Appendix A

Proposed Minimum Flows and Levels for the Little Manatee River – Peer Review DRAFT

Southwest Florida Water Management District

Proposed Minimum Flows and Levels for the Little Manatee River – Staff Draft

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Table of Contents

List of Figures

List of Tables

Executive Summary

The Little Manatee River originates in southeastern Hillsborough County and meanders through southern Hillsborough and Northern Manatee counties. The river travels primarily west approximately 36 miles before entering the Gulf of Mexico in Tampa Bay. Much of the Little Manatee River is designated an Outstanding Florida Waters (OFW). The watershed covers approximately 224 square miles. For the purpose of the Minimum Flows and Levels (MFL) presented in this report, the freshwater portion of the Little Manatee River extends from the headwaters to the U.S. Highway 301 crossing (Little Manatee River near Wimauma United States Geological Survey gage).

For development of MFLs for the Little Manatee River, the District identified seasonal blocks corresponding to periods of low, medium and high flows. MFLs for the freshwater segment of the river were established for the Little Manatee River near Wimauma United States Geological Survey (USGS) gage 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 surface water withdrawals permitted when flows are above, or greater than, the threshold, and no surface water withdrawals permitted when flows are below, or less than the threshold. For the Little Manatee River near Wimauma, the low flow thresholds was determined to be 35 cubic feet per second based on fish passage criteria. A prescribed flow reduction for the low flow period (Block 1, which runs from April 18 through June 21) was based on review of limiting factors developed using the Physical Habitat Simulation Model (PHABSIM) to evaluate flow related changes in habitat availability for several fish species and macroinvertebrate diversity. It was determined using PHABSIM that the most restrictive limiting factor was the loss of habitat for adult spotted sunfish. Adult spotted sunfish exhibit a 15% loss of habitat when flows are reduced by 9%.

For the high flow season of the year (Block 3, which runs from June 22 through October 18), a prescribed flow reduction was based on review of limiting factors developed using the Physical Habitat Simulation Model (PHABSIM) to evaluate flow related changes in habitat availability for several fish species and macroinvertebrate diversity. It was determined using PHABSIM that the most restrictive limiting factor was the loss of habitat for largemouth bass fry. Largemouth bass fry exhibit a 15% loss of habitat when Block 3 flows are reduced by 11%.

For the medium flow period (Block 2, which runs from October 19 of one year to April 17 of the next), PHABSIM analyses were used to model flows associated with potential changes in habitat availability for several fish species and macroinvertebrate diversity. In addition, flows associated with inundation of instream woody habitats were evaluated using a HEC-RAS model and long-term inundation analyses. Using the more conservative of the two resulting flows, it was determined that PHABSIM results would define the percent flow reduction for Block 2. Results from the PHABSIM analyses indicated that more than 15% of historically available habitat would be lost for adult spotted sunfish if flows were reduced by more than 11% as measured at the Little Manatee River near Wimauma gage site during the medium flow period.

The proposed MFL as measured at the Little Manatee River near Wimauma USGS gage allows removal of 9 percent of Block 1 (dry season) baseline flows; 11 percent of Block 2 flows; and 9 percent of Block 3 flows when flows are below and above 280 cfs, respectively. Surface water withdrawals are prohibited from depressing flows below 35 cfs in any block.

Acknowledgements

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 the next 20 years, as a result of withdrawals, then a recovery plan is developed and implemented.

According to state law, minimum flows and levels are to be established based upon the best available information (Section 373.042, F.S.), and shall be developed with consideration of "...changes and structural alterations to watersheds, surface waters and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer..." (Section 373.0421, F.S.). 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 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.

More 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.

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. These analyses result in a specific discharge limit, in CFS, at which further reductions in flow would be considered significantly harmful. 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. 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. Habitat and floodplain analyses result in percent of flow withdrawal limits for the corresponding Blocks. It would be considered significantly harmful to reduce flows beyond these limits.

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 Little Manatee 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 65-day period that extends from April 18 to June 21 (Julian day 109 to 173). Highest flows occur during Block 3, the 119-day period that immediately follows the dry season (June 22 to October 18). This is the period when the floodplain is most likely to be inundated on an annual basis; although high flows can occur at any time of the year. The remaining 181 days constitute an intermediate or medium flow period, which is referred to as Block 2.

Blocks are defined by analyzing the median daily flows for the period of record. Block 1 begins when the median daily flow drops below and stays below the 75% exceedance flow and continues until the beginning of Block 3. Block 3 begins when the median daily flow exceeds and stays above the 50% exceedance flow. Once the median daily flow fall below the 50% exceedance flow, Block 2 begins and continues until the beginning of Block 1.

On the Little Manatee River there are two major influences on discharge, as measured at the Little Manatee River near Wimauma USGS gage. The first is the inflow of agricultural irrigation water within the watershed. An analysis of the flow record and land use indicate that agricultural irrigation has increased flow by an average of 13 cubic feet per second (cfs) starting approximately in 1978. The excess flows are highly variable throughout the different crop establishment and growing periods, ranging from 0 to 80 cfs.

The second major influence on discharge is a permitted withdrawal by Florida Power and Light (FP&L) which began in December of 1976. FP&L pumps water as needed, and permitted, to fill a reservoir which is used for cooling. Withdrawal records from FP&L show a range of withdrawals from 0 to 506 cfs and averaging approximately 9 cfs, as calculated on a daily basis. In the entirety of this document and supporting analysis, the flow record used has been corrected for both of these influences.

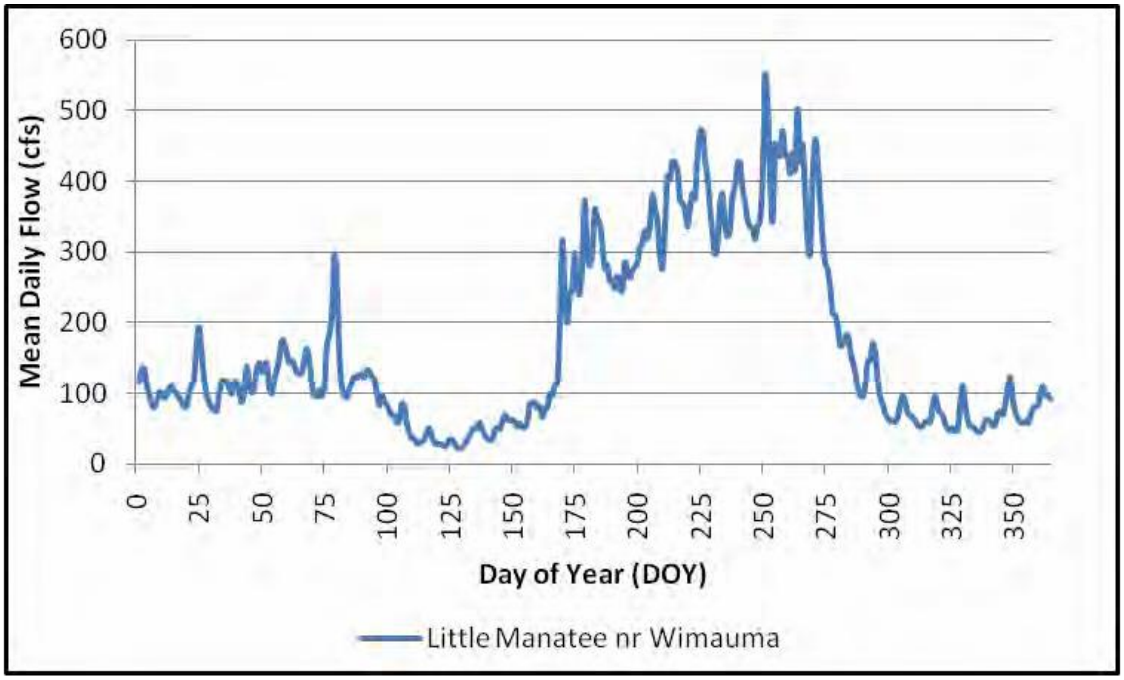


Figure 1-1. Mean daily flows for Little Manatee River near Wimauma USGS gage.

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.

For analyses and reporting the District has transitioned to the North American Vertical Datum of 1988 (NAVD 88). 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.

2 BASIN DESCRIPTION

This chapter includes a brief description of the Little Manatee River watershed including location, climate, physiographic characteristics, and hydrogeology. Material in this section was excerpted largely from the Consolidated Annual Report (SWFWMD 2009).

2.1 Geographic Location

The Little Manatee River originates in a swampy area east of Fort Lonesome, Florida in southeastern Hillsborough County and flows generally westward for about 36 miles toward its discharge point into Tampa Bay near Ruskin, Florida. The Little Manatee River watershed extends over the southern part of Hillsborough County and the northern portion of Manatee County (Figure 2-1). The watershed is bordered by the Alafia River watershed to the north, the Manatee River watershed to the south and to the east by the Peace River watershed (SWFWMD 2009). The Little Manatee drains approximately 224 square miles of land. The watershed incorporates the City of Palmetto and communities of Parrish, Ruskin, Sun City and Terra Ceia. Other features of interest include Lake Wimauma, Lake Parrish, the Little Manatee River State Recreation Area and the Cockroach Bay Aquatic Preserve.

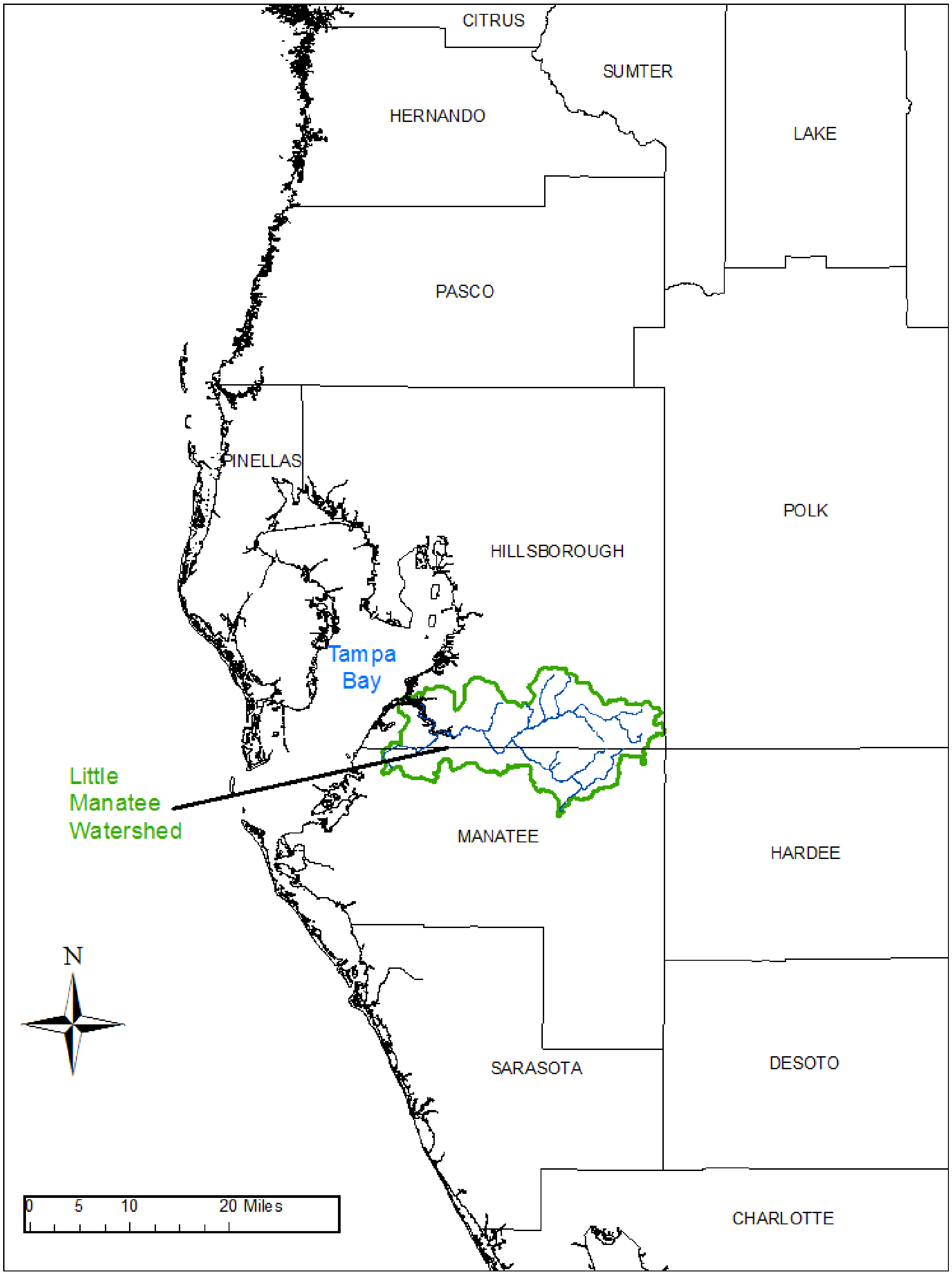


Figure 2-1. Location Map of the Little Manatee River.

2.2 Climate

West-central Florida has a humid subtropical climate. The mean normal yearly temperature for Hillsborough County is 72.2^{o} F, generally ranging from a normal maximum temperature of 91^{o} F in July and August, to a normal minimum temperature of 49^{o} F in January. Evapotranspiration for the area encompassing the Little Manatee River watershed is approximately 39 inches per year. Greatest ET rates occur in May and June and nearly 60 percent of the total yearly ET occurs during the period between May and October (citation).

For the period 1915 through 2009, the annual average rainfall for the watershed was approximately 54 inches. In a typical year, approximately 60 percent of the annual precipitation comes from convective thunderstorms during the four-month period from June to September. Periods of extremely heavy precipitation associated with the passage of tropical low pressure systems may occur during summer and early fall (June through November).

2.3 Physiography (primarily excerpted from USGS 2009)

The Little Manatee River watershed lies within three physiographic provinces; the Gulf Coastal Lowlands, DeSoto Plain and the Polk Upland. The lower portion of the watershed flows over the Gulf Coastal Lowlands province and the DeSoto Plain, relatively flat plains extending eastward with a gentle slope upward to the border with the Polk Upland physiographic province. The western edge of the Polk Upland is defined by the presence of the first of several paleoshoreline scarps associated with the Pleistocene ice-age sea level fluctuations. This physiographic feature is known as the Pamlico Scarp or shoreline. Elevations in the Gulf Coast lowlands and DeSoto Plain range from sea level to 50 feet NGVD.

The remainder of the Little Manatee River watershed is situated in the Polk Upland Province. Elevations in the extensive Polk Upland range up to between 100 and 130 feet. The watershed‟s elevations, however, range between sea level and 75 feet. Eastward of the Pamlico Scarp the river's banks attain a narrower, steeper profile and some spots are bluff-like with 20-25 feet of relief from the river's water level. In the vicinity of Wimauma, the physiography adjacent to the river is composed of low sand hills which in some cases attain 75 feet in elevation. The Talbot and Penholoway paleoshorelines pass through this area in a north-south orientation, with identifying surface features having elevations of 25 to 42 and 42 to 75 feet, respectively.

In the Polk Upland province, near the town of Fort Lonesome, the river travels over the clay-rich Bone Valley Member of the Peace River formation. This is the lithologic unit planned for mining for phosphate minerals in the eastern part of the

Little Manatee watershed. The river's banks in this region become less steep with many low relief floodplain or wetland areas surrounding the river. A portion of this area will have its physiography and associated surface water drainage systems modified by future mining activity. Altered physiographic features in this region may include water-filled, former mine pits and large, diked clay-settling areas of various rectilinear configurations similar to those in the Alafia River watershed.

Primary soil groups in the Little Manatee River watershed include the Myakka-Urban land-St. Augustine and Estero-Wulfer-Kesson groups in the coastal areas. These associations are nearly level, poorly drained black soils commonly found in swamps, tidal marshes and river flood plains. Inland from these areas, the prevalent soil types are the EauGallie-Floridana, Myakka-Bassinger-Holopaw, Malabar-Wabasso-Bassinger, Myakka Immokalee-Pomello, Myakka Waveland Classic and Waveland-Pomello-Myakka associations. These groups include nearly level and poorly to moderately drained soils characteristic of flatwood areas.

2.4 Hydrogeology (primarily excerpted from USGS 2009)

The Little Manatee watershed is underlain by water-bearing limestones and dolomites of Eocene to Miocene age, covered by a 200-300 foot layer of unconsolidated sands and sandy clays of Pliocene, Pleistocene and Recent origin. The watershed lies within the southern groundwater basin and contains three distinct aquifer systems: the surficial, intermediate and Floridan. The surficial aquifer is unconfined and is composed of variable amounts of clean quartz to clayey sand. At the base of the surficial aquifer, there may be phosphate grains and clays present that have been reworked from the underlying phosphate-bearing Bone Valley Member. The underlying intermediate aquifer is made up of the permeable lithologies present in the Hawthorne Group including the lowermost limestone unit (Tampa Member). In the Little Manatee River watershed, the intermediate aquifer serves as a locally important potable water source for domestic wells.

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 examine the potential impact of land use changes on river flow volumes and water quality trends.

3.1 Land Use Changes in the Little Manatee River Watershed

A series of maps, tables and figures were generated for the Little Manatee River for four specific years (1974, 1990, 1999 and 2004) for purposes of considering land use changes that have occurred over the last several decades. 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, 1999 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 comparative use of the two classification systems. Land use/cover types identified for our analysis included: Urban; Uplands; Wetlands (forested and non-forested); Water; Citrus; Rangeland; and Other Agriculture.

The Little Manatee watershed is comprised of 24 sub-basins mostly named after a tributary creek or branch (Figure 3-1). These 23 sub-basins were grouped into six sub-basin groups to simplify comparisons (Figure 3-2). The Mainstem Sub-basin was not grouped with any other sub-basins. The groupings were based on similarities in drainage characteristics and location (Table 3-1).

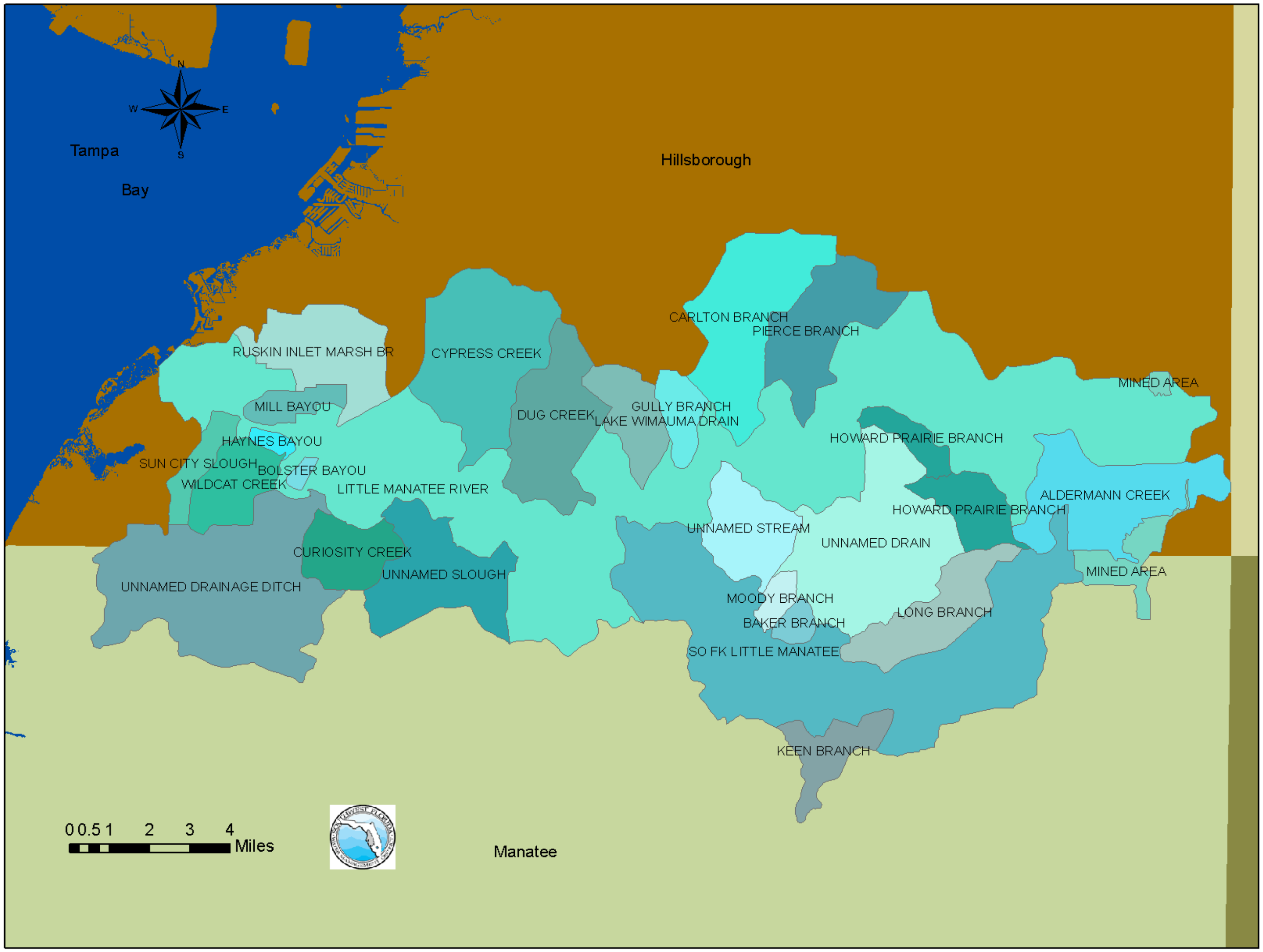


Figure 3-1. Location of all Manatee River Sub-basins

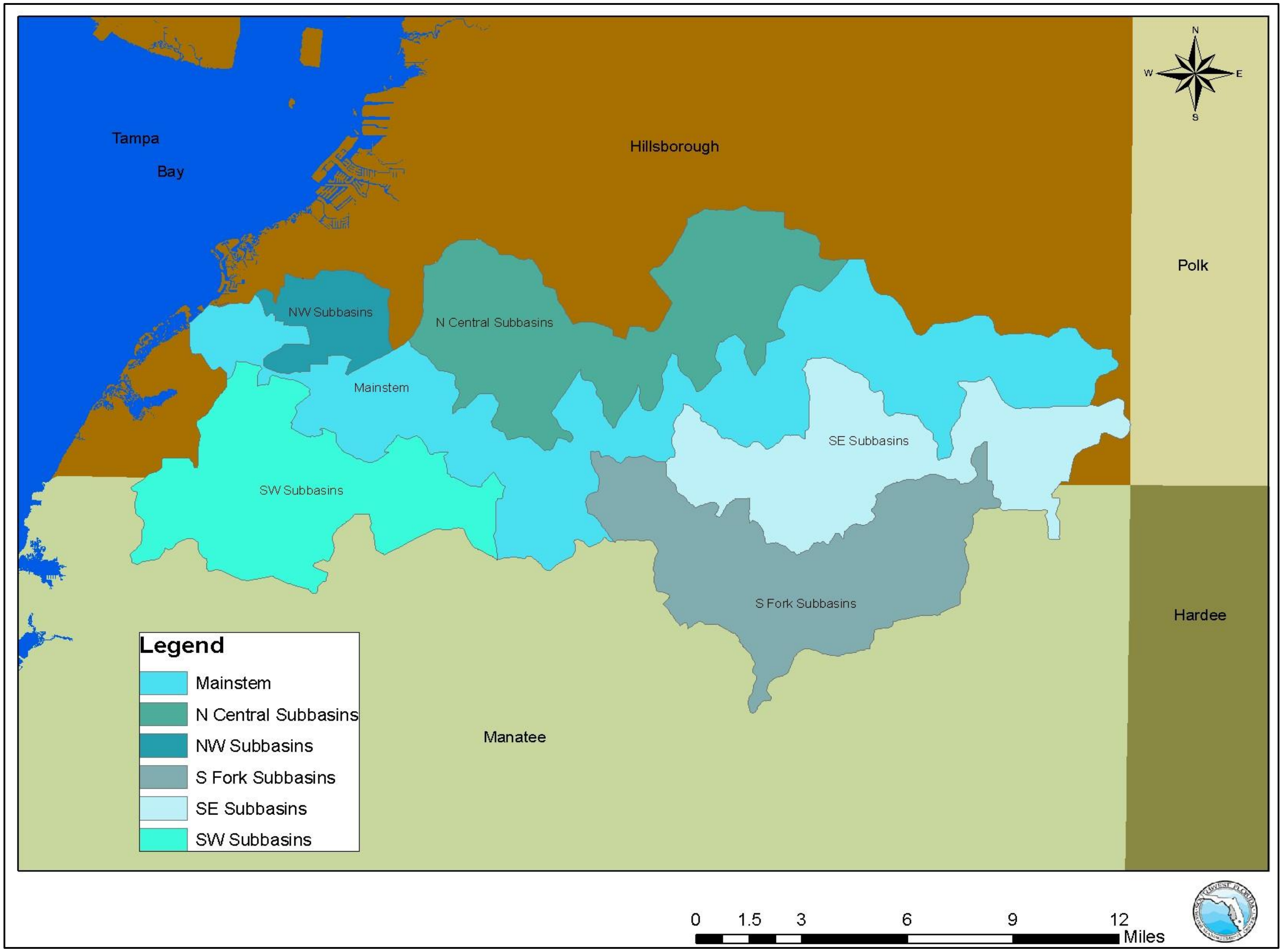


Figure 3-2. Little Manatee River grouped into six Sub-basins.

Table 3-1. Grouping of Little Manatee River Sub-basins.

South Fork Sub-	***Southeast Sub-basins***	***North Central Sub-basins***	***Southwest Sub-basins***	***Northwest Sub-basins***
South Fork	Unnamed Drain	Cypress Creek	Unnamed Slough	Mill Bayou
Keen Branch	Howard Prairie	Dug Creek	Curiosity Creek	Ruskin Inlet Marsh
Long Branch	Alderman Creek	Lake Wimauma Drain	Unnamed Drainage Ditch	
Baker Branch	Mined Area	Gully Branch	Wildcat Creek	
Moody Branch		Carlton Branch	Sun City Slough	
		Pierce Branch	Haynes Bayou	

As delineated on land use maps in this report, sub-basin groups ranged in size from 5250 acres (NW Sub-basin; approximately 8 square miles) to 41740 acres (Mainstem Sub-basin; approximately 65 square miles)(Table 3-2).

Table 3-2. Sub-basin areas within the Little Manatee Watershed.

Sub-basin Grouping	Total Acres	Square Miles
South Fork Sub-basins	25050	39
Southeast Sub-basins	21980	34
North Central Sub-basins	26260	41
Southwest Sub-basins	22770	36
Northwest Sub-basins	5250	8
Mainstem Sub-basin	41740	65

Before discussing individual sub-basin land use changes, it is informative to discuss the entire watershed of the Little Manatee River to get an appreciation of the major land uses/covers and the changes that have occurred during the 30 years for which land use maps are available. Land use/cover maps for 1974, 1990, 1999 and 2004 are shown in figures 3-3 and 3-4. Note that for mapping purposes, wetlands were separated into wetland forests and non-forested wetland sub-groupings. Sub-groupings were not maintained for tabular analysis and plotting of land use changes (Table 3-3, Figure 3-5).

The Little Manatee River watershed is approximately 224 square miles or 143,051 acres. From inspection of percentage changes as shown in either Table 3-3 or Figure 3-5, several land use/cover changes are readily apparent. From 1974 to 2004 there was a 400% increase in urban land use from 3,970 to 15,890 acres. Urban land use represented 11.1% of the land use in 2004.

Even more apparent in the Little Manatee Watershed is the growth of the mining land use area. From 1974 to 2004 there have been 17,576 acres added to the mining land use. This increase, primarily in the upper reaches of the watershed, has taken mining from approximately 0% of the watershed to over 12% of the watershed. Lands in the mined lands category may include, in addition to lands being actively mined, lands in varying stages of reclamation.

The majority of lands now under mining and urban land use were previously rangeland. There was a reduction of rangeland of 52,514 acres between 1974 and 2004. It should also be noted that many of the discrepancies between the 1974 land use maps and the other three maps are due to methodology variations.

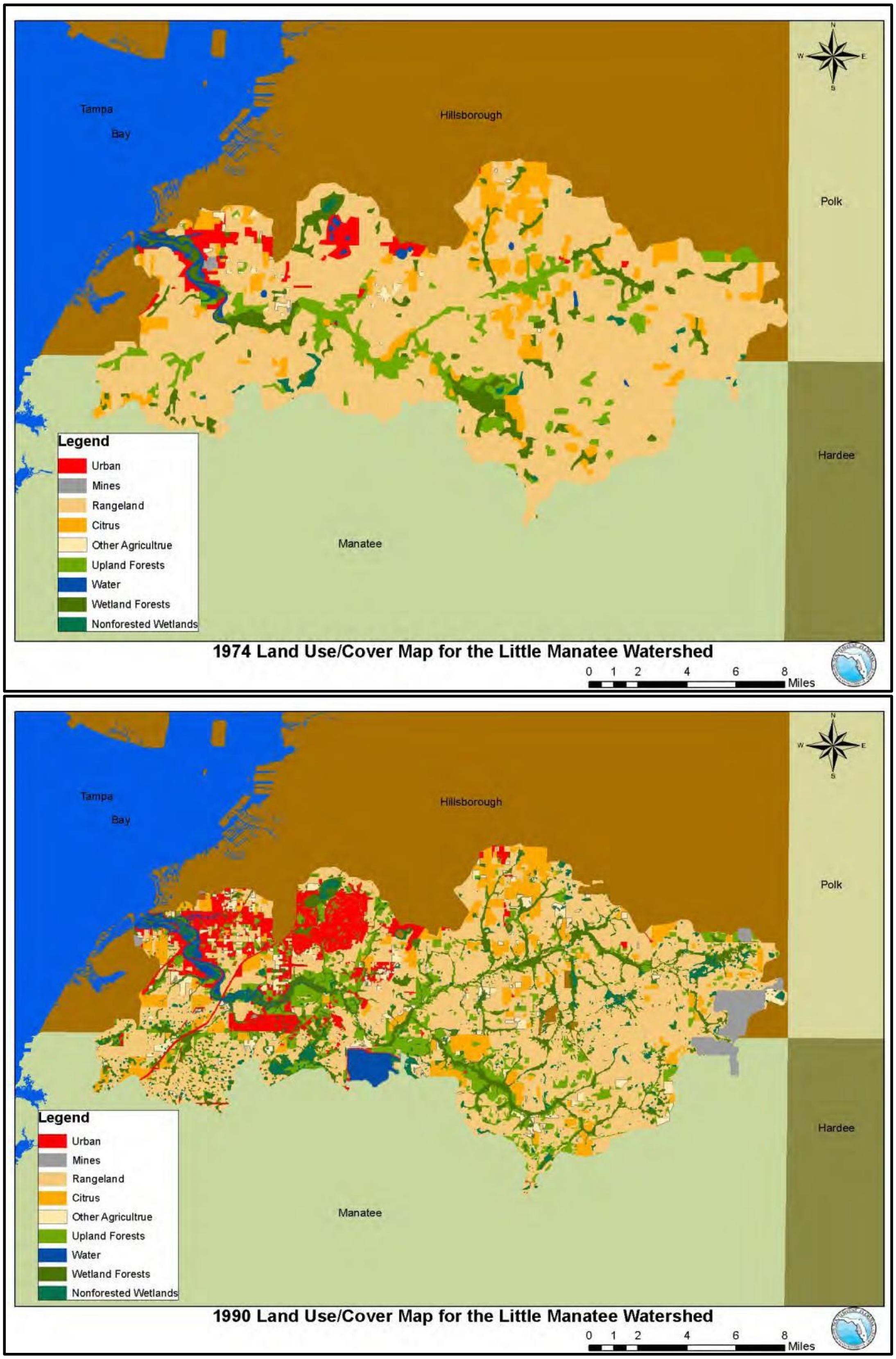


Figure 3-3. 1972 and 1990 Land Use/Cover maps of the Little Manatee River watershed, FL.

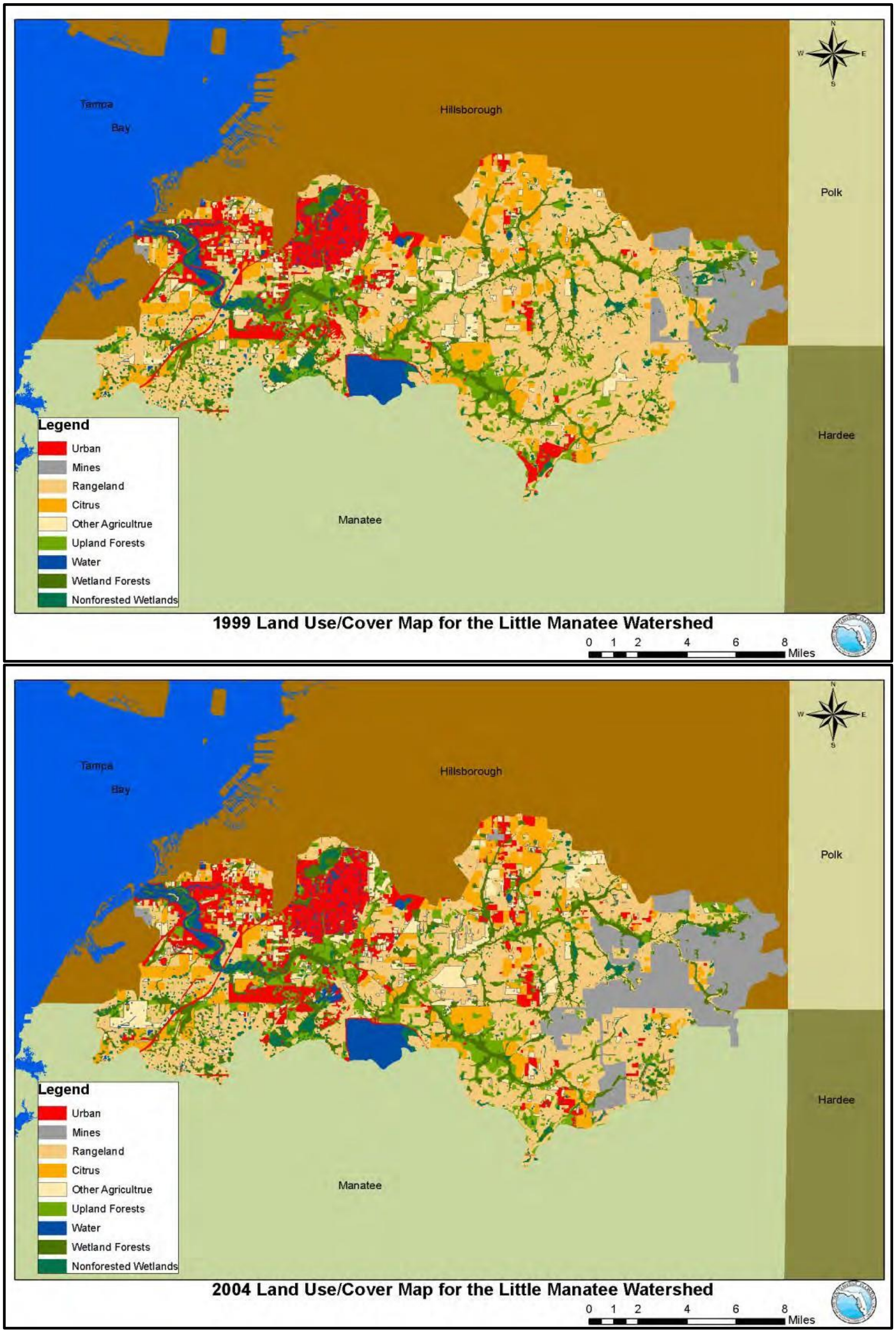


Figure 3-7. 1999 and 2004 Land Use/Cover maps of the Little Manatee watershed, FL.

Table 3-3. Land Use/Cover (by acres) changes in the Little Manatee River watershed (143,051 acres) for four time periods; 1974, 1990, 1999, 2004.

Land Use	1974	1990	1999	2004
Urban	3969.5	11270.0	13032.0	15890.0
Citrus	13203.7	12816.4	13896.5	12981.4
Other Agriculture	840.8	5980.0	6617.0	9604.3
Uplands	10723.0	14569.2	13741.4	12389.9
Wetlands	10369.4	21489.2	19800.6	19304.0
Mines	45.1	3288.7	8924.8	17621.2
Water	1657.8	4984.4	5175.6	5475.2
Rangeland	102299.4	68640.4	61863.3	49785.1

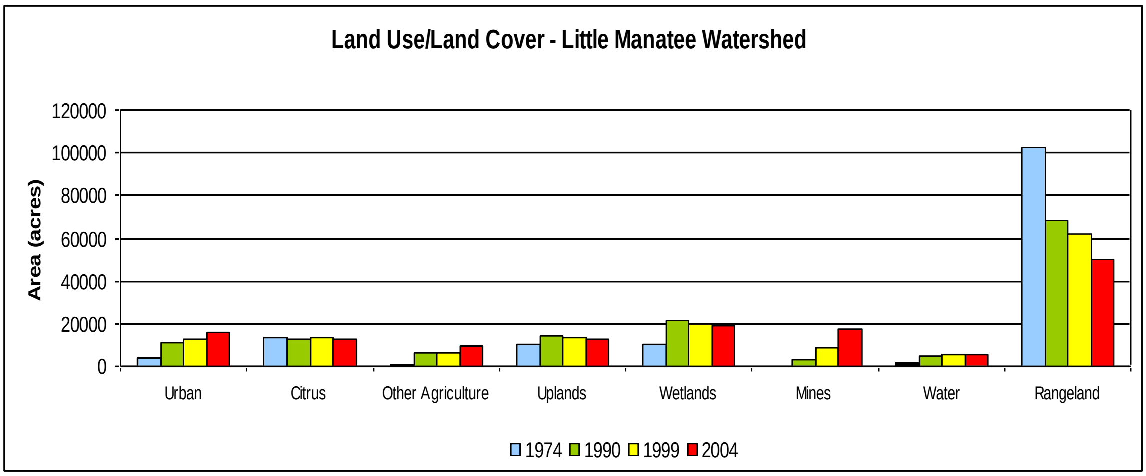


Figure 3-5. Comparison of land use/cover changes in the Little Manatee watershed.

3.1.1 Little Manatee Mainstem Sub-basin

The Little Manatee Mainstem Sub-basin (Table 3-4 and Figure 3-6) is the largest sub-basin delineated for this report. Total area is 41,738 acres (65 square miles). This sub-basin is over 11 miles long and encompasses the majority of the river's floodplain. Most of the urban development in the Mainstem Sub-basin has occurred in the lower central portion from U.S. 301 downstream to I-75. An additional 2500 acres were converted to urban land use between 1974 and 2004.

From 1974 to 2004, the largest increase in land use was for mining. Mining went from 0.1% of the sub-basin (45 acres) in 1974 to nearly 13% of the sub-basin (5280 acres) in 2004. The majority of this mined land was converted from rangeland (Figures 3-7 & 3-8).

Figure 3-8. 1974 and 1990 Land Use/Cover maps of the Mainstem Sub-basin.

Table 3-4. Land use/cover (by percentage) changes in the Little Manatee Mainstem Sub-basin (41,737 acres) for four time periods; 1974, 1990, 1999 and 2004.

Little Manatee - Mainstem	1974	1990	1999	2004
Urban	2.0	5.8	6.6	8.0
Citrus	9.3	7.2	6.0	6.3
Other Agriculture	0.7	4.0	4.4	7.7
Uplands	13.4	11.6	11.0	9.9
Wetlands	8.1	16.8	15.4	14.8
Mines	0.1	0.7	8.3	12.7
Water	2.1	9.0	9.1	9.7
Rangeland	64.2	44.8	39.2	30.9

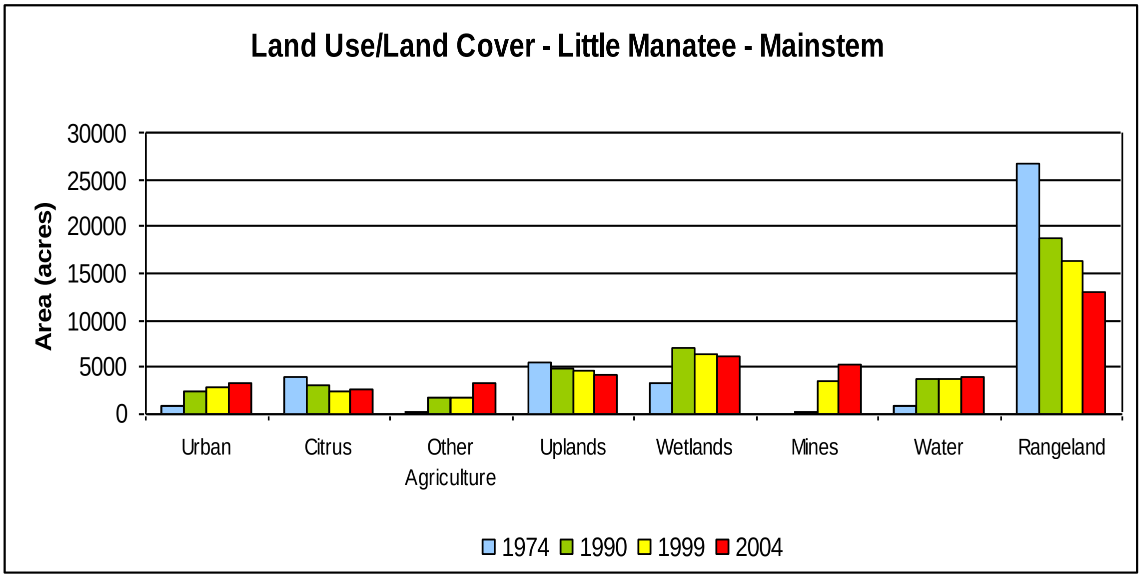


Figure 3-6. Comparison of land use/cover changes in the Little Manatee Mainstem Sub-basin.

Figure 3-9. 1974 and 1990 Land Use/Cover maps of the Mainstem Sub-basin.

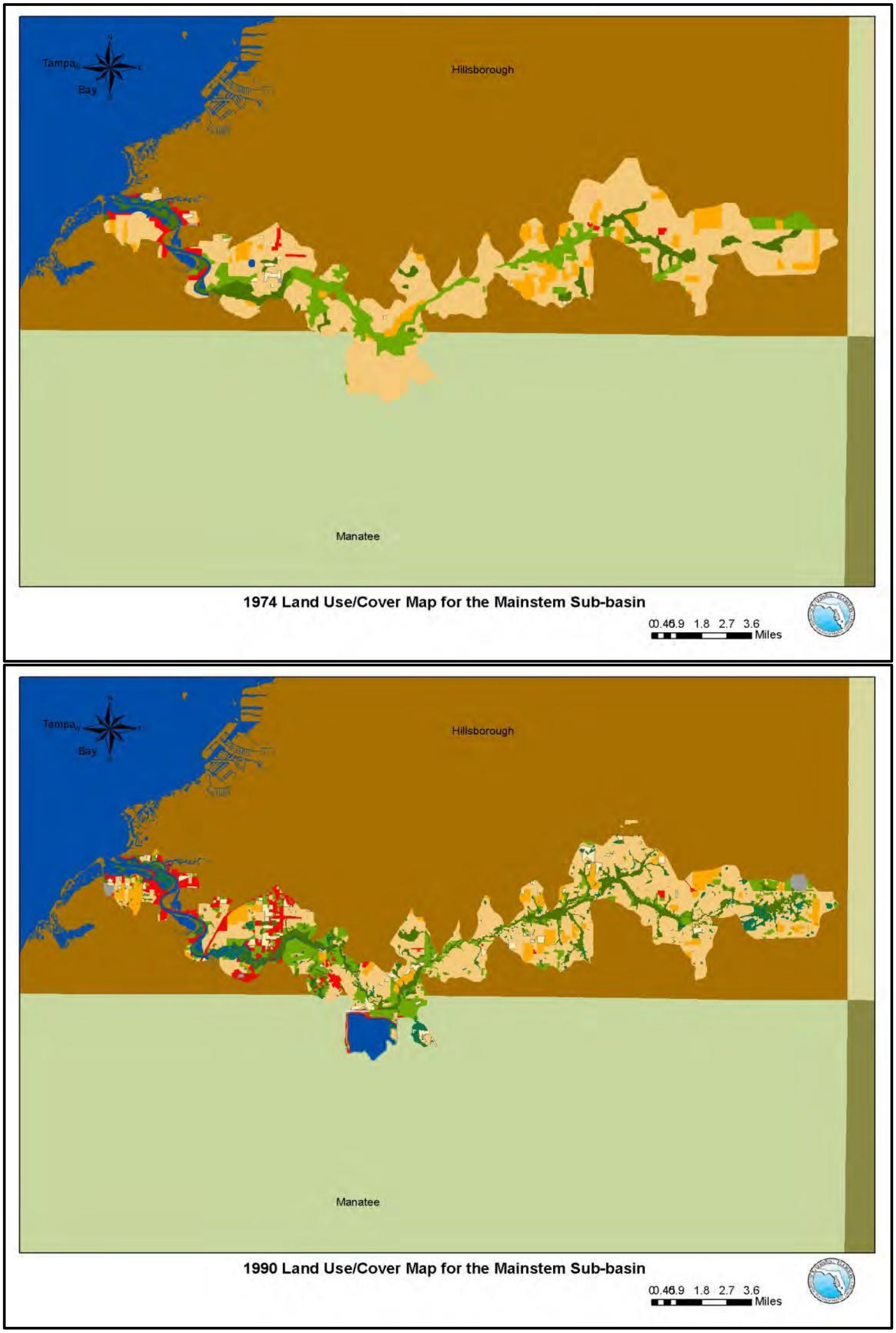
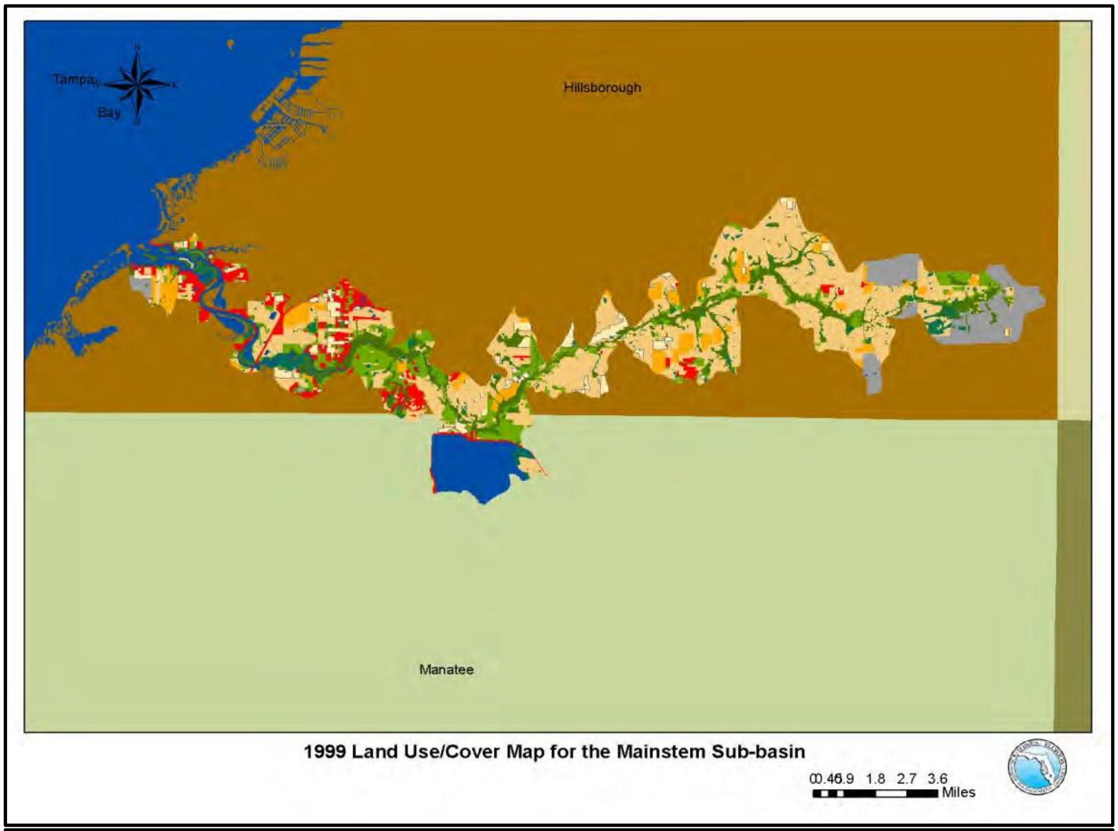


Figure 3-7. 1974 and 1990 Land Use/Cover maps of the Mainstem Sub-basin.



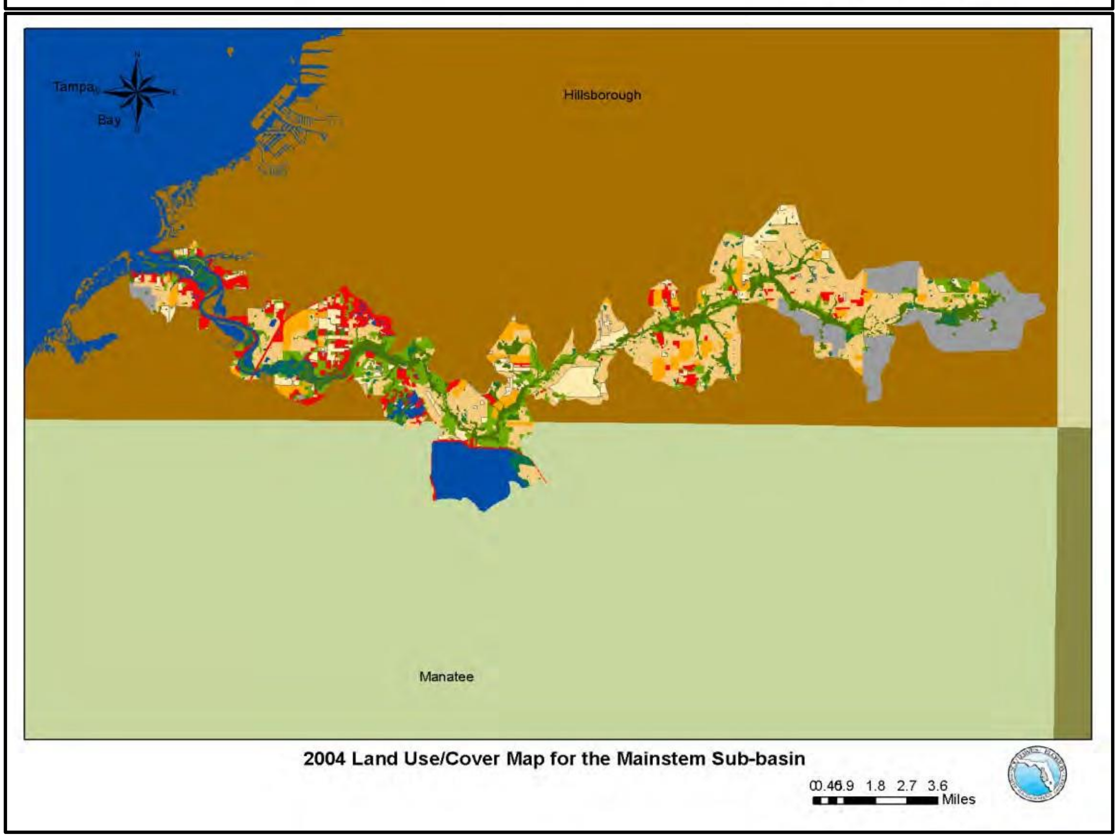


Figure 3-8. 1999 and 2004 Land Use/Cover maps of the Mainstem Sub-basin.

3.1.2 North Central Sub-basin

The North Central Sub-basins grouping includes six sub-basins (Table 3-5). The largest land use/cover increase in the sub-basin has been in the urban land use. In 1974 approximately 6% (1539 acres) of the sub-basin was it urban land use and by 2004 had increased to over 25% (6630 acres) (Table 3-5 & Figure 3-9). The majority of this increase occurred in the western end of the sub-basin (Figures 3-10 & 3-11). Another notable change in the North Central Sub-basin is the reduction in rangeland. From 1974 to 2004 the amount of the sub-basin in rangeland dropped from nearly 17,000 acres to less than 7,500 acres. Most of this loss in rangeland was due to conversion to urbanized areas.

Table 3-5. Land use/cover (by percentage) changes in the North Central Sub-basin (26,260 acres) for four time periods; 1974, 1990, 1999 and 2004.

Little Manatee - NCentral Sub-basin	1974	1990	1999	2004
Urban	5.9	17.9	20.6	25.3
Citrus	17.6	15.4	17.8	13.9
Other Agriculture	1.0	3.9	5.6	9.5
Uplands	2.3	8.6	7.9	7.8
Wetlands	7.4	12.2	11.5	11.6
Mines	0.0	0.0	0.0	0.5
Water	1.3	2.2	2.7	2.9
Rangeland	64.5	39.8	33.9	28.5

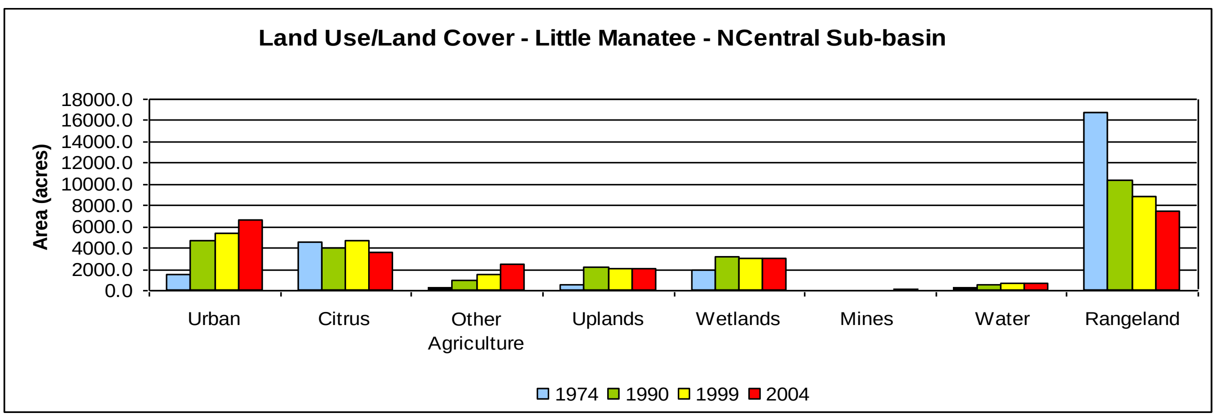


Figure 3-9. Comparison of land use/cover changes in the North Central Sub-basin.

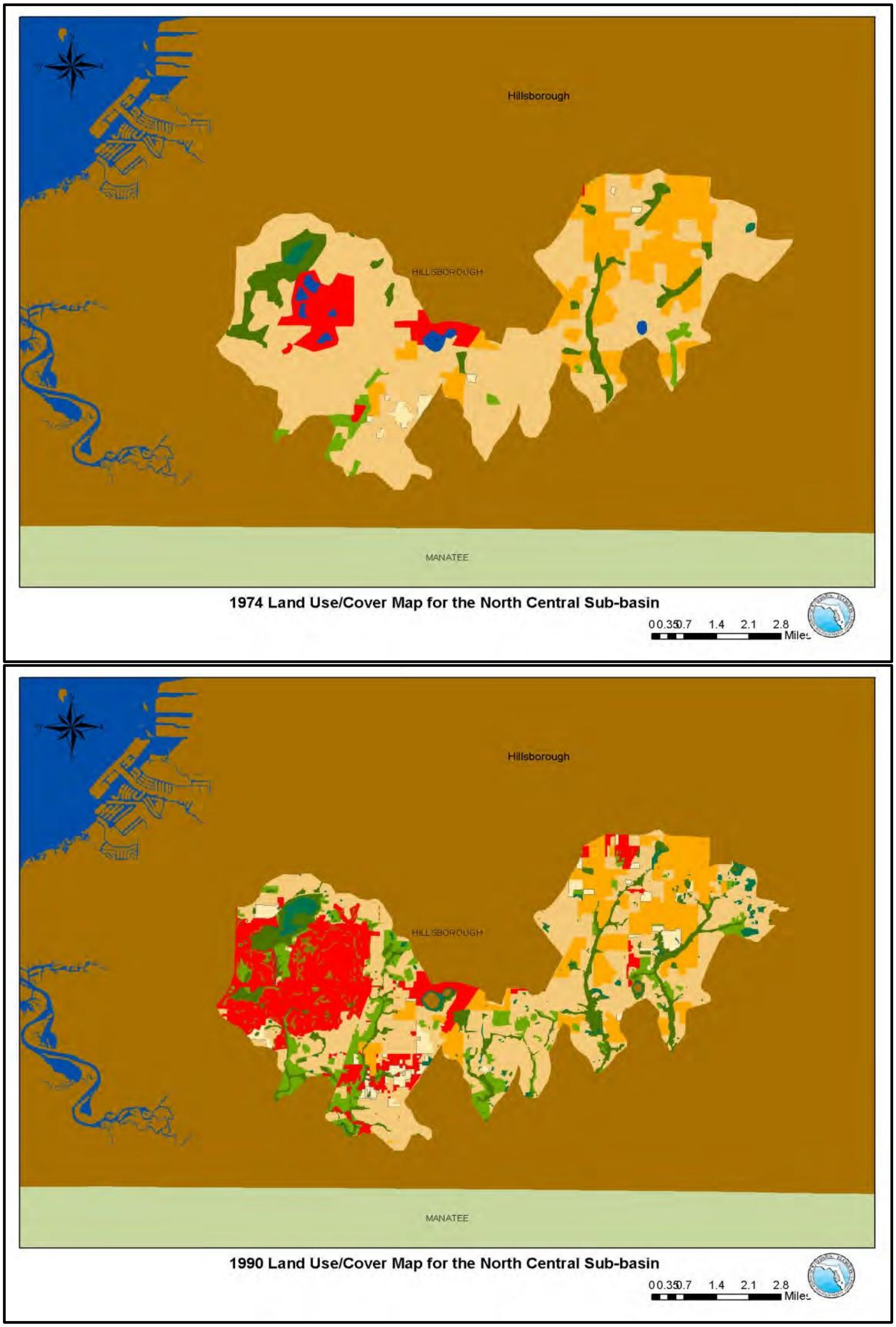
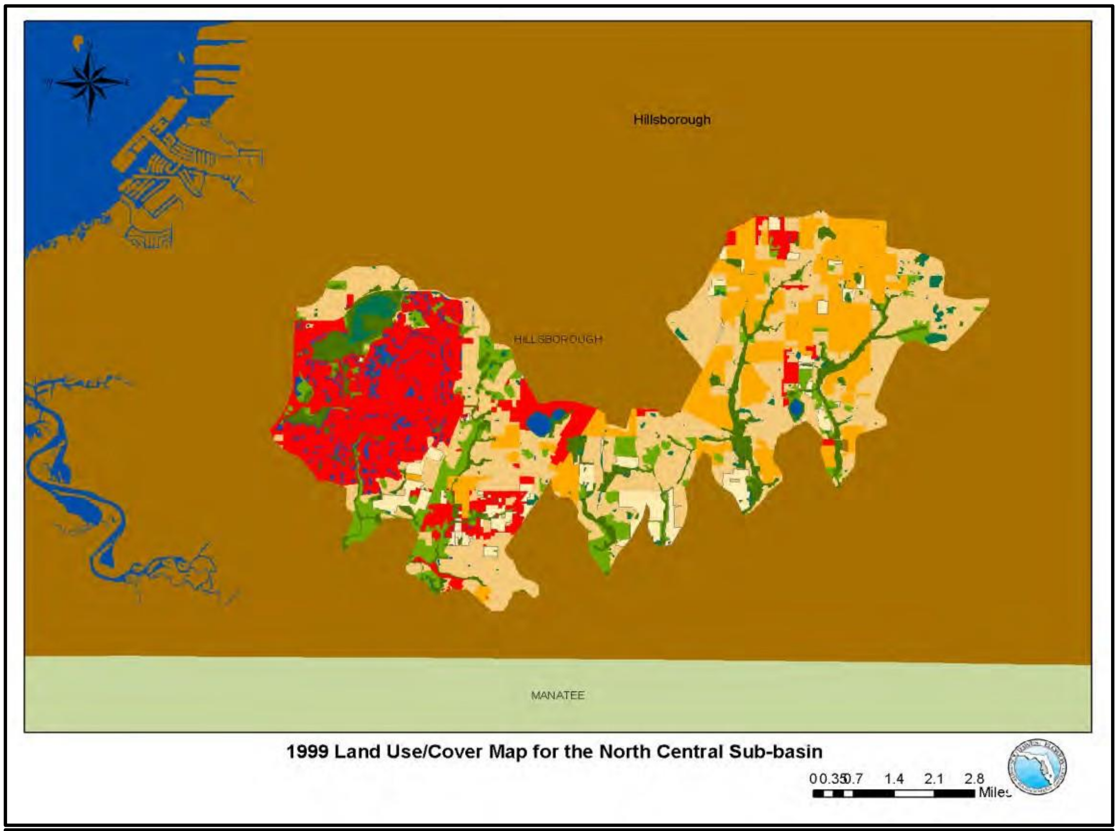


Figure 3-10. 1974 and 1990 Land Use/Cover maps of the North Central Sub-basin.



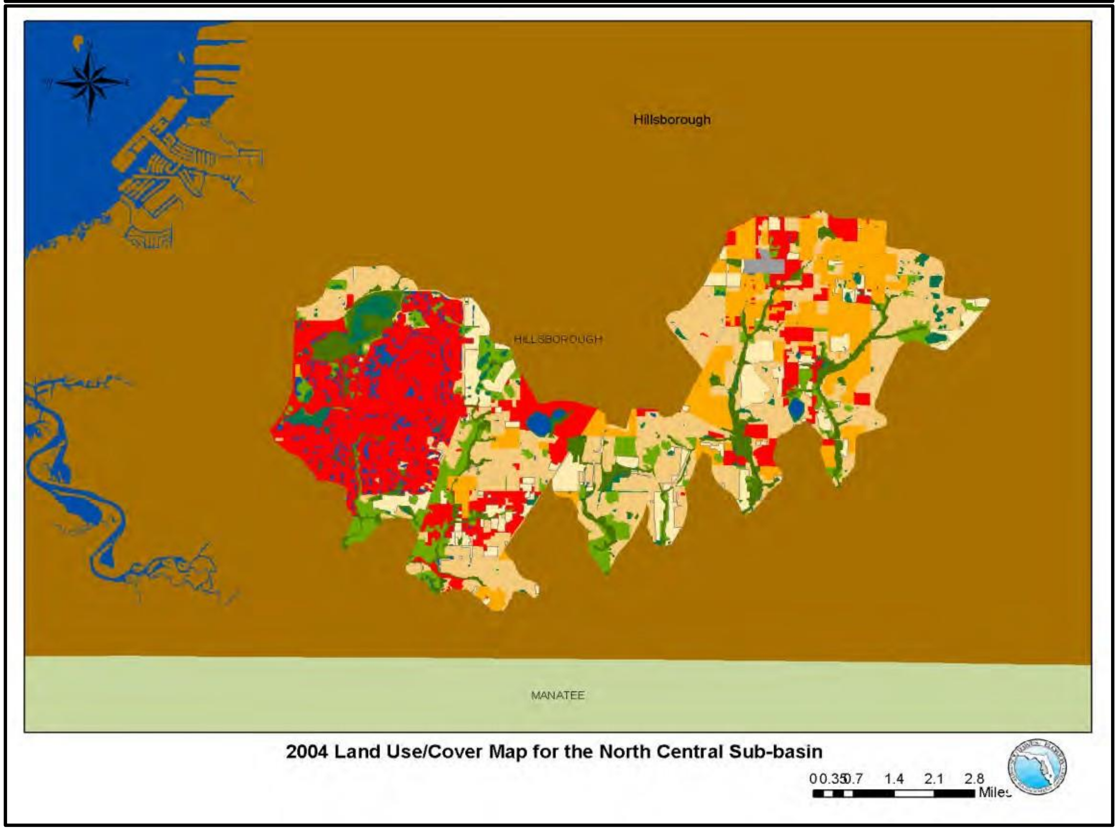


Figure 3-11. 1999 and 2004 Land Use/Cover maps of the North Central Sub-basin.

3.1.3 South Fork Sub-basin

The South Fork Sub-basin grouping includes five sub-basins (Table 3-6). Urban land use has increased moderately with less than one thousand acres being converted between 1974 and 2004 (Table 3-6 and Figure 3-12). Most of the urbanization has occurred on lands previously occupied by rangelands.

Mining in the South Fork Sub-basin has grown a little more rapidly increasing from 0% of the sub-basin in 1974 to 7.3% of the sub-basin in 2004 (Figure 3-13 & 3-14). That was a conversion of approximately 1830 acres, most of which was previously rangeland. During this period rangeland has declined from 75% (18,700 acres) of the sub-basin to less than 50% (12,250 acres) of the sub-basin. This is probably partial an artifact of the classifications systems utilized for the 1974 mapping versus the later mappings.

Table 3-6. Land use/cover (by percentage) changes in the South Fork Sub-basin (25,053 acres) for four time periods; 1974, 1990, 1999 and 2004.

Little Manatee - SFork Sub-basin	1974	1990	1999	2004
Urban	0.0	0.1	3.7	3.3
Citrus	6.3	10.1	11.1	10.7
Other Agriculture	0.0	3.6	3.6	3.8
Uplands	9.2	17.0	14.7	13.2
Wetlands	9.8	13.6	12.6	12.7
Mines	0.0	0.1	0.3	7.3
Water	0.1	0.2	0.2	0.2
Rangeland	74.6	55.3	53.8	48.9

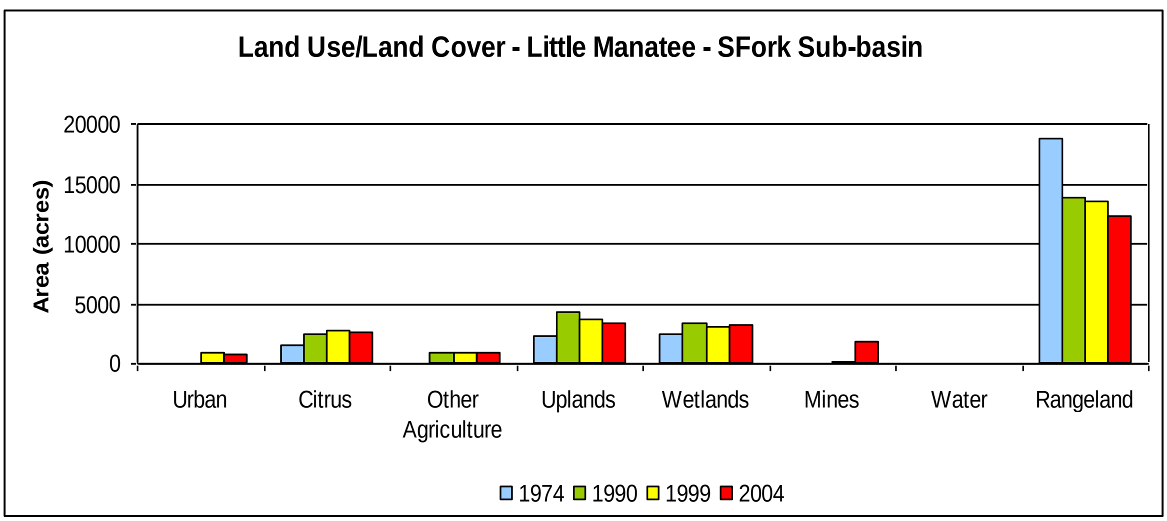


Figure 3-12. Comparison of land use/cover changes in the South Fork Sub-basin.

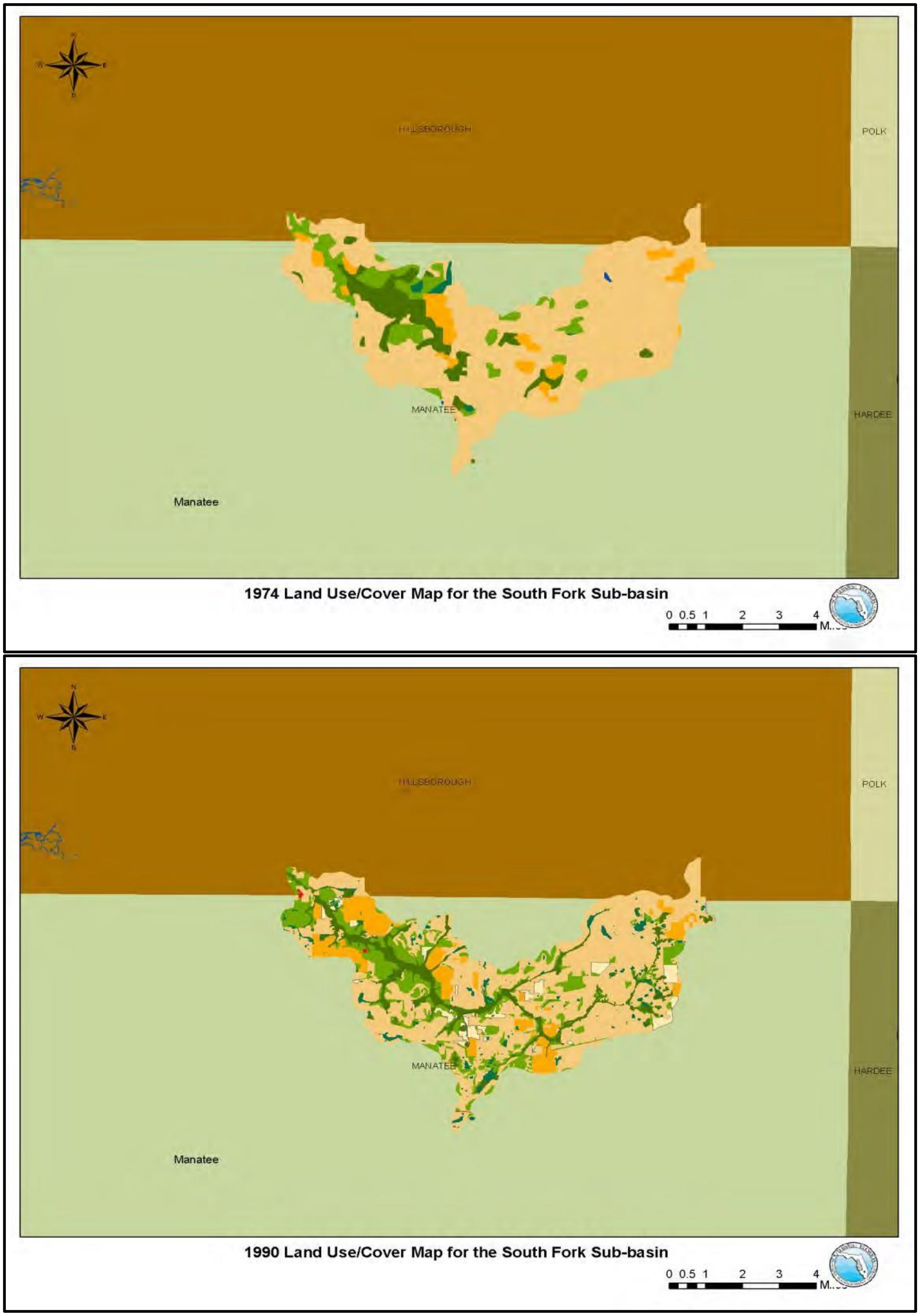
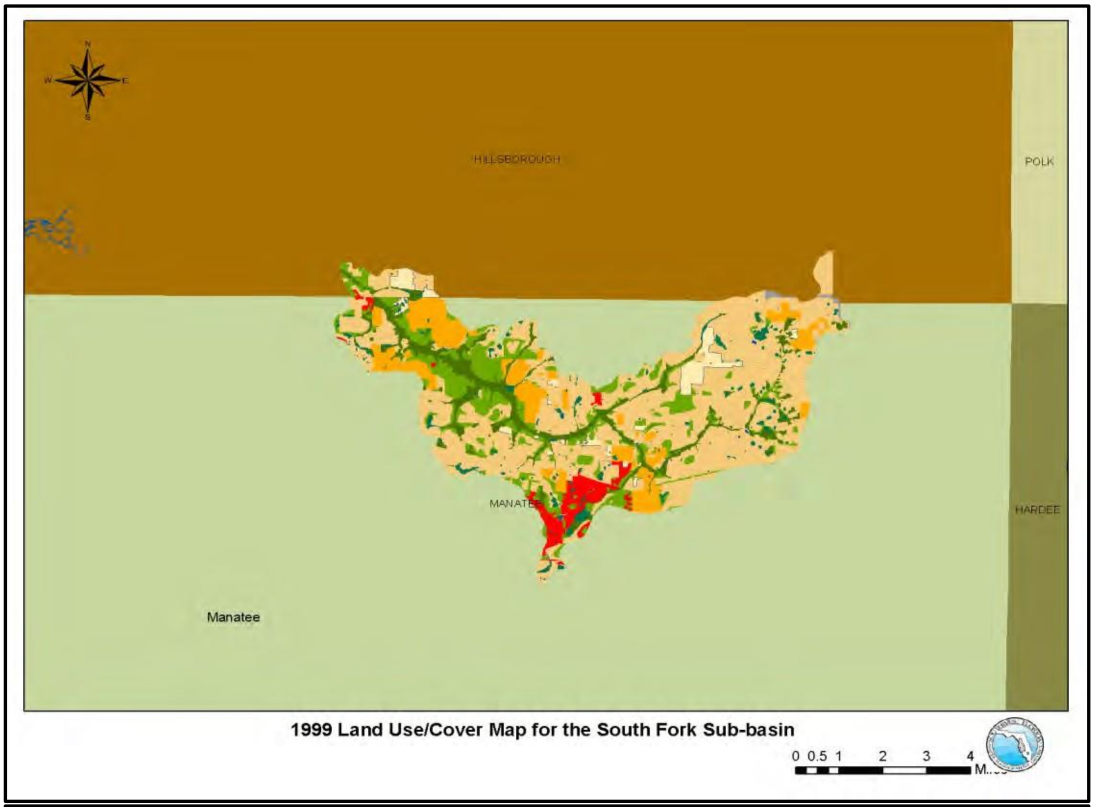


Figure 3-13. 1974 and 1990 Land Use/Cover maps of the South Fork Sub-basin.



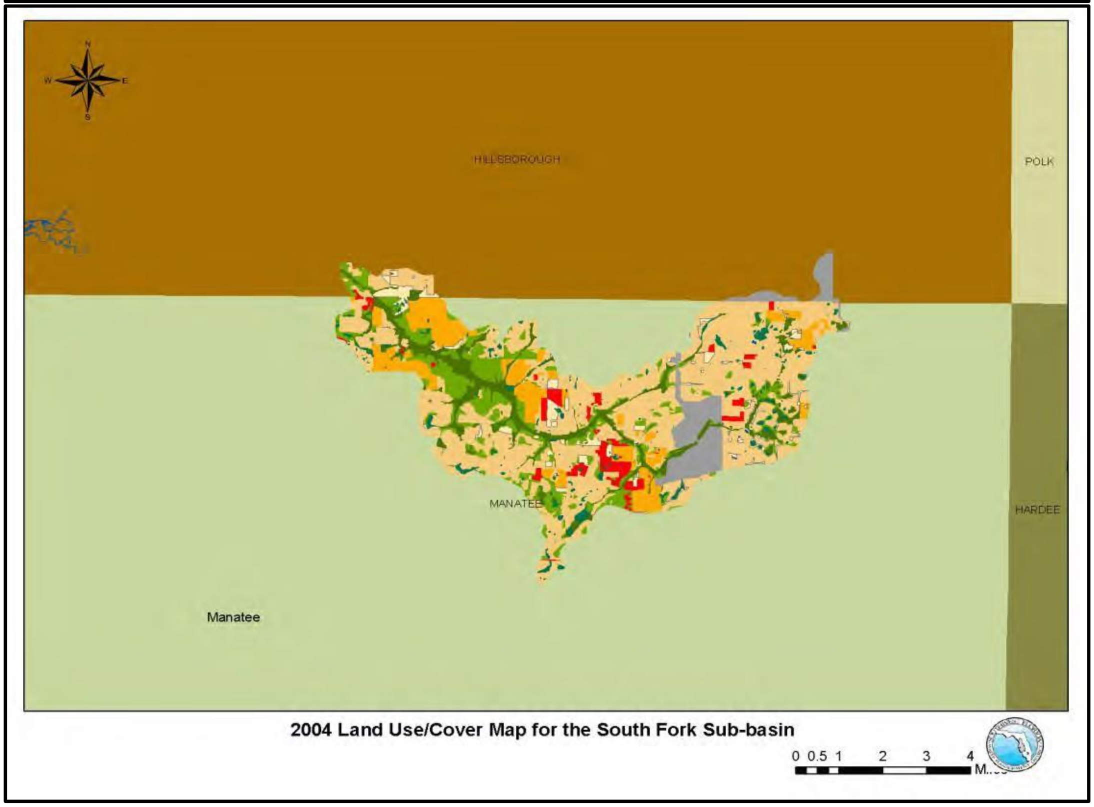


Figure 3-14. 1999 and 2004 Land Use/Cover maps of the South Fork Sub-basin.

3.1.4 Southwest Sub-basin

The Southwest Sub-basin grouping includes six sub-basins (Table 3-7). The sub-basin saw the largest developmental increase in urban land use. The majority of this increase was seen between 1974 and 1990. During this period urban land use increased from less than 1% (192 acres) to over 11% (2642 acres) of the sub-basin (Table 3-7 & Figure 3-15). The vast majority of this urban land use was converted from rangeland (Figure 3-16 & 3-17).

It should be noted that the large jump in wetlands and uplands from 1974 to 1990 is probably partially due to mapping technique/resolution differences and most likely does not show a true land cover conversion. Utilize in previous highlighted area!!!

Table 3-7. Land use/cover (by percentage) changes in the Southwest Sub-basin (22,770 acres) for four time periods; 1974, 1990, 1999 and 2004.

Little Manatee - SW Sub-basin	1974	1990	1999	2004
Urban	0.8	8.6	8.2	11.6
Citrus	5.5	8.4	11.2	11.2
Other Agriculture	0.0	4.2	6.4	7.5
Uplands	5.5	9.1	10.0	9.2
Wetlands	6.8	20.0	19.4	19.5
Mines	0.0	0.1	0.0	0.0
Water	0.7	1.4	1.5	1.5
Rangeland	80.7	48.3	43.4	39.4

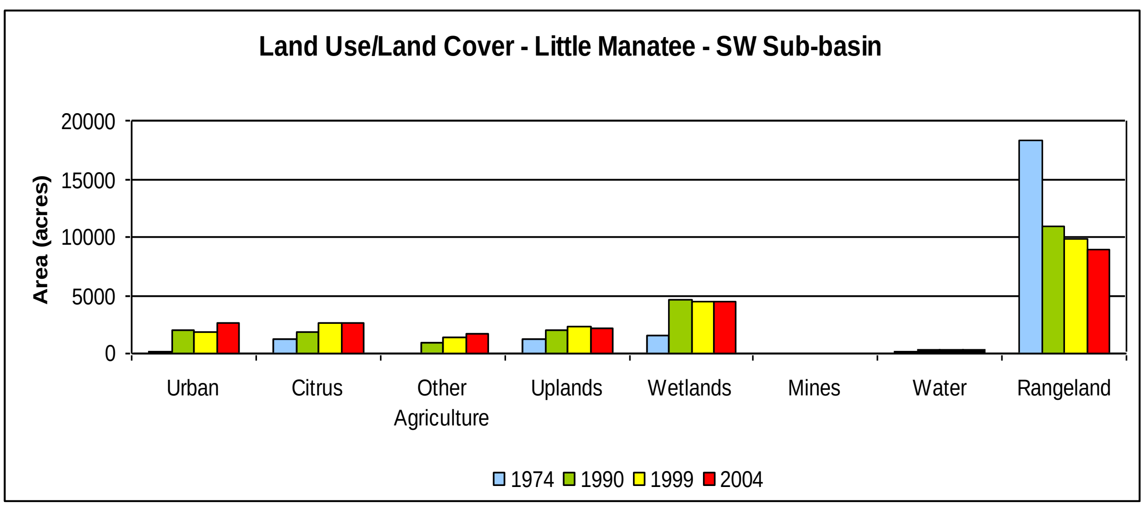
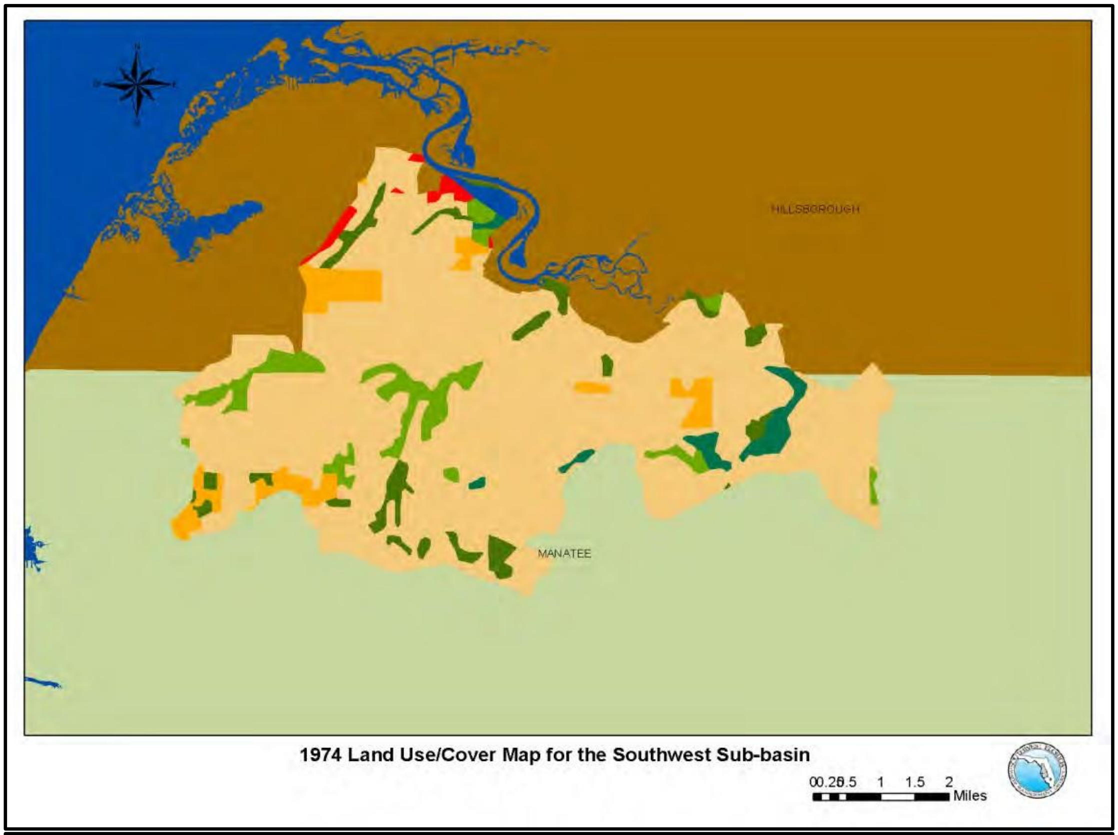
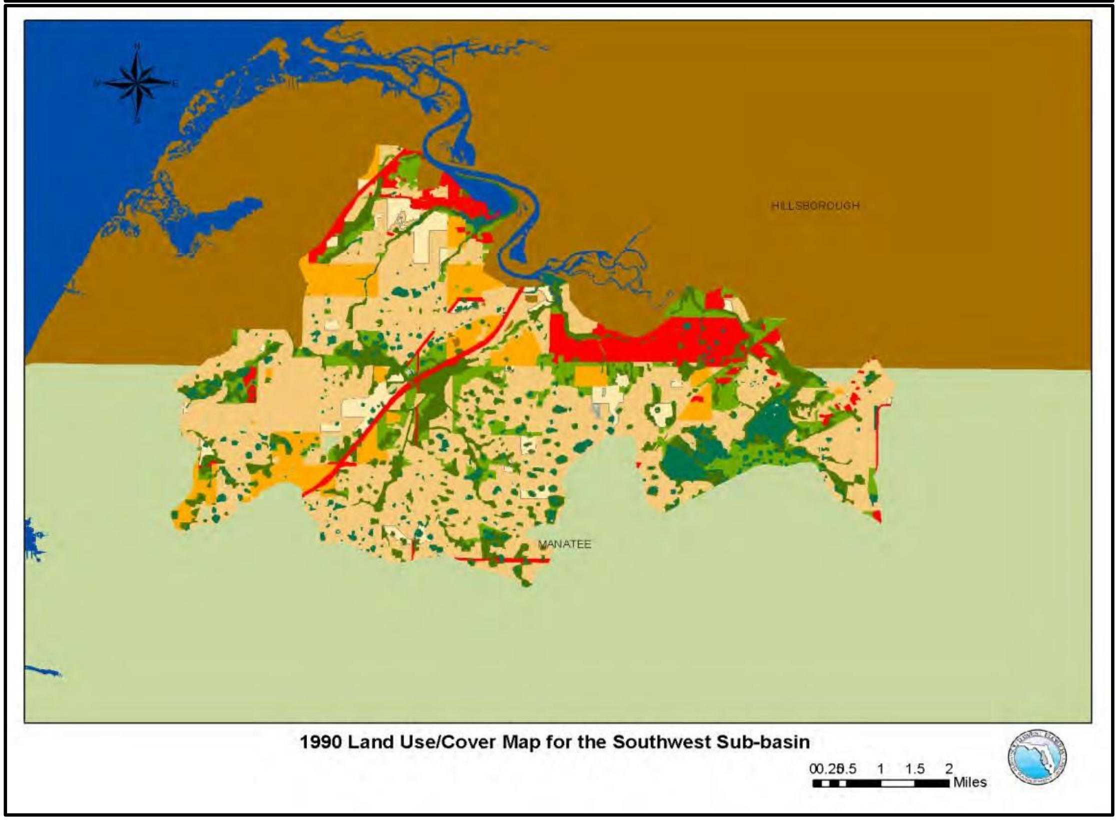


Figure 3-15. Comparison of land use/cover changes in the Southwest Sub-basin.

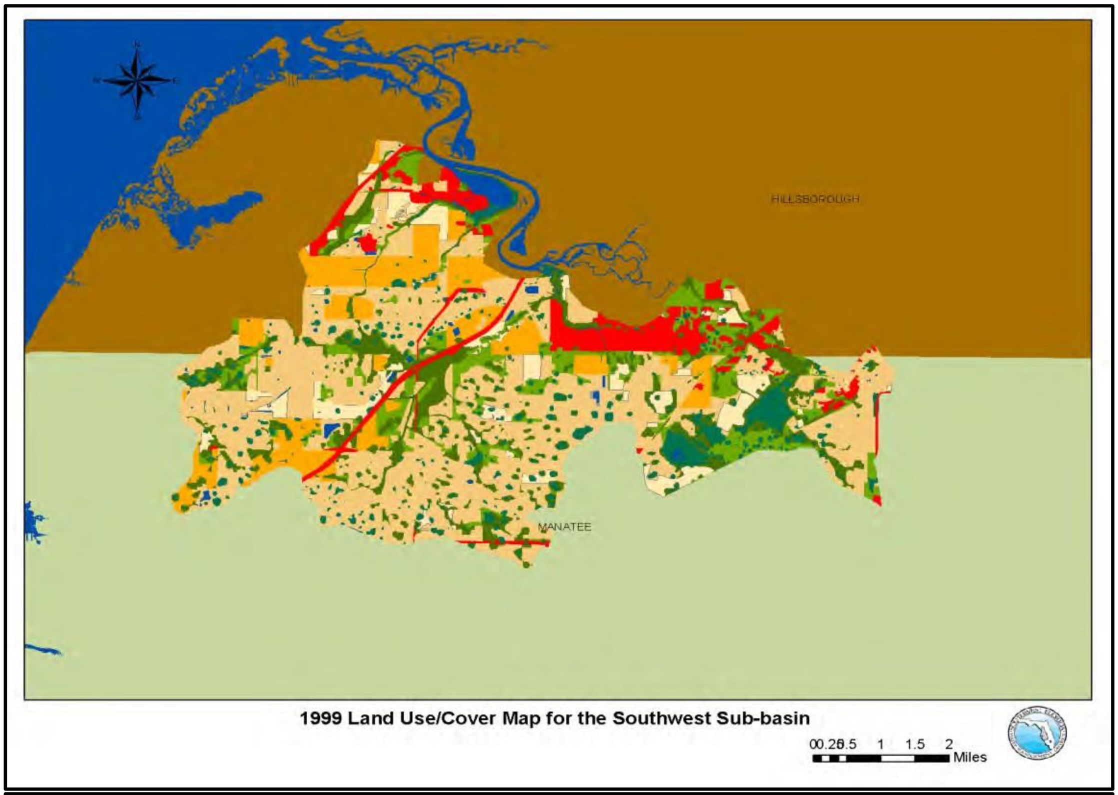


1974 Land Use/Cover Map for the Southwest Sub-basin



1990 Land Use/Cover Map for the Southwest Sub-basin

Figure 3-16. 1974 and 1990 Land Use/Cover maps of the Southwest Sub-basin.



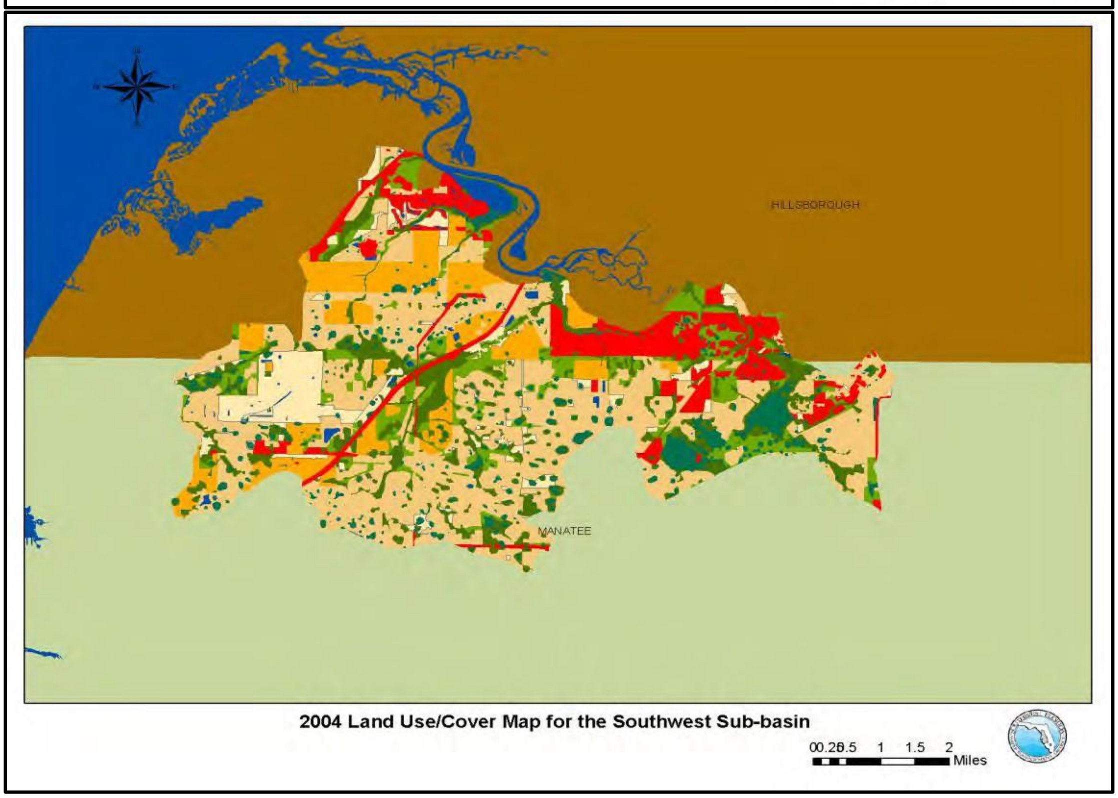


Figure 3-17. 1999 and 2004 Land Use/Cover maps of the Southwest Sub-basin.

3.1.5 Southeast Sub-basin

The Southeast Sub-basin grouping includes four sub-basins (Table 3-8). This sub-basin had the most growth of mining land use of all sub-basins delineated for this report (Table 3-8 & Figure 3-18). Mining category may include, in addition to lands under active mining, lands in various stages of reclamation. In 1974 there was no mining land use in the Southeast Sub-basin and by 2004 over 47% (10,377 acres) of the sub-basin had been converted, mostly from rangeland, to mining (Figure 3-19 & 3-20).

The Southeast sub-basin has the least urbanization of all sub-basins delineated for this report. From 1974 to 2004 there has been less than 2% (382 acres) of the sub-basin converted to urban land use. Nearly all of the urban land use is in a low-density residential area off of Keene Road in Hillsborough County that was previously in citrus groves.

Table 3-8. Land use/cover (by percentage) changes in the Southeast Sub-basin (21,980 acres) for four time periods; 1974, 1990, 1999 and 2004.

Little Manatee - SE Sub-basin	1974	1990	1999	2004
Urban	0.0	0.0	0.4	1.7
Citrus	5.0	3.4	3.9	3.9
Other Agriculture	0.0	4.2	2.1	3.0
Uplands	3.8	3.8	3.7	2.3
Wetlands	4.2	13.6	11.2	9.7
Mines	0.0	13.4	24.3	47.2
Water	0.3	0.1	0.1	0.1
Rangeland	86.8	61.5	54.2	32.1

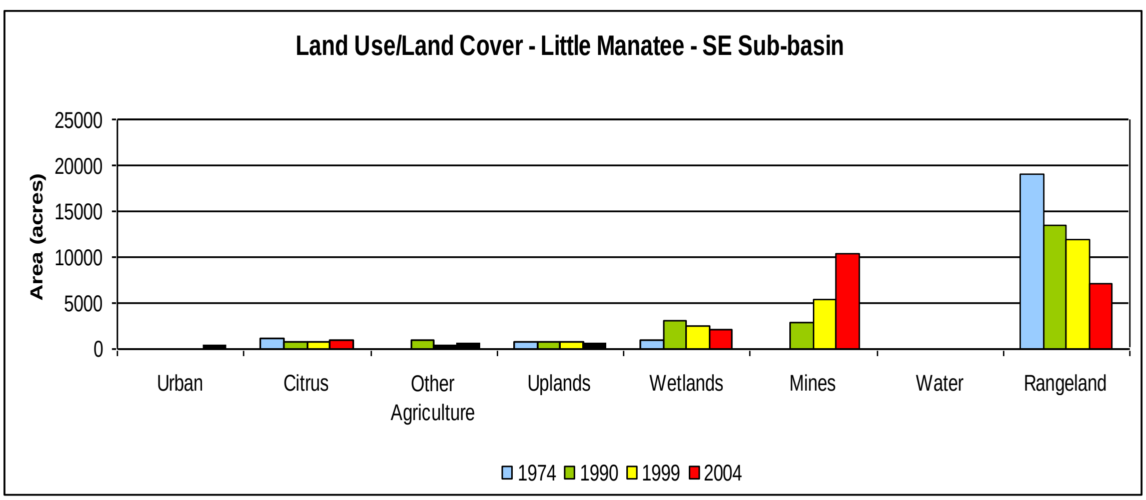
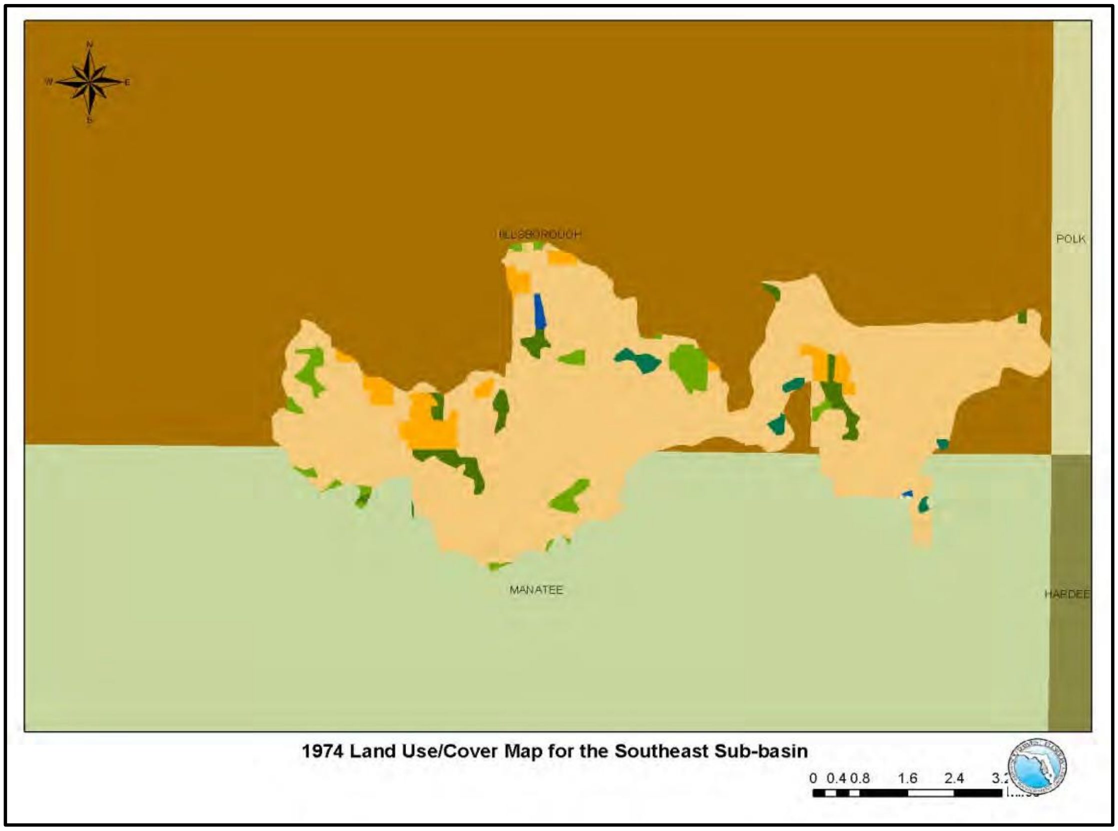


Figure 3-18. Comparison of land use/cover changes in the Southeast Sub-basin.



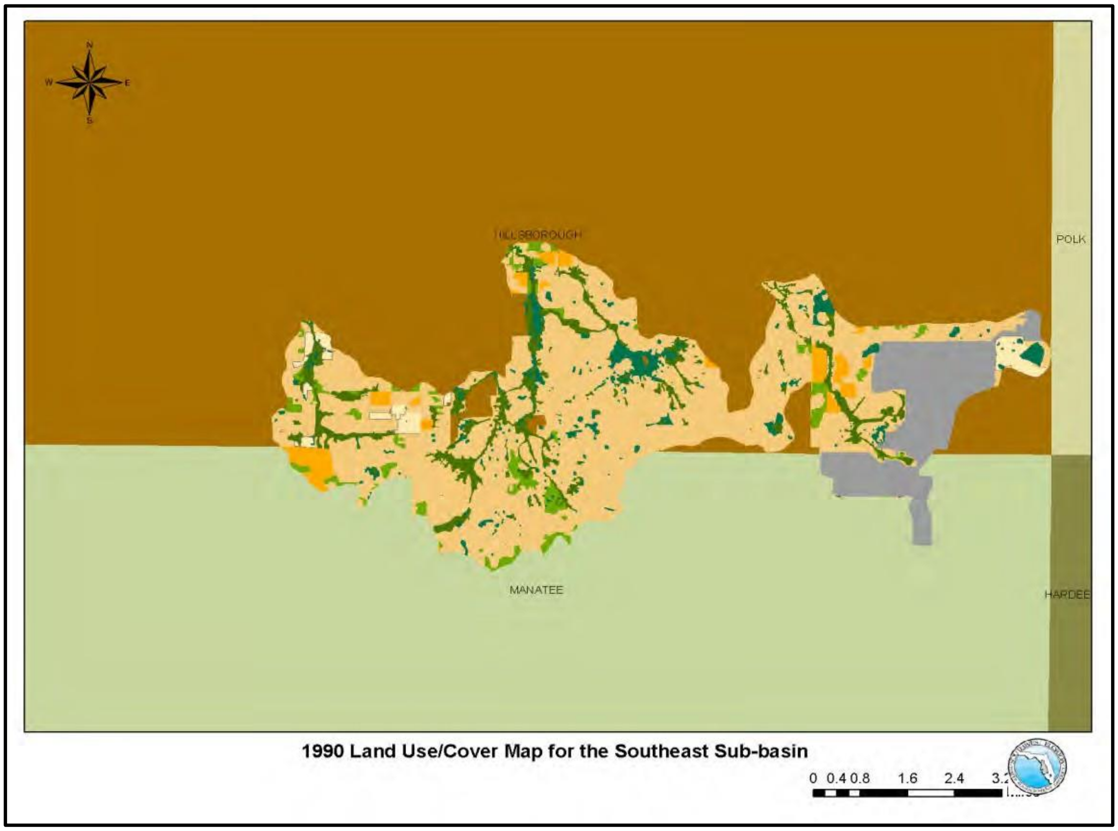
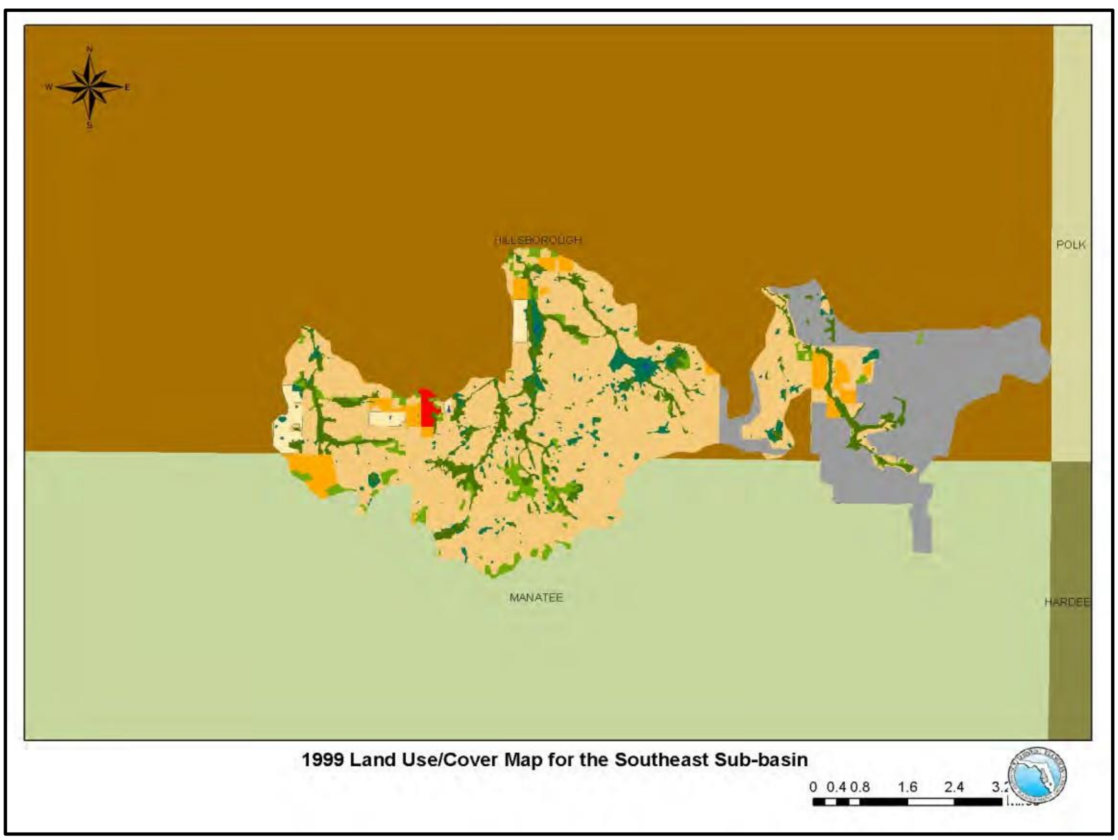


Figure 3-19. 1974 and 1990 Land Use/Cover maps of the Southeast Sub-basin.



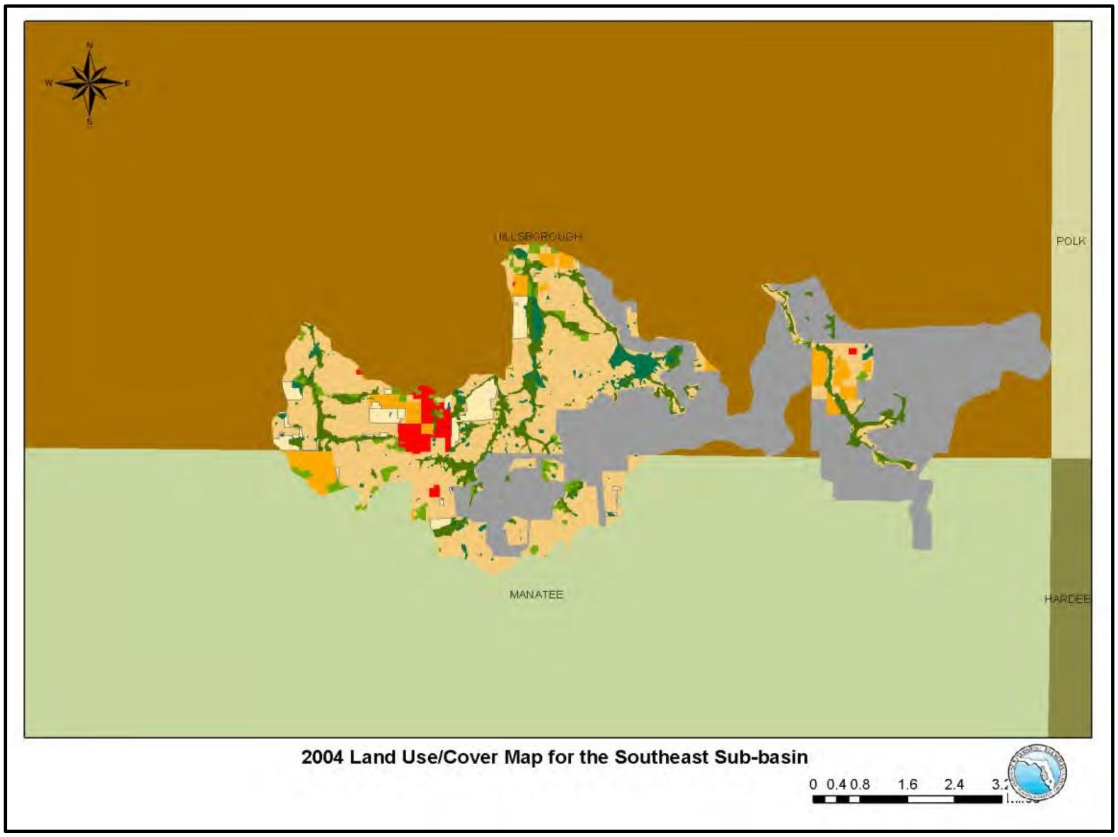


Figure 3-20. 1999 and 2004 Land Use/Cover maps of the Southeast Sub-basin.

3.1.6 Northwest Sub-basin

The Northwest Sub-basin grouping includes two sub-basins (Table 3-9). This sub-basin is the smallest sub-basin (5253 acres) delineated for this report and contains no mining land use (Table 3-9 & Figure 3-21).

The Northwest Sub-basin has had only moderate land conversions with the largest single land use being urban. Urban land use in the sub-basin grew from 27% (1392 acres) of the sub-basin in 1974 to 39% (2068 acres) of the sub-basin in 2004. The urbanized areas within the sub-basin are fairly equally distributed. The majority of land converted for urban land use were previously citrus and rangelands.

Table 3-9. Land use/cover (by percentage) changes in the Northwest Sub-basin (21,980 acres) for four time periods; 1974, 1990, 1999 and 2004.

Little Manatee - NW Sub-basins	1974	1990	1999	2004
Urban	26.5	41.2	37.6	39.4
Citrus	16.1	10.9	10.0	11.8
Other Agriculture	5.4	9.4	9.6	10.1
Uplands	2.5	5.8	5.9	5.9
Wetlands	2.9	5.9	6.3	6.2
Mines	0.0	0.3	0.2	0.0
Water	3.7	5.1	5.2	5.3
Rangeland	42.9	21.4	25.2	21.3

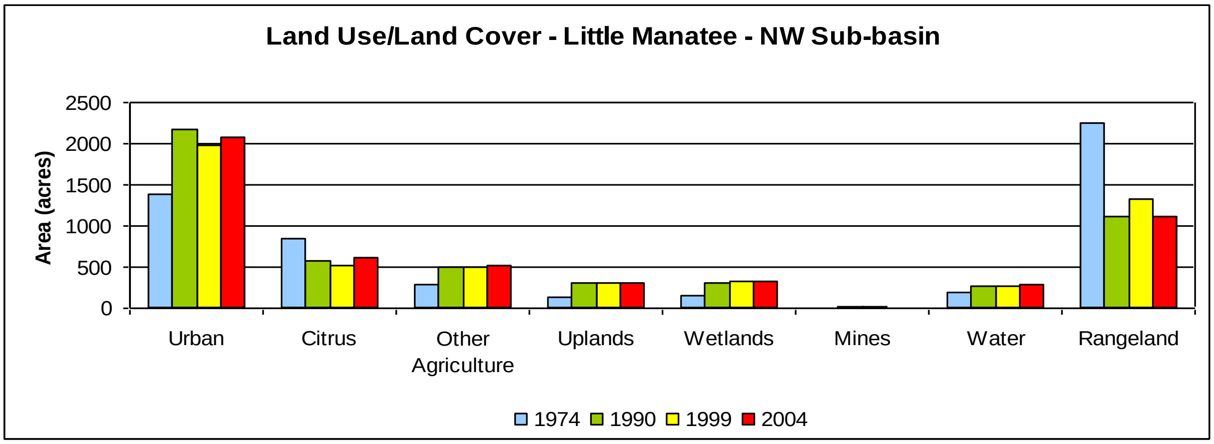


Figure 3-21. Comparison of land use/cover changes in the Northwest Sub-basin.

4 Hydrology

4.1 Overview

The Little Manatee River basin comprises about 10% of the entire Tampa Bay watershed. The mean discharge for the river is 170 cubic feet per second (cfs) based on data from the USGS Little Manatee River near Wimauma (02300200) gage for the period 1940 to 2009 corrected as discussed in Section 4.2 (Figure 4-1). Figure 4-1 also displays data as reported by USGS (not corrected for agriculture runoff or FPL withdrawals).

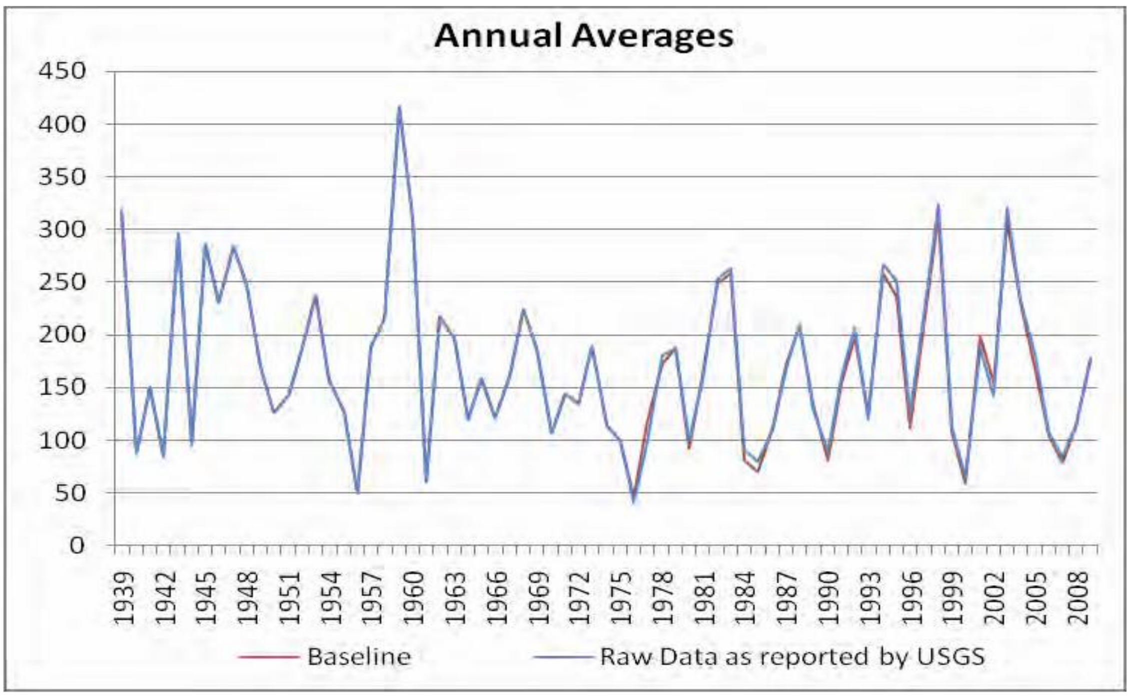


Figure 4-1. Mean annual discharge for the Little Manatee River near Wimauma USGS gage.

4.2 Little Manatee River Flow Trends

Flows on the Little Manatee River were analyzed to determine possible increases or decreases due to various factors. This included analyses of withdrawals, land use and rainfall trends to assist in developing a flow record that is representative of natural conditions. A baseline flow record corrected for anthropogenic effects is useful for analyses of flow reductions.

4.2.1 Effects of Land Use Changes on River Flows

One of the most significant changes in the watershed has been an increase in agricultural land use. The amount of citrus in the watershed has remained fairly constant over the 30 years of analysis (1974-2004). However, there has been a large increase in row crops, which are included in the other agriculture category. The other agriculture category increased from 840 acres to 9604 acres from 1974-2004, over a ten-fold increase. These row crops are largely for vegetables, with tomatoes being the primary crop, but cucumbers, melons, strawberries and other crops are grown as well.

In addition to an increase in agricultural land cover, there has been a large increase in agricultural water use. Increasing groundwater use in the southern part of the District, generally south of Interstate 4, has resulted in declining water levels and saltwater intrusion in the Floridan aquifer, impacts to water levels in lakes in the Highlands Ridge, and reduced flows in the Upper Peace River. In response to these concerns, the District established the Highlands Ridge and Eastern Tampa Bay Water Use Caution Areas in 1989. An overarching Southern Water Use Caution Area (SWUCA) was established in 1992 that includes all or portions of eight counties in the Southern portion of the District, including the areas of Hillsborough and Manatee Counties that comprise the Little Manatee River watershed. In 2007, a recovery strategy for the SWUCA that was adopted by the District Governing Board became effective to address resource concerns. However, regulatory programs to address resource issues within the SWUCA had been ongoing for quite some time.

The Little Manatee River basin lies within the sub-region of the SWUCA formerly designated as the Eastern Tampa Bay Water Use Caution Area, which includes all of Manatee County, the southern half of Hillsborough County, and small region in northern Sarasota County (Figure 4-2). The effects of increasing water use on saltwater intrusion has been particularly acute in the area, and a special sub-region designated as the Most Impacted Area was established over the western half in order to more tightly control coastal groundwater withdrawals. Approximately half of the Little Manatee River watershed lies within the Most Impacted Area (Figure 4-2).

Resource issues within the Eastern Tampa bay region were summarized in a report for the Eastern Tampa Bay Water Resource Assessment Project (ETB-WRAP). That report (SWFWMD, 1993) presented extensive information regarding the status and trends in land and water use, groundwater levels, and groundwater quality in the region (prior to 1992). The report found that agricultural water use had increased dramatically since the 1950s. Acknowledging that water use estimates prior to 1970 are meager, the report cited Peek (1958) who determined that average water use in Manatee county was 15 to 20 million gallons per day (mgd) in 1958. By contrast, estimated total water use in the ETB region had increased to 269 mgd in 1990. Of this quantity, agriculture accounted for 55 percent of the total water use and 69 percent of the groundwater use in the region. Large increases were reported in the acreage and irrigation quantities for tomatoes and other vegetable crops in the region. Even though the acreage of citrus did not increase, the proportion of citrus that was irrigated had increased resulting in a net increase in irrigation use.

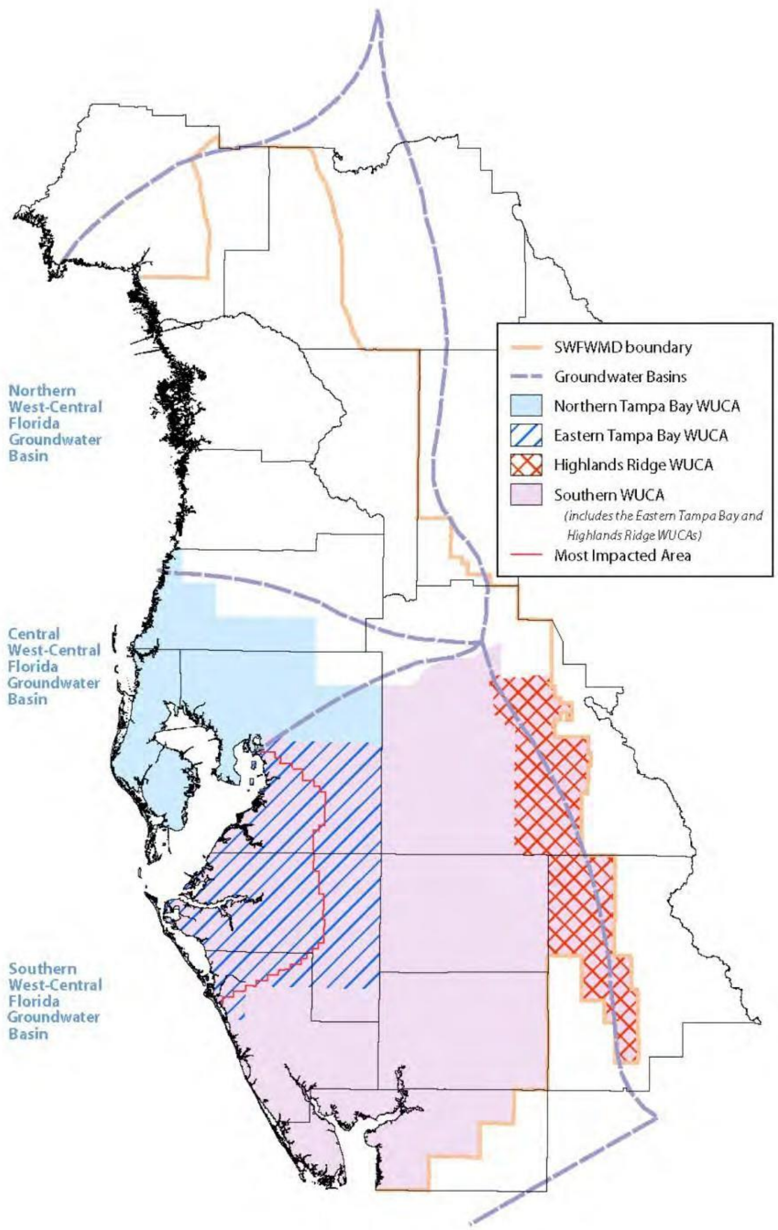


Figure 4-2. Approximate boundaries of the major groundwater basins in the SWFWMD and delineation of the four Water Use Caution Areas, including the Most Impacted Area within the Eastern Tampa Bay Water Use Caution Area.

Since the ETB WRAP report was published, trends in water use throughout the District have been presented in a series of Estimated Water Use Reports, with the most recent published for 2009 data (SWFWMD 2011). That report found there was an average of 64 mgd agricultural water use in Hillsborough County, with strawberries, citrus, and tomatoes receiving the highest use. Estimated agricultural water use in Manatee County was 72 mgd with citrus, tomato, and vegetables receiving the highest use.

Nearly all agricultural water users in the region hold water use permits issued by the SWFWMD, since the water quantities for these uses trip the criteria established by the District requiring a water use permit. A map of permitted wells for groundwater withdrawals located within the Little Manatee River watershed is shown in Figure 4-3. These wells include withdrawals for agricultural irrigation, aquaculture, public supply, recreational (chiefly golf courses), and mining. The symbols in Figure 4-3 are grouped into different size classes of withdrawals based on their permitted average annual daily use, ranging from less than 0.25 mgd to greater than 2.5 mgd. More than one well may be associated with a single water use permit.

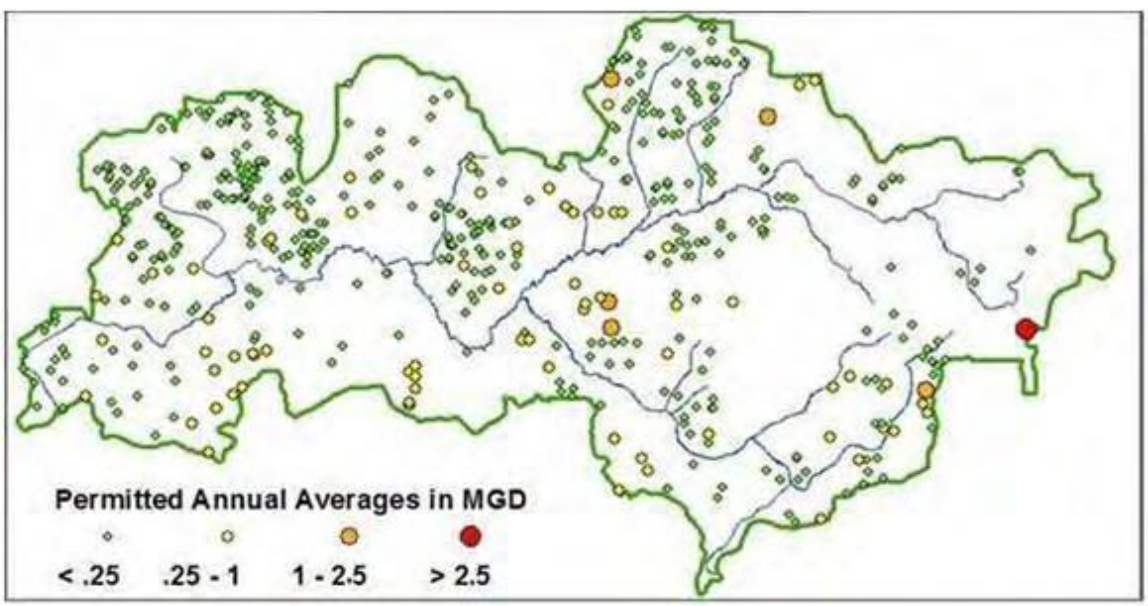


Figure 4-3. Location and permitted quantities for wells for groundwater withdrawals within the Little Manatee River watershed.

The total permitted groundwater use in the watershed is approximately 85 mgd, with agricultural water use comprising 74% of this amount. There are a number of large individual agricultural operations in the basin, with five permit holders having permitted annual water use quantities over 2 mgd. The Mosaic Company is permitted to withdraw an annual average of 3.6 mgd in the easternmost portion of the watershed for mining operations, shown by the red dot in Figure 4-3.

It is important to emphasize the quantities cited above are annual average permitted amounts established in water use permits. Restrictions are also put in water use permits on peak month use. By regulation, withdrawals are not to exceed the permitted average annual and peak month quantities. However, actual pumpage can be less than the permitted quantities. The information cited above is presented to provide an overview of water use in the Little Manatee River basin.

As will be discussed in Section 4.2.5, increasing agricultural water use has resulted in increased flows in the Little Manatee River. However, this augmentation of streamflow has likely varied through time, for not only has the total amount of land in agriculture changed over time, but agricultural water use practices have changed as well. With the implementation of the Water Use Caution Area rules in 1989, rule requirements for higher irrigation efficiency resulted in reductions in quantities withdrawn through conversion to higher-efficiency irrigation systems and improved system management. In recent years, there has been an increased emphasis on improving the efficiency of agricultural water use through the implementation of Best Management Practices (BMPs), including conversion of irrigation systems to more efficient technologies (e.g. from seepage irrigation to drip irrigation) and use of weather stations, soil moisture sensors, evapotranspiration (ET) sensors and automated valves. Additional BMPs are designed to reduce the amount of groundwater used, to be replaced by surface water sources, through the construction of surface water reservoirs to capture stormwater and tailwater for reuse, and through rainwater harvesting in greenhouse nurseries.

Replacement of groundwater with surface water will reduce the overall amount of water added to the river and its tributaries by agricultural lands. Specifically, some of the BMPs being implemented are partially funded through the District‟s Facilitating Agricultural Resource Management Systems (FARMS) cost-share program. As of August, 2011, there are six (6) FARMS projects located in the Little Manatee River Watershed, including three (3) surface water reservoir projects, a rainwater harvesting project, an irrigation conversion from seepage to center pivot, and an electronics project involving the use of a weather station, soil moisture and ET sensors, and automated valves. Increases in water use associated with farming are not expected in the western half of the watershed due to the region‟s designation as part of the Most Impacted Area, where new groundwater quantities in the Floridan aquifer are generally not available. Increases in groundwater quantities in the eastern half of the watershed may occur if agricultural lands are converted from pasture, rangeland or citrus to row crop production, as row crops generally require higher quantities of irrigation water.

4.2.2 Long-term Rainfall Trends

As will be discussed in Section 4.2.6, various streamflow parameters have shown significant increasing trends at the long-term streamflow gage on the Little Manatee River. To determine if changes in seasonal or yearly rainfall may be related to these trends, long-term changes in rainfall were examined for the two data sources. Deviations from average for yearly rainfall totals and running three-year average rainfall values are plotted for the Bradenton-Plant City average values and the District watershed estimates in Figure 4-4. Both data sources show similar long-term patterns, with a period of above average rainfall in the late-1950s, a prolonged dry period in the 1970s through 1981, wet years in 1994 and 1995, a major drought from 1999 to 2001, wet years from 2002 through 2005, and dry years from 2006 through 2008.

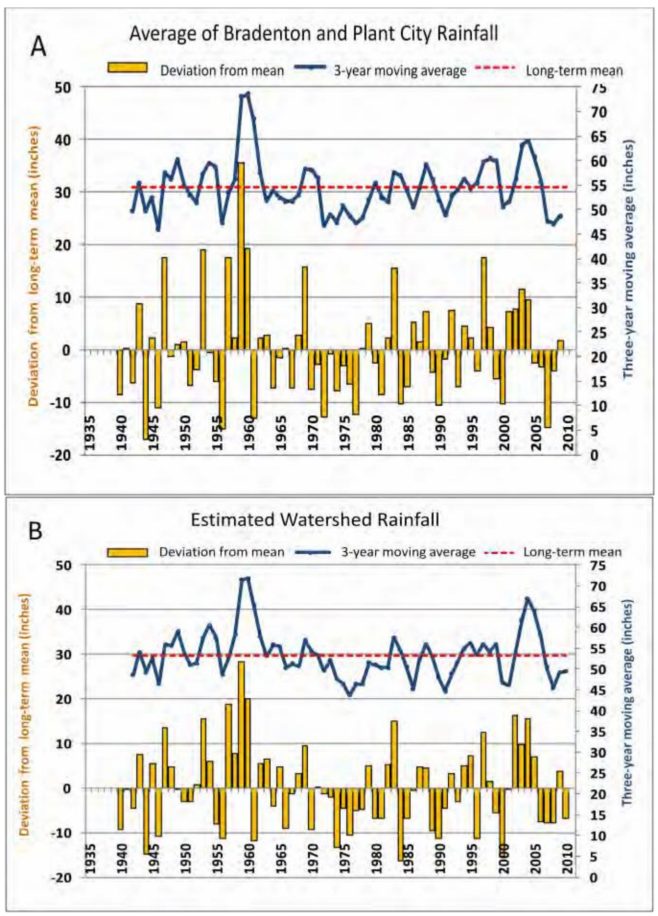


Figure 4-4. Yearly deviations from average rainfall and moving average 3-year rainfall for the average of the Bradenton and Plant city stations (A) and the District estimates for the Little Manatee River watershed (B).

Statistical tests were also performed to determine if there have been any trends in rainfall over the period of study. Using the non-parametric seasonal Kendall test on rainfall throughout the year, there was no indication of significant trends in rainfall for either the Bradenton-Plant City values or the District watershed estimates (Table 4-1).

Rainfall trends were also examined for three seasonal blocks. As described in Section 4.2.1, District minimum flow analyses typically divide the year into three seasonal blocks based on streamflow characteristics. These blocks are designated to identify the spring low flow period (Block 1), and fall and winter intermediate flow period (Block 2), and the summer wet season (Block 3). The dates for the blocks indentified for the Little Manatee River are listed below. The Bradenton-Plant City daily rainfall records were analyzed for these block dates within each year.

Blocks for analysis of Bradenton Plant City Values

Block 1 - April 18 - June 22
Block 2 - Oct. 22 - April 17
Block 3 - June 23 – Oct. 21

The District watershed rainfall estimates were available only as monthly values, so dividing the blocks within the middle of any month was not possible. Instead, monthly groups were indentified that included the months that principally comprise each seasonal block. The months that were included within each block for the District watershed estimates are listed below. June was included with Block 3 since most of the rain in June occurs in the later part of the month, so it was concluded that June would be linked with the summer wet season.

Month groups for analysis of District watershed rainfall estimates

Spring - April – May
Fall/Winter - October - March
Summer - June - September

Time series plots of rainfall within each block for the Bradenton/Plant City values during 1940-2009 are shown in Figure 4-5, while plots of the three month groups for the watershed rainfall estimates are shown in Figure 4-6. Reference lines corresponding to the mean rainfall for each block or group are also shown for comparison. Results of Kendall tau trend tests on the block and month group values are shown in Table 4-1.

Table 4-1. Results of trend analyses (Kendall tau) of yearly and seasonal rainfall for the Bradenton/Plant City daily values and the District estimated watershed monthly values.

Yearly or seasonal	Data Source	Tau Statisti	P Value	Slope (Inches/yr)
Yearly	Bradenton/Plant City Average	0.04	0.598	0.03
Block 1 (Spring)	Bradenton/Plant City Average	0.14	0.092	0.03
Block 2 (Fall/Winter)	Bradenton/Plant City Average	0.00	0.959	0.00
Block 3 (Summer)	Bradenton/Plant City Average	-0.01	0.859	-0.01
Yearly	Estimated Watershed Average	-0.03	0.685	-0.02
April – May	Estimated Watershed Average	0.05	0.574	0.01
October - March	Estimated Watershed Average	-0.02	0.808	-0.01
June - September	Estimated Watershed Average	-0.02	0.796	-0.01

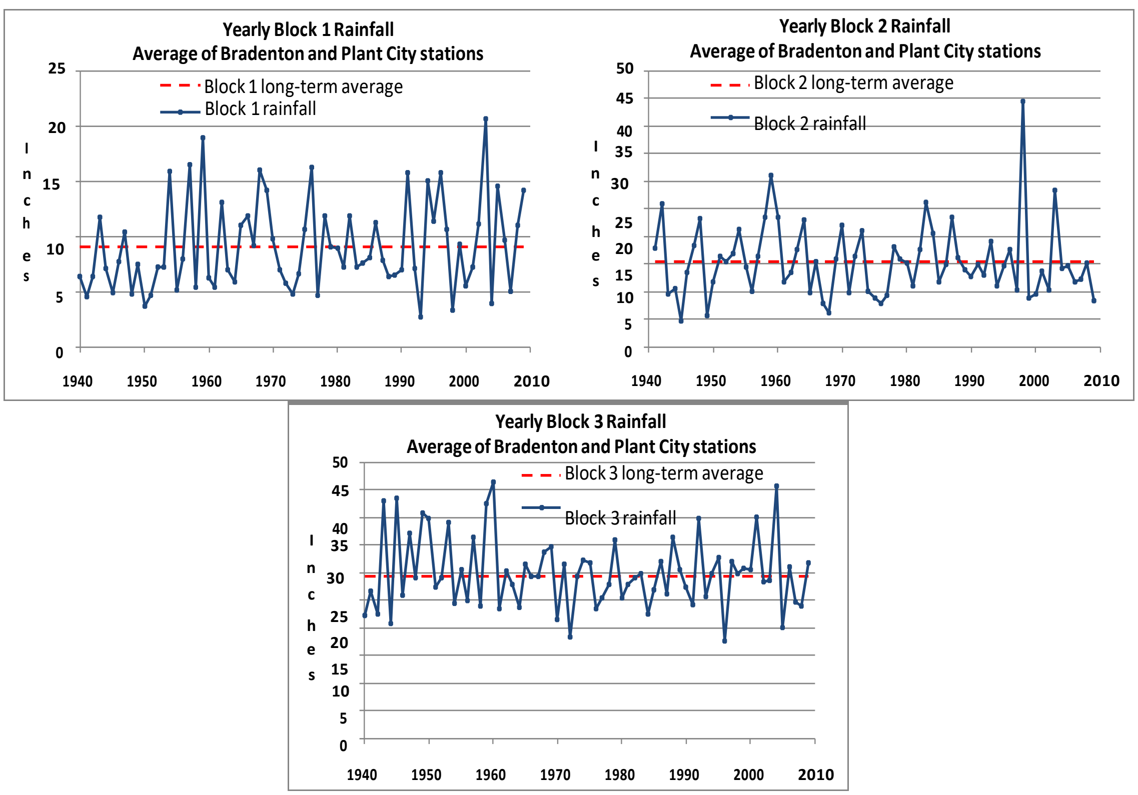


Figure 4-5. Yearly rainfall totals for seasonal Blocks 1, 2 and 3 computed from daily averages of rainfall at the Bradenton and Plant City stations.

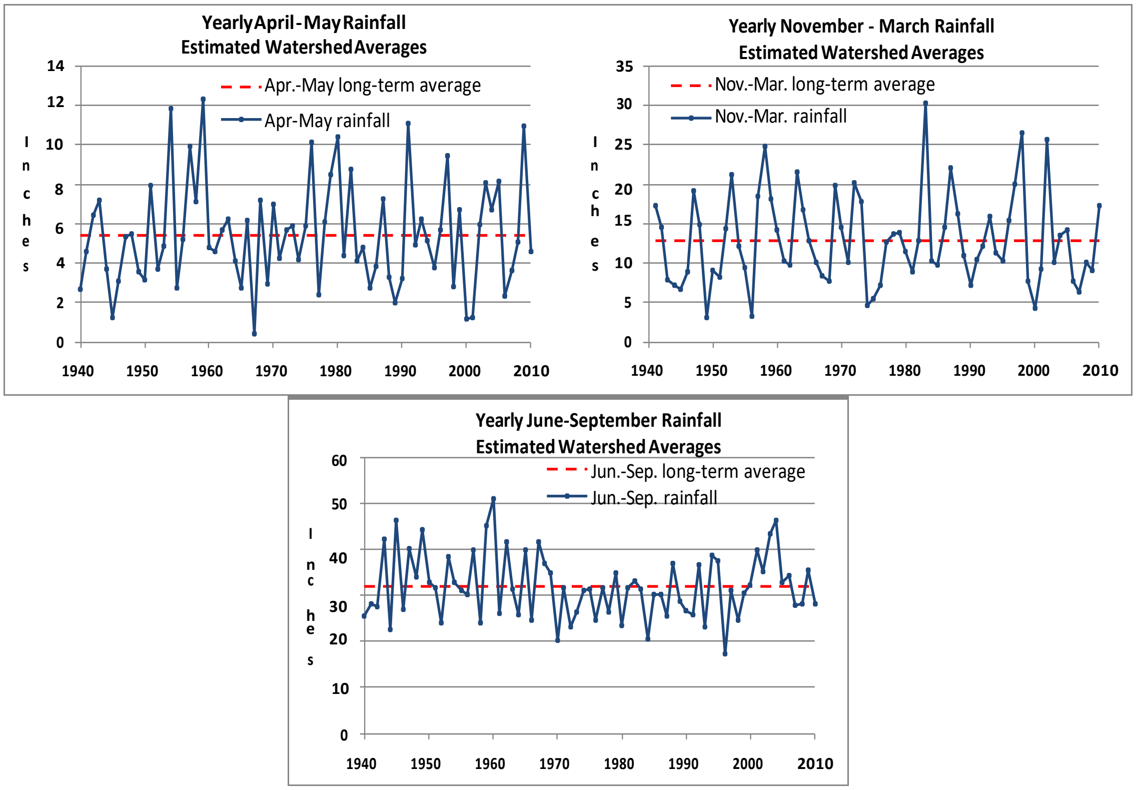


Figure 4-6. Yearly rainfall totals for three monthly groups computed from monthly estimates of average rainfall for the Little Manatee River watershed.

There were no significant trends at the $p<.05$ level for any of the seasonal blocks or monthly groups. There was some indication ($p<.092$) of a trend for Block 1 rainfall for the Bradenton/Plant City values, but all other tests had very high probabilities of type 1 error. The patterns through time appeared particularly flat for the fall/winter period, while it appears the indication of a positive trend in the spring is influenced by low values in the 1940s and periodic high values since 1995. Although there were no significant trends in the summer, there appear to have been a relatively high number of wet summers from the early 1940s to the late 1960s, and a high number of below average wet seasons from the 1970s through the mid-1990s.

4.2.3 Streamflow at the long–term gage site – Seasonal and flow duration characteristics

Since April 1939, streamflow has been monitored by the U.S. Geological Survey (USGS) at a gage located at the US Highway 301 bridge called the Little Manatee River near Wimauma (gage #1 in Figure 4-7). Another active USGS streamflow gage with records, that date back to 1963, is the Little Manatee River near Ft. Lonesome (#2), which measures flow from approximately 15% of the watershed in its upper reaches. The USGS has operated a number of other gages in the watershed for shorter periods of time. An active gage on the south fork of the river (#3) has been operation since October 2000. That gage was also operated during 1987-1989, with several other gages (#"s 4, 5, 6) that were part of a study of the watershed that was conducted by the District and other agencies in the late 1980s (Flannery et al. 1991).

A discussion of streamflow presented in this report primarily centers on the Little Manatee River near Wimauma gage (LMR Wimauma), since this is the most downstream gage on the river which measures freshwater flow to the lower river.

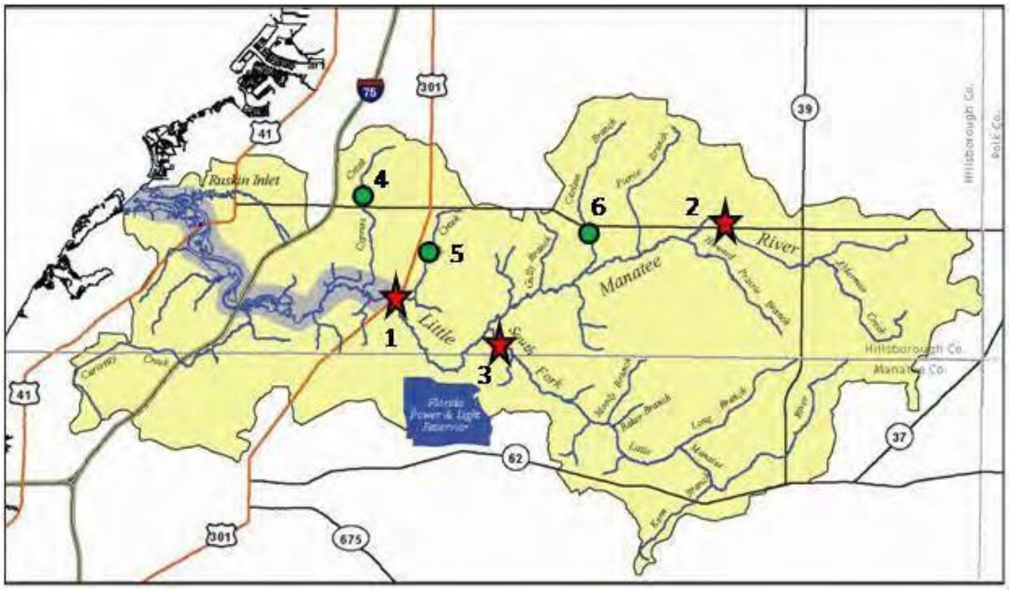


Figure 4-7. Location of currently active (red stars) and previously operated (green circles) streamflow gages in the Little Manatee River watershed maintained by the USGS.

The LMR Wimauma gage measures flow from 149 square miles, equivalent to two-thirds (67%) of the entire river watershed. The average flow for this gage for the 1939-2009 record is 176 cfs, which is equivalent to an average yearly runoff rate of 16.0 inches of water distributed over the gaged drainage basin. This is fairly high runoff rate for rivers in west-central Florida, as average runoff rates for long-term gages on other rivers in the region for the 1939-2009 period are as follows:

<u>Average yearly runoff rates for the 1939-2009 as inches over each gaged basin</u>

Little Manatee River near Wimauma	15.8 inches
Hillsborough River near Zephyrhills	14.7 inches
Alafia River at Lithia	13.3 inches
Peace River near Arcadia	10.5 inches
Myakka River near Sarasota	14.5 inches
Withlacoochee River near Holder	7.1inches

A cumulative distribution curve of daily flows for complete years of record (1940-2009) at the LMR Wimauma gage is shown in Figure 4-8, with the values of selected percentile flows listed in Table 4-2. All values after 1976 were corrected for upstream withdrawals by the Florida Power and Light Company (withdrawals added back in). The median flow of the river (63 cfs) is only 36% of the mean value, demonstrating that the mean is influenced by periodic high flows and the median is more representative of typical flow rates in the river. The highest recorded daily flow rate was 11,100 cfs in September 1960 during Hurricane Donna, while the smallest daily flow of 0.9 cfs was recorded in December 1976. The interquartile range (between the 25th and 75th percentiles) is 32 to 155 cfs, meaning half the time flow has fluctuated in this range.

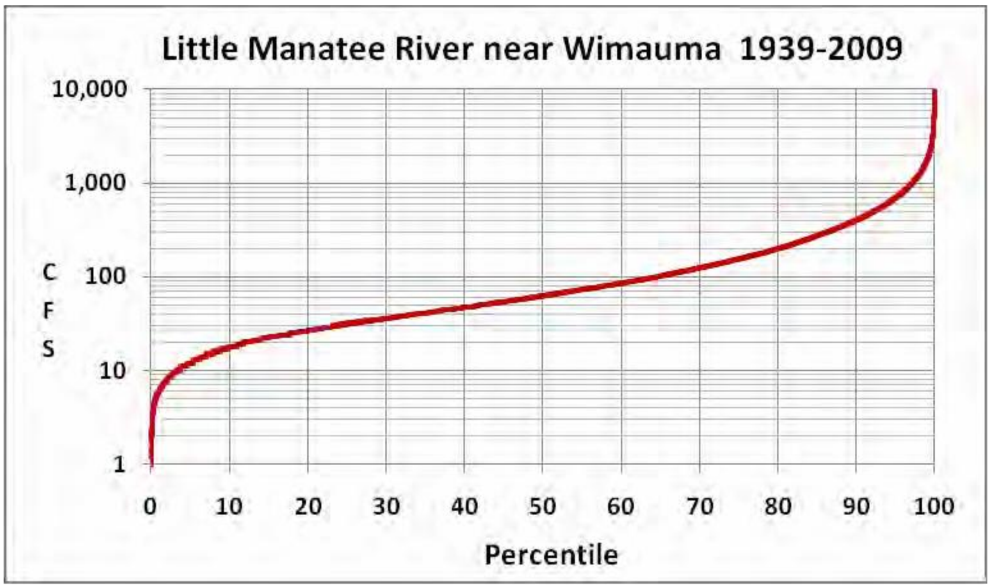


Figure 4-8. Cumulative Distribution curve of daily flows at the Little Manatee River near Wimauma gage for the period 1939-2009).

Table 4-2. Minimum, Maximum and selected percentile values for daily flows at the Little Manatee River near Wimauma gage for 1940-2009. All values in cfs.

Percentile	Minimum	10th	25th	50th	75th	90th	Maximum
Flow (cfs)	0.9	18	32	63	155	402	11,100

The distribution of average monthly flows is similar to the distribution of monthly rainfall, with a summer wet season that follows a dry season that extends from October to May (Figure 4-9). However, the relative difference between minimum and maximum monthly streamflow values is greater than for monthly rainfall. The percentages of yearly rainfall and streamflow that occur on average each month are shown in Figure 4-10. Streamflow reaches its lowest levels relative to rainfall in May, when evapotranspiration rates are high, groundwater levels are low, and there considerable surface water storage available in depressions and wetlands. In contrast, streamflow is relatively high compared to rainfall in the late summer when soils are more saturated, groundwater levels are high, and there is less available surface water storage. As a result, streamflow has delayed and more pronounced seasonal variations than rainfall.

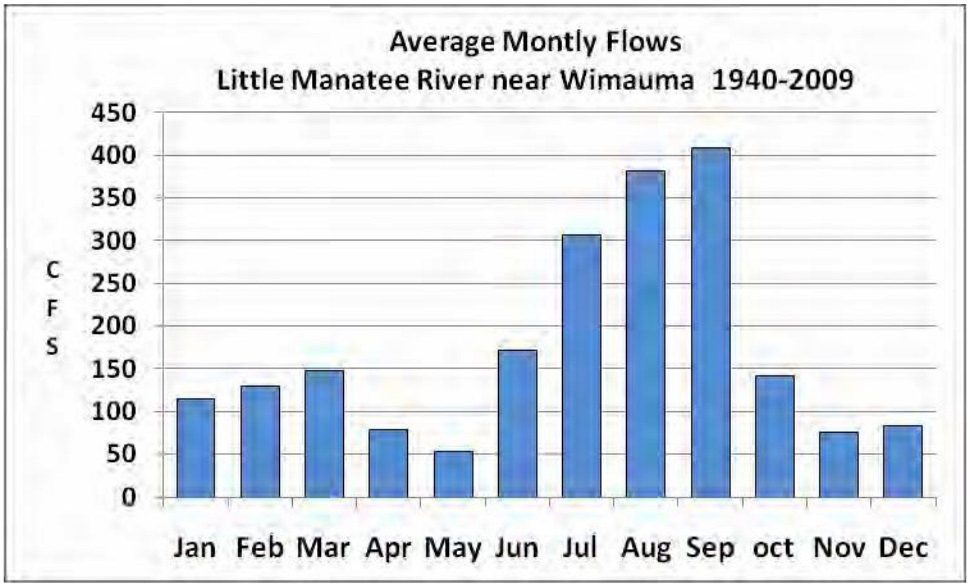


Figure 4-9. Average monthly rates of flow for the Little Manatee River near Wimauma for the years 1940-2009.

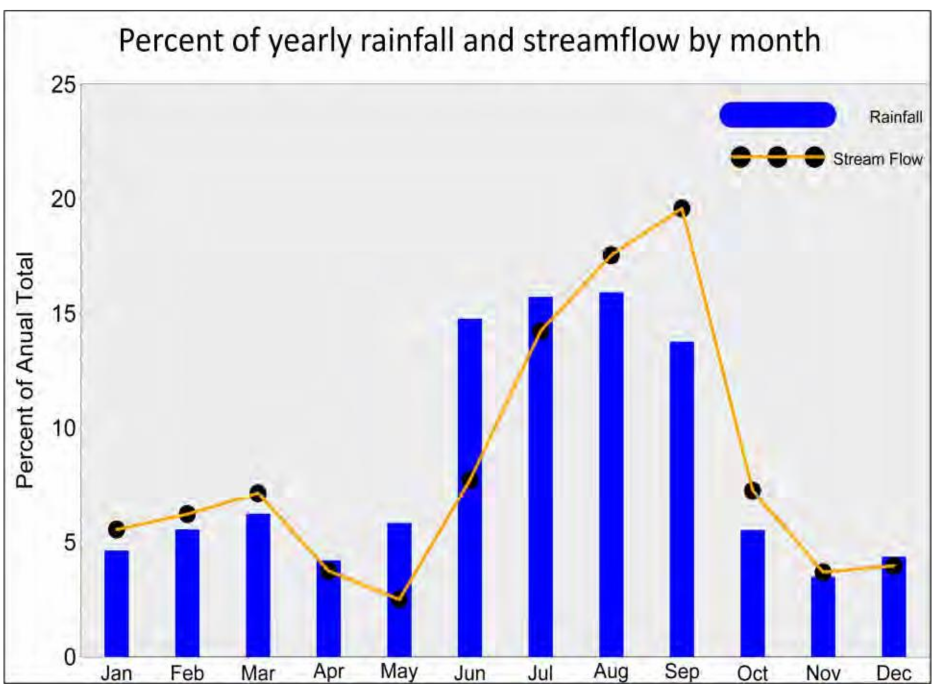


Figure 4-10. The percentage of yearly rainfall and streamflow by month for the Little Manatee River watershed and the LMR Wimauma gage.

4.2.4 Withdrawals from the river by the Florida Power and Light Company

Flows in the Little Manatee River are affected by permitted surface water withdrawals by the Florida Power and Light Company (FPL), which operates an electrical power generation plant just south of the main river channel in Manatee County (Figure 2-2). The history of FPL‟s water use from the river is summarized below, along a description of the withdrawal schedule under which the plant currently operates. The FPL Manatee Plant represents the only water user in the watershed that withdraws surface water from the Little Manatee River or its tributaries. Surface water withdrawals are also made from a number of stormwater retention and tail-water recovery ponds in the watershed, but these ponds largely capture excess irrigation water from golf courses and agricultural operations, and are not discussed further in this report.

The FPL Manatee plant is located near the southwest corner of the cooling pond shown in Figure 4-11. The Plant has three units (Units 1, 2 & 3). Unit 1 began operation in 1976. Units 1 & 2 can now use either natural gas or residual oil as the source for power generation. In 2003, Unit 3 was approved by the under the Power Plant Siting Act by the Governor and Cabinet. Unit 3 uses natural gas as the fuel source for power generation.

Cooling water for the power plant is stored in the 4,000 acre off stream cooling pond that was constructed in the early 1970s. Above-grade earthen dikes comprise the three sides of the cooling pond embankment, and natural ground elevation is sufficiently high to contain the water on the eastern shore. The cooling pond contains two splitter dikes to prevent short circuiting of the cooling water, thus enhancing the plant‟s heat dissipation efficiency. A spillway is located on the northern embankment to safeguard against overtopping the storage volume in the pond. The only planned releases from the pond are annual testing of the spillway gates. Seepage from the cooling pond through the embankment is captured in a system of toe drains and sumps and is returned to the cooling pond. In addition to storing cooling water, the cooling pond is used to provide general service and process water for plant operation. Potable water inside the plant is provided by an onsite well.

Because water losses from the cooling pond due to evaporation and downward groundwater seepage are not fully replaced by rainfall during most years, make-up water for the cooling pond is provided by withdrawals from the Little Manatee River. An intake facility is located on the south bank of the river, where pumps are used to withdraw water from the river. The initial regulatory schedule that determined allowable withdrawals from the river was established in a permit agreement established between FPL and the District in 1973. That schedule established three seasonal low-flow thresholds below which withdrawals could not reduce flow. The low-flow thresholds were 40 cfs for the months October through July, 112 cfs for August, and 97 cfs for September. When flows were above these low-flow thresholds, allowable diversions were established by three separate curves for the months August, September, and the period from October through July (Figure 4-11).

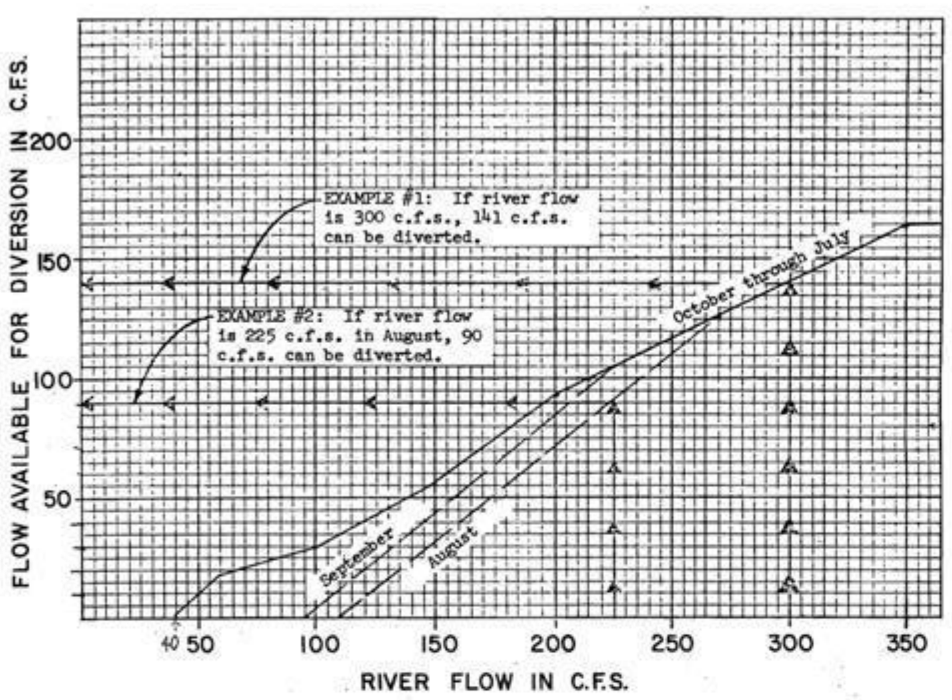


Figure 4-11. Diversion curves for withdrawals from the Little Manatee River for the FPL power plant that were in effect for the period 1976 – September 2004.

The curve for September merged with the October – July curve at a river flow rate of 225 cfs, while the curve for August merged with the October – July curve at a flow rate of 270 cfs. A maximum withdrawal rate of 190 cfs was also established, which effectively served as the withdrawal limit when river flows were above 400 cfs. Based on these curves, withdrawals could range as high as 47 percent of stream flows during moderately high flows (225 – 400 cfs), but allowable percentage withdrawals were less at lower flows and also at very high flows, with the latter being due to the 190 cfs withdrawal limit.

The schedule for river withdrawals was substantially revised in 2004 as part of the recertification of the power plant that accompanied the addition of natural gas fuel. In order to minimize potential impacts to the Little Manatee River, withdrawals are currently restricted to 10% of river flow at the intake site, with a 40 cfs low-flow threshold applied year round. However, the revised withdrawal schedule allows for an emergency diversion schedule (EDS) to be applied when water levels in the cooling pond fall below 62 feet above mean sea level. When water levels reach 62 ft., FPL can revert to the previous October through July diversion curve until the water levels in the cooling pond rebound to 63 ft.

Withdrawals from the Little Manatee River have averaged 9.1 cfs (equal to 5.9 mgd day) since withdrawals began in December 1976. However, this mean is largely driven by withdrawals during high flows, as no withdrawals occurred on 71% of the days during the 1976-2009 period of record assessed for this study. A hydrograph of withdrawals from the river by FPL from the beginning of plant operation through 2009 is shown in Figure 4-12. The highest withdrawal rates occurred in December 1976 and early 1977 when the cooling pond was first being filled. Since that time, there has been considerable variation in the amount of water that has been diverted each year.

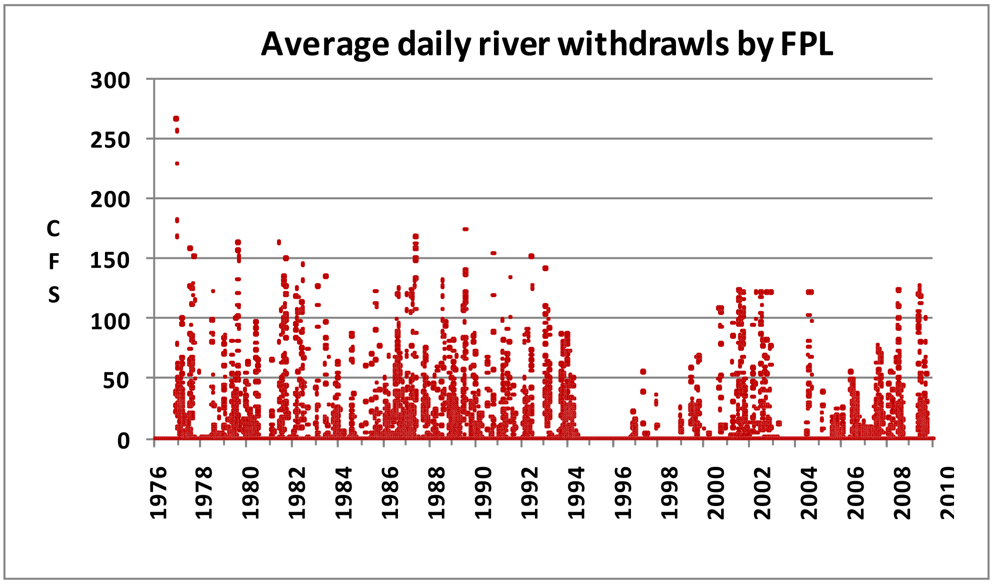


Figure 4-12. Average daily withdrawals from the Little Manatee River by FPL for the period 1976-2009.

No withdrawals occurred during the wet year of 1995 and generally remained low through 1998. The highest yearly withdrawal rates occurred in 2001 and 2002, when average yearly withdrawal rates of 22.2 and 20.5 cfs were diverted from the river. These withdrawals largely occurred during periods of high flows in those years, which followed a prolonged drought from 1999 through the early part of 2001. The largest withdrawals by FPL have typically occurred during high flows in the summer which have followed prolonged dry periods when water levels in the cooling pond became low and the pond needed re-filling.

Expressed as percentage of same-day flow in the river at the USGS long-term gage near Wimauma, withdrawals were similarly highest in late 1976 and early 1977, briefly ranging from over 50% to nearly 100% of flows (Figure 4-13). Since that time withdrawals have been much less, as daily withdrawal rates above 40% of gaged flow have been fairly infrequent. From the years 1978 to 2009, the median daily flow reduction on days when withdrawals occurred was 16 percent. The median withdrawal rate was zero when all days during that period of record are considered.

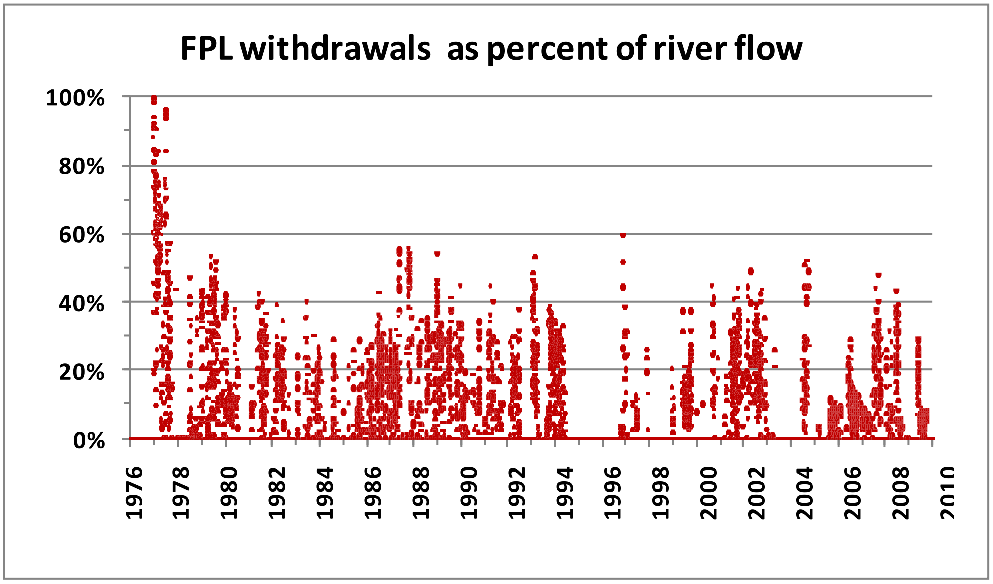


Figure 4-13. Average daily withdrawals from the river by FPL expressed as percent of the same-day flow at the USGS Little Manatee River near Wimauma gage.

These records show that FPL has frequently not pumped from the river on days when withdrawals were allowed. For example, in the period before the use of natural gas as fuel in 2004, the river was above its low-flow cutoffs about 75% of the time, but FPL withdrew water on only about 28% of the total days during that period. Similarly, FPL often did not pump the maximum quantities of water allowed by the diversion curves, and often ran the plant at only one-third to one-half of its capacity during this period. Greater power generation would have caused greater water demands from the river.

It is also important to note that the withdrawal rates used by FPL are based on a stream gage maintained by FPL near their intake site; whereas the percentages of river flow plotted in Figure 4-13 were calculated using the USGS near Wimauma streamflow gage at the Highway 301 bridge. The USGS gage is located about three miles downstream of the FPL site, and the difference in drainage areas between these two sites is fairly small. Because the USGS records are long-term, published on the internet and are readily available for analysis, the FPL withdrawals are compared to the USGS records in this report to assess their effects on the river‟s hydrology. These plots, however, should not be used to evaluate compliance with FPLs regulatory conditions, as periodic shifts in the streamflow rating curves applied at either the USGS or FPL sites could affect differences in the reported rates of flow.

Since the recertification of the power plant in 2004, the EDS has been applied four times within the ranges of dates listed in Table 4-3. As listed in the table, withdrawals were not made on all days within each of the four time periods. The percentage of days when withdrawals did not occur ranged from 6% to 60% for the four periods. The maximum withdrawal rates that occurred during these periods ranged from 56 to 127 cfs, while the average withdrawal rates that occurred on days when pumpage was occurring ranged from 22 to 59 cfs. The EDS was typically applied at the beginning of the wet season when high flows resumed in the river. The onset of high flows in May 2009 was an unusual occurrence in that summer rains began early in May of that year.

Table 4-3. Time periods since 2004 that the emergency diversion schedule has been employed by FPL for withdrawals from the Little Manatee River. Also listed are the average flow in the river at the USGS gage, average and maximum withdrawal rates, and the percentage of days when there were no withdrawals during each period. The average values for river flow and withdrawals were calculated for days when withdrawals occurred within each period. All values are in cfs.

Time Period	Average River Flow	Average daily withdrawal rate	Maximum daily withdrawal rate	Percent of days with withdrawal
June 13, 2006 – July 27, 2006	296	36	56	82%
June 14, 2007 – Oct. 31, 2007	225	33	78	58%
Jan. 20, 2008 – April 14, 2008	195	22	57	40%
June 12, 2008 – July 28, 2008	250	59	124	94%
May 15, 2009 – June 18, 2009	313	59	127	94%

Hydrographs of withdrawals from the river since the power plant was recertified are shown in Figure 4-14, differentiating periods when the standard and emergency diversion schedules were in effect. Data are not shown for the last three months of 2004, because no withdrawals occurred in that year after October 1st when the new schedules went into effect. Daily withdrawals stayed very close to the 10% limit when the standard withdrawal schedule was in effect. However, daily percentage withdrawal rates frequently ranged between 10 and 40% when the EDS was used, with the highest rate of 49% of daily flow occurring on September 18, 2007.

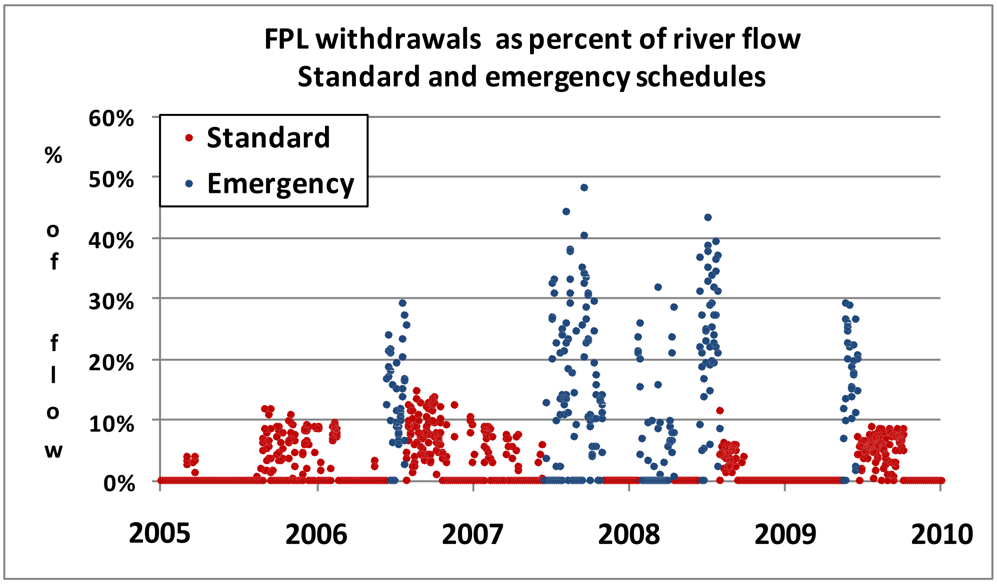


Figure 4-14. Withdrawals by FPL expressed as percentage of the same-day flow at the USGS Little Manatee River near Wimauma gage.

The five applications of the EDS between 2006 and 2009 were due to very low dry season rainfall and streamflow which resulted in low water levels in the cooling pond. On average, it is unlikely that the EDS will need to be applied with this frequency in the future, if that rainfall fluctuates around long-term average values. However, the application of the EDS is greater than what was anticipated at the time of the site recertification, as model simulations conducted for the recertification indicated the EDS would have only been applied three times in the 24-year historical period that was simulated for that analysis. However, climatic conditions during that period (I need find what 24 years were used) had a significant effect on the results compared to the subsequent 2006-2009 conditions

According to the conditions of the site certification, FPL must notify the director of the Resource Regulation at the District prior to implementing the EDS. After ceasing the EDS, FPL must provide a summary of the EDS use including the number of days the EDS was in effect, the percent of river flow diverted each day, and the total volume that was diverted over the time. These reports also apply empirical salinity models to two sites in the Lower Little Manatee River to simulate the changes in salinity that occurred as a result of applying the EDS. FPL has submitted reports corresponding to applications of the EDS since 2006.

4.2.5 Point-source discharges from phosphate mining operations by the Mosaic Company

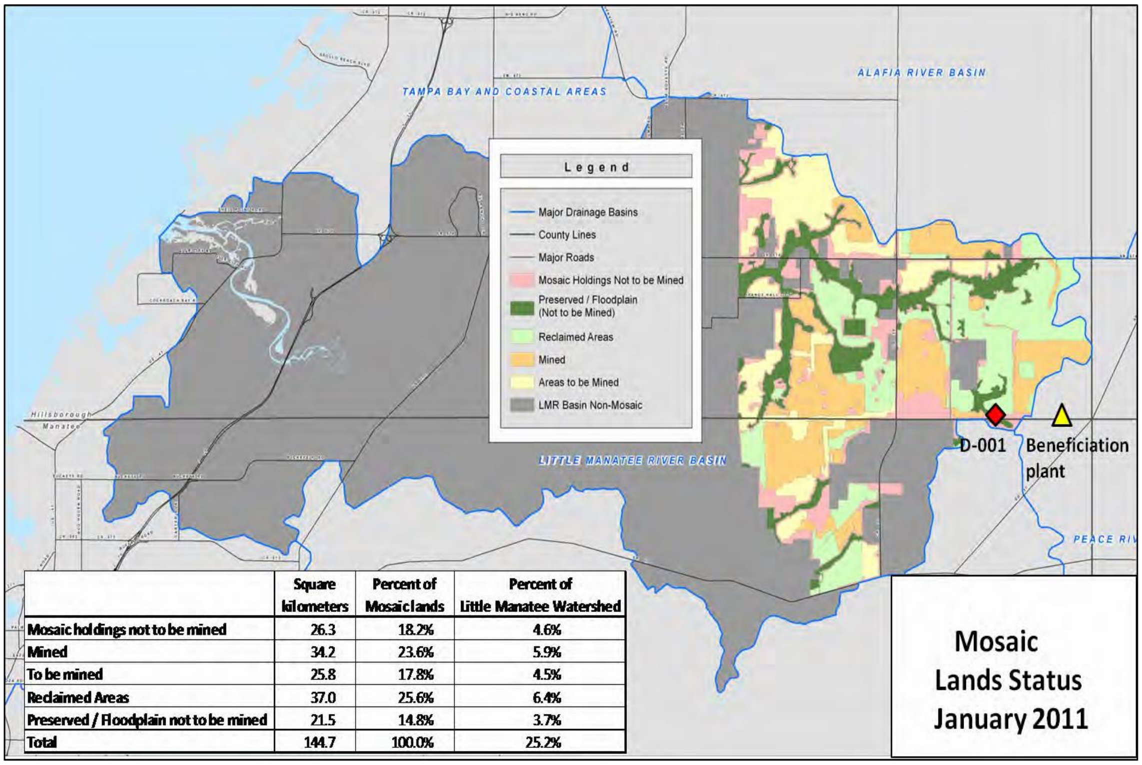
The Mosaic Company (Mosaic) owns approximately 59 square miles of land in the eastern portion of the Little Manatee River watershed for the purpose of phosphate mining. Mosaic‟s land holdings comprise approximately 26% of the entire river watershed. This land was previously owned and operated by the International Minerals Corporation (IMC), which merged with Cargill Inc. to form the Mosaic Company in 2004. Mosaic‟s mining operations in the Little Manatee River watershed are part of what is known as the Four Corners mine, which extends into the Peace and Alafia river basins.

Phosphate ore mined from the Little Manatee River watershed is processed for the production of fertilizer and related products (e.g. diammonium phosphate, monoammonium phosphate, animal feed ingredients). The complete phosphate mining process is done in series of steps including land acquisition, permitting (including delineation of mineable lands), mining, beneficiation (separation of the phosphate ore), and land reclamation. The processed ore is transported to other facilities to produce fertilizer and other products.

Phosphate mining in the Little Manatee River watershed began in the mid-1980s and is expected to extend another 9 years until 2020, though this timetable could change due to various factors. A map of the status of major land categories owned by Mosaic is shown in Figure 4-15, with an inserted table that lists the area of each category and its percentage of total Mosaic holdings and the entire Little Manatee watershed on an aerial basis. As of January 2011, lands that are currently being mined comprised 23.6% of Mosaic‟s holdings and 6.4% of the entire river watershed. Another 17.8 % of Mosaic‟s holdings (4.6% of the river watershed) is yet to be mined. Reclaimed lands that were previously mined comprised 25.6 % of Mosaic‟s holdings or 6.5% of the river watershed. Totaling the mined, to be mined and reclaimed categories, approximately 17% of the Little Manatee River watershed will have been mined when operations are completed. Preserved lands and lands not to be mined together comprise 33 % of Mosaic‟s total land holdings or 8.3% of the river watershed. These values will also apply when operations are completed.

The soil and rock matrix that contains the phosphate ore is mined with draglines. Water is used to create a slurry of the mined matrix, which is transported via pipes to a beneficiation plant where the phosphate ore is separated from the matrix, that contains much sand and clay. The beneficiation plant for the Four Corners mine is located just east of Mosaic‟s lands in the Little Manatee River watershed (Figure 4-15). This beneficiation plant also receives matrix from adjacent mines in the region that are located in the Alafia and Peace River watersheds.

Phosphate mining is a water intensive process as water is used to transport the matrix and separate the phosphate ore. Most of the water used by Mosaic at the Lonesome mine originates from permitted groundwater wells. However, once brought to the land surface, this groundwater essentially becomes surface water that is recycled and used repeatedly in mining and beneficiation processes. The phosphate industry has become efficient in its water use in recent decades, as approximately 90 to 95 percent of the water used daily at the mine is surface water that is recycled within the system. A series of ditches and retention ponds on the mined lands are used to store the recycled surface waters. These water storage systems also capture rainfall upon and runoff from the mined lands. When a land unit has been fully mined, the surface water systems are no longer needed and the land is contoured to provide a more natural land surface and drainage patterns.



	Square kilometers	Percent of Mosaic lands	Percent of Little Manatee Watershed
Mosaic holdings not to be mined	26.3	18.2%	4.6%
Mined	34.2	23.6%	5.9%
To be mined	25.8	17.8%	4.5%
Reclaimed Areas	37.0	25.6%	6.4%
Preserved / Floodplain not to be mined	21.5	14.8%	3.7%
Total	144.7	100.0%	25.2%

Figure 4-15. Lands owned by the Mosaic Company in the Little Manatee River watershed shaded by current status, with the area and percent of the river watershed comprised by each status category listed. Also shown in the location of the D-001 outfall (red diamond) and the beneficiation plant (yellow triangle) associated with the Four Corners Mine.

During times of high rainfall, these surface water storage systems become full and Mosaic must discharge water to the river system. Mosaic has a permitted surface water discharge site, termed D-001, that is located in the headwaters of the river on Alderman Creek (Figure 4-15). This outfall is managed under a permit issued by the Florida Department of Environmental Protection. Records for average monthly discharges for the D-001 site begin in April 1985, while records for daily discharge values begin in January 1995. A hydrograph of daily discharges from D-001 is shown in Figure 4-16. It is apparent the high discharges occur during wet periods, such as the El Nino winter of 1997-1998 and the generally wet period of 2003-2005. There were no discharges from D-001 for 643 consecutive days during the 1999-2001 drought. Daily discharges can periodically reach relatively high values, reaching over 100 cfs during nine of the fifteen years shown in Figure 4-16, with peak daily discharges of over 200 cfs during 2001 and 2004.

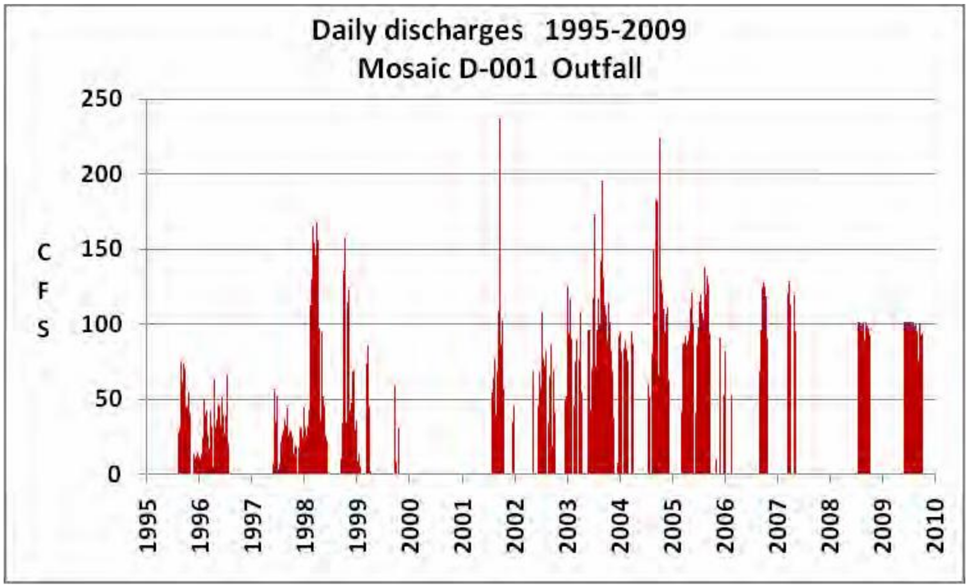


Figure 4-16. Daily discharge values for the D-001 outfall. Daily records begin Jan. 1, 1999

A hydrograph of average monthly discharges from D-001 is shown in Figure 4-17. There has been a general increase in discharges from D-001. The greatest average monthly discharge rate (124 cfs) occurred in March 1998 at the end of an unusually wet El Nino winter during 1997-1998.

It is difficult to assess the relative impact of previous and existing phosphate mining in the Little Manatee River watershed, including discharges from D-001, on the flow regime of the river. Since the amount of mined land changes from year to year, the proportion of the river watershed that is captured by mining and drains to the Mosaic surface water storage system changes over time. Similarly, the amount of land in the Little Manatee River watershed that is reclaimed and reconnected to the river and its tributaries changes over time. Also, some of the discharge from D-001 originates from mined lands outside the Little Manatee watershed in mines in the Alafia and Peace River watersheds that are connected to this surface water system. For these reasons, it is difficult to compare the amount of flow from the mined lands to what would be the natural flows of the river and its tributaries in the mining region.

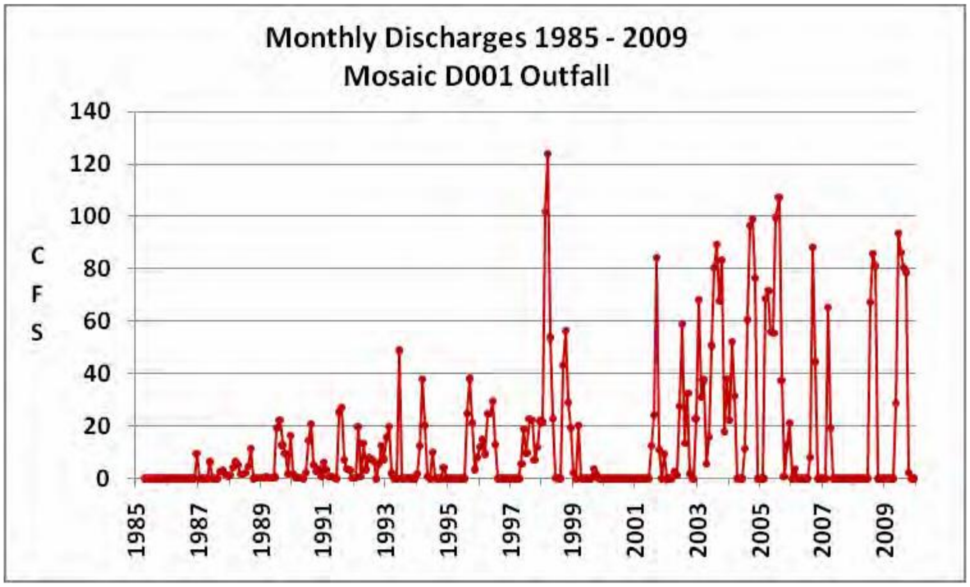


Figure 4-17. Average monthly discharge values for the D-001 outfall for the period April 1985-December

It is reasonable to conclude that the flow regime of the upper reaches of the Little Manatee River, particularly near the D-001 outfall, has been affected to some extent by previous and current mining in the watershed. Conceivably, a detailed historic hydrologic analysis that examined the constantly changing land use conditions in the mining region could estimate these effects. When mining is completed in the Little Manatee River watershed, the mined lands will be contoured and connected to the river to approximate natural drainage features and the existing surface water storage system and the D-001 outfall will no longer exist. It is the intent of reclamation to return baseflow and runoff from the reclaimed lands to near pre-mining conditions. However, it was also beyond the scope of this report to evaluate the effectiveness of current mine reclamation techniques and their potential effects on the existing and future flow regime of the river.

A number of analyses of flow trends and historic hydrologic data are presented in this report and in the minimum flows report for the freshwater reaches of the Little Manatee River. Because the effects of mining in the watershed are difficult to quantify, there was no attempt to account for any effects or potential effects of mining on historic flow trends or other characteristics of the streamflow data.

4.2.6 Trend analyses of gaged flows

Time series data and trend analyses were examined for flow records at the USGS streamflow gage on the Little Manatee River near Wimauma to determine if the flow regime of the river has shown any shifts due possibly to changes in climate or human activities within the watershed. Streamflow records at this site date back to April 1939, providing over seventy years of data to examine trends in flow. To keep the data seasonally balanced within the year, the staring date for trend analyses was January 1, 1940. Unless indicated otherwise, the ending date for the analyses presented below was December 31, 2010. The streamflow trend analysis was revisited late in the project, so the 2010 ending date for the analyses presented in this section is one year later than some other analyses in the report that end with data from 2009. All flows analyzed for trends were corrected for upstream withdrawals by Florida Power and Light (withdrawals added back in).

A hydrograph of yearly mean flows at the Little Manatee River near Wimauma gage is shown in Figure 4-18. The highest yearly mean flow (416 cfs) occurred in 1959 and the lowest yearly mean flow (46 cfs) occurred in 1976. There does not appear to be clear long-term pattern in the data and no significant ($p<0.05$) trend was found for yearly mean flows (Kendall Tau test).

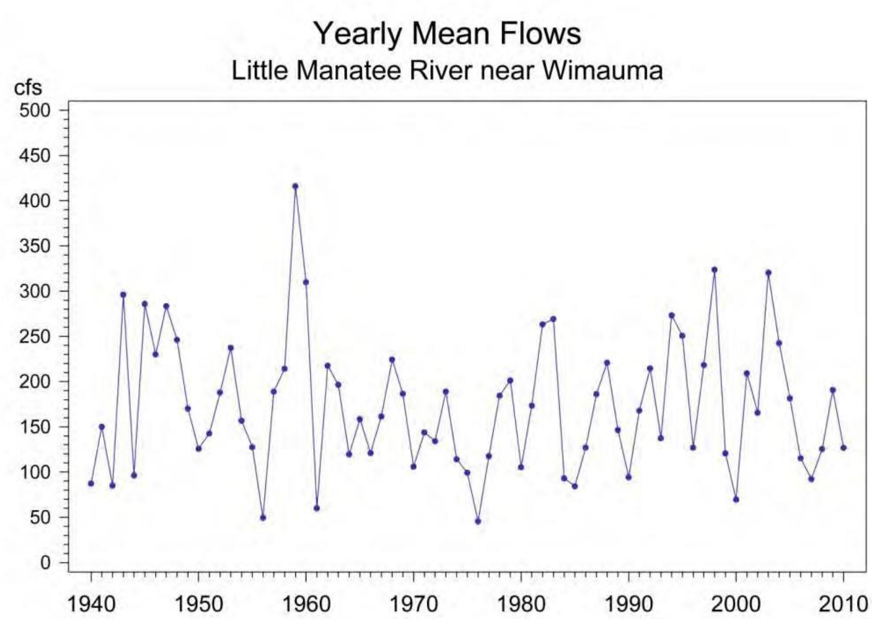


Figure 4-18. Yearly mean flows at the Little Manatee River near Wimauma gage.

A somewhat subtle but different pattern is observed when monthly flows are plotted (Figure 4-19). There does not visually appear to be an overall trend in flows, but flows in the lower range of monthly values seem to have increased over time, as monthly mean flows < 40 cfs were more frequent prior to the late 1970s. The non-parametric seasonal Kendall Tau test, which accounts for seasonal patterns in the data, was run on the complete set of monthly values and significant increasing trend in flow was found ($P < 0.05$). However, it appears this finding is largely being driven by an increase in the lower monthly flow values, which typically occur in the dry season.

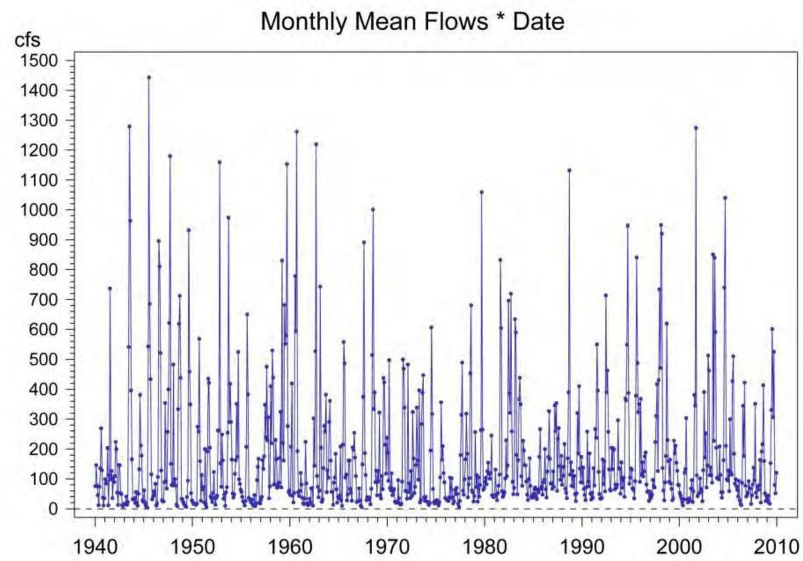


Figure 4-19. Monthly mean flows at the Little Manatee River near Wimauma.

Trends were examined for a number of additional streamflow parameters to determine what components of the flow regime of the river may have changed over time. Time series plots of yearly mean values for the three seasonal blocks are shown in Figure 4-20. For Block 2, which runs from October 22nd to April 17th, the year value is assigned to the year in which the block ends. Note that the scale of the y axis is different among graphs, as the blocks correspond to what are typically the low (Block 1), medium (Block 2), and high (Block 3) flow periods during each year.

Kendal Tau trend tests were run on both yearly mean and median flows within each block (Table 4-4). Using mean values, a significant increasing trend was observed for flow Block 1. However, when median flows within each block were tested, significant increasing trends were observed for both Blocks 1 and 2. Block 3 showed no significant trends for either mean or median flows, although there were several high mean flows for Block 3 in the early part of the record (1940s). Median flows within each block are plotted and discussed in Section 4.2.7.

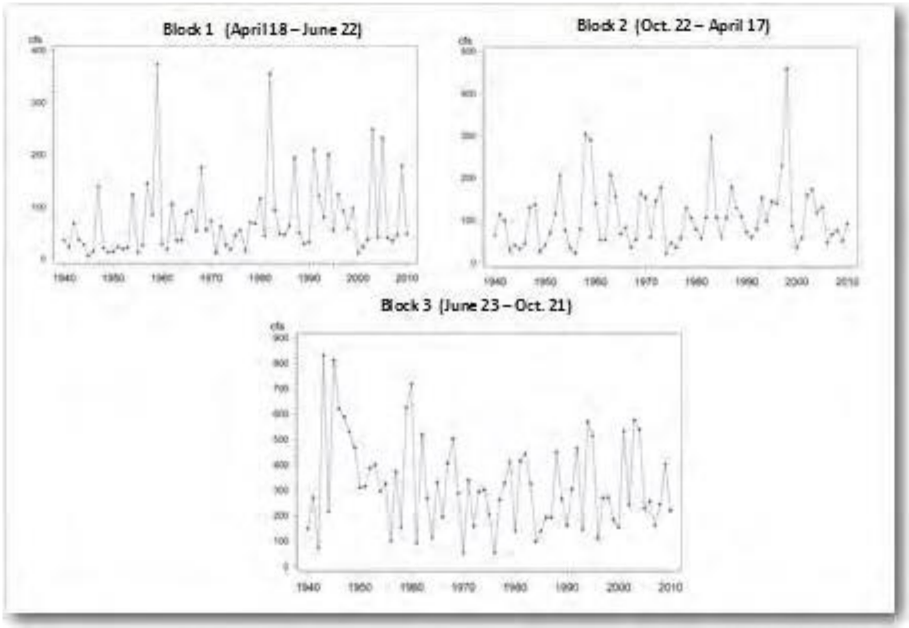


Figure 4-20. Time series plots of yearly mean flow values for the three seasonal blocks.

Table 4-4. Results of Kendall Tau test of trends over time for mean and median yearly flow values within three seasonal blocks.

		Tau statistic	P value	Estimated slope
Block 1 (spring)	mean	0.22	0.007	0.604
	median	0.35	0.001	0.465
Block 2 (fall/winter)	mean	0.1	0.216	0.412
	median	0.25	0.002	0.509
Block 3 (summer)	mean	-0.1	0.203	-1.337
	median	0.02	0.781	0.113

Trends were also tested for flows within each month. The results of Kendall Tau tests of mean monthly flows are listed in Table 4-5 and plots of the mean monthly values are presented in Appendix Monthly Flows. Significant increasing trends were observed for the months April, May, November and December, which are typically the lowest flow months of the year (see Figure 4-9). There were no significant trends for the other months, but there was a pattern of non-significant negative slopes for July through October, which together largely comprise block 3.

Table 4-5. Results of Kendall Tau tests for trends in mean monthly flows for the Little Manatee River near Wimauma

Month	Tau Statistic	P Value	Estimated Slope
January	0.13	0.1056	0.417
February	0.12	0.157	0.433
March	0.08	0.302	0.402
April	0.19	0.017	0.646
May	0.25	0.002	0.456
June	0.07	0.421	0.441
July	0.00	0.960	-0.081
August	-0.11	0.171	-2.031
September	-0.02	0.766	-0.367
October	-0.04	0.620	-0.295
November	0.18	0.023	0.431
December	0.20	0.014	0.398

The trend tests by block and month indicate that the low flows of the river are increasing, while high flows have shown no trends. An informative way to examine trends in low, medium and high flows is to test percentile flows within each year. Time series plots of the 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th}, percentiles within year are shown in Figure 4-21, with the results of trend tests listed in Table 4-6. Significant increasing trends were found for the 5^{th}, 10^{th}, 25^{th}, and 50^{th} percentiles, indicating that low flows of the river, up through the median flows, are increasing. The hydrographs indicate increases began occurring in the mid to late 1970s, with some decline after 2005. Non-significant negative slopes were found for the 75^{th} and 90^{th} percentiles, which similar to the tests of monthly flows, indicate the high flows of the river have not been increasing.

Table 4-6. Results of Kendall Tau tests for trends in yearly percentile flows

Percentile	Tau Statistic	P Value	Estimated Slope
5^{th} Percentile (low flows)	0.38	0.001	0.264
10^{th} Percentile	0.37	0.001	0.304
25^{th} Percentile	0.36	0.001	0.394
50^{th} Percentile (medians)	0.31	0.001	0.616
75^{th} Percentile	-0.07	0.399	-0.870
90^{th} Percentile (high flows)	-0.09	0.251	-2.286

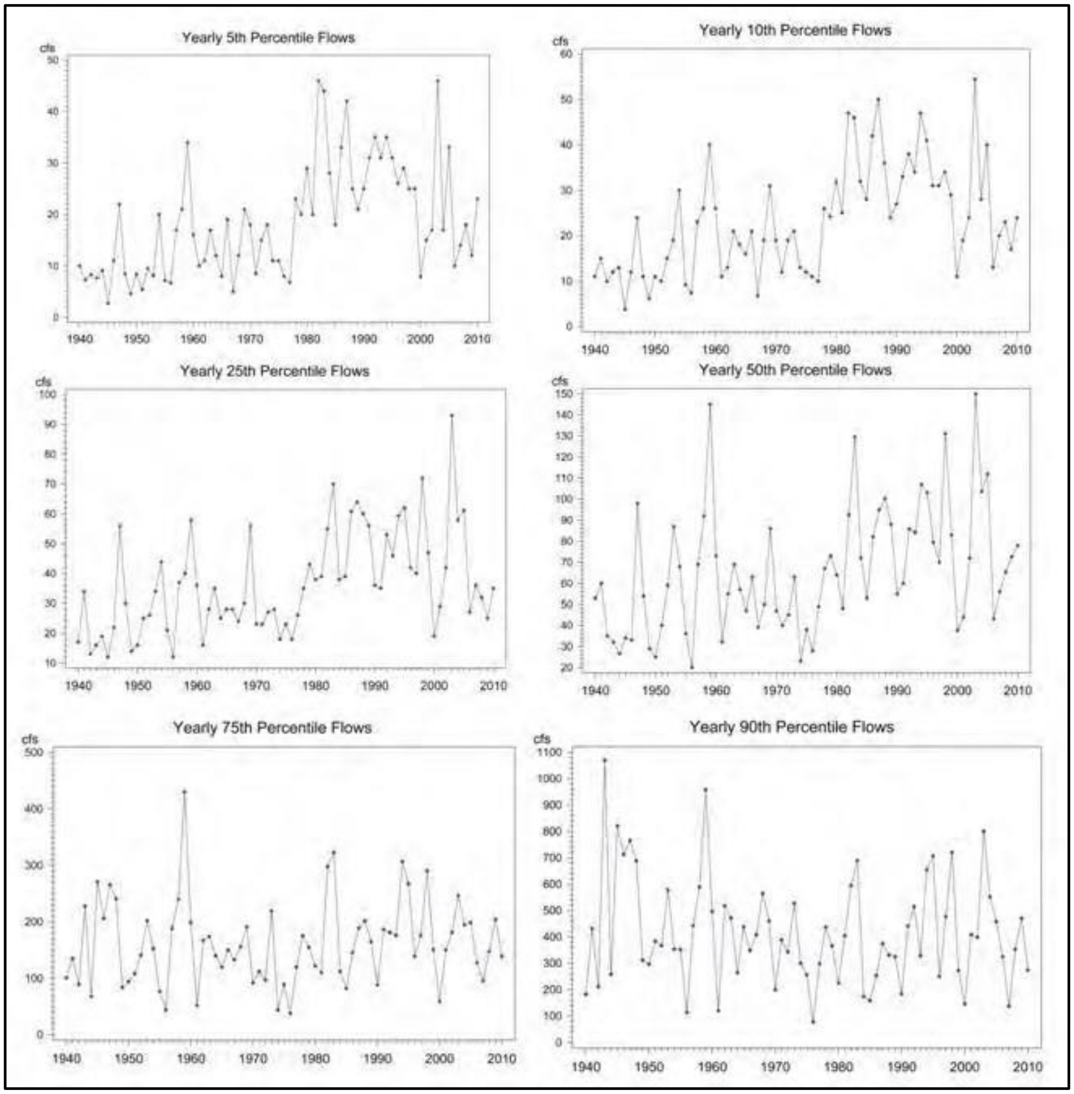


Figure 4-21. Hydrographs of the 5th, 10th, 25th, 50th, 75th, and 90th percentile flows within each year for the Little Manatee River near Wimauma.

A final set of trend tests were conducted on moving average flows with each year, ranging in length for 3 to 120 days. Preceding average flow terms for lengths of 3, 10, 30, 60, 90, and 120 days were calculated for each day of the period of record. The lowest, average, and highest moving average flow values within each year were recorded and tested for trends. Hydrographs of the yearly minimum values are shown in Figure 4-22, while the results of the trend tests for the yearly minimum, average and maximum values are in listed in Table 4-7.

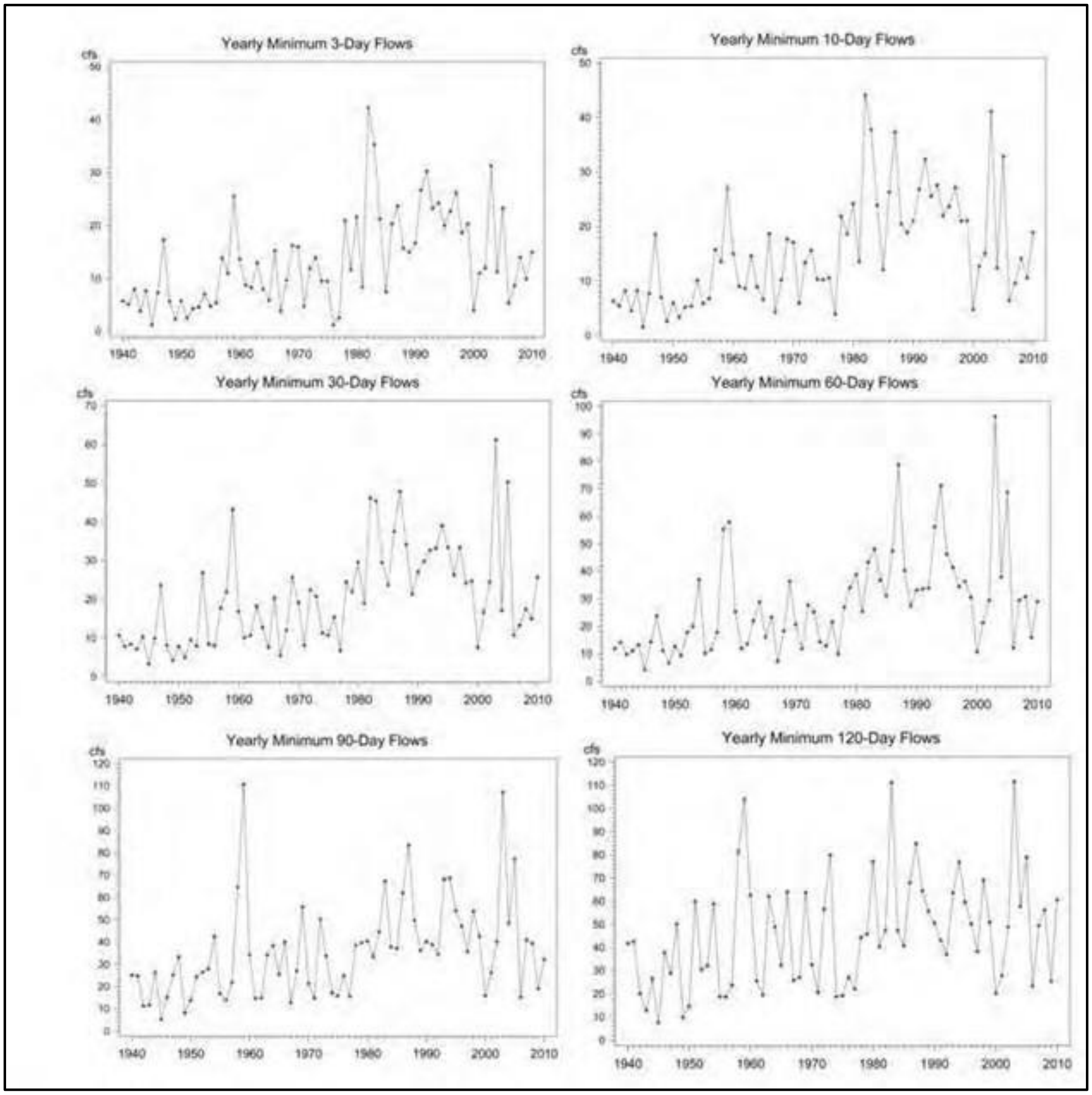


Figure 4-22. Hydrographs of the yearly minimum values of moving average flows for 3, 10, 20, 60, 90, and 120 day intervals at the Little Manatee River near Wimauma.

Significant increasing trends were observed for all the yearly minimum flow values. This has particular significance to the baseflow of the river, as prolonged flows during the driest times of year have been increasing. There were no significant trends in either the yearly mean or maximum values of the moving average flows (Table 4-7). Probability values of Type 1 error (P) were particularly high for mean flows, indicating very little evidence of any trend. Probability values were lower for the yearly maximum values which had negative slopes, which if anything, could indicate there is some slight, statistically non-significant, evidence of declining high flows in the river. Hydrographs for mean and maximum yearly values are shown in Appendix Moving Flows.

Table 4-7. Results of Kendall Tau test for trends in yearly minimum, mean and maximum values for moving average flows for the Little Manatee River near Wimauma

Minimum yearly values moving average flows	Tau Statistic	P Value	Estimated Slope
3-Day	0.36	0.001	0.207
10-Day	0.40	0.001	0.248
30-Day	0.39	0.001	0.311
60-Day	0.40	0.001	0.405
90-Day	0.35	0.001	0.482
120-Day	0.25	0.002	0.416
Mean yearly values moving average flows			
3-Day	-0.03	0.732	-0.152
10-Day	-0.03	0.710	-0.157
30-Day	-0.04	0.652	0.188
60-Day	-0.04	0.655	-0.223
90-Day	-0.04	0.589	-0.197
120-Day	-0.04	0.599	-0.183
Maximum yearly values moving average Flows			
3-Day	-0.12	0.128	-10.650
10-Day	-0.11	0.188	-5.329
30-Day	-0.13	0.115	-3.350
60-Day	-0.12	0.142	-2.570
90-Day	-0.09	0.270	-1.635
120-Day	-0.009	0.271	-1.144

The combined trend tests presented above clearly indicate that the low flows of the river, including median flows, are increasing. Various lines of evidence indicate that increased agricultural land and water use in the basin are the principal cause of these flow increases. As will be discussed further in Chapter 5, the water quality characteristics at the Little Manatee Rive near Wimauma have also changed over time. In particular, there has been a significant increasing trend in specific conductance at this site, with a pronounced rise in values in the mid-1970s (Figure 4-23).

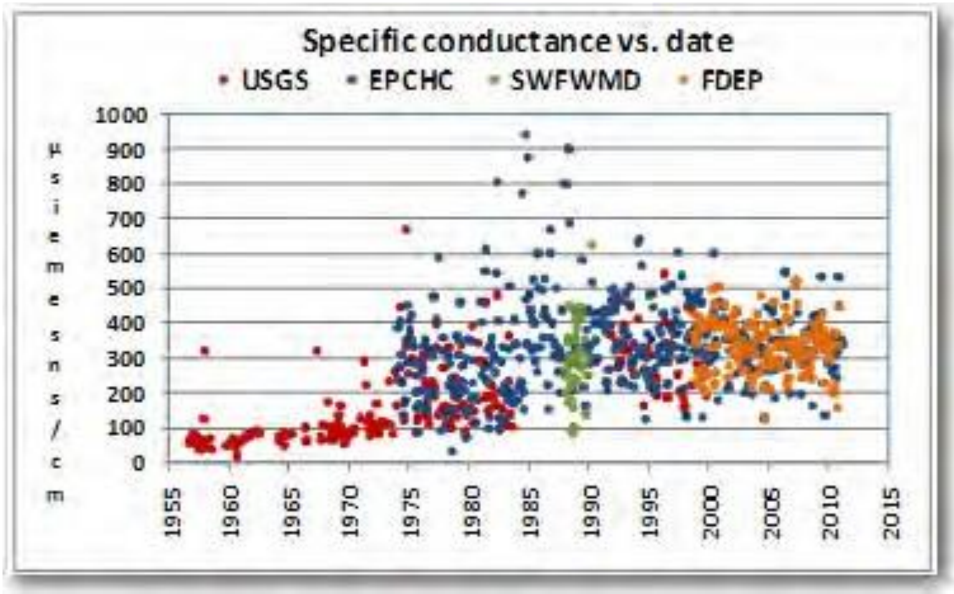


Figure 4-23. Specific conductance values at the Little Manatee River near Wimauma gage recorded by four different agencies (U. S. Geological Survey, Environmental Protection Commission of Hillsborough County, Southwest Florida Water Management District, and the Florida Department of Environmental Protection).

Specific conductance measures the ability of water to conduct an electrical current, which increases with the mineral content of the water. Under natural conditions, ground water in the Little Manatee River basin has greater mineral content than river water. Prior to the 1970s, specific conductance value in the river were typically below 100 microsiemens/cm, reflecting the mineral poor content of rainwater and the sandy soils that comprise the surficial aquifer, from which most of the groundwater baseflow originates. In contrast, the specific conductance values of water in the Floridan aquifer range typically range from 350 to 1,000 microsiemens/cm, depending on proximity to the coast and depth within the aquifer, although much higher concentrations can occur in deeper zones near Tampa Bay.

The increases in the river‟s low flow characteristics and specific conductance values in the mid-1970s correspond to when there began a pronounced increase agricultural water use in the southern part of the District. Much of the irrigation water that was pumped from the Floridan aquifer that was not used by the crops or lost by non-crop evapotranspiration made its way to the streams. Under high irrigation rates, actual surface runoff of excess irrigation water to the streams was observed. Even when runoff does not occur, excess irrigation water can supplement the surficial aquifer, resulting in increased groundwater baseflow to the river.

Baseflow supplementation and the increased mineralization of river water due to increased agricultural land and water use has been reported for several other streams in the southern part of the District, including Joshua Creek (Flannery and Barcelo, 1998; PBS&J 2007), Shell Creek (PBS&J, 2007), the Manatee River (Brown 1982; Camp Dresser and McKee 1992), and the Myakka River (SFWFWMD, 2010). The most extensive assessment of this phenomenon comes from the Myakka, where hydrologic monitoring has shown that flows in the Myakka River and a number of its tributaries have clearly increased (Coastal Environmental 1996 and 1998; Interflow Engineering 2008a; SWFWMD 2010). To address the impacts these increased flows have had on riparian wetlands, a detailed integrated surface water / groundwater model of the Upper Myakka Basin was developed using the MIKE SHE modeling platform to examine the effect of land and water use changes on flows in the river and its tributaries (Interflow Engineering 2008a, 2008b). That analysis has shown that not only has the baseflow of the river increased, but agricultural land use has also increased the storm runoff response in the Myakka, particularly in the early part of the wet season (Interflow 2008b, SWFWMD 2010).

Increased flows and mineralization were also previously reported for the Little Manatee River in a watershed assessment conducted by the District with other agencies in 1988 and 1989 (Flannery et al. 1991). In addition to increases in specific conductance, significant increases in nitrate nitrogen concentrations were observed at the long-term gage, again with a major rise in concentrations beginning in the mid 1970s. Based on the monitoring of six sub-basins in the watershed, it was found that the highest rates of nitrate flux in kilograms per square kilometer were from those sub-basins with the greatest percentages of agricultural land use. Similarly, the highest rates of dry season flow normalized to basin area were from the sub-basins with the greatest percentages of agricultural land use.

The results cited in this minimum flows report and findings from previous studies clearly indicate that the low flow characteristics of the Little Manatee River has changed due to increased agricultural land use in the basin. Rainfall-runoff modeling was not conducted for the minimum flows project, but there are no apparent rainfall trends that would explain the observed increases in low and median flows.

It is important to note, however, there is no evidence that high flows in the Little Manatee have increased. It may be that land use changes in the watershed have not strongly affected the high flow characteristics of the river. The non-trending of high flows may also be related to climatic factors, for although there were no significant trends reported for wet season rainfall, there did appear to be a higher percentage of wet years prior to 1960 (see Figures 4-4, 4-5, and 4-6). A high proportion of wet years in the decades prior to 1960 has been reported for other sites in peninsular Florida and attributed to a warm Atlantic Multidecadal Oscillation period that extended from 1940-1969 (Kelly, 2004). Frequent occurrences of high wet season rainfall in the early part of the record for the Little Manatee could act in the trend analysis to counter any effects that land use changes might have on increasing flows in the river. Considering all factors, the findings generated to date do not indicate that the high flow characteristics of the river have changed over time. More sophisticated rainfall – runoff modeling that examines the effects of historical and current land use conditions on streamflow could be pursued to address this question, but such analyses did not seem necessary for this minimum flows analysis.

4.2.7 Adjustment of the streamflow record for minimum flows analysis

As discussed further in Chapter 1, the basic goal of minimum flows analysis is determine the limit at which further withdrawals will cause significant harm to the water resources or ecology of the area. In addressing this objective, the District normally uses the natural flow regime of the river as the baseline for assessing the effects of existing or potential withdrawals. However, the minimum flows assessment can account for how the flow regime of a river and the associated ecosystem have been affected by structural alterations, such as dams, canals, causeways, or other major physical modifications.

Although there have been substantial changes in land and water use in the Little Manatee River watershed, there have not been any major structural alterations of the river channel. The Florida Power and Light cooling pond is an offstream reservoir that does not impede river flow. There has been hardening of some shorelines in the brackish portion of the river in the town of Ruskin, but these alterations do not impede flow. The mining operations in the eastern portions of the watershed have left the channel of the river and a number of its tributaries intact, with reclamation to be pursued on the surrounding mined lands. Agricultural land use in basin has resulted in some erosion and deposition of upland soils in the river channel, but in general, the natural physical characteristics of the Little Manatee River channel largely remain in good condition.

Although there have not been major structural alterations to the river‟s drainage network, it is increasing agricultural land and water use that have changed the low flow characteristics of the river, even up to the median flows. It is the District‟s objective to reduce these excess agricultural flows through the application of best management practices, more efficient irritation methods, tailwater recovery ponds, and other water conservation measures. The implementation of these measures should result in the flow regime of the Little Manatee River returning to more natural conditions.

Considering these factors, the District concluded that the minimum flows analysis for the Little Manatee should be oriented to the river‟s natural flow characteristics. The goal of this approach is to determine allowable limits for river withdrawals assuming that the excess flows will be reduced by the implementation of best management practices and water conservation measures in the watershed. This approach is environmentally conservative, for it determines allowable withdrawal rates (and remaining instream flows) that protect the river"s ecology assuming that low flows will decline to more natural levels. If flows remain elevated, the withdrawal rates established in this manner should also to be protective of the natural resources of the river in their existing condition. For example, a 15% allowable withdrawal limit based on the reduced natural flows should also be protective of the river if the flows remain elevated. Similarly, the withdrawal supply quantities established by this approach should be conservative, in that the water supply quantities corresponding to the allowable withdrawal limits will only go up if flows in the river remain elevated.

To create a more natural flow record of the river for the minimum flows analysis, the District adjusted the existing flow record by various hydrologic factors. After pursuing various lines of evidence, a method was chosen that adjusts the existing flows within each of the three seasonal blocks, because the data indicate the relative effects of the excess flows differ between the spring dry season (Block 1), the fall/winter intermediate flow season (Block 2), and the summer wet season (Block 3). All adjustments to the existing flows were done after adding back in the surface water withdrawals from the river by Florida Power and Light since 1978.

The District"s method for adjusting the existing flows was based on changes in yearly percentile flows within the three seasonal blocks. Trends within each block were tested for ten percentile flow increments between the 10^{th} and 90^{th} percentile flows, plus the 1^{st} and 5^{th} percentile flows and the 95^{th} and 99^{th} percentile flows. Additional high flow percentiles were tested for Block 1 because significant trends were found above the 90^{th} percentile. The results of these trend tests, which were run for the years 1940 - 2009, are listed in Table 4-8.

Table 4-8. Trends (Kendall Tau) for yearly percentile flows within seasonal blocks for the Little Manatee River near Wimauma gage. Trends not significant at p <.05 highlighted in gray.

Block (Season)	Percentile	1940 - 2009 Time Interval		
		Tau Statistic	P Value	Estimated Slope
Spring Block 1	Qp1	0.33	0.000	0.20
	Qp5	0.35	0.000	0.24
	Qp10	0.36	0.000	0.27
	Qp20	0.36	0.000	0.31
	Qp30	0.35	0.000	0.33
	Qp40	0.35	0.000	0.35
	Qp50	0.36	0.000	0.48
	Qp60	0.32	0.001	0.54
	Qp70	0.31	0.002	0.67
	Qp80	0.25	0.002	0.87
	Qp90	0.19	0.020	1.18
	Qp92	0.17	0.039	1.29
	Qp94	0.16	0.047	1.69
	Qp96	0.16	0.049	1.93
	Qp99	0.10	0.246	1.66
Fall / Winter Block 2	Qp1	0.35	.0001	0.318
	Qp5	0.39	.0001	0.368
	Qp10	0.38	.0001	0.393
	Qp20	0.36	.0001	0.450
	Qp30	0.32	.0001	0.470
	Qp40	0.27	.0001	0.468
	Qp50	0.25	0.002	0.508
	Qp60	0.22	0.006	0.577
	Qp70	0.18	0.025	0.588
	Qp80	0.12	0.145	0.533
	Qp90	0.05	0.516	0.466
	Qp95	0.06	0.503	0.68
	Qp99	0.00	0.967	0.15
Summer Block 3	Qp1	0.22	0.009	0.27
	Qp5	0.21	0.010	0.33
	Qp10	0.11	0.177	0.22
	Qp20	0.08	0.301	0.27
	Qp30	0.09	0.294	0.38
	Qp40	0.07	0.383	0.38
	Qp50	0.03	0.707	0.16
	Qp60	-0.02	0.808	-0.23
	Qp70	-0.07	0.389	-0.83
	Qp80	-0.11	0.187	-2.14
	Qp90	-0.14	0.095	-4.25
	Qp95	-0.14	0.081	-8.14
	Qp99	-0.15	0.070	-12.5

Significant increasing trends (<0.05) were observed for all percentiles below the 99th percentile in Block 1, which extends from April 18 to June 22. Although this is typically the low flow time of year, these results indicate that nearly all components of the flow regime have increased in Block 1. Increasing trends were found for the 1st through the 70th percentile in Block 2, indicating the low and medium flows in the fall/winter period have increased, but the higher flows have not.

The results for Block 3 are very different in that significant increasing trends were observed only for the 1st and 5th percentiles, or the very low flows that occur during that block. Such low flows can occur in late June or early July, near the time of the switch from Block 1 to Block 3 if the summer rains are late to begin. The higher percentile flows within Block 3 had negative slopes, meaning if anything, these flow may have declined, but the slopes were not significant at $P < 0.05$.

To illustrate these trends, hydrographs of six yearly percentile flows within each block are presented in Figures 4-24, 4-25 and 4-26. The 25th and 75th percentile flows are plotted rather than the 20th or 70th percentiles listed in Table 4-9 in order to graphically characterize the interquartile percentile flows within each block. Also shown as separate red bars are the flows that correspond to that percentile computed from all days within either the 1940-1970 and 1978-2009 periods. In other words, the red bars were computed from all days in either the early or recent record, and opposed to the plotted data points that are percentile values computed in within that block each year. The 1940 -1970 period was selected to represent early period when the augmentation of river flow by excess agricultural water was very slight. The 1978-2009 period was selected to represent the recent period when augmentation of the river with excess agricultural flow was apparent, based on the results of the streamflow and water quality analyses previously discussed.

Changes in the percentile flows between the two periods for the three seasonal blocks are apparent from the graphics, noting that the scale of the y axes differ between blocks. The relative changes in percentile flows were greatest for Block 1, intermediate for Block 2, and least for Block 3. Within each block, the relative increases in percentile values between the two periods were greatest for the lower percentiles (e.g. 5th, 10th 25th percentiles). Decreases in percentile values for the 75th and 90th percentiles were found for Block 3.

To summarize these results, changes in percentile values computed from all the days in the recent or early period are listed Table 4-9, including the percentage changes for each percentile between the 1940-1970 and the 1978-2009 periods.

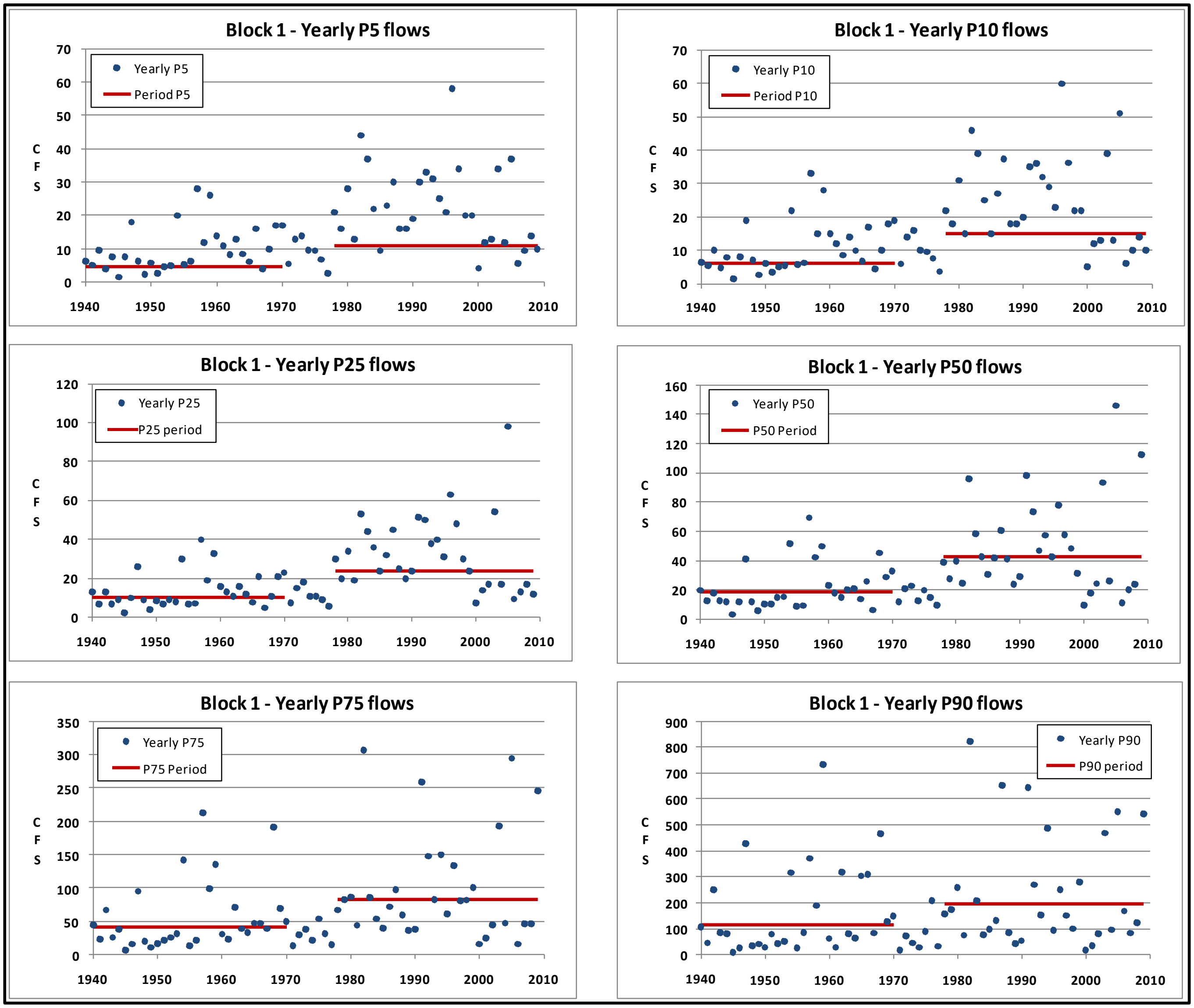


Figure 4-24. Plots of yearly values of the 5th, 10th, 25th, 50th, 75th, and 90th percentiles within Block 1 (April 18-June 22) with red bars representing percentiles calculated from all days in either the 1940-1970 and the 1978-2009 periods.

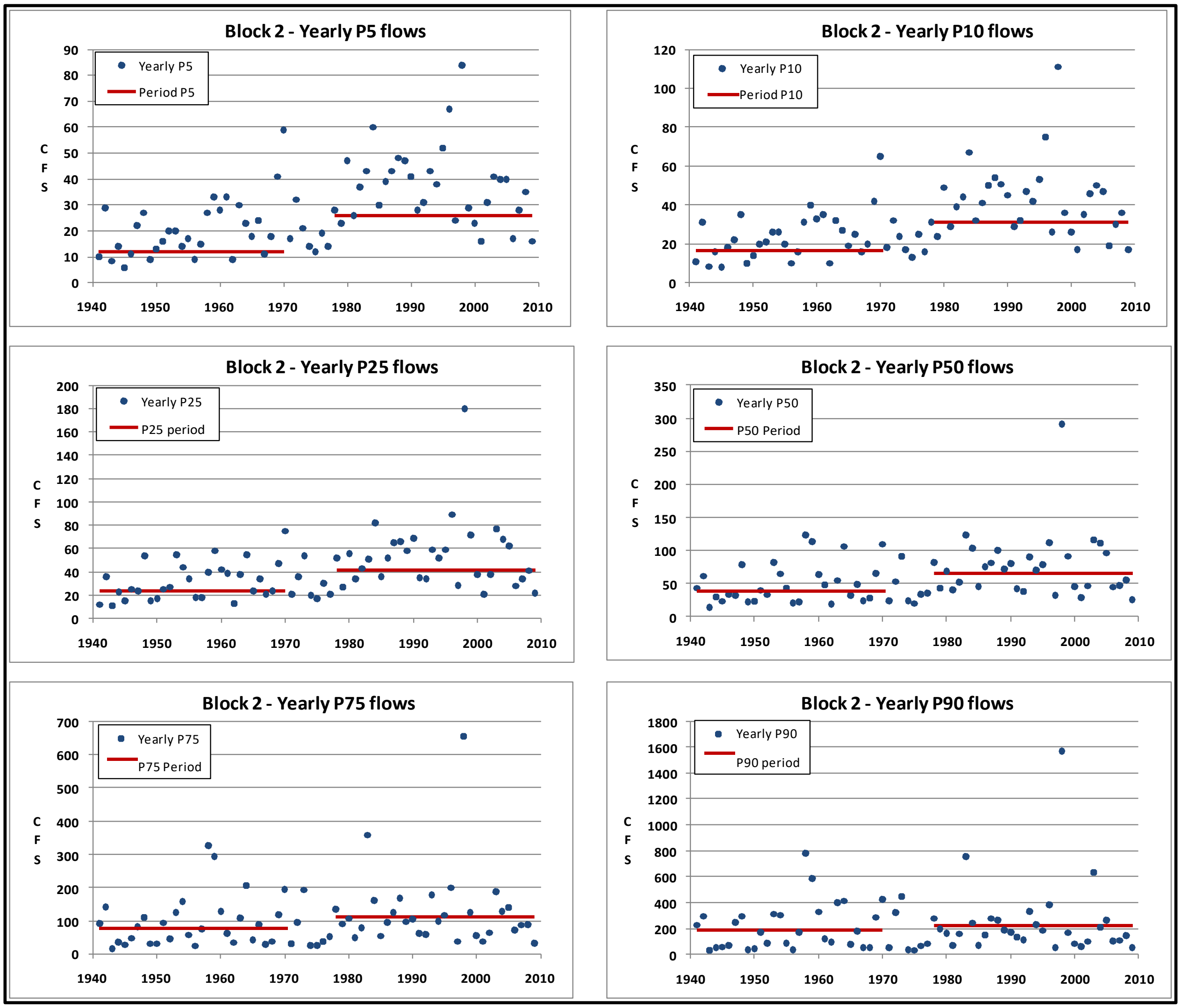


Figure 4-25. Plots of yearly values of the 5th, 10th, 25th, 50th, 75th, and 90th percentiles within Block 2 (October 22 -April 23) with red bars representing percentiles calculated from all days in either the 1940-1970 and the 1978-2009 periods.

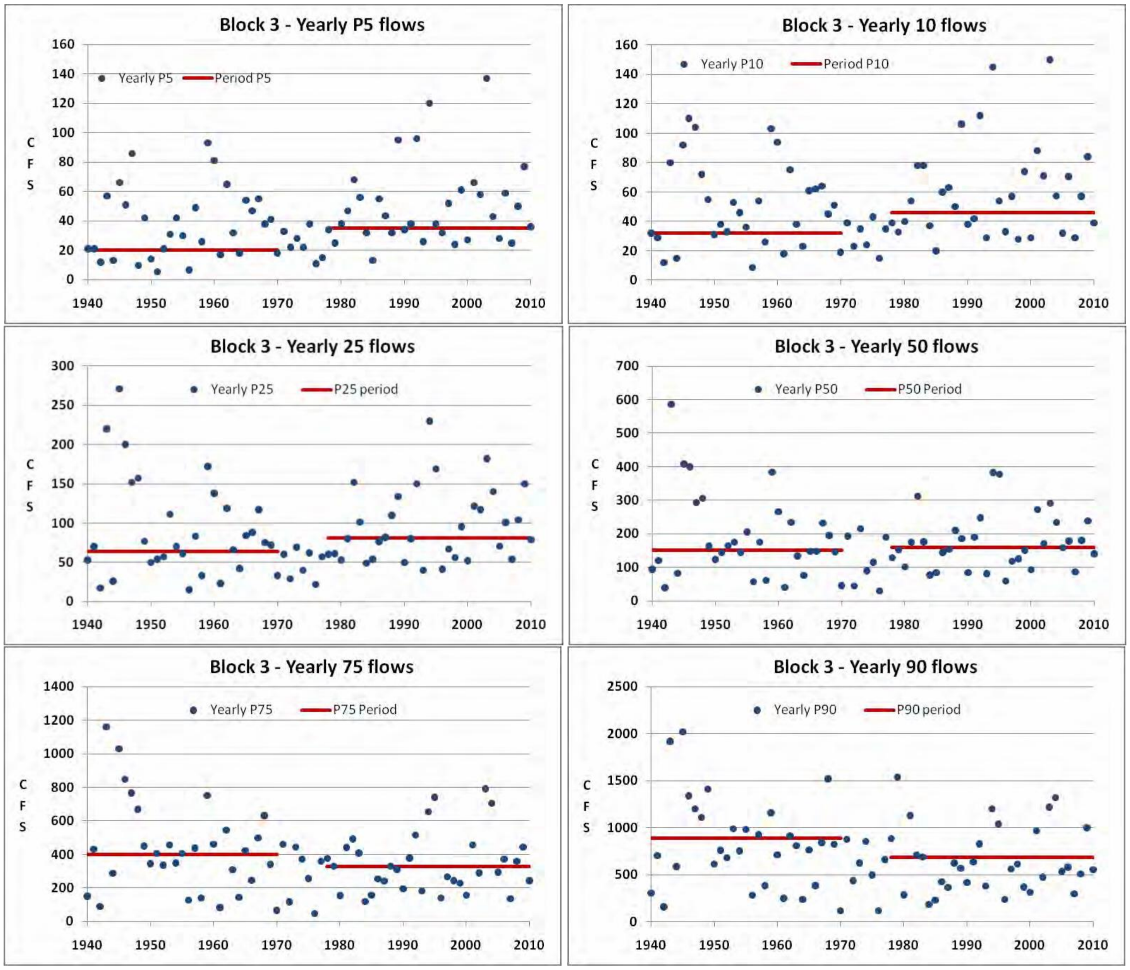


Figure 4-26. Plots of yearly values of the 5th, 10th, 25th, 50th, 75th, and 90th percentiles within Block 3 (June 23 – October 21) with red bars representing percentiles calculated from all days in either the 1940-1970 and the 1978-2009 periods.

Table 4-9. Flows (cfs) for various percentiles within three seasonal blocks for the 1940-1970 and 1978-2009 periods. Changes in percentile values in cfs and percent changes in each percentile from the early to the recent period shown in blue. For results shaded in gray, there were no significant trends for the yearly percentiles within that block for the entire 1940-2009 period.

Block 1				
	1940-1970 median	1978-2009 median	Difference	Percent change
p1	2.4	7.1	4.7	196%
p5	4.8	11	6.2	129%
p10	6.2	15	8.8	142%
p20	8.6	21	12.4	144%
p30	12	27	15	125%
p40	15	35	20	133%
p50	19	43	24	126%
p60	25	54	29	116%
p70	35	70	35	100%
p80	53	103	50	94%
p90	116	196	80	69%
p92	148	237	89	60%
p94	217	325	108	50%
p96	314	442	128	41%
p99	732	887	155	21%

Block 2				
	1940-1970 median	1978-2009 median	Difference	Percent change
p1	8.3	18	9.7	117%
p5	12	26	14	117%
p10	16	31	15	94%
p20	22	38	16	73%
p30	27	46	19	70%
p40	33	55	22	67%
p50	40	66	26	65%
p60	51	80	29	57%
p70	68	98	30	44%
p80	102	132	30	29%
p90	192	225	33	17%
p99	1140	1071	-69	-6%

Block 3				
	1940-1970 median	1978-2009 median	Difference	Percent change
p1	10	24	14	140%
p5	20	35	15	75%
p10	32	46	14	44%
p20	52	68	16	31%
p30	76	94	18	24%
p40	111	124	13	12%
p50	151	160	9	6%
p60	217	203	-14	-6%
p70	317	278	-39	-12%
p80	500	401	-99	-20%
p90	886	683	-203	-23%
p99	2940	2150	-790	-27%

The largest relative increases in percentile values between the two periods were for Block 1, as changes of 100% or greater were found for all percentiles below the 70th percentile. For Block 2, percent changes in percentiles ranged from 44% to 117% for percentiles less than the 70th, which are the percentiles shaded in gray that showed significant increasing trends over the entire 1940-2009 period. For Block 3, positive changes were found for the 50th percentile and below, with negative changes for the higher percentiles. However, significant trends in yearly percentile values were found only for 1st and 5th percentiles.

The District used the changes in the percentiles values within the blocks between the 1940-1970 and 1978-2009 periods to create an adjusted flow record or the years 1978-2009. The purpose of this adjusted flow regime was to estimate the flow characteristics of the river without the excess agricultural flow. Although water quality data indicate that augmentation of the river began in the mid-1970s, there were a series of very dry years in the mid-1970s, and increases in yearly percentile flows within the blocks weren‟t apparent until 1978. It was thus concluded that adjusting the flows in the mid-1970s might result in an over correction for those years.

Based on review of the data, it was concluded one single number (e.g. 15 cfs) could not be used to represent the excess agricultural flow within each block. Instead, the adjustment of the flows within blocks should be scaled to the rate of streamflow. For example, the increase in 70th percentile flows in Block 1 was 35 cfs, compared to 8.8 cfs for the 10th percentile flows. During very dry periods, more of the irrigation water is taken up by the crops or lost to evapotranspiration, with less excess flow. Also, based on detailed modeling of agricultural effects in the Myakka River, excess irrigation water affects not only the baseflow characteristics of the streams, but by raising the water table and creating more saturated soil conditions, the runoff response to rainfall events as well. The data from the Little Manatee support these processes, for in the spring dry season, greater increases in flow were observed for the higher percentiles.

A similar, but not as strong a pattern, was observed in Block 2, but the there were no significant increasing trends for percentiles above the 80th percentile when rainfall runoff processes are dominant. As previously described, significant increasing trends were observed only for the 1st and 5th percentiles in Block 3, when irrigation is minimal and summer rains increasingly affect streamflow generation.

The approach taken by the District was to adjust the flows within each block for those percentiles that showed significant increasing trends based on yearly percentile values (Table 4-9). In some cases, increases in percentiles calculated from all days in each period were observed when here was no trend in yearly percentile values (e.g. 80th percentile in Block 2 in Table 2-10). Because the District did not want to overcorrect the record, flows we not adjusted for those percentiles. Instead, flow adjustments were limited to those percentiles where there significant ($p<0.05$) increasing trends in the yearly values. For those percentiles, the differences in percentiles between the 1940-1970 and 1978-2009 periods listed in Table 4-10 were used to adjust the 1978-2009 flows. Each daily flow record in the recent flow record was assigned to a percentile class (e.g. 20th percentile within the recent period). The change in the percentile value between the recent and early periods was then subtracted from the recent flow value for that day to produce the adjusted value. The approach was pro-rated, in that the adjustment for daily flows values that were between two percentile values (e.g. 20th and 30th) used a weighted value that was calculated from the two percentile values that spanned the existing flow value for that day.

Using the results listed in Table 4-10, an example of this approach from Block 1 is as follows. The increase in the 30th percentile values between the early and recent periods was 15 cfs, while the increase in the 40th percentile values was 20 cfs (Table 4-10). If a daily flow rate in the recent record was at its 30th percentile value (27 cfs), then 15 cfs was subtracted to produce the adjusted flow values for that day. If the daily flow rate in the recent record was at its 40th percentile value (35 cfs), then 20 cfs was subtracted to produce the adjusted flow value. When flows were between the 30th and 40th percentiles, a weighted factor was subtracted that was calculated between the adjustment factors for the 30th and 40th percentiles.

This approach was conducted progressively up through the percentiles until it reached a percentile at which there was no significant trend. When that rate of flow was reached (e.g. 80th percentile in Block 2), that percentile was given an adjustment factor of zero and values below that were adjusted using a weighted factor that also incorporated the highest percentile which has significant increasing trend (70th percentile from Block 2). Flows were adjusted up through the 99th percentile flow in Block 1, through the 80th percentile flow in Block 2, and only up through the 10th percentile flow in Block 3. Flows above these percentile values were not adjusted.

There was also a caveat to not adjust very low flows below the 5th percentile in Block 1. The lowest yearly 5th percentile flow in the early record was 1.5 cfs. If a recent record was adjusted to a value of less than 1.5 cfs, it was set to 1.5 cfs. This caveat was applied because there were some pronounced droughts in the recent record (2000, 2001), and adjusting the very low flows with the standard protocol resulted in zero flows which were not observed in the historic record. The caveat to adjust these very flows was applied to only 35 days in the 1978-2009 period and had no real effect on the findings of the minimum flow analysis.

The result of this approach was a complete daily flow record for 1978-2009 that represented flows at the long-term stream gage with the estimated agricultural water taken out. It should be emphasized these values are only estimates, for the excess agricultural water was neither measured nor modeled. The approach used seasonal approach to adjusting the flow, but the amount of excess agricultural flow to the river surely varied with year to year changes in land use, water use, and climate. The approach could not account for this year to year variation, and applied the same adjustment factors for all years in the recent period. The end result was a record of flows for 1978-2009 that were adjusted to statistically more closely correspond to the flows that occurred from 1940-1970.

Table 4-10 lists unadjusted percentile flow values for three time periods: all years from 1940-2009; the early 1940-1970 period; and the recent 1978-2009 periods. Values are also listed for adjusted flows for the 1978-2009 period. The results clearly show how the flow duration characteristics of the river have changed between the early and recent periods. The adjusted flows for the recent period closely correspond to the flows for the early period at flow rates below the 60th percentile. Because the high flows of the rive have not shown significant trends, the flows were adjusted at high flows, so the percentiles for the adjusted flows more closely correspond to the recent flow record at high flows.

The adjusted flows from 1978-2009 can be combined with unadjusted flows prior to 1978 to create a synthesized, long-term natural flow record for the river. Hydrographs of yearly percentile flows using this long term record are shown in Appendix Yearly Flows. Time series plots of the 5th and 50th percentiles flows for Blocks 1 and 2 using this long term natural flow record are shown as examples in Figure 4-27. Compared to the plots of actual data, which showed an increase in values after 1978, the percentile values appear non-trending over time. The low adjusted values for several recent dry years appear reasonable, given the very dry conditions that occurred during those years.

Table 4-10. Minimum, maximum, and selected percentile values for daily flows (cfs) at the Little Manatee River near Wimauma gage for three time periods: Long-term (1940-2009); Early (1940-1970); and Recent (1978-2009). Values for the recent period are for observed flows and adjusted flows in which excess agricultural flows have been subtracted. All values are corrected for any upstream withdrawals by the Florida Power and Light Company.

Percentile	1940-2009	Recent (1978-2009)	Early (1940-1970)	Adjusted (1978-2009)
Minimum	0.9	3.8	0.9	1.5
5	12	22	9	9
10	18	28	13	13
20	27	38	21	21
30	36	49	28	29
40	47	62	38	40
50	63	78	51	56
60	85	101	73	84
70	124	140	114	135
80	199	208	200	204
90	400	384	433	384
95	692	651	771	651
Maximum	11,100	10,455	11,100	10,455

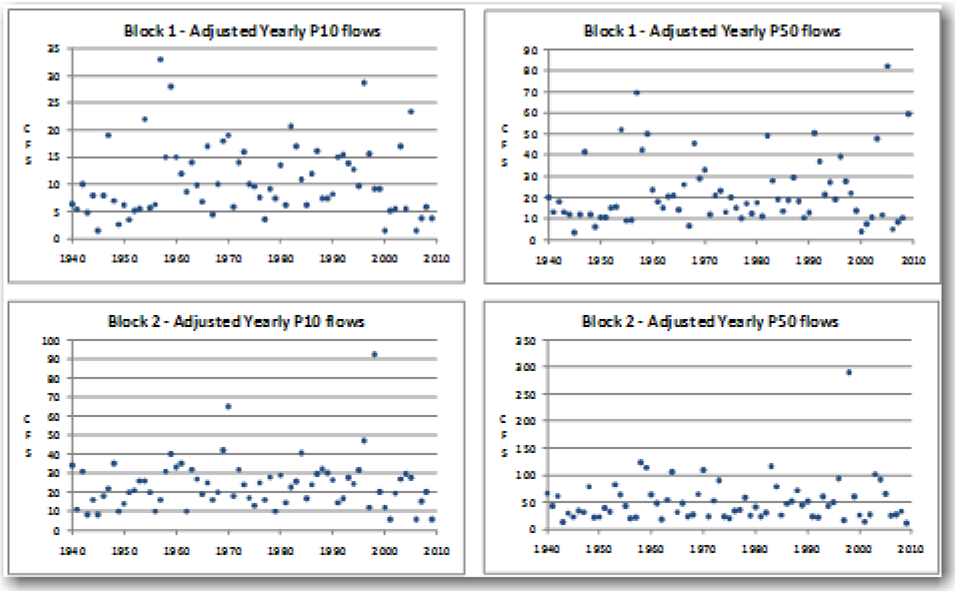


Figure 4-27. Time series plots of the 10th and 50th percentile flows in Blocks 1 and 2 for 1940-2009 with values from 1978 to 2009 adjusted to remove estimated excess agricultural water.

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 Little Manatee River will necessarily lead to substantial changes in water quality. However, it is appropriate to review the water quality of the Little Manatee River to fully appreciate how land use changes may have affected the system.

Long-term water quality changes were evaluated using USGS data gathered at the Little Manatee River near Wimauma gage site (see Appendix WQ). Comparison of water quality data with flow records was made for evaluation of possible relationships between flow and land use.

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

Data for each parameter discussed in the following sections of this chapter are typically presented in three plots: a time-series plot, a plot of the parameter versus flow, and a plot of the residuals obtained from a LOWESS regression of the parameter versus flow. The last plot was used to evaluate if a parameter's loading has increased or decreased over time irrespective of flow. The results of a Kendall's tau analysis on the residuals were used to help determine if apparent increasing or decreasing trends in a parameter were statistically significant (Table 5-1).

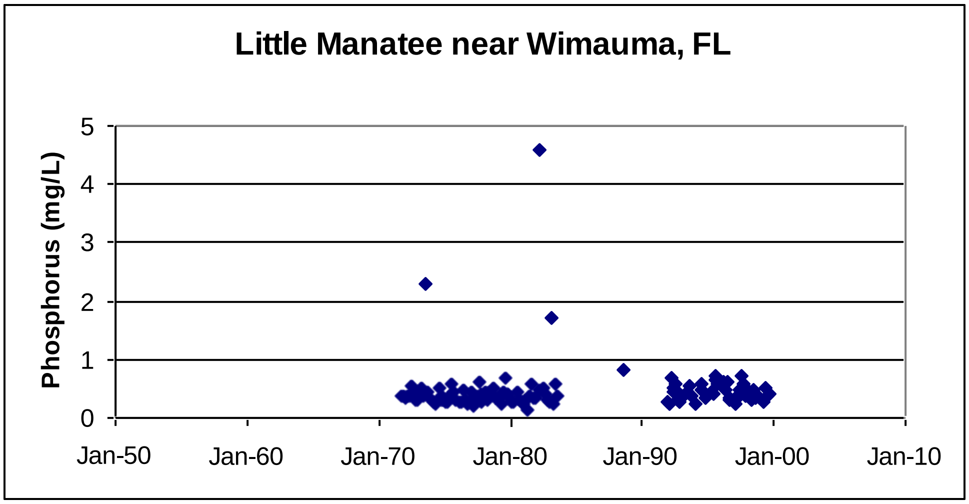
5.1.1 Macronutrients: Phosphorus and Nitrogen

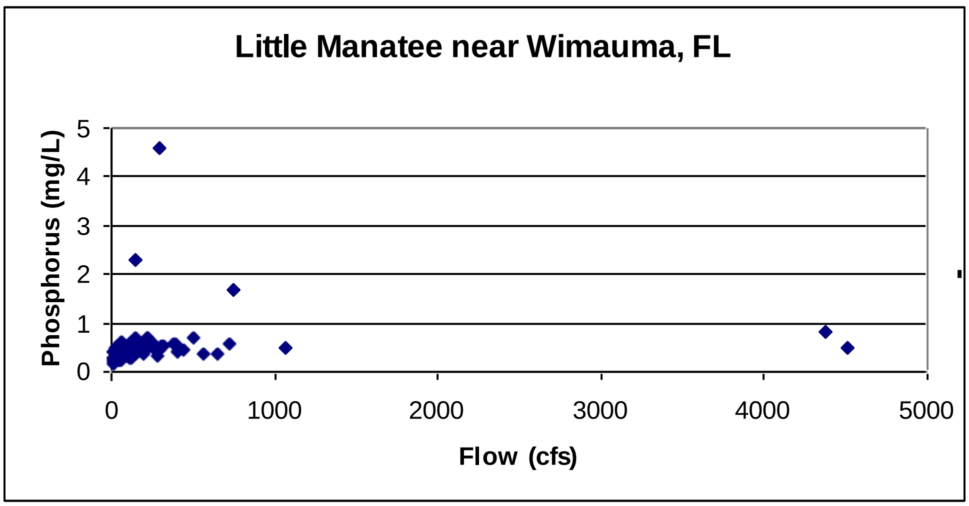
Concentrations of the two major macronutrients, phosphorus and nitrogen, have been monitored for some time at the Wimauma gage site. The exact chemical form of the nutrients monitored has changed over time (e.g. total nitrate, dissolved nitrate, nitrite+nitrate, etc.), however, for purposes of the discussion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

5.1.1.1 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 at the Wimauma gage were below this level with the exception of three sampling events, which occurred from July of 1973 to March of 1983 (Figure 5-1). In looking at flow and rainfall within the basin, there seem to be no apparent reasons for these spikes. Forty percent of all phosphorous measurements were above the proposed numeric nutrient criteria (0.415 mg/L) for the Bone Valley Region of Florida. This standard has been proposed by the Environmental Protection Agency. Inspection of the residuals (Figure 5-1, bottom graph) show no increasing or decreasing trends in phosphorous.





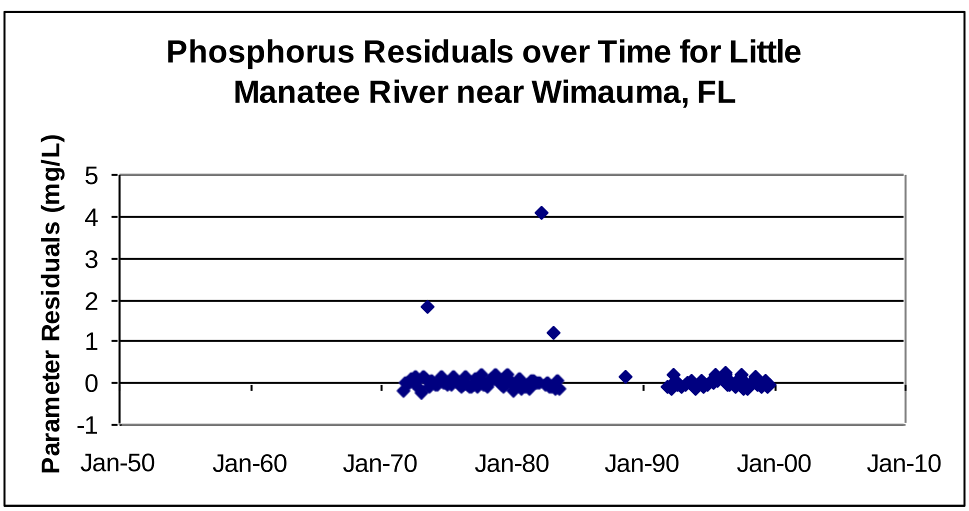
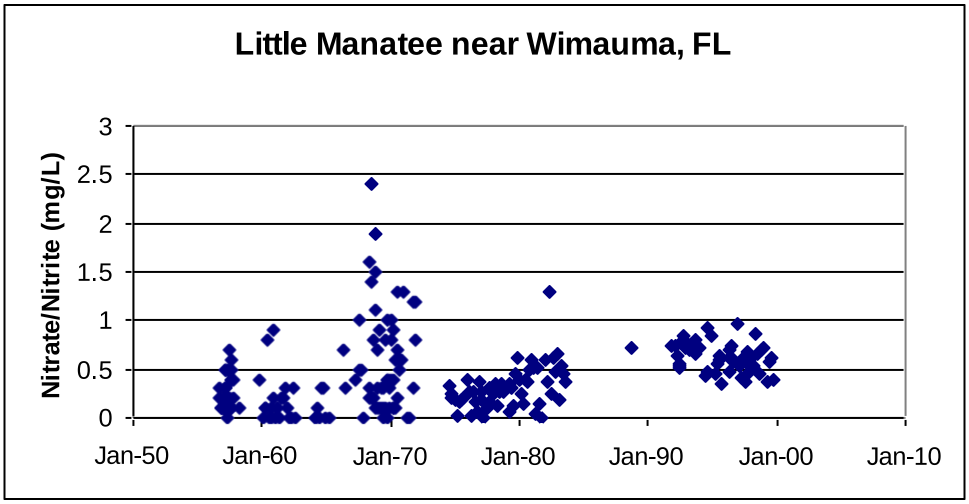


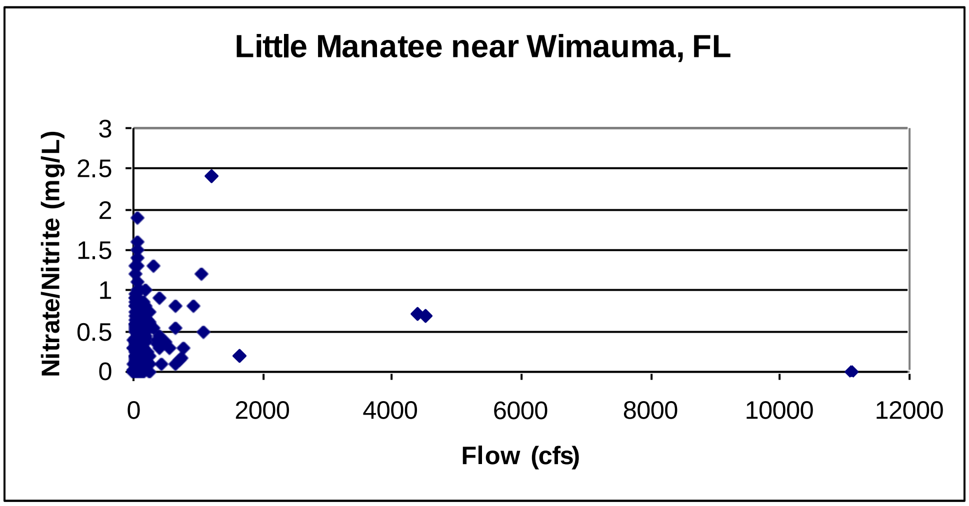
Figure 5-1. Trend analysis of Phosphorus for Little Manatee River near Wimauma, FL.

5.1.1.2 Nitrogen

Nitrogen has most often been reported by the USGS 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 (Figure 5-2), there has been an upward trend in Nitrate/Nitrite (NOx). These increases occur irrespective of flow and may be at least partially attributable to the increase in row crops in the watershed agriculture. Although the amount of row crows is not known for the 1974 land use maps, there was a 4,609 acre (3.2% of the entire watershed) increase in row crops between 1990 and 1999. Area in row crops remained stable from 1999 to 2004. The majority of measurements were above the proposed numeric nutrient criteria (0.35 mg/L).





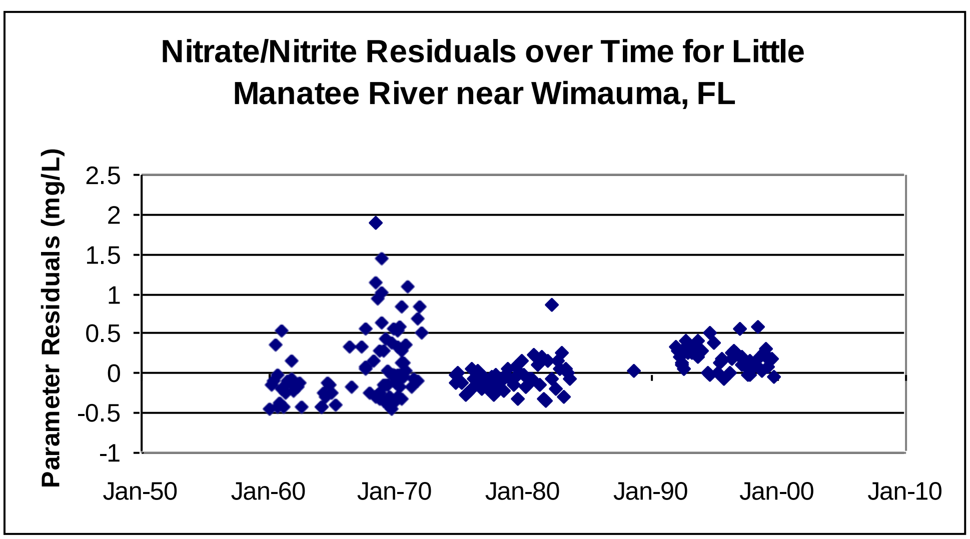


Figure 5-2. Trend analysis of Nitrate/Nitrite for Little Manatee River near Wimauma, FL.

5.1.2 Trend Analysis of Selected Chemical Constituents

Analysis of Little Manatee near Wimauma water quality data reveals an apparent increasing trend in conductance, pH, hardness, Calcium, Chloride, Fluoride, Magnesium, Potassium, Silica, Sodium, and Sulfate (Figures 5-3 through 5-5, Table 5-1 and Appendix WQ). Statistical analyses show that these trends are unrelated to increases or decreases in flow, indicating an increasing rate of loading from the watershed. It is speculated that these trends, along with the increasing Nitrate/Nitrite loading, may be a result of increased land use being in agriculture and the subsequent increase in irrigation using groundwater.

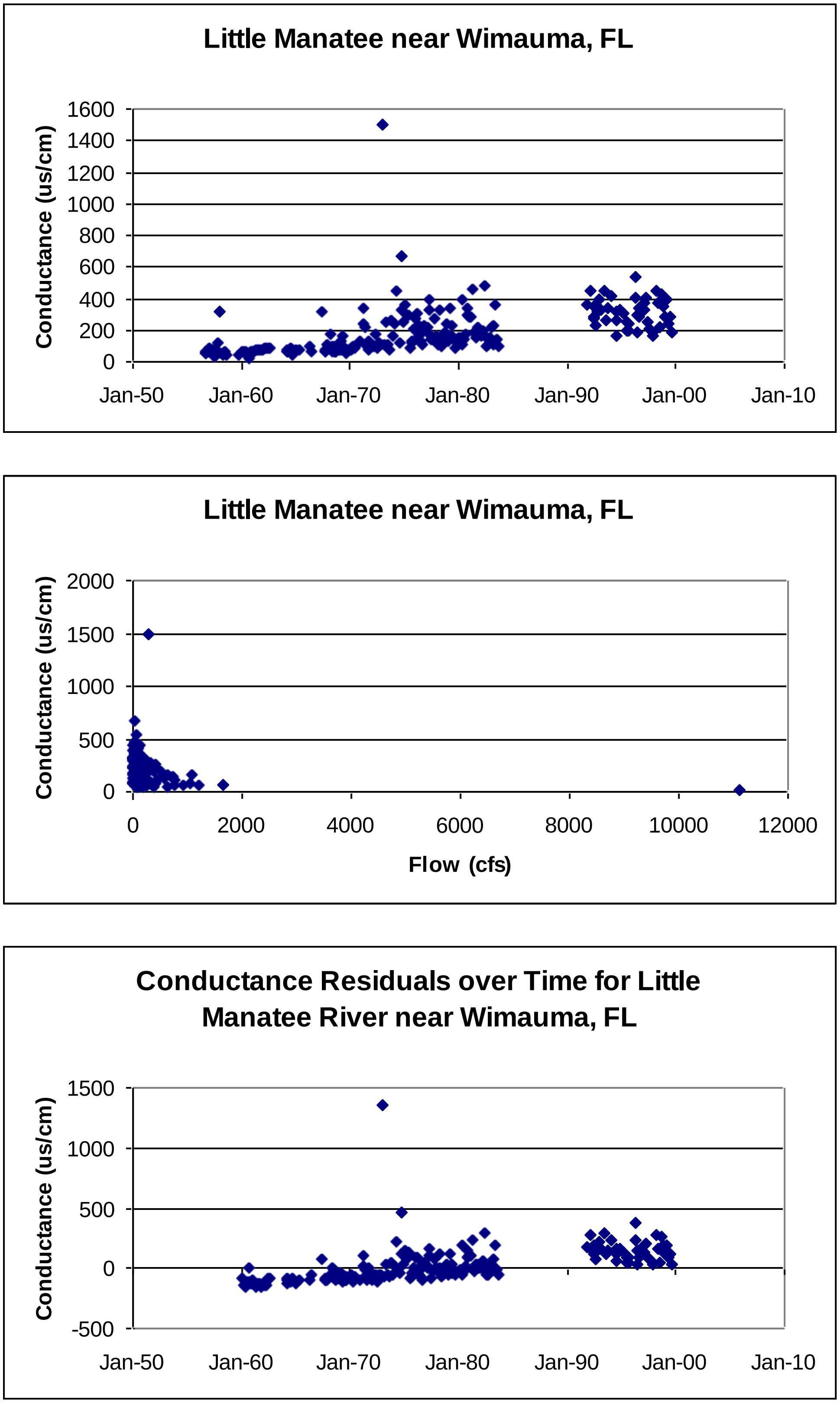
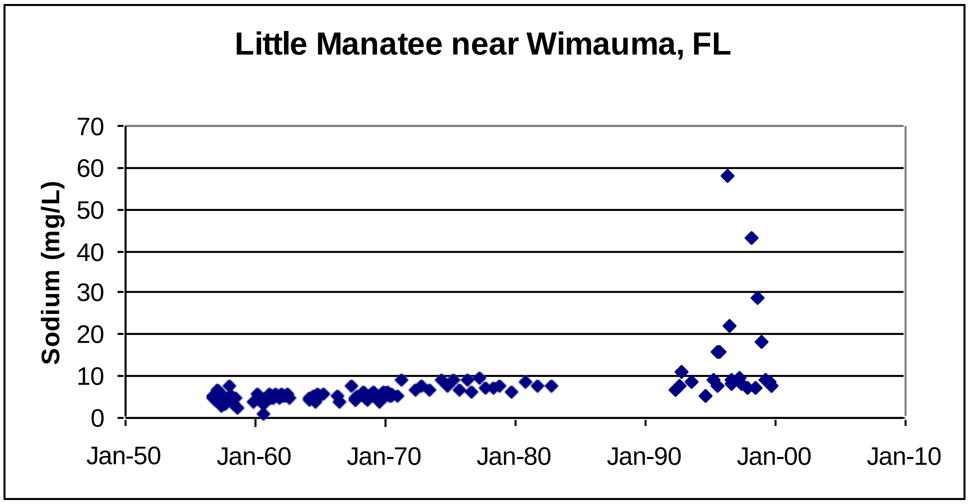
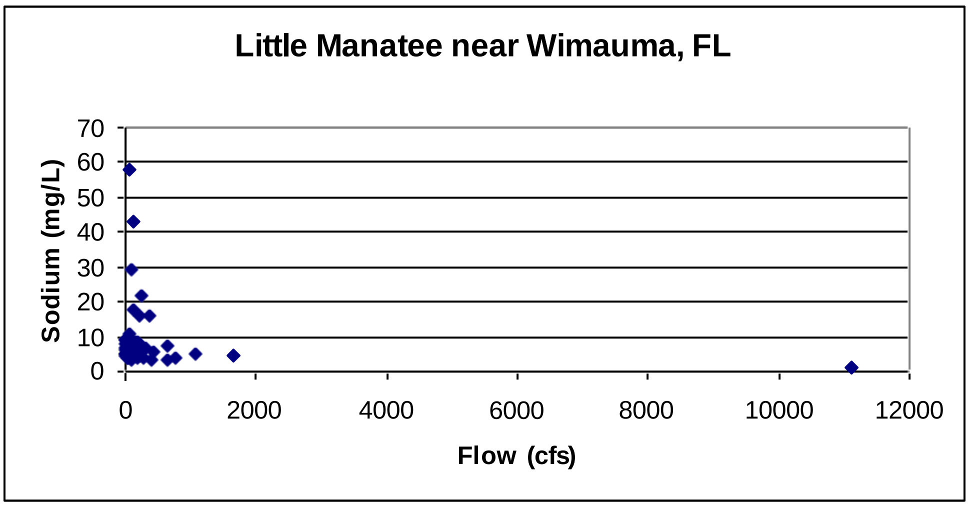


Figure 5-3. Trend analysis of Conductance for Little Manatee River near Wimauma, FL.





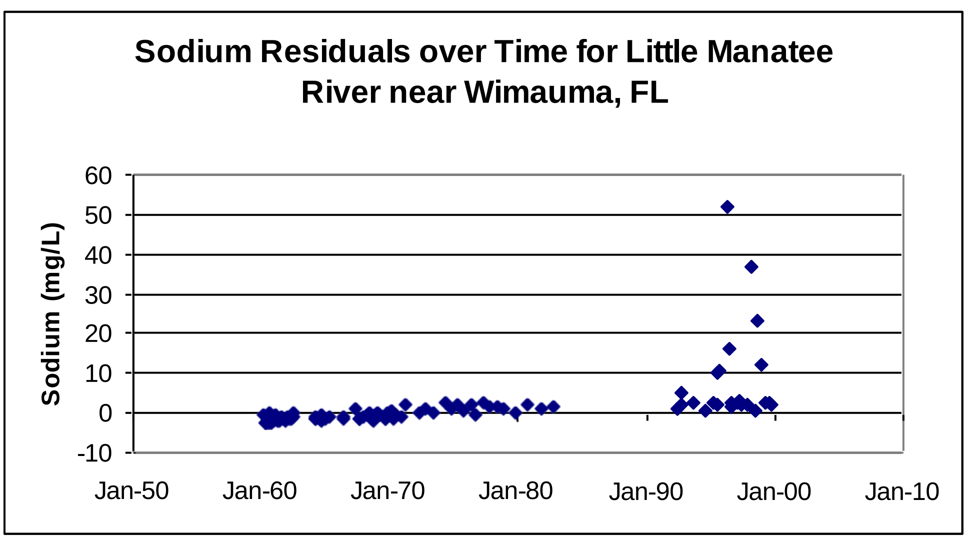
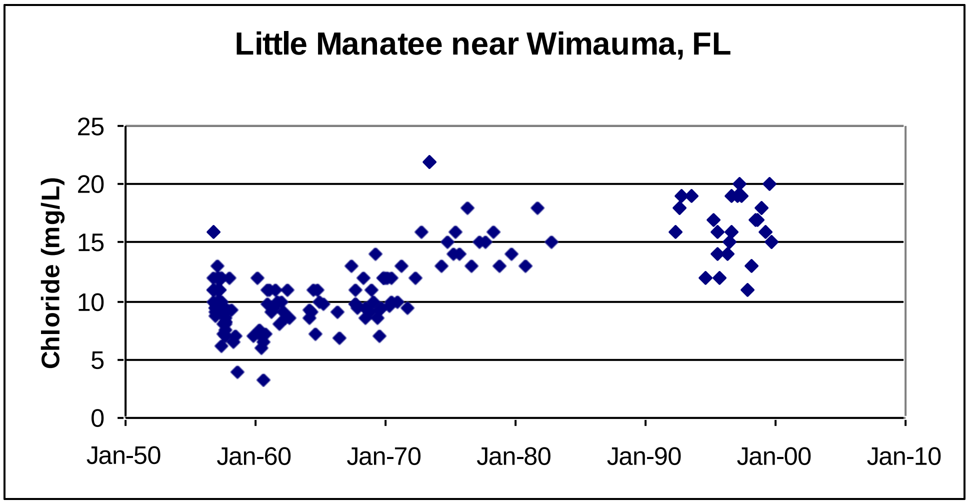
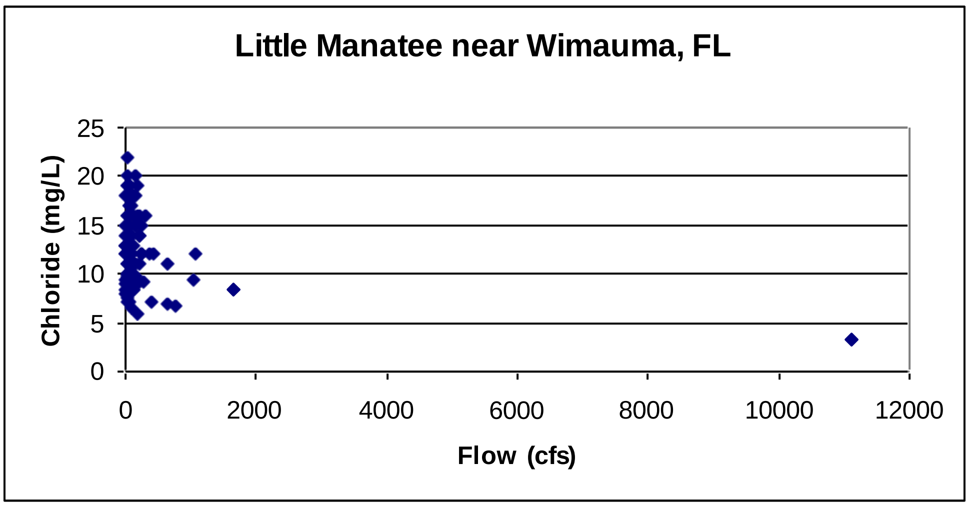


Figure 5-4. Trend analysis of Sodium for Little Manatee River near Wimauma, FL.





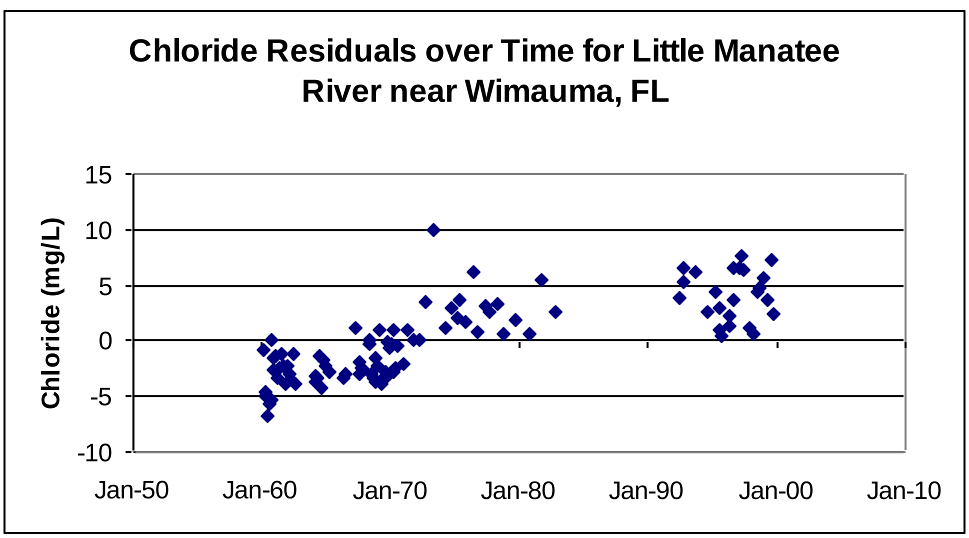


Figure 5-5. Trend analysis of Chloride for Little Manatee River near Wimauma, FL.

Parameter Residual	Residual Median	n	p Value	intercept	slope
Conductance	-16.6800	212	0.00000	-543.67700	0.01898
Dissolved Oxygen	0.0039	133	0.49601	0.90050	-0.00003
pH	-0.0322	173	0.00000	-1.92056	0.00007
NOx	-0.0075	195	0.00000	-0.67146	0.00002
Phosphorus	-0.0024	125	0.50144	0.04805	0.00000
Hardness	-0.6210	73	0.00000	-150.20700	0.00598
Calcium	-3.7578	98	0.00000	-39.42140	0.00139
Chloride	-0.1622	99	0.00000	-16.29750	0.00063
Fluoride	-0.0286	96	0.03756	-0.12553	0.00000
Iron	-0.1520	37	0.05790	-249.17100	0.01007
Magnesium	-1.4814	99	0.00000	-18.56180	0.00067
Potassium	-0.5034	97	0.00000	-9.30239	0.00034
Silica	0.0299	109	0.00000	-5.13683	0.00020
Sodium	-0.0246	96	0.00000	-9.55508	0.00037
Sulfate	-10.2280	98	0.00000	-130.328	0.00470

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

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." After reviewing numerous case studies from around the world, Richter et al suggested that protecting 80% of a river‟s daily flow will maintain ecological integrity in most rivers (Richter 2011). They also caution that 90% of the daily flow may need to be protected in rivers with at-risk species.

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 in streams is largely 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 Gum Slough Spring Run 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.

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 these 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 (**Error! Reference source not found.**). 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. 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. As the Little Manatee River is primarily well incised with very high banks, PHABSIM analyses are appropriate for the entire flow regime.

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. Although very thorough analyses of the Little Manatee river floodplain were conducted, lack of well developed wetlands led to the decision not to utilize vegetation analyses for MFL establishment. With the river having a well incised channel, it was determined that PHABSIM analysis would be a more appropriate metric for Block 3 flows.

7 Technical Approach for Establishing Minimum Flows and Levels for the Little Manatee

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.

Given that protection of a river's flow regime is critical to protecting the biological communities associated with that system, the District has employed a percent-of-flow method in determining minimum flows and levels. The percent-of-flow method determines percentage rates that flows can be reduced without causing significant harm. In both the evaluation and application of the minimum flows, these percentage limits are applied to daily flow records at or very near the time of withdrawal. If necessary, these percentages can vary by season or flow ranges to reflect changes in the sensitivity of the stream to flow reductions. MFLs determined for the freshwater reaches of the Middle Peace, Myakka, Alafia, Withlacoochee and Upper Hillsborough River that used the percent-of-flow method have all received independent scientific peer review, which generally supported this technical approach.

All analyses were performed on two flow records. The flow records were for the wet climatic period (1940-1969) and the dry climatic period (1970-2009). The overwhelming majority of analyses resulted in more restrictive flow reductions for the dry period. Unless otherwise mentioned, the results from dry 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 for the Little Manatee River is contained in Appendix HEC-RAS.

Elevation data in the Little Manatee River were compiled from multiple sources. These sources included surveyed transects from the SWFWMD survey section conducted in support of MFLs, data gathered by ZFI, Inc. from Florida Department of Transportation, and instream transect data collected by SWFWMD staff in support of MFL development. Additionally, LiDAR data was available from the Districts GIS and Mapping department for the Little Manatee

River watershed. These data sources and break-lines were used to generate a triangulated irregular network (TIN).

Using HEC-GeoRAS, an Arcmap extension, cross-sections were generated in Arcmap and exported into HEC-RAS (Figure 7-1). There is a data variance during the conversion from a TIN to a DEM. The DEM cannot conserve the same values stored in the TIN, because the value of the grid is calculated in ArcGIS by averaging the elevation data in a given surface area, which is 25 square feet.

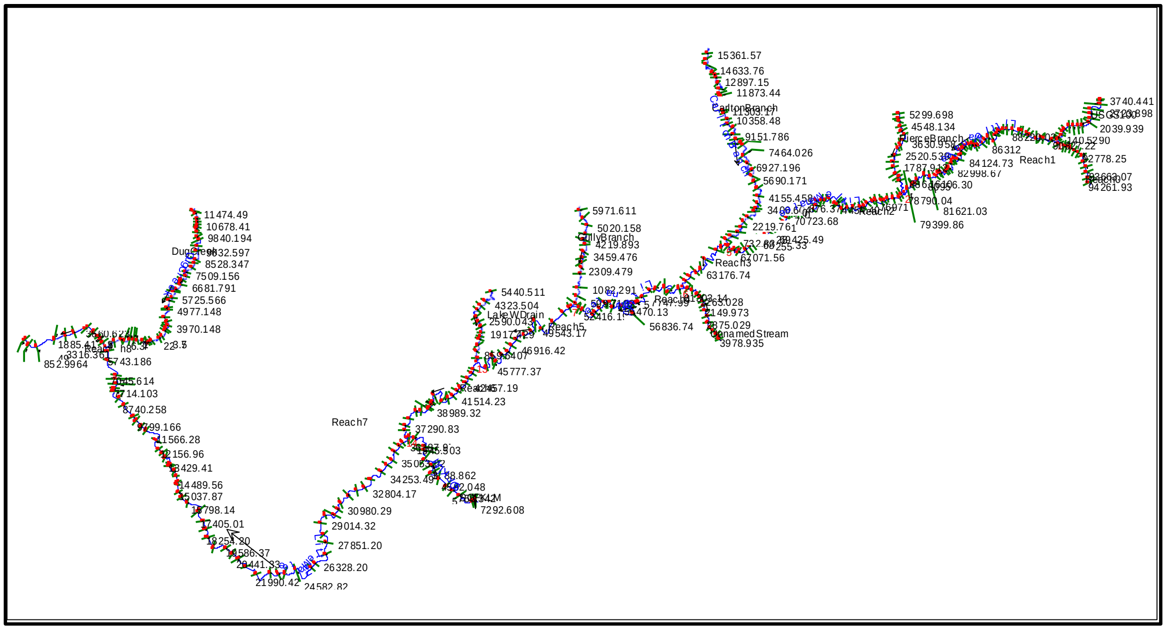


Figure 7-1. Location of HEC-RAS cross-sections in the Little Manatee River and tributaries (Map produced by ZFI, Inc.).

7.3 PHABSIM Cross-Sections

Physical Habitat Simulation (PHABSIM) cross-sections, designed to quantify specific habitats for fish and macroinvertebrates at differing flow conditions, were established at two representative sites on the Little Manatee River (see Figure 7-22). Bottom substrata consist mainly of shifting sand. Very little 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 recreational 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 StreamPro 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, relative to the North American Vertical Datum of 1988 (NAVD 88). 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. Upon modeling the three PHABSIM sites, the Masonic Park site did not calibrate properly and had to be discarded.

7.4 Instream Habitat Cross-Sections

Cross-sections for assessing instream habitats were examined at ten sites (eight vegetation only and two PHABSIM/vegetation) on the Little Manatee River (see Figure 7-2). 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 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 30 instream cross-sections were sampled (10 cross-sections x 3 replicates at each site).

For each instream habitat cross-section, the range in elevations (feet above the NAVD 88 and feet above the North American Vertical Datum of 1988) and linear extent (along the cross-section) for the following habitats were determined:

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

Following the collection of cross-section substrate/cover/habitat data, additional elevations of woody habitats were also collected at each instream habitat site. Belt transects along the banks of the Rainbow 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 differs 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.

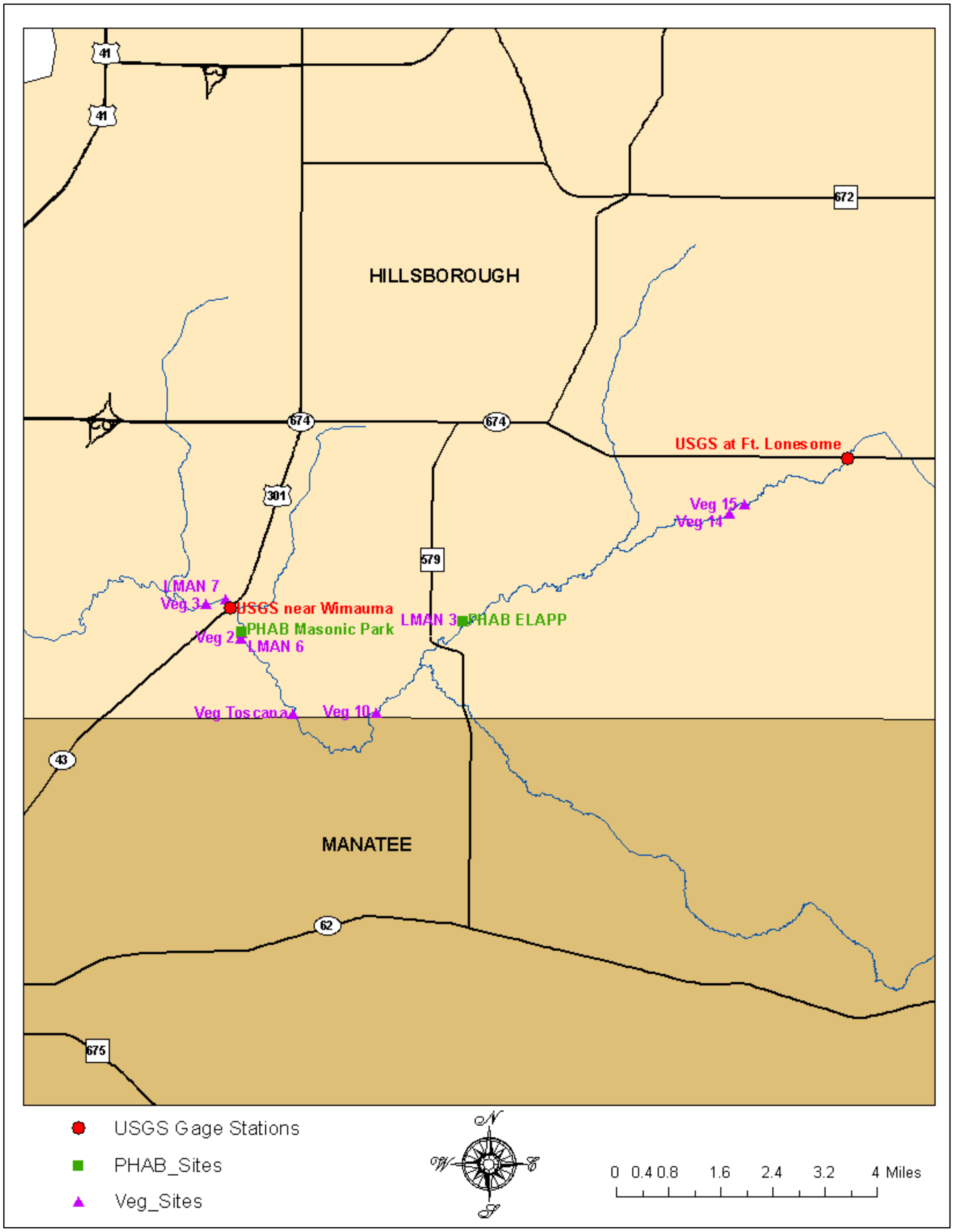


Figure 7-2. PHABSIM and vegetation sites on the Little Manatee River.

7.5 Floodplain Vegetation/Soils Cross-sections

For floodplain vegetation/soils cross-section site selection, the river corridor was stratified using criteria described by PBS&J (2008). Ten representative cross-sections were established perpendicular to the river channel within dominant

National Wetland Inventory vegetation types (Figure 7-3). Cross-sections were established between the 0.5 percent flow exceedance levels on either side of the river channel, based on previous determinations of the landward extent of floodplain wetlands in the river corridor. At the time of the vegetation and soils analyses, ground elevations, in feet above the NGVD 1929, were initially determined by District surveyors at 50-foot intervals along transects using standard surveying equipment, and were measured at shorter intervals where changes in elevation were conspicuous. These elevations were later converted to NAVD 88 projections to correspond to the elevations used in the HEC-RAS analyses.

7.5.1 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 PBS&J 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.

7.5.2 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.

7.5.3 Hydrologic Indicators and Floodplain Wetted Perimeter

Key physical indicators of historic inundation were identified if encountered, including: cypress buttress inflection elevations; cypress knees; lichen lines and/or moss collars; hypertrophied lenticels; stain lines; and scarps (Gilbert et al. 1995). Ground elevation data were used to compare vegetation and soils within and among 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 was used to determine corresponding flows at the USGS gage Little Manatee River near Wimauma that would be necessary to inundate specific floodplain elevations (e. g., mean vegetation zone and soils elevations).

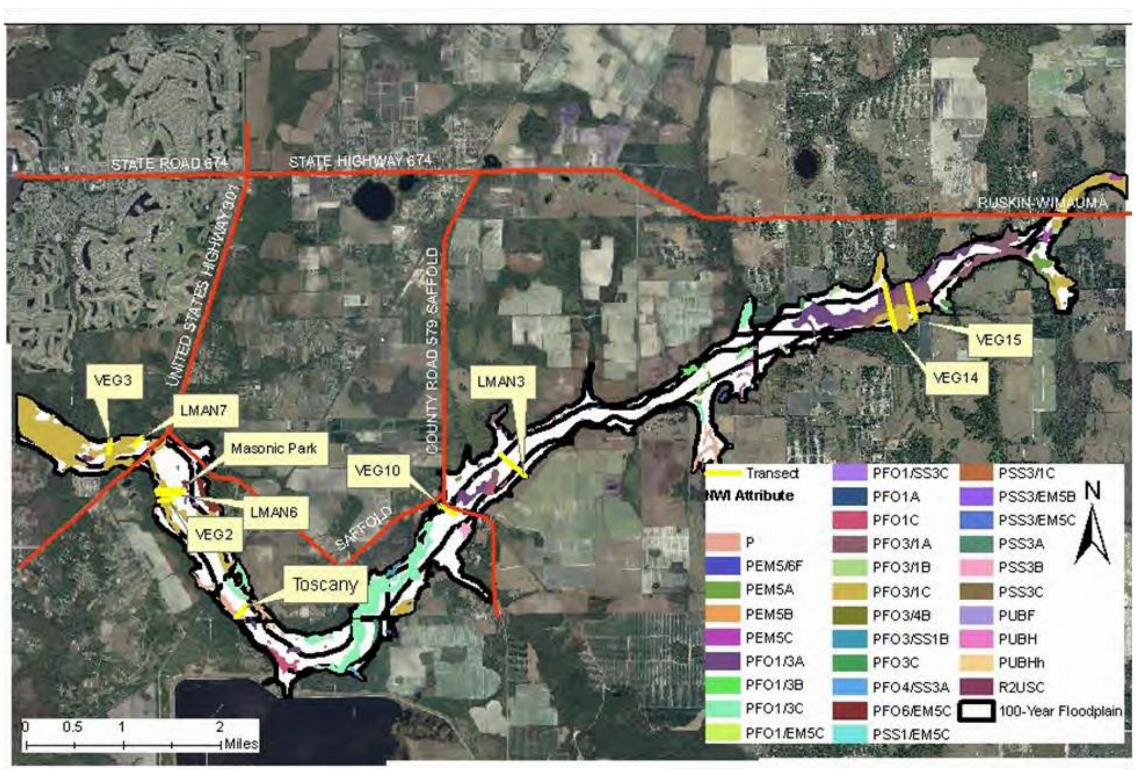


Figure 7-3. Location of vegetation transects and their extent are indicated along the Little Manatee River study corridor. Color legend refer to NWI community coverages within the riparian corridor. Map as referenced in PBS&J (2008).

7.6 Modeling Approaches

A variety of modeling approaches was used to develop minimum flows and levels for the Little Manatee 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

The HEC-RAS model 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 and available flow records for the USGS Little Manatee River near Wimauma and Little Manatee River near Fort Lonesome gages (Figure 7-2) were used to simulate flows at cross-sections within the Little Manatee 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. Elevation data (in feet above NAVD88) for the more than 400 cross-sections were derived from a TIN generated for the Little Manatee River and tributaries. The complete model construction and calibration report is provided in the HEC-RAS Appendix.

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 Little Manatee 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 (approximately 20%, 50%, and 80% exceedance flows) 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 7-44). 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.

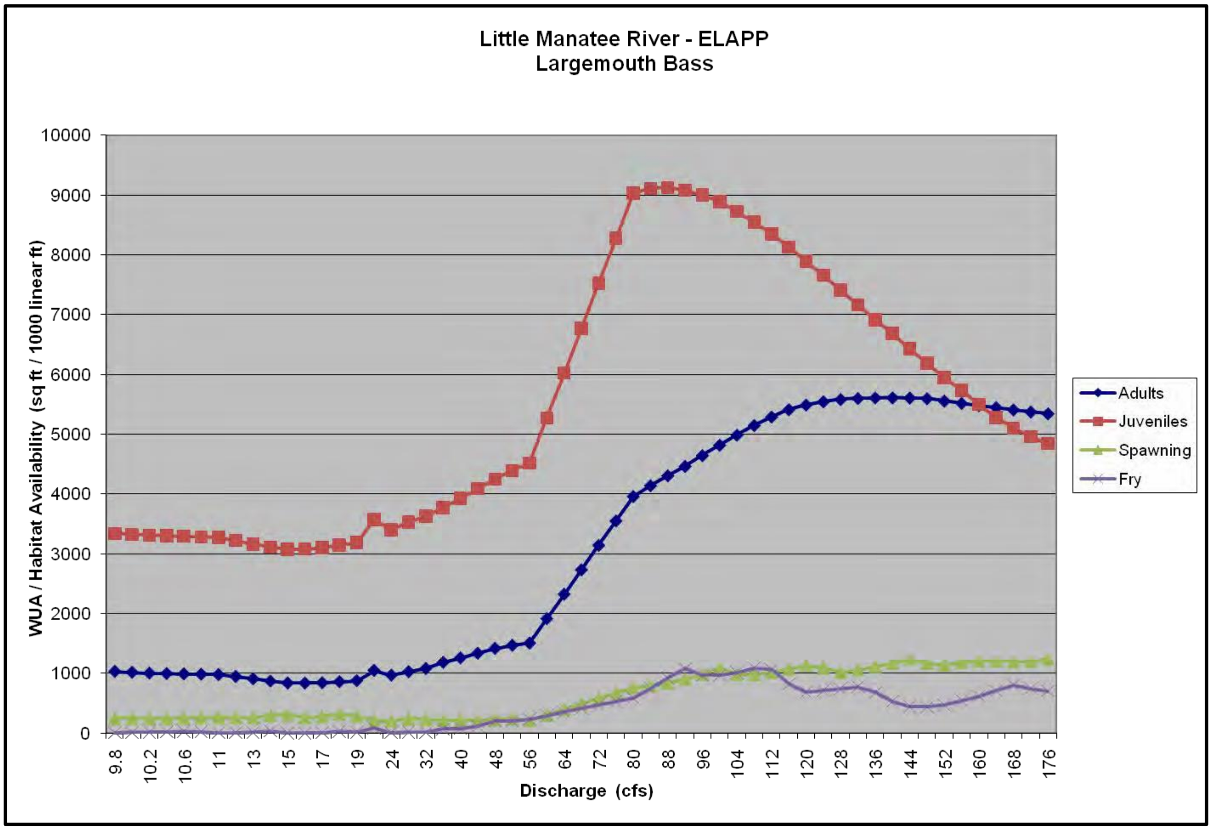


Figure 7-4. Weighted usable area (WUA) versus discharge for three life history stages (fry, juvenile, adult) and spawning activity of Largemouth Bass at the ELAPP PHABSIM site in the Little Manatee River.

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. This is calculated by combining the WUA for all PHABSIM sites for each species, life stage, or guild. The assumption is made that the entirety of the study reach is represented equally by the selected PHABSIM sites, as was the goal during the site selection process. Figure 7-5 shows an example of habitat gain/loss plots, which display changes in WUA (habitat) relative to flow reductions of 10, 20, 30, and 40%.

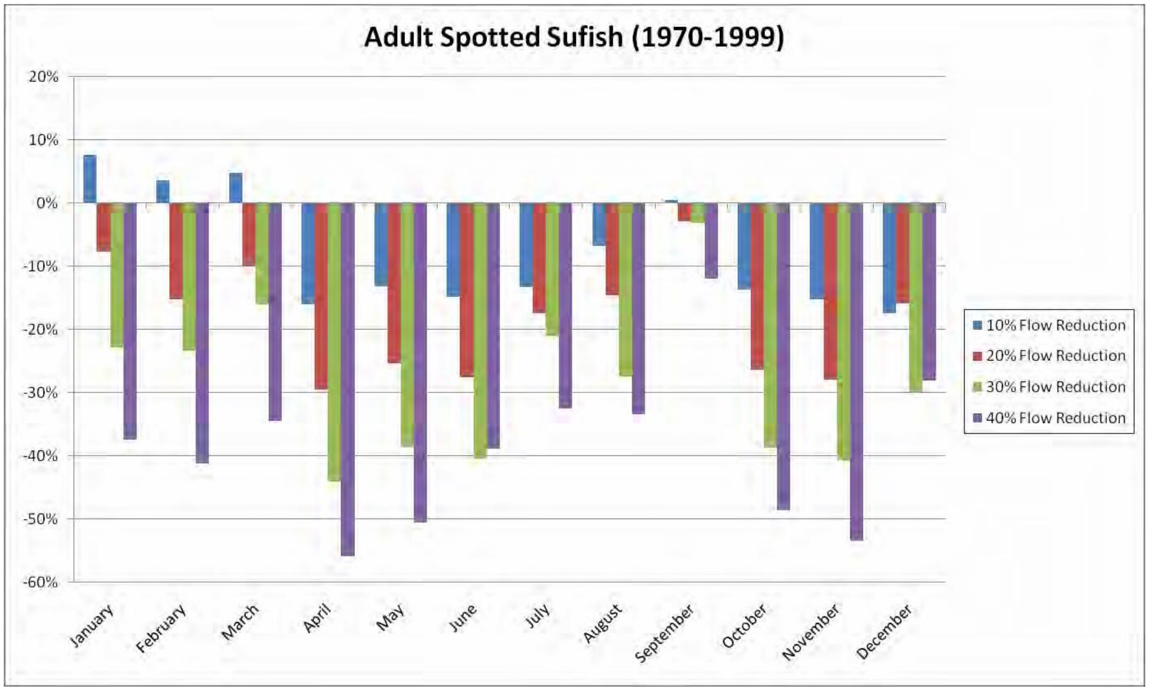


Figure 7-5. Example plot of habitat gain/loss relative to flow reductions of 10, 20, 30, and 40%. Habitat loss is shown for spotted sunfish based on historic flow records from 1970 to 1999.

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 Little Manatee 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. Type III curves have been refined for the spotted sunfish and new Type III curves have been developed for species representative of various fish guilds including shallow-fast (SF) guild and deep slow (DS) guild.

A separate study was also conducted by Dutterer and Allen (2008) to confirm the use of the above listed fish species for PHABSIM analyses in the Little Manatee River (and two other waterbodies, the Anclote and the Manatee River). Their findings show that the family Centrarchidae was most commonly found with eight species represented. Furthermore, specific habitat selection metrics by spotted sunfish in these river systems were also used to refine the habitat suitability curve.

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 adjusted flow records.

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 7-6). Utilizing this tool, we identify flow reduction thresholds for mean elevations of live or dead woody habitats. These flow reductions identify potentially acceptable temporal habitat losses and also provide for woody habitat protection on a spatial basis (Munson and Delfino 2007).

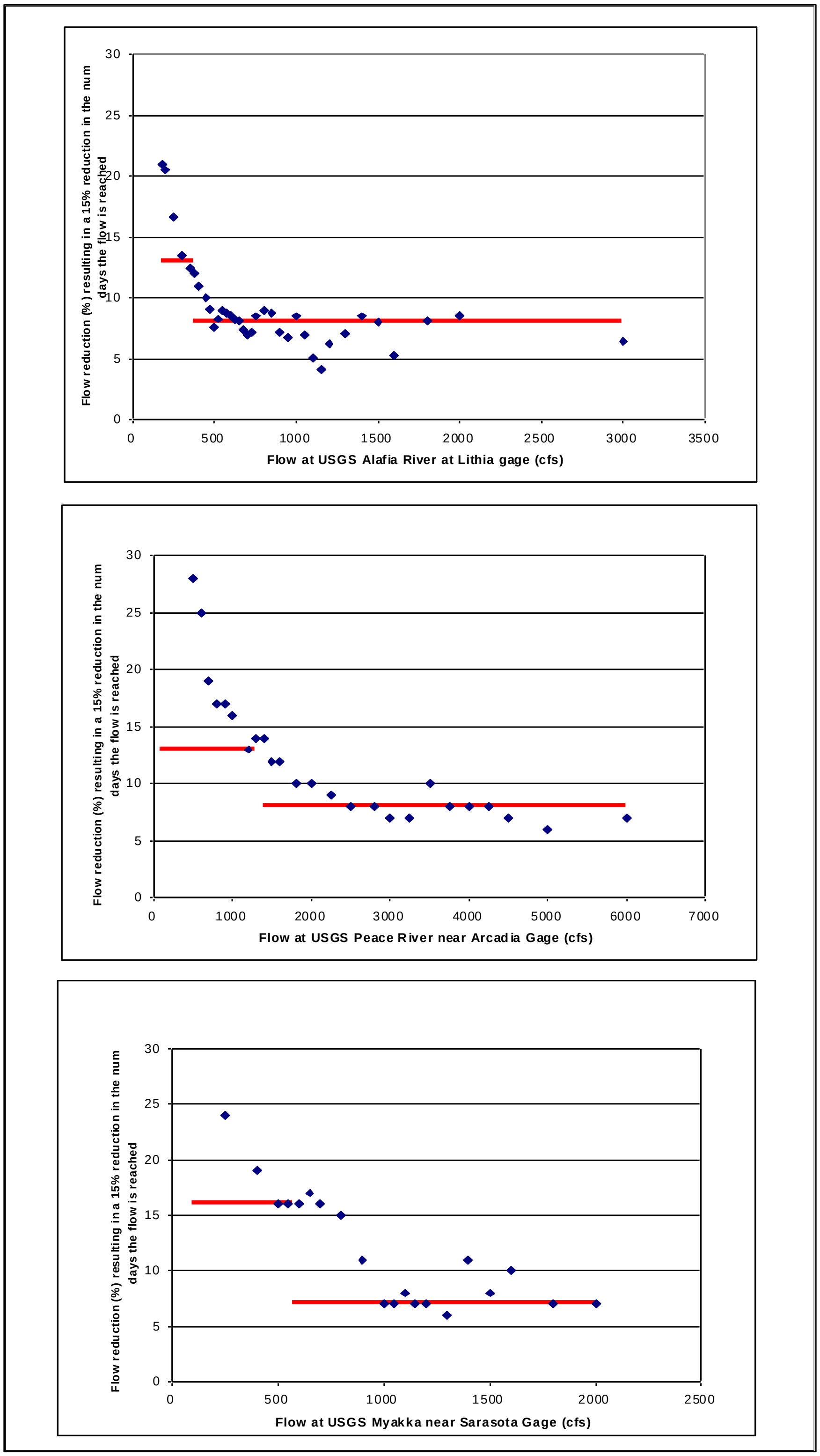


Figure 7-6. Percent-of-flow reductions that result in a 15% reduction in the number of days that flows on the Alafia, middle Peace, and Myakka rivers are reached. Horizontal lines represent the flow reduction standards identified by the District for specific flow ranges in each river. Graphs are adapted 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 freshwater segment of the Little Manatee 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 65-day period that extends from April 18 to June 2 (Julian day 109 to 173). Highest flows occur during Block 3, the 119-day period that immediately follows the dry season (June 22 to October 18). 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.

Blocks are defined by analyzing the median daily flows for the period of record. Block 1 begins when the median daily flow drops below and stays below the 75% exceedance flow and continues until the beginning of Block 3. Block 3 begins when the median daily flow exceeds and stays above the 50% exceedance flow. Once the median daily flow fall below the 50% exceedance flow, Block 2 begins and continues until the beginning of Block 1.

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 with respect to perenniality or non-perenniality of flow. 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 217 HEC-RAS cross-sections of the mainstem of the Little Manatee River (see Figure 7-7). All plots are provided in the Wetted Perimeter Appendix. 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. The lowest wetted perimeter inflection point was identified for each cross-section. Most cross-section plots displayed no apparent inflection points that occur relatively low in the channel. For cross-sections that display 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 flows at each HEC-RAS cross-section were used to develop the wetted perimeter criterion for the Little Manatee River near Wimauma gage site.

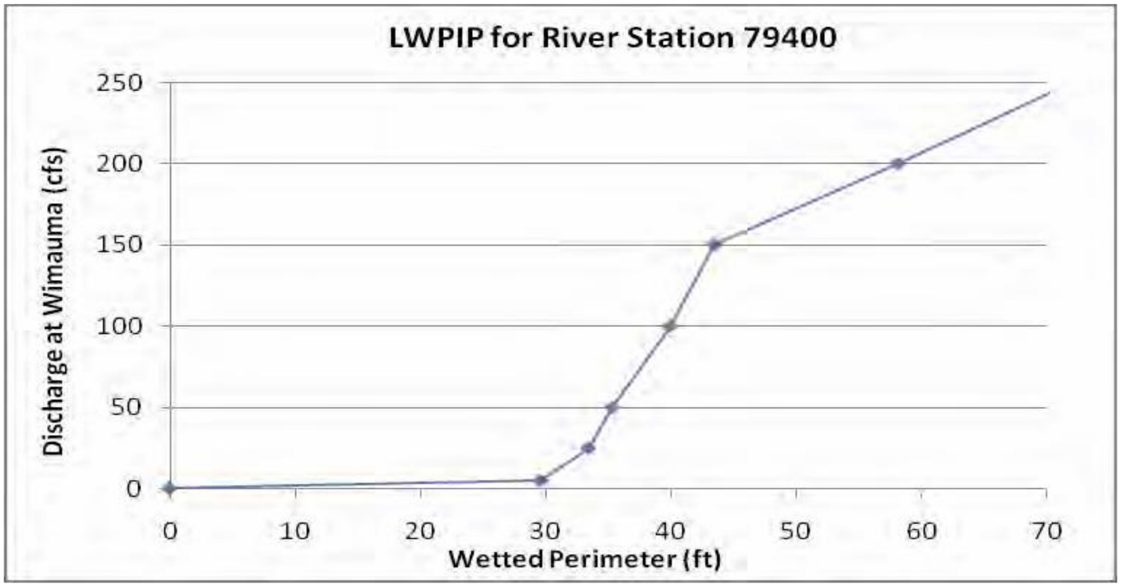


Figure 7-7. Wetted perimeter versus discharge at HEC-RAS station number 79400 (feet upstream of USGS Little Manatee River near Wimauma gage) in the Little Manatee River. Wetted perimeter values for modeled flows up to 250 cfs are shown and the LWPIP for this cross-section is identified to occur at 30 cfs as measured at the Wimauma gage.

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 Little Manatee 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. 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

7.9.1 PHABSIM

PHABSIM was used to evaluate potential changes in habitat associated with variation in instream flows. For the analyses, historic, corrected time series data from the Little Manatee River near Wimauma gage site was used to model changes in habitat at two 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 both sites on the Little Manatee River. Flow reductions that resulted in no more than a 15% reduction in available habitat from baseline conditions were determined to be limiting factors. This is calculated by combining the WUA for all PHABSIM sites for each species, life stage, or guild. The assumption is made that the entirety of the study reach is represented equally by the selected PHABSIM sites, as was the goal during the site selection process. These factors were used to identify acceptable flow reductions for the Wimauma gage site 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 10 instream habitat cross-section sites. Flows at the cross-section sites and corresponding flows at the Wimauma gage 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 wet and dry 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

Although floodplain connection analyses were conducted for the Little Manatee River, they were not utilized for MFL establishment. The Little Manatee River is incised and has very high banks. PBS&J, who were hired to collect data on woody vegetation and soils along the river, found that only two vegetation classes (tupelo swamp and hardwood swamp) "would provide criterion on which to establish MFLs for vegetation communities (PBS&J 2010)." Only two of the ten selected vegetation sites contained either or both of these vegetation classes. At both sites these vegetation classes occurred at elevations consistent with the 98.65% exceedance flow or higher. This indicates that these vegetation classes are likely located at these elevations due to water from another source. This source may be the artificially high surficial aquifer level (due to irrigation), small tributaries (also often augmented by irrigation water), or some other. With the lack of applicable vegetation classes and other hydrologic indicators it was decided to utilize PHABSIM results for Block 3.

8 Results and Recommended Minimum Flows

8.1 Overview

Results from modeling and field investigations on the Little Manatee River were assessed to develop minimum flow criteria/standards for ensuring that ecological functions are protected from significant harm. All analyses were performed on two flow records. The flow records were for the wet climatic period (1940-1969) and the dry climatic period (1970-2009). The overwhelming majority of analyses resulted in more conservative flow reductions for the dry period; therefore, unless otherwise mentioned, the results from the dry 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 Little Manatee River, a low-flow threshold was developed for the Wimauma gage site.

8.2.1 Fish Passage

Flows necessary to maintain a minimum water depth of 0.6 feet to allow for fish passage at each cross-section in the HEC-RAS model are shown in Figure 8-1. At many cross-sections, the minimum water surface elevation that would allow for fish passage was lower than the elevation associated with the lowest modeled flow particularly towards the downstream extent. The data indicates that to maintain fish passage depth at the most restrictive cross-section, a flow of 35 cfs is required at the Wimauma gage. Thirty-five cfs is used to define the fish passage criteria for the Little Manatee River near Wimauma gage.

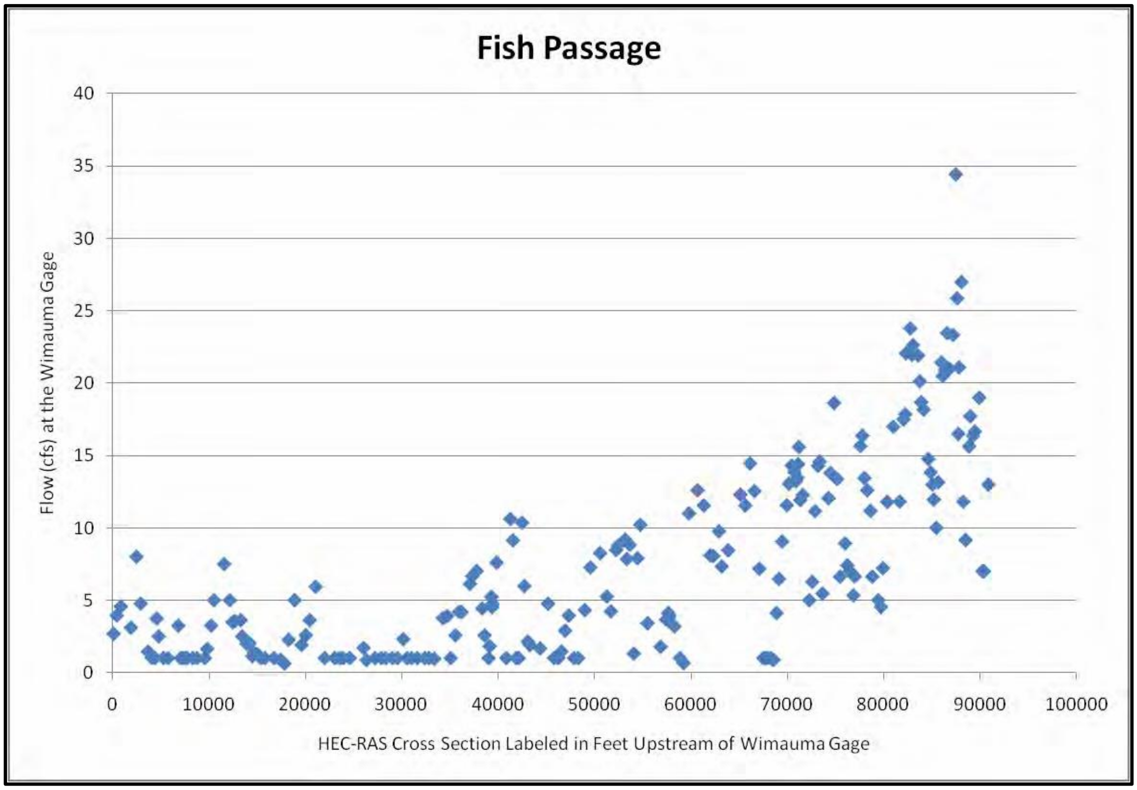


Figure 8-1. Plot of flow required at the Little Manatee River near Wimauma gage to inundate the deepest part of the channel at 217 HEC-RAS cross-sections in the Little Manatee River to a depth of 0.6 ft.

8.2.2 Lowest Wetted Perimeter Inflection Point (LWPIP)

Wetted perimeter plots (wetted perimeter versus flow at the Wimauma gage) were developed for each HEC-RAS cross-section of the Little Manatee River (Figures 8-2). Plots for each individual cross-section are provided in the Wetted Perimeter Appendix. The majority of cross-sections exhibited no LWPIP or LWPIPs that occurred at the lowest modeled flow (5 cfs). At two of the cross-sections the LWPIP occurs at 25 cfs and at one transect the LWPIP occurs at 35 cfs. Because only one cross-section, out of over 200 analyzed, exhibited a LWPIP greater than 30 cfs, a flow of 30 cfs at the Wimauma gage was used to define the LWPIP criterion.

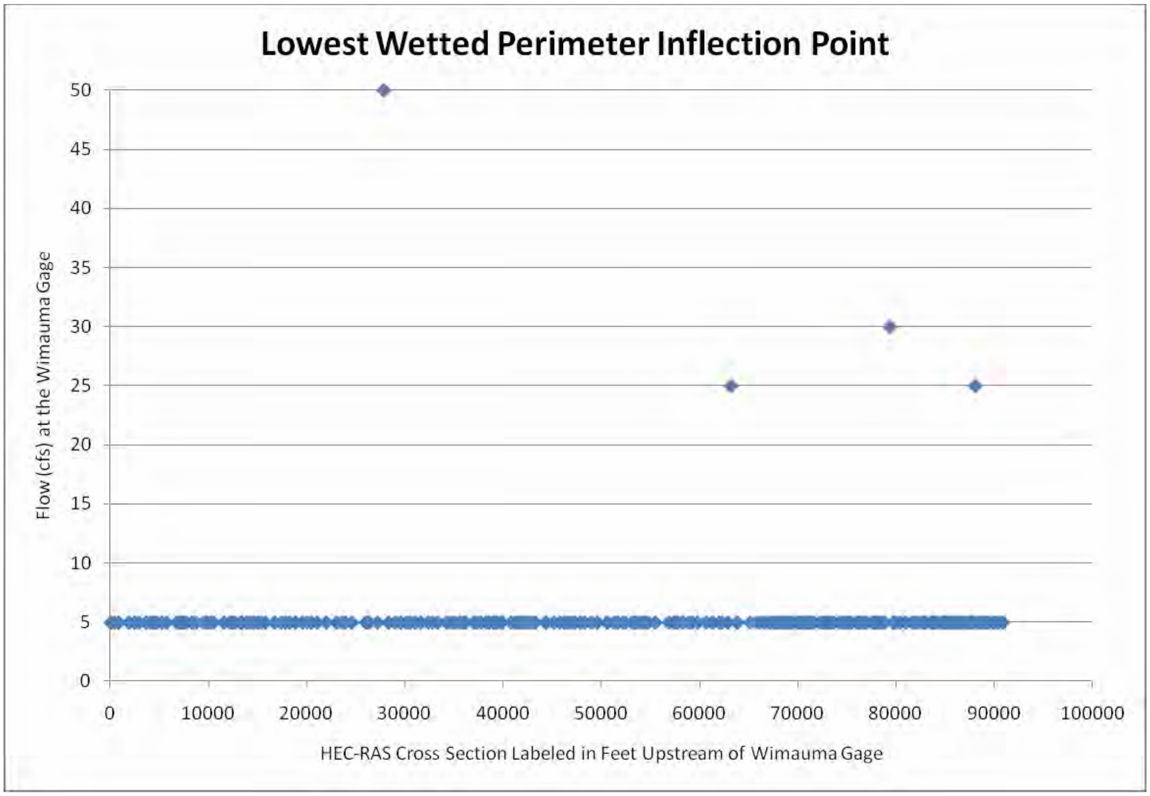


Figure 8-2. Plot of flow at the Little Manatee River near Wimauma gage required to inundate the lowest wetted perimeter inflection points at 217 HEC-RAS cross-sections in the Little Manatee River.

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, a LFT was set at 35 cfs at the Little Manatee River near Wimauma gage. Although flows in the river may be expected to drop below the LFT, 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 Wimauma gage site was developed based on the use of PHABSIM to model potential changes in habitat availability for several fish species, fish guilds, and macroinvertebrate diversity at four representative sites.

8.3.1 PHABSIM Results

Physical Habitat Simulation analyses were conducted for two representative sites on the Little Manatee River (Figure 7-2). Dry climatic period (1970-2009) and 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 available historic 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.

Flow reductions that resulted in no more than a 15% reduction in available habitat from historic conditions were determined to be limiting factors. This is calculated by combining the WUA for all PHABSIM sites for each species, life stage, or guild. The assumption is made that the entirety of the study reach is represented equally by the selected PHABSIM sites, as was the goal during the site selection process. This calculation was made for each block. The resulting allowable percent reductions for the Wimauma gage were 9, 11 and 11 percent for Blocks 1, 2 and 3, respectively.

8.4 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 Block 2.

8.4.1 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 ten Little Manatee River habitat cross-sections. Based on HEC-RAS output, flows at the Little Manatee River near Wimauma USGS gage. Flows 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 10 sites ranged from 49 to 207 cfs at the Little Manatee River near Wimauma gage (Table 8-1). Similarly, when snag habitats were characterized via a longitudinal belt method combined with a cross-section method, flows at 10 sites ranged from 31 to 186 cfs (Table 8-1). Three of the analyses required flows that were below the low flow threshold (LFT).

Table 8-1. Mean elevation of instream woody habitats (exposed roots and snags) at various instream habitat cross-section sites, corresponding flows at the USGS Little Manatee River near Wimauma 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 Elev (ft NAVD)	Flow (cfs) Required at Wimauma Gage for Inundation	Allowable Percent of Flow Reduction
Exposed Roots	Veg 3	4.38	148	11
Exposed Roots	Lman 7	3.86	88	14
Exposed Roots	Masonic	4.68	83	20
Exposed Roots	Lman 6	3.53	31	Below LFT
Exposed Roots	Veg 2	4.66	77	19
Exposed Roots	Toscana	6.79	55	15
Exposed Roots	Veg 10	17.19	74	21
Exposed Roots	Lman 3	20.69	49	15
Exposed Roots	Veg 14	38.73	207	11
Exposed Roots	Veg 15	39.28	110	18
			MEAN	**16**

Habitat	Site	Mean Elev (ft NAVD)	Flow (cfs) Required at Wimauma Gage for Inundation	Allowable Percent of Flow Reduction
Snags	Veg 3	4.21	137	11
Snags	Lman 7	4.17	105	19
Snags	Masonic	6.19	186	12
Snags	Lman 6	4.03	50	15
Snags	Veg 2	6.04	156	10
Snags	Toscana	6.42	15	Below LFT
Snags	Veg 10	16.64	43	14
Snags	Lman 3	20.28	31	Below LFT
Snags	Veg 14	38.51	179	12
Snags	Veg 15	39.3	110	18
			MEAN	**14**

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 dry climatic period of 1970 to 2009 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.

8.4.2 Results of Woody Habitat Protection Criteria

The goal of the woody habitat protection criteria is to limit to 15 percent the reduction in number of days that the mean elevation of woody habitat is inundated. 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. This is considered to be protective of the woody habitat in study reach as a whole. The resulting allowable percent withdrawal is 14 percent and is based on inundation of snag habitat. This percentage represents the more restrictive of the exposed root and snag means.

8.5 Proposed Minimum Flows for the Little Manatee River

For the Little Manatee River the minimum flow recommendation is stated as a percent of flow reduction at the USGS Little Manatee River near Wimauma. 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 8-2 and in the text below.

Table 8-2. Flow reduction recommendations for each individual criterion based on a composite of all individual criterion for each analysis.

Analysis Name	Measure / Goal	Block	Maximum Allowable Flow Reduction Recommendation
Fish Passage	Maintaining depth of 0.6' across shoals	ALL	35 cfs
Wetted Perimeter	Maximizing inundated river channel	ALL	5 cfs
PHABSIM	Avoid reductions >15% in habitat for various species	1	9%
PHABSIM	Avoid reductions >15% in habitat for various species	2	11%
Intream Habitat - Snags	Avoid reductions >15% in temporal snag habitat	2	16%
Instream Habitat - Exposed Roots	Avoid reductions >15% in temporal exposed root habitat	2	14%
PHABSIM	Avoid reductions >15% in habitat for various species	3	11%

Utilizing the most restrictive criteria for each block and for the low flow threshold, the minimum flows for the Little Manatee River are as follows. Figure 8-3 illustrates the flow prescription criteria.

> The proposed MFL as measured at the Little Manatee River near Wimauma USGS gage allows removal of 9 percent of Block 1 (dry season) baseline flows; 11 percent of Block 2 flows; and 11 percent of Block 3 flows. Surface water withdrawals are prohibited from depressing flows below 35 cfs in any block.

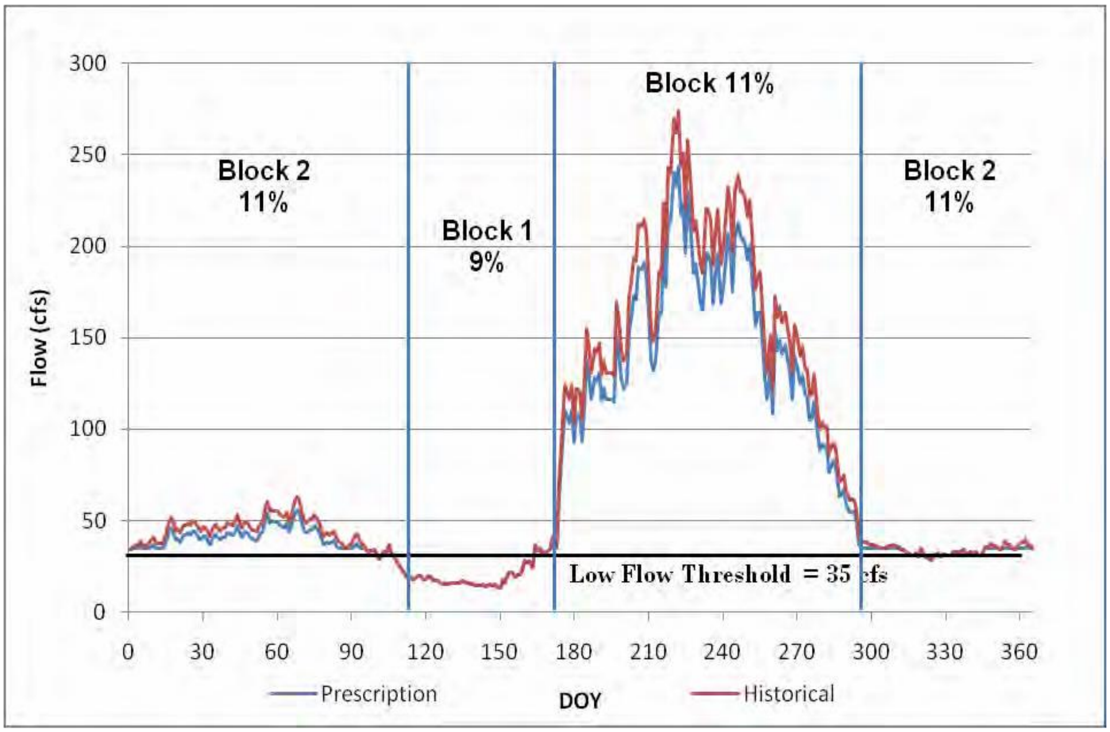


Figure 8-3. Flow prescription and historical flows for Little Manatee River near Wimauma.

Minimum five-year and ten-year moving annual average values are set forth in Table 8-3 as a tool to assess whether flows to the Little Manatee River remain above flow rates that are expected to occur with implementation of the Minimum Flow. 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 8-3. Minimum Five-Year and Ten-Year Moving Mean and Median Flows for the Wimauma gage with the application of the proposed Minimum Flow based on the flow record from 1940 through 2009.

Minimum Flow	Hydrologic Statistic	Flow (cfs)
Annual Flow	10-Year Mean	117
	10-Year Median	34
	5-Year Mean	99
	5-Year Median	33
Block 1	10-Year Mean	29
	10-Year Median	10
	5-Year Mean	18
	5-Year Median	10
Block 2	10-Year Mean	60
	10-Year Median	28
	5-Year Mean	168
	5-Year Median	80
Block 3	10-Year Mean	205
	10-Year Median	109
	5-Year Mean	168
	5-Year Median	80

Hydrologic statistics are generated by simulating the maximum allowable withdrawal (as determined by the MFL) being withdrawn from the daily flows for the period of record flows. Five and ten year running yearly means and medians are then calculated for the period of record and the minimums are displayed (Table 8-3).

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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 dry and wet 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.

Proposed Minimum Flows and Levels for Little Manatee River Appendices

Photo by: Richard Gant

Southwest Florida Water Management District

Table of Contents

PHABSIM Appendix

IFIM/PHABSIM PROTOCOL – Little Manatee

Started with IFG4 deck/file containing all transects and all calibration sets. These were entered from downstream to upstream with a dummy transect.

Two sets of transects were examined:

- ELAPP with data from low flow measurement of 24.46 cfs, a medium flow of 68.42 cfs, and a high flow of 84.65 cfs. The range of simulated flows ranged from 9.78 cfs to 169.3 cfs.
- Toscana with low flow (40.94 cfs), medium flow (72.53 cfs) and high flow (263.45 cfs). The range of simulated flows ranged from 16.37 cfs to 526 cfs.

The simulated flow ranges used in two time-series analyses were from gaging records between 1940 and 1969 and between 1970 and 1999.

The following codes were entered on the N/S lines:

CODE	DESCRIPTION
0	**Delimiter**
1	No cover and silt **or** terrestrial vegetation
2	No cover and sand
3	No cover and gravel
4	No cover and cobble
5	No cover and small boulder
6	No cover and boulder, angled bedrock, or woody debris
7	No cover and mud or flat bedrock
8	Overhead vegetation and terrestrial vegetation
9	Overhead vegetation and gravel
10	Overhead vegetation and cobble
11	Overhead vegetation and small boulder, boulder, angled bedrock, or woody debris

12	Instream cover and cobble
13	Instream cover and small boulder, boulder, angled bedrock, or woody debris
14	Proximal instream cover and cobble
15	Proximal instream cover and small boulder, boulder, angled bedrock, or woody debris
16	Instream cover or proximal instream cover and gravel
17	Overhead vegetation or instream cover or proximal instream cover and silt or sand
18	Aquatic Vegetation – macrophytes
100	**Delimiter**

The IFG4 predicted WSL's were placed in a (hand-made) table to be compared with observed WSL's for the given discharges on the CAL lines. The predicted WSL's were all within 0.2 ft of the observed values [accepted surveying error for the "touch" technique] and IFG4 was considered to be an adequate predictor.

A second discharge is added to each CAL line (see A.51 from the PHABSIM user's manual). This second discharge is the calculated flow for that transect using the velocities measured. This is used as a secondary adjustment factor when predicting velocities and roughness coefficients.

The IFG4 input decks/files were then converted to several IFG4 input decks/files, each with a single velocity set, corresponding to measured calibration sets. The simulated discharges overlap but encompass the measured discharge for that calibration set.

	TosA. in4	TosB.in4
Simulated Discharge Range	16 – 74 cfs	66 – 525 cfs
	ELAPPA.in4	ELAPPB.in4
Simulated Discharge Range	9.8 – 76 cfs	60 – 176 cfs

For each *.IN4 model, an IFG4 run was made. VAF (Velocity Adjustment Factor) values are checked. The slope of the VAF values must be positive. The VAF value at the discharge for which the velocity set is given should be between 0.85 and 1.15. Ideally, such a tight fit allows expansion of the simulation beyond .4 x the lowest discharge and 2 x the highest discharge. If the VAF values are low, no such expansion is recommended.

- Where VAF slope was a problem for a particular transect, WSL's are adjusted up or down [usually lowering WSL increases VAF value and increasing WSL decreases VAF value for given discharge] (based upon the range of WSL's [right bank, center, and left bank] measured in the field).

In all cases, VAF values were found to be acceptable, but low, since all slopes were positive (ranging from 0.714 to 1.172 in each case).

[Note: the table of VAF values is presented after adjustment of Manning's "n" values for some data points]

Discharge	Tosa	Tosb
40.9		
Tr 1	1.027	.960
Tr 2	1.033	.930
Tr 3	1.164	.99
72.5		
Tr 1	.915	.89
Tr 2	1.00	.935
Tr3	.983	.891
263		
Tr 1	.875	.9
Tr 2	1.09	1.069
Tr 3	.844	.861
Discharge	ELAPPa	ELAPPb
24.46		

Tr 1	1.007	.843
Tr 2	.991	.928
Tr 3	.949	.944
68.42		
Tr 1	.921	.843
Tr 2	1.428	.944
Tr 3	.654	.871
84.65		
Tr 1	.913	.853
Tr 2	1.623	.943
Tr 3	.622	.872

Both Toscana and ELAPP were considered to be unreliable simulation at high flows for transect 3; may not be critical to MFL evaluation

After each *.IN4 file/model was calibrated to produce the best VAF's possible, the roughness values ("n") **calculated by IFG4** for each transect was checked. Those with values greater than 0.2 are chosen for adjustment. For each transect with some "n" values greater than 0.2, the mean value for "n" is calculated. Those "n" values above the median value are replaced with the mean value on the NS lines of the *.IN4 deck/file. This approach tries to adjust the worst problems without making drastic changes in WSL predictions and it is transect-specific [as compared to creating an NMAX line]. Professional judgment was also used, in some cases, to adjust other "n" values, where appropriate.

After "n" adjustments, IFG4 was run, again, with the adjusted roughness values and particular attention was placed on the predictions of velocities at the highest discharges. Each IFG4 output was checked for velocity "hot spots" at the high discharge simulations. Where predicted velocities exceeded 4.5 fps in a single cell **and** adjacent cells had low velocities, higher "n" values for that vertical/cell were added to the NS lines in the *.IN4 deck/file. This inserted "n" value was usually derived from the "n" values predicted by IFG4 for adjacent cells. When several contiguous cells had velocities that ranged from 3 to 6 fps (especially at high discharges), they were considered to be acceptable (i.e., **not** hot spots).

HABTAV was run with the appropriate HSI models for the "A", "B", "C", etc., models and the ZHAQF output files were examined. These contained habitat (WUA) versus discharge relationships for overlapping discharge ranges.

The overlapping ZHAQF values were combined on a spreadsheet (XCEL or SigmaPlot) into a single habitat versus discharge relationship. Weighted averages were used to combine the overlapping WUA values (these were different since different VAF values to adjust predicted velocities were not the same for comparable discharges in different runs). When an abrupt "jump" in the relationship occured, a plot of WUA/Q values is created and a curve smoothing routine (usually a third or fourth-order polynomial regression in SigmaPlot) was used for those values.

The WAU / Discharge results were prepared for the final report of WUA and Discharge and were the values used for time-series analysis.

Time-Series Analysis

Two sets of discharge data were assessed, from 1940-1969 [roughly equivalent to wet AMO years] and 1970-1999 [roughly equivalent to dry AMO years].

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. HAQ files (habitat availability) were created for the high discharge events by linear (first-order regression) or curvilinear (second-order polynomial regression) fits. 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.

During this analysis, habitat suitability curves for both “catalog” (USGS Blue Books of habitat suitability) and locally derived HIS’s were compared. Although the catalog and locally derived curves were quite similar, there was sufficient difference in at least one category of local preference (usually in substrate/cover preference, more often than not) that the predicted amount of available habitat was an order of magnitude less for Florida curves as opposed to catalog curves. This result supports conclusions by Gore and Nestler (1988) and Gore et al. (2001) who have indicated that habitat-specific derivations of suitability curves are the most appropriate application for this type of analysis.

The following habitat suitability criteria were used:

Habitat Guilds:

1. Shallow-Slow
2. Shallow-Fast
3. Deep-Slow
4. Deep-Fast

Largemouth Bass

1. Adult
2. Juvenile
3. Spawning
4. Fry

Bluegill

1. Adult
2. Juvenile
3. Spawning
4. Fry

Spotted Sunfish

1. Adult
2. Juvenile
3. Spawning
4. Fry

Benthic Macroinvertebrates

1. Total Community Diversity

Cyprinidae (minnows)

2. Combined all life stages

Since predictions of less initial habitat availability are predicted in the PHABSIM runs for Florida curves, losses in smaller amounts of habitat result in larger incremental gains or losses in habitat. [For example if the catalog curves predict 2350 square feet of habitat under existing conditions (per 1000 linear feet of river) and the time series predicts a loss of 50 square feet of habitat, this results in a 3% habitat loss; however, if Florida curves for the same species predict only 235 square feet of habitat under existing conditions and the time series predicts only a loss of 20 square feet of habitat, the result is a 9% loss]. It should not be surprising, then, that some habitat gain / loss analyses are dramatically different using locally derived habitat information where a much lower initial habitat availability is predicted.

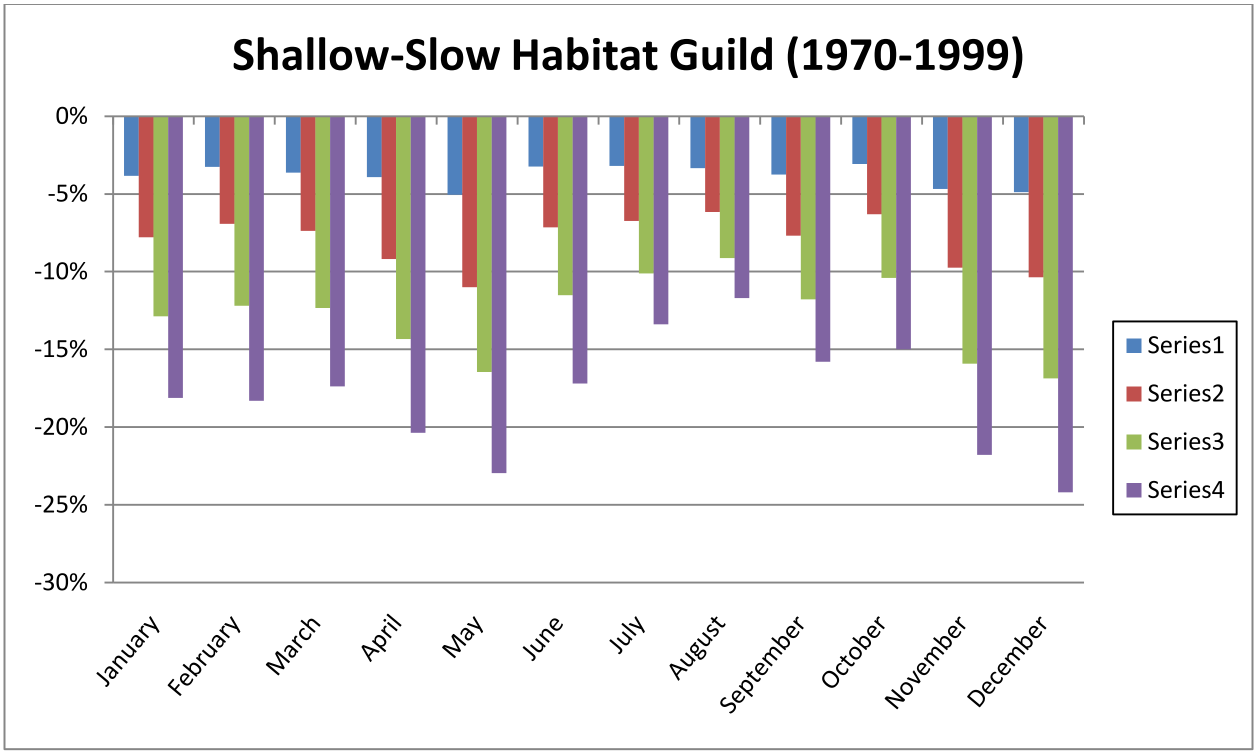
References:

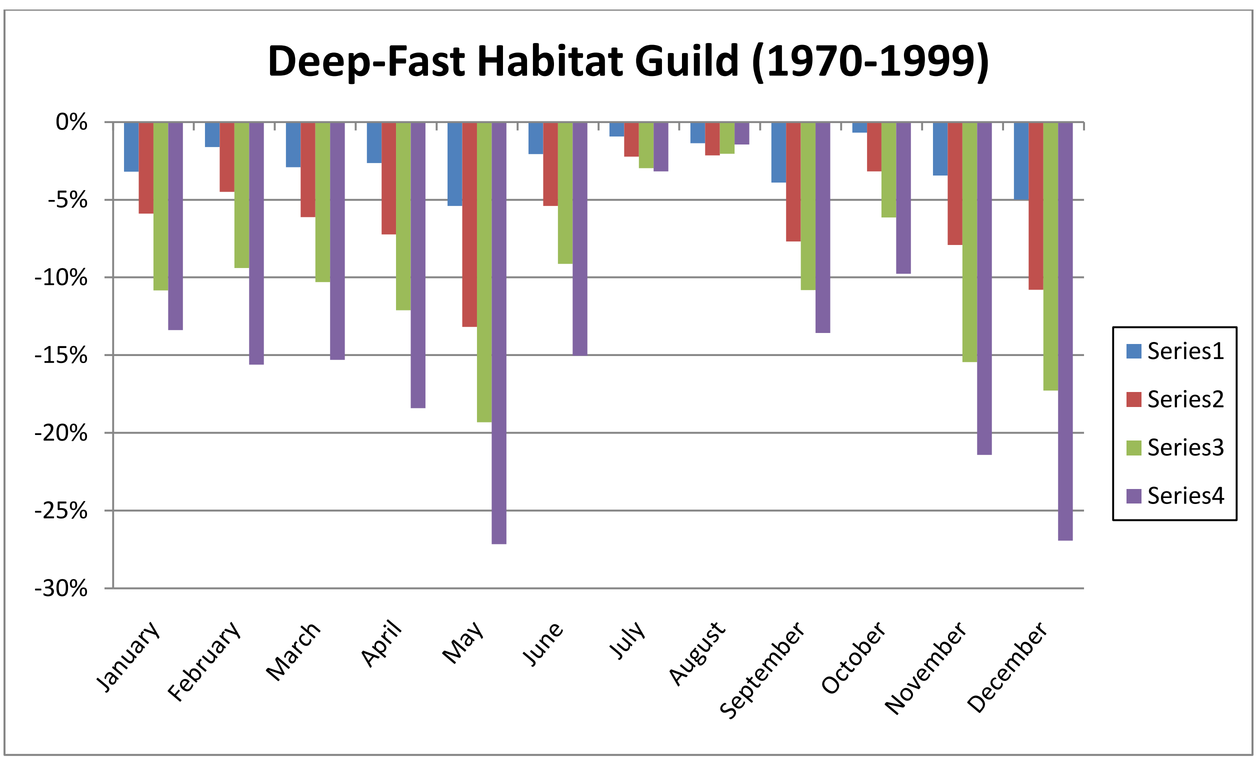
Gore, J.A., and J.M. Nestler. 1988. Instream flow studies in perspective. *Regulated Rivers* 2: 93-101.

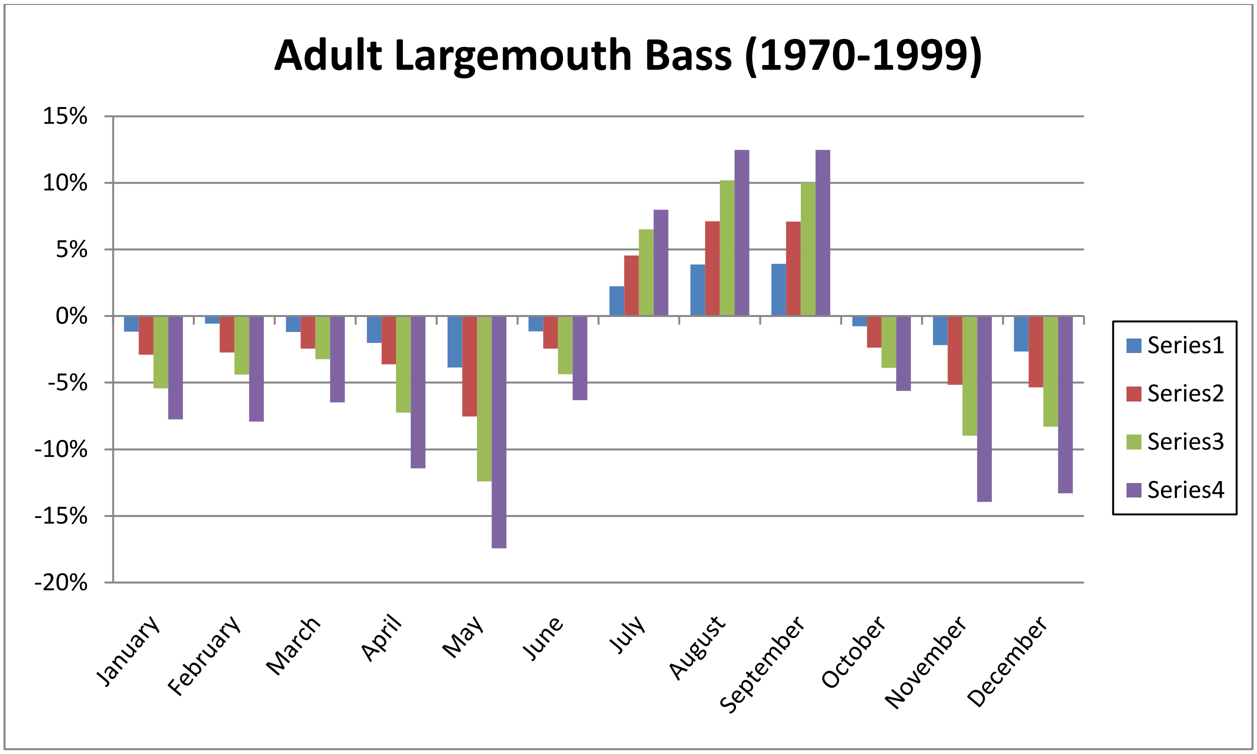
Gore, J.A., J.B. Layzer, and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: a role in stream and river restoration. *Regulated Rivers* 17: 527-542.

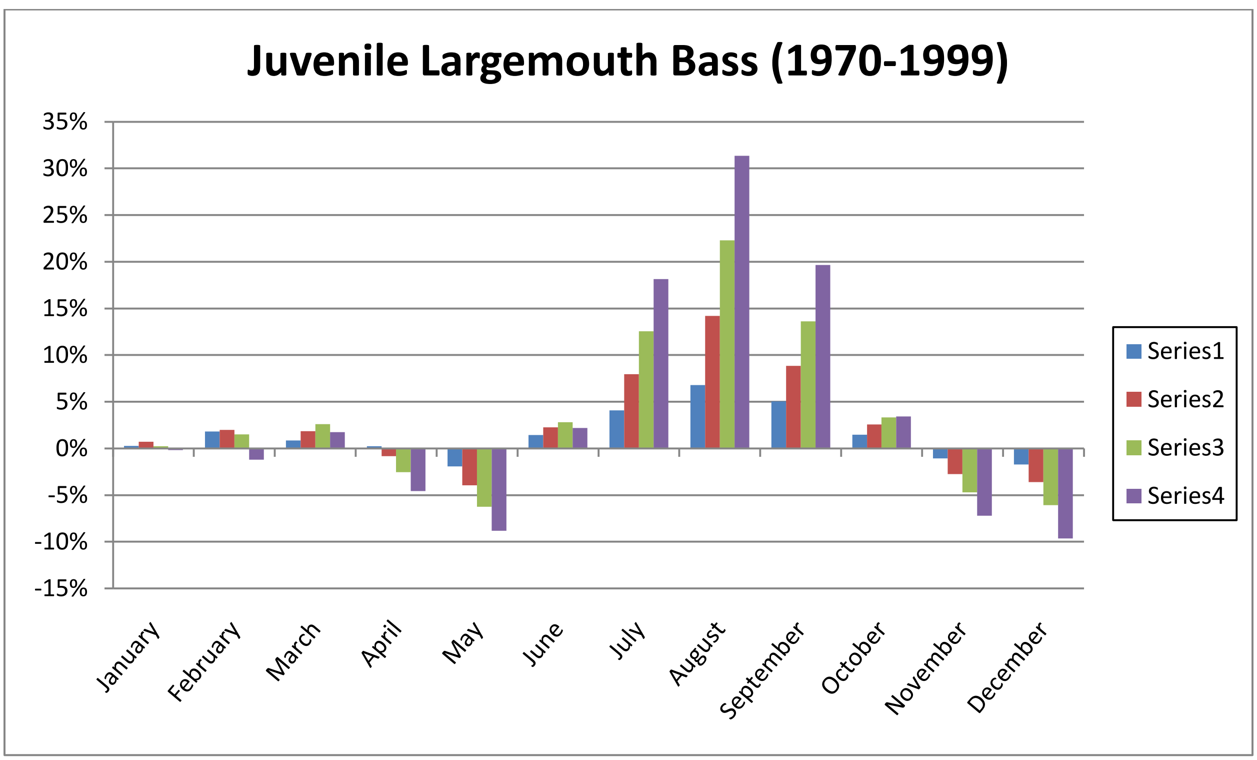
PHABSIM analysis, when given hydrologic data and habitat preferences, establishes a relationship between hydrology and WUA which allows examination of habitat availability in terms of the historic and altered flow regimes. Determining from these data the amount of loss, or deviation from the optimum, that a system is capable of withstanding is based on professional judgment. For the purpose of minimum flows and levels development, we have defined percent-of-flow reductions that result in 15% reduction in habitat from historic conditions as limiting factors. This representation was determined by combining the WUA for all PHABSIM sites for each species, life stage, or guild. The inference is made that the entire study reach is represented equally by the selected PHABSIM sites, which was also the intention when establishing sites. In addition, PHABSIM is typically utilized by the District to determine allowable flow reductions for Block 1 and Block 2 period of the year, utilizing inundation of floodplain features for Block 3 analyses.

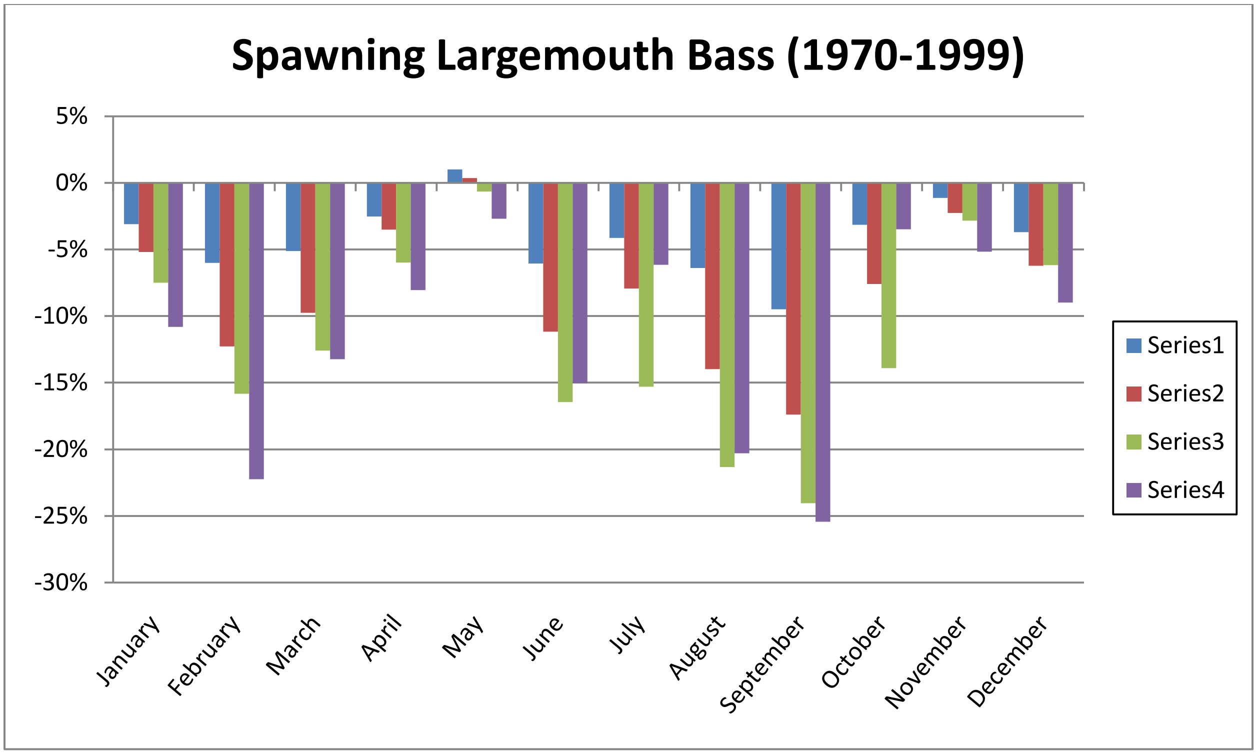
Below are graphics generated for visual inspection of PHABSIM output. They are arranged by species and depict total weighted usable area for the entire reach of the study (all sites combined).

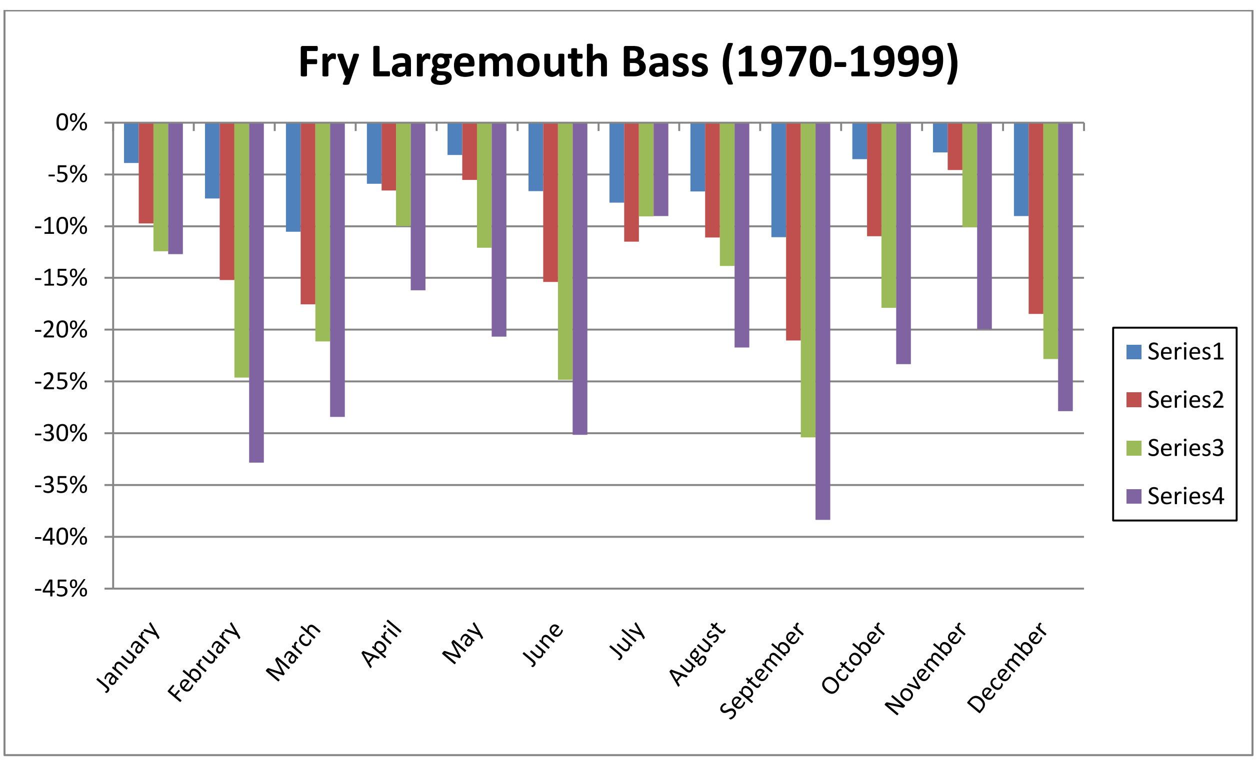


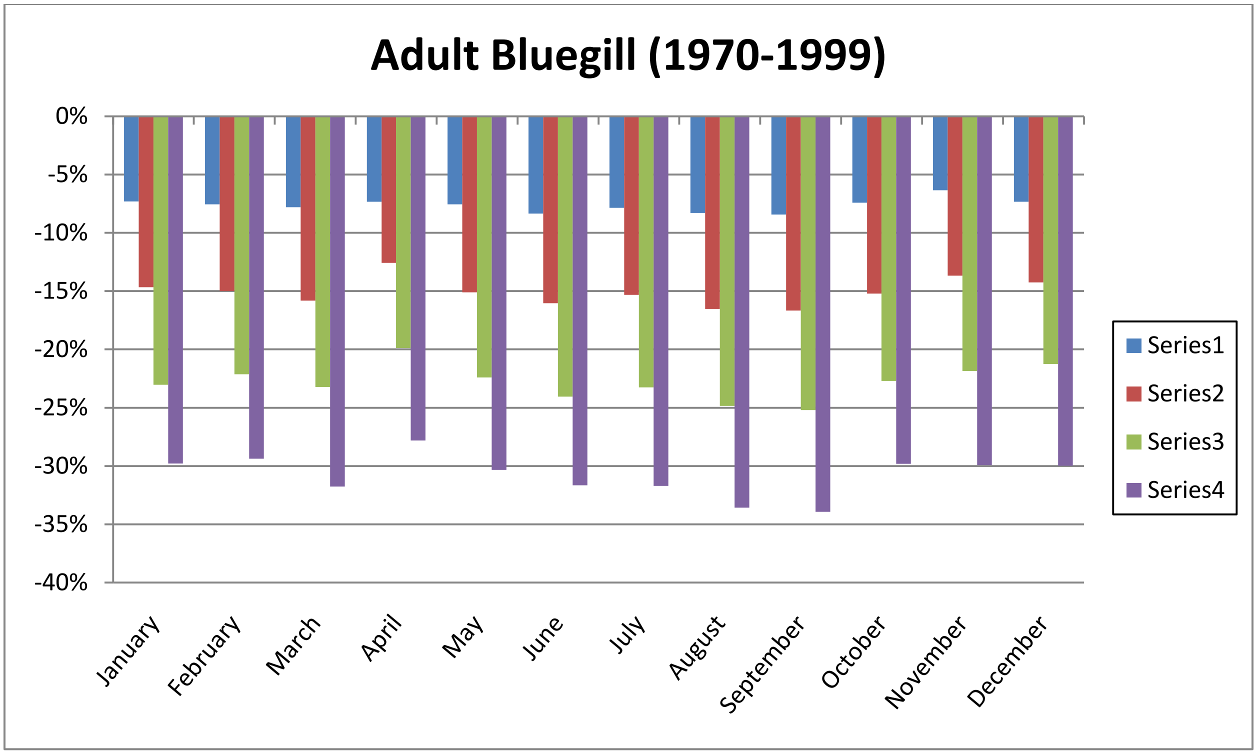


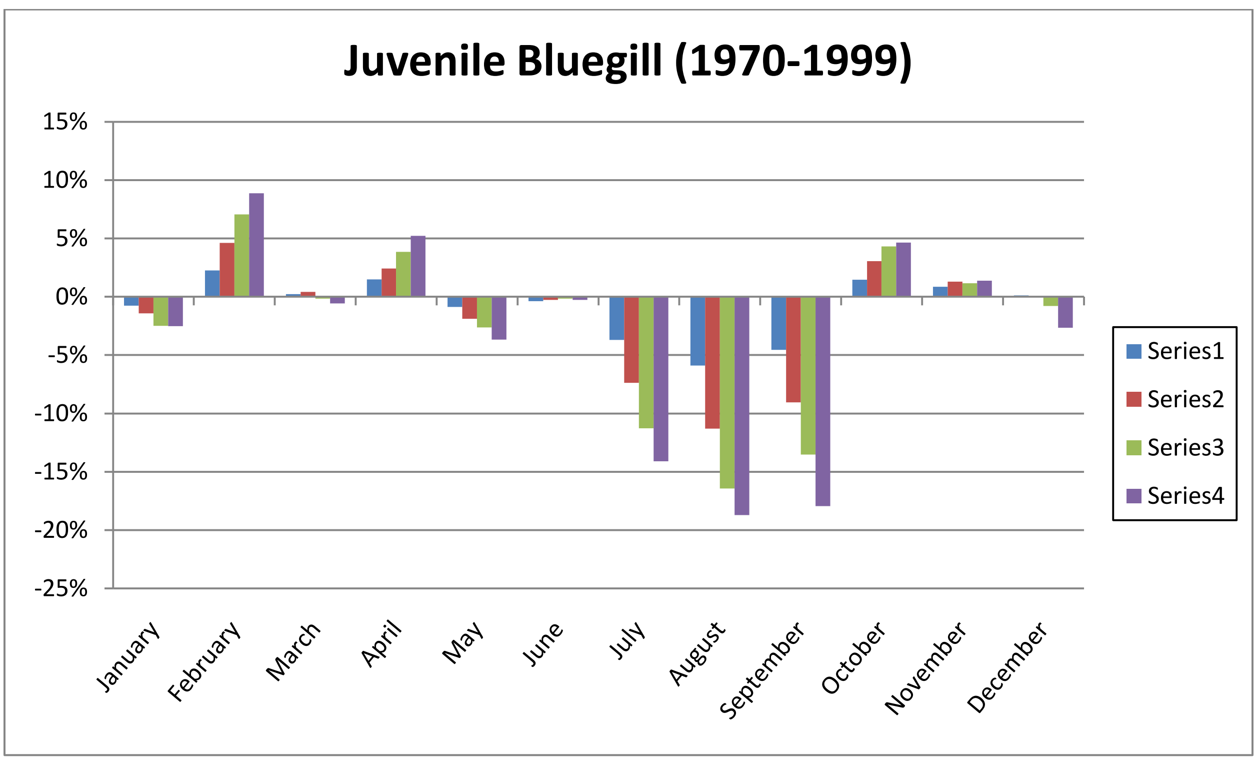

Adult Largemouth Bass (1970-1999)
15%
10%
5%
0%
-5%
-10%
-15%
-20%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

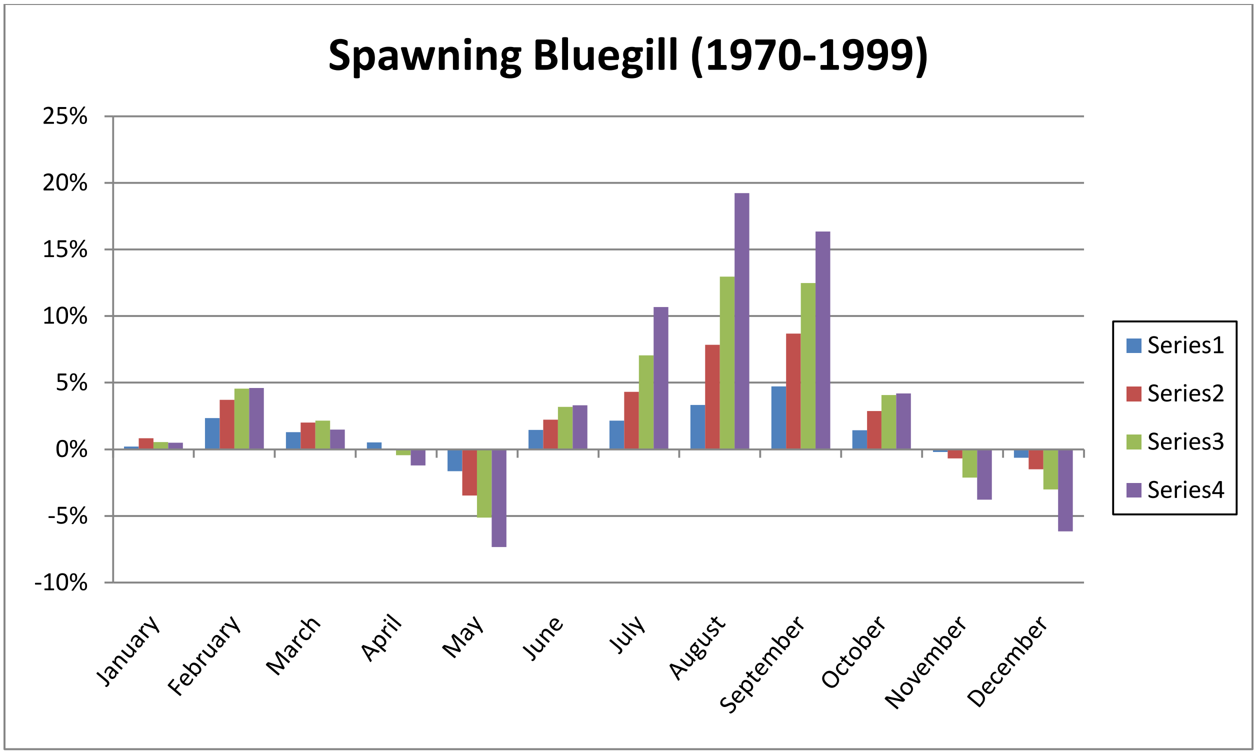

Juvenile Largemouth Bass (1970-1999)
35%
30%
25%
20%
15%
10%
5%
0%
-5%
-10%
-15%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

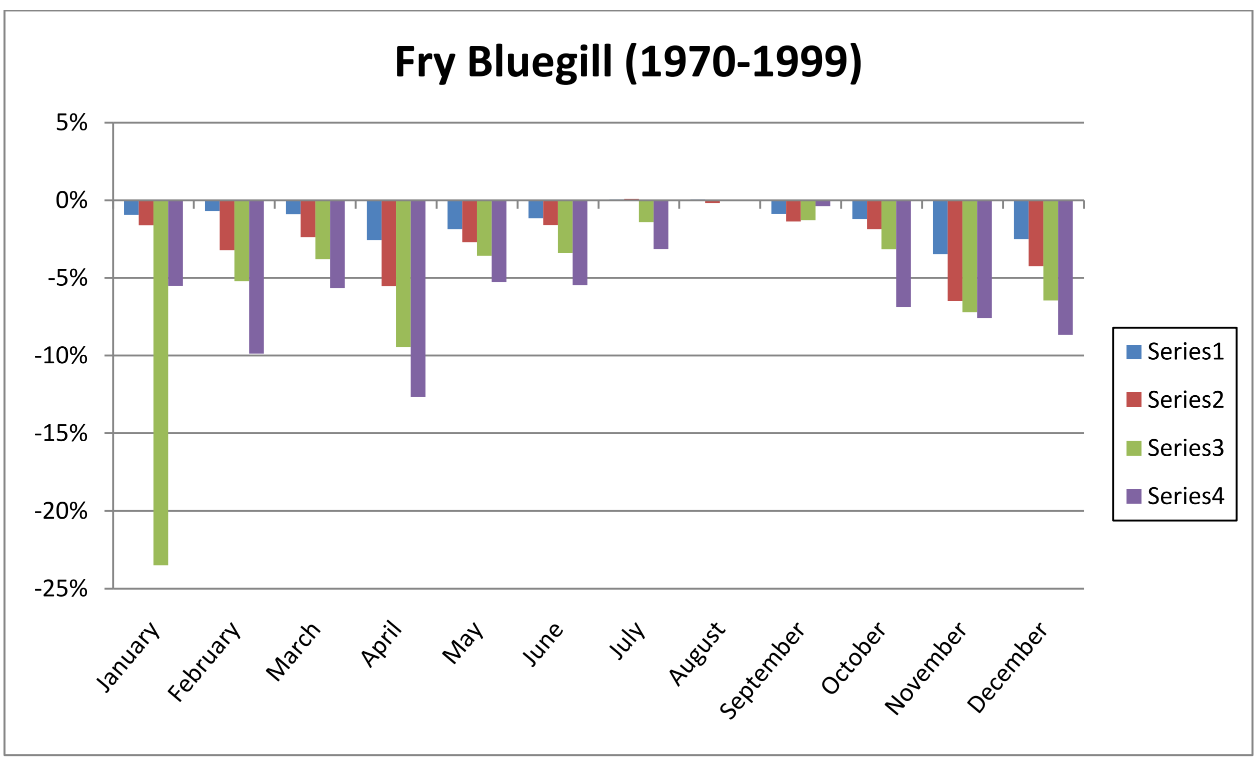

Spawning Largemouth Bass (1970-1999)
5%
0%
-5%
-10%
-15%
-20%
-25%
-30%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

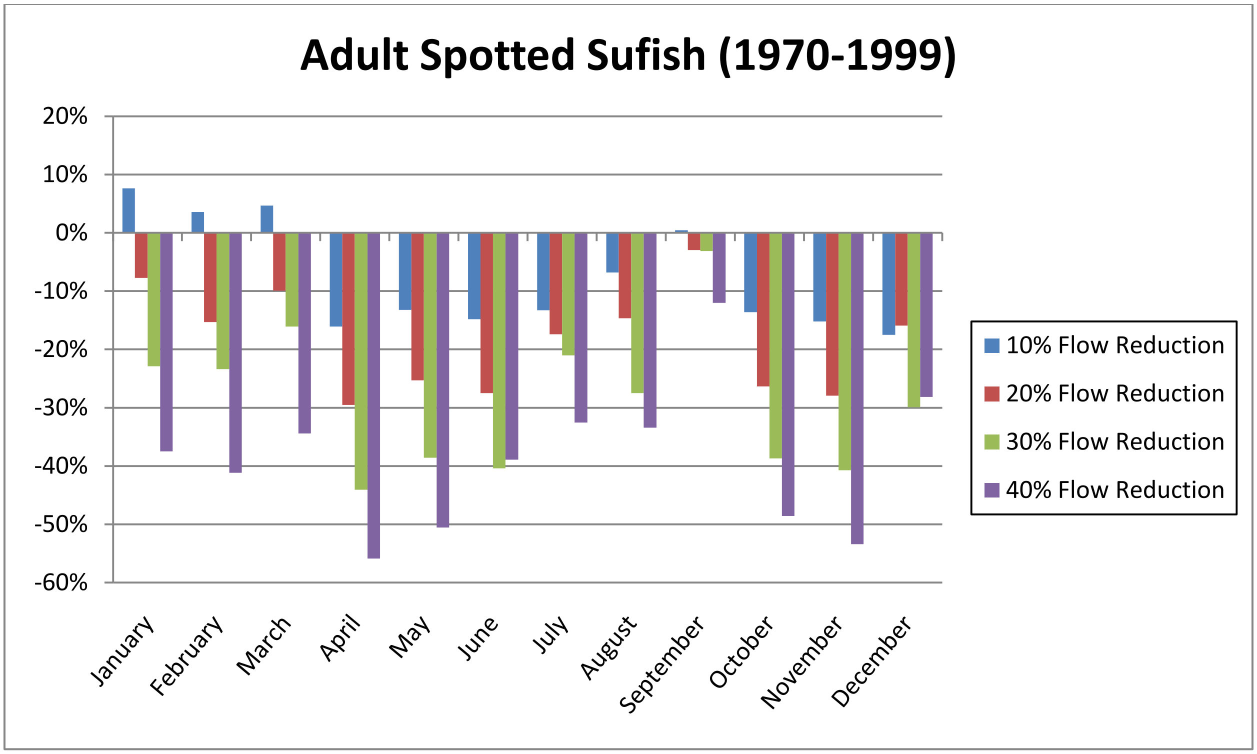

Fry Largemouth Bass (1970-1999)
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
-45%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

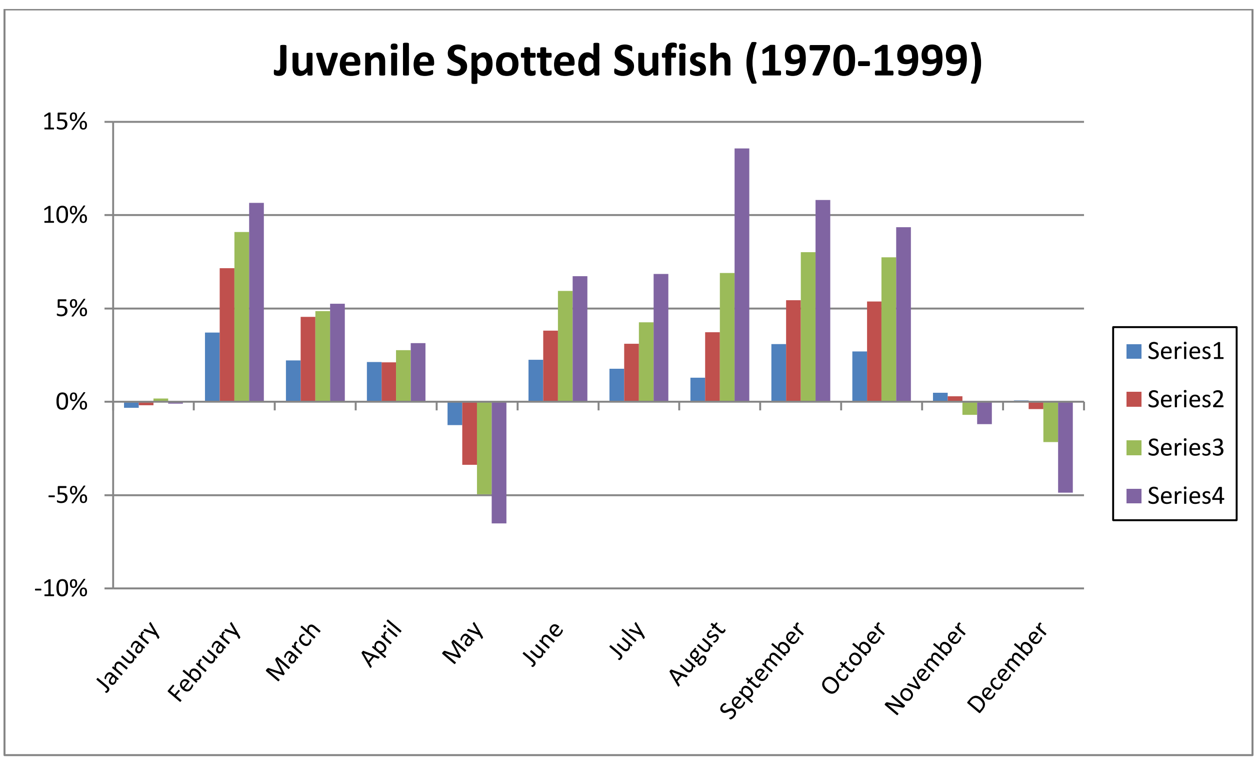

Adult Bluegill (1970-1999)
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

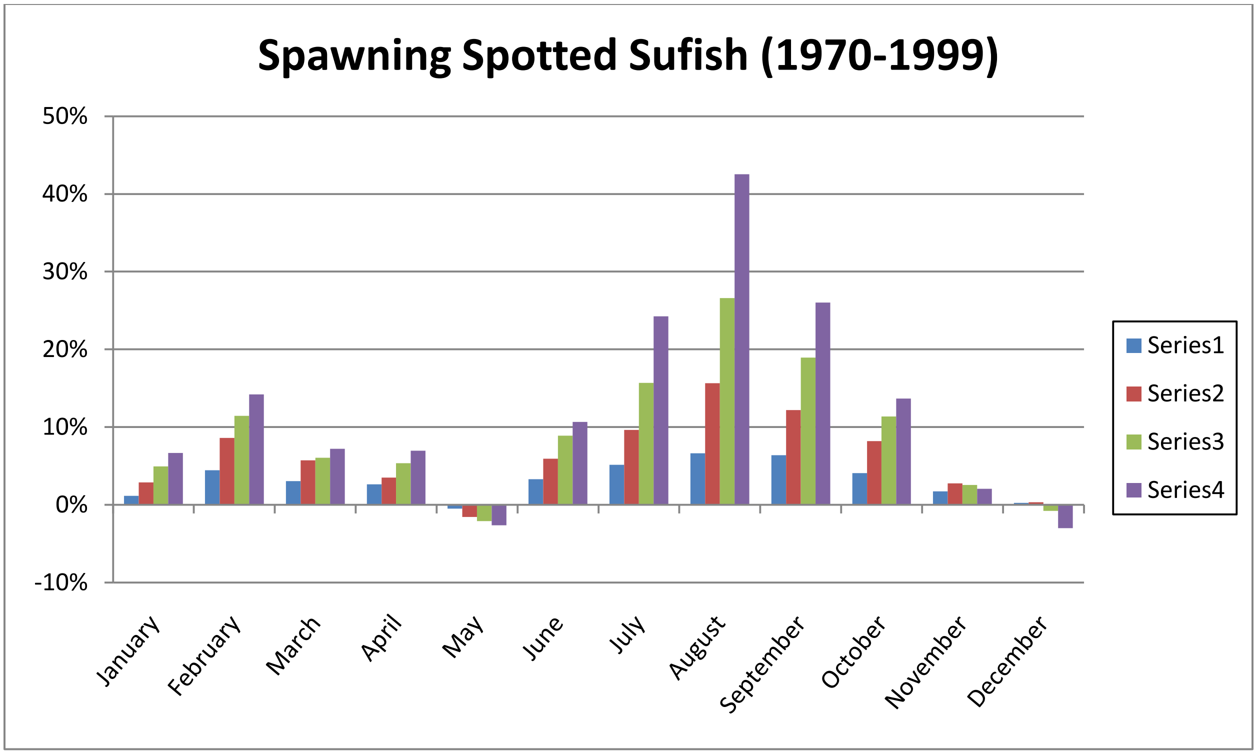

Juvenile Bluegill (1970-1999)
15%
10%
5%
0%
-5%
-10%
-15%
-20%
-25%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

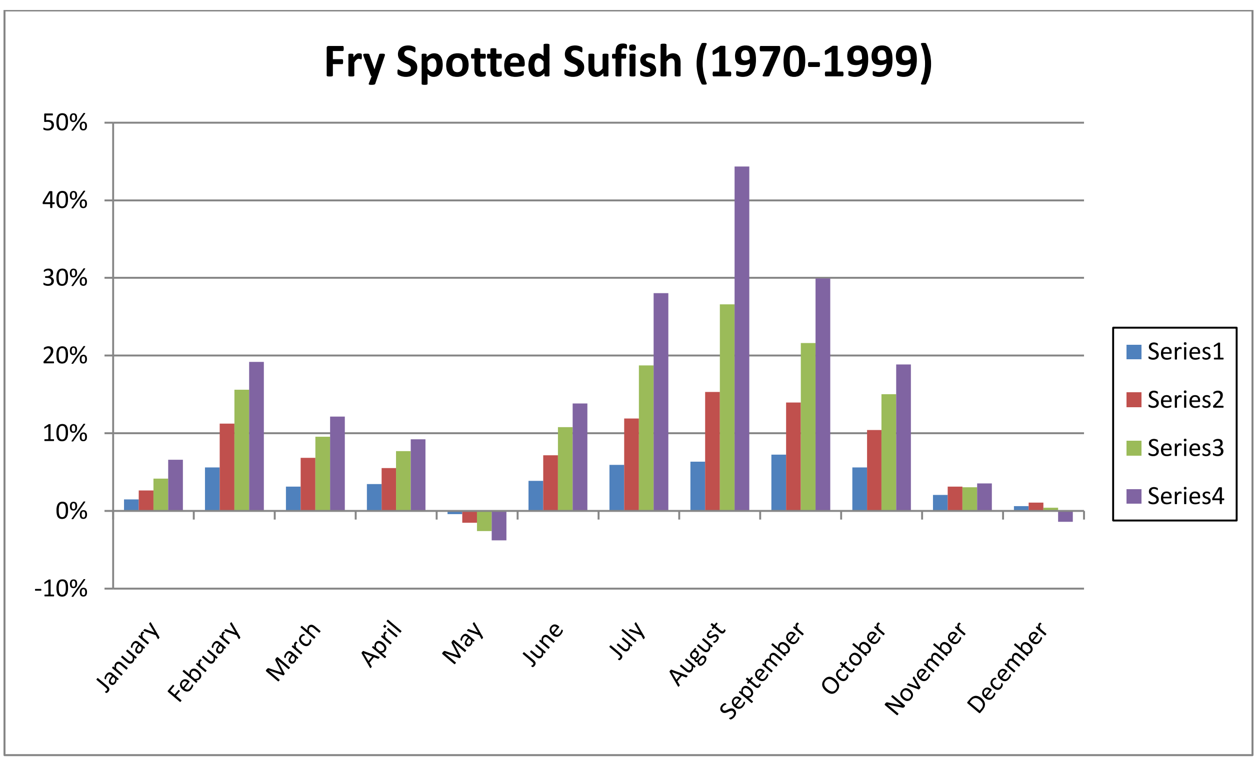

Spawning Bluegill (1970-1999)
25%
20%
15%
10%
5%
0%
-5%
-10%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

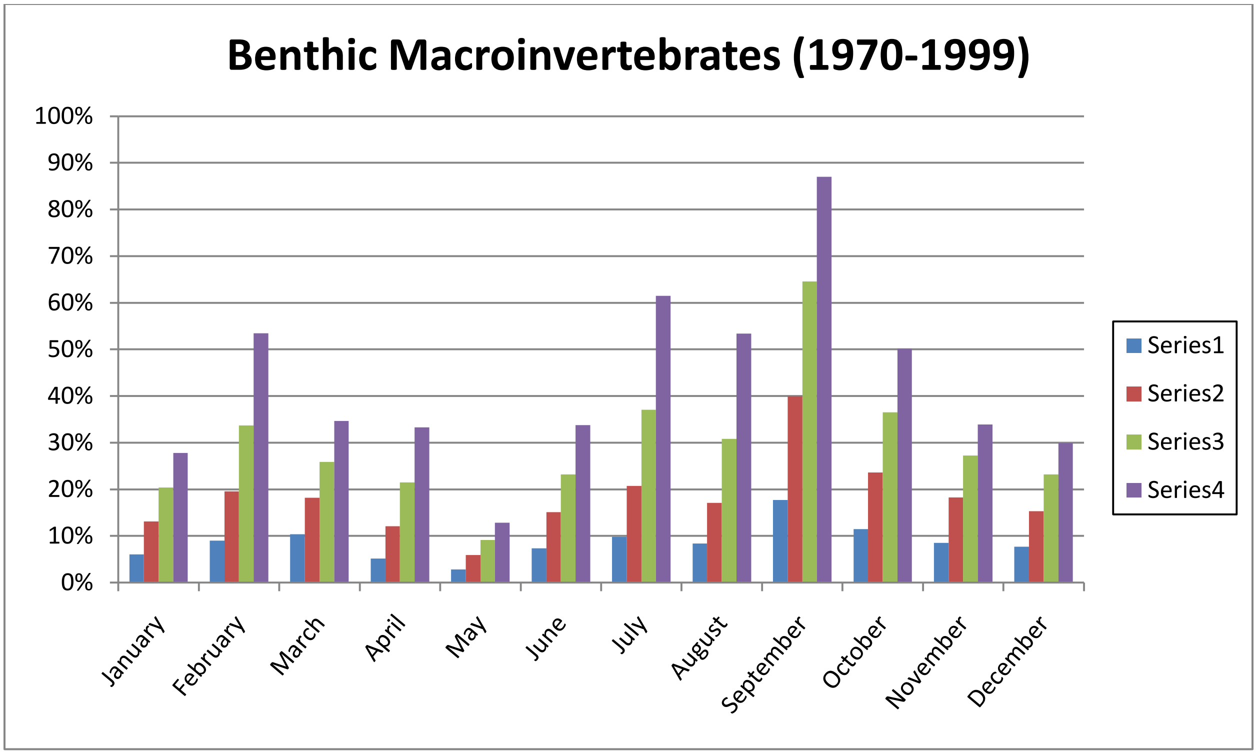

Fry Bluegill (1970-1999)
5%
0%
-5%
-10%
-15%
-20%
-25%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4


Adult Spotted Sufish (1970-1999)
20%
10%
0%
-10%
-20%
-30%
-40%
-50%
-60%
January
February
March
April
May
June
July
August
September
October
November
December
10% Flow Reduction
20% Flow Reduction
30% Flow Reduction
40% Flow Reduction

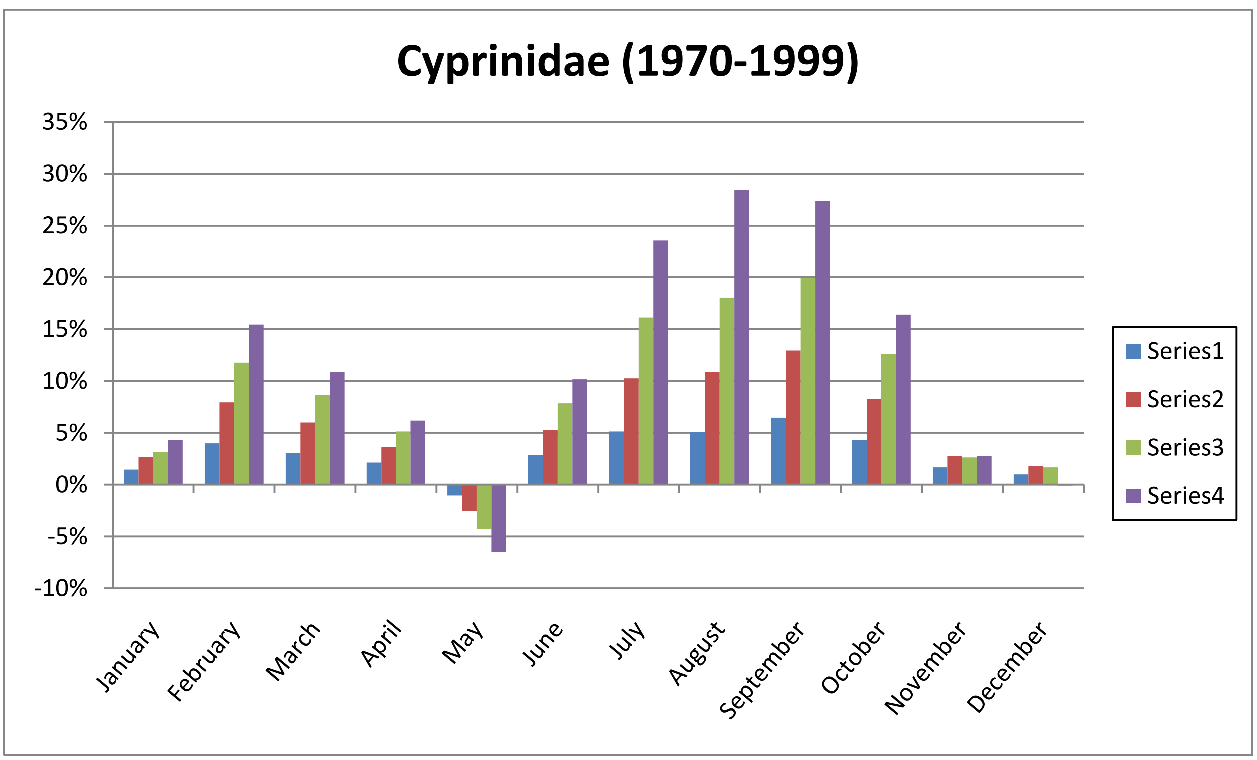

Juvenile Spotted Sufish (1970-1999)
15%
10%
5%
0%
-5%
-10%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4


Spawning Spotted Sufish (1970-1999)
50%
40%
30%
20%
10%
0%
-10%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4


Fry Spotted Sufish (1970-1999)
50%
40%
30%
20%
10%
0%
-10%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4



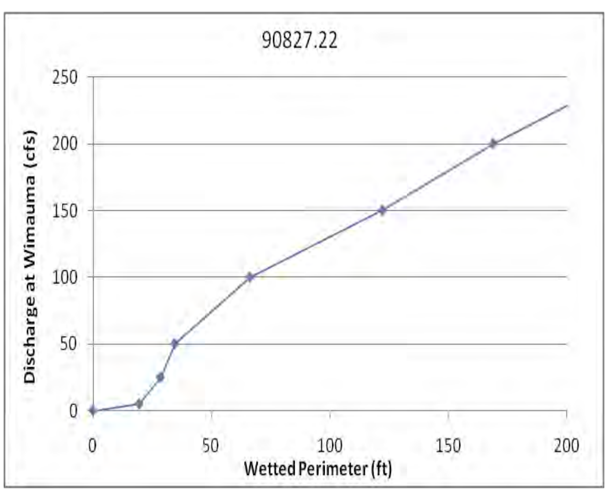
Benthic Macroinvertebrates (1970-1999)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

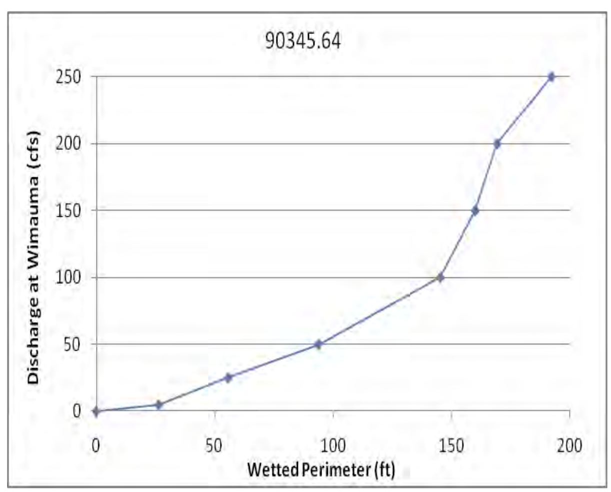


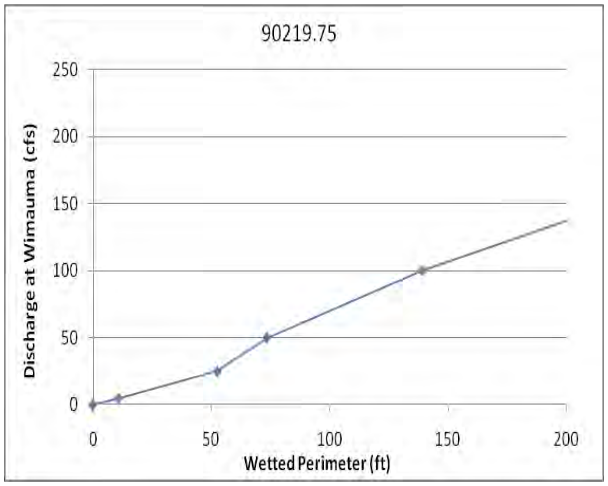
Cyprinidae (1970-1999)
35%
30%
25%
20%
15%
10%
5%
0%
-5%
-10%
January
February
March
April
May
June
July
August
September
October
November
December
Series1
Series2
Series3
Series4

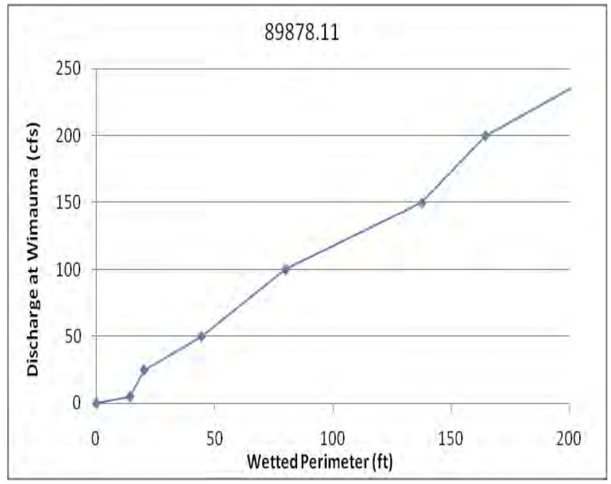
Wetted Perimeter Appendix

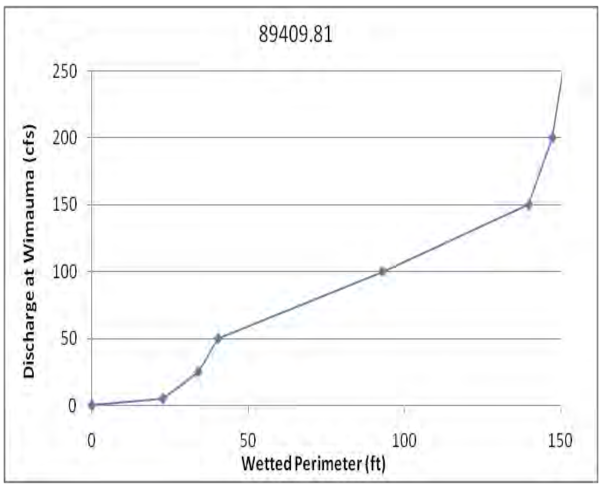
The graphs below represent wetted perimeter versus discharge at HEC-RAS stations based on the feet upstream of USGS Little Manatee River near Wimauma gage.

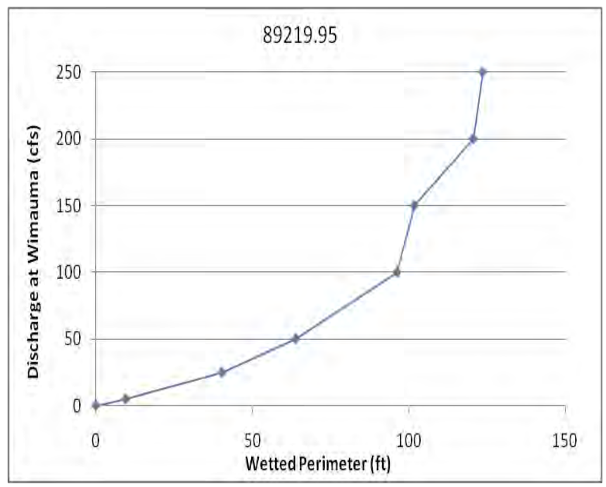


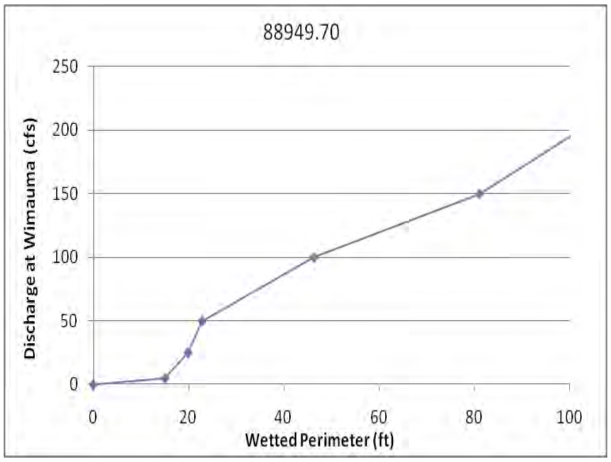


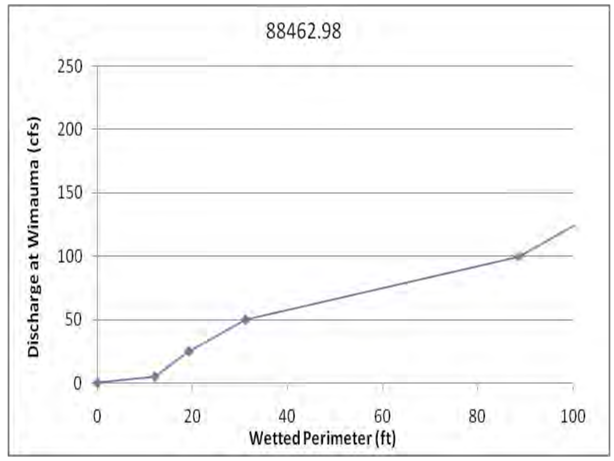

90219.75
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
50
100
150
200
Wetted Perimeter (ft)

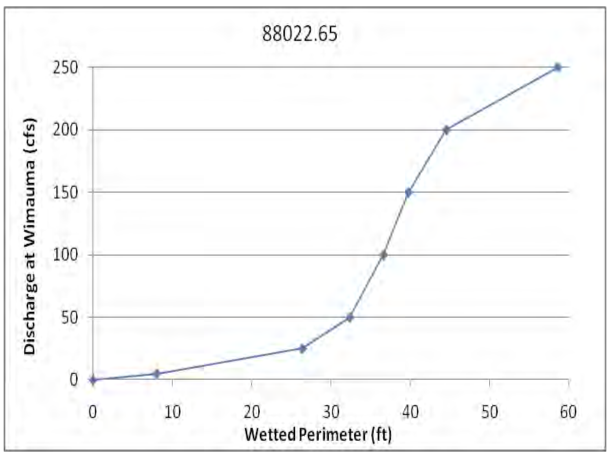

89878.11
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
50
100
150
200
Wetted Perimeter (ft)

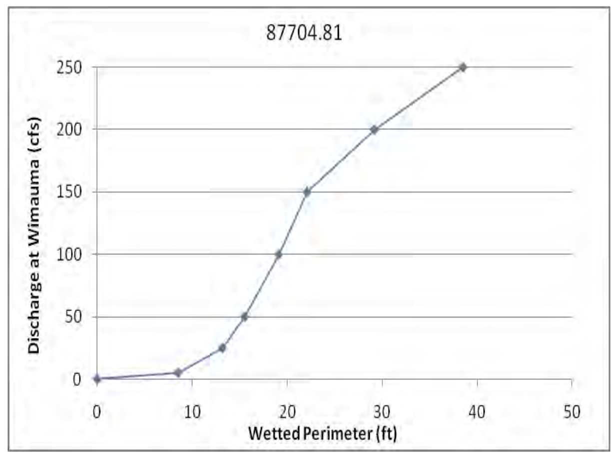

89409.81
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
50
100
150
Wetted Perimeter (ft)

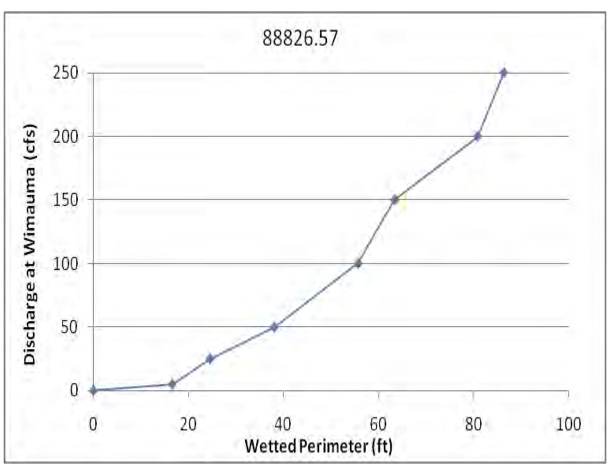

89219.95
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
50
100
150
Wetted Perimeter (ft)

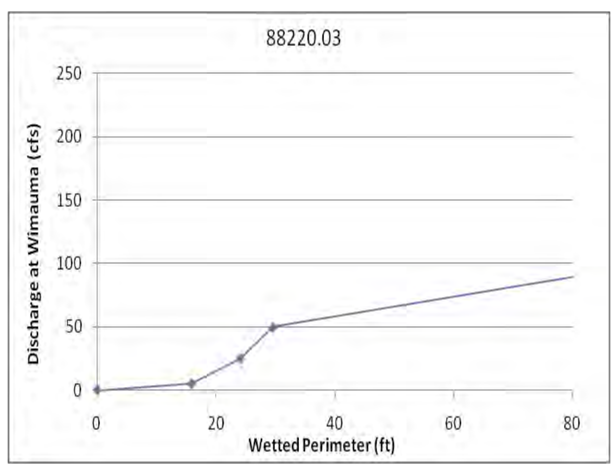

88949.70
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100

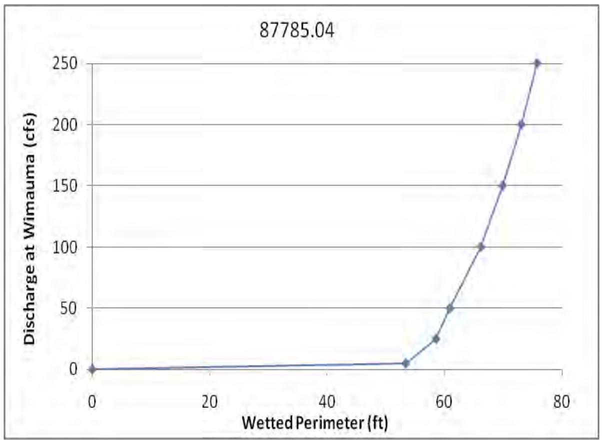

88462.98
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100

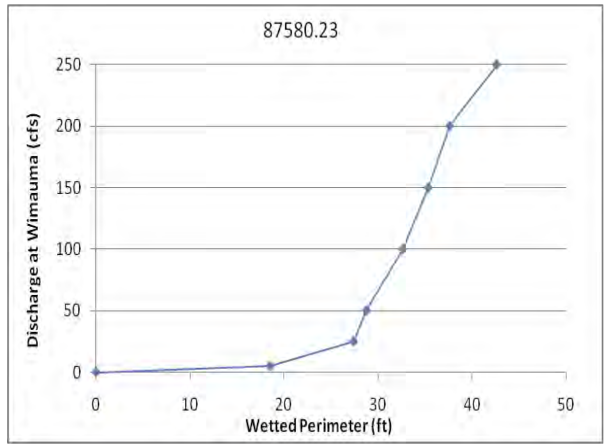

88022.65
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60

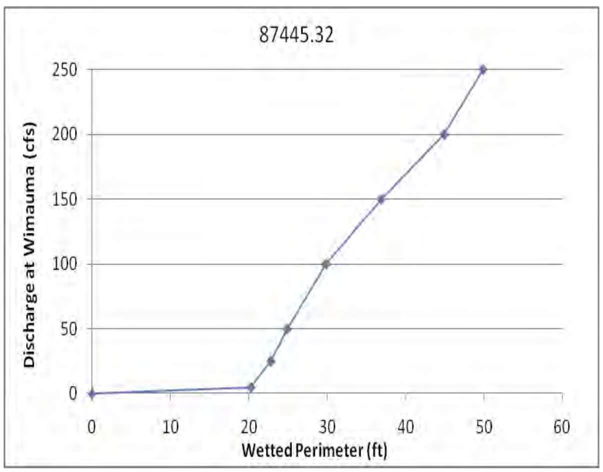

87704.81
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50

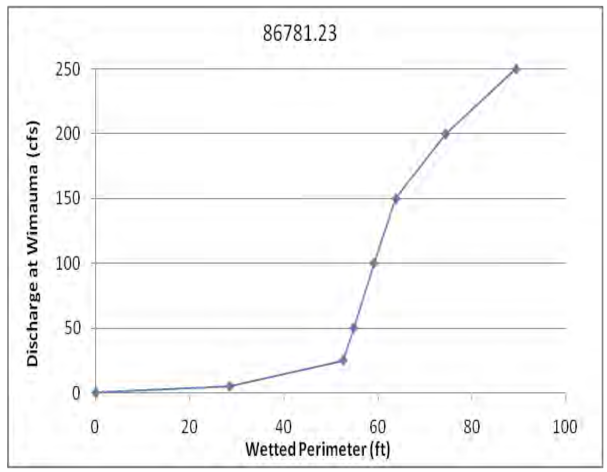

88826.57
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100

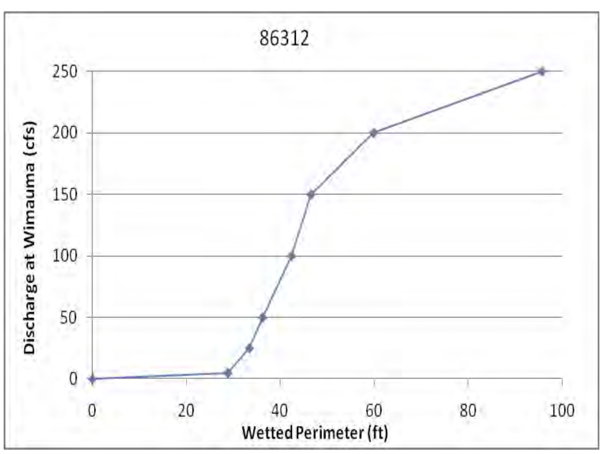

88220.03
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80

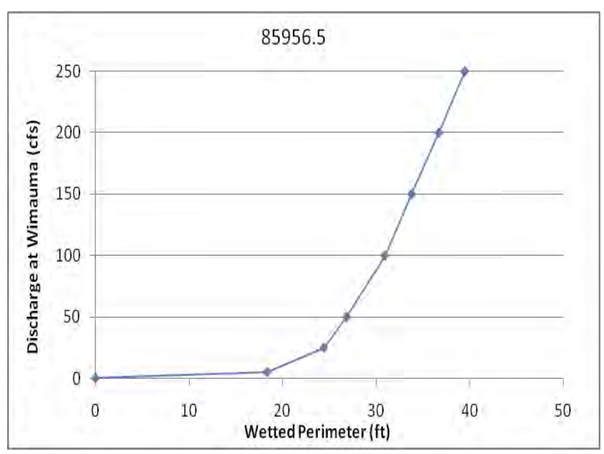

87785.04
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
20
40
60
80
Wetted Perimeter (ft)

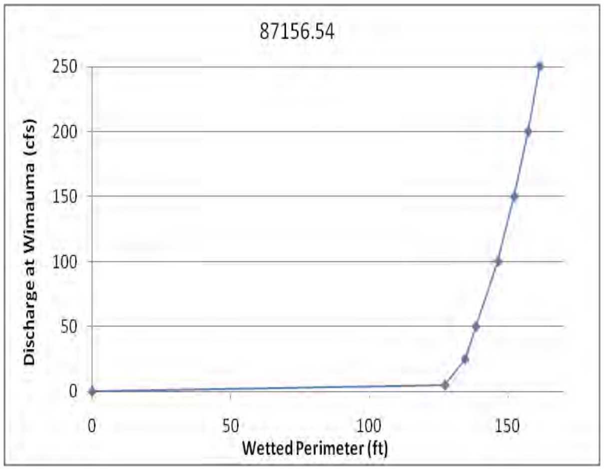

87580.23
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
Wetted Perimeter (ft)

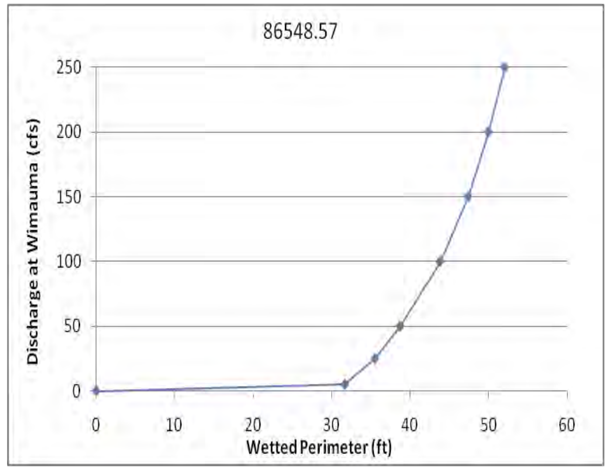

87445.32
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
60
Wetted Perimeter (ft)

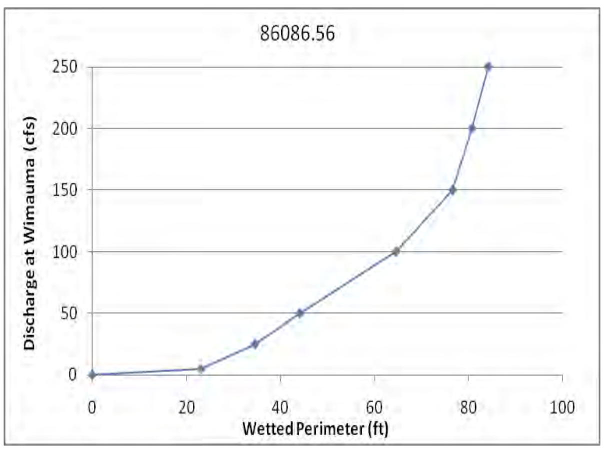

86781.23
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
20
40
60
80
100
Wetted Perimeter (ft)

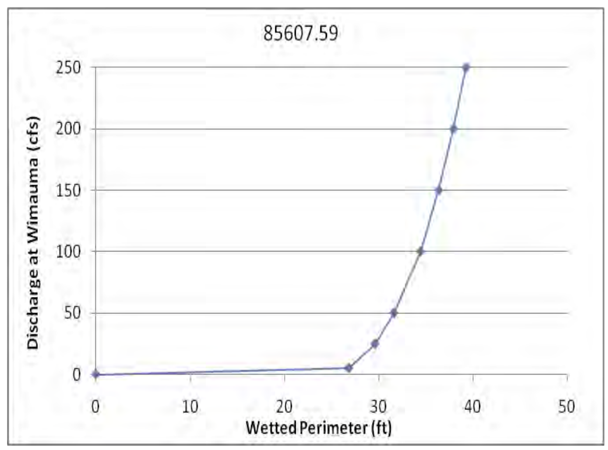

86312
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
20
40
60
80
100
Wetted Perimeter (ft)

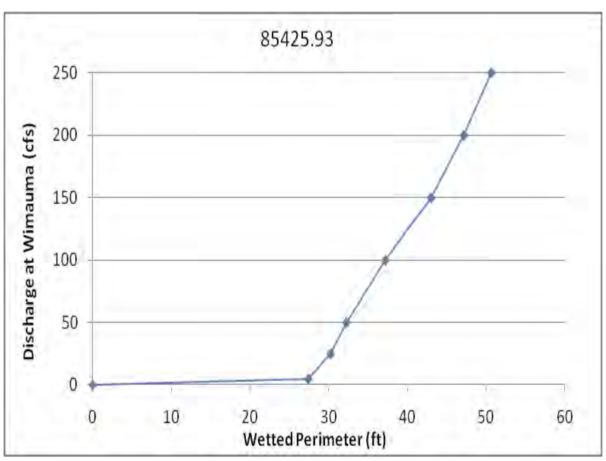

85956.5
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
Wetted Perimeter (ft)

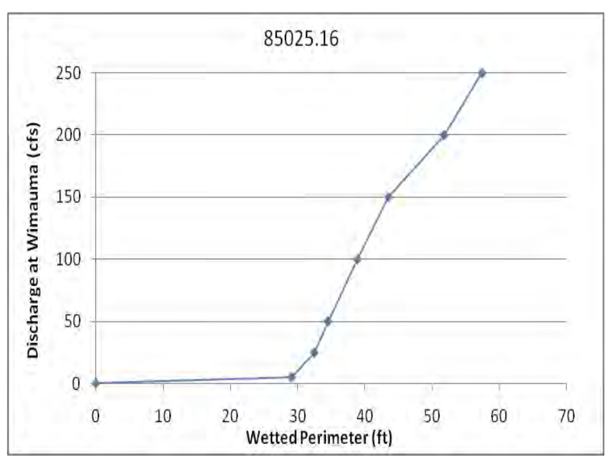

87156.54
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
50
100
150

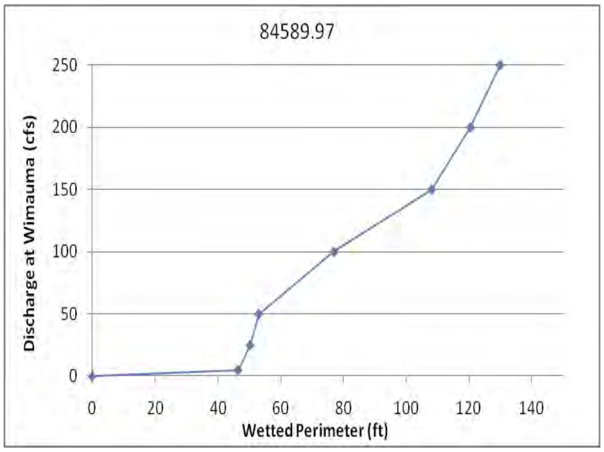

86548.57
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60

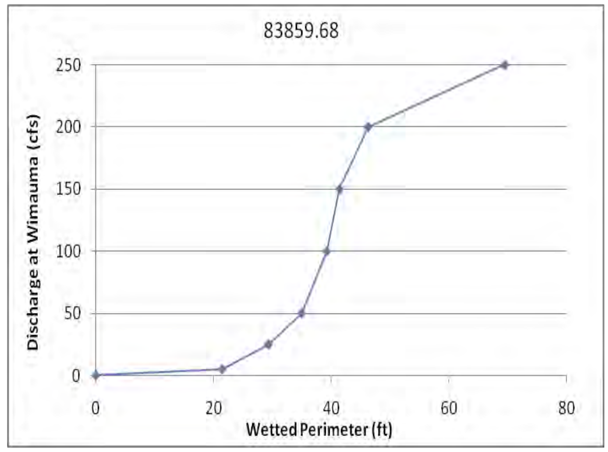

86086.56
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100

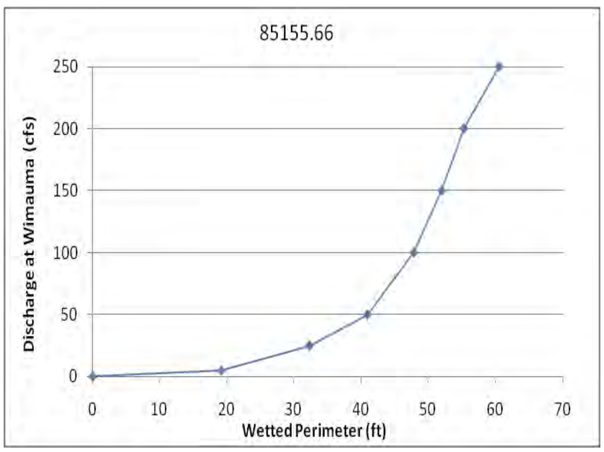

85607.59
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50

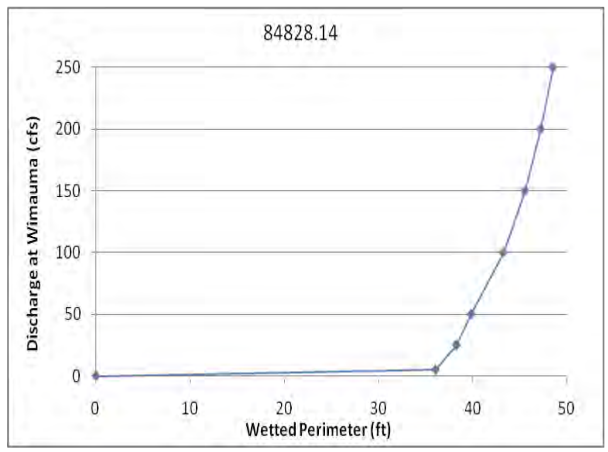

85425.93
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60

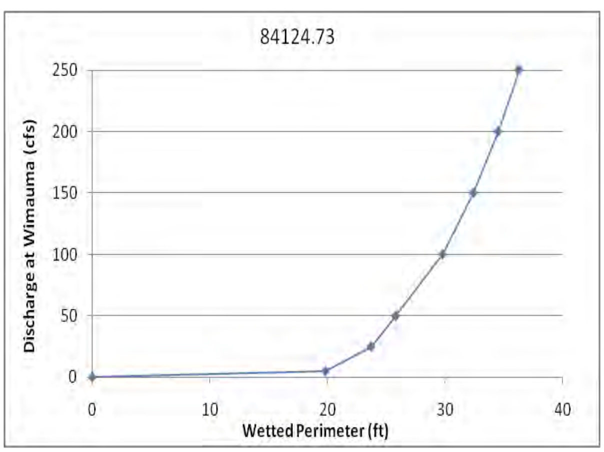

85025.16
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70

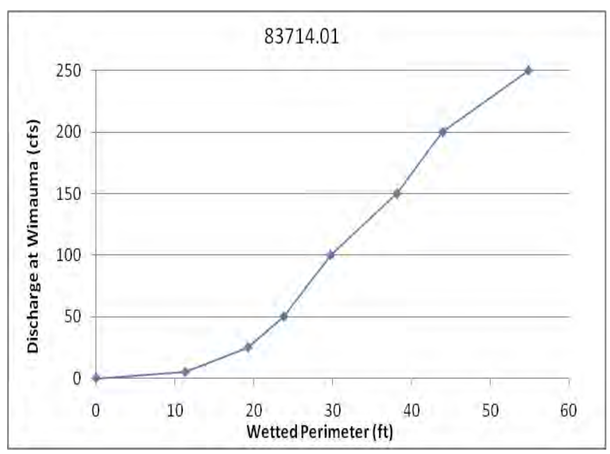

84589.97
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
20
40
60
80
100
120
140
Wetted Perimeter (ft)

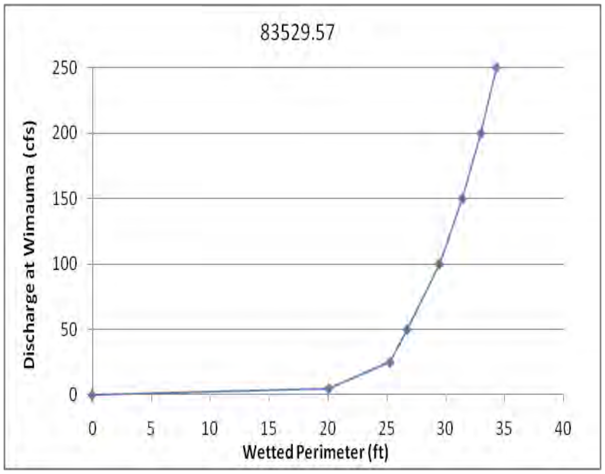

83859.68
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
20
40
60
80
Wetted Perimeter (ft)

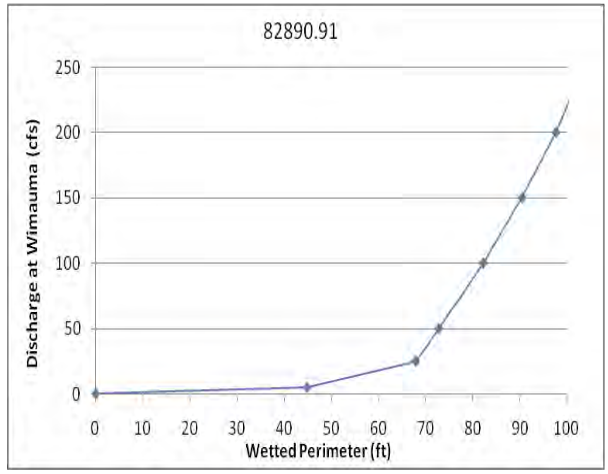

85155.66
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
60
70
Wetted Perimeter (ft)

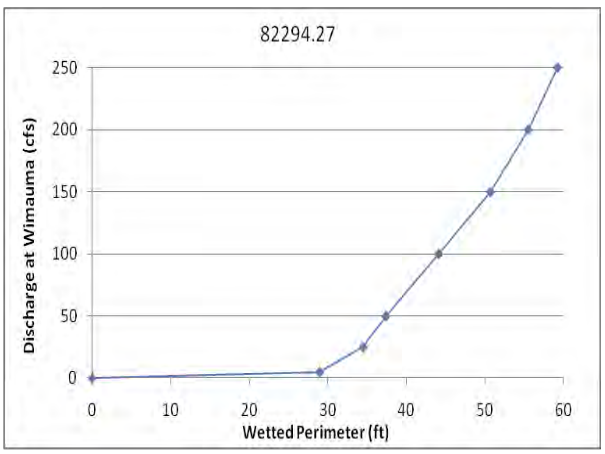

84828.14
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
Wetted Perimeter (ft)

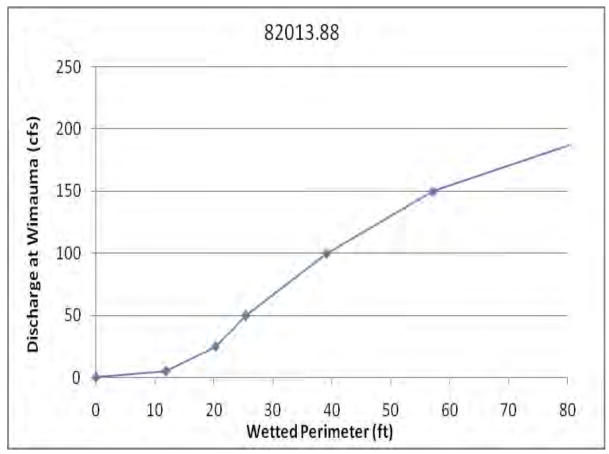

84124.73
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
Wetted Perimeter (ft)

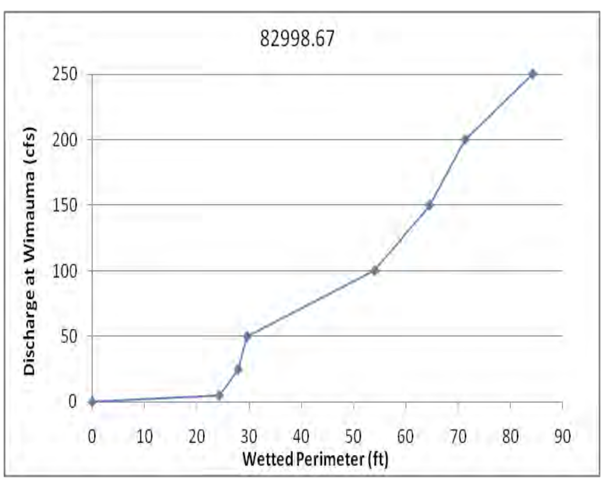

83714.01
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
60
Wetted Perimeter (ft)

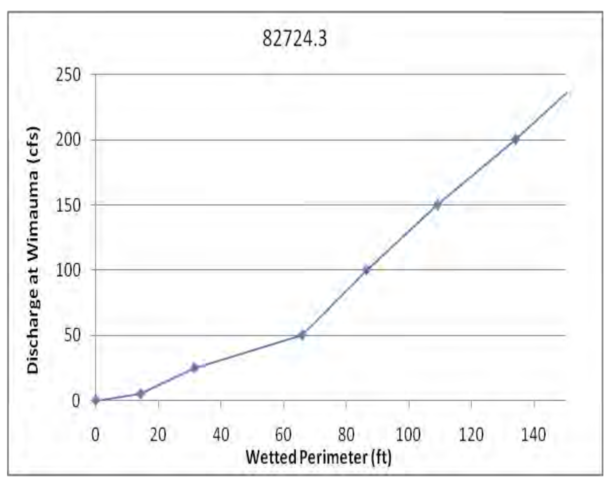

83529.57
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

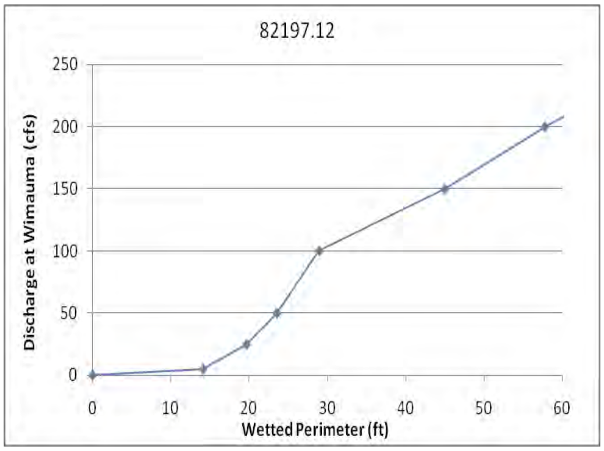

82890.91
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

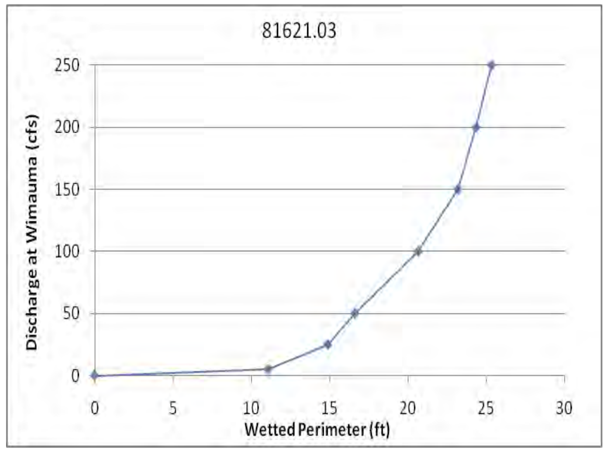

82294.27
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

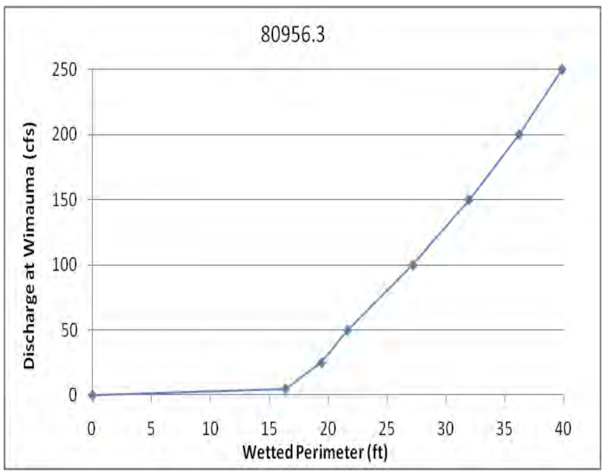

82013.88
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

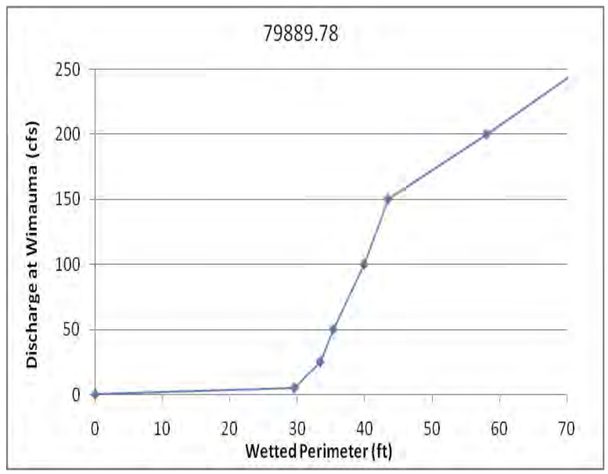

82998.67
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

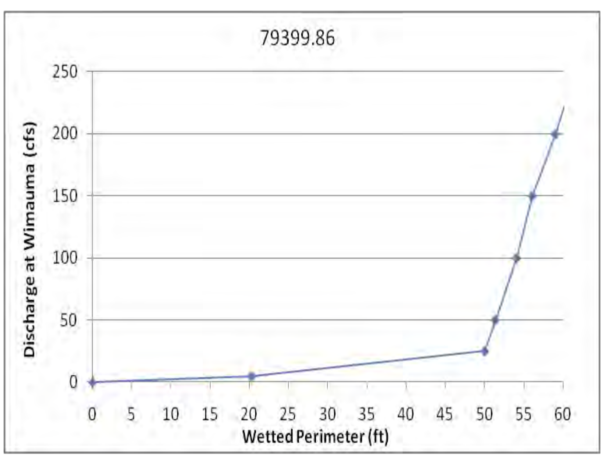

82724.3
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

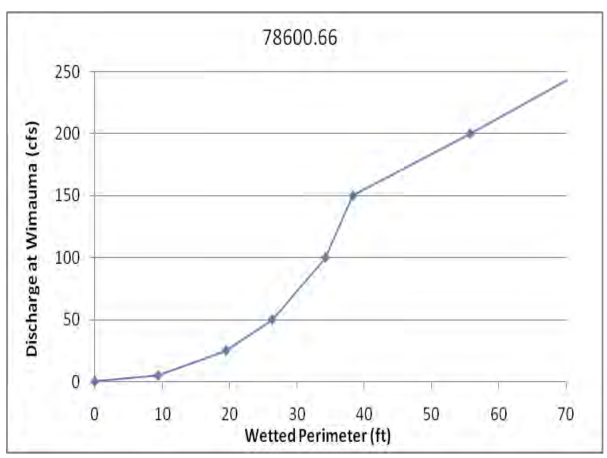

82197.12
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

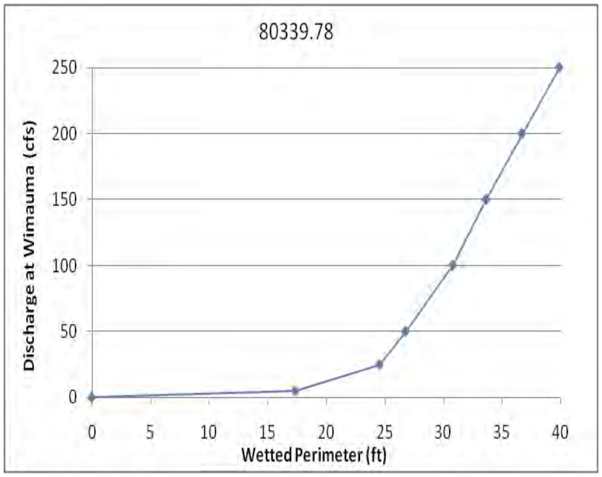

81621.03
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

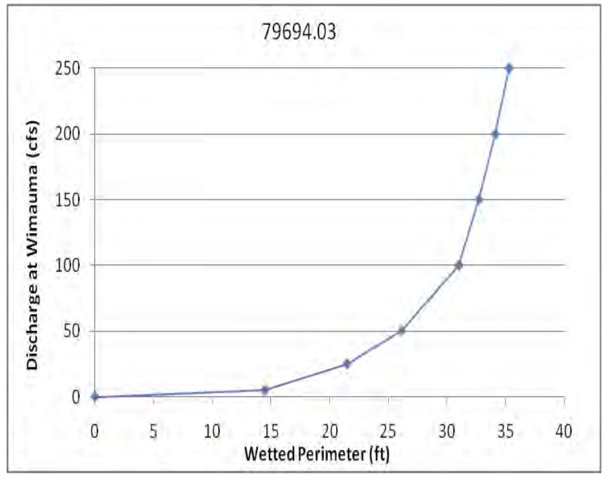

80956.3
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

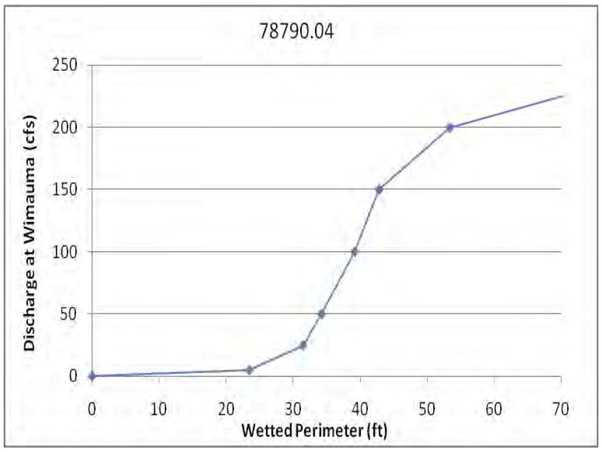

79889.78
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

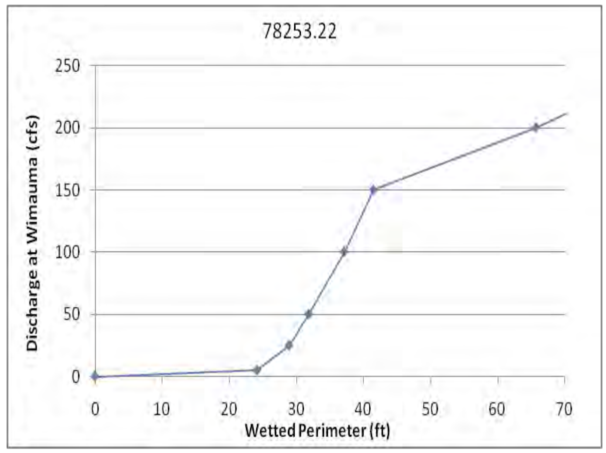

79399.86
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

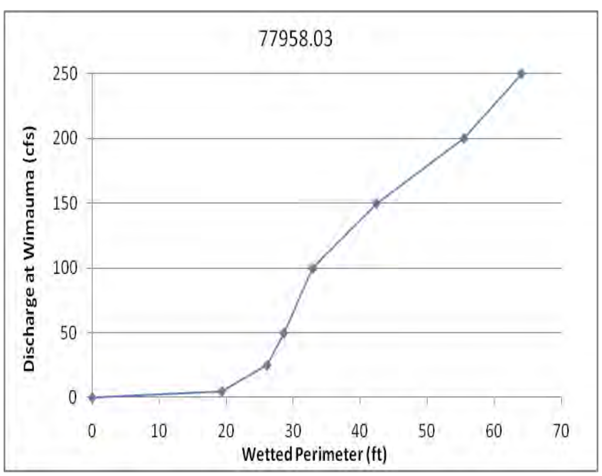

78600.66
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

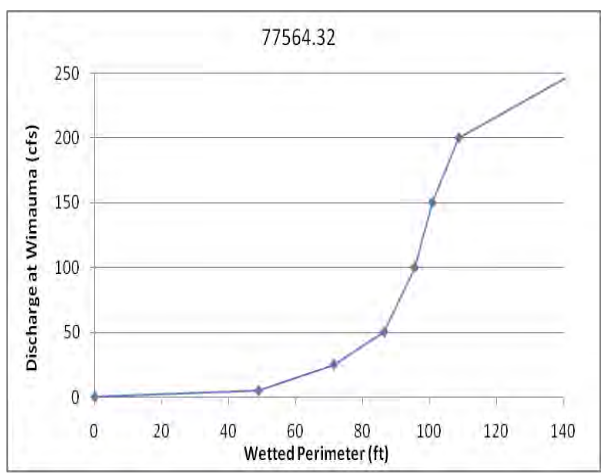

80339.78
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40

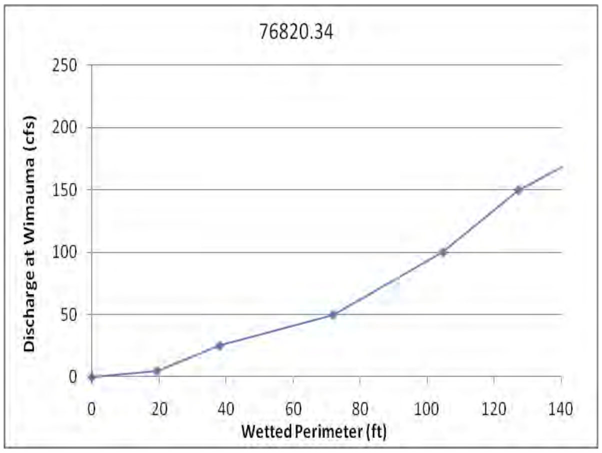

79694.03
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40

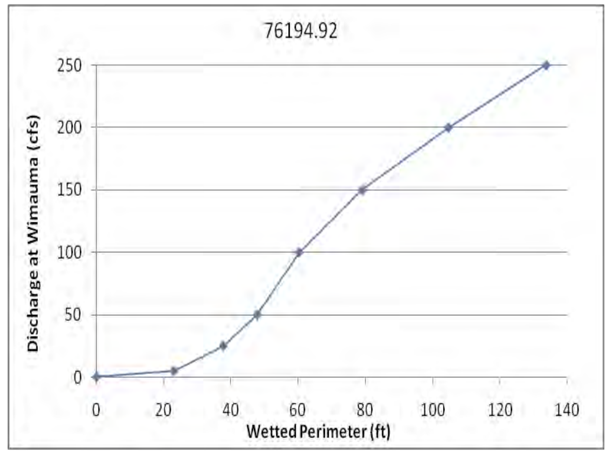

78790.04
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70

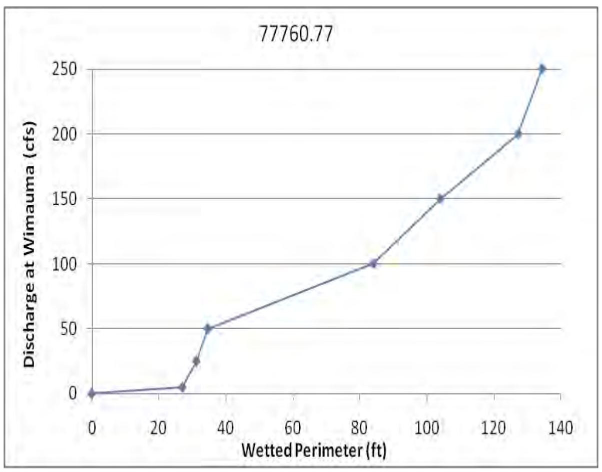

78253.22
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70

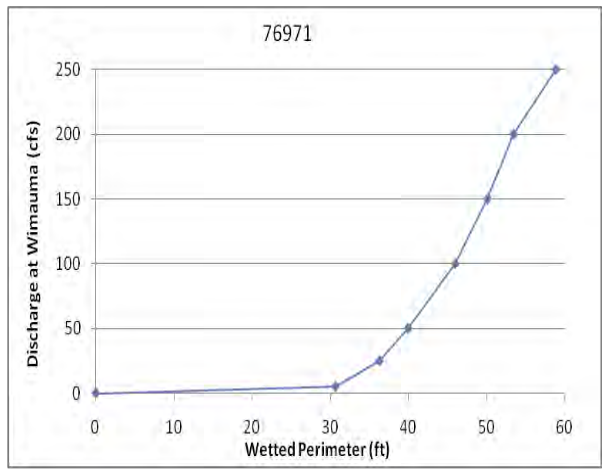

77958.03
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70

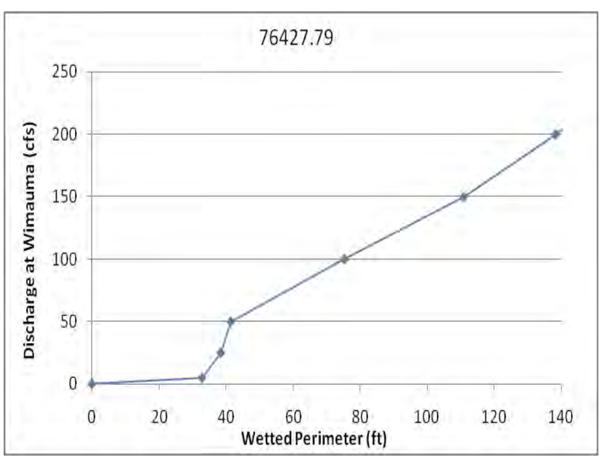

77564.32
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140

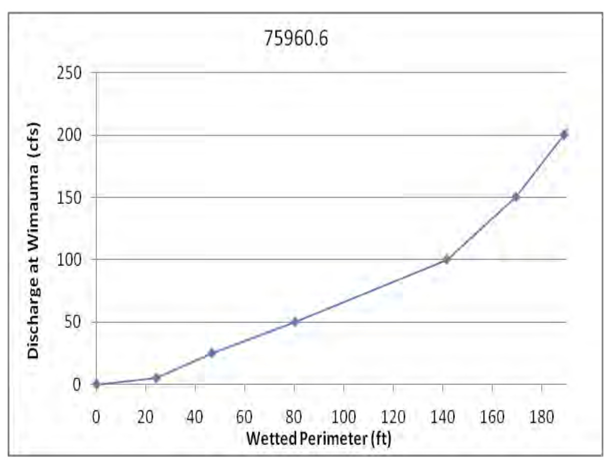

76820.34
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
Wetted Perimeter (ft)

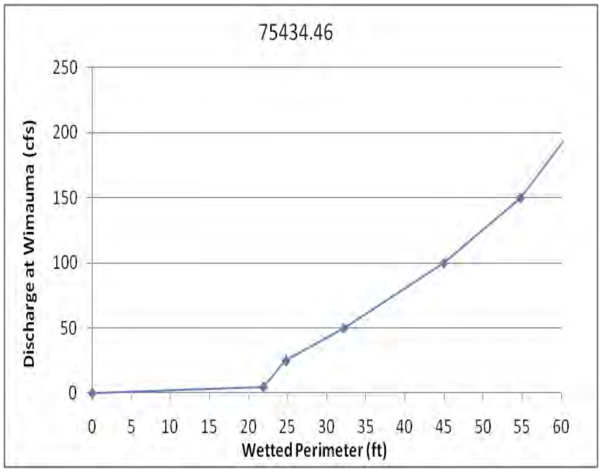

76194.92
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
Wetted Perimeter (ft)

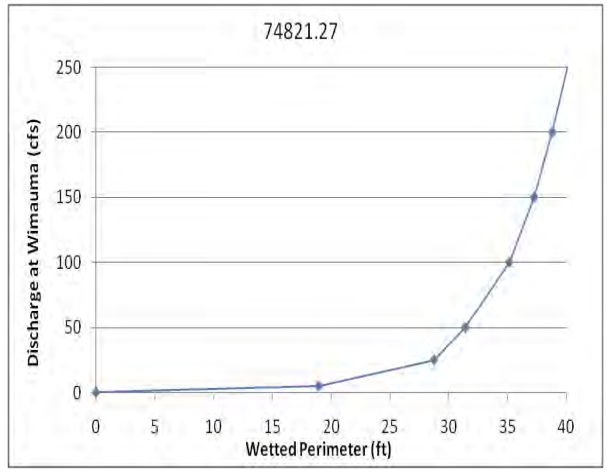

77760.77
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
Wetted Perimeter (ft)

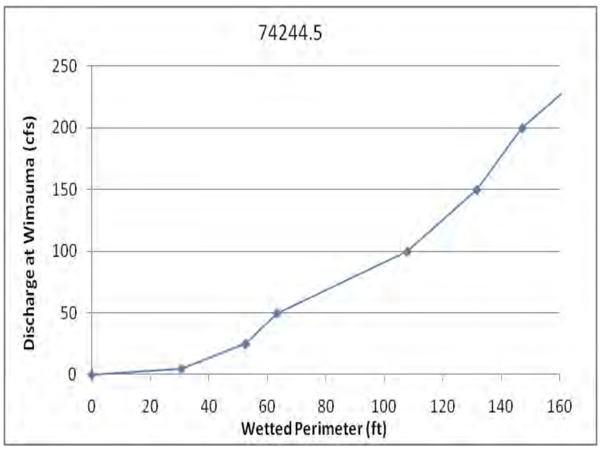

76971
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
10
20
30
40
50
60
Wetted Perimeter (ft)

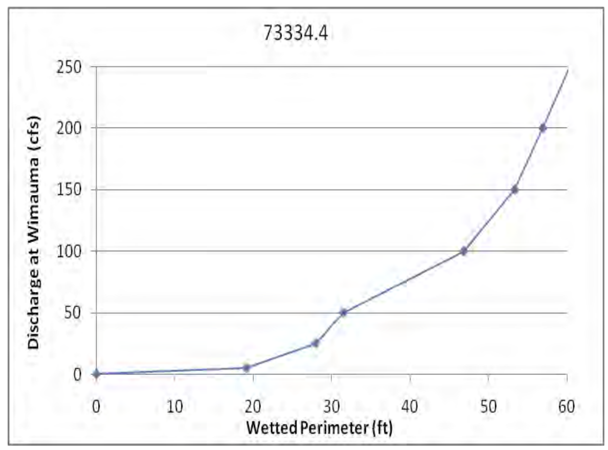

76427.79
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
Wetted Perimeter (ft)

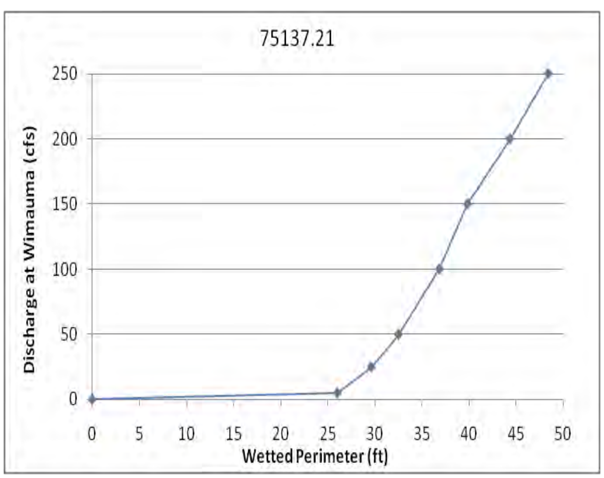

75960.6
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
Wetted Perimeter (ft)

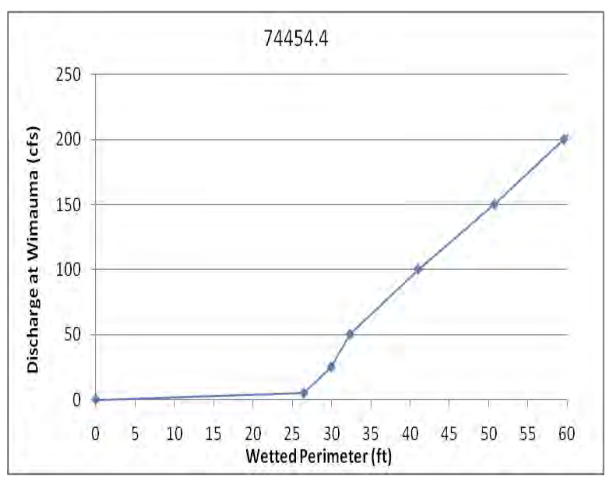

75434.46
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40
45
50
55
60

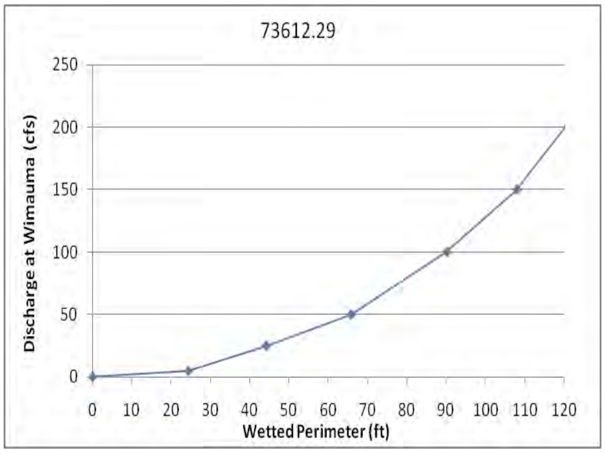

74821.27
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40

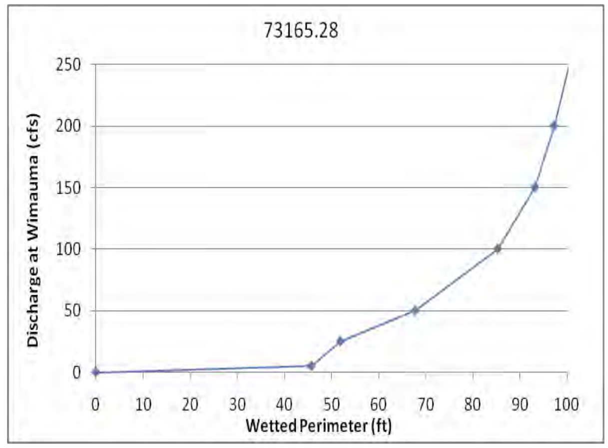

74244.5
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160

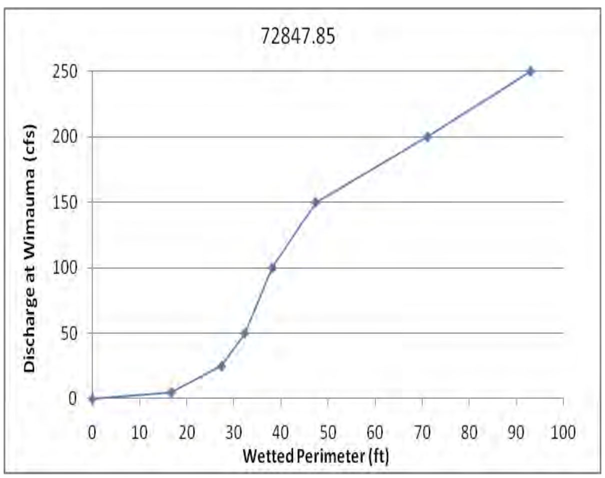

73334.4
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60

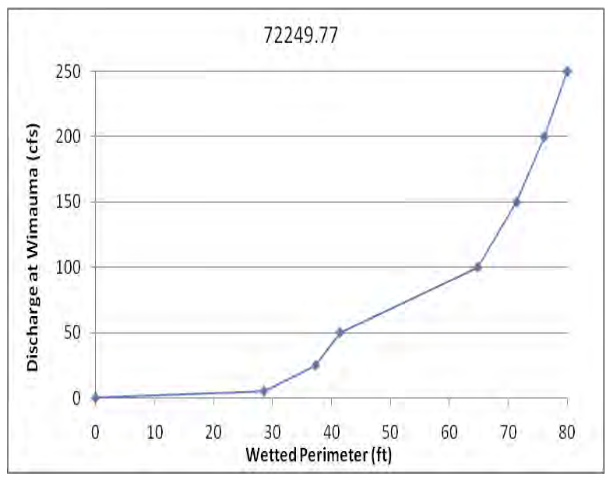

75137.21
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40
45
50

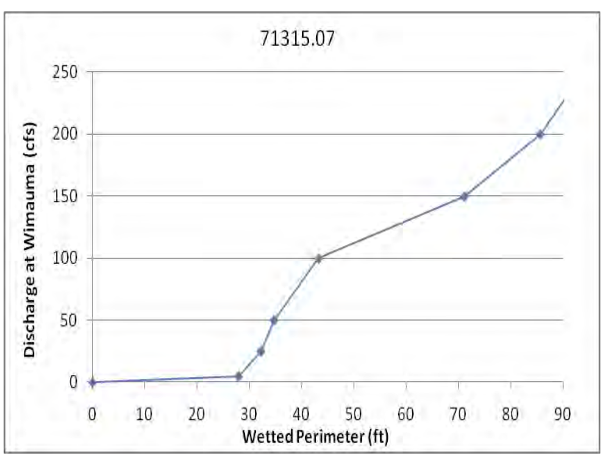

74454.4
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40
45
50
55
60

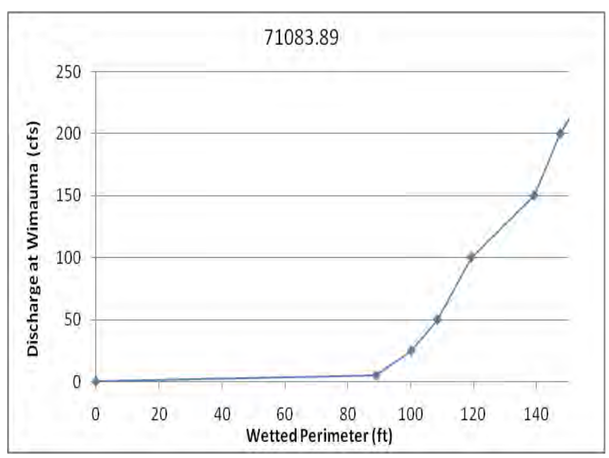

73612.29
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90 100 110 120

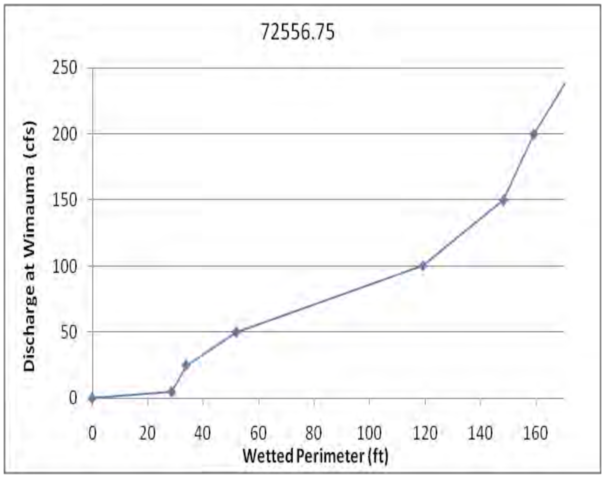

73165.28
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90 100

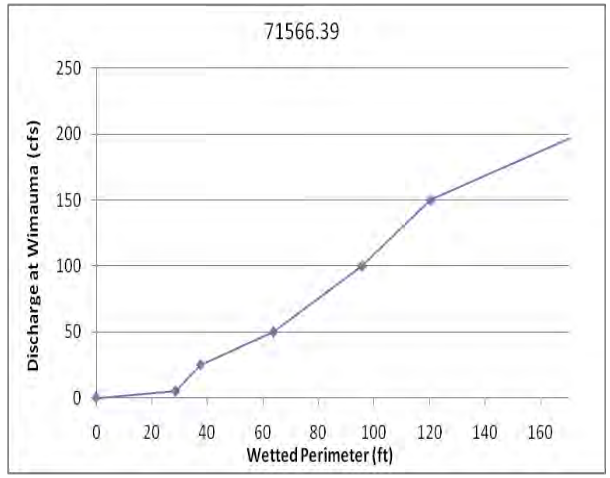

72847.85
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90 100

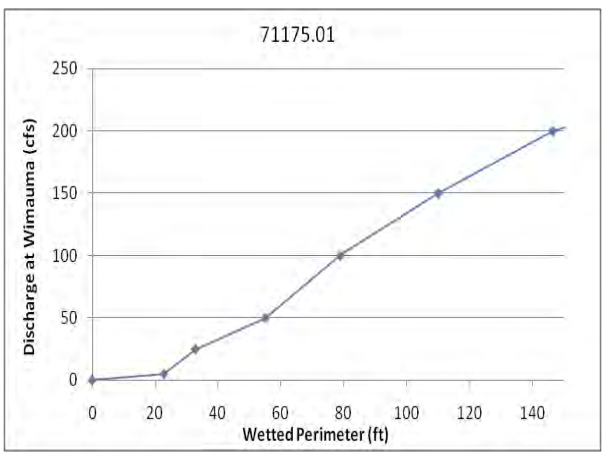

72249.77
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80

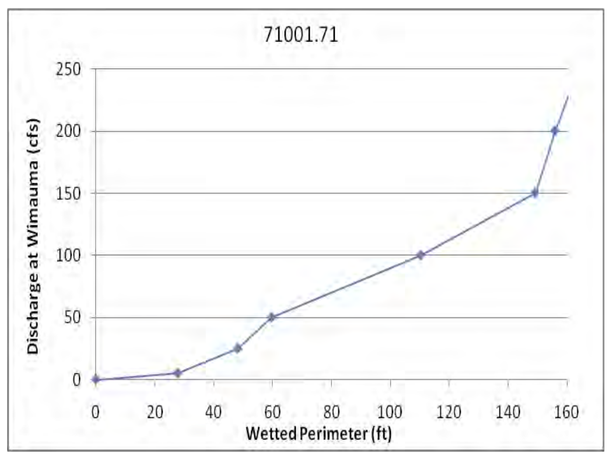

71315.07
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90

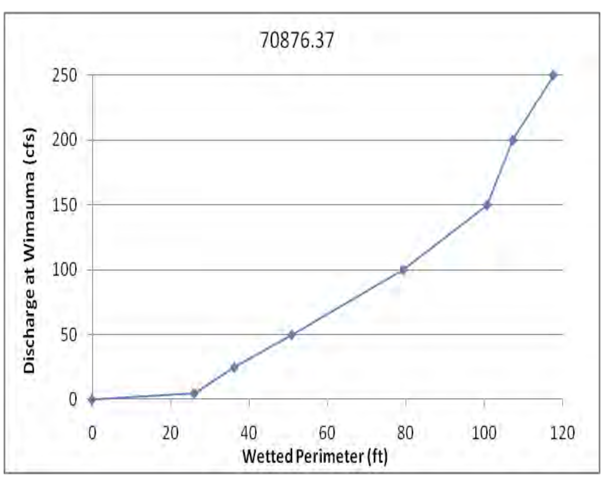

71083.89
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 20 40 60 80 100 120 140

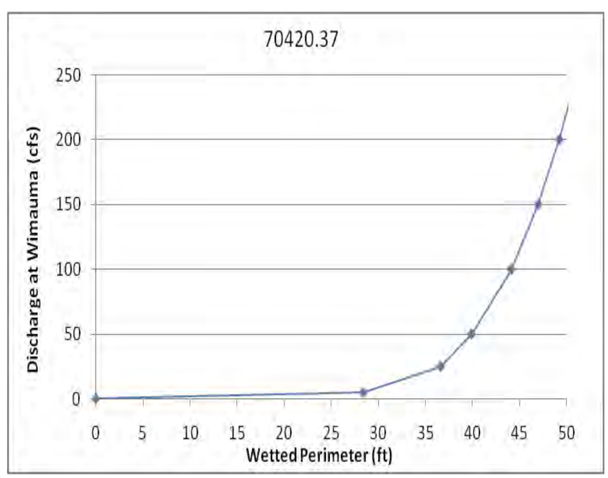

72556.75
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
Wetted Perimeter (ft)

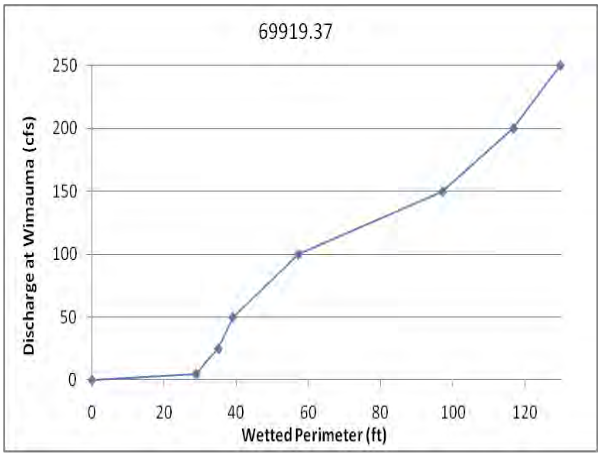

71566.39
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
Wetted Perimeter (ft)

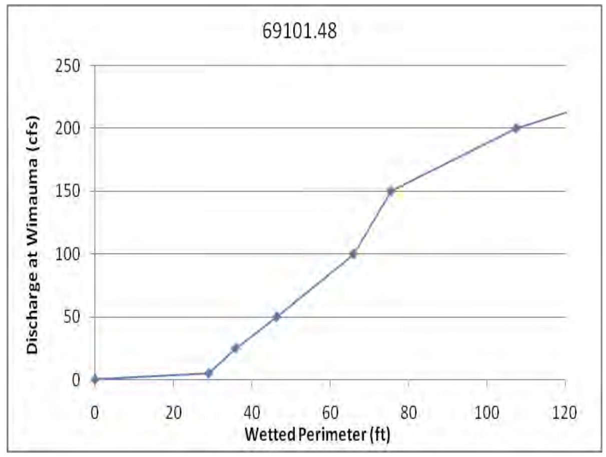

71175.01
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
Wetted Perimeter (ft)

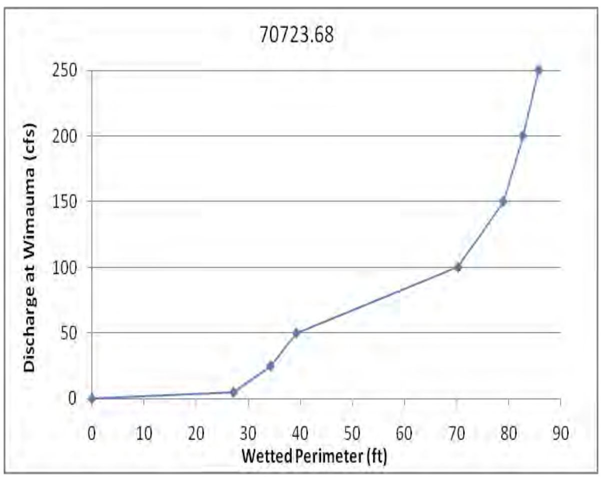

71001.71
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
Wetted Perimeter (ft)

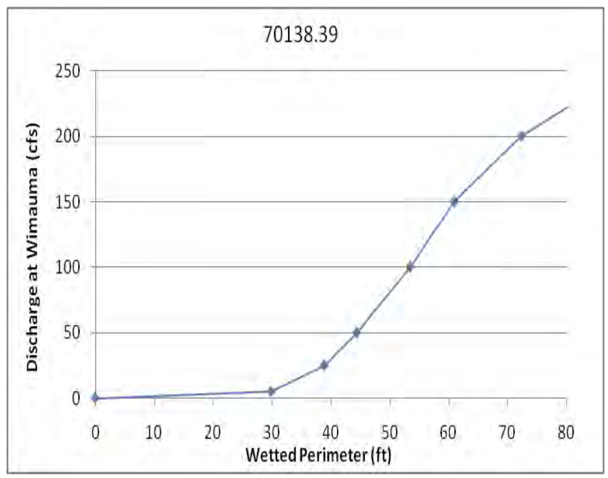

70876.37
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
Wetted Perimeter (ft)

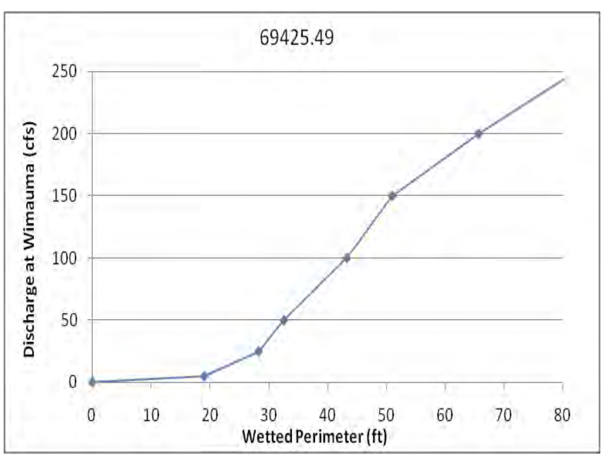

70420.37
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40
45
50
Wetted Perimeter (ft)

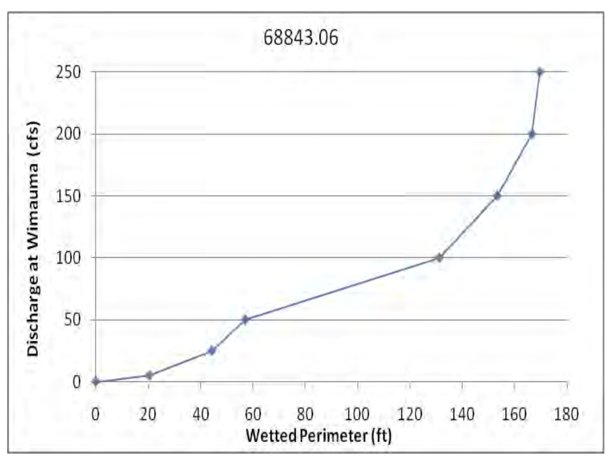

69919.37
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

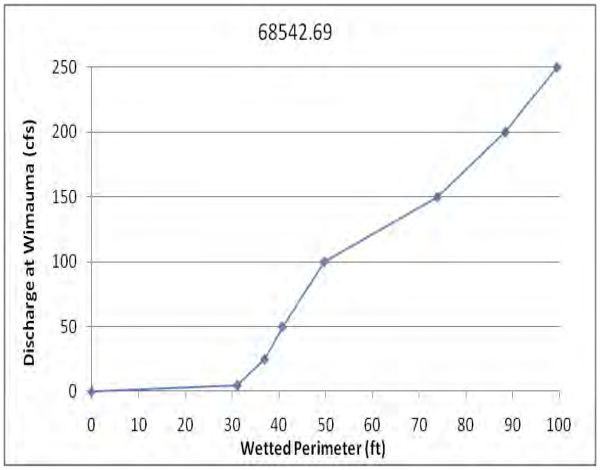

69101.48
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

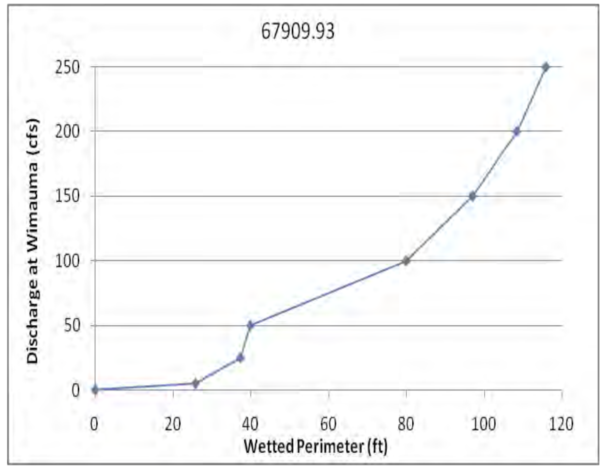

70723.68
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

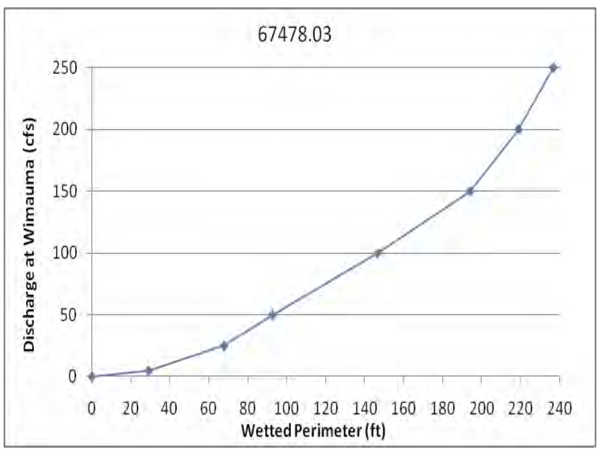

70138.39
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

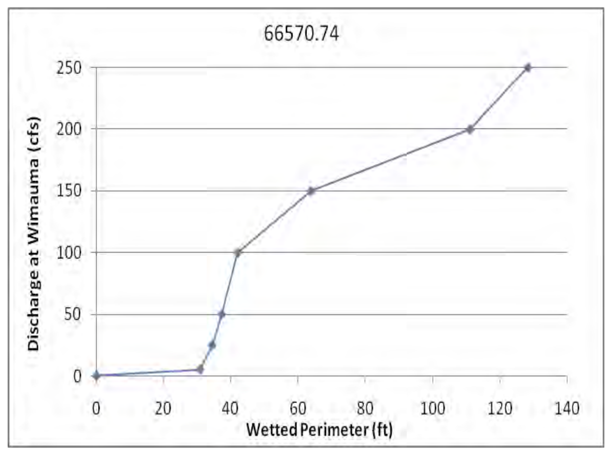

69425.49
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

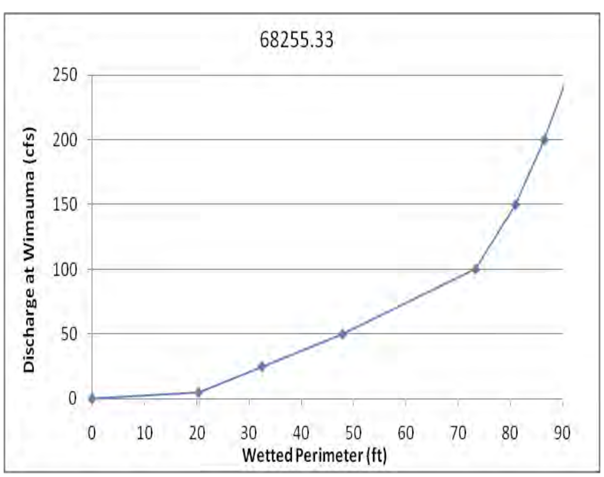

68843.06
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

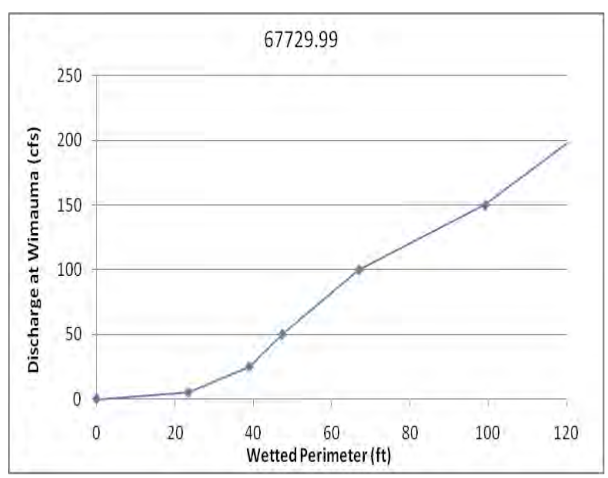

68542.69
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100
Wetted Perimeter (ft)

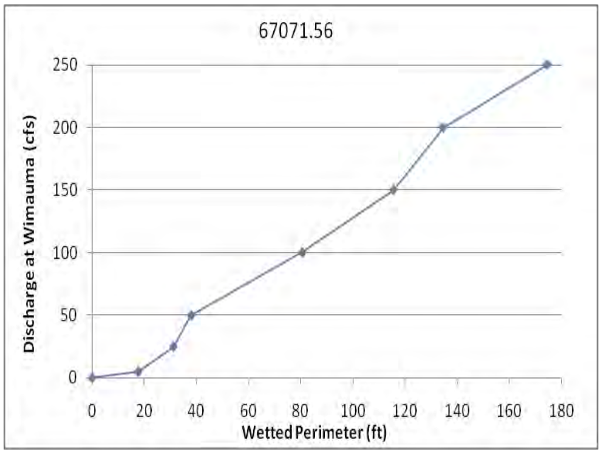

67909.93
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120
Wetted Perimeter (ft)

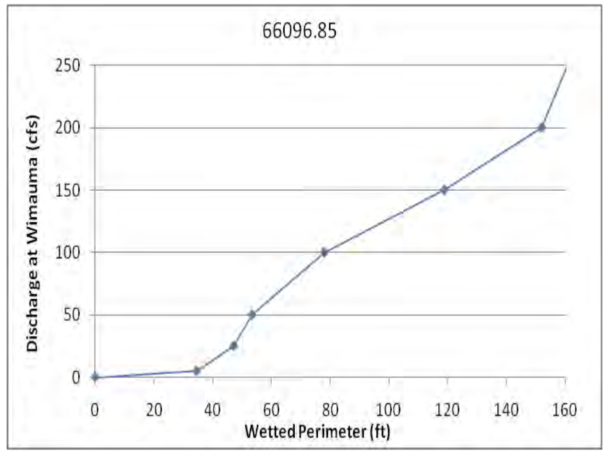

67478.03
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120 140 160 180 200 220 240
Wetted Perimeter (ft)

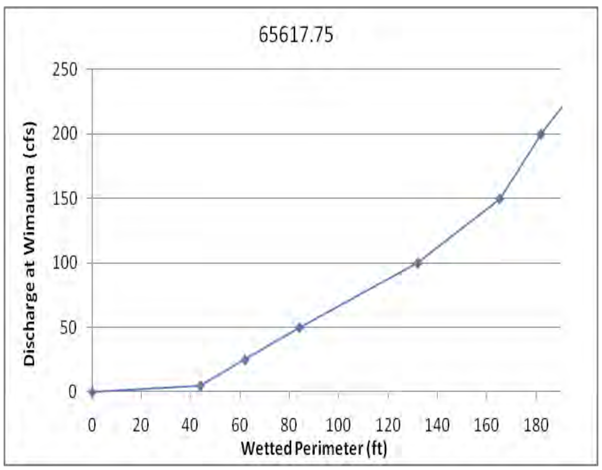

66570.74
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120 140
Wetted Perimeter (ft)

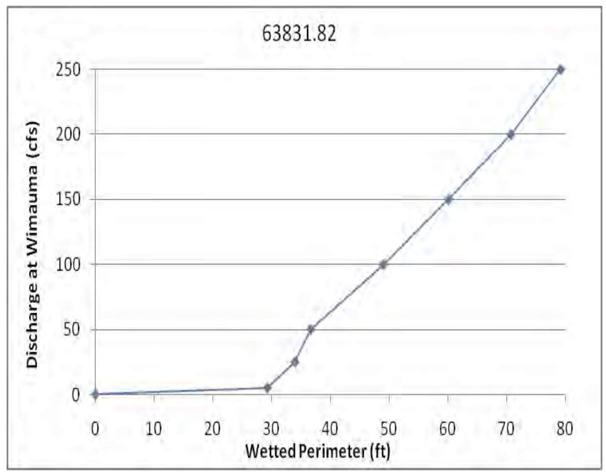

68255.33
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90
Wetted Perimeter (ft)

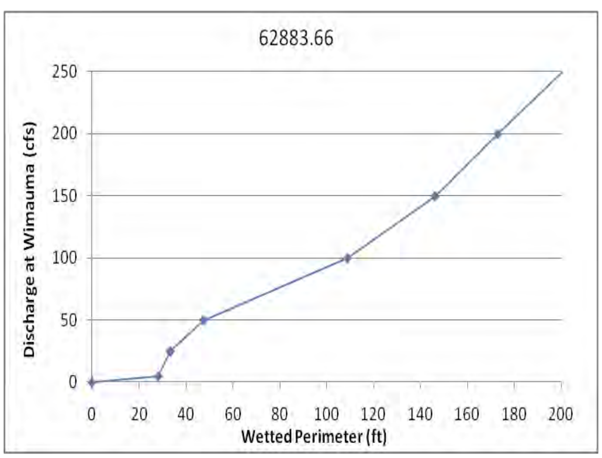

67729.99
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120
Wetted Perimeter (ft)

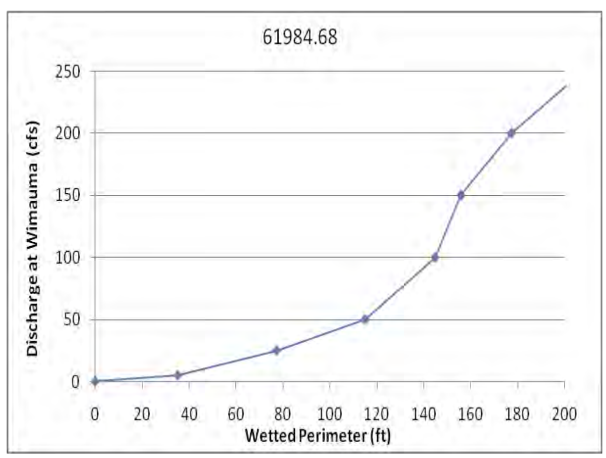

67071.56
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 20 40 60 80 100 120 140 160 180

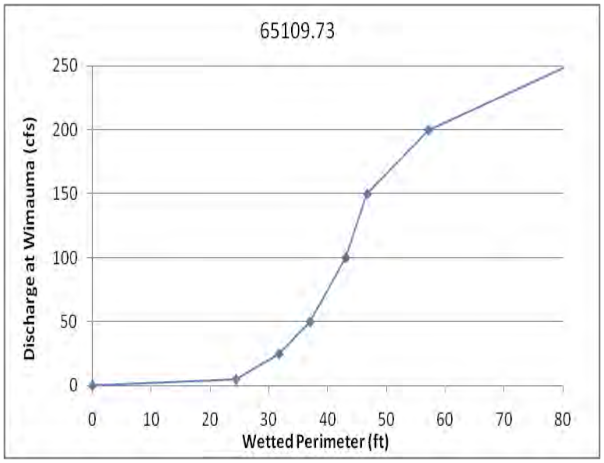

66096.85
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 20 40 60 80 100 120 140 160

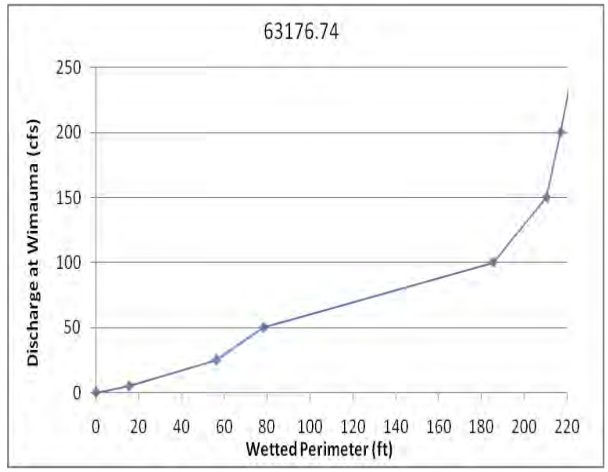

65617.75
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 20 40 60 80 100 120 140 160 180

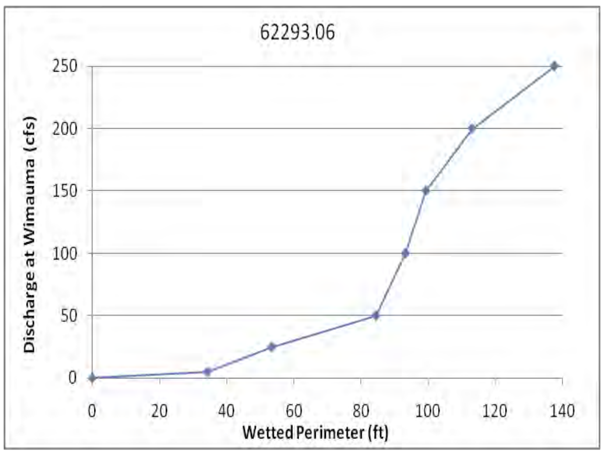

63831.82
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80

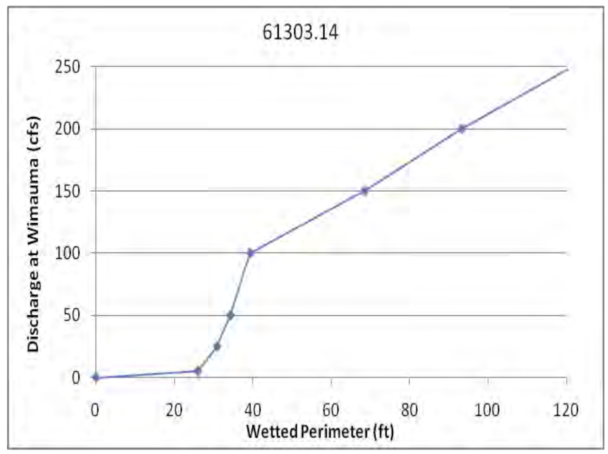

62883.66
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 20 40 60 80 100 120 140 160 180 200

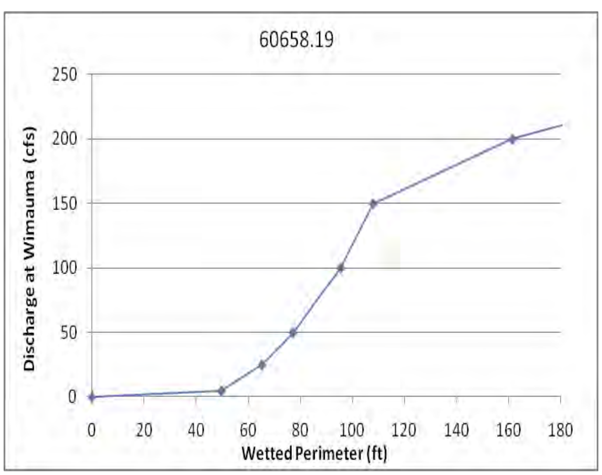

61984.68
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 20 40 60 80 100 120 140 160 180 200

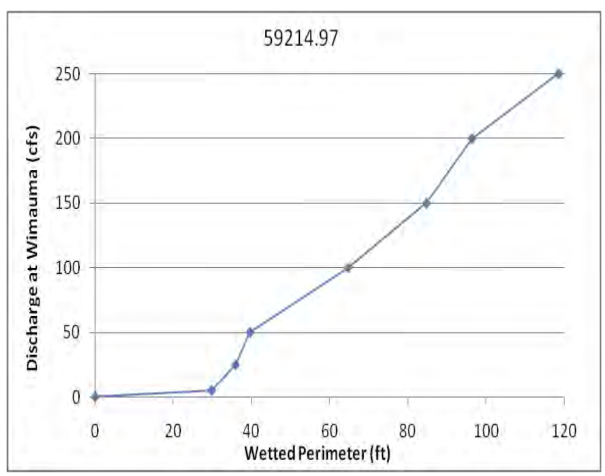

65109.73
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80
Wetted Perimeter (ft)

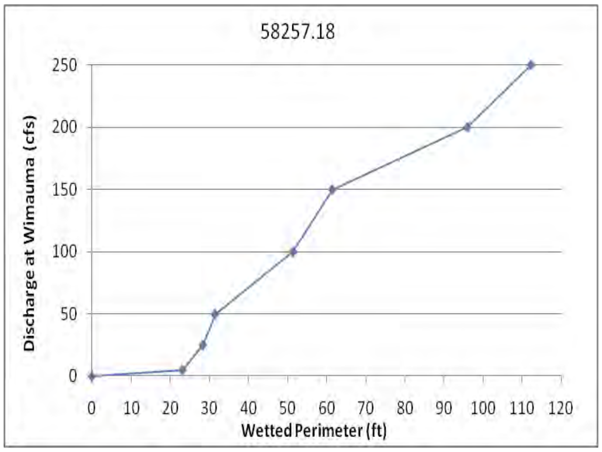

63176.74
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200
220
Wetted Perimeter (ft)

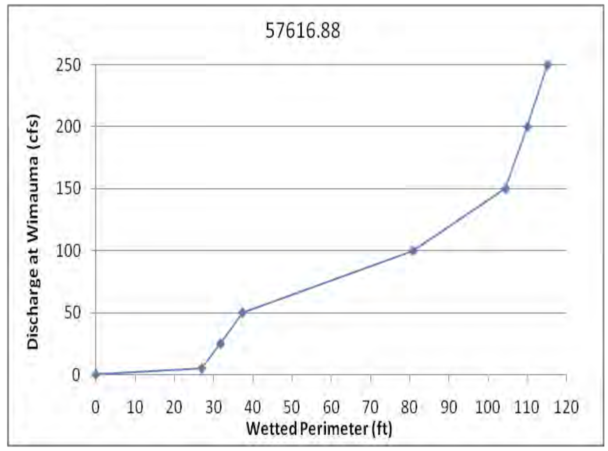

62293.06
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
Wetted Perimeter (ft)

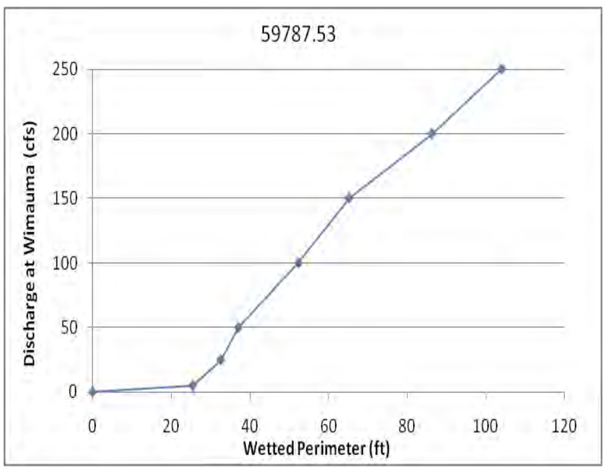

61303.14
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
Wetted Perimeter (ft)

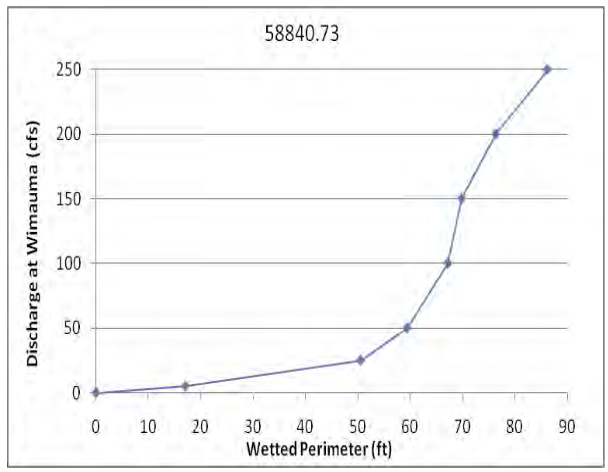

60658.19
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
Wetted Perimeter (ft)

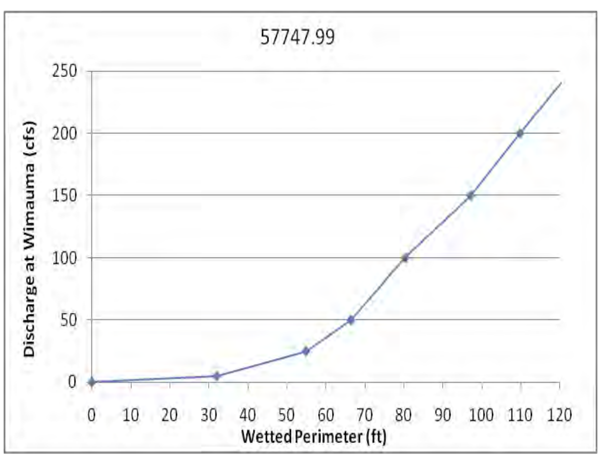

59214.97
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
Wetted Perimeter (ft)

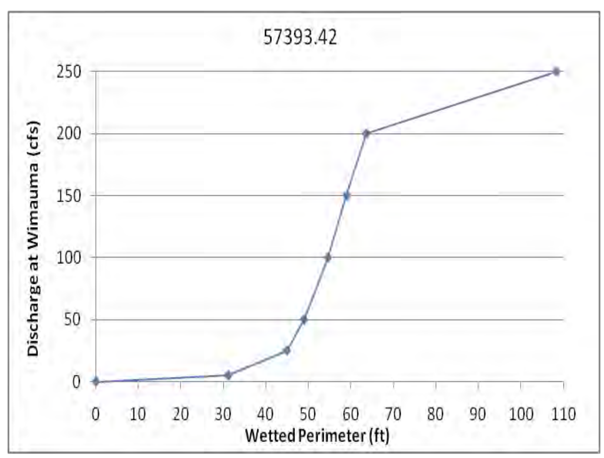

58257.18
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

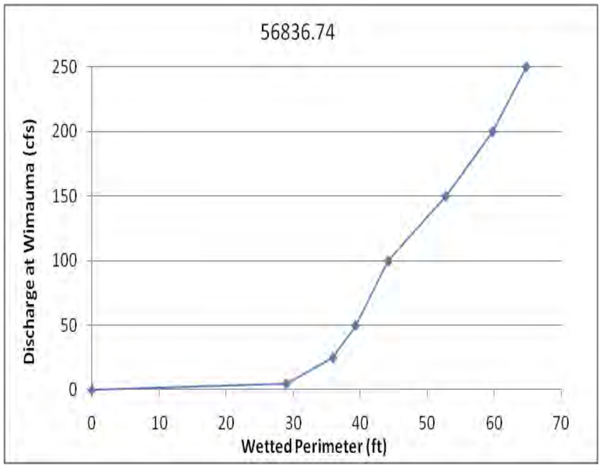

57616.88
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

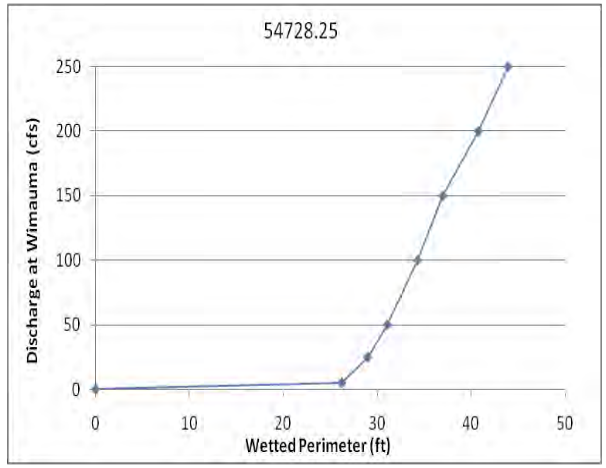

59787.53
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

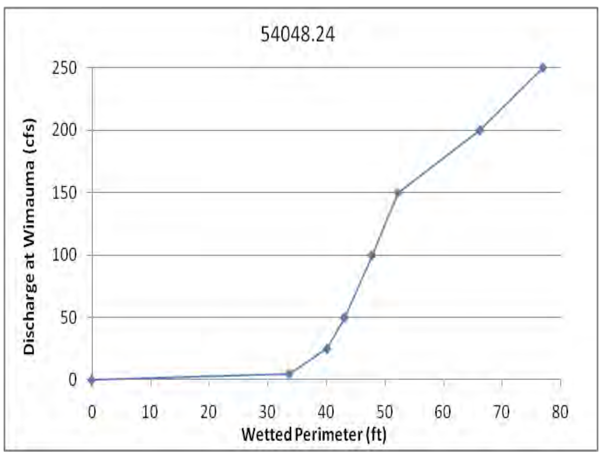

58840.73
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

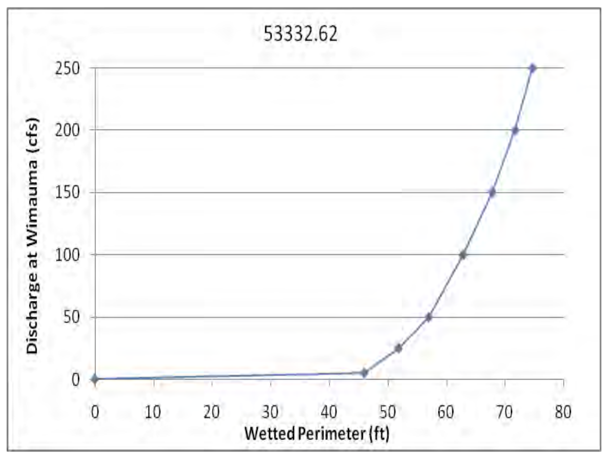

57747.99
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

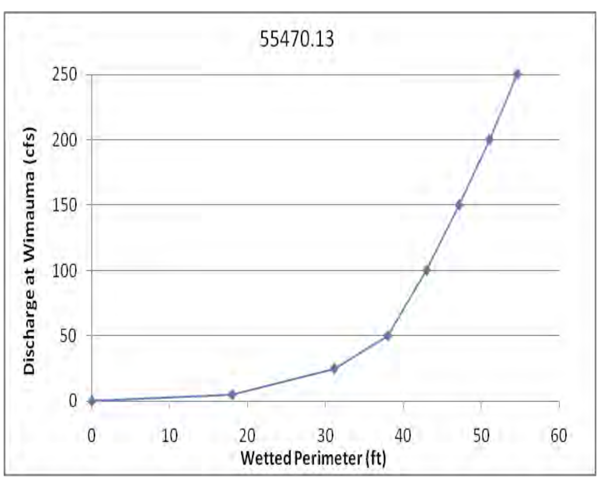

57393.42
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

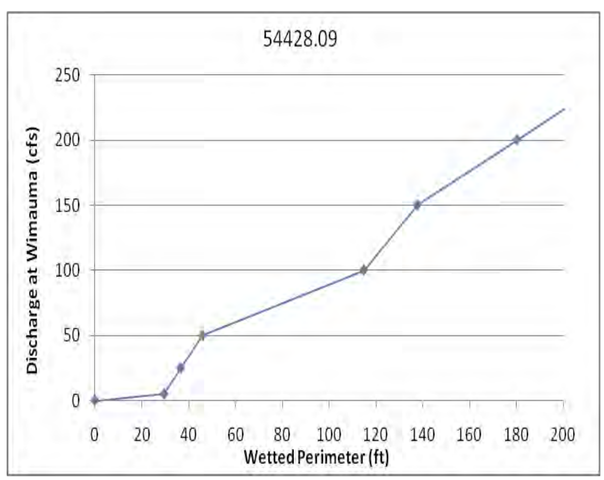

56836.74
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
60
70
Wetted Perimeter (ft)

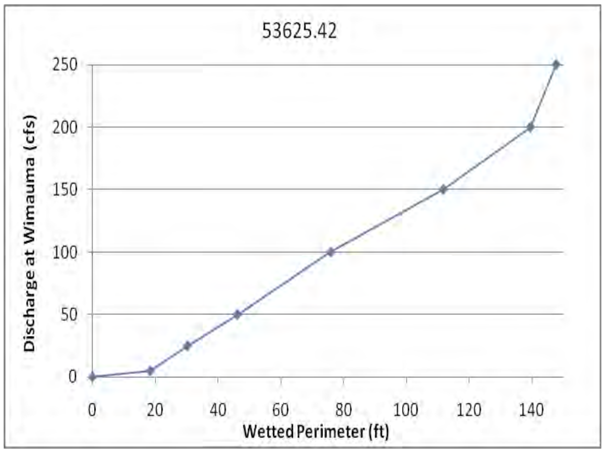

54728.25
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
Wetted Perimeter (ft)

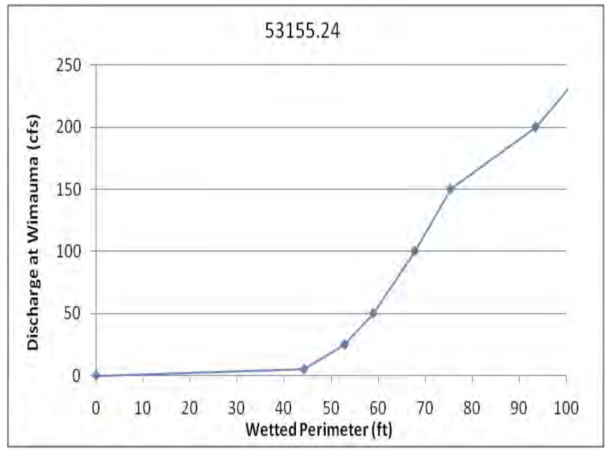

54048.24
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
Wetted Perimeter (ft)

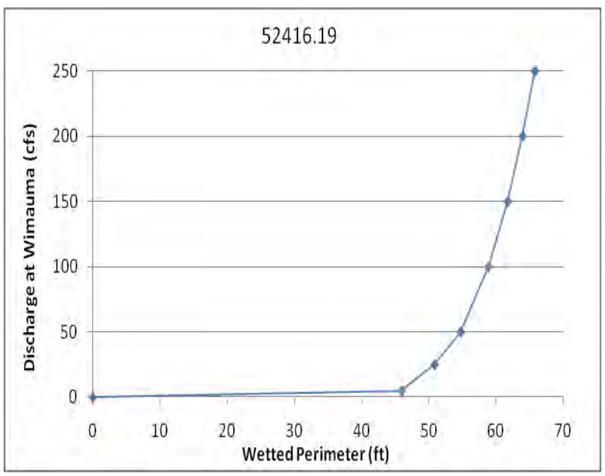

53332.62
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
Wetted Perimeter (ft)

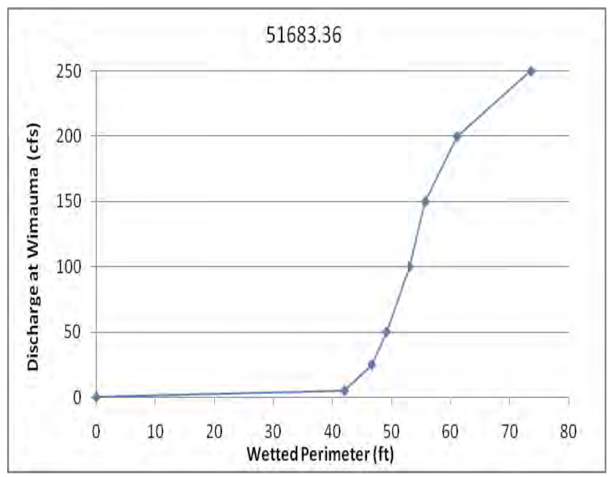

55470.13
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
10
20
30
40
50
60
Wetted Perimeter (ft)

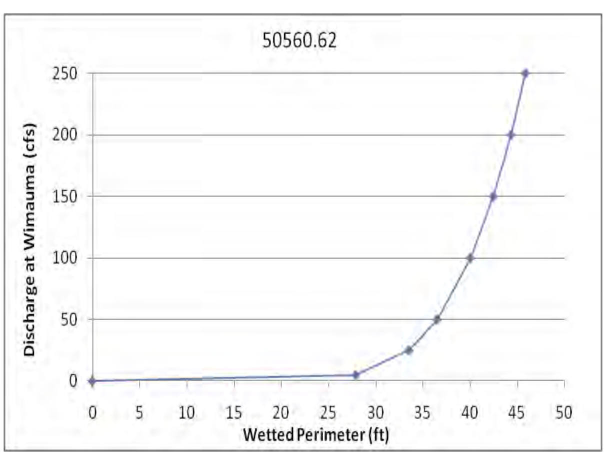

54428.09
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
Wetted Perimeter (ft)

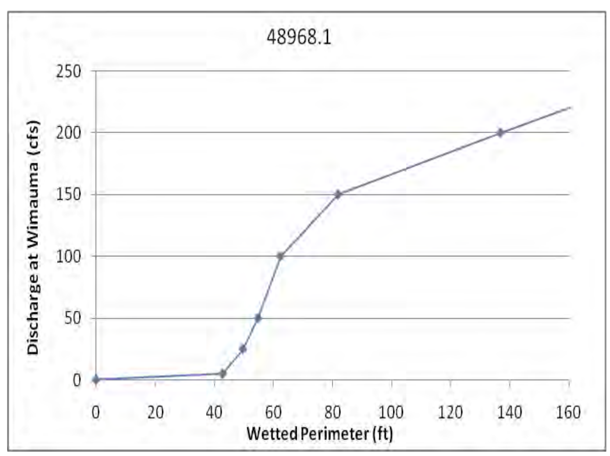

53625.42
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140

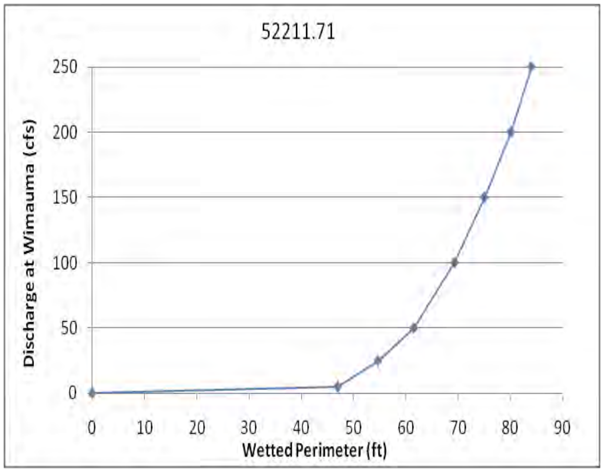

53155.24
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80
90
100

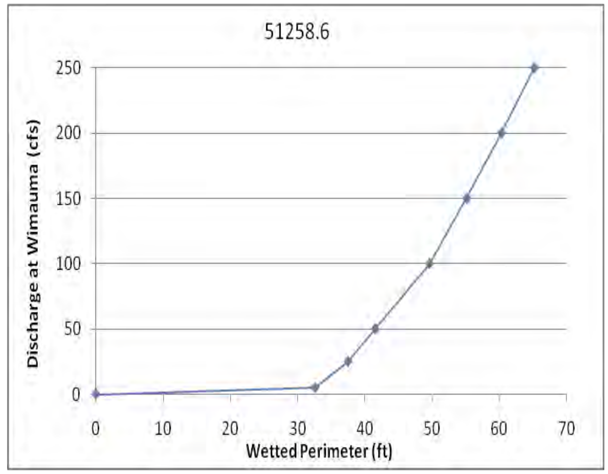

52416.19
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70

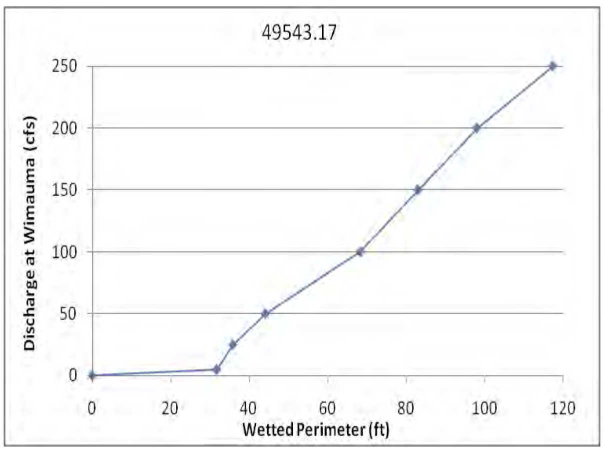

51683.36
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80

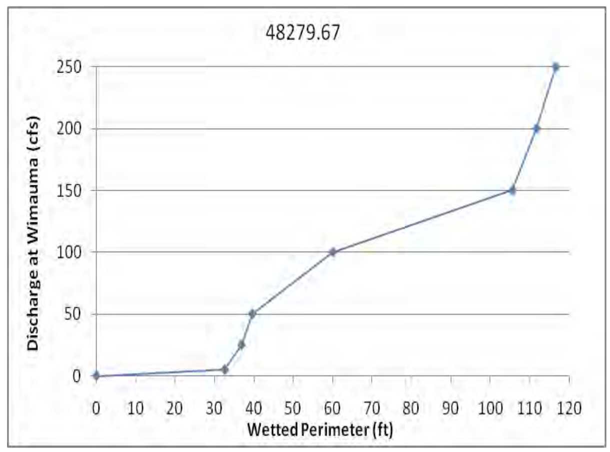

50560.62
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40
45
50

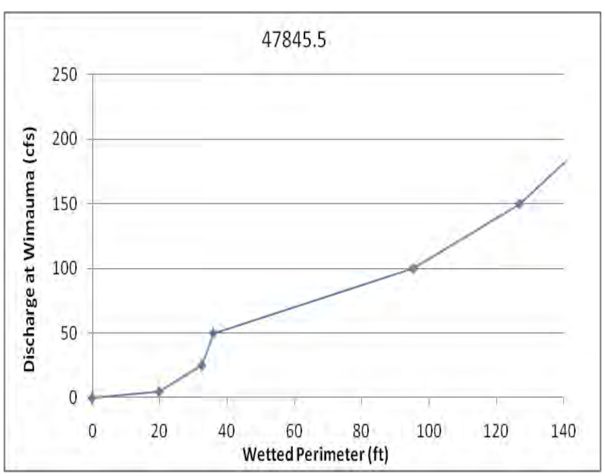

48968.1
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160

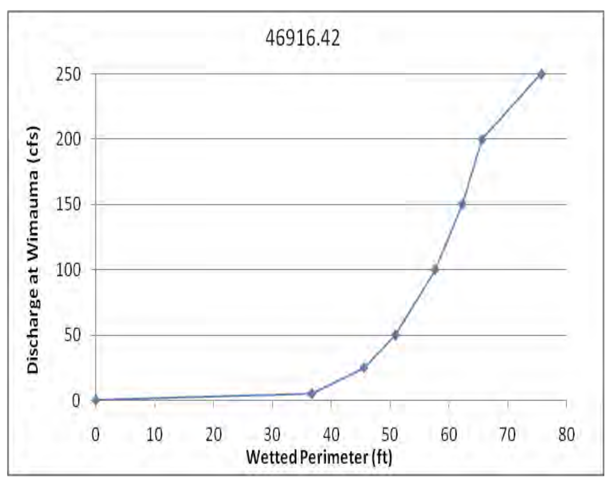

52211.71
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90
Wetted Perimeter (ft)

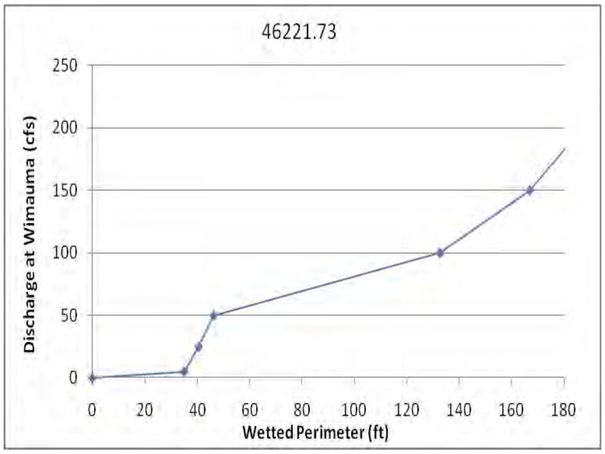

51258.6
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 10 20 30 40 50 60 70
Wetted Perimeter (ft)

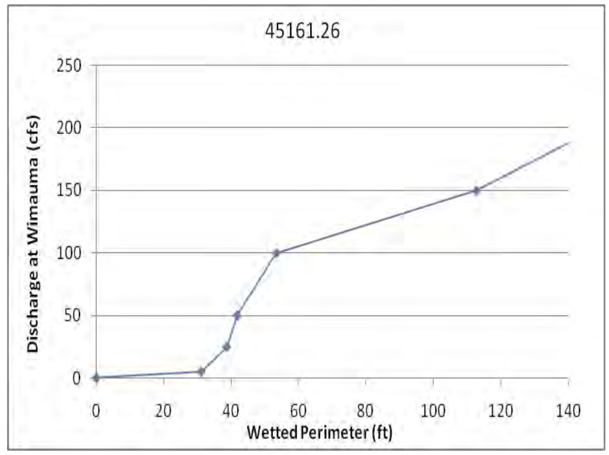

49543.17
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 20 40 60 80 100 120
Wetted Perimeter (ft)

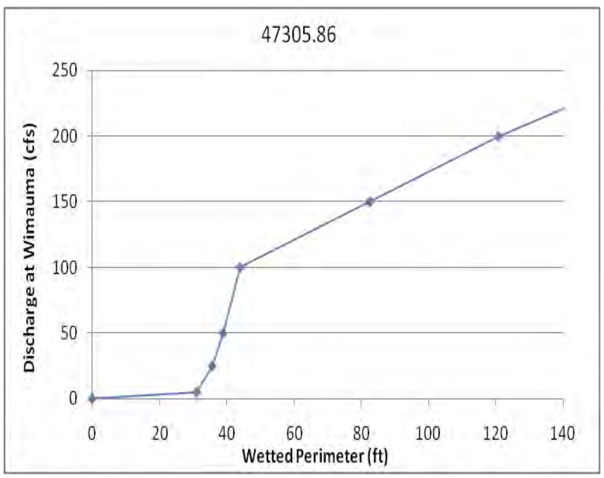

48279.67
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90 100 110 120
Wetted Perimeter (ft)

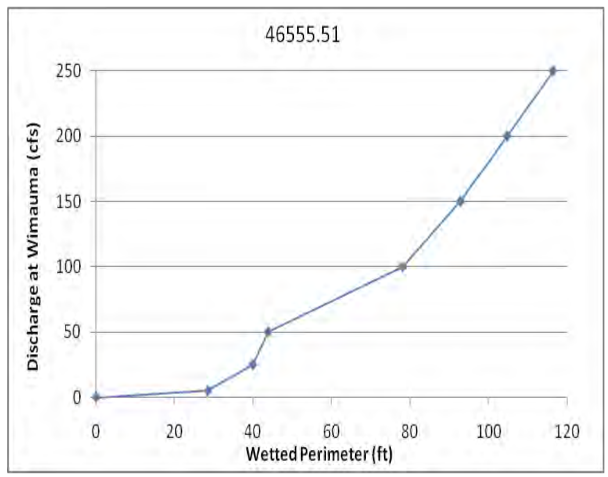

47845.5
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 20 40 60 80 100 120 140
Wetted Perimeter (ft)

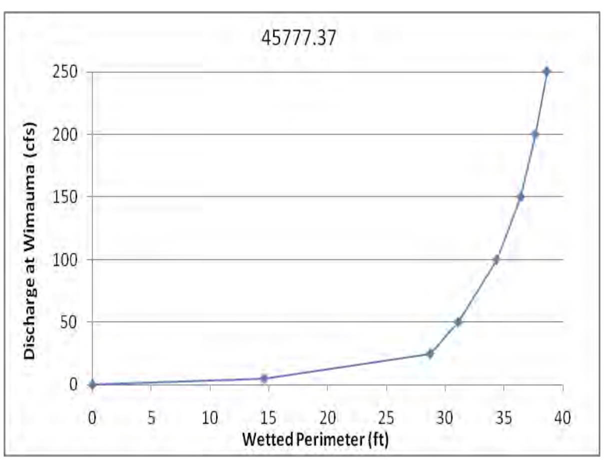

46916.42
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80
Wetted Perimeter (ft)

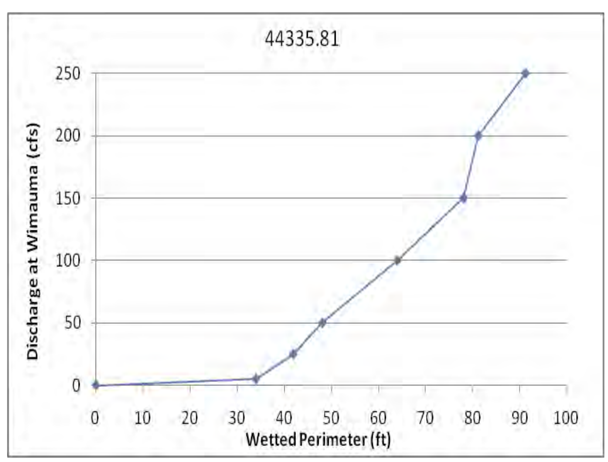

46221.73
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

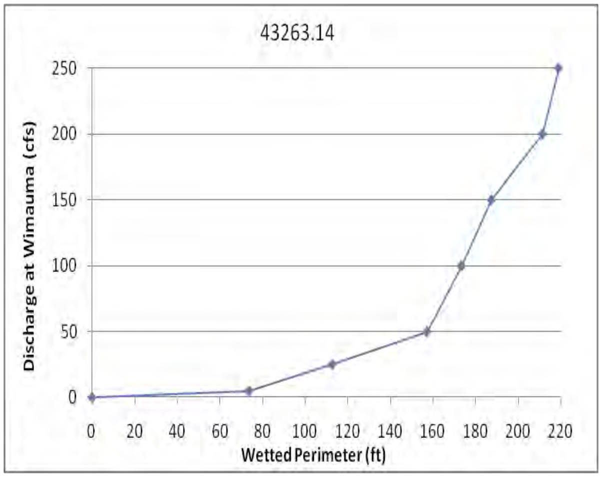

45161.26
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

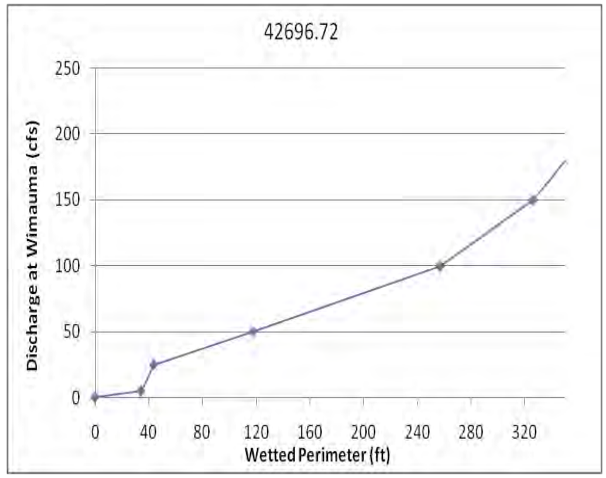

47305.86
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

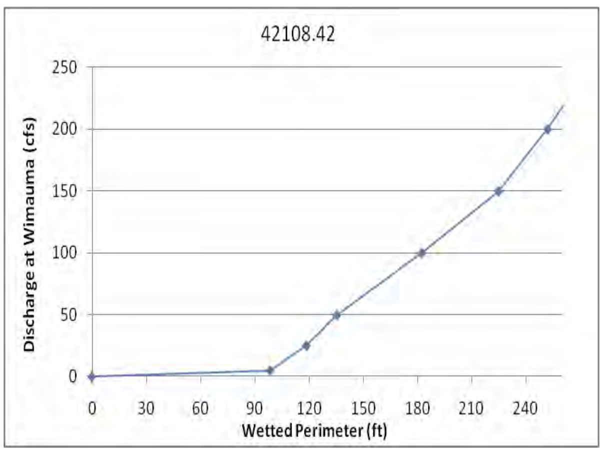

46555.51
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

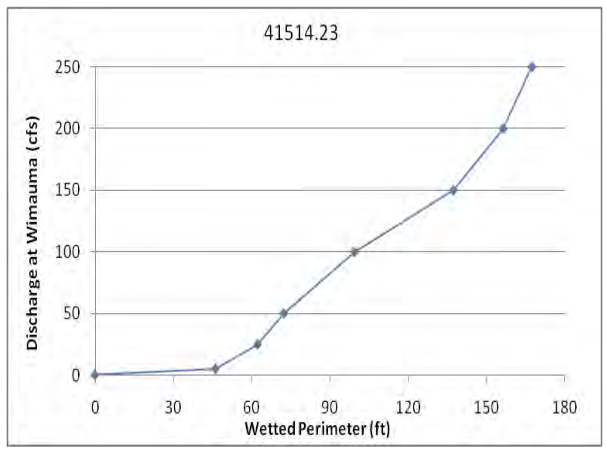

45777.37
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

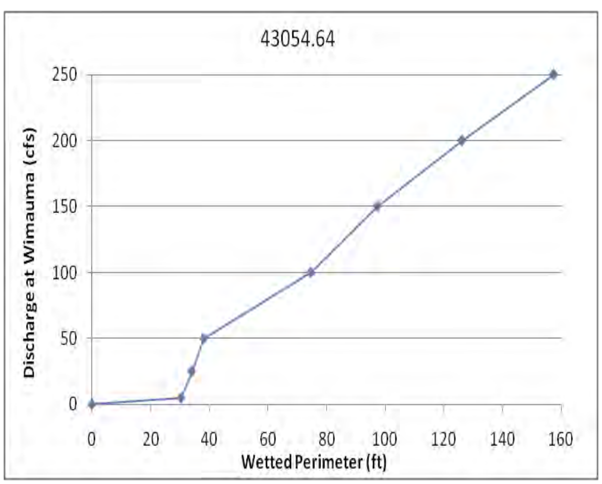

44335.81
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

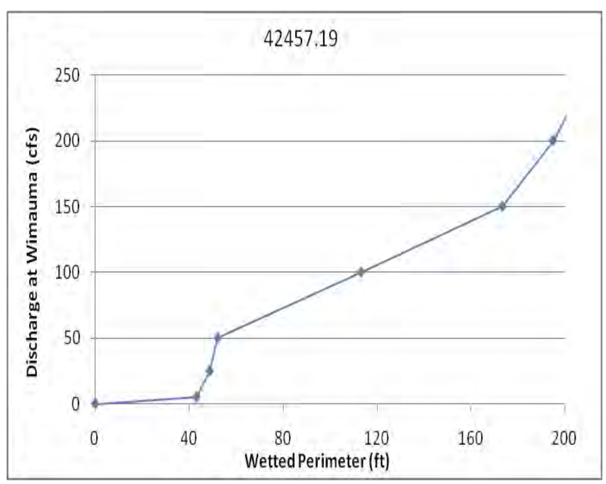

43263.14
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

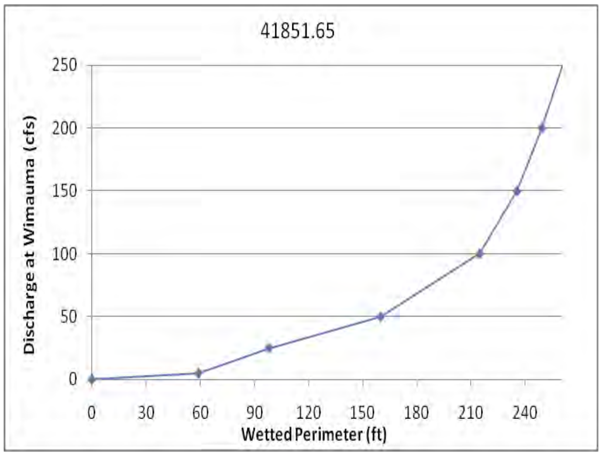

42696.72
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

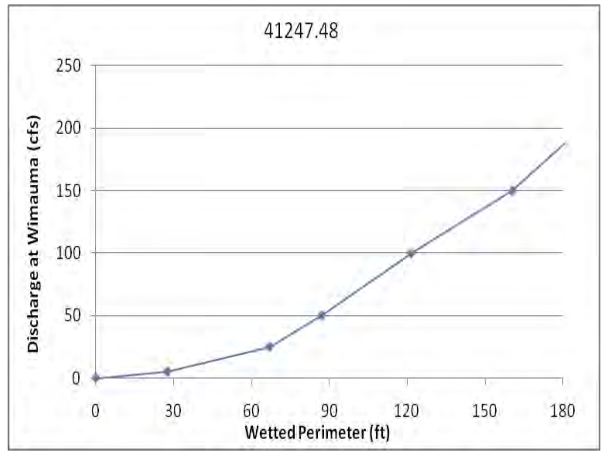

42108.42
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

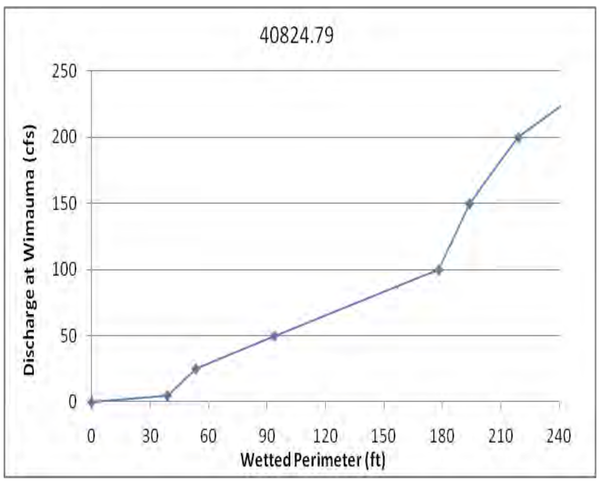

41514.23
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

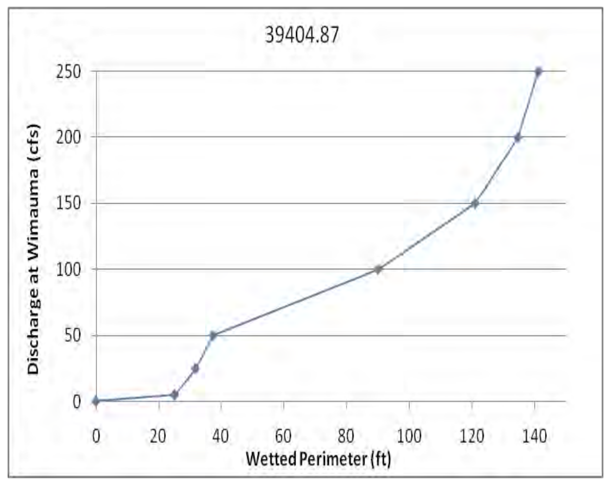

43054.64
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

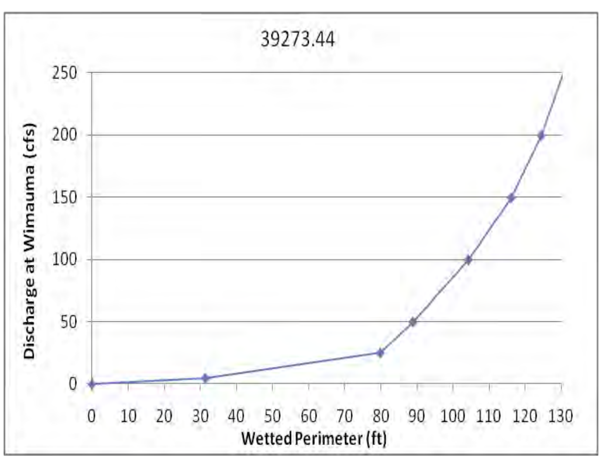

42457.19
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

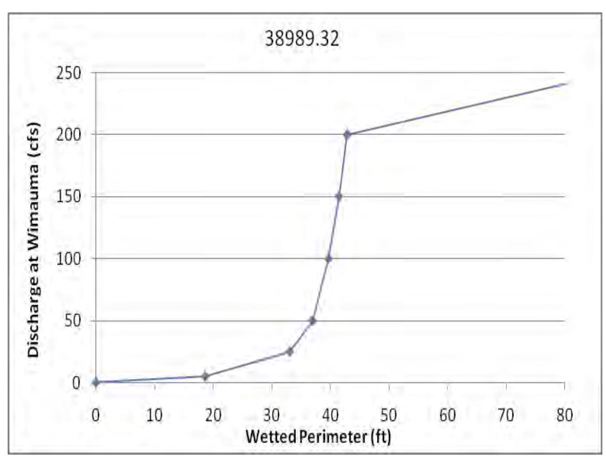

41851.65
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240

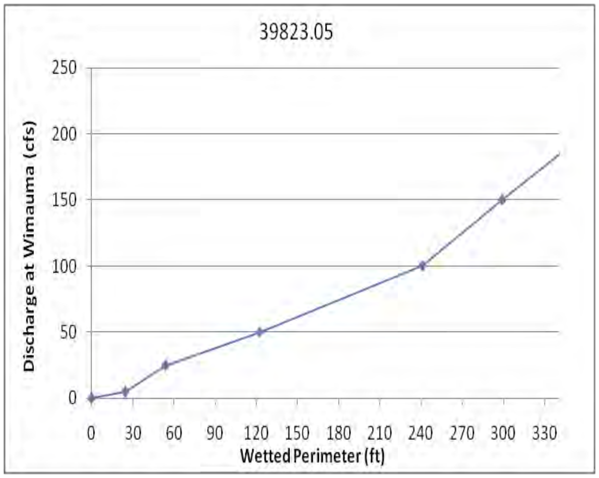

41247.48
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
30
60
90
120
150
180

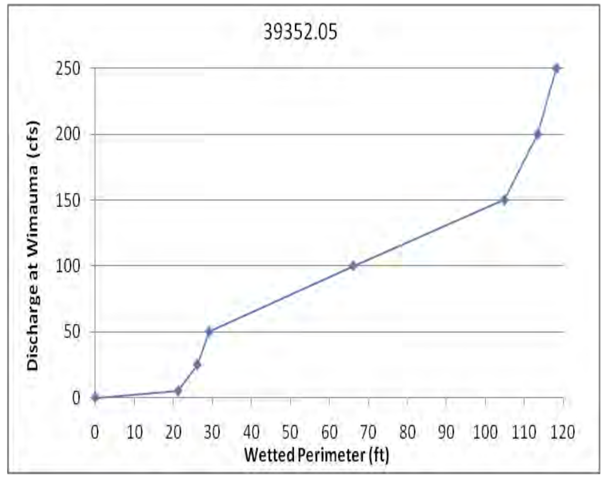

40824.79
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240

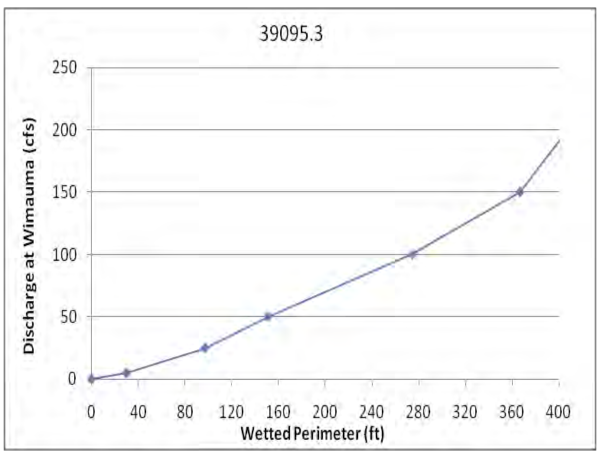

39404.87
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140

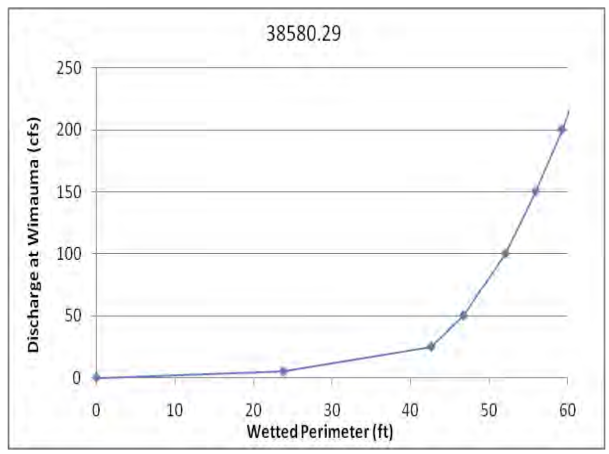

39273.44
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80
90
100
110
120
130

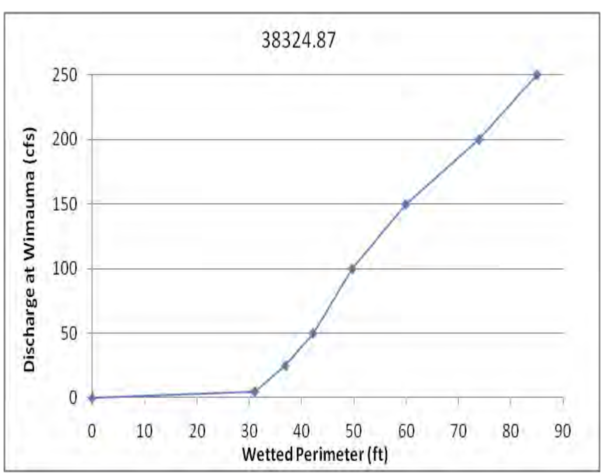

38989.32
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80

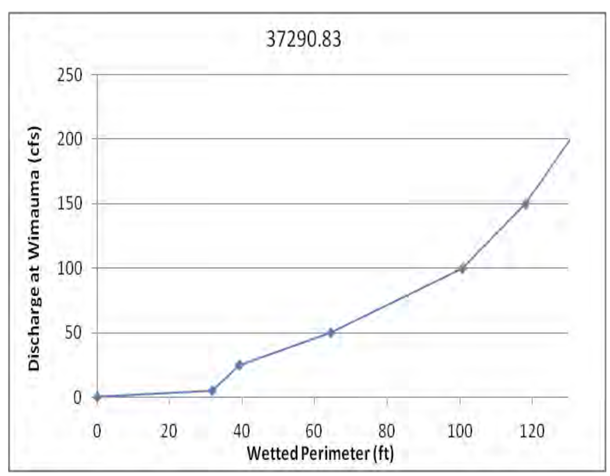

39823.05
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 30 60 90 120 150 180 210 240 270 300 330
Wetted Perimeter (ft)

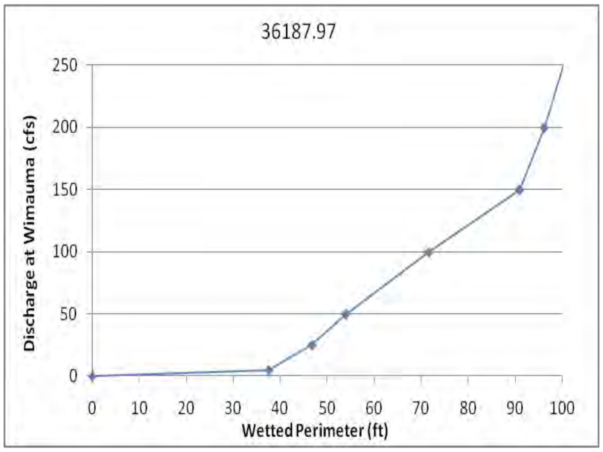

39352.05
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90 100 110 120
Wetted Perimeter (ft)

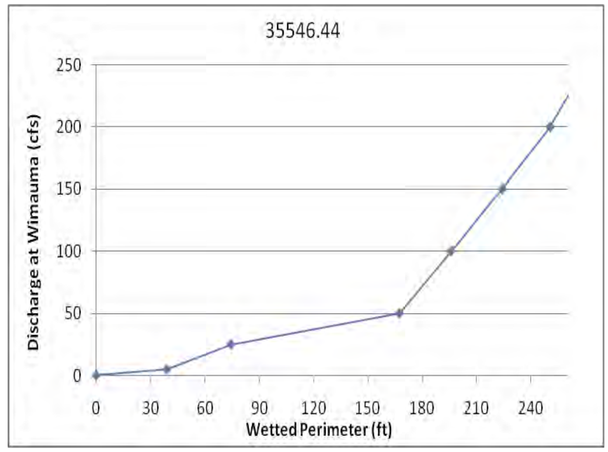

39095.3
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 40 80 120 160 200 240 280 320 360 400
Wetted Perimeter (ft)

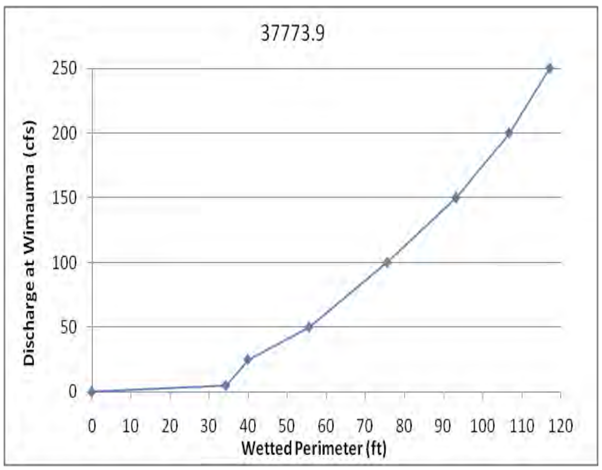

38580.29
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 10 20 30 40 50 60
Wetted Perimeter (ft)

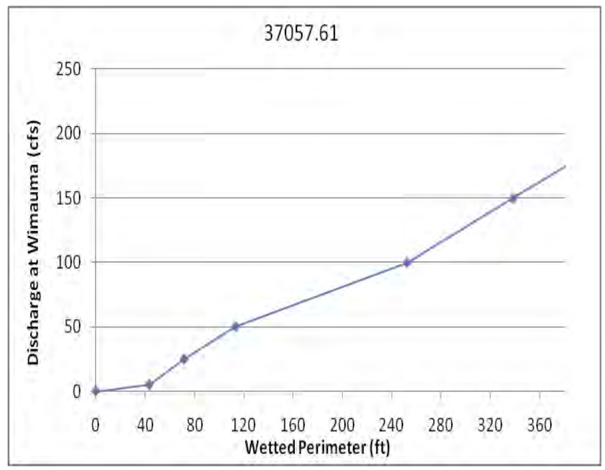

38324.87
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90
Wetted Perimeter (ft)

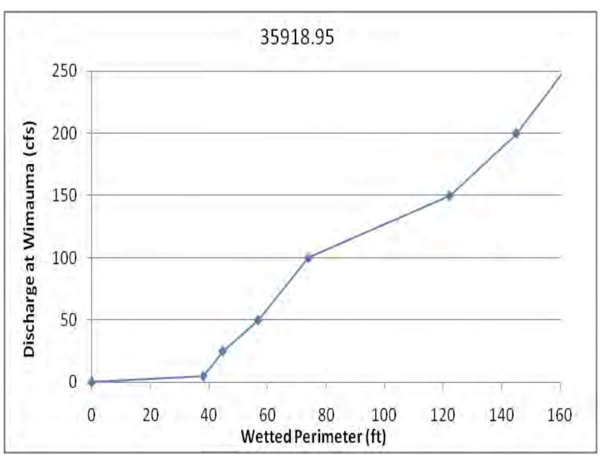

37290.83
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0 20 40 60 80 100 120
Wetted Perimeter (ft)

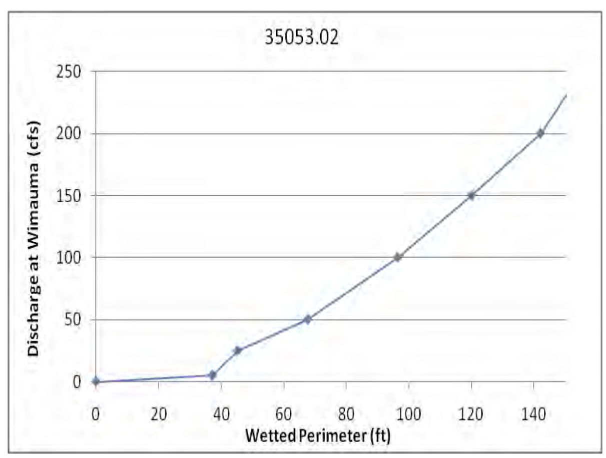

36187.97
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100

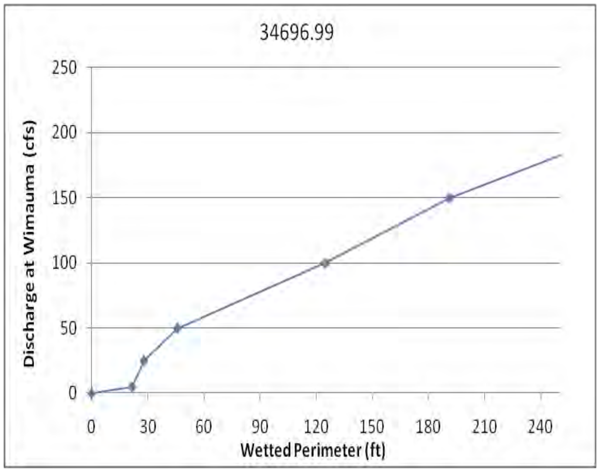

35546.44
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
250
200
150
100
50
0
0 30 60 90 120 150 180 210 240

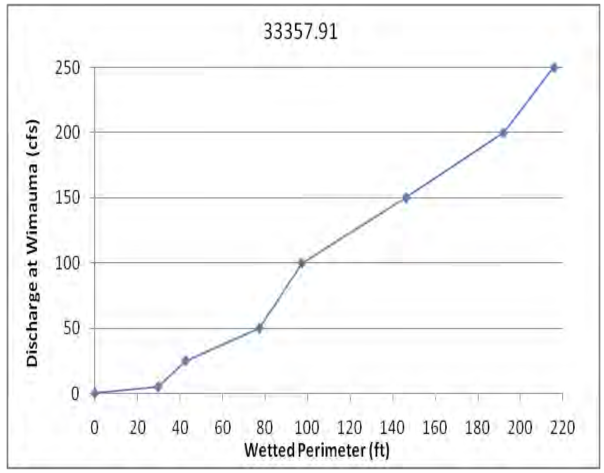

37773.9
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120

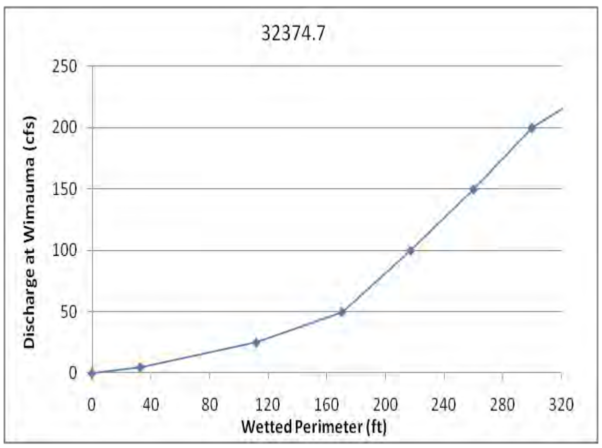

37057.61
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
250
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360

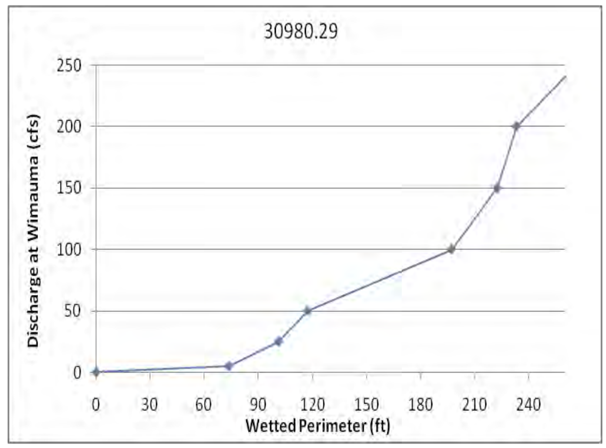

35918.95
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
250
200
150
100
50
0
0 20 40 60 80 100 120 140 160

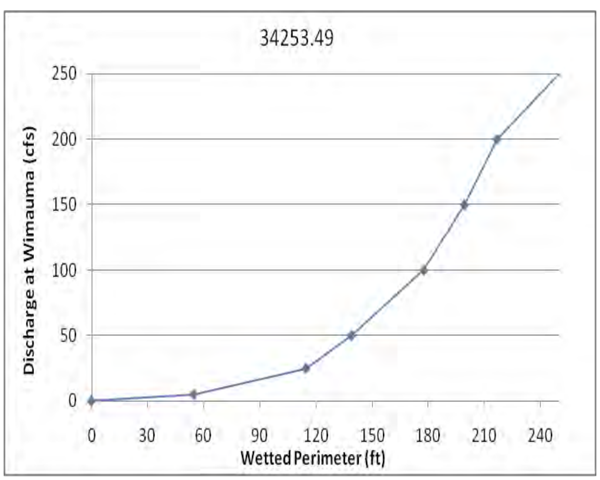

35053.02
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
250
200
150
100
50
0
0 20 40 60 80 100 120 140

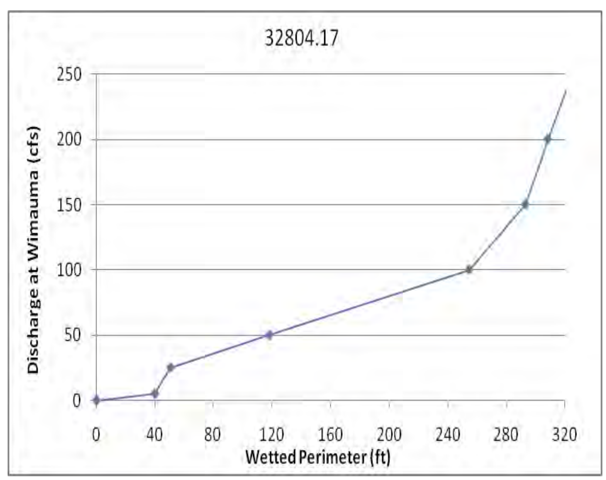

34696.99
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240
Wetted Perimeter (ft)

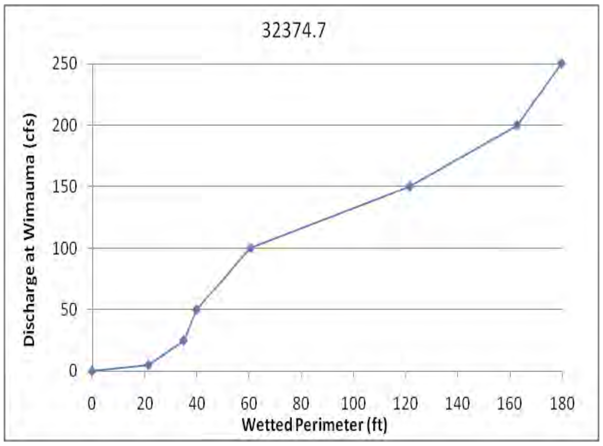

33357.91
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200
220
Wetted Perimeter (ft)

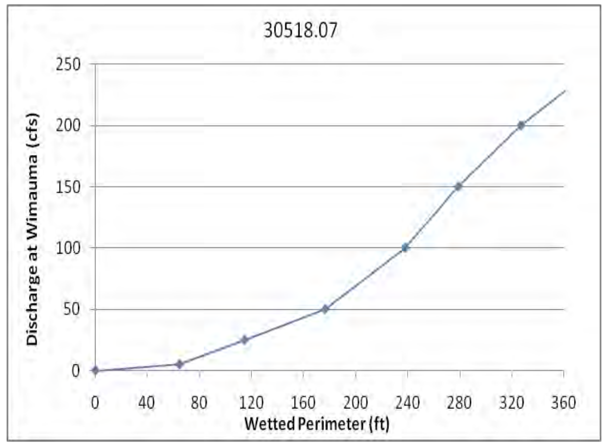

32374.7
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
40
80
120
160
200
240
280
320
Wetted Perimeter (ft)

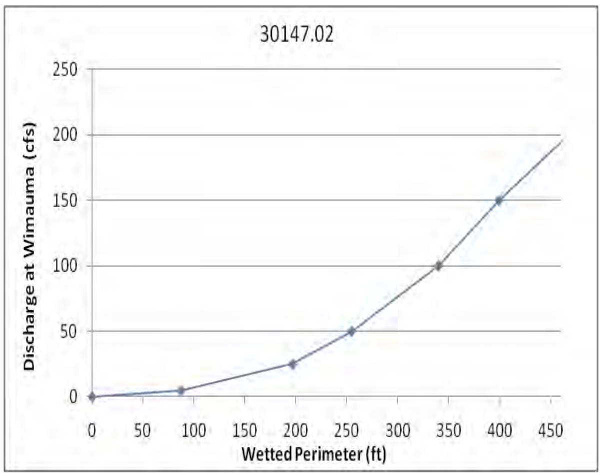

30980.29
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240
Wetted Perimeter (ft)

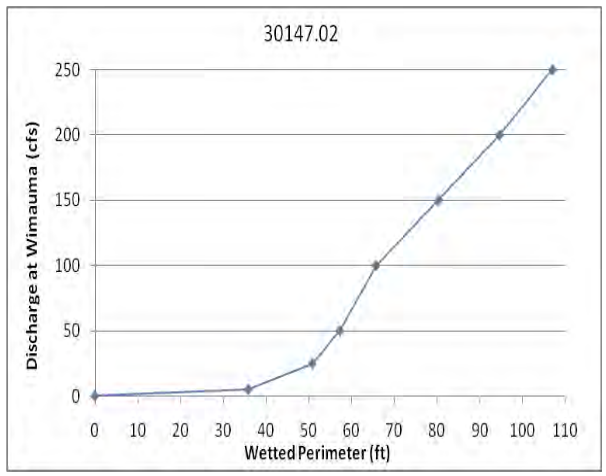

34253.49
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240
Wetted Perimeter (ft)

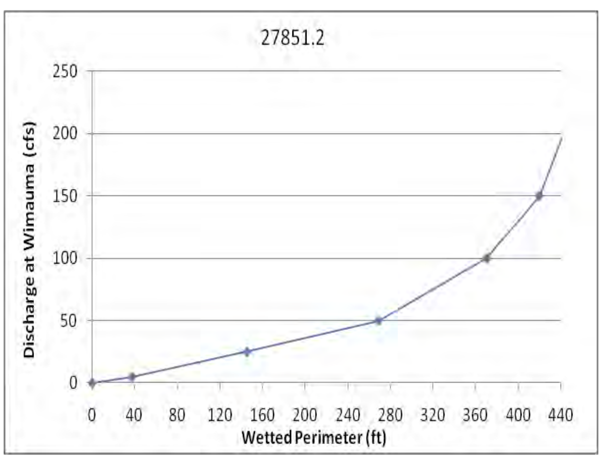

32804.17
Discharge at Wimauma (cfs)
0
50
100
150
200
250
0
40
80
120
160
200
240
280
320
Wetted Perimeter (ft)

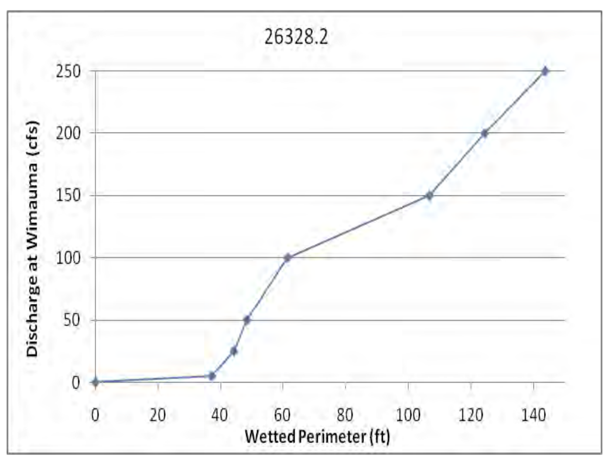

32374.7
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120 140 160 180
Wetted Perimeter (ft)

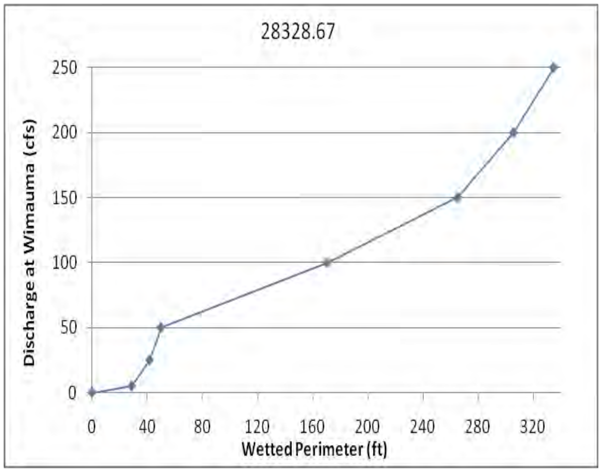

30518.07
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360
Wetted Perimeter (ft)

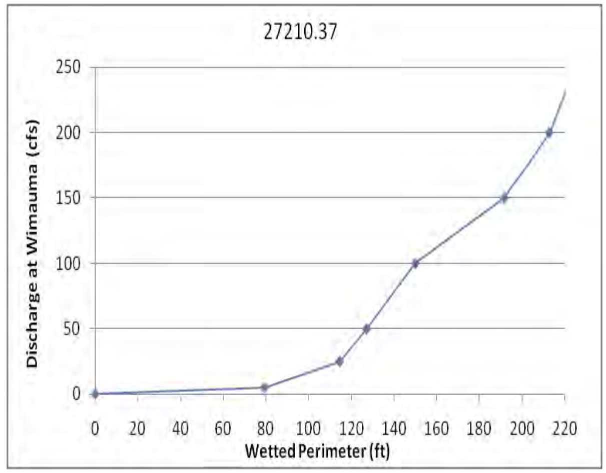

30147.02
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 50 100 150 200 250 300 350 400 450
Wetted Perimeter (ft)

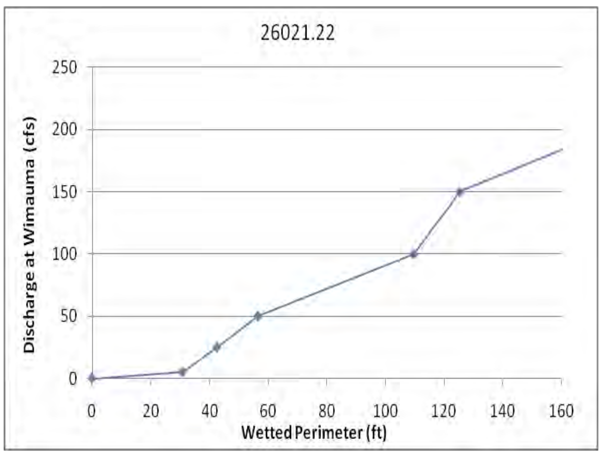

30147.02
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110
Wetted Perimeter (ft)

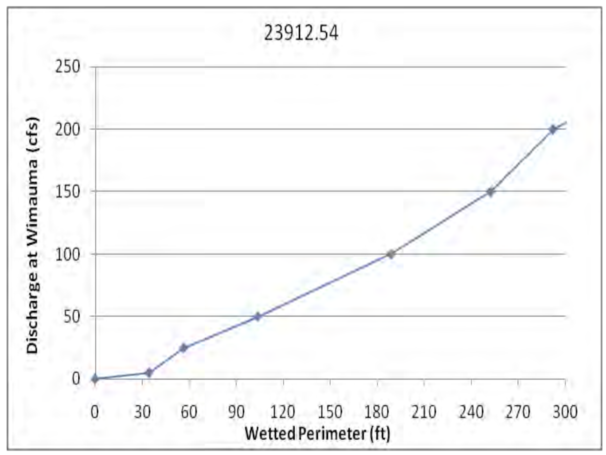

27851.2
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360 400 440
Wetted Perimeter (ft)

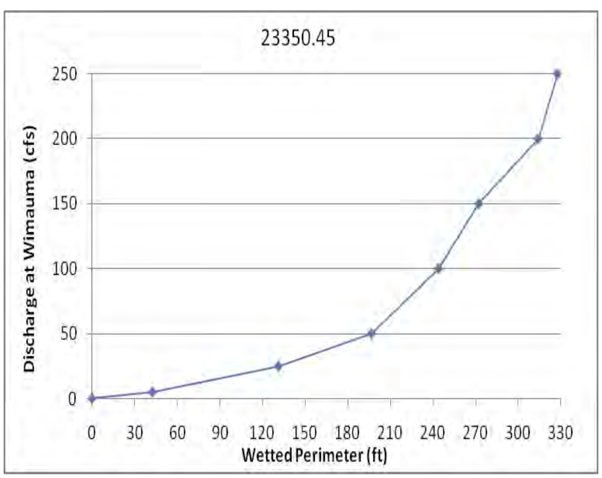

26328.2
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120 140
Wetted Perimeter (ft)

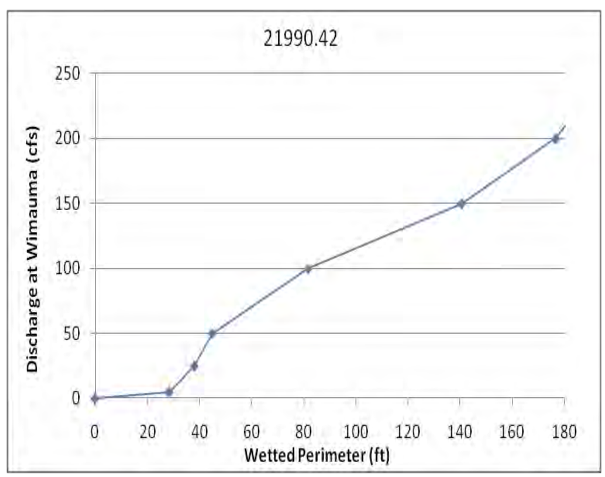

28328.67
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
40
80
120
160
200
240
280
320

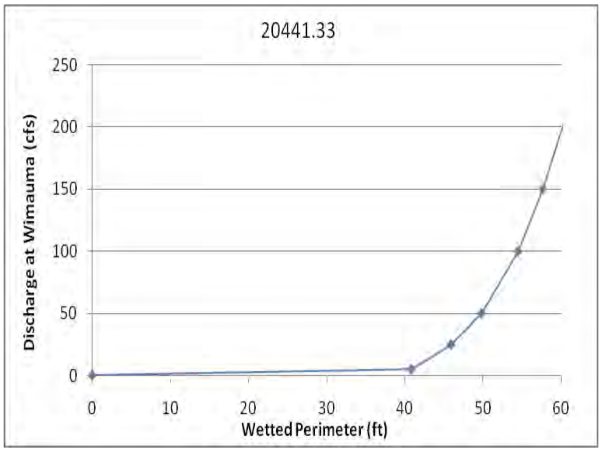

27210.37
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200
220

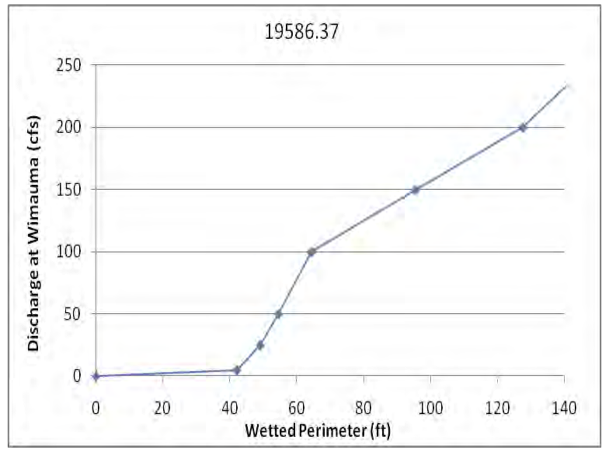

26021.22
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160

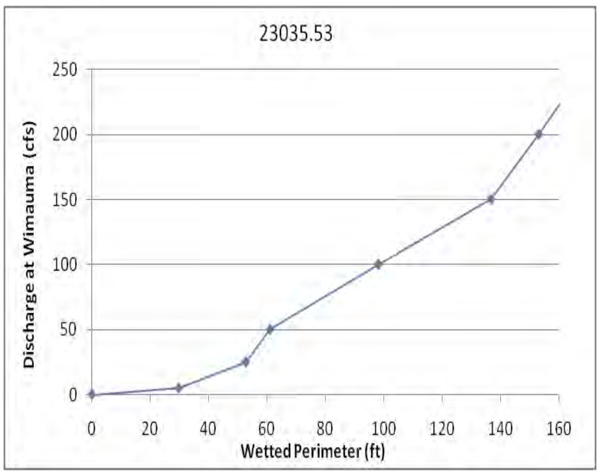

23912.54
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240
270
300

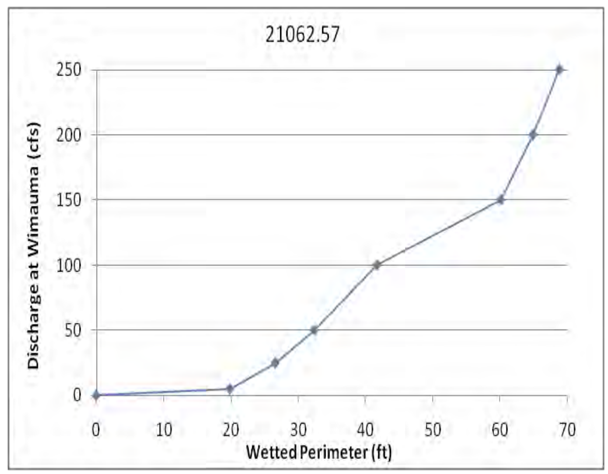

23350.45
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240
270
300
330

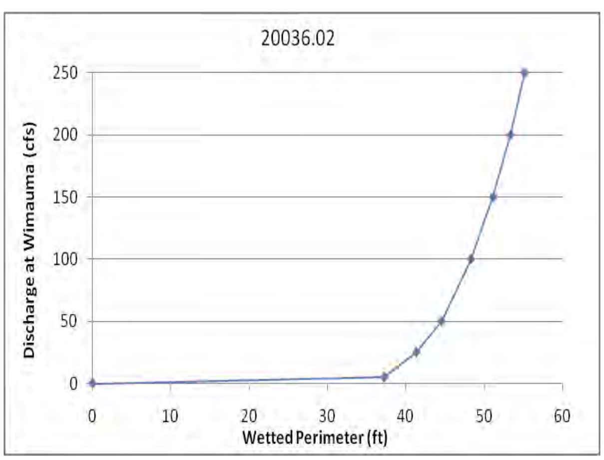

21990.42
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180

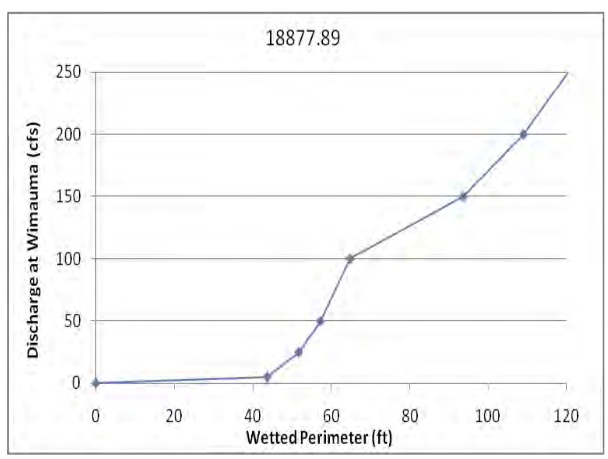

20441.33
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60

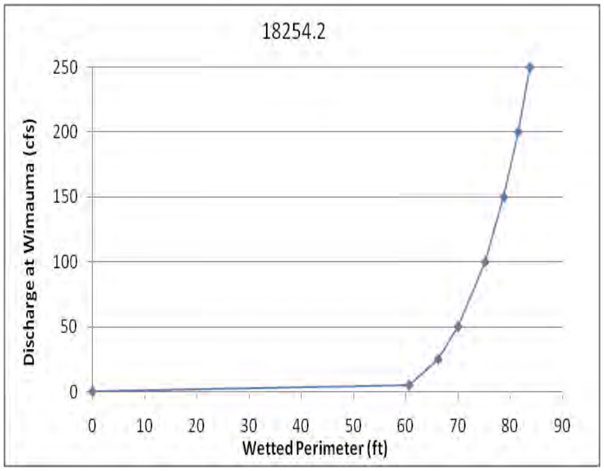

19586.37
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140

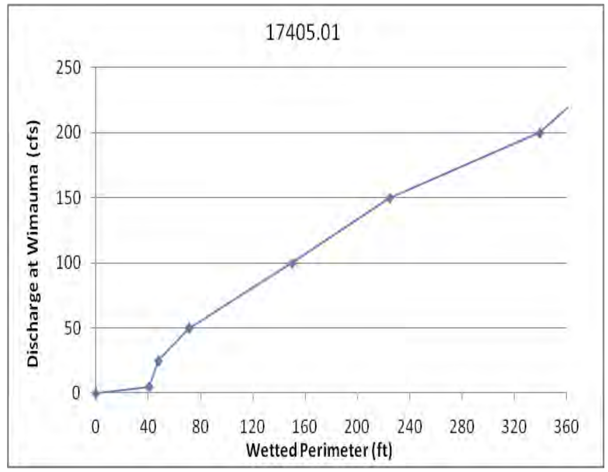

23035.53
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160

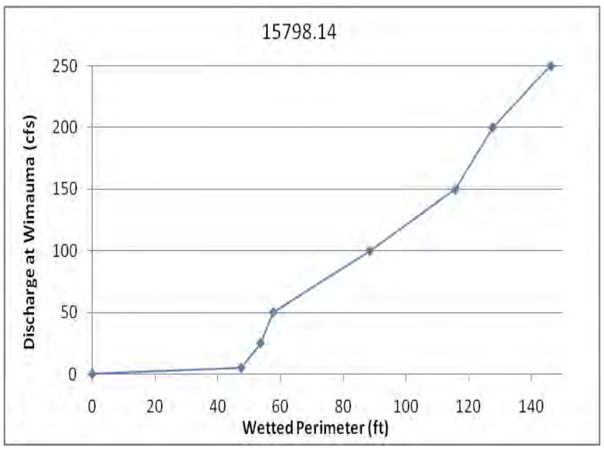

21062.57
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60
70

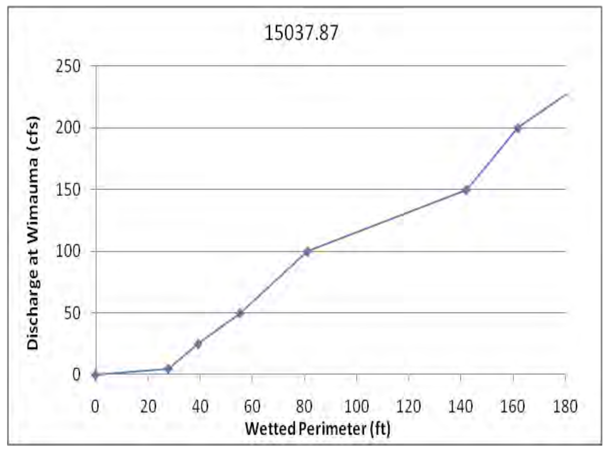

20036.02
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
10
20
30
40
50
60

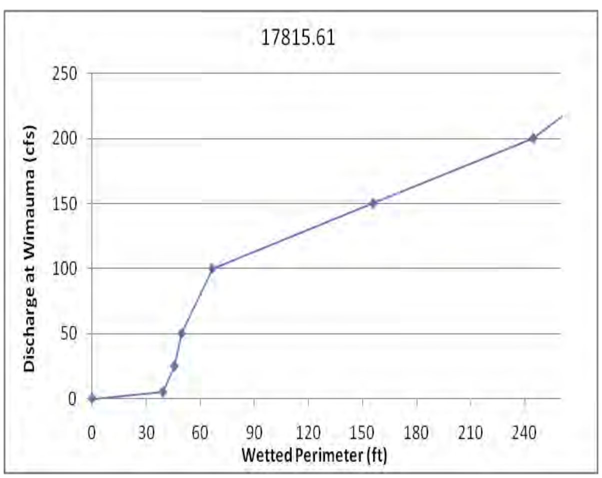

18877.89
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120

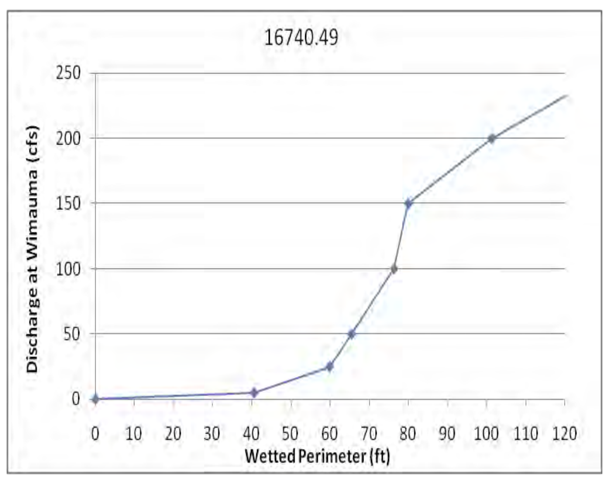

18254.2
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90
Wetted Perimeter (ft)

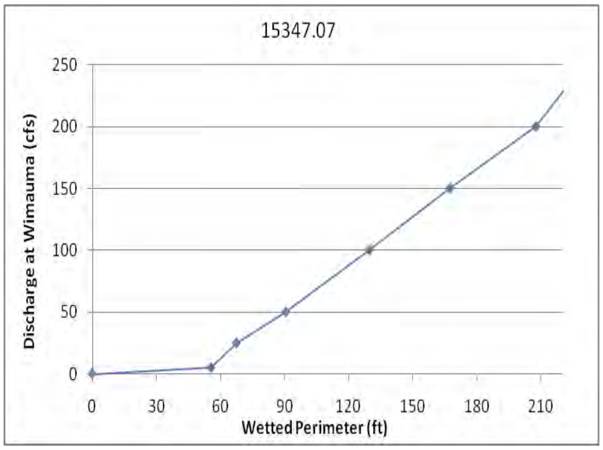

17405.01
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 40 80 120 160 200 240 280 320 360
Wetted Perimeter (ft)

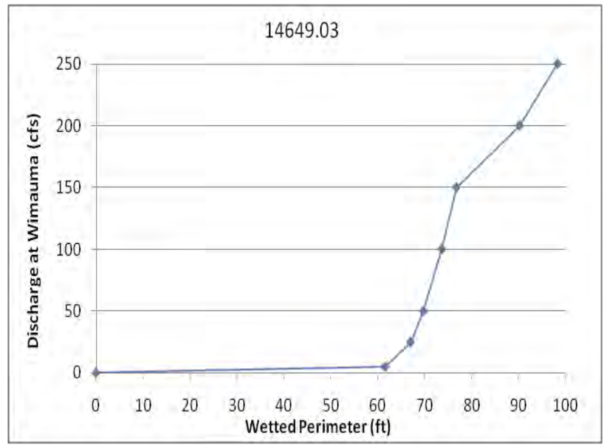

15798.14
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120 140
Wetted Perimeter (ft)

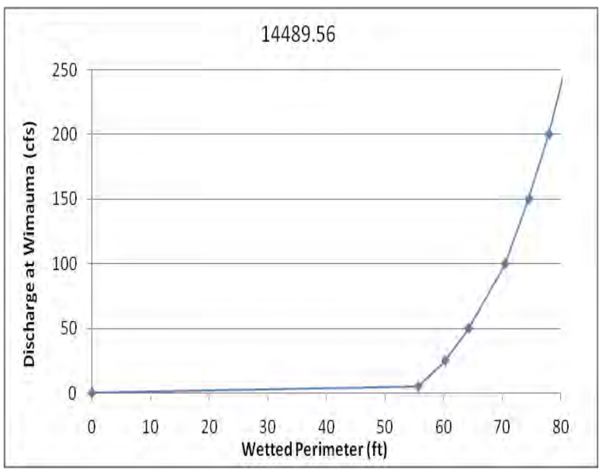

15037.87
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 20 40 60 80 100 120 140 160 180
Wetted Perimeter (ft)

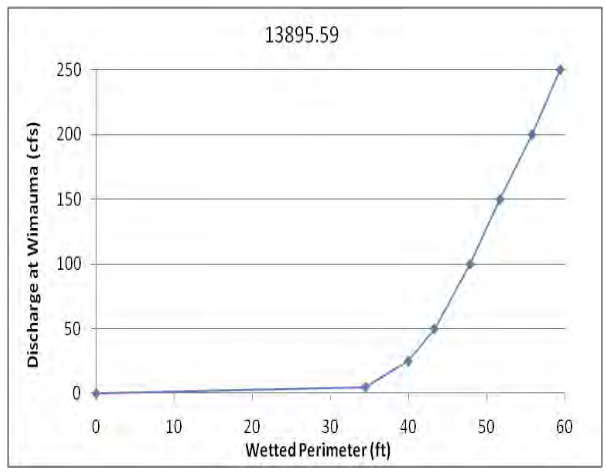

17815.61
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 30 60 90 120 150 180 210 240
Wetted Perimeter (ft)

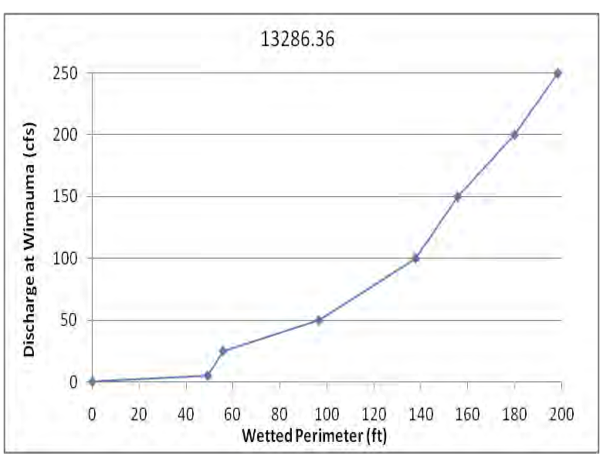

16740.49
Discharge at Wimauma (cfs)
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120
Wetted Perimeter (ft)

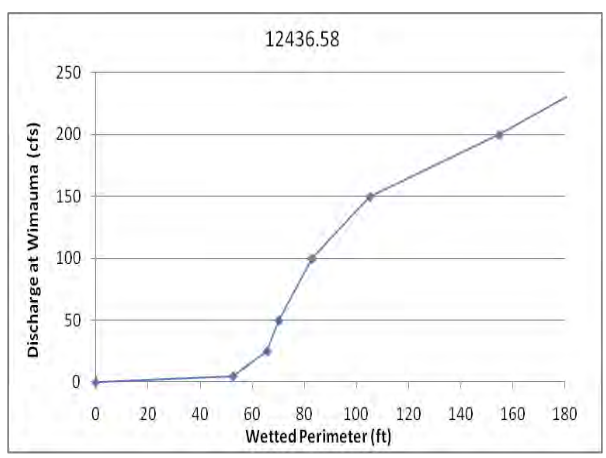

15347.07
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

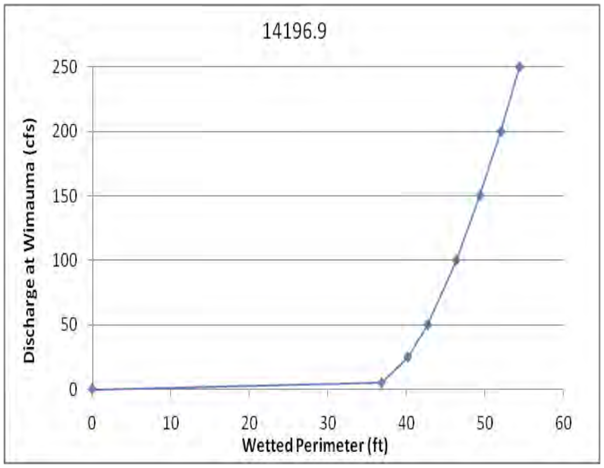

14649.03
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

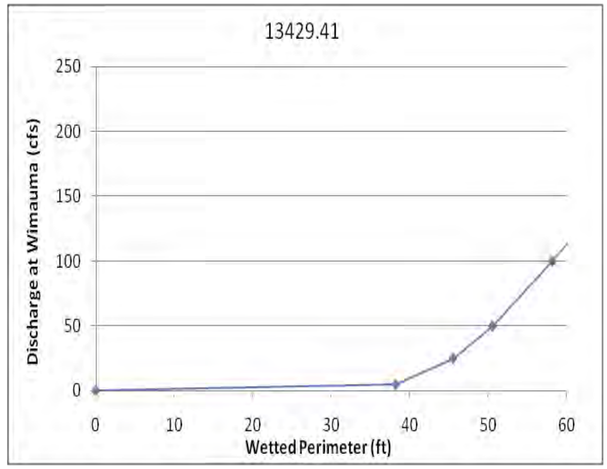

14489.56
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

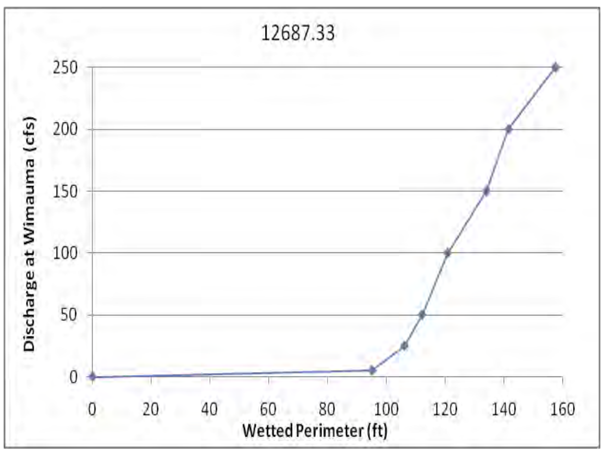

13895.59
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

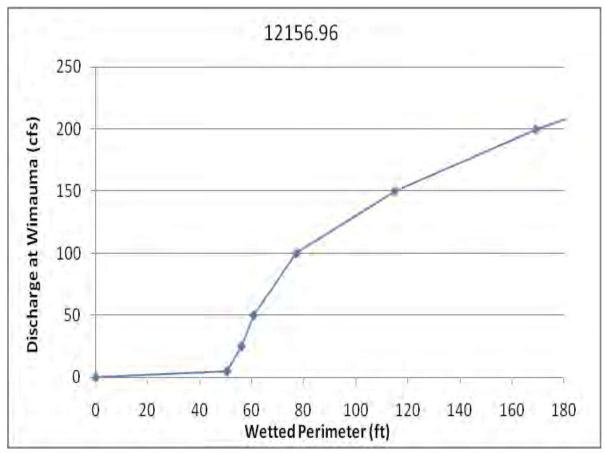

13286.36
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

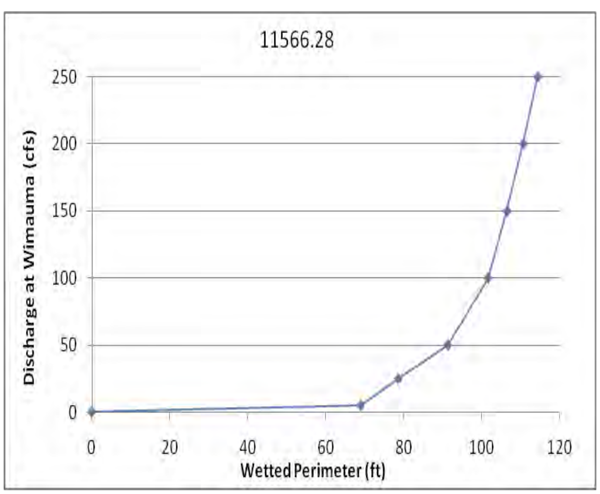

12436.58
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

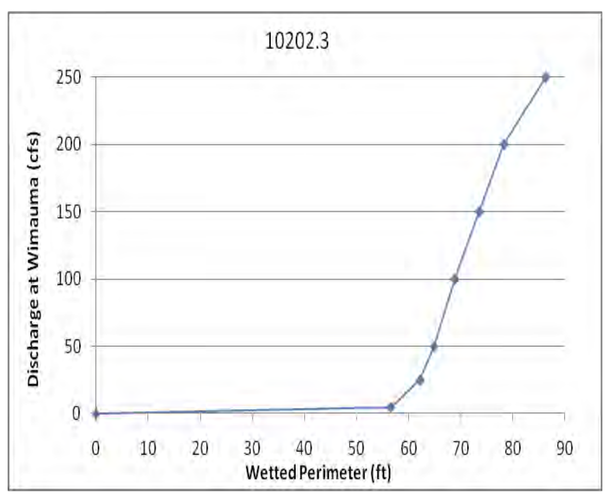

14196.9
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

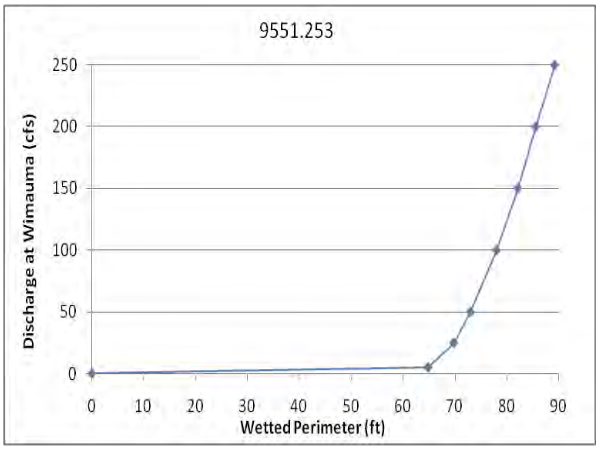

13429.41
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)


12687.33
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

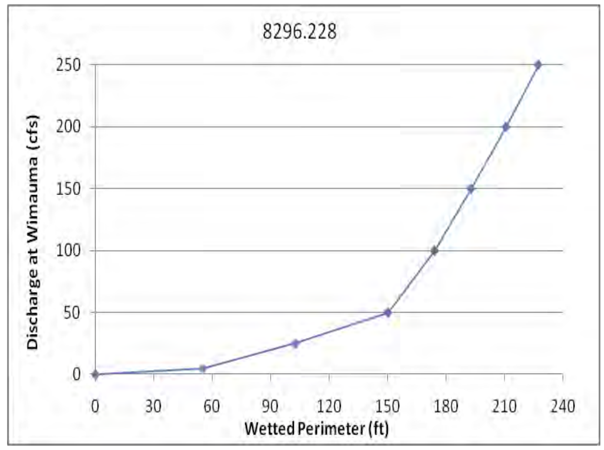

12156.96
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)


11566.28
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

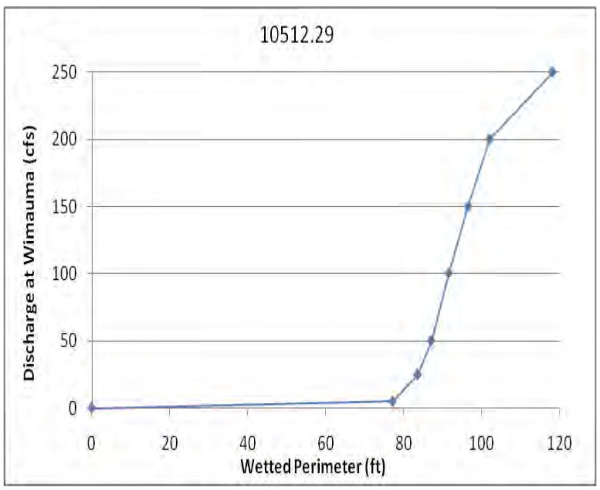

10202.3
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)



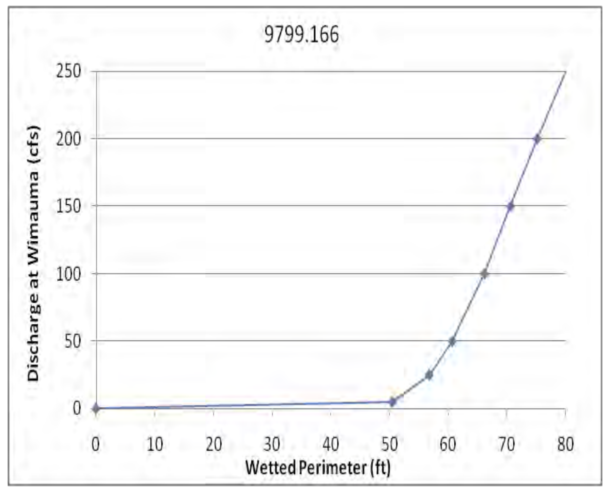
9551.253
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)



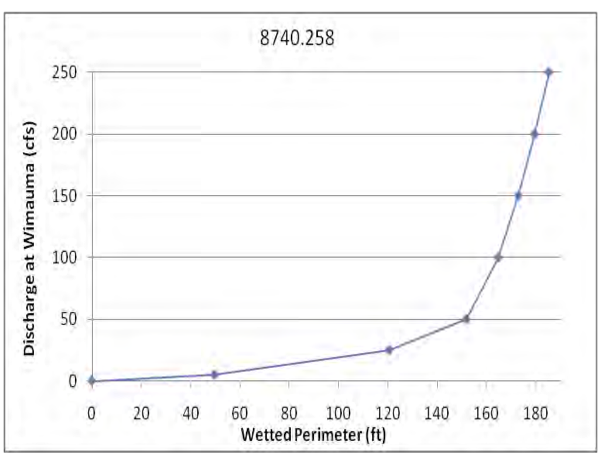
8296.228
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)



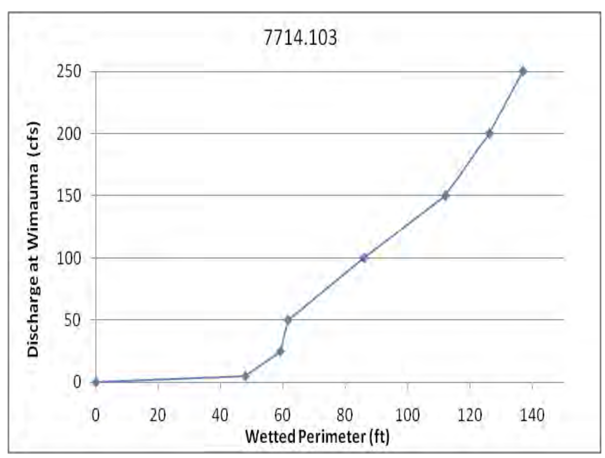
10512.29
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)



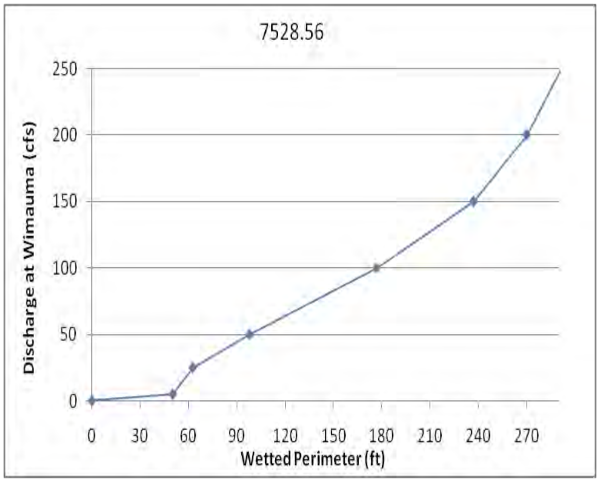
9799.166
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

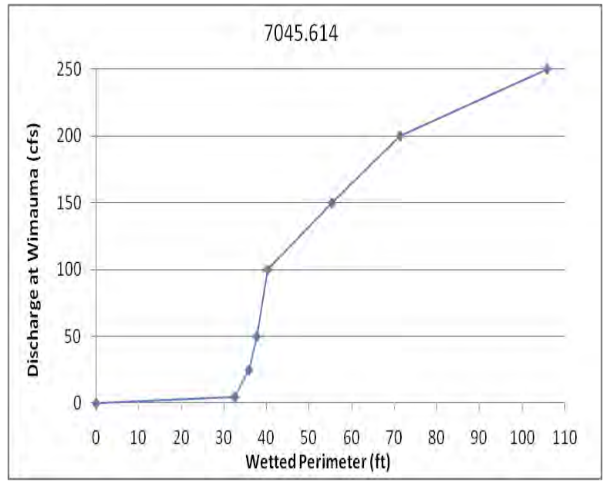


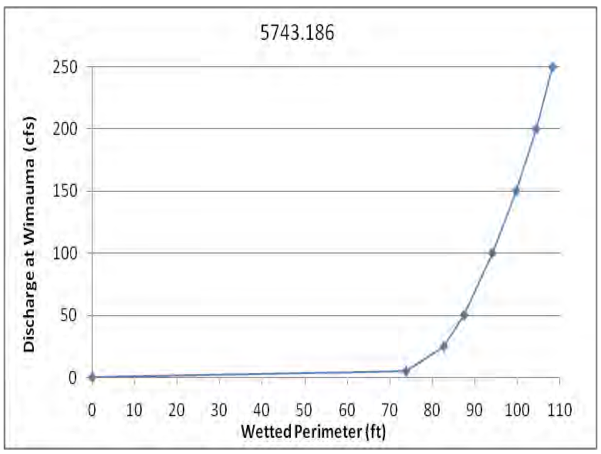
8740.258
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

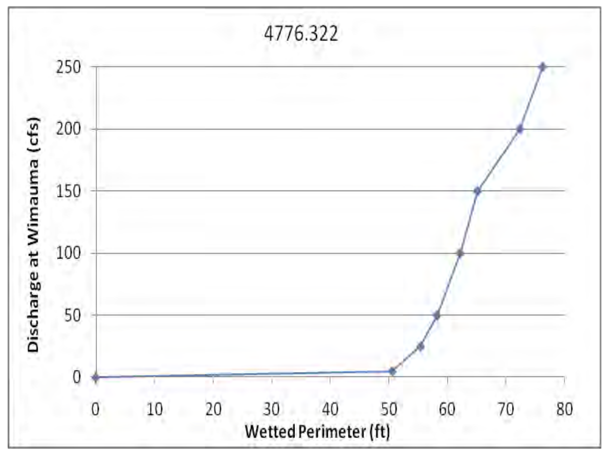


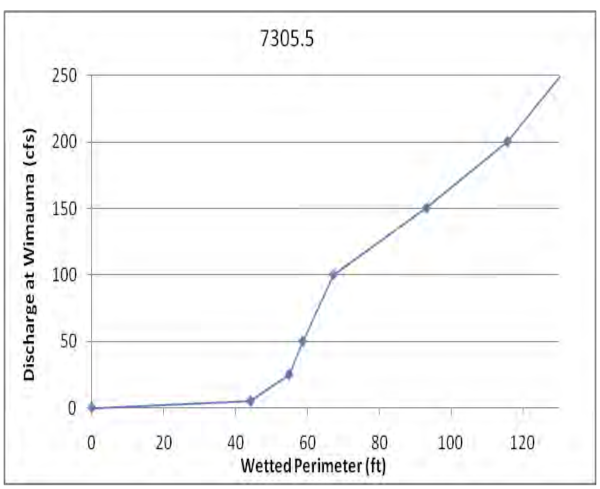
7714.103
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)

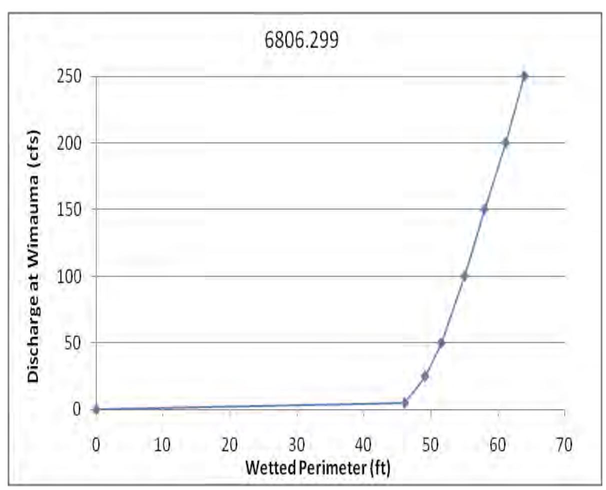

7528.56
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 30 60 90 120 150 180 210 240 270

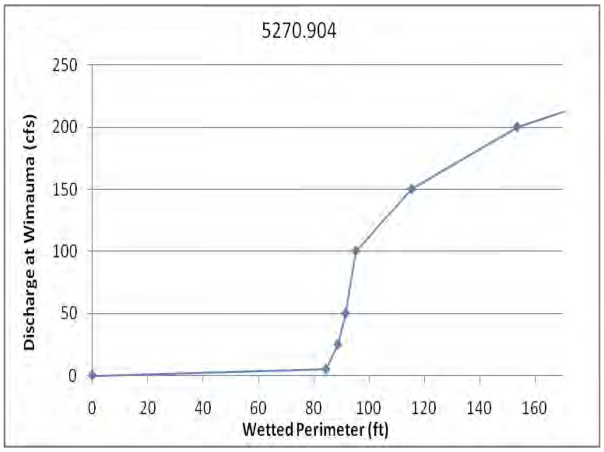

7045.614
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90 100 110

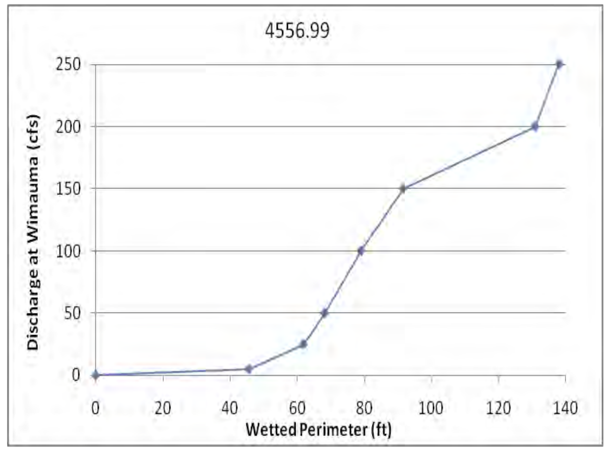

5743.186
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80 90 100 110

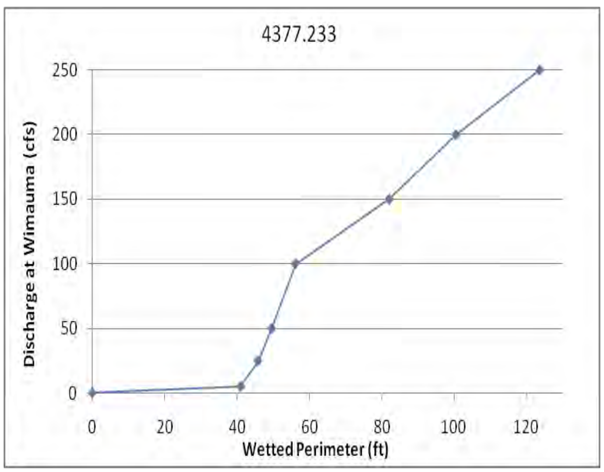

4776.322
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70 80

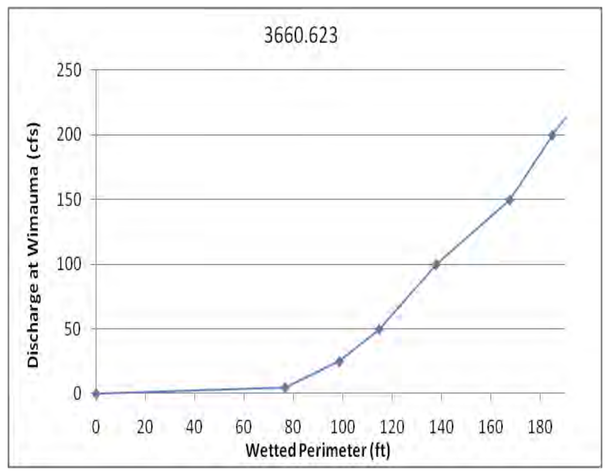

7305.5
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 20 40 60 80 100 120

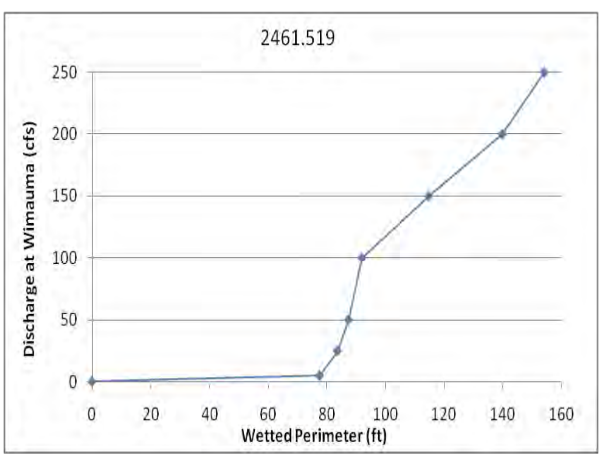

6806.299
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0 10 20 30 40 50 60 70

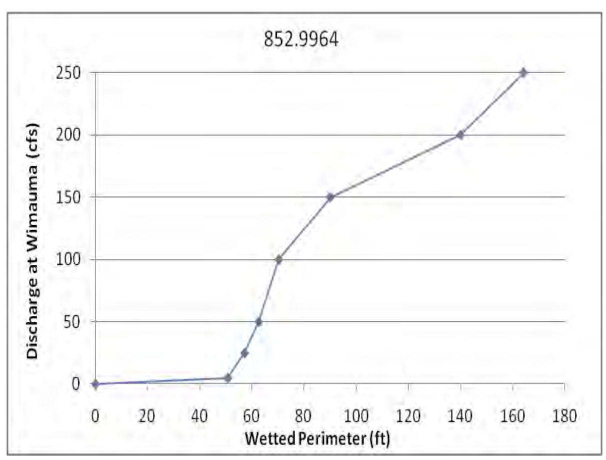

5270.904
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160

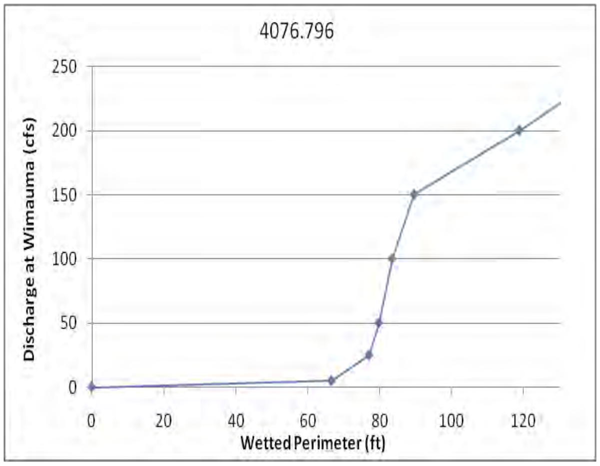

4556.99
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140

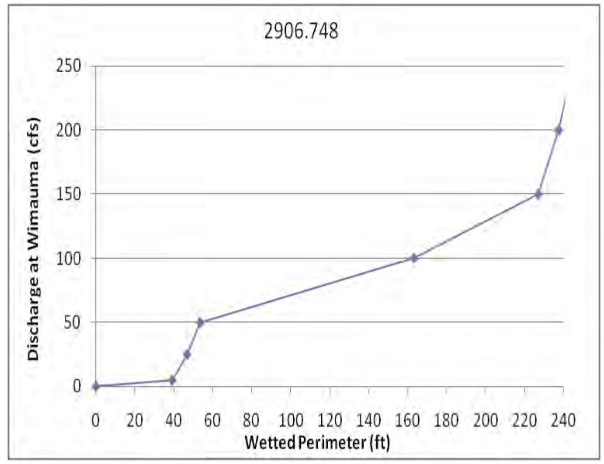

4377.233
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120

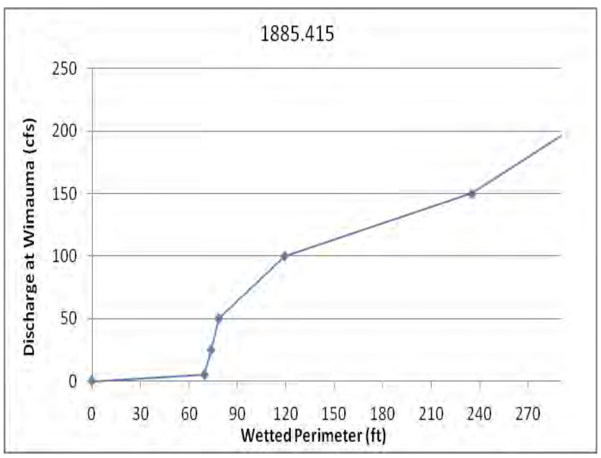

3660.623
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180

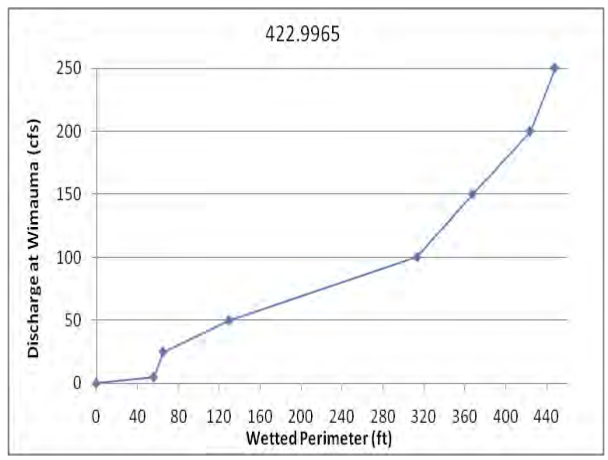

2461.519
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160

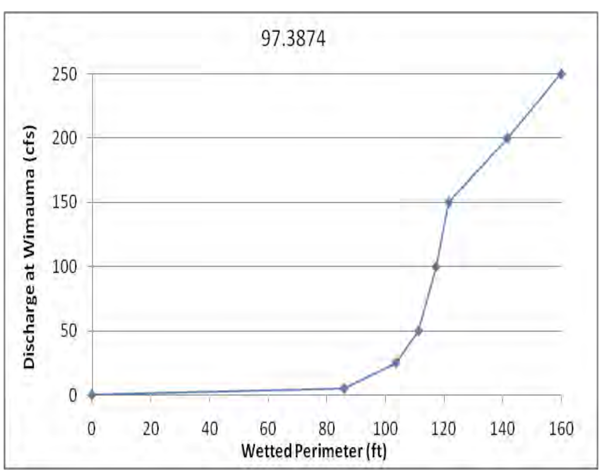

852.9964
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180


4076.796
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120

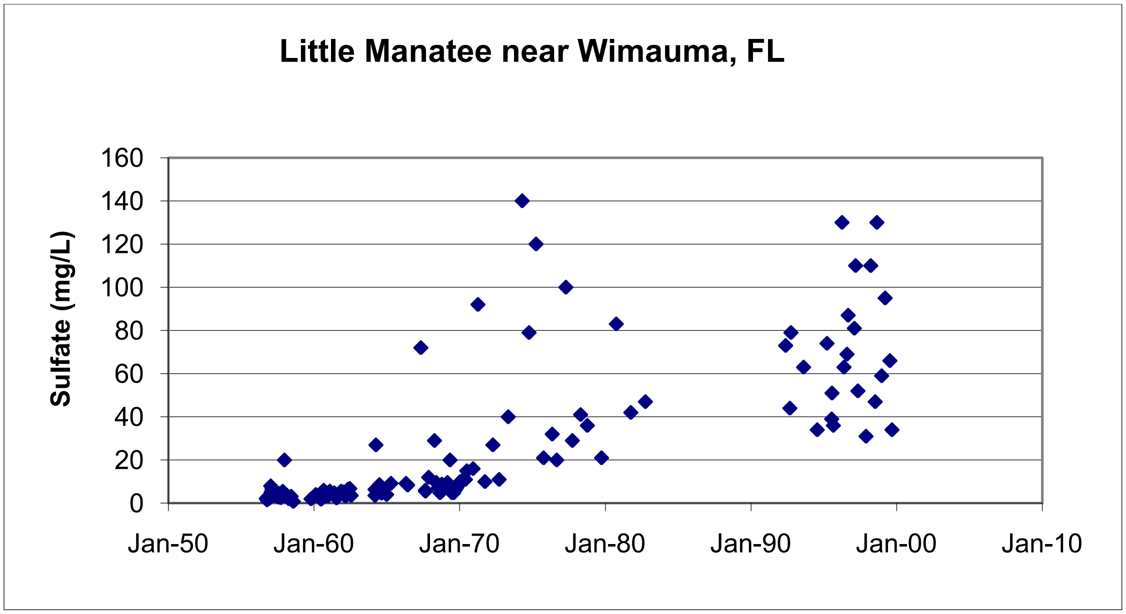

2906.748
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160
180
200
220
240

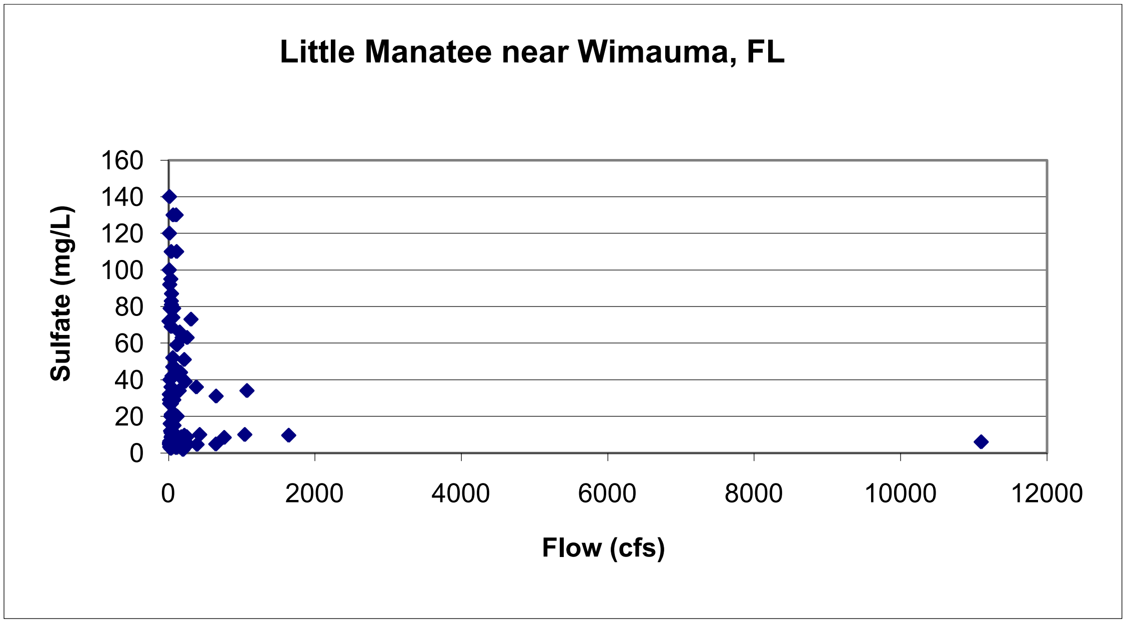

1885.415
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
30
60
90
120
150
180
210
240
270

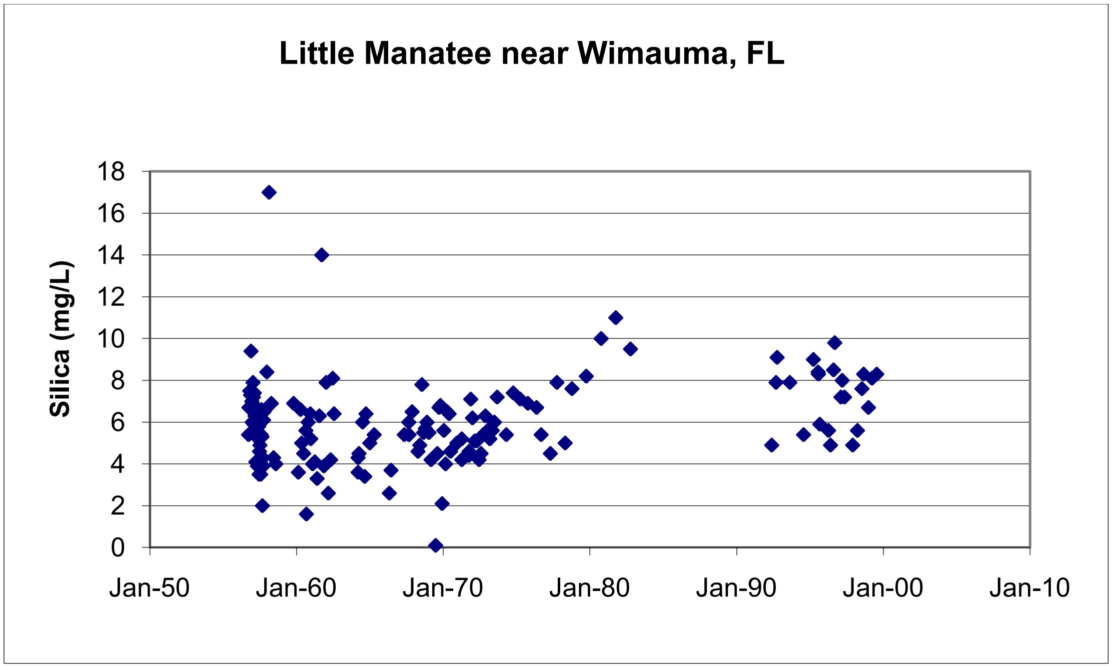

422.9965
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
40
80
120
160
200
240
280
320
360
400
440

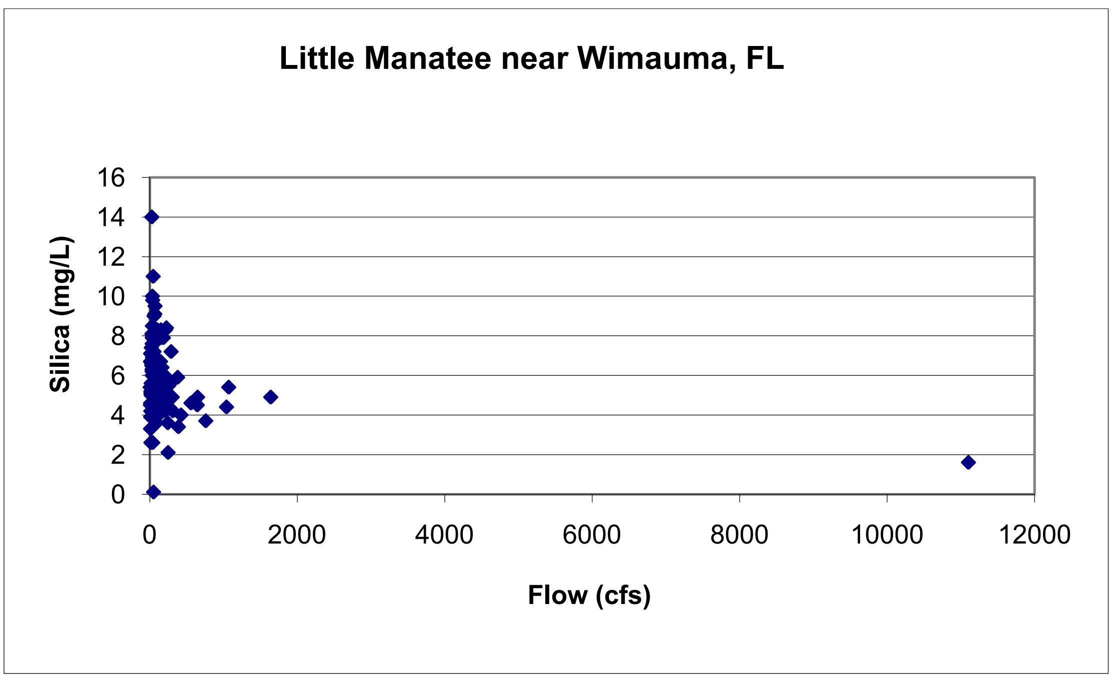

97.3874
Discharge at Wimauma (cfs)
Wetted Perimeter (ft)
0
50
100
150
200
250
0
20
40
60
80
100
120
140
160

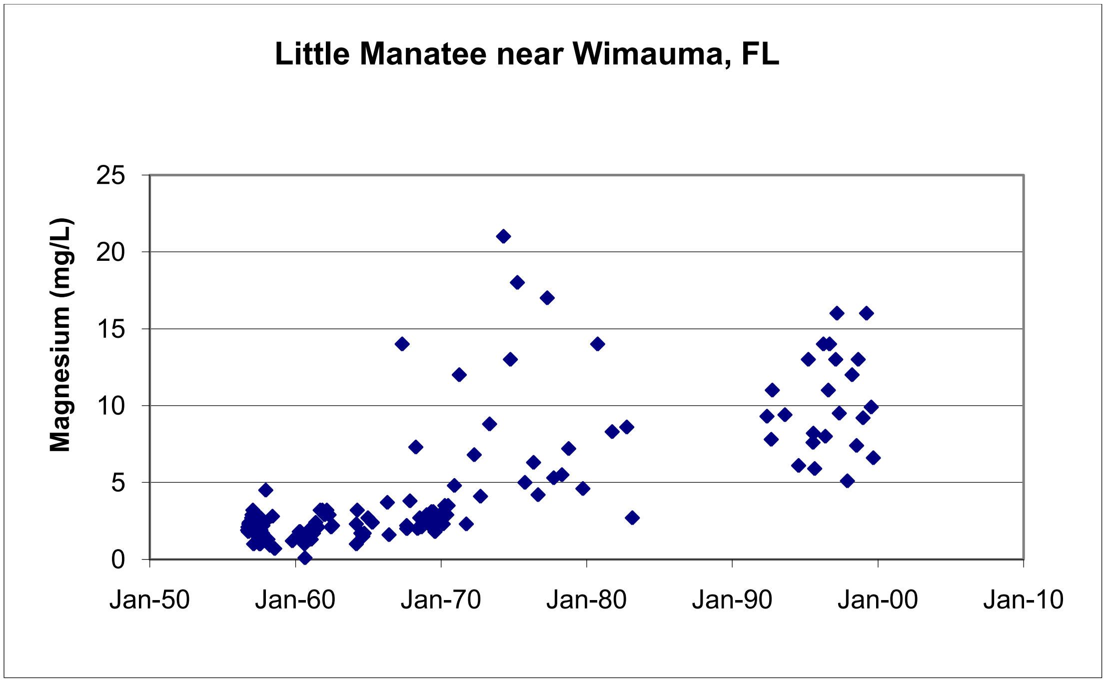
Water Quality Analyses for Little Manatee River near Wimauma

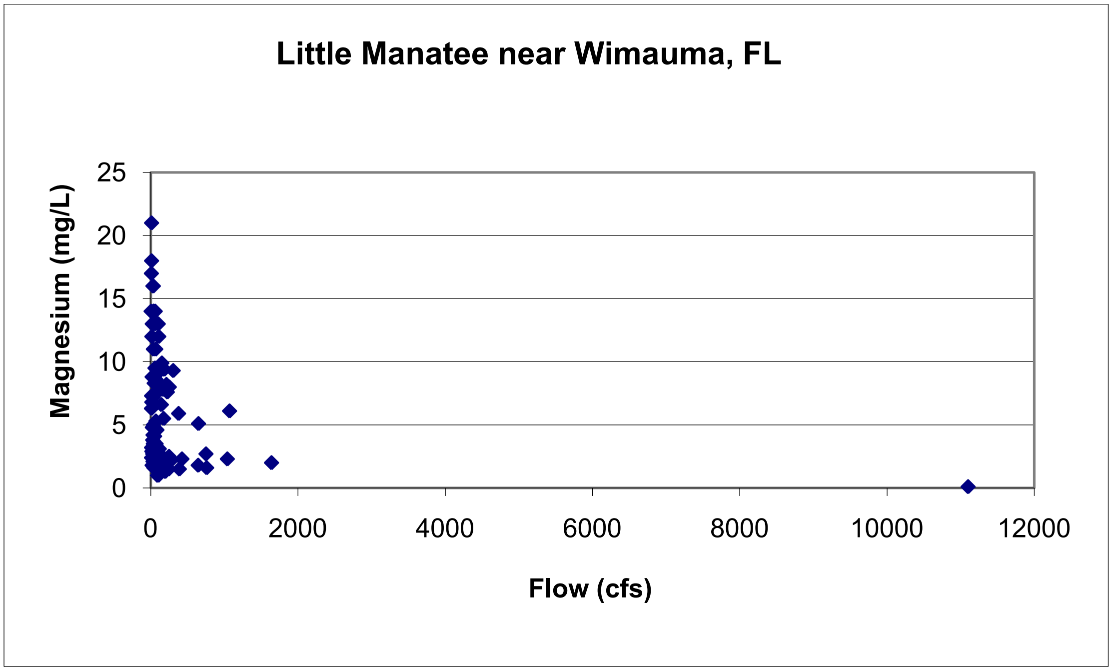


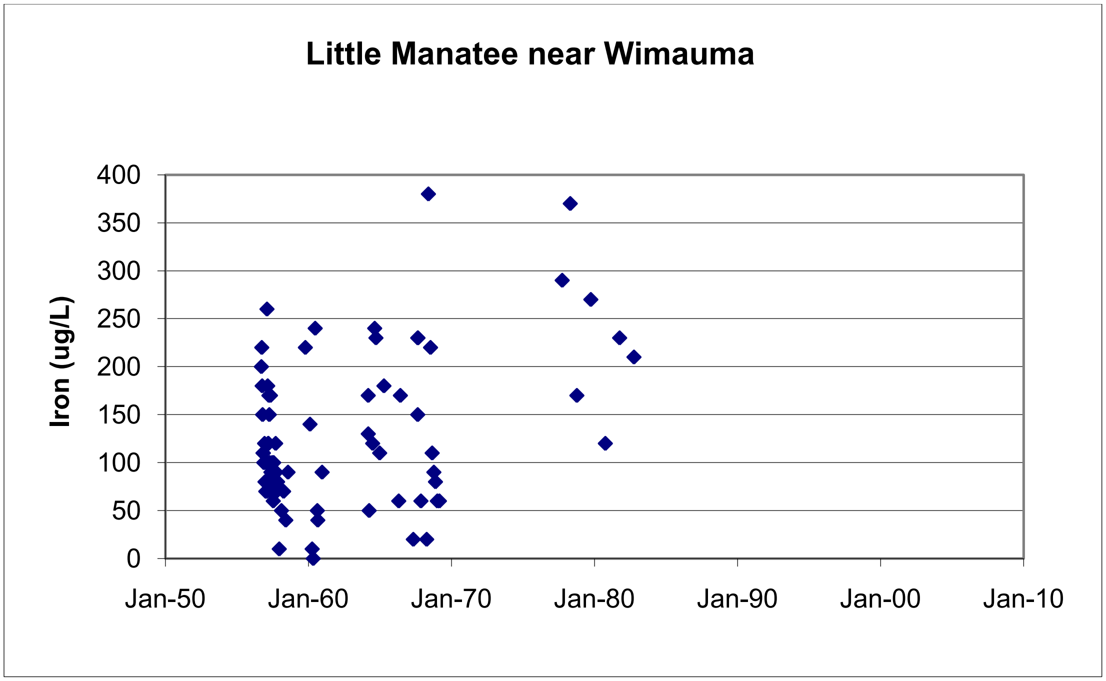



Little Manatee near Wimauma, FL
Silica (mg/L)
0
2
4
6
8
10
12
14
16
18
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

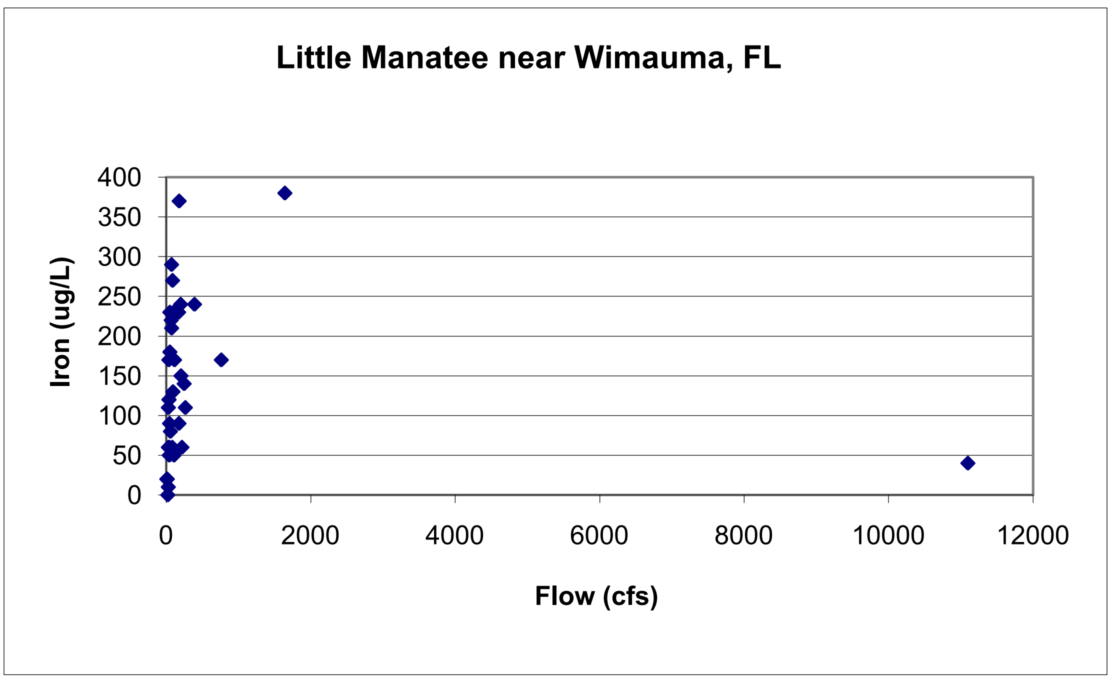

Little Manatee near Wimauma, FL
Silica (mg/L)
0
2
4
6
8
10
12
14
16
0
2000
4000
6000
8000
10000
12000
Flow (cfs)


Little Manatee near Wimauma, FL
Magnesium (mg/L)
25
20
15
10
5
0
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

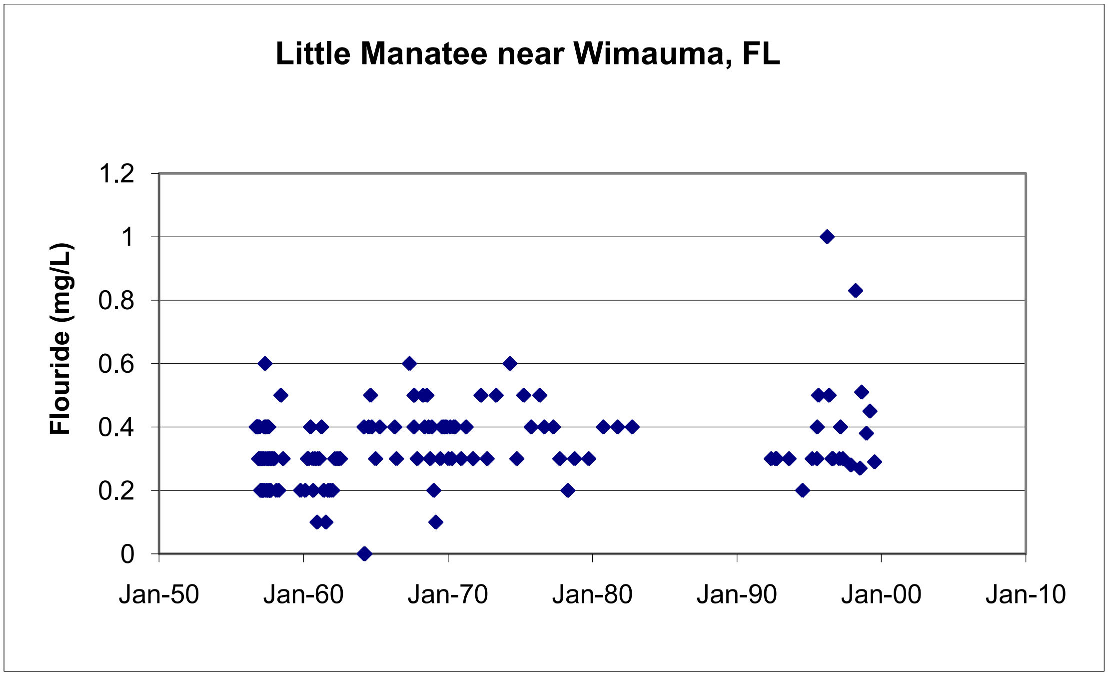

Little Manatee near Wimauma, FL
Magnesium (mg/L)
25
20
15
10
5
0
0
2000
4000
6000
8000
10000
12000
Flow (cfs)

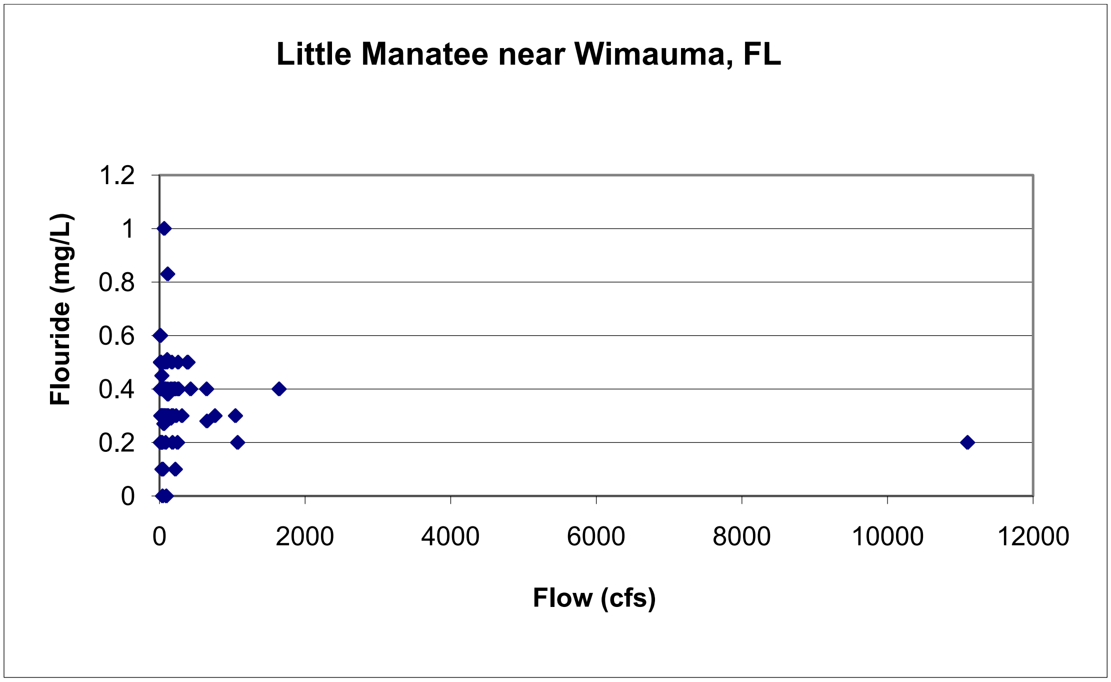


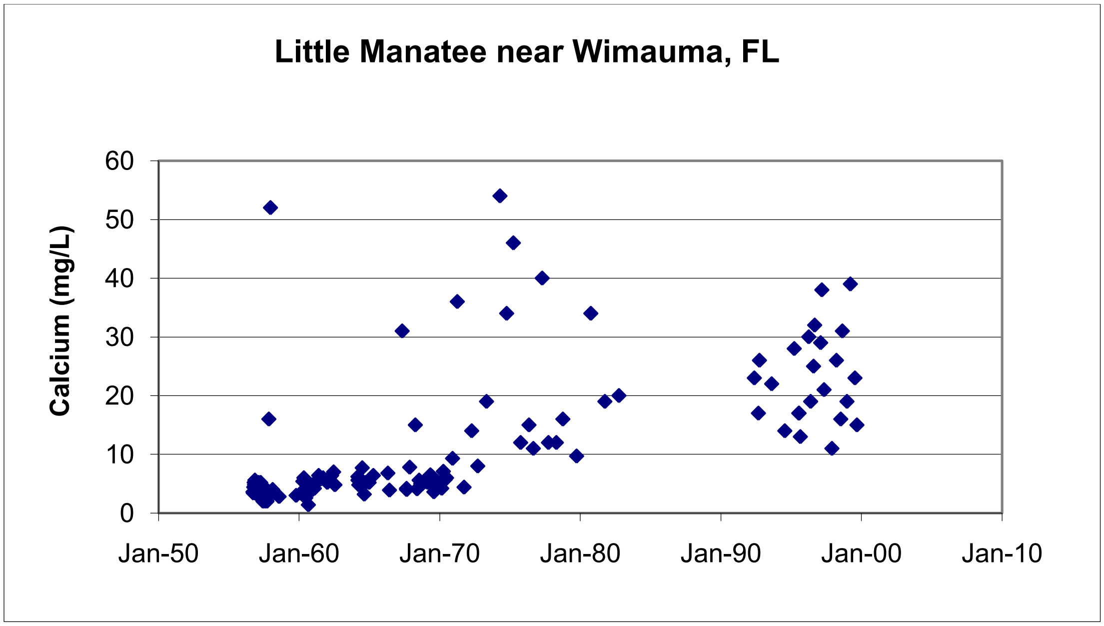
Little Manatee near Wimauma
Iron (ug/L)
400
350
300
250
200
150
100
50
0
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

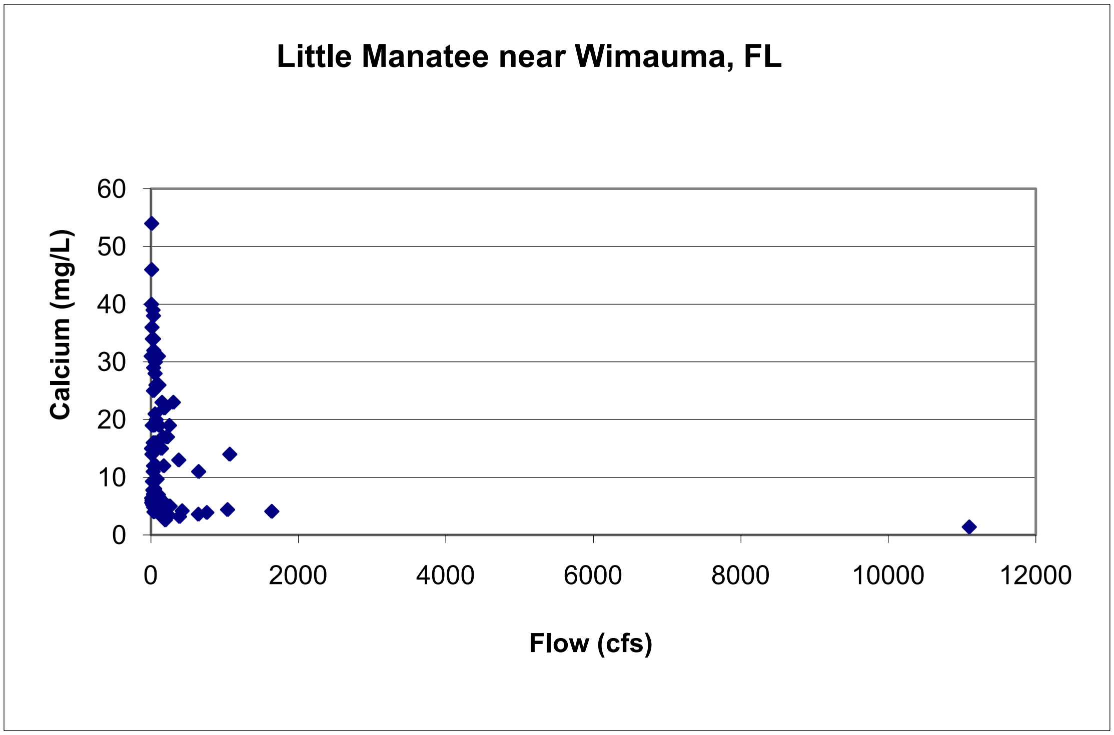


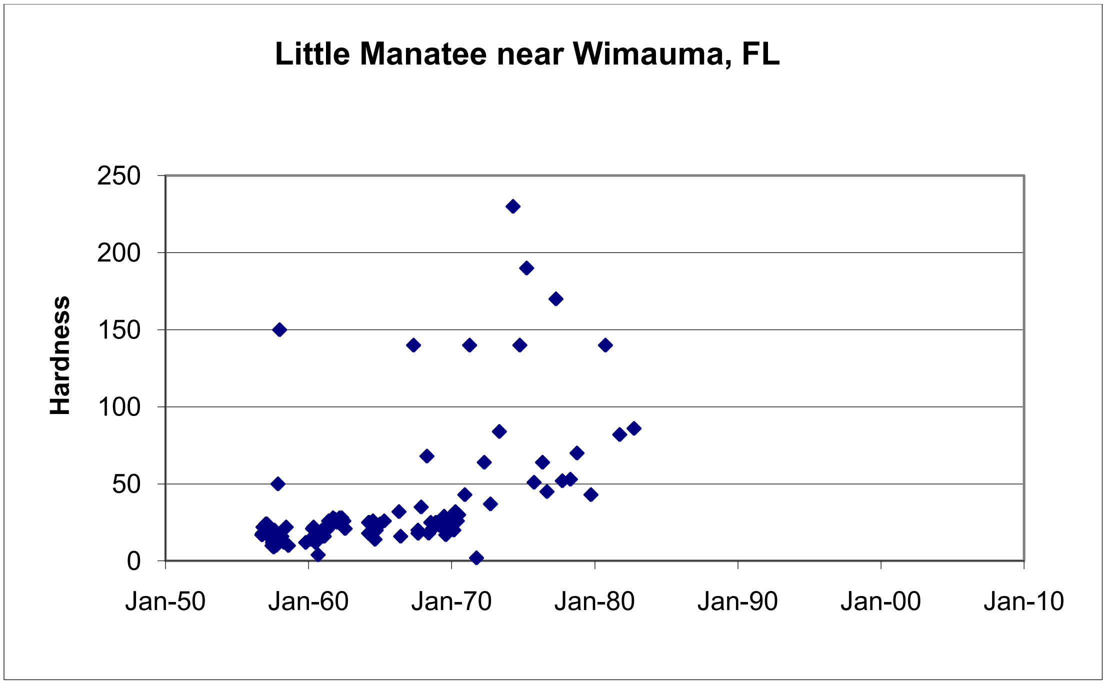
Little Manatee near Wimauma, FL
Iron (ug/L)
400
350
300
250
200
150
100
50
0
0
2000
4000
6000
8000
10000
12000
Flow (cfs)


Little Manatee near Wimauma, FL
Flouride (mg/L)
1.2
1
0.8
0.6
0.4
0.2
0
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

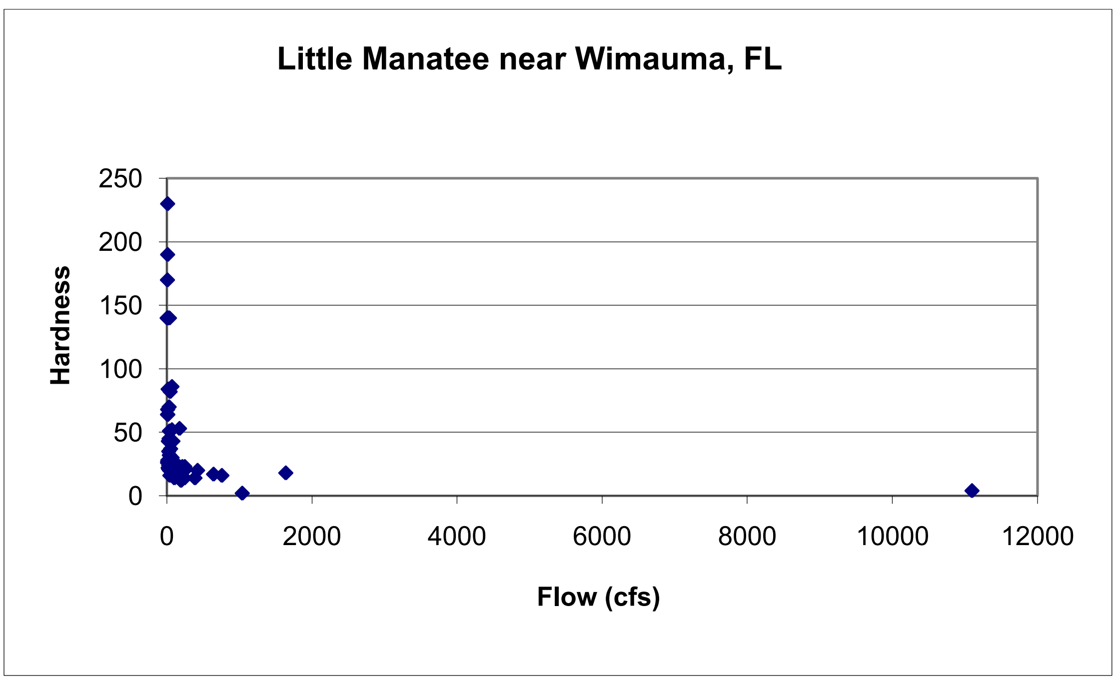

Little Manatee near Wimauma, FL
Flouride (mg/L)
1.2
1
0.8
0.6
0.4
0.2
0
0
2000
4000
6000
8000
10000
12000
Flow (cfs)


Little Manatee near Wimauma, FL
Calcium (mg/L)
0
10
20
30
40
50
60
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

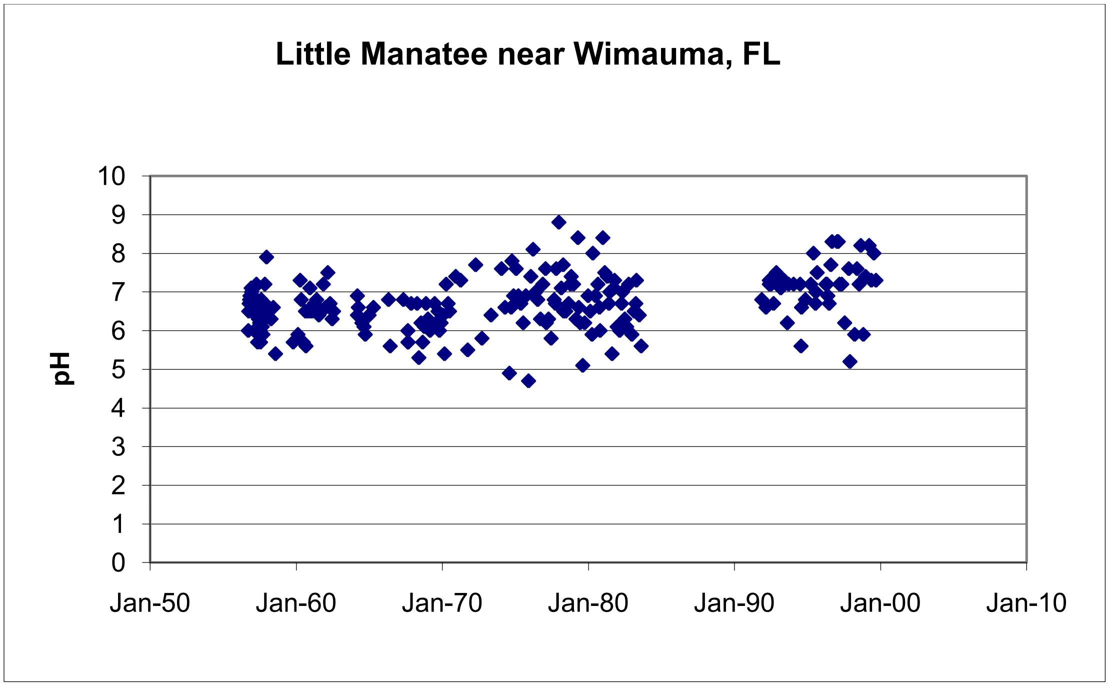

Little Manatee near Wimauma, FL
Calcium (mg/L)
0
10
20
30
40
50
60
0
2000
4000
6000
8000
10000
12000
Flow (cfs)

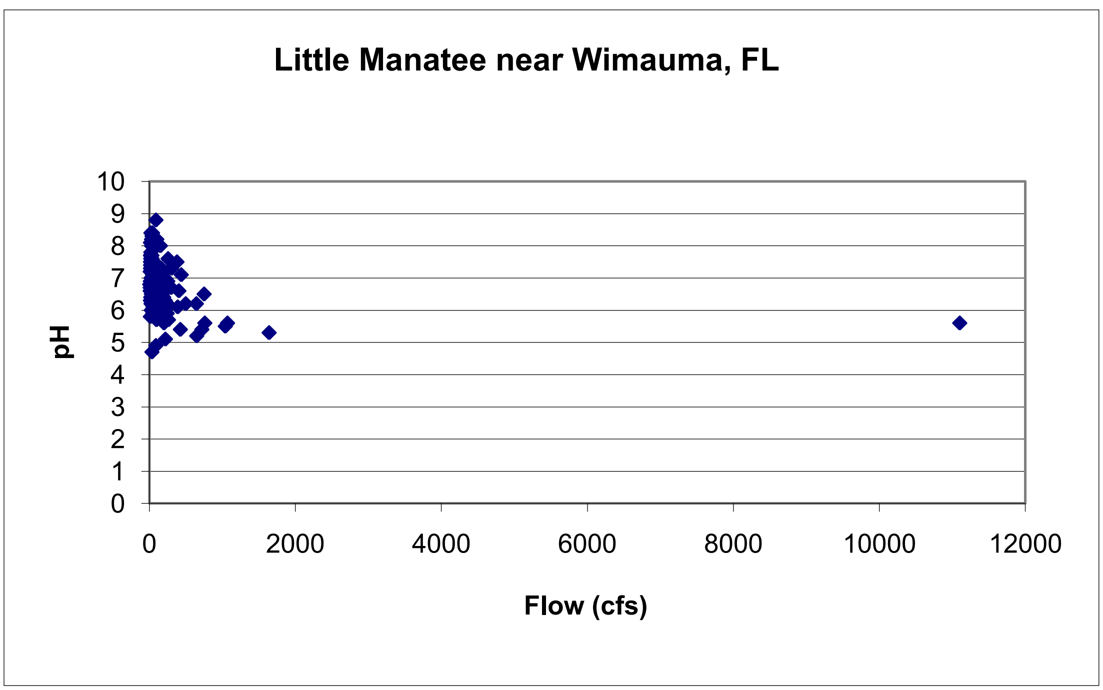


Little Manatee near Wimauma, FL
Hardness
250
200
150
100
50
0
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10



Little Manatee near Wimauma, FL
Hardness
250
200
150
100
50
0
0
2000
4000
6000
8000
10000
12000
Flow (cfs)


Little Manatee near Wimauma, FL
pH
10
9
8
7
6
5
4
3
2
1
0
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


Little Manatee near Wimauma, FL
pH
10
9
8
7
6
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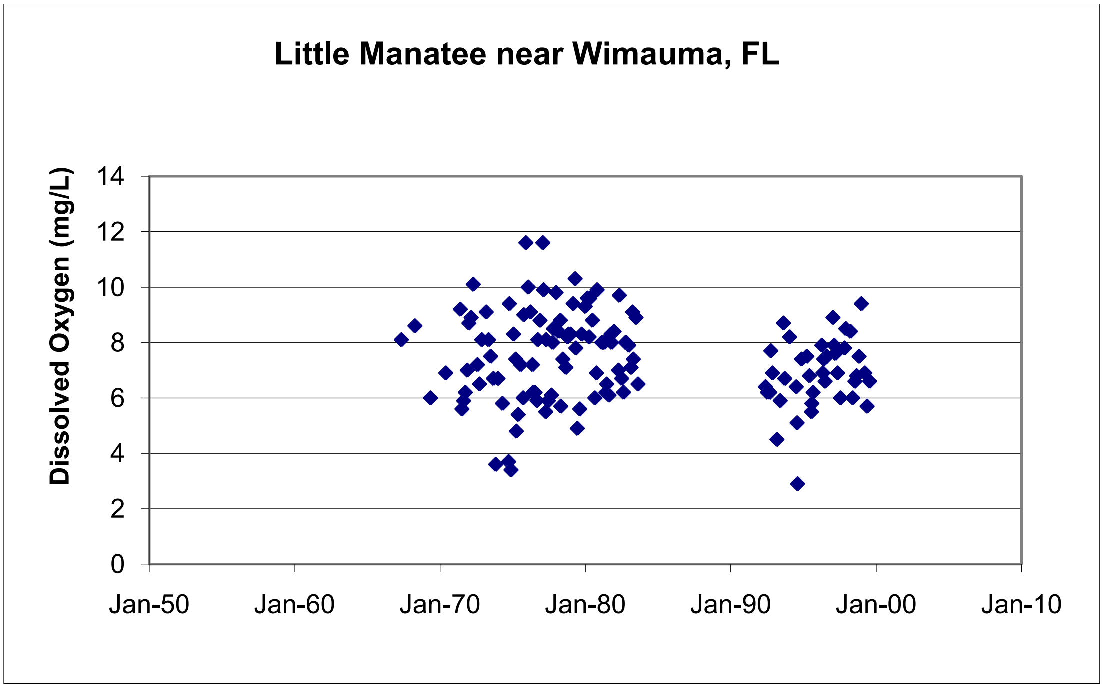
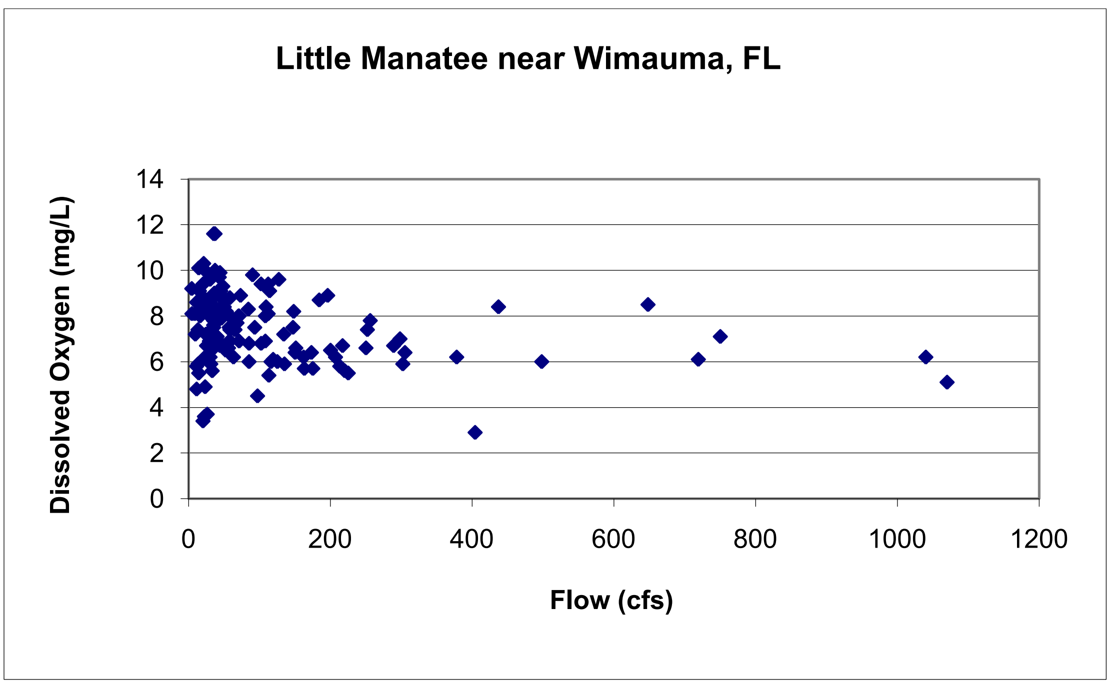
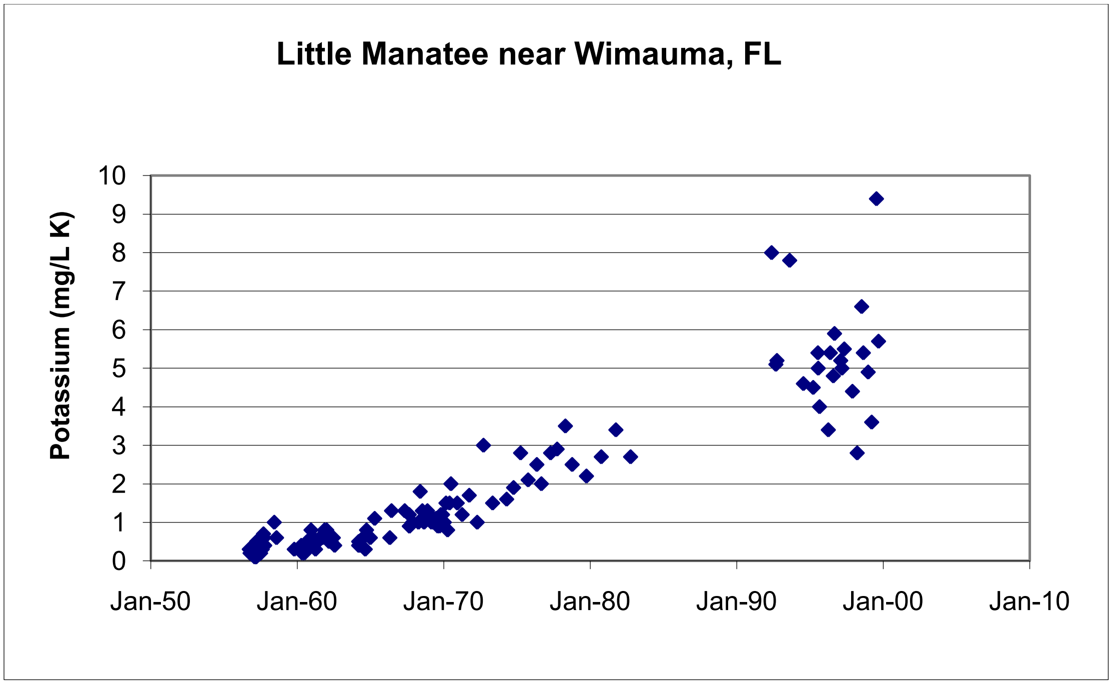
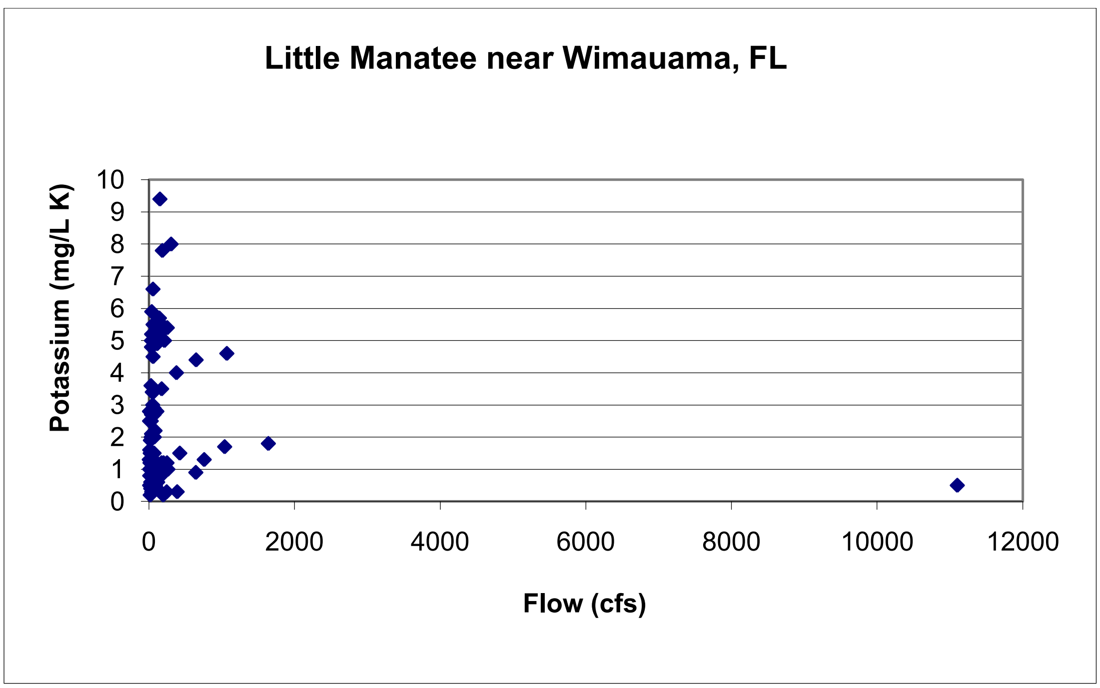
3
2
1
0
0
2000
4000
6000
8000
10000
12000
Flow (cfs)


Little Manatee near Wimauma, FL
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10


Little Manatee near Wimauma, FL
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
Flow (cfs)



Little Manatee near Wimauma, FL
Potassium (mg/L K)
10
9
8
7
6
5
4
3
2
1
0
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10



Little Manatee near Wimauama, FL
Potassium (mg/L K)
10
9
8
7
6
5
4
3
2
1
0
0
2000
4000
6000
8000
10000
12000
Flow (cfs)

Vegetation Appendix

Characterization of Woody Wetland Vegetation Communities along the Little Manatee River

DRAFT

February 2008

Submitted to

Southwest Florida Water Management District

Submitted by

PBS&J

5300 West Cypress Street

Tampa, Florida 33607

Executive Summary

The purpose of this study was to characterize relationships among vegetation, soils, and elevation in wetlands along the Little Manatee River and assist the Southwest Florida Water Management District (District) in establishing MFLs for the river. Vegetation classes, plant species importance, soil characteristics, and elevations were evaluated for 10 transects along the Little Manatee River study corridor. The study corridor extended approximately 12 miles downstream of State Road (S.R.) 64 to just downstream of U.S. Highway 301.

Vegetation. Differences in vegetation classes along the Little Manatee River study corridor were significant based on importance values (IVs) that were calculated using tree species density, basal area, and frequency, and provided a relative measure of species dominance (no units). Three wetland vegetation classes were identified in the study corridor. The classes included only obligate and facultative wetland tree species, including Carolina willow (*Salix carolinana*), tupelo (*Nyssa sylvatica*), sweet bay or swamp bay (*Magnolia virginiana*), water oak (*Quercus nigra*), and popash (*Fraxinus caroliniana*). These classes (below) included six or fewer species.

- Willow marsh: comprised exclusively of the obligate wetland species Carolina willow, with smaller components of popash and holly (*Ilex cassine)*.
- Tupelo swamp: characterized by only two tree species, primarily swamp tupelo (obligate wetland species), in addition to a small component of slash pine (*Pinus elliottii*) (facultative wetland species).
- Hardwood swamp: included six species and characterized by predominantly swamp bay (obligate) and water oak (facultative wetland).

Transition vegetation classes (between wetlands and uplands) were characterized by predominantly facultative wetland species such as laurel oak (*Q. laurifolia*) and slash pine in combination with other facultative species. The transition classes included laurel oak/ pine hammock, pine/ laurel oak hammock, pine/ maple hammock, and laurel oak hammock vegetation classes. These classes were composed of six to 23 different species. Species in the two upland classes included primarily the facultative cabbage palm (*Sabal palmetto*) and the upland scrub hickory (*Carya glabra*). Total numbers of species in the upland classes ranged from six to 11. The upland classes were palm hammock and oak scrub.

Species IVs for the 29 tree species in the nine vegetation classes indicated a shift in importance from willows, tupelo, and sweet bay to laurel oak and slash pine to scrub oak and sand pine coincided with a gradual transition from wetland to upland vegetation classes. Overall trends in species dominance and diversity are summarized below.

- Laurel oak, slash pine, tupelo, and Carolina willow made up approximately 56 percent of the total IVs (by species) among all classes. Cabbage palm, water oak, popash, live oak, and scrub hickory made up approximately 29 percent of the total IVs by species. The remaining 20 species made up approximately 28 percent of the total IVs.

- Laurel oak occurred in seven of the nine vegetation classes. Slash pine and live oak (*Q. virginiana*) were in five classes. The remaining 26 species occurred in five or fewer vegetation classes.
- The oak hammock class had the largest number of tree species (23). The total number of tree species in other classes ranged from two to 15. The laurel oak hammock class also had the largest total basal area (35,718 in^2/acre) and lowest density (approximately 12 trees/acre), indicating older stands of larger trees.
- The willow marsh and tupelo swamp had the highest tree densities (90 and 135 trees/acre, respectively), and relatively low total basal areas (3,743 and 19,215 in^2/acre, respectively), indicating younger trees.
- Laurel oak (21,099 in^2/acre) in the laurel oak hammock class and tupelo (19,010 in^2/acre) in the tupelo swamp class had the highest basal areas of any other tree species in any other vegetation class. The remaining seven vegetation classes had 50 trees/acre or less.

Elevations and Soils. River channel elevations declined from 38.0 feet NGVD at the most upstream transect to 0.1 feet NGVD at the transect farthest downstream, a decline of just over 38 feet over about 12 miles (0.3 feet/mile). In contrast, elevation changes along transects ranged from 11.6 to 22.8 feet over a half mile or less (22.4 feet/mile). The median elevation along the most upstream transect was 46.5 feet NGVD, about 36.5 feet higher than the median elevation at the most downstream transect (10.0 feet NGVD). Changes in elevation along the two most upstream transects were only 11.6 to 12.8 feet, while elevation changes along the more downstream transects ranged from to 16.6 feet to 22.8 feet.

Changes in vegetation were more conspicuous along transects than along the upstream – downstream river channel gradient and may reflect the steeper elevation change along transects when compared with the upstream to downstream elevation gradient. Wetland vegetation communities occurred along the three upstream and three downstream transects and were absent along the four mid-reach transects.

Median elevations among wetland vegetation classes ranged from 10.1 to 7.3 feet NGVD and ranged from 7.6 to 11.9 feet NGVD in transition vegetation classes. Elevations ranged from 7.4 to 17.7 feet NGVD in the two upland classes. Median relative elevations of vegetation classes were often, but not always, lower for the willow marsh, tupelo swamp, and hardwood swamp when compared with other communities along a transect.

Hydric soils were found along nine of the 10 study transects and in all vegetation classes except the scrub oak class. Muck soils were found at all transects. The tupelo swamp and hardwood swamp classes were the only classes with exclusively hydric soils. Median elevations of hydric soils were lower when compared with nonhydric soils and elevation differences between hydric and nonhydric soils ranged from 0.3 to 0.9 feet at the two most upstream transects to a difference of about seven feet at mid-reach transects (VEG10, VEG2, LMAN6) to a difference of about three feet at the two most downstream transects. Both hydric and nonhydric conditions occurred in many vegetation classes, although hydric soils consistently occurred at lower elevations when compared with nonhydric soils in all but one instance (laurel oak hammock class).

Discriminant Function Analysis (DFA). DFA was used to measure the contribution of elevation, distance from river channel, and soil parameters in characterizing vegetation classes along the Little Manatee River study corridor. Vegetation classes were classified correctly 40 percent of the time for willow marsh and 100 percent of the time for tupelo and hardwood swamp classes (willow marsh was classified incorrectly more frequently than correctly). Transition vegetation classes were correctly classified in 13.5 to 80 percent of the cases. The two upland classes were classified correctly in 88.9 and 66.7 percent of the cases. Overlap among classes was greatest among classes that were sampled less frequently, had greater variability in species, and occurred along more transects.

Vegetation classes were distinct in terms of species composition and IV, and environmental variables were significant in accounting for differences between vegetation classes. Elevations, relative elevations along transects, distance from channel, and hydric soil index were significant in separating vegetation classes from each other, although overlap in environmental parameters between vegetation classes was frequent. Correlations between environmental variables and vegetation class were not strong. However, relative elevation was more strongly correlated with vegetation class ($r^2 = 0.32$) when compared with soils ($r^2 = 0.29$), and distance to channel ($r^2 = 0.28$), and elevation ($r^2 = 0.23$), respectively.

Wetted Perimeter. There was no consistent steep increase in cumulative wetted perimeter (inundated habitat) coincident with a particular shift in vegetation classes along the Little Manatee River transects. The sigmoid-shaped curve generally associated with corresponding changes in habitat and elevation was apparent along six of the 10 study transects, but wetland classes did not consistently align with a particular portion of the curve. These characteristics reflect the variation in habitat, from an incised channel through uplands to broader floodplain areas that occur along the Little Manatee River.

Conclusions. Nine distinct vegetation classes were identified along the Little Manatee River study corridor based on woody species composition and IV. Soils, elevations, and distances from river channel were significantly related to vegetation classes, but not highly correlated. Willow marsh, tupelo swamp, and hardwood swamp vegetation classes generally occurred at lower elevations on hydric and/or saturated soils in contrast with the upland palm hammock and oak scrub vegetation class. However, wetland vegetation classes were encountered along only four of the ten transects, while each of the remaining six vegetation classes occurred along three or more transects. Based on the results of this study, only the tupelo swamp and hardwood swamp vegetation classes may provide a criterion on which to establish MFLs for vegetation communities along the Little Manatee River.

Wetland systems are not well developed along the Little Manatee River and minimum flows that rely on fish passage will likely include a small extent of wetlands in the river corridor. No cypress wetlands were encountered along the river channel during the vegetation studies, and the three wetland classes sampled are characterized by species less tolerant of flooding than cypress.

Table of Contents

Section ***Page Number***

List of Tables

List of Figures

• Purpose

The statutory directive for minimum flows and levels (MFLs) included in the Water Resources Act was enacted by the Florida Legislature in 1972. Section 373.042 F.S. of the Act directs each water management district to establish MFLs for surface water bodies, watercourses, and aquifers within their respective jurisdictions. Under the statute, the minimum flow for a given watercourse is defined as the limit at which further withdrawals would be "significantly harmful" to the water resources or ecology of the area. In addition, the determination of MFLs must be based on the "best available" information.

The purpose of this study was to characterize relationships among vegetation, soils, and elevation in wetlands along a portion of the Little Manatee River (Figure 1-1). Given the assumption that vegetation is a good and easily measured integrator of environmental and historical site conditions, vegetation, soils, and elevation will be used to support the Southwest Florida Water Management District (District) in establishing MFLs for the Little Manatee River.

Instream flows are important to maintaining a functional river or stream system, fish and wildlife habitat, recreation, navigation, and consumptive uses such as irrigation and domestic water supply. MFLs are intended to guide water resource and water supply development to ensure water resource sustainability for people and the natural environment. They will also be used to assist in making water use and other permitting decisions. In summary, MFLs are being established to:

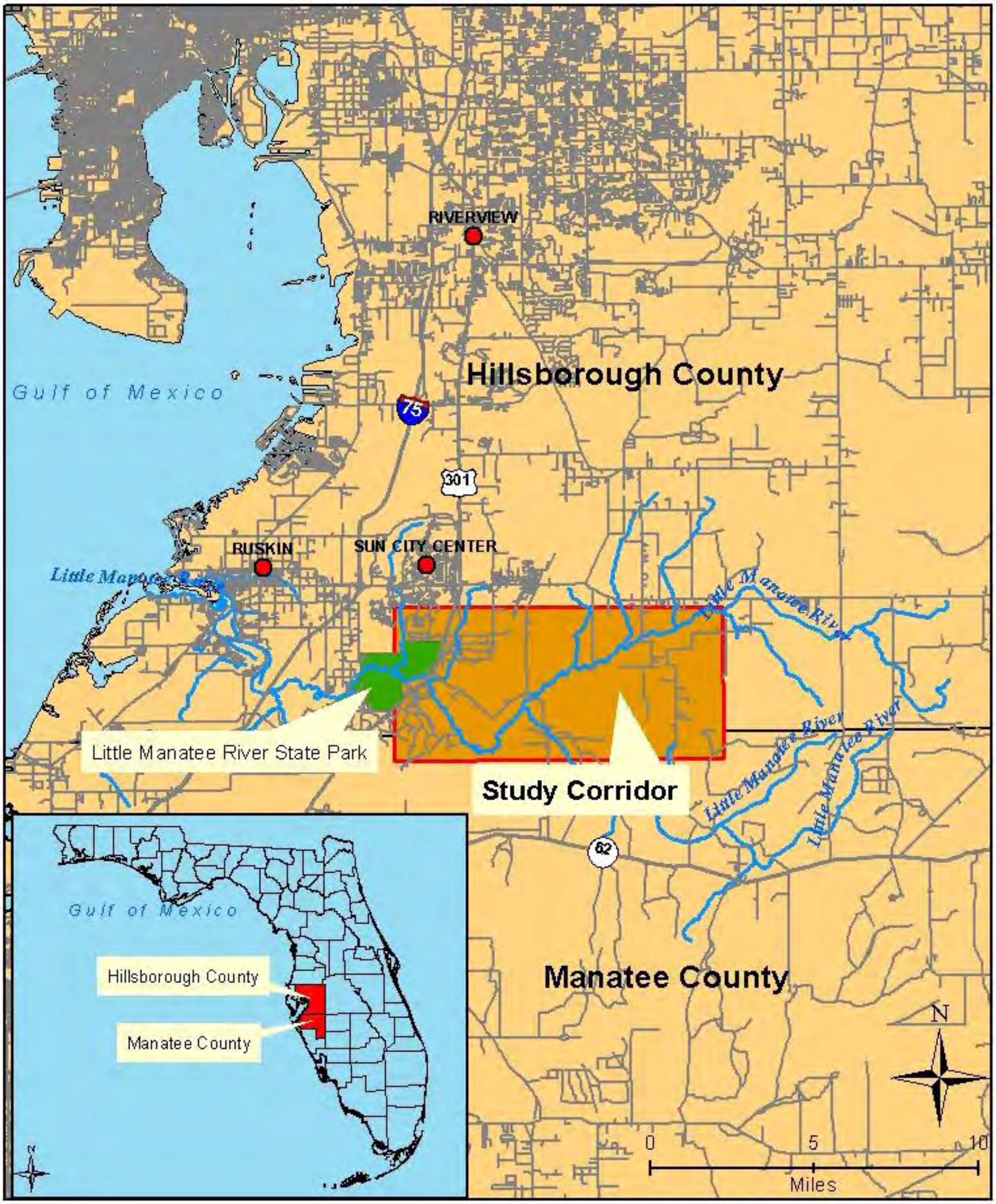
- Address Florida Statute 373.042(1)(a)&(b)
- Protect water resources and ecology
- Determine water availability

The District Governing Board has the final authority to set MFLs within its jurisdiction, using several guidelines provided by the state (and listed below).

- Using the best information available
- When appropriate, setting MFLs to reflect seasonal variations
- Considering the protection of non-consumptive uses of water (e.g. recreation)

This report presents the relationships among vegetation and physical factors, such as elevation and soils that characterize the Little Manatee River study corridor and may be used in establishing MFLs for vegetation communities.

Figure 1-1
Location of the Little Manatee River Study Corridor
in Hillsborough County, Florida



• Background

The Little Manatee River flows west about 40 miles from its headwaters east of Fort Lonesome in southeastern Hillsborough County before emptying into Tampa Bay near Ruskin. The main channel of the Little Manatee River begins at the confluence of the North and South Fork tributaries about 22 miles upstream of the river mouth. The North Fork, however, is often referred to and considered an extension of, the Little Manatee River, while the South Fork is considered a separate tributary. Several smaller tributaries also flow into the Little Manatee River, including Dug, Cypress, and Carlton Branch creeks.

The tidal reach of the Little Manatee River extends approximately 15 miles upstream from the river mouth (SWFWMD 1988a) to approximately one mile upstream of U.S. 301 (Fernandez 1985). The channel ranges in width from approximately 4,000 feet at Shell Point at the mouth of the river to 400 feet at U.S. 41, and narrows to 40 to 150 feet at U.S. 301.

The Little Manatee River watershed includes 222 square miles in southern Hillsborough County and northern portion of Manatee County and includes the City of Palmetto and the communities of Parrish, Ruskin, Sun City, Wimauma, and Terra Ceia. Port Manatee is a port/industrial facility on Manatee County's northern coastline. In terms of port activity, the facility is the fifth largest in the state of Florida (Bureau of Economic and Business Research (BEBR 2001).

The Little Manatee River State Park is located just downstream (east) of U.S. 301 and the Cockroach Bay Aquatic Preserve is located at the mouth of the river. Lake Wimauma, in the central portion of the watershed, and Carlton Lake, in the eastern portion of the watershed, are the only naturally occurring lakes in the Little Manatee River watershed. Lake Parrish is a 3,500 acre cooling reservoir for the Florida Power and Light (FPL) facility and is located about 1.5 miles downstream of the confluence of the South Fork of the Little Manatee River.

Land uses along the downstream reaches of the Little Manatee River are predominantly row crops and residential land uses and smaller areas of commercial and industrial land uses. Farther upstream, urban development includes high density residential associated with Sun City and Lake Wimauma. The upper reaches of the Little Manatee River include primarily agricultural uses such as pasture and crop lands, while phosphate mining dominates the far eastern portion of the watershed.

○ Physiography

The Little Manatee River watershed occurs across three physiographic provinces: the Gulf Coastal Lowlands, DeSoto Plain, and the Polk Upland (White 1970). The lower portion of the watershed flows over the relatively flat plains of the Gulf Coastal Lowlands province and DeSoto Plain that extend eastward with a gentle slope upward to the border with the Polk Upland physiographic province. The western edge of the Polk Upland is defined by the presence of the first of several paleoshoreline scarps associated with the Pleistocene ice-age sea level fluctuations. This physiographic feature is known as the

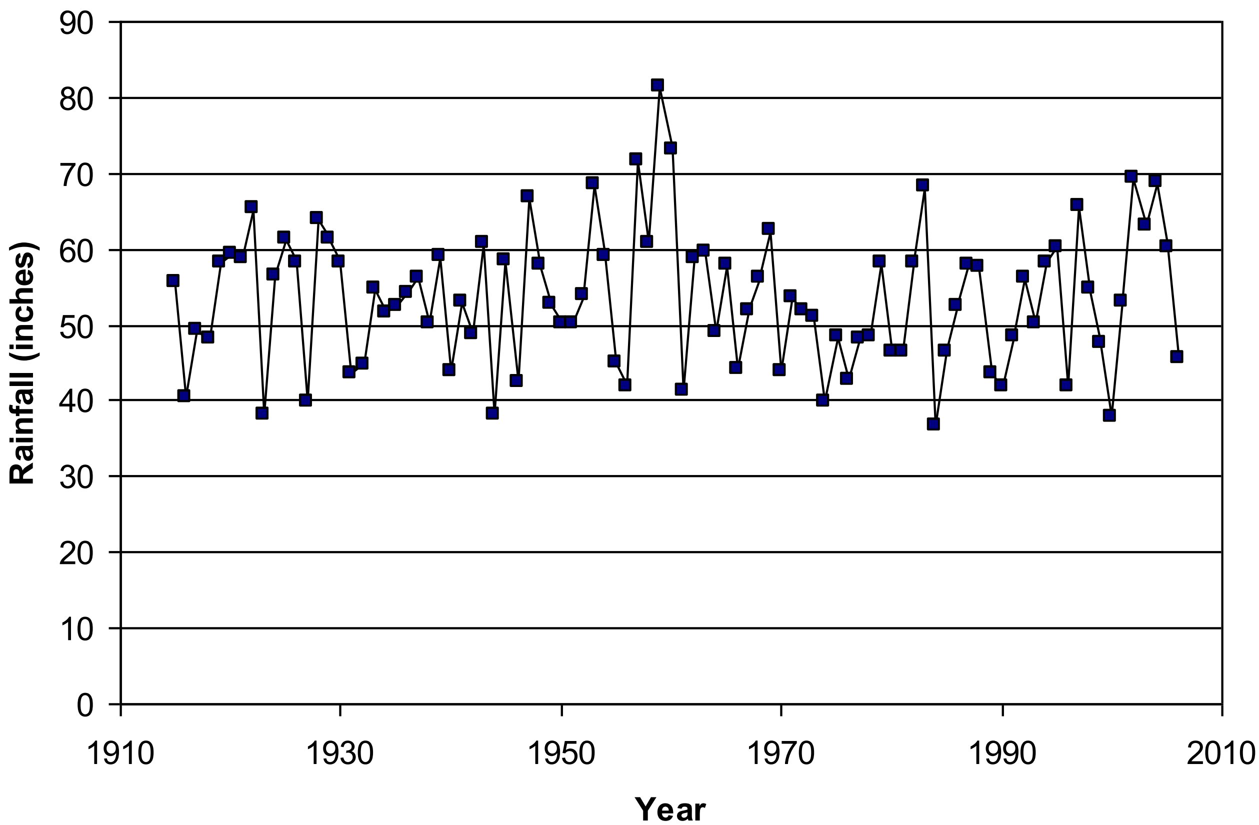
Pamlico Scarp or shoreline (Healy 1975). Elevations in the Gulf Coast lowlands and DeSoto Plain range from sea level to 50 feet.

Elevations in the Little Manatee River watershed are lower and range between 25 and 75 feet. In the vicinity of Wimauma, sand bluffs along the river may reach 75 feet in elevation. Near the town of Fort Lonesome, the river flows over the Bone Valley Member of the Peace River formation. This is the lithologic unit mined for phosphate minerals in the eastern part of the Little Manatee River watershed. The floodplain here has less topographic relief when compared with the mid-reaches of the river and is characterized by scattered wetlands.

○ Climate and Precipitation

The annual average precipitation in the Little Manatee River near Wimauma for the period 1915-2006 was 53.24 inches. The lowest rainfall was 36.70 inches for the year 1984 and 81.45 in 1959 (SWFWMD Water Management Database) (Figure 2-1). Evapotranspiration the Little Manatee River watershed and surrounding areas is approximately 39 inches per year (SWFWMD 1994) and is highest in May and June and nearly 60 percent of the total yearly evapotranspiration occurs between May and October.

Figure 2-1
Total Annual Rainfall for the Little Manatee River (Wimauma Gage)



Climate conditions in west-central Florida are humid subtropical climate. The mean normal yearly temperature for Hillsborough County is 72.2 ^{o}F, generally ranging from a normal maximum temperature of 91 ^{o}F in July and August, to a normal minimum temperature of 49 ^{0}F in January. In a typical year, approximately 60 percent of the annual precipitation comes from convective thunderstorms during the four-month period between June through September. Heavy precipitation periods associated with the passage of tropical low pressure systems occur during summer and early fall.

○ Surface and Ground Water

Water supply issues in the Little Manatee watershed include ground water use, surface water use, development of alternative water supplies, and establishment of minimum flows and levels. Alternative water supply sources are being developed in the Tampa Bay region as part of an approach to reduce/supplement existing ground water supplies and alleviate pressure on the aquifers. Water projects currently being developed in the Tampa Bay region to address future water supply include diverting flows from the Alafia and Hillsborough rivers and the Tampa Bypass Canal, as well as the construction of a reservoir in the Alafia River watershed. The desalination facility adjacent to the Tampa Electric Company (TECO) Big Bend facility in southern Hillsborough County began operation in March 2007.

○ Surface Water

The Little Manatee River is considered the least impacted of the rivers flowing into Tampa Bay. Among the rivers in west central Florida, the Alafia and Little Manatee Rivers have the highest rates of surface water runoff because of soil characteristics and topographic gradients in the respective watersheds (Estevez et al. 1991). There are no records of springs in the Little Manatee River watershed and stream flow and water quality data indicate that dry season flows are significantly supplemented by farm irrigation that is pumped from deep aquifers.

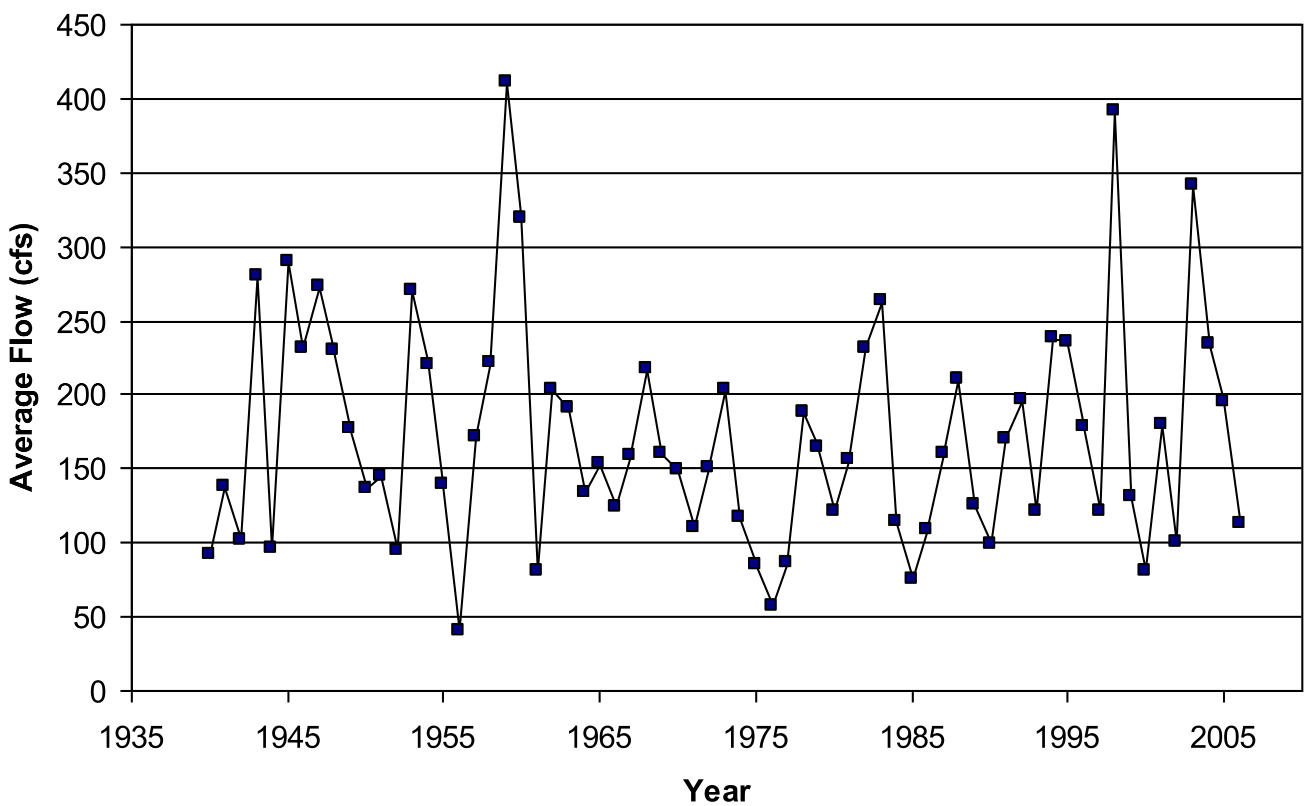
Mean annual flow in the Little Manatee River recorded at the United States Geological Survey (USGS) gage near Wimauma was 171.4 cfs for the period of record from 1940 to 2006 and ranged from about 100 cfs to 300 cfs. Mean annual flows were less than 100 cfs in only 11 of the 67 years measured and exceeded 300 cfs except in 1959, 1960, 1998, and 2003. The highest recorded mean annual flow was 410 cfs (in 1959) and the lowest mean annual flow was 40.2 cfs (1956). Average annual flows measured at the Wimauma gage are graphed in Figure 2-2.

Except for the most upstream portions of the Little Manatee River, the river channel is well-defined, becoming narrow and well-incised along the North and South forks. At the U.S. 301 gage, 15 miles upstream of the river mouth, the river bottom is less than two feet NGVD. About 22 miles upstream, elevations reach 100 feet NGVD. The hydraulic gradients along the tributaries and upstream of U.S. 301 are much steeper when compared with the gradual slope and tidal influence in the river that occur downstream of U.S. 301.

Low recharge to the aquifer in the Little Manatee River and watershed results in relatively large flows during short periods of time due and makes the system “flashy”. Stream flow records and associated land use influences suggest that agricultural practices have increased flows in the river due to excessive irrigation of row crops that subsequently flows off the land and into the river. In contrast, total annual discharge from the watershed decreased from the 1960s to 1990 and coincided with reduced rainfall in southwest Florida. Also as a result of the low recharge, there are few lakes and wetlands in the Little Manatee River watershed below the upper reaches.

The Little Manatee River below State Road 674 has been designated as an Outstanding Florida Water. As such, special permitting criteria are used by the Florida Department of Environmental Protection for activities that might impact the water quality of the river. This section of the river below U.S. Highway 301 is also designated as an aquatic preserve, which has implications for various types of activities on and along the river.

Figure 2-2
Annual Mean Daily Stream Flows for the Little Manatee River (Wimauma Gage)



- **Ground Water**

The Little Manatee watershed is underlain by water-bearing limestones and dolomites of Eocene to Miocene age and covered by a 200-300 foot layer of unconsolidated sands and sandy clays of Pliocene, Pleistocene and Recent origin. The watershed is in the southern ground water basin, and includes the surficial, intermediate and Floridan aquifers. The surficial aquifer is unconfined and varies in composition from clean quartz to clayey sand (Upchurch 1985). The underlying intermediate aquifer is made up of permeable lithologies in the Hawthorne Group, including the lowermost limestone unit (Tampa Member). The intermediate aquifer is a locally important potable water source for domestic wells.

The average thickness of the Floridan aquifer system is approximately 1,100 feet in the Little Manatee River watershed area (Wolansky and Thompson 1987) and is the potable water source for most of the watershed. In the coastal areas, the Floridan aquifer contains high total dissolved solids and is less desirable for potable water and for some agricultural purposes. The surficial aquifer is usually unconfined. Depth to the water table ranges from near land surface along the coast and in flat poorly drained areas to as many as ten feet below land surface on higher sand ridges (SWFWMD 1992). Seasonal fluctuations in the water table are generally less than five feet and are lower in the spring and higher in the summer.

The Upper Floridan aquifer is the principal water bearing unit in the region and ranges from 1,200 to 1,300 feet thick along the Little Manatee River. The Hawthorn Formation forms a clay confining unit approximately 75 to 150 feet thick that restricts the downward movement of water from the surficial layer to the Upper Floridan aquifer and limits recharge to the Upper Floridan aquifer. Karst activity is also limited and few sinkholes and no springs have been identified in the watershed, although artesian flow in coastal wells was apparently common in the past (CBAPMP 1999).

The Little Manatee River is included in the Southern Water Use Caution Area (SWUCA) designated by the SWFWMD based on declines in ground water. Declines in ground water potentiometric surfaces in southern Hillsborough County and northern Manatee County over the past decades have been attributed to a combination of rainfall deficit, low natural recharge, and increased consumptive use.

Agriculture has the largest number of ground water withdrawal permits in the watershed and ground water withdrawals in the southeastern portion of the watershed are primarily used for phosphate mining and associated activities.

○ Topography and Soils

Land surface elevations near the headwaters of the Little Manatee River reach about 125 feet NGVD. Immediately to the west, much of the drainage system crosses a small northern lobe of the DeSoto Plain, and the lower third of the watershed lies in the Gulf Coast Lowlands, where elevations range from sea level to 50 feet NGVD. The two principal tributaries of the river are narrow and well incised, as described previously. The average channel slope for the northern tributary is 0.13 percent in the Fort Lonesome area. Near the USGS stream gauge at U.S. 301, the channel slope of the river becomes gentler and minor tidal fluctuations are observed at the gauge during low flow periods. Along the lower 10 miles, the river channel and floodplain are much wider. Tidal creeks, bayous, and mangrove-dominated islands become prevalent in this river section. Western portions of the watershed are characterized by floodplains that are nearly level to level and gently sloping, while higher, gently rolling areas characterize the central and eastern portions.

Soils in the watershed are typically poorly drained sandy soils with an organic pan that impedes vertical water infiltration and account for the high runoff potential in the Little Manatee River watershed. About 90 percent of the soils have a B/D, C, or D hydrologic soils group (HSG) classification, indicating runoff rather than infiltration. Primary soil associations in the Little Manatee River watershed include the Myakka-Urban land-St. Augustine and Estero-Wulfer-Kesson associations in the coastal areas. These are nearly level, poorly drained black soils commonly found in swamps, tidal marshes and river floodplains. Inland, the prevalent soil types are the EauGallie-Floridana, Myakka-Basinger-Holopaw, Malabar-Wabasso-Bassinger, Myakka Immokalee-Pomello, Myakka Waveland and Waveland-Pomello-Myakka associations. These associations include nearly level and poorly to moderately drained soils characteristic of flatwood areas (USDA/SCS 1983 and 1959).

○ Vegetation

Natural vegetation along the freshwater portion of the Little Manatee River is often characterized by forested swamps along the banks and floodplain transition to hydric and mesic forests of mixed hardwoods and pine. Landward of these, pine flatwoods and scrub and brushlands are common (SWFWMD 1992).

The study area for the District's Resource Evaluation of the Little Manatee River Project for the Save our Rivers (SOR) Program (SWFWMD 1992) begins just down stream of U.S. 301 and extends upstream almost to S.R. 674 and includes the South Fork of the Little Manatee River. Coincidentally, the study corridor for the present area falls within the SOR study area. The SOR report describes the river corridor as predominantly uplands (about 74 percent). Uplands include primarily cropland and pastureland (about 16 percent) and relatively unaltered uplands (16 percent). Uplands include pine flats, shrub and brush lands, and mixed hardwoods and pines.

Forested wetlands and open water and non-forested wetlands make up about 27 percent of the Little Manatee River corridor. Forested wetlands along the river itself include water oaks (*Quercus nigra*), red maple (*Acer rubrum*), sweet gum (*Liquidambar styraciflua*), willows (*Salix* spp.), bays (*Magnolia virginiana* and *Persea palustris*), pop ash (*Fraxinus caroliniana*), and hickories (*Carya* spp.). The understory is usually sparse due to low light penetration. Wet prairies are infrequent to absent in the watershed.

Several agencies have land-acquisition programs in the Little Manatee River watershed, including the Department of Environmental Protection's Conservation and Recreational Lands program, the District's Save Our Rivers and Florida Forever (formerly Preservation 2000 (P2000)) program, and Hillsborough County's Environmental Lands Acquisition and Preservation Program. Some areas along the river corridors have been purchased for flood control, water quality, and habitat protection. Typically, these programs emphasize preservation of natural systems and enhancement/ preservation of water quality. These areas are often flood prone and acquisition serves to prevent development in these natural flood storage areas.

○ Issues

Water supplies for primarily agricultural uses, but also for industrial and municipal uses, have been an issue in recent decades due to increased populations and declining water supplies. Consequently, the watershed is an area of induced recharge due to intense agricultural pumping demands. Ground water withdrawals from the upper Floridan aquifer have lowered the potentiometric surface and intermediate aquifer, creating an induced recharge area. Consequently, special regulatory measures have been developed for the Southern Water Use Caution Area (SWUCA), including the Little Manatee River watershed. Parts of the Little Manatee River watershed are also within the Most Impacted Area (MIA), an area in the SWUCA where no new Floridan aquifer withdrawals are allowed. The SWUCA Information Report provides a concise summary of the history, current conditions and future plans for the SWUCA within the District.

The shift to induced recharge also increases the potential for ground water contamination. The degree of ground water contamination potential in areas of induced recharge depends on both hydrogeologic properties and the rate of ground water withdrawal. Potential pollutant sources in the Little Manatee River watershed include landfills, borrow pits, mining activities, stormwater ponds, septic systems, and urban and agricultural runoff. A detailed discussion of the potential for ground water contamination from man-made byproducts in the Tampa Bay area is presented by SWFWMD (1995).

Surface water use in the watershed, in contrast to ground water, is limited primarily to a permitted withdrawal from the river by FPL. The principal studies related to surface water supplies from the Little Manatee River pertain to the FPL facility. Studies to assess the feasibility of withdrawing cooling water from the Little Manatee River were conducted in the early and mid- 1970s (Brown and Root 1973, FPL 1979) and focused on the impacts of the proposed conversion to orimulsion fuel. The use of orimulsion was not approved by the Florida Cabinet, however, and the findings of the studies were not considered relevant to the existing permit. Consequently, the FPL withdrawal schedule remains as it was initially permitted in 1973.

A hydrobiological study of the Little Manatee River conducted in the late 1980s identified increasing base flow in the main river channel and some tributaries and attributed the increase to excess irrigation water not used by crops (Flannery *et al*. 1991). These findings suggest that there is a considerable amount of water savings that can be accomplished in the watershed through the use of more efficient agricultural water use practices.

• Sampling Methods

An underlying assumption of vegetation classification is that vegetation is the best and most easily measured integrator of environmental and historic site conditions. Sampling methods for this study were designed to provide data needed to characterize the wetlands and associated vegetation and soils along the Little Manatee River. The methods used in transect selection, data collection, and data analyses are described in the following sections.

○ Transect Selection

Ten sampling transects were established along the Little Manatee River study corridor, perpendicular to the river channel, as requested by the District. The first step in assigning transect locations was a thorough review of potential criteria on which to base the selections. The data used to examine potential criteria for selecting transects are listed below.

- Vegetation communities based on NWI and Florida GAP vegetation classification
- U.S. Department of Agriculture/ Soil Conservation Service (SCS) soils classifications and Hydric Soils Groups
- USGS elevation/topography
- USGS water level gage locations
- Aerial photography
- Land use, e.g. historical alterations

NWI and GAP classifications were compared with available aerial photography, soils maps, and field observations. NWI classes were more consistent with aerial photography than GAP classifications in the study corridor, and priority communities were identified in which sampling efforts would be focused. NWI data were subsequently used for mapping and selecting transects. Numbers of acres and corresponding percent of NWI classes in the Little Manatee River study corridor are listed in Table 3-1. A diagram of the distinguishing features of the NWI palustrine vegetation classes are presented in Figure 3-1 for illustrative purposes and are further described in Table 3-2.

Transects and associated NWI vegetation classes for river reaches are mapped in Figure 3-2. Transects were initially numbered in order from upstream to downstream and designated with a prefix of PHABSIM or VEG to identify the transect consistent with the District's instream transects or PBS&J's wetland transects. However, several transects were omitted, added, and/or replaced due to access issues, disturbance, or other issues. Added transects were subsequently assigned the prefix LMAN (Little Manatee transect) or VEG (vegetation transect) and two were named for nearby features (for example, the transect "Masonic" is in the vicinity of Masonic Park).

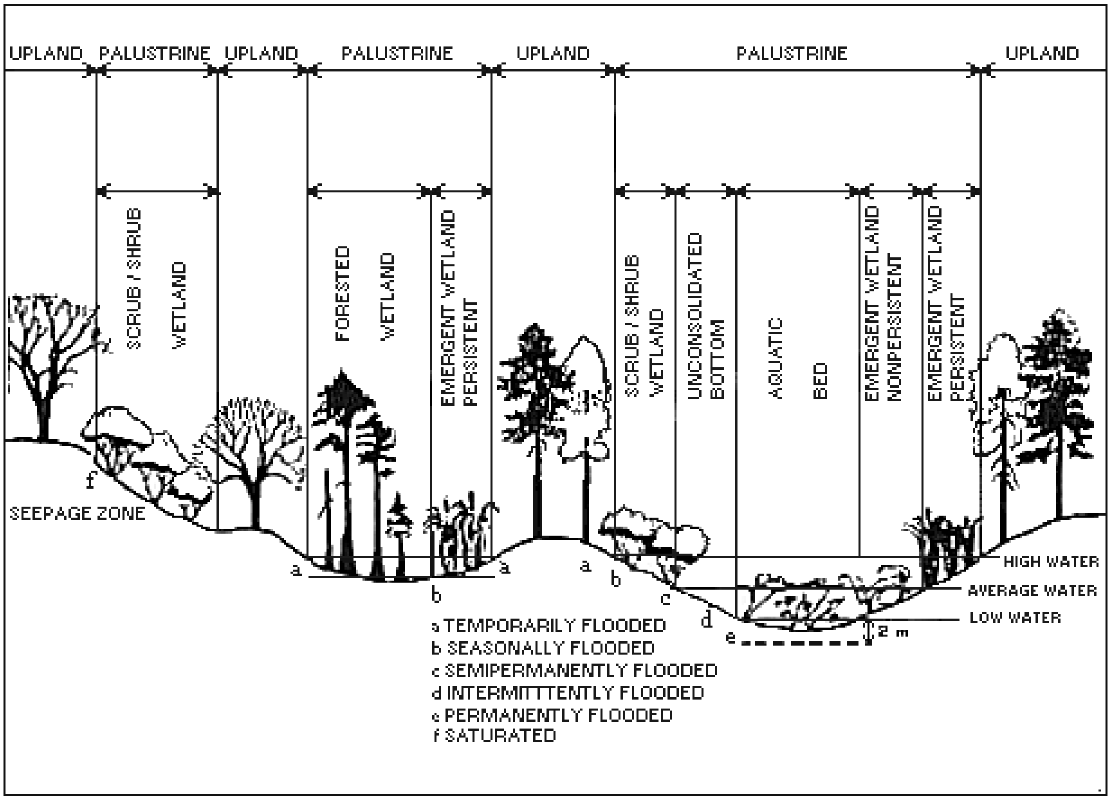
An analysis of the NWI vegetation classes was used as the basis on which to allocate transects among vegetation communities along the river channel. Corridors 500 feet wide were used to quantify the vegetation classes along each transect and identify the dominant vegetation classes along transects. The percent of each NWI vegetation class present along the 10 sampling transects are listed in Table 3-3. Potential transects were assigned in areas characterized by native vegetation, while residential and commercial development were omitted. The vegetation classes identified for this study were based on woody species dominance and generally corresponded with NWI vegetation classes.

NWI mapping indicated broad-leaved deciduous and evergreen tree (P_FO3 or P_FO1) species along all transects and a single transect (in the mid-reach of the study corridor) included an emergent (herbaceous) component. No needle-leaved (e.g. cypress) forested classes were identified in the NWI data. Upstream transects included only temporarily flooded wetlands, while downstream transects included seasonally flooded wetlands.

Table 3-1
Percent Cover of NWI Classes in the Little Manatee River Study Corridor

NWI Classification	Description	Acres	Percent of Total	
			Including Uplands	Excluding Uplands
U	Uplands	2,529	68	-
P_FO3/FO1_C	Palustrine Forested Broad-leaved Evergreen / Broad-leaved Deciduous Seasonally Flooded	456	12	38
P_FO1/FO3_C	Palustrine Forested Broad-leaved Deciduous / Broad-leaved Evergreen Seasonally Flooded	202	5	17
P_FO1/FO3_A	Palustrine Forested Broad-leaved Deciduous / Broad-leaved Evergreen Temporarily Flooded	150	4	12
P_FO3/FO1_A	Palustrine Forested Broad-leaved Evergreen / Broad-leaved Deciduous Temporarily Flooded	143	4	12
Additional classes and subclasses	Additional Palustrine Forested, Emergent, and Scrub-shrub classes and subclasses and combinations; each no more than 1 percent.	255	7	21
Total		3,735	100	100

Figure 3-1
Distinguishing Features and Examples of Habitats in the Palustrine System



*After Cowardin, L. M., V. Carter, F. C. Golet, E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/ resource/ 1998/ classwet/classwet.htm (Version 04DEC98).

Table 3-2
Descriptions of Florida NWI Classifications in the Little Manatee River Study Corridor

NWI Class		Class Description
P_ **Palustrine** (no further classification)		Nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and same wetlands in tidal areas with ocean-derived salinity < 0.5 ‰. Includes wetlands lacking such vegetation, but with (1) area < 20 acres; (2) no active wave-formed or bedrock shoreline features; (3) deepest water depth < 2 m at low water; and (4) salinity less than 0.5 ppt.
P_EM **Palustrine Emergent**		These wetlands are usually dominated by perennial plants. Characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens that are present for most of the growing season in most years. Vegetation types may include: grasses, bulrushes, spikerushes and various other marsh plants such as cattails, arrowheads, pickerelweed and smartweeds. Subclasses: persistent and nonpersistent
P_FO Palustrine Forested		Woody vegetation greater than 6 meters (20 feet) tall. Species include both broad and needle leaved deciduous and evergreen categories, e.g. red maple, ash, willows, dogwoods, cypress.
	_4 ***Needle-leaved Evergreen***	Species dominating this class may include slash (*Pinus elliottii*) and long leaf (*P. palustris*) dominate this palustrine forested class. Spruce, pond pine, red cedar (*Juniperus virginiana*), and more rarely, Atlantic white cedar (*Chamaecyparis thyoides*) are other needle-leaved evergreens in Florida.
	_6 ***Indeterminate Deciduous***	This class may include a mix of broad-leaved and needle-leaved deciduous trees such as slash pine, oak, popash, maple, and others. This general description may be due to the difficulty in identifying species as broad-leaved or needle-leaved in aerial photography taken when leaves are absent.
	_7 ***Indeterminate Evergreen***	This class may include a mix of broad-leaved and needle-leaved evergreen trees such as slash pine, cabbage palm, oak, and others. This general terminology may be due to the difficulty in identifying species in aerial photography or timing of photography.
Hydrologic Modifiers For Classes and Subclasses (see Figure 3-1 for further detail)		
A		Temporarily Flooded
F		Saturated
C		Seasonally Flooded
D		Seasonally Flooded/Well Drained
E		Seasonally Flooded/Saturated
F		Semi-permanently Flooded

NWI Class	Class Description
H	Permanently Flooded

Figure 3-2
Transect Locations and Vegetation along the Little Manatee River Study Corridor (based on data from the NWI)

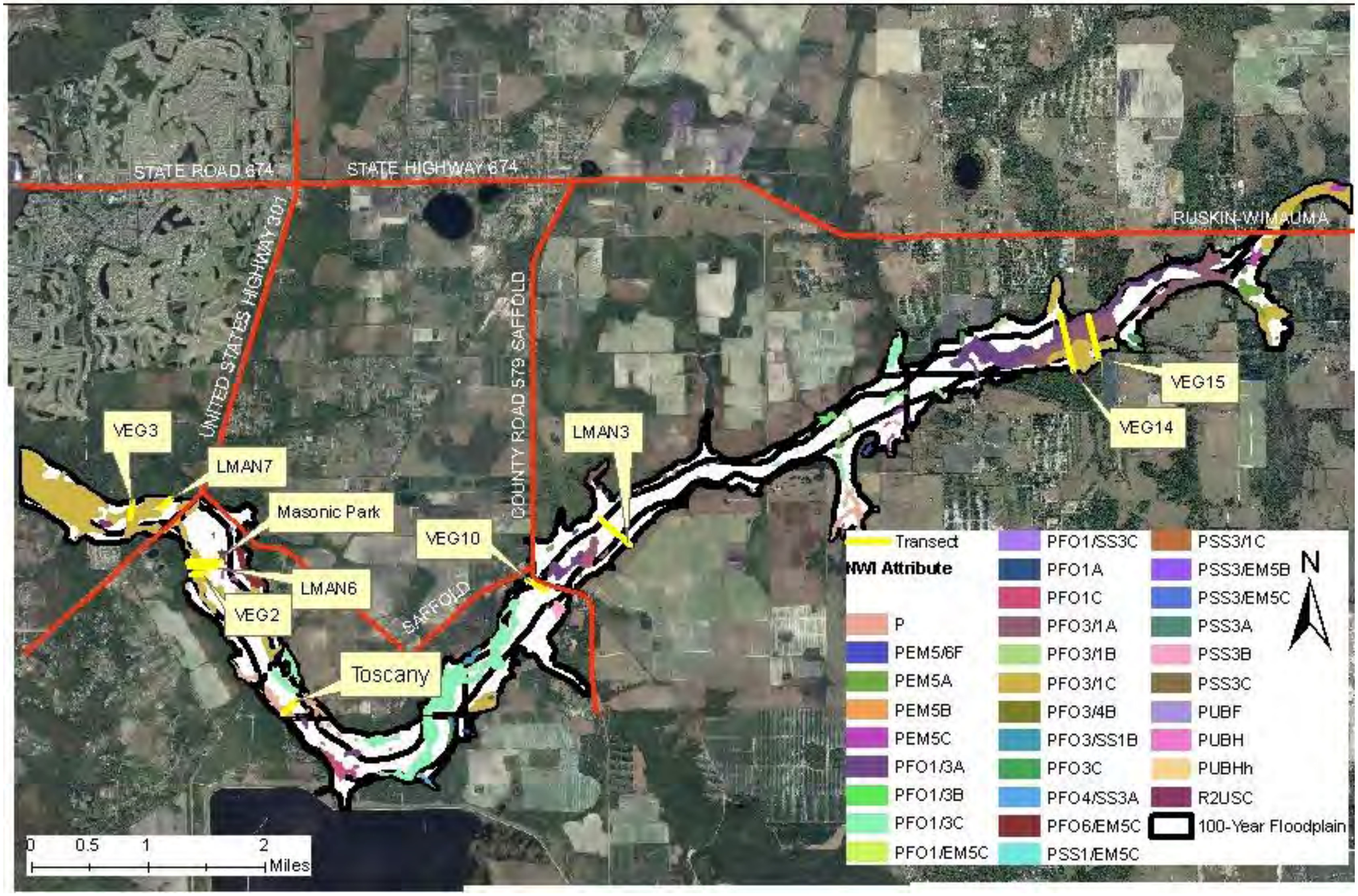


Table 3-3
Percent Cover by NWI Class and Transect in the Little Manatee River Study Corridor

Transect		Upland	Wetlands				
			Palustrine Forested (P_FO)			Palustrine Emergent (P_EM)	Palustrine, not classified further (P)
			Broad-leaved deciduous (1) or evergreen (3)				
			Temporarily Flooded (A)		Seasonally Flooded (C)		
	NWI Class	U	P_FO3/1A	P_FO1/3A	P_FO3/1C	P_EM_C	P
	VEG15	22.5	53.9	10.9	12.8		
	VEG14	27.0	16.2	22.2	34.6		
Upstream	LMAN3	100.0					
	VEG10	65.3				34.7	
	Toscany	60.0					40.0
↓	VEG2	29.6			70.4		
Downstream	LMAN6	51.9			48.1		
	Masonic	64.3			35.7		
	LMAN7	62.2			37.8		
	VEG3	43.2			56.8		

○ Elevation Surveys and Distance to Channel

The landward extent of wetlands along sampling transects generally coincided with the FEMA-designated 100 year floodplain. Transects were subsequently located to include the area between 100 year floodplain elevations on the north and south sides of the river channel. Elevations were surveyed at 50-foot intervals along transects and more frequently where changes in elevation were conspicuous. Distances from the center of the river channel were recorded as reference points for pairing with vegetation and soils data. Beginning and ending points for each change in plant community were recorded to evaluate the potential influence of distance from channel on vegetation communities. Elevation data were plotted against distances along transects.

Hydrologic indicators of ordinary high water, buttressing, lichen lines, moss lines, and stain lines on trees were also recorded if found along transects. Height of the indicator from the ground surface was measured and included in the elevation surveys.

o Vegetation Characterization

Vegetation class (plant community) identification, nomenclature, and characterization in the study corridor were based on plant species importance. Based on NWI-designated wetlands (Table 3-1), upstream transects were drier (temporarily flooded), compared with seasonally flooded wetlands farther downstream. Upstream transects VEG15 and VEG14 included both evergreen and deciduous broad leaved, forested wetlands and a mix of the evergreen and deciduous species.

The five downstream transects (VEG2, LMAN6, Masonic, LMAN7, and VEG3) included only the mix of evergreen and deciduous broad leaved forested wetlands. The seasonally flooded emergent vegetation class was included in NWI data only along Transect VEG10 at the mid-reach of the river. Also in the mid-reaches of the river, NWI data indicated palustrine wetlands along the Toscany transect, but did not further differentiate any of the vegetation. A single transect, LMAN3, had no wetlands along the transect (based on NWI data). Vegetation classes were further differentiated by dominant species identified during sampling along individual transects. Individual subclasses that made up no more than one percent of the study corridor comprised 255 acres and included palustrine forested, emergent, and scrub-shrub subclasses. None of these classes occurred along sampling transects.

While these NWI classes were adequate for identifying general vegetation classes for sampling purposes, they were considered too broad for the level of community characterizations in this study. Boundaries between communities were identified in the field using a combination of indicators, including, but not limited to the following:

- General community type (e.g. wetland to upland)
- Species cover (e.g. popash to oak, obligate wetlands to facultative wetlands)
- Elevation (e.g. scarp presence)
- Soils (e.g. hydric or nonhydric)

Subsequently, a general method of vegetation class nomenclature was developed based on species dominance (below).

- Vegetation classes with greater than 40 percent tree cover were designated based on dominant tree species (Cowardin *et al*. 1979)
- Species dominance was used to further refine classes using importance values (IVs) of tree species, an index that combines relative density, frequency, and basal area of tree species

Sampling plots were located randomly along transects in each vegetation class and the point-centered-quarter (PCQ) sampling method (Mueller-Dombois and Ellenberg 1974) was used to characterize the vegetation. A minimum of three plots from each vegetation class was sampled at each change in dominant species. Density, basal area, and IV were calculated for each tree species, by transect and vegetation class. Density, basal area, and relative dominance values were calculated for each tree species, by transect and vegetation class:

- Density/ 100 square meters = 100/(average measured distance, in meters)^2

- Basal area = basal area of individual trees (cm^2)
- Dominance = (relative density) (basal area, in cm^2)

○ Soils Characterization

The U.S. Army Corps of Engineers (USACE) Wetlands Delineation Manual defines a hydric soil as one that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part. These definitions were used in evaluating soils.

Under saturated or flooded conditions that are anaerobic for part of the growing season, soil profiles usually acquire unique characteristics that can be relied upon as positive indicators of hydric conditions. Most organic soils (histosols) are hydric, and the extent of decomposition of organic plant materials can be used to classify these soils as muck (highly decomposed remains of plants and other organisms), peaty muck, mucky peat, and peat (partially decomposed remains of plants and other organisms).

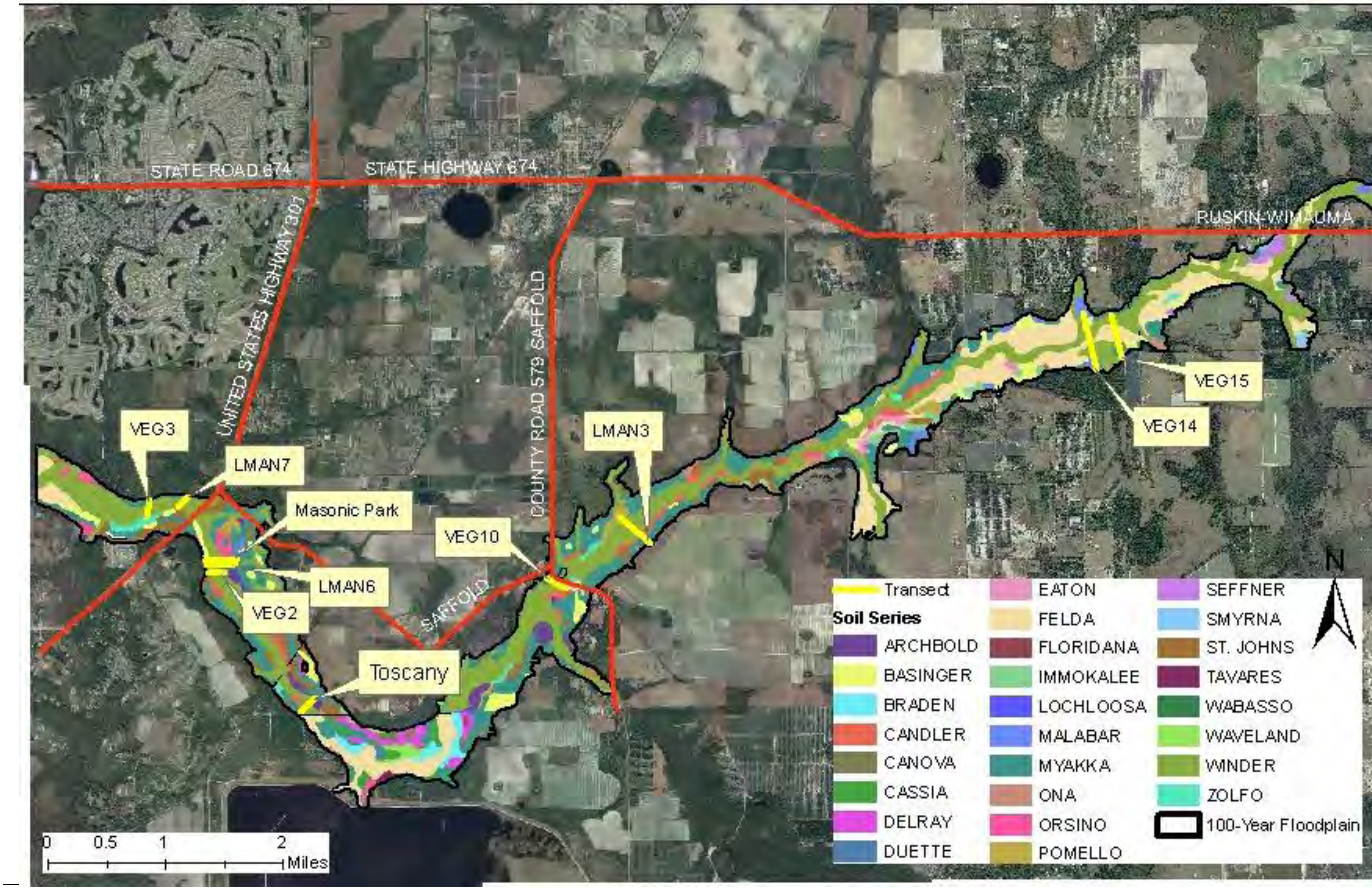
Soils data along the Little Manatee River study corridor (USDA/NRCS 1996) are mapped in Figure 3-3. Soils along the Little Manatee River are typically poorly drained sandy soils characteristic of flatwoods and primary soil associations in the Little Manatee River watershed were described earlier (Section 2). The Winder soils series is the dominant soil type along the river and are very deep, poorly drained, slowly to very slowly permeable soils on broad, low flats and depressional areas that formed in loamy marine sediments on the Lower Coastal Plain. The two upstream transects (VEG14 and VEG15) occur in an area of Felda soils in addition to the Winder soils. Felda soils are very deep, poorly drained and very poorly drained, moderately permeable soils in drainageways, sloughs and depressions, and on flood plains and low flats. These soils formed in stratified, unconsolidated marine sands and clays

Flatwoods soils, like those along the study corridor, generally have an organic pan that impedes vertical water infiltration. About 90 percent of the soils in the Little Manatee watershed have a B/D, C, or D hydrologic soils group (HSG) classification, indicating high runoff potential rather than infiltration of water into the soils. These soils are mineral, rather than organic, and consist primarily of sand, silt, and/or clay sized particles of minerals or rock fragments rather than being dominated by organic materials. Wetland conditions associated with mineral soils typically have:

- Histic epipedon (organic surface horizon)
- Hydrogen sulfide odor and other sulfidic material
- Aquic conditions (oxygen-deficient soil saturation)
- Soil series on hydric soil lists
- Redoximorphic features such as gleyed soil matrix color, low chroma matrix color with or without bright mottling and segregated iron and manganese concretions

Evidence in soil profiles can also be used as an indication of flooding in soils that may not be hydric. Importantly, hydric soils are used in characterizing wetlands, not river channels in which organics are washed downstream. For example, flooded river banks that have a high sand content

Figure 3-3
Transect Locations and Soils along the Little Manatee River Study Corridor



and occur at elevations high enough that flooding is infrequent generally have nonhydric soils, but show signs of flooding such as thin strata of gravel, sand, silt, or clay deposited by flood waters. Other evidence of flooding includes cypress buttressing, moss collars, lichen lines, and water stains.

Soil cores were examined for each sampling point along each transect. Soil cores were exhumed with a shovel. The presence of hydric or flooding indicators, as well as saturation and/or inundation conditions were evaluated and recorded. The soil profile was examined to a minimum depth of 50 cm (20 inches). In addition, several indicators described in the *Hydric Soil Delineation Indicators* (A5-A9, S5-S6) were evaluated and recorded: a numeric code of “0” was recorded if a characteristic was absent, and a “1” was recorded if the characteristic was present. Soils data were subsequently paired with vegetation and elevation data for analysis.

Once soils data were compiled, hydric indicators were assigned a composite soil index for each core sampled. As noted previously, some soils have evidence of flooding, e.g. sandy and steep river banks, although the soils may not show indications of hydric conditions. Consequently, soils with no evidence of wetland indicators (uplands) were given a soils index of zero. In contrast, saturated hydric soils received a maximum value of three. Soils indices were assigned as described below.

0 = soil showed no evidence of flooding or hydric conditions
1 = hydric soils
2 = soil was hydric with muck
3 = soil was hydric and saturated

○ Data Analysis

Elevation, soils, and vegetation data were compared among and between vegetation classes identified in the river corridor. Statistical analyses were performed using SAS statistical software (Cary NC 1998). Hydrologic flow analyses were performed by the District and used to characterize inundation conditions based on median elevations of vegetation classes and were not part of the present study.

▪ Elevations and Wetted Perimeter

Ground elevation data (feet NGVD) were used to compare vegetation, soils, and distance from channel among transects. Normalized (relative) elevations were calculated as the difference between the transect elevations and the river bottom to account for variation due to downstream-upstream elevation gradients.

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. Wetted perimeter changes, relative to changes in elevation, were compared using the Kruskal Wallis test, a nonparametric analog to a one-way analysis of variance (ANOVA).

▪ Vegetation and Soils

Relationships between vegetation classes and corresponding environmental parameters were examined for this study to ascertain whether there were differences in:

- Species composition and dominance between or among vegetation classes
- Elevation, soils, and distance from channel between or among vegetation classes

Plant species IVs were calculated for woody species in vegetation classes along sampling transects. Due to small sample size (N = 10 transects, N = 9 vegetation classes) and non-normal data distributions, nonparametric statistics were applied to comparisons of species dominance between vegetation classes. The Kruskal Wallis test was used to measure the difference (or lack of difference) in species dominance among vegetation classes. The Wilcoxon Signed Rank test (a nonparametric analog to the paired-t test) was used to evaluate differences in species importance (or “dominance”) between individual communities, for example differences in species dominance between willow marsh and hardwood swamp vegetation classes.

The sample size for comparisons of elevation and soils among vegetation classes was relatively large and a parametric discriminant function analysis (DFA) was used to quantify the contribution of elevation, soils, and distance from river channel in defining vegetation classes, based on relationships between environmental variables and species composition and dominance along sampling transects. A “successful” DFA is one that results in correct pairing of vegetation types and environmental parameters into vegetation classes. P-values indicate the significance of a relationship, e.g. the ability to predict a vegetation class using elevation, while r^2 values indicate the amount of variation in vegetation classes accounted for by each variable.

• Results and Discussion

The relationships among vegetation classes and environmental variables along the Little Manatee River study corridor were evaluating using DFA. Elevations, soils, and distance to channel were significant in characterizing environmental conditions of vegetation classes along the river, although there was overlap among vegetation classes that was associated with similar measures of elevation, soils, and/or distance to river channel.

○ Elevations

River channel elevations declined dramatically downstream along the Little Manatee River, from 38.0 feet NGVD (Toscany) to 0.1 feet NGVD at the VEG3 transect farthest downstream (just east of U.S. Highway 301), a change in elevation of approximately 38 feet over about 12 miles (0.3 feet/mile) (Table 4-1 and Figure 4-1). In contrast, elevation changes along transects ranged from 11.6 to 22.8 feet over a half mile or less (22.4 feet/mile). For illustrative purposes, the elevation profile and associated vegetation along the Masonic transect are graphed in Figure 4-2 and all 11 transects are graphed individually in Appendix A.

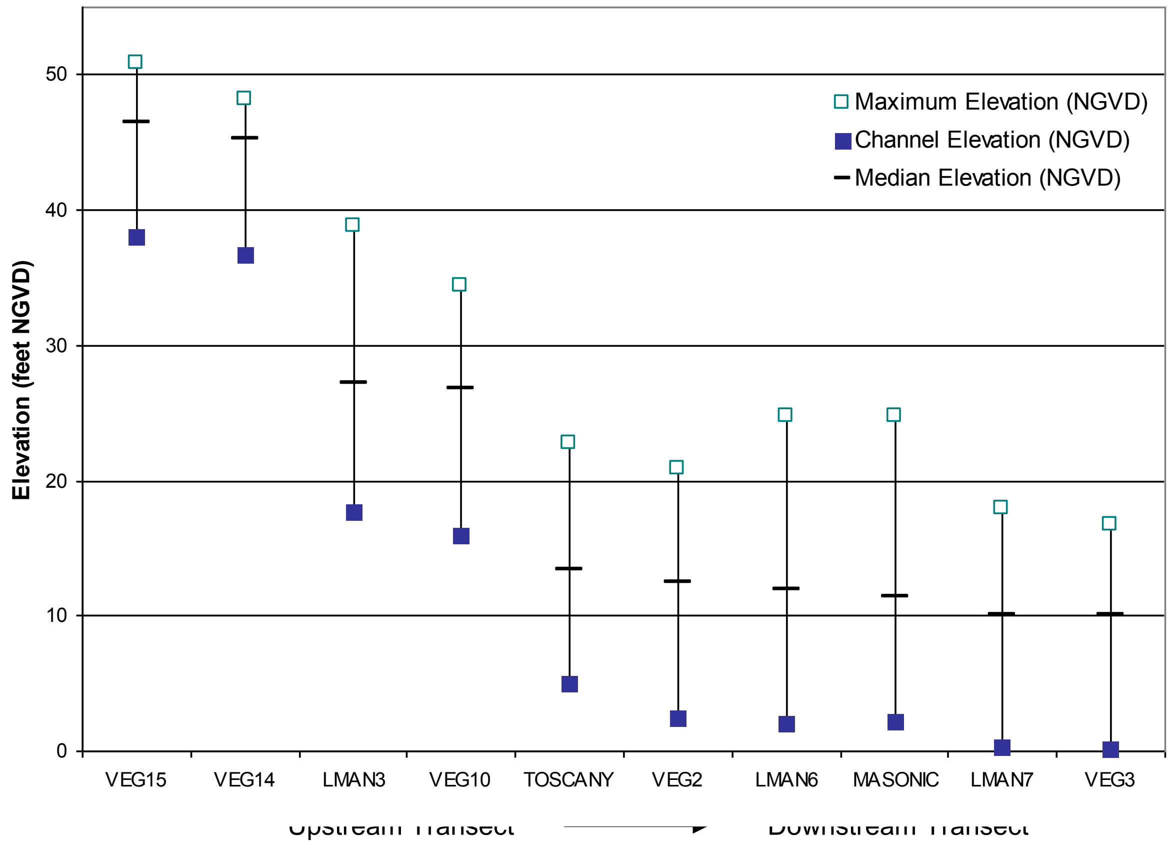
Channel elevations decreased from 38.0 and 36.6 feet NGVD at upstream transects VEG15 and VEG14 to 17.7 and 15.9 feet NGVD at the next two downstream (LMAN3 and VEG10). Median relative elevations (elevation relative to channel bottom) ranged from 8.5 to 10.9 feet. Changes in elevation along the two most upstream transects were only 11.6 to 12.8 feet, while elevation changes along the more downstream transects ranged from to 16.6 feet to 22.8 feet.

Table 4-1
Elevation and Distance along the Little Manatee River Transects

Transect		Transect Distance (feet)	Maximum Elevation (NGVD)	Channel Elevation (NGVD)	Maximum Elevation Change	Median Elevation (NGVD)	Median Relative Elevation	N
Upstream ↓ Downstream	VEG15	2025	50.8	38.0	12.8	46.5	8.5	98
	VEG14	2665	48.2	36.6	11.6	45.2	8.6	109
	LMAN3	1857	38.8	17.7	21.1	27.1	9.4	108
	VEG10	994	34.4	15.9	18.5	26.8	10.9	58
	TOSCANY	950	22.8	5.0	17.8	13.4	8.4	82
	VEG2	749	20.9	2.4	18.5	12.4	10	66

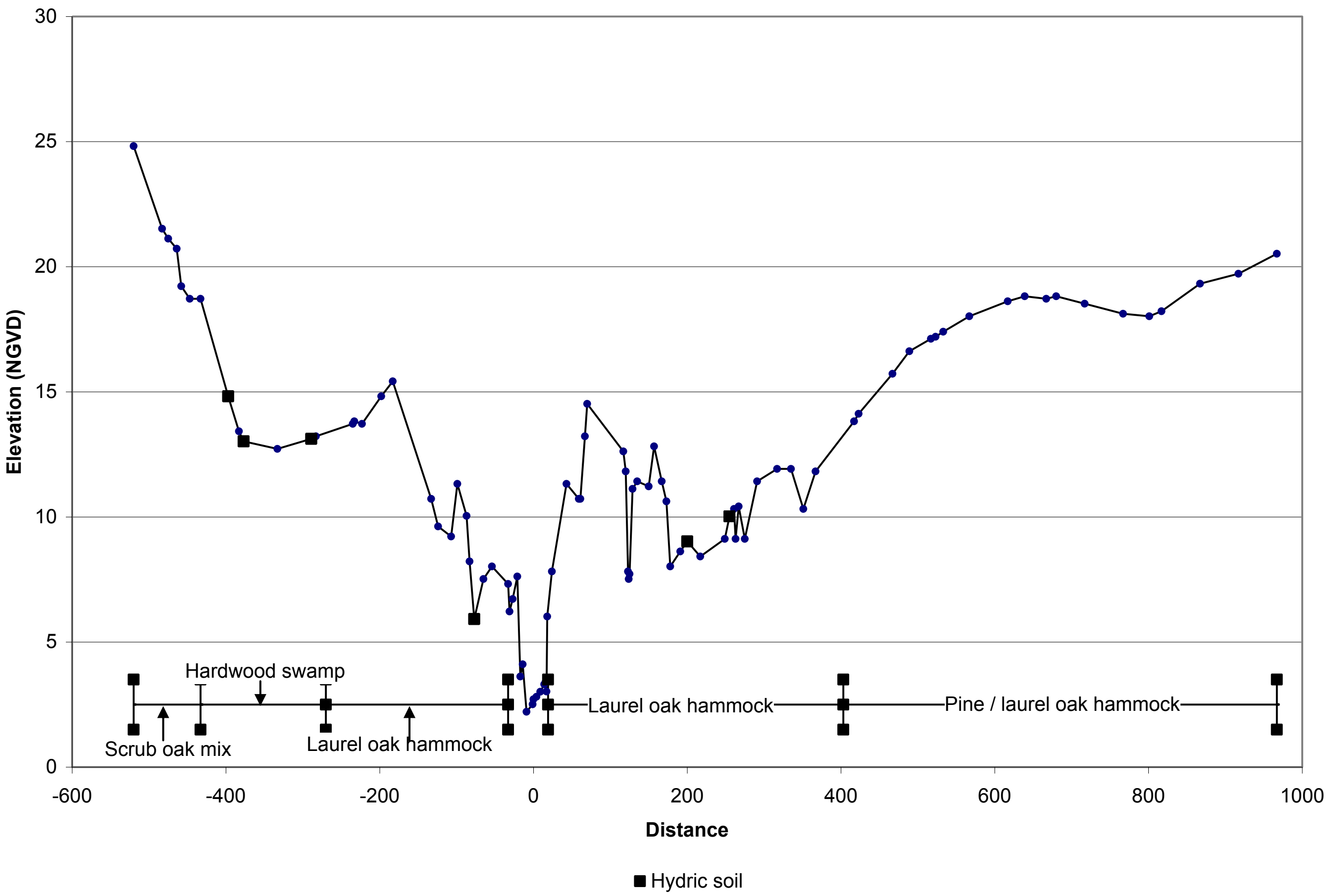
	LMAN6	1350	24.8	2.0	22.8	11.9	9.9	93
	MASONIC	1487	24.8	2.2	22.6	11.4	9.2	93
	LMAN7	720	17.9	.3	17.6	10.0	9.7	51
	VEG3	771	16.7	.1	16.6	10.0	9.9	47

Figure 4-1
Channel Bottom, Maximum, and Median Elevations along Transects in the Little Manatee River Study Corridor



Changes in vegetation were more conspicuous along study transects than along the upstream – downstream river channel gradient and may reflect the steeper elevation change along transects when compared with the upstream to downstream elevation gradient. Wetland vegetation communities occurred along the upstream (VEG15, VEG14, and LMAN3) and downstream (Masonic, LMAN7, VEG3) transects, and were absent along the mid-reach (VEG10, Toscany, VEG2, and LMAN6) study transects. No upland classes occurred along the five most upstream transects.

Figure 4-2
Elevation and Vegetation Profile along the Masonic Transect in the Little Manatee River Study Corridor



○ Soils

The soils along the Little Manatee River (refer back to Figure 3-3), like other rivers in southwest Florida, are part of the southwestern flatwoods physiographic district developed on rocks and sediments primarily from the Miocene to Pleistocene age (Myers and Ewel 1990). These soils are dominated by sand, limestone, and clay (USDA/ SCS 198) rather than organic materials. These contrast with soils along the St. Johns and Wekiva rivers in the eastern flatwoods physiographic district which originated along a series of barrier islands. Soils of the eastern flatwoods district are primarily sandy with significant peaty deposits that indicate extreme anaerobic conditions, saturation for at least 30 consecutive days in most years.

FDEP, under FAC Chapter 62-340.550 (Delineation of the Landward Extent of Wetlands and Surface Waters), indicates that inundation for at least seven consecutive days or saturation for at least twenty consecutive days annually constitutes long term hydrologic conditions necessary for the maintenance of hydric soils. Thus, the minimum period of inundation to maintain hydric soil conditions is shorter than that required to exclude upland vegetation, which may be as little as two weeks.

Hydric soils were found along nine of the 10 study transects and in all vegetation classes except the scrub oak class. Muck soils were found at all transects (Figures 4-3 and Table 4-2). The tupelo swamp and hardwood swamp classes were the only classes with exclusively hydric soils. Median elevations of hydric soils were lower when compared with nonhydric soils (Wilcoxon Signed Rank; S = 52.5, $p < 0.0001$). Elevation differences between hydric and nonhydric soils ranged from 0.3 to 0.9 feet at the two most upstream transects to a difference of about seven feet at mid-reach transects (VEG10, VEG2, LMAN6) to a difference of about three feet at the two most downstream transects. Both hydric and nonhydric conditions occurred in many vegetation classes, although hydric soils still occurred at lower elevations when compared with nonhydric soils in all but one instance (laurel oak hammock class).

Figure 4-3
Median Elevations of Hydric and Nonhydric Soils along the Little Manatee River Study Corridor

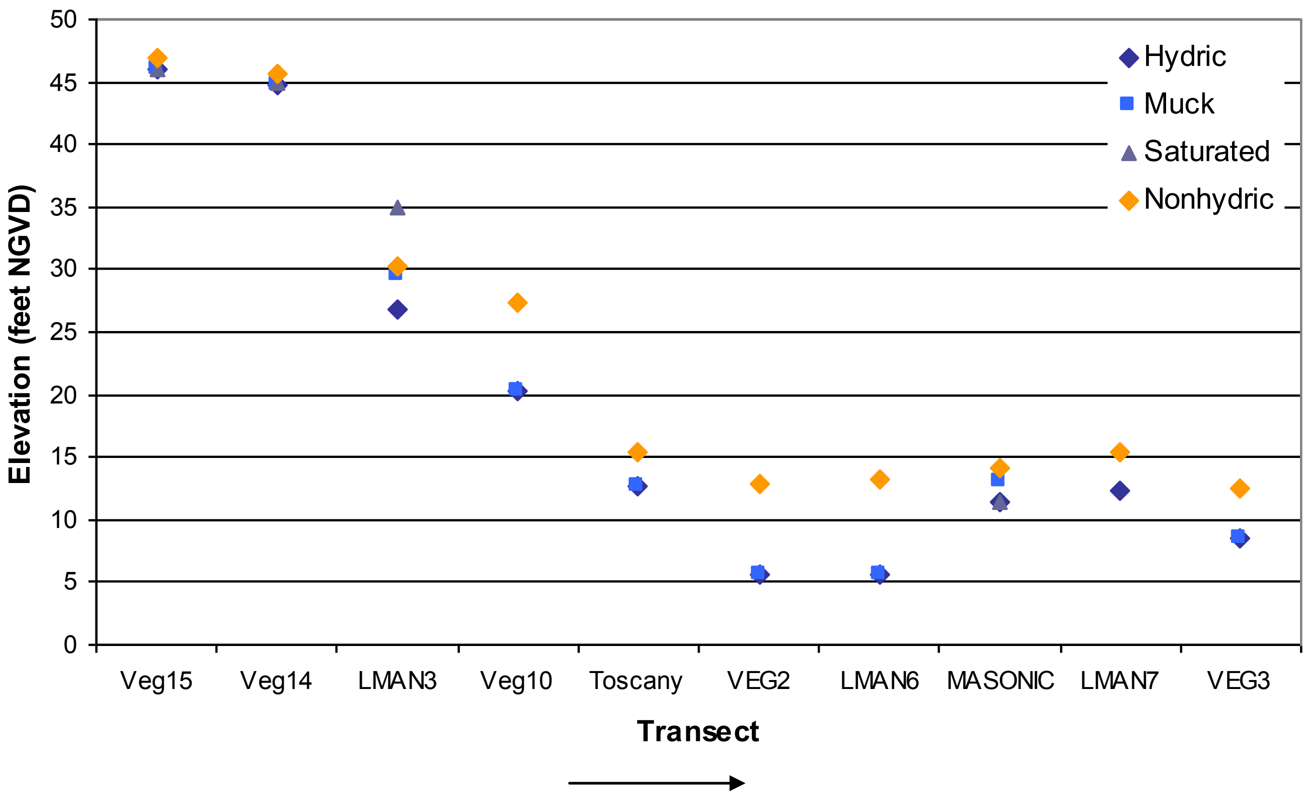


Table 4-2
Median Elevations (feet NGVD) of Hydric, Muck, and Saturated Soils along Transects in the Little Manatee River Study Corridor *

	Transect	Hydric		Not Hydric		Muck		Not Muck		Saturated		Not Saturated	
Downstream ⟵ Upstream	VEG15	46.3	(10)	46.9	(19)	46.3	(10)	46.9	(19)	46.3	(7)	46.6	(22)
	VEG14	44.8	(7)	45.7	(26)	44.8	(6)	45.6	(27)	44.9	(3)	45.5	(30)
	LMAN3	26.8	(9)	30.2	(10)	30.2	(4)	28	(15)	34.9	(1)	28.1	(18)
	VEG10	20.3	(6)	27.3	(11)	20.3	(6)	27.3	(11)			26.8	(17)
	Toscany	12.6	(3)	15.4	(12)	12.6	(3)	15.4	(12)			14.6	(15)
	VEG2	5.6	(1)	12.9	(9)	5.6	(1)	12.9	(9)			12.8	(10)
	LMAN6	5.6	(1)	13.2	(21)	5.6	(1)	13.2	(21)			13.2	(22)
	MASONIC	11.5	(6)	14.1	(15)	13.0	(5)	13.9	(16)	11.5	(2)	13.7	(19)
	LMAN7	12.3	(1)	15.4	(6)			15	(7)			15	(7)
	VEG3	8.6	(3)	12.5	(6)	8.6	(3)	12.5	(6)			11.2	(9)

* Shaded cells indicate absence of conditions. Numbers in parentheses are N.

○ Vegetation Relationships

Differences in vegetation classes along the Little Manatee River study corridor were significant based on importance values (IVs) that were calculated using tree species density, basal area, and frequency and provide a relative measure of species dominance (no units).

○ Vegetation Classes

Nomenclature. Vegetation classes identified for this study were consistent with, although more specific than, the NWI vegetation classes initially used to map vegetation along transects. The NWI classification system does specifically address cabbage palm, while authors such as Myers and Ewel (1990) recognize its importance in Florida systems. In addition, the presence of popash is better addressed by NWI than by the SCS.

The species-specific designations used in this study were retained so that they could be easily combined into a more general context or class. While the NWI classes were too general for use in this study, the

NWI flooding component may be useful in addressing MFLs. Forested wetlands along the river are seasonally or temporarily flooded, rather than permanently or semi-permanently flooded, consistent with NWI and SCS mapping.

Class Comparisons. Comparisons between vegetation classes based on IV indicated significant differences between vegetation classes for all comparisons (Table 4-3). For example, when species IVs were compared between the willow marsh (first row heading) and the hardwood swamp (second column heading), the S-value (22.5) is significant at the $p < 0.01$ level, which means that the probability that two vegetation classes are the same is less than one percent.

Table 4-3
Wilcoxon Signed Rank Test (S Values) for Comparisons between Vegetation Classes along the Little Manatee River Study Transects

Vegetation Class	Vegetation Class								
	Permanent – Semi-permanent Wetlands			Transition to Uplands			Uplands		
	Willow Marsh	Tupelo Swamp	Hardwood Swamp	Pine / Laurel Oak Hammock	Laurel Oak / Pine Hammock	Pine / Maple Hammock	Laurel Oak Hammock	Palm Hammock	Oak Scrub
Willow Marsh		7.5*	22.5***	18.0***	27.5***	85.5***	138.0***	18.0***	60.0***
Tupelo Swamp			18.0***	14.0**	18.0***	68.0***	150.0***	27.5***	52.5***
Hardwood Swamp				27.5***	33.0***	85.5***	150.0***	27.5***	52.5***
Pine/ Laurel Oak Hammock					27.5***	95.0***	150.0***	27.5***	60.0***
Laurel Oak/ Pine Hammock						76.5***	138.0***	33.0***	60.0***
Pine Maple Hammock							175.5***	85.5***	105.0***
Oak Hammock								150.0***	175.5***
Palm Hammock									52.5***
Oak Scrub									

***p < 0.01; **p < 0.05; *p < 0.1

Comparisons of vegetation classes with themselves (such as willow marsh with willow marsh) were unnecessary and consequently, these cells were left empty. Likewise, repeated comparisons (willow marsh row with tupelo swamp column v. tupelo swamp row with willow marsh column) were also left empty.

IVs of individual species for each of these vegetation classes are summarized in Table 4-4 and illustraged in Figure 4-4. The IVs provide a relative measure of species dominance (no units) and were calculated using tree species density, basal area, and frequency, as described previously.

Based on vegetation classes and species composition and IVs, three wetland vegetation classes were identified in the study corridor. The classes included only obligate and facultative wetland tree species, including Carolina willow (*Salix carolinana*), tupelo (*Nyssa sylvatica*), sweet bay or swamp bay (*Magnolia virginiana*), water oak (*Quercus nigra*), and popash (*Fraxinus caroliniana*). These classes (below) included six or fewer species.

- Willow marsh: comprised exclusively of the obligate wetland species Carolina willow, with smaller components of popash and holly (Ilex cassine).
- Tupelo swamp: characterized by only two tree species, primarily swamp tupelo (obligate wetland species), in addition to a small component of slash pine (facultative wetland).
- Hardwood swamp: included six species and characterized by predominantly swamp bay (obligate) and water oak (facultative wetland).

Transition vegetation classes (between wetlands and uplands) were characterized by predominantly facultative wetland species such as laurel oak (*Q. laurifolia*) and slash pine (*Pinus elliottii*) in combination with other facultative species. The transition classes (below) included six to 23 different species.

- Laurel oak/ pine hammock: characterized by primarily laurel oak with a smaller component of slash pine, but also included the obligate wetland species American snowbell (*Styrax americanus*) and two upland species.
- Pine/ laurel oak hammock: dominated by slash pine, but otherwise similar in composition to the laurel oak/pine hammock.
- Pine/ maple hammock: differed from the laurel oak/pine and pine/ laurel oak classes due to a large red maple and water oak components that were small to absent in the other transition classes. This class also includes eight upland species, compared with less than three in the pine/ laurel oak and laurel oak/pine classes.
- Oak hammock: primarily laurel oak, but also a relatively large component of live oak (*Q. virginiana*). This class had the largest number of different tree species (23) when compared with the other classes, although like the other transition classes, it included primarily obligate and facultative wetland species.

Table 4-4
Importance Values for Tree Species in Vegetation Classes along the Little Manatee River Study Corridor*

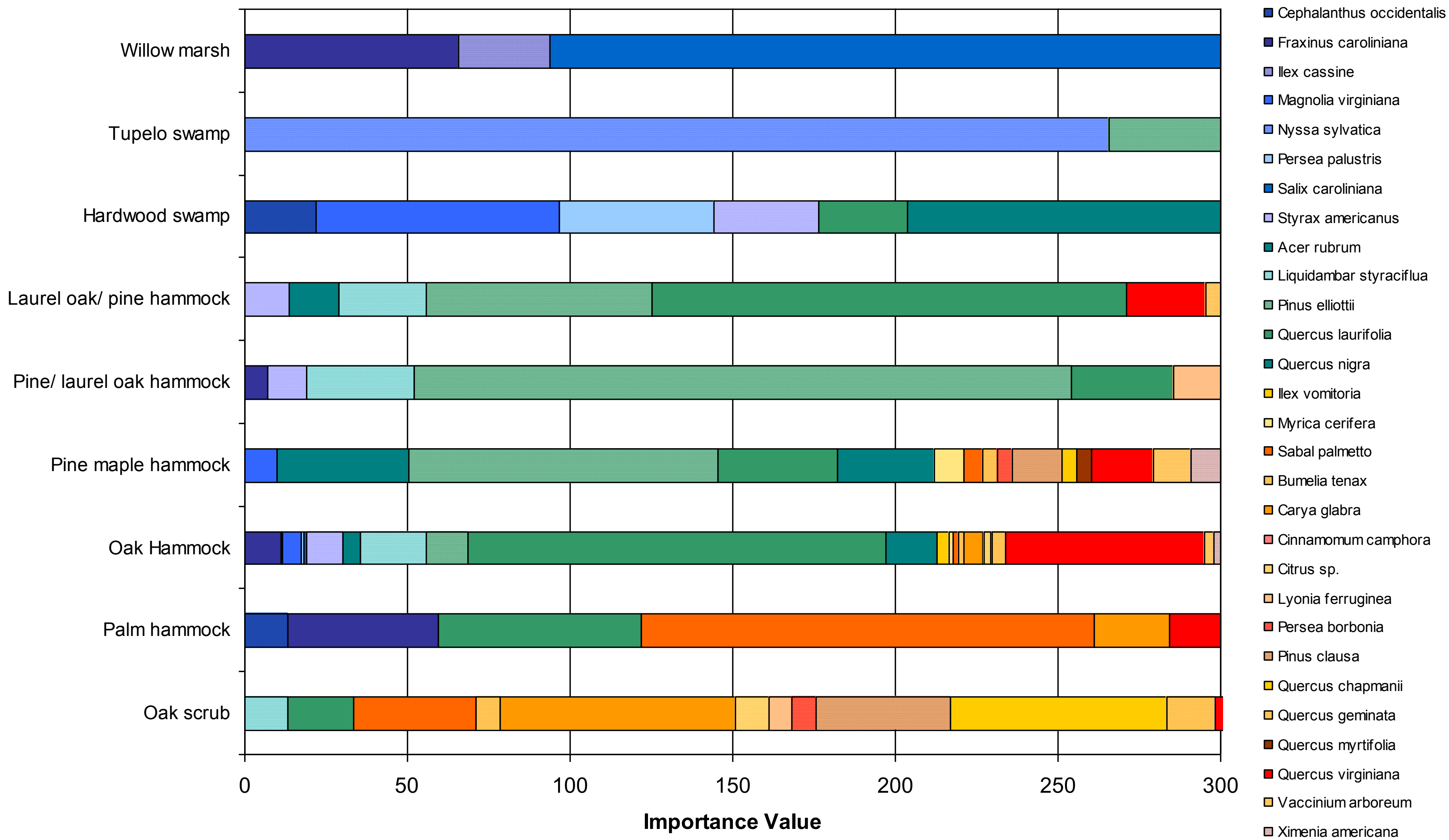
Status	Species	Willow Marsh	Tupelo Swamp	Hardwood Swamp	Pine / Laurel Oak Hammock	Laurel Oak / Pine Hammock	Pine / Maple Hammock	Laurel Oak Hammock	Palm Hammock	Oak Scrub
OBL	*Cephalanthus occidentalis*			22.0					13.4	
OBL	*Fraxinus caroliniana*	65.8			7.0			11.0	46.2	
OBL	*Ilex cassine*	28.0						0.7		
OBL	*Magnolia virginiana*			74.5			9.9	5.6		
OBL	*Nyssa sylvatica*		265.6							
OBL	*Persea palustris*			47.8				0.8		
OBL	*Salix caroliniana*	206.2						0.7		
OBL	*Styrax americanus*			32.1	12.0	13.7		11.2		
FACW	*Acer rubrum*					15.4	40.5	5.4		
FACW	*Liquidambar styraciflua*				32.8	26.5		20.5		13.1
FACW	*Pinus elliottii*		34.4		202.1	69.6	95.0	12.5		
FACW	*Quercus laurifolia*			27.2	31.7	145.8	36.7	128.6	62.5	20.5
FACW	*Quercus nigra*			96.4			3.0	15.8		
FAC	*Ilex vomitoria*							3.7		

FAC	*Myrica cerifera*						9.1	1.3		
FAC	*Sabal palmetto*						5.5	1.8	139.0	37.4
UPL	*Bumelia tenax*						4.5	1.5		7.4
UPL	*Carya glabra*							5.7	23.1	72.4
UPL	*Cinnamomum camphora*							0.7		
UPL	*Citrus sp.*							1.8		10.2
UPL	*Lyonia ferruginea*				14.3					7.1
UPL	*Persea borbonia*						4.6			7.4
UPL	*Pinus clausa*						15.5			41.6
UPL	*Quercus chapmanii*						4.6	0.7		66.2
UPL	*Quercus geminata*							3.9		15.1
UPL	*Quercus myrtifolia*						4.6			
UPL	*Quercus virginiana*					24.4	18.9	61.3	15.9	9.0
UPL	*Vaccinium arboreum*					4.5	11.3	2.7		
UPL	*Ximenia americana*						9.3	2.2		

*Shaded cell indicates absence of species

Figure 4-4

Importance Values for Tree Species in Vegetation Classes along the Little Manatee River Study Corridor



Species in the two upland classes included primarily the facultative cabbage palm (*Sabal palmetto*) and the upland scrub hickory (*Carya glabra*). Species numbers ranged from six to 11.

- Palm hammock: cabbage palm dominated this vegetation class, followed by laurel oak and popash, and smaller components of both upland and wetland species.

- Oak scrub was the only vegetation class dominated by upland species, including primarily scrub hickory (Carya glabra), scrub oak (Q. chapmanii), and sand pine (Pinus clausa). This was also the only class that included no obligate wetland species.

Species Composition in Vegetation Classes. Differences in species IVs for the 29 species in the nine vegetation classes represent a shift in importance from obligate wetland species such as willows, tupelo, and sweet bay to laurel oak and slash pine to upland scrub oak and sand pine coincided with a gradual transition from wetland to upland vegetation classes.

- Laurel oak occurred in seven of the nine vegetation classes, and was the largest component in two classes (laurel oak/ pine and laurel oak hammock). Slash pine and live occurred in five classes, while four species occurred in four classes, and the remaining species occurred in fewer than four of the vegetation classes.

- The largest number of tree species (23) occurred in the laurel oak hammock class, followed by the pine/ maple hammock (15 species) and the oak scrub (12 species). The total number of tree species in other classes ranged from two to seven.

Species Importance. Species IVs comparisons (Table 4-4) indicate that the overall dominant species were the facultative wetland species laurel oak and slash pine. A shift in importance from willows, tupelo, and sweet bay to laurel oak and slash pine to scrub oak and sand pine coincided with a gradual transition from wetland to upland vegetation classes. Overall trends in species dominance and diversity are summarized below.

- Five species had IVs that exceeded 100 in a single class: cabbage palm (139), tupelo (IV=265.6), slash pine (IV=202.1), willow (IV=206.2) laurel oak (IV=145.8 in the laurel oak/pine hammock and IV=128.6 in the laurel oak hammock) had IVs that exceeded 100.

- Four species made up approximately 56 percent of the total IVs (by species) among all classes: laurel oak (453), slash pine (414) had the largest IVs, followed by tupelo (266) and Carolina willow (207).

- Five species made up approximately 29 percent of the total IVs by species: cabbage palm, water oak, popash, live oak, and scrub hickory ranged from 101 to 184.

- The remaining 20 species had IVs less than 100 and made up approximately 28 percent of the total IVs.

These vegetation classes were used in further analyses and, for organizational purposes, are presented in general order from those nearest the river channel (willow marsh) to those farthest from the channel (scrub oak).

Density and Basal Area. Species IVs for each vegetation class totaled 300, as described in Section 3.0, and provide a means of comparison among species. However, total basal area and density were also calculated for each vegetation class (Table 4-5) and species (Table 4-6) to provide a means of comparison between vegetation classes (Figure 4-5) and among species.

Comparisons of tree basal areas and densities can indicate whether a population is more mature (smaller numbers of larger trees) or in transition in response to a disturbance or change of some sort (increased numbers of smaller trees). A developed tree canopy will shade out new seedlings and inhibit invasion by other species or individuals, which may have an opportunity only when a gap is created by the loss of an older tree and an opening in the canopy. A disturbance that produces a gap in the canopy provides the light necessary for the expansion of new species and individuals. Reduced or loss of stream flows due to rainfall patterns or local ground water withdrawals can also alter vegetation growth and distribution patterns.

Table 4-5
Basal Area and Density* in Vegetation Classes along the Little Manatee River Study Corridor

Parameter	Vegetation Class								
	Willow Marsh	Tupelo Swamp	Hardwood Swamp	Pine/ Laurel Oak Hammock	Laurel Oak/ Pine Hammock	Pine / Maple Hammock	Laurel Oak Hammock	Palm Hammock	Oak Scrub
Density (trees/acre)	90	135	45	18	39	45	12	45	25
Basal Area (in^2)	3,743	19,215	8,274	9,297	25,194	17,479	35,718	20,637	8,728
Basal Area/tree/acre	42	142	183	515	652	388	3,036	458	355

*Rounded to the nearest whole number.

Differences in basal area and densities varied among vegetation classes along the river. The oak classes had the lowest density and the greatest basal area/tree, indicating an older aged stand, while the wetland classes had higher densities and lower basal areas, indicating a younger age class. In general:

- The laurel oak hammock class had the largest total basal area (35,718 in^2/acre) and lowest density (approximately 12 trees/acre), indicating older stands of larger trees.

- The willow marsh and tupelo swamp had the highest densities (90 and 135 trees/acre, respectively), and relatively low total basal areas (3,743 and 19,215 in^2/acre, respectively), indicating younger trees.

- Laurel oaks (21,099 in^2/acre) in the laurel oak hammock class and tupelos (19,010 in^2/acre) in the tupelo swamp class had substantially higher basal areas than any other tree species in any other vegetation class. There were less than 50 trees/acre in the remaining seven vegetation classes.

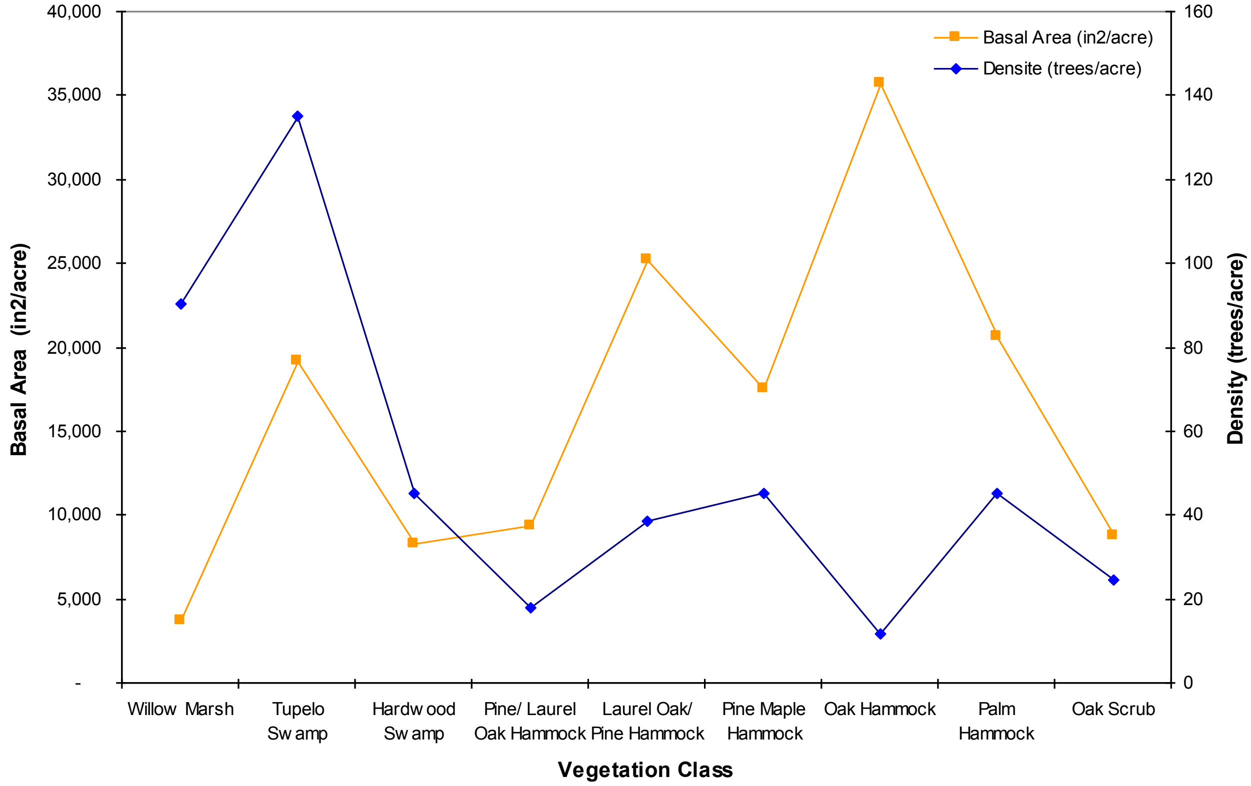
Table 4-6
Basal Area and Density of Tree Species in Vegetation Classes along the Little Manatee River Study Corridor

Wetland Status	Species	Total Basal Area (in^2)	Density (trees/acre)
OBL	*Cephalanthus occidentalis*	39.1	16.9
OBL	*Fraxinus caroliniana*	1,701.9	99.9
OBL	*Magnolia virginiana*	1,098.2	22.4
OBL	*Nyssa sylvatica*	1,241.5	16.2
OBL	*Persea palustris*	487.3	8.9
OBL	*Salix caroliniana*	190.9	1.0
OBL	*Styrax americanus*	186.1	71.1
FACW	*Acer rubrum*	670.1	37.8
FACW	*Liquidambar styraciflua*	2,196.7	123.9
FACW	*Pinus elliottii*	13,045.6	135.7
FACW	*Quercus laurifolia*	70,656.2	427.7
FACW	*Quercus myrtifolia*	5.0	2.5
FACW	*Quercus nigra*	3,834.7	94.4
FAC	*Ilex cassine*	4.3	1.2
FAC	*Ilex vomitoria*	19.1	7.8
FAC	*Myrica cerifera*	67.3	13.9

FAC	*Sabal palmetto*	7,163.2	72.0
UPL	*Carya glabra*	1,591.3	44.5
UPL	*Lyonia ferruginea*	21.7	3.7
UPL	*Persea borbonia*	8.6	2.5
UPL	*Persea humilis*	7.7	1.2
UPL	*Pinus clausa*	295.4	17.3
UPL	*Quercus chapmanii*	73.0	23.7
UPL	*Quercus geminata*	518.8	36.5
UPL	*Quercus virginiana*	41,983.5	184.1
UPL	*Vaccinium arboreum*	62.6	18.3
UPL	*Ximenia americana*	53.2	17.4

Figure 4-5
Basal Area and Density for Vegetation Classes along the Little Manatee River Study Corridor

Cabbage palms, like all palms, have no “bark” (secondary phloem) and consequently do not grow in diameter as they grow in height. All the cabbage palms measured were approximately 11 inches in diameter. Therefore, basal area can be considered a constant among cabbage palms and differences in IV among cabbage palms in vegetation classes can be attributed to density alone. Cabbage palm had its highest IV and was the dominant species in the palm hammock class.



Percent Occurrence along Transects. Based on NWI data, vegetation along most transects is broad leaved deciduous and evergreen in temporarily and seasonally flooded conditions (Table 4-7). Based on NWI data, upstream transects (VEG15 and VEG14) are only temporarily flooded, compared with seasonally flooded at the five transects farthest downstream (VEG2, LMAN6, Masonic, LMAN7, and VEG3) and therefore, downstream transects would be expected to have better developed wetlands. Transect VEG10 was classified in NWI as emergent (or herbaceous) and the transect LMAN3 was classified as all uplands. While two of the three transects farthest downstream did have wetlands, two of the three wetlands farthest upstream also had wetlands. The remaining transects were characterized by transition and upland classes. One-hundred percent of the transect length at transects Toscany and VEG10 (mid-reaches of the river) were laurel oak hammock. The two upland classes (palm hammock and oak scrub occurred along the six most downstream transects, and were absent at the six most upstream transects. No needle-leaved vegetation was identified in the NWI data and no cypress or cedar were found along the study transects.

Table 4-7
Percent Composition of Vegetation Class along the Little Manatee River Transects*

Transect	Willow Marsh	Tupelo Swamp	Hardwood Swamp	Pine/ Laurel Oak Hammock	Laurel Oak/ Pine Hammock	Pine / Maple Hammock	Laurel Oak Hammock	Palm Hammock	Oak Scrub
VEG15				5.3	7.0	8.4	79.2		

	VEG14		14.6			3.4	24.9	57.1		
	LMAN3	15.5						84.5		
	VEG10							100.0		
	TOSCANY							100.0		
	VEG2				21.5			24.5	54.0	
	LMAN6				36.5		8.4	13.3	3.6	38.2
	MASONIC			11.3		39.3		43.3		6.1
	LMAN7	19.2		5.0	30.5			8.6		36.7
	VEG3				26.2	35.4		30.6	7.8	

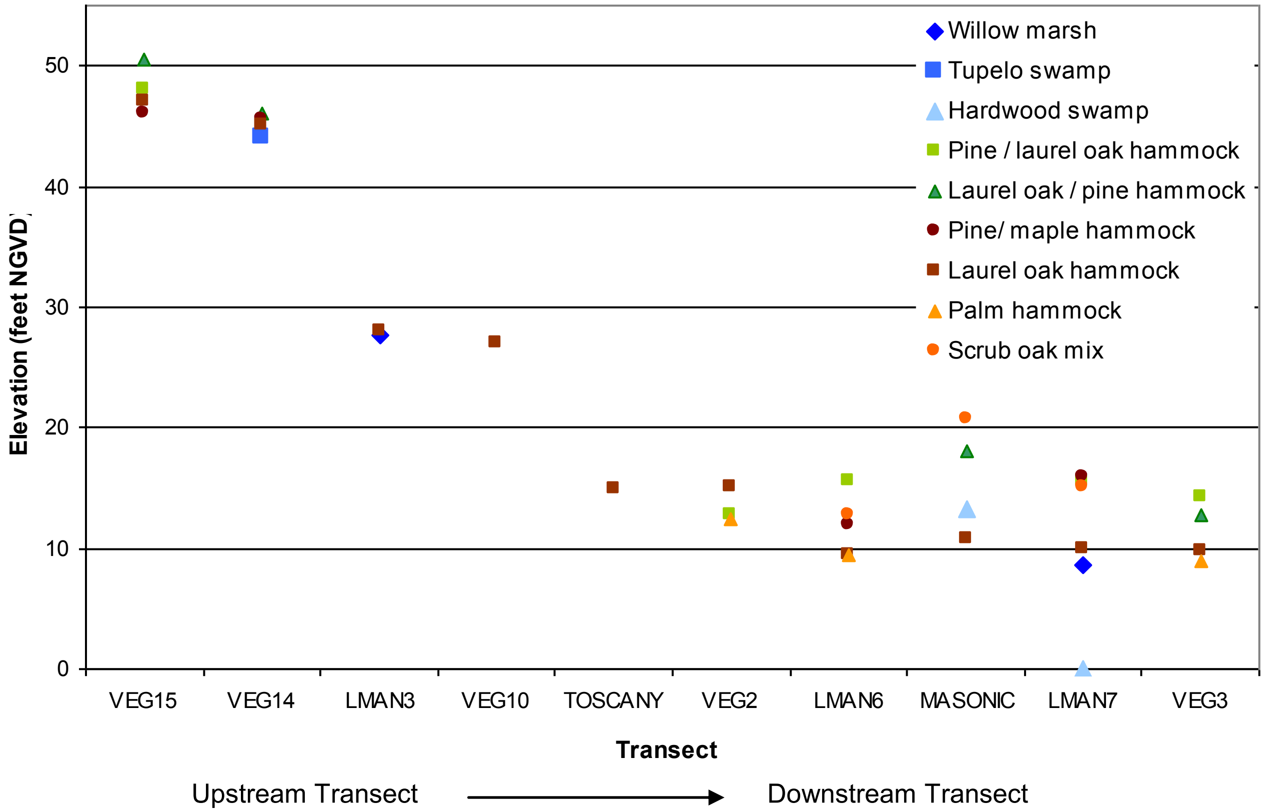
*Shaded cells indicate absence of vegetation class.

▪ Elevations and Vegetation Classes

Wetland vegetation classes generally had lower elevations when compared with transition and upland classes, although because of the relatively small number of wetlands, variability was high. Median elevations of vegetation classes along the river corridor and for each transect are graphed in Figure 4-6. Median elevations were generally lower in willow marsh, tupelo swamp, and hardwood swamp vegetation classes when compared with the remaining transition and upland classes (Table 4-8 and Table 4-9). Median elevations were highest at the most upstream transect (VEG15) and ranged from 46.0 feet NGVD to 50.5 feet NGVD, and the relative elevations of vegetation classes along VEG15 were consistently lower when compared with other transects, i.e. upstream transects had less elevation relief than downstream transects.

Wetland classes occurred along only four of the 10 transects. Median relative elevations in the wetland classes (Figure 4-7) ranged from 7.0 feet NGVD (willow marsh) to 10.2 feet NGVD (hardwood swamp), while elevations ranged from 6.2 (laurel oak hammock) to 15.7 (laurel oak/pine hammock) feet NGVD in the remaining classes. Median relative elevations in willow marsh were 7.0 and 8.4, compared with 7.3 in the tupelo swamp and 10.2 in the hardwood swamp.

Figure 4-6
Median Elevations of Vegetation Classes along Transects in the Little Manatee River Study Corridor

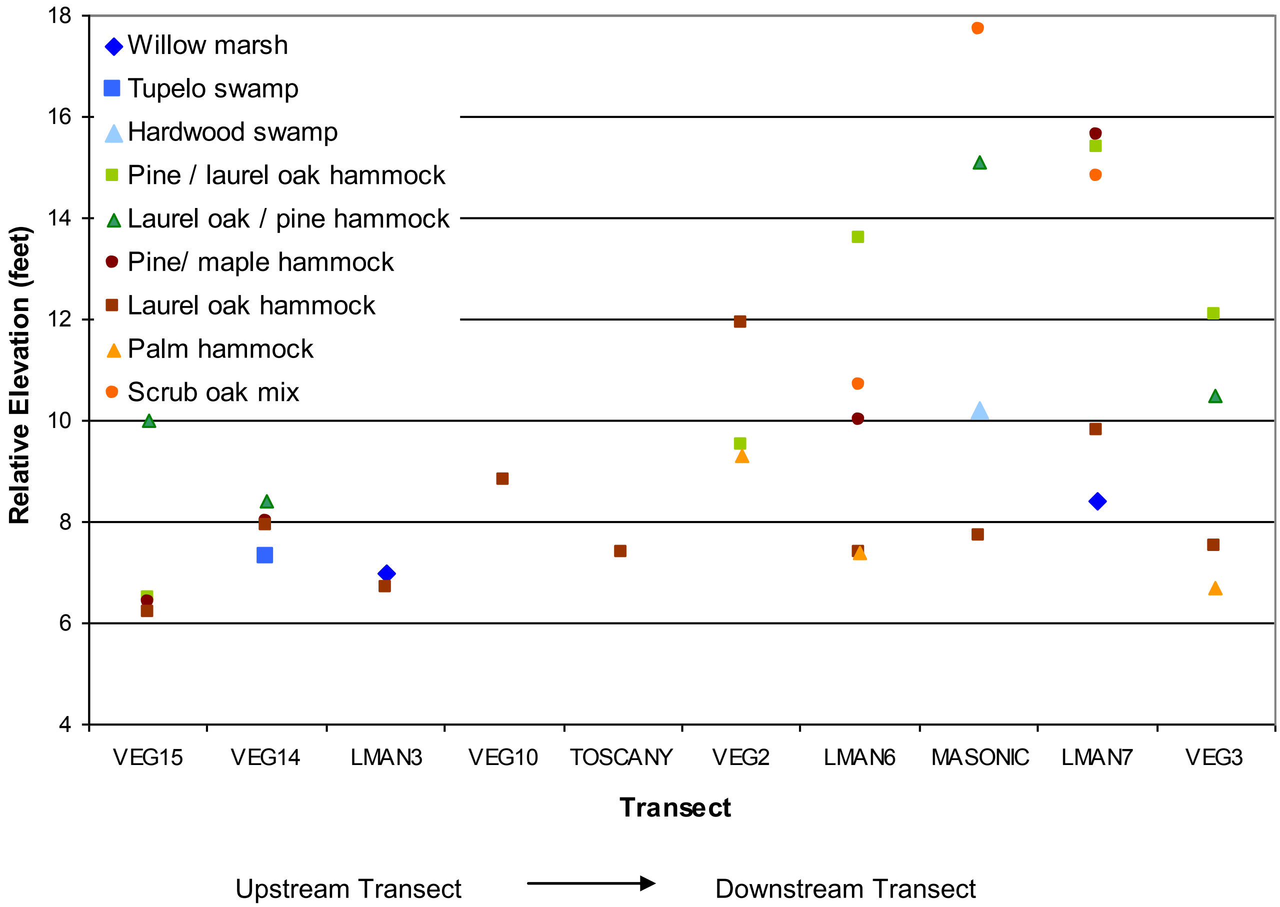


▪ Soils, Distance to Channel, and Vegetation Classes

Changes in elevation associated with vegetation classes were not as consistent as the elevation gradients associated with soils. While hydric soils consistently occurred at lower elevations when compared with nonhydric soils, wetland vegetation classes did not consistently occur at lower elevations when compared with transition or upland vegetation classes. Within vegetation classes that had both hydric and nonhydric soils, hydric soils consistently occurred at lower elevations and illustrate the broad overlap among vegetation classes.

Results indicate that soils were a more consistent indicator of wetlands along the Little Manatee River than elevation changes. Median relative elevations of hydric soils by vegetation class indicated that in vegetation classes with both hydric and nonhydric soils, hydric soils occurred at lower elevations. Also, median elevations (feet NGVD) of hydric soils in wetland classes were the same as the elevations of the wetland class (Table 4-10), i.e. wetlands had almost exclusively hydric soils, while hydric soils were not limited to wetlands (consequently, the cells filled in Table 4-10 do not always coincide with Tables 4-8 and 4-9). Muck soils were found along several transects (Figure 4-3), but did not occur at elevations that were any lower than hydric (but not muck) soils.

Figure 4-7
Median Relative Elevations of Vegetation Classes along Transects in the Little Manatee River Study Corridor



Inconsistencies in vegetation-elevation relationships are likely due to the broad environmental tolerance of wetland species and the small number of study transects (four) that included wetlands. The broad environmental range of wetland and transition vegetation when compared with upland species results in greater overlap of wetland and transition species across elevation and soils gradients. For example, overlap was most conspicuous for the laurel oak hammock class, which was the only vegetation class present along all transects and the variation in elevation along this transect was therefore higher when compared with other vegetation classes.

Distance to river channel may provide a proxy for combinations of elevation, wave energy, soils, and vegetation if distance coincides with these other variables. Such a pattern was not apparent along the Little Manatee River transects and may also be a result of the small number of wetlands sampled. Mean distances of vegetation classes from the river channel were not correlated strongly with vegetation class. The willow marsh vegetation class occurred along or close to the river channel (mean distance =

76.9 feet from the channel). The tupelo swamp class occurred at a mean distance of 739.4 feet from the river channel, followed by hardwood swamp at a mean distance of 321.2 feet. The remaining vegetation classes ranged from 160.6 to 1,073.0 feet from the river channel.

Table 4-8
Median Elevation (NGVD) of Vegetation Classes along the Little Manatee River Transects*

Transect		Willow Marsh	Tupelo Swamp	Hardwood Swamp	Pine / Maple Hammock	Pine / Laurel Oak Hammock	Laurel Oak / Pine Hammock	Laurel Oak Hammock	Palm Hammock	Oak Scrub
Upstream	VEG15				46.8	50.5	46.0	46.5		
	VEG14		44.9			46	45.6	45.5		
	LMAN3	27.6						27.3		
	VEG10							27		
	TOSCANY							14.9		
	VEG2				12.8			15.1	12.5	
	LMAN6				15.6		12	9.4	9.4	12.7
	MASONIC			13.2		18.1		10.7		20.7
	LMAN7	7.4		5.3	15.6		15.9	10		15
Downstream	VEG3				14.3	12.7		9.7	8.9	

*Shaded cells indicate absence of vegetation class.

Table 4-9
Median Relative Elevation (feet above channel bottom), of Vegetation Classes along the Little Manatee River Transects*

Transect		Willow Marsh	Tupelo Swamp	Hardwood Swamp	Pine / Maple Hammock	Pine / Laurel Oak Hammock	Laurel Oak / Pine Hammock	Laurel Oak Hammock	Palm Hammock	Oak Scrub
m Up str	VEG15				6.5	10.0	6.4	6.2		

	VEG14		7.3			8.4	8.0	7.9		
	LMAN3	7.0						6.7		
	VEG10							8.8		
	TOSCANY							7.4		
	VEG2				9.5			11.9	9.3	
	LMAN6				13.6		10.0	7.4	7.4	10.7
	MASONIC			10.2		15.1		7.7		17.7
	LMAN7	8.4		2.3	15.4		15.7	9.8		14.8
	VEG3				12.1	10.5		7.5	6.7	

*Shaded cells indicate absence of vegetation class.

Table 4-10
Median Elevations (feet NGVD) of Hydric Soils by Vegetation Class along the Little Manatee River Study Corridor*

	Transect	Willow marsh	Tupelo swamp	Hardwood swamp	Pine/ laurel oak hammock	Laurel oak/ pine hammock	Pine / maple hammock	Laurel oak hammock	Palm hammock	Oak scrub
Upstream	VEG15				48.3			46.2		
	VEG14		44.9			44.8				
	LMAN3	27.4						33.6		
	VEG10							20.3		
	TOSCANY							13.05		
	VEG2								5.6	
	LMAN6								5.6	
	MASONIC			13.1				5.9		
	LMAN7									
Downstream	VEG3							9.3	7.1	

*Shaded cells indicate absence of hydric soils.

▪ Discriminant Function Analysis (DFA)

DFA was used to examine relationships among vegetation classes and environmental variables along the Little Manatee River study corridor. Elevations, soils, and distance to channel accounted for a significant amount of variation in among vegetation classes.

Correlation Results. DFA results indicated that the contributions of elevation, distance from river channel, and hydric soils index were significant in separating vegetation classes (Wilks' Lambda = 0.48; $p < 0.001$) (Table 4-11). Elevation and relative elevation had the strongest correlations with vegetation class ($r^2 = 0.23$ and 0.32, respectively), while correlations with soils ($r^2 = 0.29$) and distance from river channel ($r^2 = 0.28$) were lower.

Vegetation classes were distinct in terms of species composition and IV, and environmental variables were significant in accounting for these differences. The wetland vegetation classes (willow marsh, tupelo swamp, and hardwood swamp) generally, but not always, had lower mean elevations and more hydric soils characteristics. Only the willow marsh occurred closer to the river channel when compared with the other vegetation classes. The tupelo swamp was a depressional swamp rather than connected to the river as the willow marsh and hardwood swamp often were. The hydric soils conditions were the best predictors of wetland vegetation.

Elevation (NGVD), relative elevations along transects, distance from channel, and hydric soil index were significant in separating vegetation classes from each other, although overlap in environmental parameters between vegetation classes occurred.

Classifications and Misclassifications. DFA was used to measure the contribution of elevation, distance from river channel, and soil parameters in characterizing vegetation classes along the Little Manatee River study corridor. Vegetation classes were classified correctly 40 percent of the time for willow marsh and 100 percent of the time for tupelo and hardwood swamp classes (willow marsh was classified incorrectly more frequently than correctly). Transition vegetation classes were correctly classified in 13.5 to 80 percent of the cases. The two upland classes were classified correctly in 88.9 and 66.7 percent of the cases. Overlap among classes was greatest among classes that were sampled less frequently, had greater variability in species, and occurred along more transects.

Row totals (the "to" classes) in Table 4-11 indicate the percent of the time (and number of times) a vegetation class was classified correctly and incorrectly. For example, willow marsh was identified in the field on five occasions (100 percent), but was classified as willow marsh using environmental measures on only two (40 percent) of those occasions. Willow marsh was incorrectly classified as hardwood swamp once, laurel oak/pine hammock once, and palm hammock once. In contrast, tupelo swamp was correctly classified as tupelo swamp all three times it was encountered (100 percent of the time.

Column totals in Table 4-11 (the "from" classes) represent the total number of times a group of measurements recorded in the field was classified as a target community (column heading) in the DFA analysis. Using the tupelo swamp example again, the number of observations classified as tupelo swamp was 10 (five percent) based on field measurements. While tupelo swamp was correctly classified 100 percent of the time (3 times), laurel oak hammock (row heading) was also classified as tupelo swamp (column heading) 6.4 percent of the time (in seven of the 110 times it was encountered).

Tupelo swamp and hardwood swamp were classified correctly 100 percent of the time. Laurel oak/pine hammock, pine/maple hammock, palm hammock, and oak scrub were classified correctly between 66.7 and 88.9 percent of the time. Pine/ laurel oak and laurel oak hammock were classified correctly 54.5 and 13.5 percent of the time and laurel oak hammock was classified as every other vegetation class. Willow marsh was correctly classified as willow marsh 40 percent of the time (2 cases), while it was incorrectly classified as hardwood swamp, laurel oak/ pine hammock, and palm hammock the remaining 60 percent of the time. Of the total 179 field samples, only six samples (3.4 percent) were classified as hardwood swamp, in contrast with 38 samples (21.2 percent) classified as palm hammock.

Vegetation classes were distinct in terms of species composition and IV, and environmental variables were significant in accounting for differences between vegetation classes. Elevations, relative elevations along transects, distance from channel, and hydric soil index were significant in separating vegetation classes from each other, although overlap in environmental parameters between vegetation classes was frequent. Correlations between environmental variables and vegetation class were not strong.

Table 4-11

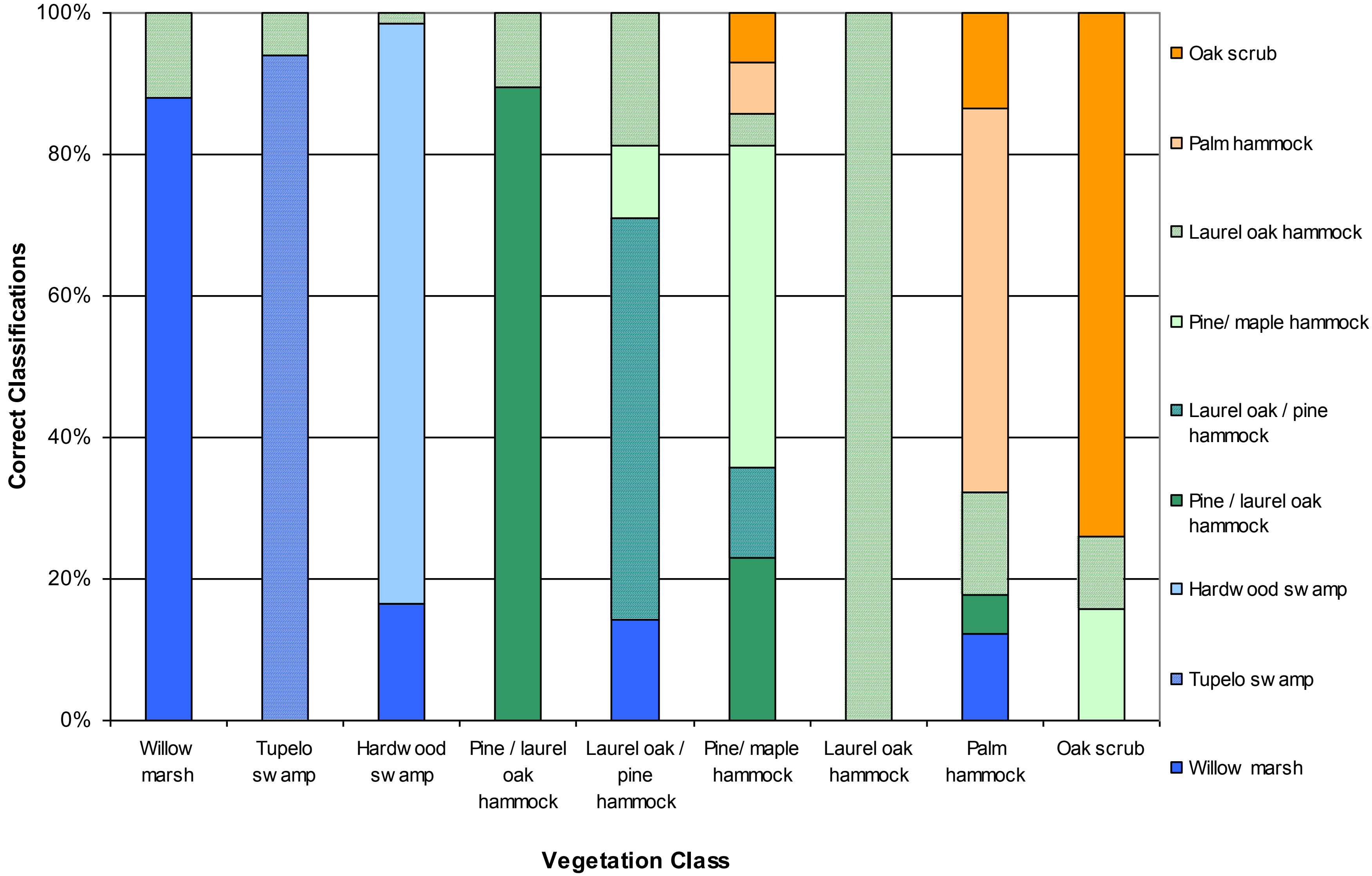
DFA Results for Vegetation Classifications*

Vegetation Class	Willow Marsh	Tupelo Swamp	Hardwood Swamp	Pine / Laurel Oak Hammock	Laurel Oak / Pine Hammock	Pine / Maple Hammock	Laurel Oak Hammock	Palm Hammock	Oak Scrub	Total
Willow marsh	40 (2)		20 (1)		20 (1)			20 (1)		100 (5)
Tupelo swamp		100 (3)								100 (3)
Hardwood swamp			100 (3)							100 (3)
Pine / laurel oak hammock				54.5 (6)		36.4 (4)		9.1 (1)		100 (11)
Laurel oak / pine hammock					80 (12)	20 (3)				100 (15)
Pine / maple hammock					14.3 (2)	71.4 (10)			14.29 (2)	100 (14)
Laurel oak hammock	5.5 (6)	6.4 (7)	1.8 (2)	6.4 (7)	26.4 (29)	7.3 (8)	13.5 (15)	23.6 (26)	9.1 (10)	100 (110)
Palm hammock						11.1 (1)		88.9 (8)		100 (9)
Oak scrub						11.1 (1)		22.2 (2)	66.7 (6)	100 (9)
Total	4.5 (8)	5. (10)	3.4 (6)	7.3 (13)	24.6 (44)	15.1 (27)	8.4 (15)	21.2 (38)	10.1 (18)	100 (179)
Wilks' Lambda=0.47624; F=19.35; DF=12										
Variable			**R-Square**			**F Value**		**Pr>F**		

Elevation	0.2262	6.21	<.0001
Relative elevation	0.3232	10.15	<.0001
Soils	0.2936	8.83	<.0001
Distance	0.2756	8.08	<.0001

*Shaded cells indicate zero classes and zero percent. Numbers in parentheses are N.

Figure 4-8
Percent Correct Classifications of Vegetation Classes along the Little Manatee River Study Corridor



However, relative elevation was more strongly correlated with vegetation class (r^2 = 0.32) when compared with soils (r^2 = 0.29), and distance to channel (r^2 = 0.28), and elevation (r^2 = 0.23), respectively. Environmental parameters accounted for a significant amount of variation among vegetation classes and correct classifications ranged from 53.6 percent to 100 percent in three other classes. The percent correct for each classification (outlined in bold in Table 4-11) is graphed in Figure 4-8 and are briefly summarized below.

- Tupelo swamp and hardwood swamp were classified correctly 100 percent of the time, followed by palm hammock (88.9 percent) and laurel oak / pine hammock (80 percent).
- The laurel oak hammock class was classified incorrectly 85 percent of the time, predominantly as laurel oak/ pine hammock (26.4 percent) and palm hammock (23.6 percent), overlapped with all the remaining vegetation classes, and was the most common vegetation class sampled.
- Vegetation classes were significantly correlated with measured environmental variables, although no correlation accounted for more than 32 percent of the variability.

Misclassifications in the DFA occur when a vegetation class is not successfully paired with corresponding environmental parameters and subsequently overlaps with other vegetation classes in regards to soil index, relative elevation, and distance from channel. Overlapping vegetation classes can indicate shared, or similar, habitat based on measured parameters (McNeely 1987). The overlap itself gives no indication of the resource preferences of overlapping species, although it does indicate the habitat being used (Colwell and Futuyama 1971), as well as the similar resource requirements of most plants (Goldberg and Werner 1983).

The mean values for elevation (NGVD), relative elevation, soils index, and distance from channel associated with each vegetation class through the DFA are listed in Table 4-12. The three wetland vegetation classes frequently corresponded to lower relative elevations, higher soils index values, and shorter distances to the river channel than the transition and upland vegetation classes.

Table 4-12

Mean Values of Parameters Used in DFA for Vegetation Classes along the Little Manatee River Study Corridor

	Willow marsh	Tupelo swamp	Hardwood swamp	Pine/ laurel oak hammock	Laurel oak/ pine hammock	Pine / maple hammock	Laurel oak hammock	Palm hammock	Oak scrub
Elevation (NGVD)	20.3	44.9	13.6	32.5	38.8	19.4	28.8	9.3	17.0
Relative Elevation (feet)	7.9	7.3	10.6	10.0	7.8	11.9	7.6	6.7	15.3

Soil Index	0.6	3.0	1.3	0.2	0.2		0.3	0.3	
Distance (feet)	76.9	739.4	321.2	1,073.0	421.8	563.9	376.8	160.6	238.7

▪ Wetted Perimeter

The wetted perimeters of vegetation classes in the study corridor are listed in Table 4-13 and indicate the linear distance inundated along a transect at a particular elevation or water level (river stage) in the Little Manatee river channel. The total wetted perimeter increases as elevation increases and does not vary significantly among vegetation classes. For example, if river stage was level with the median elevation for at the swamp vegetation class at the Masonic transect, 699 linear feet of habitat would be inundated below the median elevation of the hardwood swamp class (Table 4-13). Similarly, at a river stage equal to the median elevation of the oak scrub class along the same transect, 1,482 linear feet of habitat would be inundated.

The wetted perimeter along the Masonic transect is graphed in Figure 4-9 (all 10 transects are graphed in Appendix B). The graph is a standard x-y graph: the independent variable, elevation, is plotted along the x-axis, and the dependent variable, wetted perimeter, is plotted along the y-axis (elevation changes along transects were presented earlier in Section 4.1).

Typically, a sigmoid-shaped wetted perimeter curve coincides with a large increase in habitat across a small elevation gradient in floodplains (e.g. VEG15 and VEG14, Appendix B). Changes in wetted perimeter are also typically greater over more gradual changes in elevation than across steeper gradients (e.g. Masonic and LMAN7, Appendix B).

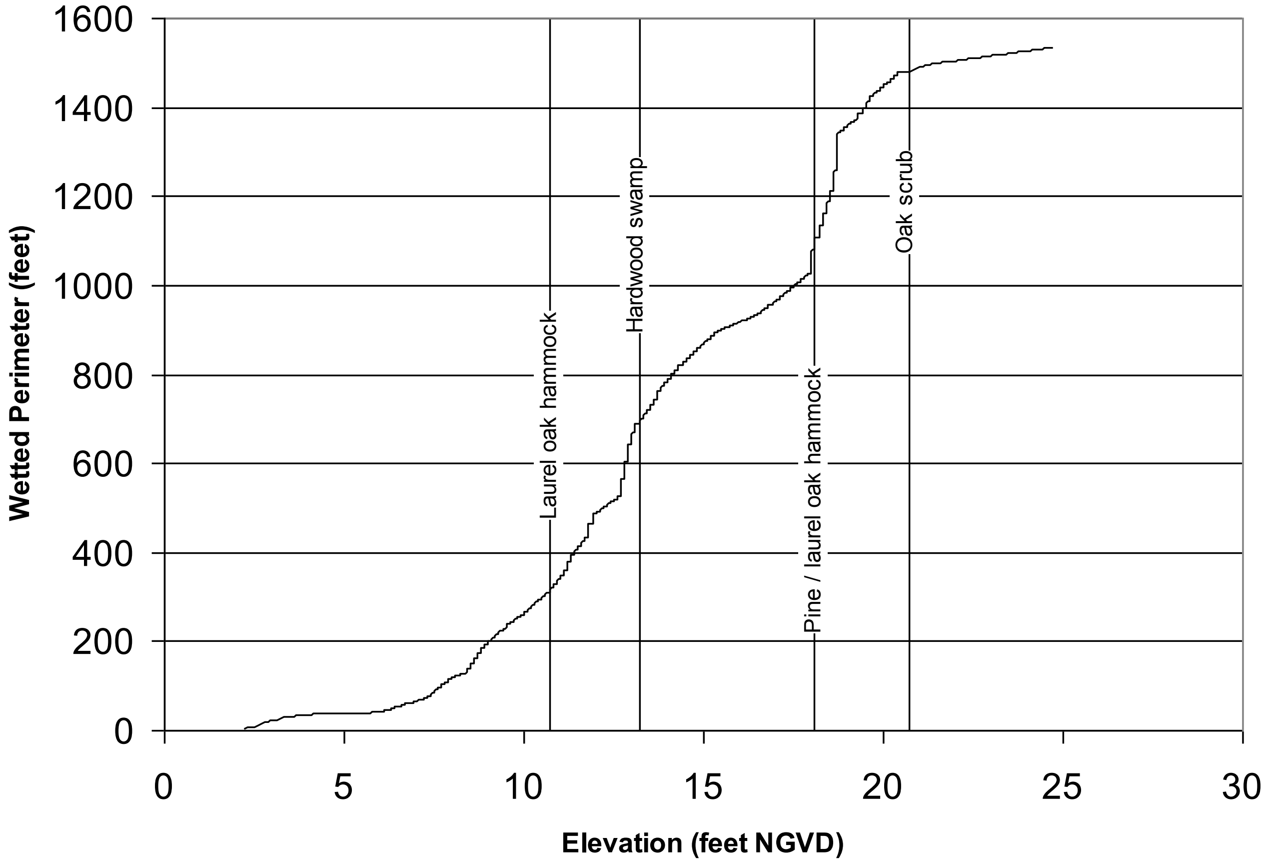
Table 4-13
Wetted Perimeter (linear feet), by Vegetation Class and Transect, along the Little Manatee River Study Corridor

Transect		Willow marsh	Tupelo swamp	Hardwood swamp	Pine / maple hammock	Pine / laurel oak hammock	Laurel oak / pine hammock	Laurel oak hammock	Palm hammock	Oak scrub
Downstream / Upstream	**VEG 15**				1383	2,235	351	1,132		
	VEG 14		867			2,204	1,786	1,634		
	LMAN3	729						678		

	VEG 10							485		
	TOSCANY							482		
	VEG 2				431			671	318	
	LMAN6				944		461	205	205	600
	MASONIC			699		1,108		319		1,482
	LMAN7	246		186	419		436	284		388
	VEG 3				689	550		268	153	

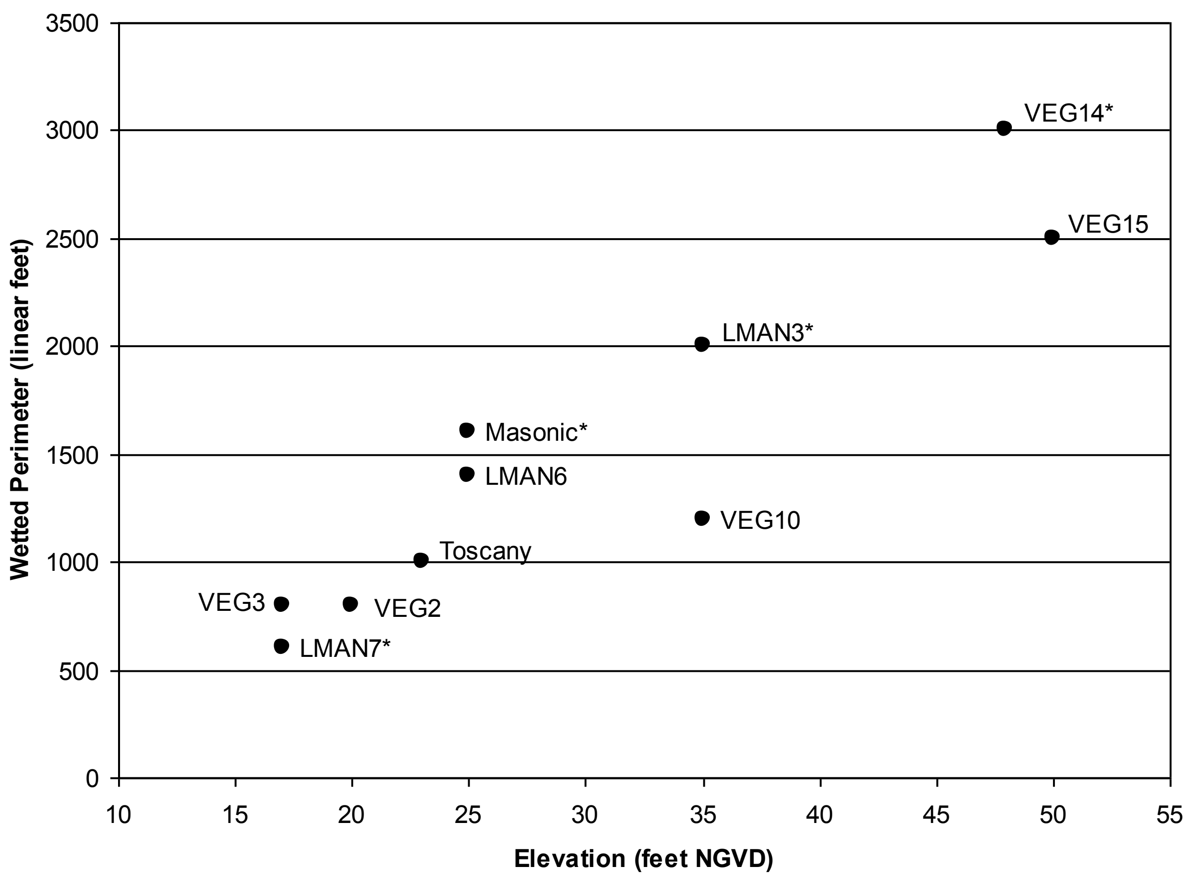
*Shaded cells indicate absence of vegetation class.

Figure 4-9
Wetted Perimeter and Associated Median Elevations along the Masonic Transect in the Little Manatee River Study Corridor



Wetted perimeters along the Little Manatee River transects corresponded with the upstream-downstream elevation gradient and were significantly ($p < 0.01$) and highly ($r^2 = 0.84$) correlated with elevation (feet NGVD) along the river (Figure 4-10). Wetted perimeter in the floodplain of the upper reaches of the river (transects VEG15, VEG14, and LMAN3) was greater than along the downstream reaches (VEG3, LMAN7, VEG2, and Toscany, etc.). Wetted perimeter did not correspond well with vegetation classes along the river and when wetlands were present along a transect (identified with asterisks in Figure 4-10), wetted perimeter differences were not apparent between wetlands and other vegetation classes that could not be accounted for by elevation differences. In other words, the upstream-downstream elevation differences were greater than the differences between vegetation classes. In addition, the small number of wetland classes may have obscured any elevation trends among wetland, transition, and upland vegetation classes, as described previously.

Figure 4-10
Wetted Perimeter and Associated Median Elevations along the Masonic Transect in the Little Manatee River Study Corridor



○ Relationship of Vegetation with Environmental Variables

Relationships among river stage, flow, and elevations were developed by the District for the Little Manatee River and are not presented here. However, it is appropriate to address hydrologic conditions such as saturation and inundation that are critical to the development of hydric soils and associated wetland vegetation.

Hydrology. Saturation and/or inundation are critical to the maintenance of wetlands vegetation in floodplains, although overbank flooding is not necessary (Cowardin *et al*. 1979, Reid and Wood 1976), and ground water can strongly influence the extent of wetlands (Light *et al.* 2002). Wetland trees are relatively fast-growing and in five years can generally grow to a height at which inundation will not kill it. For example, cypress trees can exceed one meter tall in one to two years (Harms 1973). Cabbage palms are unusual in that they require an initial establishment phase of 30 to 60 years during which they have no above-ground trunk (McPherson and Williams 1996) and flood events at 25 year intervals or more probably restrict the regeneration of cabbage palm. Once established, they are susceptible to only rising sea level, hurricanes, and fires. Therefore, under existing conditions, the tree communities along the Little Manatee River are not anticipated to change in composition or structure.

Competition. Wetland species occur in wetlands because they are tolerant of saturated and anoxic conditions that preclude upland species. Several studies have indicated that environmental gradients are more important in determining species distributions under physiological stressful conditions such as flooding, while competition may be more important under relatively benign environmental conditions (Latham *et al.* 1994, Grace and Wetzel 1981, others). Species such as laurel oak, which is relatively intolerant of persistent inundation when compared with a species such as cypress or tupelo, can be at a competitive advantage in the absence of persistent flooding and subsequently expand into areas previously dominated a wetland species such as popash or tupelo. The basal area and densities of oaks in the laurel oak vegetation class suggest that this is a well-established stand of vegetation. There was no indication of recent invasion of wetlands by upland species along the study corridor.

Disturbance. Invasive and nonnative species such as Brazilian pepper (*Schinus terebinthifolius*) and paragrass have a competitive advantage under disturbed conditions. Disturbances can occur as fire, flooding, animal activity, etc. and provide an opening into which a species that may not otherwise survive can become established due to the absence of other species. Mature native trees can continue to shade out many invasive species until the native trees die and create openings into which invasive species expand. No exotic species such as Brazilian pepper, punk trees (*Melaleuca quinquenervia),* Chinese tallow *(Sapium sebiferum),* or camphor tree *(Cinnamomum camphora),* were observed along any of the transects. Nor were any signs of serious invasion by nonnative and invasive species observed.

Inundation Periods in Southeastern Wetlands. The vegetation classes along the Little Manatee River are not typical of forested southeastern flood plains (described by Light *et al*. 2002 and Wharton *et al*. 1982), but are more consistent with seasonally and temporarily flooded river systems that are characterized by a wider range of environmental conditions and extremes, similar to the Braden River in Manatee County. Seasonal and temporarily flooded wetlands may be more sensitive to changes in natural flow regimes and hydrological variability (quantity, timing and duration of flows and floods, and periods of low flows) and subsequent effects on biodiversity and fisheries (Poff *et al.* 1997).

Alterations in the historical inundation patterns in the upper reaches of the Little Manatee River have not been documented. The vegetation along the study corridor appears consistent with species of temporarily flooded dry hardwood hammocks and in some cases the wet hardwood hammocks described for the southeastern U.S. (Table 4-14). Only the hardwood and tupelo swamps encountered along VEG14 and the Masonic transect appeared to be seasonally or possibly permanently flooded. Wetland vegetation in the study corridor indicates that the river channel itself is deep enough for more than three weeks during the wet season to preclude the expansion of upland species into the river itself and along the river banks. Cypress trees occur infrequently along the Little Manatee River and none were encountered along sampling transects in the study corridor. Cypress is an obligate wetland species, tolerant of up to three meters of inundation for more than 10 years, and more tolerant of wetland conditions than the species documented as part of this study. Tupelo trees are also very tolerant of flooding, although like the cypress, they occur in depressional areas that intercept the water table and have fluctuating water levels. Cypress cannot germinate under flooded conditions and do not grow quickly enough to successfully compete with other wetland tolerant species. Fire following logging or drainage can destroy both seeds and roots in the soil and favor replacement by willows and then mixed hardwoods (Myers and Ewel 1990). The paucity of cypress in south Hillsborough and Manatee counties in general has been attributed to logging, fire, declines in ground water levels, and differences in geomorphology. Unfortunately, no documentation of the actual cause(s) is available.

Climate. Large-scale climatic events may also influence long term stream flows and should be considered when establishing MFLs for the Little Manatee River. For example, seasonal and long term flow pattern differences between north Florida rivers (Suwannee River, Apalachicola River, Withlacoochee River) and south Florida rivers (Alafia River, Peace River, Myakka River) appear to coincide with the Atlantic multi-decadal oscillation (AMO) events (Basso and Schultz 2003). These events affect ocean temperature and rainfall patterns that ultimately influence regional stream flows, floodplain inundation, and vegetation patterns. In the Peace River watershed, wet periods correspond to higher wet season flows, but not dry season flows. Stream flow and rainfall data recorded since the 1900s indicate flow declines in the Peace River even when these rainfall patterns are accounted for. The conditions in the Little Manatee River watershed appear similar and at low flows in the river have been attributed at least in part to agricultural withdrawals.

Table 4-14
Typical Hydrology, Soils, and Species Composition in Floodplain Communities in the Southeastern U.S.

Vegetation Community[1]	Hydrology[2,3,4]	Soils[1,2]	Dominant Trees[1]
Cypress, palm/ cypress, and hardwood swamps, semi-permanently flooded	Inundated avg. 7 mo./yr.[2] Flooded 4-7 mo./yr. Saturated 9 mo.[3,4] Min. 14-day flood/2 yr. at 1m. Range of 5-10 mo./yr.[5]	Hydric- clay, muck, loam	Cypress dominant in lower swamp, mixed in higher swamp.
Wet hardwood hammock, seasonally flooded	Flooded avg. of 2 mo./year. Saturated 3 mo.[2,3,4] Min. 14-day flood/2 yr.	Hydric- loam, sand, clay	Cypress, hickory, ash, water oak, maple
Dry hardwood hammock, temporarily flooded	Flooded up to 1 month of growing season[3,4] Minimum 14-day flood/5 yr.	Hydric/ nonhydric	Maple, elm, ash, gum, oak.

[1]Peace and Myakka Rivers (PBS&J 2002). [2]Light *et al.* 2002). [3]Wharton *et al.* 1982. [4]Cowardin *et al.* 1979. [5]Coultas and Deuver 1984.

• Conclusions

Forested systems within the 100 year floodplain of the Little Manatee River study corridor were comprised of nine distinct vegetation classes based on tree species diversity and IV. Wetland, transitional, and upland vegetation classes generally coincided with commensurate changes in elevations, soils, and distance to channel, although soils corresponded better with elevation than vegetation and overlap among vegetation classes was frequent. The small number of wetlands along the sampling transects contributed to the high variability in elevation within vegetation classes, and consequently, to the overlap among vegetation classes.

Vegetation. Differences in vegetation classes along the Little Manatee River study corridor were significant based on importance values (IVs) that were calculated based on tree species density, basal area, and frequency and provide a relative measure of species dominance (no units). Three wetland vegetation classes were identified in the study corridor. The classes included only obligate and facultative wetland tree species, including Carolina willow (*Salix carolinana*), tupelo (*Nyssa sylvatica*), sweet bay or swamp bay (*Magnolia virginiana*), water oak (*Quercus nigra*), and popash (*Fraxinus caroliniana*). Transition vegetation classes (between wetlands and uplands) were characterized by predominantly facultative wetland species such as laurel oak (*Q. laurifolia*) and slash pine (*Pinus elliottii*) in combination with other facultative species and up to 23 different species. Species in the two upland classes included primarily the facultative cabbage palm and the upland scrub hickory and included from six to 11 different species.

Species IVs indicated a shift in importance from willows, tupelo, and sweet bay to laurel oak and slash pine to scrub oak and sand pine coincided with a gradual transition from wetland to upland vegetation classes. Laurel oak, slash pine, tupelo, and willow made up approximately 56 percent of the total IVs (by species) among all classes. Five species made up approximately 29 percent of the total IVs by species: cabbage palm, water oak, popash, live oak, and scrub hickory. The laurel oak hammock class had the largest total basal area (35,718 in^2/acre) and lowest density (approximately 12 trees/acre), indicating older stands of larger trees. The willow marsh and tupelo swamp had the highest densities (90 and 135 trees/acre, respectively), and relatively low total basal areas (3,743 and 19,215 in^2/acre, respectively), indicating younger trees.

Elevations and Soils. River channel elevations declined appreciably downstream, from 5.0 feet to 0.1 feet NGVD at the transect farthest downstream (just east of U.S. Highway 301), a change in elevation of approximately 38 feet over about 12 miles (0.3 feet/mile). In contrast, elevation changes along transects ranged from 11.6 to 22.8 feet over a half mile or less (22.4 feet/mile).

Changes in vegetation were more conspicuous along study transects than along the upstream – downstream river channel gradient and may reflect the steeper elevation change along transects when compared with the upstream to downstream elevation gradient. Wetland vegetation communities were absent along the mid-reach study transects and no upland classes occurred along the five most upstream transects.

Hydric soils were found along nine of the 10 study transects and in all vegetation classes except the scrub oak class. Muck soils were found at all transects. The tupelo swamp and hardwood swamp classes were the only classes with exclusively hydric soils. Median elevations of hydric soils were lower when compared with nonhydric soils in all but the laurel oak hammock class.

Discriminant Function Analysis (DFA). Vegetation classes were distinct in terms of species composition and IV, and environmental variables were significant in accounting for differences between vegetation classes. Elevations, relative elevations along transects, distance from channel, and hydric soil index were significant in separating vegetation classes from each other, although overlap in environmental parameters between vegetation classes was frequent. Correlations between environmental variables and vegetation class were not strong. Relative elevation was more strongly correlated with vegetation class ($r^2 = 0.32$) when compared with soils ($r^2 = 0.29$), and distance to channel ($r^2 = 0.28$), and elevation ($r^2 = 0.23$), respectively.

Vegetation classes were classified correctly 100 percent of the time for tupelo and hardwood swamp classes. Willow marsh and laurel oak hammock were classified incorrectly more frequently than correctly. Overlap was greatest among vegetation classes with the fewest samples, greatest variation in species, and those that occurred along more transects. The laurel oak hammock vegetation class overlapped with all other vegetation classes, but predominantly with the palm hammock and the pine/maple hammock.

Wetted Perimeter. Wetted perimeters along the Little Manatee River transects corresponded with the upstream-downstream elevation gradient and were significantly ($p < 0.01$) and highly ($r^2 = 0.84$) correlated with elevation (feet NGVD) along the river In contrast, wetted perimeter did not correspond well with vegetation classes and when wetlands were present along a transect, wetted perimeter differences were not apparent between wetlands and other vegetation classes that could not be accounted for by elevation differences. The small number of wetland classes may have contributed to the absence of any identifiable trends in wetted perimeter and vegetation class.

Conclusions. Nine distinct vegetation classes were identified along the Little Manatee River study corridor based on woody species composition and IV. Soils, elevations, and distances from river channel were significantly related to vegetation classes, but not highly correlated. Willow marsh, tupelo swamp, and hardwood swamp vegetation classes generally occurred at lower elevations on hydric and/or saturated soils in contrast with the upland palm hammock and oak scrub vegetation class. However, wetland vegetation classes were encountered along only four of the ten transects, while each of the remaining six vegetation classes occurred along three or more transects.

Based on the results of this study, only the tupelo swamp and hardwood swamp vegetation classes may provide a criterion on which to establish MFLs for vegetation communities along the Little Manatee River. Hydric soils appeared to be better indicators of wetland conditions than most vegetation classes. No cypress wetlands were encountered along the river channel during the vegetation studies, and the three wetland classes sampled are characterized by species less tolerant of flooding than cypress.

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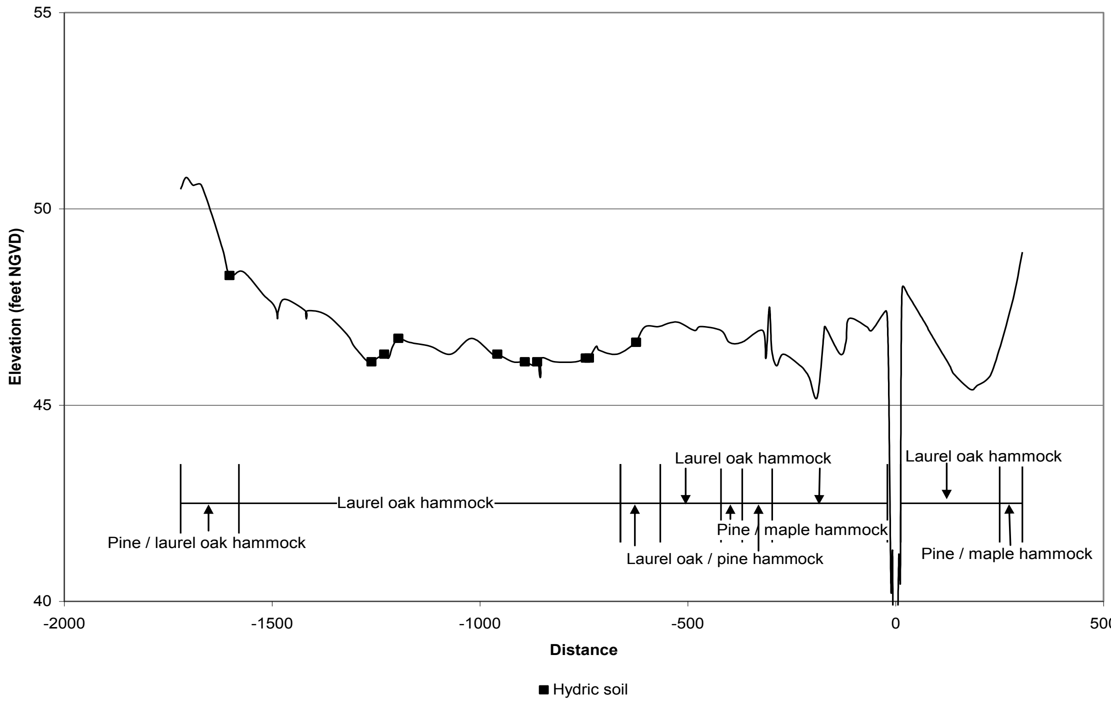
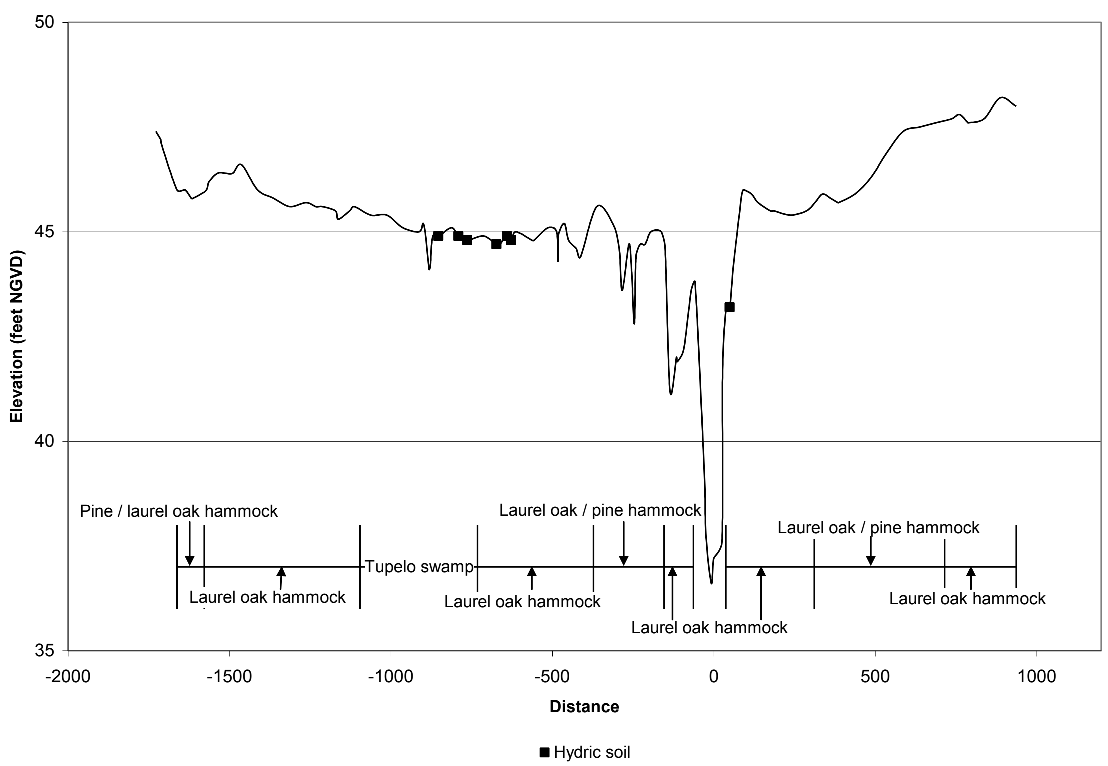
Appendix A

Elevation and Vegetation Profiles for the Little Manatee River Study Corridor

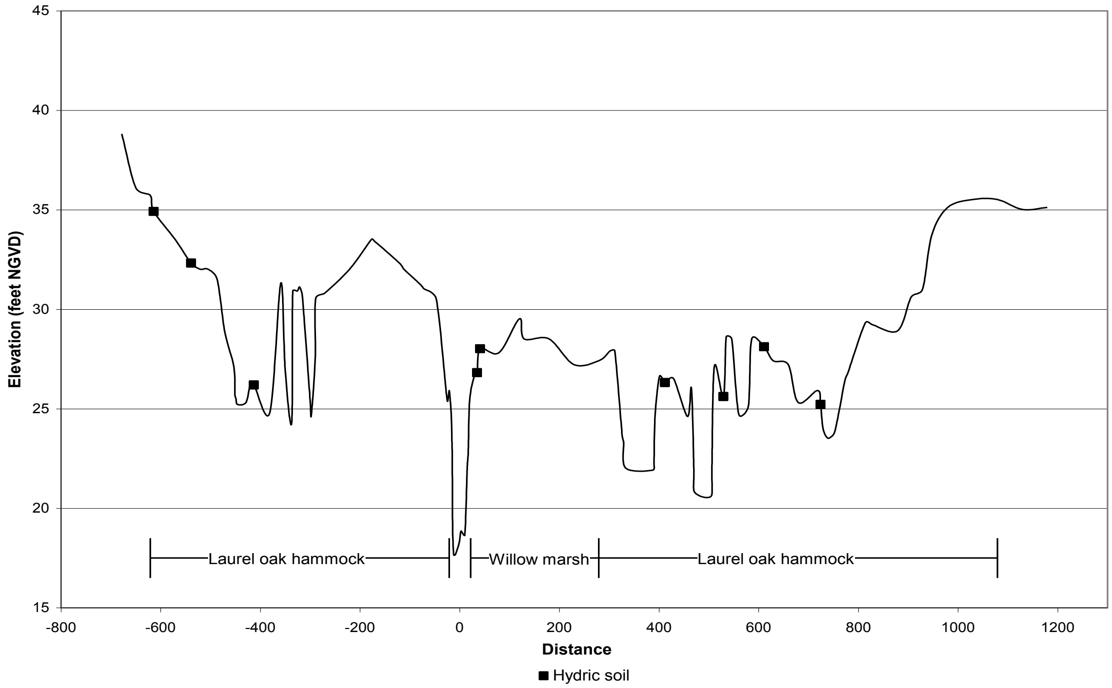
VEG15


55
50
45
40
Elevation (feet NGVD)
-2000
-1500
-1000
-500
0
500
Distance
Laurel oak hammock
Laurel oak hammock
Laurel oak hammock
Pine / laurel oak hammock
Pine / maple hammock
Laurel oak / pine hammock
Pine / maple hammock
■ Hydric soil

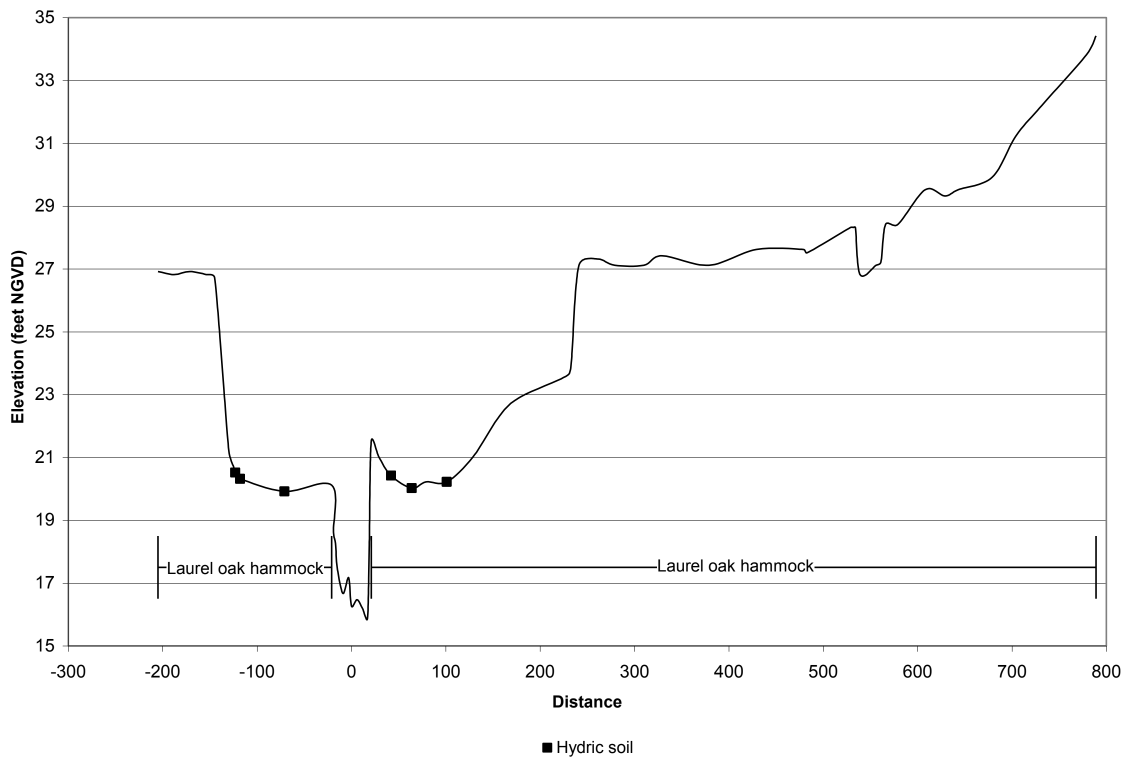
VEG14

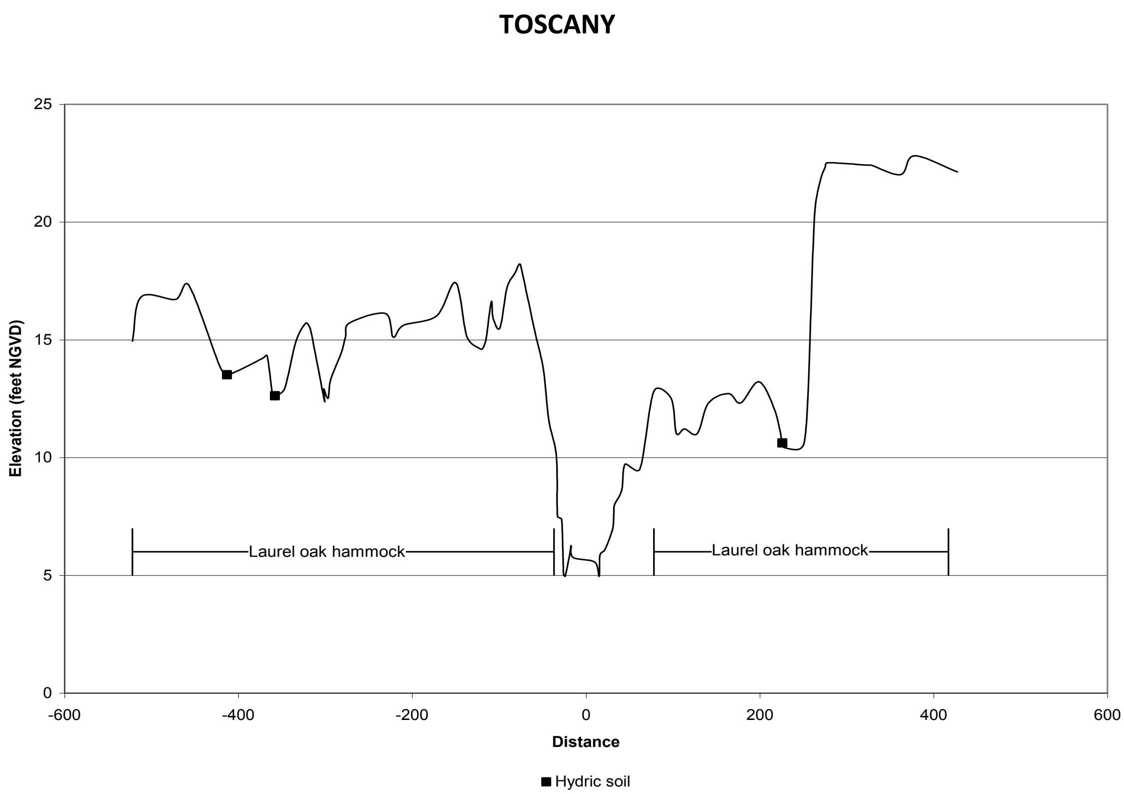

50
45
40
35
Elevation (feet NGVD)
-2000
-1500
-1000
-500
0
500
1000
Distance
Pine / laurel oak hammock
Laurel oak / pine hammock
Laurel oak / pine hammock
Tupelo swamp
Laurel oak hammock
Laurel oak hammock
Laurel oak hammock
Laurel oak hammock
■ Hydric soil

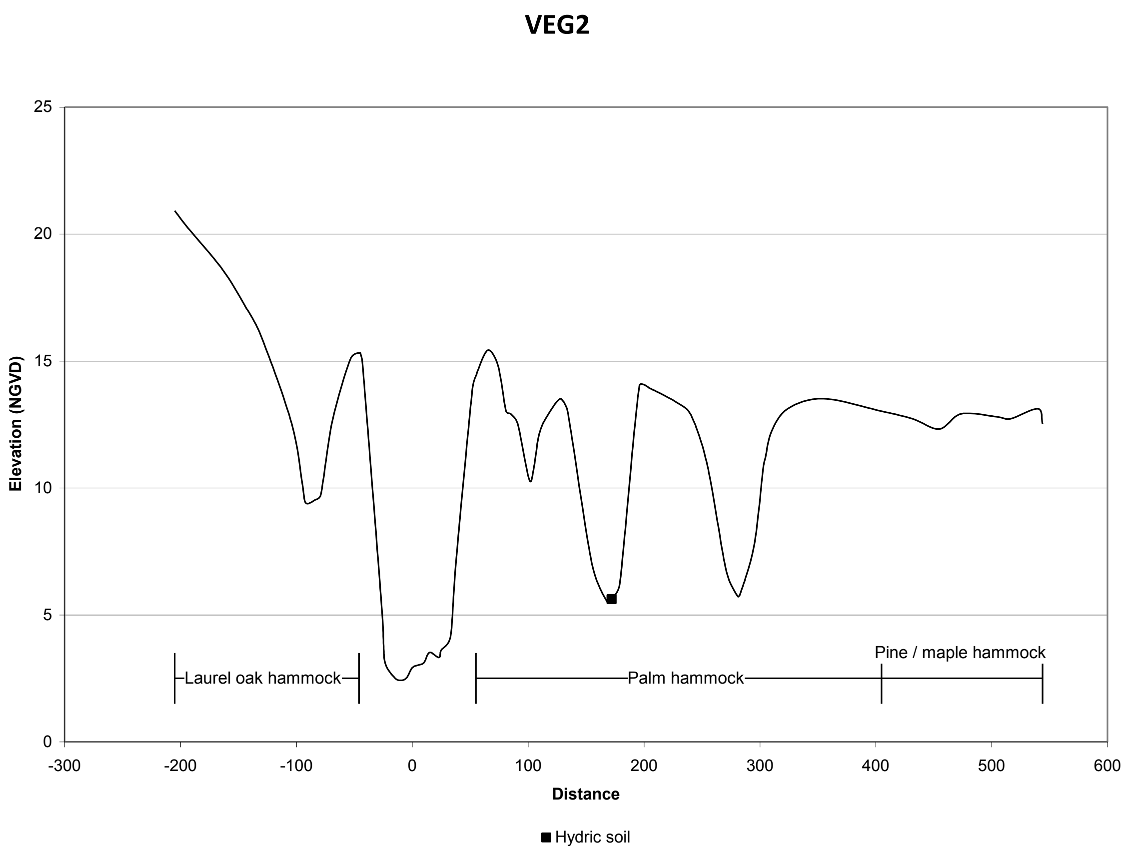
LMAN3

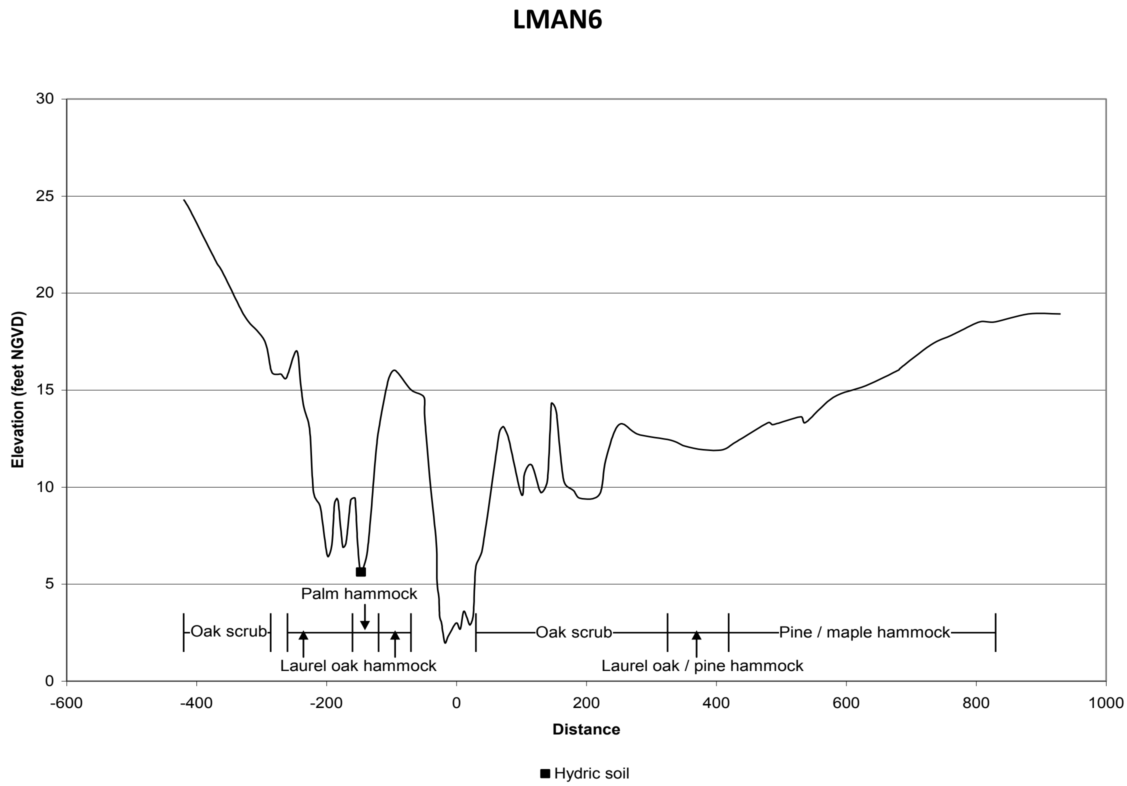

45
40
35
30
25
20
15
Elevation (feet NGVD)
-800
-600
-400
-200
0
200
400
600
800
1000
1200
Distance
Laurel oak hammock
Willow marsh
Laurel oak hammock
■ Hydric soil

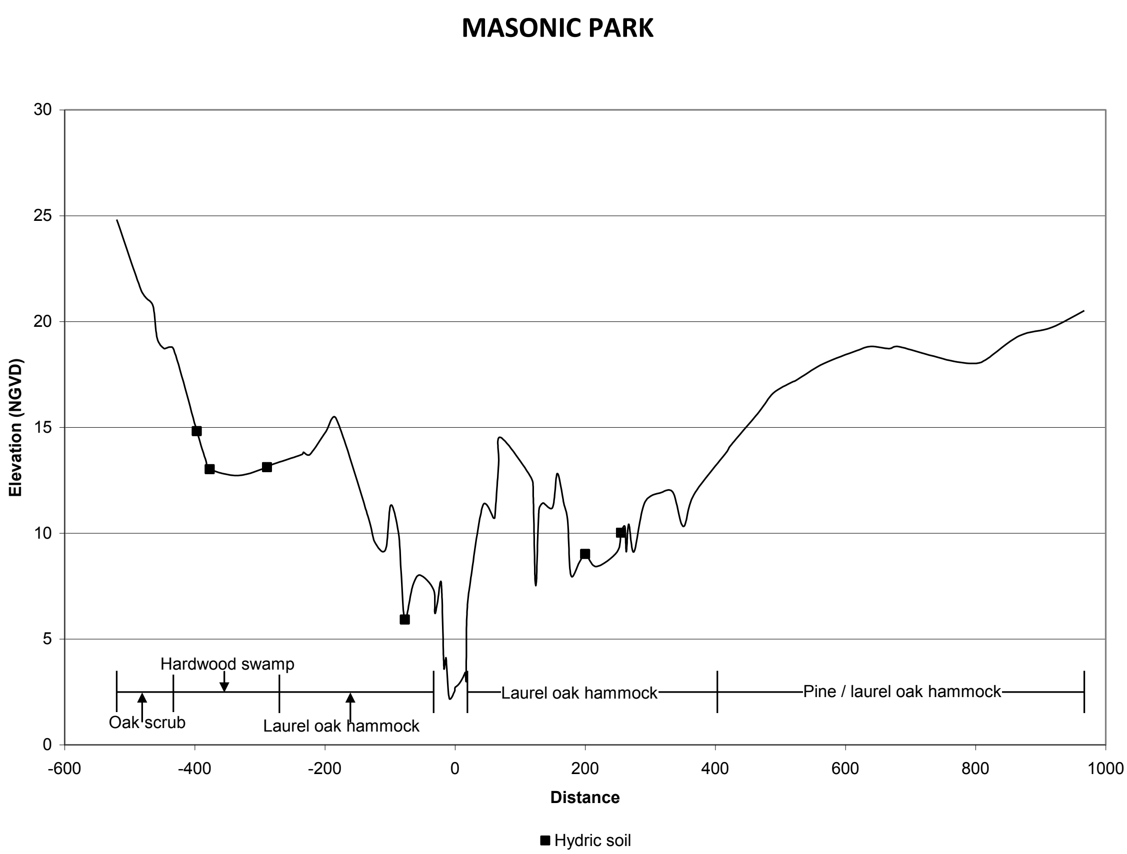
VEG10


35
33
31
29
27
25
23
21
19
17
15
Elevation (feet NGVD)
-300
-200
-100
0
100
200
300
400
500
600
700
800
Distance
Laurel oak hammock
Laurel oak hammock
■ Hydric soil

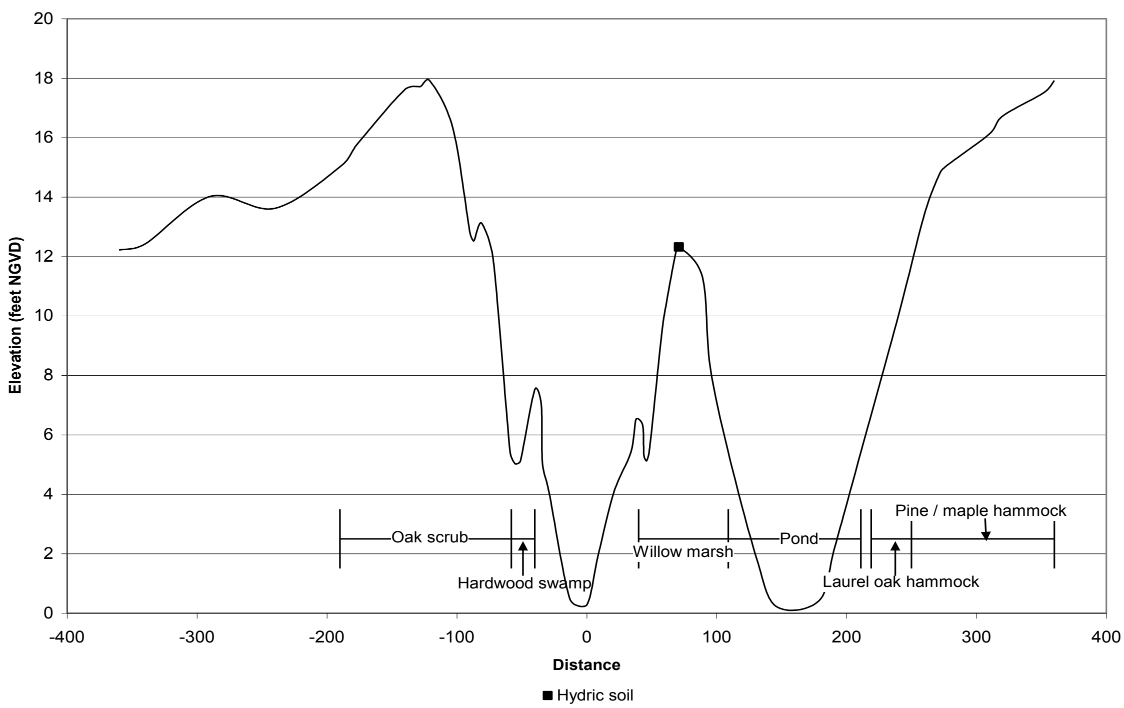

TOSCANY
25
20
15
10
5
0
Elevation (feet NGVD)
-600
-400
-200
0
200
400
600
Distance
Laurel oak hammock
Laurel oak hammock
Hydric soil


VEG2
25
20
15
10
5
0
Elevation (NGVD)
-300
-200
-100
0
100
200
300
400
500
600
Distance
Laurel oak hammock
Palm hammock
Pine / maple hammock
Hydric soil

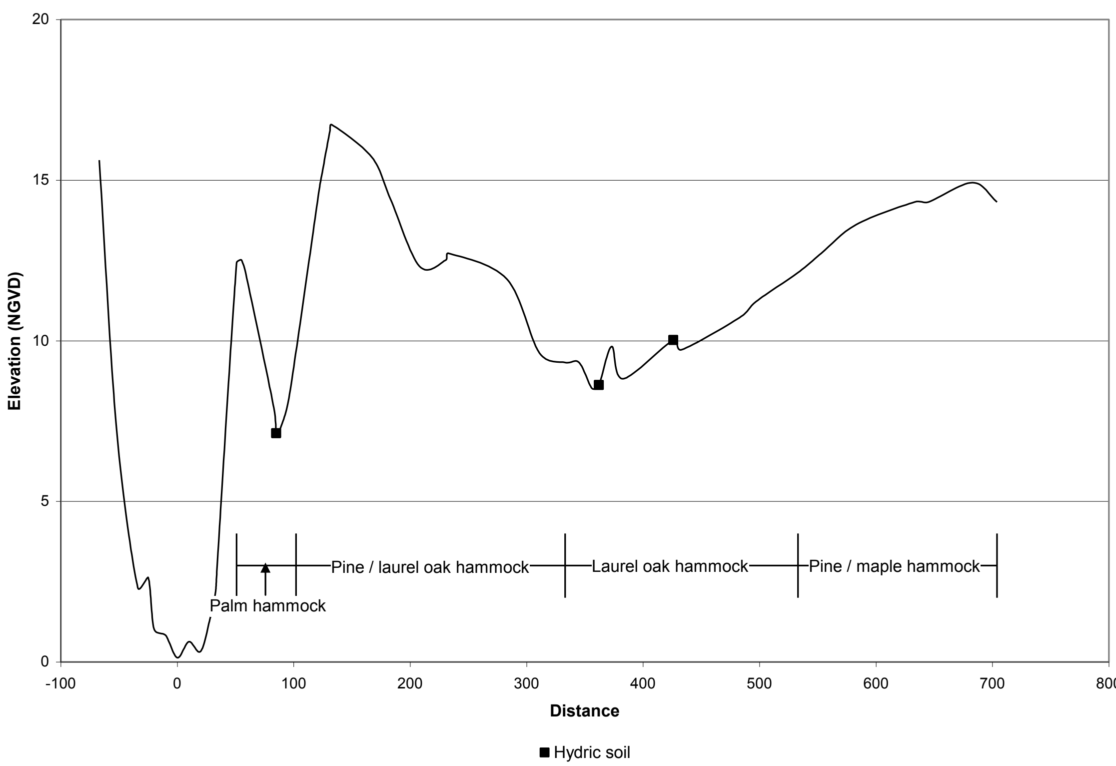

LMAN6
Elevation (feet NGVD)
30
25
20
15
10
5
0
-600
-400
-200
0
200
400
600
800
1000
Distance
Palm hammock
Oak scrub
Laurel oak hammock
Oak scrub
Pine / maple hammock
Laurel oak / pine hammock
Hydric soil


MASONIC PARK
Elevation (NGVD)
30
25
20
15
10
5
0
-600
-400
-200
0
200
400
600
800
1000
Distance
Hardwood swamp
Oak scrub
Laurel oak hammock
Laurel oak hammock
Pine / laurel oak hammock
Hydric soil

LMAN7


20
18
16
14
12
10
8
6
4
2
0
Elevation (feet NGVD)
-400
-300
-200
-100
0
100
200
300
400
Distance
Oak scrub
Hardwood swamp
Willow marsh
Pond
Pine / maple hammock
Laurel oak hammock
Hydric soil

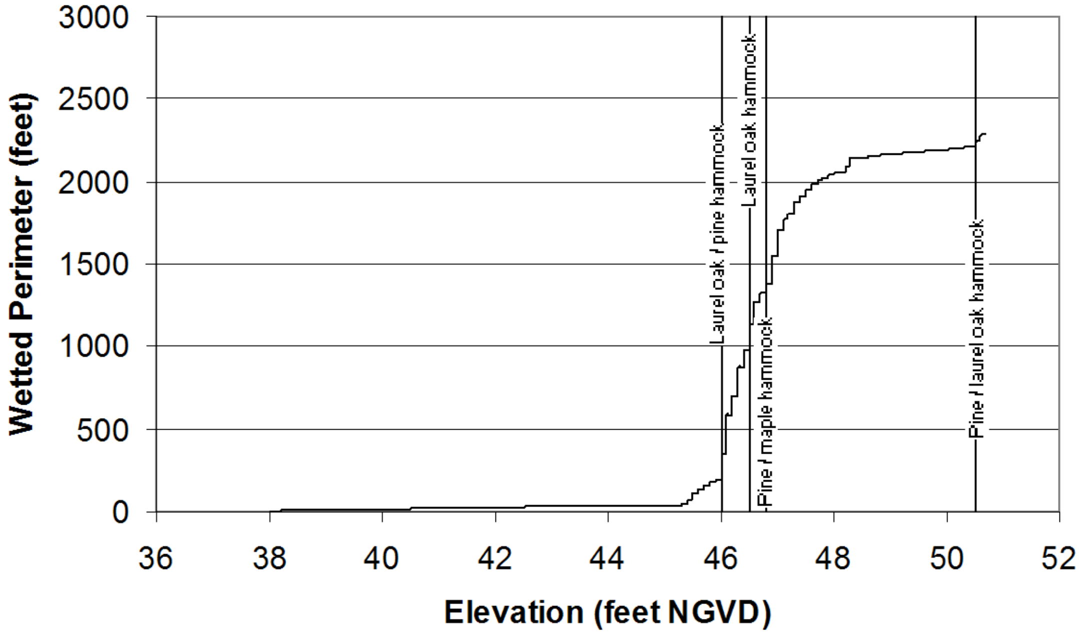
VEG3


20
15
10
5
0
Elevation (NGVD)
-100
0
100
200
300
400
500
600
700
800
Distance
Palm hammock
Pine / laurel oak hammock
Laurel oak hammock
Pine / maple hammock
Hydric soil

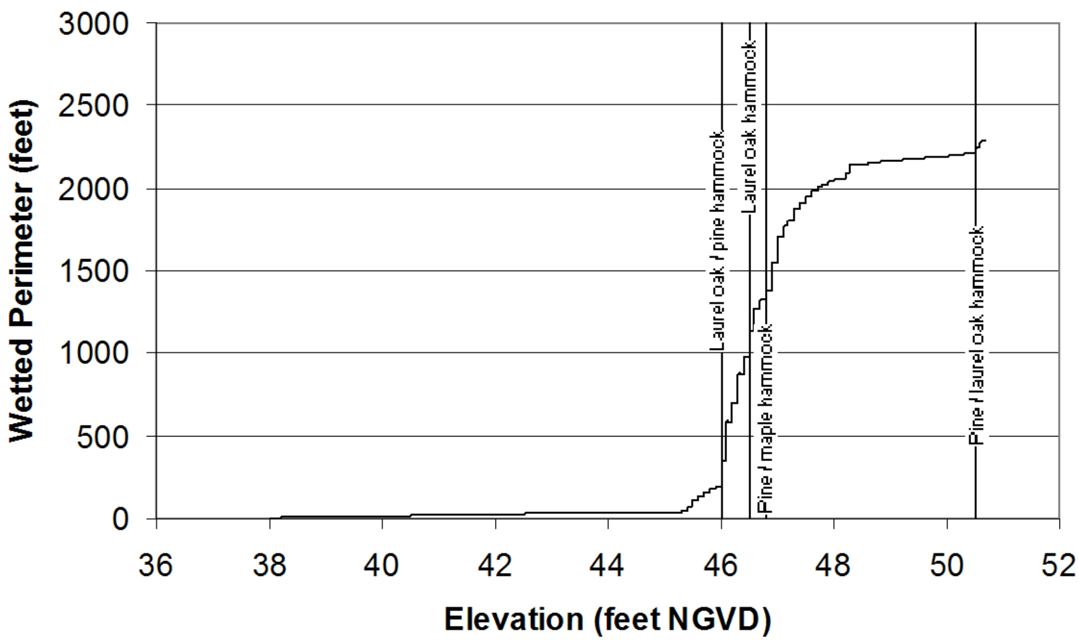
Appendix B

Wetted Perimeter Graphs for the Little Manatee River Study Corridor (In upstream-to-downstream order)

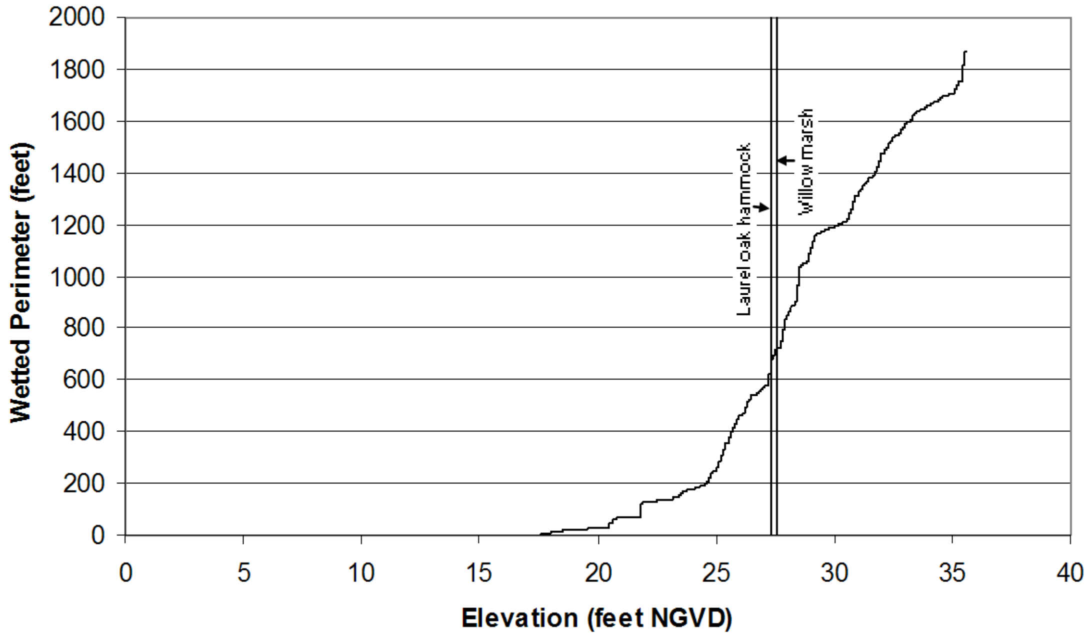
Transect VEG 15



Transect VEG 14



Transect LMAN3



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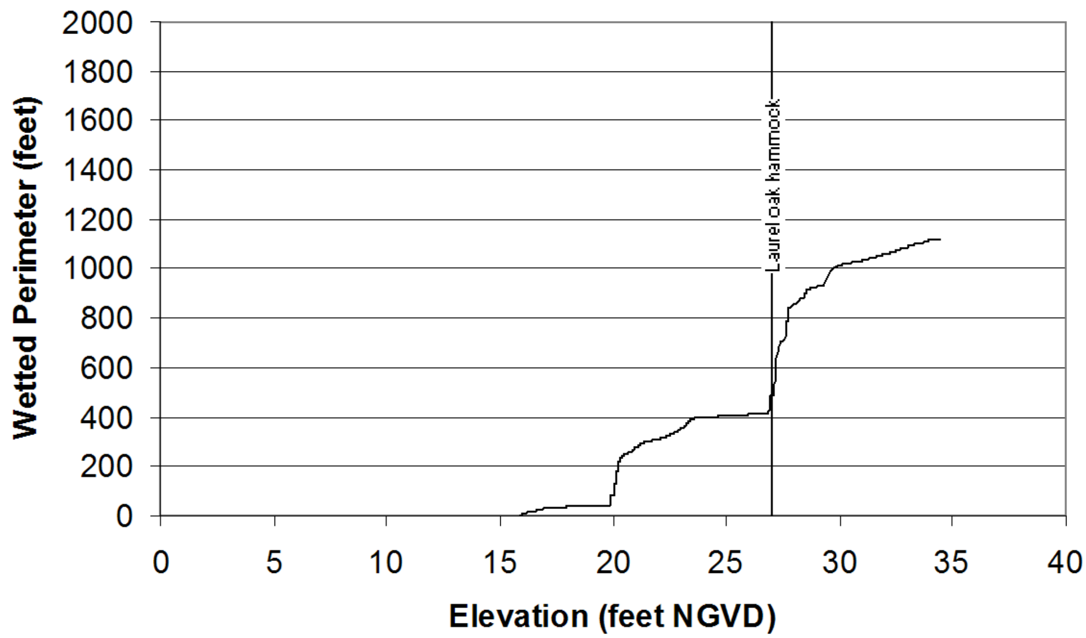
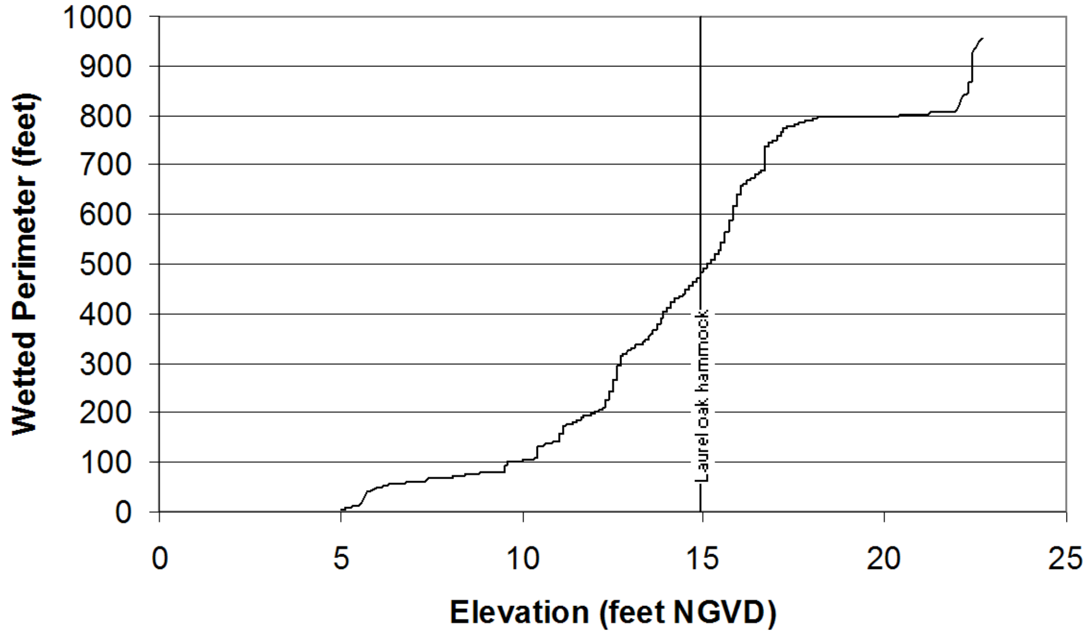


Transect Toscany



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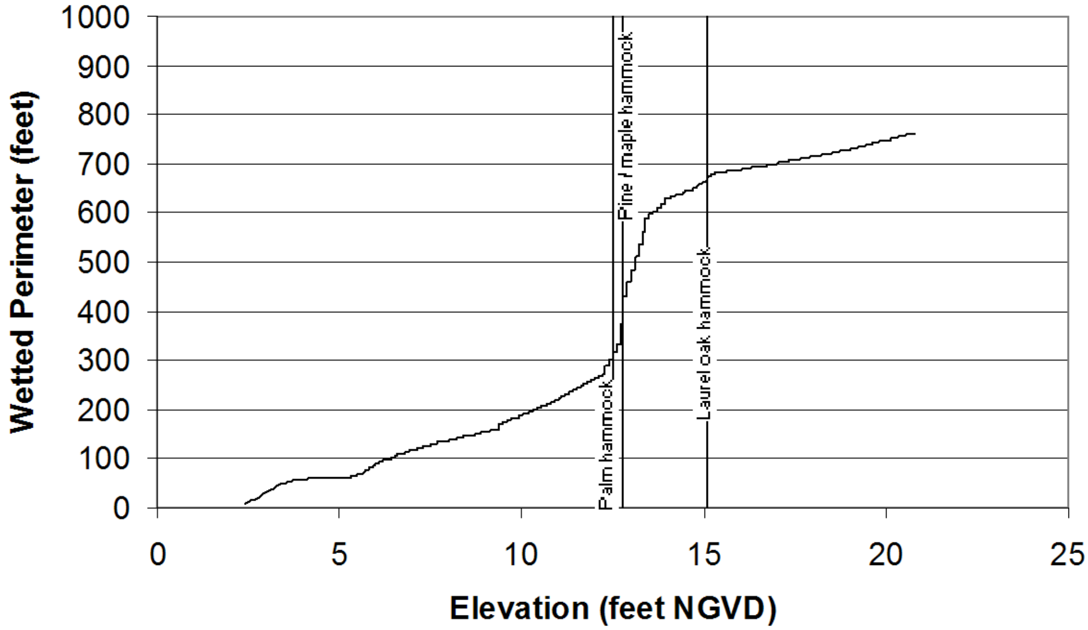
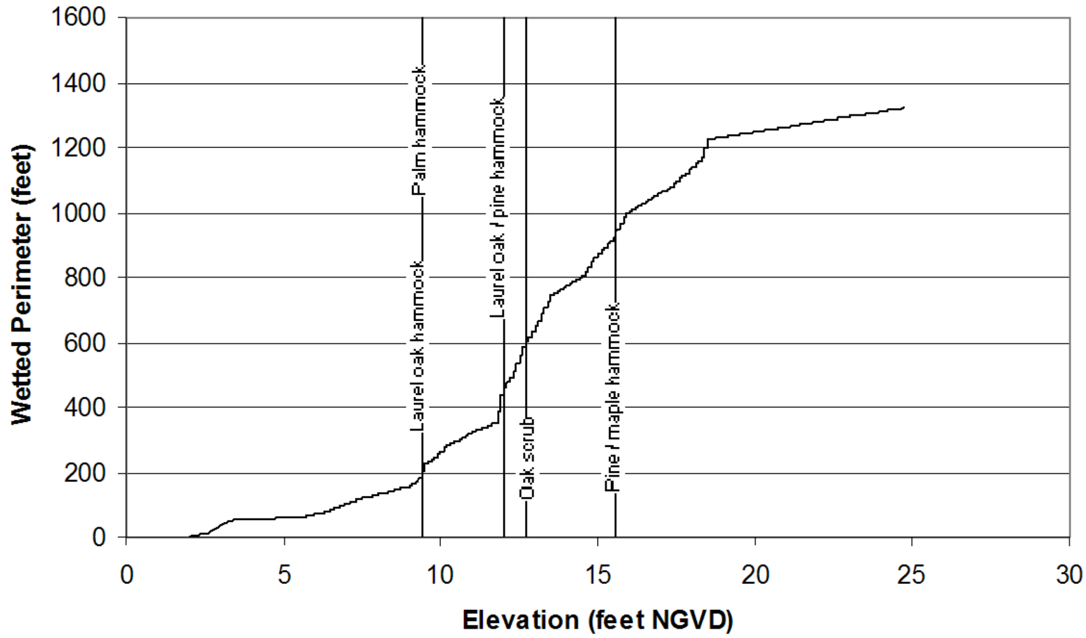
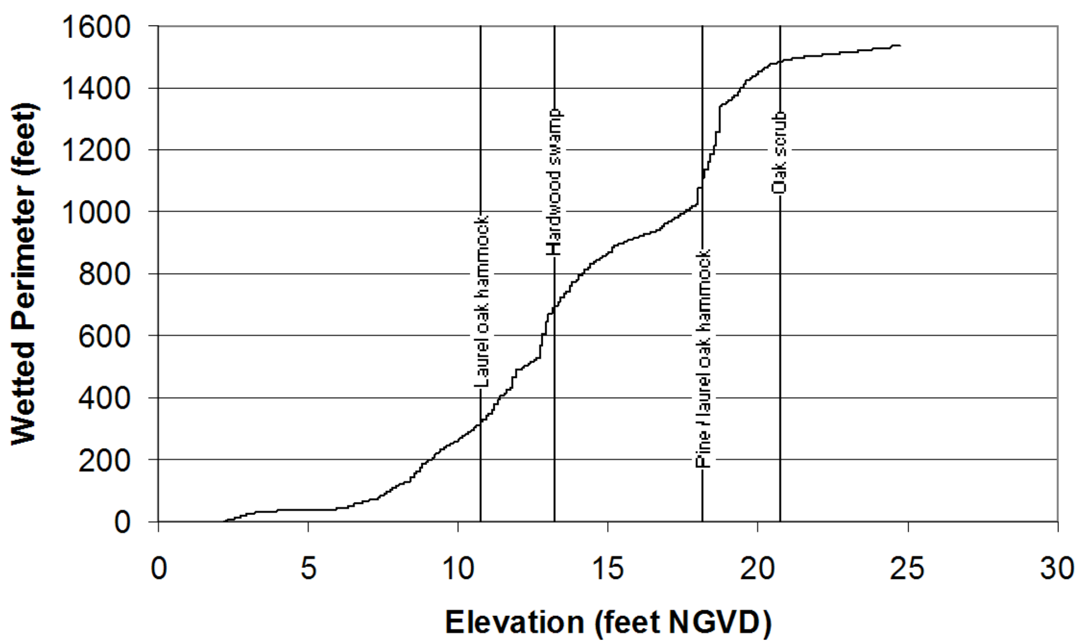


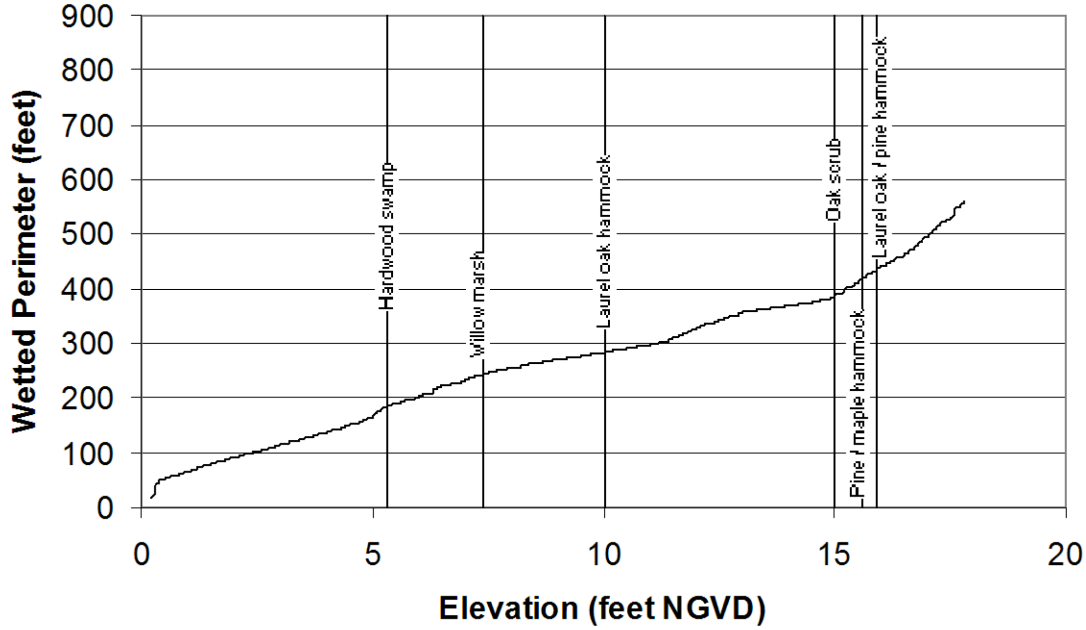
Transect LMAN 6



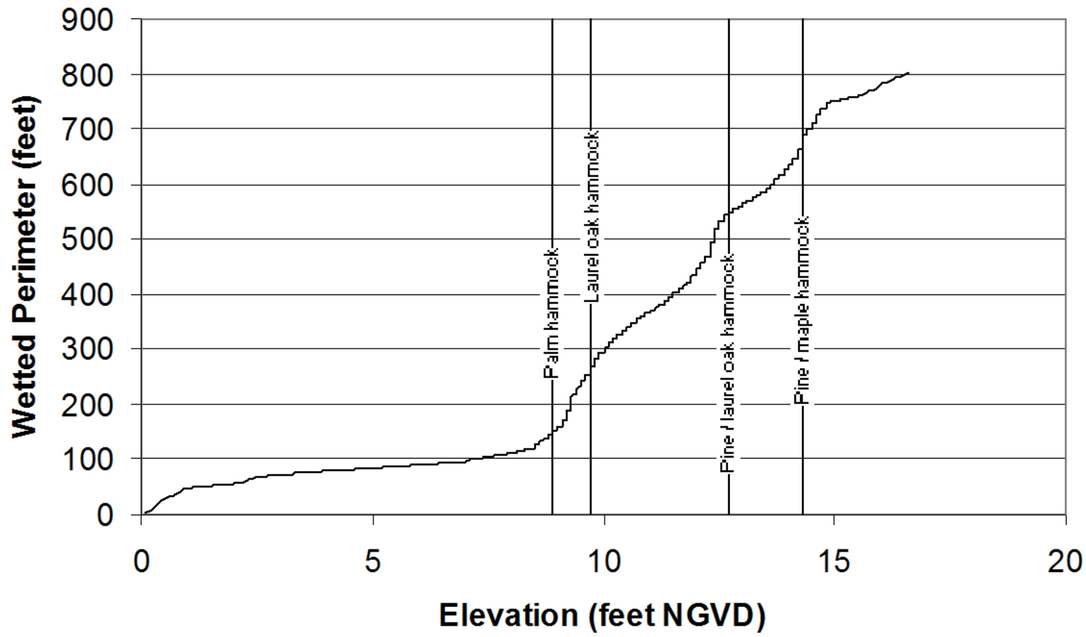
Transect Masonic Park



Transect LMAN 7



Transect VEG 3



Appendix C

Photographs from the Little Manatee River Study Corridor

Willow Marsh

Tupelo Swamp

Hardwood Swamp

Pine / Laurel Oak Hammock

Laurel Oak / Pine Hammock

Laurel Oak Hammock

Palm Hammock

Oak Scrub

HEC-RAS Appendix – HEC-RAS Modeling of Little Manatee River

Prepared for

South West Florida Water Management District

HEC-RAS MODELING OF LITTLE MANATEE RIVER

10POSOW0468

Final Report

Prepared by

Engineering & Construction, Inc.

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July, 2010

Client

SOUTH WEST FLORIDA WATER MANAGEMENT DISTRICT

Project

HEC-RAS MODELING OF LITTLE MANATEE RIVER

10POSOW0468

PJE0654a

Report No.	*Copy No.*

Date of Issue

July, 2010

Report Title

Final Report

		Date
Prepared by	***Tony Guan (ZFI)***	***6/29/2010***

Reviewed by	***Antonio De Corral (ZFI)***	***7/1/2010***
Submitted to	***Jason Hood (SWFWMD)***	***7/2/2009***

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TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

Introduction

Project Background

ZFI Engineering and Construction Inc. (ZFI), is undertaking the HEC-RAS Modeling of Little Manatee River Project (10POSOW0468) provided by the Southwest Florida Water Management District. The District is committed to developing scientifically defensible methodologies to be used in the establishment of minimum flows on priority watercourses within its boundaries as required by Sections 373.042 and 373.0421 of the Florida Statutes.

This project pertains to technical assistance in the determination of minimum flows for Little Manatee River. One methodology, Hydrologic Engineering Centers River Analysis System (HEC-RAS), has been used throughout the United States. HEC-RAS has been utilized by the District for the Alafia, Upper Myakka, Hillsborough, Braden and Middle Peace Rivers. This approach is based on determining the river stages along the study reach under various flow conditions, which is the major objective of this project. The data can then be used to determine fish passage and wetted perimeter requirements, inundation of snag habitat, and inundation frequency/duration of riverine vegetation and floodplains.

Project Location and General Description

The Little Manatee River (LMR) watershed lies primarily in southern Hillsborough County and northern Manatee County, Florida. The study area in the project does not cover the entire LMR watershed which is bordered by the Alafia River and Bullfrog Creek watersheds on the north, the Manatee River watershed on the South, the Peace River watershed on the east and Tampa Bay on the west. Instead, only part of river, which is from USGS02300100 near Ft. Lonesome, FL to USGS02300500 near Wimauma, FL is studied in this project.

The main channel of the river in the study area flows from east to west for approximately 15 miles, providing surface drainage for approximately 200 square miles. It contains several major named tributaries, including Howard Prairie Branch, Pierce Branch, Carlton Branch, Gully Branch, Lake Wimauma Plain, Dug Creek, and South Fork, etc..

Ecosystems observed along the River included Oak Hammocks, Scrubby High Pines, and Temperate Hardwood Forests (possibly in some areas of the river). Flora observed included various Oak species (i.e. Chapman Oak, Live Oak), Saw Palmetto, Rosemary, and Sand Pines. The topography is mainly low-lying hilly areas and the substrate was mostly sandy. The River banks were primarily steep and sandy. Water flow along the River is generally regulated by natural controls, including both rocky and sandy shoals.

The LMR watershed contains only two natural lakes, Carlton Lake and Lake Wimauma, and a 4,000 acre cooling water reservoir located south of the river where it dips into Manatee County. Water from the reservoir is withdrawn from the Little Manatee River and is used to cool the existing Florida Power and Light (FP&L) electric generating facility.

Description of the Study Area

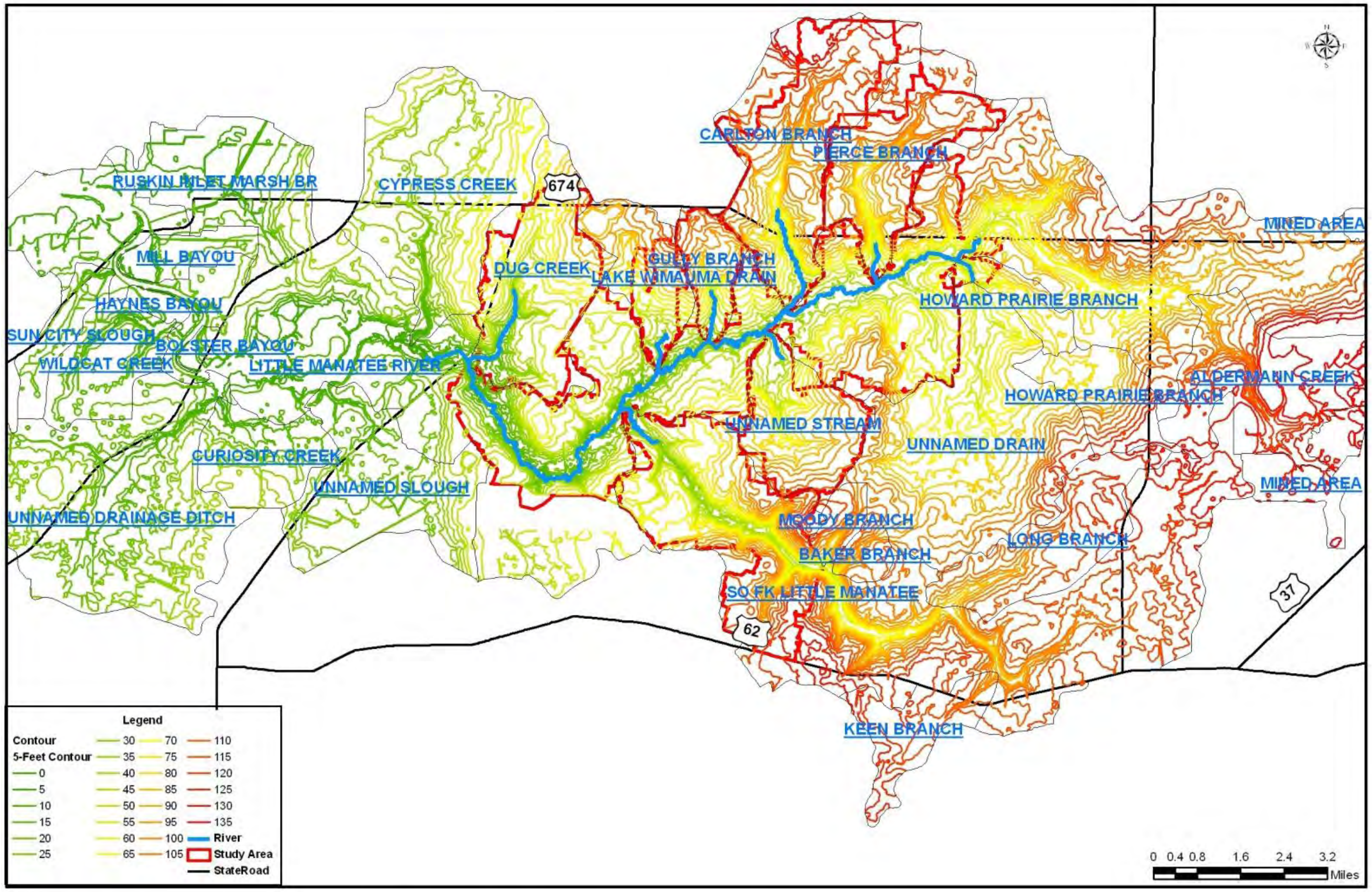
Local Climate

The climate in the study area can be characterized as subtropical, typified by warm, humid summers, mild winters, and dry spring and fall seasons. The annual mean temperature is about 72 degree F (Fahrenheit). The mean monthly temperature ranges from a low of approximately 60 degree F in January to a high of approximately 82 degree F in August. Summer daytime temperatures commonly exceed 90 degrees F. Typical winter low temperatures generally range above freezing into the 40's; only occasionally dropping into the low 20's and teens.

Average annual precipitation for the NWS Parrish Station (1958-2009) is approximately 53.8 inches. More than half of the annual rainfall typically falls during the four-month rainy season that extends from June through September. This time frame coincides with the occurrence of most tropical storms and hurricanes and the conditions are ripe for regular, convective afternoon and evening thunderstorms. Winter rainfall is historically relatively light and is generally associated with the weak cold fronts that descend from the northern part of the country and travel south through the region.

Topography

The LMR watershed rises from sea level at Tampa Bay to about 50 feet NAVD88 at USGS02300100 near Ft. Lonesome, FL. Slopes are relatively mild in the basin, with more pronounced slopes east of US 301 and Wimauma. Areas with the steepest topographic slopes include the Lake Wimauma Drain and Gully Branch tributaries in Hillsborough County and portions of the South Fork tributary located primarily in Manatee County. Figure 0-1 shows the contour lines for the LMR watershed. Red color indicates areas of high elevation and green lines indicate topographically lower areas.



Five-Feet Contour Lines (Topography)

HEC-RAS MODELING OF LITTLE MANATEE RIVER
10POSOW0468

Figure 0-1 Five-feet Contour Lines (Topography)

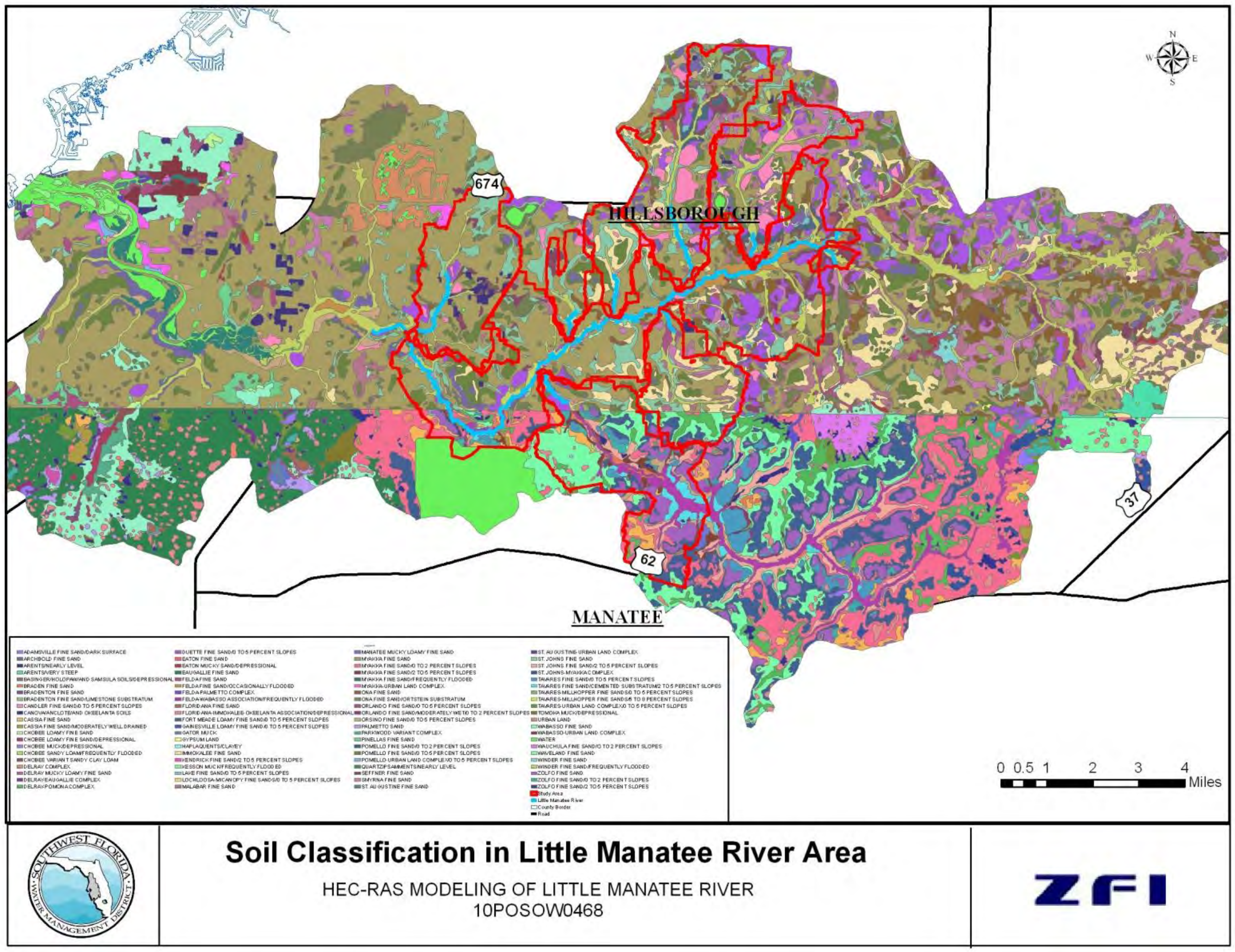
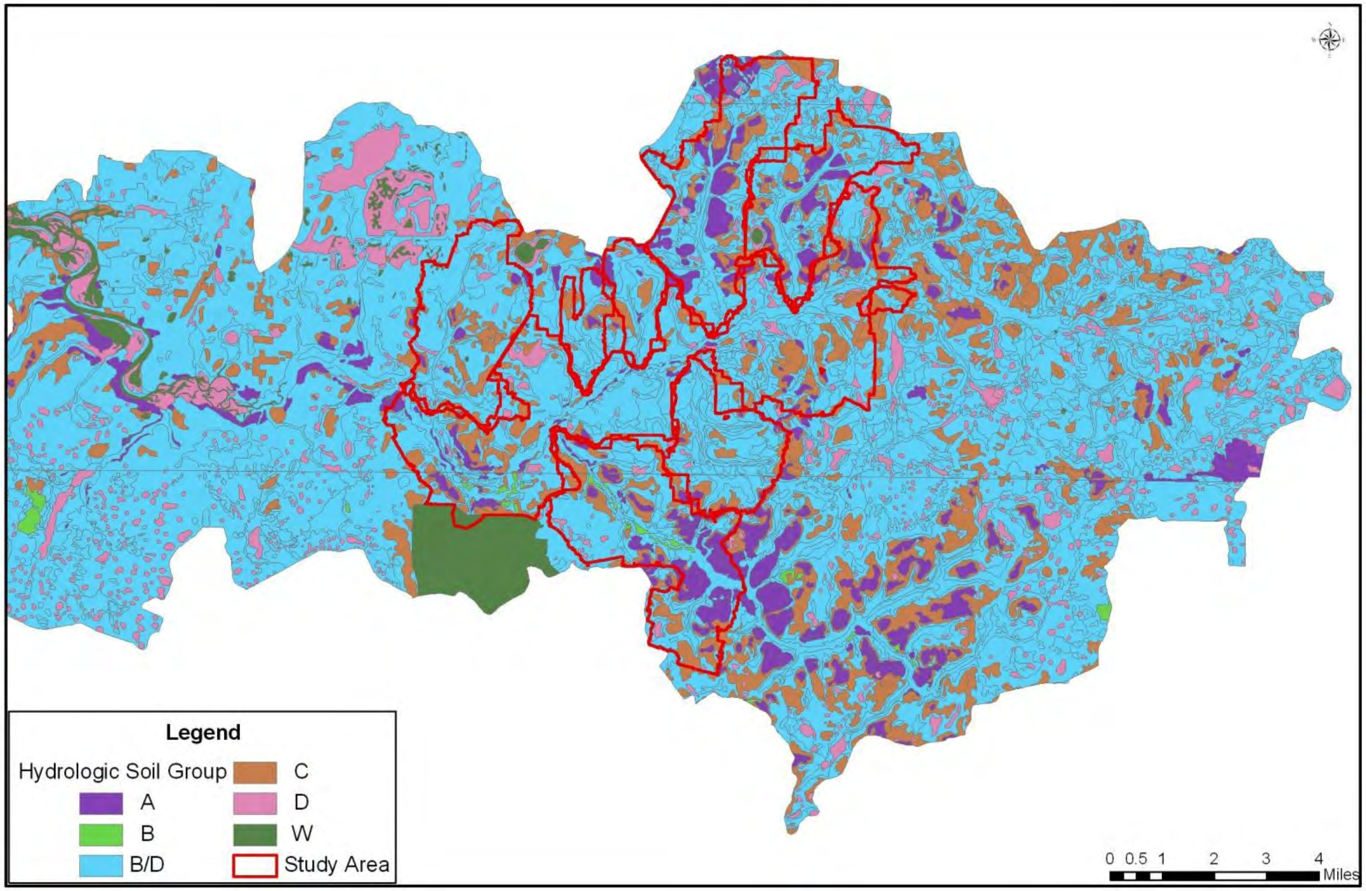


Figure 0-2 Soil Classification



Hydrologic Soil Group

HEC-RAS MODELING OF LITTLE MANATEE RIVER

10POSOW0468

ZFI

Figure 0-3 Hydrologic Soil Group

Soils

Primary soil group in the LMR watershed is the Myakka Fine Sand which is characterized by wet, sandy soils with an organic-stained subsoil layer. Figure 0-2 shows the location of soil classifications in the LMR watershed. This information was developed based on SCS Soil Survey with GIS coverages developed by SWFWMD.

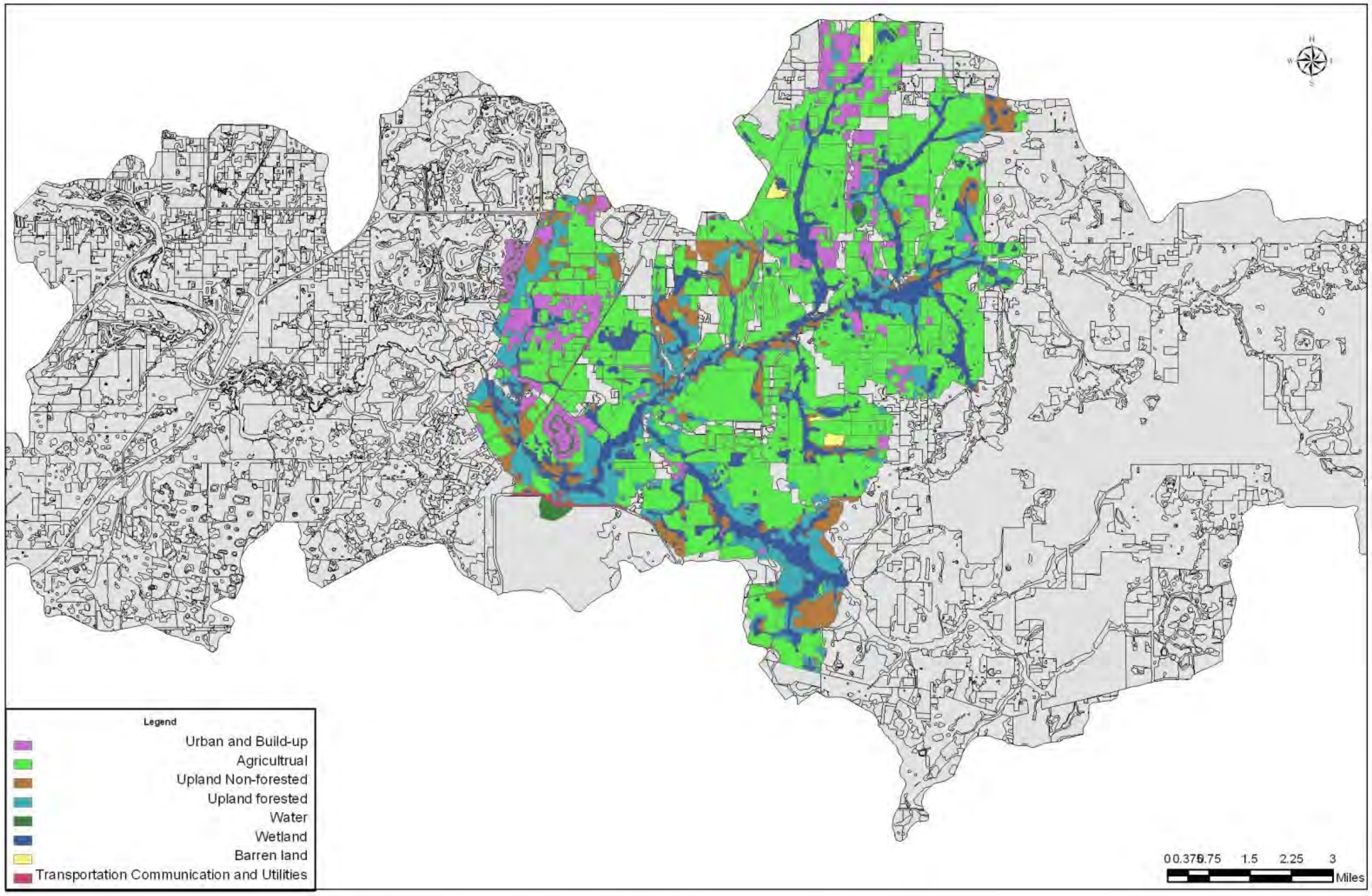
Soils are also classified by their hydrologic characteristics. The Hydrologic Soil Groups (HSG) designation for soils is used to estimate infiltration rates, moisture capacity and runoff from precipitation. Hydrologic soil polygons were developed from the SCS Soil Survey of Hillsborough County, Florida, 1989 (USDA SCS, 1989). Each soil with identification numbers contained in the Soil Survey can be associated with its corresponding Hydrologic Soil Group. Hydrologic Soil Groups in the LMR watershed consist of the following designations as shown in Figure 0-3.

- Group A (low runoff potential) soils have high infiltration rates and a high rate of water transmission even when thoroughly wetted. They have typical infiltration rates of 10 in/hr when dry and 0.50 in/hr when saturated.
- Group B (moderate runoff potential) soils have moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. They typically have infiltration rates of 8 in/hr when dry and 0.40 in/hr when saturated.
- Group C (moderately high runoff potential) soils have low infiltration rates when thoroughly wetted and a low rate of water transmission. They typically have infiltration rates of 5 in/hr when dry and 0.25 in/hr when saturated.
- Group D (high runoff potential) soils have very slow infiltration rates when thoroughly wetted and a very low rate of water transmission. They typically have infiltration rates of 3 in/hr when dry and 0. 10 in/hr when saturated.
- Dual classifications (e.g. A/D or B/D) can be assigned to soils that exhibit substantially different hydrologic characteristics during the wet and dry seasons. Soils that have a seasonal high water

table but can be drained are assigned first to a hydrologic soil group that represents the drained conditions of the soil and then to a hydrologic group that denotes the undrained condition. Many soils in the LMR watershed have dual HSG designations. The predominate Hydrologic Soil Group within the LMR watershed is B/D comprising almost 70% of the watershed.

Land Use / Land Cover

The SWFWMD has developed GIS coverages for the 2008 land use/land cover for the entire LMR watershed. The GIS coverage was developed using the Florida Land Use/Cover Classification System (FLUCCS) to define land use/land cover in one of about 50 categories. Each polygon in the coverage has been assigned a FLUCCS code corresponding to the existing land use for that area. As shown in Figure 0-4, existing land use/land cover in the Little Manatee River basin is dominated by agriculture which encompasses more than 40 percent of the total basin area. The primary agricultural uses include pastureland, citrus and row crops. Table 0-1 contains the distribution of existing land use/land cover (2008) for the watershed.



Land Use (2008) in Little Manatee River Area

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10POSOW0468

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Figure 0-4 Land Use (2008)

Table 0-1 Existing Land Use / Land Cover (2008) Distribution

FLUCCS Codes	Land	Percentage	Area (sq mles)
1100	Residential Low Density < 2 Dwelling Units	5.64%	3.07
1300	Residential High Density	0.27%	0.15
1300	Residential High Density	0.18%	0.10
1400	Commercial And Services	0.29%	0.16
1500	Industrial	0.07%	0.04
1600	Extractive	0.35%	0.19
1700	Institutional	0.07%	0.04
1900	Open Land	1.31%	0.71
2100	Cropland And Pastureland	20.53%	11.17
2140	Row Crops	10.83%	5.89
2200	Tree Crops	9.21%	5.01
2400	Nurseries And Vineyards	3.02%	1.64
2550	Tropical Fish Farms	1.02%	0.55
2600	Other Open Lands <Rural>	11.03%	6.00
3100	Herbaceous	0.19%	0.10
3200	Shrub And Brushland	6.83%	3.72
3300	Mixed Rangeland	0.42%	0.23
4110	Pine Flatwoods	6.31%	3.44
4200	Upland Hardwood Forests - Part 1	0.33%	0.18

4340	Hardwood Conifer Mixed	5.72%	3.11
4400	Tree Plantations	0.14%	0.08
5200	Lakes	0.15%	0.08
5300	Reservoirs	0.70%	0.38
6150	Stream And Lake Swamps (Bottomland)	12.30%	6.70
6210	Cypress	0.40%	0.22
6410	Freshwater Marshes	0.97%	0.53
6430	Wet Prairies	0.64%	0.35
6530	Intermittent Ponds	0.06%	0.03
8100	Transportation	0.67%	0.37
8200	Communications	0.04%	0.02
8300	Utilities	0.29%	0.16

Major Tributaries

Major tributaries contained in the study area include Howard Prairie Branch, Pierce Branch, Carlton Branch, Gully Branch, Lake Wimauma Plain, Dug Creek, and South Fork. There are also several smaller unnamed tributaries that drain into the main channel of the little manatee river.

Howard Prairie

The Howard Prairie Branch lies in upstream portion of the study area. The tributary has two major branches. Both tributaries have a relatively mild slope. The headwaters of the western branch fall in Manatee County. Flow for this branch is in a northerly direction where it crosses Stanland Road approximately one mile upstream of its confluence with the eastern branch. A potential connection exists between the west branch of Howard Prairie and Moody Branch of the South Fork tributary under high flow conditions. Flow for the eastern branch is in a northwesterly direction toward the main channel of the river. Grange Hall Loop crosses both branches just upstream of their confluence. Downstream portions of both branches of the system contain a series of wetlands connected by channels with wide floodplains.

Pierce Branch

The Pierce Branch tributary lies north of the main channel of the river. Headwaters for the tributary lie north of SR 672. Since the watershed boundary crosses Hurrah Bay, flow transfer between Pierce Branch of the LMR and Lewis Branch of the Alafia River is possible at high flows. In addition to the above mentioned crossing, this six mile tributary intersects the major road crossings of Sweat Loop Road, Owens Road and SR 674. Several unnamed tributaries discharge to Pierce Branch north of the SR 674 crossing. One of the two natural lakes in the watershed, Carlton Lake outfalls to Pierce Branch. This is a 34 acre natural feature surrounded primarily by agricultural lands. Although there is no man-made control structures on the lake, once the lake reaches flood stage, flows can pass to Pierce Branch through an open channel.

Carlton Branch

Carlton Branch is located north of the main channel of the river between Pierce Branch and Gully Branch. The headwaters of the tributary are in the vicinity of SR 672. Flow from the headwaters travels in a southwesterly direction and crosses under Carlton Lake Road, Sweat Loop Road and Colding Loop. Downstream of these crossings, several smaller unnamed tributaries confluence with Carlton Branch. Flow then follows a southerly direction for approximately two miles and then crosses SR 674. A historic USGS discharge/stage gage is located on the downstream side of this road crossing. The tributary continues to flow south for about another two miles where it converges with the main channel of the river.

Gully Branch

Gully Branch lies north of the main channel of the river between Pierce Branch and Lake Wimauma Drain. This tributary has one branch located west of the main tributary channel. Flow is in a north to south direction. The headwaters for the main channel of Gully Branch lie south of SR 674. The main tributary is approximately two miles long and has a relatively steep bottom profile.

Lake Wimauma Drain

The Lake Wimauma drain tributary lies north of the main channel of the river between Gully Branch and the C.S.X. railroad. As the name would indicate, this channel provided a historical outfall for Lake Wimauma. However, this historical surficial connection no longer exists. The main channel of this tributary, as well as the connecting branches, flow from north to south and discharge into the main channel of the river. The channel bottom slope for Lake Wimauma Drain is slightly milder than that for Gully Branch.

Dug Creek

Dug Creek is located in the downstream portion of the study area west of US 301 and east of Cypress Creek. Headwaters for the tributary lie in a small wetland adjacent to US 301, north of SR 674. Land use surrounding the creek is primarily agriculture. Tropical fish farms are located in the downstream reaches of the creek. The creek flows in a southerly direction, crossing an unnamed dirt road and SR 674 to a large wetland. Flow continues to the south where several tributaries join the main channel of the creek before it crosses Bishop Road. A discontinued USGS discharge/stage gage is located at the downstream side of this road crossing. The creek continues in a southwesterly direction and crosses Saffold Road before discharging to the main channel of the river.

South Fork

The South Fork basin is almost entirely contained in Manatee County. The basin is roughly bounded by the IMC mine on the east, SR 579 on the west, Manatee County on the north and SR 62 on the south. South Fork is the largest tributary to the Little Manatee River, providing surface drainage for approximately 38.5 square miles. This tributary consists of five named tributaries including: Long Branch, Baker Branch, Moody Branch, Keen Branch, and Graveyard Creek. There are also a number of unnamed contributing tributaries. The headwaters for the main channel of South Fork lie near the IMC Mine. From the headwaters, flow is in a southwesterly then northwesterly direction until the tributary discharges into the main channel of the river downstream of SR 579. Other major road crossings include: County Road 39, Bunker Hill Road, Taylor Grade Road, Trail Arch Road, Trail Road.

Hydrology Model Development

Introduction

This section summarizes the methodology used to develop the hydrologic model for the Little Manatee Watershed Study. The modeling was performed using USACE's Hydrologic Engineering Center's Hydrologic Modeling System program (HEC-HMS) Version 3.4. The HEC-HMS model is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest.

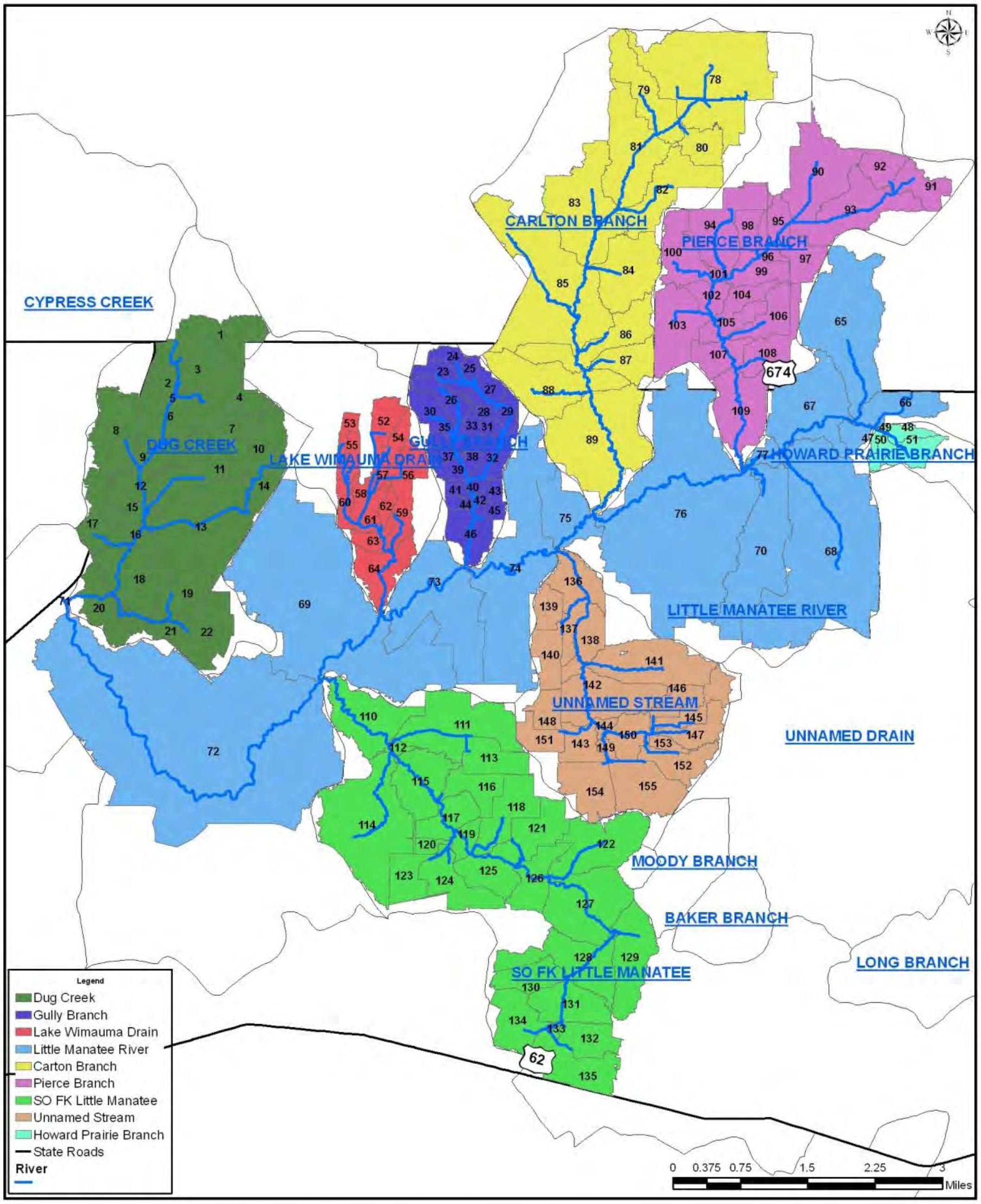
Hydrology Methodology

The HEC-HMS model was used to simulate runoff volumes and hydrographs resulting from design storms for 5, 10, 25, 50 and 100 year return periods using the design storms outlined in the Hillsborough County Storm Water Management Technical Manual and SWFWMD Watershed Management Program Guidelines and Specifications. The hydrology methodology contains five primary components: subarea delineation, rainfall, runoff volume, runoff hydrographs and routing.

Subarea Delineation

The study area in the Little Manatee Watershed was divided into 8 sub-basins based on the GIS coverage provided by the District. All the sub-basins were further delineated into 151 sub-areas. A map showing the sub-area boundaries are shown on Figure 0-1. The delineation was performed using ArcGIS, HEC-GeoHMS, and the digital elevation model (DEM) developed from the LiDAR data provided by the District. The HEC-GeoHMS tool runs within ArcGIS and uses the DEM to delineate subareas and to determine the overland flow path for each subarea.

Using the HEC-GeoHMS tool, the approximate locations for subarea outlets, such as stream crossings and tributaries were identified using ArcGIS and available GIS data. The HEC-GeoHMS tool used these points to automatically delineate the subarea boundaries based on DEM. The preliminary HEC-HMS model was then created based on the automated subarea delineations. The auto-delineated subareas were manually checked against contours and drainage structure locations to accurately define the boundaries. The preliminary HEC-HMS model was manually modified to reflect updated subarea boundaries. All subareas were given a unique alphanumeric name with the format “AAA-Wxxx”. “AAA” is the two or three letter code showing the sub-basin name. “xxx” is a three digit code to identify the subarea. The sub-area identification table is shown in Table 0-1.



Little Manatee River Sub-Area Delineation

HEC-RAS MODELING OF LITTLE MANATEE RIVER
10POSOW0468

Figure 0-1 Little Manatee River Sub-Area Delineation
Table 0-1 Sub-Area Identification Table

NO.	Sub-Basin Name	Sub-Area ID	NO.	Sub-Basin Name	Sub-Area ID
1	Dug Creek	DC-W260	79	Carton Branch	CB-W370
2	Dug Creek	DC-W270	80	Carton Branch	CB-W380
3	Dug Creek	DC-W280	81	Carton Branch	CB-W390
4	Dug Creek	DC-W290	82	Carton Branch	CB-W400
5	Dug Creek	DC-W300	83	Carton Branch	CB-W430
6	Dug Creek	DC-W310	84	Carton Branch	CB-W480
7	Dug Creek	DC-W320	85	Carton Branch	CB-W490
8	Dug Creek	DC-W330	86	Carton Branch	CB-W510
9	Dug Creek	DC-W340	87	Carton Branch	CB-W520
10	Dug Creek	DC-W350	88	Carton Branch	CB-W540
11	Dug Creek	DC-W360	89	Carton Branch	CB-W550
12	Dug Creek	DC-W370	90	Pierce Branch	PB-W230
13	Dug Creek	DC-W380	91	Pierce Branch	PB-W240
14	Dug Creek	DC-W390	92	Pierce Branch	PB-W250
15	Dug Creek	DC-W400	93	Pierce Branch	PB-W260
16	Dug Creek	DC-W410	94	Pierce Branch	PB-W270
17	Dug Creek	DC-W420	95	Pierce Branch	PB-W280
18	Dug Creek	DC-W430	96	Pierce Branch	PB-W290
19	Dug Creek	DC-W440	97	Pierce Branch	PB-W300

NO.	Sub-Basin Name	Sub-Area ID	NO.	Sub-Basin Name	Sub-Area ID
20	Dug Creek	DC-W450	98	Pierce Branch	PB-W310
21	Dug Creek	DC-W460	99	Pierce Branch	PB-W320
22	Dug Creek	DC-W470	100	Pierce Branch	PB-W330
23	Gully Branch	GB-W270	101	Pierce Branch	PB-W340
24	Gully Branch	GB-W290	102	Pierce Branch	PB-W350
25	Gully Branch	GB-W300	103	Pierce Branch	PB-W370
26	Gully Branch	GB-W310	104	Pierce Branch	PB-W380
27	Gully Branch	GB-W320	105	Pierce Branch	PB-W390
28	Gully Branch	GB-W330	106	Pierce Branch	PB-W400
29	Gully Branch	GB-W340	107	Pierce Branch	PB-W410
30	Gully Branch	GB-W350	108	Pierce Branch	PB-W420
31	Gully Branch	GB-W360	109	Pierce Branch	PB-W430
32	Gully Branch	GB-W370	110	SO FK Little Manatee	SF-W290
33	Gully Branch	GB-W380	111	SO FK Little Manatee	SF-W310
34	Gully Branch	GB-W390	112	SO FK Little Manatee	SF-W320
35	Gully Branch	GB-W400	113	SO FK Little Manatee	SF-W330
36	Gully Branch	GB-W410	114	SO FK Little Manatee	SF-W340
37	Gully Branch	GB-W420	115	SO FK Little Manatee	SF-W350
38	Gully Branch	GB-W430	116	SO FK Little Manatee	SF-W360
39	Gully Branch	GB-W440	117	SO FK Little Manatee	SF-W370
40	Gully Branch	GB-W450	118	SO FK Little Manatee	SF-W380

NO.	Sub-Basin Name	Sub-Area ID	NO.	Sub-Basin Name	Sub-Area ID
41	Gully Branch	GB-W460	119	SO FK Little Manatee	SF-W390
42	Gully Branch	GB-W470	120	SO FK Little Manatee	SF-W400
43	Gully Branch	GB-W480	121	SO FK Little Manatee	SF-W410
44	Gully Branch	GB-W490	122	SO FK Little Manatee	SF-W420
45	Gully Branch	GB-W500	123	SO FK Little Manatee	SF-W430
46	Gully Branch	GB-W510	124	SO FK Little Manatee	SF-W440
47	Howard Prairie Branch	HPB-W120	125	SO FK Little Manatee	SF-W450
48	Howard Prairie Branch	HPB-W130	126	SO FK Little Manatee	SF-W460
49	Howard Prairie Branch	HPB-W140	127	SO FK Little Manatee	SF-W470
50	Howard Prairie Branch	HPB-W150	128	SO FK Little Manatee	SF-W480
51	Howard Prairie Branch	HPB-W160	129	SO FK Little Manatee	SF-W490
52	Lake Wimauma Drain	LWD-W360	130	SO FK Little Manatee	SF-W500
53	Lake Wimauma Drain	LWD-W370	131	SO FK Little Manatee	SF-W510
54	Lake Wimauma Drain	LWD-W380	132	SO FK Little Manatee	SF-W520
55	Lake Wimauma Drain	LWD-W410	133	SO FK Little Manatee	SF-W530
56	Lake Wimauma Drain	LWD-W420	134	SO FK Little Manatee	SF-W540
57	Lake Wimauma Drain	LWD-W440	135	SO FK Little Manatee	SF-W550
58	Lake Wimauma Drain	LWD-W480	136	Unnamed Stream	US-W270
59	Lake Wimauma Drain	LWD-W510	137	Unnamed Stream	US-W280
60	Lake Wimauma Drain	LWD-W520	138	Unnamed Stream	US-W290
61	Lake Wimauma Drain	LWD-W540	139	Unnamed Stream	US-W340

NO.	Sub-Basin Name	Sub-Area ID	NO.	Sub-Basin Name	Sub-Area ID
62	Lake Wimauma Drain	LWD-W550	140	Unnamed Stream	US-W350
63	Lake Wimauma Drain	LWD-W610	141	Unnamed Stream	US-W360
64	Lake Wimauma Drain	LWD-W630	142	Unnamed Stream	US-W370
65	Little Manatee River	LMR-W160	143	Unnamed Stream	US-W390
66	Little Manatee River	LMR-W280	144	Unnamed Stream	US-W400
67	Little Manatee River	LMR-W190	145	Unnamed Stream	US-W410
68	Little Manatee River	LMR-W200	146	Unnamed Stream	US-W420
69	Little Manatee River	LMR-W430	147	Unnamed Stream	US-W430
70	Little Manatee River	LMR-W230	148	Unnamed Stream	US-W440
71	Little Manatee River	LMR-W330	149	Unnamed Stream	US-W450
72	Little Manatee River	LMR-W380	150	Unnamed Stream	US-W460
73	Little Manatee River	LMR-W480	151	Unnamed Stream	US-W470
74	Little Manatee River	LMR-W530	152	Unnamed Stream	US-W480
75	Little Manatee River	LMR-W580	153	Unnamed Stream	US-W490
76	Little Manatee River	LMR-W630	154	Unnamed Stream	US-W500
77	Little Manatee River	LMR-W640	155	Unnamed Stream	US-W510
78	Carton Branch	CB-W360			

Rainfall

As recommended by the Hillsborough County Storm Water Management Technical Manual, SCS (the Soil Conservation Service, now called the Natural Resources Conservation Service - NRCS) design storm with a 24-hour SCS Type II Florida modified distribution was used to simulate rainfall events for each return interval. This rainfall distribution is also required by SWFWMD.

The Technical Manual also indicates that a value of 256 with a corresponding dimensionless unit hydrograph is appropriate for simulating hydrologic processes in the study area. Therefore, the shape factor (or peaking factor) was modified to 256 to account for the relatively flat terrain of the watershed.

Rainfall depths were estimated from isohyetal maps and procedures contained in the SWFWMD's Environmental Resource Permitting (ERP) Information Manual. Where the LMR watershed was located between two isohyets, the rainfall amount was estimated using a straight line interpolation between two isohyets. The rainfall depths used for the 24-hour design events are as follows:

Table 0-2 Rainfall Depths for the 24-hour Design Events

Storm Event Precipitation	24-hour Depth (inches)
Mean Annual	4.5
5-Yr	5.6
10-Yr	6.75
25-Yr	8.0
50-Yr	9.5
100-Yr	10.2

Runoff Volume (SCS CN)

The Natural Resource Conservation Service (NRCS) Curve Number (CN) method was used to predict rainfall excess for each sub-basin. The SCS Curve Number option in the HEC-HMS model uses an initial abstraction value and composite curve number (CN) to estimate runoff volumes from each subarea for a particular design rainfall event.

Initial abstraction is defined as losses from rainfall before runoff begins. Initial abstraction is a function of the composite CN and is calculated using the following equation.

$$Ia = 0.2(1000/CN - 10) \qquad \text{Equation 1}$$

The CN is a function of the land use condition and hydrologic soil group (HSG). For each subarea, a composite CN was developed using the GIS by overlaying the soils and land use coverages and spatially analyzing the percent of each land use and soil condition in each sub-area.

Hydrologic soils groups are used to classify soils based on runoff potential. Soils are grouped into four hydrologic soil groups (A through D), which reflect varying levels of infiltration rates and soil moisture capacities. In Florida, certain soils can also have dual hydrologic soil group classifications (B/D). The first hydrologic soil group designates the drained condition and the second hydrologic soil group designates the undrained condition of the soil.

The latest SWFWMD Land Use GIS coverage was used to represent existing conditions land use in the watershed. Each land use polygon in the GIS coverage is associated with an attribute that designates a classification from the Florida Land Use Classification System (FLUCS).

Runoff CN tables were used to assign a CN to each soil and land use combination. The runoff CN lookup table is provided below. The CNs listed represent average Antecedent Moisture Conditions (AMC II conditions).

Table 0-3 Runoff CN Lookup Table

LUValue	Description	A	B	C	D
1100	Residential Low Density < 2 Dwelling Units	50	68	79	84
1200	Residential Low Density 2->5 Dwelling Units	57	72	81	86
1300	Residential High Density	77	85	90	92
1400	Commercial and Service	89	92	94	95
1500	Industrial	81	88	91	93
1600	Extractive	77	86	91	94

1700	Institutional	89	81	87	90
1800	Recreational	49	69	79	84
1900	Open Land	39	61	74	80
2100	Cropland and Pastureland	49	69	79	84
2140	Row Crops	49	69	79	84
2200	Tree Crops	44	65	77	82
2300	Feeding Operation	73	83	89	92
2400	Nurseries and Vineyards	57	73	82	86
2420	Sod Farms	57	73	82	86
2440	Vineyards	57	73	82	86
2500	Special Farms	59	74	82	86
2550	Tropical Fish Farms	0	0	0	0
2600	Other Open Lands (Rural)	30	58	71	78
3100	Herbaceous	63	71	81	89
3200	Shrub and Brushland	35	56	70	77
3300	Mixed Rangeland	49	69	79	84
4100	Upland Coniferous Forest	45	66	77	83
4110	Pine Flatwoods	57	73	82	86
4120	Longleaf Pine – Xeric Oak	43	65	76	82
4200	Upland Hardwood Forest – Part 1	36	60	73	79
4300	Hardwood Forest	36	60	73	79
4340	Hardwood Conifer Mixed	36	60	73	79

4400	Tree Plantations	36	60	73	79
5100	Streams and Waterways	100	100	100	100
5200	Lakes	100	100	100	100
5230	Lakes < 100 Acres, > 10 Acres	100	100	100	100
5240	Lakes < 10 Acres	100	100	100	100
5300	Reservoirs	100	100	100	100
5310	Reservoirs > 500 Acres	100	100	100	100
5320	Reservoirs > 100 Acres, <500 Acres	100	100	100	100
5330	Reservoirs > 10 Acres, <100 Acres	100	100	100	100
5340	Reservoirs < 10 Acres	100	100	100	100
5400	Bays and Estuaries	100	100	100	100
6100	Wetland Hardwood Forests	98	98	98	98
6110	Bay Swamps	98	98	98	98
6120	Mangrove Swamps	98	98	98	98
6150	Stream and Lake Swamps (Bottomland)	98	98	98	98
6200	Wetland Coniferous Forests	98	98	98	98
6210	Cypress	98	98	98	98
6300	Wetland Forests Mixed	98	98	98	98
6400	Vegetated Non-Forested Wetland	98	98	98	98
6410	Freshwater Marshes	98	98	98	98
6420	Saltwater Marshes	98	98	98	98
6430	Wet Prairies	98	98	98	98

6440	Emergent Aquatic Vegetation	98	98	98	98
6500	Non-Vegetated	98	98	98	98
6510	Tidal Flats/Submerged Shallow Platform	98	98	98	98
6520	Shorelines	98	98	98	98
6530	Intermittent Ponds	98	98	98	98
7100	Beaches Other Than Swimming Beaches	77	86	91	94
7400	Disturbed Land	77	86	91	94
8100	Transportation	81	88	91	93
8200	Communications	81	88	91	93
8300	Utilities	81	88	91	93
9113/9116	Seagrass	100	100	100	100

The AMC of the soil is unknown at the time of the event, but is often estimated by the accumulated rainfall depth in the five-day period prior to the event. The moisture condition can also be determined according to the runoff volume. During model calibration, additional simulations of the hydrologic model were performed with the same rainfall depth but higher or lower AMC to bracket the observed runoff volume at some gages. The selected AMC was determined by the closest volumetric match found during the hydrologic calibration. The following table was used as a guide to convert between the average AMC II to wet (AMCIII) and dry (AMCI) SCS runoff curve numbers (Wanielista, Yousef, 1993).

Table 0-4 AMC Curve Number Conversion Guide

AMC2	AMCI	AMC3
100	100	100
95	87	98

90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70
45	26	65
40	22	60
35	18	55
30	15	50

The rainfall depth estimated AMC and volumetric match determined AMC are different for some gages. This could be due to a number of factors including depth to water table, availability of soil storage and amount of depression storage among others. Where a discrepancy exists, the AMC determined by the volumetric calibration was used for hydrologic and hydraulic calibration.

Runoff Hydrographs

The SCS Dimensionless Unit Hydrograph was used to distribute the runoff volume to a unit hydrograph. The determination of an SCS lag time was required for this method. Consistent with the methodology of the SCS's Technical Release-55 Urban Hydrology for Small Watersheds published June 1986, the lag time for a subarea was assumed to equal 0.6 times the time of concentration. The time of concentration, in turn, was defined as the time required for water to travel to the subarea outlet from the most hydraulically distant point in the subarea.

The time of concentration for each subarea was calculated using the methodology outlined in TR-55 (SCS 1986). For each subarea, the longest flow path to the subarea outlet was determined using the DEM and ArcGIS tools that divided the flow path into four elements:

- Sheet flow
- Secondary channel
- Shallow concentrated flow
- Primary channel

The travel times associated with each of the four elements were added to calculate the time of concentration for each subarea.

a. Sheet Flow

Sheet flow is assumed to occur at the most hydraulically distant portion of the flow path. The sheet flow length was calculated using GIS. Physical data are required to calculate the travel time associated with sheet flow using the TR-55 methodology, including flow length, slope, and overland flow roughness coefficient. The surface condition was determined from the aerial photos.

b. Shallow Concentrated Flow

Shallow concentrated flow occurs between the areas of sheet flow and open channel flow. Shallow concentrated flow for urban areas may include gutters, swales, and sometimes small ditches. Open channels are assumed to begin where channels are visible on aerial photographs and include major conveyances, including creeks and rivers. To calculate the travel time associated with shallow concentrated flow by the TR-55 methodology, physical data including the shallow concentrated flow length, slope, and surface conditions along the path are required.

c. Secondary Channel Flow and Primary Channel Flow

Secondary channel flow occurs between the end of shallow concentrated flow and the flow path intersection with the primary stream network, while primary channel flow occurs along the primary stream network to the subarea outlet. The primary stream network is the main channel of Little

Manatee River and its tributaries. For both types of channel flow, travel time was calculated based on channel length and velocity. The velocity, in turn, was estimated based on channel slope and assumed flow depth and cross-sectional geometry. All of these data were developed from GIS. Slope data were calculated by using the upstream and downstream elevations and the stream length in GIS. Cross-section geometries were assigned based on review of stream geometry data developed by using GIS tools and DEM.

Routing (Muskingum-Cunge)

The Muskingum-Cunge Routing method was used to route runoff through the watershed. A channel cross section was developed for each routed reach using ArcGIS. The channel length, slope and other parameters were also determined using DEM data, digital aerial photos and field photographs.

Hydraulic Model Development

Introduction

This section provides a description of the methodology used to develop the hydraulic model for the Little Manatee River Watershed study. The hydraulic model was used to simulate the watershed's primary stream network based on existing land use conditions and estimate water surface elevations and to determine the river stages along the study reach under various flow conditions. The hydraulic modeling was performed using USACE's HEC-RAS Version 4.0 steady state option.

HEC-RAS Model Development

HEC-RAS model data requirements can be summarized into the following model parameters.

- Stream network
- Cross sections (river station and geometry data)
- Downstream reach lengths (channel and overbanks)
- Channel bank stations
- Manning's n-values
- Roadway crossings
- Expansion and contraction coefficients
- Boundary conditions
- Ineffective flow areas

Table 0-1 lists these parameters, the data and the methods used to develop the data requirements. All the model parameters were developed using a combination of manual procedures and automation tools using ArcGIS and HEC-GeoRAS in conjunction with GIS data.

Table 0-1 HEC-RAS Parameter Development

HEC-RAS Model Parameter	Data Requirements	Data Used	Development Method
Stream network	Stream centerline coverage with unique stream reach names	DEM, Contours	ArcGIS and HEC-GeoRAS
Cross sections (river station and geometry data)	Cross section cut line coverage	DEM, TIN, Contour	ArcGIS and HEC-GeoRAS
Downstream reach lengths (channel and overbanks)	Stream centerline and overbank (left and right) flow path coverage	DEM, Contours	ArcGIS and HEC-GeoRAS
Channel bank stations	Cross section geometries (station and elevation data)	DEM, Contours	Manual input using standard procedures and engineering judgment
Manning's n-values	Mannings n-value assigned	land use data, digital aerial, field survey photos, field observations	Manual input using standard values and engineering judgment
Roadway crossings	Roadway profile and bridge or culvert geometry information	Field survey data, as-built information	Manual input
Expansion and contraction coefficients	Cross section cut line coverage	DEM, Contours	Manual input using standard values and engineering judgment
Boundary conditions	Normal depth boundary conditions	DEM, Contours, stream centerline, cross section cut line coverage	ArcGIS

Ineffective flow areas	Cross section cut line coverage	DEM, Contours	Manual input using standard procedures and engineering judgment

The HEC-RAS model development procedures are described in the subsequent sections.

Stream Network, Cross Sections, and Reach Lengths

The first step in developing the HEC-RAS model was to create a HEC-RAS geometry file containing the stream network, cross section river stations & geometries and channel & overbank downstream reach lengths. The stream network defines the extent of the model. Cross section river stations define the location of the cross section along the stream. Downstream reach lengths define the distance to the next downstream cross section along the stream reach and along the left and right overbanks.

HEC-GeoRAS and ArcGIS were used to prepare a model input file that can be directly imported into HEC-RAS, creating a geospatially referenced HEC-RAS geometry file.

HEC-GeoRAS uses the following data to create the model import file:

a. Triangular Irregular Network

The TIN was created from the LiDAR/DEM data using ArcGIS. The TIN is a surface representing the ground topography and is used in conjunction with the cross section cut line coverage to develop station and elevation information for cross section geometry data. A ground surface elevation was recorded at each station along the cross section cut line that crosses the TIN edge.

b. Stream Centerline Coverage

The stream centerline coverage was manually digitized in ArcGIS to represent the center line of the main channel. HEC-GeoRAS requires a river name and reach name be assigned to each line segment. For the purpose of this study, the river name was assigned “Little Manatee River” and the reach name was assigned to “Reach 1” – “Reach 8”.

c. Cross Section Cut Line Coverage

The cross section cut line coverage is a GIS line coverage that identifies the location and extent of each cross section. The cross section cut line coverage was generated in ArcGIS. Additional cut lines were located along the stream centerline at points that represent the average geometry of the stream reach and at changes in geometry, slope, channel, overbank roughness, and discharge. Available aerial photographs and contour information were used to lay out the cross section cut lines. The FEMA 100-year floodplain boundary was used as a guide in determining the extent of the cross sections. The average distance between cross sections was approximately 400 feet, with less distance between cross sections in the vicinity of structures and abrupt changes in channel geometry. There are more than 400 cross sections created for the entire watershed. All the cross sections plots are provided in Appendix A.

The cross section cut lines are oriented from left to right looking downstream. Each cross section was identified by the stream name, reach name, and river station. The river station for each cross section is the cumulative distance from the model outfall in feet.

d. Overbank Flow Path Coverage

The overbank flow path coverage is a GIS line coverage that represents the average left and right overbank flow paths between each cross section. The overbank flow path coverage was used to determine the downstream reach lengths for the left and right overbanks. The FEMA 100-year flood plain boundary and the contour information were used as a guide to locate the overbank flow paths.

The developed stream network and cross section river stations were imported into HEC-RAS and are presented in Figure 0-1.

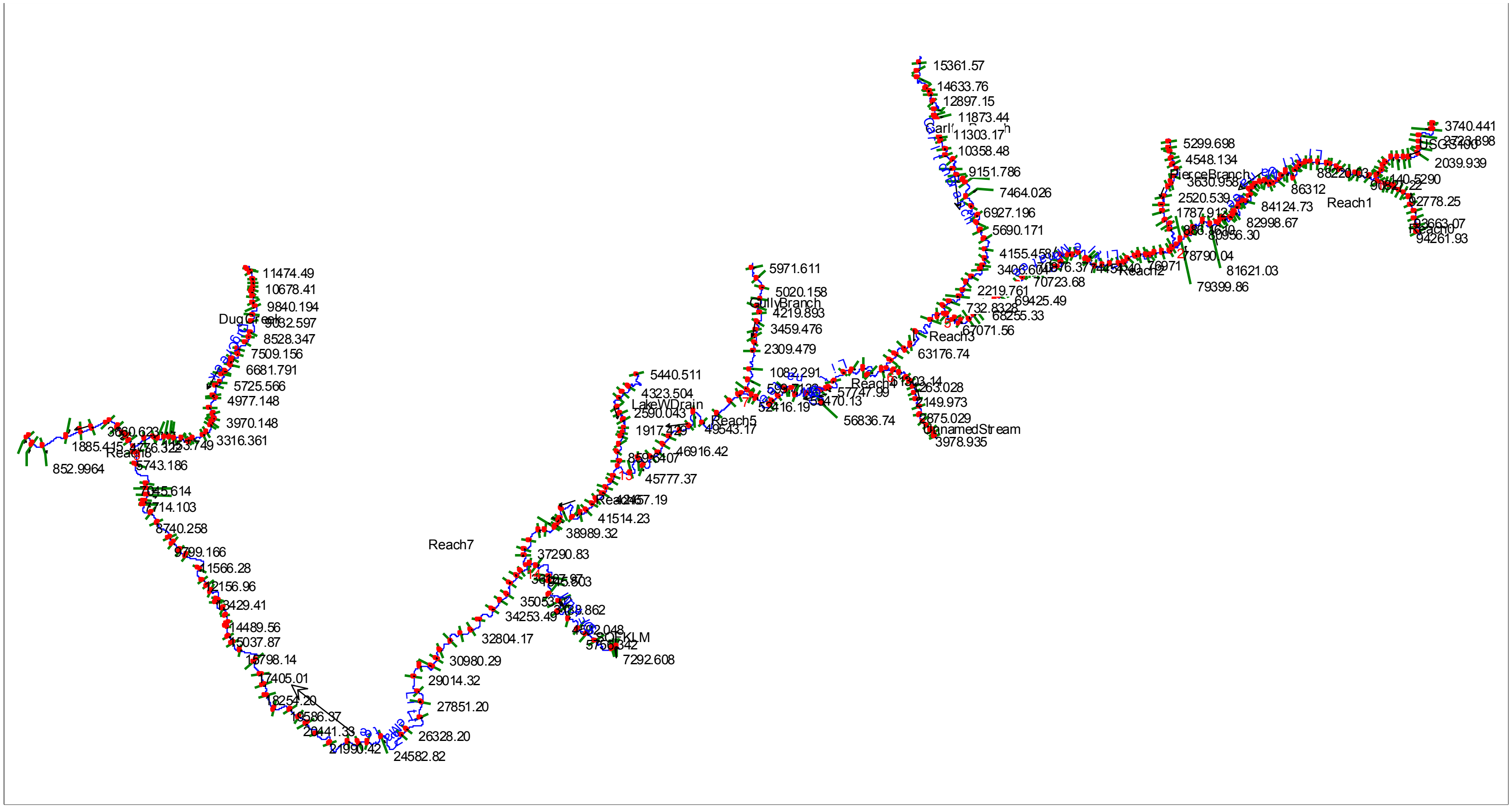


Figure 0-1 Steam Network and Cross Section River Stations

Manning's n-Values

The Manning's n-values at each cross section were estimated using land use data, digital aerial and field photographs. Manning's n-values are assigned with the purpose to represent land surface characteristics identified in Table 0-2. The initial n-values were used as a model starting point and were adjusted within the provided ranges during calibration. Horizontally varied Manning's n-values were entered in the HEC-RAS model to capture changes in land use spanning the cross section.

Table 0-2 Land Surface Characteristics and Associated Manning's n-Values

Land Surface Type	Initial n-Value	Range of n-Value
Grass, urban and maintained	0.030	0.025–0.035
Trees and brush	0.090	0.035–0.160
Brush	0.060	0.035–0.160
Residential areas2	0.150	0.035–0.2
ADF Plant - (developed area)2	0.100	0.035–0.2
Agricultural, Pasture	0.035	0.025–0.050
Pavement	0.020	0.013–0.025
Lake	0.025	0.0160–0.033

Channel n-values were manually adjusted using the HEC-RAS cross section data editor. A combination of digital aerial photos, field photographs, and site visits was used to select an appropriate n-value. Table 0-3 lists channel descriptions and associated ranges of n-values used for Little Manatee River.

Table 0-3 Channel Descriptions and Associated Manning's n-Values

Channel Description	Initial n-Value	Range of n-Value
Clean, straight	0.030	0.025 - 0.033

Straight channels, weeds	0.035	0.030 - 0.040
Clean, meandering	0.040	0.033 - 0.045
Meandering, weedy	0.045	0.045 - 0.050
Sluggish, weedy	0.070	0.050 - 0.080
Very weedy, floodways with heavy timber and underbrush	0.13	0.075 - 0.150

Roadway crossings

Roadway profile and bridge or culvert geometry information were determined according to field surveys and as-built information provided by FDOT and Hillsborough County. These data were manual entered into HEC-RAS and were summarized in the following table.

Table 0-4 Summary of Bridges in the Study Area

No.	Structure Name	ID	County	River/Tributary	Stationing	Lat.	Long.
1	US 301/ LMR	100003	Hillsborough	LMR/Reach 8	4501.3555	27°40'16.953"N	82°21'9.545"W
2	CR579/ LMR	100260	Hillsborough	LMR/Reach 6	39313.551	27°39'46.264"N	82°18'4.25"W
3	SR 674 / CARLTON BRANCH	100501	Hillsborough	Carton Branch	11779.413	27°42'18"N	82°15'22.37"W
4	CR579 OVER SOUTH FORK	100259	Hillsborough	SO FK Little Manatee	7225.6328	27°38'58.888"N	82°17'39.532"W
5	GRANGE HALL LOOP/ LMR	104332	Hillsborough	LMR/Reach 2	71052.453	27°41'20.961"N	82°14'41.501"W
6	Dug Creek	10346	Hillsborough	Dug creek	2509.4968	27°40'16.241"N	82°20'41.108"W

7	Leonaldo Lee Road/ LMR	104307	Hillsborough	Reach 4	57683.965	27°40'37.347"N	82°16'9.42"W

Expansion and contraction coefficients

The expansion and contraction coefficients were estimated based on the ratio of expansion and contraction of the effective flow area in the floodplain occurring at cross sections and at roadway crossings. An expansion coefficient of 0.3 and a contraction coefficient of 0.1 are used in the analysis. These coefficients can be manually adjusted using HEC-RAS cross section data editor.

Boundary Conditions

Normal depth was used as the downstream boundary condition. This is explained in detail in Section 5.

Ineffective Flow Areas

Ineffective flow areas were determined using the cross section plots and contour information. Ineffective flow areas were entered manually using the HEC-RAS cross section data editor.

Model Calibration and Verification

The approach, methodology and results of the hydrologic and hydraulic model calibration and verification efforts are described in this section. The primary purpose of performing model calibration and verification is to ensure that the developed models reflect observed conditions in the watershed. A model is considered well-calibrated when model results of stage, flow, and volume are in reasonable agreement with the recorded data at the gage stations. Once this agreement is achieved, the model can then be verified by comparing model results of a different storm event to the observed values without making adjustments to the model. This ensures the reliability of the results.

Hydraulic and Hydrologic Data Collection

The HEC-RAS model will perform one dimensional hydraulic calculations for the full network on natural streams that encompass the Little Manatee River study area. To model the study area in HEC-RAS, hydrological data was required for the approximately 15.6 mile reach. Hydraulic data input required by the model includes flow data and stage data for the boundary conditions. The SWFWMD provided data pertaining to flow and stage which was collected by the USGS. The daily data provided include flow in cfs and stage in ft for three locations which bounded the study area: USGS near Wimauma 02300500, USGS south fork near Wimauma 02300300, and USGS at Ft. Lonesome 02300100. However, additional branches/creeks feed the Little Manatee River within the boundary conditions. These branches/creeks include: Howard Prairie Branch, Pierce Branch, Carlton Branch, Gully Branch, Lake Wimauma Plain, Dug Creek, South and several unnamed streams

Data of the three USGS stations were not enough on their own to run the HEC-RAS model for the Little Manatee River. The data points are too spatially large and there are multiple tributaries entering the river branch between the stations. Flow/stage data for the above listed tributaries is needed to input in the HEC-RAS model of Little Manatee River. A search for flow/stage data in the seven locations revealed no useful information/data. Therefore, daily runoff figures along with flow depths for each sub-basin were created using the HEC-HMS model.

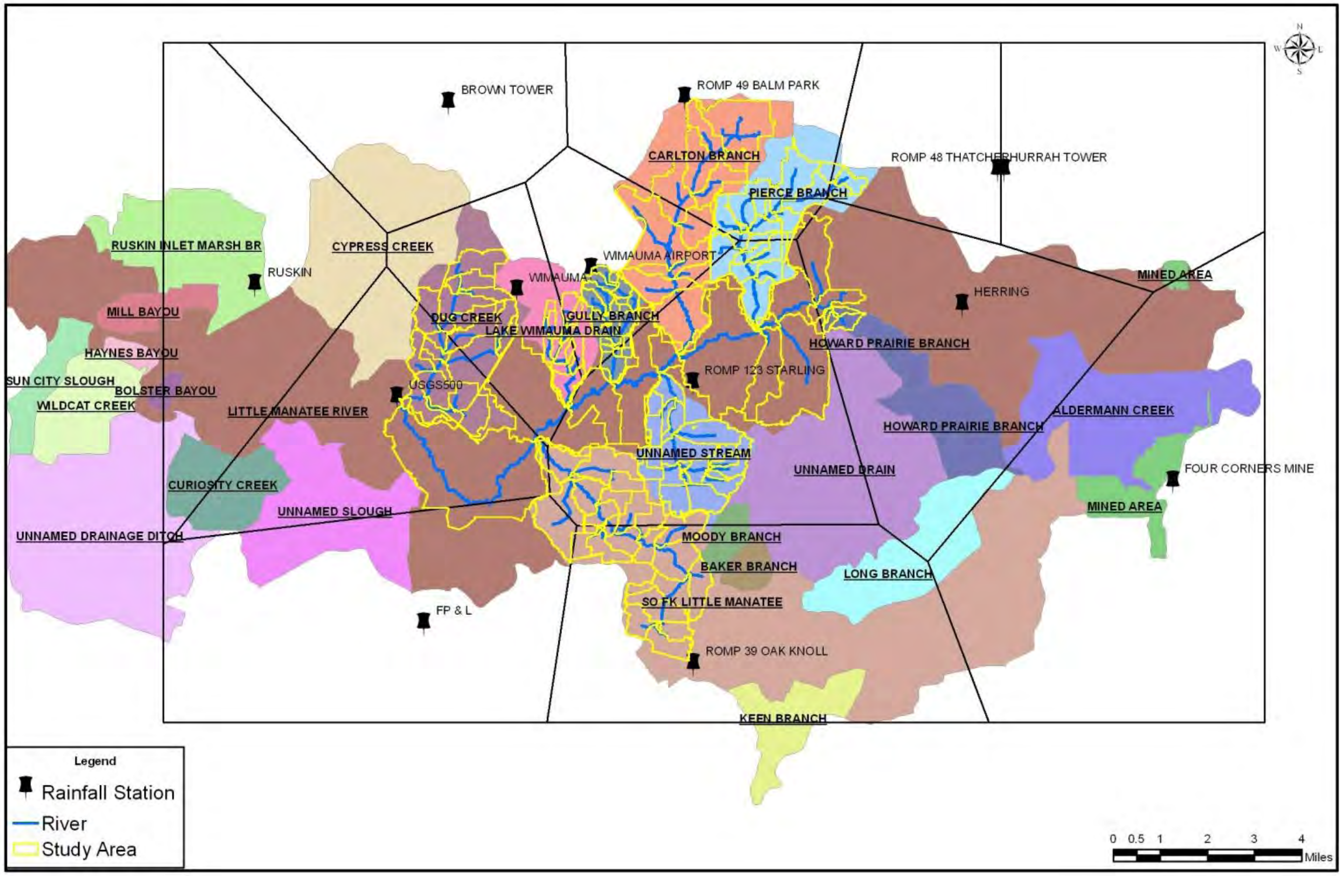
Precipitation data is required to run the HEC-HMS model. Precipitation data would have to encompass a period which SWFWMD would analyze in model runs of the HEC-RAS model. A review of existing data prepared by the USGS on locations 02300500, 02300300, and 02300100 showed best period of record to perform a search. The Period of Record (POR) was decided by the best available data string which was 1/1/1988 thru 12/31/2009.

A data search on the USGS site, SWFWMD site and GIS data for records available in the POR or encompassing those dates was performed. A series of precipitation recording stations were located and a review of the recording station data yielded 13 useful locations. The 3 USGS sites and 13 rainfall stations are summarized in the following table.

Table 0-1 Rainfall, Stage and Discharge Gages

Site Number	Data Type	Site Name	Site Location (State Plan)	
			SPFN	SPFE
USGS02300100	Stage and discharge	Little Manatee River Near Ft. Lonesome FL	1225308.419	592083.7205
USGS02300300	Stage and discharge	South Fork Little Manatee River Near Wimauma FL	1205274.767	560847.3491
USGS02300500	Stage, discharge and rainfall	Little Manatee River Near Wimauma FL	1213201.083	541985.4626
17958	Rainfall	WIMAUMA	1225182.244	555383.16
17960	Rainfall	HURRAH TOWER	1238614.741	609086.7717
17961	Rainfall	BROWN TOWER	1246106.588	547739.2717
17964	Rainfall	HERRING	1223572.867	605114.1076
18133	Rainfall	ROMP 123 STARLING	1214837.106	574985.1509
18135	Rainfall	WIMAUMA AIRPORT	1227585.853	563686.7618
18145	Rainfall	RUSKIN	1225771.972	526112.5164
18151	Rainfall	ROMP 48 THATCHER	1238613.898	609805.5709

18153	Rainfall	ROMP 49 BALM PARK	1246649.281	574151.6043
25610	Rainfall	FOUR CORNERS MINE	1203857.792	628650.0525
25611	Rainfall	ROMP 39 OAK KNOLL	1183531.722	575101.5354
26073	Rainfall	FP & L	1188047.329	544972.4475



Little Manatee River Thiessen Polygon

HEC-RAS MODELING OF LITTLE MANATEE RIVER
10POSOW0468

ZFI

Figure 0-1 Thiessen Polygon Network for Rainfall and USGS Station

Figure 0-1 shows the Little Manatee study area and the previously discussed sub-basins, stream reaches, rainfall recording stations, and a rainfall delineation grid know as the Thiessen Polygons. Thiessen polygons define individual areas of influence around each of a set of points. The weights of the rainfall gages for each sub-area are calculated using the Thiessen Polygon Method. Thiessen polygons are polygons whose boundaries define the area that is closest to each point relative to all other points. They are mathematically defined by the perpendicular bisectors of the lines between all points. A TIN structure is used to create Thiessen polygons. This TIN structure can be created by GIS and be directly imported to HEC-HMS model. The model can use this precipitation or hydrological information to route the overland runoff and provide output data to be used in the HEC-RAS model.

QA/QC of Hydraulic and Hydrologic Data

Hydraulic and Hydrologic data delivered to, and extracted by ZFI was reviewed, scrutinized, and patched prior to use in the HEC-RAS model for the Little Manatee River. First, the data important to the model and what data could be finalized as model quality data was identified. The water stream data of the USGS which would be used for the HEC-RAS model was reviewed. Three data locations were provided and two data sets were included in each of the locations. Data locations ID's are 02300100, 02300300, and 02300500 and each included stage and flow data. These hydraulic data are crucial inputs to the HEC-RAS model, therefore the Period of Record (POR) was determined with this data source. Data of ID location 02300100 spans from 1/1/1964 to 12/31/2009, ID location 02300300 spans from 1/1/1988 to 12/31/2009 (large gap of missing data spans from 2/1/1989 to 9/30/2000), and ID location 02300500 spans from 1/1/1940 to 12/31/2009. Of these the POR of significant quality data was determined to be 1/1/1988 thru 12/31/2009 and a large patch was performed on Station ID 02300300 to fill in missing data points.

All ID locations had small and some large gaps in daily data throughout the POR. Data patching came about through methods such as matching similar string of daily conditions in the ID locations (based on flow, stage, and/or precipitation) while other statistical methods were incorporated by means of linear regression and trend prediction. Small gaps of stage data (where flow data was known) were filled by matching other similar stage/flow relationship (of the ID location in close range of missing date), this was feasible in free-flowing river systems. Small gaps of flow data were patched with the comparison of flow data of the other ID locations of the same date and logical linear trend. In addition, to support these flow patches, local precipitation data was analyzed to verify the patches. This was useful to verify if flows were increasing, steady, or decreasing but mainly useful for steady or decreasing flows since the river's increasing rate can be considerable.

In larger periods of missing data Linear Regression or Trend functions were used to patch the portions of missing data. Linear Regressions were preformed with Excel - LINEST function. This function calculates the statistics for a line by using the least squares method to calculate a straight line that best fits the data, then returns an array that describes the line. The data in the array provides one with details on how data of missing series relates to other similar data (e.g. local precipitation data & USGS data sets which are intact and in close proximity have a correlation). An R^2 value is returned in the array, this provides a measure of how well future outcomes are likely to be predicted (calculated R^2 values averaged at 90% indicating strong correlation). In addition to LINEST, the Excel - Trend function was used. The Trend function returns values along a linear trend, which also fits a straight line to the array known and returns a new value y for a specified value of x. The Trend is very useful for filling large stage gaps.

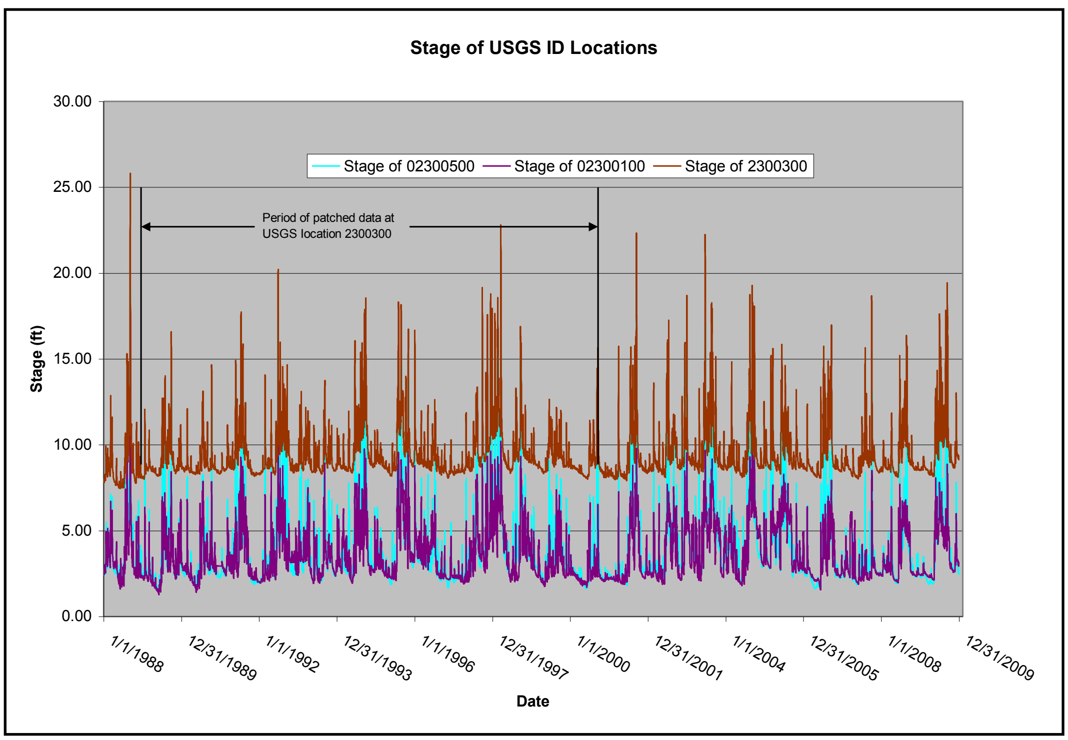


Figure 0-2 USGS Stage Data Patched thru POR

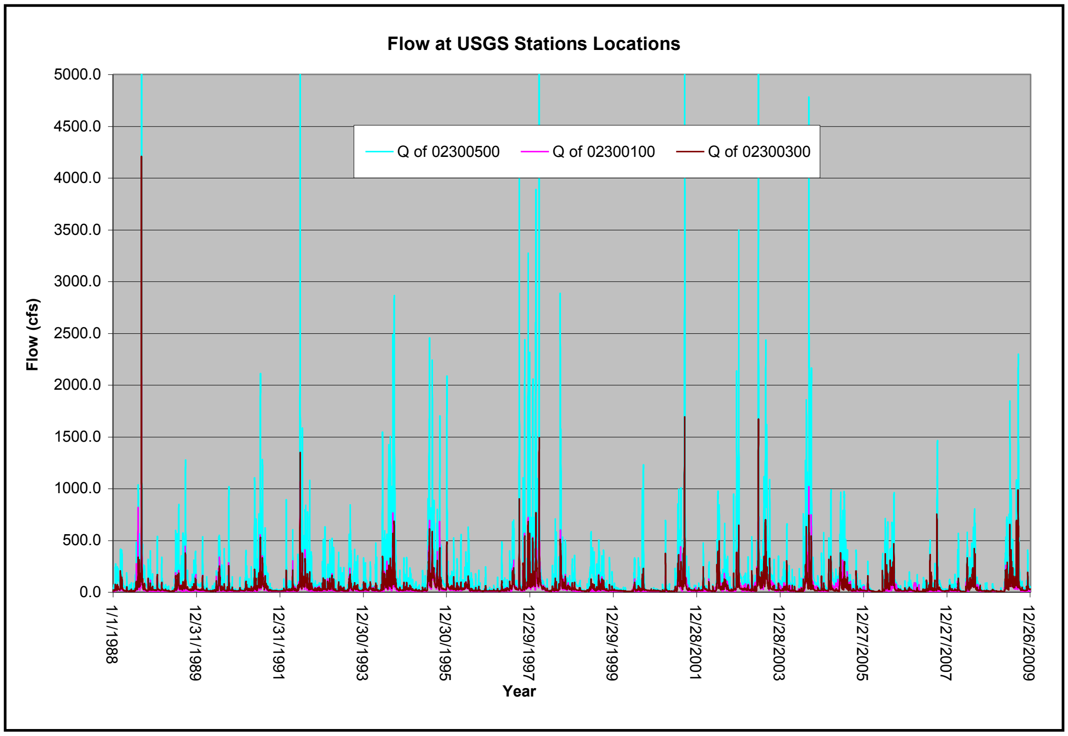


Figure 0-3 USGS Flow Data Patched thru POR

The trend function was used exclusively in providing the adjusted stage value to the adjusted flow at station 02300500. These adjusted values were requested by the District. The adjustment removed runoff volumes known to discharge to the river from agricultural sources (15 cfs daily) and reincorporated pumping volumes removed from the FP&L's consumptive use records. Some outliers were created using the TREND function and were reviewed and rejected. These outliers amounted to less than 0.6% of the stage data or 48 out 8036 data sets. These outliers were manually adjusted to match existing measured stage data.

Precipitation data from many of the rainfall stations, required data patching. Data was patched in the same methods as listed above but spatial consideration was taken. There were 13 rainfall station locations and the approach to patching missing data strings was done with the Nearest Neighbor method. Most of the precipitation data adjustments were performed with a linear match or linear regression.

Event Selection

Important factors considered in selecting storm events for calibration and verification include the magnitude of the storm event, spatial distribution of observed data locations and the measurement interval of the data.

The Oct 2-8, 2007 storm event was picked up for calibration purposes after reviewing all the measured data. This large event produced extreme measurements for the water year for most gages and provided observed data at all 13 rainfall gages in the watershed. Approximately 7 inches of rainfall fell during this period. The Sep10-20, 2009 storm event was selected for model verification due to its magnitude and relatively recent occurrence. Approximately 5 inches of rainfall occurred during this period, producing large peak stages and discharges within the LMR watershed.

Boundary Condition

Normal depth was used as the downstream boundary condition for all modeled reaches. This boundary condition requires the input of the energy grade line (EGL) slope at the downstream boundary of each reach. The downstream EGL slope can be approximated as the channel invert slope from the contour data. Therefore, the slope between the two most downstream cross sections was used to calculate the normal depth boundary condition. This slope was calculated in ArcGIS using the DEM data, cross section cut line coverage, and stream centerline coverage. The calculated normal depth at the downstream of the river in the study area is 0.0001.

Hydrologic Model Calibration and Verification

Because of insufficient stream flow and stage data for most of the tributaries, the HEC-HMS model was not calibrated using historical data. The model results were compared to the Federal Emergency Management Agency (FEMA) Hillsborough County Flood Insurance Study (FIS) (2008) (Flood Insurance Study Number 12057CV001A). Table 0-2 through Table 0-5 provide comparisons of the HEC-HMS results compared to effective FIS flow information at downstream of the major tributaries.

Table 0-2 Carlton Branch Flow (cfs) Comparisons

	10 Year	50 Year	100 Year
FEMA FIS	1,210	2,270	2,650
Model	1273.8	2205.9	2467.2
Percent Difference	5.0%	-2.9%	-7.4%

Table 0-3 Dug Creek Flow (cfs) Comparisons

	10 Year	50 Year	100 Year
FEMA FIS	1,240	2,010	2,230
Model	1243	2223.1	2474.4
Percent Difference	0.2%	9.6%	9.9%

Table 0-4 Gully Branch Flow (cfs) Comparisons

	10 Year	50 Year	100 Year
FEMA FIS	577	1,130	1,130
Model	574	1007.4	1122.9
Percent Difference	-0.5%	-12.2%	-0.6%

Table 0-5 Pierce Branch Flow (cfs) Comparisons

	10 Year	50 Year	100 Year
FEMA FIS	1,270	2,410	3,040
Model	1351.2	2361.2	2675.4
Percent Difference	6.0%	-2.1%	-13.6%

On average, the peak runoff rates estimated by the HEC-HMS model under existing land use conditions are within 5-10 percent of the FEMA published flows.

Hydraulic Model Calibration and Verification

Model Calibration

A calibration effort was undertaken after a fundamental hydraulic model check, to compare the observed and simulated values and to make adjustments to the calibration parameters in order to produce a model that would yield reasonable results. The hydraulic model for the October 2-8, 2007 event was simulated using the calibrated hydrologic parameters. Simulated stage and discharge values were compared and adjustments to the Manning roughness coefficients and other parameters were made where appropriate. Figure 0-4 and Figure 0-5 show graphical comparisons of simulated and observed discharge and stage values for the USGS 02300500 used for calibration. As shown in the two figures, though the simulated peak discharge is somewhat higher than the observed peak value, generally, the simulated discharge and stage values and observed values appear to follow the same pattern.

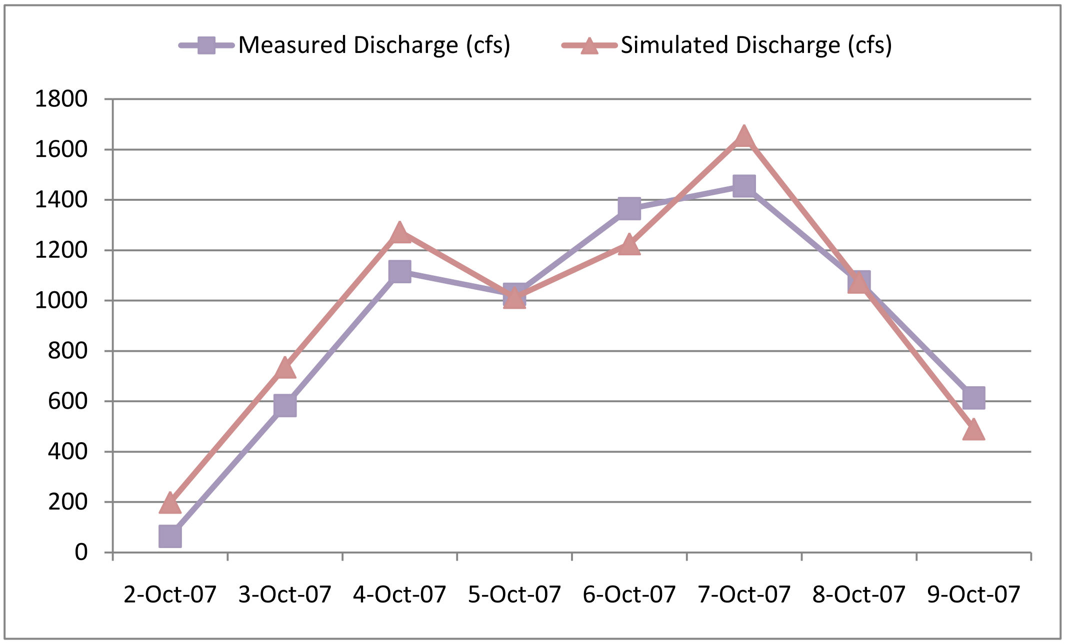


Figure 0-4 Comparison of Observed and Simulated Discharge (cfs) USGS 02300500 October 2 - 9, 2007

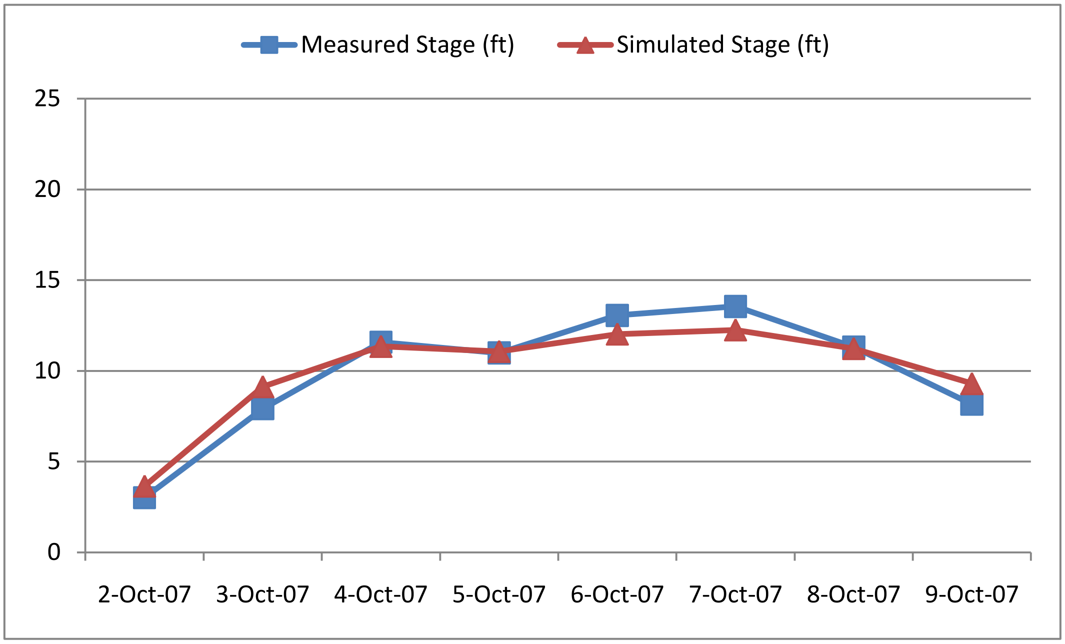


Figure 0-5 Comparison of Observed and Simulated Stage (ft)
USGS 02300500 October 2 - 9, 2007

Model Verification

Hydraulic model verification is conducted to ensure adjustments made to the model during calibration are appropriate and to ensure that the model will produce reliable results. Using the same method described for model calibration, observed and simulated runoff volumes were compared for the selected verification event, September 10 – 20, 2009. With the exception of initial conditions, no changes were made to the hydraulic model during the model verification process. The comparison results are presented in Figure 0-6 and Figure 0-7.

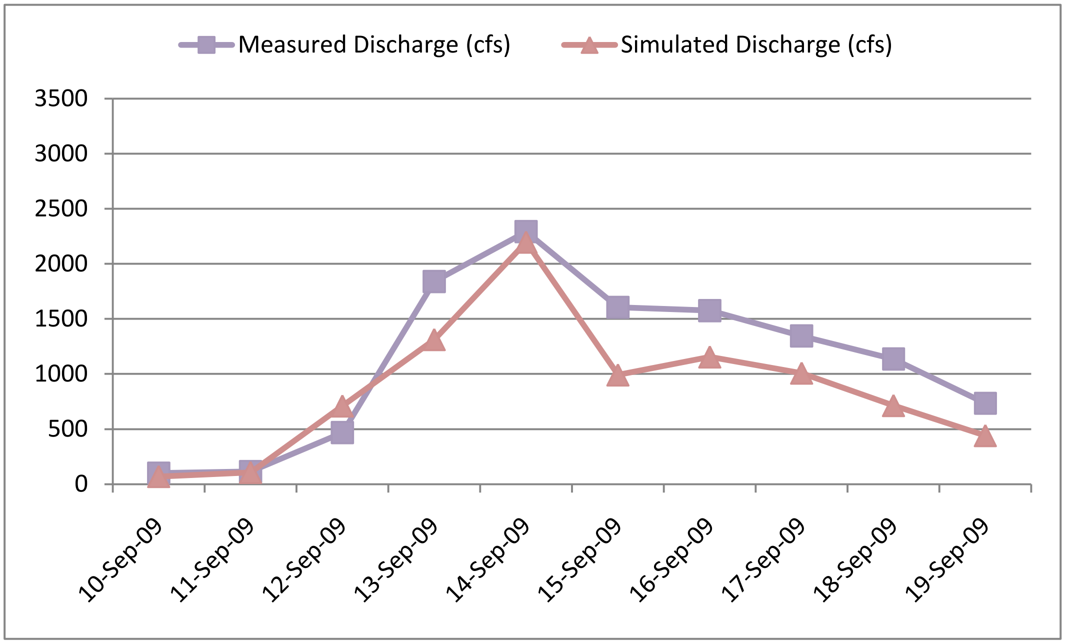


Figure 0-6 Comparison of Observed and Simulated Discharge (cfs) USGS 02300500 September 10 - 20, 2009

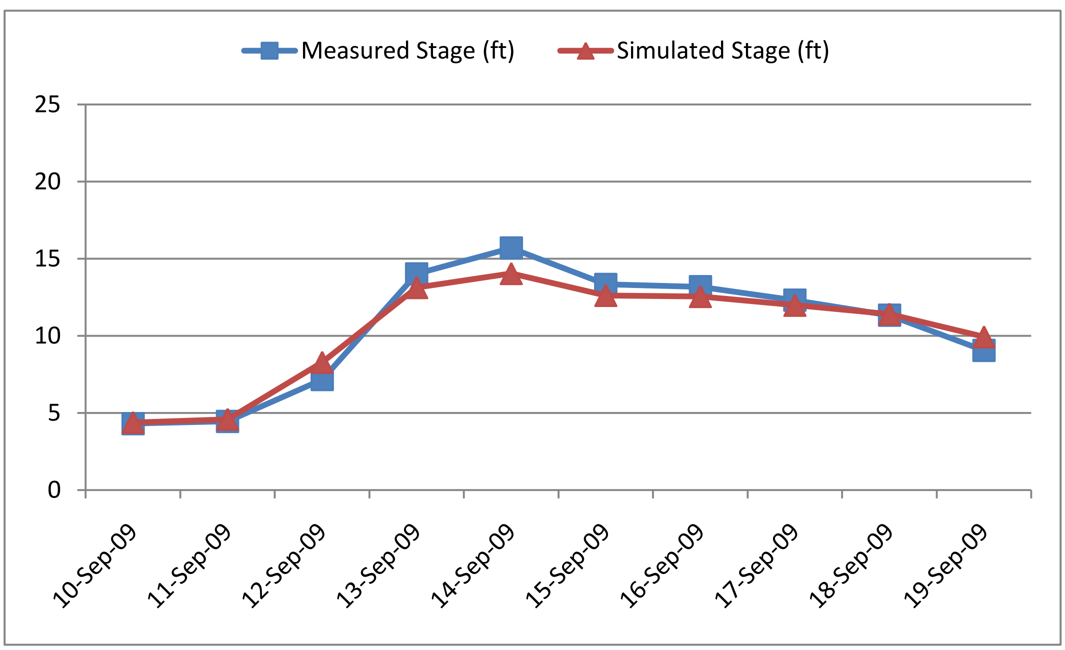


Figure 0-7 Comparison of Observed and Simulated Stage (ft)
USGS 02300500 September 10 - 20, 2009

As shown in Figure 0-6, a good match is observed for the discharge patterns and peak values for the simulated model. Observed discharge is slightly higher than simulated values. The difference may be explained by use of a constant shape factor in the hydrologic model. Discrepancies between observed and simulated values may also be attributed to limitations of the SCS methodology and the limited spatial and temporal rainfall data. The simulated and observed stage values evaluated for the verification events yielded a similar trend as shown in Figure 0-7.

References

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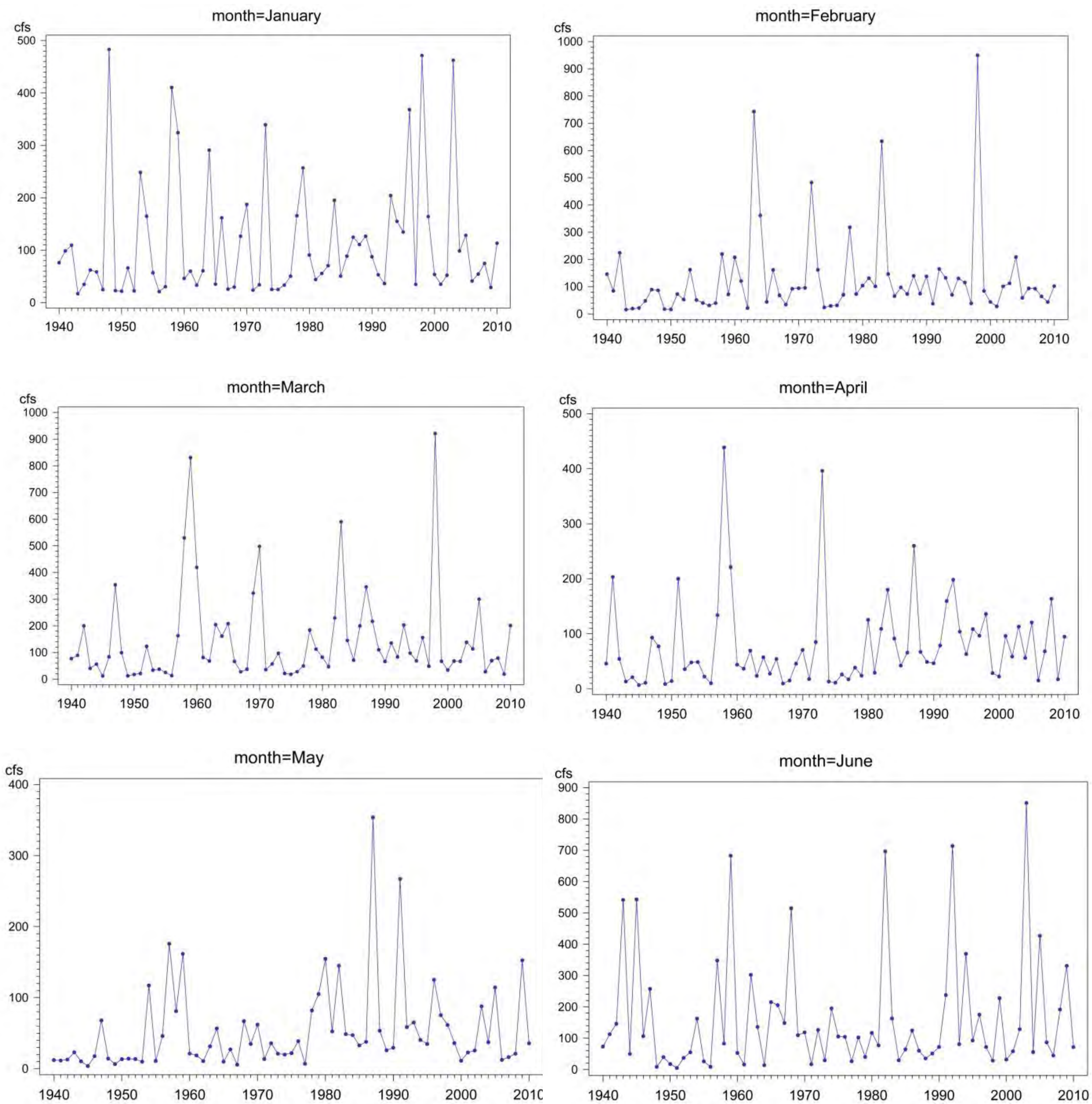
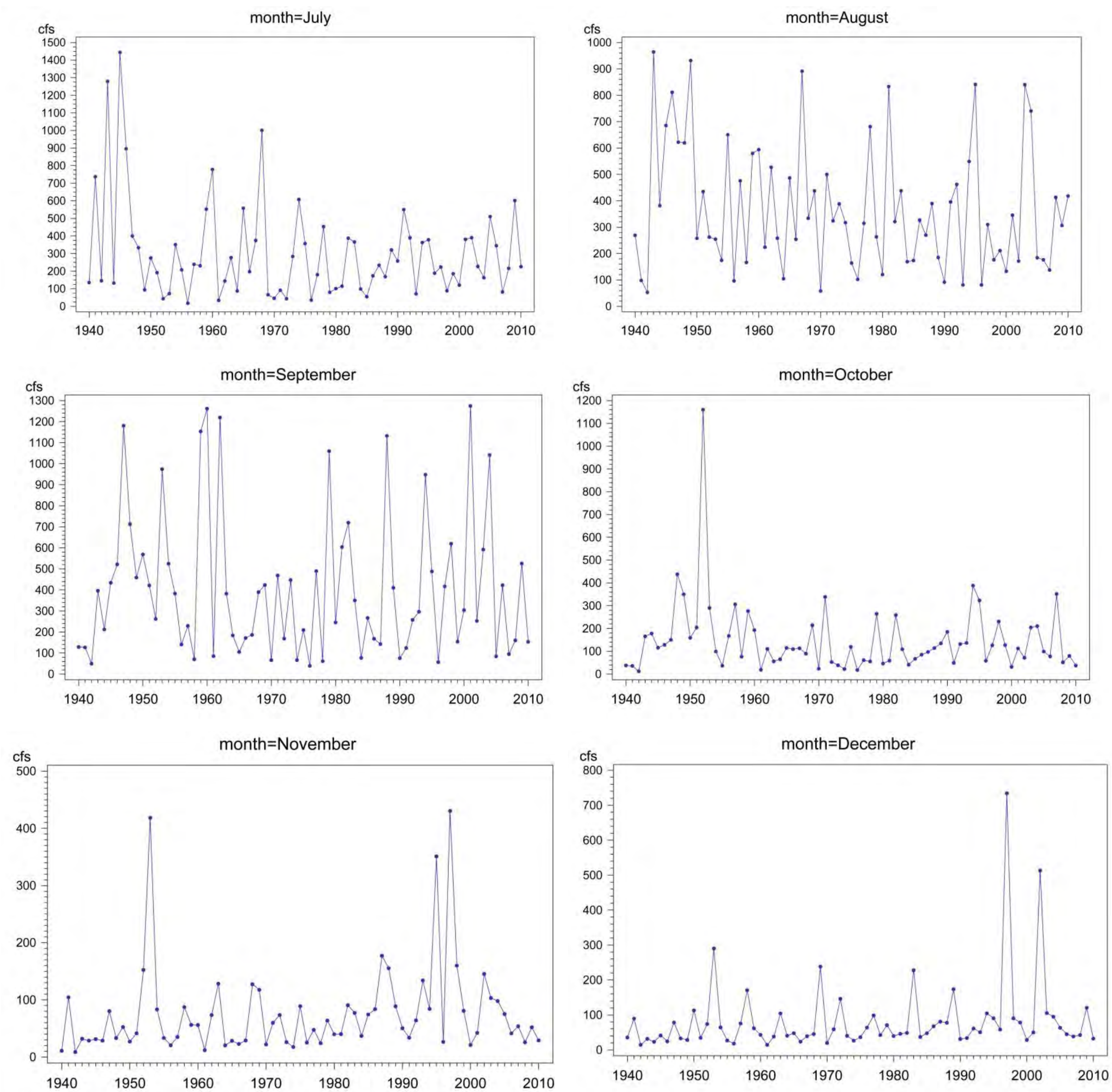
Appendix 2A

Hydrographs of Mean Monthly Flows for the Little Manatee River near Wimauma gage for 1940-2010.



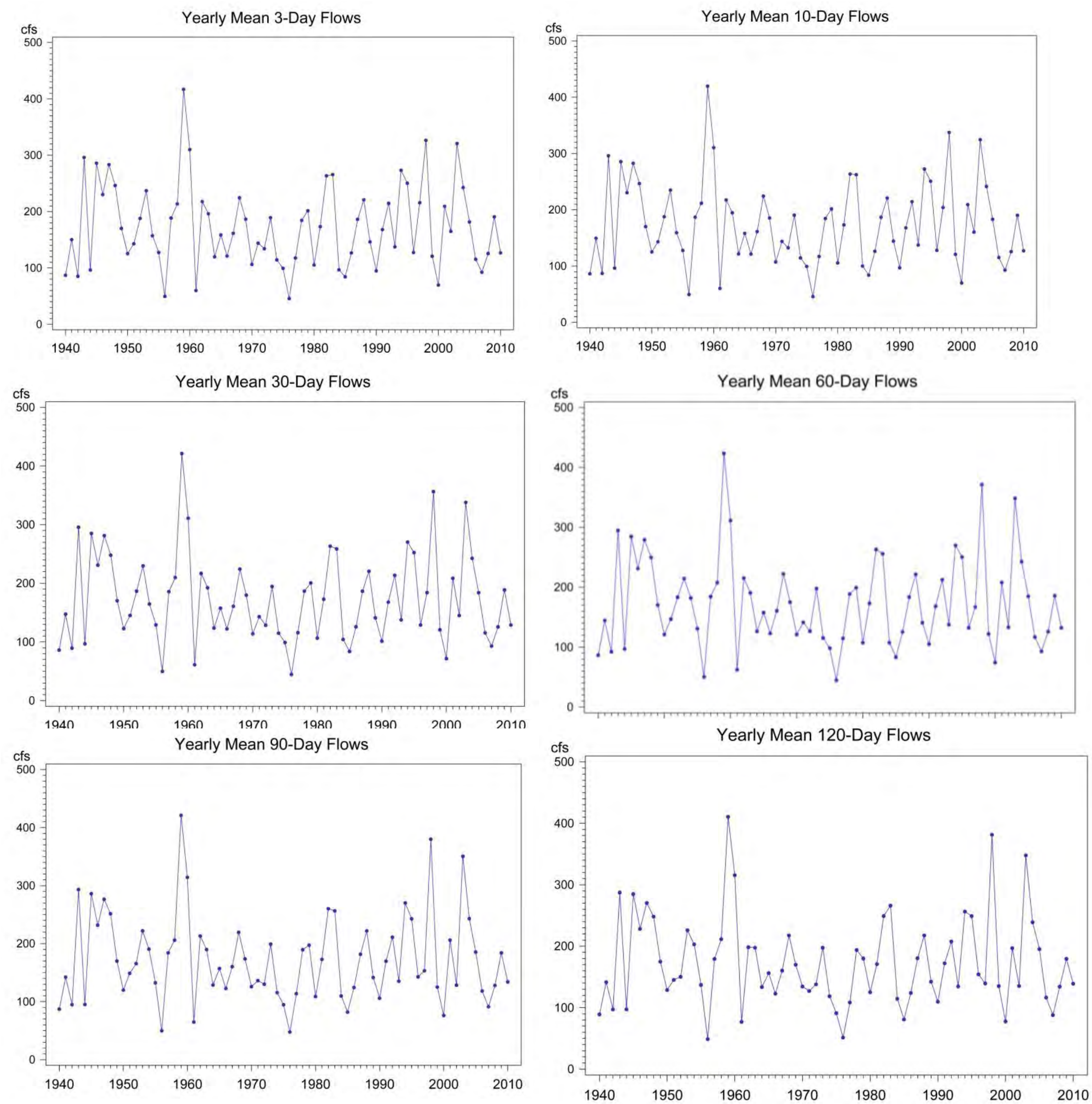
Hydrographs of mean monthly flows for the Little Manatee River near Wimauma, January – June, 1940-2010



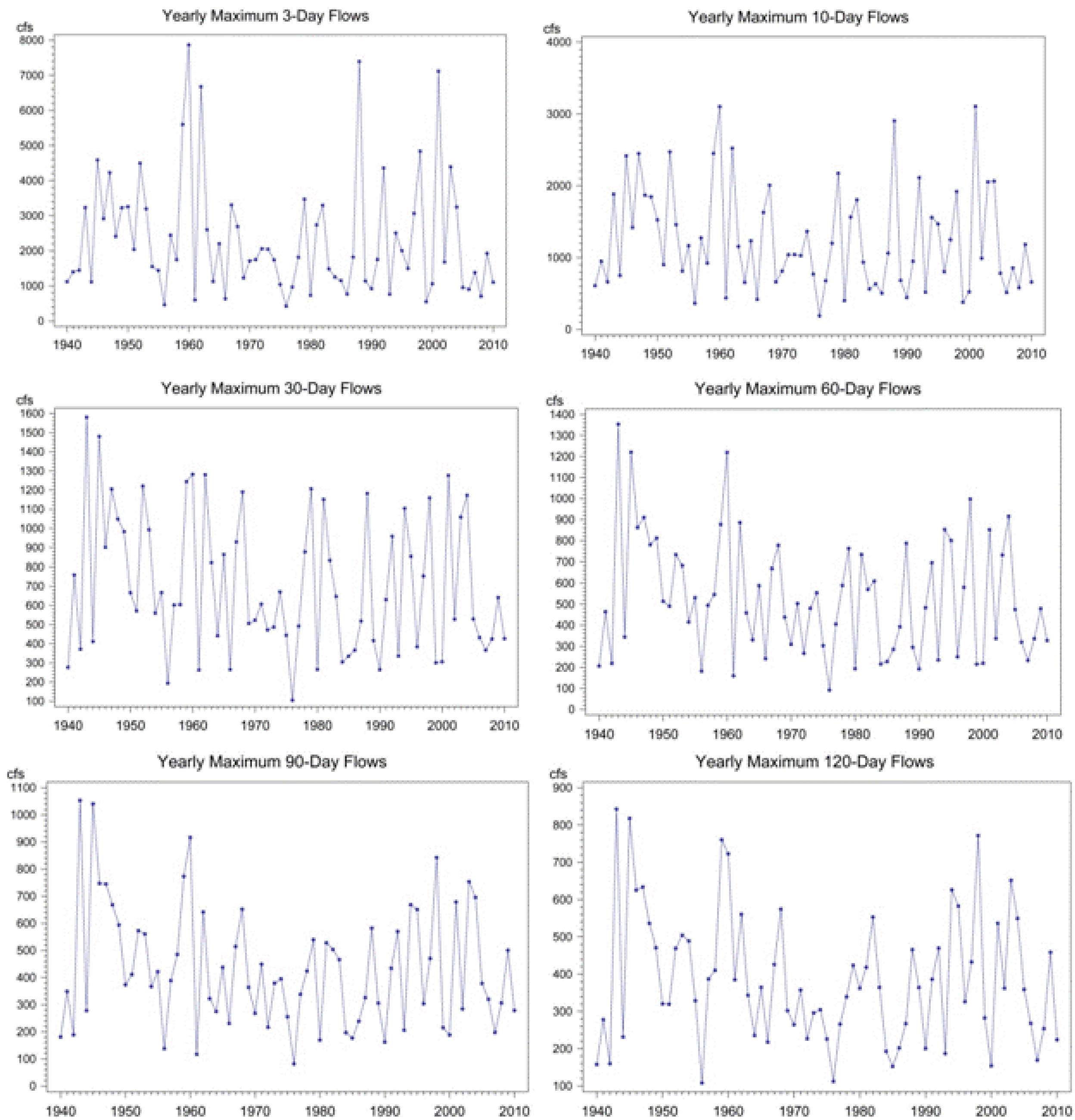
Hydrographs of mean monthly flows for the Little Manatee River near Wimauma: July – December, 1940-2010

Appendix 2B

Hydrographs of Mean and Maximum Values of Moving Average Flows within each year for the Little Manatee River near Wimauma gage:
1940-2010.



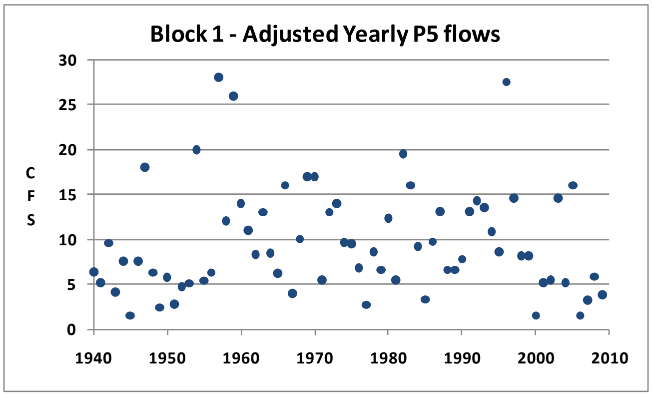
Hydrographs of mean values for moving average flows of different durations within each year for the Little Manatee River near Wimauma, 1940-2010

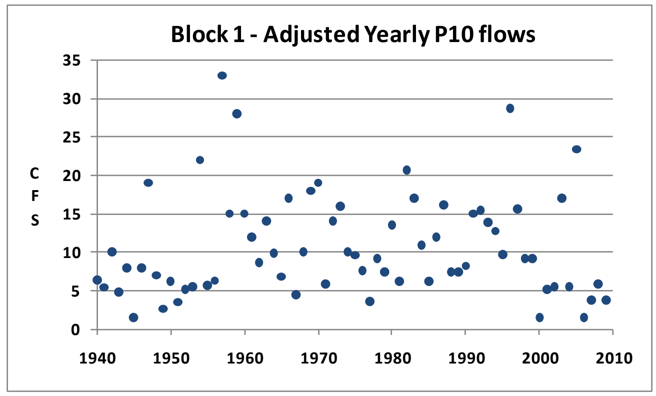


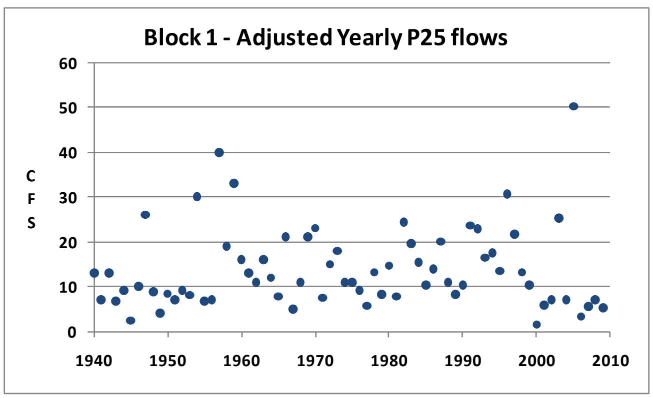
Hydrographs of maximum values for moving average flows of different durations within each year for the Little Manatee River near Wimauma, 1940-2010

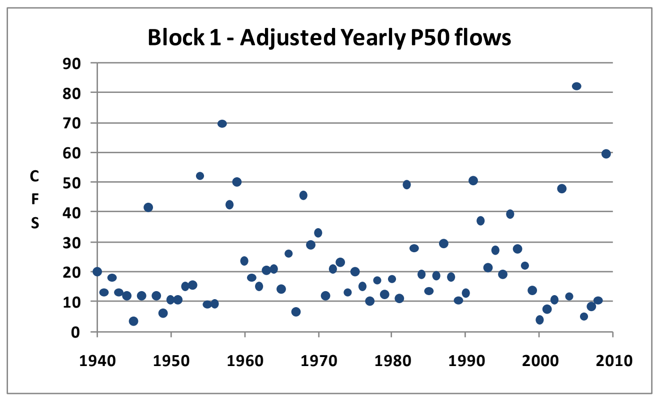
Appendix 2C

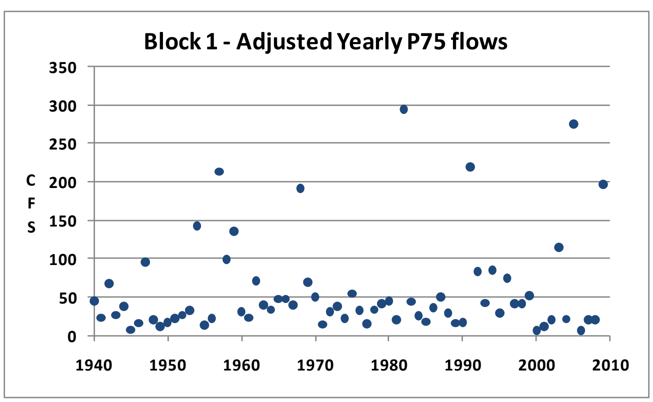
Hydrographs for selected yearly percentile flows for the adjusted flow record for the Little Manatee River near Wimauma gagefor three seasonal blocks: 1940-2009

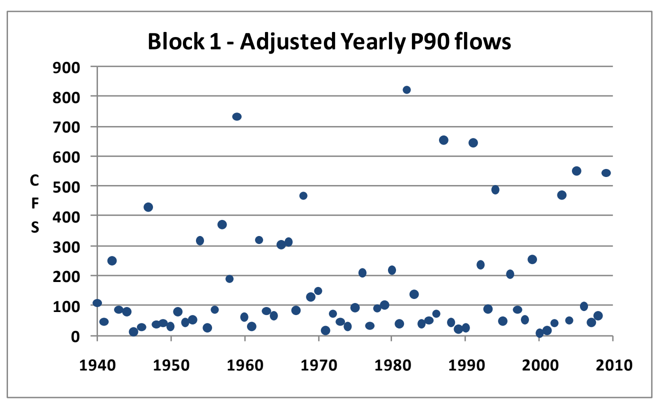




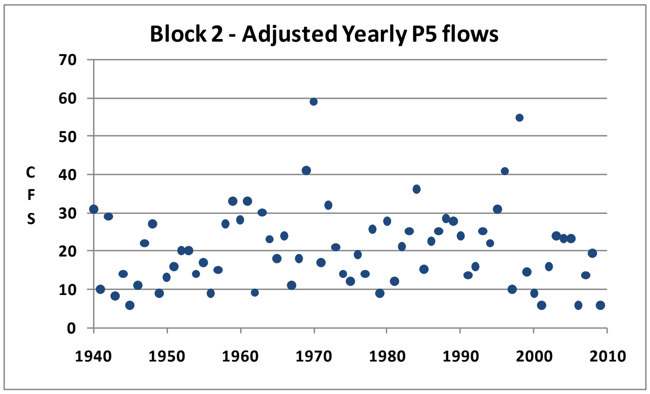


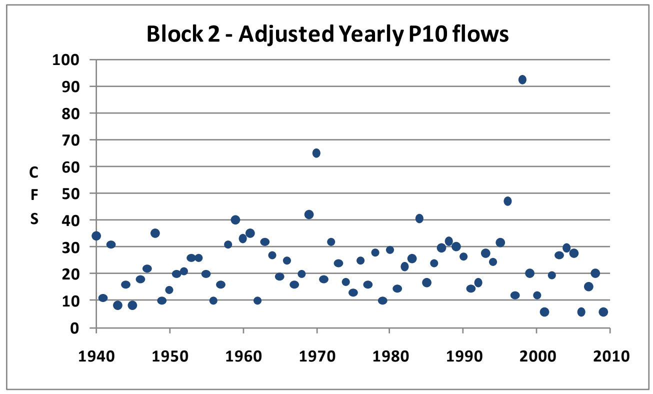


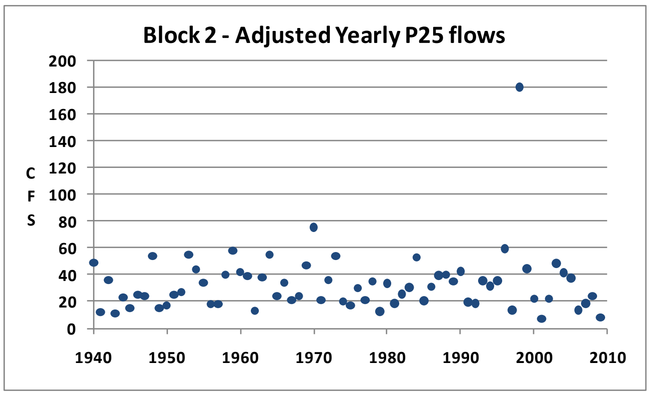


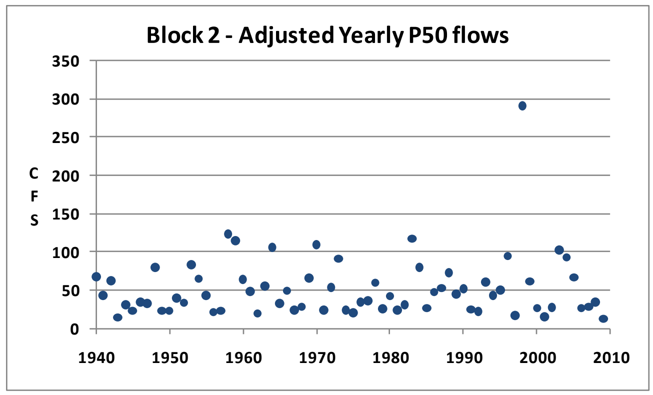


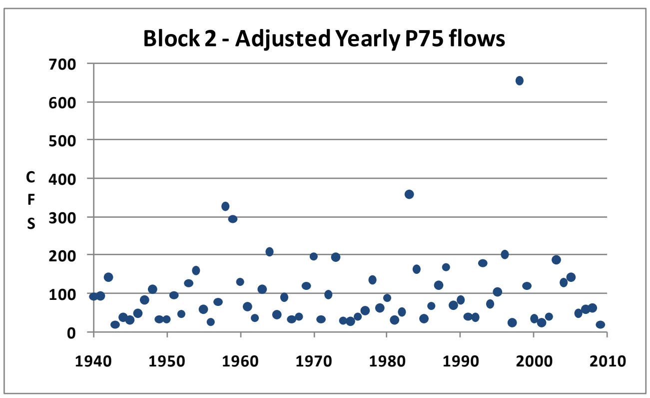
Hydrographs of selected yearly percentile flows for the adjusted flow record for the Little Manatee River near Wimauma gage: Block 1, 1940-2009

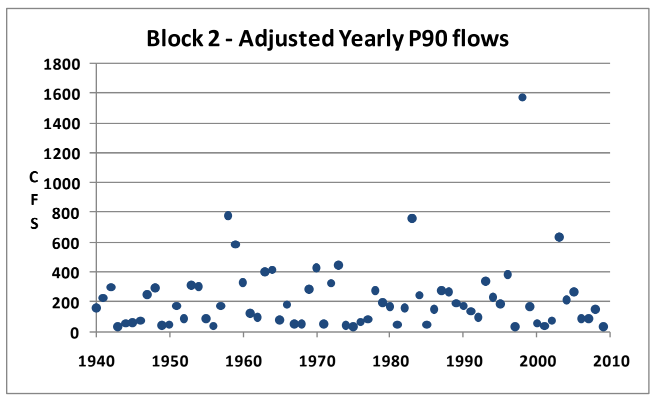




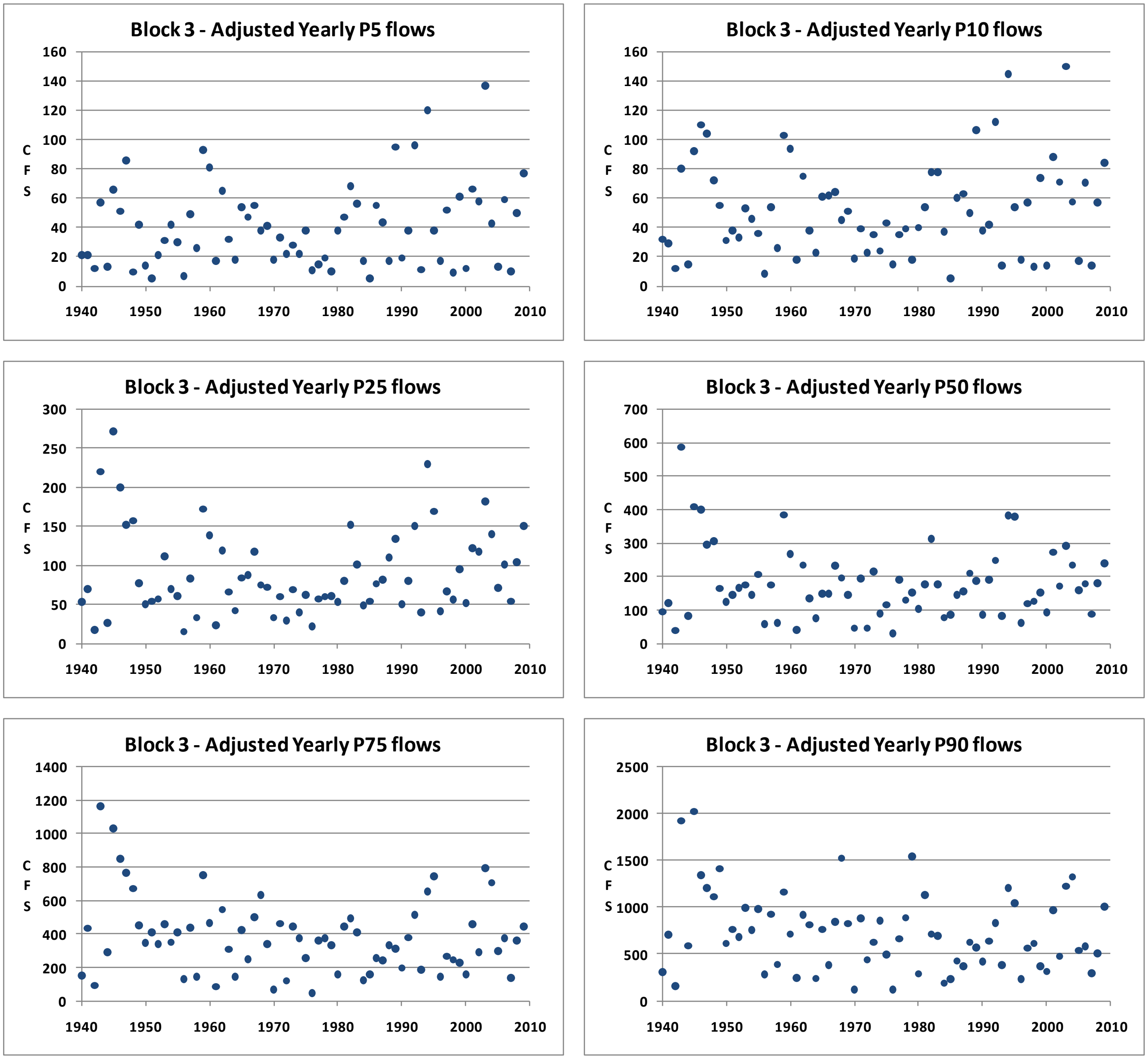








Hydrographs of selected yearly percentile flows for the adjusted flow record for the Little Manatee River near Wimauma: Block 2, 1940-2009



Hydrographs of selected yearly percentile flows for the adjusted flow record for the Little Manatee river near Wimauma: Block 3, 1940-2009