM/PHABSIM methodology. For example, it appears from Figure 4-3 that all four life stages of largemouth bass are relatively insensitive to changes in flow, and therefore changes in depth and velocity. Assuming there would be zero habitat at zero discharge, the river would in essence be a series of disconnected pools. Then adding the slightest amount of water to have barely a trickle over the hydraulic control results in a near optimal habitat condition. The amount of habitat at this "barely a trickle" flow is the same as at flows in the 940 cfs range. If the objective is to develop MFLs, then it is necessary to have a species that is much more sensitive to changes in flow.

In keeping with previous peer reviews, the Panel recommends that the District invest the resources necessary to 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 those used here.

Of particular concern would be any listed, imperiled, or endemic species, species tracked by the Florida Natural Areas Inventory (FNAI), 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. Species and communities in the upper Hillsborough basin tracked by FNAI include ironcolor shiner (*Notropis chalybaeus*), peninsular floater (a mussel, *Utterbackia peninsularis*), Chapman's sedge (a wetland plant, *Carex chapmanii*), bald eagle (*Haliaetus leucocephalus*) and hydric hammock, a natural community of the river's floodplain. (FNAI Element Occurrence Database, 2007).

In the draft report, Section 4.2.2, it is stated that cross sections were established for fish habitat at three sites and the reader is referred to Figure 4-1. As noted in the errata section, several sites mentioned in the narrative, including the "7R, Hillsborough River State Park, or Sergeant Park" are not labeled in the figure. It is not clear how many PHABSIM transects were used for each study site; however, we assume that there were three for each study site in keeping with standard practice. If that is the case, then there should be a description of how the habitat types (riffle / run / pool) represented by the three transects were in the same relative percent proportion for the entire study reach they are representing. For most studies where the PHABSIM models are used, it is fairly standard practice to show a detailed diagram of each study site with 5-7 transects needed per riffle-pool sequence.

It should be indicated if the time step is daily or weekly in Section 4.6.1, the last paragraph on page 4-19, for each benchmark period (e.g. 1940-1969) for the Block 1 time period (April 20 to June 24). It would also help to clarify that the 15% habitat reduction metric is the average habitat reduction for all the days, (or weeks if that is the time step) for April 20 to June 24 for the 1940-1969 benchmark period and similarly for the 1970-1995 benchmark period. For example, there are 2,349 days (81 days x 29 years) for the 1940-1969 benchmark period. During any one of these days, The habitat reduction could be greater than 15% during any one of these days, but it is not greater than 15% on average.

Habitat Criteria and Characterization Methods Used to Develop MFLs

FISH PASSAGE

The approach of defining a threshold for loss of fish habitat in terms of percent reduction of fish habitat and setting a low-flow threshold based on fish passage is consistent with today's understanding of maintaining self sufficient populations of fish that are able to move up and downstream and between different kinds of aquatic habitat.

Fish passage was used to estimate flows sufficient to permit fish movement throughout the upper Hillsborough River. Flows of this magnitude would also likely permit recreation (i.e., canoeing) though this is not substantiated in the draft report. 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 MFLs (SWFWMD 2002, 2005a, b, c) and has been found acceptable by previous peer reviewers (Gore et al. 2002; Cichra et al. 2005; Shaw et al. 2005).

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 and peer reviewers. 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 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. If flows were to be lowered due to consumptive use of water to depths of 0.6 ft, when depths would under natural flow conditions be much greater, would water quality issues arise? Of concern would be dissolved oxygen (DO) and temperature conditions near the limit of tolerance for fish and other aquatic life. If these questions cannot be answered at this point, then the Panel strongly suggests the District commit to studying what the fish passage criterion set as the low flow threshold means to the aquatic ecosystem (e.g., flow versus DO relationships, fish survival in pools, etc). Similar to the 15% habitat loss threshold discussed above, the minimum fish passage depth used by the District in this and previous MFLs is merely a presumptive criterion absent site-specific follow-up studies to evaluate ecological conditions under such a low-flow scenario.

In order to ensure there is 0.6 ft of water depth along the thalweg in the entire river reach being addressed, the authors would need to demonstrate that they have undertaken the necessary work to identify the most critical hydraulic control points in the river. This would presumably require a detailed survey of the thalweg for the entire river reach in question in order to determine this critical point of elevation. As the authors note, transects in pools or runs would not be in locations where this critical fish passage point is located. It would be on a rock ledge or other similar natural hydraulic control point. These are "critical" transects and are areas that go dry first as flows are lowered. Longitudinal studies of the thalweg may indeed have been done, but the Panel seeks assurances that the identification of hydraulic control points was done systematically as there is no documentation in the draft report of how control points were selected.

WETTED PERIMETER

The biological rationale for using the wetted perimeter, *"…the greatest amount of macroinvertebrate biomass per unit reach of stream occurs on the stream bottom…"* is sound, and it is widely accepted that a break point in the slope of the line represents the point at which there is an accelerated loss of habitat relative to reductions in flow. The authors also clearly point out that one of the difficulties in using this method is that there are no well defined break points in the slope (incorrectly referred to in the narrative as an "inflection point") more often than not. The results in Figure 5-2 are not surprising, and illustrate the difficulties with using the wetted perimeter method. Of all the reported transects, only one seemed to have a defined break point in the modeled flow range of interest. Difficulties encountered by the authors raise the question of how appropriate the use of this method is in a river like the Hillsborough River. The Instream Flow Council recommends this method should only be used in riffle mesohabitat types (Annear et al. 2004). If the transects, particularly the single transect at the Morris Bridge gage site where the low flow threshold value was determined, are located in riffles that are representative of food producing riffles in the river, then the basis for using the method should be adequate.

DAYS OF FLOODPLAIN INUNDATION

Low gradient rivers, like the upper Hillsborough, 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. For example, 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 upper Hillsborough River. 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 Panel feels that consideration of high flows and patterns of floodplain inundation is commendable and documentation of methods in the draft report is excellent.

COMPLIANCE STANDARDS AND PROPOSED MINIMUM FLOWS

The compliance standards, or recommended instream flow prescription to prevent significant harm, are well articulated and clearly indicate that the "50% anthropogenic reduction scenario" was selected as the "natural flow scenario" upon which the percent flow reduction factors are applied. Figure 5-13 on page 5-25 is useful as it shows how the flow reduction factors are applied to each seasonal flow block. However, the blue line, *"…the calculated natural flow corrected for withdrawals"*, is very difficult to see (see Errata).

It is always a challenge to know how much information to include (e.g., tables and graphs) to illustrate what is a very complex subject matter to a wide array of potential readers. The Panel notes that flow duration curves, the common currency of hydrologists, are a useful way to present information of this type and may be beneficial to the reader in that the full range of flows that can occur in any given time step can be seen. It also is easy to see where the low flow threshold occurs in terms of a percent exceedance value and relative to historic natural low flows.

The peer review panel endorses the District's proposed minimum flows for the upper Hillsborough River 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 and multiple assessment methods and habitat criteria for identifying the limiting flow reductions in each seasonal block represents best practice for determining instream flow needs and demonstrates a commitment to a comprehensive aquatic ecosystem approach to this very challenging issue. We again 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," 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.

It is interesting to note that ecosystem functions requiring higher flows tolerate a lower percent reduction than those for low flows, perhaps due to differences in the way the 15% habitat loss threshold is interpreted for different metrics (e.g., temporal loss of habitat with floodplain functions vs. spatial loss of habitat for

PHABSIM). In Figure 5-8, it appears that a smooth curve can be fit to the data, suggesting that a max reduction of 5% could be set for flows above 1250 cfs. Nevertheless, the recommended percent flow reductions for the upper Hillsborough appear to be quite consistent with those prescribed for other rivers in the SWFWMD. In fact, a table comparing the flow reduction values for upper Hillsborough with those of other rivers in the SWFWMD with proposed or adopted MFLs might be useful to include in the report.

Analysis of Spring Flows and Chemistry

Chapter 2 of the draft report provides a thorough and lengthy overview of the basin. The background information is extensive with particularly good information on land use change and hydrology. The placing of the hydrology into the context of multidecadal climate variability is particularly forward thinking in terms of setting MFLs in systems where state changes are characterized by thresholds and step shifts. However, as noted above, the Panel would be more comfortable simply identifying the different climate periods, without ascribing them to a particular climate index, given uncertainty about how various climate oscillations combine to affect stream flow in this region and the lack of predictability of the different phases of such indices.

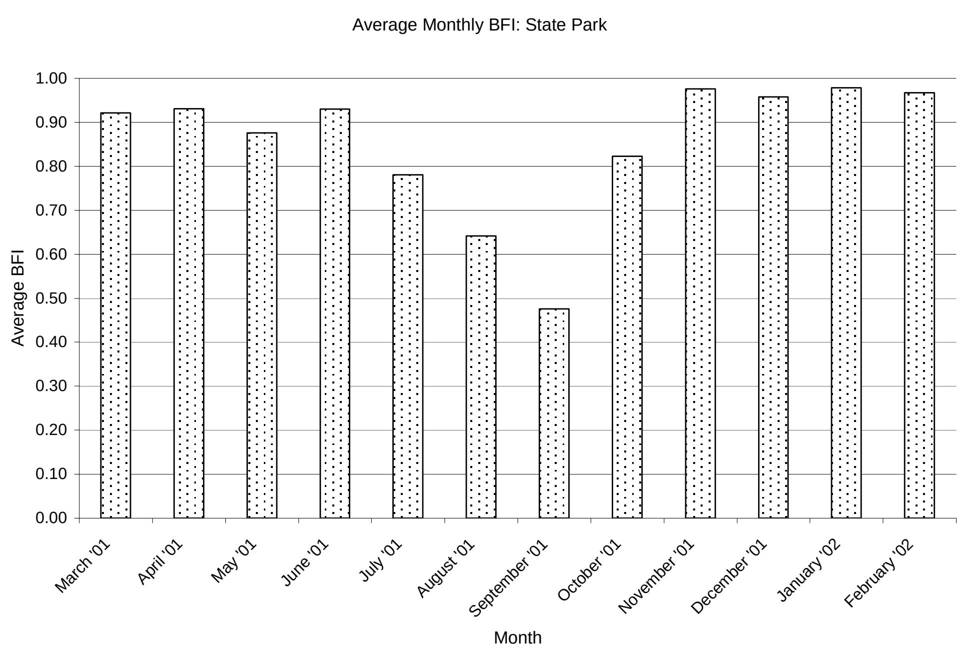
Comment [CD3]: Again, I concur about the predictability comment but feel the evidence to a clear link to the AMO is strong and justified.

The narrative of chapter 2, especially section 2.6, is extremely difficult to follow and has been frustrating for several of the Panel members to review. Conclusions are often presented before the evidence, terminology is inconsistent, crucial explanations that would greatly aid understanding and improve clarity are missing and figures are often poorly labeled and poorly connected with the narrative. There is also a considerable amount of redundant and occasionally inconsistent narrative in this section. Some sections contain analysis, results and discussion all in one paragraph. If the analysis, results and discussion could be separated, if only within sections, it would make the report easier to read.

The Panel cautions the authors to be extremely careful to distinguish between conclusions drawn directly from the data and interpretations of results or data which are really hypotheses, not conclusions. One gets the feeling the authors are often arguing with themselves about what conclusions to make, but the salient points and findings of the work are lost among the data explorations, speculation, counter arguments and asides. Some important insights or assumptions are taken as common knowledge without further explanation, justification or citation, including the observation that the long-term mean and median of flow from springs should be the same, that the mean annual flows of different springs in central Florida should be highly correlated, despite differences in geologic setting, lag times or response to recharge events, and that Rainbow Springs is suitable as a reference for unimpacted spring flow. It is never completely clear in the text which Crystal Springs flow data set among the several that are analyzed early in section 2.6 are used for each of the analyses later in the same chapter. Additional, more specific recommendations are made in the errata section of this peer review. In short, the Panel believes the underlying work described in section 2.6, is likely sound, but clear communication of the approach and main findings, notably from pages 2-59 to 2-79 and from 2-104 to 2-107, is lacking. We recommend that the authors rewrite these sections and edit figures to improve clarity and eliminate inconsistencies, redundancies and extraneous arguments.

By contrast, the sections describing the use of the groundwater model and the wavelet approach for analyzing the springflow data in the frequency domain are much more clearly written, and the tables and figures are easy to understand and relate to the narrative. Both approaches appear technically sound and correctly applied. Of the three methods discussed -- wavelet, z-score, and model -- the wavelet and z-score analyses use actual flow data, whereas the model results do not. Therefore, the z-score and wavelet analyses should be given considerably more weight in this analysis than the model results.

These general findings notwithstanding, some important observations were drawn from our review of this chapter. In section 2.2.1, the text states that the mean flow of the river is 446 cfs. However, this flow is greater than daily flows much of the year. As with most hydrologic time series, the distribution of flow is non-normal and strongly skewed toward low flows.



Note also that base flow contributed more than 80% of flow for 9 months out of 12 for the period 3/01 to 2/02, including a very large flow event on 9/13/01 ('BFI' in the graph above is fraction of flow that is base flow). When base flow exceeds 80% of flow at the State Park gage (Hills River near Zephyrhills), total flow is usually less than 200 cfs, and often less than 100 cfs.

Regarding the hydrologic mass balance that is presented on pages 2-35 to 2-36, Several observations can be made:

- there is a ‘recovery’ of flows starting in the mid-1990s from the low-flow period of 1970-1995. This suggests that the decrease in flows between the 1940-1969 period and 1970-1995 are probably not all anthropogenic, although the 1996-97 partnership agreement began to decrease groundwater withdrawals in the late 90s.
- a mass balance analysis should yield reasonable results in this situation, as the volume of water available in the basin is derived largely from rainfall. In the Hillsborough Basin, there are wet season overflows from the Withlacoochee Basin, and there may be groundwater inflows from outside the surface water basin. On the other hand, there may be recharge to the Floridan Aquifer within the basin that is not discharged within the basin.

Having made those observations;

$P = ET + Q + GW_n + A_e$, where

P = precipitation
ET = evapotranspiration
Q = stream flow
GW_n = net ground water flux (out is +)
A_e = anthropogenic effect (out is +)
All values are in in/yr over the basin

Changing to differences;

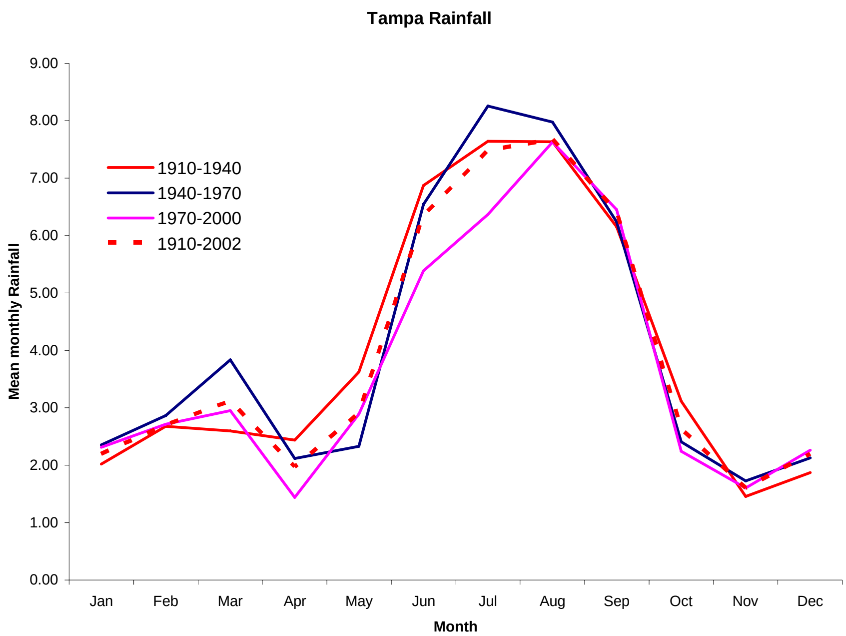
$dP = dET + dQ + dGW_n + dA_e$

Inserting values from 1940-1969 versus 1970-1994;

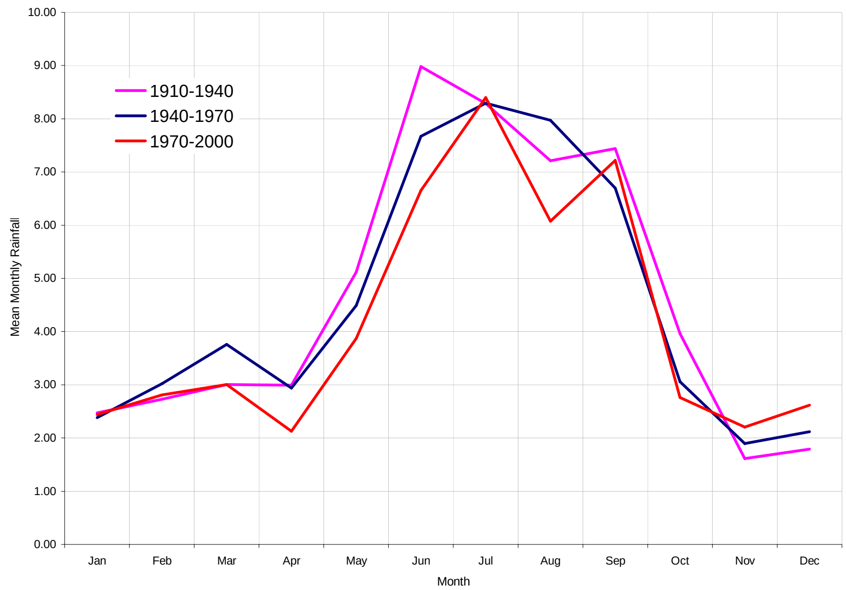
$-2 = (dET+dGW_n+dA_e) - 6.5$ -2” in P is from St Leo and HRSP

$+4.5 = (dET + dGW_n + dA_e)$

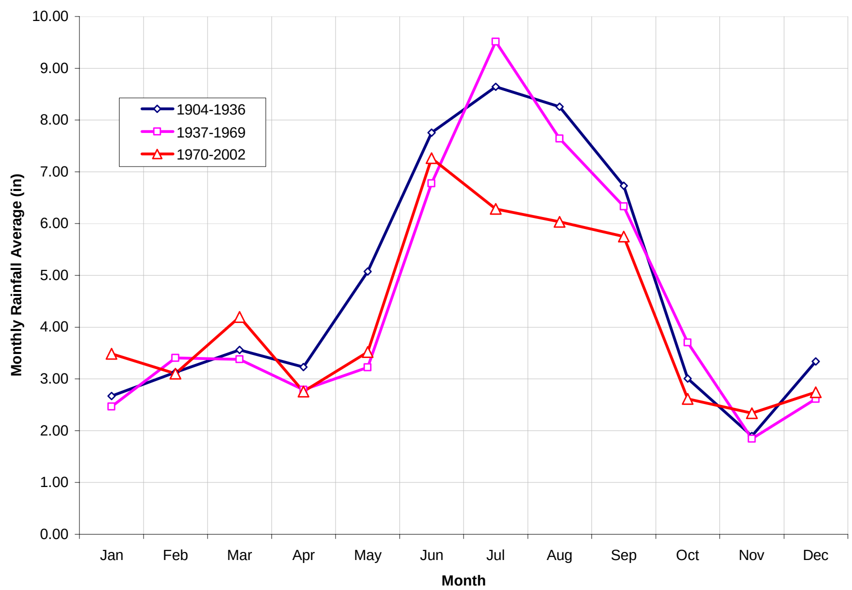
So, by the mass balance, either the decrease in rainfall caused an increase in ET, a decrease in ground water inflows, an increase in deep recharge, or an increase in anthropogenic effects, algebraically totaling 4.5 inches. For comparison, the amount of ground water pumped for potable use in the northern Tampa Bay region is roughly 4 inches. The text suggests that this result may be because the data may not be valid to differences of a few inches. However, those differences are then used in later analyses. The suggestion that summer rainfall may be part of the explanation may be valid, as there appears to be a decrease (albeit not statistically significant for the Hillsborough basin) in summer rainfall from the high-flow to low-flow periods, and possibly a slight increase in winter rainfall. This might suggest that summer rainfall, which generates the higher flows and roughly half the annual flow volume at the Zephyrhills gage, might have decreased more from 1970-1994 than indicated by the annual differences. However, anthropogenic effects can't be dismissed, and we don't think the District would want to question the credibility of the data set this early in the MFL report.



Bartow



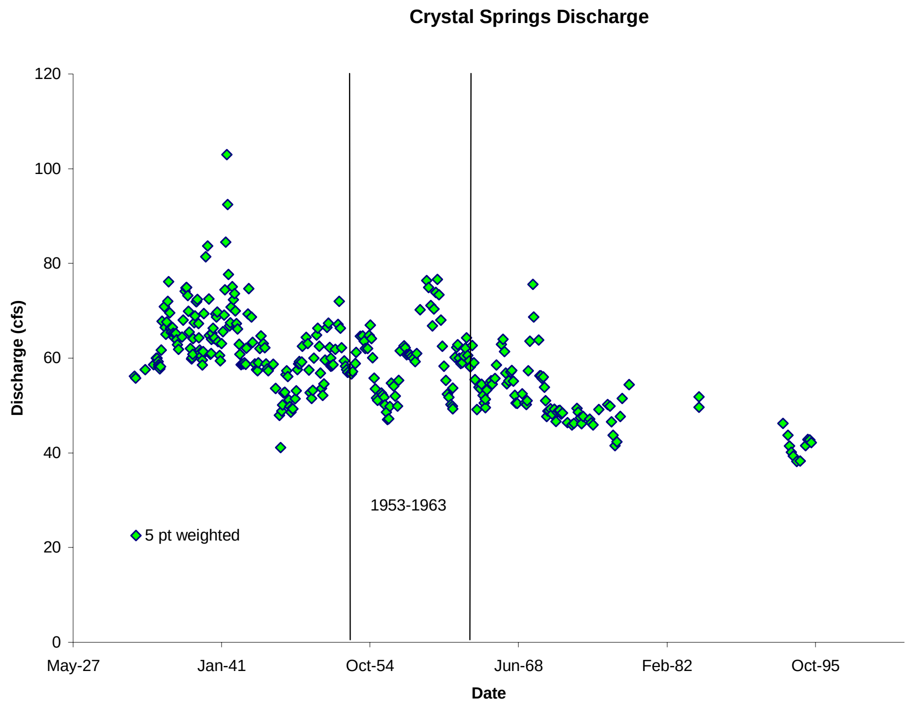
Ocala



The plots of discharge vs. time for Crystal Springs seem to suggest a moderate rate of decline in flow from the 1930s to about 1960, after which time a steeper decline begins. The total decline is from about 60 cfs to 40 cfs, with a suggestion of some recovery since about 2000. The Panel agrees that the measured values of discharge for Crystal Springs are problematic. The water quality database discharges are probably best, as they are direct measurements. It is uncertain what effect the structural modifications in the 1940s had on discharge and discussion of this issue in the text appears to be little more than speculation.

On page 2-63, the suggestion that later correlations support smaller anthropogenic influence can be turned around to say that the lack of correlation from 1935 to 1955 suggests a lack of regional influence during that period, which doesn't make much sense to the Panel. We conclude from this that it is difficult to conclude anything firm from the correlation patterns.

It is suggested that the Crystal Springs discharge data are in 'error' from 1953 to 1963. This is based on the wavelet analysis. A plot of the long-wavelength components seems to separate the 1953-1963 data from the rest of the record (Figures 2-53 – 2-56). On this basis, the data are 'corrected' by using the correlation between the Sharpes Ferry well and Crystal Springs to reconstruct the suspected data. However, unless there is some other really good reason to reject the data, throwing out 10 years of USGS stream gaging data is pretty radical and the Panel strongly cautions against such practice. A plot of the original data (below) does not show any 'anomaly', and the 1953-1963 data fall right in with data from earlier and later years. The only 'anomaly' in the original data is the higher discharges caused by the tropical storms of 1959 and 1960. This discharge peak shows up in discharge and rainfall records all over central Florida, so it is expected. The Panel suggests at a minimum redoing the wavelet analysis using the original, uncorrected data. "Correcting" the data has the effect of reducing discharges from Crystal Springs during a time when it has been assumed that anthropogenic effects were minimal. This biases later determinations of the anthropogenic effects.



Another section that requires additional attention is the section on river water and spring chemistry. The six pages of graphs of river chemistry trends for the upper Hillsborough River have three of the figure legends incorrectly identifying the variables being presented. In addition, figures 2-71, 2-72, 2-74, and 2-75 are not referenced in the text, and the description of these data in the six figures is terse and uninformative. There also are some significant problems with the chemistry data for Crystal Springs and some of the comparative springs. The monotonic trend in nitrate-nitrite nitrogen to values above 2.5 mg/L should be shown graphically in the report. Figures 2-77, 2-78, 2-79, 2-80, 2-82, 2-84, and 2-85 go unreferenced and described in the text, and legend and graphs are a mismatch for figure 2-78. Overall, the chemistry description needs a rewrite and many of the figure legends need correcting (see Errata).

Regarding comparisons of Crystal Springs and other springs in central Florida, very little justification is given for the assumption that flow from Rainbow Springs is unimpacted by anthropogenic effects, other than to show that the mean of its flows has remained relatively stable since the 1950s. Among other questions that could be raised, the extensive development that has occurred in the Rainbow springshed raises questions about whether recharge to the spring has been altered. More solid justification is needed in the draft report to support the District's assumption here. Also, in the water chemistry section, comparisons are made between Crystal Springs and several other springs in St. Johns River Water Management District, including Miami, Palm and Sanlando Springs. It should be noted that of these Palm and Sanlando springs are very close together, close enough to be considered by many to be different vents of the same spring system, perhaps limiting the usefulness of including both in the chemistry section. Nearby Miami Springs is a hydrogen sulfide-producing spring containing mats of sulfur-oxidizing bacteria, indicative of spring water that flows through geologic formations containing gypsum and exhibits significantly different water chemistry from typical “blue water” springs such as Crystal Springs.

Minimum Flows and Levels for Crystal Springs

The MFL for Crystal Springs is proposed as the mean/median spring flow that would cause the number of days that the 52 cfs low-flow threshold for the river to be achieved to decline by no more than fifteen percent. Focusing the Crystal Springs MFL on the river is logical and reasonable, especially given that the spring in question is no longer in a natural condition and has no true spring run in which the District could apply its river flow analysis tools. However, the Panel has concerns that the rationale for this proposal, and perhaps more importantly, assumptions made regarding possible alternative formulations of the MFL for Crystal Springs, are not well documented in the draft report. For example, it is not clear from the narrative why “it would not be appropriate to require that mean/median flow from Crystal Springs be maintained at 52 cfs…” This would seem to be a subjective decision not justified by the analysis or the discussion. On page 5-29, the report states that at low flow “essentially all flow” in the river is from Crystal Springs. If the low flow threshold based on fish habitat considerations is 52 cfs, and Crystal Springs provides all (or most) of the flow, we are puzzled why the minimum flow at Crystal Springs should not be 52 cfs.

The Panel is uneasy about setting an MFL for Crystal Springs that allows a 15% increase in the number of days the low-flow threshold in the river is violated. It would appear that this provides a loophole for water users to get around the low-flow threshold by withdrawing groundwater instead of surface water, but perhaps with additional discussion the rationale and implications of this proposal could be made clear. As was suggested above, this situation is another in which including a flow duration curve might help the reader better understand the implications of the spring MFL on the flow in the river. Again, the Panel urges the District to implement the necessary monitoring and evaluation to better understand what happens ecologically when the river falls to or below the low-flow threshold (minimum fish passage depth) and the implications on fish and aquatic life of a 15% increase in the time of excursion below this level.

In a similar vein, more discussion is needed regarding the closing paragraph of the report, where it is stated that “no further recovery strategy is warranted, until the effect of the existing [Northern Tampa Bay] strategy can be fully evaluated.”

The Panel has not reviewed the Northern Tampa Bay recovery plan, but hopes that it includes a rigorous plan for evaluating the effectiveness of any strategies that are implemented and is appropriately designed to enable District staff to make informed decisions regarding the need for additional recovery strategies, specifically for Crystal Springs. We suggest that additional discussion about these issues and appropriate citations be included in the draft report.

Evaluating Assumptions and Adaptive Management

We applaud the District's commitment to periodic reassessment of the MFLs for the upper Hillsborough River and other water bodies as structural alterations or substantial changes in watershed conditions occur. However, the Panel thinks that this commitment does not go far enough, and we are concerned that the District has so far taken no visible steps to assess some of the more uncertain and subjective elements of its MFL approach, namely the adequacy of the 15% habitat reduction criterion and the low flow threshold. We strongly recommend that the District begin now to develop and implement the process and methodology by which such assessment would occur. We recommend that an adaptive management framework be adopted for evaluating the effectiveness of the proposed MFLs for the upper Hillsborough and other rivers where similar MFLs have already been adopted. 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, specifically focusing on ecological conditions that occur at or near the low flow threshold and 15% habitat reduction scenarios.

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Errata / Comments by Page Number in 01-30-07 upper Hillsborough MFL Draft Report

xiv 2nd paragraph, line 5 – add comma after “task”
xiv 2nd paragraph, last line - add “of” before “flows”
xiv 3rd paragraph, line 7 – hyphenate “low flow”
xiv 3rd paragraph, line 8 – hyphenate “wetted perimeter”
xiv 3rd paragraph, last line - add “(LFT)” after “low flow threshold”
xiv 4th paragraph, line 1 – hyphenate “low flow”
xiv 4th paragraph, line 3 – hyphenate “low flow”
xiv 4th paragraph, line 4 – remove capitalization from “Prescribed Flow Reduction”
xiv 4th paragraph, line 4 – hyphenate “low flow”
xv 1st line - “site” should be “sites”
xv 1st paragraph, line 7 – add comma after “(470 cfs)”
xv 2nd paragraph, line 1 – hyphenate “medium flow”
xv 2nd paragraph, last line – hyphenate “medium flow”
xv 3rd paragraph, line 5 – hyphenate “low flow”
xv 3rd paragraph, line 6 – add comma after “periods”
xv 3rd paragraph, 7 – change “the 15%” to “than 15%”
xv 4th paragraph, line 5 – change “short term-“ to “short-term”
xvii line 10 – add comma after “For fieldwork”
1-1 1st paragraph, line 13 – change “”significant harm”” to “”significant harm,””
1-1 1st paragraph, line 15 - change “during next 20” to “during the next 20”
1-2 Section 1.2, 1st paragraph, line 2 – change “biolo0gists” to biologists”
1-3 Last paragraph, line 10 - Remove parenthesis before “typically”
1-6 1st complete paragraph, line 13 – hyphenate “high flow”
1-9 3rd paragraph, line 9 – change “of three” to “of the three”
2-2 Fig 2-1 - Show locations of rain gauges on this map
2-3 2nd line - “Hillsborough State Park” should be “Hillsborough River State Park”
2-3 1st paragraph, line 7 - “West” should be lower case
2-7 Last line – “e.g,” should be “e.g.,”
2-10 3rd line – add comma after “basis”
2-10 Delete space at beginning of table caption
2-10 Table 2-1 caption – hyphenate “432,176 acre”
2-10 Table 2-1 – delete “%” symbols throughout table
2-11 2nd line – Add “(Table 2-3, Figures 2-6, 2-7, and 2-8)” after “use”
2-12 Table 2-3 caption – hyphenate “202,873 acre”
2-12 Table 2-3 caption – change “periods,” to “periods:”
2-15 3rd line – add comma after “1990”
2-15 7th line – add “(Figures 2-10 and 2-11)” after “defined”
2-15 Table 2-4 caption – hyphenate “72,430 acre”
2-15 Table 2-4 caption – change “periods,” to “periods:”
2-18 6th line – add comma after “1972”
2-18 7th line – add comma after “1999”

2-18 8th line – add “(Figures 2-13 and 2-14)” after “35%”

2-18 Table 2-5 caption – hyphenate “45,674 acre”

2-21 6th line – add “(Table 2-6, Figures 2-15, 2-16, and 2-17)” after “1999”

2-21 Table 2-6 caption – hyphenate “111,199 acre”

2-24 4th line – change “is discussed” to “are discussed”

2-24 2nd paragraph under section 2.4.2, 1st sentence: “While much of Florida has a summer monsoon…” Strictly speaking, Florida does not experience a true monsoon. Perhaps should just call this a summer wet season or rainy season.

2-26 2nd paragraph, line 7 – add comma after “time”

2-26 3rd paragraph, line 9 – hyphenate “low flow”

2-26 3rd paragraph, line 10 – add comma after “Conversely”

2-27 Last paragraph, line 3 – “mainstem” is misspelled as “mainsterm”

2-28 Figure 2-19 - The identifier for site 3 is not on the mainstem of the Hillsborough River

2-30 Figure 2-21 – Change 4 “X”s to “Flow” in 2 labels at tops of 2 graphs

2-30 Bottom paragraph, line 1 – add commas after “River” and “Creek”

2-32 Figure 2-22 – use same Y-axis label on both graphs

2-33 Figure 2-23 – use same labels as those used in Figure 2-22 “Flow/WA (cfs/sq mile)”

2-33 Figure 2-23 – Legend: How did you decide when to remove or add flow to each day’s flow reading?

2-35 2nd paragraph, line 6 – hyphenate “6.5 inch”

2-35 2nd paragraph, line 8 – hyphenate “4.8 inch”

2-36 Lines 2-3 - please delete parenthetical remark “which apparently we should not”

2-36 1st paragraph, last sentence - consider adding the following to the end of the sentence: “…high flows in this part of the watershed or the inherent weaknesses in averaging a complex process like runoff over a large watershed.”

2-36 2nd paragraph – this paragraph presents the conclusion before any evidence is presented.

2-37 Table 2-7 - please spell out the entire year in the table; e.g., “1940” instead of “40” throughout to make more readable. Same for Table 2-8, p. 2-39, Table 2-13, p. 2-46, and Table 2-14, p. 2-48.

2-37 Table 2-7 - not cited in text

2-37 Table 2-7 – move column headings to right to match up with numbers. Same for Table 2-8, p. 2-39, Table 2-13, p. 2-46, Table 2-14, p. 2-48

2-37 Table 2-7 – give correct number of significant figures – last 2 rows of numbers. Same for Table 2-8, p. 2-39, Table 2-13, p. 2-46, Table 2-14, p. 2-48

2-39 Table 2-8 - not cited in text. A comment that applies to this table and to the entire text is that measured discharges are not valid to hundredths of cfs, so calculations based on measured flows aren’t valid to many decimal places. Probably three significant figures is the limit.

2-40 Line 7 - “Mann-Whitney test results” instead of “Mann-Whitney tests results”

2-40 Statement “These results are an indication of an anthropogenic decrease presumably due to groundwater withdrawals” is not supported by any evidence at this point in the narrative. Similar concern about other statements near the end of that same paragraph.

2-41 Table 2-11 – delete the “%” signs from within the table. Add “% Exceedance” as new column heading

2-41 Table 2-11 – shift column headings to right to line up with the data in columns

2-44 2nd paragraph, line 6 – first word should be “of” rather than “off”

2-44 2nd paragraph, 1st sentence - please add “the” before “1970 to 1994 dry period”

2-44 2nd paragraph, last sentence: “a increase” should be “an increase”

2-44 3rd paragraph, 3rd sentence - “…most of this year” should be “…most of the year”

2-44 3rd paragraph, 4th sentence - insert a semi-colon after “however” This sentence should be rewritten – it doesn’t make sense as written.

2-44 3rd paragraph - you don’t need apostrophes before plurals of multiple years in eight places.

2-50 Line 3 - “Multidecal” should be “Multidecadal”

2-50 2nd paragraph, line 8 – “Table 2-15” should be “Table 2-17”

2-50 2nd paragraph, line 9 – “Table 2-16” should be “Table 2-18”

2-50 2nd paragraph, 2nd last line – “Table 2-15” should be “Table 2-17”

2-51 Line 2 – add “(Table 2-18)” after “(p=0.0855)”

2-52 Figure 2-30 – change first two X-axis labels to “Year”

2-52 Figure 2-30 – correct legend on right of all three graphs – “o”, “.”, and “..”

2-56 3rd paragraph - it may not make sense to some readers why blocks are defined by averaging dates from several rivers as opposed to using the data derived from the Hillsborough River itself. Should probably add a note saying that the District is attempting to define these blocks consistently for multiple rivers to clarify.

2-56 3rd paragraph, line 3 – “Table 2-12” should be “Table 2-19”

2-57 3rd paragraph, last line – “Table 2-13” should be “Table 2-20”

2-56 4th paragraph, 1st sentence - “USGA” should be “USGS”

2-57 Table 2-19 – Why is text in table bold?

2-58 1st paragraph, last line – change “rivers flow” to “river’s flow”

2-58 2nd paragraph, line 1 - change “springs” to “Springs” after Crystal

2-58 2nd paragraph, line 1 – delete apostrophe from “1940’s”

2-59 Section 2.6 – you might want to consider adding a sub-heading here signifying the discussion will be about the USGS water quality sampling database

2-59 Line 4 – change “vents feed” to “vents that feed”

2-59 Line 5 - “Floridian” should be “Floridan”

2-59 Last line – delete apostrophe from “1960’s”

2-60 Figures 2-33 and 2-34 – need better headings and labeling to link figures with narrative and with each other. Are the blue data points in Fig 2-34 the same as those in Fig 2-33? I had a lot of trouble following the narrative throughout Section 2.6 – see peer review comments. This needs a thorough rewrite, just stating the findings and important insights. Whole section seems to include a lot of what appears to be the author arguing with himself, which makes it very difficult to follow.
2-61 2nd paragraph, line 5 – add comma after record
2-61 Section 2.6.1, 1st paragraph, 2nd sentence: what is meant by "…the spring's area."? Language seems a bit sloppy.
2-61? Section 2.6.1, 1st paragraph, last sentence - reference is made to the "HFR Section" of the appendix. This appendix was not included in our review draft.
2-61 Last paragraph - Delete sentence beginning "Increasing the head in the pool…" through the first sentence at the top of page 2-62 ending with "…significantly higher in the pool." This discussion adds little to the report and is quite speculative.
2-62 Fig 2-35 caption - mention is made in the caption of the "spring run," but previously in the narrative it was noted that there is no defined spring run. Please reconcile language.
2-62 Section 2.6.2, 1st sentence - the word "assumption" should more appropriately be "hypothesis"
2-62 Section 2.6.2, last sentence on page - the word "bridged" is a little confusing. Perhaps "includes" is a better word choice.
2-62 Section 2.6.2, last sentence on page - the word "where" should be replaced with "when"
2-63 Line 6 – delete apostrophe from "1960's"
2-63 Line 9 - "lead" should be "led" or "resulted in"
2-63 1st paragraph – does this paragraph refer to Figure 2-38? If so, then add reference
to table in this paragraph
2-63 2nd paragraph, line 10 – change "anthropogenic affects" to "anthropogenic effects"
2-63 2nd paragraph, line 10 – change "localized affects" to "localized effects"
2-66 Figure 2-38 legend and top titles – should these be "1955 to 1965" rather than "1935 to 1965"?
2-66 This figure (2-38) is not cited in the text
2-68 Section 2.6.3, 1st paragraph, 1st sentence - add …"as shown in Figures 2-33 through 2-35" to the end of this sentence. Add "It is likely that…" to the beginning of the 2nd sentence.
2-68 Section 2.6.3, 1st paragraph, sentence beginning "These approaches provided estimates of…" - "provided" should be "provide" and "ranged" should be "range."
2-68 3rd paragraph, line 3 – delete "When" at beginning of sentence
2-68 3rd paragraph, line 4 - add comma after "score analysis"
2-68 3rd paragraph, line 5 – add comma after "to 1975)"

2-68 3rd paragraph, line 9 – “It this data is…” should be “If these data are…”
2-69 Line 9 - “Stewart, et al 1971” should be “Stewart et al. 1971”
2-69 1st paragraph, last line - “Stewart et al occurred” should be “Stewart et al. (1971)
occurred”
2-69 Section 2.6.3.1, 1st paragraph, 2nd sentence - “a couple of” seems sloppy language. Change to “certain” or even “several”. Either would be better.
2-69 Last paragraph - the sentence “In order to make comparisons between the two, a good predictable relationship needs to exist between historic flows…” is vague. Comparisons between the “two” what? Relationship between historic flows and what? Also, delete the parenthetical remark “(climatic variability is eliminated…)” from this sentence as it is not needed.
2-70 2nd paragraph, line 13 – add “[“ before “actual flow”
2-70 2nd paragraph, line 14 – add “]” after “period mean”
2-70 2nd paragraph, line 21 - “anthropogenic affect” should be “anthropogenic effect.” The z-scores deviate in 1965, as do the discharges plotted from the USGS water quality database, which is expected as the z-scores are simply normalized values of the same data.
2-70 2nd paragraph, line 23 – “Figure 2-42” should be “Figures 36 to 39”?
2-70 2nd paragraph, lines 23-24 – The phrase “to overcome this confounding issue” doesn’t sound very objective. Suggest rewording.
2-70 3rd paragraph, line 1 – “anthropogenic affects” should be “anthropogenic effects”
2-70 3rd paragraph, line 10 – add comma after “was different”
2-71 General – The word “data” is plural. The singular is “datum.”
2-71 Line 7 – “Crystal z-scores” should be “Crystal Springs z-scores”
2-71 Line 15 - “anthropogenic affect” should be “anthropogenic effect”
2-71 Line 20 - “anthropogenic affect” should be “anthropogenic effect”
2-71 2nd paragraph, line 12 – “absent” should be “absence”
2-71 2nd paragraph - this is the first time that the Sharpes Ferry Monitoring Well is mentioned in the report. Describe the location or refer readers to a map.
2-71 Figures 2-45 to 2-48 and Table 2-23 need to be cited on this page (?)
2-71 Last sentence – “40-75%” should be “35-75%” or “approximately 40-75%”
2-73 Figures 2-40 and 2-41 top titles – delete extra space before “Rainbow River”,
need space before “(light blue)”
2-74 Figures 2-42 and 2-43 top titles – delete extra space before “Rainbow River”,
need space before “(light blue)”
2-75 Figure 2-44 top title – delete extra space before “Rainbow River”, need space
before “(light blue)”
2-76 Multiple changes of “affects” to “effects”
2-77 Figures 2-45 and 2-46 top titles – delete extra space before “Sharpes”

2-78 Figures 2-47 and 2-48 top titles – delete extra space before “Sharpes”
2-79 Multiple changes of “affects” to “effects”
2-80 Section 2.6.3.2 header - The personal communication cite is not necessary, especially since no affiliation or any other information is given that would allow a reader to contact R. Schultz or track this citation back to the source.
2-80 1st paragraph, line 5 – change “data is” to “data are”
2-80 2nd paragraph, line 2 – change “The data is” to “The data are”
2-80 2nd paragraph, lines 3 and 4 – change “high frequency portion, mid-frequencies and low frequencies.” to “high frequency, mid-frequency, and low frequency portions.”
2-80 2nd paragraph, lines 3 and 4 – change “data used is annual data, the…” to “data are annual in nature, the…”
2-80 4th paragraph, line 4 – “affects” should be “effects”
2-80 5th paragraph, line 5 – add comma after “data”
2-80 5th paragraph, line 6 – add comma after “plots”
2-80 5th paragraph, line 8 – change “data is” to “data are”
2-81 Line 1 – add comma after “crystals”
2-81 Lower graph – add X-axis label
2-81 Figure caption – add period to end of caption
2-81 1st paragraph below the figures, last sentence - statement is made that “it is generally agreed that there are no anthropogenic impacts at the well.” This seems to be an unsupported assertion. Can you add a citation to support this?
2-81 Last paragraph, line 1 – add “(Figure 2-50)” to end of first sentence. That said, the reviewers do not agree that a 25-year cycle is apparent in the data nor that it is “most apparent” in the s3 crystal.
2-82 Figure 2-50 – right side of 3 graphs are cut off
2-82 Figure 2-50 – add X-axis labels to graphs
2-82 Figure caption – add period to end of caption
2-82 Line 3 – add comma after “data”
2-82 Line 4 – add comma after “data”
2-83 Top left graph – add “Rainfall (in)” as Y-axis label
2-83 Top right graph – flip Y-axis label
2-83 Bottom left graph – add “Water elevation (ft)” as Y-axis label
2-83 Bottom right graph – flip Y-axis label
2-83 Figure caption – add period to end of caption
2-83 Figure 2-51 - This figure is the first time that the term “filtered” is used. It should be explained in the caption that “filtered” means that the “noise” from crystals d1 and d2 have been removed.
2-83 1st paragraph, line 4 – add comma after “constant”
2-83 2nd paragraph, line 2 – change “Rainfall” to “rainfall”
2-83 2nd paragraph, line 3 – change “Rainbow” to “the Rainbow River”
2-84 Figure 2-52 – add “Cumulative Flow (cfs)” as Y-axis label
2-84 Figure 2-52 caption – add period to end of caption
2-84 Table 2-24 caption – add period to end of caption

2-84 Line 1 – change “Rainbow” to “The Rainbow River”
2-84 Last line – add “Springs” after “Crystal”
2-85 Top of page - please delete the sentence “Clearly something is occurring within the data.” This is a throwaway and near-meaningless statement.
2-85 Figure 2-53 – add leading zeroes to two R-squared values
2-85 Last paragraph, line 1 – add comma after “Silver Springs”
2-85 Last paragraph, line 4 – change “r-squared” to “R-squared”
2-86 Figure 2-54 - add leading zero to R-squared value
2-86 Figures 2-54 and 2-55 captions – add period to end of captions
2-87 Figure 2-56 caption – add period to end of caption
2-87 1st period, line 8 – change “was used to…” to “were used to…”
2-87 2nd paragraph, line 1 – add comma after “data”
2-88 Table 2-25 caption – add period to end of caption
2-88 Table 2-25: Adjusted Crystal correlations for 1970-2003 should be shaded green like those for 1948-69.
2-88 1st paragraph, line 3 – change “springs” to “Springs”
2-88 2nd paragraph, line 1 – add comma after “2-59”
2-88 2nd paragraph, line 2 – change “is shown” to “are shown”
2-89 Figures 2-57 and 2-58 - The label “wavelet filtered data” should be in a consistent location and style in all figures where it is present. See also Figs 2-54-2-56.
2-89 Figure 2-57 – delete one of the periods (“.”) at the end of the caption
2-89 Figure 2-58 caption – add period at end of caption
2-89 Figures 2-57 and 2-58 - add leading zeroes to three R-squared values
2-90 Figure 2-59 caption – add period at end of caption
2-90 Figure 2-59 - add leading zeroes to two R-squared values
2-90 The formal term for this kind of regression model is “intervention model.” Also, please delete the sentence “This is similar to a model that takes into account wet and dry seasons.” This will be baffling to most readers.
2-91 Line 1 - change “to quantity” to “to the quantity”
2-91 3rd paragraph, line 5 – change “92%” to “0.92”
2-91 Figure 2-60 – change R-squared value from “=92%” to “=0.92”
2-92 Line 1 - change “affect” to “effect”
2-92 Line 2 – change “R-square” to “”R-squared”
2-92 Line 7 – add comma after “1990”
2-92 Add 1 or 2 blank lines between 1st paragraph and Figure 2-61
2-92 Figure 2-61 top title – change “Affect” to “Effect”
2-92 Figure 2-61 – How did you pick 1966 as the critical year from this graph?
2-92 Figure 2-61 caption – change “R-square” to “R-squared”
2-92 2nd paragraph, line 1 – add comma after “In general”
2-92 Last line – add comma after “2-26”
2-92 Table 2-26 caption – add period at end of caption
2-92 3rd paragraph, line 1 – change “Silver springs” to “Silver Springs”
2-93 last paragraph before section 2.6.3.3 beginning “Overall,…” Please delete entire paragraph. Entire books have been written about frequency domain

transformations of hydrologic data. No need to act as if you are introducing these concepts to the world.

2-93 1st 3 pages of section 2.6.3.3 – delete right justification and use the same size font as used in the rest of the document

2-94 5th paragraph, last line – delete space before period at end of line

2-94 last paragraph, sentence "Model-wide mean error…" - add "(UFA)" following "Upper Floridan aquifers"

2-95 last line of text – delete space in "s hown"

2-99 4th paragraph, line 8 – delete italics from "*four*"

2-99 Last line – add comma after "i.e."

2-100 Line 4 - change "Counties" to "counties"

2-100 Figure 2-66 - Even in color, the lines for "current conditions" and "upper Hill Basin w/o Pumpage (69 mgd)" are difficult to distinguish.

2-101 Figure 2-67 - the various time series lines in this figure are almost impossible to distinguish

2-103 Figure 2-69 - It would be helpful to identify county names on this map.

2-103 Section 2.6.4, line 1 – add comma after "As noted above"

2-104 1st paragraph, 3rd sentence - is poorly constructed. It should probably be turned into two sentences.

2-104 1st paragraph – It is not clear why all this material is being repeated here. Also in the 3rd sentence in this paragraph, "although" should be "however." In the 4th sentence in this paragraph, please replace "determined (assumed)" with "estimated."

2-104 2nd paragraph, 3rd sentence - the word "now" should be deleted

2-104 3rd paragraph, line 7 – change "St Johns WMD" to "St. Johns River WMD"

2-104 3rd paragraph, 4th line from end – add comma after "occurred"

2-104 3rd paragraph, 3rd line from end – add period after "etc"

2-105 Figure 2-70 – end of Y-axis label is cut off

2-106 Line 4 - change "withdrawal affect" to "withdrawal effect"

2-106 Line 5 – change "Corporation" to "Corp." to be consistent with rest of text

2-106 Lines 11 and 13 – delete apostrophe from "1950's"

2-106 3rd line above table caption – add comma after "in 1991"

2-106 3rd line from bottom – change "little affect on" to "little effect on"

2-107 You shouldn't have to use language such as 'it is admitted that it could be as much as 75%'. Makes it sound as if you feel guilty about something that you have to admit to.

2-107 last sentence before section 2.7 is completely unintelligible. Please rewrite for clarity.

2-107 2nd paragraph under Section 2.7, 4th sentence - please delete ";" between "section" and "rather"

2-108 Line 1 – add "(Figures 2-71 through 2-76)" after "versus flow'

2-108 Section 2.7.2.1, 2nd paragraph, line 6 – add "(Figure 2-71)" after "detected during this time"

2-108 Section 2.7.2.1, 2nd paragraph, line 10 – change "Kelly et. al." to "Kelly et al."

2-108 Section 2.7.2.1, 2nd paragraph, 6th sentence, please delete the word "actual." For the last sentence, a citation is needed to support the claim that the mining industry has decreased its water use. Also it would be simpler to say "a considerable decrease in water use" rather than "a considerable improvement related to water use"
2-109 2nd paragraph, line 2 – add "(Figure 2-72)" after "over time"
2-109 3rd paragraph, line 9 – add "(Figure 2-74)" after "Hillsborough River"
2-109 3rd paragraph, line 10 – delete apostrophes from "1950's" and "1970's"
2-109 Figure 2-75 needs to be cited in the text. A discussion also needs to be added.
2-110 Bottom graph – add "(mg/l)" after "Parameter Residuals" on Y axis
2-110 Figure 2-71: scale of middle graph (P vs. flow) obscures any relationships that might be present at low flows. All we see is a dilution effect. There are possible similar problems with middle graphs in Figs 2-72 to 2-76.
2-111 Bottom graph – add "(mg/l N)" after "Parameter Residuals" on Y axis
2-111 Figure caption, first line – "Nitrate/Nitrite" should be "nitrate/nitrite"
2-111 Figure caption, last line – replace "phosphorus" with "nitrate or nitrate/nitrite"
2-112 Figure caption, line 3 – replace "phosphorus" with "potassium"
2-114 Middle graph – change "(umhos)" to "(umhos/cm)" in Y-axis label
2-114 Bottom graph – change "(mg/l)" to "(umhos/cm)" in Y-axis label
2-114 Figure caption, line 2 – replace "concentration" with "conductance"
2-115 Bottom graph – add "(mg/l)" after "Parameter Residuals" on Y axis
2-115 Figure caption, first line – add "concentrations" after "Fluoride"
2-115 Figure caption, line 3 – replace "conductance" with "fluoride concentration"
2-116 Delete first sentence on page. Also, citations are needed to support the assertions in the second paragraph regarding NOx trends and sources at Crystal Springs, especially where it is stated "…and has previously been documented for Crystal Springs."
2-116 Paragraph (3) starting with "While…", line 5 – add "(Figures 2-77 through 2-87)" after "in the state" as most of these figures are not currently cited
2-116 3rd paragraph, last sentence: Miami Springs is used as an example where spring flows are increasing. Be aware that there are some data sets and graphs in circulation showing Miami Springs to have a sharply <u>decreasing</u> flow trend. It might be better to use a different spring as an example.
2-116 Last paragraph, line 6 – change "1970's" to "1970s"
2-116 Last paragraph, line 6 – add "(Figure 2-86)" after "were quite low"
2-116 Last paragraph, line 8 – change "inflection – see Figure 2-86)" to "inflection)"
2-116 Last paragraph, line 9 – change "1980's" to "1980s"
2-116 Last paragraph, line 10 – delete "see " at beginning of line
2-116 Last paragraph, in the sentence that starts "Rainbow Springs in Marion County…" - a citation is needed to support the information in the parenthetical remark. Otherwise, this is just speculation. Text in lines 12-13 should be changed from "…were probably taken at a slightly different…" to "…were taken at a different" Mike Mumma (UF Department

of Fisheries and Aquatic Sciences may have cited this in his thesis) – there was a change in sites as documented in a USGS fax

2-117 1st line, parenthetical remark that begins on the previous page "(although this may be related to a change in how this stream is now rated)" needs a citation, even if just a personal communication with USGS staff.

2-117 Sentence beginning "One also has to wonder…" - "larger spring systems such as Rainbow River and Silver Springs" would be more precise if changed to "larger spring-fed systems such as Rainbow River and Silver River…"

2-117 2nd paragraph, line 11 - "been" should be changed to "be" at beginning of line

2-118 Bottom graph – add "(umhos/cm)" after "Parameter Residuals" in Y-axis label

2-118 Figure caption, first sentence – replace current sentence with "Conductance in water samples collected by the USGS at Crystal Springs"

2-118 Figure caption, line 3 – replace "concentrations" with "conductance"

2-119 Replace entire figure caption with "Time series plots of sulfate, chloride, and calcium concentrations in water samples collected by the USGS at Crystal Springs"

2-120 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-121 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-122 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-122 Figure caption – "Spring" should be "Springs"

2-123 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-123 Figure caption – "Spring" should be "Springs"

2-124 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-124 Figure caption – "Spring" should be "Springs"

2-125 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-126 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-126 Figure caption – "Spring" should be "Springs"

2-127 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-128 Figure caption – "Time series plot of" should be "Time series plots of flow and"

2-128 Figure caption – "Spring" should be "Springs"

3-2 1st paragraph, line 9 – change "then 20%" to "than 20%"

3-2 1st paragraph, last line – change "/freashwater/" to "/freshwater/"

3-2 1st paragraph, last sentence: "MFL for Matagorda Bay" is not correct. Strictly speaking, Texas has no "MFL" program. Please change this to the terminology used in Texas. Also, the web citation shown at the end of this sentence appears to be inactive or incorrect, possibly due to typos in the URL (but even correcting for what appear to be obvious typos, I was unable to link to this web document).

3-3 7th line from bottom – "low flow" should be hyphenated as these two words together are used as one adjective

3-4 Section 3.3.2, 1st paragraph, line 12 – "low flow" should be hyphenated

3-4 Section 3.3.3, line 1 – add comma after "flows"

3-4 Section 3.3.3, line 2 – add comma after "perimeter"

3-7 2nd paragraph, line 13 - change "potentially effect" to "potentially affect"

3-7 3rd paragraph, citations would be helpful to support the assertion in the first sentence (which I don't think is really correct) and as examples of the kind of "published inundation needs" referred to in the 2nd sentence. For the last sentence in this paragraph, you might also add "…or are areas within the floodplain sustained by locally high water tables."

3-7 Last paragraph, line 1 – add comma after "approach"

3-7 Last paragraph, line 2 – add comma after "functions"

4-1 1st paragraph, line 4 – hyphenate "low flow"

4-1 1st paragraph, line 6 – hyphenate "low flow"

4-2 Figure 4-1 - On this map, vegetative cross sections and gaging stations are both identified numerically and in some cases the labels for the vegetative cross sections obscure the labels or symbols for the gaging stations. Later, a slightly different numeric label is used in Fig 4-2 for the vegetative cross sections. "Site" (cross section?) "7R" is referred to in the narrative on page 4-3, but this site is not shown on Fig 4-1. It is, however, shown on Fig 4-2. All of which leads to confusion.

4-3 Section 4.2.1, line 1 – add comma after "geometry data"

4-3 Section 4.2.1, line 2 – add comma after "River"

4-3 Section 4.2.2, 1st paragraph - all important cross sections, referred to in this paragraph, should be identified on Fig 4-1.

4-3 Section 4.2.2, 1st paragraph, line 10 – "sergeant Parks" should be "Sergeant Park"

4-4 Line 1 – add commas after "Cross-sections" and "habitats"

4-6 Move page number to bottom of page

4-9 Section 4.3.2, line 1 - change "Gore et. al" to "Gore et al."

4-11 Figure 4-4, top title – delete "Adult" from beginning of title

4-13 Line 2 – add comma after "snags"

4-14 Figure 4-6, top title – add space between "400" and "cfs" in two places

4-14 Figure 4-6, top title – "Compaired should be "Compared"

4-16 1st paragraph, lines 3, 5, 7, and 10 – hyphenate "low flow"

4-16 2nd paragraph, line 12 – hyphenate "low flow"

4-16 2nd paragraph, line 16 – hyphenate "wetted perimeter"

4-16 3rd paragraph, line 5 – hyphenate "wetted perimeter"

4-17 1st paragraph, line 8 – change "Kelly et. al." to "Kelly et al."

4-18 Figure 4-8 – label the X and Y axes of the four graphs

4-19 Section 4.6.1, 1st paragraph, line 4 – add comma after "Zephyrhills gage"

4-19 Section 4.6.1, 2nd paragraph, line 1 - “trend” should be “tend”
4-19 Section 4.6.1, 2nd paragraph, line 2 - “affects” should be “effects”
4-19 Section 4.6.1, 3rd paragraph, line 1 – add comma after “River”
4-19 Section 4.6.1, 3rd paragraph, line 3 – add comma after “one”
4-19 Section 4.6.1, 3rd paragraph, line 5 – add comma after “report”
4-20 1st paragraph, line 5 – hyphenate “low flow”
4-20 2nd paragraph, line 3 – hyphenate “low flow”
4-20 3rd paragraph, line 3 – add comma at end of line after “gage”
4-20 3rd paragraph, last line – add “assumption” after “anthropogenic” in two places
4-20 Last paragraph, line 8 – hyphenate ‘low flow”
4-21 1st paragraph, last line – hyphenate “low flow”
4-22 Lots of redundant narrative in Chapter 4 throughout.
5-1 1st paragraph, lines 4 and 6 – hyphenate “low flow”
5-1 Section 5.2 heading – hyphenate ‘Low Flow”
5-1 2nd paragraph, lines 1, 2, and 5 – hyphenate “low flow”
5-3 Figure 5-2 caption, last line - change “shown the” to “shown for the”
5-3 Section 5.2.3 heading – hyphenate “Low Flow”
5-3 1st paragraph, lines 1, 3, 6, and 7 – hyphenate “low flow”
5-3 1st paragraph, line 3 – add “gage” after “Zephyrhills”
5-3 1st paragraph, last line – change “lose” to “loss”
5-4 3rd line from top of page - “show” should be “shown”
5-4 1st full paragraph beginning “The State Park site…” This entire paragraph makes little sense and could be deleted without loss of information. Much of the narrative on page 5-4 is redundant. If this paragraph is kept and reworded, all common names of fishes should be in lower case (i.e., spotted sunfish and largemouth bass) – five places
5-4 3rd paragraph, line 5 – add comma after “Therefore”
5-4 4th paragraph, line 1 – add comma after “MFLs”
5-4 4th paragraph, line 4 – add comma after “benchmark period”
5-4 4th paragraph, line 6 – capitalize “park”
5-6 Item 1 – hyphenate “low flow”
5-6 Section 5.4, last paragraph, line 2 – hyphenate “low flow”
5-7 Line 1 – add comma after “470 cfs”
5-7 Lines 1 to 2 – hyphenate “low flow”
5-7 Last paragraph, line 4 – add comma after “flows”
5-7 Last paragraph, line 5 – add comma after “banks”
5-8 Move page number to bottom of page
5-9 Table 5-2 caption – It should be noted that the percentages shown in the table are percent length along each transect, unless the numbers have been converted to an areal measure.
5-10 Table 5-3, text – “Palmetto” should not be capitalized in cell 3:2. Should “Americana” be capitalized in cells 2:2 and 2:3? Change “rean” to “near” in table cell 3:3
5-13 Line 2 – change “such soil horizon” to “such as soil horizon”

5-13 Table 5-5, cell 3:4 – change “indication prolonged” to “indicating prolonged”
5-14 Table 5-6, cell 1:3 - change “inundation” to “inundate”
5-15 2nd paragraph, line 11 - add comma after “To develop the plots”
5-15 2nd paragraph, 15 – change “to1999” to “to 1999”
5-15 3rd paragraph, line 2 – add comma after “reductions”
5-15 3rd paragraph, line 3 – add comma after “achieved”
5-15 3rd paragraph, line 3 – change “for Morris Bridge” to “for the Morris Bridge”
5-16 Figure 5-8 caption, line 2 – change “near Morris Bridge” to “near the Morris Bridge”
5-16 Last line of text - change “near Morris Bridge” to “near the Morris Bridge”
5-17 1st paragraph under section 5.7, next to last sentence - “conservative” could be more appropriately worded “protective”
5-18 Table 5-7 caption – change “Based” to “based”
5-19 1st paragraph, line 5 – hyphenate “long term”
5-21 Figure 5-12 - There are 12 transects shown in the figure, but a transect 13 is mentioned in the caption
5-21 1st paragraph, line 2 – hyphenate “medium flow”
5-22 2nd line from bottom of page – change “488cfs” to “488 cfs”
5-23 Table 5-8 caption, line 3 – change “site” to “sites”
5-23 Table 5-8 caption, last line – change “flow sufficient” to “flow is sufficient”
5-23 Table 5-8, 3rd footnote – change “then” to “than”
5-24 2nd line from top of page - would “acceptable” be better worded as “appropriate”?
5-25 Figure 5-13 caption, line 2 – change “Blocks 1, 2 and, 3” to “Blocks 1, 2, and 3”
5-25 Figure 5-13 - the blue line is not really visible in this graph
5-28 I realize that you have internalized the concept and terminology of the “southern river pattern water year” and its acronym “SRPWY”, but the rest of the world has not. Please change or convert to more familiar terminology like water year or calendar year.
5-28 4th line from the bottom of the page - change “no met” to “not met”
5-29 1st line of text – change “The Low Flow Cutoff…” to “The low-flow cutoff…”
5-29 1st line of text - change “based a consideration” to “based on a consideration”
5-29 Section 5.11: This may be a good place to reiterate that the head springs at Crystal Springs is not in natural condition and there is no defined spring run, preventing use of the methods employed in the attempt to set MFLs for Lithia and Buckhorn Springs or consideration of alternative methods suggested in the peer review for those MFLs.
5-29 Line 5 – add comma after “flow conditions”
5-30 Line 9 – change “60 cfs x .76).” to “60 cfs x 0.76).”
5-30 1st paragraph, last sentence: “is 4 cfs (2.5 mgd) and possibly 7 cfs (4 mgd)” would be less awkward if written instead as “is between 4 and 7 cfs (2.5 to 4 mgd)”
6-1 Annear et al., line 2 – delete period after “Management”

6-1 Berryman and Henigar, line 3 – change “Tampa Florida” to “Tampa, FL”
6-2 Bunn and Arthington, line 3 – change “Management.30” to “Management 30”
6-2 Champion and Starks, line 1 – change “2001The” to “2001. The”
6-3 Hickey, line 2 – Change “Florida” to “FL”
6-4 Jones et al. – combine lines 3 and 4 and change “Florida” to “FL.”
6-5 Manly et al., line 3 – change “London.” to “London, England.”
6-6 SWFWMD 1993 – change three commas to periods and “119 p.” to “Brooksville, FL. 119 pp.”
6-6 SWFWMD 1994 – change “1992,” to “1992. Brooksville, FL.“
6-7 Sepulveda, line 3 – change “130 p.” to “130 pp.”
6-7 Stanford et al., line 3 – “Regulated Rivers” should not be italicized
6-8 Weber and Perry – add volume and page numbers of article

9 Appendix B – Staff Response to the Peer Review Report

Staff Response to

"A Review of 'Proposed Minimum Flows and Levels for the Upper Segment of the Braden River, from Linger Lodge to Lorraine Road'"

Specific comments identified by the peer review panel are reproduced below along with staff responses. Comments are organized under section headings used in the peer review report.

MFL Benchmarks and Resource Protection Goals

Benchmarks and the Atlantic Multidecadal Oscillation (AMO)

1) **The panel continues to "endorse and applaud" the use of the multiple benchmark periods, based on multidecadal climate variability, for MFL determinations. They, however, suggest removing more than a reference to the link between the variability in stream flow and the Atlantic Multi-decadal Oscillation (AMO). As they state: "**Although we are suggesting de-emphasizing the narrative connection with AMO, the panel strongly believes the idea of multidecadal variations in streamflow is valid."

Staff agrees that the link between streamflow and the AMO offers no predictive power. However, it does offer a mechanistic hypothesis for explaining long-term streamflow variability. Staff believes that dividing the flow record into periods of relatively high and low flows without offering some explanation for why we might expect continued phasing of these flow conditions reduces the value of observing past variations in stream flow. Though the AMO offers no predictive power in terms of when we might expect a change in flow conditions, the argument made by the District, which the panel terms "a strong case", is that future cycles can be expected, and that the shifts observed in the past, are not random or one-time steps but rather indicative of cyclic events. If there is not a case for linking the stream flow variations to a cyclic mechanism, then there is not necessarily any reason to use multiple benchmarks for developing minimum flows. Staff does however, agree that after publication of multiple peer reviewed MFLs documents, discussion of the AMO in subsequent reports can be minimized.

2) The peer review panel states that the evidence presented in the report suggest to them that "the anthropogenic effects at Crystal Springs represent as much as a 60-70% of the observed decline, rather than 50%", selected by staff. The panel "strongly recommends the District consider using an anthropogenic effect of >60%, rather than 50%."

The historic flow decline of Crystal Springs is based on about a 15 cfs reduction in flow over the period of record. The z-score and wavelet analyses both depend upon the accuracy of the discharge record for Crystal Springs prior to 1965 - which due to structural changes affecting the spring pool elevation, imprecise measurement procedures employed during high river flows, and generally poor correlation with three other major springs - is of questionable accuracy. In addition, both statistical methods rely upon a selection of a benchmark period where subjective judgment is introduced as to when anthropogenic impacts were minimal.

The z-score and wavelet analyses are approximation techniques with a range of solutions based upon the assumptions of the benchmark period and the selection of individual rainfall stations that are selected in the wavelet method. For instance, the percentage of flow decline due to anthropogenic influences using the z-score analysis ranges from 42 to 63 percent if one excludes the structurally altered discharge record prior to 1945 and applies decadal or two decade periods prior to 1975 as benchmark eras. The actual anthropogenic change in flow rate ranges from 3.3 to 9.5 cfs (42 to 63 percent). The wavelet analysis varies from 35 percent (5.4 cfs) using the St Leo rainfall station to 40 percent (6.1 cfs) if Plant City rainfall is utilized. The numerical model impacts ranged from 26 percent (4.0 cfs) to 33 percent (5 cfs) depending on the model used and the area of groundwater influence.

District staff believe that due to the uncertainly with the early discharge record, the assumptions used in the statistical techniques, and the limitations of numerical models, that no single analysis tool should be given more weight than the other. Therefore, the 50 percent flow decline due to anthropogenic effects is District staff's best estimate based on a consensus of three separate evaluations. Since there is a total decline of 15 cfs in spring flow over the period of record, the difference between a 50 percent impact and a 65 percent impact is a little more than two cfs. Due to the limitations in the analysis techniques, we do not feel there is a strong scientific foundation to differentiate impact to this level.

Seasonal Building Blocks

3) **The peer review panel wonders if flow blocks need to be pre-assigned or could all the tools used in the approach be applied to all weeks of the year and then the most conservative, or protective, factor be applied.**

Staff agree that pre-assigned flow blocks based on regional river systems are no longer necessary and for the Braden River and other river systems for which MFLs are currently being established, has developed flow blocks based on river-specific flow records . Staff believes that use of a seasonal or flow-block approach is reasonable, given the presumed adaptation of stream-dependent biota to seasonal flow variability. However, staff acknowledges that the addition of flow-range specific tools may be appropriate for MFLs development. Staff will also examine the use of weekly time-steps in subsequent modeling efforts supporting MFLs development and will compare these results with seasonally based time-steps to determine whether the current approach should be modified.

Resource Protection Goals

4) **The panel suggests that the District has not fully addressed the subset of factors listed in the Florida Administrative Code (Rule 62-40.473 F.A.C) that are to be considered when setting MFLs. Specifically, they note that there should be concern from the District for maintaining a minimum dissolved oxygen level and sustaining temperature below some undefined threshold.**

Not every one of the ten factors listed in Rule 62-40.473, F.A.C. is expressly addressed in the MFLs documents generated by the District. Staff does believe, however, that the percent-of-flow approach to surface water regulation provides protection for each of the listed factors. Staff have not interpreted the F.A.C. directive to consider the listed factors to mean that each must be expressly studied on each river, when it is reasonable to assume that other factors examined would be expected to afford protection to the factors not explicitly studied. With respect to this position, the panel notes that another state water management districts has developed reports in which it has been concluded that many of the factors listed in the F.A.C are not applicable to specific water bodies. The District has engaged external expertise during the Rainbow River MFL process to evaluate the efficacy of such studies.

Staff agrees with the panel's specific comment that dissolved oxygen and water temperature should be considered when developing minimum flows. To address this issue, staff has recently concluded a study examining the effects of flow variability across river shoals on temperature and dissolved oxygen. Details on the study were not included in the upper Hillsborough River MFL report because they were not used in the generation of the recommended upper Hillsborough River MFLs.

Preventing Significant Harm – 15% Change n Habitat Availability

5) **The authors of the peer review report state that the 15% habitat loss criterion remains one of the most subjective aspects of the District's approach. They do, however, note that staff correctly points out that there are few thresholds or "bright lines" which can be identified for establishing MFLs, and that previous peer review panels found the criterion to be "reasonable and prudent." The panel acknowledges that the use of the criterion is rational and pragmatic, but claims that the specific value of 15% is subjective.**

Staff agrees that the use of the15% habitat loss criterion for establishing MFLs may be considered subjective. The criterion was, however, developed based on review of threshold values used for other minimum flow determinations reported in the literature and a previous peer review recommendation. Staff acknowledges that additional documentation could be gathered and reviewed to support or potentially refine use of a percentage-based habitat-loss criterion for MFLs development, and plans to hire a consultant to complete this effort. Staff has also engaged the peer review panel in discussions concerning a potential study for validating and refining the assumptions associated with use of the 15% habitat-loss criterion.

Analytical Tools Used to Develop MFLs

PHABSIM

6) **The peer review report notes that bluegill and largemouth bass are generalist and not especially sensitive to change in hydrologic regime and may, therefore, be inappropriate species for use in the PHABSIM analyses used to develop MFLs. The review panel suggests that the District generate habitat suitability curves (for use in the PHABSIM system) for species that are more sensitive to changes in flow and also suggests that it may be appropriate to incorporate species or community types tracked by the Florida Natural Areas Inventory (e.g., peninsular floater, ironcolor shiner, Chapman's sedge. bald eagle, and hydric hammock) into the modeling effort.**

Staff agrees that development of additional habitat suitability curves, or refinement of existing curves would be a means of improving the PHABSIM analysis used in the MFLs process. The District has contracted Dr. James Gore of the University of South Florida to complete this work. To date Dr. Gore has developed and used Florida-specific data to refine about half of the curves currently used for District MFLs analyses,. Staff continues to work with Dr. Gore to identify the most practical and useful candidates for development of new habitat suitability indeces or curves.

Staff notes that it may be possible to incorporate species or community types tracked through the Florida Natural Areas Inventory program into the District's PHABSIM modeling efforts. With respect to the specific taxa and community identified by the panel, staff consulted with Dr. James Gore on the potential for developing data sets that could be used for PHABSIM analyses supporting MFLs development. Comments provided by Dr. Gore are summarized below.

(1) Ironcolor shiner (*Notropis chalybaeus*) - Indices or curves for this small fish species could be developed if it is possible to identify this shiner in the field during electrofishing. Field identification of minnow species is typically difficult, however, and the ironcolor shiner is a relatively nondescript minnow. Use of a recently developed habitat suitability curves for "forage fish" a collection of small fish species, may be an appropriate substitute for species-specific curves for small fish taxa and will be used in future river MFLs studies.

(2) Peninsular floater (*Utterbackia peninsularis*) – Development of habitat suitability curves for this mussel species would be problematic at best since mussels do not "respond" to changing flows in the same way that fish and mobile invertebrates do - their only choice is to either starve to death slowly because

they aren't getting enough particulates delivered to them or they dry up and die Use of PHABSIM analyses is not appropriate for relatively stationary species.

This issue is discussed in greater detail in the published paper listed below, which proposes an alternative way to address mussels and instream flows. Basically, the recommended approach would be to map mussel beds in river segments and use the PHABSIM modeling system to examine changes in inundation depths and flow velocities with changes in river flows. This can be an arduous process but has been accomplished for a couple of streams in Tennessee and Alabama.

Gore, J.A., J.B. Layzer, and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: a role in stream and river restoration. Regulated Rivers 17: 527-542

(3) Chapman's sedge (*Carex chapmanii*), a wetland plant, is also stationary. Like the peninsular floater and most mussel species, individual plants cannot relocate in response to changing flows, although it likely that distribution of propagules is influenced by variations in flow. Existing stands of the sedge could be mapped and hydraulic models used to predict inundation of the stands under varying flow regimes. Information on preferred habitat variables (e.g., water depth and velocity) could be developed and used to predict potential habitat availability for the species.

(4) Bald eagle (*Haliaetus leucocephalus*) - Field observations and photography from blinds could be used to pinpoint the "use" / capture points of fish, etc., for individual eagles and then water velocities, depths, and substrate conditions associated with the points could be used to create habitat suitability curves. This would probably be a difficult and potentially unreliable process as the species is not entirely water dependant.

(5) Hydric hammock, a natural community of the river's floodplain. Hydraulic models could be used to predict inundation patterns for this floodplain community, but it seems unreasonable that PHABSIM could be utilized for evaluating changes in this habitat type. Current District methods for establishing MFLs include analysis of inundation patterns for this and other floodplain communities.

As part of its adaptive management approach the District continues to develop new and refine existing habitat suitability curves. Consultants have already refined some of the initial curves used in MFL studies to be Florida specific. The newer curves are consistent with the earlier curves though they exhibit a higher level of detail.

7) **Peer reviewers mentioned that having a schematic or aerially-based map showing PHABSIM transects and some general features would be informative to the reader, and they recommend including this type of figure in future reports. There also note that a description of the ratio of habitat types (riffle / run / pool) that are represented in the study sites by the three PHABSIM transects should be include in future reports. They also note that future reports should include a discussion of the ratio of habitat types in the study sites relative to the ratio of these habitat types in the entire reach of the river that the study sites represent.**

Staff understands the points made and has tried to select representative site for location the PHABSIM transects in the past. As always access granted by private land owners has played a role in site selection. The comments of the panel are appreciated and their suggestions for schematics and better description of the transect selection process will be incorporated into future MFLs reports.

Habitat Criteria and Characterization Methods Used to Develop MFLs

Fish Passage

8) **The peer review panel has questioned the adequacy of the fish passage depth for maintaining negative effects associated with low flows in warm water ecosystems (*i.e.*, temperature, dissolved oxygen, and algal blooms). The peer review staff further seeks assurance that the hydrologic control points were systematically identified.**

As noted in item (5) above the District has committed to the study and confirmation of its low flow threshold criteria (e.g., fish passage water depth). The dissolved oxygen and water temperature study currently being conducted by staff seeks to validate or improve the fish passage estimate with regard to the implied protection of oxygenation and thermal characteristics associated with flow across river shoals.

With respect to the panel's concerns regarding description of the control points, staff notes that the lowest spot in the channel refers to the lowest surveyed elevation in the respective shoal cross-section. Staff has revised the MFLs report to clarify this description.

Wetted Perimeter

9) **Given that this method [identification of the lowest wetted perimeter inflection point for establishing a low flow threshold] should only be applied in shallows, riffles or ledges, it is not clear why the authors choose to establish the wetted perimeter for all the reported transected. Perhaps, it would be better to simply eliminate these transects from the analysis since transects through pools should not be used.**

Staff agrees with this comment and actually uses only the results from shallow areas for determination of low flow thresholds. Deep pools which have inflection points established below or at the lowest modeled flow are ignored when evaluating the lowest wetted perimeter inflection point. Clearly it would be inappropriate to do otherwise. Staff does however report this data for completeness, and views it as similar to a chemistry lab reporting below detection limits as the detection limit or Secchi disk depth which hits the bottom as being recorded as bottom depth.

Compliance Standards and Proposed Minimum Flows

10) **The Panel notes that flow-duration curves, the common currency of hydrologists, are a useful way to present information of this type and may be beneficial to the reader in that the full range of flows that can occur in any given time step can be seen.**

Staff agrees that flow duration curves are effective for conveying hydrologic information. However, staff believes that the median annual flow hydrographs presented in District MFLs reports are easily understood by both experts and laypersons and that they are appropriate for comparing potential hydrologic regimes associated with the proposed minimum flows with historic or natural flows. Staff will include flow-duration curves in future MFLs reports as an addition to the currently used hydrographs.

Evaluating Assumptions and Adaptive Management

11) **The Panel thinks that the District should develop a methodology to confirm the adequacy of the 15% habitat reduction criterion and the low flow threshold. They recommend an adoptive management framework for this work and suggest ongoing monitoring of key ecosystems components, specifically focusing on ecological conditions that occur at or near the low-flow threshold and 15% habitat reduction scenarios.**

The 15% habitat reduction and low flow threshold criteria are used to identify acceptable ecological changes associated with long-term decreases in flow, not short-term flow variations that may occur on a seasonal basis. Manipulative studies, involving long-term flow reductions would be necessary to fully evaluate the adequacy of the flow criteria. Staff is evaluating the means by which such studies could be conducted.

Results of the Peer Review and Staff Response to Comments on the Proposed Minimum Flows for Crystal Springs

12) The panel's report in general comments that Chapter 2 should be reorganized and rewritten. Specific attention is paid to the various analysis of the anthropogenic portion of the observed declines. With respect to the various analyses the panel concludes that the z-score and wavelet analysis should be given considerably more weight then the model results. They also, however, caution against the removal of a 10-year period of data from the wavelet analysis.

The historic flow decline of Crystal Springs is based on about a 15 cfs reduction in flow over the period of record. The z-score and wavelet analyses both depend upon the accuracy of the discharge record for Crystal Springs prior to 1965 - which due to structural changes affecting the spring pool elevation, imprecise measurement procedures employed during high river flows, and generally poor correlation with three other major springs - is of questionable accuracy. In addition, both statistical methods rely upon a selection of a benchmark period where subjective judgment is introduced as to when anthropogenic impacts were minimal.

The z-score and wavelet analyses are approximation techniques with a range of solutions based upon the assumptions of the benchmark period and the selection of individual rainfall stations that are selected in the wavelet method. For instance, the percentage of flow decline due to anthropogenic influences using the z-score analysis ranges from 42 to 63 percent if one excludes the structurally altered discharge record prior to 1945 and applies decadal or two decade periods prior to 1975 as benchmark eras. The actual anthropogenic change in flow rate ranges from 3.3 to 9.5 cfs (42 to 63 percent). The wavelet analysis varies from 35 percent (5.4 cfs) using the St Leo rainfall station to 40 percent (6.1 cfs) if Plant City rainfall is utilized. The numerical model impacts ranged from 26 percent (4.0 cfs) to 33 percent (5 cfs) depending on the model used and the area of groundwater influence.

District staff believe that due to the uncertainly with the early discharge record, the assumptions used in the statistical techniques, and the limitations of numerical models, that no single analysis tool should be given more weight than the other. Therefore, the 50 percent flow decline due to anthropogenic effects is District staff's best estimate based on a consensus of three separate evaluations. Since there is a total decline of 15 cfs in spring flow over the period of record, the difference between a 50 percent impact and a 65 percent impact is a little more than two cfs. Due to the limitations in the analysis techniques, we do not feel there is a strong scientific foundation to differentiate impact to this level.

13) The presumption that Rainbow Springs is relatively free of impact is not supported strongly. A more solid justification is desirable.

We agree that more supporting information could be included regarding the assumptions that mean annual flows from different springs in central Florida should be highly correlated and that Rainbow Springs is suitable as a reference for unimpacted spring flow. As was stated in the report, the comparison of mean annual flow of Crystal Springs to Weeki Wachee, Rainbow, and Silver Springs indicates fairly high correlation amongst all springs for the post-1965 record. One must question why would the correlation be good for the last 40 years and very poor when discharge was matched prior to 1965? Even in the presence of withdrawals, spring flow (as well as lake stages and river flows) should be highly correlated with climatic conditions. These springs and their contributing areas tend to represent regional conditions of the Upper Floridan aquifer. The springs listed in the report are all within a similar climate zone (National Weather Service Region 3). SWFWMD (2004) found that similar long-term climatic patterns exist for rivers in this region. Overall long-term climatic trends should be reflected in all springs by using the mean annual flow values despite variations in recharge, lag times, or local geologic settings.

Rainbow Springs Basin, located in eastern Levy and western Marion Counties, contains widely dispersed withdrawals of relatively low extraction. The basin is internally drained with little or no surface water runoff. The total spring basin area is approximately 640 square miles (Knowles, 1996). Water budget analysis indicates average annual recharge of 15 in/yr over the Rainbow Springs Basin based on the period-of-record mean flow for Rainbow Springs of 708 cfs. Currently, about 20 mgd of groundwater is withdrawn in this basin. The amount of groundwater withdrawn equates to about 0.7 in/yr over the basin or about 4 percent of annual recharge. In addition, the USGS Mega Model predicts long term lowering in the unconfined Upper Floridan aquifer of about 0.3 feet in the Rainbow Springs Basin. This value represents a small amount of anthropogenic impact that is generally below measurement detection in regional monitor well data. Therefore, District staff believes that this spring basin is relatively unimpacted by current withdrawals in the area. We can include this analysis and other information to support some of the statements listed above.

14) The report states that the peer review panel is puzzled why the minimum flow at Crystal Springs should not be 52 cfs. They suggest that this is a loop-hole around the low flow threshold which allows water users to withdrawal groundwater but not surface water.

The flow record at Crystal Springs suggests that the discharge from the springs naturally drops below 52 cfs. Therefore, 52 cfs is inappropriate as a minimum flow for crystal springs. Because the District currently permits surface water withdrawals as a percent of flow approach and these withdrawals utilize off-line storage facilities, it is reasonable to limit surface water withdrawals under the lowest flow conditions.

15) The panel feels that additional information concerning the Northern Tampa Bay recovery strategy is warranted. They suggest that since this strategy is being employed for the recovery of Crystal Springs that staff should evaluate the effectiveness of it for that purpose.

The northern Tampa Bay recovery strategy is documented in 40D-80.073 F.A.C. While this rule does not mention Crystal Springs specifically, it does specify recovery levels to be obtained in groundwater wells throughout the northern Tampa Bay area. One anticipated effect of raising the well levels will be to increase flows from artesian springs (i.e. Crystal Springs) in the area. Further, 40D-80.073(8) F.A.C. requires the evaluation of the recovery strategy in 2010 including analysis of all information and reports submitted regarding minimum flows and levels for the priority water bodies in the area. If deemed necessary by the evaluation of the initial recovery strategy, the Rule (40D-80.073, F.A.C.) may be revised to incorporate a second phase as necessary.

16) The Panel is concerned about the discarding of ten years of U.S. Geological Survey streamflow data in the hydrologic analysis without convincing justification for doing so, and recommends that the wavelet analysis be re-run using the original "uncorrected" data.

The discharge measurements for Crystal main spring are determined by subtracting the upstream river gaged flow from the downstream river gaged flow since there is no "spring run" that is measured directly from the spring. It is recorded along the Hillsborough River about 1,500 feet above and 3,000 feet below where the spring flow enters the river. This method of discharge calculation for Crystal Spring is inherently more uncertain than other methods such as gaged measurements from a single channel immediately downstream of a spring vent or from correlations with a nearby Upper Floridan aquifer well, which is what the USGS uses to calculate discharge for Weeki Wachee, Rainbow, and Silver Springs.

A review of the USGS flow data indicates that prior to 1965 there is a high degree of variability in the discharge measurements. An inspection of USGS data from 1937-1964 indicated that when measured stream flow at the station above Crystal Spring was compared with the datum elevation, there was a significant deviation of recorded flow when the datum elevation exceeded 15 ft – with values varying by as much as 80 cfs with the same datum elevation. Upstream river flow graphed against calculated spring flow shows a high degree of variability when spring discharge is above 55 cfs. A plot of Crystal Springs discharge record shows about 75 percent of all measured discharge was above 55 cfs prior to 1965. Post-1965, recorded discharge above 55 cfs makes up just 15 percent of the values. An examination of the USGS comments from the 1937-1964 period shows that discharge was measured at over *20 different locations* from the gaged sites. In addition, several comments in 1948 indicated that all previous river flow measurements included multi-channel flow but thereafter they did not. There were also two datum elevation changes that occurred in 1937 and 1964 which suggests new rating curves and perhaps relocation of the stream flow measuring stations.

In the report, the District regressed mean annual flow from Silver Springs, Rainbow Springs, and Weeki Wachee Spring against Crystal Springs and found very poor correlation between these springs for two periods: 1935-1955 and 1945-1965. Regressions for the period 1965 to 1995 showed much better relation in flow amongst all springs. If the regression equation between all three major springs and Crystal Springs from 1965-2004 is applied to calculate a synthetic discharge history for the early record, then Crystal Springs pre-1965 flow would be much lower than observed (Figure 1). In fact, the average discharge for the period from 1933-1964 would be approximately 12 cfs lower than the observed record if the computed discharge from the regression equations is averaged from all three major springs (Rainbow, Silver, and Weeki Wachee) (Figure 2).

One might argue that the post-1965 relation in flow between Crystal Springs and the other major springs is a reflection of anthropogenic impact on Crystal Springs and therefore would not be a suitable surrogate to estimate the pre-1965 data. However, Figure 1 shows there is a relatively consistent graphical separation between Rainbow and Crystal Springs discharge from 1965-2004. One would expect this graphical separation, albeit smaller, to exist in the pre-1965 comparison of the two springs. Yet, only the period from 1945 through 1953 shows this separation while the periods prior to

1945 and from 1954-1964 do not. Clearly, there appears to be some abnormality in the Crystal Springs discharge record during those periods when compared to natural climatic variability from background springs.

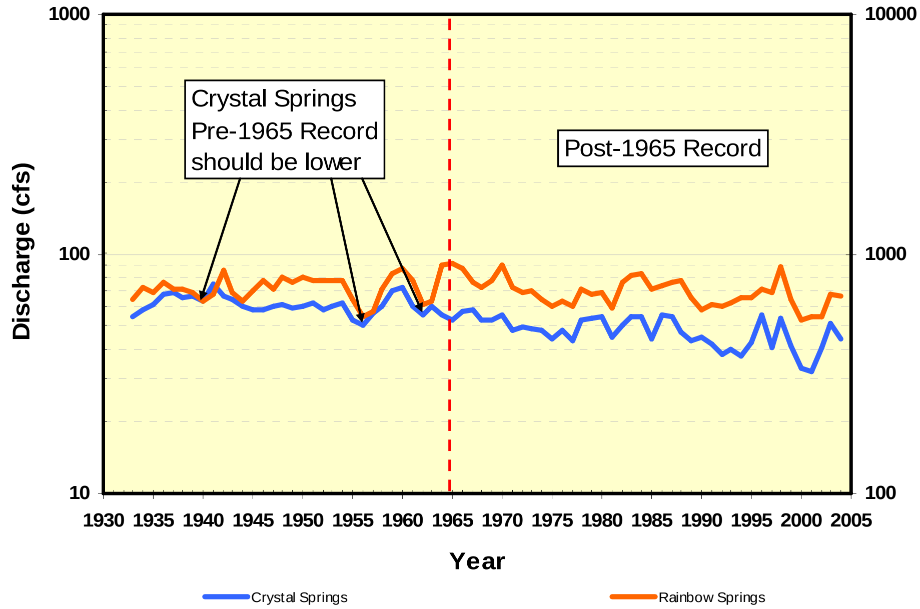

Figure 1. Mean annual discharge of Crystal Springs and Rainbow Springs (1933-2004).

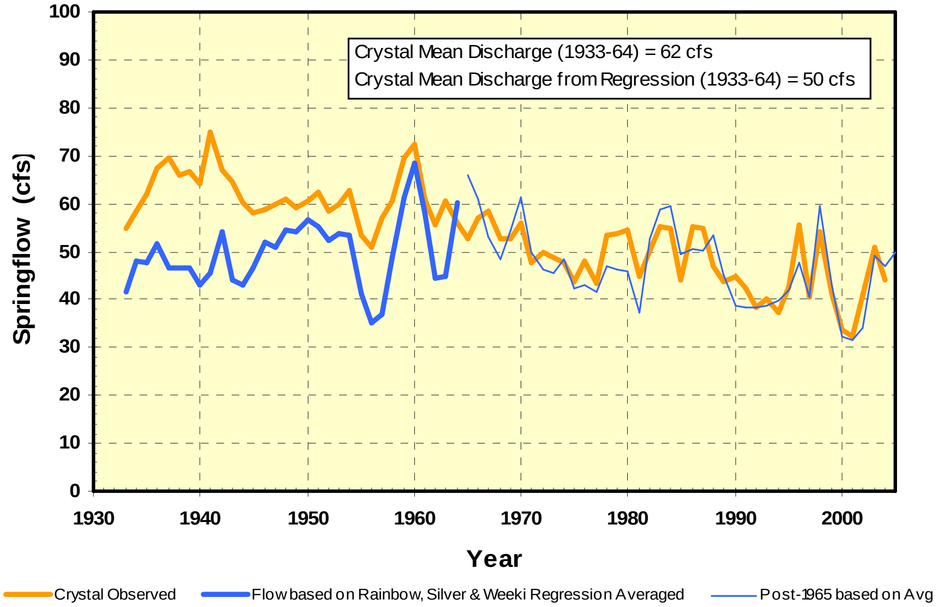

Figure 2. Synthetic Crystal Springs discharge prior to 1965 using the average of three regressions with Weeki Wachee, Rainbow, and Silver Springs from 1965 through 2004.

Errata / Comments by Page umber in the May 18, 2007 Upper Braden River MFL peer review draft report

All errata listed in the peer review report were addressed in the revised version of the report with the exception of the following.

2-28 Figure 2-19 - The identifier for site 3 is not on the mainstem of the Hillsborough River

Actually it is.

2-57 Table 2-19 – Why is text in table bold?
Because we wanted to emphasize that these were means and not individual rivers.

2-66 Figure 2-38 legend and top titles – should these be "1955 to 1965" rather than "1935 to 1965"?
Correct as shown.

2-104 1st paragraph – It is not clear why all this material is being repeated here.
To Recap for the reader. Some will read only part of the document and not the entirety.

2-110 Figure 2-71: scale of middle graph (P vs. flow) obscures any relationships that might be present at low flows. All we see is a dilution effect. There are possible similar problems with middle graphs in Figs 2-72 to 2-76.

5-25 Figure 5-13 - the blue line is not really visible in this graph
The lines are nearly the same and one lies partially on the other.