Proposed Minimum Flows and Levels for the Upper and Middle Withlacoochee River – Peer Review DRAFT

Southwest Florida Water Management District

July 1, 2010 – Peer Review DRAFT

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

Jason Hood, M.S.
Marty Kelly, Ph. D.
Ron Basso, P.G.
Jonathan Morales, Ph. D.

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Executive Summary

The Withlacoochee River, designated an “Outstanding Florida Waters” by the Department of Environmental Protection, originates from the Green Swamp in Lake, Pasco, Polk, and Sumter counties. The river crosses through or serves as the boundary of eight counties as it travels north and northwest approximately 160 miles before entering the Gulf of Mexico near Yankeetown. The Withlacoochee River watershed covers approximately 2,060 square miles. Land use is primarily rangeland, wetland forest, and upland forest. The Minimum Flows and Levels (MFL) presented in this report are for the Upper and Middle segments of the Withlacoochee River. These segments cover the reach from River Road (near the Green Swamp) to Holder (at the Highway 200 bridge).

For development of MFLs for the Withlacoochee River, the District identified seasonal blocks corresponding to periods of low, medium and high flows. MFLs for three United States Geological Survey (USGS) sites along the Withlacoochee River were developed for each of these seasonal periods using a "building block" approach. The MFLs 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 MFL.

The low flow threshold is defined to be a flow that serves to limit surface water withdrawals, with no surface water withdrawals permitted unless the threshold is exceeded. For the USGS Withlacoochee River gage sites at Croom, at Wysong, and near Holder, the low flow thresholds was determined to be 30, 60, and 150 cubic feet per second (cfs), respectively. A prescribed flow reduction for the low flow period (Block 1, which runs from April 28 through July 31) 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, fish guilds, and macroinvertebrate diversity. Various species/life stages were determined to be restrictive factors. Averages of the most restrictive species/life stages were calculated for the three gage sites. Percent of flow reduction limits were calculated to be 11, 15, and 13 percent of the flow as measured at the Croom, Wysong, and Holder gage sites respectively. These determinations were based on nine PHABSIM sites and historic flow records for the Croom, Wysong, and Holder gages.

For the high flow season of the year (Block 3, which runs from August 1 through October 28), the allowable flow reduction was based on review of limiting factors developed using the Hydrologic Engineering Centers River Analysis System (HEC-RAS) floodplain model and long-term inundation analyses to evaluate percent of flow reductions associated with changes in the number of days of inundation of floodplain features. A stepped flow reduction was used to protect habitats inundated by high flows. For the reach of the river upstream of the

Croom gage, it was determined that a stepped flow reduction of 16% and 9% of historic flows (with the step occurring at the flow required for out-of-bank conditions; 400 cfs) limits the decrease to 15% or less of the number of days that flows would inundate floodplain features as measured at the Croom gage. For the reach of the river between the Croom gage and the Wysong gage, it was determined that a stepped flow reduction of 15% and 8% of historic flows (with the step occurring at the flow required for out-of-bank conditions; 600 cfs) limits the decrease to 15% or less of the number of days that flows would inundate floodplain features as measured at the Wysong gage. For the reach of the river between the Wysong gage and the Holder gage, it was determined that a stepped flow reduction of 9% and 7% of historic flows (with the step occurring at the flow required for out-of-bank conditions; 1250 cfs) limits the decrease to 15% or less of the number of days that flows would inundate floodplain features as measured at the Holder gage.

For the medium flow period (Block 2, which runs from October 29 of one year to April 27 of the next), PHABSIM analyses were used to model flows associated with potential changes in habitat availability for several fish species, fish guilds, and macroinvertebrate diversity. In addition, flows associated with inundation of instream woody habitats were evaluated using a HEC-RAS model and long-term inundation analyses. Using the more conservative of the two resulting flows, it was determined that instream woody habitat inundation results would define the percent flow reduction for Block 2. Results from the woody habitat inundation analyses indicated that more than a 15% reduction in the number of days that the mean elevation for woody habitat would be inundated would occur if flows were reduced by more than 16%, 13%, and 7% as measured at the Croom, Wysong, and Holder gages during the medium flow period.

	Withlacoochee MFL Summary			
USGS Gage	**Low Flow Threshold**	**Maximum Allowable Percent Reductions Block 1**	**Maximum Allowable Percent Reductions Block 3**	**Maximum Allowable Percent Reductions Block 2**
Croom	30 cfs	11%	16% when discharge at or below 400 cfs 9% when discharge above 400 cfs	16%
Wysong	60 cfs	15%	15% when discharge at or below 600 cfs 8% when discharge above 600 cfs	13%
Holder	150 cfs	13%	9% when discharge at or below 1250 cfs 7% when discharge above 1250 cfs	7%

Acknowledgement

To be added later.

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.” Development or adoption of a minimum flow or level does not in itself protect a water body from significant harm. However, protection, recovery or regulatory compliance can be gauged and achieved 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 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. 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. It has been noted:

> *"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).

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.

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 dependent 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 non-perenniality 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 a range of flows. And while the term "minimum flows" is still used, the concept has evolved to one that recognizes the need to maintain a "minimum flow regime". In Florida, for example, the St. Johns River Water Management District typically develops multiple flow requirements when establishing minimum flows and levels (Chapter 40-C8, F.A.C) and for the Wekiva River noted that, "[s]etting multiple minimum levels and flows, rather than a single minimum level and flow, recognizes that lotic [running water] systems are inherently dynamic" (Hupalo et al. 1994). Also, 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) of the State Water Resources Implementation Rule currently directs that "minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime". This change was intended to protect variation in water flows and levels that contributes to significant functions of ecosystems. An alternate approach which also maintains a flow regime is to develop MFLs using a 'percentage of flow approach' as discussed in Flannery et al. (2002) and has been incorporated into several SWFWMD surface water use permits and existing MFLs in the SWFWMD.

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.

In addition to Beecher's requirements, researchers (Seerley et al. 2006) at the University of Georgia Carl Vinson Institute of Government have identified the following seven guiding principles for instream flow protection:

1) Preserving whole functioning ecosystems rather than focusing on a single species.
2) Mimicking, to the greatest extent possible, the natural flow regime, including seasonal and inter-annual variability.

3) Expanding the spatial scope of instream flow studies beyond the river channel to include the riparian corridor and floodplain systems.
4) Conducting studies using an interdisciplinary approach.
5) Using reconnaissance information to guide choices from among a variety of tools and approaches for technical evaluations in particular river systems.
6) Practicing adaptive management, an approach for recommending adjustments to operational plans in the event that objectives are not achieved.
7) Involving stakeholders in the process.

The District's approach for minimum flows development incorporates the five elements listed by Beecher (1990). The goal of a MFLs 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 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) or the North American Vertical Datum of 1988 (NAVD1988) 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. The SWFWMD has adopted an approach for establishing benchmark flow periods that involves consideration of the effects of climatic changes on river flow patterns. The approach, which led to identification of separate benchmark periods for flow records collected prior to and after 1970, is now routinely used to develop MFLs for the freshwater segments of rivers within the SWFWMD.

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. Criterion associated with fish passage in the river channel and maximization of the wetted perimeter are routinely used in the establishment of freshwater MFLs in the SWFWMD. Criterion associated with medium and high flows that result in the inundation of woody habitats associated with the river channel and vegetative communities on the floodplain are also used. The District routinely uses fish passage, wetted perimeter and other 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 MFLs 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 MFLs development and implementation, the building block approach is viewed as a reasonable means for ensuring the maintenance of similar, although dampened**,** natural hydrographic conditions.

For development of minimum flows and levels for the freshwater segment of the Withlacoochee 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 mean or median daily flows for the river (Figure 1-1). Lowest flows occur during Block 1, a 95-day period that extends from April 28 to July 31 (Julian day 118 to 212). Highest flows occur during Block 3, the 89-day period that immediately follows the dry season (August 1 to October 28). 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 181 days constitute an intermediate or medium flow period, which is referred to as Block 2.

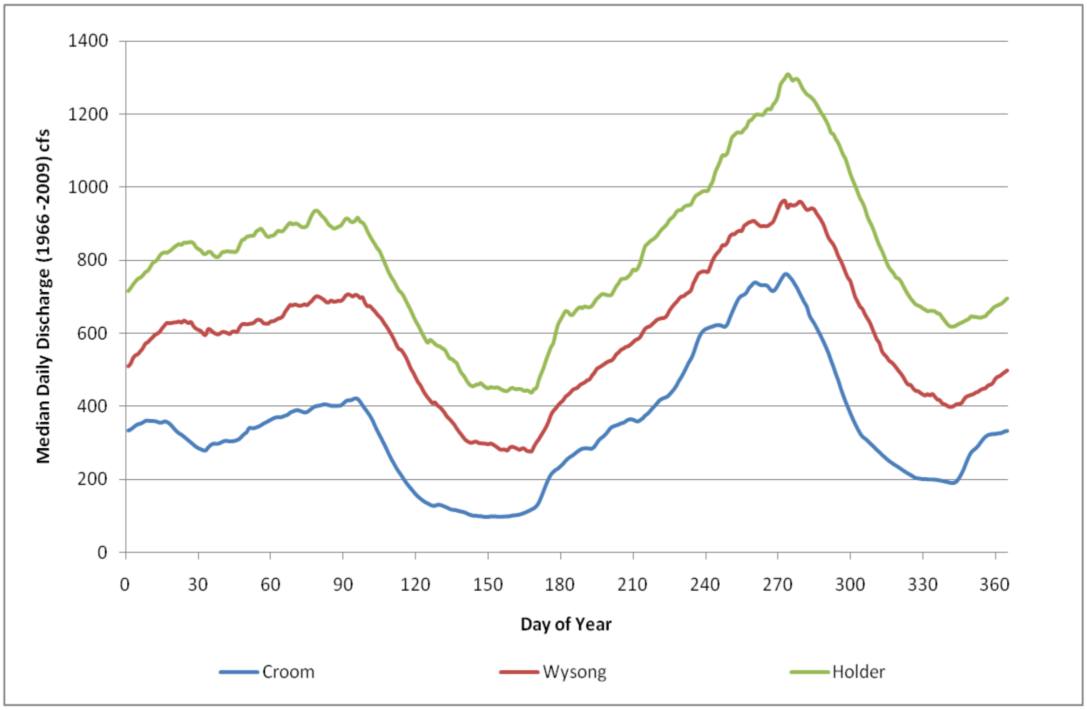

Figure 1-1. Mean daily flows for various Withlacoochee sites.

1.6 Flows and Levels

Although somewhat semantic, there is a distinction between flows, levels and volumes that should be appreciated when considering MFLs 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 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, often 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 generally 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.

2 BASIN DESCRIPTION

This chapter includes a brief description of the Withlacoochee River watershed including location and climate. A complete description of physiography and hydrogeology are included in section 4.4.

2.1 Geographic Location

The Withlacoochee River, designated as "Outstanding Florida Waters" by the Department of Environmental Protection, originates in the Green Swamp which is located in Lake, Pasco, Polk, and Sumter counties. The river crosses through or serves as the boundary of eight counties as it travels north and northwest approximately 160 miles before entering the Gulf of Mexico near Yankeetown (Figure 2-1). For the purpose of this report, the Withlacoochee River watershed boundaries were those delineated by the United States Geological Survey (Sepulveda 2002).

The Withlacoochee River watershed is approximately 2,060 square miles or 1,320,000 acres. Currently, the three dominant land uses in the watershed are urban, rangeland, and upland forest. This report covers the Upper and Middle Withlacoochee River which is defined as the reach between the Dade City and Holder USGS gage sites (Figure 2-1).

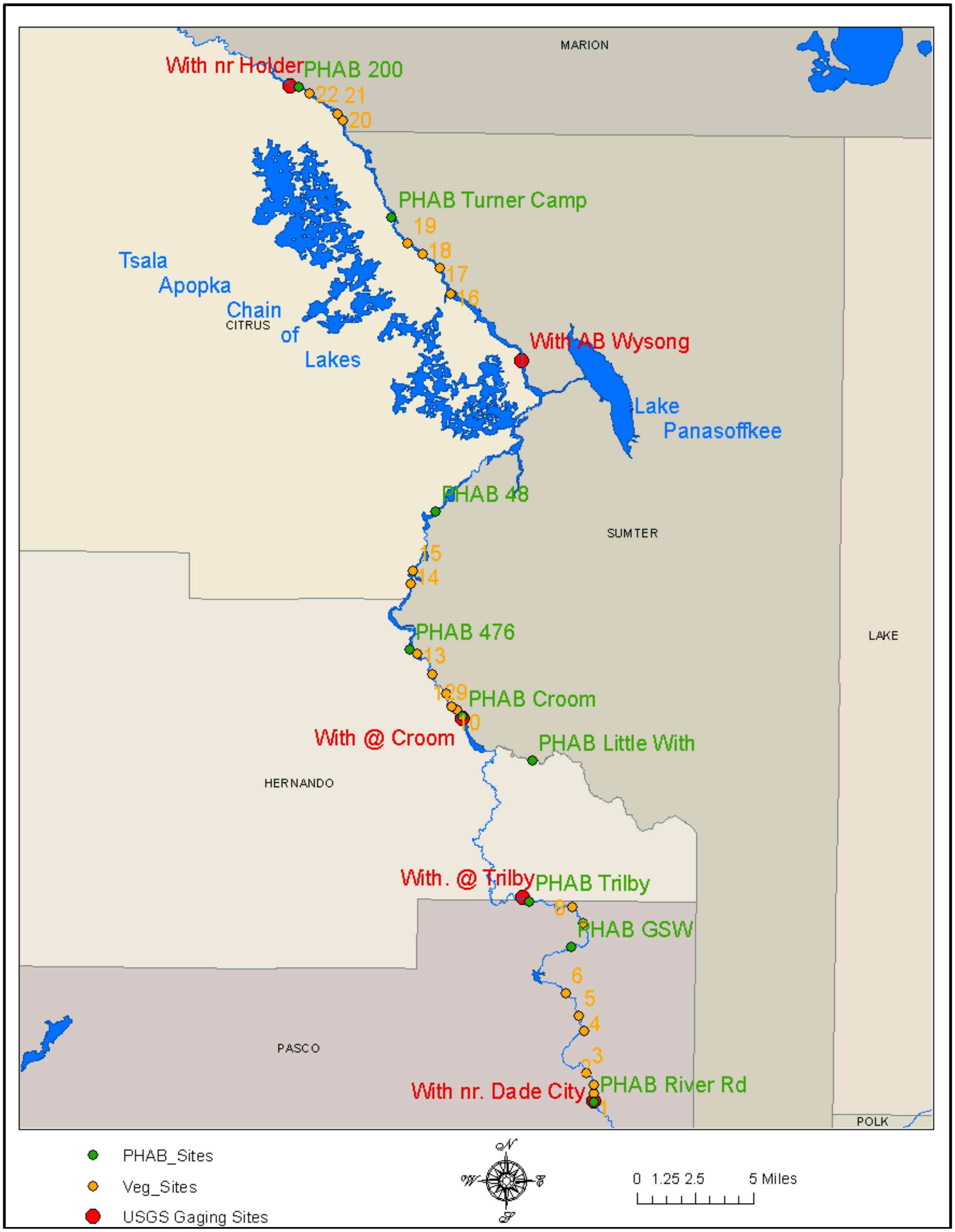

Figure 2-1. Map of the Withlacoochee River showing UGSG gaging stations and sampling locations.

2.2 Climate

The Withlacoochee River watershed lies within the subtropical climatic zone. Average rainfall is approximately 54 inches but varies widely from season to season and year to year. A large portion of the rainfall in the watershed occurs between June and September. Stream flow shows a lag behind the beginning of the rainy season due to the vast size of the Green Swamp and the time required for filling prior to water beginning to overflow the swamp and enter the river (Figure 2-2).

The average mean daily temperature is approximately 72° F (22° C). Mean summer temperatures are in the low 80's (°F) and the mean winter temperatures are in the upper 50's (°F).

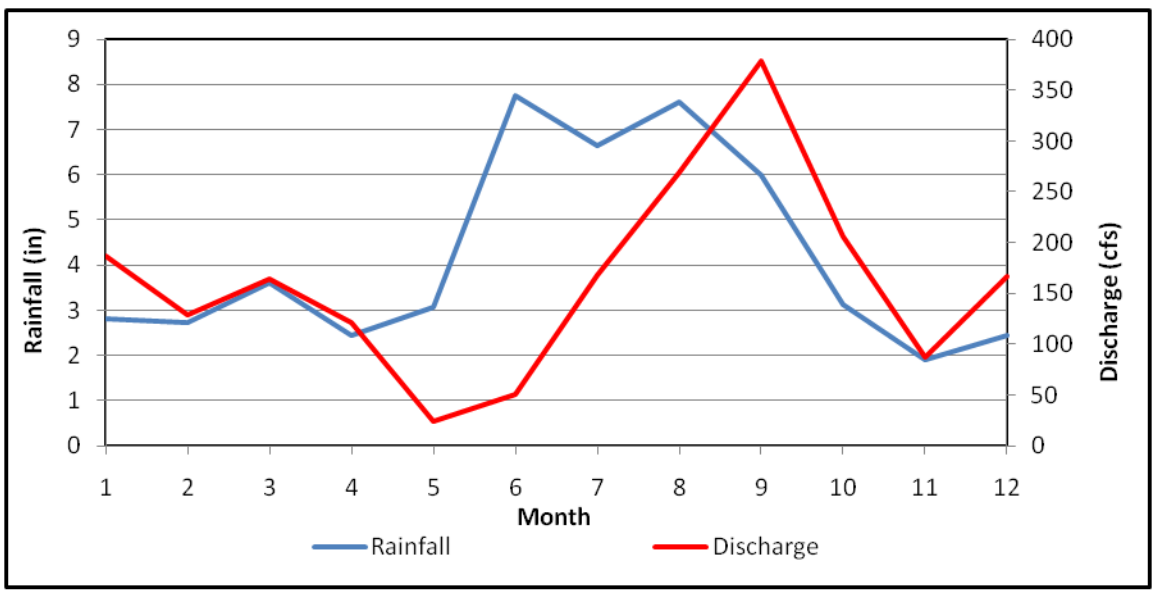

Figure 2-2. Average monthly rainfall (Green Swamp Tower) and discharge (Withlacoochee River near Dade City) for upper Withlacoochee River.

3 Land Use

This chapter includes a presentation and discussion of land use data relevant to the development of MFLs on river. Land use changes within the watershed are evaluated to address questions that have been raised regarding the potential impact of land use changes on river flow volumes and water quality trends.

3.1 Land Use Changes in the Withlacoochee River Watershed

A series of maps, tables and figures were generated for the Withlacoochee River watershed for four specific years (1974, 1990, 1995 and 2004) for purposes of considering land use changes that have occurred over the last several decades (Figure 3-1 through 3-4). The 1974 maps, tables and figures represent land use and cover generated using the USGS classification system (Anderson et al. 1976). The USGS classification has a minimum mapping unit of 10 acres for man-made features with a minimum width of 660 feet. The minimum mapping unit for non-urban and natural features is 40 acres with a minimum width of 1320 feet. The 1990, 1995 and 2004 maps represent land use and land cover information from the Florida Department of Transportation (FDOT). The FDOT (1999) developed the Florida Land Use, Cover and Forms Classification System (FLUCCS) using the USGS classification system as its basis. Unlike the USGS classification system, the FLUCCS is a hierarchical system with four different levels of classification. Each level contains information of increasing specificity to describe land cover conditions. Minimum mapping units are also smaller. The minimum mapping unit for uplands is 5 acres; for wetlands the minimum mapping unit is 0.5 acres.

The 1990, 1995 and 2004 land use/land cover maps are more detailed than the 1974 maps due to the higher resolution of the latter maps and differences in land use categories. As a result, some of the changes in land uses between the USGS and FLUCCS derived maps are likely the result of differences in methodologies rather than actual land use changes. However, for presentation and discussion purposes, we combined numerous land use types into fairly broad categories, and thereby eliminated much of the error associated with the use of the two classification systems. Land use/cover types identified for our analysis included: Urban and Built-up, Rangeland, Citrus, Pasture and Other Agriculture, Wetlands (forested and non-forested), Water, Uplands, and Other.

The Withlacoochee River watershed is approximately 2,060 square miles or 1,320,000 acres. From inspection of percentage changes as shown in either Table 3-1 or Figure 3-5, several land use/cover changes are readily apparent. There has been a noticeable increase in urban land use. As of 2004, 20% of the watershed was urbanized. In 1974, urban land was approximately 4% of the watershed, which amounts to the urbanization of 212,000 acres over a 30 year period.

The remaining land use categories remained fairly stable with the exception of a few changes between 1974 and 1990 which may be attributable to mapping differences and improvements.

For the purpose of comparing water chemistry changes to land use changes, the portion of the watershed upstream of the Withlacoochee River near Croom site was analyzed independent of the downstream changes. Land use changes observed in the portion of the watershed are very similar to those seen in the entire watershed (Table 3-2 and Figure 3-6). This portion of the watershed is 370 square miles (327,000 acres).

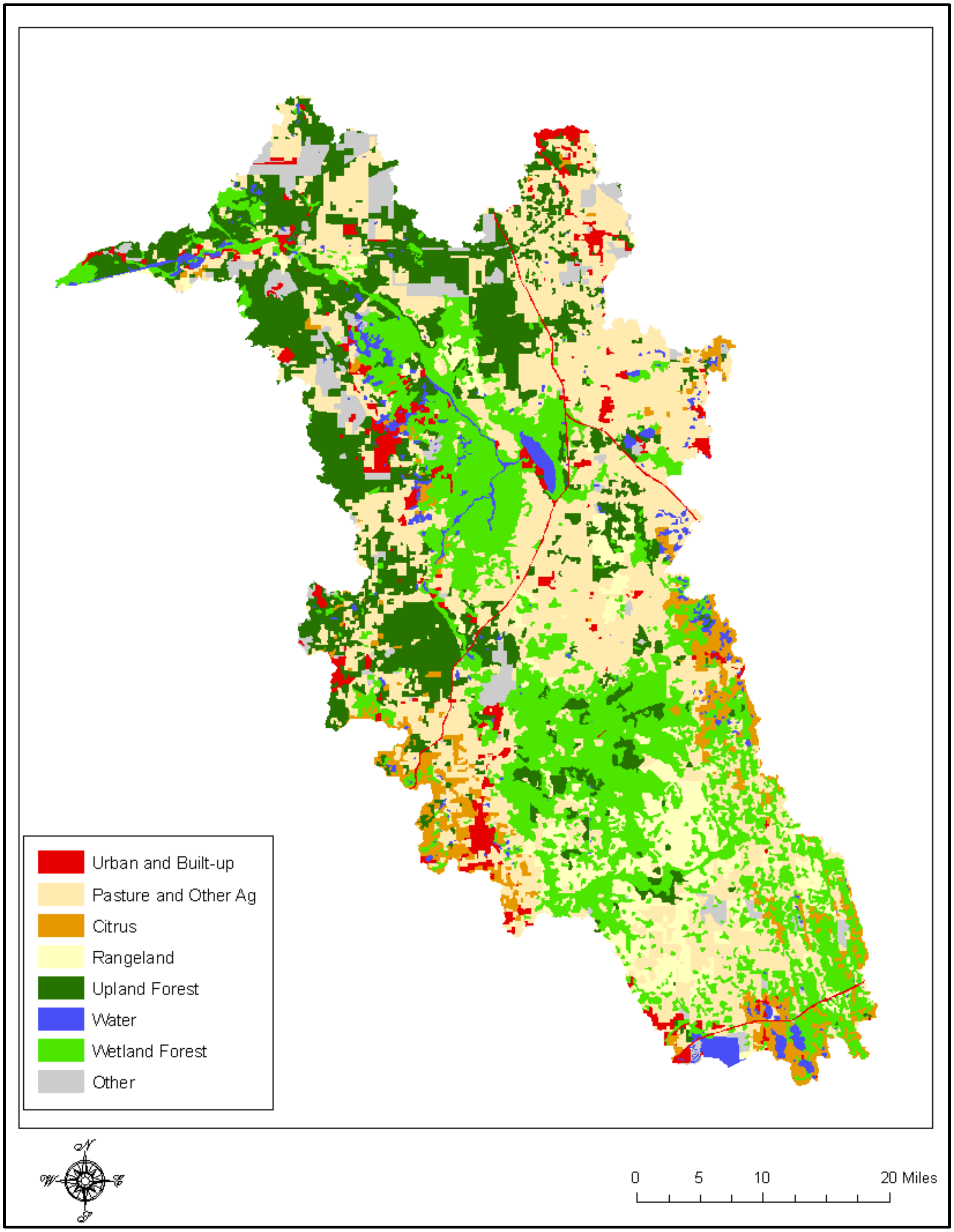

Figure 3-1. 1974 Land Use/cover maps of the Withlacoochee River watershed, Florida.

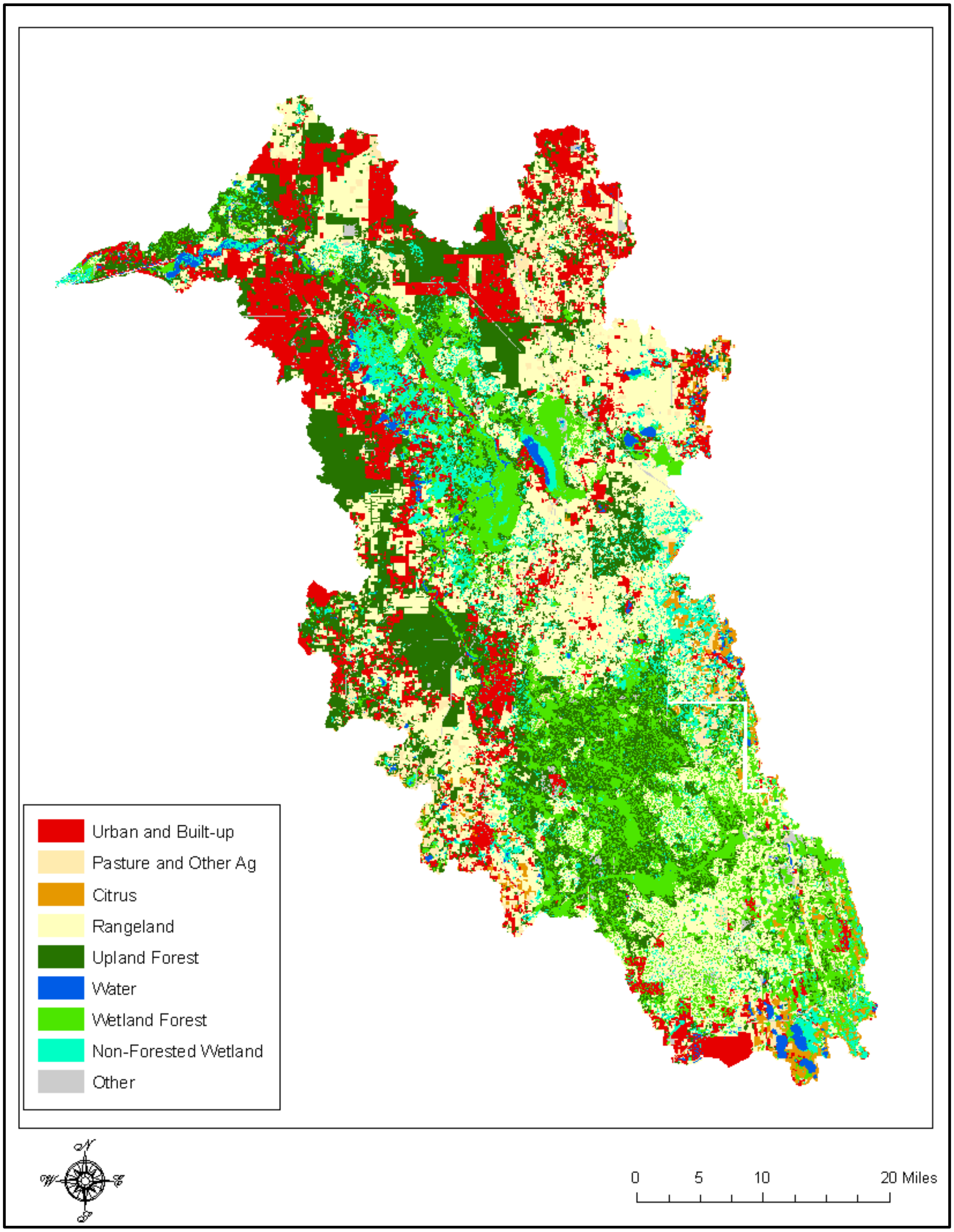

Figure 3-2. 1990 Land Use/cover maps of the Withlacoochee River watershed, Florida.

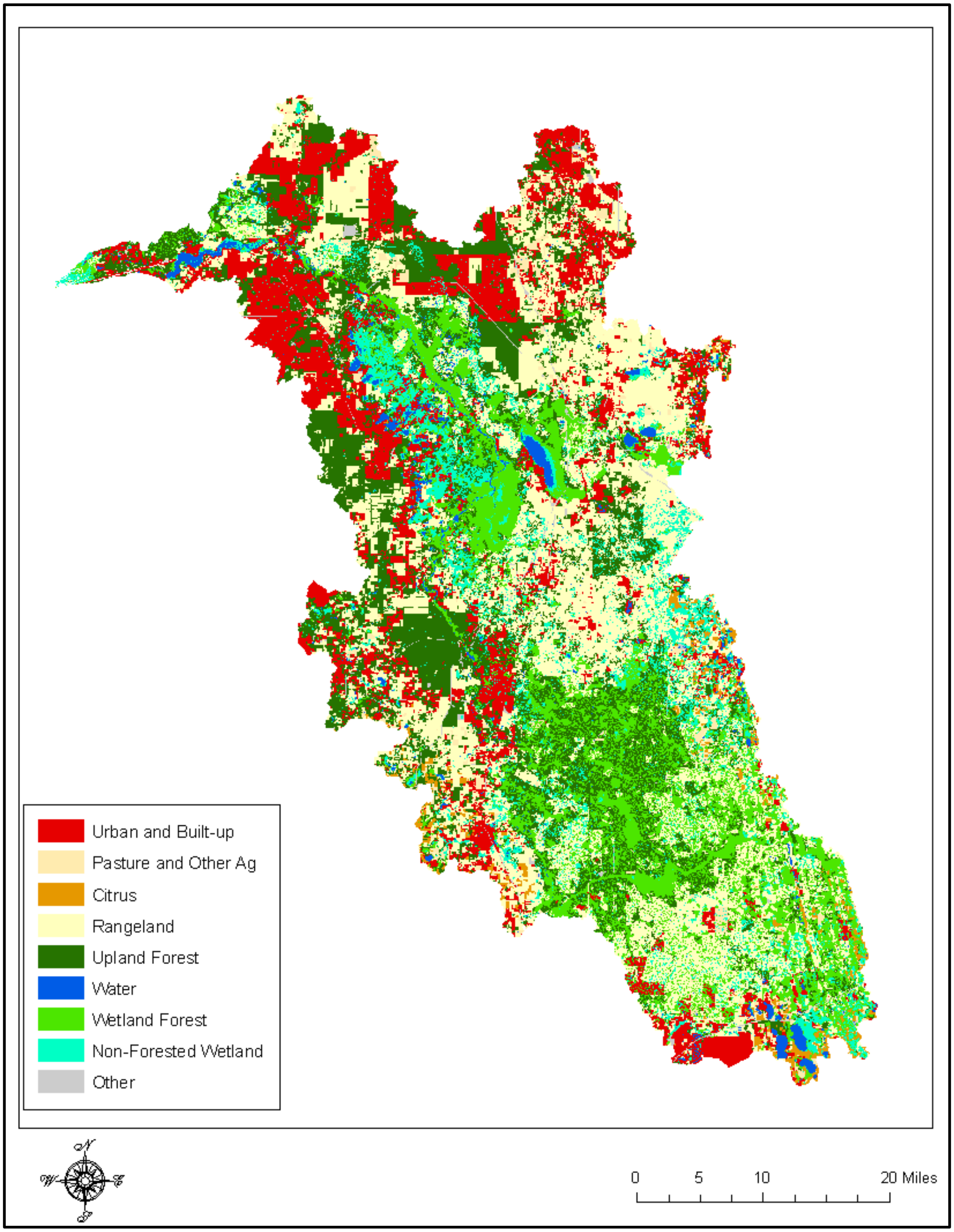

Figure 3-3. 1995 Land Use/cover maps of the Withlacoochee River watershed, Florida.

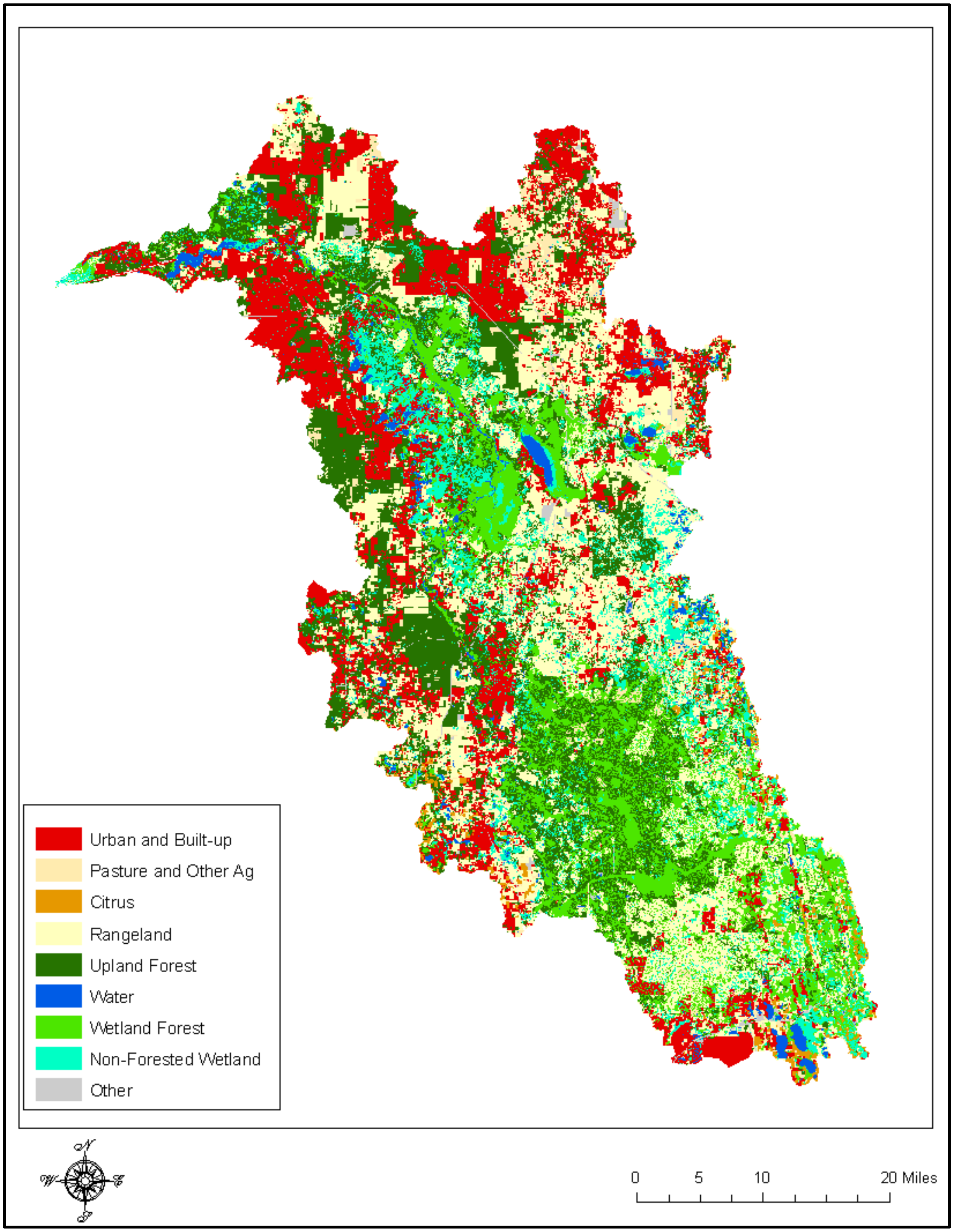

Figure 3-4. 2004 Land Use/cover maps of the Withlacoochee River watershed, Florida.

Table 3-1. Land use and land cover (by percentage) changes in the Withlacoochee River Watershed (1,320,000 acres) for four time periods; 1974, 1990, 1995 and 2004.

Withlacoochee River Watershed	1974(%)	1990(%)	1995(%)	2004(%)
Urban and Built-up	4	15	18	20
Rangeland	40	28	30	25
Citrus	5	2	2	1
Pasture and Other Ag	0	4	3	4
Upland Forest	19	24	23	23
Water	3	2	2	2
Wetland Forest	25	16	15	15
Non-Forested Wetland	0	8	8	8
Other	5	1	1	1

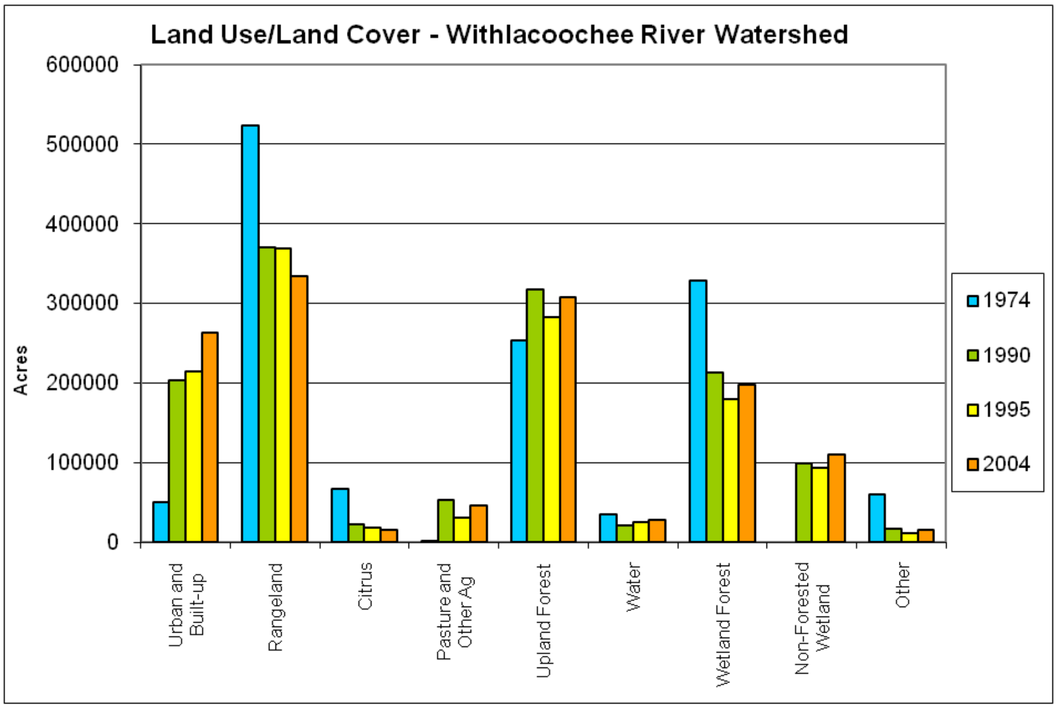

Figure 3-5. Comparison of land use and land cover changes in the Withlacoochee River watershed.

Table 3-2. Land use and land cover (by percentage) changes in the portion of the Withlacoochee River Watershed upstream of the Withlacoochee River near Croom site (327,000 acres) for four time periods; 1974, 1990, 1995 and 2004.

Withlacoochee River Watershed	1974(%)	1990(%)	1995(%)	2004(%)
Urban and Built-up	4	15	18	20
Rangeland	40	28	30	25
Citrus	5	2	2	1
Pasture and Other Ag	0	4	3	4
Upland Forest	19	24	23	23
Water	3	2	2	2
Wetland Forest	25	16	15	15
Non-Forested Wetland	0	8	8	8
Other	5	1	1	1

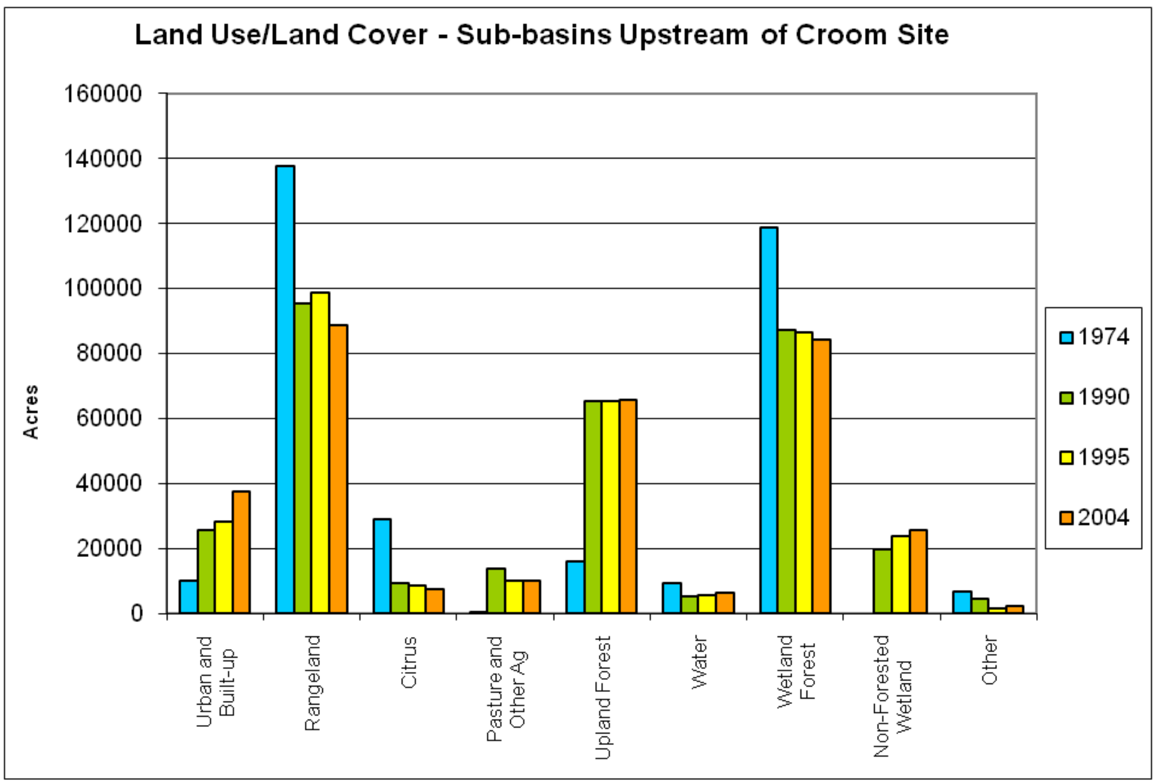

Figure 3-6. Comparison of land use and land cover changes in the Withlacoochee River watershed upstream of the Withlacoochee River near Croom site.

4 Hydrology

4.1 Overview

The Withlacoochee River, originates from the Green Swamp in Lake, Pasco, Polk, and Sumter counties. The river crosses through or serves as the boundary of eight counties as it travels north and northwest approximately 160 miles before entering the Gulf of Mexico near Yankeetown. The average flow for the selected sites of importance on the Withlacoochee River are shown in table 4-1 and the daily data is presented in Figure 4-1 for each respective period of record (POR).

Table 4-1. POR averages for discharge at selected sites on Withlacoochee River.

Site	Average Discharge (cfs)	POR
Withlacoochee River at Croom	414	1939-current
Withlacoochee River at Wysong	595	1965-current
Withlacoochee River nr. Holder	981	1928-current

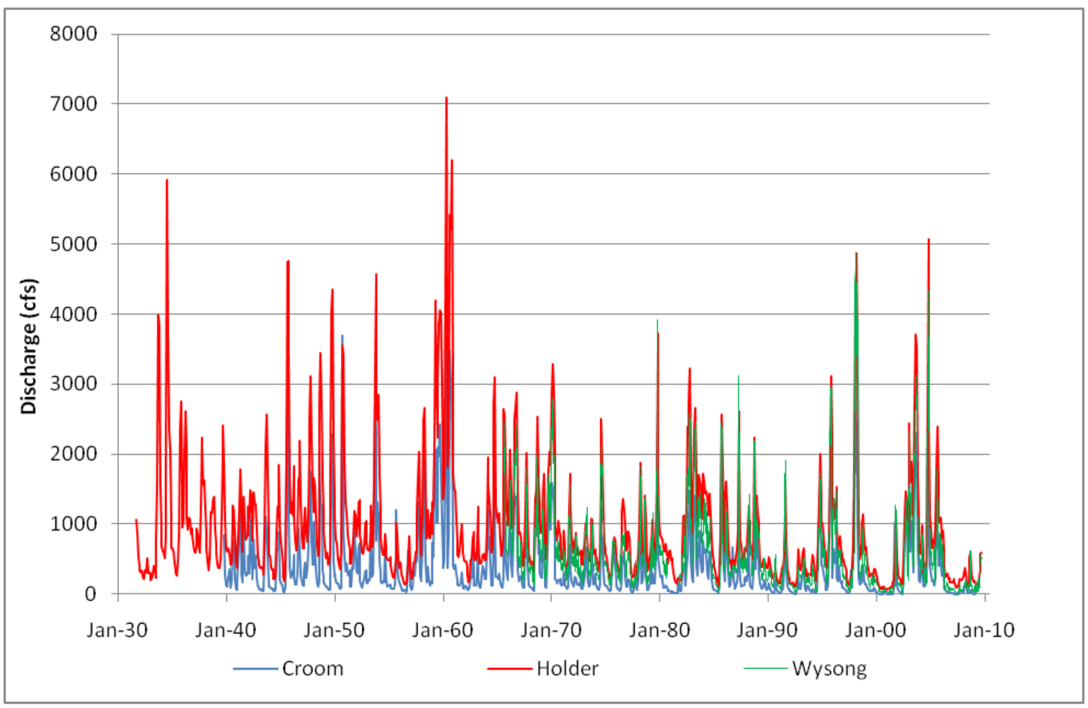

Figure 4-1. Discharge for selected sites on Withlacoochee River.

4.1.1 Florida River Flow Patterns and the Atlantic Multidecadal Oscillation

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

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

While much of Florida has a summer 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 4-2, 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 4-2, top panel), while those north of the line exhibit highest flows in the spring (Figure 4-2, middle panel).

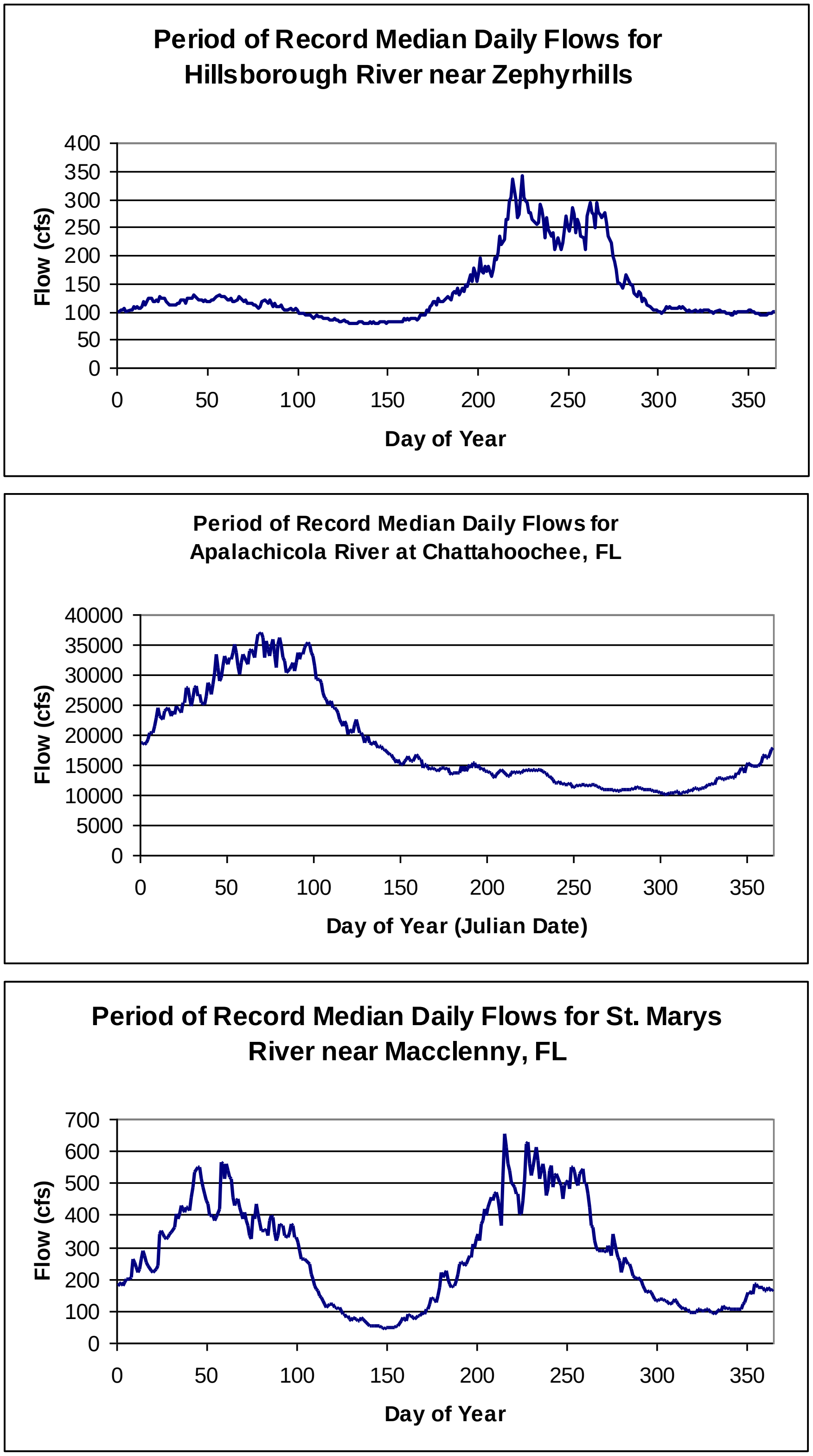

Figure 4-2. Examples of three river flow patterns: the Southern River Pattern (upper panel), the Northern River Pattern (center panel) and Bimodal River Pattern (bottom panel).

4.1.2 Multidecadal Benchmark Periods

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. It is believed that warm AMO periods increase the likelihood of more tropical storms and hurricanes. It should be noted that the tropical storm (hurricane) season in the Atlantic and Gulf coincides with the typical rainy season in peninsular Florida, typically beginning in June and extending for four months regardless of whether the Atlantic Sea surface temperatures are in a cool or warm multidecadal period.

In central Florida, sixty percent of annual precipitation usually occurs during this four to five month period. It is thus expected that increased tropical storm activity during warm AMO periods should contribute additional rainfall above that contributed by convective storms that develop during the rainy season thus increasing rainy season totals and river flows (see Appendix Rainfall).

Daily Withlacoochee River flow records for Croom, Wysong, and Holder gages extend from 1939, 1965, and 1928 respectively. Although a shift to a warm AMO was expected to occur around 1995, an increase in total annual rainfall, and therefore mean annual river flows, has not been observed. As a result, all analyses for MFL purposes were performed on three flow records for each gage. The flow records were for a period that spanned a warm AMO period (1940-1969), a cool AMO period (1970-1999), and for the entire period of record for each gage. The overwhelming majority of analyses resulted in more restrictive flow reductions (percentage wise) for the cool AMO period (i. e. , 1970-1999). Unless otherwise noted, the results from flows records for the cool AMO period were used for establishment of MFLs.

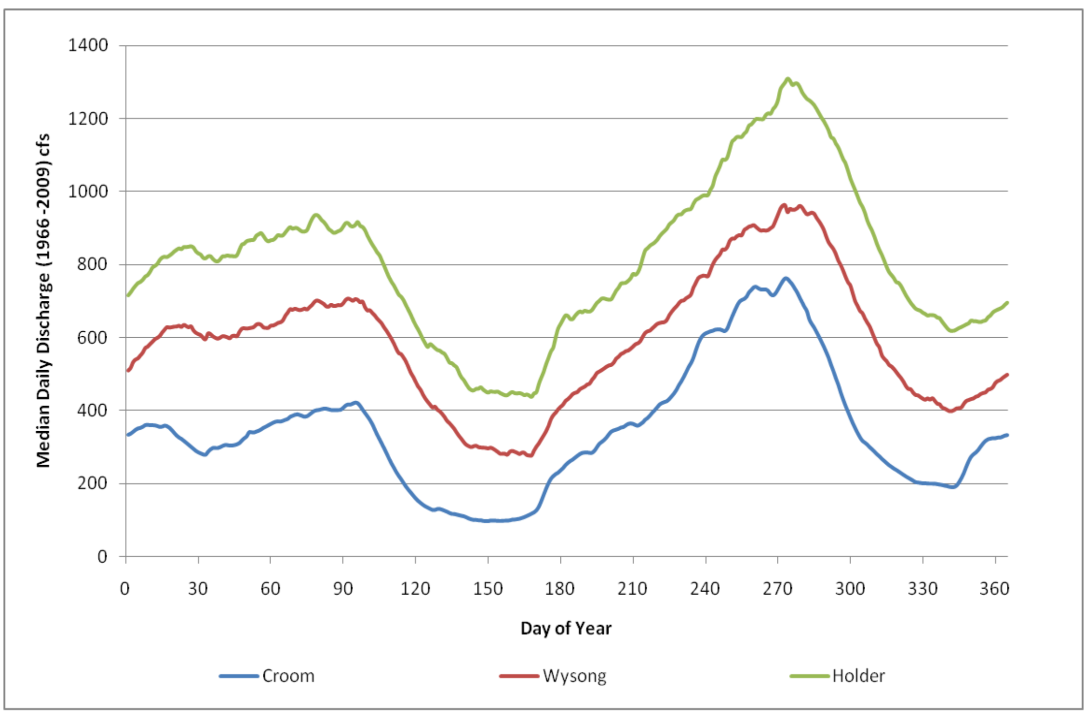

Figure 4-3. Day of Year (DOY) means for discharge at three Withlacoochee River gaging sites.

4.2 Hydrologic Analysis of Flow Decline

The Withlacoochee River originates in the Green Swamp area in northern Polk County and flows north until merging with the Gulf of Mexico in southwest Levy County. Over the last 70 years, stream discharge has been measured by the USGS along a 108-mile length of river from the station at Compressco near its headwaters to the USGS station at Holder in southwest Marion County (Figure 4-5). This section of the river encompasses a drainage basin of about 1,820 square miles.

Prior to establishment of a Minimum Flows for flowing water bodies in the District, an evaluation of hydrologic changes in the vicinity of the river or spring is necessary to determine if the water body has been significantly impacted by existing groundwater withdrawals. This section describes the hydrologic setting near the river and provides the results of a numerical model simulation of predicted river flow change due to existing groundwater withdrawals.

4. 2.1 Hydrogeologic Conditions

The hydrogeologic framework in the Withlacoochee River area includes a surficial aquifer system, a discontinuous intermediate confining unit, and a thick carbonate Upper Floridan aquifer. At land surface and extending several tens of feet deep are generally fine-grained quartz sands that grade into clayey sand just above the contact with limestone. A thin, sometimes absent, sandy clay layer forms the intermediate confining unit (ICU) and overlies the limestone units of the Upper Floridan aquifer (UFA). In general, a regionally extensive surficial aquifer system is not present because the clay confining unit is thin, discontinuous, and breeched by numerous karst features. Because of this geology, the UFA is mostly unconfined over most of the middle and lower portions of the Withlacoochee River.

The geologic units, in descending order, that form the freshwater portion of the UFA include the Oligocene age Suwannee Limestone, the upper Eocene age Ocala Limestone, and the middle Eocene age Avon Park Formation (Table 4-2). In northern Pasco and Hernando counties, the Suwannee Limestone is the uppermost unit. Further north in Citrus County, the Ocala Limestone forms the top of the Upper Floridan aquifer, except in extreme southern Levy County where the Avon Park Formation is exposed at land surface. The entire carbonate sequence of the UFA

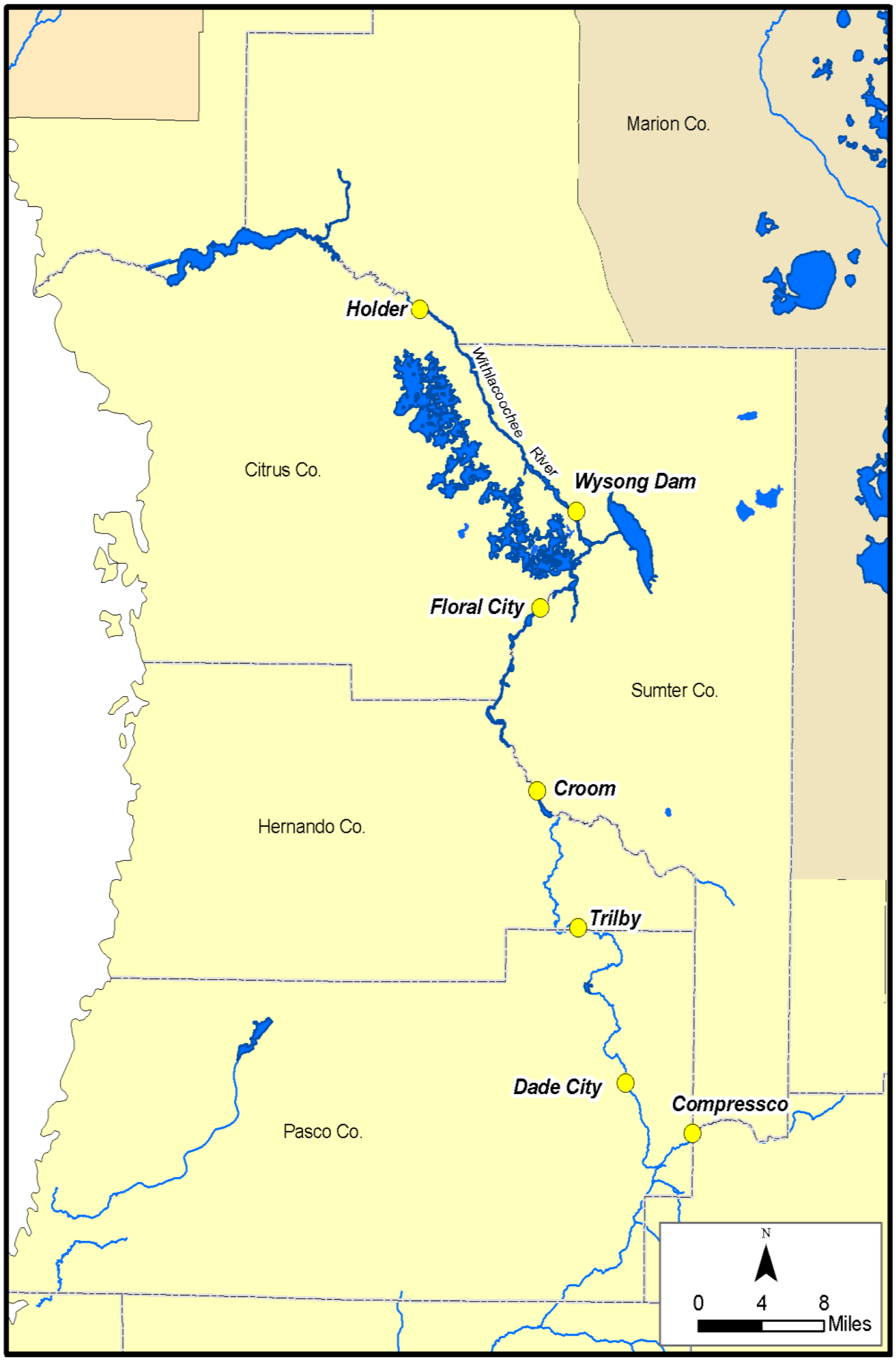

Figure 4-4. Location of long-term USGS flow stations on the Withlacoochee River.

Table 4-2. Hydrogeology of the Withlacoochee River Area (Modified from MIller1986, Sacks and Tihansky 1996).

Series	Stratigraphic Unit	Hydrogeologic Unit		Lithology
Holocene to Pliocene	Undifferentiated Surficial Deposits	Unsaturated Zone, Surficial Aquifer or locally perched Surficial Aquifer		Sand, silty sand, clayey sand, sandy clay, peat, and shell
Oligocene	Suwannee Limestone	Upper Permeable Zone	Upper Floridan Aquifer	Limestone,cream to tan, sandy, vuggy, fossiliferous
Eocene	Ocala Limestone			Limestone,white to tan, friable to micritic, fine-grained, soft, abundant foraminifera
	Avon Park Formation	Middle Confining Unit 2		Dolomite is brown, fractured, sucrosic, hard. Interstitial gypsum in MCU 2
		Lower Permeable Zone	Lower Floridan Aquifer	Limestone and dolomite. Limestone is tan, recrystallized. Anhydrite and gypsum inclusions.
	Oldsmar Formation			
Paleocene	Cedar Keys Formation	Basal Confining Unit		Massive anhydrites

thickens and dips toward the south and southwest. Average thickness of the UFA ranges from 500 feet in southern Levy County to 1,000 feet in central Pasco County (Miller 1986). The base of the UFA generally occurs at the first, persistent sequence of evaporitic minerals such as gypsum or anhydrite that occur as nodules or discontinuous thin layers in the carbonate matrix. This low permeability unit is regionally extensive and is generally referred to as middle confining unit II (Miller 1986).

In the upper reaches of the Withlacoochee River, a shallow surficial aquifer overlies a leaky semi-confined Upper Floridan aquifer. In the middle and lower portions of the Withlacoochee River Basin, however, the UFA becomes regionally unconfined and is located within a highly karst-dominated region (Hydrogeologic, Inc. 2008). Dissolution of limestone is an active process via infiltration of rainwater because the limestone units of the UFA are close to land surface and poorly confined. Numerous sinkholes, internal drainage, and undulating topography that are typical of karst geology dominate the landscape. These active karst processes lead to enhanced permeabilities within the Floridan aquifer. The median transmissivity value of the UFA based on 29 aquifer performance tests within or near the Withlacoochee River Basin is 210,000 ft2/day (Figure 4-6) (SWFWMD 2006). Although highly variable due to karst activity, UFA transmissivity is about 10 to 100 times greater near the middle and lower reaches of the river compared to its headwaters within the Green Swamp.

There are two first-magnitude springs (flow greater than 100 cubic feet per second (cfs) discharge) found within or near the drainage basin: the Rainbow Springs group and Silver Springs. Both major springs are located in Marion County. These two springs together discharge approximately one billion gallons per day of water from the UFA. The Rainbow Springs group discharges approximately 400 mgd to the Rainbow River which provides tributary inflow to the Withlacoochee River just east of Lake Rousseau. A second-magnitude spring, Gum Springs, discharges an average flow of 65 cfs (42 mgd) into the Withlacoochee River between the Wysong and Holder gaging stations in northwest Sumter County. In addition, very high recharge rates to the UFA occur in west-central Marion, eastern Citrus and northern Sumter Counties with values ranging between 10 and 25 inches per year (Sepulveda 2002).

4.2.1.1 Groundwater withdrawals in the vicinity of the Withlacoochee River

The SWFWMD currently maintains a database of metered and estimated water use for the period from 1992 through 2006. Groundwater withdrawals in the vicinity of Withlacoochee River for 2005 are shown in Figure 4-7, based on District data and 2002 water use estimates from the St. Johns River Water Management District. Groundwater withdrawn within the basin was 65. 3 million gallons per day (mgd) in 2005. Over the entire river basin, groundwater withdrawn was 0. 65 inches per year in 2005 based on a total basin drainage area of 2,100 square miles (Tetra Tech, Inc. 2004). Most of the individual groundwater withdrawals are small and dispersed within the Withlacoochee River Basin except within the Villages Development in northeast Sumter County and the City of Ocala in Marion County.

4.2.1.2 Baseflow contributions to the Withlacoochee River

Baseflow separation is a process that estimates the groundwater contribution to the total river flow. Baseflow contributions to the river from the groundwater system were examined two ways. The first method, used to develop calibration targets for the Northern District groundwater flow model for the 1995 steady-state simulation, was a separation technique developed by Perry (1995) and has been utilized extensively in west-central Florida by the University of South Florida and the District. The technique is a low-pass filter and works with a specific time-window, in this case 121 days. The 121-day period represents a time span of 60 days prior to a specified date, the specified date, and 60 days after the specified date. The minimum flow, i. e. , the lowest daily flow and not the regulatory Minimum Flow, is calculated for a 121-day period and is recalculated on a daily basis by moving the window forward one day at a time. Another time series is then created, also using a 121-day moving window, which averages the minimum flows generated from the initial time-series of 121-day lowest daily flows. The result is a smoothed time series of minimum flows, the assumed baseflow. This method was utilized to calculate average yearly baseflow for the long-term USGS gaging stations on the river for 1995 (Table 4-3).

The second baseflow estimation method involved direct seepage measurements conducted during the spring dry seasons of 2004 through 2006 (Table 4-4). As part of a cooperatively funded project between the USGS and the District, direct baseflow measurements were made along the entire river from the headwaters to the Holder gage (Trommer et al. 2009). Baseflow was counted as direct seepage along the river channel along with tributary inflow from springs. The baseflow measurements from the USGS are generally consistent with the 1995 estimates derived using the Perry (1995) moving average technique, but vary due to differing climatic conditions observed throughout the 2004 to 2006 period.

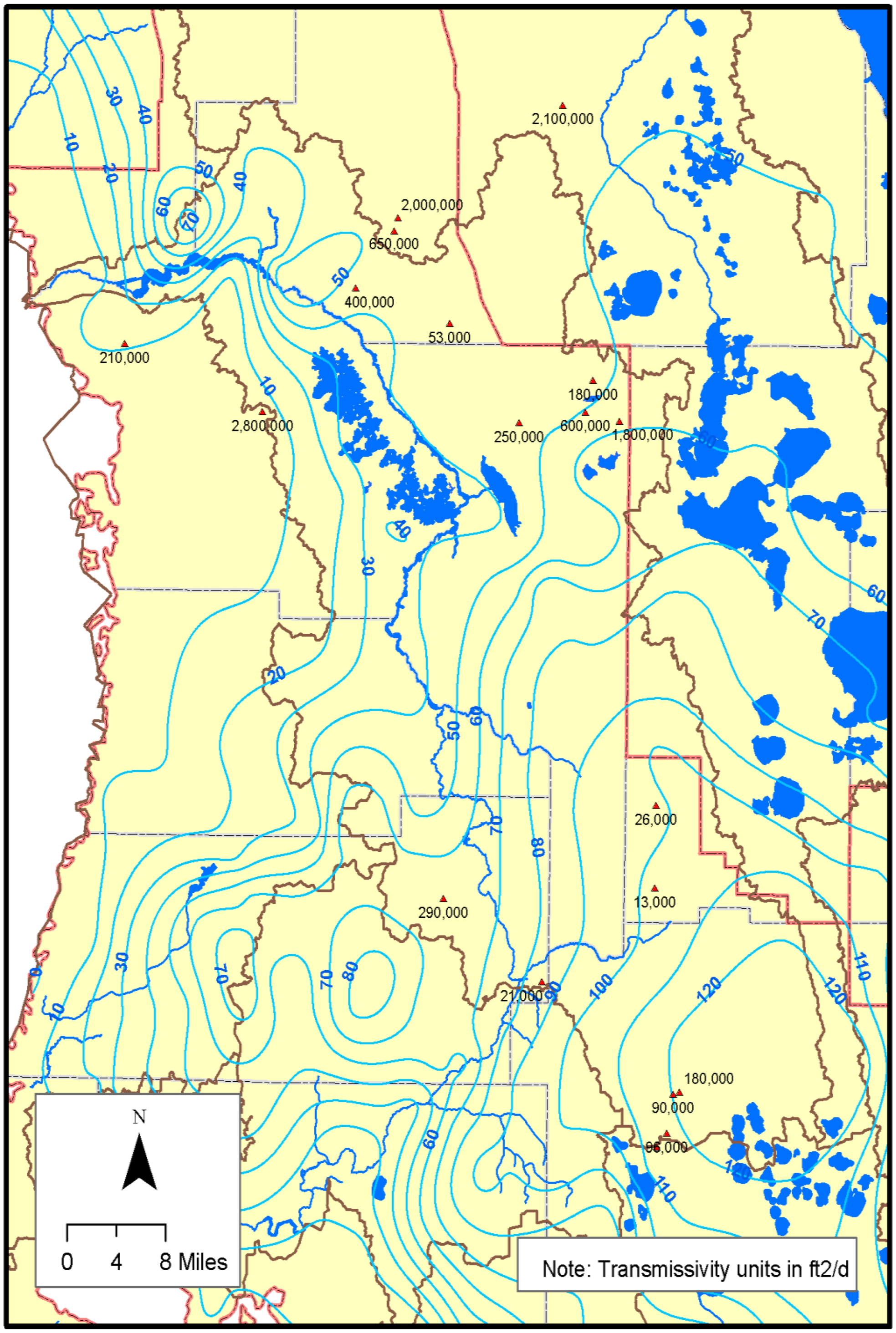

Figure 4-5. Location of Withlacoochee River basin, transmissivity from aquifer performance tests, and September 2008 potentiometric surface (Ft NGVD) of the Upper Floridan aquifer.

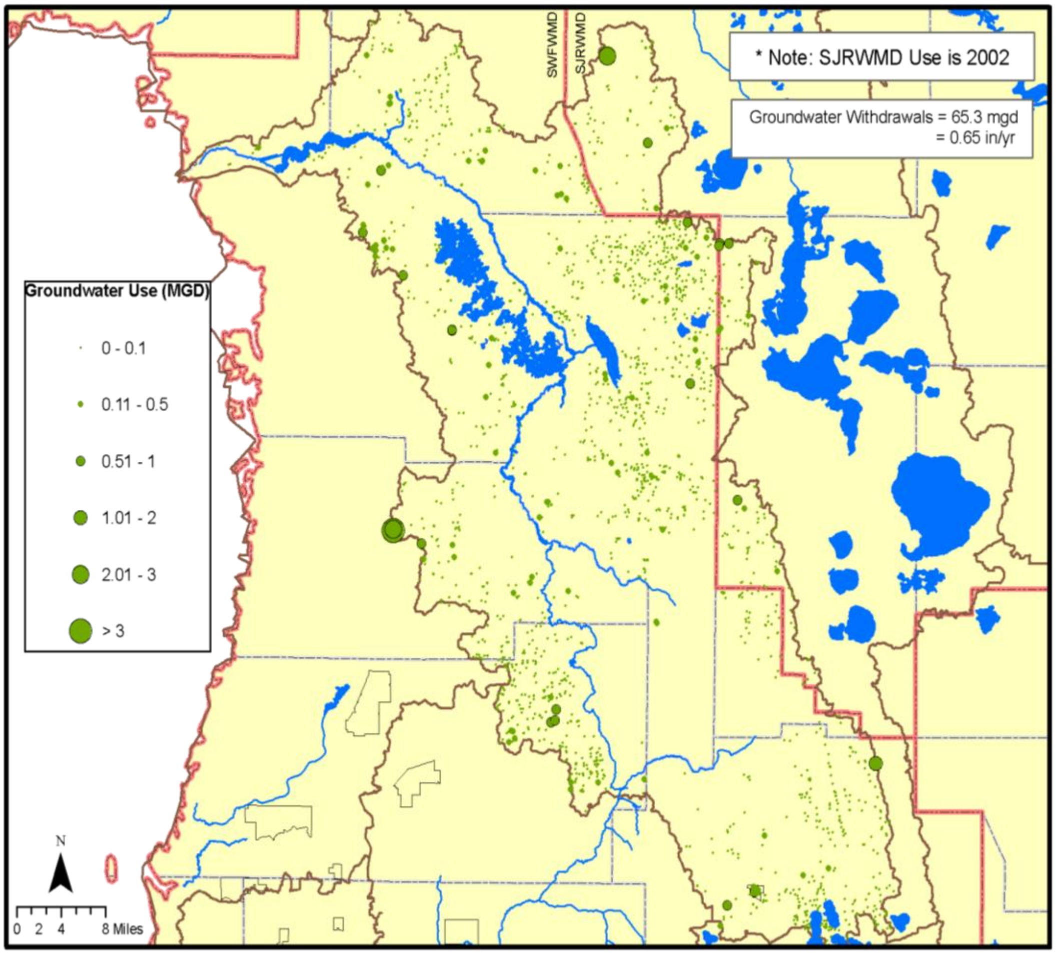

Figure 4-6. UFA groundwater withdrawals within the Withlacoochee River basin during 2005.

Table 4-3. Estimated 1995 baseflow contributions to the Withlacoochee River based on the Perry (1995) method.

USGS Gaging Station	1995 Estimated Baseflow (cfs)	1995 Observed Mean Flow (cfs)	Baseflow (Percent of Mean Flow)
Compressco	8	215	4
Dade City	12	313	4
Trilby	37	457	8
Croom	70	549	13
Holder	313	1117	28

Table 4-4. Baseflow contributions to the Withlacoochee River measured by the USGS from 2004 through 2006 (Trommer et al. 2009).

USGS Gaging Station	2004 Observed Baseflow (cfs)	2004 Observed Mean Flow (cfs)	Baseflow (Percent of Mean Flow)
Compressco	0	255	0
Dade City	2	290	1
Trilby	40	472	8
Croom	109	720	15
Holder	230	1284	18

USGS Gaging Station	2005 Observed Baseflow (cfs)	2005 Observed Mean Flow (cfs)	Baseflow (Percent of Mean Flow)
Compressco	5	124	4
Dade City	15	170	9
Trilby	64	298	21
Croom	151	453	33
Holder	485	1164	42

USGS Gaging Station	2006 Observed Baseflow (cfs)	2006 Observed Mean Flow (cfs)	Baseflow (Percent of Mean Flow)
Compressco	0	14	0
Dade City	4	24	17
Trilby	34	51	67
Croom	71	89	80
Holder	323	366	88

Note: Observed baseflow values exclude contribution from the Lake Panasoffkee outlet canal.

The baseflow estimation methods indicate that very little groundwater contribution occurs along the Withlacoochee River upstream of Dade City. In this region, the river is shallow, better confined, and connected only to the surficial aquifer. Baseflow contributions are small due to the limited permeability and saturated thickness of the surficial aquifer. Downstream of Dade City, however, the ICU becomes thin or non-existent which enhances the hydraulic connection of the river to the UFA. Limestone outcrops occur within the river bed generally north of the Dade City gage. Groundwater contribution to river flow increases to 22 percent of average flow at Croom and 34 percent of mean flow at Holder based on the average of all baseflow calculations (Table 4-5).

Table 4-5. Average baseflow quantities as a percentage of mean flow for the Withlacoochee River.

USGS Gaging Station	Mean of Estimated and Observed Baseflow (cfs)	Observed Stream Flow (cfs)	Baseflow (Percent of Mean Flow)
Compressco	3	152	2
Dade City	8	199	4
Trilby	44	320	14
Croom	100	453	22
Holder	338	983	34

Note: Based on the average of 1995, 2004, 2005, and 2006 data.

During extremely dry climatic conditions, such as in 2006, baseflow made up over two-thirds of mean annual flow at Trilby and over 80 percent of flow further downstream at the Croom and Holder gages.

In general, the Withlacoochee River is a gaining stream from its headwaters to the Holder gage except for a 5. 2 mile section just north of Croom and a 2. 1 mile section just south of where Gum Slough enters the river (Figure 4-8; Trommer et al. 2009). In these areas, the river stage is usually above the water level elevation of the UFA resulting in a losing stream. This situation is a natural occurrence due to changes in land surface elevation, river bed morphology, and the configuration of the UFA regional flow system. Water level elevations in the UFA are lowest along these sections compared to the remainder of the river from its headwaters to the Rainbow River (Figure 4-8).

4.2.1.3 River discharge and rainfall

Withlacoochee River discharge has been recorded by the USGS since 1928 at the Trilby and Holder stations and since 1939 at the Croom station. Long-term flow history at the Trilby and Holder gages shows a general decline in stream flow since 1970 (Figures 4-9 and 4-10). This is consistent with long-term variation in rainfall when the Atlantic Multidecadal Oscillation (AMO) transitioned from a warm (wet) cycle to a cool (dry) one in 1970 (Kelly 2004).

Analysis of rainfall averaged from the Brooksville, Inverness, and Ocala National Oceanic and Atmospheric Administration stations from 1930 through 2008 shows a declining trend after 1970, especially pronounced after 1989. Cumulative departure from mean annual rainfall for the 1970 to 2008 period is -71. 2 inches. In contrast, the cumulative department from mean rainfall from 1931-1969 is +74 inches (Figure 4-11). Annual departure in mean rainfall shows that 26 out of 38 years since 1970 have recorded below average rainfall (Figure 4-12).

The rainfall record was also parsed into 3, 6, and 10-year average periods from 1901 through 2008. Each period was compared to the highest ten percent (P10), the median, and the lowest ten percent (P90) values of rainfall (Figures 4-13 through 4-15). Both the 3-year and 10-year values ending in 2008 were at or below the 90 percent exceedance rainfall. The majority of values for the 3, 6 and 10-year periods were substantially below median rainfall after 1970.

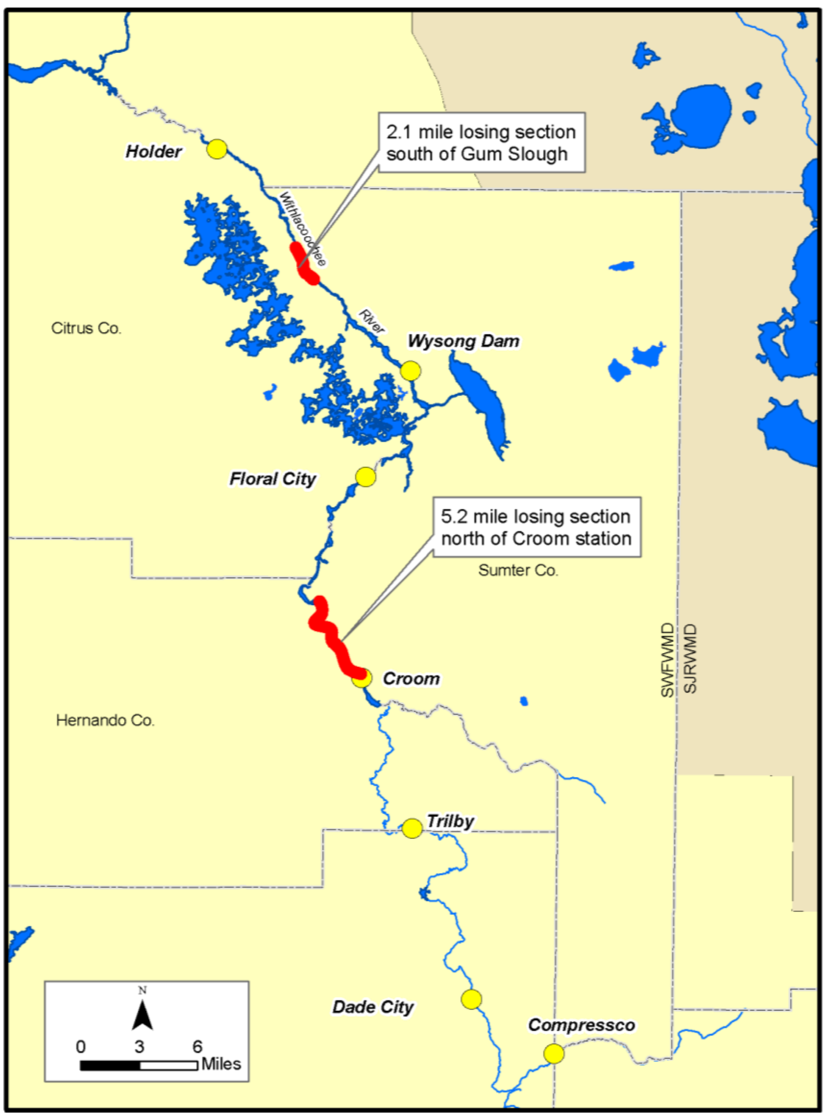

Figure 4-7. Location of river segments where the Withlacoochee River loses water to the groundwater system (Trommer et al. 2009).

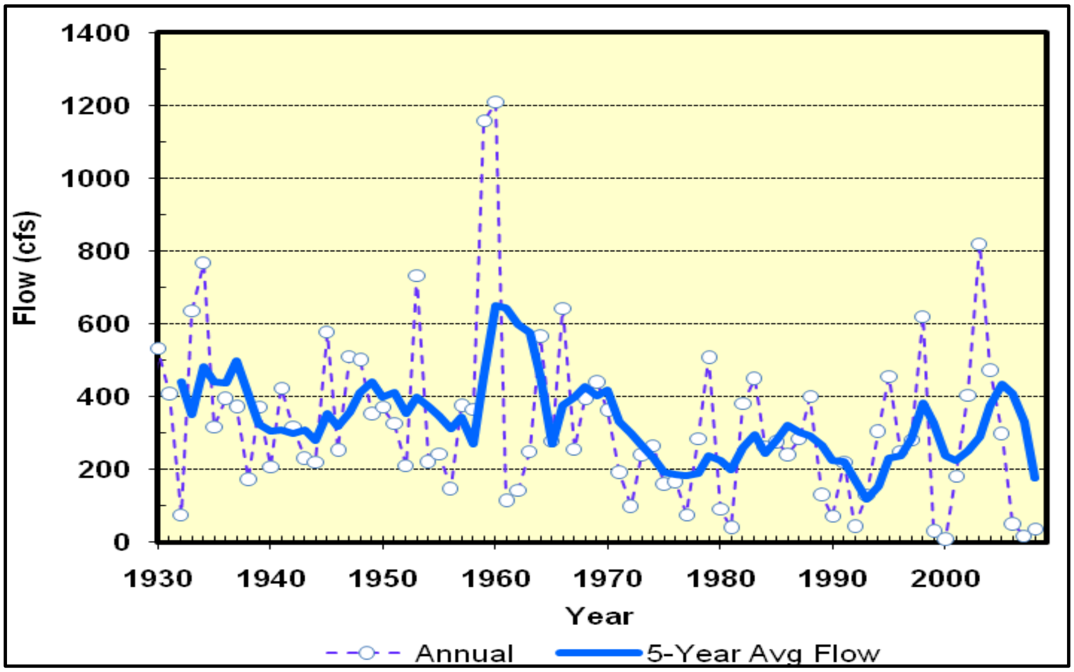

Figure 4-8. Mean annual and 5-Year moving average flow at the Trilby station.

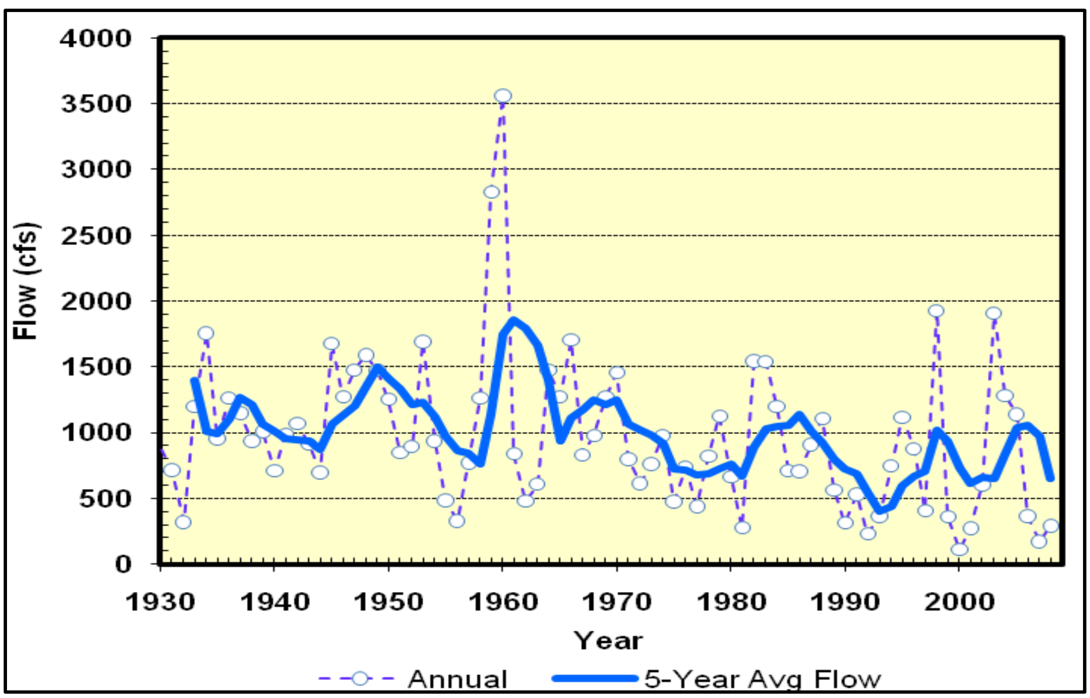

Figure 4-9. Mean annual and 5-Year moving average flow at the Holder station.

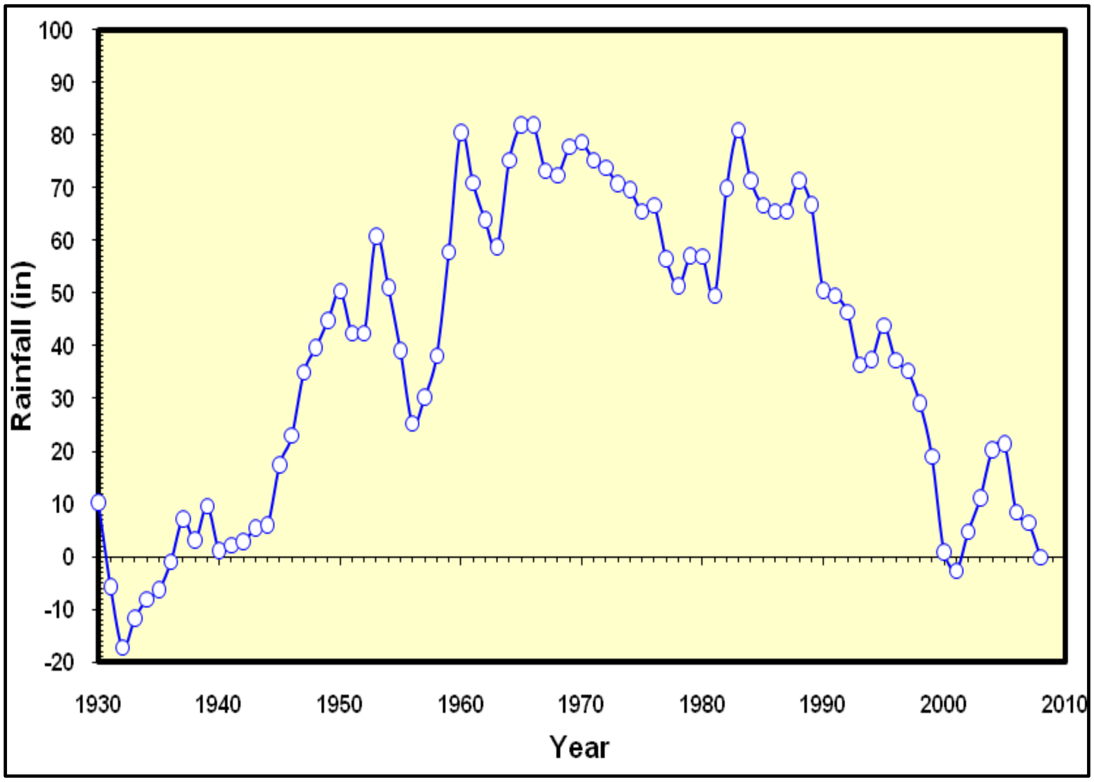

Figure 4-10. Cumulative departure from mean annual rainfall from 1930 through 2008, based on mean rainfall values for the Inverness, Ocala and Brooksville rainfall stations.

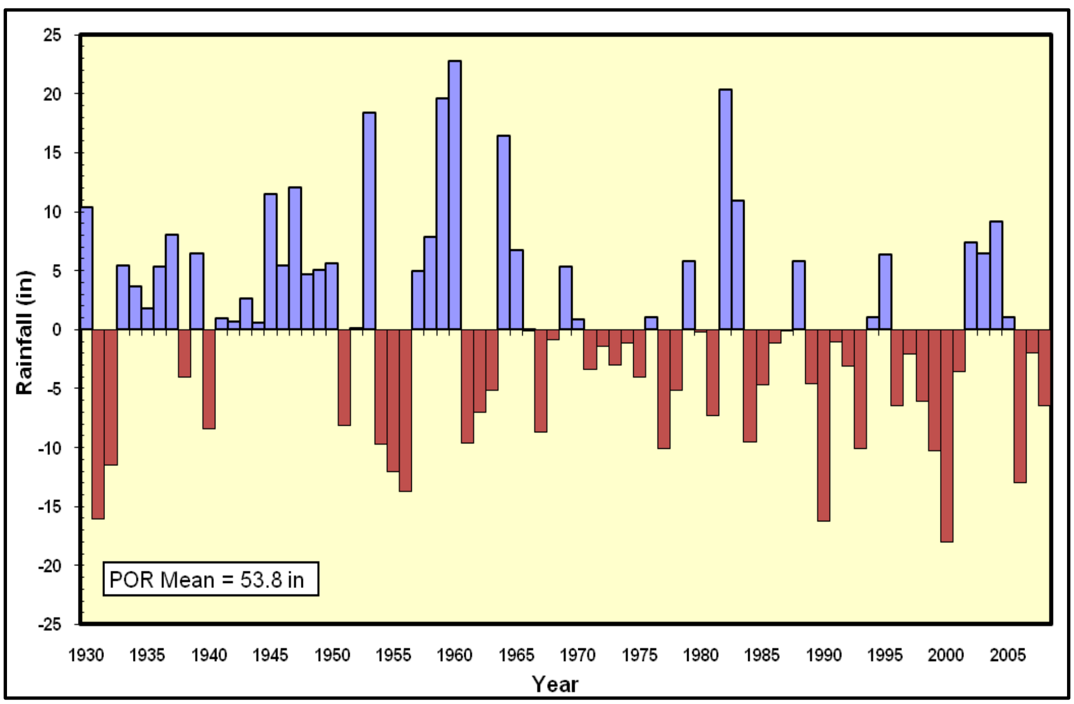

Figure 4-11. Annual departure in mean rainfall from data averaged from the Brooksville, Inverness, and Ocala stations (1930-2008).

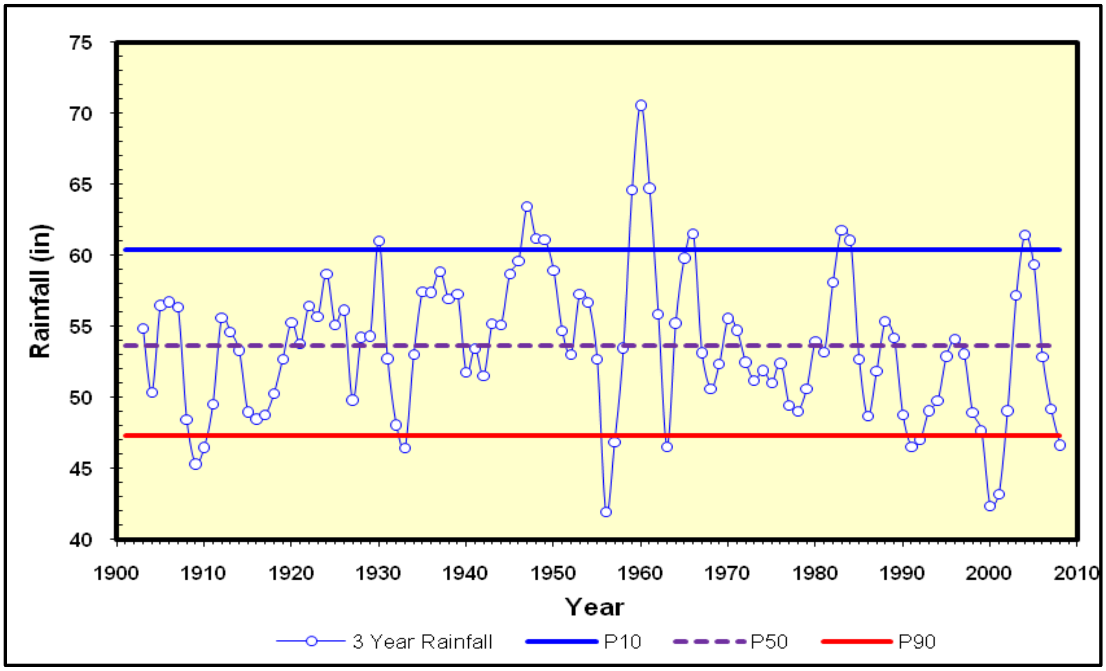

Figure 4-12. Three-year average rainfall compared to the P10, P50, and P90 percentiles (1901-2008). Average rainfall based on records from the Inverness, Ocala and Brooksville stations.

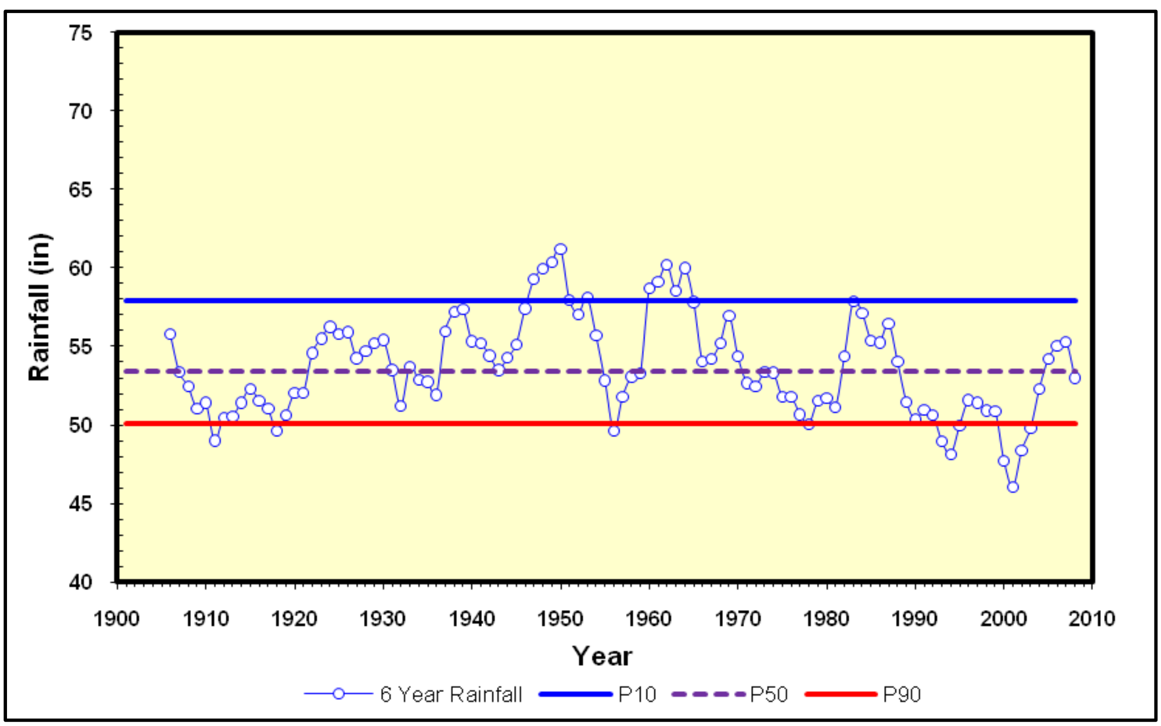

Figure 4-13. Six-year average rainfall compared to the P10, P50, and P90 percentiles (1901-2008). Average rainfall based on records from the Inverness, Ocala and Brooksville stations.

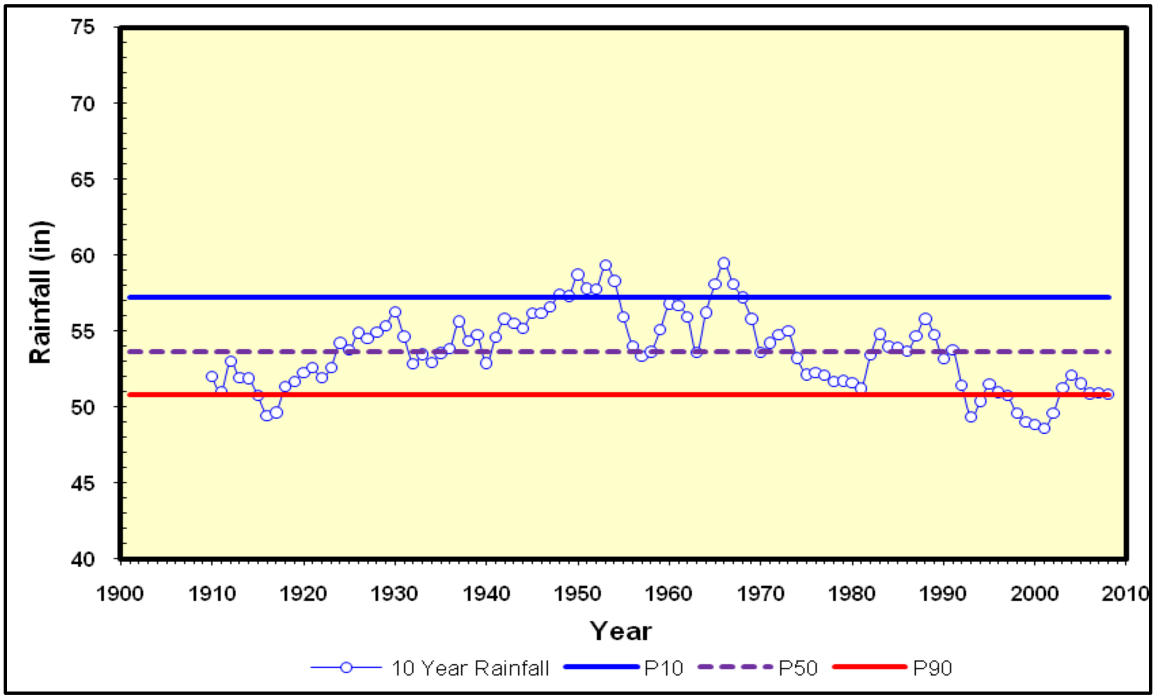

Figure 4-14. Ten-year average rainfall compared to the P10, P50, and P90 percentiles (1901-2008). Average rainfall based on records from the Inverness, Ocala and Brooksville stations.

A cumulative sum graph of stream flow versus time was constructed for the Holder gage on the Withlacoochee River and rainfall versus time averaged from the Brooksville, Inverness, and Ocala stations (Figures 4-16 and 4-17). In the cumulative sum analysis, any major deviation in slope that occurs for more than five years would indicate a substantial change in stream flow or rainfall. Both cumulative sum analyses indicate a downward break in slope around 1970 corresponding to change in climate from a wet to dry period (Enfield et al. 2001).

4.2.2 Numerical Model Results

A number of regional groundwater flow models have included the Withlacoochee River area. Ryder (1982) simulated the entire extent of the SWFWMD. In 2002, the USGS simulated the entire Florida peninsula in their Mega Model of regional groundwater flow (Sepulveda 2002).

4.2.2.1 Northern District Model

The SWFWMD Northern District groundwater flow model (NDM) was completed in May 2008 by the consulting firm HGL, Inc (Hydrogeologic, Inc. 2008). The domain of the NDM includes portions of the SWFWMD, the St. Johns River Water Management District (SJRWMD), and the Suwannee River Water Management District (SRWMD). The flow model encompasses the entire extent of the Central West-Central Florida Groundwater Basin (CWCFGWB) and the Northern West-Central Florida Groundwater Basin (NWCFGWB). The eastern boundary of the regional groundwater flow model extends just east of the Lake County/Orange County line. The western boundary of the model domain extends approximately five miles offshore of the Gulf of Mexico.

The regional model finite-difference grid consists of 182 columns and 275 rows of 2,500 ft uniform grid spacing (Figure 4-18). The NDM is fully 3-Dimensional with top and bottom elevations specified for each model layer. Topographic elevations were assigned to the top of model layer 1 from a digital elevation model provided by SWFWMD, based on the USGS 30m National Elevation Dataset (NED). The Florida Geological Survey supplied elevation data for all other layers in the model.

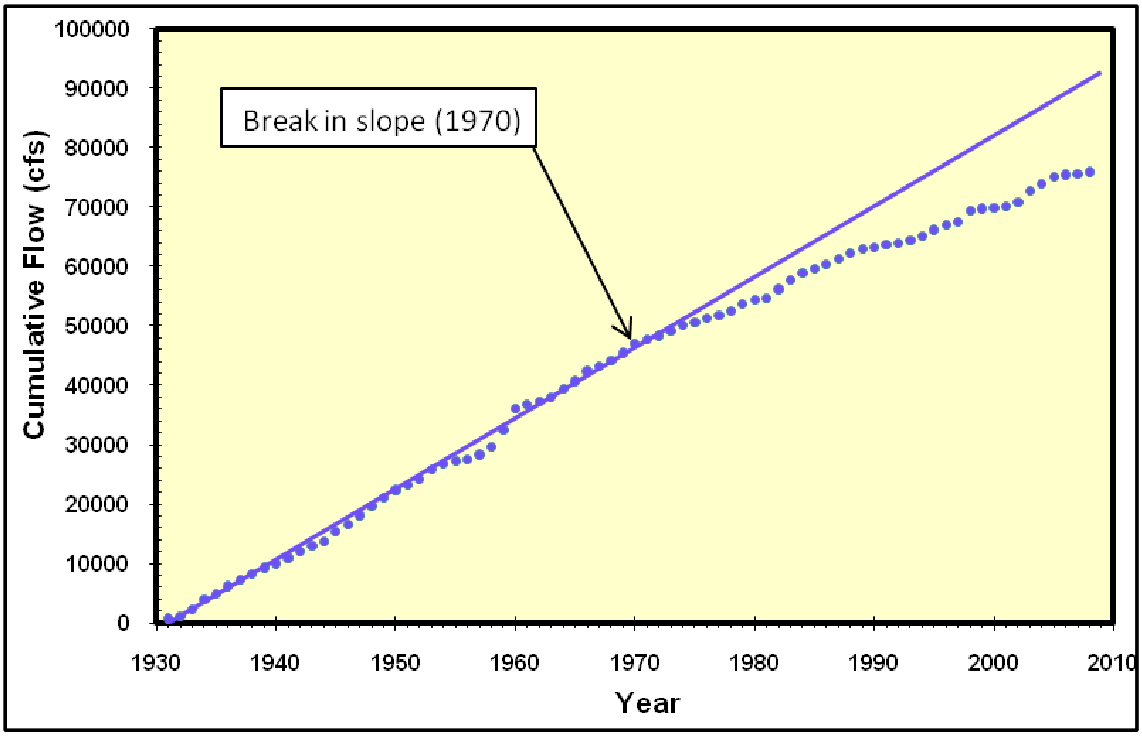

Figure 4-15. Cumulative sum of Withlacoochee River mean annual flow at Holder from 1931-2008.

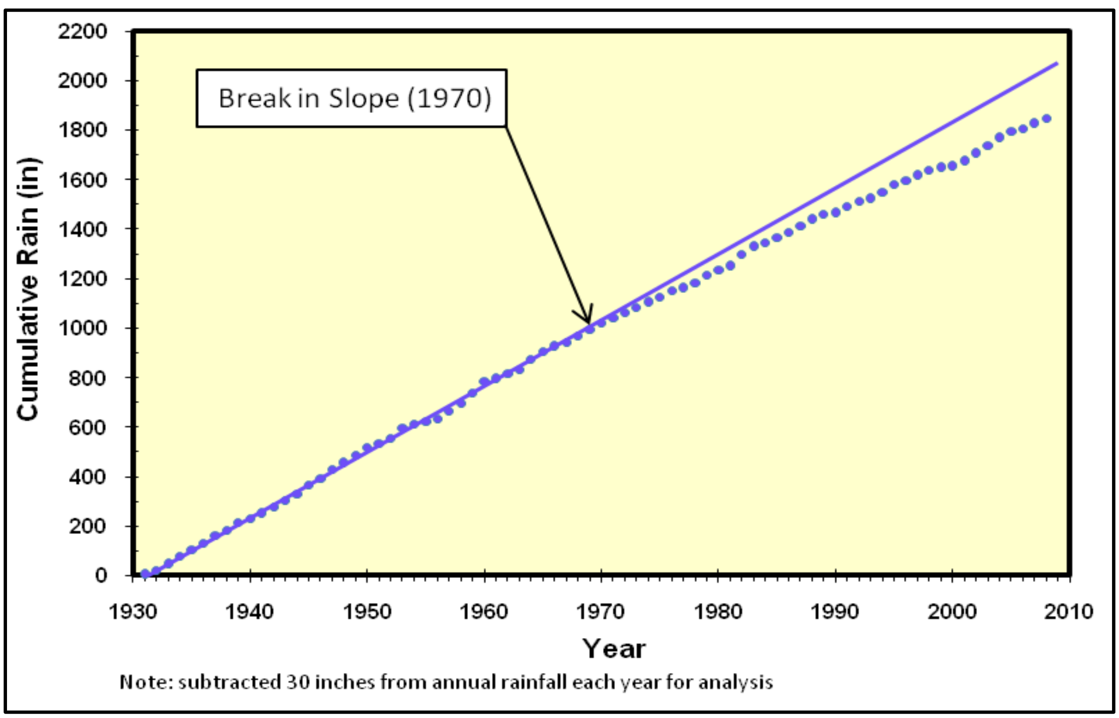

Figure 4-16. Cumulative sum of annual rainfall averaged from the Brooksville, Inverness, and Ocala stations from 1931-2008.

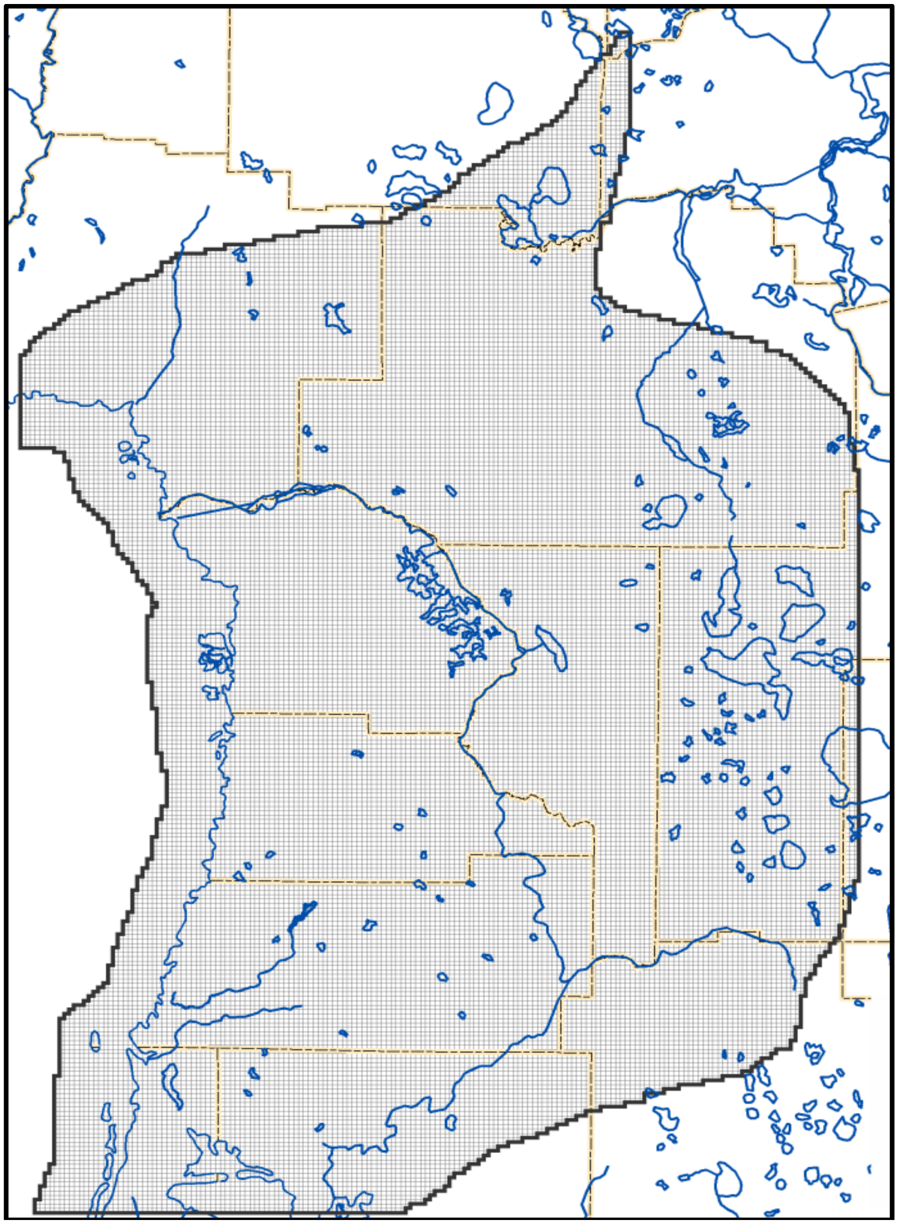

Figure 4-17. Groundwater grid in the Northern District model.

The NDM consists of seven layers that represent the primary geologic and hydrogeologic units including: 1. Surficial Sands; 2. Intermediate Confining Unit (ICU); 3. Suwannee Limestone; 4. Ocala Limestone; 5. upper Avon Park Formation; 6. Middle Confining Unit (MCU) I and MCU II; and 7. lower Avon Park Formation or Oldsmar Formation. The UFA is composed of the Suwannee Limestone, Ocala Limestone, and Upper Avon Park; the Lower Floridan aquifer (LFA) is composed of the permeable parts of both the lower Avon Park and the Oldsmar Formation. Due to the permeability contrasts between the units, each unit is simulated as a discrete model layer rather than using one model layer to represent a thick sequence of permeable units (e. g. , UFA).

In regions where the UFA is unconfined, the second model layer represents the uppermost geologic unit in the UFA. The Suwannee Limestone is absent over a large part of the model domain. Where the Suwannee Formation is absent, model layers 3 and 4 represent the Ocala Limestone. The Ocala Limestone is absent in some local areas in the northernmost region of the model domain. In those areas, model layers 3 through 5 represent the Avon Park Formation. With the exception of the eastern part of the domain, the Oldsmar Formation is assumed to have a relatively low permeability being similar to the permeability of the overlying MCU II, which includes the lower Avon Park. Consequently, with the exception of the eastern part of the model domain, the finite-difference cells representing the LFA (model layer 7) are inactive and groundwater flow is not simulated.

The NDM was calibrated to steady-state 1995 calendar year conditions and transient conditions from 1996 through 2002 using monthly stress periods. This model is unique for west-central Florida in that it is the first regional flow model that represents the groundwater system as fully three-dimensional. Prior modeling efforts, notably Ryder (1985), Sepulveda (2002), and Knowles et al. (2002), represented the groundwater system as quasi-three-dimensional.

The groundwater flow and solute transport modeling computer code MODFLOW-SURFACT was used for the groundwater flow modeling (Hydrogeologic, Inc. 2008). MODFLOW-SURFACT is an enhanced version of the USGS modular three-dimensional groundwater flow code (McDonald and Harbaugh 1988).

4.2.2.2 2005 Scenario

To determine drawdown in the UFA and potential impacts to Withlacoochee River flow, 2005 groundwater withdrawals were simulated in the NDM under long term transient conditions (five years) and compared to pre-pumping conditions (zero withdrawals). UFA heads generated at the end of the 2005 simulation were subtracted from UFA heads at the end of the pre-pumping simulation to determine aquifer drawdown. The model predicts UFA drawdown of less than 0. 25 feet from pre-pumping to 2005 conditions along the Withlacoochee River (Figure 4-19). Based on the impacts of groundwater withdrawals of 438. 1 mgd over the NDM domain in 2005, predicted reduction in Withlacoochee River baseflow was less than three percent at all gaging stations (Table 4-6).

4.2.3 Summary

The Withlacoochee River headwaters occur within the Green Swamp and the river flows north until emptying into the Gulf of Mexico in southwest Levy County. The gaged sections of the river upstream from Lake Rousseau include about 108 miles of river length from the Compressco gage near its headwaters to the

Holder gage in southwest Marion County. The entire Withlacoochee River drainage basin extends over 2,060 square miles.

In the upper reaches of the Withlacoochee River, a shallow surficial aquifer overlies a leaky semi-confined Upper Floridan aquifer. Very little groundwater contribution occurs along the Withlacoochee River upstream of Dade City. In this region, the river is shallow and connected only to the surficial aquifer. Baseflow contributions are small due to the limited permeability and saturated thickness of the surficial aquifer. In the middle and lower portions of the Withlacoochee River Basin, however, the UFA becomes regionally unconfined and is located within a highly karst-dominated region. Downstream of Dade City, the groundwater contribution to river flow increases to 22 percent of average flow at Croom and 34 percent of mean flow at Holder.

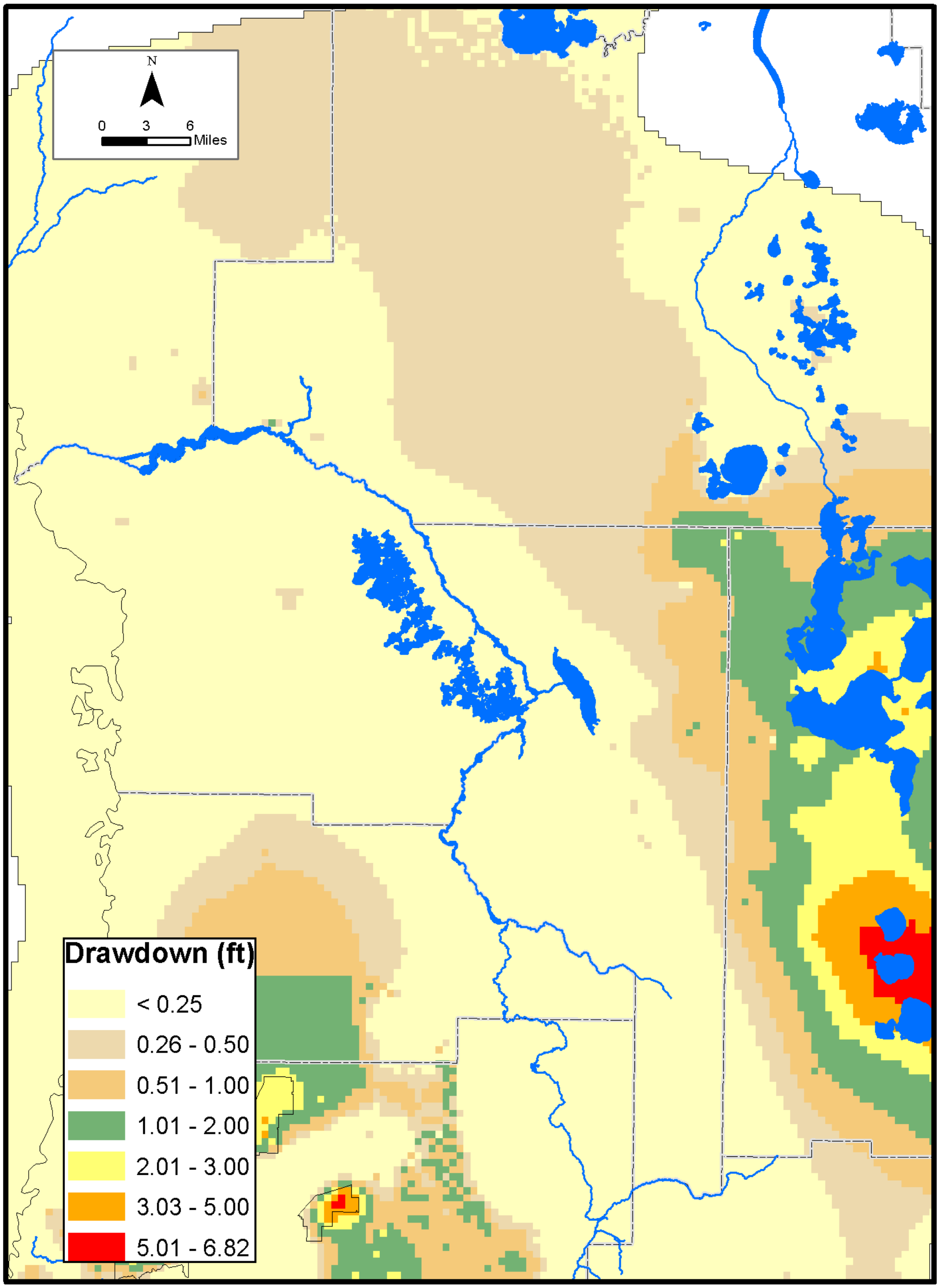

Figure 4-18. Predicted drawdown in the UFA due to 2005 groundwater withdrawals.

Table 4-6. Predicted baseflow changes from pre-pumping to 2005 conditions based on the Northern District groundwater flow model.

USGS Gaging Station	No Pumping Baseflow (cfs)	2005 Baseflow (cfs)	Percent Change (%)
Compressco	8.92	8.80	-1.3
Dade City	12.61	12.31	-2.3
Trilby	56.62	56.15	-0.8
Croom	99.36	101.36	2.0
Floral City	95.16	97.43	2.4
Wysong Dam	152.54	155.58	2.0
Holder	235.58	231.13	-1.9

Statistical analysis of Withlacoochee River flow shows a decreasing trend after 1970. Analysis of rainfall data also indicates a decline in rainfall after 1970 with the pre-1970 period much wetter than the post-1970 period. The change in both streamflow and rainfall that occurred in 1970 corresponds to the transition from a warm (wet) AMO cycle to a cool (dry) one. Based on the flow and rainfall analysis, most of the historic streamflow decline in the Withlacoochee River can be attributed to climatic conditions.

Groundwater withdrawals in the NDM were simulated for 2005 under transient conditions. Aquifer heads and Withlacoochee River baseflow quantities were subtracted from a separate run of the NDM under non-pumping conditions. The model results indicate that predicted drawdown within the Upper Floridan aquifer near the Withlacoochee River is less than 0. 25 feet. Predicted baseflow decline for the Withlacoochee River under current pumping conditions at all gaging stations was less than three percent.

5 Water Chemistry

This chapter includes analyses and discussion of water chemistry changes 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.

5.1 Overview

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

Long-term water quality changes were evaluated using USGS (generally prior to 1995) and District (generally from 1998 to current) data gathered on the Withlacoochee River. Two USGS sites were selected on the Withlacoochee River in an effort to examine the upper, primarily surface water driven, portion of the river separately from the lower portion, which is at the downstream end of the study reach. Water quality samples collected by the District were collected at the same locations sampled by the USGS. The two selected sites were the Withlacoochee River at Croom and the Withlacoochee River near Holder (Figure 4-4). The watershed area above the Croom site is approximately 370 square miles (327,000 acres) and the area above the Holder site is approximately 1,825 square miles (1,168,000 acres). Water quality samples have periodically been collected for a span of nearly 60 years at each site.

For the following analysis, available water quality data for selected gages were retrieved from the USGS on-line database and from the District's Water Management Information System 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 sets for each parameter were analyzed combined (USGS and District data) and independently. 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. 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 for each individual agency's dataset were statistically significant (figures 5-1 through 5-6). Figures not displayed in this chapter can be seen in Appendix Water Quality.

5. 2 Macronutrients: Phosphorus and Nitrogen

Concentrations of the two major macronutrients, phosphorus and nitrogen, have been monitored for 30 and 50 years respectively on Withlacoochee River. 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.

5.2.1 Phosphorus

Phosphorus has over the years been variously reported by the USGS and SWFWMD 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 in Withlacoochee River were well below this level for the entire period of record (Figure 5-1 and 5-2) for both the Croom and Holder sites.

For the entire period of record (POR) (USGS and District data analyzed together), results of the trend analysis showed that phosphorus has a statistically significant decreasing trend (Table 5-3) at the Croom site. The downward trend is very slight and might be at least partially attributable to the slight reductions in the citrus, rangeland, pasture, and other agriculture land uses in this portion of the watershed. When USGS and District data were analyzed separately for the Croom site, the downward trend was statistically significant in the USGS data set, but not in the District data set.

For the Holder site, a statistically significant increasing trend was noted in the POR dataset and in the USGS dataset (Table 5-4 and 5-6). When the District dataset was analyzed independently, this trend was not present.

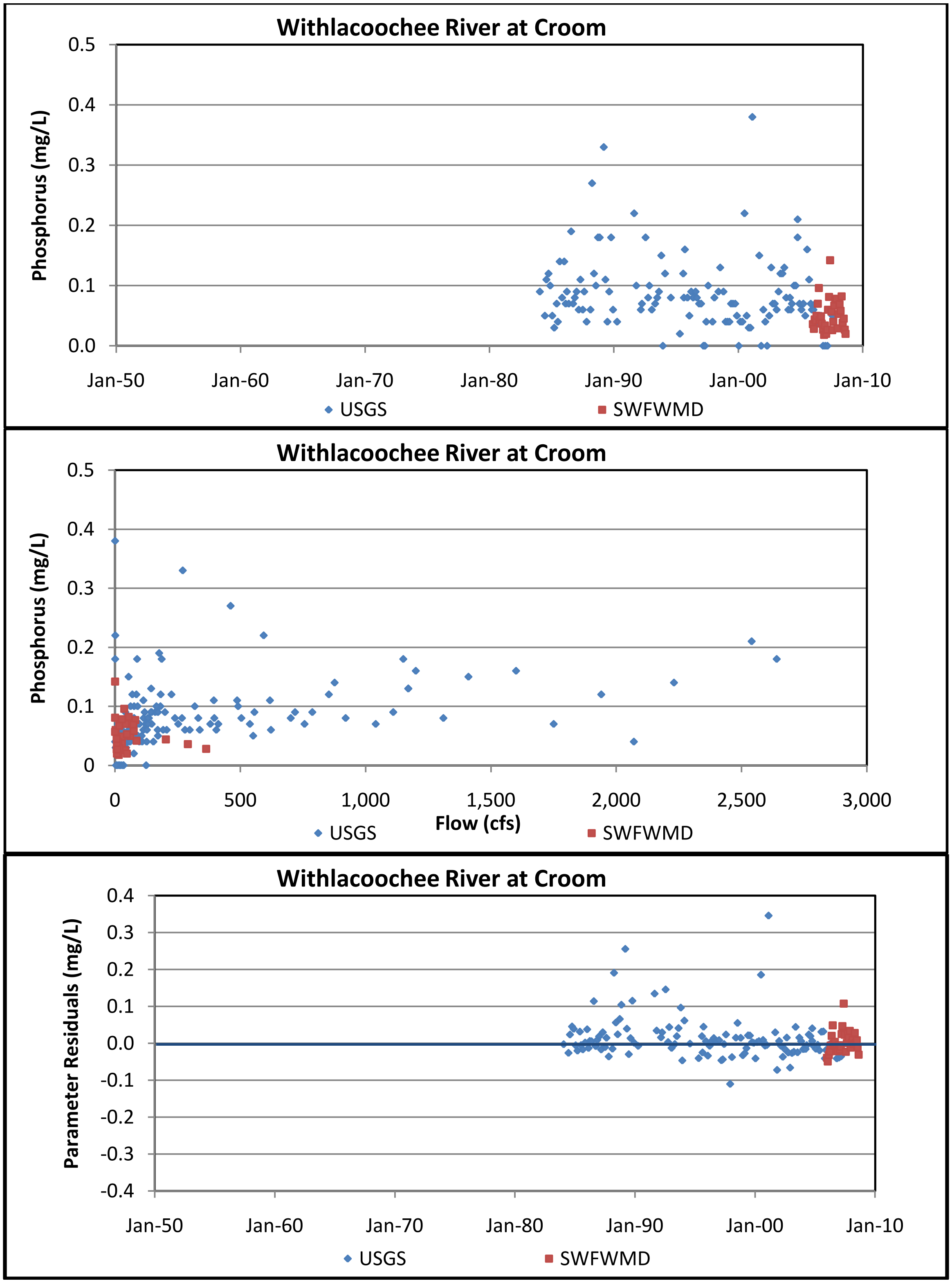

Figure 5-1. Trend analysis of Phosphorus for Withlacoochee River at Croom.

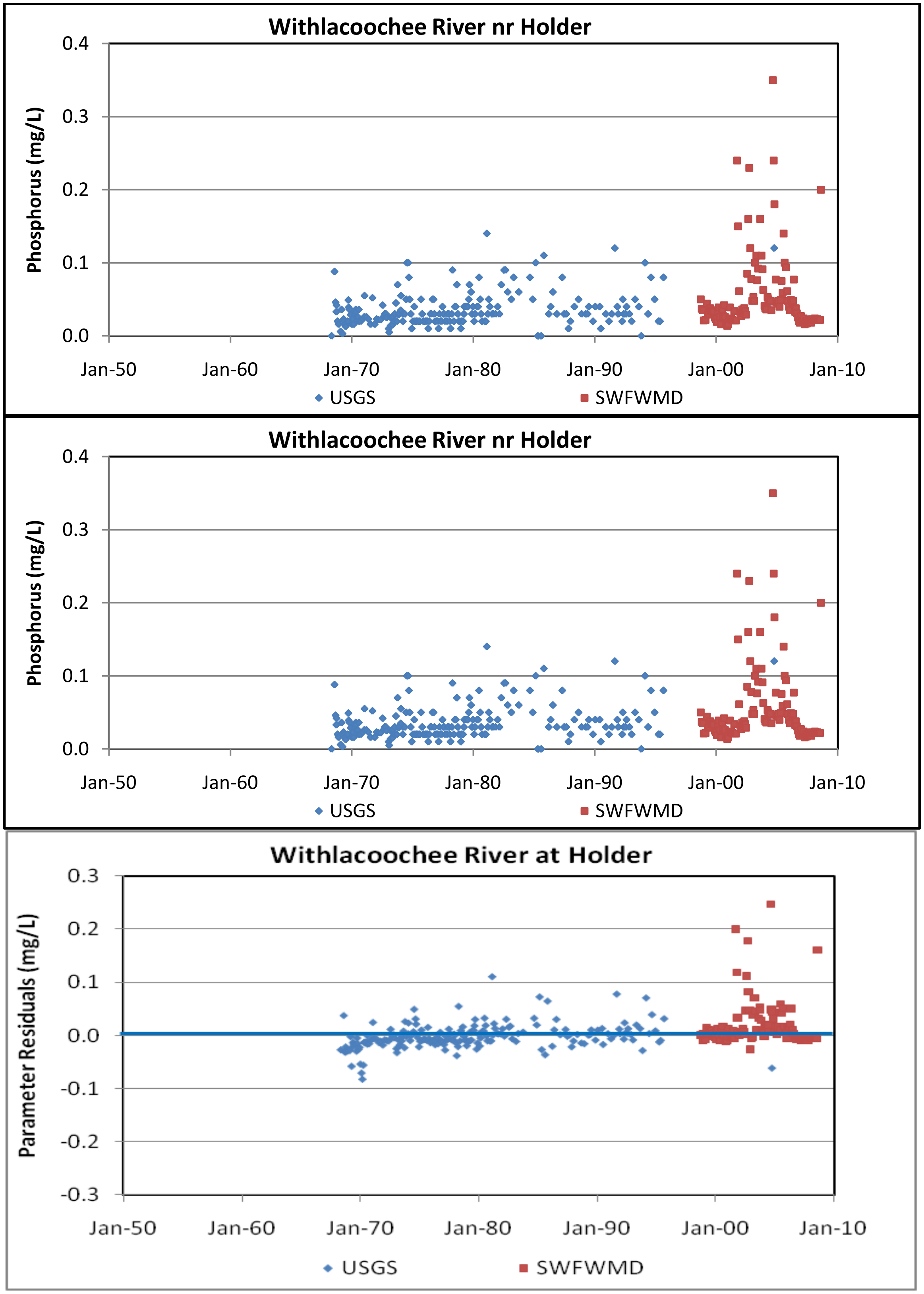

Figure 5-2. Trend analysis of Phosphorus for Withlacoochee River near Holder.

5.2.2 Nitrogen

Nitrogen has most often been reported by the USGS and SWFWMD as either nitrate or nitrate+nitrite. For our analysis, 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.

As seen in the time series plot (Figures 5-3 and 5-4), there has been an upward trend in Nitrate/Nitrite (NOx) at both sites. These increases occur irrespective of flow and, similar to the phosphorous analysis, land use changes do not appear to conclusively explain the water quality changes. All of the increasing trends are statistically significant with the exception of the POR dataset for Croom and the District dataset for Holder (Table 5. 3 and 5. 5).

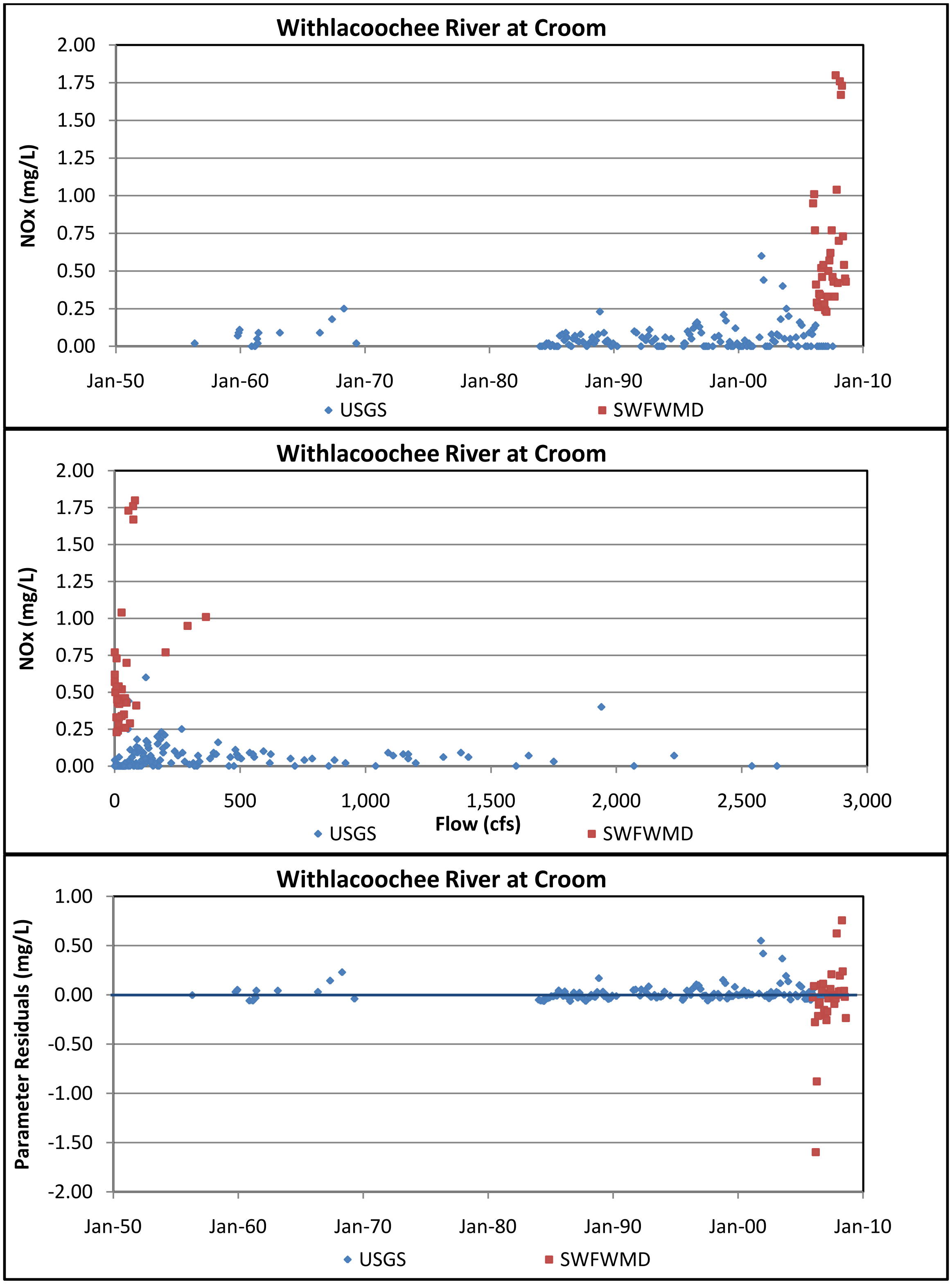

Figure 5-3. Trend analysis of Nitrate/Nitrite for Withlacoochee River at Croom.

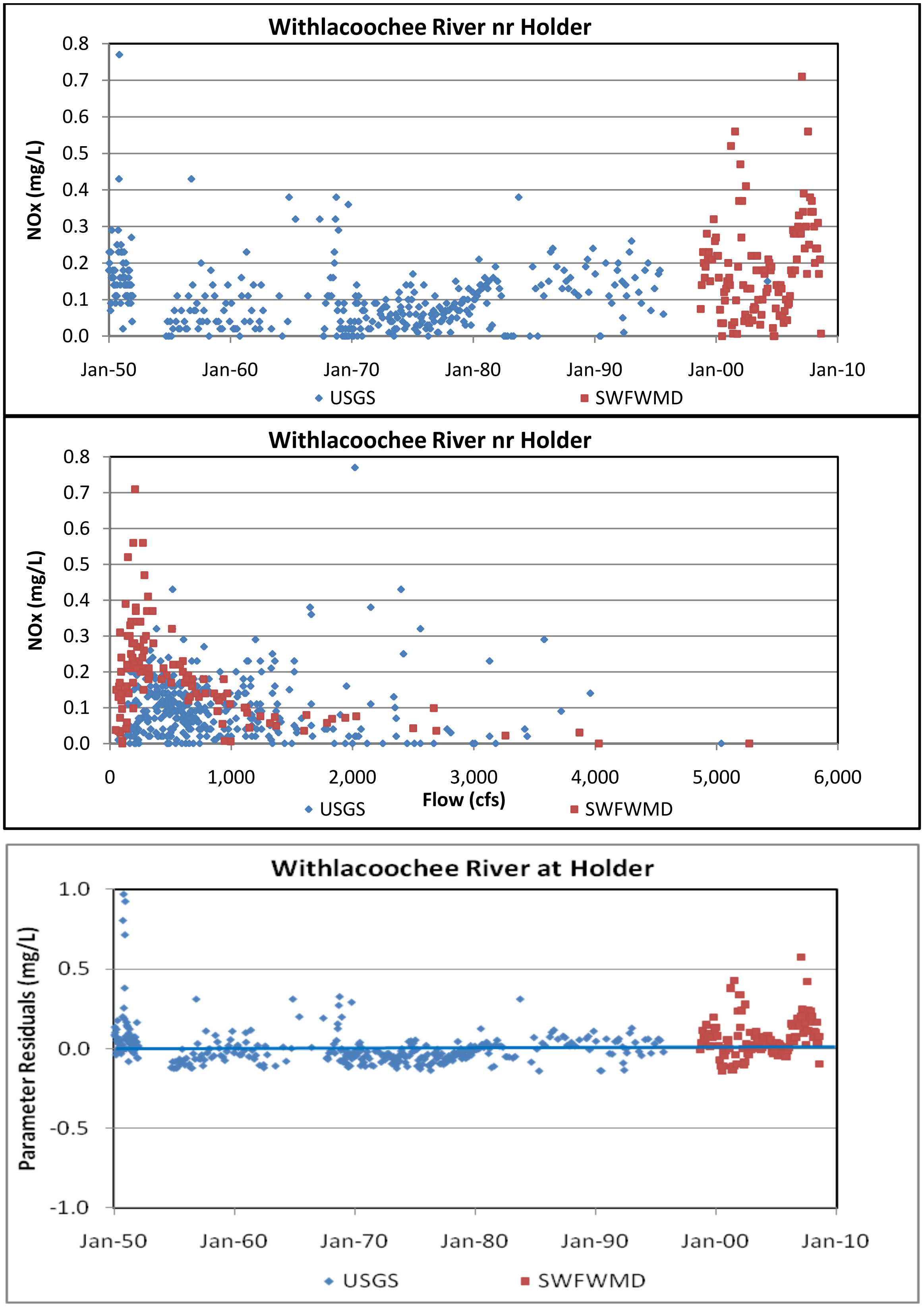

Figure 5-4. Trend analysis of Nitrate/Nitrite for Withlacoochee River near Holder.

5. 3 Trend Analysis of Selected Chemical Constituents

Analyses of the POR data for the Withlacoochee River at Croom site show two additional statistically significant trends. Downward trends in both fluoride and magnesium (Figure 5-5, 5-6 and Table 5. 3) were noted which may be due to reduced groundwater contribution in recent years.

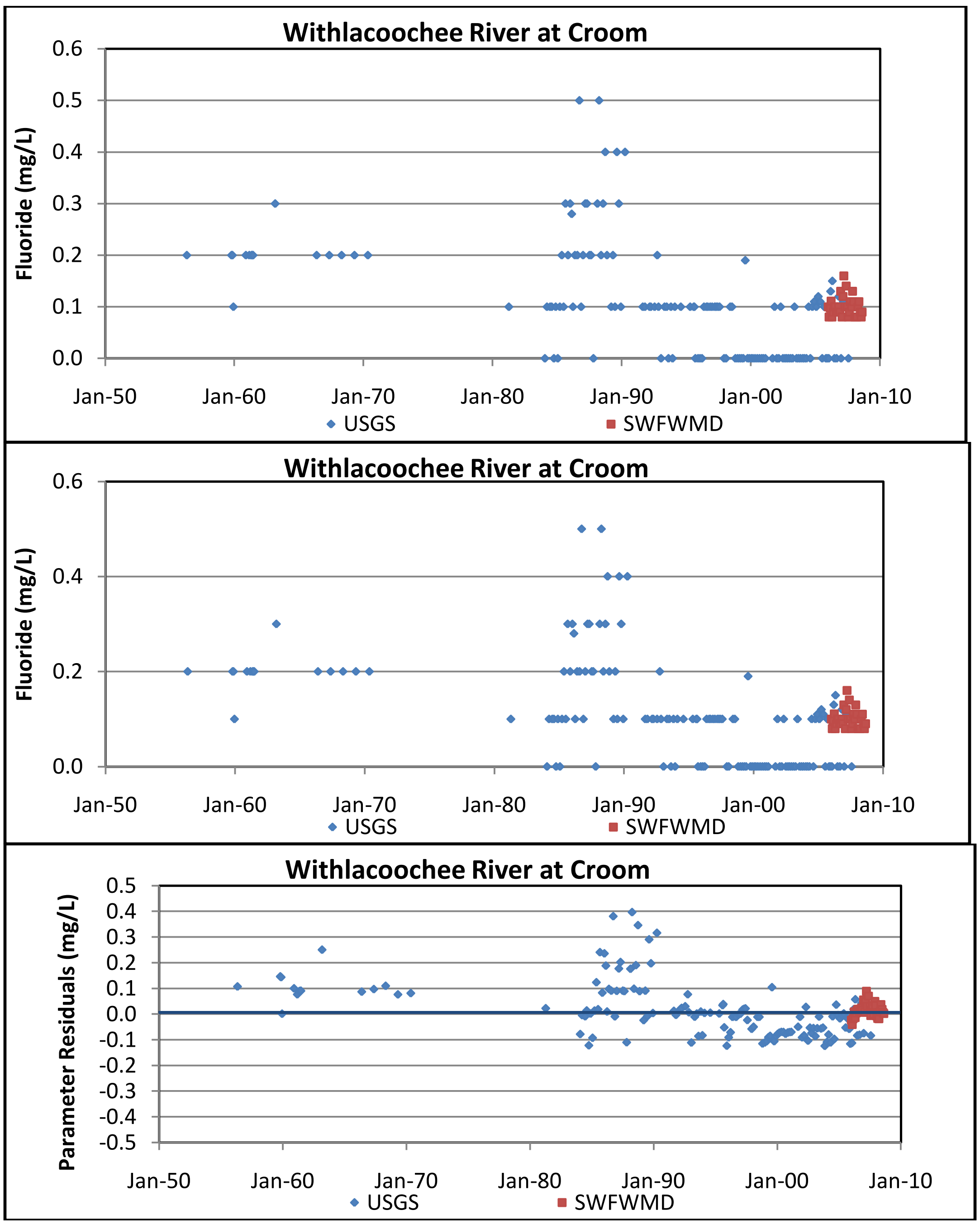

Figure 5-5.   Trend analysis of Fluoride for Withlacoochee River at Croom.

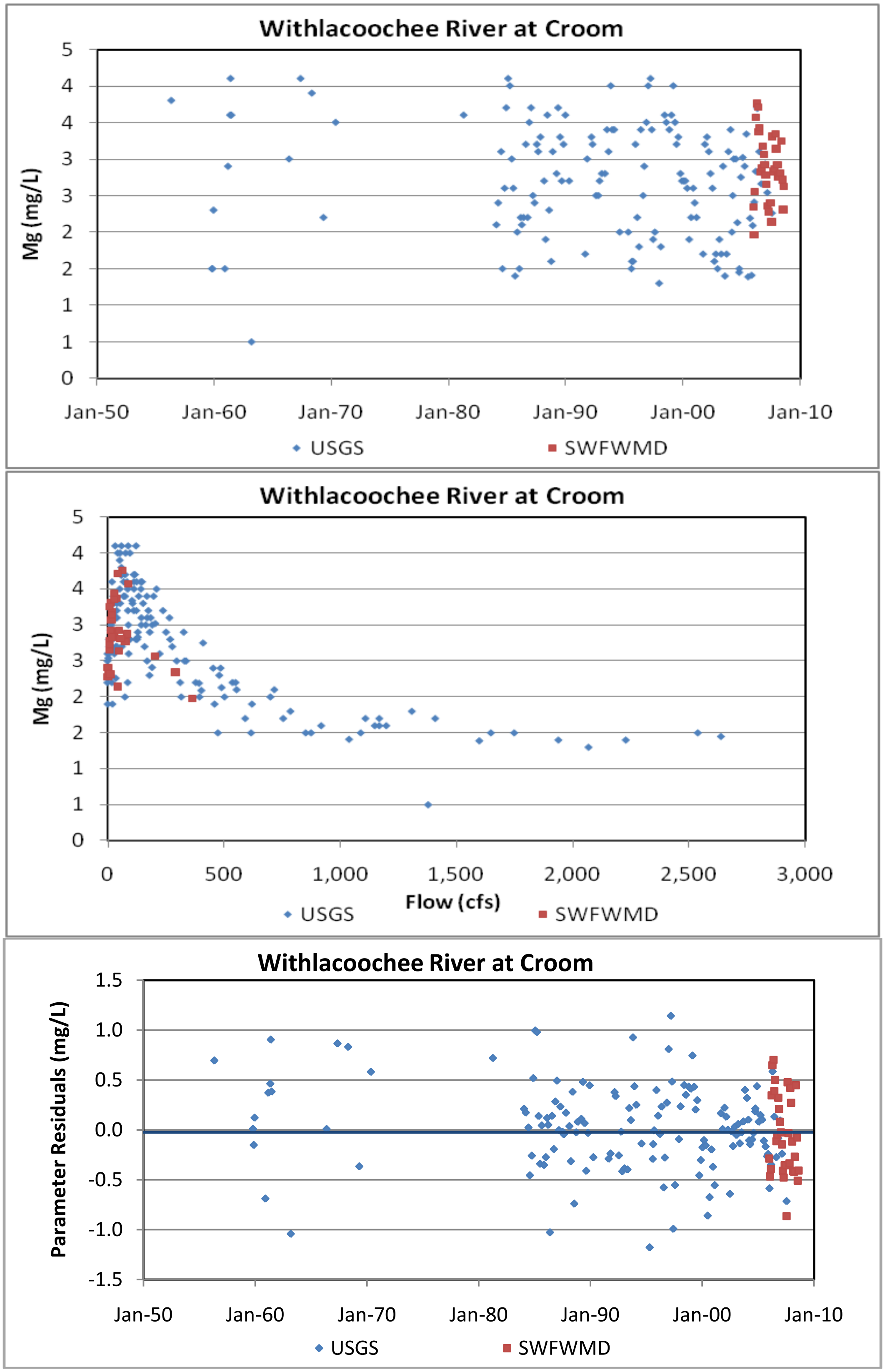

Figure 5-6. Trend analysis of Magnesium for Withlacoochee River at Croom.

Based on Friedemann and Hand's (1989) findings, 90% of all Florida streams exhibited fluoride concentrations less than 0. 9 mg/l (5-5). Fluoride, which is a naturally occurring chemical constituent, concentrations Withlacoochee River at Croom were well below this level for the entire period of record.

Analyses of the POR data for the Withlacoochee River at Holder show many more statistically significant trends than at Croom. Increasing trends were noted in calcium, chloride, conductance, magnesium, potassium, sodium, sulfate, and total dissolved solids (Table 5-4 through 5-6). All of these parameters are considered rock indicators (FGS 2009) which may indicate groundwater has recently made up a larger portion of the flow at Holder due to low rainfall totals and/or the groundwater that makes up a portion of the total flow has been in contact with the rock matrix within the aquifer longer due to lower discharge from these sources. It is suspected that a combination of both of these possible causes contributes to these trends. A downward trend in pH for the POR data at Holder suggests similar explanations since pH decreases in spring discharge usually indicates drought or drawdown (FGS 2009).

Dissolved Oxygen (D. O.) shows a statistically significant increasing trend at the Holder site (Table 5-6). D. O. trends were intensively monitored during 2006-2007 to determine, if there are any issues with low D. O. concentrations under low flow conditions. Low D. O. concentrations generally occur upstream of shoals where water velocities drop (Hood 2007). D. O. concentrations were monitored for eight months just upstream of a restrictive shoal on the Withlacoochee River (Hood 2007). Concentrations remained above the Environmental Protection Agency standard of 5 mg/L during periods when fish passage requirements (0. 6 feet) were met or exceeded.

Table 5-1. USGS dataset statistical results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant increasing trend; blue shading indicates a statistically significant decreasing trend.

Withlacoochee River at Croom, FL (USGS Only)			
Parameter Residual	**n**	**p Value**	**slope**
Calcium	145	0.38704	0.00012
Chloride	145	0.30424	-0.00004
Conductance	273	0.58842	0.00024
Dissolved Oxygen	211	0.15302	-0.00004
Fluoride	143	0.00000	-0.00001
Hardness	145	0.58553	0.00018
Magnesium	145	0.0299295	-0.00002
NH3	128	0.76834	-0.00000
NOx-N	140	0.03219	0.00000
pH	173	0.11548	0.11548
Phosphorus	129	0.00178	-0.00000
Potassium	145	0.07742	0.00002
Silica	146	0.25412	0.00003
Sodium	145	0.74922	-0.00001
Sulfate	145	0.13922	-0.00005
Total Dissolved Solids	139	0.00998	0.00126

Table 5-2. SWFWMD dataset statistical results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant increasing trend; blue shading indicates a statistically significant decreasing trend.

Withlacoochee River at Croom, FL (SWFWMD Only)			
Parameter Residual	**n**	**p Value**	**slope**
Calcium	23	0.29078	0.00870
Chloride	24	0.86216	0.00014
Conductance	33	0.49534	-0.01141
Dissolved Oxygen	33	0.23284	-0.00137
Fluoride	33	0.31387	-0.00001
Hardness	N/A	N/A	N/A
Magnesium	33	0.0126099	-0.00050
NH3	33	0.97154	0.00000
NOx-N	33	0.00967	0.00032
pH	33	0.10376	-0.00023
Phosphorus	33	0.81622	-0.00000
Potassium	N/A	N/A	N/A
Silica	N/A	N/A	N/A
Sodium	33	0.23284	0.00081
Sulfate	24	0.00193	0.00676
Total Dissolved Solids	33	0.06521	0.03404

Table 5-3. Combined dataset statistical results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant increasing trend; blue shading indicates a statistically significant decreasing trend.

Withlacoochee River at Croom, FL (Combined)			
Parameter Residual	**n**	**p Value**	**slope**
Calcium	169	0.34681	-0.00012
Chloride	169	0.38573	-0.00003
Conductance	306	0.83775	-0.00008
Dissolved Oxygen	244	0.23885	-0.00003
Fluoride	176	0.00004	-0.00001
Hardness	145	0.58553	0.00018
Magnesium	178	0.01006	-0.00002
NH3	158	0.44769	-0.00000
NOx-N	158	0.44769	-0.00000
pH	206	0.38293	-0.00001
Phosphorus	162	0.01130	-0.00000
Potassium	145	0.07742	0.00002
Silica	146	0.25412	0.00003
Sodium	178	0.75218	-0.00001
Sulfate	169	0.51053	-0.00002
Total Dissolved Solids	172	0.06823	0.00096

Table 5-4. USGS dataset statistical results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant increasng trend; blue shading indicates a statistically significant decreasing trend.

Withlacoochee River at Holder, FL (USGS Only)			
Parameter Residual	**n**	**p Value**	**slope**
Calcium	307	0.18343	0.00010
Chloride	347	0.00035	0.00005
Conductance	425	0.16373	0.00080
Dissolved Oxygen	224	0.33319	0.00003
Fluoride	287	0.00969	0.00000
Hardness	351	0.25224	0.00018
Magnesium	307	0.79328	-0.00000
NH3	171	0.21021	0.00000
NOx-N	387	0.00114	0.00000
pH	390	0.66551	-0.00000
Phosphorus	208	0.00000	0.00000
Potassium	295	0.00131	0.00000
Silica	322	0.00040	-0.00009
Sodium	297	0.04549	0.00001
Sulfate	317	0.68187	-0.00003
Total Dissolved Solids	291	0.02089	0.00058

Table 5-5. SWFWMD dataset statistical results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant increasing trend; blue shading indicates a statistically significant decreasing trend.

Withlacoochee River at Holder, FL (SWFWMD Only)			
Parameter Residual	**n**	**p Value**	**slope**
Calcium	118	0.00052	0.00335
Chloride	118	0.00021	0.00031
Conductance	117	0.00297	0.02547
Dissolved Oxygen	116	0.56526	0.00006
Fluoride	118	0.00107	0.00006
Hardness	N/A	N/A	N/A
Magnesium	118	0.00034	0.00027
NH3	N/A	N/A	N/A
NOx-N	118	0.14787	0.00002
pH	117	0.12227	-0.00002
Phosphorus	118	0.12998	-0.00000
Potassium	118	0.22470	-0.00002
Silica	N/A	N/A	N/A
Sodium	118	0.19195	0.00006
Sulfate	118	0.04964	0.00349
Total Dissolved Solids	118	0.01233	0.01008

Table 5-6. Combined dataset statistical results of Kendall's tau analysis on residuals (from various water quality parameters regressed against flow) versus time. Yellow shading indicates a statistically significant increasing trend; blue shading indicates a statistically significant decreasing trend.

Withlacoochee River at Holder, FL (Combined)			
Parameter Residual	**n**	**p Value**	**slope**
Calcium	425	0.00000	0.00042
Chloride	465	0.00000	0.00005
Conductance	542	0.00000	0.00206
Dissolved Oxygen	340	0.02304	0.00004
Fluoride	405	0.91428	-0.00000
Hardness	351	0.25224	0.00018
Magnesium	425	0.00003	0.00002
NH3	171	0.21021	-0.00000
NOx-N	505	0.01316	0.00000
pH	507	0.00193	-0.00000
Phosphorus	326	0.00000	0.00000
Potassium	413	0.00000	0.00001
Silica	322	0.00040	-0.00009
Sodium	415	0.00000	0.00002
Sulfate	435	0.01144	0.00018
Total Dissolved Solids	409	0.00000	0.00141

6 Goals, Ecological Resources of Concern and Key Habitat Indicators

6. 1 Goal – Preventing Significant Harm

The goal of a MFLs 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 potentially 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 was 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. "

6. 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.

6. 3 Resource Management Goals and Key Habitat Indicators

The District 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 Withlacoochee 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 7, and results of the minimum flows and levels analyses are presented in Chapter 8.

6. 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 non-perenniality 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 6-1). 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).

6. 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". It is not assumed that flows associated with the lowest wetted perimeter inflection point meet fish passage needs or address other wetted perimeter inflection points outside the river channel. However, identification of the lowest wetted perimeter inflection point permits evaluation of flows that provide the greatest amount of inundated bottom habitat in the river channel on a per-unit flow basis.

6. 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.

6. 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 indicate 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.

6. 3. 5 Hydrologic Connections Between the River Channel and Floodplain

A goal of the District'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 yields 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 environs, and mucky or peaty organic soils can develop in saturated or inundated floodplain zones (Tate 1980, Brown et al. 1990). Although these soils may dry out on a seasonal basis, typically long hydroperiods contribute to their high organic content. Plant species that grow on flooded, organic soils are tolerant of anoxic conditions and the physical structure of these soils (Hook and Brown 1973, McKevlin et al. 1998). Such adaptations can be an important selective mechanism that determines plant community composition. Because changes in river hydrology can potentially 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 MFLs 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.

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 based on temporal loss of habitat (Munson and Delfino 2007).

Figure 6-1. Example of low flow at 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.

7 Technical Approach for Establishing Minimum Flows and Levels for the Withlacoochee River

7.1 Overview

For most surface water dominated systems the MFL methodology employed by the SWFWMD utilizes a seasonal approach which involves identification of a low flow threshold and development of prescribed flow reductions for periods of low, medium and high flows, sometimes termed Blocks 1, 2 and 3. 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. All analyses were performed on three flow records for each corresponding gauge. The flow records were for the warm climatic period (1940-1969), the cool climatic period (1970-1999), and the entire period of record. The overwhelming majority of analyses resulted in more restrictive flow reductions for the cool period. Unless otherwise mentioned, the results from cool climatic period analyses were used for establishment of MFLs.

7.2 HEC-RAS Cross-Sections

The entire Hydrologic Engineering Centers River Analysis System (HEC-RAS) model development and calibration report is contained in Appendix HEC-RAS. An internal review was conducted of the model and model report and the associated memo is contained in Appendix Review of HEC-RAS model.

Elevation data in the Withlacoochee River were compiled from multiple sources. These sources included surveyed transects from the SWFWMD survey section conducted in support of minimum flows and levels, surveyed transects from Jones Edmunds and Associates collected in support of the District's watershed management plans, and bathymetric data (point data) collected by SWFWMD engineering staff. Additionally, Light Detection and Ranging (LiDAR) data was available from the District's Geographic Information System (GIS) and Mapping Department for the Withlacoochee River watershed. Figures 7-1 through 7-3 illustrate the cross-sections generated from the elevation data.

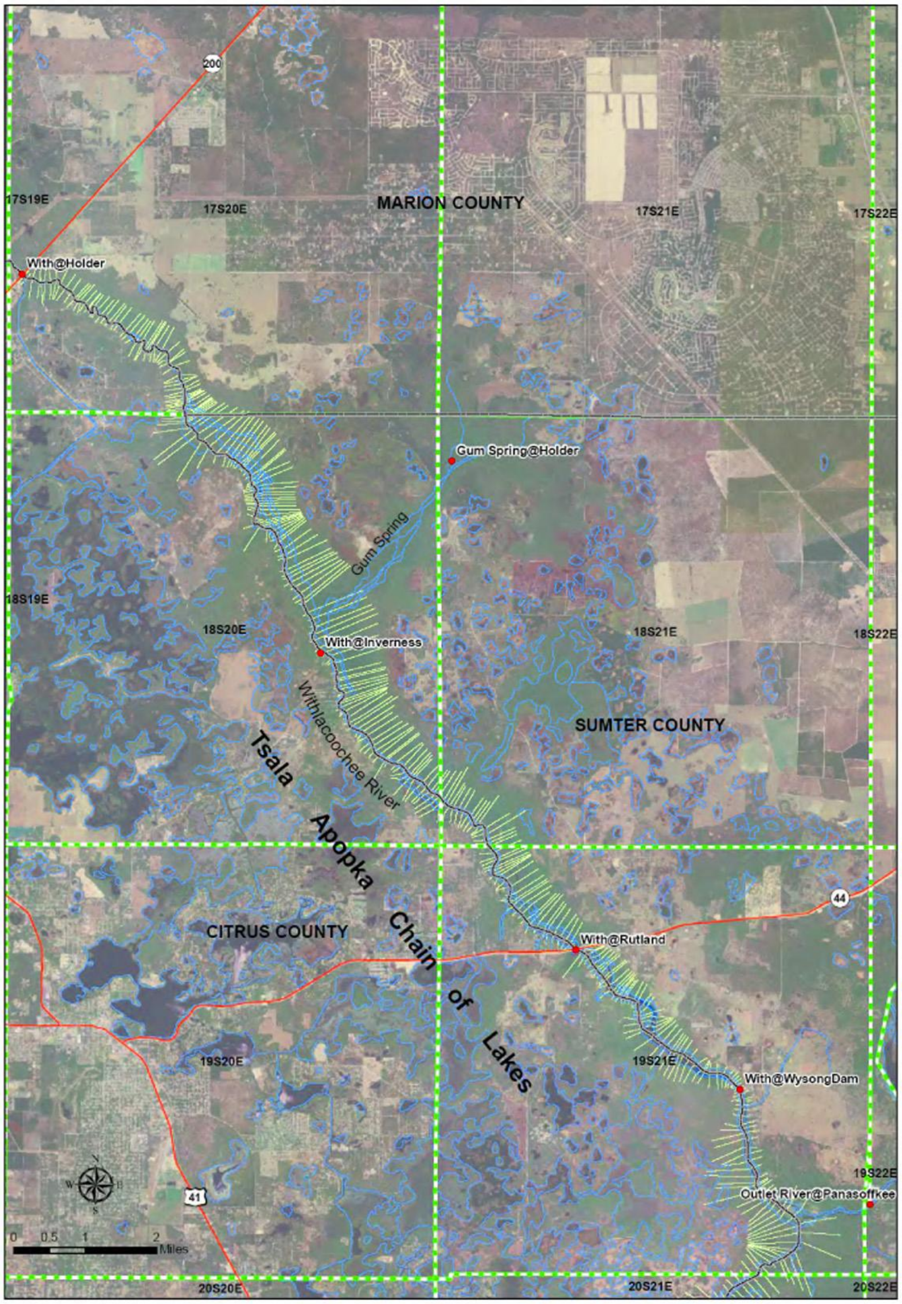

Figure 7-1. Location of HEC-RAS cross-sections in the Withlacoochee River between Holder and the Wysong-Coogler Water Control Structure (Map produced by EAS).

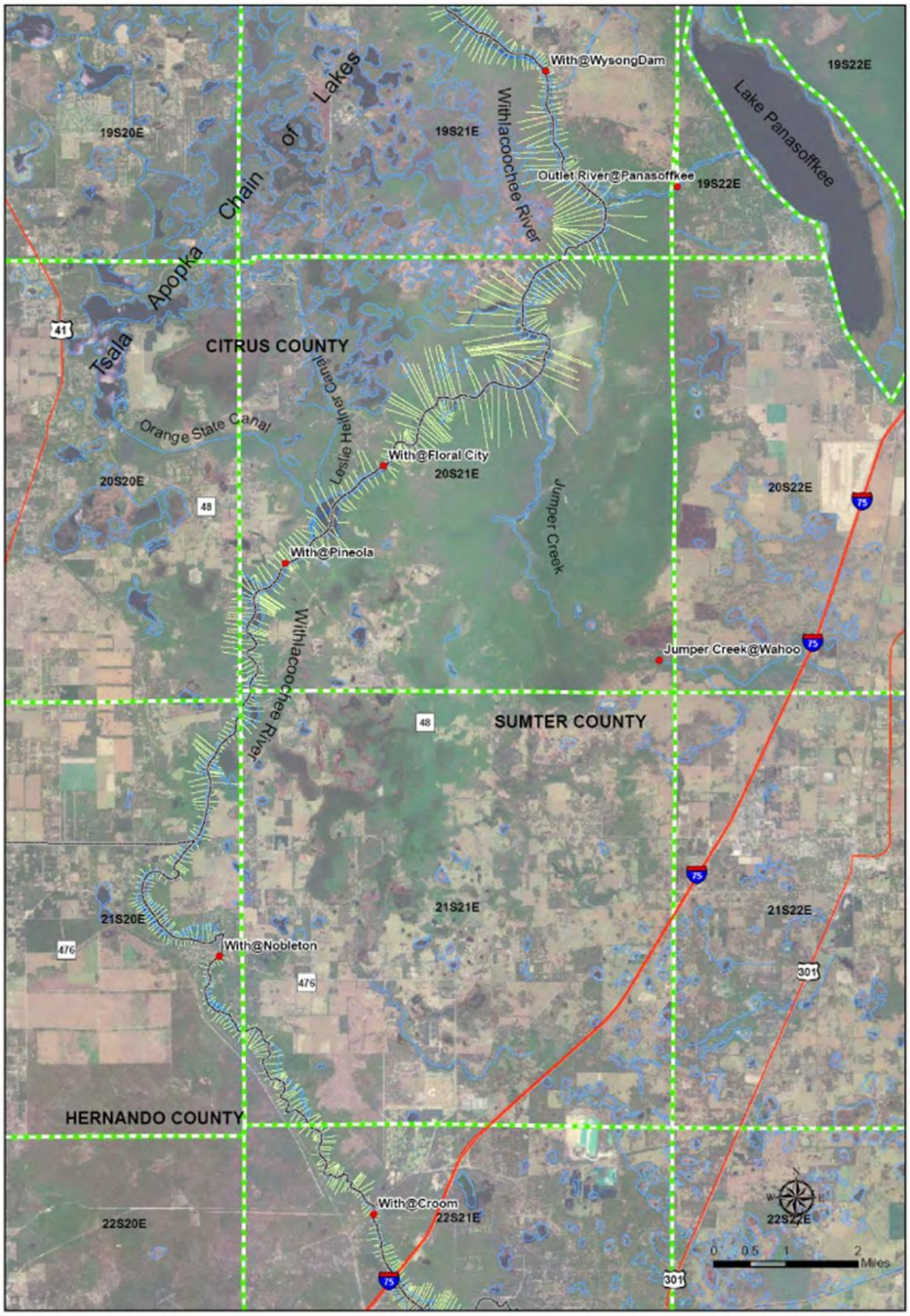

Figure 7-2. Location of HEC-RAS cross-sections in the Withlacoochee River between the Wysong-Coogler Water Control Structure and Croom (Map produced by EAS).

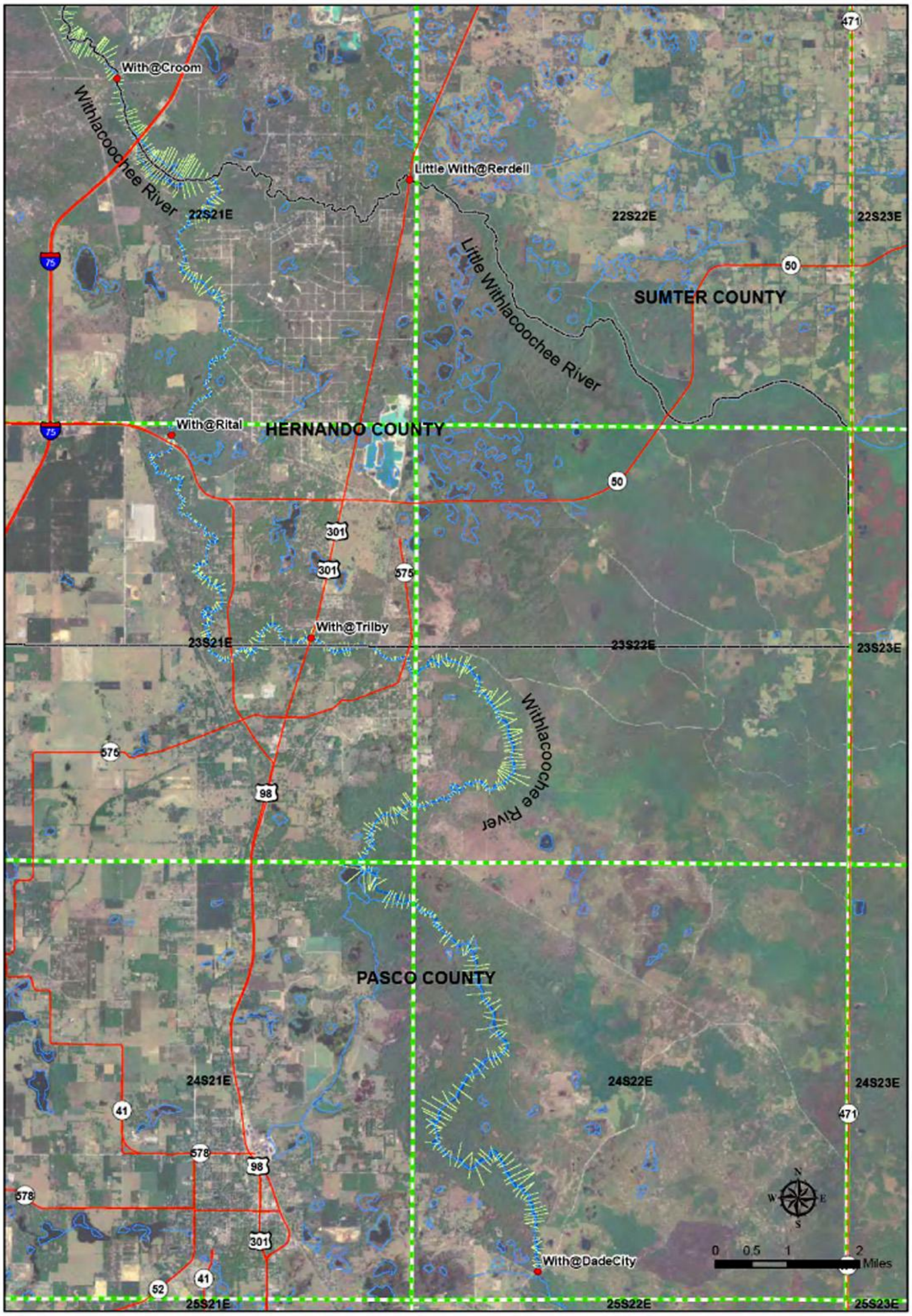

Figure 7-3. Location of HEC-RAS cross-sections in the Withlacoochee River between Croom and Dade City (Map produced by EAS).

7.2.1 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 nine representative (see Figure 7-4) sites. Eight of the nine sites are located on the main stem of Withlacoochee River. One site is located on the Little Withlacoochee River approximately six tenths of a mile upstream of the confluence with the Withlacoochee River. Bottom substrata consist mainly of shifting sand, bedrock or muck. Various densities of submersed vegetation were observed at the sites.

Identification of shoal locations in the study reach was important for PHABSIM analyses because these features represent hydraulic controls used in developing hydraulic simulation models with PHABSIM software. The shoals restrict flow and can be sites where loss of hydraulic connection may occur or may present barriers to fish migration or hamper canoeing. Field reconnaissance of shoals in the entire study reach was conducted for selection of the nine PHABSIM data collection cross-sections.

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 RDI RioGrande 1200 Acoustic Doppler Current Profiler and/or a Sontek Flow Tracker Handheld Acoustic Doppler Velocimeter at intervals determined for each site. Interval selection is based on the criteria of obtaining a minimum of 20 measurements per cross-section. Stream depth, substrate type and habitat/cover were recorded along the cross-sections. Other hydraulic descriptors measured included channel geometry (river bottom-ground elevations), water surface elevations across the channel and water surface slope determined from points upstream and downstream of the cross-sections. Elevation data were collected relative to temporary bench marks that were subsequently surveyed by District surveyors to establish absolute elevations. 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.

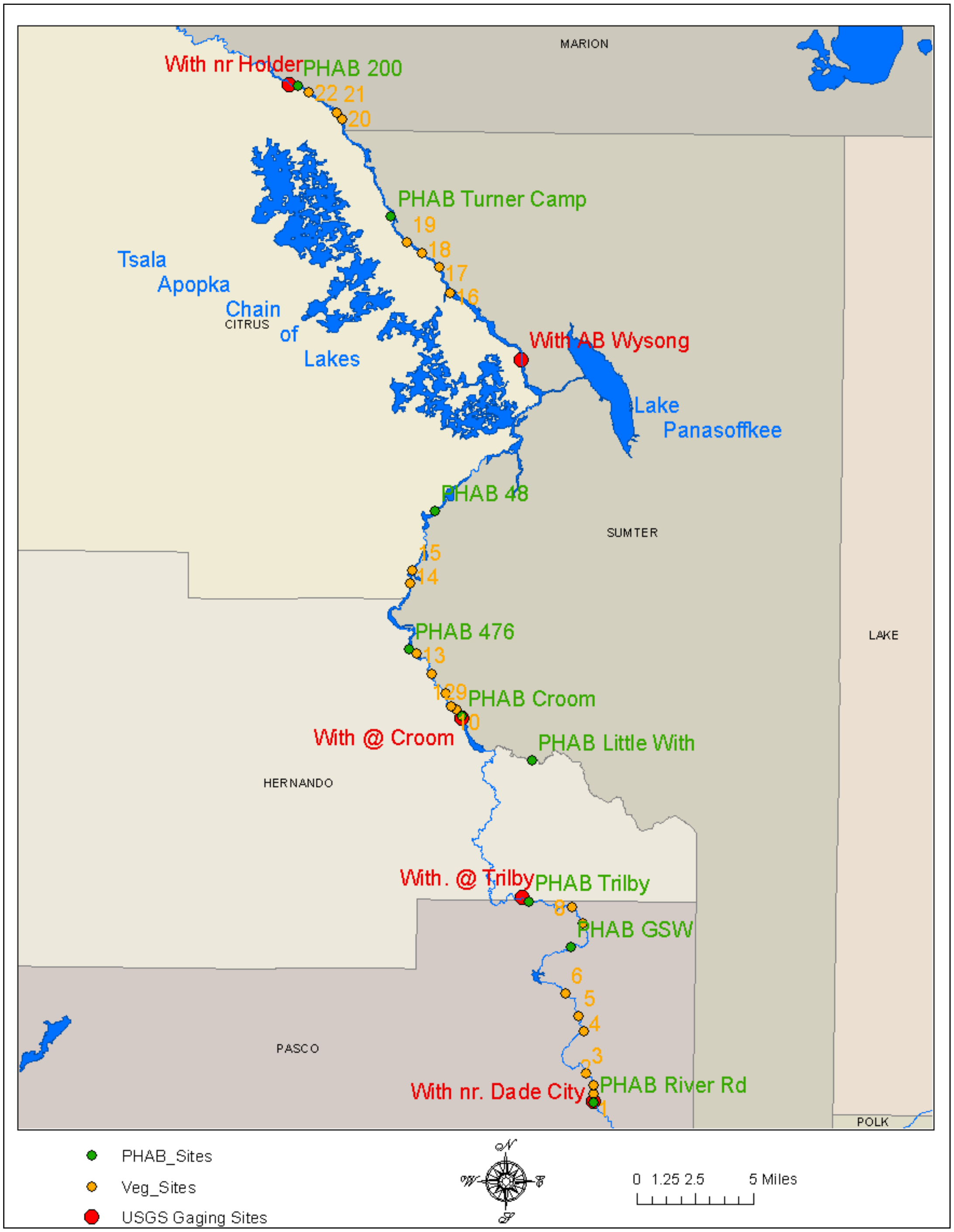

Figure 7-4. PHABSIM sites on the Withlacoochee River.

7.2.2 Instream Habitat Cross-Sections

Cross-sections for assessing instream habitats were examined at 26 sites on the Withlacoochee River. These sites were also utilized in assessing floodplain vegetation and in PHABSIM analyses (20 vegetation-only and 6 PHABSIM/vegetation). 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. Typically, one of the three instream cross-sections at each site was situated along the floodplain vegetation transect line and the other two replicate cross-sections were located 50 ft upstream and downstream. A total of 78 instream cross-sections were sampled (26 cross-sections x 3 replicates at each site).

For each instream habitat cross-section, the range in elevations (in feet above the North American Vertical Datum of 1988) and linear extent (along the cross-section) for the following habitats were determined:

- bottom substrates (such as sand, mud, gravel, clay or bedrock);
- exposed roots;
- woody debris or snags;
- wetland (herbaceous or shrubby) vegetation;
- wetland trees;
- submersed aquatic vegetation;
- floating aquatic vegetation;
- emergent aquatic vegetation.

Following the collection of cross-sectional habitat data, additional elevations of woody habitats were also collected longitudinally at each instream habitat site. Belt transects along the banks of the Withlacoochee River were used to document the elevational distribution of woody habitats such as snags or exposed roots.

Live (exposed roots) and dead (snag) woody habitats were measured along both river banks from the center cross-section upstream to the upstream cross-section. If the water surface elevation change between the two transects differ by more than 0. 5 feet (taken at the transect centers), woody habitat sampling along the banks were collected further upstream by another 50 feet.

Elevations for up to 15 samples of exposed root and snag habitat were collected from each bank between the center and upstream cross-sections. Measured woody habitats are representative of the vertical distribution of woody habitats in the sample corridor (between the two instream cross-sections). The upper and lower vertical extent of each encountered woody habitat sample (referred to as High and Low front shots, respectively) were measured using survey equipment.

7.2.3 Floodplain Vegetation/Soils Cross-sections

Twenty-six transect locations were identified along the upper and middle Withlacoochee River study corridor (Figure 7-4 through 7-7) using criteria described by Entrix (2010). Among the 26 locations, 8 of them were also utilized for PHABSIM analyses. Each transect was oriented perpendicular to the river channel and extended across the river corridor and floodplain in order to identify and to characterize elevations, soils, physical features, and vegetation. Of the 26 total transects used for vegetative and soil evaluations, ten were located on only one side of the river, while the remaining 16 transects extended across both sides of the river spanning the entire floodplain. 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.

7.3 Vegetation Characterization

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, rather than shrubs and herbaceous species, were used to define vegetation communities, because relatively long-lived tree species are better integrators of long-term hydrologic conditions. At least three samples located within each vegetation zone were collected using the Point Centered Quarter method (see Cottam and Curtis 1956, as cited in Entrix 2010). Shrubs and ground cover plant species were also noted. Sampling points were distributed along transects to capture conspicuous changes in topography, soils, or vegetative composition. Sampling points were between 50 and 200 feet apart, depending on the length of the communities within the transects, and every attempt was made to overlap sampling points with existing survey stakes for ease of surveying. At each sampling point, four quadrants were established using two, 1-meter PVC rods at right angles to each other. In each quadrant, the closest tree and shrub were identified. Data collected included the distance from the center point, species identification, and the diameter at breast height (dbh) of recorded trees.

7.4 Soils Characterization

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.

7.5 Hydrologic Indicators and Floodplain Wetted Perimeter

Key physical indicators of historic inundation were identified, including: cypress buttress inflection elevations; cypress knees; lichen and/or moss lines;

hypertrophied lenticels; stain lines; and scarps. The number of physical indicators of historic inundation varied by transect, depending on availability and reproducibility.

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. Wetted perimeter was calculated for vegetation classes in the study corridor to evaluate the potential change in inundated habitat that may be anticipated due to changes in river stage. The wetted perimeter for a vegetation class is the linear distance inundated along a transect, below a particular elevation or water level (river stage). Consequently, as distance from the river channel increases, the total wetted perimeter also increases, but can vary among vegetation classes. The HEC-RAS floodplain model (see Section 7.2) was used to determine corresponding flows at the Croom, Wysong, and Holder gages that would be necessary to inundate specific floodplain elevations (e. g. , mean vegetation zone and soils elevations).

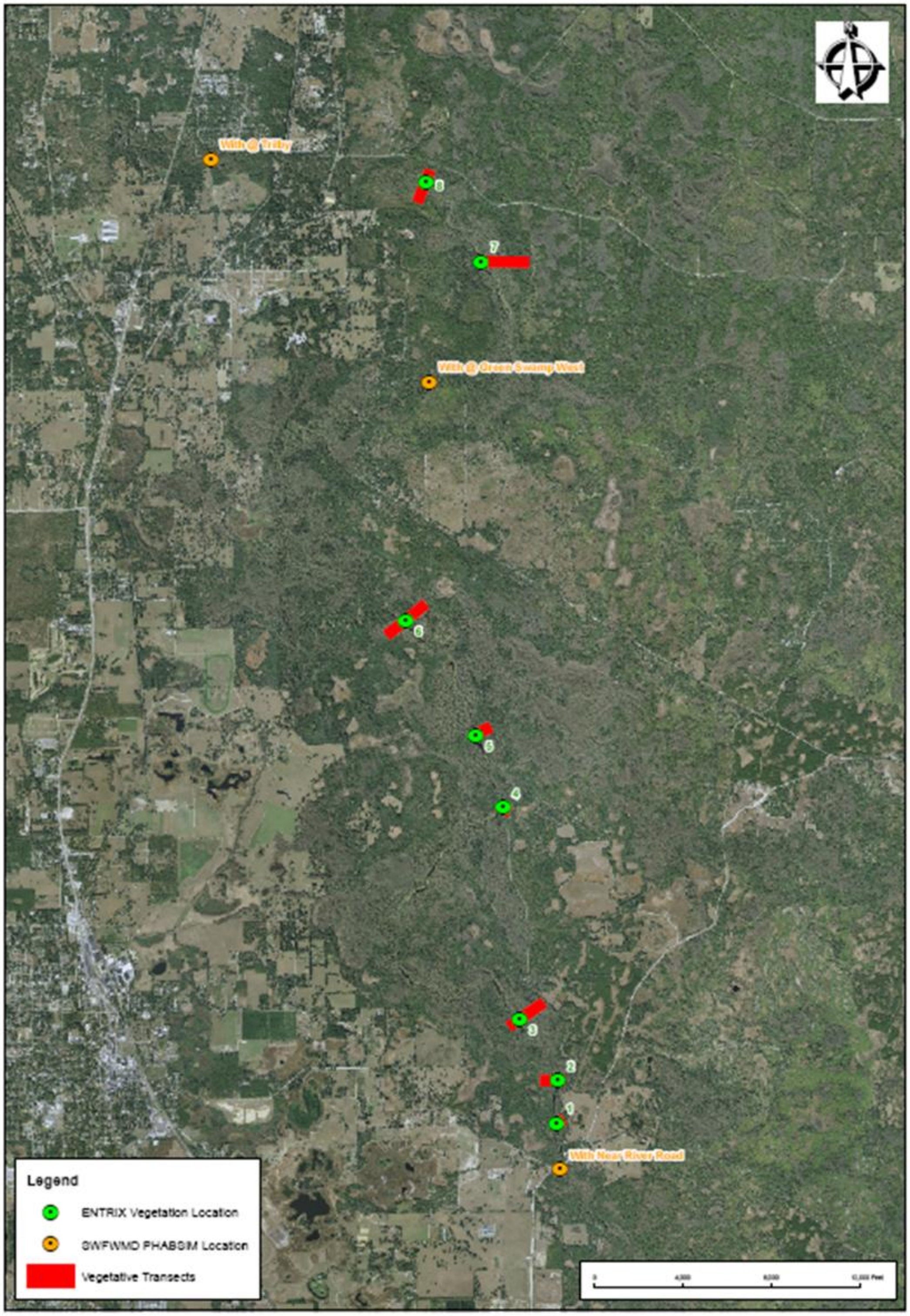

Figure 7-5. Location of vegetation transects and their extent as indicated by the red bars along the Withlacoochee study corridor. This region encompasses the southernmost assemblage of vegetation transects considered near the upstream portion of the watershed. Map produced by Entrix (2010).

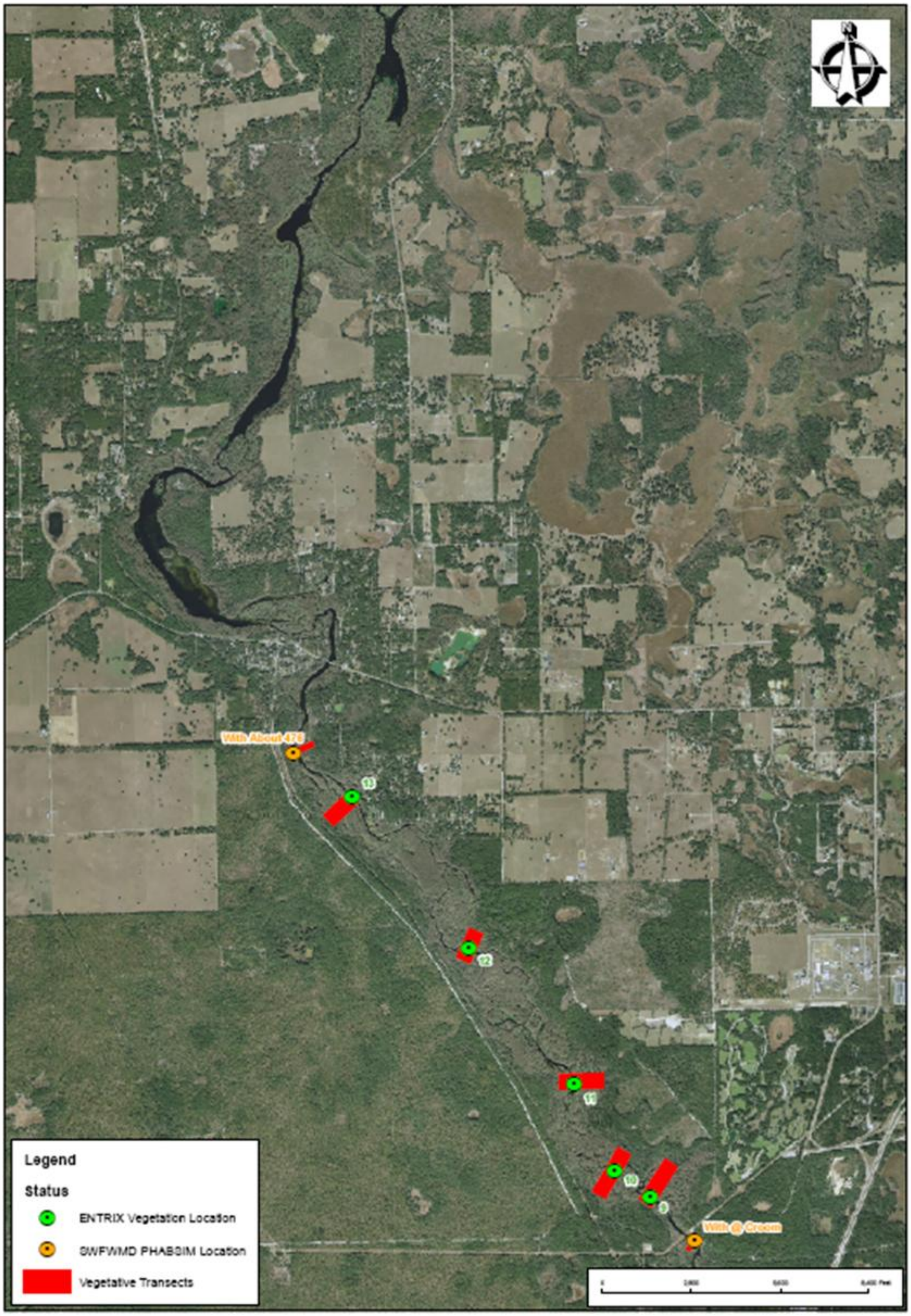

Figure 7-6. Location of vegetation transects and their extent as indicated by the red bars along the Withlacoochee study corridor. This region encompasses the middle grouping of vegetation transects. Map produced by Entrix (2010).

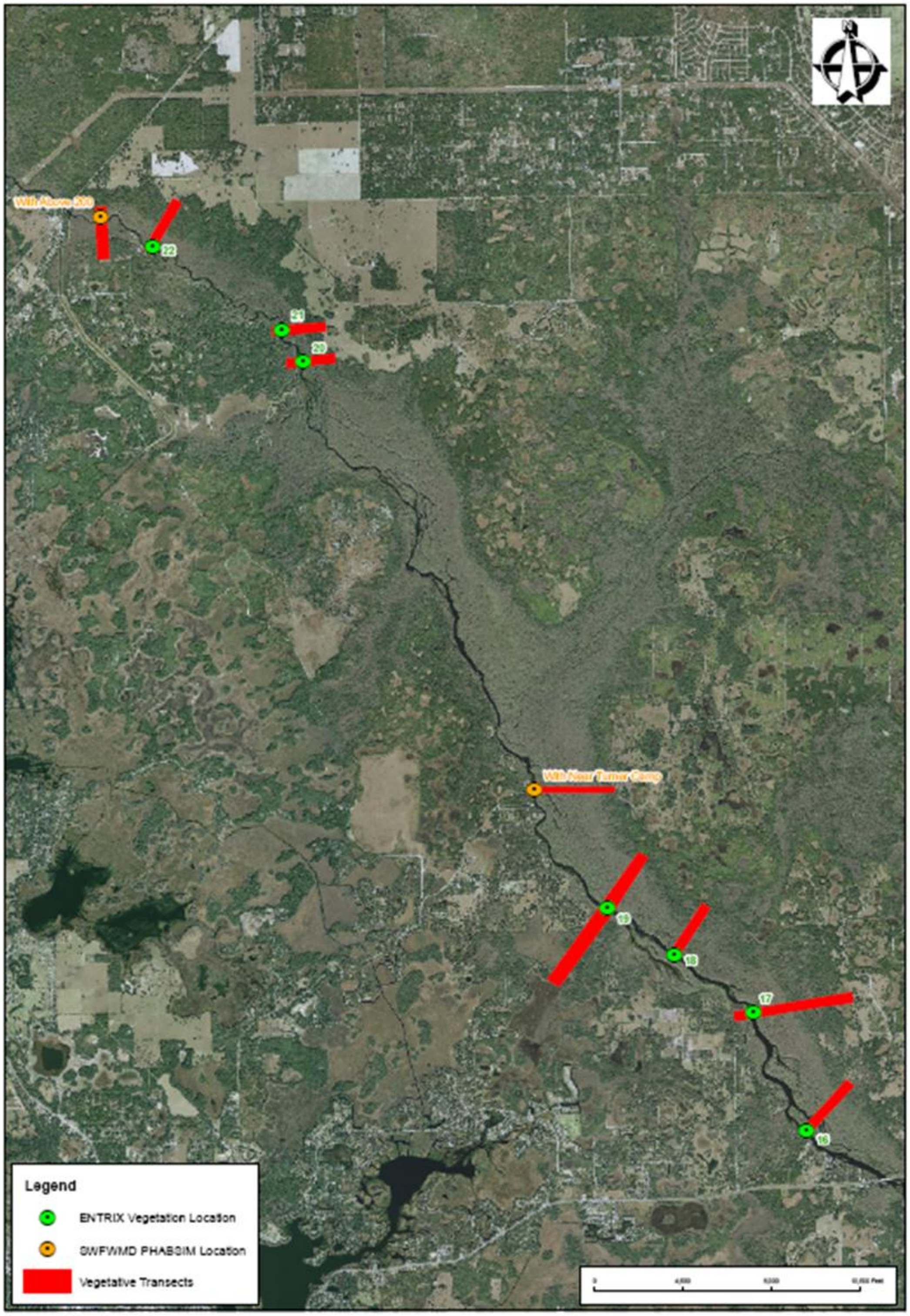

Figure 7-7. Location of vegetation transects and their extent as indicated by the red bars along the Withlacoochee study corridor. This region encompasses the northernmost assemblage of vegetation transects considered near the downstream portion of the watershed. Map produced by Entrix (2010).

7.6 Modeling Approaches

A variety of modeling approaches were used to develop minimum flows and levels for the Withlacoochee River. A HEC-RAS model was 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. Long-term inundation analysis was used to examine inundation durations for specific habitats or floodplain elevations and to also examine changes in inundation patterns that could be expected with changes to the flow regime.

7.6.1 HEC-RAS Modeling

This description of the HEC-RAS modeling for the Withlacoochee River is largely excerpted from the EAS (2009; Appendix HEC-RAS). HEC-RAS is a one-dimensional hydraulic model that can be used to analyze river flows. Version 4. 0 of the HEC-RAS model was released by the U. S. Army Corps of Engineers Hydrologic Engineering Center in March 2008 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).

A HEC-RAS model utilizing available flow records for the USGS Withlacoochee River at Holder, Gum Spring at Holder, Withlacoochee River at Inverness, Withlacoochee River at Rutland, and Withlacoochee River at Wysong Dam, Outlet River at Panasoffkee, Jumper Creek at Wahoo, Withlacoochee River at Floral City, Withlacoochee River at Pineola, Withlacoochee River at Nobleton, Withlacoochee River at Croom, Little Withlacoochee River at Rerdell, Withlacoochee River at Rital, Withlacoochee River at Trilby, and Withlacoochee River at Dade City gages (Figure 7-4) was used to simulate flows at cross-sections within the Withlacoochee River study area. Data required for performing HEC-RAS simulations included geometric data and steady-flow data connectivity data for the river system, reach length, energy loss coefficients due to friction and channel contraction/expansion, stream junction information, and hydraulic structure data, including information for bridges and culverts.

Geometric data used for our analyses consisted of surveyed transects from the SWFWMD survey section, surveyed transects from Jones Edmunds and Associates, and bathymetric data (point data) collected by SWFWMD engineering. Additionally, LiDAR data was available from the District's GIS and Mapping Department for the Withlacoochee River watershed. These data sources and break-lines were use to generate a triangulated irregular network (TIN) which was converted to Digital Elevation Model (DEM) within the main channel. Required steady-flow data was retrieved for the previously mentioned the USGS gages.

Elevation data (in feet above the North American Vertical Datum of 1988) for the 1,026 cross-sections were derived from TIN generated for the Withlacoochee River. LiDAR and break-line elevation data, in feet relative to NAVD88, were obtained from flights in 2003 by using an ALS40 LiDAR system flown at an altitude of 1,500 meters, with a 30-degree field of view. Data acquisition/processing involved a 6-feet post-spacing interval, digital one-foot orthophotographs and 2D breakline features necessary to produce a one-foot elevation contour interval product. Horizontal accuracy was estimated to have a root mean square error of 2. 5 feet and vertical accuracy of the LiDAR data was specified at as a root mean square error of 0. 23 feet in well-identified, unobscured terrain.

As noted by EAS (2010)

> *There are two major challenges in modeling the middle part of the study area in HEC-RAS. The first challenge is to model the flow diverting from the Withlacoochee River to the Tsala Apopka Chain of Lakes. The chain of lakes are currently connected with the Withlacoochee River by two (2) intake canals, one outfall canal, and the associated gates and control structures. Another challenge is to model the Wysong-Coogler Adjustable Water Conservation Structure (Wysong AWCS, a. k. a. Wysong Dam), which was removed in 1988 and rebuilt in 2002. The Wysong AWCS has significantly altered the existing river flow regime, for example, the stage/flow relationship upstream of the dam. USGS With @ Croom is documented to be outside of the backwater impact zone of the Wysong AWCS, and therefore it is appropriate to be used as the downstream boundary for the HEC-RAS modeling of the river segment upstream.*
>
> *To better resolve the complexity due to the Wysong Dam as well as the flow diversion to Tsala Apopka Chain of Lakes, the study area is intentionally divided into three small segments: Lower Segment, Middle Segment, and Upper Segment. The Lower Segment is from USGS With @ Holder to USGS With @ Wysong Dam; Middle Segment is from USGS With @ Wysong Dam to USGS With @ Croom; and Upper Segment is from USGS With @ Croom to USGS With @ Dade City. In the Middle Segment, more*

consideration will be undertaken to simulate the structure operations and to evaluate the flow diversion. The approach of using three segments also takes advantage of three reliable long-term USGS gages (USGS With @ Holder, With @ Wysong Dam, and With @ Croom), which were designated as the downstream boundaries for the segments.

Fifteen gages are used in the HEC-RAS modeling of the Withlacoochee River MFL project. These gages have varying lengths of record (Table 7-1).

Table 7-1. Period of Record for USGS sites on Withlacoochee River.

USGS Site Name	USGS Site Number	POR
Withlacoochee River at Holder	02313000	1928 - current
Gum Springs at Holder	02312764	2003 - current
Withlacoochee River at Inverness	02312762	2001 - current
Withlacoochee River at Rutland	02312722	2005 - current
Withlacoochee River at Wysong Dam	02312719	1984 - current
Outlet River at Panasofkee	02312700	1962 - current
Jumper Creek at Wahoo	02312645	1979 - current
Withlacoochee River at Floral City	02312600	1983 - current
Withlacoochee River at Pineola	02312598	2005 - current
Withlacoochee River at Nobelton	02312558	2004 - current
Withlacoochee River at Croom	02312500	1939 - current
Little Withlacoochee River at Rerdell	02312200	1958 - current
Withlacoochee River at Rital	02312300	2004 - current
Withlacoochee River at Trilby	02312000	1928 - current
Withlacoochee River at Dade City	02311500	1984 - current

The HEC-RAS model was run using 17 steady-flow rates to determine stage vs. flow and wetted perimeter versus flow relationships for each surveyed 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). A thorough discussion of the HEC-RAS model can be found in Appendix HEC-RAS.

7.6.2 Physical Habitat Simulation (PHABSIM) Modeling

In their review of the District's minimum flow methods, Gore et. al (2002) suggested the 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 Withlacoochee River.

PHABSIM analysis requires acquisition of data concerning channel composition, hydraulics, and habitat suitability or preferences for individual species or groups of organisms. 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 collected under a range of flow conditions for model calibration. Habitat suitability criteria are required for each species or group of interest. Criteria may be empirically derived 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 7-8). 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/altered flow records.

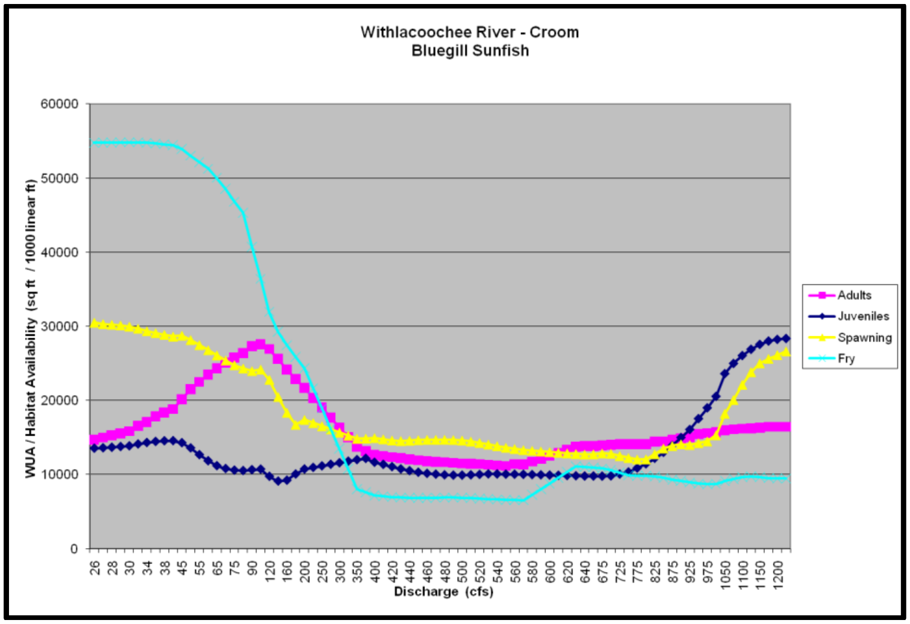

Figure 7-8. Weighted usable area (WUA) versus discharge for three life history stages (fry, juvenile, adult) and spawning activity of Spotted Sunfish at the Croom PHABSIM site in the Withlacoochee River.

PHABSIM analysis does not prescribe an acceptable amount of habitat loss for any given species or assemblage. Rather, given hydrologic data and habitat 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 7-9 shows an example of habitat gain/loss plots, which display changes in WUA (habitat) relative to flow reductions of 10 to 40%.

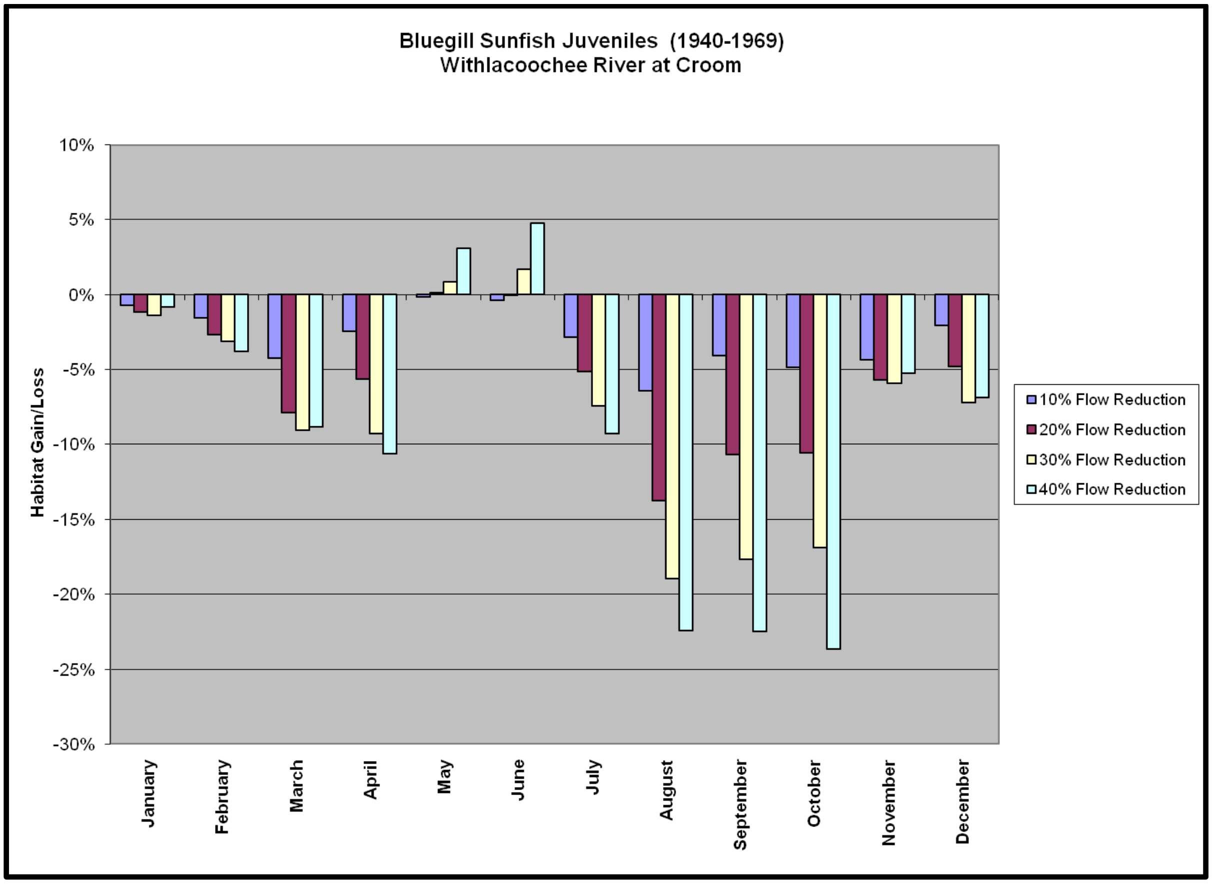

Figure 7-9. Example plot of habitat gain/loss relative to flow reductions of 10, 20, 30, and 40%. Habitat loss is shown for Bluegill Sunfish juveniles at the Croom site in the Withlacoochee River based on historic flow records from 1970 to 1999.

7.6.2.1 Development of Habitat Suitability Curves

Habitat suitability criteria used in the PHABSIM model include continuous variable or univariate curves designed to encompass the expected 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 survey. 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 District, 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 Rainbow 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 developed additional habitat suitability curves for species of interest. Curves have been refined for the spotted sunfish, new curves have been developed for species representative of various fish guilds including shallow-fast (SF) guild and deep slow (DS) guild.

7.6.3 Long-term Inundation Analyses

Long-term inundation 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. For the analyses, spreadsheets and associated plots are developed using measured elevations for habitats or other features (that were converted from a NGVD29 to a NAVD88 standard), HEC-RAS model output and available flow records. The SWFWMD has transitioned away from NGVD29 for the following reasons:

- This datum was created using surveying technologies that were available in the early twentieth century. Its accuracy is limited when compared to the current state of the art in surveying and mapping.
- Nationally, many of the NGVD29 physical benchmarks have been destroyed or have invalid elevations because of ground subsidence, crustal deformation or glacial rebound.
- New surveying technologies such as global position systems (GPS) cannot effectively utilize NGVD29.

For the purpose of developing minimum flows and levels, percent-of-flow reductions that result in greater than a 15% reduction in the number of days of inundation from historic conditions are determined. In addition to identifying these flow reduction thresholds for specific target elevations (e. g. , mean elevations of floodplain vegetation classes), flow reductions are also calculated for flows throughout the natural flow range and results are plotted (e. g. , see Figure 7-10). Inspection of the plots allows identification of percent-of-flow reductions that can be associated with specific ranges of flow. These flow reductions identify potentially acceptable temporal habitat losses and also provide for wetland habitat protection on a spatial basis (Munson and Delfino 2007).

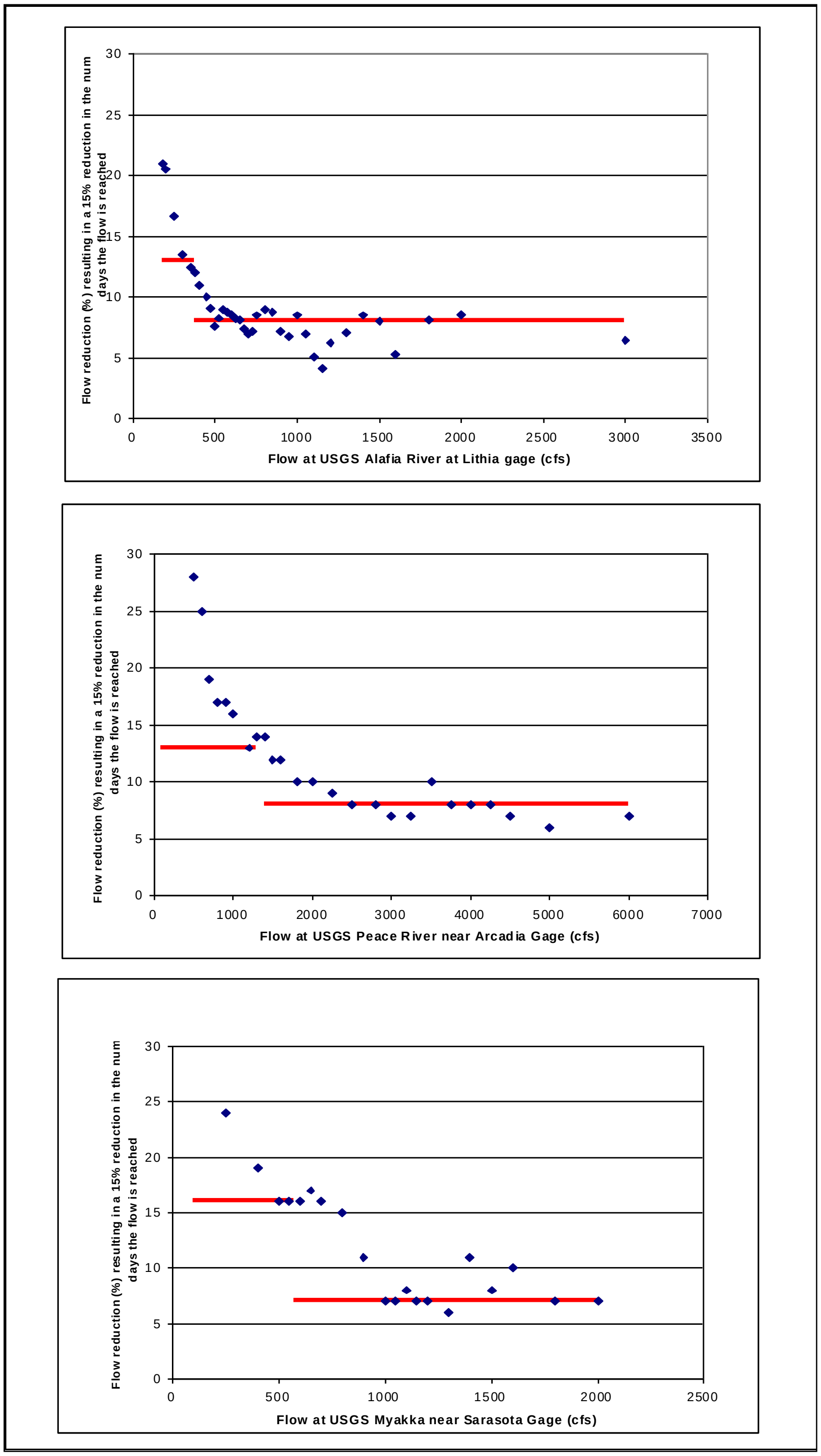

Figure 7-10. Percent-of-flow reductions that result in a 15% reduction in the number of days that flows on the Alafia, middle Peace, and Myakka rivers are reached. Horizontal lines represent the flow reduction standards identified by the District for specific flow ranges in each river. Graphs are adapted from Kelly et al. 2005a, b, and c.

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

For development of minimum flows and levels for the Withlacoochee River, we identified three seasonal blocks corresponding to periods of low, medium, and high flows. Due to the length of the Withlacoochee River and variation in the proportion of baseflow throughout the study reach, blocks vary slightly as you proceed down the river. It was decided to use the blocks developed for the Croom gage for the entire study reach. The block assignments by day of year (DOY) are shown in Table 7-2.

Table 7-2. Block Assignments for the Withlacoochee River.

	Beginning DOY	Ending DOY	Duration
Block 1 (Low)	118	212	95
Block 2 (Med)	302	117	181
Block 3 (High)	213	301	89

7.8 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 criteria 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 low-flow criteria, provided that comparison of that criterion with historic flow records indicates that the criterion 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.

7.8.1 Wetted Perimeter

Output from multiple runs of the HEC-RAS model was used to generate a wetted perimeter versus flow plot for each of the HEC-RAS cross-sections of the Withlacoochee River (see Appendix Wetted Perimeter / Fish Passage). Plots were visually examined for lowest wetted perimeter inflection points (LWPIP), which identify flow ranges that are associated with relatively large changes in wetted perimeter for relatively small increases in flow (e. g. , Figure 7-11). The lowest wetted perimeter inflection point was identified for each cross-section. Higher inflection points were disregarded, since the goal was to identify the lowest wetted perimeter infection point for flows contained within the stream channel. Most cross-section plots displayed no apparent LWPIPs, because they occurred below the lowest modeled flow. For cross-sections that displayed no distinct break or where the majority of the wetted perimeter is inundated below the lowest modeled flow, the LWPIP was established at the lowest modeled flow. The LWPIP flow at each HEC-RAS cross-section was used to develop a wetted perimeter criterion for the Croom, Wysong, and Holder gage sites.

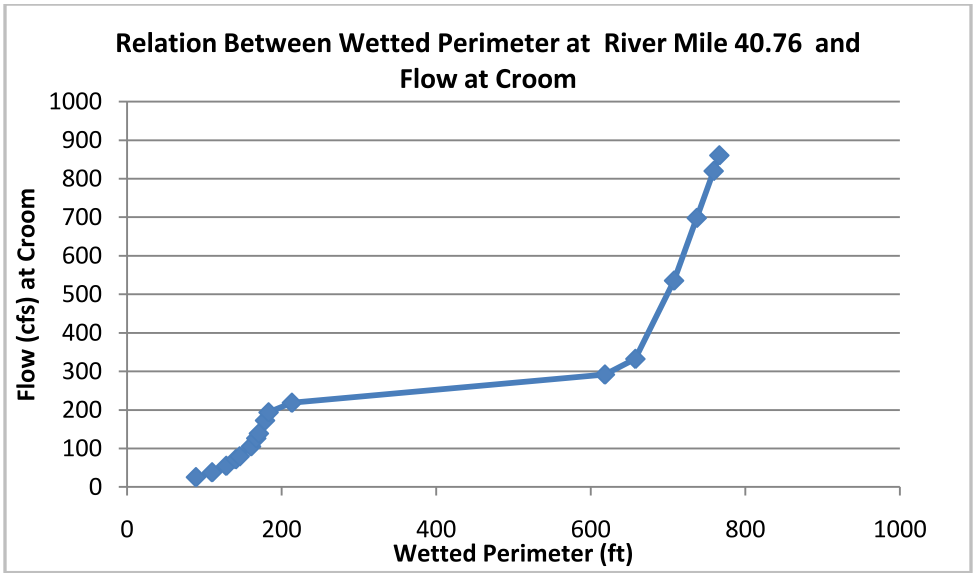

Figure 7-11. Wetted perimeter versus discharge at HEC-RAS station number 40. 76 in the Withlacoochee River. In this example, the LWPIP was below the lowest modeled flow of 15 cfs.

7.8.2 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 Withlacoochee River. The fish-passage criterion is routinely used by the District for development of MFLs and was found to be acceptable by the panel that reviewed the proposed upper Peace River flows (Gore et al. 2002) as well as subsequent peer review panels. 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 foot depth fish-passage criterion to the elevation of the lowest spot in the channel cross-section and determining the flow necessary to achieve the resultant elevations. It should not be surprising that the fish passage criterion was exceeded at most cross-sections since shoals areas are typically the controlling features. The flow necessary to meet fish passage criteria were interpolated from the modeled flows that bracketed the required fish passage depth of 0. 6 feet.

7.9 Prescribed Flow Reduction

When flows exceed the low-flow threshold, there may exist some portion of the flow that can be withdrawn for consumptive use without causing significant harm. To identify these quantities, a variety of criteria are utilized to analyze the loss of various habitats associated with flow reductions over the range of flows historically demonstrated with the river. Some criteria focus on out of bank flow and floodplain habitat connection while others target habitat associated with lower flow conditions.

7.9.1 PHABSIM

PHABSIM was used to evaluate potential changes in habitat associated with variation in instream flows. For the analyses, historic time series data from the Croom, Wysong, and Holder gauge sites were used to model changes in habitat at nine representative sites.

Simulations were conducted for various life-history stages of spotted sunfish, largemouth bass, bluegill, shallow-fast (SF) fish guild, deep-slow (DS) fish guild, and for macroinvertebrate diversity at all nine sites on the Withlacoochee River. Flow reductions that resulted in no more than a 15% reduction in available habitat from historic conditions were determined to be limiting factors. These factors were used to identify acceptable flow reductions for the Croom, Wysong, and Holder gage sites above the low-flow threshold.

7.9.2 Snag and Exposed Root Habitat Analyses

Mean elevations of snag and exposed root habitats were determined for 26 instream habitat cross-section sites. Flows at the cross-section sites and corresponding flows at the Croom, Wysong, and Holder gages that would result in inundation of the mean habitat elevations at each cross-section were determined using the HEC-RAS model. The daily period of record and the warm and cool period long-term flow records were used to determine the number of days that the mean elevations for snag and exposed root habitat were inundated in each block. These flow records were examined to identify percent-of-flow reductions that would result in no more than a 15% reduction in the number of days of inundation from direct river flow. 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 (Munson and Delfino 2007), the peer review panel for the middle Peace River MFLs noted, “that the 15% threshold selected for preventing significant harm is appropriate” (Shaw et al. 2005).

7.9.3 Floodplain Connection Analyses

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. Mertes (1997) notes that groundwater seepage, hyporheic inputs, discharge from local tributaries and precipitation can also lead to floodplain inundation. However, because river channel-floodplain connections are important, can be influenced by water use, and are a function of out-of-bank flows, it is valuable to characterize this connectivity for development of minimum flows and levels.

HEC-RAS model output and daily flow records were used to evaluate floodplain inundation patterns associated with river flows at the 26 floodplain vegetation cross-sections and associated flows at the Croom, Wysong, and Holder gage sites. Since floodplain connection occurs predominately during Block 3 in most years, it was not used as a Block 1 or 2 criteria. Inundation of elevations associated with floodplain features, including vegetation classes 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. These percent-of-flow reductions were considered to be limiting factors and used at Croom, Wysong and Holder sites.

8 Results and Recommended Minimum Flows

8.1 Overview

Results from modeling and field investigations on the Withlacoochee River were assessed to develop minimum flow criteria/standards for ensuring that ecological functions are protected from significant harm. All analyses were performed on three flow records for each corresponding gauge. The flow records were for the warm climatic period (1940-1969), the cool climatic period (1970-1999), and the entire period of record. The overwhelming majority of analyses resulted in more conservative flow reductions for the cool period; therefore, unless otherwise mentioned, the results from the cool period analyses were used for establishment of MFLs.

8.2 Low-Flow Threshold

The low-flow threshold defines flows that are to be protected from surface water withdrawals 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 Withlacoochee River, low-flow thresholds were developed for the Croom, Wysong, and Holder gage sites.

8.2.1 Fish Passage

Flows necessary to maintain a minimum water depth of 0. 6 foot to allow for fish passage at each cross-section in the HEC-RAS model are shown in Figure 8-1 through 8-3. (Data and plots for individual transects are available in the Fish Passage Wetted Perimeter section of the Appendix.) 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.

For the reach between the Wysong-Coogler WCS and the gage at Holder the flow necessary to maintain fish passage was below the lowest modeled flow (150 cfs as measured at the Holder gage). Likewise, the flow at the Wysong gage necessary to maintain fish passage was below the lowest modeled flow (60 cfs as measured at the Wysong gage) for the reach between the gage at Croom and the Wysong-Coogler WCS. For the reach between the Withlacoochee River near Dade City (River Rd.) gage and the gage at Croom the flow at Croom necessary to maintain fish passage was generally below the lowest modeled flow (15 cfs as measured at the Croom gage). The data indicated that flows at

Croom necessary to maintain fish passage were above the lowest modeled flow at nine transects. All of these transects require 30 cfs or less at Croom to maintain fish passage with the exception of one transect requiring 62 cfs at Croom. Because only one transect requires greater than 30 cfs at Croom to maintain fish passage and this flow only occurs 61% of the time historically under Block 1 conditions, a flow of 30 cfs at the Croom gage was used to define the fish passage criterion. A flow of 60 cfs at the Wysong gage, and a flow of 150 cfs at the Holder gage were used to define the fish passage criteria.

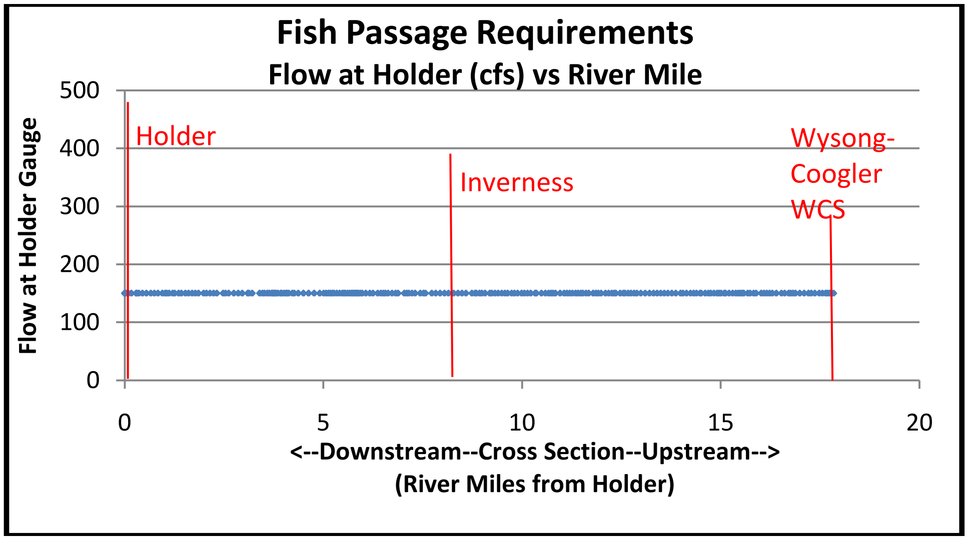

Figure 8-1. Plot of flow required at the Croom gage to inundate the deepest part of the channel at HEC-RAS cross-sections in the Withlacoochee River to a depth of 0. 6 ft. Lowest modeled flow was 150 cfs.

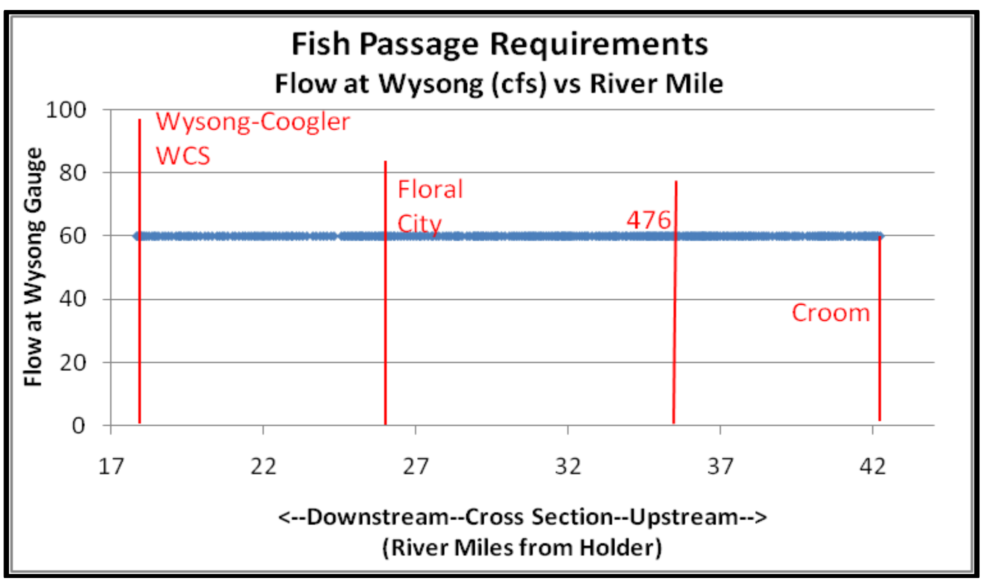

Figure 8-2. Plot of flow required at the Wysong gage to inundate the deepest part of the channel at HEC-RAS cross-sections in the Withlacoochee River to a depth of 0. 6 ft. Lowest modeled flow was 60 cfs.

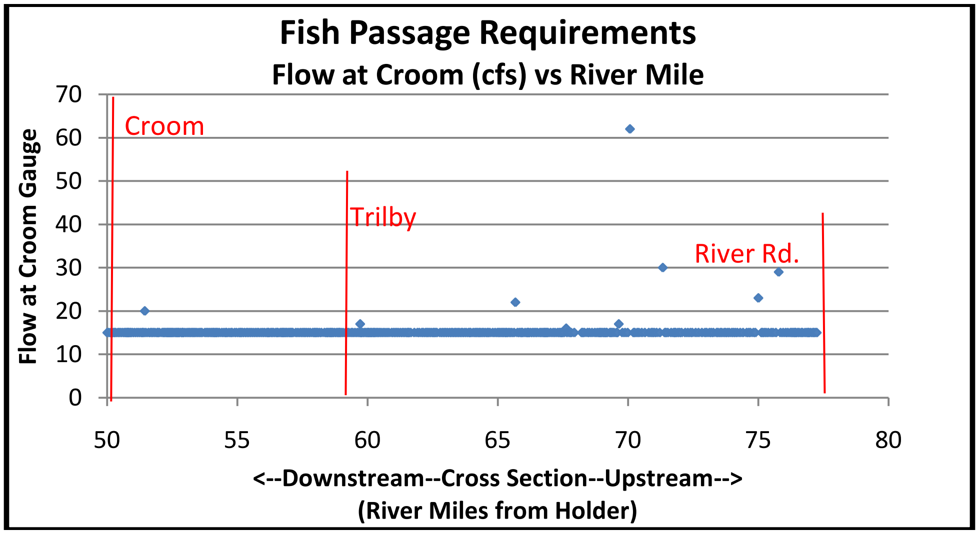

Figure 8-3. Plot of flow required at the Croom gage to inundate the deepest part of the channel at HEC-RAS cross-sections in the Withlacoochee River to a depth of 0. 6 feet. Lowest modeled flow was 15 cfs.

8.2.2 Lowest Wetted Perimeter Inflection Point (LWPIP)

Wetted perimeter plots (wetted perimeter versus flow at the Croom, Wysong and Holder gages) were developed for each HEC-RAS cross-section of the Withlacoochee River (Figures 8-4 through 8-6). From these plots, it was determined that the LWPIP was below the lowest modeled flow for most sites. Inspection of the data indicated that flows equal to or greater than 50 cfs at the Croom gage would be sufficient to meet the LWPIP criterion at all sites between the Dade City and Croom gage sites; however, since only two of the 525 modeled transects had LWPIPs above the lowest modeled flow (15 cfs), it was decided to use the lowest modeled flow as the criteria for the Croom gage.

All LWPIPs were below the lowest modeled flow for the reach between the Croom and Wysong gages (i. e. , 60cfs) and for the reach between the Wysong and Holder gage sites (i. e. , 150 cfs). Therefore, flows of 15 cfs at the Croom**,** 60 cfs at the Wysong, and 150 cfs at the Holder gages were used to define the LWPIP criterion.

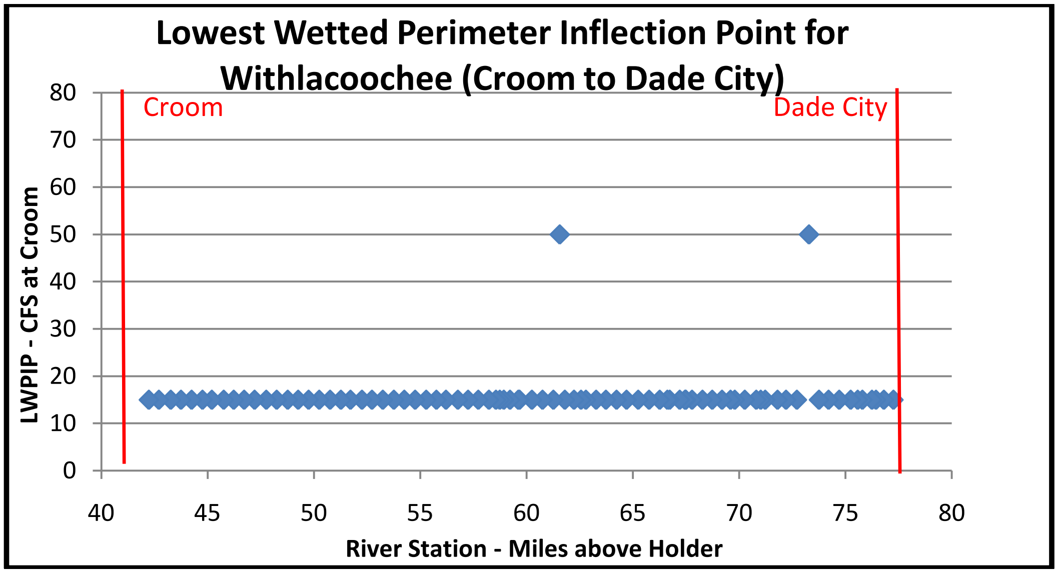

Figure 8-4. Plot of flow at the Croom gage required to inundate the lowest wetted perimeter inflection point at HEC-RAS cross-sections in the Withlacoochee River.

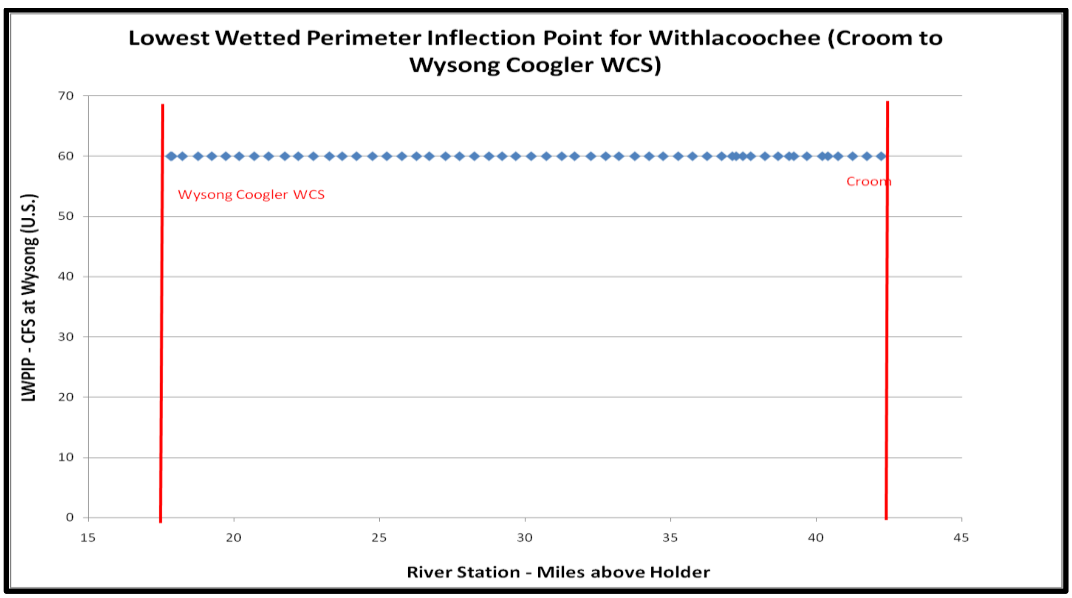

Figure 8-5. Plot of flow at the Wysong gage required to inundate the lowest wetted perimeter inflection point at HEC-RAS cross-sections in the Withlacoochee River.

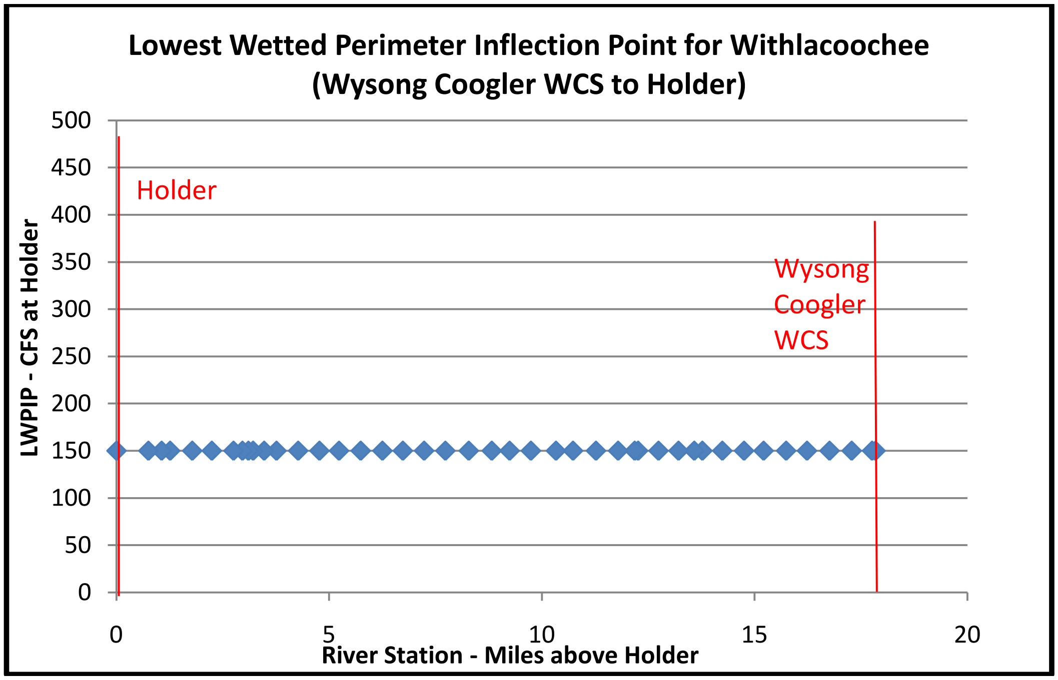

Figure 8-6. Plot of flow at the Holder gage required to inundate the lowest wetted perimeter inflection point at HEC-RAS cross-sections in the Withlacoochee River.

8.2.3 Low-Flow Threshold

The low-flow threshold (LFT) 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. Therefore, LFTs were set at 30, 60, and 150 cfs at the Croom, Wysong, and Holder gages, respectively. Although flows in the river may be expected to drop below the LFT naturally, the threshold is defined to be a flow that serves to limit surface water withdrawals.

8.3 PHABSIM Flow Reduction

Prescribed flow reductions at the Croom, Wysong, and Holder gage sites were developed based on the use of PHABSIM to model potential changes in habitat availability for several fish species, fish guilds, and macroinvertebrate diversity at nine representative sites.

8.3.1 PHABSIM Results

Physical Habitat Simulation analyses were conducted for nine representative sites on the Withlacoochee River. The PHABSIM sites were routinely co-located with vegetative cross-sections as shown in Figure 7-4.

Each PHABSIM site uses the closest USGS gage for its corresponding flow record. Cool (dry) climatic period (1970-1999) and warm (wet) climatic period (1939-1969) time-series were run for each site. The TSLIB (time-series library) from the USGS Mid-Continent Research Laboratories was used to conduct the analysis.

Monthly discharge files were created for existing conditions, 10% monthly flow reductions, 20% monthly flow reductions, 30% monthly flow reductions, and 40% monthly flow reductions. For each set of discharge conditions, a monthly time-series was created as the amount of habitat (WUA) available for each discharge for each month. The simulated flow ranges did not encompass all low flows in the historical records available, in some instances, and did not encompass a few of the highest flows. An appropriate regression (usually first- or second-order polynomial or piece-wise linear regression) was used during time-series analysis to create WUA values for the very low and high flows. Since these flow values occurred less than 5% of the time in the historical record, they are unlikely to affect the overall estimate of MFL's at a 15% habitat loss. Duration analysis was then accomplished through the percentage of time that the average and median habitat values were met or exceeded for each month over the period of record. Comparisons to existing conditions were made to evaluate the amount of habitat gain or loss under conditions of reduced flow.

The percent allowable reduction that would result in no more than a 15% loss of available habitat for each life stage, species, or guild was calculated for each site. Spotted Sunfish were generally the most restrictive species. To calculate the withdrawal limitation, an average was taken of the most restrictive of the percent allowable reductions from each transect for the associated gage (Table 8-1). This calculation was made for each block.

The resulting allowable percent reductions for the Croom gage were 11 and 17 percent for Blocks 1 and 2, respectively. Fifteen and 19 percent were the allowable percent reductions for Blocks 1 and 2, respectively for the Wysong gage. Holder percent allowable reduction calculations resulted in a 13 and 15 percent reduction for Blocks 1 and 2, respectively.

Table 8-1. PHABSIM percent flow reduction calculations.

	Corresponding Gauge	Block 1	Decription	Block 2	Decription
	Croom	18	Spot Sun/Adult	19	Spot Sun/Juv
	Croom	10	Spot Sun/Juv	15	Spot Sun/Juv
	Croom	7	Spot Sun/Adult	14	Spot Sun/Adult
	Croom	14	Spot Sun/Adult	21	Spot Sun/Adult
	Croom	8	Spot Sun/Adult	16	Spot Sun/Adult
Average		**11**		**17**	
	Corresponding Gauge	Block 1	Decription	Block 2	Decription
	Wysong	15	Spot Sun/Adult	23	Spot Sun/Fry
	Wysong	18	Spot Sun/Spawn	20	Spot Sun/Juv
	Wysong	12	Spot Sun/Adult	15	Spot Sun/Adult
Average		**15**		**19**	
	Corresponding Gauge	Block 1	Decription	Block 2	Decription
	Holder	13	SF Fish/Guild	15	SF Fish/Guild
Average		**13**		**15**	

8.4 Inundation/Connection of Floodplain Features

Although it is generally appreciated that the river-floodplain connection is important to riverine ecology (see Section 7. 9. 3), few environmental flows have been based on a quantitative assessment of this feature. However, we assessed a number of factors to develop allowable flow reductions that we felt would be protective of this connection. 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 indication of potential changes in inundation patterns for floodplain features, including those that were not identified.

8.4.1 Inundation of Floodplain Geomorphological Features.

The 100-year floodplain along the Withlacoochee River corridor consisted of cross-sections ranging from 212 to 4199 ft in length (Table 8-2). The distribution of vegetation transects in the Withlacoochee River appears to be grouped into three general clusters. The southernmost group (Withlacoochee near River Road through Withlacoochee at Trilby), near the headwaters has an elevation range of 68. 3 to 47. 8 feet NAVD88, taken from the bottom of the river channel. Along the floodplain transects in this group, the elevation varied from 75. 1 to 53. 8 feet NAVD88. The middle group of transects (Withlacoochee at Croom through Withlacoochee above 476) has an elevation range from 35. 8 to 34. 4 feet NAVD88. Elevations along transects at the mid-reaches of the river ranged from

48. 4 to 38. 1 feet NAVD88. Finally, the northernmost group (Transect 16 through Withlacoochee above 200), located downstream, has an elevation range in the channel from 28. 6 to 24. 9 feet NAVD88. In this region, the elevation among the transects ranged from 39. 9 to 29. 9 feet NAVD88.

Table 8-2. **Elevations and lengths of floodplain vegetation/soils cross-sections (transects) along the Withlacoochee River. N is the number of elevation measurements made along each transect.**

	Transect	Transect Distance (feet)	Transect Maximum Elevation (NAVD88)	Transect Minimum Elevation (NAVD88)	Channel Minimum Elevation (NAVD88)	Maximum Elevation Change	Top of Bank Elevation (NAVD 88)		N
							West Bank	East Bank	
Upstream	**Near River Road**	212	75.1	71.1	68.3	6.8	72.8	73.9	40
	1	499	72.9	66.1	60.7	12.2	71.6	73.4	49
	2	1127	74.2	68.2	60.0	14.2	74.0	74.6	67
	3	1876	71.5	67.4	64.4	7.1	68.0	69.0	65
	4	413	70.0	66.3	59.8	10.2	65.5	69.0	54
	5	808	70.1	65.4	59.7	10.4		65.6	65
	6	2077	70.1	64.5	58.5	11.6	68.5	70.0	81
	7	1737	64.7	60.5	52.6	12.1	60.6	63.7	45
	8	1537	64.4	55.1	50.4	14.0	59.7	60.3	67
	Trilby	313	58.6	53.8	47.8	10.8	56.4		27
	Croom	639	48.4	42.2	35.8	12.6	48.4		47
	9	1239	46.9	39.5	32.6	14.3	44.6	46.0	79
	10	1531	46.7	39.6	35.4	11.3	45.7	46.0	82
	11	1330	46.8	39.6	32.2	14.6	41.6	42.6	60
	12	1061	47.1	38.8	33.2	13.9	43.6	44.8	79
	13	533	45.4	37.4	30.5	14.9	40.9		73
	Above 476	684	49.6	38.1	34.4	15.2	40.0	44.1	91
	16	2500	39.9	29.0	28.6	11.3		35.5	92
	17	4199	47.0	32.4	24.9	22.1	34.3	36.3	123
	18	2455	43.0	33.6	28.0	15.0		35.0	87
	19	4173	40.8	33.2	28.1	12.7	34.3	36.4	87
	Turner Camp	3358	38.9	28.3	28.1	10.8		34.4	73
	20	2037	36.9	32.2	23.9	13.0	32.6	33.1	56
	21	1643	38.0	31.6	18.8	19.2	32.9	33.1	50
	22	1406	36.9	29.1	24.0	12.9	32.6	32.9	57
Downstream	**Above 200**	2092	34.9	29.9	24.9	10.0	31.6	31.8	51

Floodplain profiles and vegetation communities occurring along the transects, as shown for Transect 11 in Figure 8-7, were developed for all twenty-six floodplain vegetation/soils cross-sections (see Appendix Vegetation Report). These figures summarize the general location of the various vegetation communities found in each transect. Horizontal lines also denote the mean elevation of other features such as hydrologic indicators (lichen lines and/or saw palmetto edge denoting the upper extent of the floodplain).

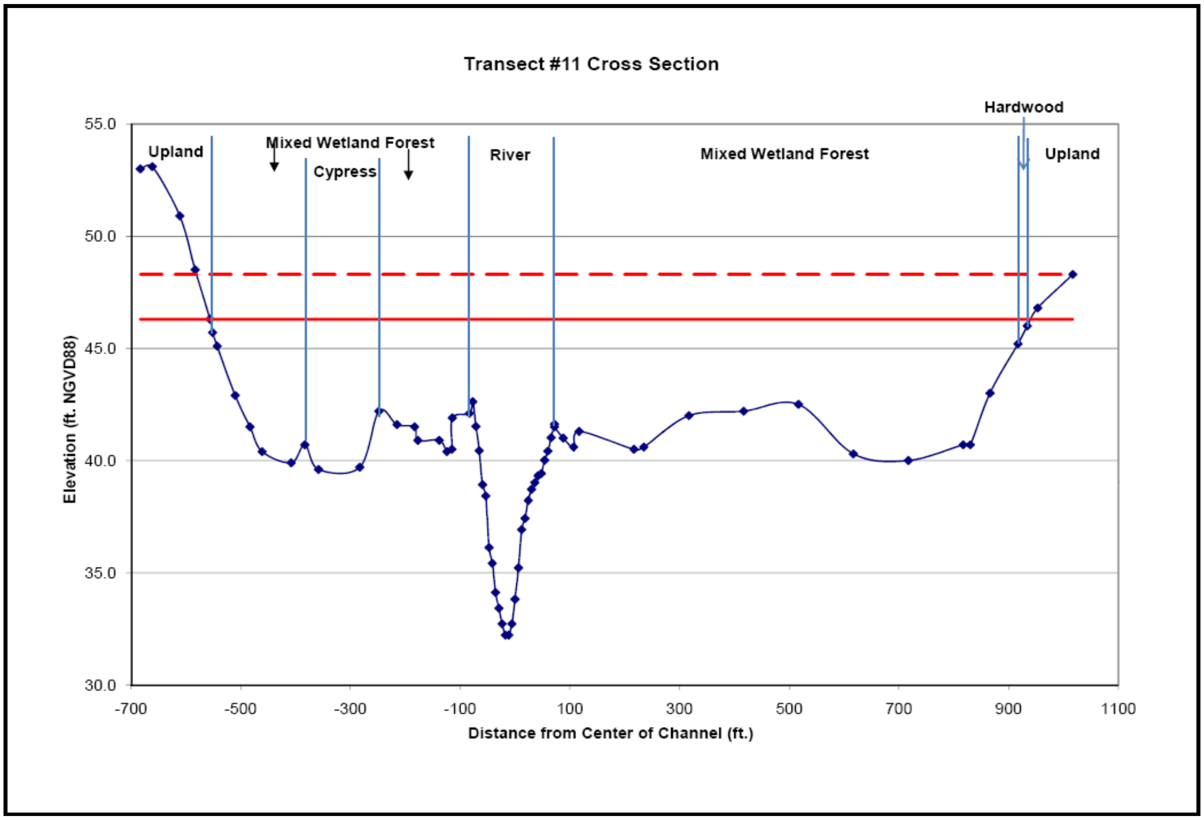

Figure 8-7. Elevation (feet in NAVD88) profile for floodplain vegetation/soils cross-section Transect 11. Distances (cumulative length) are shown centered on the middle of the river channel. Solid red line represents the saw palmetto elevation denoting the upper extent of the floodplain. Dashed red line represents the seasonal high lichen line hydrologic indicator.

Local (cross-section site) flows needed to overflow at least one of the river's banks were calculated using HEC-RAS and tied to one of three potential USGS gages found within the study area (Tables 8-5 through 8-7). Flows needed to inundate one side or both sides of the floodplain by breaching the top of bank varied considerably between sites. Overall, more flow is required to inundate both sides of the floodplain as seen for the other gages (Wysong and Holder) where localized flows need to exceed the elevation of the top of bank.

Floodplain wetted perimeter plots (patterned after the wetted perimeter plots used for identification of the lowest wetted perimeter inflection point) were developed for each floodplain vegetation cross-section (see Appendix Vegetation Report). The plots were developed to show the linear extent of inundated floodplain (wetted perimeter) associated with measured floodplain elevations, including the mean elevations of the floodplain vegetation communities and some hydrologic indicators. For example, Figure 8-8 shows a floodplain wetted perimeter plot for floodplain vegetation Transect 11. Based on the plot, approximately 320-340 linear feet of floodplain bottom would be inundated when the river is staged at the mean elevation of the cypress swamp and mixed wetland forest vegetation community. This is in contrast to around 1,700 linear feet of floodplain that would be inundated at the mean elevation of the hardwood swamp community.

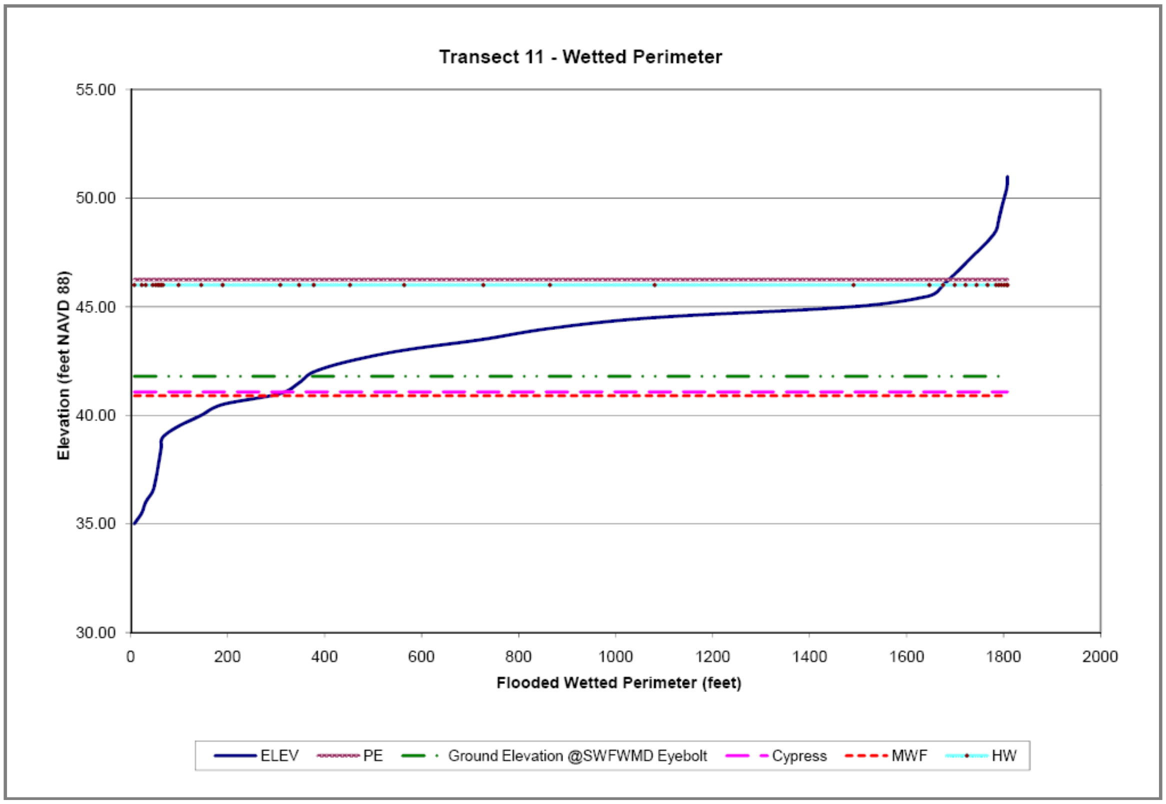

Figure 8-8. **Floodplain wetted perimeter versus elevation at a sample floodplain vegetation/soils cross-section (Transect 11). Horizontal lines indicate mean elevations of three floodplain vegetation communities, palmetto edge and edge of water observed at the site.**

Subsequently, local flows, necessary to inundate the first and second major slope changes in wetted perimeter beyond the top of bank at each transect were evaluated using the HEC-RAS model (see Table 8-5 through Table 8-7). For example, a mean flow range of 460-900 cfs would be necessary at the Wysong gage to inundate the lowest major inflection point associated with maximizing floodplain inundation levels for the minimum amount of river flow. If higher flows were to occur and inundate the next major breakpoint in its floodplain wetted perimeter, then a flow range of 1,300-1,500 cfs would be required at the Wysong gage. Overall, a flow range of 140-450 cfs is required at all gaging stations to attain the narrowest floodplain wetted perimeter. However, flows up to as much as 2,500 cfs are needed to yield the widest floodplain wetted perimeter as shown by the Holder gage modeled flows (Table 8-7).

8.4.2 Inundation of Floodplain Vegetation Classes, Soils and Hydrologic Indicators

8.4.2.1 Vegetation Classes

Three vegetation community types were characterized as wetland classes along the Withlacoochee River study corridor according to Entrix (2010). These major communities are described below:

- The Cypress Swamp - is typically located closest to the river and is labeled as a Palustrine, Forested, Needle-leaved Deciduous, Semi-permanently Flooded Wetland per Cowardin et al. (1979). This plant community is dominated by bald cypress, pop ash, red maple, blackgum, American elm, and laurel oak, in descending order of relative abundance. While bald cypress alone accounts for 80% of the relative basal area within this community type, it only accounts for 38% of the relative abundance. This indicates that the individual cypress trees tend to be fewer of larger sizes, especially when compared to pop ash and red maple. Both pop ash and red maple are less represented via basal area compared to relative abundance, which indicates a prevalence of younger (smaller) trees.
- The Hardwood Swamp - is typically the most landward of the forested wetland plant communities identified within the project area. This community is labeled as a Palustrine, Forested, Broad-leaved Deciduous/Broad-leaved Evergreen, Seasonally Flooded Wetland per Cowardin et al. (1979). This community type is dominated by ironwood, laurel oak, sweetgum, and American elm in descending order of relative abundance. Laurel oak accounts for 34% of the relative basal area for this community type, but only 21% of the relative abundance. Ironwood contains the most number of individuals (n=33) and accounts for almost 22% of the relative abundance, but is only 2% of the relative basal area. Thus, while ironwood is prevalent in the canopy, it is primarily younger (smaller) trees. American elm and sweetgum also provide a low basal area in relation to their relative abundance across this community, indicating younger and smaller trees on average, though these trees occur less frequently than ironwood. In contrast, live oak and sabal palm, and water hickory to a lesser extent, account for more basal area than simple number of individuals alone, indicating the prevalence of larger individuals.
- The Mixed Wetland Forest - is transitional in character between the Cypress and Hardwood Swamps within the project area and is labeled as a Palustrine Forested, Needle-leaved Deciduous/Broad-leaved Evergreen, Seasonally Flooded Wetland per Cowardin et al. (1979). This community type is dominated by bald cypress, laurel oak and sweetgum, in descending order of relative abundance. Sweetgum consistently ranks lower by relative basal area than by relative abundance indicating the prevalence of smaller (younger) trees. Pop ash, red maple and American elm are consistent with

sweetgum in typical size class. Cypress and laurel oak consistently have a larger relative basal area versus relative abundance, indicating the prevalence of larger trees.

Of the 26 total transects, 12 were dominated by Cypress and 11 by Mixed Wetland Forest. The remaining three were either evenly split between Cypress and Mixed Wetland Forest (T#9) or between Cypress, Mixed Wetland Forest, and Hardwood Swamp (T#10 and 19). A breakdown of community types by transect is shown in Table 8-3.

Table 8-3. Community distribution by transect for dominant wetland communities observed in the Withlacoochee River floodplain (highlighted in bold for each transect).

Transect IDs	Total Length	Cypress Swamp	Mixed Wetland Forest	Hardwood Swamp
Sampling Points		**125.0**	**157.0**	**41.0**
Transects		**19.0**	**24.0**	**14.0**
With Near River Road	212		**100.00%**	
1	499		**100.00%**	
2	1127	43.84%	**56.16%**	
3	1876	**88.63%**	11.37%	
4	413		**100.00%**	
5	808	45.25%	**49.77%**	4.98%
6	2077	18.46%	**81.54%**	
7	1737		**69.60%**	30.40%
8	1537	**67.05%**		32.95%
With at Trilby	313		**54.97%**	45.03%
Croom	639	38.87%	**52.92%**	8.21%
9	1239	50.23%	49.77%	
10	1531	33.09%	33.09%	33.82%
11	1330		**98.25%**	1.75%
12	1061	**43.49%**	40.05%	16.46%
13	533	**86.44%**		13.56%
WithAbove476	684	**76.71%**	23.29%	
16	2500		**100.00%**	
17	4199	**88.30%**	10.82%	0.88%
18	2455	**80.26%**	19.74%	
19	4173	39.33%	33.08%	27.59%
WithNearTurnerCamp	3358	**84.49%**	11.00%	4.51%
20	2037	**44.97%**	28.75%	26.29%
21	1643	**93.73%**	6.27%	
22	1406	**63.61%**	36.39%	
WithAbove200	2092	**49.68%**	34.89%	15.43%

8.4.2.2 Soils

Soils closer to the river banks tended to be finer materials than soils farther from the river banks, where coarser sandy material typically dominated the surface horizons. The most prominent hydric soil indicator was Muck Presence (A8), followed by 5 cm Mucky Mineral (A7), and Dark Surface (S7). Other hydric soil indicators identified at least once along the transects include Redox Dark Surface (F6), Depleted Matrix (F3), Thin Dark Surface (S9), Sandy Redox (S5), Stripped Matrix (S6), and Organic Bodies (A6). Cypress Swamp soils were entirely hydric, with muck presence accounting for 74% of the soils (Figure 8-9). Mixed Wetland Forest was 80% hydric soils with approximately 40% containing muck. The Hardwood Swamp was only 40% hydric soils, with only 20% of those hydric soil pits containing muck. The Upland Forest had entirely non-hydric soils, consistent with what was expected for this habitat. Mean elevations of hydric soils were significantly lower than non-hydric soils, with mucky soils occurring at significantly lower elevations than non-mucky hydric soils (P<0. 01).

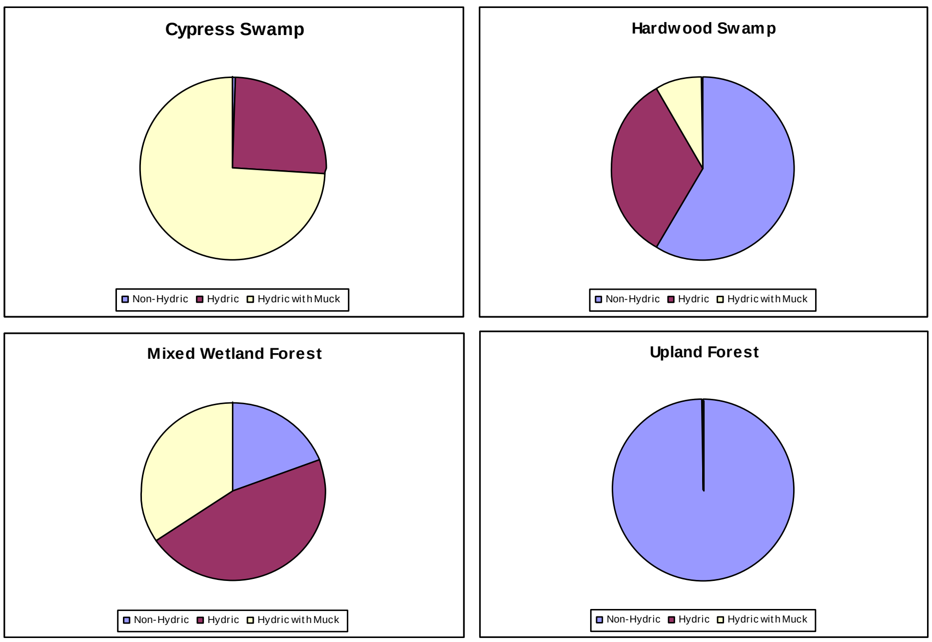

Figure 8-9. Frequency of hydric, hydric with muck and non-hydric soil indicators by community type found in the Withlacoochee River floodplain.

8.4.2.3 Hydrologic Indicators

Hydrologic indicators were evaluated within the riverine floodplain to determine how these indicators compared with other vegetative and elevation data. Elevations were determined for palmetto edge lines, moss collars and lichen lines, where present. Lichen lines were typically several feet higher than the wetland edge elevations indicating substantial difference between historical and present inundation conditions. Lichen lines across all transects were very precise, typically within 1-2 tenths of a foot along each transect, though they were not consistent with the wetland edge elevations. The difference between the jurisdictional wetland limits and the lichen lines ranged from 3. 4 feet below the wetland limits to 6. 3 feet above the wetland limits. Other indicators such as adventitious rooting were noticeably lacking.

Table 8-4 summarizes the ecological data in terms of mean elevation summary of major vegetation classes (cypress swamp, hardwood swamp, and mixed wetland forest), wetland soil types (hydric and mucky soils) and general hydrologic indicators (lichen line and saw palmetto line) encountered in the Withlacoochee River floodplain. These floodplain features and their associated elevations are sorted for each transect sampled and also includes sample size considerations in obtaining the mean elevation data.

Table 8-4. Mean elevations (feet NAVD88, shaded cells) and sample size (N, unshaded cells) of major vegetation communities, hydric and mucky soils and hydrologic indicators by transect along the Withlacoochee River study corridor.

Transect	Cypress Swamp Elevation (ft NAVD88)	Number of Cypress Swamp Points	Mixed Wetland Forest Elevation (ft NAVD88)	Number of MWF Points	Hardwood Swamp Elevation (ft NAVD88)	Number of HW points	Saw Palmetto Elevations (ft NAVD88)		Lichen Line Elevation (ft NAVD88)	N (Lichen lines)	Hydric Soils Elevation (ft NAVD88)	N (hydric)	Mucky Soils Elevation (ft NAVD88)	N (muck)
							WEST BANK	EAST BANK						
Withlacoochee Near River Road			71.67	3				72.6	76.2	3	71.40	1		
1			71.41	8			72.7	72.9	75.2	9	70.90	3		
2	70.3	2	71.62	12			72.6	73.1	74.6	6	72.50	1	70.8	3
3	67.8	5	68.83	3			71.5	72.5	73.6	6	70.20	1	68.9	2
4			67.98	5	69	2	69.6	69.9	71.5	6	67.50	3	66.3	1
5	65.9	3	67.22	11	69.1	1	69.9	70.1	72.3	4	67.50	1	65.8	3
6	66.2	6	68.28	14			68.8	68.1	72.0	4	67.40	4	66.8	3
7			61.34	12	62.8	5	63.8	64.7	67.5	5	61.70	2	61.7	1
8	56.9	9			61.58	5	64.1	64.4	67.2	5	58.90	4	56.6	1
Withlacoochee at Trilby	65.4	2	54.3	1	58.1	1		58.6	64.9	3	55.70	4		
Croom	43.2	2	45.83	3	46.9	1		47.2	49.5	3	44.60	5		
9	43.1	4	45.13	3			47.6	46.3	49.5	8	44.40	7	41.3	5
10	42.6	3	42.5	7	45.3	5	46.7	46.0	49.0	7	43.80	8	40.3	2
11	41.3	4	40.96	9	46	1	45.7	46.8	48.3	7	42.20	3	40.5	3
12	41.6	6	43.35	2	45.13	3	45.5	47.1	47.8	7	42.90	10	40.6	2
13	40.0	4			44.2	1	45.4		47.1	3	41.30	3	39.6	1
Withlacoochee Above 476	39.2	1	42.78	4	45.18	4	44.1	43.7	46.7	5	42.10	4	39.2	1
16			35.26	14				39.4	40.3	2	37.80	3	34.9	13
17	34.7	14	40.03	4				39.1	40.3	3	37.70	9	34.3	12
18	35.8	10	37.8	3	38.7	2		38.0	40.2	2	38.30	1	36.1	16
19	35.3	13	35.51	8	33.77	3	37.7	40.8	36.9	4	35.10	3	35.2	19
Withlacoochee Near Turner Camp	34.1	15	36.7	1	37.3	2		38.9	39.8	2	37.40	5	34.3	15
20	33.0	6	35	6	35.55	2	36.0	36.9	38.8	4	34.90	6	33.4	5
21	32.4	9					33.6	38.0	38.9	4	34.40	1	32.4	8
22	31.3	7	33.7	1	33.8	1	36.9	36.1	38.3	3	33.80	3	31.5	9
Withlacoochee Above200	30.7	5	32.37	3	33.75	2	34.9	34.2	37.9	2	32.70	4	32.6	7

Modeled flows at the various USGS gages along the Withlacoochee River, specifically Croom, Wysong and Holder gages, were utilized to predict the needed flows to inundate the mean elevations of floodplain vegetation classes, wetland soils, and hydrologic indicators (Table 8-5 through 8-7). It was important to assign the various transects to the nearest downstream USGS gage because this provided a better estimate of the amount of flow to inundate the floodplain feature. Consequently, estimates of percent-of-flow reductions associated with up to 15% reduction in the number of days sufficient to inundate the specific floodplain feature would be more representative since these gages were more localized.

Among the vegetation zones, range in percent-of-flow reduction varied typically from 5-29% among all the transects seen for all the gages used. However, a narrower range, 7-12%, was seen for the hardwood swamp vegetation community modeled by the Croom gage. Some parameters that were consistently located above the 1% exceedance level included the mean elevation of the palmetto edge and the lichen line hydrologic indicator modeled from the Wysong gage.

For hydric and mucky soil elevations in the area modeled from the Wysong gage, a narrower and smaller flow range requirement was seen (188-460 cfs for mucky soils and 650-1,250 cfs for hydric soils) compared for those same floodplain features modeled at the Croom and Holder gages. This is equivalent to about 10-36 percent-of-flow reductions to affect up to a 15% reduction in the number of days needed to inundate these soil types.

Table 8-5. **Flow range at the Withlacoochee River near Croom gage required for inundation of floodplain features (mean elevation of vegetation classes, wetland (muck and hydric) soils, and selected geomorphological features) at 11 of 26 floodplain vegetation/soils transects. Percent-of-flow reductions associated with up to a 15% reduction in the number of days of flow sufficient to inundate the mean feature elevations are also listed.**

Floodplain Feature	Number of Floodplain Transects Containing Feature and Number of Floodplain Transects Containing Feature that Exceeded Modeled Flow Range (n)	Mean Elevation Range among Floodplain Transects Containing Feature (in feet NAVD88)	Corresponding Guage	Flow Range Required for Inundation (cfs)	Range of Percent of Flow Reduction
Mean Elevation of Cypress Vegetation Zone	6	43.7 - 72.1	Croom	220 - 1350	12 - 29
Mean Elevation of Hardwood Swamp Vegetation Zone	5 (1)	47.5 - 69.5	Croom	800 - 1350	7- 12
Mean Elevation of Mixed Wetland Forest Vegetation Zone	10	45.8 - 72.4	Croom	220 - 1500	5 - 29
Mean Elevation of Palmetto Edge	11 (6)	47.2 - 72.9	Croom	1000 - 1500	5 - 12
Mean Elevation of Lichen Line	11 (9)	49.5 - 76.2	Croom	1000 - 1500	5 - 9
Mean Elevation of Hydric Soils	11	44.6 - 72.5	Croom	500 - 1500	8 - 14
Mean Elevation of Muck Soils	8	56.6 - 70.8	Croom	140 - 800	8 - 29
First major low inflection point on wetted perimeter	11(1)	55 - 72.6	Croom	140 - 1000	5 - 29
First major high inflection point on wetted perimeter	11(3)	57 - 73	Croom	300 - 1900	4 - 25
Lowest Elevation to Inundate One Side of Floodplain	11 (2)	48.4 - 74	Croom	50 - 1100	5 - 55
Lowest Elevation to Inundate Both Sides of Floodplain	8 (4)	60.3 - 74.6	Croom	400 - 1500	5 - 17

Table 8-6. **Flow range at the Withlacoochee River near Wysong gage required for inundation of floodplain features (mean elevation of vegetation classes, wetland (muck and hydric) soils and selected geomorphological features) at 6 of 26 floodplain vegetation/soils transects. Percent-of-flow reductions associated with up to a 15% reduction in the number of days of flow sufficient to inundate the mean feature elevations are also listed. AMF refers to above modeled flow.**

Floodplain Feature	Number of Floodplain Transects Containing Feature and Number of Floodplain Transects Containing Feature that Exceeded Modeled Flow Range (n)	Mean Elevation Range among Floodplain Transects Containing Feature (in feet NAVD88)	Corresponding Guage	Flow Range Required for Inundation (cfs)	Range of Percent of Flow Reduction
Mean Elevation of Cypress Vegetation Zone	6	39.9 - 43.6	Wysong	300 - 900	10 - 26
Mean Elevation of Hardwood Swamp Vegetation Zone	4 (4)	43.6 - 45.6	Wysong	AMF	N/A
Mean Elevation of Mixed Wetland Forest Vegetation Zone	5 (1)	41.2 - 45.7	Wysong	510 - 1500	7 - 19
Mean Elevation of Palmetto Edge	6 (6)	43.9 - 47	Wysong	AMF	N/A
Mean Elevation of Lichen Line	6 (6)	46.7 - 49.5	Wysong	AMF	N/A
Mean Elevation of Hydric Soils	6	41.3 - 44.4	Wysong	650 - 1250	10 - 14
Mean Elevation of Muck Soils	5	39.2 - 40.6	Wysong	188 - 460	16 - 36
First major low inflection point on wetted perimeter	6 (1)	39.5 - 44.5	Wysong	460 - 900	14 - 19
First major high inflection point on wetted perimeter	6 (4)	43 - 48.5	Wysong	1300 - 1500	7 - 8
Lowest Elevation to Inundate One Side of Floodplain	6 (1)	40 - 45.7	Wysong	460 - 1500	6 - 19
Lowest Elevation to Inundate Both Sides of Floodplain	5 (4)	42.6 - 46	Wysong	750	11

Table 8-7. **Flow range at the Withlacoochee River near Holder gage required for inundation of floodplain features (mean elevation of vegetation classes, wetland (muck and hydric) soils and selected geomorphological features) at 8 of 26 floodplain vegetation/soils transects. Percent-of-flow reductions associated with up to a 15% reduction in the number of days of flow sufficient to inundate the mean feature elevations are also listed.**

Floodplain Feature	Number of Floodplain Transects Containing Feature and Number of Floodplain Transects Containing Feature that Exceeded Modeled Flow Range (n)	Mean Elevation Range among Floodplain Transects Containing Feature (in feet NAVD88)	Corresponding Guage	Flow Range Required for Inundation (cfs)	Range of Percent of Flow Reduction
Mean Elevation of Cypress Vegetation Zone	7	31.3 - 35	Holder	450 - 1250	8 - 21
Mean Elevation of Hardwood Swamp Vegetation Zone	6	33.7 - 38	Holder	450 - 3000	5 - 21
Mean Elevation of Mixed Wetland Forest Vegetation Zone	7 (1)	32.4 - 41.5	Holder	700 - 2500	6 - 13
Mean Elevation of Palmetto Edge	8 (5)	33.7 - 39.4	Holder	1400 - 4500	5 - 6
Mean Elevation of Lichen Line	8 (6)	36.9 - 40.3	Holder	2120 - 5000	7
Mean Elevation of Hydric Soils	8 (2)	32.7 - 37.8	Holder	850 - 2500	7 - 15
Mean Elevation of Muck Soils	8	31.5 - 35.2	Holder	450 - 2000	8 - 21
First major low inflection point on wetted perimeter	8	32 - 36	Holder	450 -2120	7 - 21
First major high inflection point on wetted perimeter	8 (1)	33 - 37	Holder	1100 - 2500	6 - 9
Lowest Elevation to Inundate One Side of Floodplain	8	31.6 - 35.5	Holder	450 - 1650	6 -21
Lowest Elevation to Inundate Both Sides of Floodplain	6	31.8 - 36.4	Holder	1100 - 1800	6 - 11

8.4.3 Development of Percent-of-Flow Reductions for Floodplain Features

To further investigate limiting factors associated with the Withlacoochee River, percent-of-flow reductions that would result in a 15% loss of the number of days river flows reached a range of target flows were identified. This was done using the dry period (1970-1999) for the Croom, Wysong, and Holder gages (Figure 8-10 through 8-12).

Figure 8-10 indicates that flow reductions that result in a 15% reduction in the number of days the flow is achieved tend to stabilize around 9% for the Croom gage site. This percent-of-flow reduction is comparable to the flow reduction values derived for mean flows that would inundate dominant wetland vegetation classes, mucky soils, and other hydrologic indicators. Figure 8-10 also shows that there is a range of flows that occur which do not require flow reductions to be limited to 9% to avoid a 15% reduction in the number of days the flows are achieved. Using the flow required for out of bank flow, 400 cfs at the Croom gage, as a cutoff for this range of flows, we can apply a stepped prescription. This allows a 16% reduction in flows when flows are at or below 400 cfs, and a 9% reduction in flows when the flow is above 400 cfs (Figure 8-10). While additional flow reduction steps or percentages could be identified, or an algorithm applied to determine allowable percent-of-flow reductions, the single step approach provides a conservative means for assuring that unidentified factors are likely to be protected and that flows not necessary for prevention of significant harm are available for consumptive use. Unidentified factors could include vegetative classes or species that we did not examine, or inundation of vegetative classes to specified depths.

Utilizing the same technique, a stepped prescription allows a 15% reduction in flows when flow is at or below 600 cfs, and an 8% reduction in flows when the flow is above 600 cfs at the Wysong gage (Figure 8-11). For the Holder gage a stepped prescription allows a 9% reduction in flows when flow is at or below 1,250 cfs and 7% when flows are above 1,250 cfs (Figure 8-12).

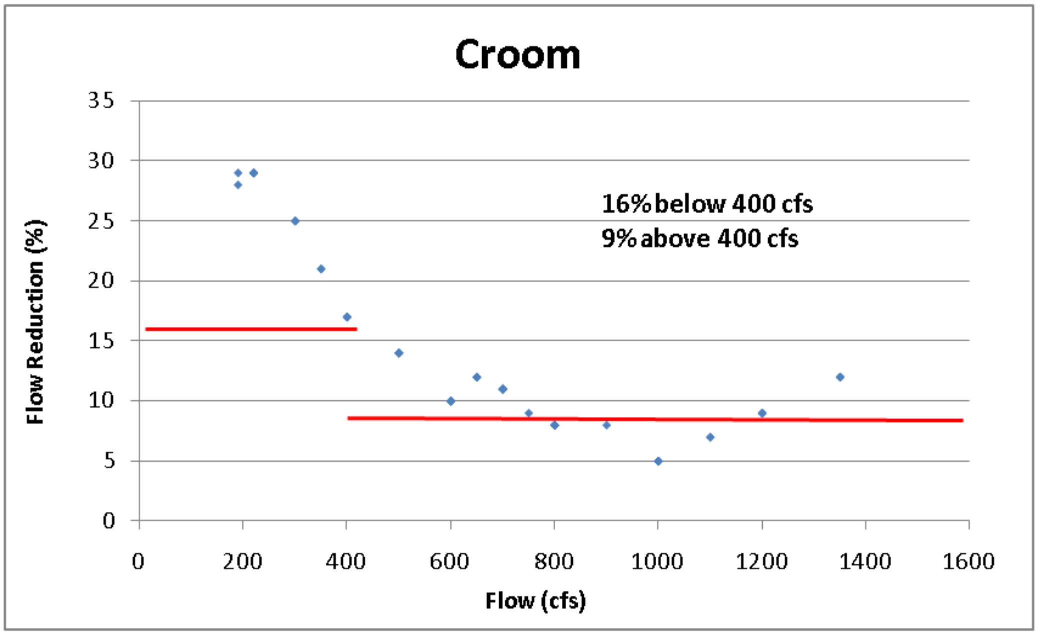

Figure 8-10. Percent-of-flow reductions that result in a 15% reduction in the number of days flow are achieved, based on the dry period (1970-1999) from the USGS Withlacoochee River at Croom gage.

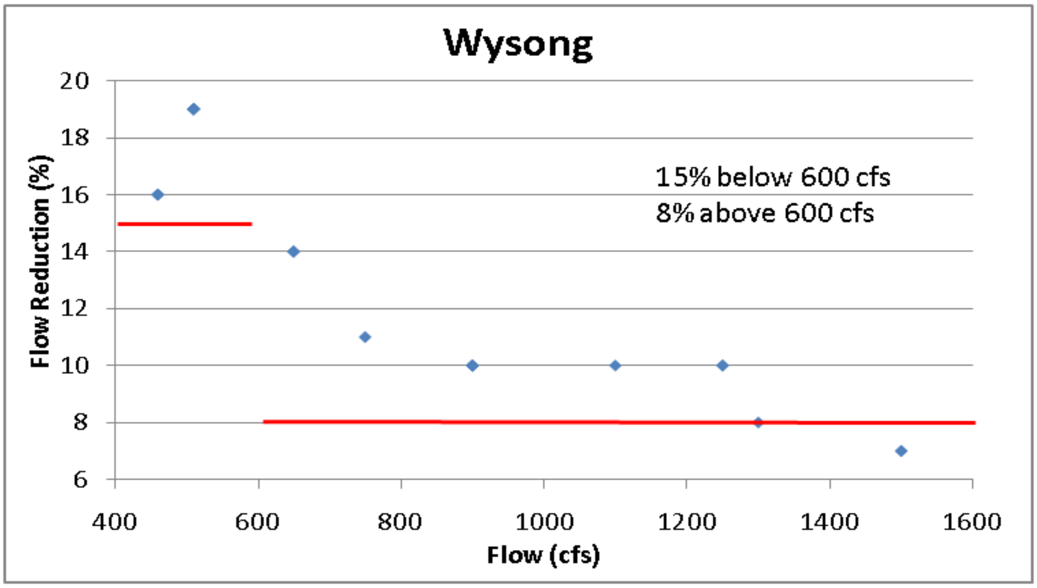

Figure 8-11. Percent-of-flow reductions that result in a 15% reduction in the number of days flow are achieved, based on the dry period (1970-1999) flows from the USGS Withlacoochee River at Wysong gage.

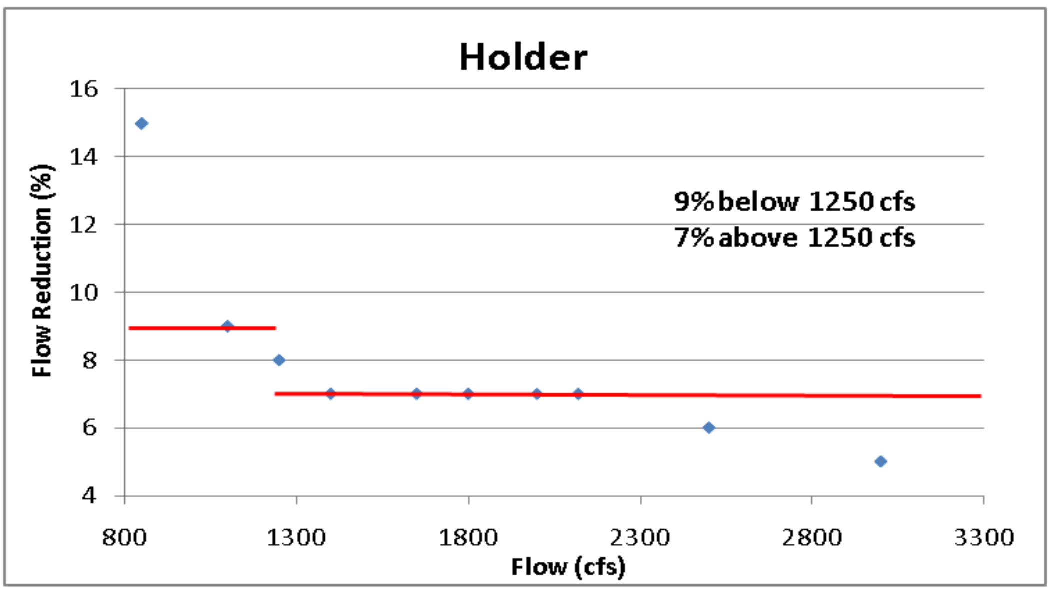

Figure 8-12. Percent-of-flow reductions that result in a 15% reduction in the number of days flow are achieved, based on the dry period (1970-1999) flows from the USGS Withlacoochee River near Holder gage.

8.5 Instream/Woody Habitat Protection

A prescribed flow reduction for criterion based on long-term inundation analyses to specifically evaluate changes in inundation patterns of woody habitats was also used to evaluate habitat loss. The prescribed flow reductions were established by calculating the percent-of-flow reduction, which would result in no more than a 15% reduction in the number of days of inundation of exposed root habitat for blocks 2 and 3.

8.5.1 Instream Habitats

Bottom substrates, combining both inorganic (e. g. , bedrock, sand, gravel, clay) and organic (e. g. , algae, leaf packs, mud) components were the dominant instream habitats, based on the linear extent of the habitat along the twenty-six instream habitat cross-sections evaluated for the Middle and Upper Withlacoochee River (Figure 8-13). This was followed by exposed roots and snags, which was also found in all transects but seems to be more dominant in extent of linear habitat in the upper two-thirds of the study region. Aquatic plants, categorically distinguished as emergent, floating and submersed aquatic vegetation represent the third big group of available instream habitation. *Sagittaria kurziana*, *Hydrilla verticillata* and *Vallisneria americana* were identified as the three most common submersed aquatic vegetation (SAV) species.

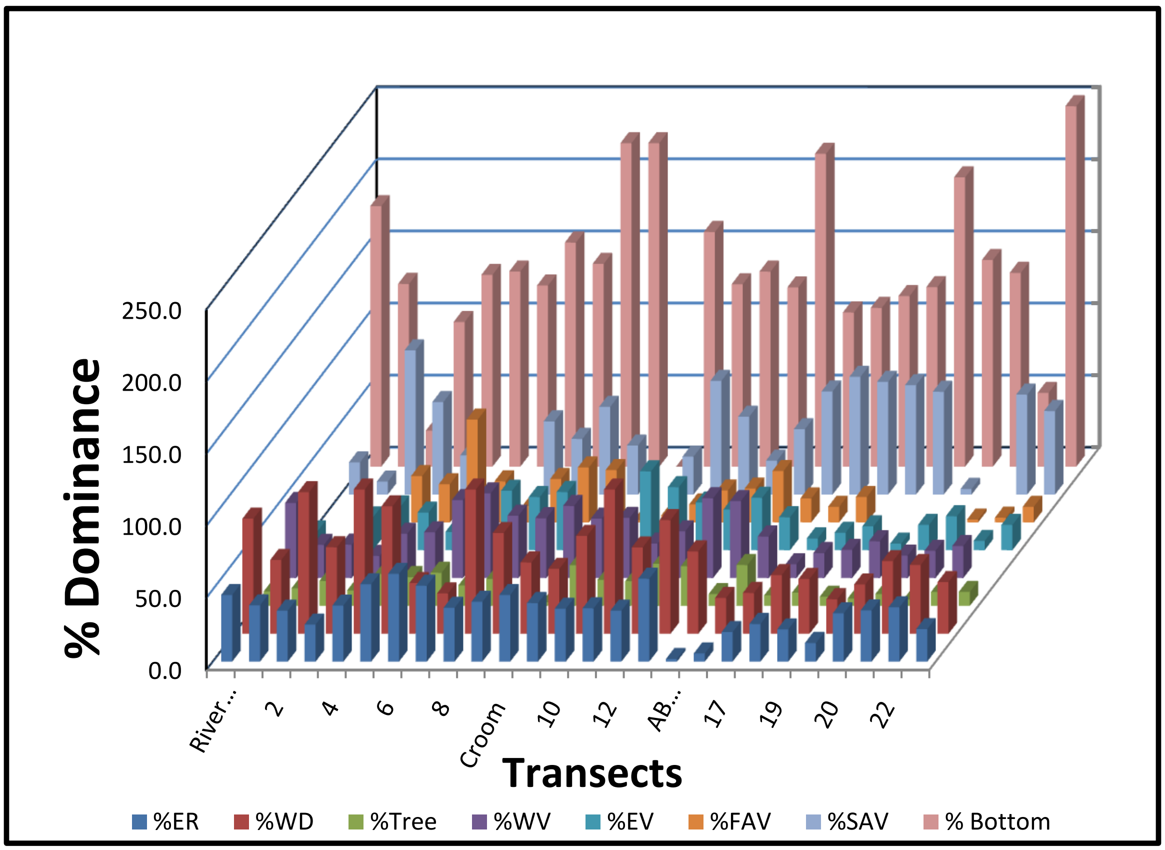

Figure 8-13. Percent dominance of instream habitats based on linear extent of the habitats along twenty-six cross-sections on the Withlacoochee River.

Relative elevations of the habitats were consistent among the cross-sections (Figure 8-14). Wetland trees were typically situated near the top of the banks with understory wetland vegetation, woody debris and exposed roots occurring at slightly lower elevations. Predictably, submerged aquatic plants were found in association with the bottom substrates. The occurrence of exposed roots at relatively high elevations is important because inundation of this habitat results in inundation of habitats located at lower elevations. Maintaining a mosaic of aquatic and wetland habitats provides the greatest potential for stream productivity and ecosystem integrity (Pringle et al. 1988).

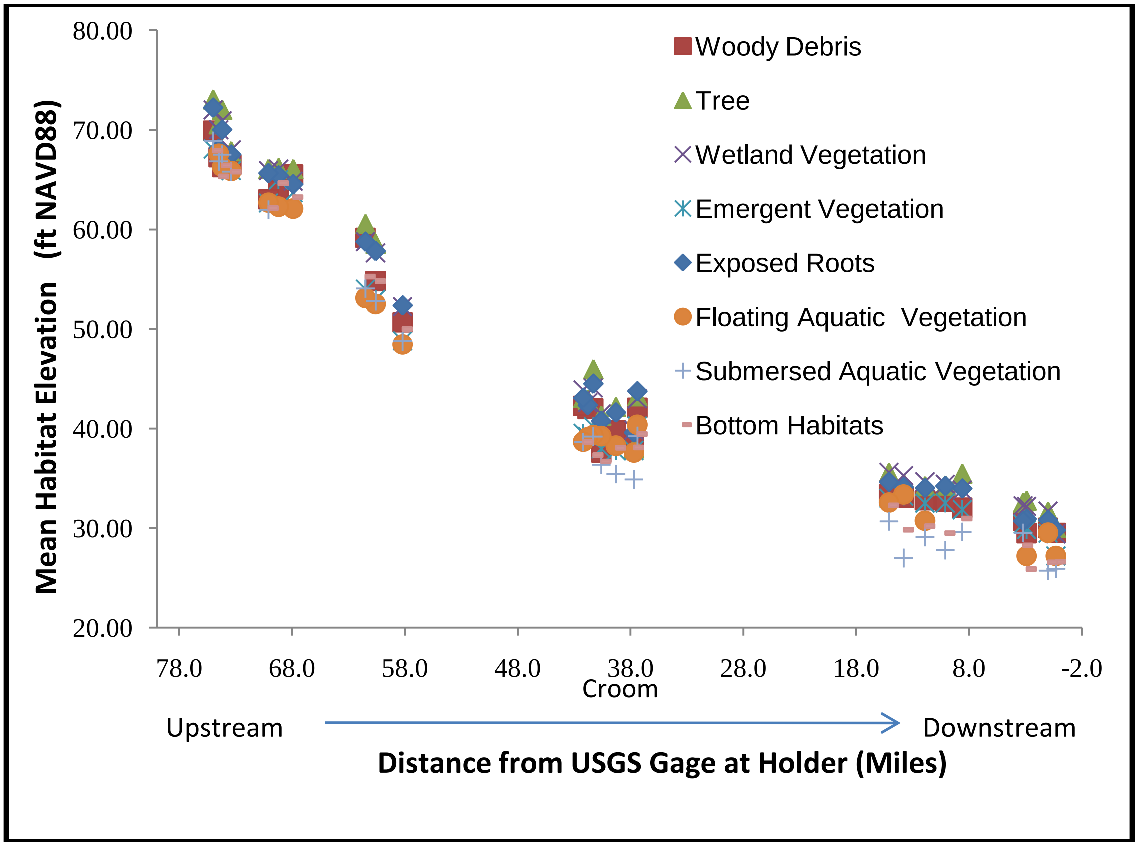

Figure 8-14. Mean elevations of instream habitats at twenty-six cross-section sites on the Withlacoochee River.

8.5.2 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 25 Withlacoochee River instream habitat cross-sections. Based on HEC-RAS output, flows at the respective USGS gages that are sufficient for inundation of the mean elevation of exposed root habitat as measured using the combined data from the cross-section method and the belt transect method at the 25 sites ranged from 190 to 800 cfs, 292 to 860 cfs, and 850 to 1,100 cfs at Croom, Wysong, and Holder gages respectively (Table 8-8). Similarly, when snag habitats were characterized via a longitudinal belt method combined with a cross-section method, flows at 25 sites ranged from

172 to 600 cfs, 292 to 535 cfs, and 450 to 1,250 cfs at Croom, Wysong, and Holder gages respectively. (Table 8-9).

Table 8-8. **Mean elevation of instream woody habitats (exposed roots) at various instream habitat sites, corresponding flows at the USGS gages required for inundation of the mean elevations, and maximum percent-of-flow reductions associated with less than a 15% reduction in the number of days flow sufficient to inundate the mean habitat elevations.**

Habitat	Site	Mean Elevation (ft NAVD)	Flow (cfs) at Gage Required for Inundation	Gauge	Allowable Percent of Flow Reduction Block 2
Exposed Roots	River Rd.	71.94	800	Croom	17
Exposed Roots	Veg 1	70.25	300	Croom	17
Exposed Roots	Veg 2	69.97	300	Croom	17
Exposed Roots	Veg 3	69.2	140	Croom	21
Exposed Roots	Veg 4	66.73	220	Croom	17
Exposed Roots	Veg 5	66.5	400	Croom	12
Exposed Roots	Veg 6	65.57	220	Croom	17
Exposed Roots	Veg 7	59.57	300	Croom	17
Exposed Roots	Veg 8	57.79	300	Croom	17
Exposed Roots	Trilby	52.75	190	Croom	17
Exposed Roots	Croom	44.08	535	Croom	11
Mean at	**Croom**		**337**	**Croom**	**16**
Exposed Roots	Veg 9	43.31	332	Wysong (U.S.)	13
Exposed Roots	Veg 10	45.95	860	Wysong (U.S.)	8
Exposed Roots	Veg 11	42.23	332	Wysong (U.S.)	13
Exposed Roots	Veg 12	41.4	332	Wysong (U.S.)	13
Exposed Roots	Veg 13	40.97	332	Wysong (U.S.)	13
Exposed Roots	476	40.49	292	Wysong (U.S.)	18
Mean at	**Wysong**		**413**	**Wysong (U.S.)**	**13**
Exposed Roots	Veg 16	36.13	1100	Holder	7
Exposed Roots	Veg 17	35.9	1100	Holder	7
Exposed Roots	Veg 19	35.39	850	Holder	8
Exposed Roots	Turner	35.1	1100	Holder	7
Exposed Roots	Veg 20	33.21	1100	Holder	7
Exposed Roots	Veg 21	32.8	1100	Holder	7
Exposed Roots	Veg 22	32.3	1100	Holder	7
Exposed Roots	200	30.34	1100	Holder	7
Mean at	**Holder**		**695**	**HOLDER**	**7**

Table 8-9. **Mean elevation of instream woody habitats (snags) at various instream habitat sites, corresponding flows at the USGS gages required for inundation of the mean elevations, and maximum percent-of-flow reductions associated with less than a 15% reduction in the number of days flow sufficient to inundate the mean habitat elevations.**

Habitat	Site	Mean Elevation (ft NAVD)	Flow (cfs) at Gage Required for Inundation	Gauge	Allowable Percent of Flow Reduction Block 2
Snags	River Rd.	71.31	600	Croom	13
Snags	Veg 1	70.97	600	Croom	13
Snags	Veg 2	69.19	140	Croom	21
Snags	Veg 3	69.2	400	Croom	12
Snags	Veg 4	62	15	Croom	70
Snags	Veg 5	66.12	300	Croom	17
Snags	Veg 6	66	400	Croom	12
Snags	Veg 7	59.2	300	Croom	17
Snags	Veg 8	27.28	220	Croom	17
Snags	Trilby	50.37	175	Croom	17
Snags	Croom	41.56	172	Croom	17
Mean at	**Croom**		**302**	**Croom**	**21**
Snags	Veg 9	43.24	332	Wysong	12
Snags	Veg 10	43.5	535	Wysong	12
Snags	Veg 11	43.07	535	Wysong	12
Snags	Veg 12	42.4	332	Wysong	12
Snags	Veg 13	41.23	332	Wysong	12
Snags	476	39.83	292	Wysong	18
Mean at	**Wysong**		**393**	**Wysong**	**13**
Snags	Veg 16	36.29	1250	Holder	8
Snags	Veg 17	35.9	1100	Holder	7
Snags	Veg 19	35.39	850	Holder	8
Snags	Turner	33.34	450	Holder	14
Snags	Veg 20	33.34	1250	Holder	8
Snags	Veg 21	32.7	1100	Holder	7
Snags	Veg 22	32.3	1100	Holder	7
Snags	200	30.5	1100	Holder	7
Mean at	**HOLDER**		**644**	**HOLDER**	**8**

Based on historic flow records, inundation of exposed roots and snag habitat occurs regularly during Block 2 flows. For this reason, inundation of woody habitats was only used as a Block 2 criterion. The cool climatic period of 1970 to 1999 was selected as the bench mark period for woody habitat analyses as it resulted in a more conservative allowable withdraw percentage than the warm climatic period or the period of record.

8.5.3 Results of Woody Habitat Protection Criteria

The goal of the woody habitat protection criteria is to limit the reduction in number of days that the mean elevation of woody habitat is inundated to 15%. Although some sites resulted in higher and lower percent allowable reductions, it was decided to calculate the average of all sites for each corresponding gage. The resulting allowable percent withdraws for exposed roots are 23, 21, and 10 % at Croom, Wysong, and Holder, respectively. These percentages represent the more restrictive of the exposed root and snag means.

8.6 Proposed Minimum Flows for the Withlacoochee River

For the Withlacoochee River the minimum flow recommendation is stated as a percent of flow reduction at the USGS Withlacoochee River at Croom, at Wysong, and near Holder gages. Reductions apply to seasonal blocks with the exception of the low flow threshold set utilizing fish passage and wetted perimeter that apply to the entire year.

A number of different flow reduction criteria were analyzed during the development of the minimum flow. The results of these criteria are summarized in Table 8-10 and in the text below.

Table 8-10. Flow reduction recommendations for each individual criterion based on a composite of all individual criterion for each analysis.

Block	Analysis Name	Measure / Goal	Maximum Allowable Flow Reduction Recommendation (Croom)	Maximum Allowable Flow Reduction Recommendation (Wysong)	Maximum Allowable Flow Reduction Recommendation (Holder)
ALL	Fish Passage	Maintaining depth of 0.6' across shoals	30 cfs	60 cfs	150 cfs
ALL	Wetted Perimeter	Maximizing inundated river channel	15 cfs	60 cfs	150 cfs
1	PHABSIM	Avoid reductions > 15% in habitats for various species	11%	15%	13%
2	PHABSIM	Avoid reductions > 15% in habitats for various species	17%	19%	15%
2	Instream Habitat - Exposed Roots	Avoid reductions > 15% in exposed root availability	16%	13%	7%
2	Instream Habitat - Snags	Avoid reductions > 15% in snag availability	21%	19%	8%
3	Floodplain Inundation (LTPH)	Avoid reductions > 15% in temporal floodplain habitat	16% below 400 cfs 9% above 400 cfs / Block 3	15% below 600 cfs 8% above 600 cfs / Block 3	9% below 1250 cfs 7% above 1250 cfs / Block 3

Utilizing the most restrictive criteria for each block and for the low flow threshold, the minimum flows for the Withlacoochee River are as follows. Figures 8-15 through 8-17 illustrate the flow prescription criteria for each gage site.

> At the Croom gage, the proposed MFL allows removal of 11 percent of Block 1 (dry season) baseline flows; 16 percent of Block 3 flows (wet season) when flow is at or below 400 cfs and 9% when the flow is above 400 cfs; and 16 percent of Block 2 flows. Surface water withdrawals are prohibited from depressing flows below 30 cfs in any block.

At the Wysong gage, the proposed MFL allows removal of 15 percent of Block 1 (dry season) baseline flows; 15 percent of Block 3 flows (wet season) when flow is at or below 600 cfs and 8% when the flow is above 600 cfs; and 13 percent of Block 2 flows. Surface water withdrawals are prohibited from depressing flows below 60 cfs in any block.

At the Holder gage, the proposed MFL allows removal of 13 percent of Block 1 (dry season) baseline flows; 9 percent of Block 3 flows (wet season) when flow is at or below 1,250 cfs and 7% when the flow is above 1,250 cfs; and 16 percent of Block 2 flows. Surface water withdrawals are prohibited from depressing flows below 150 cfs in any block.

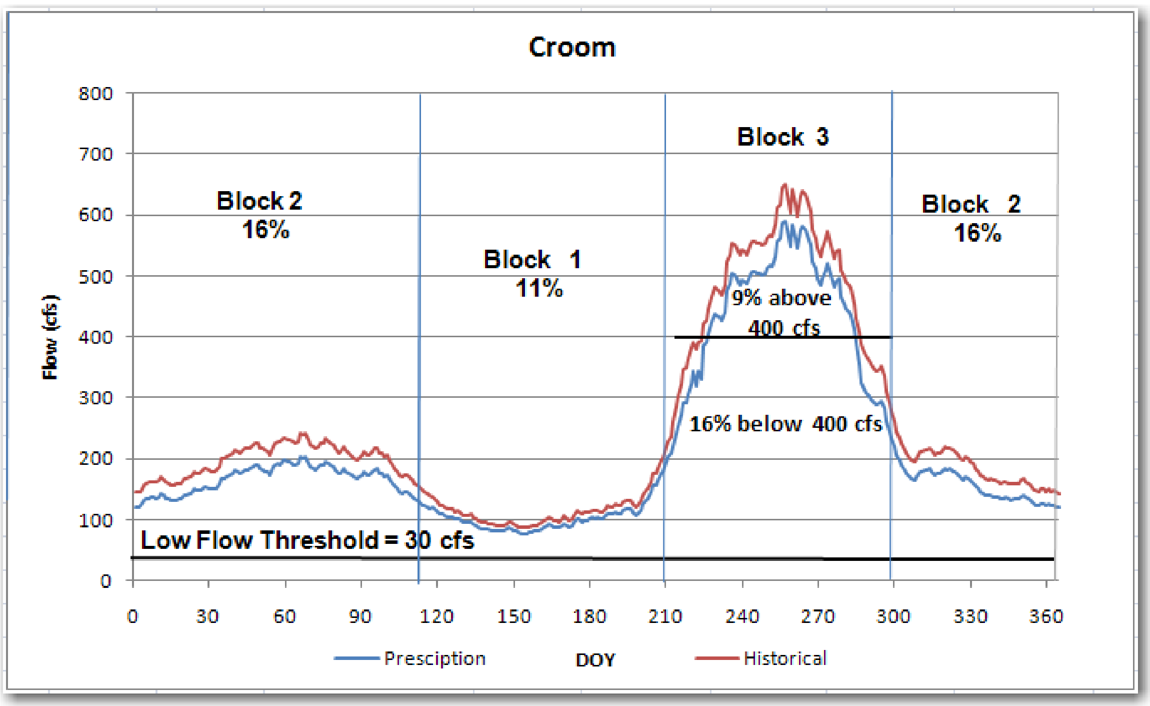

Figure 8-15. Flow prescription and historical flows for Withlacoochee River at Croom.

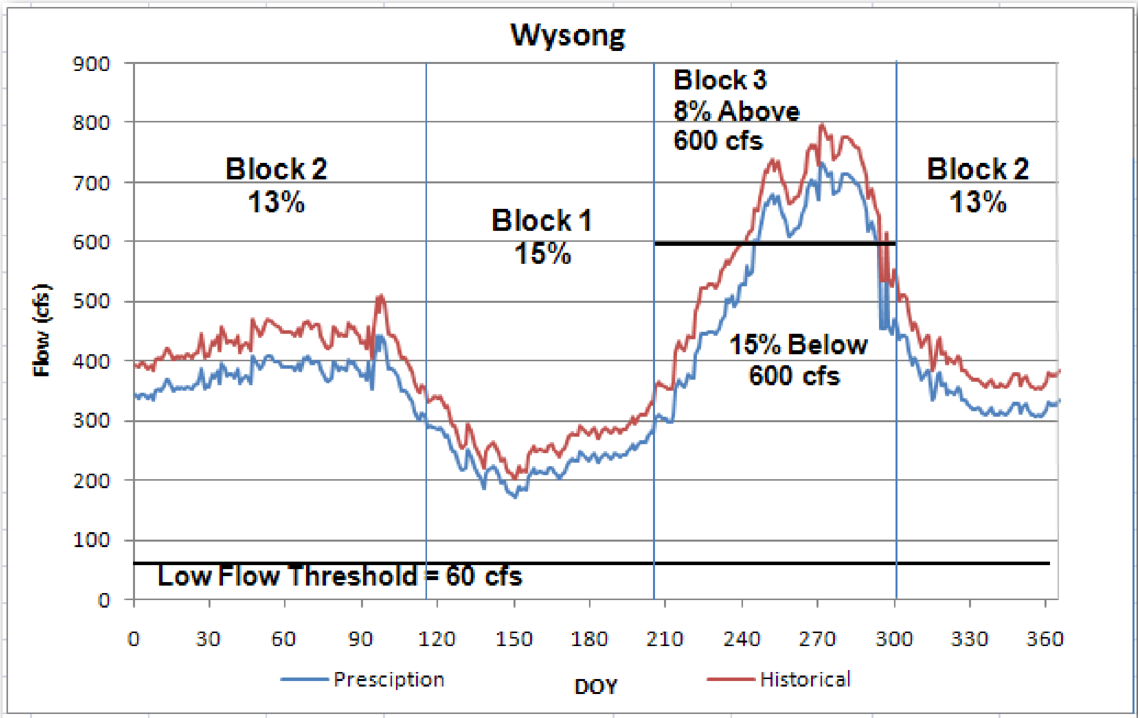

Figure 8-16. Flow prescription and historical flows for Withlacoochee River at Wysong.

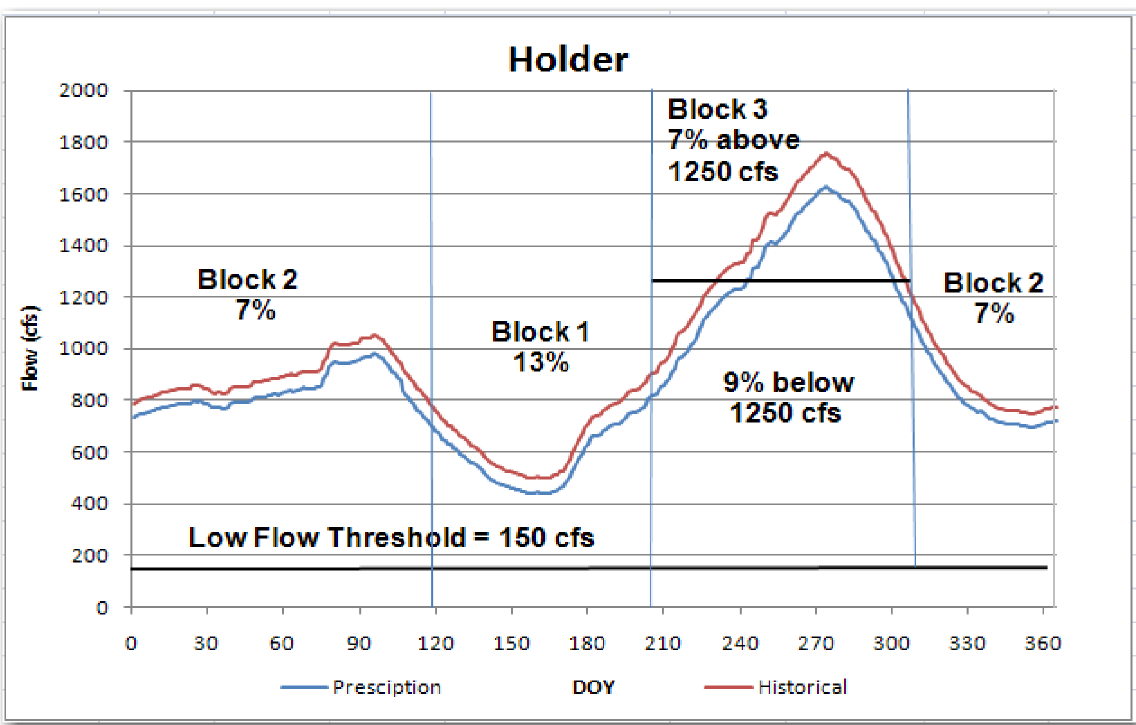

Figure 8-17. Flow prescription and historical flows for Withlacoochee River near Holder.

Minimum five-year and ten-year moving annual average values for each gage are set forth in Table 8-11 through 8-13 as a tool to assess whether flows to the Withlacoochee River remain above flow rates that are expected to occur with implementation of the Minimum Flow described in Table 8-10. The means and medians are based on evaluation of daily flow records for the each gage for the period of record. Yearly means and medians are computed for January 1 through December 31 of each year. Therefore, the means and medians are hydrologic statistics that represent the flows that will be met or exceeded if compliance with the Minimum Flow is maintained during hydrologic conditions similar to the period shown for each gage. However, since changes in the watershed such as future structural alterations and climatic change could potentially affect surface water or groundwater flow characteristics and additional information relevant to Minimum Flows development may become available, the District is committed to periodic re-evaluation of the Minimum Flows.

Table 8-11. Minimum Five-Year and Ten-Year Moving Mean and Median Flows for the Croom gage with the application of the proposed Minimum Flow based on the flow record from 1939 through 2009.

Croom		
Minimum Flow	Hydrologic Statistic	Flow (cfs)
Annual Flow	10-Year Mean	224
	10-Year Median	40
	5-Year Mean	125
	5-Year Median	34
Block 1	10-Year Mean	68
	10-Year Median	23
	5-Year Mean	46
	5-Year Median	7
Block 2	10-Year Mean	167
	10-Year Median	55
	5-Year Mean	94
	5-Year Median	43
Block 3	10-Year Mean	362
	10-Year Median	134
	5-Year Mean	142
	5-Year Median	29

Table 8-12. Minimum Five-Year and Ten-Year Moving Mean and Median Flows for the Wysong gage with the application of the proposed Minimum Flow based on the flow record from 1965 through 2009.

Wysong		
Minimum Flow	Hydrologic Statistic	Flow (cfs)
Annual Flow	10-Year Mean	395
	10-Year Median	118
	5-Year Mean	266
	5-Year Median	99
Block 1	10-Year Mean	169
	10-Year Median	78
	5-Year Mean	122
	5-Year Median	34
Block 2	10-Year Mean	342
	10-Year Median	160
	5-Year Mean	275
	5-Year Median	128
Block 3	10-Year Mean	479
	10-Year Median	174
	5-Year Mean	275
	5-Year Median	128

Table 8-13. Minimum Five-Year and Ten-Year Moving Mean and Median Flows for the Holder gage with the application of the proposed Minimum Flow based on the flow record from 1928 through 2009.

Holder		
Minimum Flow	Hydrologic Statistic	Flow (cfs)
Annual Flow	10-Year Mean	566
	10-Year Median	227
	5-Year Mean	365
	5-Year Median	222
Block 1	10-Year Mean	330
	10-Year Median	188
	5-Year Mean	288
	5-Year Median	149
Block 2	10-Year Mean	495
	10-Year Median	248
	5-Year Mean	367
	5-Year Median	272
Block 3	10-Year Mean	655
	10-Year Median	351
	5-Year Mean	367
	5-Year Median	272

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10 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.

Baseflow – 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.

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 than by criterion developed to protect in-channel features. The high flow step is therefore, a 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.

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 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 surface water 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 seasonal 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.

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 feed, 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.