Weeki Wachee River System Recommended Minimum Flows and Levels October 30, 2008 Final

Prepared by
Southwest Florida Water Management District
Pursuant to 373.042 F.S.

Photo: R. Gant

Weeki Wachee River Recommended Minimum Flows and Levels

October 30, 2008
Ecologic Evaluation Section
Resource Projects Department
Southwest Florida Water Management District
Brooksville, Florida 34604-6899

Michael G. Heyl, MS
Chief Environmental Scientist

Conversion Table		
	Metric to U.S. Customary	
Multiply	By	To Obtain
cubic meters per second (m^3/s)	35.31	cubic feet per second (cfs)
cubic meters per second (m^3/s)	23	million gallons per day (mgd)
millimeters (mm)	0.03937	inches (in)
centimeter (cm)	0.3937	inches (in)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	statute miles (mi)
square meters (m^2)	10.76	square feet (ft^2)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	0.0008110	acre-ft
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
Celsius degrees (^oC)	1.8*(^oC) + 32	Fahrenheit (^oF)
	US Customary to Metric	
inches (in)	25.40	millimeters (mm)
inches (in)	2.54	centimeter (cm)
feet (ft)	0.3048	
statute miles (mi)	1.609	
square feet (ft^2)	0.0929	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
acres	0.4047	hectares (ha)
gallons (gal)	3.785	liters (l)
cubic feet (ft^3)	0.02831	cubic meters (m^3)
acre-feet	1233.0	cubic meters (m^3)
Fahrenheit (^oF)	0.5556*(^oF-32)	Celsius degrees (^oC)
	US Customary to US Customary	
acre	43560	square feet (ft^2)
square miles (mi^2)	640	acres
cubic feet per second (cfs)	0.646	million gallons per day (mgd)

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Preface

This report was prepared by the Southwest Florida Water Management District pursuant to Florida Statute 473.042. A draft was made available to the public on April 14, 2008 and submitted to an independent peer review panel consisting of Dr. Joseph Boyer (Fla. International University), Dr. 'Billy' Johnson (Computational Hydraulics Inc), Mr. Gary Powell (Aquatic Science Associates) and Dr. Sam Upchurch (SDII Global). Among other things, the panel was directed to determine whether the methods used for establishing the minimum flow are scientifically reasonable, if the assumptions and procedures are reasonable and consistent with the best information available and if the District's conclusions are supported by the data. The panel submitted their report on July 31, 2008, which is appended to this along with the District's response. In addition, the US Fish and Wildlife Service and the Florida Fish and Wildlife Conservation Commission reviewed the report and submitted comments that are also appended. This final report reflects the comments and suggestions received.

Acknowledgements

I would like to thank my colleagues for the many useful suggestions and discussions pertinent to completion of this project. In particular I would like to acknowledge Marty Kelly, Rich Schultz, Ron Basso for their assistance in deriving corrections to the historical flow record. I would also like to thank Sid Flannery, XinJian Chen and Tony Janicki and his staff. I would like to offer a special thanks to Michelle Dachsteiner for her dedication to the field work and data management as well as Barbara Matrone for her assistance in document production.

Finally I would like to thank the many District contractors that contributed to this report. Ernst Peebles (and his staff at USF) and Tim MacDonald and his colleagues at Florida Fish and Wildlife Conservation Commission collected and analyzed the fish and invertebrate data. Ernie Estevez conducted field surveys of mollusk use of the Weeki Wachee, and along with Jay Leverone conducted a survey of the macrophyte community. Paul Montagna provided insightful analysis of mollusc data. The staff at Janicki Environmental conducted a survey and analysis of the benthic community and along with staff from Applied Technology and Management, provided numeric modeling results for the thermal refuge analysis. While several of these projects were regional in nature, the cost of outside support is approximately $300,000 which was provided by Coastal Rivers Basin Board and the Governing Board.

Executive Summary
Minimum Flows and Levels – Weeki Wachee River

The Weeki Wachee River originates from Weeki Wachee Spring which discharges at a relatively constant rate from the Floridan aquifer. The river receives a small amount of surface runoff from its 38 mi^2 watershed, but the overwhelming majority of flow arises from the 260 $\pm$ mi^2 springshed. The river flows 7.4 miles (12 km) from the headspring to the Gulf of Mexico at Bayport in Hernando County, Florida. Daily discharge is estimated by the United States Geological Survey (USGS) as a function of water level in a nearby well completed in the Floridan. By comparison to other rivers on the west coast of Florida, the estuarine portion is very compressed with rapidly decreasing salinities over a short stretch of the river. Typically freshwater ($\leq$ 0.5 ppt) is encountered 1.6 miles (2.6 km) upstream from the confluence with the Gulf. Near Gulf salinity tends to be relatively low along the shallow, but open coastal area west of the Weeki Wachee River. Average (1985-2005) bottom salinity at the mouth ($\pm$ 0.5 km) is approximately thirty percent (11 ppt) of full seawater strength.

The salinity structure within the Weeki Wachee River is complicated by discharge from the Mud River which joins the Weeki Wachee River 0.9 miles (1.4 km) from the Gulf. Flow in the Mud River originates from Mud Spring and Salt Spring located approximately 1.6 miles (2.5 km) up the Mud River. This river is tidally influenced to the headwaters. Discharge from these two sources has not been routinely monitored, although sporadic measurements have been made and the discharge ranges from –51 to +78 cfs. The discharge is saline (~ 12 ppt) and discharge is sufficient to cause a measurable increase in salinity (reverse estuary) at the confluence of the Mud River with the Weeki Wachee River.

Discharge from the Weeki Wachee Spring has averaged approximately 174 cfs for the period of record (1935-2004) and 162 cfs for the baseline period (1984-2004) chosen for establishing the MFL. Daily estimates are available from 1974 to present, and annual average flows peaked in 1960 at 253 cfs. Anthropogenic impacts, primarily ground water pumpage from the springshed, have resulted in an estimated 17 cfs decline since 1961, or the equivalent of a eight percent reduction in flow during 2004.

A broad spectrum of ecological resources were identified and evaluated for sensitivity to reduced flows using both numeric models and empirical regressions. Resources considered included salinity habitat, fish and invertebrates, benthic communities, mollusc, submerged aquatic vegetation (SAV) and thermal refuge for manatees in the estuary. Criteria evaluated for the freshwater reaches included twelve life-stage habitat requirements for fish and an evaluation of benthic community diversity. Break-points in ecological response were not observed, and a fifteen percent loss of resource was adopted as representing significant harm.

After evaluation, the results for several resources were excluded from the determination of the MFL. While the loss of thermal refuge for manatees exceeded the *a priori* criterion at a five percentage flow reduction, the amount of refuge remaining at even a twenty five percent flow reduction was sufficient in volume and area to support 40 (low flow scenario) to 120 times (high flow scenario) the number of animals that currently use the Weeki Wachee River and was sufficient to house the entire manatee population found north of Tampa Bay. Based on aerial surveys, the average number of manatees using the Weeki Wachee/Mud River system is 10 animals. The northern Tampa Bay population is estimated at 400 animals. Thus, the *a priori* fifteen percent reduction was deemed inappropriately conservative for application in the Weeki Wachee River.

The response (abundance) of fish and invertebrates to reductions in flow was not incorporated into the recommended MFL. Flow during the period of time when fish / invertebrate abundance was measured was abnormally high which severely limits the range over which estimates can be made. Applying the abundance to flow response developed with the higher flows resulted in a prediction that certain fish common to the Weeki Wachee would be essentially absent during median flow conditions that existed throughout the baseline period.

Finally, the SAV results were inconsistent. The approach utilized was to relate the location of maximum density for each native species to the estimated long-term bottom salinity at that location. However, when the median salinity at the location of various taxa in the Weeki Wachee River were compared with the median salinity at the location of the same species in the Mud River, inconsistencies became apparent that suggest that factors other than salinity may be more important in shaping the SAV distributions.

Ordinarily, the MFL recommendation is based on the resource most sensitive to reduced flow. In the case of the Weeki Wachee, the loss of 15 ppt habitat was most sensitive, but this salinity was predicted to occur below the Mud River during the low flows evaluated and in the Gulf of Mexico beyond the mouth of the river during high flow. The latter necessitated extrapolating results from within the defined river channel. The high salinity of the Mud River and the fact that Mud River discharge is not well characterized led to a decision to not base the MFL on these higher salinity results, but rather to include those results as part of an average of all the remaining resource responses.

A total of sixteen responses were averaged for both low flow conditions and high flow conditions. In each case the reduction in flow resulting in a fifteen percent loss of resource or habitat was determined and included. The mean reduction in flow for the wet season evaluations was 10.7 percent while the mean reduction for the dry season was 10.1 percent. In consideration of the results, the proposed MFL for the Weeki Wachee spring and river s a ten percent reduction in flows that have been corrected for pumpage impacts. There are no consistent, long-term flow measurements for Mud Springs, Salt Springs, Mud River, Jenkins Springs or Twin Dees Spring. Thus, in the absence of sufficient data to evaluate these individually, the assumed MFL for these waterbodies is also ten percent reduction in baseline flows.

CHAPTER 1 - PURPOSE & BACKGROUND OF MFL

1.1 Overview and Legislative Direction

The Southwest Florida Water Management District (District or SWFWMD), by virtue of its responsibility to permit the consumptive use of water and a legislative mandate to protect water resources from “significant harm”, has been directed to establish minimum flows and levels (MFLs) for streams and rivers within its boundaries (Section 373.042, Florida Statutes). As currently defined by statute, “**the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.**” Mere development or adoption of a minimum flow, of course, does not protect a water body from significant harm; however, protection, recovery or regulatory compliance can be gauged once a standard has been established. The District's purpose in establishing MFLs is to create a yardstick against which permitting and/or planning decisions regarding water withdrawals, either surface or groundwater, can be made. Should an amount of withdrawal requested cause “significant harm” then a permit cannot be issued. If, when developing MFLs, it is determined that a system is already significantly harmed as a result of existing withdrawals, then a recovery plan is developed and implemented.

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

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

10) Navigation".

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

1.2 Historical Perspective

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

1.3 The Flow Regime

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

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

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

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

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

Common to this list and the flow requirements identified by Hill et al (1991) is the recognition that in-stream flows and out of bank flows are important and that seasonal variability of flows should be maintained. Based on these concepts, the preconception that minimum flows (and levels) are a single value or the absolute minimum required to maintain ecologic health in most systems has been abandoned in recognition of the important ecologic and hydrologic functions of streams and rivers that are maintained by different ranges of flow. And while the term "minimum flows" is still used, the concept has evolved to one that recognizes the need to maintain a "minimum flow regime". In Florida, for example, the St. Johns River Water Management District (typically develops multiple flows requirements when establishing minimum flows and levels (Chapter 40-C8, F.A.C) and for the Wekiva River noted that, "[s]etting multiple minimum levels and flows, rather than a single minimum level and flow, recognizes that lotic [running water] systems are inherently dynamic" (Hupalo et al. 1994). An alternate approach which also maintains a flow regime is to develop MFLs using a 'percentage of flow' as discussed in Flannery et al. (2002) and has been incorporated into several SWFWMD surface water use permits.

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.

1.4.1 Defining Significant Harm

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

Ideally there will be a clear 'break point' that identifies significant harm. Unfortunately, more often in nature there is simply a monotonic continuum with a changing rate of response, but one that does not provide an easily identifiable break-point. Little guidance is found in the literature, and the definition of 'significant harm' often becomes a policy decision rather than a technical decision.

In their peer review report o 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." Powell et al. (2002) developed a procedure using optimization modeling techniques which the state of Texas applied to Galveston Bay and the Trinity-San Jacinto estuaries. The procedure is based on a harvest constraint that no individual species would be less than eighty percent of historical average. An additional constraint was imposed that the optimal solution falls between the 10^{th} and 50^{th} percentile of historical flows[1].

[1] http://www.tpwd.state.tx.us/texaswater/coastal/freashwater/matagorda/matagorda.phtml

1.4.2 Minimum Evaluation Criteria

Relating inherently variable biological responses to MFL objectives will ultimately require setting criteria for taking management action based on the strength of the biological response to flows or levels. The science of establishing MFLs is evolving and many researchers have turned to regression statistics to determine the statistical strength between biological responses and inflows. The most common measure of the strength is the correlation coefficient (r) which ranges from +1.0 to 0.0 for a response that increases with increasing flow (conversely r can range from -1.0 to 0 for an inverted response). The coefficient of determination (r^2) is convenient, because it reflects the fraction of response that is attributable to changes in flow. However, it must be recognized that a statistically significant relationship may still be of limited value in the management of the resource. Taking an example from fish monitoring, it is possible to have statistically significant relationships that relate the number of animals to flow, but often the coefficient of determination is very low (e.g. 0.1). The interpretation is that while there is a significant relationship between the number of organisms and flow, flow only accounts for 10% of the change in numbers. The remaining 90% of variation in numbers is due to residual variation in flow and to factor(s) other than flow.

The management question then becomes *'How much weight do we place on this relationship? Should we set flow limits when the majority of response is due to something other than flow?* '. Comrey and Lee (1992) attempted to qualify correlation coefficient levels[2] according to the following schema:

Coefficient of Determination(r^2)	Descriptor
0.50	Excellent
0.40	Very Good
0.30	Good
0.20	Fair
0.10	Poor

A similar problem facing the decision-makers is '*how much data do we need*?'. Taken in the context of establishing statistical relationships between flow and ecological resources the analogous question is "*How many data points should I have to develop my regression equation?*' Research has shown that as the strength of the relationship diminishes, the number of observations required increases (so called 'effect size'). Brooks and Barcikowski (1994) summarized several 'rule-of-thumb' approaches (Table 1-1) taken from the literature and contrasted those results (Table 1-2) derived from their own Monte Carlo simulations and those promoted by Park and Dudycha (1974).

[2] Described in the context of evaluating orthogonal factor loadings resulting from factor analysis

Table 1-1
Rule-of-Thumb Estimates for Number of Observations Needed

Number of Observations/ parameter	Citation
10 * p	Miller & Kenuc, 1973. p 162 Neter, Wasserman & Kutner. 1990. p 467
> 15 * p	Stevens, 1992. p 125
20 * p	Tabachnick & Fidell. 1989 p128 (N>100 preferred) Halinski & Feldt 1970 p157 (for identifying predictors)
30 * p	Pedhazur & Schmelkin. 1990. p 447
> 40 * p	Nunnally 1978. Tabachnick & Fidell 1989. p 129 (for step-wise)
50 + p	Harris, 1985. p 64
10p + 50	Thorndike, 1978. p 184
> 100	Kerlinger & Pedhazur. 1973. p 442 (preferably > 200)
Adapted from Brooks, G.P. and R.S. Barcikowski 1994. A New Sample Size Formula for Regression. Presented at the Annual Meeting of the American Educational Research Association. New Orleans, LA April 1994.	

Table 1-2
Number of Observations Considering Strength of Correlation

Number of Independent Variables	Brooks & Barcikowski			Park & Dudycha		
	$r^2 \geq$ 0.50	$r^2 \geq$ 0.25	$r^2 \geq$ 0.10	$r^2 \geq$ 0.50	$r^2 \geq$ 0.25	$r^2 \geq$ 0.10
2	42	62	122	31	45	85
3	63	93	183	50	71	133
4	84	124	244	66	93	173

While, it would be desirable to have the number of observations suggested by Brooks and Barcikowski, most of the environmental observations used to develop an MFL cannot be designed and tested in laboratory conditions. The practical reality is that achieving the recommended number of observations rarely happens. Furthermore, the infrequent event is often the one of most interest. For example, it is important to know the maximum upstream penetration of saline water during abnormally dry conditions. As a second example, the fishery biologist has no real control over how many fish of a particular taxa will be caught in a seine.

Thus, it often becomes necessary to try and develop relationships between flow and some response with considerably fewer observations than recommended or desirable. While the legislature has indicated that an MFL should be based on the 'best information available', at some point it becomes questionable whether a management decision should be based on a very low number of observations or a very low correlation, and it becomes preferable to establish acceptance criteria *a priori.* For purposes of the present MFL a minimum threshold coefficient of determination ($r_{adj.}^2$) of 0.30 and a minimum number of ten observations per parameter has been adopted, acknowledging both the limitations of the data available and that the literature would argue for considerably more observations.

1.5 Summary of the SWFWMD Approach for Developing Minimum Flows

1.5.1 Elements of Minimum Flows

It should be noted that this Weeki Wachee MFL report includes an MFL determination for both the freshwater riverine and the downstream estuarine portion of the river. While the approaches and tools differ between these two evaluations, both share a common philosophical approach in attempting to establish a flow regime instead of a single threshold flow. In addition, both the riverine and the estuarine evaluation embody recommendations by Beecher (1990) who noted *"it is difficult [in most statutes] to either ascertain legislative intent or determine if a proposed instream flow regime would satisfy the legislative purpose"*. According to Beecher (as cited by Stalnaker et al. (1995)), an instream flow standard should include the following elements:

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

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

Fundamental to the approach used for development of minimum flows and levels is the realization that a flow regime is necessary to protect the ecology of the river system. The initial step in this process requires an understanding of historic and current flow conditions to determine if current flows reflect past conditions. If this is the case, the development of minimum flows and levels becomes a question of what can be allowed in terms of withdrawals before significant harm occurs. If there have been changes to the flow regime of a river, these must be assessed to determine if significant harm has already occurred. If significant harm has occurred, recovery becomes an issue. For development of minimum flows for the Weeki Wachee, the District used a "reference" period, from 1967 through 2004 (freshwater.) and 1984 through 2004 for the estuarine evaluation (corresponding to the majority of the water quality data) to evaluate flow regime changes. In consideration of seasonal flow variation, the District evaluates hydrologic seasons separately. Termed "Blocks", these periods correspond to a low-flow season (Block 1), a period of intermediate flow (Block 2) and a high-flow season (Block 3) [For further discussion, see Section 2.6]

Following assessment of historic and current flow regimes and the factors that have affected their development, the District develops protection standard statistics or criteria for preventing significant harm to the water resource. For the freshwater segment of the Weeki Wachee criteria associated maintenance of habitat (as predicted using the ecological model Physical Habitat Simulation Model). The District has established criteria to protect these habitats for each Block per recommendations contained in the peer review of the proposed upper Peace River minimum flows (Gore et al. 2002).

The approach to protection of the downstream resources varies by resource. For example, fish and invertebrate resources (expressed as abundance) are evaluated as direct response(s) to changing flows whereas the benthic community is indirectly evaluated as a change in the volume or area of the estuary which is at, or below an ecologically important salinity. At the other end of the spectrum, the thermal refuge provided to the marine manatee was evaluated as the volume (and area) of winter habitat that remains above a critical temperature (e.g. 20^{o} C).

1.5.2 Flows and Levels

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

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

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

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

1.6 Content of Remaining Chapters

In this chapter, we have summarized the requirements and rationale for developing minimum flows and levels in general and introduced the need for protection of the flow regime rather than protection of a single minimum flow. The remainder of this document considers the development of minimum flows and levels specific to the Weeki Wachee River, which is defined as the river reach from the head springs near US Highway 50 to the confluence with the Gulf of Mexico at Bayport, FL.

Chapters 2 through 5 are intended to be largely descriptive of the system. Not all of the material presented in these chapters was used in setting the MFL, but it is important to characterize the nature of the system under investigation. For example, watershed land-use cannot be reasonably managed as an MFL issue, but it is important to understand that highly urbanized systems generally offer less habitat than relatively pristine systems, and this may have a bearing on the outcome of the MFL.

In Chapter 2, we provide a short description of the entire river basin and springshed; the hydrogeologic setting, and consider historical and current river flows and the factors that have influenced the flow regimes. Seasonal blocks corresponding to low, medium and high flows are identified. In Chapter 3 the focus changes to a description of the estuarine characteristics. Chapter 4 is devoted to water quality with a focus on salinity and the relationships with flow.

Biological resources are described in Chapter 5 along with quantifiable relationships to flow that have been developed for the MFL evaluation. Goals and specific MFL resource criteria are defined in Chapter 6 while Chapter 7 is devoted to application of evaluation tools to determine what minimum flow(s) achieve the criteria established in the prior chapter. Finally, Chapter 8 provides a definition of the Weeki Wachee MFL. Chapters 9 and 10 contain literature cited and appendices respectively for the prior chapters.

With the exceptions noted, the British system of measurement units has been utilized in this report. This will promote consistency with other SWFWMD reports and Governor Crist's *Plain Language Initiative*[3] that promotes a writing style easily understood by the public. The two exceptions to the British system are river distance (expressed in kilometer) and sample depth (expressed in meters) A table of common conversions is provided following the Table of Contents.

One final comment regarding establishment of the MFL is the issue of hydrologic alterations. It is both a practical, and a statutory requirement (373.0421, FS) that the establishment of an MFL shall consider changes and structural alterations. Examples within the District include in-stream impoundments such as exist on the Hillsborough, Manatee, Braden, Withlacoochee Rivers, Shell Creek, Tampa Bypass Canal (TBC) and

[3] State initiative can be found at http://www.flgov.com/pl_home

Cow Pen Slough (CPS). Some exist for flood control or navigation (Withlacoochee, TBC and CPS), but most have been constructed as potable surface water supplies.

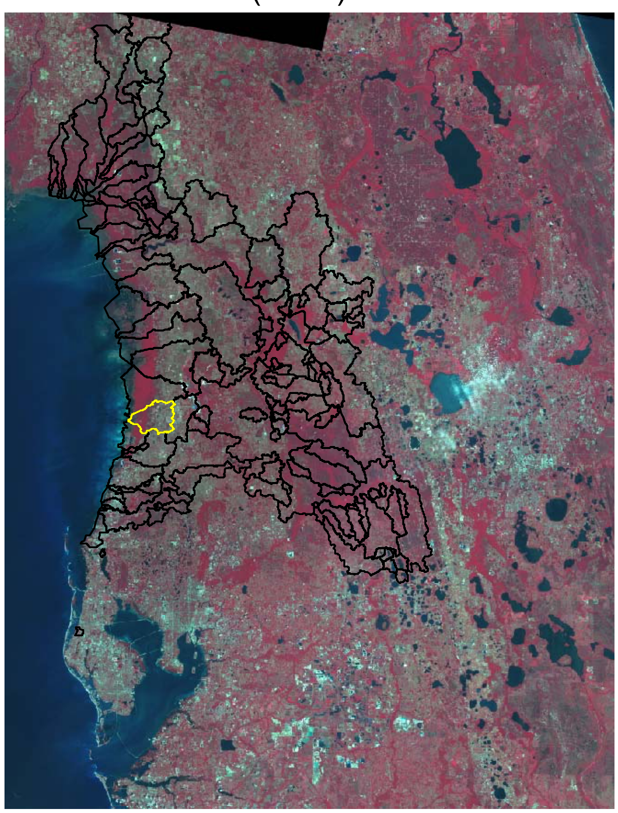
The District's policy has been to evaluate free-flowing, un-impounded rivers and estuaries in a 'top-down' manner by attempting to re-create a baseline historical flow as free of anthropogenic impacts as possible. This flow becomes the reference from which 'significant harm' is evaluated. In contrast, systems severely, and irreversibly impacted by hydrologic control structures are evaluated in a 'bottom up' manner. For these systems, the current conditions generally become the starting point for evaluating improvements to minimum system flows and incrementally larger flows are evaluated in order to determine the maximum benefit ratio. In the case of the Weeki Wachee, there are no significant physical hydrologic alterations to the system and a 'top down' approach was utilized.

CHAPTER 2 - WATERSHED CHARACTERISTICS – PHYSICAL AND HYDROLOGY

2.1 Watershed / Springshed

Weeki Wachee River is a short (12 km) spring-fed river located on a portion of the west coast of Florida (Figure 2-1) known as the Florida Springs Coast[4] (Wolfe 1990) which includes the coast from the Pithlachascotee to Wacasassa River. The main spring is a circular vent located near the intersection of Highway 50 and US 19 in Hernando County. Spring depth is 14 meters over the vent and discharge is into a pool approximately 50 by 64 meters (Florida Geological Survey 2002). A north-south trending linear-fracture type of vent exists below the vent. At the 56 meter level the dimensions are 6 x1 meters. Below 76 meters there is a large cavern. Passages at both ends of the cavern convey water away from the vent (Knochenmus and Yobbi 2001). Recent average flow (1994-2004) is 153 cfs (4.3 m^3/s) which qualifies as a 1st magnitude spring (e.g. > 100 cfs).

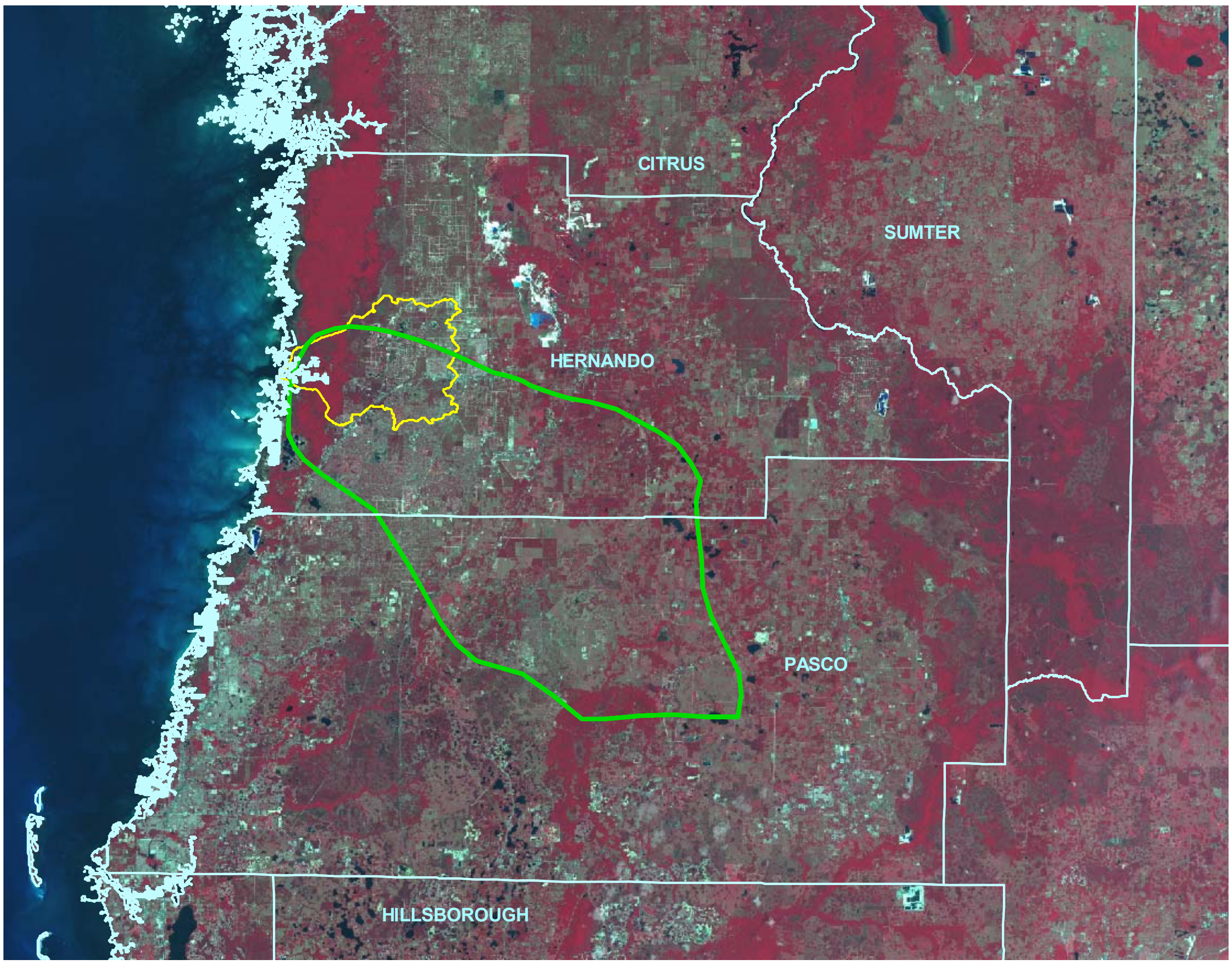
Figure 2-1
Florida Springs Coast Sub-basins (black) and Weeki Wachee Watershed (yellow)



[4] A complete listing of springs in Florida is available through the Florida Springs Database at http://www.thiswaytothe.net/springs/index.shtml .

The surface drainage area is approximately 38 mi^2, but the springshed is significantly larger. Sinclair (1978) estimated contributing groundwater area to be 100 – 150 mi^2 but a recent re-evaluation (D. Witt, SWFWMD) illustrated in Figure 2-2 indicates groundwater contribution from a 260 mi^2 area. The watershed is completely within Hernando County, whereas the springshed is approximately evenly distributed between Hernando and Pasco Counties.

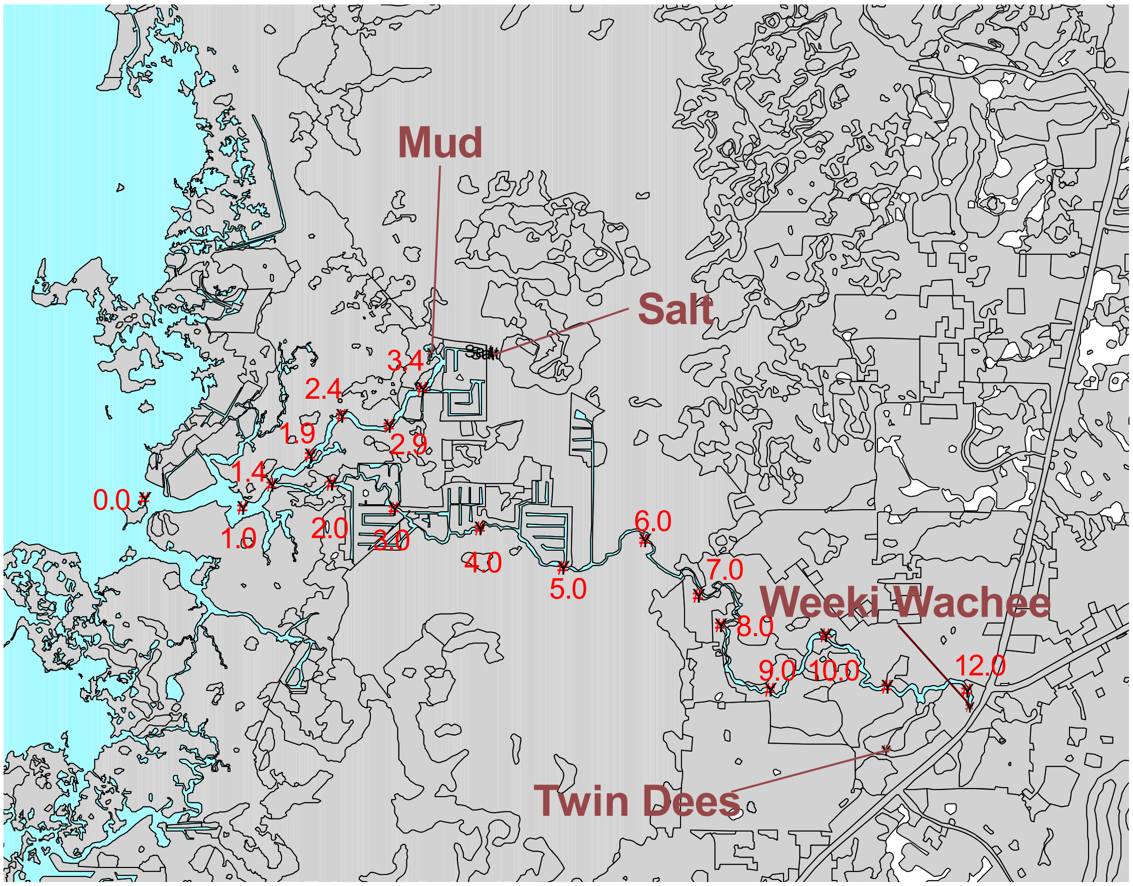
Figure 2-2
Weeki Wachee Watershed (yellow) and Springshed (green)



Little Springs (also known as Twin Dees) discharges through 0.3 km of marsh and joins the Weeki Wachee River approximately 0.9 km downstream of the main spring (ibid). Little Springs is 1.2 meter circular vent extending to a depth of approximately 15 m, below which the vent angles north.

Approximately 10.7 km downstream from the main spring, the Weeki Wachee River is joined by the Mud River which converges from the north. The Mud River system consists of both Mud Spring (circular vent with 56 meters drop) and Salt Spring, (also a circular vent 1.8 meters in diameter by 52 meters deep). The relationship of all the spring sources is given in Figure 2-3.

Figure 2-3
Location of Springs and River Kilometers



2.1.1 Land Use

The Weeki Wachee springshed is largely undeveloped (springshed was 27 percent urbanized in 1999, but the existing urbanization is concentrated in the watershed (watershed was 43 percent urban) and rapidly increasing. Table 2-1 compares the 1999 land use for both the watershed and the springshed. Large (ca 140 percent) increases in urban land use have occurred during this period at the expense of rangeland and forest. Figure 2-4 illustrates the development of the canal system present within the watershed in 1974. Figure 2-5 depicts the extent of urbanization in1999 overlain on a 1972 aerial photograph.

Table 2-1
Watershed and Springshed Land Use

Springshed Land Use -1999		
	acres	**Percent**
Citrus	1,779	1%
Mines	415	0%
Nonforested Wetlands	12,234	7%
Other Agriculture	45,342	27%
Rangeland	4,041	2%
Upland Forests	43,004	26%
Urban	44,693	27%
Water	3,564	2%
Wetland Forests	13,223	8%

Watershed Land Use -1999		
	acres	**Percent**
Citrus	-	0%
Mines	-	0%
Nonforested Wetlands	2,064	8%
Other Agriculture	88	0%
Rangeland	44	0%
Upland Forests	6,965	29%
Urban	10,563	43%
Water	1,044	4%
Wetland Forests	3,574	15%

Figure 2-4
1974 Aerial with Canal Development Periods

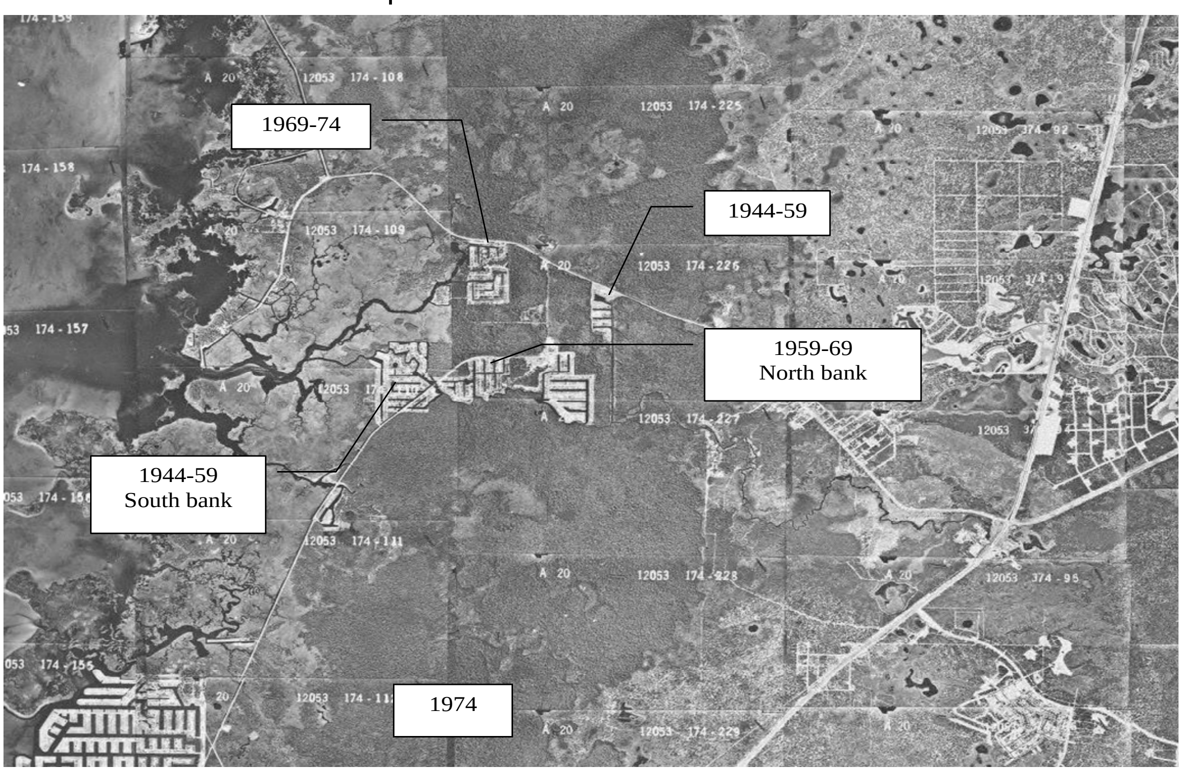
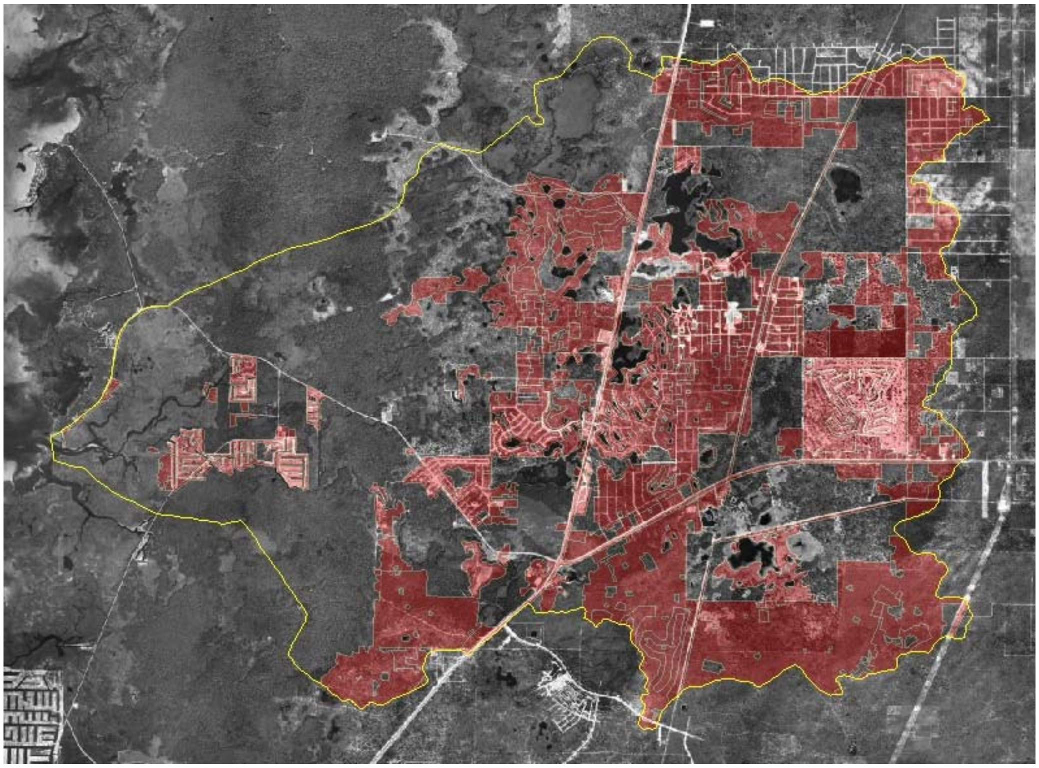


Figure 2-5
1970s Aerial with 1999 Urban Areas Shaded Red



2.1.2 Hydrogeologic Setting

The following recent synopsis of the Weeki Wachee Springs System was prepared by M. Hill (2007) for the Karst Research Group at the University of South Florida.

> *The Weeki Wachee Spring Group is located in southwestern Hernando County and has a cumulative discharge of over 200 ft3/sc (6 m3/s; Champion and Starks, 2001). It is unique relative to other first magnitude spring groups in the SWFWMD in that it consists of the fewest number of vents, has large explorable conduit systems, and data from the 1930's. Two of the vents, Weeki Wachee Main and Twin Dees discharge freshwater and [are] not tidally influenced. Salt, Mud, and Jenkins, which are located a few miles west of Weeki Wachee Main and Twin Dees, discharge brackish water and are tidally influenced. Little is known about the water quality of a sixth vent indentified as 831-237-A (Wetterhall,*

1965) or Unnamed Spring No. 3 (Rosenau et al. 1977). However, the presence of bacterial deposits associated with transition zones suggests that discharge is brackish.

Weeki Wachee Main and Twin Dees are paleo sinkholes that transitioned to points of discharge as sea level rose. Divers describe the main vent at Weeki Wachee as a narrow vertical fracture which opens into a large room at a depth of approximately 150-205 ft (46-62 m) bls (Sinclair, 1978; Jones et al., 1997). Two passages exiting the large room were identified, but their trends were not indicated. Divers report more water appears to be exiting the room through the two passages rather than through the fracture leading to the main vent (Jones et al., 1997).

Weeki Wachee Spring discharges from the bottom of a conical depression with gentle side slopes. The spring measures 165 ft (50.3 m) east to west and 210 ft (64 m) north to south. . . . Twin Dees (aka Little Spring) is approximately 3000 ft (914 m) southwest of Weeki Wachee Main. Discharge varies from zero to second magnitude at Twin Dees. Discharge is significantly lower than Weeki Wachee Main, however this relatively small spring is fed by a large conduit system with rooms that exceed 100 ft (30 m) in diameter. Divers have mapped an extensive conduit system at Twin Dees. Cave maps suggest that the geometry of the system has been influenced by both fracture sets and bedding. . . . Two vents exist at Twin Dees, but one vent, according to divers has been plugged for some time. Freshwater discharges from Twin Dees, but cave divers have identified the influx of brackish water at various locations in the conduit system (Champion and Starks, 2001).

The region surrounding Weeki Wachee Springs can be characterized as a karst terrain with internal drainage. . . . Anecdotal evidence suggests that a high degree of connection may exist among south-southeast trending conduits and Weeki Wachee Main. On or around March 19, 1976, Weeki Wachee Main became cloudy allegedly due to collapse of a conduit below Crescent Lake, which is approximately 1.6 miles southeast of the vent. . . . It has long been suspected that Weeki Wachee Main and Twin Dees are hydraulically connected. Geochemically, the discharge is very similar from the two vents. Natural tracer studies are currently in progress to evaluate response time fro the springs.

2.1.3 History

The modern recorded history of Weeki Wachee appears to begin in the early 1800's. A chronology of maps is available[5] covering the period 1776 – 1953. Although the name

[5] http://fivay.org/hpicts.html

is a variation of the Seminole word 'weekiwachee' (which means 'little spring' or 'winding river') neither the river nor the place name is identified on maps prior to 1838.

A historical marker at mouth of the River reads:

The Village of Bayport, located at the mouth of the Weekiwachee River sprang up in the early 1850's as a supply and cotton port. During the War Between the States, Union naval squadrons blockaded Florida's coasts to prevent goods and supplies from passing into and out of the State. By 1863 the East Gulf Blockade Squadron effectively closed the larger ports along the Gulf Coast. Small rivers, such as the Weeki Wachee became important trade routes. Shipping at Bayport attracted the attention of The Union Blockade Squadron which intercepted eleven blockade runners near there between 1862 and 1865. After the war Bayport became Hernando County's major outlet for lumber and agricultural products, and continued to serve as its transportation center until railroad service came to Brooksville in 1885."

1940 – Purchased by City of St. Petersburg for water supply.
1947 – First mermaid show opened on 10/13/47.
1959 – Purchased by American Broadcasting Corporation
1961 – *Follow that Dream* (Elvis Presley) filmed on site.
1982 – Buccaneer Bay Waterpark opens.
1984 – Purchased by Florida Leisure Attractions from ABC.
1989 – Purchased by Florida Leisure Acquisitions from Florida Leisure Attractions.
2001 – Purchased by SWFWMD, along with surrounding land. Attraction leased to current operators.
2003 – Attraction lease transferred to City of Weeki Wachee.

The center piece of Bayport appears to have been the Bayport Hotel which was in existence from 1842 until 1942 when it burned. Union solders escaped through Bayport following the Brooksville Raid of 1864. Bayport was a productive fishing community during its heyday and a haven for smuggling during the prohibition era. As recent as 2000, the US Census Bureau continued to recognize Bayport as a Census Designated Place (CDP) consisting of 0.7 mi^2 with a population of 36.

Arguably the strongest name recognition is associated with the tourist attraction that has existed at the head springs since 1947. For sixty years this attraction has been famous for the underwater mermaid shows and as a bathing place[6]. A chronology of events surrounding the attraction is given in the side bar.

2.2 Climate / Meteorology

The climate of the Springs Coast is mild and greatly influenced by the Gulf of Mexico. Mean daily summer high temperatures are in the low to mid 90s and the winter means are in the upper 50s with an annual average temperature of (70 F). Annual precipitation

[6] Chapter 64E-9, F.A.C. requires 500 gallons/day/bather and 100 ft^2. Capacity is space limited at Weeki Wachee as median flows (1984-2004) are adequate to support over 200,000 bathers

averages 55.8 inches at nearby Brooksville (1904-2004) and is largely the result of localized convective thunderstorms during the summer months when 31.7 inches (June through September) is normal. However, unlike runoff-dominated rivers this seasonal peak in rainfall does not translate into large differences in discharge (see Weeki Wachee Discharge). Additional rain accompanies winter frontal systems which result in a secondary peak in rainfall during February through April when another 9.8 inches can be expected. These cold fronts result in an average of 5 freezing days per year (1892-2006) but can range up to 24/yr (1920).

During the last century (1905-2005), a hurricane has passed within 65 nautical miles (nm) of the Weeki Wachee River at an average interval of 6.2 years. Table 2-2 and Figure 2-6 summarize the Category 1 or higher storms that have passed within 65 nm of Bayport during the past 100 years. Of particular note is the 27 year absence of activity between hurricane Gladys (10/1968) and hurricane Erin (8/1995).

Table 2-2
Hurricanes Passing within 65 Nautical Miles of Bayport Florida 1905-2005.

YEAR	DAY	NAME	WIND SPEED (KTS) (1)	Years Since Last
1910	18-Oct	Unnamed	70	5
1921	25-Oct	Unnamed	105	11
1925	1-Dec	Unnamed	65	4
1928	17-Sep	Unnamed	110	3
1933	4-Sep	Unnamed	110	5
1935	4-Sep	Unnamed	95	2
1944	19-Oct	Unnamed	65	9
1945	24-Jun	Unnamed	95	1
1945	16-Sep	Unnamed	110	--
1946	8-Oct	Unnamed	65	1
1949	27-Aug	Unnamed	100	3
1950	4-Sep	EASY	110	1
1950	18-Oct	KING	65	--
1960	11-Sep	DONNA	105	10
1968	18-Oct	GLADYS	70	8
1995	2-Aug	ERIN	75	27
2000	17-Sep	GORDON	65	5
2004	13-Aug	CHARLEY	125	4
http://maps.csc.noaa.gov/hurricanes/index.html				
(1) - Wind speed represents strength when center within 65 nm of Bayport				

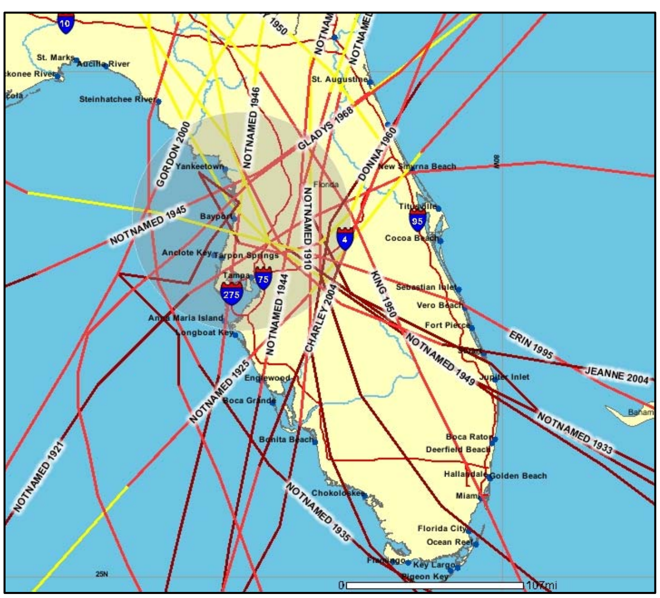
Figure 2-6
Hurricane Tracks near Bayport Florida 1905-2005

2.3 Flow and Hydrogeology (Adapted from Wolfe 1990 and Knochenmus & Yobbi 2001)

Florida as we know it is the emergent part of a land feature known as the Florida Platform that extends southward and separates the deep waters of the Atlantic from the deep waters of the Gulf. Throughout the ages, portions of this platform have been episodically submerged and emergent depending upon sea level. The near surface limestone and dolostone bedrock that underlies the platform was deposited approximately 55 (Eocene) to 15 (early Miocene) million years (my) ago when sea level was higher. The historical change in sea level gives rise to step-like terraces that progress from the shoreline to the interior.

The Weeki Wachee watershed lies largely in Palimico and Talbot terraces, while the springshed extends inland through several additional scarps. The near-Gulf terraces are part of a larger landform known as the Gulf Coastal Lowlands which includes land from the Gulf to an elevation of approximately 30 m above sea level. Further inland a prominent rise known as the Brooksville ridge begins approximately 45 km inland from the mouth of the Weeki Wachee River and extends eastward for an additional 50 km. Elevation of the southern portion of the Brooksville ridge ranges from 21 – 75 m above sea level.

The Spring Coast is a notable karst landscape, characterized by springs, sinkholes, and



undulating topography. Karst features are a result of repeated chemical dissolution and deposition of the underlying carbonate rock (upper Floridan aquifer) in response to fluctuations in sea level over geologic time. Density of karst features range from 10-25 /mi2 in the sand hill ridges of the Gulf Coastal Lowlands to 0-5 in the Brooksville Ridge. Enlarged pores (vugs) in the carbonate rock tend to concentrate groundwater flow leading to additional dissolution and/or fractures. The result is a coastline that is dominated not by surface runoff, but by discharge of groundwater. Within the Springs Coast there are five 1st order (>100 cfs), eight 2nd order (10-100 cfs) and four 3rd order (<10 cfs) named springs.

Spring discharge was estimated from water levels in Weeki Wachee well using procedures adapted from the USGS. The data, techniques and resultant discharge characteristics are discussed in the following sub-sections.

2.3.1 Discharge Estimates

The USGS has maintained two stations on the Weeki Wachee since 1917 as shown in Table 2-3. Discharge estimates are based a series of manual discharge measurements compared to water level in nearby Weeki Wachee well (283201082315601). Manual measurements include contributions from Weeki Wachee Springs, Little Springs, Unknown Spring Number 3 and flow from the bed of Little Springs run. Over the course of several decades additional manual discharge measurements were conducted by the USGS, and the relationship to static water level in the well has been updated periodically (D. Yobbi personal communication).

Table 2-3
Summary of USGS Gauges Near Weeki Wachee River

Name	Number	Location	History of Observations
Weeki Wachee Springs Near Brooksville Fl	02310500	spring pool	1917, 1929-30 - one discharge per year 02/1931 - 06/1966 - Discharge only 07/1966 - present - stage and discharge
Weeki Wachee River Near Brooksville Fl	02310525	1.3 km downstream from spring pool	10/1993 - present stage (Note - discharge measurements made ~1.6 km downstream of spring pool.
Weeki Wachee Well	283201082315601	~ 4.5 km NE of spring.	06/1966 -09/1974 - ~ 1 reading per 5.3 days 10/1974 - present - daily

In 2001, the USGS published a time series of 207 discharge measurements (Knochenmus and Yobbi 2001) along with the daily high stage in Weeki Wachee Well. Regressions were developed and compared for the following time periods: 1966-72, 1973-79, 1980-86, 1987-93 and 1994-98.   Figure 2-7 illustrates how these regressions varied by period. The variation was deemed minor and a period of record regression was developed as illustrated in Figure 2-8. [$Q = -47.487 + 12.38*WL$ $n=205$ $r^2_{adj} = 0.87$]

Figure 2-7
Weeki Wachee Flow / Water Level Regressions by Period

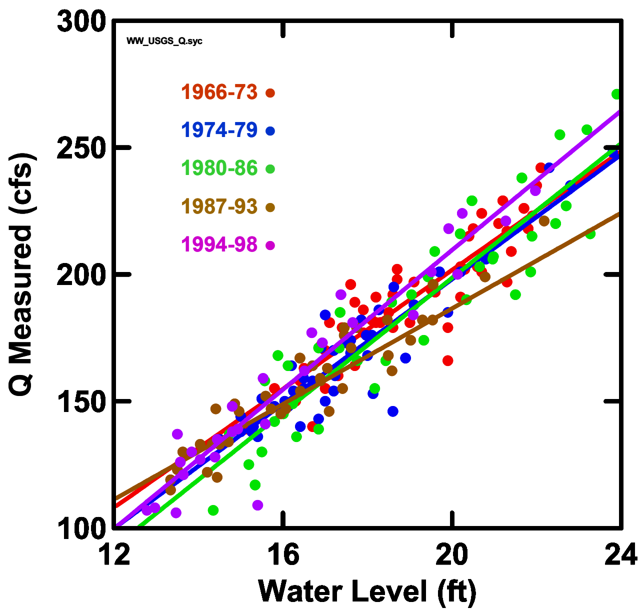
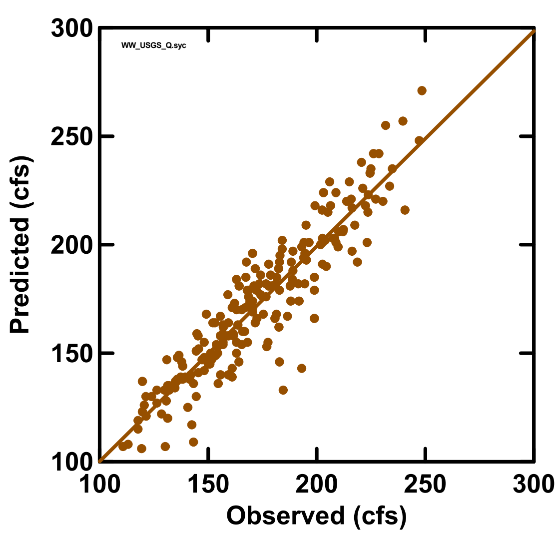


Figure 2-8
Observed vs. Predicted Flows Using All Data 1966-2004.



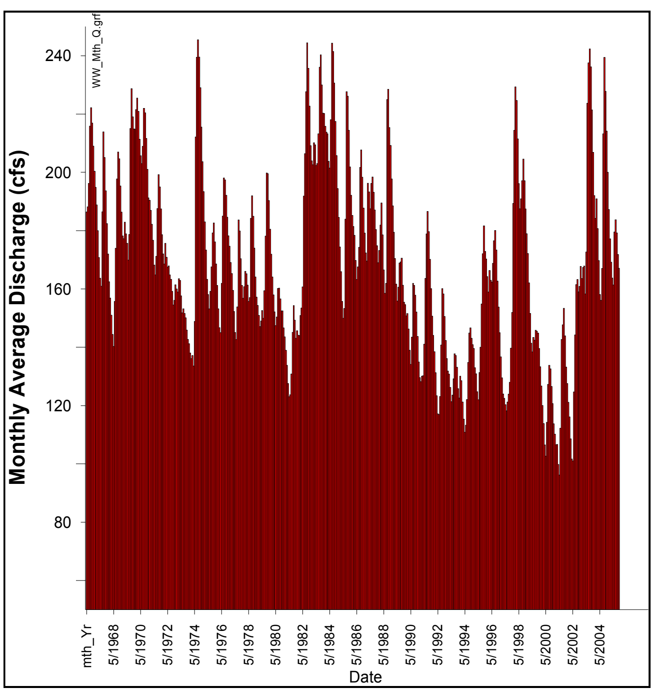
Next the Weeki Wachee Well water level record was interpolated to provide a complete daily estimate of water level for the period June 15 1966 through November 13 2005. Seventeen percent of the daily values were interpolated from before/after water levels, but virtually all of these occurred prior to 10/01/1974 when daily observations of water level commenced. The mean estimated discharge for the period of record (POR) is169 cfs with a standard deviation of 32 cfs.

Daily predicted discharges (1966-2005) are summarized by month in Table 2-4 which provided select percentile values and portrayed in Figure 2-9 as a time series of mean monthly discharge. Typically the maximum flows occur in September (median 185 cfs) through November (181 cfs) and the minimum flows occur in May (156 cfs) through July (158 cfs). Of particular note is the constancy of the flow as evidenced by a narrow range of median flows in May and September (ratio = 1.2) in contrast to runoff dominated rivers where orders of magnitude differences in monthly flows are the norm.

Table 2-4
Monthly Summary of Weeki Wachee Percentile Discharge (cfs) 1966-2005

MONTH	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	114	125	134	146	170	192	202	212	220
2	110	124	130	144	164	185	200	215	222
3	107	118	128	139	164	181	198	220	229
4	107	111	122	135	163	180	205	217	225
5	100	104	118	131	156	171	200	210	211
6	96	102	114	136	157	167	192	202	206
7	112	114	118	143	158	182	203	215	224
8	121	123	128	149	170	189	211	239	244
9	124	134	139	158	185	214	232	242	245
10	128	135	145	159	182	221	238	240	244
11	127	136	144	153	181	213	225	230	236
12	121	129	141	152	175	202	215	218	223

Figure 2-9
Mean Monthly Discharge (cfs) 1966-2005



2.3.2 Baseline Period

Figure 2-10 illustrates the daily cumulative distribution function of both the period of record values and the flow values on days when the river was sampled for water quality. The period 1984 through 2004 was selected as a recent and representative 20-yr period to serve as a baseline. Figure 2-11 compares the mean annual flows and tabulates the daily flow for the sampling days and the evaluation period and the days on which sampling occurred. The results presented in Figures 10 and 11 suggest that the period of record flow are well represented by both the sampling day flows and the 1984-2004 evaluation period.

Figure 2-10
Distribution of Daily Discharge (cfs) and Discharge on Sample Days

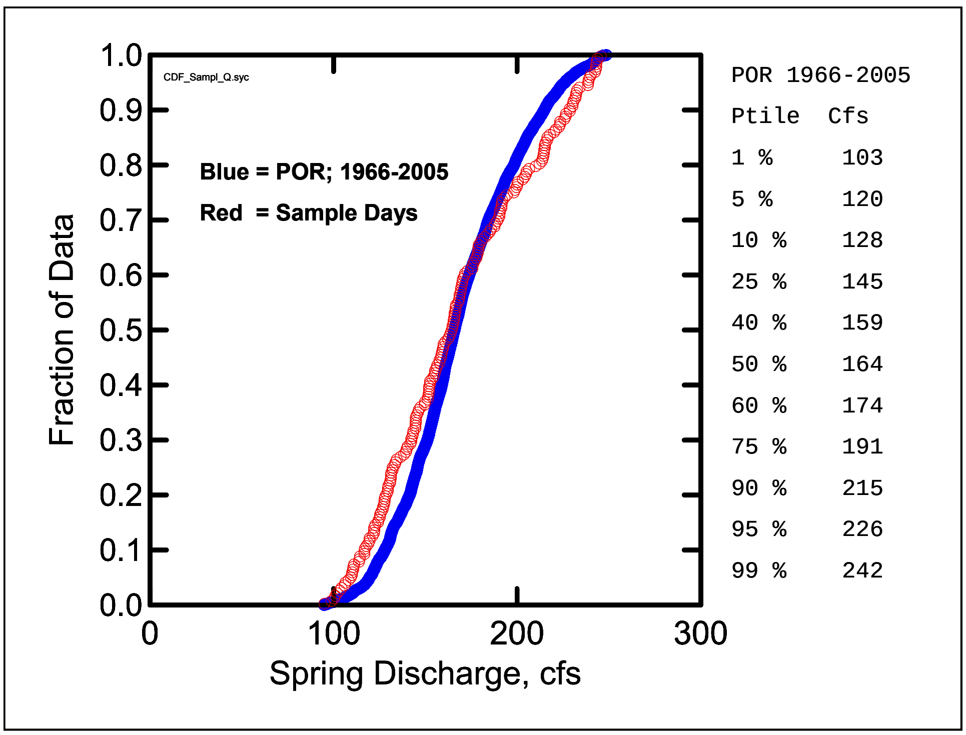
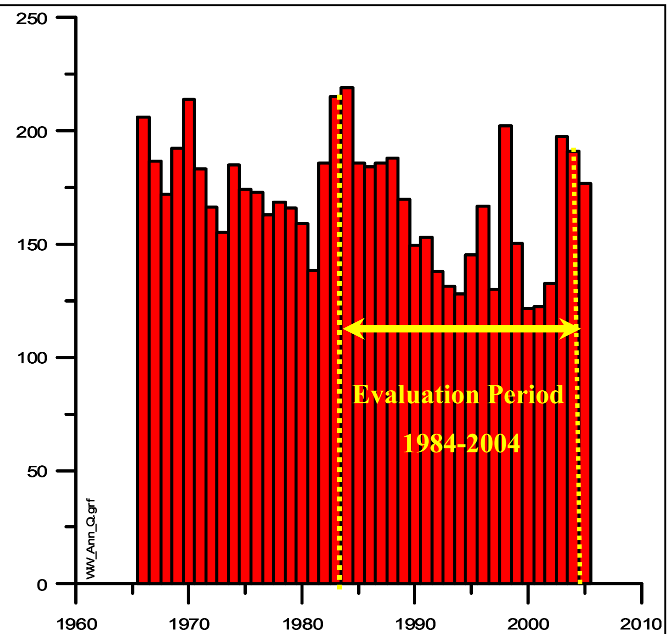


Figure 2-11
Flow Comparison - Baseline Period (1984-2004) to Period of Record (1966-2005)
Comparison of Sampling Days to Baseline Period

Daily Flow (cfs) Summary		
Percentile	Flow 1984-2004	Flow on Sample Dates
1	100	100
5	112	109
10	120	117
25	133	132
50	159	164
75	184	198
90	212	229
95	226	239
99	242	243



2.4 Historical Change in Discharge

There are no surface water withdrawals from the Weeki Wachee River. However, groundwater withdrawals can directly affect the flow. Discharge from Weeki Wachee has declined since 1960 based on a Kendall tau test ($p < 0.000$, $n = 45$) which is apparent in Figure 2-12. There has been a 63 cfs linear change since the 1960s, which was near the end of a wet Atlantic Multidecadal Oscillation (AMO) cycle and a period of unusually high flows throughout much of Florida and much of the decline in discharge is due to climatic changes. Following Kelly (2004), comparing the annual discharges[7] for the two most recent (apparent) cycles of the Atlantic Multidecadal Oscillation (AMO) there is a statistically significant (Mann –Whitney, $p < 0.03$) decline in flows between the 1940-1969 (mean and median =185 cfs) and the 1970 – 1999 period (mean= 168 cfs, median = 165). Both the monotonic Kendall tau (ktau) evaluation and the Mann-Whitney comparison of periods were statistically significant. Both anthropogenic and climatic factors are believed to be responsible for the recent declines. Annual rainfall was found to be positively related to discharge with a 1-year lag showing the highest correlation and significance (ktau $p<0.001$). Along with increased urbanization (Section 2.1.1), groundwater pumpage has increased in the area. Figure 2-13 provides a historical perspective of pumpage in the Weeki Wachee springshed. The increasing trend is statistically significant (Kendall tau) at the $p < 0.0000$ significance level. Annual pumpage was compared with annual spring discharge and an inverse relationship was

[7] Annual discharge values prior to 1967 taken from District database.

found (ktau p=0.06) between total groundwater pumpage in the springshed and spring discharge at Weeki Wachee.

In order to better characterize the impact of pumpage, a LOWESS (reference) smooth of rainfall (as independent) and spring discharge (as dependent variable was conducted and the residuals (e.g the flow variation not accounted for by rainfall) were compared to pumpage. The resultant parametric and non-parametric correlations were all significant (Pearson p=0.03, rho p = 0.01 and ktau p= 0.02) but predictive power was low (r^2 =0.13). Subsequent statistical evaluations and integrated surface/groundwater modeling incorporating rainfall confirmed that existing groundwater withdrawals are having an impact on discharge from the Weeki Wachee spring.

Figure 2-12
Weeki Wachee Annual Flow

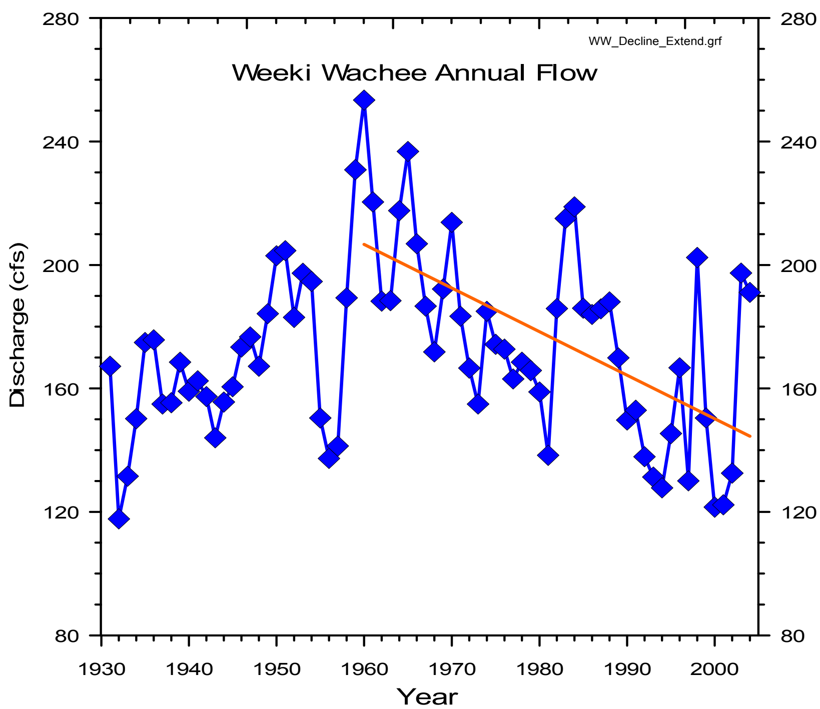
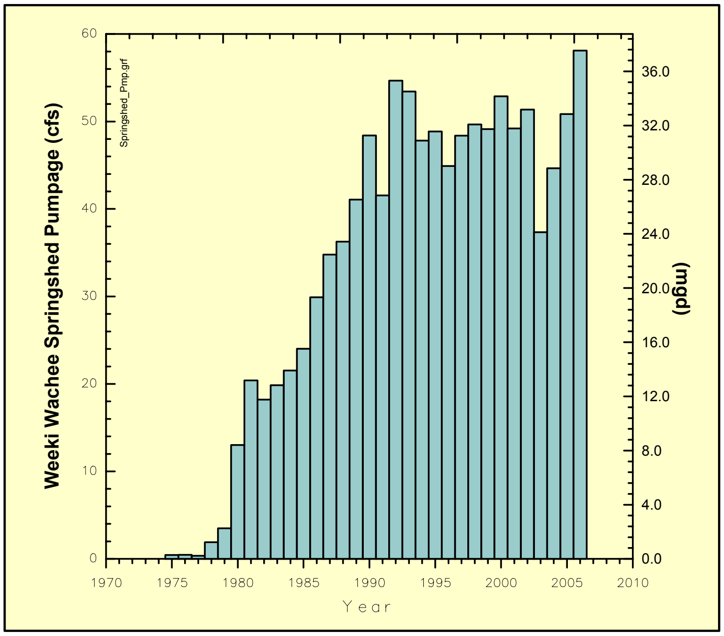


Figure 2-13
Weeki Wachee Springshed Pumpage



2.5 Corrections for Anthropogenic Impacts

As previously described (Chapter 1.6) a 'top-down' evaluation of a system MFL requires a base-line flow condition that is as free of anthropogenic impacts as possible. Three separate approaches were used to estimate human-induced loss of discharge. One approach is based on estimating unimpacted flows based on a regionally significant groundwater level (Sharpes Ferry Well located 93 km (58 mi) northeast from Weeki Wachee) that is believed to be un-impacted (reference approach). A second approach attempts to characterize and then remove the rainfall to discharge variation using wavelet analyses. Finally the third approach involved calibrating several groundwater flow models and then estimating what the discharge would have been in the absence of the groundwater withdrawals.

2.5.1 Reference Approach

The reference approach is an out-growth of resolving the Crystal Springs flow decline in which Munson et al. (2007) normalized annual discharge as z-scores (annual – period mean / period standard deviation) for a relatively un-impacted period for a reference watershed and a test watershed. Z-score analysis was used in an attempt to quantify anthropogenic affects on spring flow. If it can be assumed that rainfall has behaved similarly across the springsheds examined, then anthropogenic factors acting disproportionately between one springshed and another should show up as departures between plotted z-sores. Converting spring flows (or water well elevations) to z-scores allows a direct comparison between spring flows of different springsheds or water levels. In the absence of anthropogenic effects in the two watersheds, it might be expected that the normalized historic flows should be correlated. For example, flows for Weeki Wachee River, and Rainbow River were converted to z-scores using the mean and standard deviations for the period 1935 to 1965. The data were then plotted for the entire period of record with the assumption that the relationship between z-scores for the standardization period (1935 to 1965 in this case) should be maintained for other periods as long as other effects (e.g., anthropogenic withdrawals) did not vary among the periods examined. Any deviation represents the anthropogenic affect relative to the standardization period. To minimize reliance on a particular reference period, a number of different standardization periods (1935-65, 1945-65, 1951-63 etc) were evaluated and the strongest relationships were used (See Kelly et al. 2006 for examples). In application, the mean difference in z-scores of the non-reference period is converted back into flow by multiplying the difference by the standard deviation (in cfs) of the reference period.

Using the z-score approach, the estimated anthropogenic loss (relative to Rainbow River and 1951- 63 standardization period) is 11 cfs. A similar comparison with the Sharpes Ferry water level resulted in an estimated loss of 16.3 cfs.

2.5.2 Wavelet Analysis

Wavelet transformation of times-series discharge data was undertaken to reduce the short-term fluctuations for the period 1941 through 2004. The application is described in more detail in a technical memorandum by Schultz (2007) which is included as Appendix 2-1. The untransformed annual values and the wavelet filtered time series is given in Figure 2-14**.** Using the smoothed data as input to a regression model, Schultz analyzed the relationship to rainfall as a continuous variable and to the impact of pumpage as a categorical variable using a regression of the form:

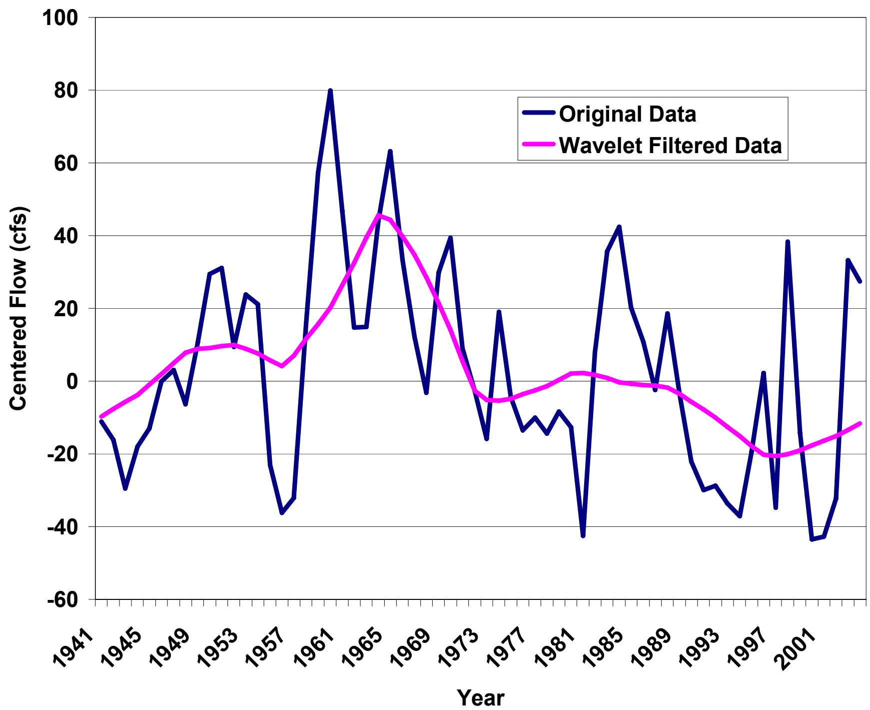
$$\text{Smoothed Discharge} = \beta_o + \beta_1 * \mathit{Rain} + \beta_2 * \mathit{Impact} + \varepsilon$$

"Impact" was defined as insignificant (= 0) or significant (=1) and was assumed to continue through time once the impact of withdrawals became significant.

The solution employed was to allow the regression model to determine the point at which pumpage impacts became significant. The initial run (1941-2004) assumed that all years were impacted. The second run assumed that years 1942 – 2004 were impacted. The third run assumed that years 1943 – 2004 were impacted etc until the point of impact was evaluated for all 64 starting points. F-test and r^2 results were compared. Same year (Lag_0), prior year (Lag_1) and rainfall from two years ago (Lag_2)

were similarly evaluated. Initial results were poor ($r^2 < 0.5$) and coefficients were inconsistent. These poor results led to further experimentation with the filtered data, and Schultz found that if the data from 1941 to 1950 were excluded, the results were notably improved.

Figure 2-14
Original Data s. Wavelet Filtered Data

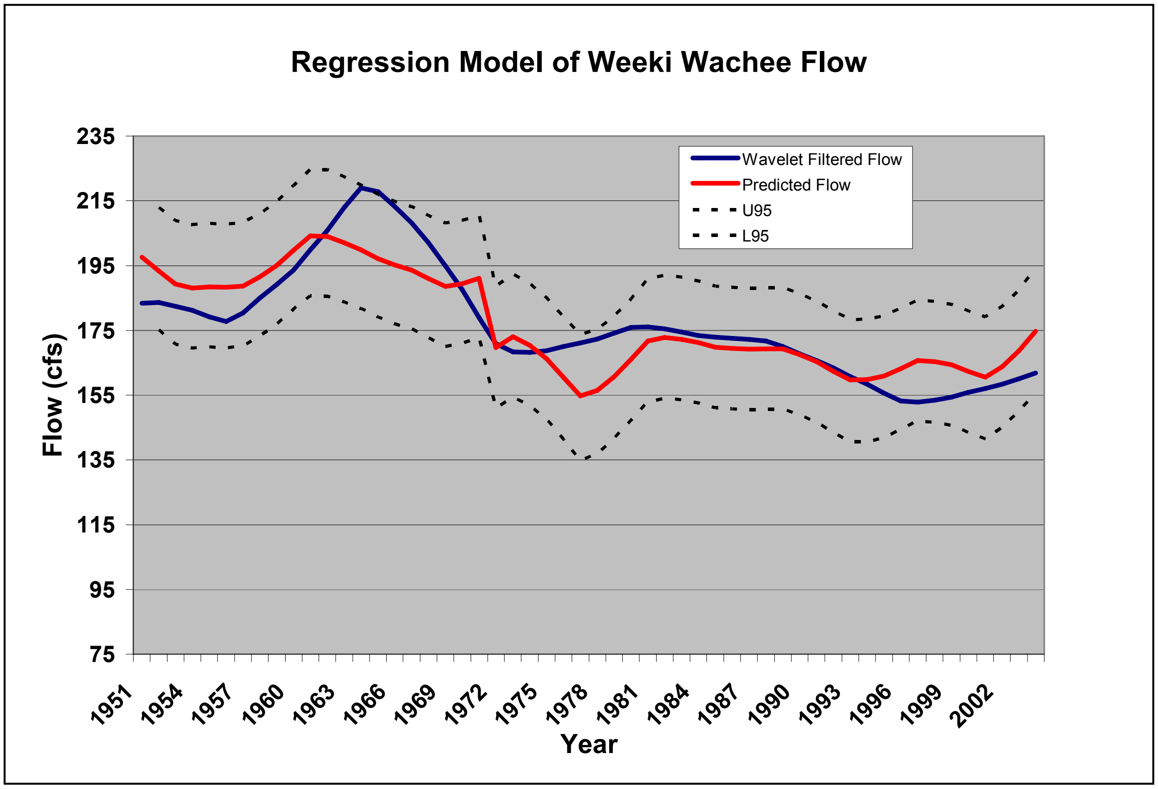


Subsequently, Schultz concluded that a) pumping impacts became significant during 1972, and b) the best estimator of wavelet smoothed discharge incorporated a 1-yr lagged rainfall of the form:

$$\text{Smoothed Discharge} = 123.4 + 1.3 * \text{Rainfall} - 25.5 * \text{Impact}$$

Thus, Impact = 0 up until 1972 and is equal to 1 beginning in 1972. The r^2 of the final model is 0.73. Schultz estimated the impact due to pumpage at a loss of 25.5 cfs. Figure 2-15 compares the wavelet filtered ("observed") discharge data with the flow predicted from the above equation.

Figure 2-15
Wavelet Filtered Discharge vs. Predicted Discharge



2.5.3 Groundwater Model Estimate

An estimate of anthropogenic impacts was derived by modeling discharge in the presence and in the absence of groundwater withdrawals. A number of regional groundwater flow models have included the Weeki Wachee Spring area. Ryder (1982) simulated the entire extent of the Southwest Florida Water Management District. In 1993, the District (SWFWMD, 1993) completed the Northern Tampa Bay groundwater flow model that covered a 2,000 square mile area of Hillsborough, Pinellas, Pasco, and Hernando Counties. In 2002, the USGS simulated the entire Florida peninsula in their Mega Model of regional groundwater flow (Sepulveda 2002). The most recent and advanced simulation of the Weeki Wachee Spring region and surrounding area is the Integrated Northern Tampa Bay model. The construction and calibration of this model was part of a cooperative effort between the SWFWMD and Tampa Bay Water, a regional water utility that operates 11 major wellfields in the area.

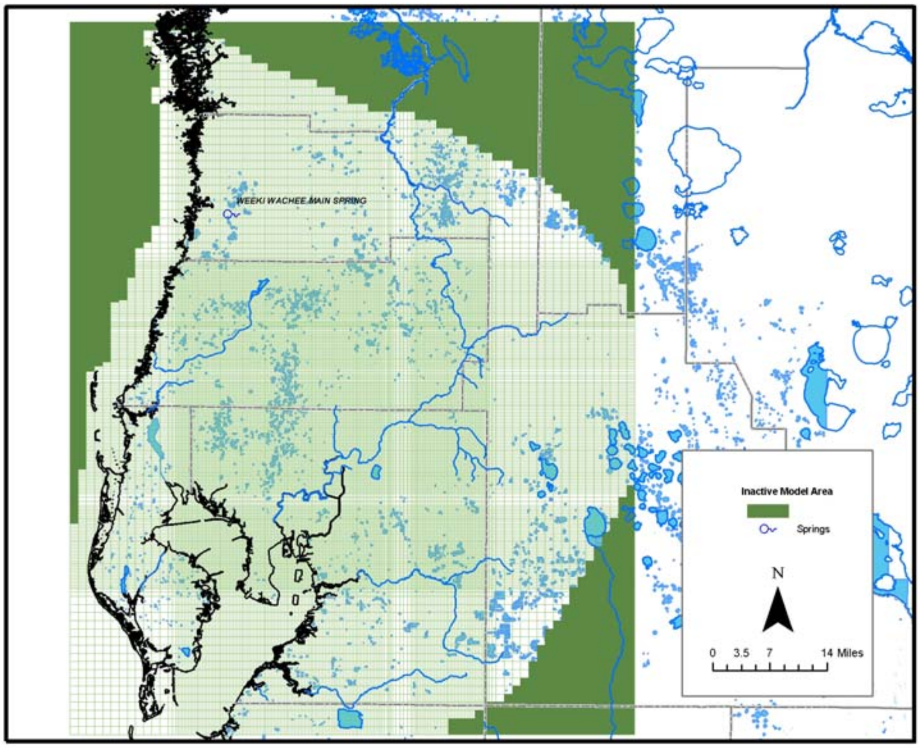
The Integrated Northern Tampa Bay (INTB) Model covers a 4,000 square-mile area of the Northern Tampa Bay region. Integrated models combine the traditional ground-water flow model with a surface water model and contain an interprocessor code that links both systems. One of the many advantages of an integrated model is that it simulates the entire hydrologic system. It represents the "state-of-art" tool in assessing changes due to rainfall, drainage alterations, and withdrawals. The model code used is called the Integrated Hydrologic Model (IHM) which combines the HSPF surface water code and the MODFLOW ground-water code using interprocessor software. More details on the application of this model to estimating declines in flow at Weeki Wachee can be found in Appendix 2-2.

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

The INTB was used to assess groundwater impacts resulting from groundwater withdrawals from 110 mgd pumpage within the Northern West-Central Florida Groundwater Basin (NWCFGWB) and 224 mgd pumpage from the Central West-Central Florida Groundwater Basin. The domain of the INTB model is shown in Figure 2-16 and the simulation period was 1993-1998. The model was adjusted to reflect recharge from septic tank leachate and for the non-consumptive groundwater withdrawals associated with mining limestone The results indicate that Weeki Wachee discharge was reduced by an average of 21.2 cfs over the five-year simulation period.

A second model (Northern District Model, NDM. Hydrogeologic, 2008) of even greater spatial extent (11,220 mi^2) was calibrated to steady-state 1995 and the results compared to pre-development conditions (zero withdrawals). Based on the impacts of the 1995 groundwater withdrawals (450 mgd) over the NDM domain, predicted reduction in the Weeki Wachee Springs discharge was 9.7 cfs.

Figure 2-16
INTB Groundwater Model Spatial Domain



2.5.4 Flow Adjustment

Table 2-5 summarizes the results of the three independent approaches. The average anthropogenic impact is seventeen cfs which was proportionally added (e.g. 0 cfs in 1961 up to 17 cfs in 2004) back to the observed discharge record in order to re-create baseline flow conditions as shown in Figure 2-17. (For the period 1984 through 2004, the median adjustment is 12.7 cfs.) Figure 2-18 reflects the five-year and ten-year moving averages of distributing impacts in this manner.

Table 2-5
Comparison of Flow Adjustment Evaluations

Basis	cfs
NDM	9.7
INTB with CWCFG + NWCFGW Basins	21.2
z score - Reference Rainbow River 1951-1963	11.0
z score - Reference Sharpes Ferry 1951-1963	16.3
Wavelet Filter Analysis	25.5
average	16.7

Tbl_ww_well_Est_Q.xls

Figure 2-17
Observed and Adjusted Flows

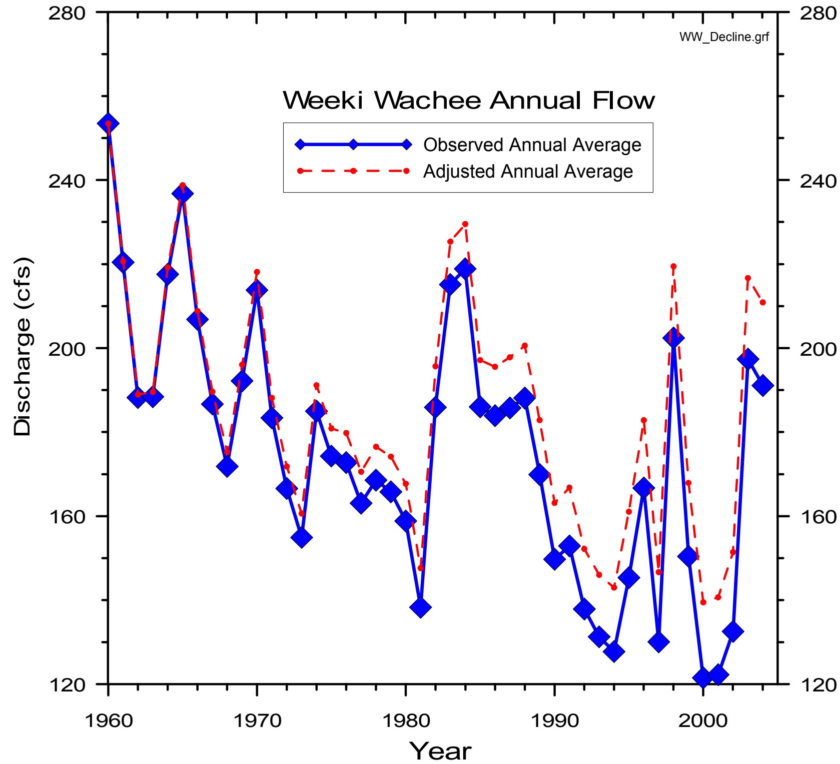
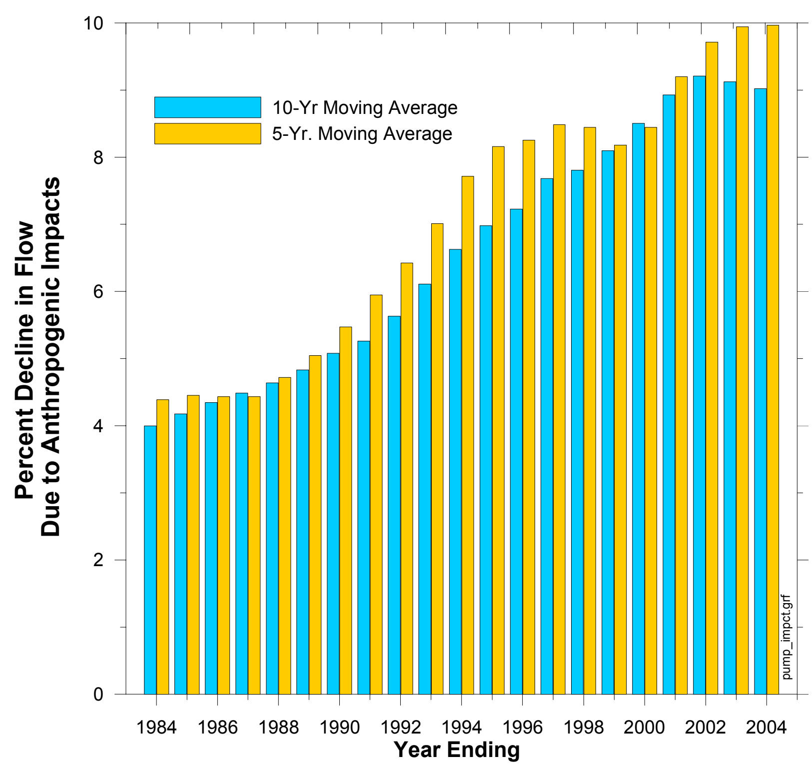


Figure 2-18
Estimated Percent of Anthropogenic Flow Declines.



2.6 Seasonal Blocks

As described in Chapter 1, the concept of "Block" seasons was adapted from earlier District work in the fresh-water rivers. The "building block" approach was initially suggested by the peer-review panel commenting on the District's proposed MFLs for the upper segment of the Peace River (Gore et al. 2002). The approach is "a way to more closely mirror original hydrologic and hydroperiodic conditions in the basin." Development of regulatory flow requirements using this type of approach typically involves description of the natural flow regime, identification of building blocks associated with flow needs for ecosystem specific functions, biological assemblages or populations, and assembly of the blocks to form a flow prescription (Postel and Richter 2003). As noted by the panelists comprising the Upper Peace River MFL review panel, "assumptions behind building block techniques are based upon simple ecological theory; that organisms and communities occupying that river have evolved and adapted their life cycles to flow conditions over a long period of pre-development history (Stanford et al. 1996). Thus with limited biological knowledge of flow requirements, the best alternative is to recreate the hydrographic conditions under which communities have existed prior to disturbance of the flow regime." Although in most cases, the District does not expect to recreate pre-disturbance hydrographic conditions through MFL development and implementation, the building block approach is viewed as a reasonable means for ensuring the maintenance of similar, although dampened, natural hydrographic conditions.

Available flow records were summarized and used to describe flow regimes for specific historical periods. Resource values associated with low, medium and high flows were identified and evaluated for use in the development of MFLs for each flow range. Low minimum flows, corresponding to maintaining instream flow requirements for fish passage and wetted perimeter were proposed. The methods focused on the inundation of desirable in-stream habitats and on floodplain wetlands. Implicit in this approach was the concept that the three ranges of flow (low, medium and high) were associated with specific natural system values or functions. For development of minimum flows and levels for the middle segment of the Peace River, the District explicitly identified three building blocks in its approach. The blocks correspond to seasonal periods of low, medium and high flows. The three distinct flow periods are evident in hydrographs of median daily flows for the river.

Since that peer review, the District has included Block seasons in all subsequent riverine MFL evaluations including the upper reaches of the Weeki Wachee River. Experience with runoff dominated fresh water rivers on the West Coast of Florida suggests the seasonal variations in discharge are fairly consistent across the rivers leading to a consistent definition of block periods. Lowest flows occur during Block 1, a 66 day period that extends from April 20 through June 25. Highest flows occur during Block 3, the 123 day period that immediately follows the dry season (June 26 through

October 26). This is the period when the floodplain is most likely to be inundated on an annual basis; although high flows can occur in early to mid-March. The remaining 176 days constitute an intermediate or medium flow period, which is referred to as Block 2 (see Figure 2-19). The resultant observed median flows and adjusted flows are provided in Table 2-6.

While seasonal variation is apparent and is generally consistent with that of nearby runoff dominated systems, the moderating effect of spring flow is evident in that the Weeki Wachee exhibits significantly less range than runoff dominated rivers. While a 'wet season' is readily apparent in Figure 2-19, there is little difference in the median value of Blocks 2 and 3. Consequently, only Blocks 1 and 3 were further evaluated. Block 1 unadjusted median flow is 144 cfs. Block 3 unadjusted flow was 162 cfs. A 12.7 cfs pumpage adjustment was applied to the baseline period of 1984-2004 resulting in respective "adjusted" flows of 157 and 175 cfs.

Figure 2-19
Building Blocks for Development of Minimum Flows (Weeki Wachee 1984-2004)

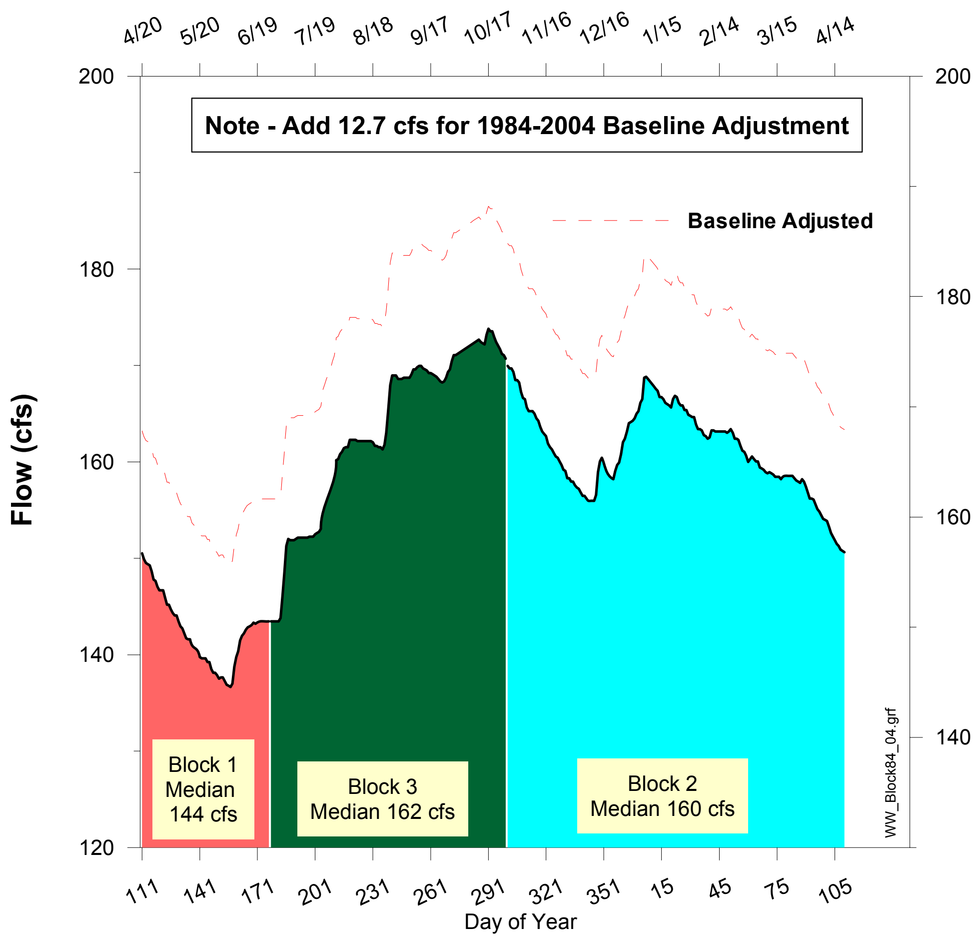


Table 2-6
Median (cfs) Flow by Blocks for Weeki Wachee River 1984-2004

Block	Begin	End	Observed Median	Adjusted Median
1	20-Apr	25-Jun	144	157
3	26-Jun	26-Oct	162	175
2	27-Oct	19-Apr	160	173

Tbl_ww_well_Est_Q.xls

2.7 Mud River Discharge

Unlike the Weeki Wachee River, discharge from the Mud River has not been systematically measured. Mote Marine Lab (1986) citing Roeseneau (1977) notes that the Mud River receives flow from Salt Springs (25-38 cfs) and the tidally influenced Mud Springs (range of flows 83-128 cfs) as well from an unnamed spring (5 cfs). Yobbi and Knochenmus (1989) report an average discharge of 30.6 cfs (range 25-92 cfs) measured at Salt Spring during 1961-75 (n = 11). Mud Spring averaged 52.0 cfs for the same period (n=11) with a range of 0-128 cfs.

Yobbi (1992) revisited the issue during 1988-89 (n= 5) and found a mean discharge of 45 cfs at Mud Spring (range -50.8 to +78.4 cfs). During the same period an additional 34 measurements were made at Salt Spring resulting in an average discharge of 33.4 cfs (range 27.7 to 40.4 cfs). The lack of a consistent long-term record of discharge hampers setting a site-specific MFL for these two springs. In consideration of these limitations, the MFL for the Weeki Wachee, expressed as an allowable percent reduction, will be applied to the Weeki Wachee estuarine system which includes Mud Springs and Salt springs as well as Twin Dees and Jenkin's Spring.

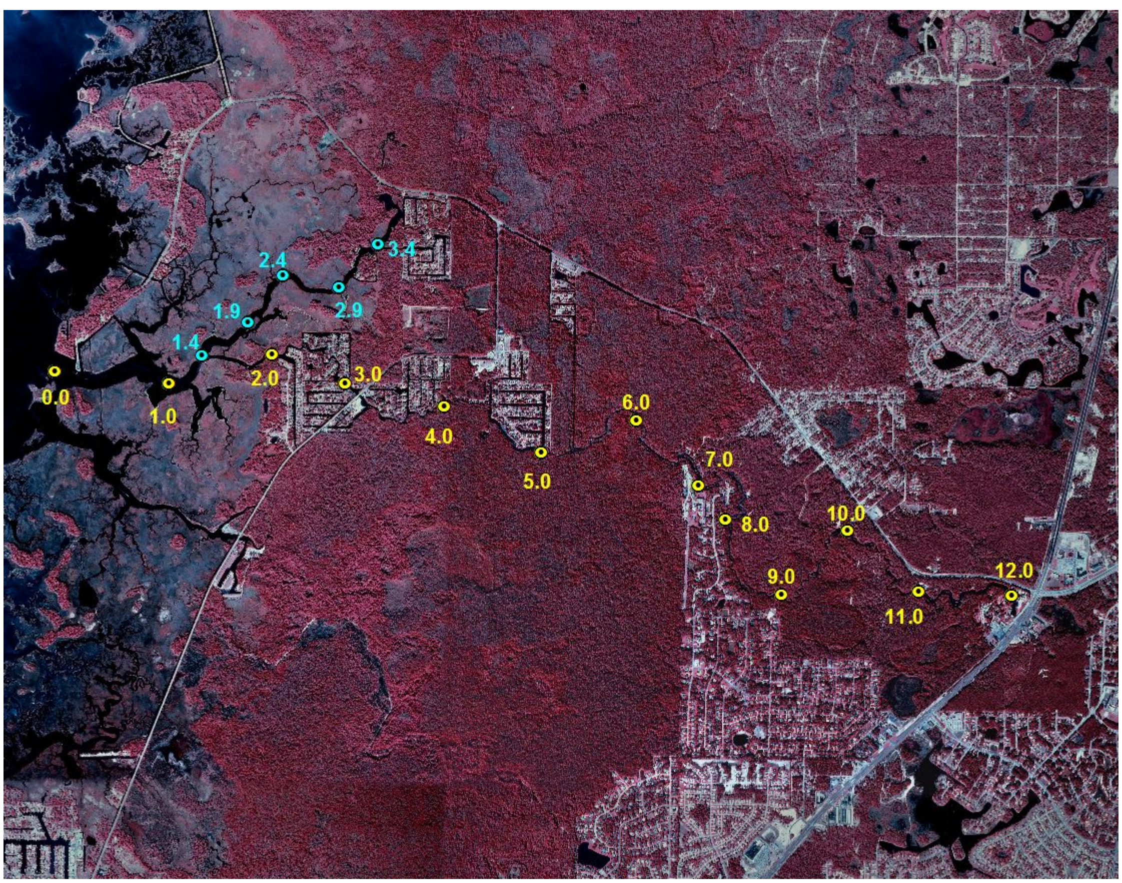
The discharges from these systems tend to be very saline. The mean chloride of Mud Spring was 8,000 mg/l during 1961-75, and an average conductivity of 21,000 µmho/cm was recorded during the 1988-89 monitoring. Salt Spring exhibited mean chloride of 900 mg/l during 1961-75 and a mean conductivity of 6,340 µmho/cm during 1988-89. The discharge of this highly saline water into the Mud River upstream results in a reverse-estuary.

CHAPTER 3 - ESTUARY CHARACTERISTICS
3.1 Physical

3.1.1 Linear

Weeki Wachee River meanders from the head spring near SR 50 approximately 13 km (8.1 mi) (Figure 3-1) to the confluence with the Gulf of Mexico at Bayport which is approximately 7.9 km (5.5 mi) straight line to the northwest. The freshwater portions are generally narrow (< 20 m, 66 ft), and the flow is swift. The width of the lower reach (<Rkm 1.3, 0.8 mi) is 60 m (ft). The tidal reach is the shortest of any river in southwest Florida, and tidal fluctuations extend to approximately 11 km (6.8 mi) upstream (Clewell et. al. 2002). Brackish water is generally limited to the lower 3 kms (1.9 mi). The Mud River joins the Weeki Wachee about 1.4 km (0.9 mi) from the Gulf and continues for an additional 2.5 river kilometers (1.6 mi) to the headspring. (Straight line distance from the spring to the confluence is 1.9 km (1.2 mi).

Figure 3-1
River Kilometer System



Surface waters in this stretch of the coast are also affected by several forcing functions (Wolfe 1990) not exerted on inland waters. Winds play a major role in setting up circulation on the shallow coast, resulting in a net long-term movement of coastal waters north and west during late spring, summer and early fall. In contrast during the winter months a net circulation to the south and east results from the winds associated with passage of cold fronts. Short-term convective on-shore /off-shore forcing functions characterize the summer months.

3.1.2 Area / Volume

Distance upstream from the Gulf (as defined by the SWFWMD GIS basin boundary closure across the river) is illustrated in Figure 3-2. High resolution (typically 50 -150 meter transects) bathymetry referenced to NGVD29 was prepared, and a standard river kilometer was assigned to the mid-point of each transect. Observations were converted to mean tide level (mean tide level = NGVD + 0.59 ft) using an average of the NOAA tidal benchmarks within a 25-mile radius (Table 3-1). Mean cross-sectional areas were developed for each transect. The volume between adjacent transects was calculated and a line of organic correlation (LOC) fitted to the cumulative volume and area as a function of river kilometer (Figure 3-3). Correlations were limited to river kilometers less than 5 to improve the fit, and because there is only one bottom salinity observation available above Rkm 4.6 (See Figure 4-6)

Figure 3-2
Location of bathymetric survey transects.

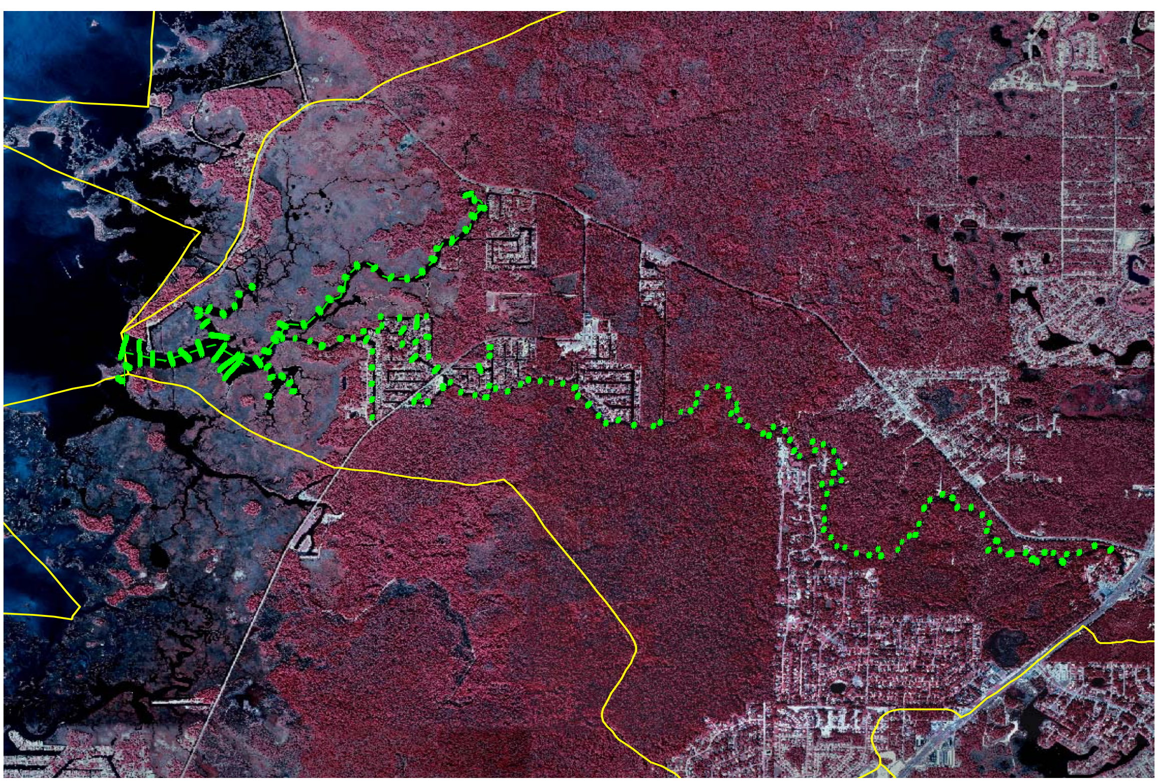
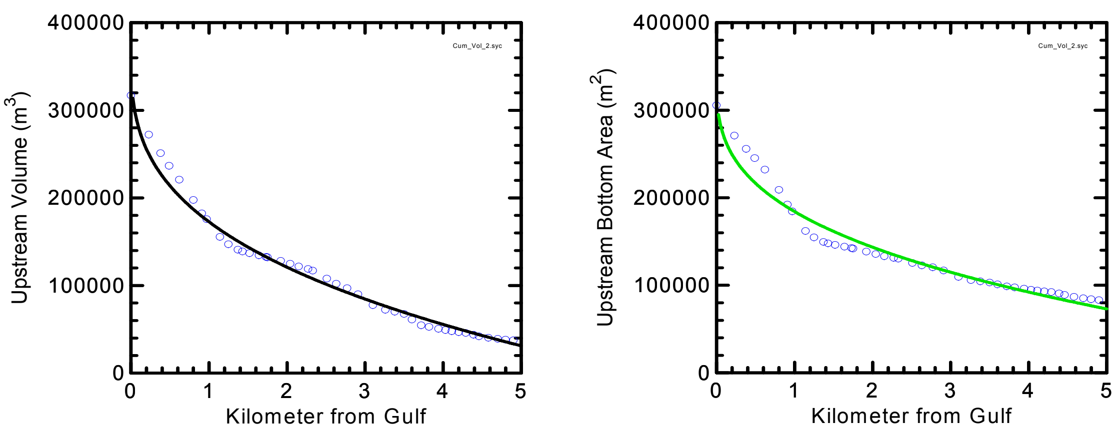


Table 3-1
Bayport (28^o 32.0' N 82^o 39.0' W) Tidal Benchmarks

PID	Station	Lat	Long	MTL NGVD (ft)
AL6198	8726905	28.16000	-82.76750	0.64
AL0743	8726853	28.09889	-82.77278	0.57
AL6619	8726892	28.14889	-82.75694	0.61
AL0303	8726892	28.14556	-82.75667	0.61
AL6197	8726905	28.16000	-82.76750	0.64
AL6199	8726905	28.16000	-82.76750	0.64
AL0060	8726906	28.15389	-82.74000	0.62
AL0059	8726906	28.15667	-82.74000	0.62
AL0301	8726908	28.16333	-82.75694	0.63
AL6624	8726908	28.16361	-82.75694	0.59
AL0402	8726908	28.15667	-82.75694	0.59
AL6626	8726924	28.17222	-82.78333	0.49
AL6628	8726924	28.17167	-82.78472	0.49
AL0061	8726924	28.15500	-82.74000	0.85
AL6627	8726924	28.17444	-82.78528	0.49
AL7357	8726924	28.17222	-82.78194	0.49
AL7358	8726924	28.17167	-82.78278	0.49
AL7359	8726924	28.17222	-82.78333	0.50
			Mean --->	0.59
			Range --->	0.36

Figure 3-3
Cumulative Upstream Volume and Area vs. River Kilometer

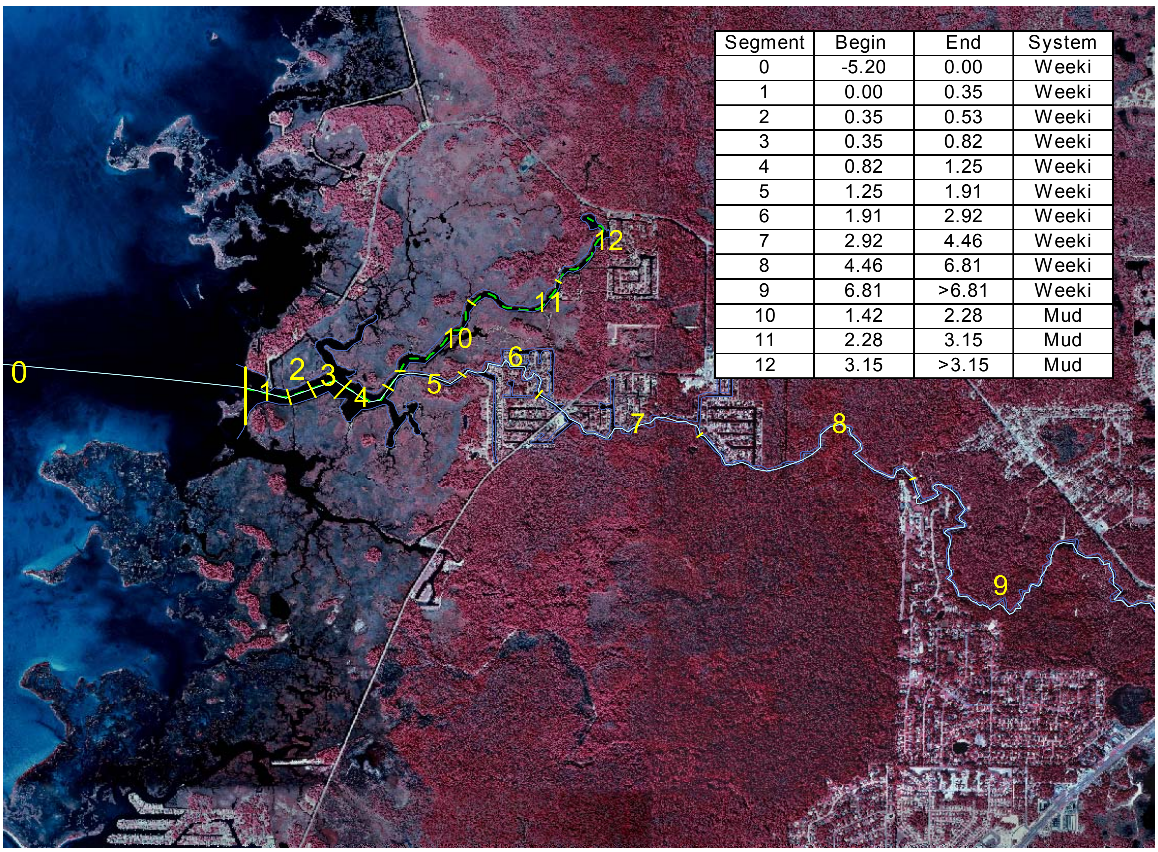


Volume = 372,095–199,442*(km^0.3333) / n =43 r^2 = 0.970
Area = 340,748–156,607*(km^0.3333) / n = 43 r^2 = 0.948

3.1.3 Segmentation

Segmentation was loosely based on cumulative river volumes (see prior section) from the respective headwater springs (Weeki Wachee and Mud Springs). The smoothed curves were used to estimate the river kilometers representing 10 equal volumes. This preliminary segmentation scheme was then converted to a GIS layer and overlain with the locations of the water quality stations. Segment boundaries were adjusted to more evenly distribute the number of stations within the segments. The final segmentation scheme is given within Figure 3-4.

Figure 3-4
Weeki Wachee and Mud River Segmentation Scheme



Segment	Begin	End	System
0	-5.20	0.00	Weeki
1	0.00	0.35	Weeki
2	0.35	0.53	Weeki
3	0.35	0.82	Weeki
4	0.82	1.25	Weeki
5	1.25	1.91	Weeki
6	1.91	2.92	Weeki
7	2.92	4.46	Weeki
8	4.46	6.81	Weeki
9	6.81	>6.81	Weeki
10	1.42	2.28	Mud
11	2.28	3.15	Mud
12	3.15	>3.15	Mud

3.2 Sediments & Bottom habitats

The lower portions of the river have a submerged aquatic vegetation (SAV) community which has been recently characterized by Estevez and Leverone (2005). This survey was limited to approximately 2.5 km (1.6 mi) from the mouth, but previous reports by Matteson (1995), Frazer (2001) and Clewell et al. (2002) describe the bottom vegetation from the Gulf to the head spring where fresh-water SAV is prevalent. Freshwater species include *Hydrilla verticillata*, *Najas guadalupensis*, *Vallisneria americana* and *Sagittaria kurziana,* and the algae *Lyngbya* sp. and *Chaetomorpha* sp. (Frazer et al., 2001; Clewell et al*.,* 2002). Earlier surveys by Mattson (1995) reported the presence of *Ruppia maritima, Chara sp., Myriophyllum spicatum, Valliserneria Americana* and *Hydrilla verticillatta* at Rkm 0.5 (0.3 mi), which was the most upstream station evaluated.

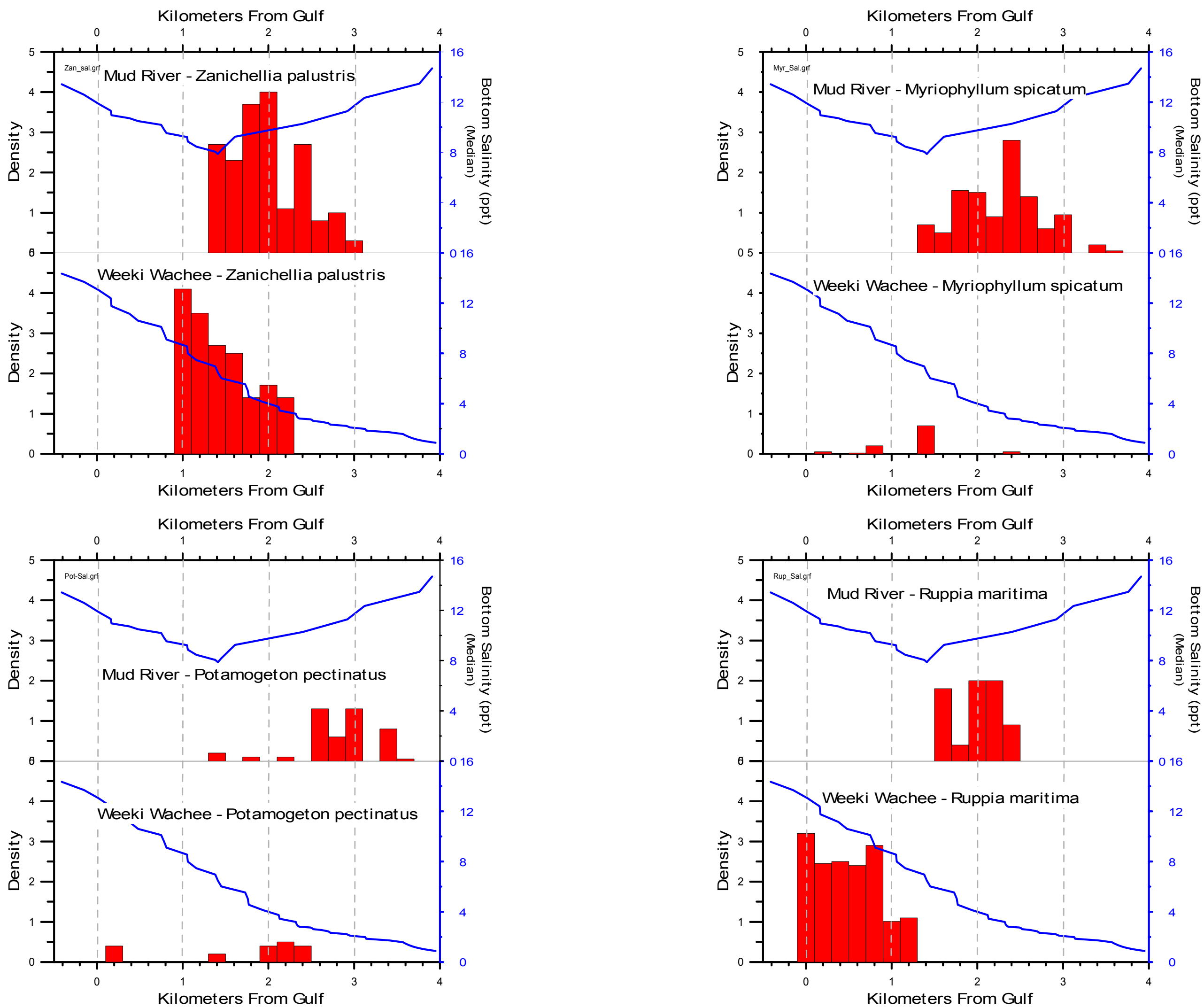
More recent data focused on the estuarine portion was desired and during 2005, Estevez and Leverone conducted twenty-six transects in the Mud and Weeki Wachee rivers on May 17, 2005. Surface salinity ranged from 0 – 7 ppt. The Mud (thirteen transects) was sampled from the sink at Rkm 3.8 (2.4 mi) to the confluence with Weeki Wachee, while the Weeki Wachee was sampled at thirteen transects from Rkm -0.5 to 2.4 (-0.3 to 1.5 mi). Bottom vegetation was quantified using standard Braun-Blanquet rapid survey technique to assess frequency, abundance and density from the results of up to ten 1 m^2 quadrats along each transect. The following scale was used to assess coverage, and the following metrics derived from the results. The results are summarized in Appendix 3-1.

A total of 8 taxa were collected: *Hydrilla verticellata*, *Myriophyllum spicatum*, *Najas guadalupensis*, *Potamogeton pectinatus*, *Ruppia maritima*, *Sagittaria kurziana*, *Vallisneria americana*, and *Zanichellia palustris*. Species richness was relatively high for vascular species, and the highest species number occurred in the Mud River, from Rkm 1.4 to 3.0 (0.9 – 1.9 mi).

Two species occurred over the full range of stations in both rivers– *Potamogeton* and *Myriophyllum*. *Ruppia* occurred in the lower Mud and lower Weeki Wachee rivers but was not collected in the Weeki Wachee upstream of the Mud River's confluence at Rkm 1.4 (0.9 mi). *Zanichellia*, or horned pondweed, had the most interesting distribution for it was not found in the lower or upper reaches of either river; its distribution was centralized near and upstream of the river juncture. Physical and chemical conditions of each river near the limits of *Zanichellia's* range may be informative in terms of defining this important species' environmental requirements. Figure 3-5 portrays the distribution of SAV from this sampling effort. Superimposed is the median bottom salinity for the period 1984-2005[8].

[8] Note – The water quality period of record is slightly longer than the adopted baseline period in order to incorporate recent systematic sampling by the District.

Figure 3-5
Dominant SAV and Median Bottom Salinity 1984-2005.

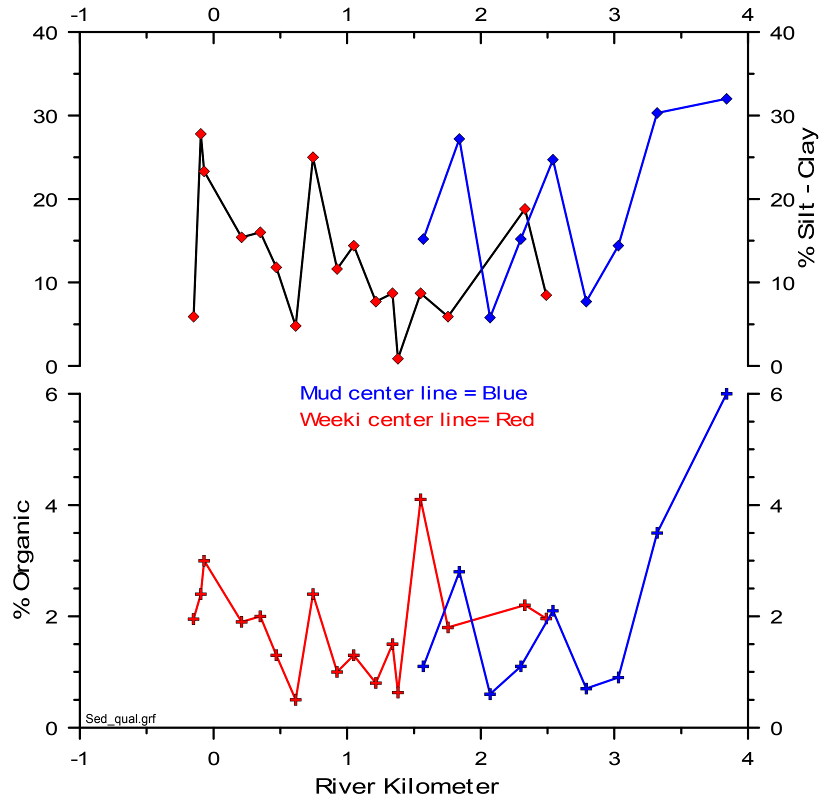


Limestone outcropping are exposed throughout the system, but characterization of sediments in the Weeki Wachee and Mud Rivers appears to be limited to those samples collected in association with benthic community analyses. Coulter (1986) included 1984 sediment analytical results for four stations, and Janicki Environmental (2006) reported 2005 results for six sites in the Weeki Wachee and five sites in the Mud River. The results of both studies are summarized in Table 3-2 and Figure 3-6. The higher velocities and resultant scour in the Weeki Wachee account for the lower fraction of finer material and also the differences between left and right bank in areas prone to sedimentation.

Table 3-2
Results of Weeki Wachee Sediment Analysis

			% Organic			%Silt/Clay			Mean phi		
Year	Station	Std_Km	north	center	south	north	center	south	north	center	south
1984	10	-5.73	1.0	1.0	0.9	2.2	1.7	1.6	2.7	2.5	2.7
1984	7	-0.15	1.6	2.0	2.2	3.4	5.9	4.4	2.7	2.7	2.8
2005	L00	-0.10	--	2.4	3.9	--	27.8	19.2	--	2.9	2.5
2005	L01	-0.07	3.2	3.0	--	26.2	23.3	--	2.8	2.7	--
2005	L02	0.21	--	1.9	4.3	--	15.4	26.6	--	2.6	2.8
2005	L03	0.35	2.3	2.0	--	20.3	16.0	--	2.7	2.6	--
2005	L04	0.47	--	1.3	2.3	--	11.8	24.5	--	2.0	2.8
2005	L05	0.62	23.0	0.5	--	32.7	4.8	--	2.8	2.6	--
2005	L06	0.75	--	2.4	1.2	--	25.0	18.1	--	2.9	2.8
2005	L07	0.93	2.0	1.0	--	24.3	11.6	--	2.8	2.7	--
2005	L08	1.05	--	1.3	2.2	--	14.4	24.7	--	2.8	2.8
2005	L09	1.22	7.3	0.8	--	30.7	7.7	--	3.0	2.4	--
2005	L10	1.34	--	1.5	2.2	--	8.7	8.4	--	2.4	2.4
1984	4	1.38	1.8	0.6	0.7	2.0	0.9	0.7	2.4	2.5	2.6
2005	U01	1.55	2.1	4.1	--	16.6	8.7	--	2.8	2.3	--
2005	U02	1.76	--	1.8	6.6	--	5.9	28.7	--	0.7	2.7
2005	U03	1.96	2.3	--	18.6	18.9	--	20.8	2.4	--	1.7
2005	U04	2.18	12.1	--	1.6	27.2	--	14.0	2.6	--	2.6
2005	U05	2.33	1.9	2.2	--	19.0	18.8	--	2.3	2.3	--
1984	1	2.49	2.1	2.0	2.7	11.0	8.5	11.1	2.5	2.6	2.8
2005	R01	1.57	--	1.1	--	--	15.2	--		2.6	--
2005	R02	1.84	--	2.8	--	--	27.2	--		2.9	--
2005	R03	2.07	--	0.6	--	--	5.8	--		2.3	--
2005	R04	2.30	--	1.1	--	--	15.2	--		2.7	--
2005	R05	2.54	--	2.1	--	--	24.7	--		2.8	--
2005	R06	2.79	--	0.7	--	--	7.7	--		2.1	--
2005	R07	3.03	--	0.9	--	--	14.4	--		2.2	--
2005	R08	3.32	--	3.5	--	--	30.3	--		2.8	--
2005	R09	3.84	--	6.0	--	--	32.0	--		2.9	--

Figure 3-6
Sediment Characteristics – Weeki Wachee and Mud Rivers



3.3 Tidal Wetlands & Riparian Habitats

The shoreline of the Weeki Wachee was characterized along with six other rivers on the west coast of Florida by Clewell et. al. (2002) in a study designed to compare vegetation distribution and salinity across multiple systems. Field studies were conducted in 1989 and 1990 and compared to long-term salinity records. The field collection was oriented to describing the distribution of herbaceous plants (including dominant marsh species) along the riverbank. Presence / absence was recorded for each plant species. A total of forty-one sites were investigated along the Weeki Wachee River, and nineteen species were identified as shown in Table 3-3.

Using data from all seven rivers, Clewell noted several potential vegetation breaks and postulated the question '*Do these break points correlate with sufficient precision across rivers with regard to salinity to make them useful as ecological indicators of the salinity regime?*' After analysis, the authors concluded '*For these reasons, breaks in vegetation that seem apparent as one travels by boat may be indicative of general salinity conditions but are not reliable as predictors of specific salinity regimes.*'

Table 3-3
Percentage of Weeki Wachee Sites Where Species Occurred

Species	**Percent of Occurrence**
Juncus roemerianus	67
Ruppia maritime	53
Spartina alterniflora	49
Cladium jamaicense	37
Typha domingensis	30
Sagittaria subulata	14
Magnolia virginiana	14
Acrostichum danaeifolium	9
Sagittaria lancifolia	7
Vallisneria Americana	7
Sabal palmetto	5
Distichlis spicata	5
Crinum americanum	2
Scirpus californicus	2
Baccharis halimifolia	2
Persea palustris	2
Liex cassine	2
Baccharis angustifolia	2
Aster subulatus	2

(Clewell.xls)

The distribution of shoreline vegetation along the Weeki Wachee and Mud Rivers is provided in Figure 3-7**.** In consideration of the limitations reported by Clewell, superimposed on the vegetation map are the median bottom salinity values (1984-2005) by segment mid-point. Despite any apparent limitations, there is a notable vegetation demarcation visible in aerial photographs (Figure 3-8) which identifies the location of the extensive saltwater marsh system. Table 3-4 provides quantification of the wetland and shoreline vegetation within a 500 meter buffer of the Weeki Wachee and Mud Rivers.

Figure 3-7
Shoreline / Buffer Vegetation – Weeki Wachee and Mud Rivers

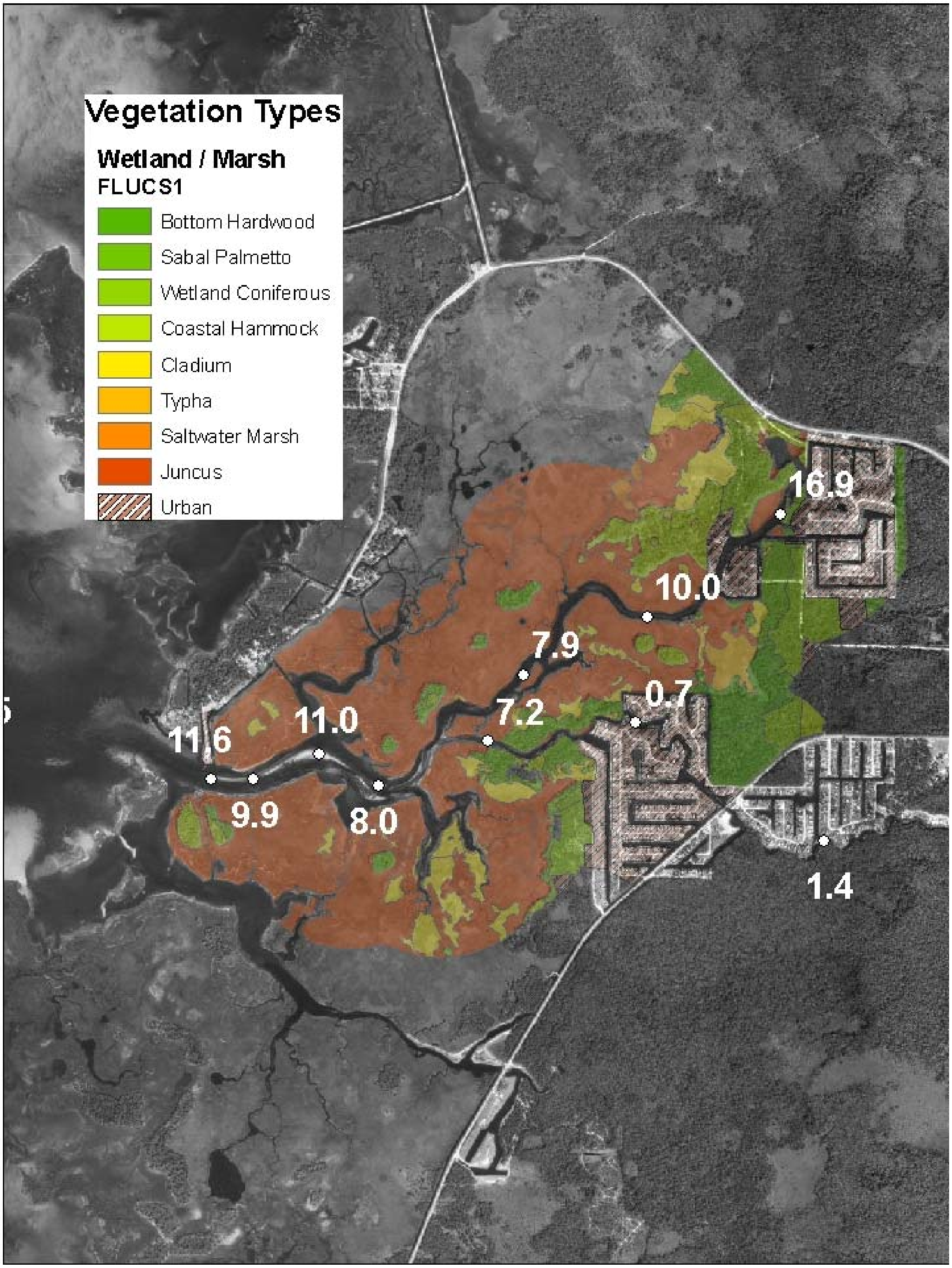


Figure 3-8
Aerial Photograph Illustrating Marsh Edge – Weeki Wachee and Mud Rivers.

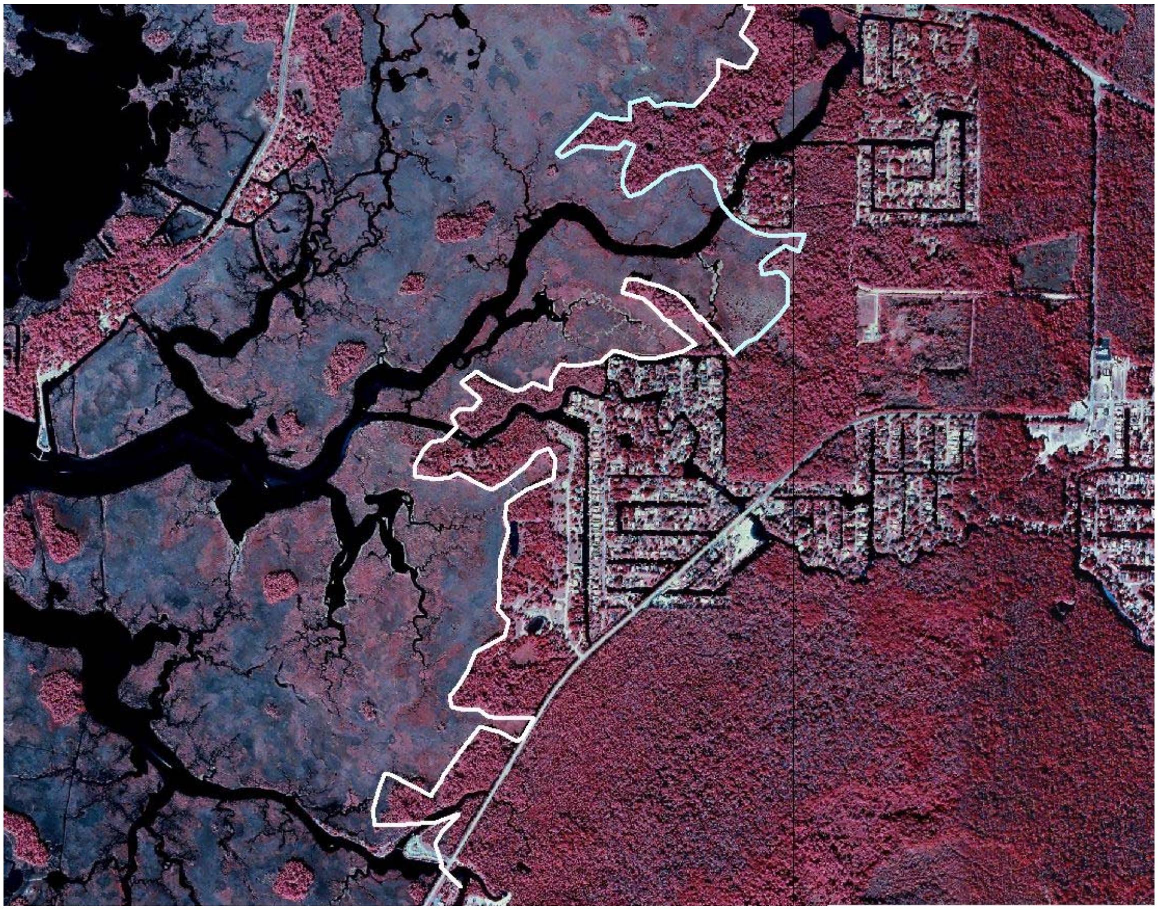


Table 3-4
Wetland and Shoreline Vegetation Within 500 meters

	FLUCS	Acres
Juncus	6422	515
Urban	1000	141
Cladium	6411	66
Sabal_Palmetto	6180	63
Wetland_Coniferous	6200	56
Coastal_Hammock	6300	48
Bottomland_hardwood	6150	44
Typha	6412	13
Saltwater_Marsh	6420	3
Others (Spartina, Freshwater Marsh, Barren Land		3
Mud_weeki_buffer_merged.xls	Total =	948

CHAPTER 4 - TIDE, SALINITY & WATER QUALITY

4.1 Tide

The tides along the Springs Coast are mixed semidiurnal. The USGS maintains a station at the mouth of the Weeki Wachee (02310600 – Gulf of Mexico at Bayport) that monitors surface and bottom temperature and conductivity as well as water level. Elevations (daily maximum and minimum) have been recorded since 1965. Water quality measurements were added in June 2003 and the logging interval of all parameters increased to 15-minutes. In addition, the USGS also maintains a gauge at a point 3.7 km upstream (0231053 - Weeki Wachee River at Weeki Wachee Springs).

Table 4-1 provides a summary of tidal fluctuations for 2001. Mean daily level is the average of all 15-minute daily recordings, while the range statistics represent daily extremes (higher high water minus lower low water). Figure 4-1 illustrates the lag between these two stations for March 2001. The year 2001 was an unusually low-flow (ranked second lowest 1967-2004) and discharge should have a minimal effect on gauge height. There is a predictable seasonal variation in mean sea level superimposed on local tides that has been characterized for Cedar Key (NOAA, 2001. Table B). March was chosen because the seasonal tide signal is minimal during March.

Table 4-1.
Comparison of Tide at Mouth and 3.7 Km Upstream

(Year = 2001, Units = ft)	Bayport	WW nr Spring
Mean Annual Stage	0.50	1.01
Average Daily Range	3.23	2.10
Median Daily Range	3.24	2.11
Maximum Daily Range	4.92	2.10
Minimum Daily Range	1.01	0.60

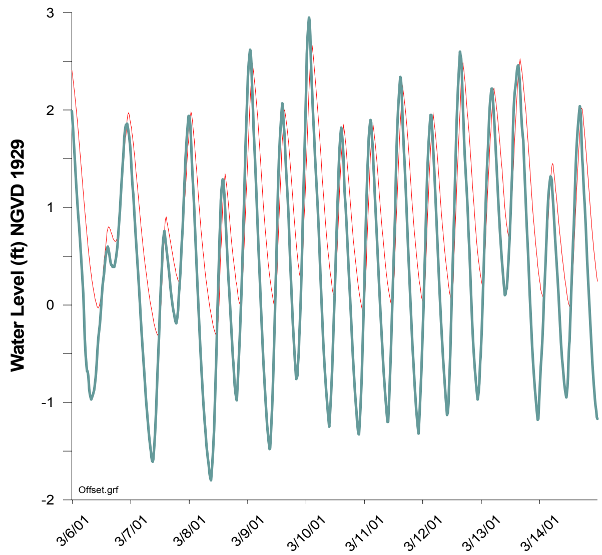
Upstream low tide occurs approximately 110 minutes later than at the mouth, and upstream high tide lags by approximately 50 minutes. Typical rate of tide change at Bayport is on the order of ± 0.24 ft/ hour.

Initially it was felt that the height of tide, along with flow would be a useful independent variable for predicting salinity. A regression model based on known tidal harmonic periods[9] (Table 4-2) was fit to the Bayport data, and the tide signal removed from the

[9] Periodic changes in water level of known frequency due to gravitational effects of sun and moon.

gauge height. Harmonics were developed from 2001 stage data because of the unusually low spring discharge (122 cfs) which minimizes water level changes.

Figure 4 -1.
Weeki Wachee Water Level at Mouth (green) and 3.7 km Upstream (red trace)



Regression coefficients for each harmonic period were developed for the following equation:

Gauge Height = $\beta_o + \beta_1 * \sin(2\pi*\text{Time} / M2) + \beta_2 * \cos((2\pi*\text{Time} / M2)) +$, [for M2]

$B_3 * \sin(2\pi*\text{Time} / S2) + \beta_4 * \cos((2\pi*\text{Time} / S2)) +$, [for S2]

etc.

$\beta_{23} * \sin(2\pi*\text{Time} / J1) + \beta_{24} * \cos((2\pi*\text{Time} / J1))$ [for J1]

Where Time is elapsed hours since 01/01/1900 00:00 AM and the principal semidiurnal and diurnal components have the following periodicity shown in Table 4-2.

Table 4-2
Principal Tide Harmonics

Name of Partial Tides	Symbol	Period (Solar Hours)
Semidiurnal Components		
Principal lunar	M2	12.42
Principal solar	S2	12.00
Larger lunar eliptic	N2	12.66
Lunisolar semidiurnal	K2	11.97
Larger solar elliptic	T2	12.01
Smaller lunar elliptic	L2	12.19
Diurnal Components		
Lunisolar diurnal	K1	23.93
Principal lunar diurnal	01	25.82
Principal solar diurnal	P1	24.07
Larger lunar elliptic	Q1	26.87
Smaller lunar elliptic	M1	24.84
Smaller lunar elliptic	J1	23.10

Two additional harmonic pairs were added to the diurnal and semidiurnal illustrated above. There is also predictable seasonal variation in mean sea level superimposed on local tides that has been characterized (Figure 4-2) for Cedar Key (NOAA 2001.). This cycle can be approximated with an annual period (8,766 hrs) as shown in Figure 4-3 which compares the long-term observed variation with that predicted from an annual harmonic. The final harmonic pair incorporated represents the lunar synodic month (708.7 hours). A complete list of harmonic coefficients is included in Appendix 4-1. Observed Bayport gauge height was regressed against the harmonics defined which resulted in an r^2_{adj} of 0.778 (n= 35,040). A comparison of observed and predicted tides for May 2001 is given in Figure 4-4.

Figure 4-2
Seasonal Variation in Mean Tide Level (NOAA 2001)

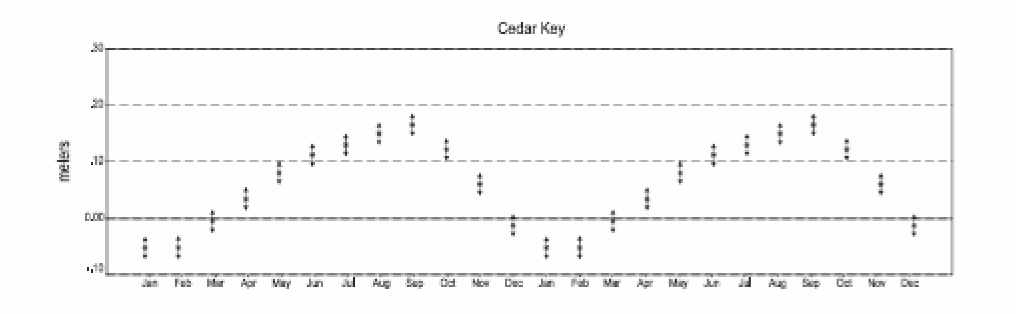
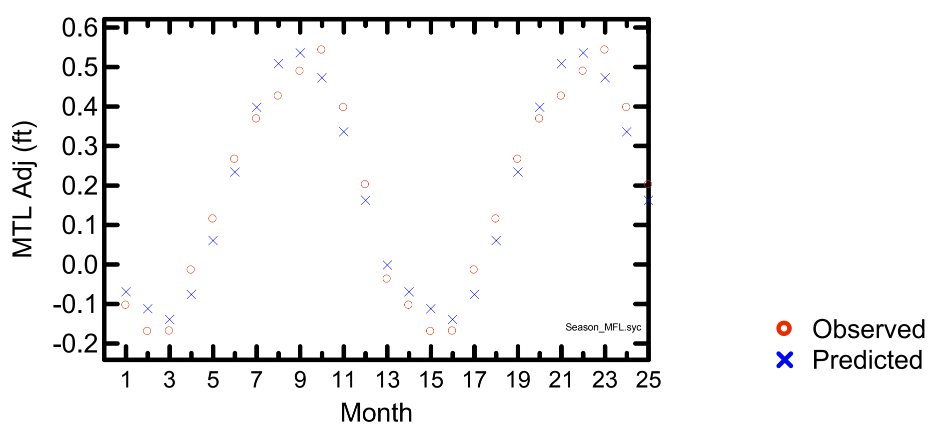


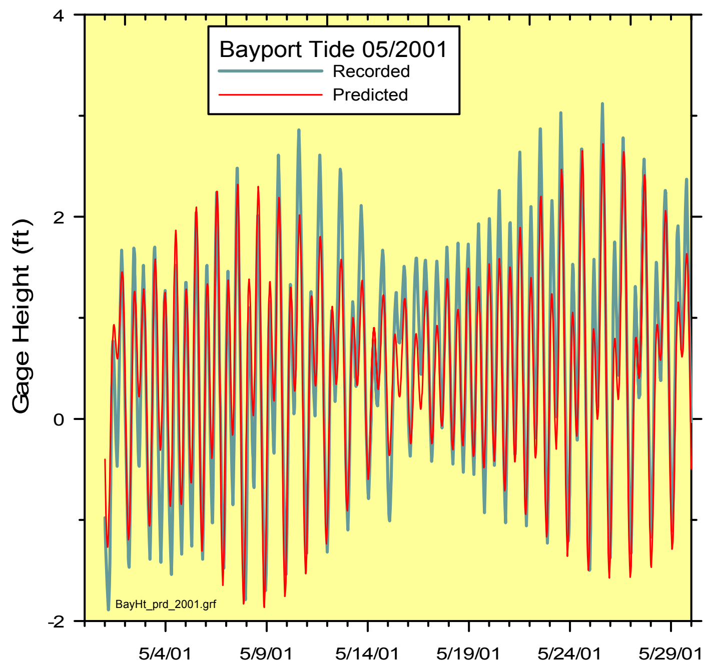
Figure 4-3
Observed and Predicted Deviations from MTL. Cedar Key, FL.



It should be noted that the predicted tides are for the mouth of the river (Bayport) and not at the point of sampling. As a gross measure of the degree of error introduced by this approach, the variation in observed tide at the upstream (Rkm=2.3) and downstream (Rkm=0) were plotted together (see Figure 4-1) for March 2001 and the lag estimated by digitizing the random peak times. The year 2001 was an unusually low-flow (122 cfs. Ranked 2nd lowest for 1967 – 2004) and March was chosen because the seasonal tide signal is minimal (see Figure 2) at – 4.4 mm. Potentially of more importance is the dampened upstream range in tidal amplitude. For 2001, the average daily tide range was 3.2 feet at Bayport, but only 2.1 feet upstream.

Thus, the approach of using predicted tide height at Bayport is imperfect and could be improved, it nevertheless was deemed acceptable as the first approximation of tide effect on salinity.

Figure 4-4
Bayport Tide, Observed and Predicted May, 2001.



4.2 Salinity

Salinity in the Weeki Wachee river system tends to be very low compared to the larger, runoff dominated rivers of the west coast of Florida. In addition, the transition from fresh water to near-Gulf strength salinity occurs very quickly which results in a compressed estuary. Figure 4-5 illustrates the median bottom salinity at fixed stations for the period 2003-2005 and the median salinity by segment for the period of record (1985-2005). Table 4-3 provides a summary of the median values. Figure 4-6 illustrates the number of observations by segment, and Figure 4-7 provides the distribution of salinity by segment (See section 4.2.1 for discussion of segmentation) which clearly illustrates the salinity compression. Several anomalies exist in both the longitudinal and the vertical pattern of salinity which is attributed to the various sampling schemes (some programs collected surface samples only) and variable flow over the decades. On the other hand, some of longitudinal anomalies are the result of the upstream discharge of saline water from Mud Spring at the head of the Mud River.

Figure 4-5.
Median Bottom Salinity at Fixed (yellow) Stations (2003-2005) and Segment (blue) Midpoints (1984-2005).

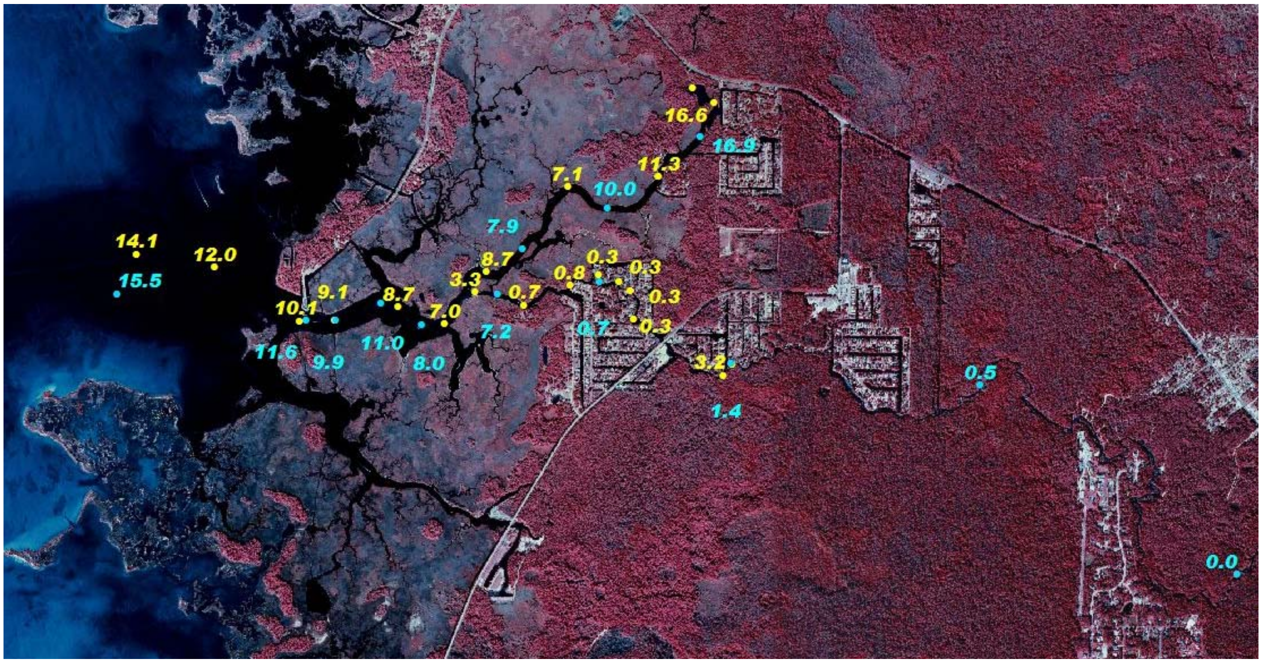
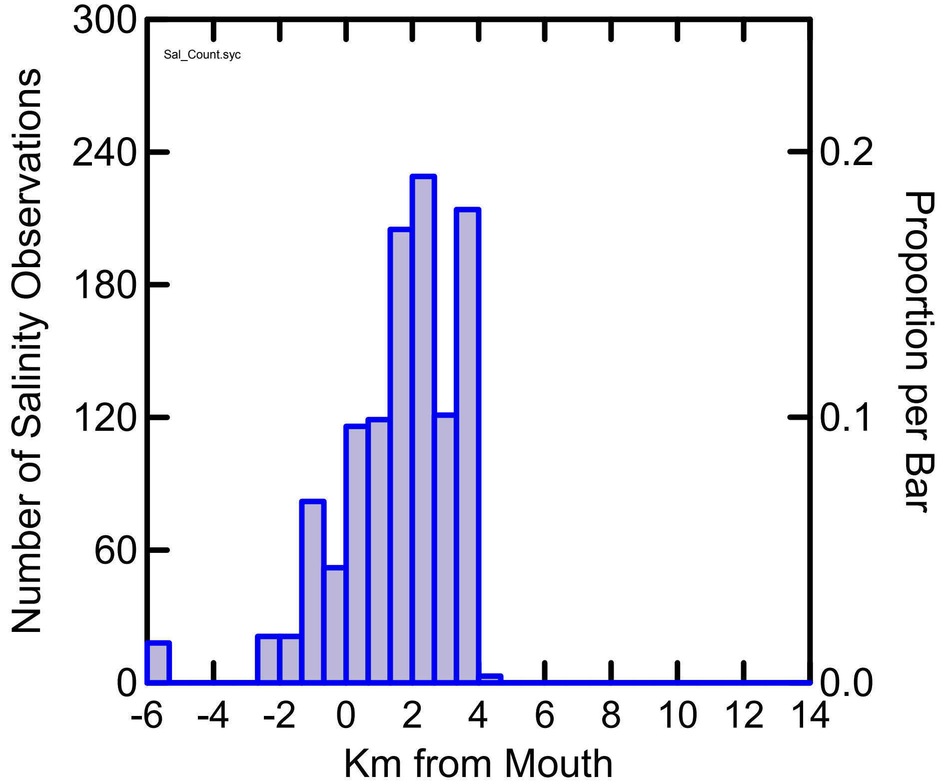


Table 4-3.
Median Salinity by River Segment

Segment	Mid-Segment Rkm	System	n = (bottom)	Median (bottom)	n = (surface)	Median (surface)
0	-1.0	Weeki	176	15.5	840	20.0
1	0.2	Weeki	77	11.6	87	10.8
2	0.4	Weeki	39	9.9	39	9.9
3	0.7	Weeki	74	11.0	77	10.5
4	1.0	Weeki	45	8.0	58	6.6
5	1.6	Weeki	156	7.2	251	2.7
6	2.4	Weeki	279	0.7	291	0.3
7	3.7	Weeki	217	1.4	330	0.3
8	5.6	Weeki	1	0.5	30	0.2
9	9.4	Weeki	0		125	0.2
10	1.9	Mud	26	7.9	39	7.6
11	2.7	Mud	45	10.0	46	6.1
12	3.5	Mud	48	16.9	50	9.7

Mid_Seg_Salinity.xls

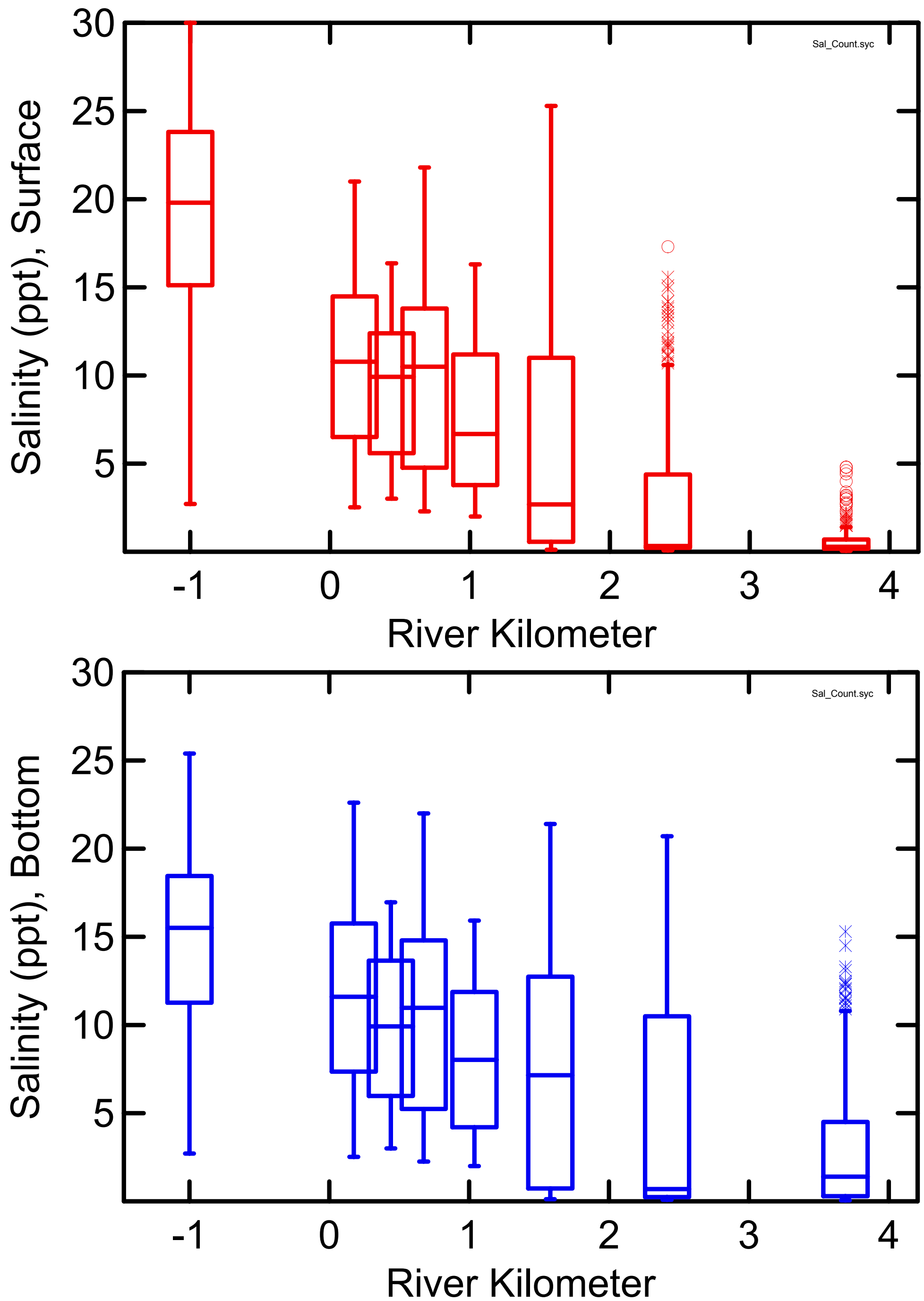
Figure 4-6
Number of Salinity Measurements (1984-2005) by River Kilometer.



It is noteworthy that the oligohaline zone (salinity < 5ppt) typically occurs within 2 km of the Gulf. Were it not for the high salinity discharge of the Mud River, it is likely that the 5 ppt isohaline would occur downstream of the Mud / Weeki Wachee confluence.

Salinity is a critical parameter for setting an estuarine MFL. Consequently, considerable effort was expended in an attempt to relate salinity to both the resources of concern as well as flow which is the sole management option. Of necessity, numerous approaches were tested to determine the best technique for relating flow and salinity. This section and subordinate sub-sections include a description of observed salinity conditions, attempts to predict salinity at Bayport using the continuous USGS recorders, and attempts to predict salinity by spatial segments of the river to predict the location of salinity isohalines.

Figure 4-7
Salinity Range (1984-2005) by Segment Mid-Point



Several physical-chemical conditions of the Weeki Wachee complicated the development of salinity predictions. In 1989, Yobbi and Knochenmus wrote:

> *Application of the regression approach to the Weeki Wachee, Crystal, and Withlacoochee River Estuaries was complicated by several factors. One factor is that salinities near the river mouths are affected by the large-scale circulation and littoral drift processes in the Gulf of Mexico. Another factor is that some spring flow to the coastal rivers is tidally influenced, and accurate flow determinations were difficult. A third factor is that spring flow, controlled by the water levels and gradients within the Upper Floridan aquifer, varies more slowly and over a much smaller range than rivers of similar size that respond to rainfall-runoff events. Consequently, the range of salinity movement due to natural variations in coastal rivers inflow was smaller than those studied by Giovannelli (1981) and Fernandez (1985). [page 14]*

The difficulty in developing predictions was reiterated later in the same report;

> *Although it was expected that high streamflow and lower high tides would push saltwater gulfward, a consistent correlation was not observed between salinity in the lower section of the river and in the Gulf of Mexico with river discharge or high-tide stage. [page 21]*

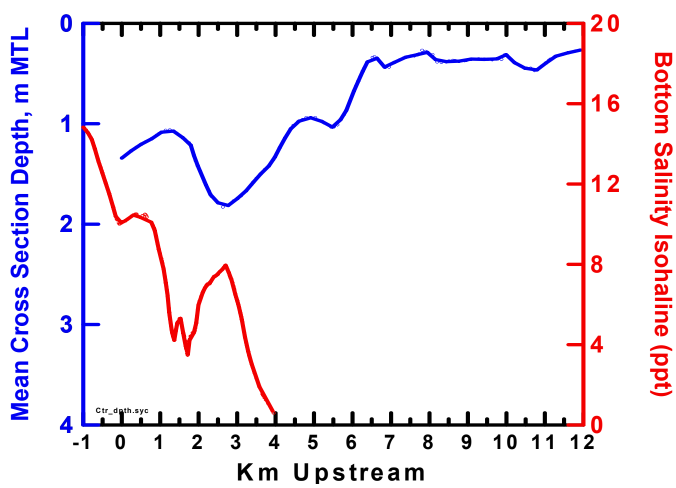
In addition to the reasons cited by the Yobbi and Knochemus, an additional confounding influence is the introduction of high salinity water to the Mud River. The Mud River received flows from both Salt Spring and Mud Spring which are characterized by high salinity water. The rate of discharge from the Mud is not well known, but estimates place the combined flow from the two major springs in the range of 108 -166 cfs. For reference, the annual average flow from Weeki Wachee springs is 168 cfs for 1967-2004. The influence of saline water is evident in the District's recently completed (See Figure 4-5) monitoring efforts, and the selection of segment bounds reflected the impact.

Two other sources of ungauged flow are probably affecting the overall water budget. There are smaller unnamed springs and seeps along the Weeki Wachee River and Cherry (1970) estimates that these additional springs may contribute up to 20 percent more flow. Unlike the Salt and Mud springs, the salinity of these sources is essentially unknown but generally believed to be fresh. Indeed, through out the system divers conducting the SAV survey noted a "shimmering" (schlieren effect) interface due to differences in refractive index and denoting the presence of fresh groundwater.

A second possible source is freshwater seep from the extensive marsh system at the mouth of the estuary. This feature is visible as the blue/grey land mass coverage in Figure 3-4. Much of this system is inter-tidal, and additional area is also subject to uncovering in response to strong winds from the north hemisphere. The shoreline adjacent to this marsh system is characterized by a mix of salt-tolerant spartina interspersed with salt sensitive leatherferns suggesting that pockets or seeps of freshwater also exist in this system. It is speculated that this may be another significant, but ungauged source of freshwater.

Another confounding influence may be that physical barriers exist that restrict the free exchange of spring and estuarine water except above certain tides. Dixon (1986) noted the presence of a shallow sill at approximately river kilometer 1.6 and speculated on the physical impact to the salinity structure. Sinclair (1978) references a sand-bag control at river km 10.9, although the existence of such a structure is not apparent in the 2005 bathymetry. The smoothed location of isohalines (See Isohaline Salinity Estimation) was superimposed (Figure 4-8) on the depth of the river in an effort to identify any physical changes that might be affecting the salinity distribution. The presence of the sill at km 1.6 is clearly indicated, and the high salinity in the depression upstream (around km 2.5 - 3.5) may be the result of saline water overtopping the sill during higher tides and becoming trapped behind the sill.

Figure 4-8
Median Bottom Salinity (2003-2005) Red Trace
Mean Cross Section Depth (m) Blue Trace



4.2.1 Segment Salinity Estimation

The Weeki Wachee and Mud Rivers were segmented (see Section 3.1.2) and evaluated for factors affecting salinity within those segments. The water quality database is described elsewhere (Chapter 4.2 and Appendix 4-2), and each observation was assigned to a segment based on a standard river kilometer.

Following segmentation, the effect of spring discharge, Withlacoochee flow[10] at Holder (as a surrogate for Gulf boundary salinity), river location and tide height were evaluated using univariate and multivariate regression techniques. Tide height was predicted from the time of sampling (EDT corrected to GMT-5 hr) using the regression coefficients described in Section 4.1. In addition to 'time of sampling' estimation of tide height, the tide height was estimated for 1-hour and 6-hours prior to the sample time. The rate of tide change (and direction, based on the sign) was calculated and used as additional independent variables.

Initially, a multilinear regression containing tide stage, 1-hr rate of tide change and spring discharge as independent variables (IV) was evaluated without regard to sample depth. Predictive power (Table 4-4) was generally poor to fair (typical r^2_{adj} 0.0 to 0.3) except for segment 6 where slightly more predictive power was realized (r^2_{adj} = 0.45). Including the natural log transformed flow (ln_flow) as an optional independent variable did not materially change the outcome.

Table 4-4.
Salinity Predictions by Segment.
Independent variables = Spring Flow, Tide Stage, and Rate of Tide Change

Segment -(n=)	**r^2_{adj}**	**Segment -(n=)**	**r^2_{adj}**
0 - (520)	0.04	7 – (1,116)	0.06
1 - (237)	0.35	8 – Insufficient data	
2 – (123)	0.21	9 – Insufficient data	
3 – (269)	0.34	10 – (89)	0.00
4 – (204)	0.27	11 – (125)	0.02
5 – (478)	0.40	12 – (198)	0.07
6 – (1,018)	0.45	Mud River = 10, 11 & 12	

Surface salinity was evaluated next focusing on spring flow and using a similar step-wise multivariate approach which resulted in similar correlation values. Five sequential additions were evaluated as shown below. While the predictability for some segments improved (particularly segment 0), there was not an overall improvement.

A) Salinity = $\beta_o + \beta_1*Flow + \beta_2*Flow^2$
B) Salinity = $\beta_o + \beta_1*Flow^2$
C) Salinity = $\beta_o + \beta_1*Flow^3$
D) Salinity = $\beta_o + \beta_1*Flow^2 + \beta_2*Ht$

[10] The Withlacoochee discharges 60% of the total freshwater to the shallow waters of the coast north of Weeki Wachee and is believed to have a significant impact on the near-shore salinity of the area.

$$E)\ Salinity = \beta_o + \beta_1{*}Flow^2 + \beta_3{*}Ht + \beta_{4*}\,Ht^2$$

River kilometer was added as an additional candidate IV, and observations were restricted to surface salinity on incoming tide only with results similar to those given in Table 4-4. As in the case of attempting to predict salinity at Bayport, additional candidate flow terms from the Withlacoochee were added and evaluated. Mixed tide surface only, incoming surface only and incoming bottom only salinity observations were evaluated separately. The best-fit correlation coefficients are summarized in Table 4-5 and combinations where spring flow was a significant term are noted. It should be noted that Withlacoochee flow at Holder (as a surrogate for Gulf boundary salinity) was more commonly a significant term than Weeki Wachee spring flow.

Table 4-5.
Summary of Salinity Regression – By Segment, Depth and Tide

	Mixed Depth-Incoming			Bottom Only- Incoming			Surface Only - Incoming		
Seg	r^2_{adj}	N=	Flow Term $p\leq0.05$	r^2_{adj}	N=	Flow Term $p\leq0.05$	r^2_{adj}	N=	Flow Term $p\leq0.05$
0	0.56	181		0.52	92		0.54	94	
1	0.44	77		0.29	33		0.41	32	
2	0.43	39		0.61	19	Yes	0.40	19	
3	0.48	77	Yes	0.39	32		0.43	31	
4	0.09	48		***	24		***	24	
5	0.22	274	Yes	0.27	65		0.28	74	Yes
6	0.62	283	Yes	0.40	104	Yes	0.40	111	Yes
7	***	356		***	54		0.05	56	
Note – Highlighted cell indicates one or more terms with illogical relationship to salinity.									
(Segments 8, 9 not shown because $\geq$90% of salinity observations are $\geq$0.2 ppt salinity.									
(*** No terms entered at tolerance = 0.01 and F to enter = 0.15)									

As is frequently the case when evaluating environmental parameters with multivariate regression, a statistically significant term may enter with an illogical coefficient. Examples include inverse relationship of tide height and salinity or positive relationship of freshwater flow and salinity. These terms remain in the results given in Table 4-5, but these terms would of necessity be removed and a new equation established prior to forward predictions. Removing these terms will result in a lowering of the r^2_{adj}. However, in the present case, the candidate independent variable terms generally explained an insufficient amount of the salinity variation, and spring flow was significant for only a few segments. Incorporating a lag term for spring flow was considered but the mean flushing time (1985-05) for the Weeki Wachee River is less than one day and lagging the flow seems inappropriate. For these reasons, segment salinity regressions were not further pursued.

4.2.2 Salinity Estimation – Bayport

The salinity of the Gulf has a controlling effect on the salinity of the incoming tide, and it was felt that this boundary condition might be a useful independent variable for

predicting salinity elsewhere in the Weeki Wachee River. The USGS maintains a station at the mouth of the Weeki Wachee (02310600 – Gulf of Mexico at Bayport) that monitors surface and bottom temperature and conductivity as well as water level. Elevations (daily maximum and minimum) have been recorded since 1965. Water quality measurements were added in June 2003 and the reporting interval of all parameters decreased to 15-minutes.
Factors potentially affecting salinity at Bayport include regional meteorological conditions and near-shore Gulf salinity. Gulf salinity in turn is affected by other coastal discharge. Withlacoochee flow was included because it is a relatively large and near-by discharge dominated largely by surface runoff.

An attempt was made to develop predictions of salinity at Bayport using multi-variate regressions from the following independent variables:

- Gauge height (tide stage), instantaneous and prior (1 and 4 hour)
- Discharge from Weeki Wachee spring (daily average)
- Daily average Withlacoochee flow at Holder (as surrogate for variation of Gulf of Mexico boundary salinity)
- Barometric pressure (daily average – Cedar Key)
- Wind velocity (daily average Cedar Key, vectored north and east)

The Gulf of Mexico is very shallow (e.g. 2.7 m at a distance of -5 km) beyond the Bayport gauge, and an extensive sub-tidal marsh characterizes the area just inside the gauge location. Barometric pressure and wind velocity were included as Independent variables primarily to capture the salinity variations due to the passage of weather systems which create a shelf set-up, or which effectively influence the transport of water through wind shear. The shoreline near Bayport is oriented $003^o/183^o$, and wind was vectored as both parallel and perpendicular to the coastline. The vectored wind squared was also included to represent wind stress.

Salinity[11] was calculated from conductivity using the Cox polynomials (Jaegar 1973) and assigned as the dependent variable (DV). The initial trial used data from June 2003 through September 2005 (n=80,051) and included only gauge height and Weeki Wachee discharge. This exploratory[12] regression resulted in an adjusted correlation coefficient (r^2_{adj}) of 0.36, but the discharge term was not significant (p=0.76). Eliminating the flow term from the analysis resulted in a virtually identical r^2_{adj} suggesting that salinity at the mouth is largely independent of spring discharge. Further evidence is provided by a univariate evaluation of salinity and discharge which resulted in an r^2 of < 0.0001.

[11] Expressed in parts per thousand (ppt) for consistency with the original literature.
[12] Initial exploratory efforts focused almost entirely on comparisons of correlation. Diagnostic issues of residuals, leverage, influence and serial correlations were not considered during these exploratory efforts.

Additional exploratory attempts using average daily salinity and gauge height, daily ranges and transformations (cube root) of flow and gauge height and/or interactive terms (e.g. gauge height * discharge), did not improve the results with r^2_{adj} ranging from 0.03 to less than 0.001.

The variation in gauge height due to a predictable tide signal was removed in an attempt to improve the sensitivity of salinity to spring flow. A regression model (Section 4.1) based on known tidal harmonics was fit to the Bayport data and the tide signal removed from the gauge height.

Other variables that could be controlling salinity were identified and evaluated through step-wise multivariate regression. Only variables that were both significant ($p \leq 0.05$) and physically logical were retained. For example, flow variables that exhibited a positive relationship with salinity were rejected.

It was theorized that discharge from the Withlacoochee River may have a major affect on Gulf salinity due to the magnitude of discharge. Daily discharge measurements from the Withlacoochee at Holder, along with several moving averages and sums (7, 15, 30, 45 and 60 days prior) were also included as candidate Independent variables. When regressed against the observed salinity at Bayport, only the daily flow and the seven day sum were negatively associated with salinity and were retained for the step-wise evaluation.

Wind can also have a dramatic effect on water levels and water movement along this portion of the coast due to the shallow nature of the Gulf in this vicinity. Hourly meteorological data was obtained for the NDBC station on Cedar Key, which is located 45 miles northwest of Bayport. Wind was converted to both North and East vectors corresponding to long-shore and offshore vectors. Daily averages were developed for each vector and used as candidate Independent variables. Each was squared to account for the wind shear force on the surface water. In addition, the daily average barometric pressure was calculated from the hourly observations. Of the possible wind variables, vector north and vector east squared explained the greatest amount of variation in observed salinity (r^2 ranging from 0.04 – 0.05) and were retained as candidate independent variables for the subsequent step-wise evaluation.

For purposes of continued evaluation, the year 2004 was chosen to maximize the impact of spring discharge on salinity. The spring discharge (191 cfs) during 2004 was ranked 7th highest out of the past 35 years, and it represents the year of highest flow with concurrent 15-minute stage data.

The final candidate variables selected were a) gauge height, b) spring discharge, c) barometric pressure, d) Withlacoochee flow at Holder, e) seven day sum of Holder flow, f) north vectored wind and g) east vectored wind squared. Table 4-6 illustrates the importance of each subsequent variable in predicting salinity at Bayport (n= 35,136).

Table 4-6.
Step-Wise Salinity Regression Bayport, Fl.

Step	Terms	r^2_{adj}
1	Intercept + Gage Height	0.415
2	Step 1 terms + Barometric Pressure	0.493
3	Step 2 terms + Holder Flow	0.552
4	Step 3 terms + Spring Flow	0.610 (1)
(1) **Spring** flow positively related to salinity – reject term		

Thus, as in the simpler regressions, discharge from the spring does not have a major effect on salinity at Bayport that can be modeled simply. and the relatively constant nature of the spring discharge (e.g. minimal variance) is probably largely incorporated into the intercept term.

4.2.3 Isohaline Estimation

Regressions predicting the location of salinity isohalines in the Weeki Wachee were developed for a suite of salinities. This discussion includes a description of the attempts to relate the location of those salinity isohalines to candidate forcing functions.

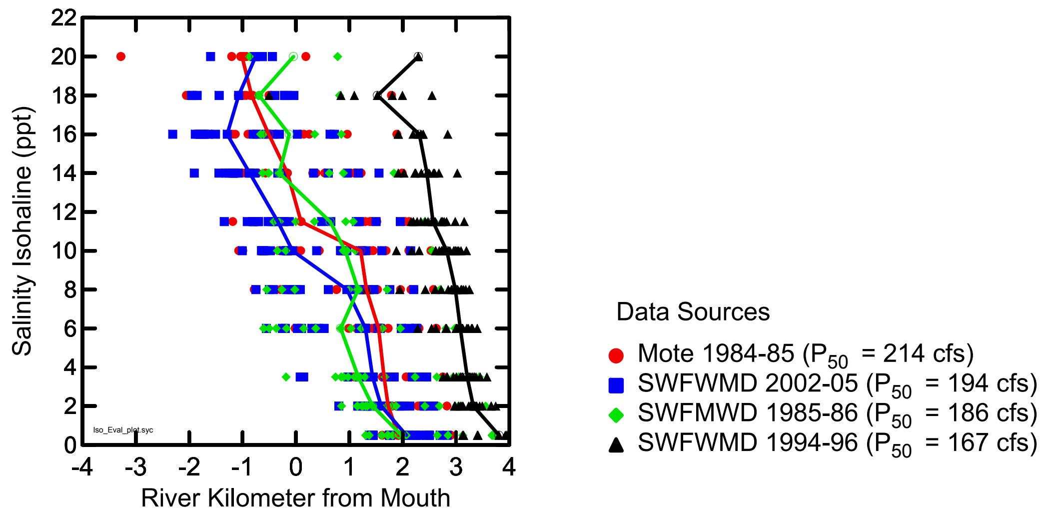
The location of each sample point on the river along a standard river kilometer system was developed from reported latitude / longitude pairs, structures or from reported distances from structures. River km zero is located at 28.5338° N / 82.6519° W which is approximately 150 meters west of the fishing pier at the mouth of the Weeki Wachee river. Distance accumulated upstream of this point is positive and distance into the Gulf is measured in negative kilometers along a thalweg corresponding to the marked approach channel (See Figure 3-1**)**.

Observations were sorted by calendar date, and the locations of bottom isohalines were estimated by linear interpolation between salinity readings bracketing the desired isohaline. The time of observation was not considered as most of the field sampling efforts appeared to progress in a monotonic fashion along the river. Locations were determined for the following salinities: 0.5 2, 3.5**[13], 6, 8, 10, 11.5**, 14, 16, 18, and 20 ppt. There are insufficient observations to estimate higher salinity isohalines. Figure 4-9 provides a summary of the interpolated locations as a function of river kilometer. The irregular lines represent the median position of each isohaline for each monitoring program. Figure 4-8 illustrates that the range of isohaline locations varies greatly with monitoring program, reflecting the differences in flow conditions with the most upstream locations associated with the 1994-96 District program and the most downstream locations associated with the 1984-85 Mote Marine program. The median flow of program sampling days is as follows: Mote Marine 1984-85 = 214 cfs, SWFWMD 1985-

[13] The 3.5 and 11.5 ppt isohalines were chosen because these values represent mid-points taken from the benthic principal component analysis described in section 5.1.2

86 = 186 cfs, SWFWMD 1994-96 = 167 cfs, and SWFWMD 2002 – 05 = 192 cfs. In general there are fewer observations of higher salinity (18 and 20 ppt) and their isohalines and tend to group further inshore than expected.

Figure 4-9
Isohaline Locations for Various Monitoring Programs (1984-2005)
(Line connects median of isohaline location by program)
The results from all monitoring programs were pooled and multivariate regressions with



river kilometer as the dependent variable were evaluated for each of the isohalines. Subset evaluations were varied by surface and bottom waters and by tide (flooding, ebbing and mixed). Candidate independent variable terms were tide height, tide rate and spring flow. In all cases, spring flow was a significant term. Additional terms, while significant in some cases did not materially improve the predictions and ultimately simple univariate equations of the following form were chosen. Table 4-7 provides a summary of the equations used, along with an estimate of the isohaline location at median Block 1 adjusted flow conditions (See Table 2-6). As in the case of cumulative volume and area equations, a line of organic correlation (LOC)[14] was used in lieu of an ordinary least squares (OLS) regression. The advantage (Helsel and Hirsch, 1992) of an LOC over the LOS is that variance in both the X and Y variable are minimized instead of just in the Y direction. This yields an equation which is identical if Y is predicted from X or if X is predicted from Y.

$$Km = \beta_o + \beta_1 * (1/Q)$$

Where Q is equal to average daily flow at Weeki Wachee Springs.

[14] Also known as 'allometric relation', 'reduced major axis', 'maintenance of variance-extension, MOVE' and 'geometric mean functional regression'.

Table 4-7.
Correlation (LOC) Summary – Isohaline Location

Surface Water, Mixed Tides					
Isohale	n=	r^2	B_o	B_1	km @ 157 cfs
0.5	71	0.674	-1.365	638.733	2.7
2	78	0.605	-1.177	540.499	2.3
3.5	77	0.517	-2.095	648.863	2.0
6	72	0.462	-3.162	773.885	1.8
8	69	0.523	-3.640	820.606	1.6
10	65	0.513	-4.234	868.916	1.3
11.5	61	0.533	-4.817	916.788	1.0
14	50	0.533	-5.495	955.052	0.6
16	38	0.486	-5.640	914.456	0.2
18	26	0.358	-5.338	822.955	-0.1
20	14	0.428	-5.366	799.837	-0.3

Bottom Water , Mixed Tides					
Isohale	n=	r^2	B_o	B_1	km @ 157 cfs
0.5	68	0.518	-1.347	666.043	2.9
2	75	0.563	-1.421	619.313	2.5
3.5	76	0.506	-2.094	698.826	2.4
6	73	0.440	-3.342	845.186	2.0
8	69	0.511	-3.700	876.222	1.9
10	66	0.537	-4.201	920.610	1.7
11.5	63	0.594	-4.790	966.636	1.4
14	53	0.563	-5.425	996.623	0.9
16	41	0.481	-5.893	1013.560	0.6
18	29	0.319	-5.034	807.913	0.1
20	17	0.371	-6.063	1009.940	0.4

isohaline_regress_tbl.xls

4.2.4 Longitudinal Salinity Estimation

Regressions predicting the location of salinity at any location in the Weeki Wachee were developed. River kilometer and all of the flow, tide and weather variables were evaluated as candidate independent variables. This section describes the results.

A regression of the form below was evaluated to estimate salinity at any location along the Weeki Wachee River. The initial river domain was from – 5.7 to +12.0 km. Surface salinities were evaluated first.

$$Salinity = \beta_o + \beta_1*Flow +\_\beta_2*R_{km}$$

Where: salinity in ppt,
Flow is spring flow (cfs), and
R_{km} is river kilometer as previously defined.

Surface salinity was evaluated first which resulted in an r^2_{adj} of 0.67 (n=2,183), but a plot of the residuals revealed a number of suspect observations. Further investigation revealed that most of the aberrant observations were very low or zero salinities. The exploratory regression was re-evaluated after filtering out all salinity values $\leq$ 0.5 ppt and one additional outlier observation that appeared to be a typographical error. The pattern of residuals improved and the r^2_{adj} improved to 0.73 (n= 1,589). An interactive term of the form $\beta_3*R_{km}*$ Flow was added, but did not improve the fit (r^2_{adj} =0.74).

Further investigation indicated that nearly half of the observations were westward of the mouth of the river. In an attempt to focus the regression to that portion of the river of interest, an additional filter was added to limit the river domain to upstream of -0.5 km. This resulted in a significant reduction in the predictive power (r^2_{adj} =0.31, n= 784), most of which resided in the river position term (r^2 =0.22 for Salinity = $\beta_o + \beta_1*R_{km}$)

A longitudinal model of bottom isohaline position was attempted next. The location of the interpolated isohaline positions described in Section 4.2.3 was coupled with flow in a model of the general form:

$$Rkm_{isohaline} = \beta_o + \beta_1*Flow +\_\beta_2*Salinity_{isohaline\ (bottom)}$$

Several flow terms were investigated (e.g. Flow, ln(Flow), and Flow $^{-1}$). The results were generally similar. The final form chosen used Flow $^{-1}$ and resulted in the following equation:

$$Rkm_{isohaline} = -0.8929 + 593.4*(1/Flow) -0.1520*Salinity_{isohaline\ (bottom)}$$
$$[n = 631,\ r^2_{adj} = 0.66]$$

This form has the advantage that one equation can be used to solve for position, flow or salinity once the other two terms are known or specified. This equation (herein termed *longitudinal salinity model,* LSM) was used extensively in evaluating the biological MFLs. **I**n the absence of a multi-variate equivalent to the bi-variate LOC**,** in cases where the values of one independent variable and the dependent variable are known, the value an independent variable was obtained through algebraic re-arrangement of the regression. Thus:

$$\text{Flow} = [\ ((\text{Rkm} - \beta_o)/\beta_1) + ((\beta_2 * \text{Salinity})/\beta_1)\ ]^{-1}$$

and

$$\text{Salinity} = ((\text{Rkm} - \beta_o)/\beta_2) - (\beta_1 * (1/\text{Flow}) / \beta_1)$$

4.3 Water Quality

The origin of source water for the Weeki Wachee River plays a significant role in the water quality. For example, the water is high pH (ca > 7.9 above km 6.8) and carbonate (135 mg/l) and low in color (ca <5 PCU) reflecting its origin from a carbonate aquifer (Table 4-8). In contrast, surface runoff water is typically low in pH, low in dissolved ions and oxygen, and high in color during periods of high runoff. Visibility (as Secchi depth) exceeded water depth in 910 of the 1,100 observations. The water is essentially devoid of ammonia and phosphorus, but nitrate is excessive. The lack of phosphorus is manifested in the very low chlorophyll levels which are usually at, or below detectable concentrations.

A major anthropogenic factor affecting Weeki Wachee and many of the Spring Coast vents is the increase in nitrate (NO_3-N) which originates from fertilizer applications along the recharge areas (Jones et al. 1997). Using isotopic signatures and other water quality characteristics, Jones reports that the water discharging has moved relatively quickly (decades) and over short distances from where it first infiltrated. The dominant source is inorganic (e.g. fertilizer) as opposed to organic sources (OSDS, sludge application, sewerage). The source area is extensive and has resulted in increasing the mean concentration of nitrate nitrogen in Weeki Wachee Spring from non-detectable (<0.01 mg/l) to 0.53 mg/l since 1960s. Figure 4-10 illustrates the relationships of nitrate nitrogen as a function of salinity within the Weeki Wachee River, while Figure 4-11 illustrates the change over time for samples with a salinity $\leq$ 5.0 ppt.

Vertical salinity and dissolved oxygen (DO) stratification is moderate (25^{th}, 50^{th}, 75^{th} salinity stratification = 0.0, 0.2, and 1.4 ppt. DO 25^{th}, 50^{th}, 75^{th} = -0.2, 0.0, +0.1 mg/l) and uniformly distributed within the river, but neither seems related to flow (Figure 4-12). DO stratification is quite common at Hospital Hole (Rkm = 3.6) due to a depth (ca 15 m) uncharacteristic of the remainder of the system.

Table 4-8
Median Water Quality of Weeki Wachee and Mud Rivers (1984-2005)

Segment	Statistic	km	Station Depth (m)	Secchi (m)	Temp °C	Cond umhos/cm	Salinity ppt	Dissolved Oxygen mg/l	pH SU	Color PCU	Turbidity NTU	NH_3-N mg/l	TN mg/l	NO_{2+3}-N mg/l	NO_2-N mg/l
All - "<"	n=									70	45	47		5	9
All - "<"	median									5	0.08	0.01		0.0025	0.005
0	n=	1185	781	660	1170	520	1179	1077	712	564	44	108	698	108	40
0	median	-1.3	1.4	1.2	24.8	25100	18.4	7.5	8.3	11	0.7	0.02	0.47	0.02	0.01
1	n=	247	59	3	245	237	247	210	220	9	0	10	10	10	0
1	median	0.2	2.0	1.4	25.8	18824	11.1	7.0	8.1	12		0.04	0.49	0.14	
2	n=	124	49	19	123	123	123	110	114	20	19	20	20	20	20
2	median	0.4	1.7	1.6	23.5	16834	9.9	7.5	8.1	10	0.1	0.02	0.56	0.19	0.01
3	n=	270	70	3	267	269	269	227	238	0	0	0	0	0	0
3	median	0.8	2.4	1.4	26.0	18239	10.8	7.0	8.1						
4	n=	215	95	20	198	187	214	163	181	28	19	29	29	29	19
4	median	1.1	6.0	1.3	23.6	11690	7.6	7.4	8.1	8	0.1	0.02	0.56	0.29	0.01
5	n=	590	203	112	586	490	572	502	466	122	36	57	118	58	20
5	median	1.6	1.5	1.4	24.6	10532	5.0	6.8	7.9	10	0.5	0.02	0.53	0.23	0.01
6	n=	1053	225	33	1019	1010	1028	888	925	58	37	60	30	59	20
6	median	2.4	2.4	2.3	24.2	769	0.4	6.6	7.8	6	0.4	0.01	0.67	0.30	0.01
7	n=	1252	88	112	1249	1132	1225	1040	1015	124	31	62	138	62	20
7	median	3.6	2.1	2.0	24.0	3090	1.2	5.6	7.6	5	0.3	0.02	0.55	0.45	0.01
8	n=	51	0	0	48	18	31	48	48	43	18	48	30	48	0
8	median	5.7			23.8	321	0.2	7.3	8.1	3	0.3	0.01	0.53	0.37	0.00
9	n=	172	86	86	168	33	125	167	109	144	36	86	136	86	1
9	median	12.0	1.5	1.5	23.9	288	0.2	3.4	7.9	1	0.2	0.01	0.52	0.40	
10	n=	89	0	3	89	89	89	54	63	0	0	0	0	0	0
10	median	1.6		1.2	24.7	13225	7.6	7.0	8.0						
11	n=	125	9	25	125	125	125	111	115	19	19	19	19	19	19
11	median	2.9	2.8	1.3	24.8	13120	7.6	6.4	7.8	10	0.1	0.02	0.60	0.36	0.01
12	n=	198	0	24	198	198	198	119	127	18	18	18	18	18	18
12	median	3.9	0.0	1.2	24.2	26375	16.1	3.9	7.5	5	0.1	0.02	0.52	0.41	0.01

Note – Medians derived disregarding remark codes (e.g. >, <). See remark code values for interpretation

Table 4-8 (Continued)
Median Water Quality of Weeki Wachee and Mud Rivers (1984-2005)

Segment	Statistic	OPO_4-P mg/l	TP mg/l	Chla Corrected ug/l	Chla ug/l	TSS mg/l	VSS mg/l	Cl mg/l	TOC mg/l	Alkalinity ($CaCO_3$) mg/l	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	SO_4-SO_4 mg/l	Total Hardness mg/l
All - "<"	n=	181	127	70	45	2	9									
All - "<"	median	0.01	0.01	1	1	0.5	0.5									
0	n=	103	715	58	699	58	40	40	40	90	40	40	40	40	40	0
0	median	0.00	0.01	1.1	0.9	3.1	1.8	8584.0	5.1	145.5	225.0	559.5	175.0	4485.0	1137.7	
1	n=	9	10	0	10	0	0	0	0	10	0	0	0	0	0	0
1	median	0.00	0.01		1.6					143.4						
2	n=	20	20	20	20	20	20	20	20	20	20	20	20	20	20	0
2	median	0.01	0.01	1.0	1.6	2.8	1.7	5538.3	3.9	150.0	167.5	385.0	113.0	3120.0	761.8	
3	n=	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	median															
4	n=	28	29	19	29	19	19	19	19	29	19	19	19	19	19	0
4	median	0.01	0.01	1.1	1.7	2.4	1.4	3267.7	3.1	144.0	133.0	248.0	78.6	1840.0	487.5	
5	n=	54	144	37	118	48	20	31	20	41	26	26	20	20	31	11
5	median	0.01	0.01	1.4	2.0	2.0	1.1	270.0	1.9	141.0	57.1	21.8	5.3	139.0	41.0	221
6	n=	57	58	38	30	50	20	32	20	42	27	27	20	20	32	12
6	median	0.01	0.01	1.6	1.8	1.0	0.9	72.6	1.5	139.5	54.2	9.6	1.5	37.9	16.6	154
7	n=	58	150	20	138	32	20	32	20	62	27	27	20	19	32	12
7	median	0.01	0.01	1.4	2.3	1.2	0.8	20.3	1.3	139.0	52.7	6.8	0.5	10.1	11.3	153
8	n=	42	48	0	30	18	0	18	0	48	13	13	0	0	18	18
8	median	0.01	0.01		2.1	1.0		13.0		136.2	43.1	5.0			7.0	132
9	n=	80	172	0	135	36	0	36	0	86	21	21	1	1	36	35
9	median	0.01	0.01		0.5	0.6		5.0		134.5	44.0	5.1			6.0	135
10	n=	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	median															
11	n=	19	19	19	19	19	19	19	19	19	19	19	19	19	19	0
11	median	0.01	0.01	1.0	1.4	2.2	1.6	2970.0	3.1	145.0	120.0	197.0	61.3	1570.0	421.0	
12	n=	18	18	18	18	18	17	18	18	18	18	18	18	18	18	0
12	median	0.01	0.01	1.0	1.1	1.7	1.1	3612.9	1.2	131.1	128.0	239.0	70.9	1915.0	501.9	

Note – Medians derived disregarding remark codes (e.g. >, <). See remark code values for interpretation

Figure 4-10
Nitrate Concentration as Function of Salinity (1984-2005)

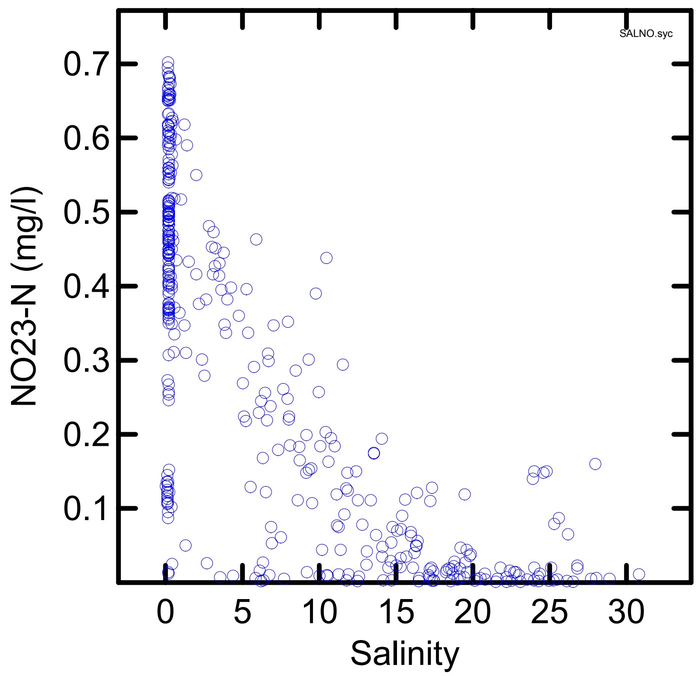


Figure 4-11
Nitrate Concentration 1984 – 2005 for Salinity <= 5 ppt.

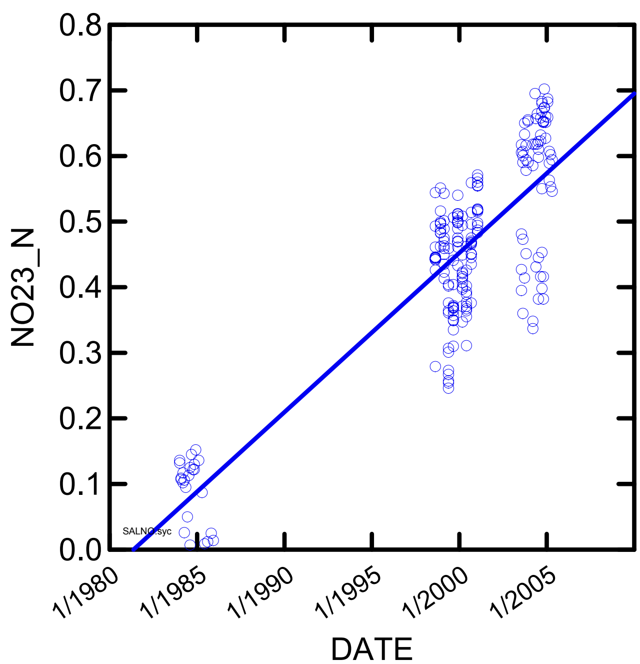
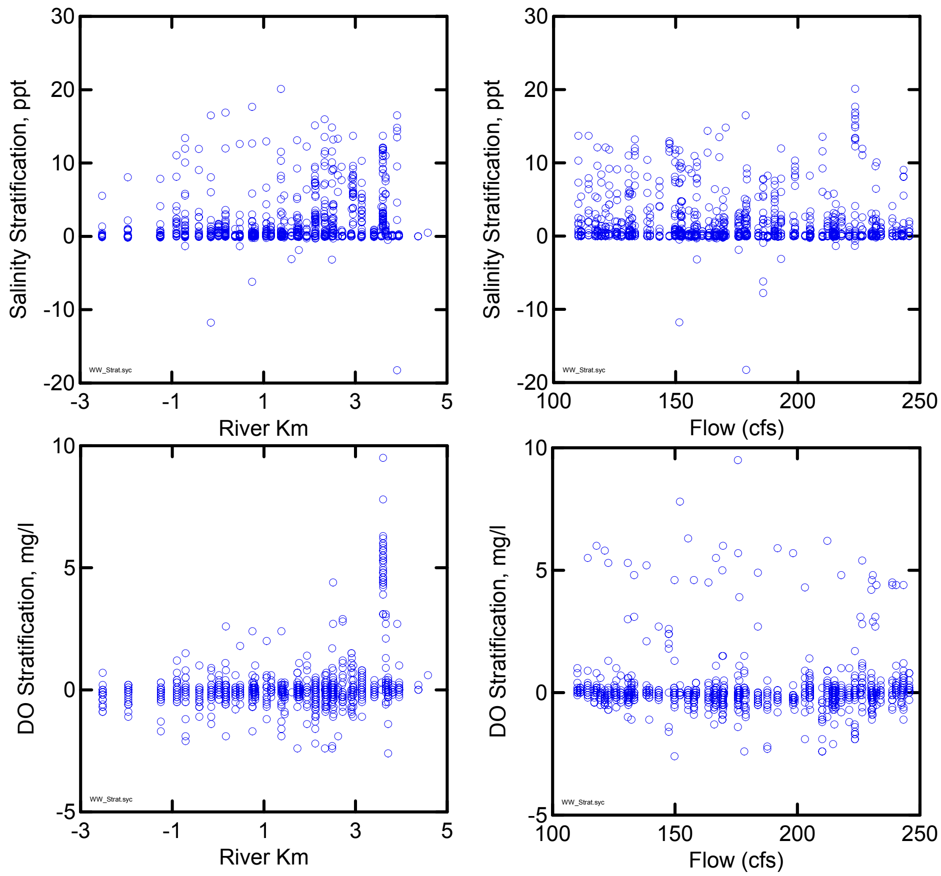


Figure 4-12
Salinity and Dissolved Oxygen Stratification – Weeki Wachee River



Numerous sources of water quality were consolidated and standardized for purposes of the MFL evaluation. Sources of the data are summarized in Appendix 4-2.
Water quality status and trends are provided graphically in Appendix 4-3 for segments as defined in Section 3.13. In general, the Weeki Wachee River is a clear, low pH water essentially devoid of phosphorus, but rich in nitrogen. As a result of the lack of phosphorus, primary productivity (as chlorophyll) is very low resulting in oligotrophic conditions which affect the entire ecology. For example, the notable lack of estuarine-dependent larval fish cited by Matheson (2005) is probably the result of this very low primary productivity.

CHAPTER 5 - BIOLOGICAL CHARACTERISTICS

5.1 Benthos

5.1.1 Descriptive

The Weeki Wachee and Mud River benthic communities were sampled in 1984-85 (Culter 1986) and again during 2005 (Janicki Environmental 2006). In the 1986 study, Culter sampled using a diver operated box corer (10 replicates per site) at four stations from 5.8 km[15] offshore up to Rkm 2.4.

In the most recent survey, round hand core samplers were used to collect infauna along fifteen transects in the Weeki Wachee and ten transects in the Mud River. Sweep nets were used to sample the epifauna. The polychaete *Laeonereis culveri* and the amphipod *Gammarus mucronatus* were among the dominant epifauna taxa. The dominant epifaunal taxa consisted of amphipods (*Gammarus mucronatus* and *Grandidierella bonnieroides*) in both the Weeki and Mud Rivers. The asellote isopod *Uronmunna reynoldsi* was also dominant in the Weeki Wachee but not the Mud River. In contrast, the tanaid *Hareria rapax* and the mysid *Taphromysis bowman*i were among the top ten dominants in the Mud River but were not ranked in the Weeki Wachee.

5.1.2 Relation to inflow

Quantitative relationships with inflow were not developed with the benthic results, although salinity was evaluated along with other physical-chemical parameters. Data from the Weeki Wachee, Mud and Chassahowitzka Rivers were pooled and several summary statistics developed. Table 5-1 presents the results for response to salinity, while Table 5-2 provides response to salinity, pH, temperature, dissolved oxygen, depth and sediment size.

Table 5-1
Benthos Response to Salinity – Weeki Wachee, Mud and Chassahowitzka Rivers

Metric	$r^2_{adj.}$	regression
Number of Taxa - $\log_{10}$(taxa +1)	0.62	= 0.66 + 0.114 * Salinity - 0.007* Salinity^2
Abundance - $\log_{10}$(N+1/m2)	0.40	= 3.42 + 0.197 * Salinity - 0.012* Salinity^2
Shannon-Wiener Diversity (H')	0.55	= 1.41 + 0.326 * Salinity - 0.012* Salinity^2
WW_Bentho_Tabs.xls		

15 Subsequent cluster analysis by Janicki (2006) indicated that the offshore sampling results represent a distinct group of organisms.

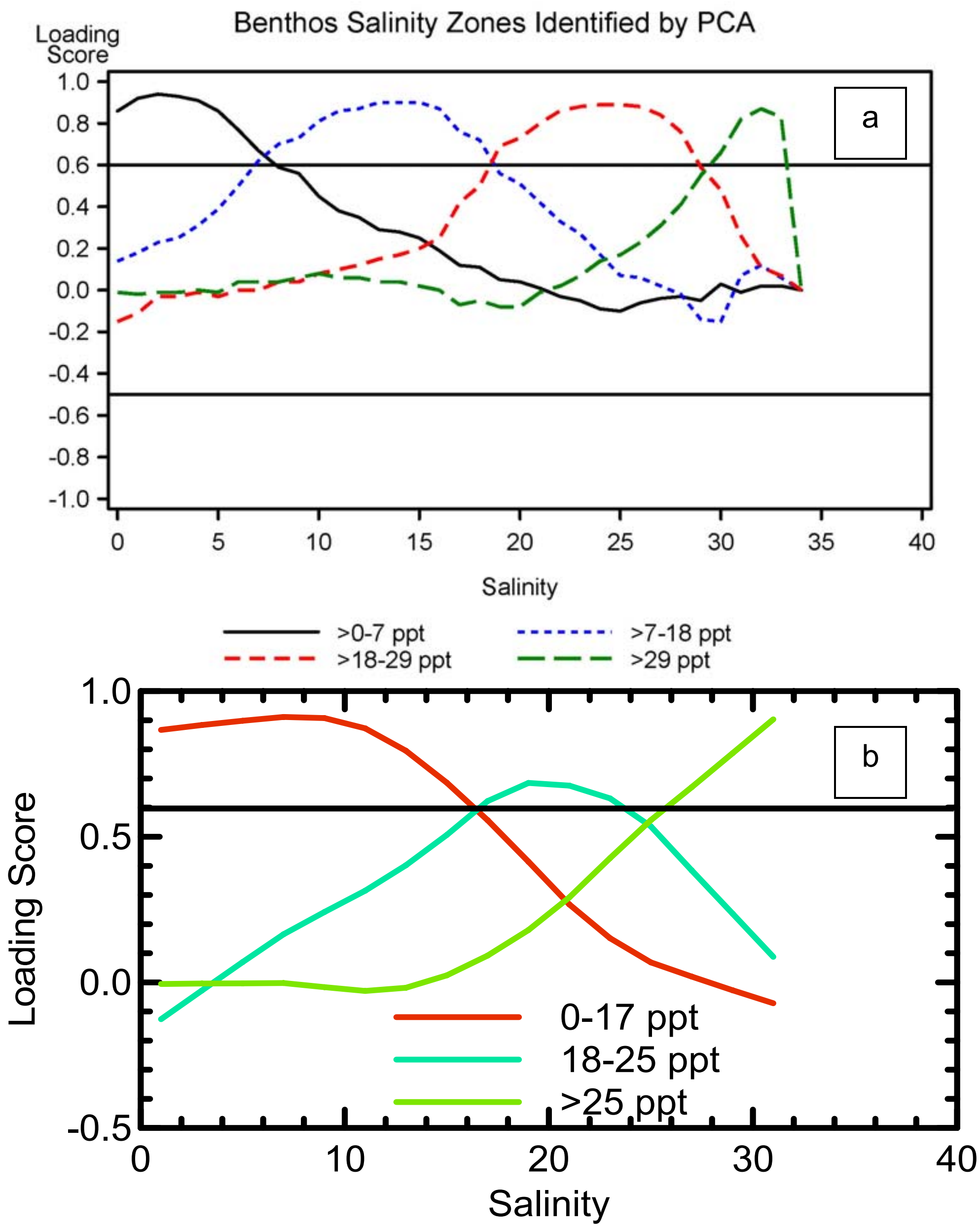
Table 5-2
Benthos Response to Normalized (Z-score). Physical – Chemical Parameters

Metric	$r^2_{adj.}$	Intercept	Depth	Temp.	Sal.	pH	Diss. Oxygen	% Silt +Clay	Mean Φ
Number of Taxa $\log_{10}$(taxa +1)	0.34	0.98	ns	ns	0.10	ns	ns	-0.08	ns
Shannon-Wiener Diversity (H')	0.18	2.28	ns	ns	0.30	ns	ns	ns	ns
Individuals $\log_{10}$(N+1)	0.25	3.99	ns	ns	0.09	ns	ns	-0.21	ns
(ns - Not significant at $p \leq 0.05$)									
WW_Bentho_Tabs.xls									

While response to inflow was not determined directly, the similarity to a community-level distribution according to salinity was evaluated. Using data from twelve southwest tidal rivers, Janicki (2006) adapted a technique of using principal component analyses (PCA) pioneered by Bulger et al (1991) to identify salinity classes based on the salinity at capture for fishes (expressed as taxa presence or absence at a given salinity). Janicki conducted a similar evaluation using benthic data from nearby tidal rivers. Those results are summarized in Figure 5-1a (top panel) which presents the loading scores for four salinity classes resulting from a PCA analysis. These ranges were operationally defined as oligohaline (Salinity 0 – 7 ppt), mesohaline (7-18 ppt), polyhaline (18-29 ppt) and euryhaline (> 29 ppt). A similar benthic PCA application was developed using benthic data (Figure 5-1b, bottom panel) from three spring-fed rivers (Weeki Wachee, Wacasassa, and Crystal River) that were not included in the prior twelve rivers. The database is small, but the results suggest less differentiation of benthic response to salinity. The reason for this may be that flow in spring-dominated systems tends to be less variable seasonally. In consideration of the larger twelve rivers database, each of the Weeki Wachee and Mud River benthic samples were assigned to one of the four salinity classes derived from the larger database and an Analysis of Similarities was applied to determine whether the identified groups differed in their composition. Pair-wise comparisons were significant for oligohaline and mesohaline but not the euryhaline and polyhaline. This suggests that the lower salinity classification derived from the twelve southwest Florida tidal rivers is applicable to the Weeki Wachee and Mud Rivers. Subsequently the midpoint of the oligohaline (3.5 ppt) and mesohaline (11.5 ppt)[16] salinity ranges were selected for further evaluation.

[16] Mesohaline mid-point taken from earlier draft of Janicki (2006)

Figure 5-1
Principal Component Analysis of Benthic Community at Capture Salinity.
Top Panel Represents 12 Runoff-Dominated Tidal Rivers in Southwest Florida
Bottom Panel Represents 3 Spring-Dominated Tidal Rivers in Southwest Florida



5.2 Fish

5.2.1 Descriptive (Adapted from Matheson et al. 2005)

Fish and invertebrate usage of Weeki Wachee was investigated at the juvenile and nekton life stages using three sampling protocols which capture differing size and habitat usage within the river. The general objective was to develop a database of use and relate the number of organisms (abundance) and location of capture to variations in freshwater inflows. The tidal Weeki Wachee, Mud River and nearshore Gulf of Mexico were divided into four zones (Table 5-3) from which twenty monthly plankton net tows, seine and trawl samples were collected along with ambient measurements of temperature, salinity, pH and dissolved oxygen.

Table 5-3
Fish / Invertebrate Sampling Zones

Zone	Zone Limits
Zone 1 – Gulf	-1.5 to 0.5 km
Zone 2 – Lower Weeki Wachee	+0.0 to 1.5 km
Zone 3 – Mud River	+1.5 to 3.8 km
Zone 4 – Upper Weeki Wachee	+1.5 to 3.8 km

The fish / invertebrate usage of the Weeki Wachee differs in several ways from other southwest Florida tidal rivers sampled using similar sampling techniques. The system is short by comparison, and the estuarine portion is very compressed, generally extending less than two kilometers from the Gulf. The Gulf and the mouth of the submerged tidal portion is heavily vegetated (See section 3.2). Furthermore, the geographic location is at the northernmost extent of mangrove, and the dominant shoreline habitat is emergent marsh. Thus, the physical habitat present is quite different from systems to the south. Finally, the system is spring-fed at relatively high discharge velocities and has a very small watershed resulting in high visibility conditions and coarse substrate.

The use of three types of gear targets both different size organisms and use of different portions of the available habitat. Seine nets (3.2 mm) were used to sample the shallow areas, while a vessel-towed trawl (3.2 mm) was used to sample the deeper confines of the main channel. Typical sampling area for the seine was approximately 68 m^2, while a typical trawl swept an area of about 720 m^2. Seine and trawl sampling was conducted during the day. Seines and trawls were used to survey larger organisms that evade the plankton net. The dominant catch from both seines and trawls is juvenile fish and adults of smaller fish. Larger macroinvertebrates (namely pink shrimp and blue crab) are also regularly captured in seine pulls and trawl tows.

A plankton net (0.5 mm) was also towed behind a vessel in such a manner as to sample from near bottom to surface. A flow meter mounted ahead of the opening cone measured volume sampled which was typically on the order of 70-80 m^3. Plankton tows were conducted at night. The small organisms collected represent a combination of zooplankton and hyperbenthos communities. The term zooplankton includes all weakly swimming animals that suspend in the water column during one, or more life stages. The distribution of these animals is largely subject to the motion of the waters in which they live.

In contrast, many of the hyperbenthos are capable of actively positioning themselves at different locations along the estuarine gradient by selectively occupying opposite tidal flows. The term refers to animals that are associated with the bottom but tend to suspend above it, rising into the water column at night.

This faunal mixture of a plankton tow includes the planktonic eggs and larvae of fishes. Taxa include bay anchovy, sheepshead minnow, killifish and silversides. However, the numbers of bay anchovy were about an order of magnitude lower than found on other tidal rivers. Although fish eggs and larvae are the target catch, invertebrate plankton and hyperbenthos almost always dominate the samples numerically, but these serve as an important food source for juvenile fish.

Fish and invertebrates can be classified according to their use of estuarine habitat. Some taxa remain in the estuary year round. This type of usage is termed 'resident'. Other taxa that utilize the estuarine habitat for only a portion of their life cycle are considered 'estuarine-dependent'. The utilization may be for spawning, nursery or both. Table 5-4 indicates usage for taxa which exhibited a statistically significant response to flow in the Weeki Wachee.

Because of the differences in habitat sampled and capture size, the results of each are discussed separately. However, at the outset it should be noted that there is an unavoidable bias in the results as the flow during the sampling period (May 2003-December 2004) was higher than the mean flow for the prior nine years.

5.2.1.1 Fish Composition

Rainwater killifish were a dominant catch in all three collection devices. Other dominant plankton net taxon included larval gobies and blennies. Killifish, pinfish and mojarras accounted for 90 percent of the trawl catch. Seine catch was more diverse with the following taxa constituting 91 percent of the catch: killifish (2 species), silversides, mojarras (2 species), pinfish, sheepshead and sailfin molly. Notably absent were sand seatrout (not collected) and bay anchovy, which was present but in low abundance. The bay anchovy typically dominates fish assemblages of tidal rivers north and south of Weeki Wachee, while the seatrout also tends to be very numerous in these rivers.

5.2.1.2 Invertebrate Composition

The invertebrate composition of plankton net catch was dominated by larval crabs, shrimp, mysids, Cumaceans, tanaids, isopods, Gammaridean amphipods and gastropods. Of note were two specimens of the mysid Spelaeomysis sp. collected from the upper reach of the Weeki Wachee. This organism is rarely collected and believed to occupy the underground water system (stygophilic). Coastal water planktonic invertebrates that are commonly captured elsewhere were uncommon or absent relative to other tidal rivers.

Table 5-4
Estuarine Usage by Taxa Captured in Weeki Wachee River

Species	Common Name	Offshore Spawner	Estuarine Spawner	Estuarine Resident
Farfanepenaeus duorarum	pink shrimp	x		
Lutjanus griseus	Gray snapper	x		
Eucinostomus gula	silver jenny	x		
Eucinostomus harengulus	tidewater mojarra	x		
Lagodon rhomboides	pinfish	x		
Callinectes sapidus	blue crab	x		
Floridichthys carpio	goldspotted killifish		x	
Syngnathus scovelli	Gulf pipefish		x	
Cynoscion nebulosus	spotted seatrout		x	
Bairdiella chrysoura	silver perch		x	
Paraclinus fasciatus	banded blenny		x	
Strongylura notata	redfin needlefish		x	
Palaemonetes intermedius	brackish grass shrimp			x
Opsanus beta	Gulf toadfish			x
Lucania parva	rainwater killifish			x
Microgobius gulosus	clown goby			x
Lophogobius cyprinoides	crested goby			x

The invertebrate seine catch was dominated by the brackish grass shrimp and the daggerblade shrimp which collectively accounted for over 90 percent of the catch. The brackish grass shrimp was also a dominant occurrence in the trawl catch. Together with the Florida grass shrimp and blue crab, these three taxa comprised 91 percent of the trawl invertebrate catch.

5.2.2 Relation to inflow

Response to inflow was assessed in terms of location of maximum occurrence and in terms of quantity (abundance) of organisms present. The location metric is based on the mean location of the catch-per-unit-effort (CPUE) where the CPUE is the number of organisms per volume (plankton net) sampled or area sampled (seine or trawl). For simplicity CPUE is abbreviated as "U". The location metric is defined as:

$$km_u = \sum (km^* U) / \sum U$$

The number of organisms collected is expressed in terms of either absolute or relative abundance ($\overline{N}$). For plankton tows, the total number (N) of organisms was estimated by summing the products of mean organism density (as # / m^3) and the volume of the river (corrected for tide stage at the time of capture). For the seine and trawl data, the relative abundance ($\overline{N}$, #/ m2) was calculated for each month as

$$(\overline{N} = 100 * N_{total} / A_{total})$$

where

N_{total} = total number of organisms capture that month, and
A_{total} = total area swept by the seine or trawl that month.

Inflow response regressions were developed for each of the gear types and both response metrics. For plankton net collections, location was used without transformation but for the seine and trawl data, the location was natural log transformed after addition of 2.5 in order to incorporate data collected at, and seaward of river km zero. Flow was natural log transformed (after addition of "1" to avoid censoring zero flows) as the independent variable . Abundance and relative abundance were also natural log-transformed. Transformations are summarized in Table 5-5**.** Mean lag flows were consecutively evaluated to find the maximum coefficient of determination. Twelve linear and non-linear regression models were evaluated for each taxa captured in the plankton tows, while the seine and trawl results were subjected to linear and quadratic regressions models. Daily mean lag flows back 120 days were evaluated for the plankton tow results and mean lag flows back to 52 weeks were evaluated at seven day intervals (i.e. average discharge for sampling day and preceding six days; average flow for sampling day and preceding thirteen days) for the seine and trawl captures.

Table 5-5
Summary of Data Transformations – Plankton and Fish

Gear	Flow	Km	Abundance	Relative Abundance
Plankton Tow	ln(lag average +1)	none	ln(N)	
Seine	ln(lag average +1)	ln(km+2.5)		$\ln(N_{rel})$
Trawl	ln(lag average +1)	ln(km+2.5)		$\ln(N_{rel})$

Data_Transforms.xls

5.2.2.1 Distribution – Plankton Net

Nine of the 55 taxa collected with the plankton net exhibited a statistically significant ($p \leq 0.05$) response to flow. Of the nine, three exceeded the minimum threshold for coefficient of determination ($\geq$ 0.30) One of these responded positively (increasing flow resulted upstream movement of Km_u) while the remaining two moved downstream in response to increased flow. **Table 5-6** provides the results for all nine significant relationships.

Table 5-6
Location Response (km_u) – Plankton Net Capture
(Coefficients of determination below acceptable threshold are highlighted in yellow)

Description	Common Name	n	Int.	Slope	P	r^2	*DW*	D
gobiid flexion larvae	gobies	16	-37.096	7.126	0.0077	0.36		120
Simocephalus vetulus	water flea	18	-16.568	3.586	0.0471	0.18		120
gobiid preflexion larvae	gobies	19	-18.116	3.477	0.0297	0.20		120
Edotea triloba	isopod	19	-13.95	2.63	0.0182	0.24		21
Erichsonella attenuata	isopod	18	-11.992	2.249	0.0306	0.21	x	120
unident. Americamysis juveniles	opossum shrimps, mysids	20	-12.135	2.238	0.0184	0.23	x	89
pelecypods	clams, mussels, oysters	19	16.421	-3.004	0.0137	0.27		1
branchiurans, Argulus spp.	fish lice	16	17.407	-3.372	0.0157	0.30		8
gastropods,opisthobranch	sea slugs	12	47.897	-8.888	0.0000	0.85		1
DW - serial correlation possible at p<0.05 for D.								
D = number of lag days averaged.								

5.2.2.2 Distribution – Seine and Trawl

Thirty-nine 'pseudo-species' (e.g. combinations of age & size class for specific taxa, gear and river combinations) were defined for evaluation. Twenty of these exhibited a statistically significant ($p \leq 0.05$) location in the river with respect to discharge. Of these twenty, twelve exceeded the minimum number of observations and the threshold coefficient of determination adopted for this study. Table 5-7 identifies all twenty significant relationships along with those which failed the minimum criteria for evaluation.

Table 5-7
Location Response (km_u) – Seine and Trawl Capture
(Number of observations and coefficients of determination below acceptable threshold are highlighted in yellow)

Species	Common Name	gear	size	n	Int.	Slope	P	r^2	*DW*	D
Farfanepenaeus duorarum	pink shrimp	seines	≤ 14	16	-5.802	1.224	0.0015	0.49		1
Farfanepenaeus duorarum	pink shrimp	seines	≥ 15	12	-8.647	1.729	0.0037	0.55		1
Farfanepenaeus duorarum	pink shrimp	trawl	≥ 15	15	-15.318	2.961	0.0007	0.57		329
Palaemonetes intermedius	brackish grass shrimp	trawl	All	18	4.710	-0.799	0.0009	0.48		49
Opsanus beta	Gulf toadfish	trawl	All	16	5.614	-0.966	0.0033	0.43		21
Lucania parva	rainwater killifish	seines	≥ 26	20	6.691	-1.05	0.0051	0.33		77
Lucania parva	rainwater killifish	trawl	≤ 25	18	4.814	-0.799	0.0352	0.20		28
Lucania parva	rainwater killifish	trawl	≥ 26	13	11.536	-2.046	0.0002	0.70		1
Floridichthys carpio	goldspotted killifish	seines	≤ 30	16	-5.208	1.194	0.0153	0.31		336
Syngnathus scovelli	Gulf pipefish	trawl	All	18	5.482	-0.941	0.0254	0.23		1
Lutjanus griseus	Gray snapper	trawl	All	15	-14.163	2.794	0.0055	0.42		294
Eucinostomus gula	silver jenny	trawl	≥ 40	15	5.803	-1.002	0.0015	0.52		1
Eucinostomus harengulus	tidewater mojarra	seines	≥ 40	17	-5.651	1.332	0.0240	0.25		203
Lagodon rhomboides	pinfish	seines	≤ 35	7	23.346	-4.133	0.0128	0.69		210
Lagodon rhomboides	pinfish	seines	≥ 71	15	-8.532	1.813	0.0322	0.25		336
Lagodon rhomboides	pinfish	trawl	36 to 71	18	5.382	-0.925	0.0165	0.27		1
Lagodon rhomboides	pinfish	trawl	≥ 71	15	5.064	-0.887	0.0208	0.30		63
Cynoscion nebulosus	spotted seatrout	trawl	All	8	6.664	-1.191	0.0193	0.56		42
Bairdiella chrysoura	silver perch	trawl	All	12	5.736	-1.013	0.0004	0.71		14
Paraclinus fasciatus	banded blenny	trawl	All	10	5.002	-0.872	0.0089	0.55		1

5.2.2.3 Abundance – Plankton Net

The abundance of fifteen taxa were significantly related to inflow, four of which were positive responses (increasing flow increases abundance). One of the important positively responding taxa was the harpacticoids which serve as prey for young estuarine-dependent fishes and appear to increase in number during a seasonal time frame (D = 120, the maximum days of lag flow evaluated). This is the only pattern in the plankton-net data that suggests a positive linkage between estuarine fish production and Weeki Wachee inflow.

The results of all statistically significant plankton-net abundance relationships are given in Table 5-8. As in previous presentations, those responses that are below the minimum management threshold are highlighted.

Table 5-8
Abundance response to Inflow, Plankton Net Capture
(Coefficients of determination below acceptable threshold are highlighted in yellow)

Description	Common Name	n	Int.	Slope	P	r^2	*DW*	D
gastropods, opisthobranch	sea slugs	12	-60.22	13.233	0.0104	0.45		3
unidentified harpacticoids	copepods	15	-50.85	11.68	0.0022	0.49		120
pelecypods	clams, mussels, oysters	19	-22.009	6.271	0.0303	0.20		1
Harrieta faxoni	isopod	20	35.393	-3.714	0.0378	0.17	x	67
Munna reynoldsi	isopod	18	37.274	-5.299	0.0120	0.29		4
unidentified Americamysis juveniles	opossum shrimps, mysids	20	46.641	-5.999	0.0284	0.20		32
Sinelobus stanfordi	tanaid	16	49.145	-7.089	0.0416	0.21	x	2
Microgobius spp. Postflexion larvae	gobies	10	54.715	-8.028	0.0372	0.37		94
Edotea triloba	isopod	19	56.784	-8.458	0.0159	0.26		94
gastropods, prosobranch	snails	20	61.87	-8.92	0.0061	0.31		39
Lucania parva postflexion larvae	rainwater killifish	15	61.021	-9.52	0.0066	0.40		10
decapod megalopae	post-zoea crab larvae	19	73.697	-11.08	0.0072	0.32	x	120
decapod mysis	shrimp larvae	20	80.664	-12.237	0.0038	0.35	x	120
decapod zoeae	crab larvae	20	81.985	-12.292	0.0033	0.36	x	120
Erichsonella filiforme	isopod	20	83.606	-13.278	0.0003	0.50	x	120
DW - serial correlation possible at p<0.05 for D.								
D = number of lag days averaged.								

5.2.2.4 Abundance – Seine and Trawl

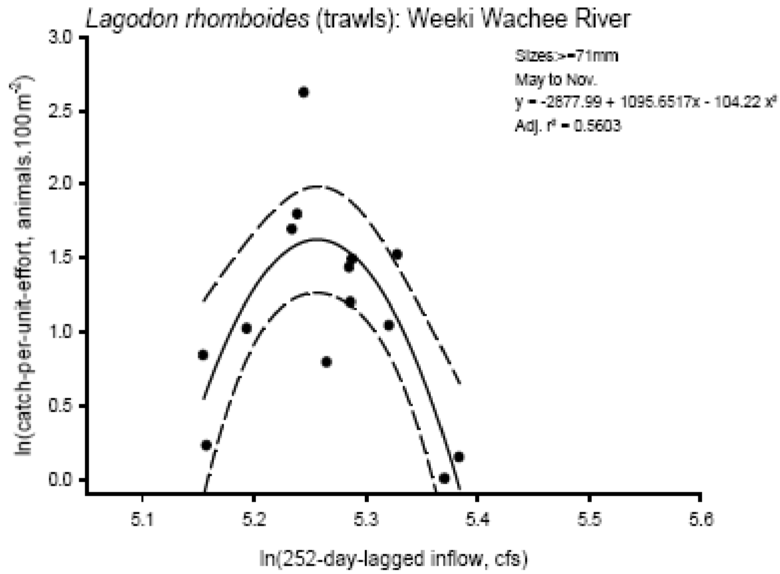
Thirty-five pseudo-species were evaluated for significant relationship between abundance and flow. Twenty (Table 5-9) of these trial resulted in statistically significant ($p<0.05$) responses, two of which were positive linear responses and four of which were negative linear responses (increased flow results in fewer organisms). The remaining fourteen significant relationships were quadratic in nature which results in a parabolic response similar to that shown in Figure 5-2. One explanation to the response illustrated in Figure 5-2 is a physical displacement at high flows and insufficient two-layered estuarine circulation at low flows to facilitate up-estuary transport.

Table 5-9
Abundance Response to Inflow - Seine and Trawl Capture
(Number of observations and coefficients of determination below acceptable threshold are highlighted in yellow)

Description	Common Name	gear	size	n	Int.	Slope	Quad slope	r^2	*DW*	D
Farfanepenaeus duorarum	pink shrimp	seines	≤ 14	17	-2034.37	772.59	-73.30	0.15		336
Farfanepenaeus duorarum	pink shrimp	seines	≥ 15	15	-3410.55	1297.33	-123.33	0.54		357
Palaemonetes intermedius	brackish grass shrimp	trawls	All	14	28.15	-4.99		0.30		112
Callinectes sapidus	blue crab	seines	≤ 35	16	-1014.42	380.27	-35.58	0.51		77
Callinectes sapidus	blue crab	trawls	≥ 36	20	660.76	-250.22	23.70	0.32		336
Strongylura notata	redfin needlefish	seines	≥ 151	12	8486.87	-3215.97	304.66	0.61	X	364
Lucania parva	rainwater killifish	seines	≤ 25	20	-2716.95	1032.67	-97.98	0.49		245
Lucania parva	rainwater killifish	seines	≥ 26	20	-23.06	4.62		0.45	X	14
Lucania parva	rainwater killifish	trawls	≤ 25	20	26.56	-4.77		0.27	X	84
Lucania parva	rainwater killifish	trawls	≥ 26	20	-513.87	193.24	-18.13	0.12	X	7
Floridichthys carpio	goldspotted killifish	seines	≤ 30	14	-2561.67	973.89	-92.51	0.30		210
Eucinostomus gula	silver jenny	seines	≥ 40	20	-2719.67	1036.08	-98.61	0.49		343
Eucinostomus gula	silver jenny	trawls	≥ 40	20	-877.00	333.18	-31.63	0.50		315
Eucinostomus harengulus	tidewater mojarra	seines	≥ 40	20	-1808.55	686.66	-65.10	0.48		203
Lagodon rhomboides	pinfish	seines	≤ 35	12	-3924.04	1486.06	-140.57	0.81		21
Lagodon rhomboides	pinfish	trawls	36 to 70	19	29.94	-5.36		0.33		147
Lagodon rhomboides	pinfish	trawls	≤ 35	12	-50.97	9.84		0.56		238
Lagodon rhomboides	pinfish	trawls	≥ 71	14	-2877.99	1095.65	-104.22	0.56		252
Microgobius gulosus	clown goby	seines	All	12	16.78	-2.94		0.35		56
Lophogobius cyprinoides	crested goby	seines	≥ 31	8	650.04	-249.37	23.91	0.91		287

DW - serial correlation possible at $p<0.05$ for D.
D = number of lag days averaged.

Figure 5-2
Abundance Response to Flow – pinfish



5.3 Manatee

5.3.1 Descriptive (Adapted from Laist and Reynolds (2005))

The Florida manatee (*Trichechus manatus latirostris*) is a marine mammal subspecies of the West Indian manatee and is found only in the southeastern United States. The U.S. Fish and Wildlife Service (USFWS 2001) estimates a Florida population of around 3,276 animals based on a Florida-wide count during January 5-6, 2001. A subpopulation of approximately 400 animals is associated with the springs north of Tampa Bay.

Many animals succumb annually to collisions with boats and from the effects of a suite of neurotoxins (brevetoxins) produced by the red-tide dinoflagellate *Karenia brevis*. The Florida manatee is Federally classified as an 'endangered' species, but on April 9, 2007 the U.S. Fish and Wildlife Service recommended[17] that the designation be reduced from endangered to 'threatened'.

Manatees are poor thermal regulators. Animals exhibit a high degree of thermal conductance (poor insulation) with relatively low metabolic rates (Rouhani et al. 2006) and are generally vulnerable to exposure to temperatures below 20^{o}C, although some

[17] http://www.fws.gov/southeast/news/2007/r07-057.html

animals can survive chronic exposure to temperatures a few degrees lower. In order to survive cold weather, manatees tend to congregate in warm water natural springs or in the cooling water discharge of power plants scattered along the coast of Florida. In developing the Blue Springs minimum flow regime, St. John's Water Management District (SJRWMD) established a critical duration of 4-7[18] days for exposure at 20^{o}C with return frequency of 50 years (long life span of a manatee). [The return interval is estimated as the joint probability product of discharge, temperature, and stage]. The potential loss of the artificial sources of warm water through plant closing and reduction of natural springflow due to groundwater withdrawals is of concern to the Warm-Water Task Force (a subcommittee of the Florida Manatee Recovery Team). Evidence suggests that the location and use of warm-water refuges is a response that calves learn from their mothers and thus the potential loss of a refuge can affect generations of manatees (Worthy 2003)

The USFWS conducts routine (approximately biweekly) aerial surveys[19] along the west coast of Florida, but the Weeki Wachee River is infrequently included in those surveys. The results vary widely by survey with an average daily count of 182 animals with a standard deviation (sd) of 80 animals. Table 5-10 and Figure 5-3 provide the number of annual surveys by refuge area. The area of heaviest use is King's Bay which averages 114 animals (sd = 80) per aerial survey which represents sixty three percent of all animals counted over the past eleven years. In contrast, the Weeki Wachee has averaged only ten animals per survey during the same period. This number is less than a usage estimate of 25 animals provided by Florida Fish and Wildlife Conservation Commission (R. Mezich, electronic communication 6/15/2006). The maximum number of manatees counted in the Weeki Wachee was 34 animals recorded on February 13, 2006

Some of the difference results from the disparity in number of surveys per year, but when only the surveys that included Weeki Wachee are compared, the number of animals using Weeki Wachee averages seven percent of the total animals counted.

5.3.2 Relation to inflow

The primary relationship between flow and the health of the manatee is a function of providing a thermal refuge during extreme cold.

[18] It should be noted that the SJRWMD evaluation used a more conservative three days for establishment of a minimum flow regime.
[19] Monthly results for 1990-2005 provided by J. Kleen. Chassahowitzka National Wildlife Refuge Complex

Table 5-10.
Average Number of Surveys and Manatee Counts – Florida West Coast 1996-2005.

Year	Total	KB	CRY	UHOM	LHOM	SR	PP	BC	WAC	WIT	SWR	SRE	CH	WW
Average Number of Manatee / Survey														
2006	167	99	9	24	9	9	13	1	2	1	1	4	2	19
2005	157	99	8	29	6	2	11	0	1	0	2	0	5	14
2004	171	103	6	38	5	3	14	1	1	0	7	0	4	5
2003	187	127	7	34	3	2	10	0	1	0	2	0	5	5
2002	211	141	5	46	4	1	11	1	1	3	6	33	3	16
2001	176	121	5	37	4	2	13	1	0	6	6	0	5	13
2000	216	132	8	40	5	2	17	1	3	2	6	10	7	12
1999	222	133	6	51	6	1	23	0	0	1	6	0	2	12
1998	141	86	5	35	6	4	2	0	7	2	1	8	12	9
1997	158	99	6	30	6	4	7	1	3	1	2	3	13	2
1996	186	120	8	33	7	6	11	0	0	0	0	5	14	3
Overall	182	114	7	36	5	3	12	1	2	1	3	4	7	10
Average Number of Surveys / Year														
2006	16	16	16	16	16	16	16	15	2	2	2	2	3	3
2005	25	25	25	25	25	25	25	24	2	2	2	2	2	2
2004	27	27	27	27	27	27	27	27	2	2	2	2	2	2
2003	18	18	18	18	18	18	17	18	6	6	6	6	6	6
2002	22	22	22	22	22	22	22	22	2	2	1	1	1	1
2001	19	18	18	18	18	18	18	19	2	3	2	2	2	2
2000	28	28	28	28	28	28	28	28	6	7	7	7	7	7
1999	24	24	24	24	24	24	23	23	3	3	4	3	5	3
1998	22	22	22	22	22	22	22	22	1	1	2	1	2	2
1997	26	26	26	26	26	26	26	24	5	5	6	5	8	1
1996	23	23	23	23	23	23	22	22	3	3	3	3	4	2
Overall	23	23	23	23	23	23	22	22	3	3	3	3	4	3

KB = King's Bay / CRY = Crystal River / UHOM = Upper Homosassa River / LHOM = Lower Homosassa River / SR = Salt River
PP = Crystal River Power Plant / WAC = Wacasassa / WIT = Withlacoochee / BC = Barge Canal / SWR = Suwannee River
SWE = Suwannee River Estuary / CH = Chassahowitzka River / WW = Weeki Wachee River

Mantee_Counts.xls

Figure 5-3
Number of Aerial Manatee Surveys by Year and Refuge

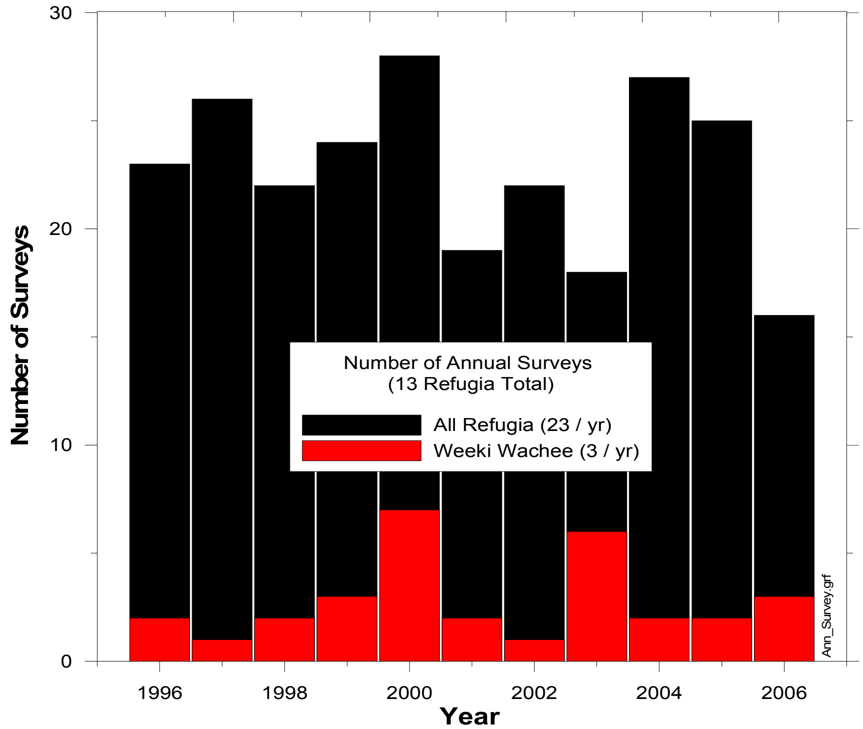
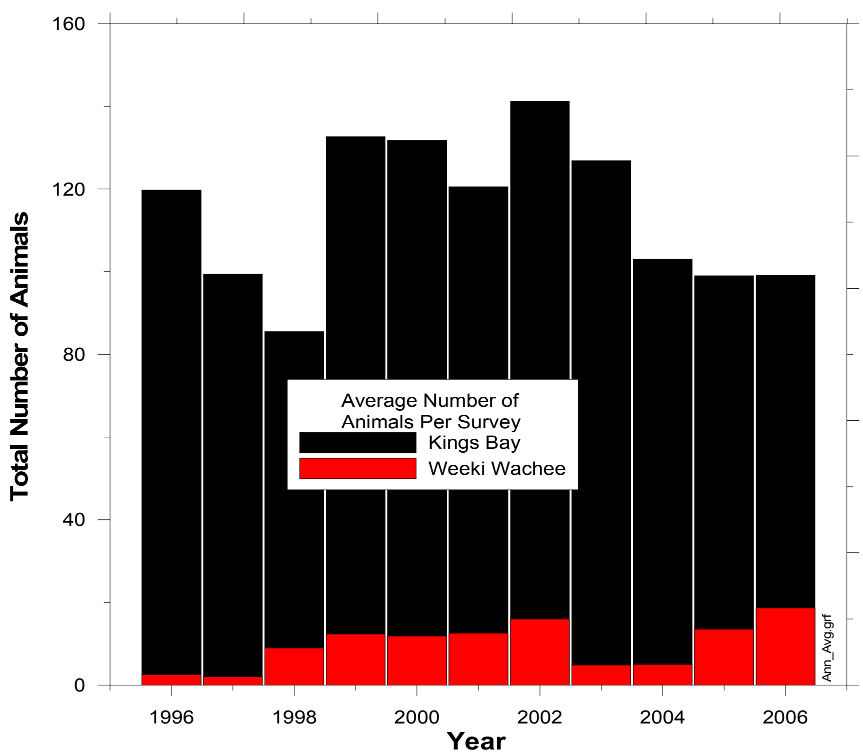


Figure 5-4
Annual Average Number of Manatees – Weeki Wachee River and King's Bay



5.4 Mollusc

5.4.1 Descriptive

During 2005, Estevez conducted a mollusc survey of the Mud and Weeki Wachee using rapid survey techniques described by Estevez (2005) and as applied to eight other tidal rivers along the west coast of Florida. The Weeki Wachee River was sampled from its mouth to river Rkm 2.5 on half-kilometer intervals. The Mud River was sampled at Rkm 2.0, 2.5, and 3.0. Both live and dead material was quantified.

The total number of taxa is similar to those observed twenty years ago (Culter 1986). Species richness remains low with fifteen taxa collected. By comparison richness for other systems sampled using similar techniques are 34 for Peace and Dona/Roberts Bay systems, 24 in the Myakka, 20 in the Alafia and 11 in Shell Creek. Reasons for low diversity and density may include the prevalence of rock substratum, poor bottom conditions in the urbanized river area, and larval export caused by the constant discharge of the spring run.

The mollusk fauna of the Weeki Wachee and Mud rivers is similar to that of other studied streams, in terms of species composition. In terms of species abundance, the Weeki Wachee and Mud rivers are distinctive in that the jackknife clam, *Tagelus plebeius*, was most common. Two intertidal species, *Polymesoda caroliniana* and *Littoraria irrorata*, also were abundant. Figure 5-5 illustrates the presence/absence of taxa by river system and kilometer, while Table 5-11 provides the rank order of abundance for the combined Mud/Weeki Wachee system.

Figure 5-5(a)
Molluscan Presence / Absence in Weeki Wachee and Mud Rivers. (Estevez 2005)

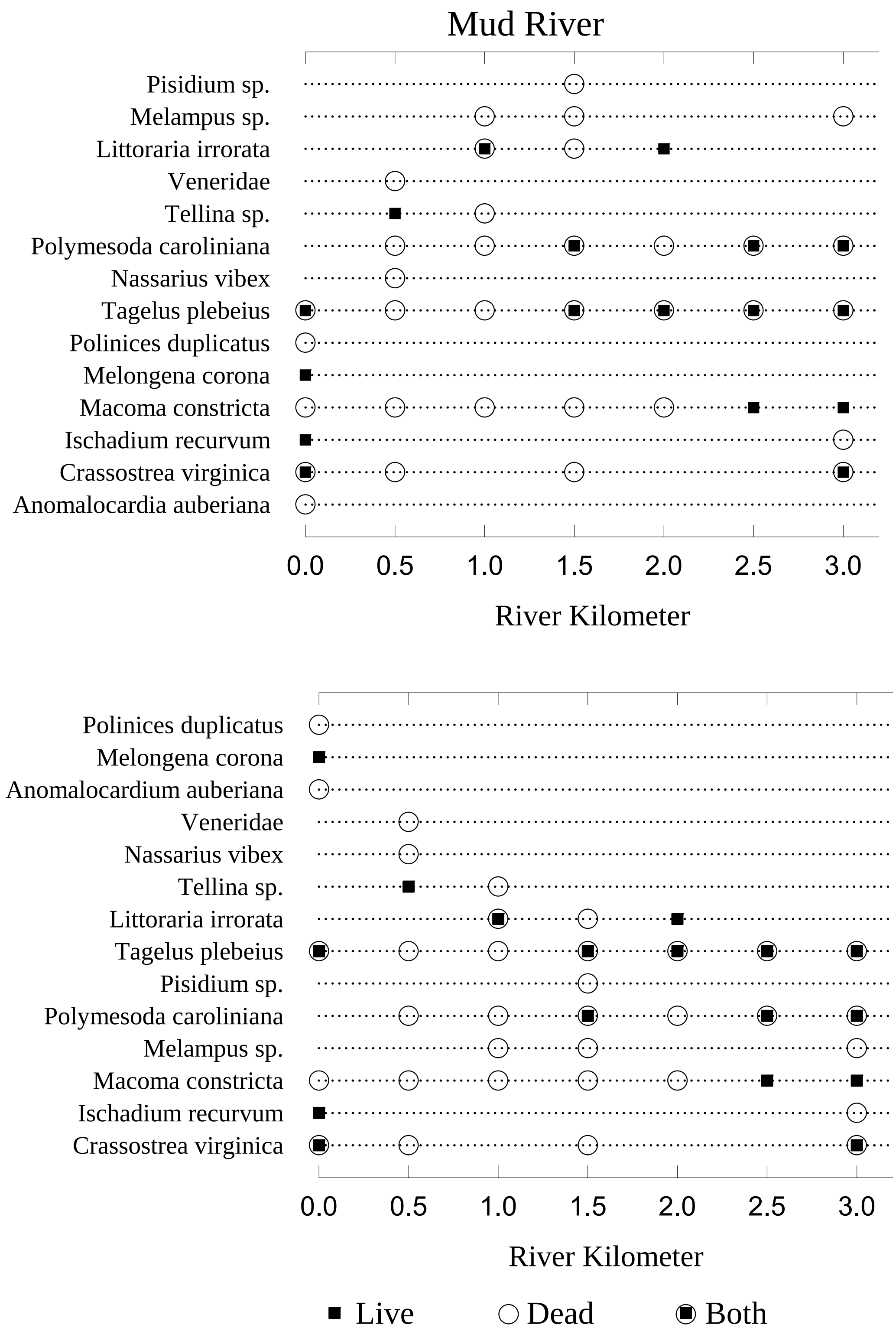
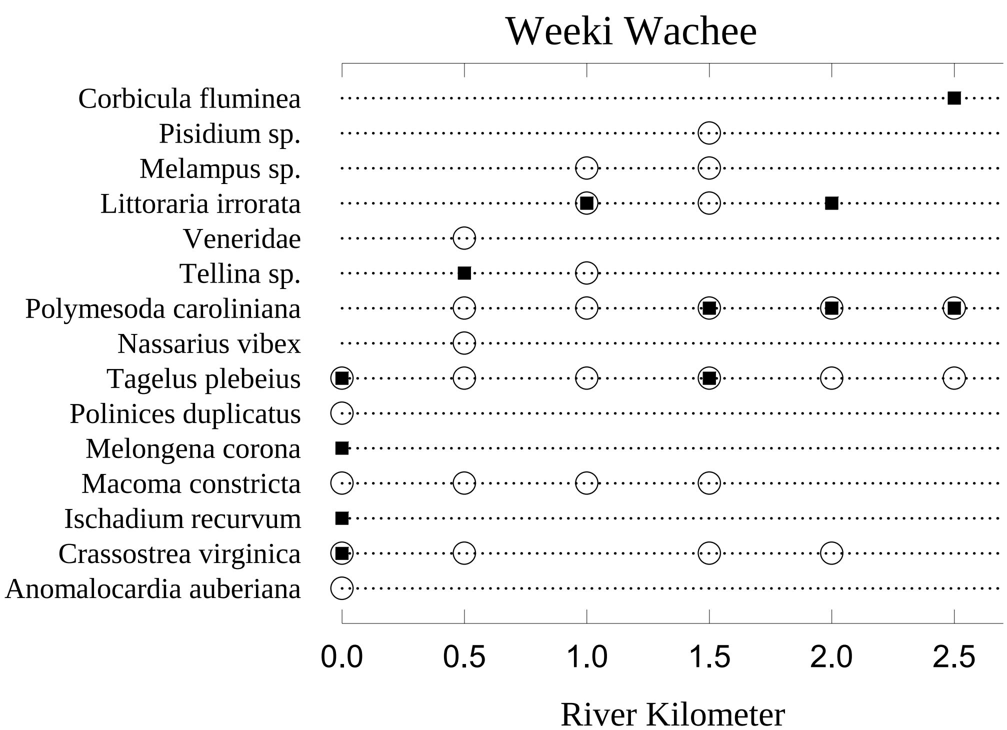


Figure 5-5(b)
Molluscan Presence / Absence in Weeki Wachee and Mud Rivers.



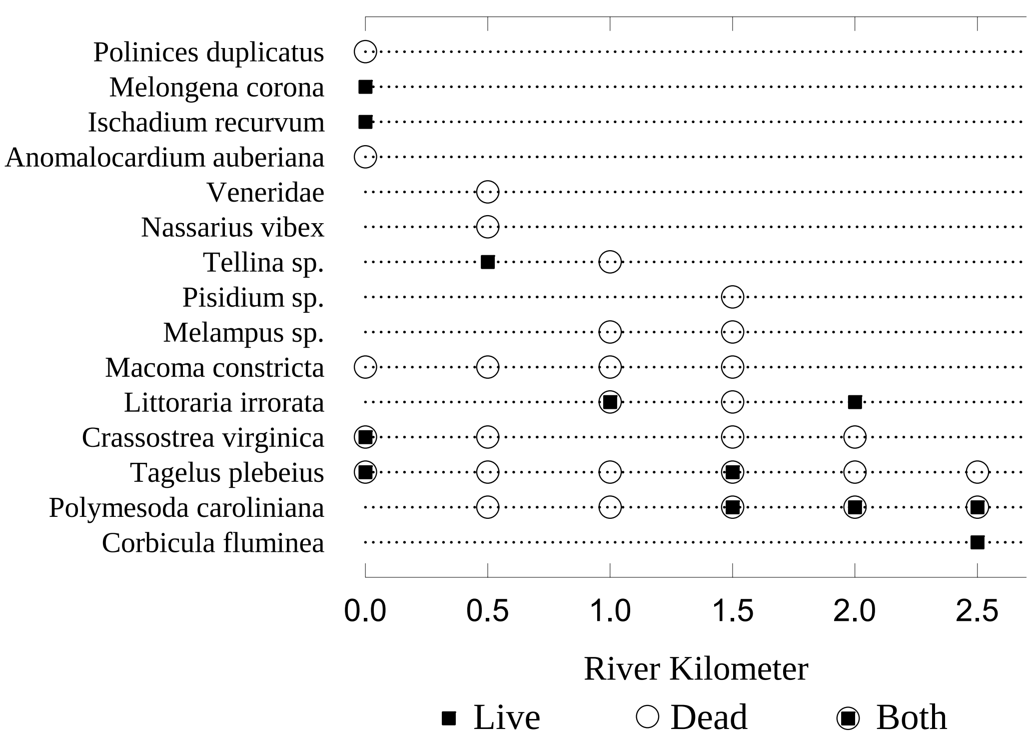


Table 5-11
Rank Order of Mollusc Abundance in the Mud and Weeki Wachee River
(Estevez 2005)

Species	Number	Percent	Cumulative Percent
Tagelus plebeius	82	40.0	40.0
Polymesoda caroliniana	47	22.9	62.9
Crassostrea virginica	31	15.1	78.0
Littoraria irrorata	13	6.3	84.4
Macoma constricta	10	4.9	89.3
Ischadium recurvum	9	4.4	93.7
Melampus sp.	4	2.0	95.6
Tellina sp.	2	1.0	96.6
Anomalocardium auberiana	1	0.5	97.1
Corbicula fluminea	1	0.5	97.6
Melongena corona	1	0.5	98.0
Nassarius vibex	1	0.5	98.5
Pisidium sp.	1	0.5	99.0
Polinices duplicatus	1	0.5	99.5
Veneridae	1	0.5	100.0
Total	205	100.0	

5.4.2 Relation to Inflow

To date, the mollusc surveys done along the west coast of Florida have been one, or two day events per river. Thus, there has been no attempt to sample across a range of stream flows. Montagna (2006), using data from the Peace, Myakka, Alafia, Weeki Wachee / Mud rivers, Shell Creek and Dona/Robert's Bay identified several species that characterize a particular salinity zone. He went on to conclude :

> " *In this limited analysis of southwest Florida mollusk communities, it is concluded that mollusk species are controlled more by water quality rather than the sediment they live in or on. The most important variable correlated with mollusk communities is salinity, which is a proxy for freshwater inflow. It is impossible to directly link community changes in response to inflow changes, because no(t) replicates over time were carried out in the rivers sampled. Although total mollusk abundance was not a good indicator of inflow effects, certain indicator species have been identified however, that characterize salinity ranges in southwest Florida rivers.*"

The most common molluscs present are included in **Table 5-12** and compared to the community observed in the Weeki Wachee/Mud River complex. Montagna found a number of significant relationships between abundance and salinity which can be expressed as :

$$y = a * \exp(-0.5*(\ln(s/c)/b)^2)$$

Where y = Number of organisms / m^2
a = maximum abundance
s = salinity (ppt)
c = maximum salinity value
b = rate of response change

The model assumes that there is an optimal range for salinity and that values will decline in a non-linear fashion for salinities on either side of optimal (Montagna et al. 2002). An example response is provided in Figure 5-5 for *Polymesoda caroliniana*. Table 5-13 provides the coefficients for significant ($r^2 \geq 0.3$) response of dominant native taxa in the Weeki Wachee and Mud Rivers.

Table 5-12
Rank Mollusc Abundance – Florida West Coast Tidal Rivers (Montagna 2006)

Percent Composition of Community Abundance		
Taxa	All Rivers	Weeki & Mud
Corbicula fluminea	40.4	1.25
Polymesoda caroliniana	11.1	21.2
Rangia cuneata	8.0	0
Tagelus plebeius	5.6	23.8
Amygdalum papyrium	5.2	0
Neritina usnea	3.7	0
Geukensia granosissima	3.4	0
Tellina versicolor	3.3	0
Crassostrea virginica	3.2	25.0
Macoma constricta	3.2	0
Ischadium recurvum	2.2	15.0
Littoraria irrorata	2.2	8.8
Mulinia lateralis	2.1	0
Nassarius vibex	1.7	0
Cumulative	95	95

Mollusc_Raw_Dat.xls

Figure 5-5
Polymesoda caroliniana Abundance as Function of Salinity in Tidal Rivers along West Coast of Florida

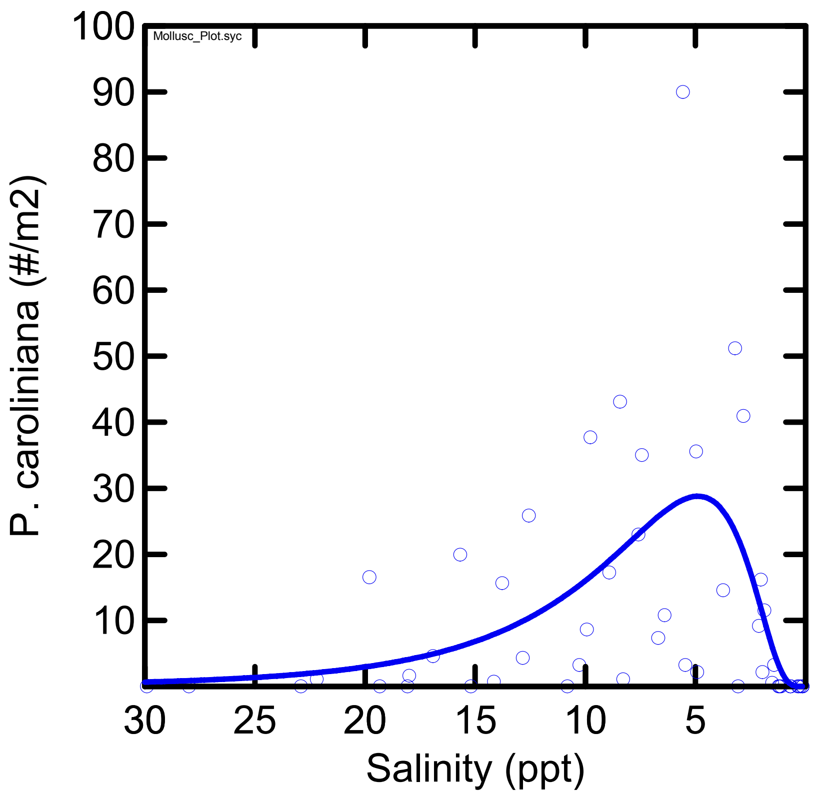


Table 5-13
Response Parameters for Dominant Native Mollusc in Weeki Wachee and Mud Rivers (Montagna 2006)

Taxa	r^2	a	b	c
Polymesoda Carolinia	0.32	28.8	0.66	4.89
Crassostrea Virginica	0.33	19.3	0.18	22.4
Littoraria irrorata	0.33	6.43	0.31	13.8

Mollusc_Raw_Dat.xls

CHAPTER 6 - RESOURCES OF CONCERN & CRITERIA

6.1 Resource Criteria / Goals - Estuarine

Evaluation criteria were established for salinity habitat, and cold weather manatee habitat using a flow record corrected for anthropogenic impacts (See Section 2.5). Additional criteria were established for fish and invertebrates, SAV, benthos and mollusc using uncorrected flow (e.g. observed record) since many of these tools were based on existing conditions and/or maximums.

6.1.1 Fish & Invertebrates

As discussed in Section 5.2.2.3, the plankton net collection resulted in three positive flow responses for taxa abundance, one of which was below the minimum explanatory criteria (e.g. $r^2 \leq 0.3$). The two remaining results (See Table 5-7) were identified as resources warranting further evaluation. Those taxa included a gastropod (sea slugs, opisthobranch) and the unidentified harpacticoid (copepod) previously discussed in Chapter 5. In addition, the three taxa from the seine and trawl results with the strongest positive abundance/flow responses were chosen for further evaluation. One[20] of these (pinfish, *Lagodon rhomboides*) exhibited a simple power relationship, while the other two (pink shrimp, *Farfantepenaeus* and blue crab, *Callinectes sapidus*) exhibited a quadratic response with an abundance maximum at mid-flow.

As stated in Section 5.2, the flow that existed during the fish and invertebrate sampling was higher than normal. Consequently, the domain (~166 – 252 cfs) of the response regressions is higher than the unadjusted Block 1 and 2 median flows (144 and 162 cfs respectively) for the baseline period chosen (1984-2004) (Figure 6-1 compares the flow on plankton tow sample dates with the median and 90th percentile flows for the entire baseline period.) In the absence of a usable baseline flow for comparison, the initial intent of establishing a criteria for the seine and trawl quadratic regressions was the flow at peak abundance. For consistency, the criteria for the plankton tow results and the linear seine / trawl was based on the mean of the flows at peak abundance as summarized in **Table 6-1**. (See Table 5-7 and Table 5-8 for response equations. For reasons described in Section 7.1, these criteria were not applied as part of the MFL evaluation.)

[20]Three pseudo-species of pinfish were the highest r^2 of all 20 pseudo-species. Rather than evaluate the same taxa repetitively, only the strongest response (seine, $\leq$ 35 mm) was retained for further evaluation.

Figure 6-1
Plankton Tow Flows Compared to Baseline

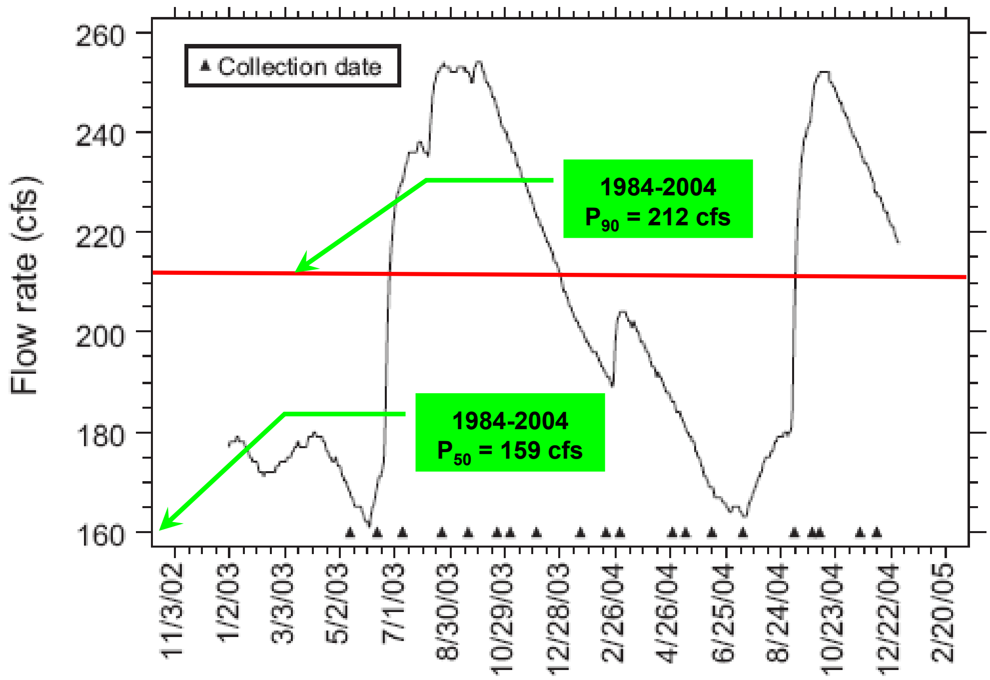


Table 6-1
Baseline Flows for Evaluation of Fish / Invertebrate Losses

Resource	Equation	Basis	cfs
Lagodon rhomboides (pinfish<= 35 mm)	Quadratic	Flow @ Peak Abundance	196
Farfanepenaeus duorarum (pink shrimp >= 15 mm)	Quadratic	Flow @ Peak Abundance	191
Callinectes sapidus (blue crab <= 35 mm)	Quadratic	Flow @ Peak Abundance	200
gastropods, opisthobranch (sea slug)	Linear (power)	mean of Above	196
unidentified harpacticoids (copepod)	Linear (power)	mean of Above	196
WW_MFL_Calcs.xls			

6.1.2 Submerged Aquatic Vegetation

It was originally intended to establish resource criterion for native submerged aquatic vegetation (SAV) based on an allowable increase in salinity at the location of maximum observed density. An estimate of the long term salinity was developed from the LSM and is provided in Table 6-2. However, when comparing the spatial distribution and salinity between the Weeki Wachee and Mud Rivers, it does not appear that salinity is the dominant factor controlling distribution. Increased boat traffic in the Weeki Wachee has been suggested (S. Flannery, personal communication) as a significant factor affecting distribution. Given the uncertainty regarding the impact of salinity on distribution, no criteria were established for SAV in the Weeki Wachee River.

Table 6-2
Dominant SAV – Location of Maximum Density and Expected Salinities

	Maximum Density	Rkm	Salinity, Estimated	Salinity Tolerance (1)
Block 1, 144 cfs				
Ruppia	3.2	0.0	21.2	0 - >35
Zanichellia	4.1	1.0	14.7	20
Potamageton	0.7	2.2	6.8	9
Block 3, 162 cfs				
Ruppia	3.2	0.0	18.2	0 - >35
Zanichellia	4.1	1.0	11.6	20
Potamageton	0.7	2.2	3.8	9

1) Batiuk, et al. 1992. Chesapeake Bay SAV Restoration Targets.
Salinity_Tolerance.xls

6.1.3 Manatee

Protection of a thermal refuge for the endangered West Indies manatee was established as a habitat resource. A total of four criteria were established as provided in Table 6-3. Two temperature extremes were defined in order to evaluate a 'sustained' exposure (> three days below 20^{o}C and an 'acute' exposure (> 4 hours at less than 15^{o}C). The volume and area of each were determined at each temperature requirement. Provided the acute criterion was not exceeded, it was assumed that animals could survive until high tide allowed access to deeper warm water upstream. [At no time in the various evaluations was the acute criteria exceeded]. Initially a minimum depth of 3.0 feet of water was chosen and is slightly above the preferred manatee depths of 2.7 to 10.2 feet reported by Worthy (2005). In addition, these criteria were evaluated under two baseline flow conditions.

In application, a baseline area and volume was determined using the public domain Environmental Fluids Dynamic Code (EFDC) model available through the US EPA[21]. EFDC is a general purpose modeling package for simulating flow, transport and biogeochemical process in surface waters. Spring discharge was then reduced by a fixed percent (e.g. 5, 10, and 25 percent) and a new volume determined. Figure 6-2 compares the two volume scenarios for the higher flow scenario. A criterion of maintaining 85 percent of the volume and area under each flow scenario was proposed. However, even at the higher reduction scenarios (e.g. 25%) there is sufficient thermal refuge remaining to accommodate forty times the number of animals that currently use the refuge. Thus, the fifteen percent loss criterion was deemed excessively restrictive and was not imposed. Additional details can be found in Chapter 7 which focuses on the technical approach.

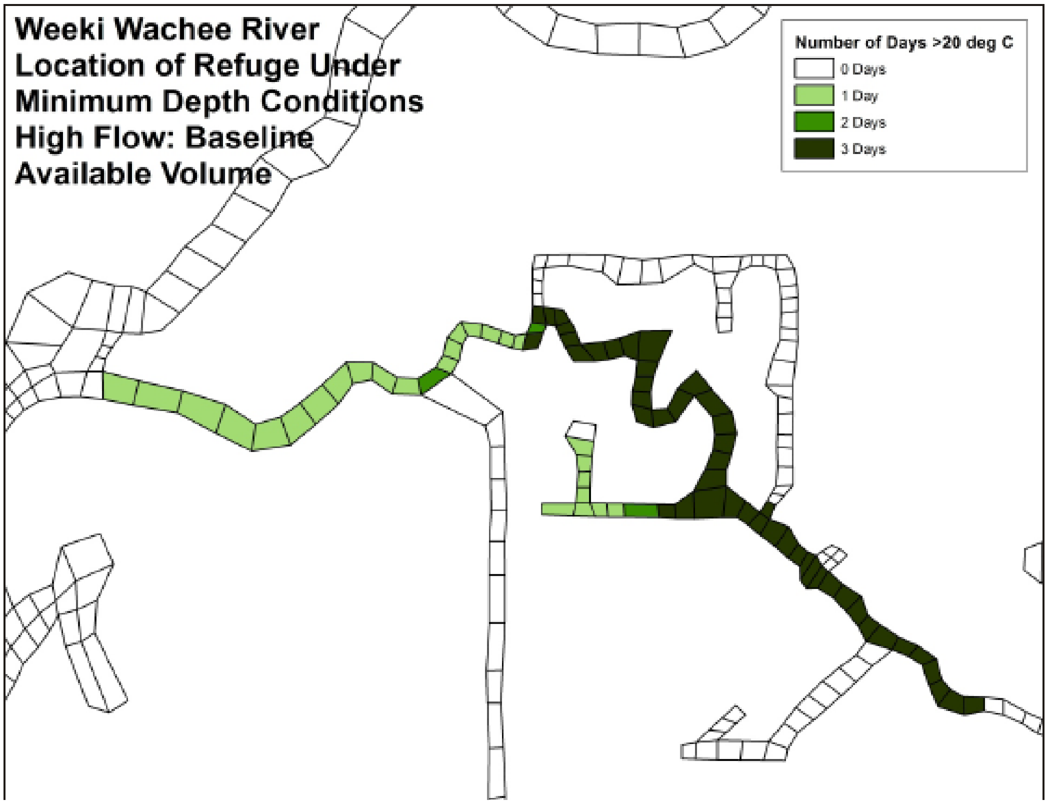
Table 6-3
Manatee Thermal Criteria

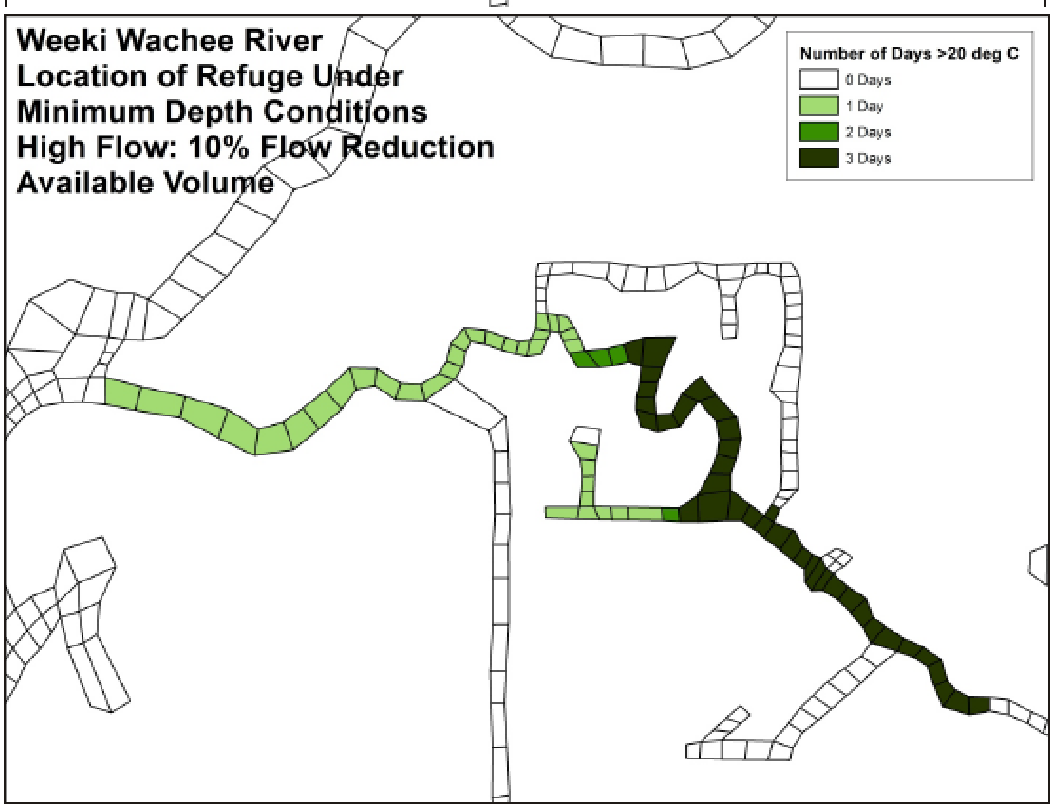
A	15% Loss in Total Volume $\geq$ 20°C - at a minimum depth of 3 feet at mean low tide - with a minimum 3 foot access at mean high tide - for a critically cold event lasting 3 days
B	15% Loss in Total Area $\geq$ 20°C - at a minimum depth of 3 feet at mean high tide - with a minimum 3 foot access at mean high tide - for a critically cold event lasting 3 days
C	15% Loss in Total Volume $\geq$ 15°C - at a minimum depth of 3 feet at mean low tide - with a minimum 3 foot access at mean high tide - and persisting for more than 4 hours
D	15% Loss in Total Volume $\geq$ 15°C - at a minimum depth of 3 feet at mean high tide - with a minimum 3 foot access at mean high tide - and persisting for more than 4 hours

criteria.xls

[21] http://www.epa.gov/athens/research/modeling/efdc.html

Figure 6-2
Example of Change in Volume > 20°C with Reduced Flows- Weeki Wachee River





6.1.4 Benthos

Protection for benthic communities was defined at several levels. Specific criteria involved estimating the reduction in flow that would cause a fifteen percent reduction in peak abundance, peak diversity and in peak total number of taxa. Baseline and threshold criteria are presented in Table 6-4**.** The salinity at peak productivity and diversity was determined from quadratic relationships with salinity (Janicki 2007).

Table 6-4
Benthic Community Criteria

Metric	Maximum Value	Allowable Threshold	Salinity @ Maximum	Salinity @ Allowable
Number of Taxa	12.3	10.5	8.0	11.2
Abundance (#/m^2)	16,900	14,400	8.0	10.6
Diversity (H')	2.7	2.3	8.0	12.0

WW_Bentho_Tabs.xls

At the more general level, benthos (and fish) habitat was evaluated in terms of volume of water at, or below some specified salinity. Isohaline values of 2, 5 and 15 ppt were chosen for evaluation and a significant loss of habitat was defined as greater than a fifteen percent loss compared to the baseline.

In addition to criteria for volume, two additional isohalines were selected for bottom area evaluation based on the results of the benthic community alignment with salinity derived from principal component analysis described in Section 5.1.2. In addition to loss of bottom area covered by the 2, 5 and 15 ppt, the 3.5 and 12.5 ppt isohalines were also evaluated. As in the case of volume, the threshold of significant harm was defined as greater than a fifteen percent loss of habitat resulting from flow reductions when compared to the baseline adjusted for declines due to pumpage.

6.1.5 Mollusc Criteria

The mollusc criteria was based on maintaining at least eighty-five percent of the abundance of three dominant and native taxa that exhibited sufficient response (e.g. $r^2 \geq 0.3$) to salinity. The three taxa chosen were *Polymesoda carolinia, Crassostrea virginica* and *Littoraria irrorata*.

6.2 Resource Criteria / Goals – Freshwater

The details of the District's protocols for setting freshwater MFL criteria and goals has been documented elsewhere (SWFWMD 2002, Kelly et al. 2005a, 2005b, 2005c, 2007a and 2007b) and is only briefly summarized herein[22].

The freshwater segment of the Weeki Wachee River was evaluated using the Physical Habitat Simulation Model (PHABSIM). Data were collected for PHABSIM analysis at three locations (Figure 6-3) in the Weeki Wachee River watershed. Two of the sites were in the main river and were called the "Sandbag" site and the "Wide" site. The third site was located on the short spring run leading from Little Weeki Wachee Spring (also known as Twin Dee's) and was named the "Little Weeki Wachee" site (Figure 6-3). For all sites, the flow record evaluated in the PHABSIM time-series analyses was the period 1967 through 2004. Evaluation was conducted on the raw data, uncorrected for anthropogenic impacts due to pumpage.

The Little Weeki Wachee site is located approximately 400 meters west of the main spring. The small spring run is highly braided and surrounded by dense vegetation. Substrate along the spring run is generally a sandy muck matrix. The Little Weeki Wachee Spring run is estimated to flow 380 meters before emptying into the main river.

The Wide site is the most upstream PHABSIM site on the main river and is located 1.2 km downstream from the head spring. Data were collected across one transect at this site. The site is highly representative of the upper portion of the river with moderately high banks, a flat sand bottom, and scarce vegetation. The river is 20 meters wide at the site under medium flow conditions.

The Sandbag site is located 1,000 meters downstream of the Wide site. The site is representative of the middle reaches of the non-tidally influenced portions of the Weeki Wachee River. Data were collected at three cross-sections for this site, a shoal, a run, and a pool. The shoal for this site is composed of a mixture of natural and man-made rocks which act as a control point for flow. The site consists of high banks on the north shore and very low relief banks on the south. The river is an average 12 meters width through the Sandbag site with a mixture of limerock, sand, and vegetated bottoms.

The freshwater criteria established for the Weeki Wachee was based on maintenance of specific habitat requirements for spotted sunfish, largemouth bass, bluegill, and macroinvertebrate diversity using habitat suitability curves within PHABSIM. A total of twelve taxa / life stage requirements were evaluated. Initial conditions are established for un-impacted flows and then flows are incrementally reduced (up to forty percent) until eighty-five percent of the original habitat remains.

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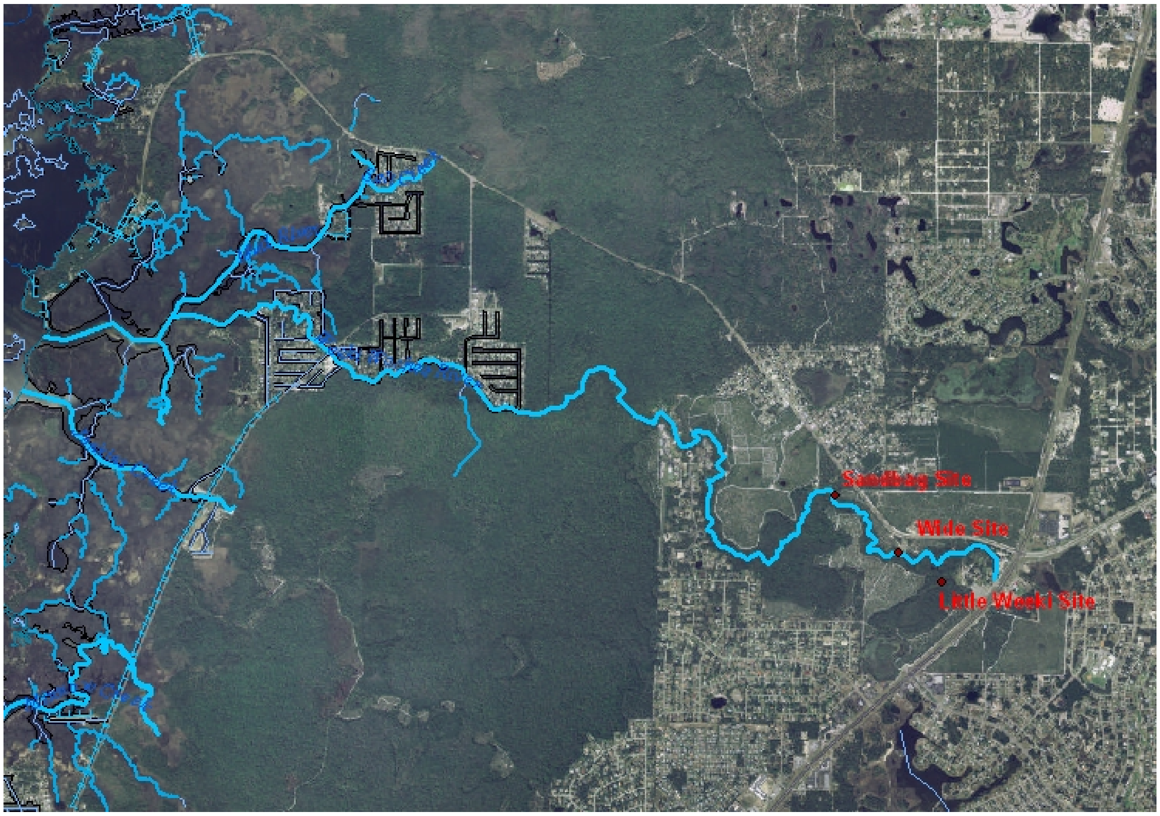
[22] Interested readers may contact the District for copies, or may download these reports at http://www.swfwmd.state.fl.us/documents/

Figure 6-3.
Location of the Three PHABSIM Sites on the Weeki Wachee River.



CHAPTER 7 - TECHNICAL APPROACH

7.1 Fish / Invertebrate Technical Approach

The fish and invertebrate models were not used in developing the Weeki Wachee MFL because (a) flows during the sampling period were abnormally high and do not represent the long-term flows and (b) the response seemed unreasonable when compared to typical flow conditions. In general, the observed flows on sample dates ranged from 166 to 252 cfs. In comparison, the median unadjusted Block 1 (April 20 – June 25) flow for the baseline period was 144, and the Block 3 (June 26 – October 26) median flow was 162 cfs which makes establishing a fish/invertebrate MFL applicable to long-term flows troublesome. The mean and median flow on sampling dates was 221 cfs which has approximately a 94th percentile rank for the baseline period.

Additional complications became apparent when the criteria were applied to the flow / abundance relationships. As shown in Table 7-1, when the flow associated with peak abundance is reduced 15-20 percent, the predicted response is that pinfish (< 35 mm) would be essentially eliminated from the Weeki Wachee system. The reduced flow that results in the predicted elimination of this size class is approximately the median flow (159 cfs) of the 1984-2004 baseline period. Thus, use of predictive equations derived from abnormally high flow conditions was considered inappropriate for typical conditions.

Table 7-1
Response of Pinfish Abundance to Reduced Flow in the Weeki Wachee River

Lagodon rhomboides (pinfish<= 35)			
Flow (cfs)	**% of Flow @ Peak Abundance**	**Abundance (# / m2)**	**% of Peak Abundance**
196	100%	32.91	100.0%
194	99%	32.22	97.9%
192	98%	30.64	93.1%
190	97%	28.29	85.9%
188	96%	25.33	77.0%
186	95%	21.98	66.8%
176	90%	6.51	19.8%
167	85%	0.74	2.3%
157	80%	0.03	0.1%
147	75%	0.00	0.0%

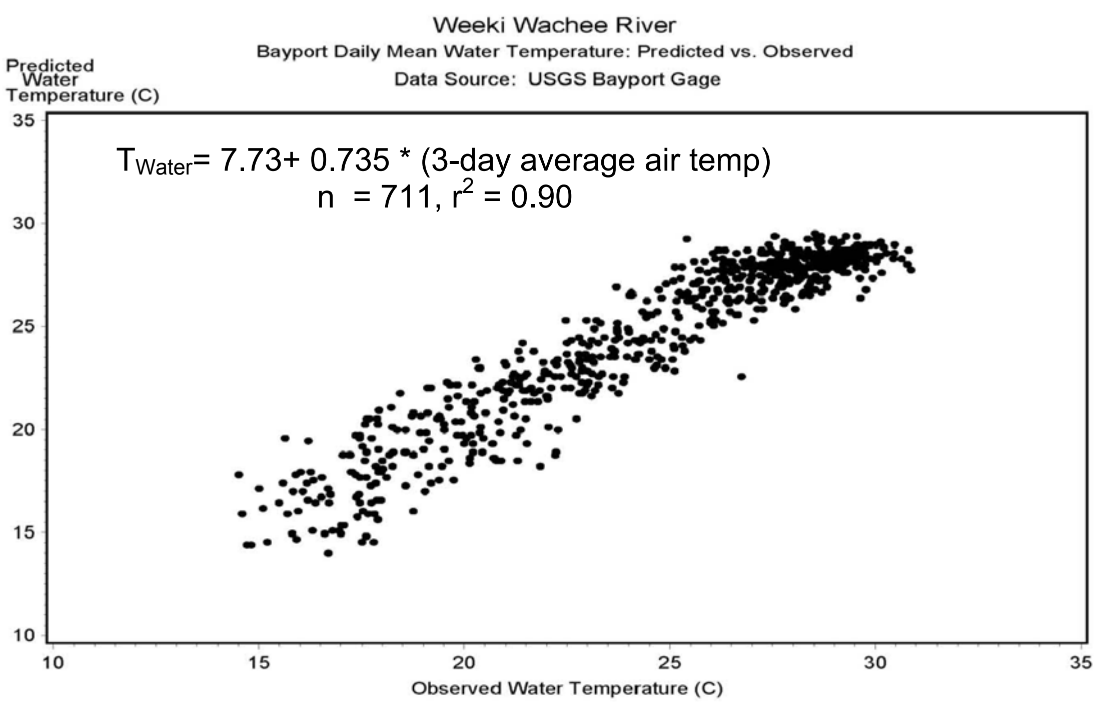
WW_Check_Calcs.xls

7.2 Manatee Approach

Establishing a thermal MFL required a number of steps in order to adequately portray critical conditions. The steps are described in detail in *Impacts of Withdrawals on the Thermal Regime of the Weeki Wachee River* [23](ATM 2007) and are summarized herein. An adequate thermal refuge results from sufficient discharge of warm water, appropriate depth and access. Tide stage can greatly affect the size of refuge as cold Gulf water is transported further inland with higher than normal tides. The thermal offset required is a function of the temperature differential between the colder Gulf waters and the warmer spring discharge.

While there is an adequate record of air temperature at Weeki Wachee, there is no long-term continuous record of water temperature in Weeki Wachee. The available continuous record of water temperature is limited to 2003-2005 at Bayport, but air temperature extends from 1970 to 2005 at Weeki Wachee. In order to evaluate a longer period, a regression was developed from air temperature to predict water temperature at Bayport. Figure 7-1 summarizes the relationship developed between air temperature and water temperature which allows an extended prediction[24] of water temperature.

Figure 7- 1
Weeki Wachee Air Temperature vs. Bayport Water Temperature



[23] Available at http://www.swfwmd.state.fl.us/documents/
[24] Some temperatures were predicted from air temperatures which were below the regression domain.

A time series(October 1, 2000 through March 31, 2001) of cold water temperature was predicted from this equation and used to establish boundary conditions for the two flow scenarios described below. Observed mean daily air temperatures ranged from 1.7 ^{o}C to 25 ^{o}C (median = 16.1) for this manatee season and included two severe cold periods which were modeled. The predicted water temperature for December 21 2000 was 11.4 ^{o}C followed by another cold front on January 6, 2001 producing a boundary temperatures of 11.1 ^{o}C.

Two flow scenarios were culled from the adjusted spring discharge record (The thermal evaluation was based on baseline flows adjusted for a 15.2 cfs[25] pumpage loss.) The 'high flow' scenario consisted of flows from October 1, 2004 through March 31, 2005. Minimum daily flow recorded during this period was 174 cfs, and the maximum observed was 242 cfs (median = 208). A 'low flow' scenario was defined as the daily flows from October 2000 through March 2001. The minimum flow during this period was 106 cfs, and the median flow was 118 cfs. Maximum daily flow recorded was136 cfs.

Finally a representative period (October 2004 through March 2005) of tide and salinity cycles was chosen and used as boundary conditions for both flow scenarios.

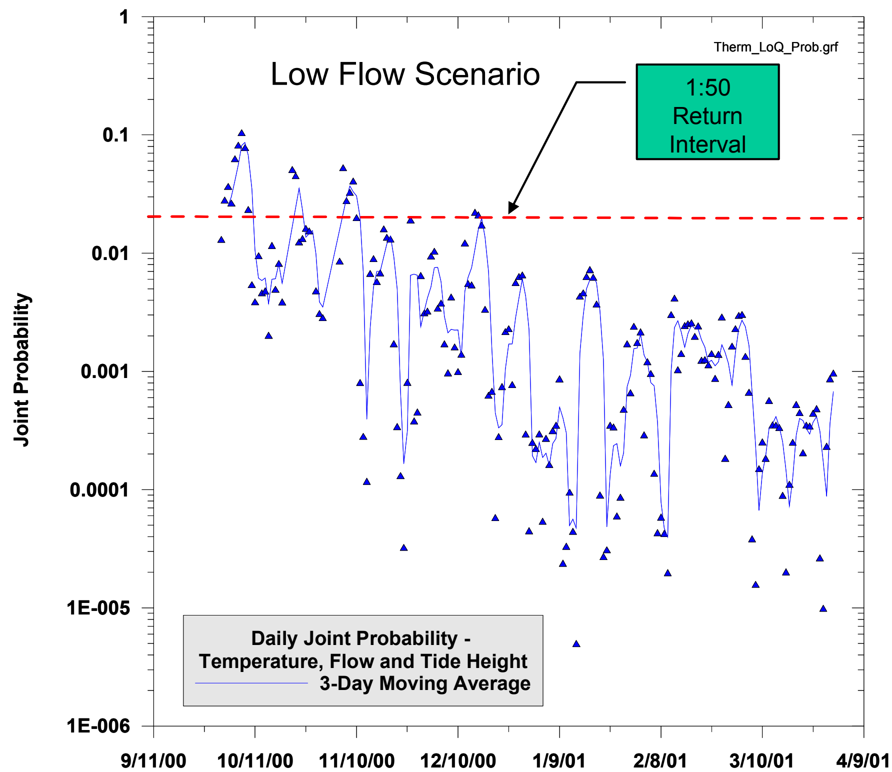
The daily joint occurrence probability of the flow, tide (daily maximum level) and temperature (daily average) was determined for the simulation scenarios. The manatee season was extracted from daily records and converted to Cunanne probabilities [probability = (rank-0.4)/ (n+0.2)]. For observed flow and air temperatures (as surrogates for water temperature), the period ranked and converted consisted of daily observations during the manatee season for 1970 through 2004, or a period covering 35 years. For stage, daily high tides for the period 1986-2004 were extracted and converted to probabilities. Joint probability was calculated at the product of the individual daily probabilities. Using December 21 2000 of the low flow scenario as an example results in a joint probability of 0.0009 from the following inputs:

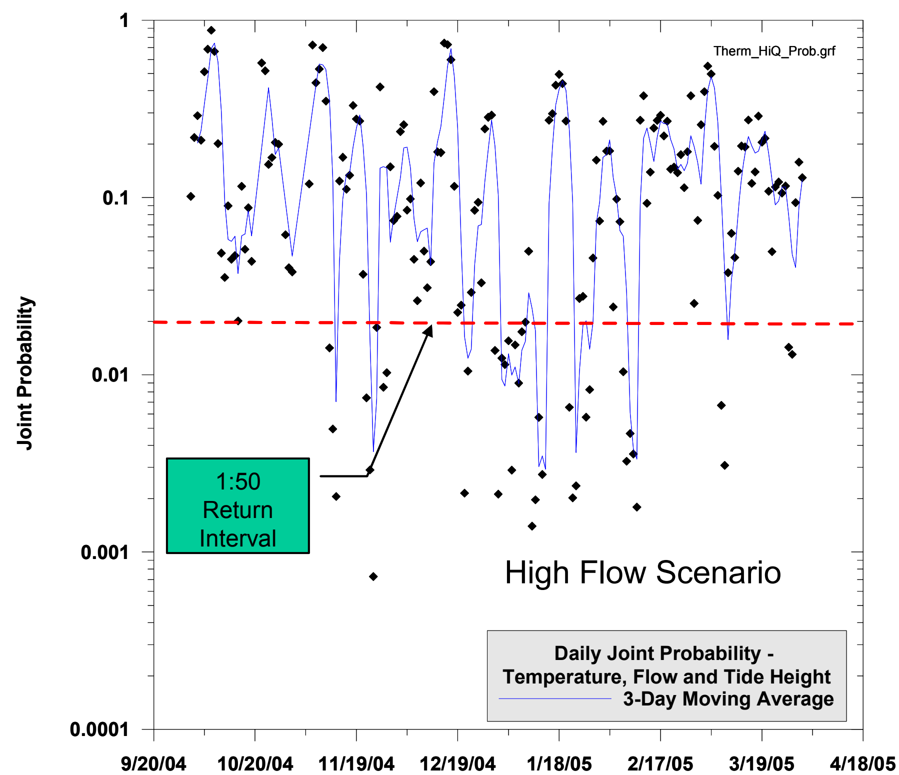
Flow –	Dec 21, 2000	= 119 cfs / p = 0.024 (ranked low to high)
Tide Max -	Dec 21, 2005	= 1.77 ft / p = 0.746 (ranked high to low)
Air Temp –	Dec 21, 2000	= 1.67 ^{o}C / p = 0.003 (ranked low to high)
	Joint probability	= 0.024 * 0.746 * 0.003 = 0.00005

The daily joint probabilities and a three-day moving average (corresponding to the critical low temperature duration) was propagated through the daily joint probabilities and plotted as Figure 7-2. The results indicate that while the high flow scenario represents a fairly frequent combination of environmental factors, the low flow scenario is very conservative and would occur only rarely.

[25] This value is based on an early estimate of pumpage losses which averaged 15.2 cfs from 1984-2004. A subsequent re-evaluation of the loss resulted in a slightly lower number (13.7 cfs) that was used in the salinity habitat

Figure 7-2
Joint Probability of Occurrence – Weeki Wachee Thermal Regime Evaluations





The loss of thermal refuge was determined for a range of assumed flow reductions (e.g. 5, 10, 25 and 50 percent) applied to the adjusted baseline flows. The results are given in Table 7-2. While shallower minimum depths (ca 2.7 feet) can be justified (Worthy, 2005) refuge volume and area were determined for a minimum depth of 3.8 feet (Rouhani et. al. 2006) for comparison with the Blue Springs evaluation. As stated in Chapter 6, initially the intention was establish a 15% loss criterion, but based on manatee usage in Blue Springs Florida the area and volume of refuge remaining even after significant flow reductions are much more than adequate for the relatively small population of animals using the Weeki Wachee and are adequate for the entire northwest Florida manatee population.

Table 7-2
Thermal Refuge Reductions Due to Reduced Flows

3.8 ft Min.	High Flow Scenario		Low Flow Scenario	
% Flow Reduction	Volume (m^3)	Area (m^2)	Volume (m^3)	Area (m^2)
0	92,000	37,200	55,700	27,500
5	85,900	34,900	46,100	21,100
10	77,400	33,500	37,900	18,200
25	43,000	18,900	11,300	6,000
50	27,400	10,700	-	-
WW_Refuge.xls				

Several pertinent benchmarks can be characterized from the manatee usage of Blue Springs (ibid) which has been monitored on a regular basis since 1978. Figure 7-3 provides insight into actual space utilization during the day of maximum density of each manatee season for the period 1981-2001. Figure 7-4 depicts the density on the coldest day or each manatee season for the same period. The combined results suggest an areal use rate of between 0.006 and 0.010 manatee / ft^2 (15- 9 m^2/ animal). The more conservative usage (15 m^2/manatee) was used to estimate the number of animals that could be supported by the baseline and reduced refuge areas presented in Table 7-2. The results are given in Figure 7-5 along with estimates based on volume usage (3.1 m^3/animal) reported for Blue Springs. Based on a comparison of current use and refuge available within the Weeki Wachee, an MFL was not proposed for the purpose of manatee protection in the Weeki Wachee River.

Figure 7-3
Maximum Day Manatee Usage – Blue Springs, Florida

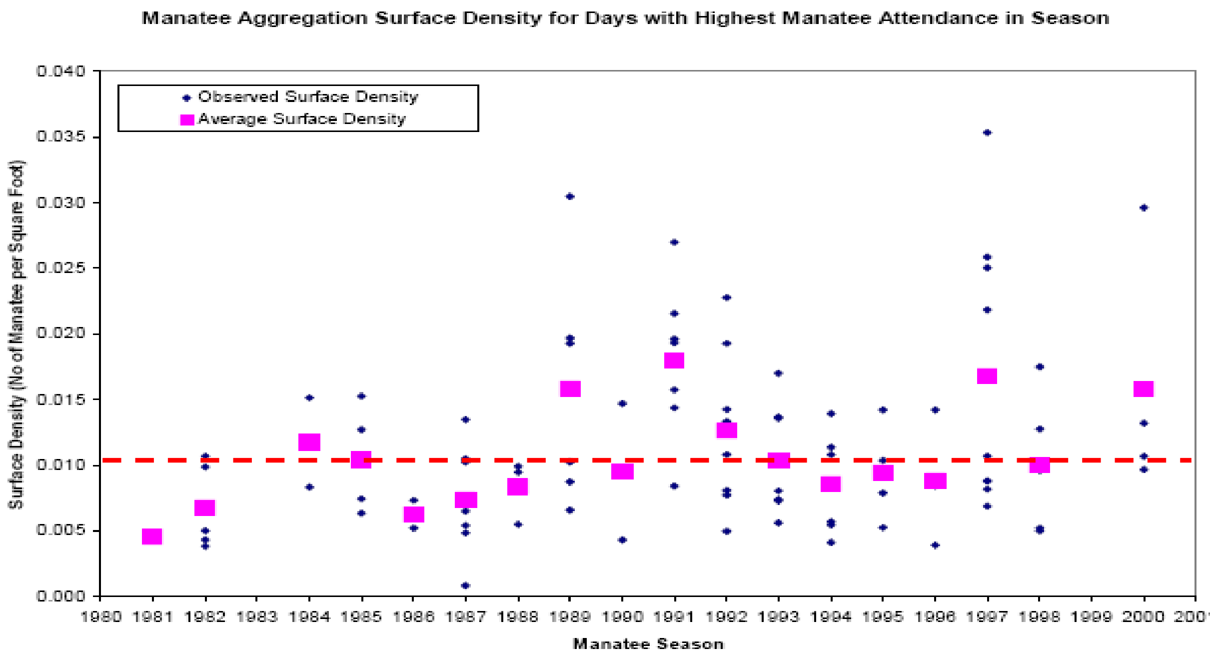


Figure 7-4
Maximum Manatee Usage on Coldest Days – Blue Springs, Florida

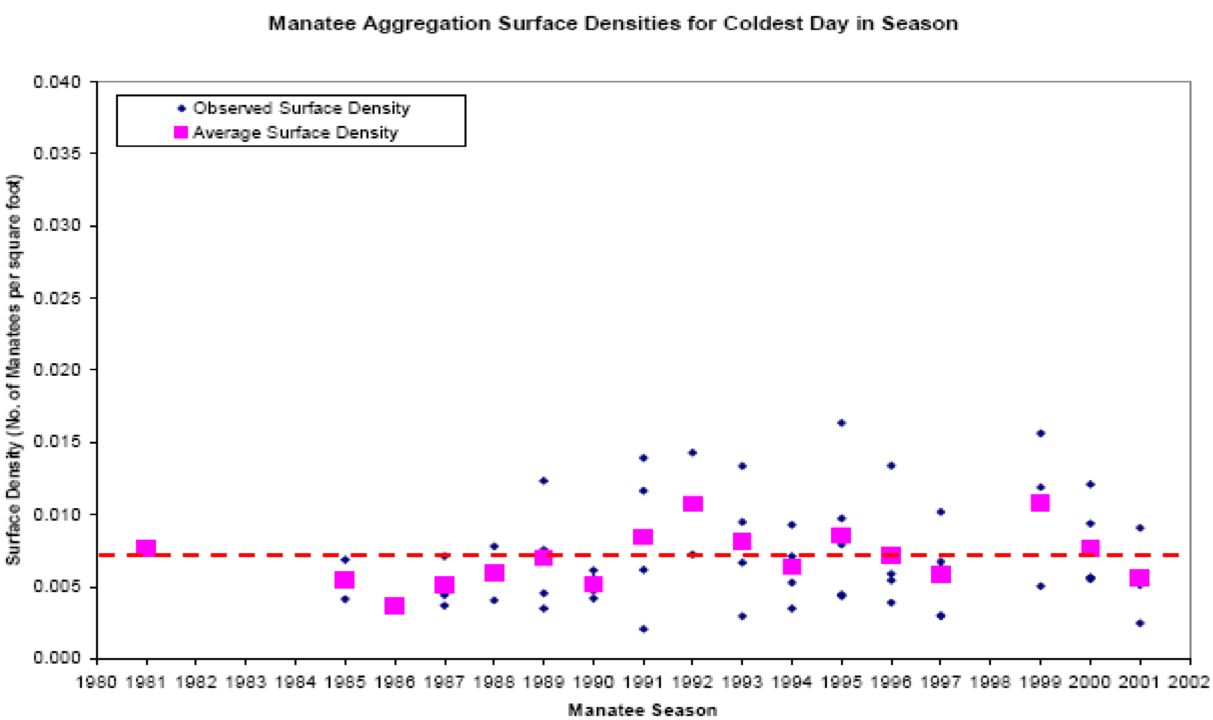
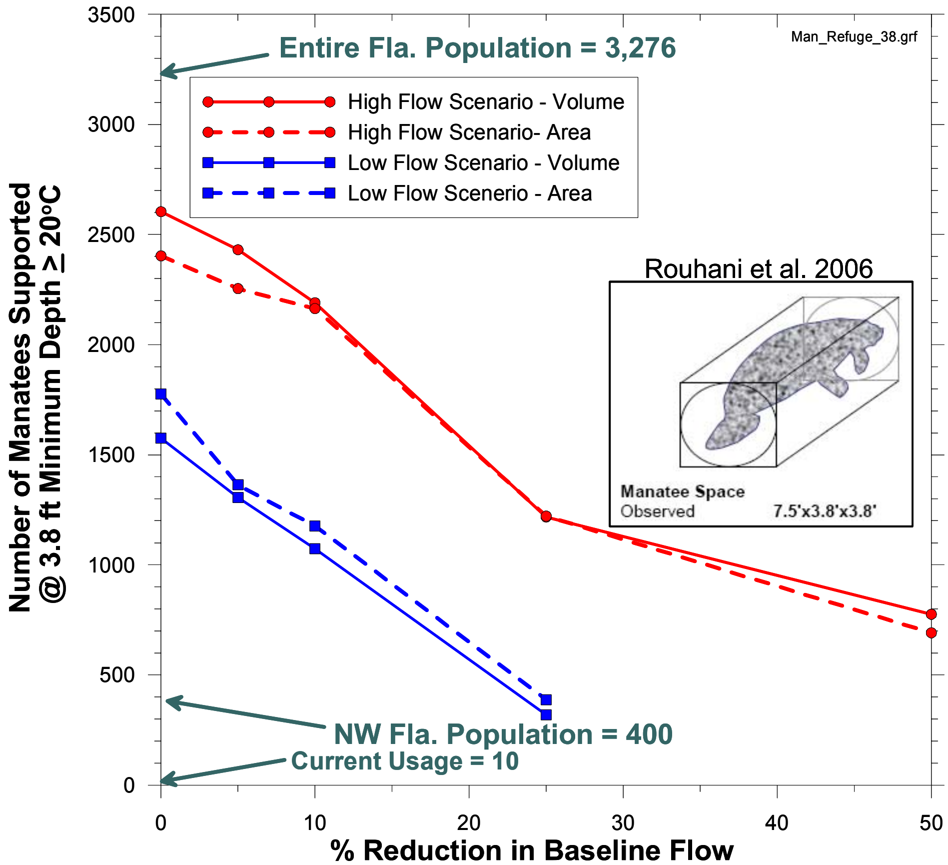


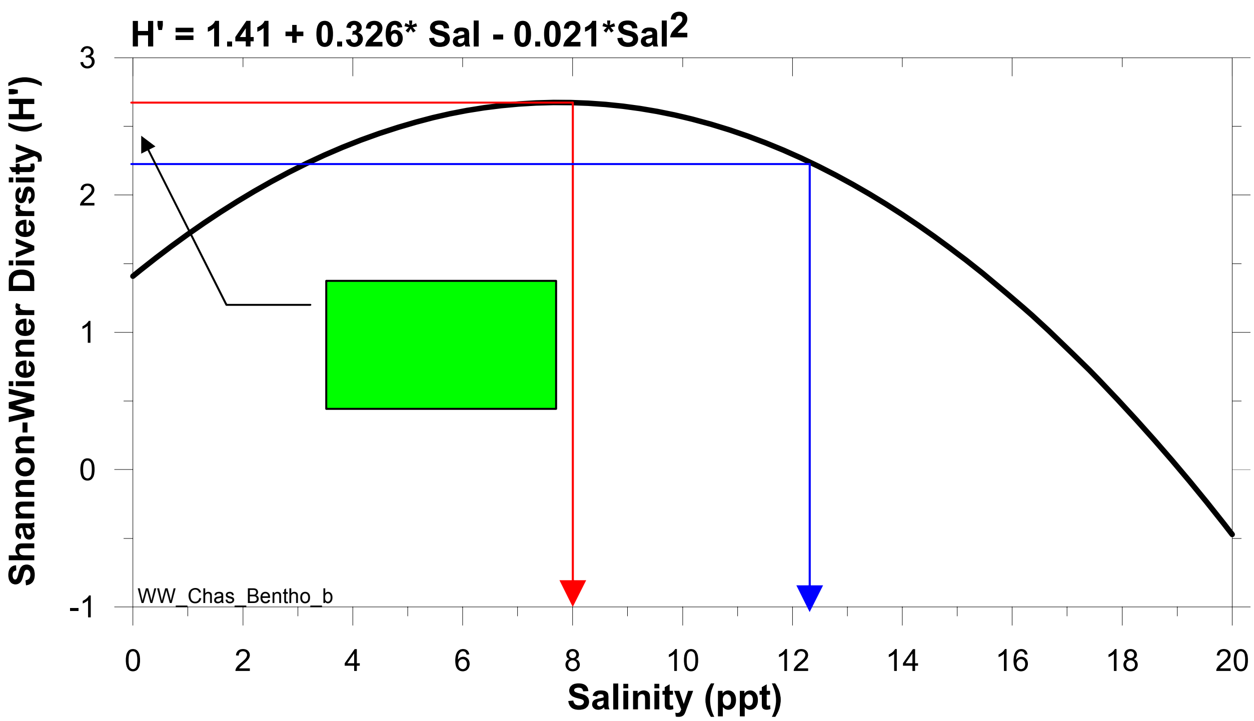
Figure 7-5
Number of Manatees Supported by Baseline and Reduced Flows – Weeki Wachee, Florida (3.8 foot minimum depth)



7.3 Benthos Technical Approach

The benthic community response to salinity was evaluated as change in number of taxa, diversity and abundance and as a change in habitat (See next section). Response of benthic metrics to salinity was determined in accordance with the governing equations provided in Table 5-1 coupled with the SLR regression in a manner analogous to the SAV application. Figure 7-6 illustrates the steps which are described in the example which follows. Observed median flow conditions (not adjusted for athropogenic impacts) were used because the observed biota from which the relationships were derived represent specific locations within the system under observed flow conditions.

Figure 7- 6
Example Calculations for Benthic Diversity



<u>Given Maximum Benthos Diversity Occurs at Salinity of 8.0 ppt.</u>

H' = 1.41 +0.326* 8.0 $_{ppt}$ -0.021 * (8 $_{ppt}$)^2
H' = 2.67
15% Reduction in Diversity = 0.85 * 2.67 = 2.27
2.27= 1.41 +0.326* X $_{ppt}$ -0.021 * (X $_{ppt}$)^2
X = 12.2 ppt
****
<u>Where does 8.0 ppt occur under Block 1 Flow of 144 cfs ?</u>
From Longitudinal Salinity Model :
Iso_km = -0.8929 + 593.4 *(1/Q)-0.152*Sal
Where Q = 144 cfs and Sal = 8.0 ppt
Iso_Km = 2.01 km

<u>Holding Iso_Km constant, what flow will result in Sal = 11.15 ppt ?</u>
2.01 km = -0.8929 + 593.4 *(1/Q)-0.152*12.2 $_{ppt}$
Q = 124.9 cfs

Flow Reduction = 100*[(144-124.9/144)] = 13.3 %

Using diversity as an example, salinity at the peak of the diversity was determined from graphs (Janicki, 2006) illustrating response to salinity. At a salinity of 8.0 ppt, the maximum diversity of 2.7 was reached. Reducing the diversity by fifteen percent and solving for salinity results in a value of 12.15 ppt.

Next, the location of peak salinity (8.0 ppt) under Block 1 flow (unadjusted) was determined to be 2.0 Rkm using the LSM regression. Holding this location and setting the salinity at this location to 12.15 ppt, the regression was solved for flow resulting in a reduced flow of 125 cfs. Recapping, a flow of 144 cfs (representing observed median block flows 9184-2004) results in a salinity of 8.0 ppt at Rkm 2.0, while a flow of 125 cfs results in a salinity of 12.15 at the same location. At salinity of 12.15, peak diversity is reduced by fifteen percent and the associated flow reduction is thirteen percent.

7.4 Application of Salinity Habitat Model

Determination of the loss of volume (or bottom area) at a given salinity was determined sequentially according to the following steps using the LOC correlations.

1) Estimate location (Rkm) of desired isohaline under baseline flows. (Bottom isohalines and median block flows, adjusted for pumpage were used. Block 1 observed median for 1984-2004 = 144 cfs plus anthropogenic adjustment of 12.7 cfs.) Block 1 flow evaluated was 157 cfs. Block 3 flow evaluated was 175 cfs)

2) Estimate upstream volume (or area as appropriate) at the river location calculated in step 1 using volume vs. Rkm equation. (See Figure 3.3)

3) Reduce the upstream volume by fifteen percent.

4) Calculate the new location of the isohaline from volume vs. Rkm equation

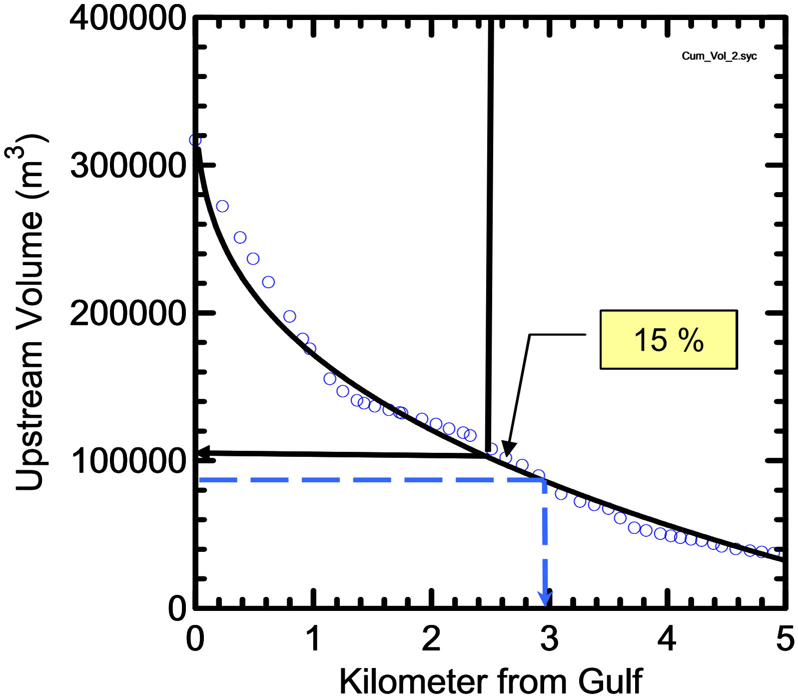
5) Calculate the reduced flow that would result in the new location of the isohaline using the LOC correlation.

The steps are graphically illustrated in Figure 7- 7 for Block 1 adjusted flows (144 cfs + 12.7 cfs adjustment) and the 2 ppt isohaline. This approach was repeated for all isohalines of interest and for both volume and bottom area. A fifteen percent loss was determined for each isohaline LOC equations presented in Table 4-7 and intermediate isohalines were interpolated from those results. For example, the Block 1 percent flow reduction for 14 ppt volume was 6.40 % and for 16 ppt volume the reduction was 5.60%. The 15 ppt volume reduction was interpolated as 6.01%

Figure 7- 7
Estimation of Flow Reduction Resulting in 15% Loss of Volume at 2 ppt.

$Km_{baseline}$ = 1.42 + 619.31 * (1/157 cfs) (See Table 4-7)
Km = 2.52;

Volume = 372,095 – 199,442 *Km^0.333 (See Figure 3-3.)
Volume = 100,576 m^3 [Note – Bold Red is Unknown]



85% * 100,576 = 85,490 m^3;

85,490 m^3 = 372,095 – 199,442 ***Km**^0.333
Km = 2.97
2.97 Km = 1.42 + 619.31 * (1/**Q'**) =====> **Q'** = 141 cfs

7.5 Mollusc Technical Approach

Evaluation of salinity requirements for dominant native mollusc was similar to that of the fish / invertebrate analysis in the sense that the abundance response has a maximum (See Figure 5-5.), and thus the evaluation results in maintaining (within fifteen percent) an optimal salinity rather than the point of 'significant' harm.

In practice, the peak abundance (# / m^2) was calculated by setting the salinity equal to parameter 'c' (e.g. Salinity at maximum abundance. See equation in Chapter 5.4.2 and

Table 5-13), resulting in an estimate of the maximum abundance for each of the three taxa selected. The peak abundance was then reduced by fifteen percent and the salinity associated with the reduced abundance was back-calculated using the Goal Seeker function in Excel. Using *P. Carolinia* as an example, the maximum abundance is 28.8 organisms / m^2 which occurs when the salinity is 4.89 ppt. Eighty five percent of the peak abundance is 24.5 organisms which occurs when the salinity is 7.02 ppt

In the next step, salinity at maximum and at the reduced abundance is related to flow. The location of the salinity associated with maximum abundance was estimated for unadjusted Block 1 median flows (144 cfs) using the LSM regression introduced in Chapter 4.2.12. In the present example, a flow of 144 cfs is expected to produce a salinity of 4.89 ppt at Rkm 2.48 in the Weeki Wachee River. Holding this location constant, but substituting the salinity (7.02 ppt) at reduced abundance, the LSM equation is solved for flow. At a reduced flow of 133 cfs (7% flow reduction) the salinity at Rkm 2.48 would be 7.02 ppt. Thus *P. Carolinia* residing at this point would experience an increase in salinity from 4.89 to 7.01 ppt resulting in an expected loss of abundance of fifteen percent.

7.6 Approach to Freshwater MFL

Three freshwater sites were evaluated using PHABSIM. Habitat for twelve taxa/life stages of ecologically significant freshwater fish and an evaluation of benthic habitat were evaluated on a seasonal basis (Blocks 1, 2, and 3) to establish baseline conditions. The models were then run assuming flow reductions (10, 20, 30 and 40 percent) and the point at which a fifteen percent loss of habitat was determined. Figures 7- 8 and 7-9 present the results of the evaluation. Flow reductions resulting in a fifteen percent loss relative to baseline for each of the thirteen habitat measures are plotted by month in the form of a box-plot.

Figure 7-8. Summary Results for the "wide" Weeki Wachee River PHABSIM Site. (Figure is a box and whisker plot for percent-of-flow reductions associated with a 15% reduction in available habitat for selected biota are shown, based on review of ten, twenty, thirty and forty percent reductions in measured flows.

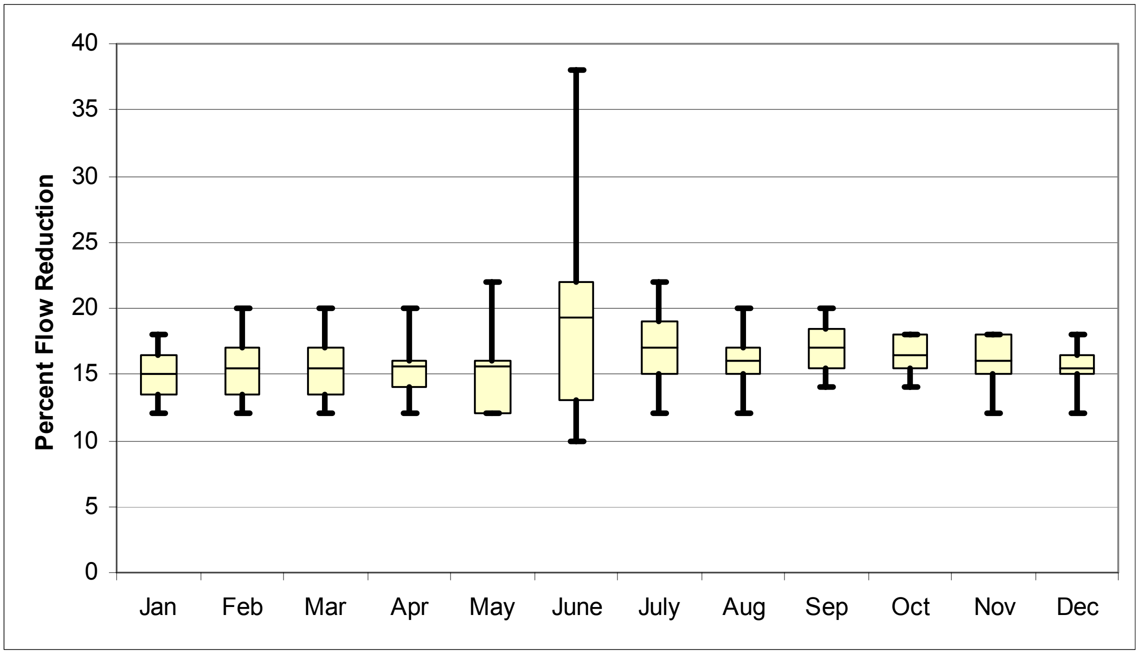
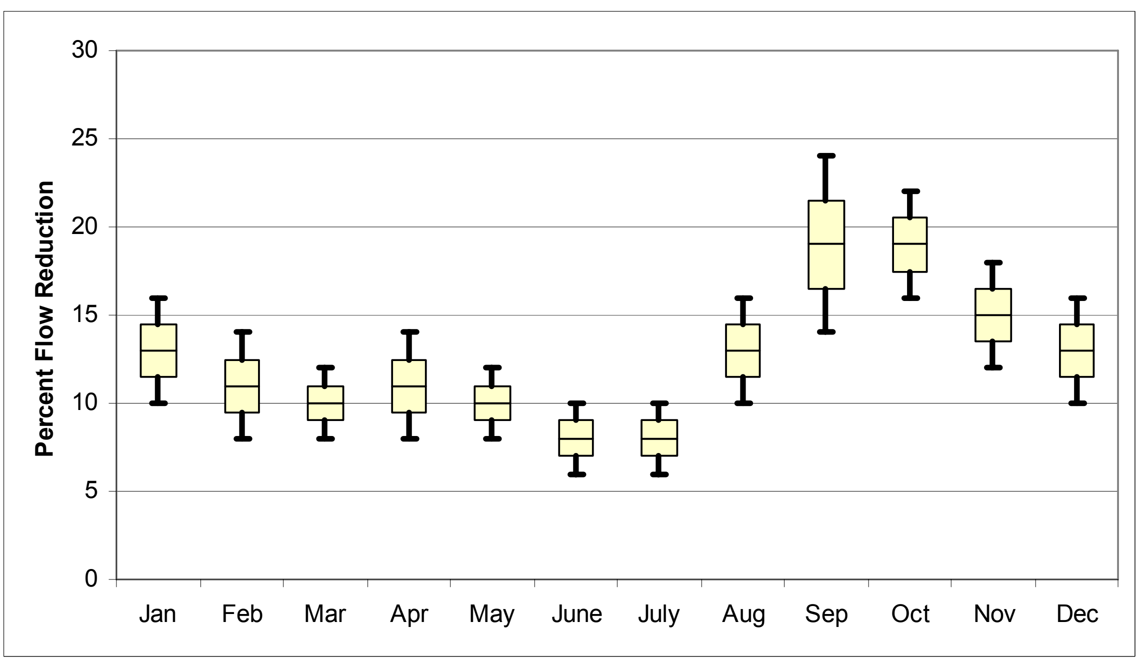


Figure 7-9. Summary results for the "sandbag" Weeki Wachee River PHABSIM site. (Figure is a box and whisker plot for percent-of-flow reductions associated with a 15% reduction in available habitat for selected biota are shown, based on review of ten, twenty, thirty and forty percent reductions in measured flows.



CHAPTER 8 - CONCLUSIONS AND DISTRICT RECOMMENDATIONS FOR MFL

8.1 Summary of Outcomes

The tools described in Chapter 5 were applied to the criteria presented in Chapter 6. Examples were given in Chapter 7. For each resource, an estimate of the percentage reduction of seasonal flow that would cause a presumed significant harm (e.g. 15% loss or resource or habitat) was determined. The resources evaluated and basis of flow evaluation include:

- Salinity habitat (adjusted flows)
  - Area
  - Volume
- Benthic Community (observed flows)
  - Abundance
  - Number of taxa
  - Diversity
- Molluscs (dominant native) (observed flows)
  - *Polymesoda caroliniana*
  - *Crassostrea virginica*
  - *Littoraria irrorata*
- Fish and Invertebrates (observed flows)
  - Gastropods, opisthobranch (sea slug)
  - Unidentified harpacticoid
  - *Lagodon rhomboides (pinfish)*
  - *Callinectes sapidus (blue crab)*
  - *Farfanepenaeus duorarum (pink shr*imp)
- Manatee Thermal Refuge (adjusted flows)
- Freshwater Habitats (adjusted flows)
  - PHABSIM

The results are summarized in Table 8-1. Not included in the table are the fish / invertebrates results because the range of flows observed during capture were at the predicted total exclusion of these taxa at flows normally encountered. Also excluded are the Manatee thermal refuge results because even at the low flow conditions with extremely low joint probability, the thermal refuge remaining after large reductions (e.g. 25 percent) is sufficient to shelter the entire Northwest Florida manatee population and is in excess of forty times the number of animals that typically use the Weeki Wachee.

Several of the results reported for the 15 ppt isohaline habitat are the result of an 'extended interpolation'. In some cases the projected location of the isohaline is in the Gulf westward of river kilometer zero. In these cases, the last rate of salinity change (Δ ppt / Rkm) within the study boundary was used to estimate the location within the Gulf.

The reductions in flow that meet the threshold criteria established in Chapter 6 are presented in both tabular (Table 8-1) and graphic (Figure 8-1) form. There is good agreement between the low flow and high flow evaluations which was expected because of the relatively narrow range and constant nature of springflow. The most conservative reduction is a 4.0 percent reduction in adjusted Block 3 flow which is the result of the 15 ppt volume criterion. The four most conservative reductions range from 4.0 to 8.1 percent flow reduction and all involve the 15 ppt salinity isohaline which is the result of the compressed nature of the system, particularly in the vicinity of isohalines greater than about 8 ppt. That is, salinities are changing rapidly in the river between kilometer 0 and 0.5. Thus, a relatively small change in flow translates to larger change in upstream volume or area than similar changes occurring upstream. For example, under high flow conditions (Block 3) the 14 ppt bottom isohaline is located at approximately Rkm = 0.24 or very near the mouth. At this location, there are 248,600 m^3 of volume upstream and the slope at this location is 124,300 m^3/km. By contrast, under the same flow conditions the 2 ppt isohaline occurs at a location where the slope is only 38,100 m^3/km. It will require only a 0.30 km upstream shift in the location of the 14 ppt isohaline to reduce the upstream volume by fifteen percent, but it will require a 0.46 km upstream shift of the 2 ppt isohaline to achieve the same percentage of volume reduction. In addition to the volume/km slope changes (Figure 3-3) the flow response term (B_1 – See Table 4-7) in the isohaline regressions is considerably greater for the 14 ppt isohaline than for the 2 ppt isohaline further increasing the sensitivity.

Table 8-1
Summary of Weeki Wachee MFL Results

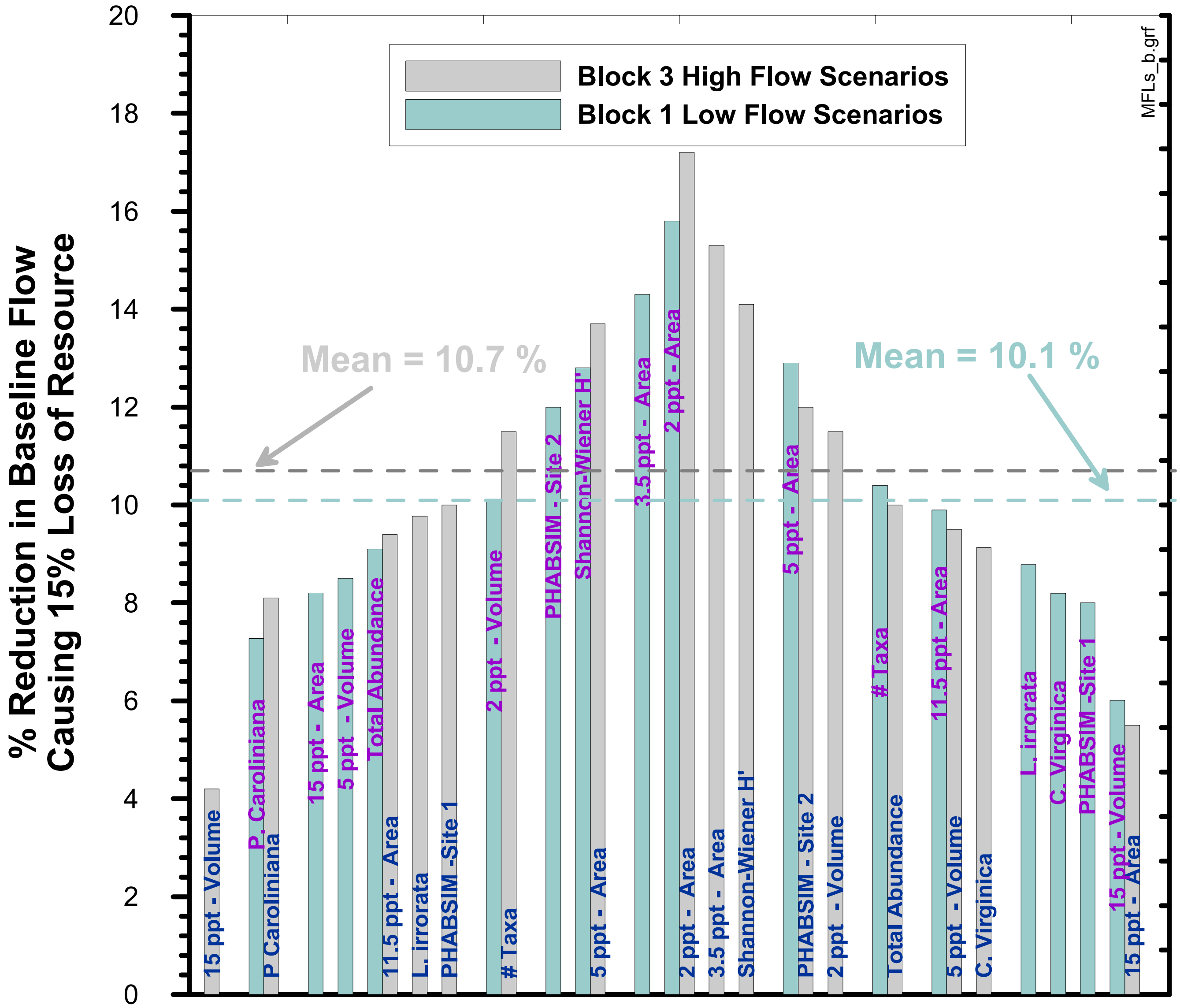
	Criteria	Flow	Adjusted Withdrawals	Block 1	Block 3 (1)
Freshwater					
Freshwater - Wide Site	PHABSIM		**Yes**	12.0%	12.0%
Freshwater - Sandbag	PHABSIM		**Yes**	8.0%	10.0%
Salinity Habitat					
2 ppt - Volume	15% Loss in volume	Median	**Yes**	10.1%	11.5%
5 ppt - Volume	15% Loss in volume	Median	**Yes**	8.5%	9.5%
15 ppt - Volume	15% Loss in volume	Median	**Yes**	6.0%	***4.2%***
2 ppt - Bottom Area	15% Loss in Area	Median	**Yes**	15.8%	17.2%
3.5 ppt - Bottom Area	15% Loss in Area	Median	**Yes**	14.3%	15.3%
5 ppt - Bottom Area	15% Loss in Area	Median	**Yes**	12.9%	13.7%
11.5 ppt - Bottom Area	15% Loss in Area	Median	**Yes**	9.9%	9.4%
15 ppt - Bottom Area	15% Loss in Area	Median	**Yes**	8.2%	***5.5%***
Benthos					
Shannon-Wiener H'	15% Loss in peak	Median	**No**	12.8%	14.1%
# Taxa	15% Loss in peak	Median	**No**	10.4%	11.5%
Total Abundance	15% Loss in peak	Median	**No**	9.1%	10.0%
Mollusc Abundance					
Polymesoda Caroliniana (n/m^2)	15% Loss in peak	Median	**No**	7.3%	8.1%
Crassostrea Virginica (n/m^2)	15% Loss in peak	Median	**No**	8.2%	9.1%
Littoraria irrorata (n/m^2)	15% Loss in peak	Median	**No**	8.8%	9.8%

(Bold red italic = based on extended interpolation into Gulf without bracketing values.)

MFL_Summary.xls

(1) Freshwater Block 2 Results

Figure 8-1
Summary of Weeki Wachee MFL Results



Ordinarily the MFL would be established based on the most restrictive outcome, or in the case of the Weeki Wachee, on the shift in the 15 ppt isohaline. However, in the case of the Weeki Wachee the 15 ppt isohaline occurs below the confluence of the Mud River in the Block 1 (low flow) evaluation and in the Gulf beyond the mouth of the river under the high flow evaluation (Block 3). Both conditions create problems for interpretation. In the former case, the discharge from the Mud River is highly saline and the rate is generally unknown. While there have been a few dozen sporadic measurements there has never been a continuous measurement. The sporadic measurements range from -51 to +128 cfs suggesting a highly variable flow. The combination of these factors probably accounts in part for the diminishing r^2 values associated with the higher salinity isohalines.

The location of the higher isohalines during high flow conditions is beyond the domain of the volume and area by river kilometer regressions which were truncated at Rkm =0. Thus, estimation of volume (or area) is based on extrapolation of the14 ppt results from inside the river mouth. Given these uncertainties and in order not to unduly weight the higher isohalines, it was decided to establish the Weeki Wachee MFL on the mean percent of flow reduction. The mean of all criteria utilized is 10.1 percent for the Block 1 period and is 10.7 percent for the Block 3 period.

8.2 Compliance Standards and Recommended Minimum Flows for the Weeki Wachee System.

In consideration of the results presented, it is recommended that both the wet season and dry season flows for the Weeki Wachee River system be maintained at 90 % of the baseline flows adjusted for anthropogenic impacts. In the absence of consistent, long-term flow measurements for Mud Springs, Salt Springs, Mud River, Jenkins Springs or Twin Dees Spring. to evaluate these individually, the assumed MFL for these waterbodies is also a ten percent reduction in baseline flows. Long-term compliance standards in the form of five and ten year mean and median flows were developed to accommodate variations in climate. These minimum long-term flow statistics should be maintained in the presence of withdrawals.

In order to define the compliance standards and to accommodate variations in climate, the recommended MFL (10% reduction) was applied to the adjusted baseline flows and the average daily flow for each calendar year was calculated for the years1967 through 2004. Next a running five year average was determined from these annual averages for the period of record and the minimum five year period identified. The process was repeated for a ten year moving average. Finally the procedure was repeated using the median daily flow for the years 1967 through 2004. The results are given in Table 8-2.

Table 8-2
Long-Term Minimum Flows Corresponding to Recommended MFL

Criterion	Minimum Flow (cfs)
Minimum 10 yr Moving Average (Based On Annual Average Flows)	141
Minimum 10 yr Moving Average (Based On Annual Median Flows)	131
Minimum 5 yr Moving Average (Based On Annual Average Flows)	136
Minimum 5 yr Moving Average (Based On Annual Median Flows)	128

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CHAPTER 10 - APPENDICES

10.1 Appendices – Chapter 2

Appendix 2-1

TECHNICAL MEMORANDUM

DATE: **January 31, 2007**

TO: **Marty Kelly, Manager & Mike Heyl, Sr. Environmental Scientist, Ecologic Evaluation Section**

THROUGH: **Mark Barcelo, Manager, Hydrologic Evaluation Section**

FROM: **R.W. Schultz, Sr. Professional Geologist, Hydrologic Evaluation Section**

SUBJECT: **Weeki Wachee Springs Anthropogenic Impact Estimation**

Flow Analysis Using Wavelet Filtering

Wavelet Transforms

The flow data for Weeki Wachee Springs is, by definition, time-series data. It is most commonly represented in the time-domain that is, different flow values are associated with specific times. It is much less common to examine flow time-series data in the frequency domain, where one is concerned with the proportion of the flows occurring at different frequencies. Generally, the only acknowledgement of the frequency aspect is in the identification of such entities as dry season versus wet season.

Classically frequency-domain analyses are often performed using Fourier transforms where the original data is represented by a series of linear combinations of sinusoidal functions. Each function represents a particular frequency observed in the data. However, the nature of flow data makes this classical form of analysis inapplicable. The problem hinges upon the Fourier assumption that the data is “stationary”. That is, it is assumed that the frequencies are fixed as well as the amplitudes. For example, using the wet and dry season breakdown that is commonly done, it is assumed that the wet season is always the same length of time each year. In fact this is known not to be the case but is nevertheless used as a simplifying assumption.

Still another difficulty in using classical frequency-domain analysis is that it is assumed that any observed frequency persists throughout the entire period of record. This is an assumption that is also not necessarily met with data such as spring flow. In other words we have no information in classical methods of the location of events in time.

Fortunately, in the mid-1980's a new form of analysis was developed and was called wavelet analysis. The assumptions of classical Fourier analysis were no longer needed. The term wavelet means "small wave", which grows and decays over time. By comparison a sine function represents a "large wave" that persists indefinitely. Using wavelets one can examine not only varying frequencies but also identify where events occur in time.

The wavelet methodology is becoming more commonplace and a full explanation far beyond the scope of this document. In any event, the wavelet filtering that was used in this analysis represents only the most basic application. Therefore, the explanation of wavelets will be kept to a minimum.

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

There is no unique wavelet; instead there are an almost unlimited number of them divided into families. Each family has its own strengths and weakness and is chosen for its compatibility with the data to be analyzed. There are though some very commonly used wavelet families and one of those, the "symmlets" family was chosen for the Weeki Wachee Spring analysis.[26]

[26] Bruce, Andrew, Gao, Hong-Ye, 1996*, Applied Wavelet Analysis with S-Plus*, Springer – Verlag New York, 338p.

The wavelet used is the symmlets wavelet identified as “S8”. As shown in the following Figure 1:

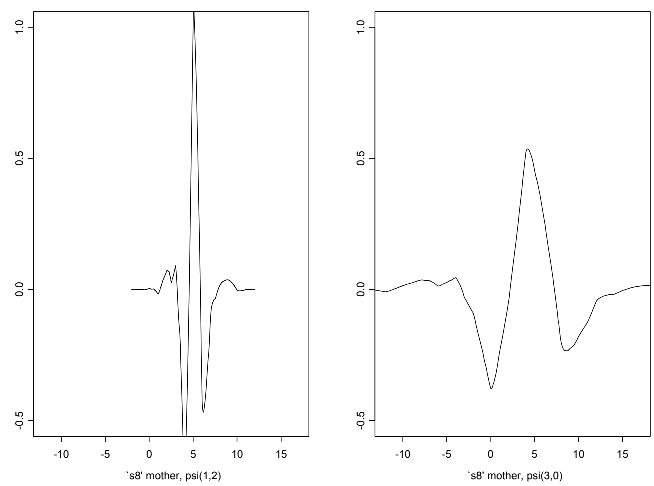

Figure 1 Scaling of Wavelets

In the figure there appear to be two wavelets but in actuality there is only one shown with two different scaling factors. In a hypothetical wavelet transformation, each would be used to scan the data. As the wavelet passes over the data it’s correlation with the data is recorded. It is apparent that the left hand scaling would be useful looking for high frequencies and short wavelengths while the right hand scaling would handle lower frequencies and longer wavelengths. In practice the wavelet algorithms compute appropriate scaling factors depending upon the data being analyzed.

One of the basic applications of wavelet transforms is to “de-noise” data.[27] Noise, in this sense is relative and depends upon the problem under consideration. For example, the method has been used to identify the tidal component of river flow.[28] For that study "noise" would be the data with long periodicity. In the case of the Weeki Wachee Springs data the premise is that the anthropogenic impacts of primary interest are not short term but rather long term.   Short-term fluctuations in the data would be relegated to "noise" that would potentially obscure the behavior of interest. The transformed flow data in Figure 2 illustrates this.

The upper graph in the figure represents the actual flow data from 1941 to 2004. As a prerequisite to transformation it has been centered about the mean of the same period. Below this graph is the wavelet transformed version of the same data. In other words the time domain representation is on top and the frequency domain representation is below.

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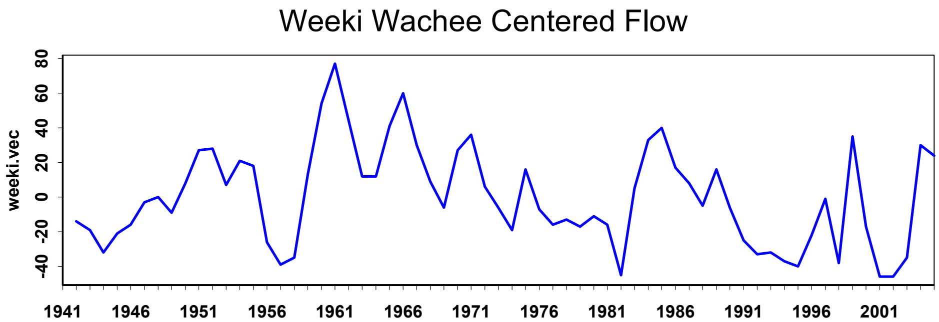
[27] Percival, Donald B., Walden, Andrew T., 2000, *Wavelet Methods for Time Series Analysis – Cambridge Series in Statistical and Probabilistic Mathematics*, Cambridge University Press, 594p.
[28] Lim, Yeo-Howe, Lye, Leonard M., 2004, Wavelet Analysis of Tide-affected Low Streamflows Series, *Journal of Data Science*, **2**, p.149-163.

The "d1" and "d2" wavelets represent the highest frequencies in the data. Both are relatively flat and show no apparent evidence of a downward trend. In fact, they were considered as "noise" in this analysis. The "d3" wavelet is more interesting. It would suggest a cyclical behavior of the spring flow. From peak to peak, as shown with the two vertical bars, it appears to have a period of approximately 25 years. Similar peaks appear in the untransformed data above. It is suggested that this periodicity reflects long term climatic fluctuations in the spring flow

It is in the "d4", "d5", and "s5" wavelets that one sees the pronounced decline in spring flow behavior. The "d4" wavelet would indicate that the decline began around 1965 and has continued up until the present.



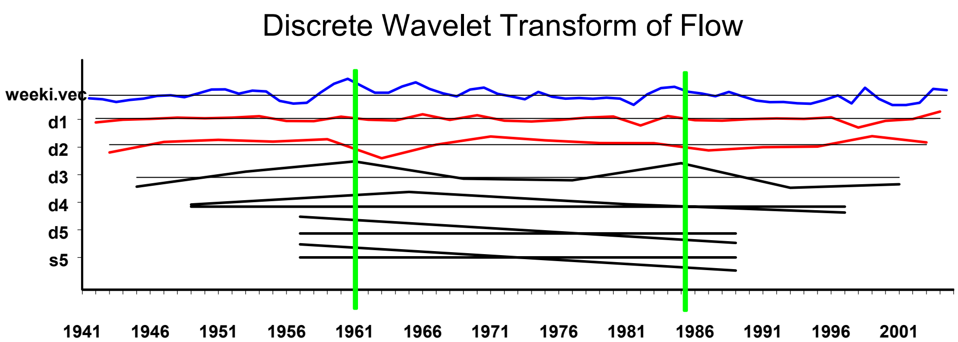


Figure 2 Weeki Wachee Flow and Transformed Flow

A similar transformation was carried out on the rainfall data from the Brooksville rain gage. The Brooksville gage is located approximately 15 miles to the northeast of Weeki Wachee Springs. The rainfall data along with the wavelet transformed data is shown in Figure 3. There are several similarities between the transformed flow data and the transformed rainfall data. The same periodicity is observed in the "d3" wavelet showing a peak to peak wavelength of approximately 25 years. Although less pronounced there is also a similar decrease seen in the "d4" and "d5" wavelets. The major difference is that the "s5" wavelet shows an increasing trend in the lowest frequency rainfall data while flow shows a pronounced downward trend for the same frequency.

A useful tool in deciding which wavelets to include and which to exclude is the energy plot. It is somewhat analogous to the R-square value in linear regression. However, instead of describing the amount of variability in the data that a regression model explains, the energy plot shows the relative portion of the data explained by the individual wavelets (energy being the sum of the squares of the wavelet coefficients). In Figure 4 there appear to be two clusters within each of the energy plots. One cluster represents higher frequency components of the data and the other cluster represents the lower frequency components. Since we are concerned primarily with the long term behavior the lower frequency components of were extracted from both the flow and rainfall data.

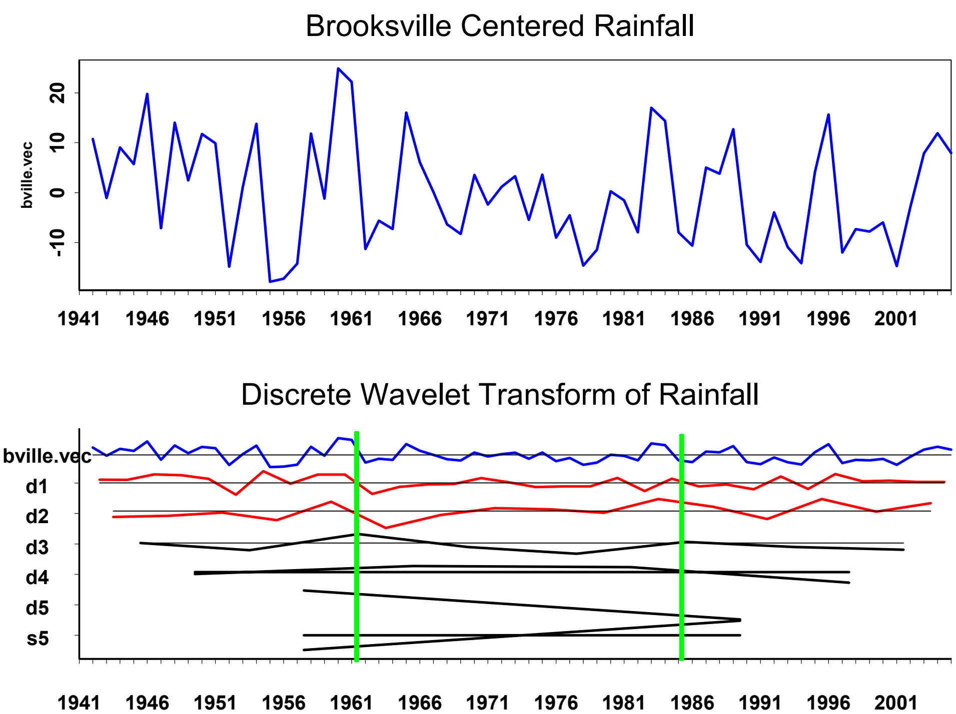


Figure 3 Brooksville Rainfall and Transformed Rainfall

Figure 5 shows the original flow data and the results of filtering using the untransformed set of "d4" through "s5" wavelets. From the graph it is obvious that what has been accomplished is that the data has been smoothed. Similar results could have been obtained using loess,

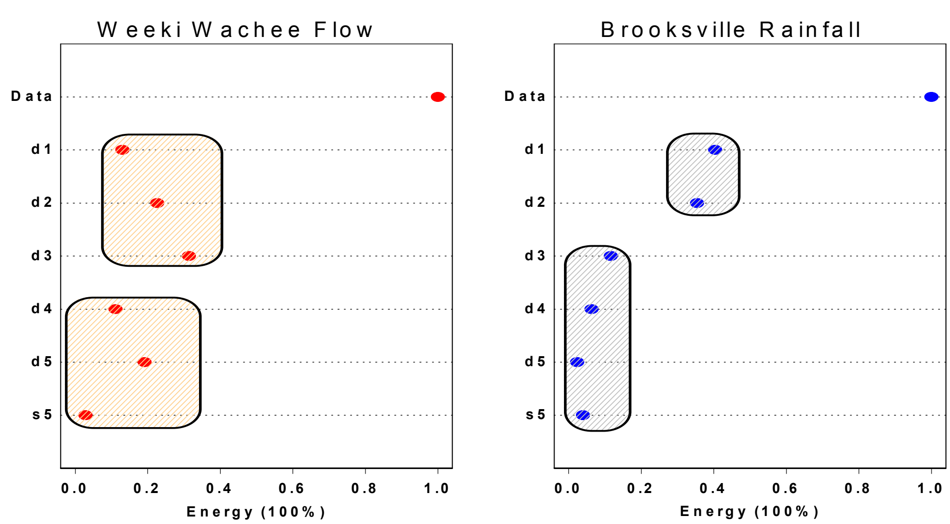


Figure 4 Wavelet Energy Diagrams

kernel smoothing, and so on. The difference, and advantage, of using wavelets is that one has an opportunity to decide which portions of the data to consider noise as well as an insight into underlying behavior over time.

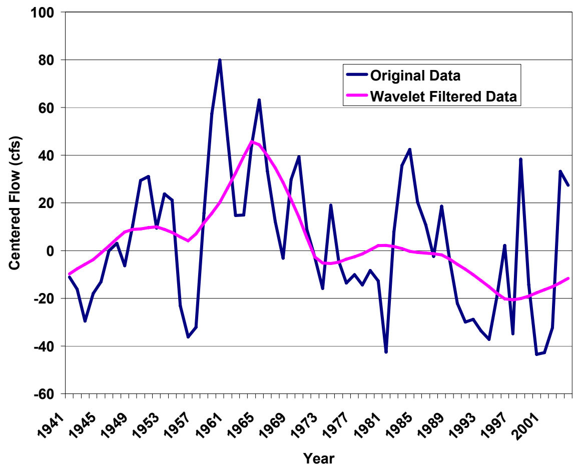


Figure 5 Original Flow Data vs. Wavelet Filtered Data

The reconstructed rainfall data shows below average rainfall (1941–2004 mean) for most of the period starting around 1965 and continuing to around 2002. Note in the prior discussion of transforming the flow data that it appeared the decline in spring flow began in 1965. Roughly the same time that a decline in overall rainfall appeared to begin. A similar smoothing effect for rainfall data is shown in Figure 6. Of course between 1965 and the present ground water usage has also increased. That the explanation for decreasing spring flow be attributable to both rainfall changes and increasing withdrawals seems reasonable. The task then is to try and quantify the relative importance of the two parameters.

<u>Regression Modeling</u>

A simple model of spring flow as a function of rainfall would have the following form:

$$Flow = \beta_0 + \beta_1 Rain + \varepsilon$$

However, if there is an additional factor, categorical in nature, that is believed to play an important role in the process it can be represented by a binary variable.[29] Examples of such would be wet vs. dry season, or in this instance, years with significant withdrawals or without significant withdrawals. In such a case it would be added to the equation where

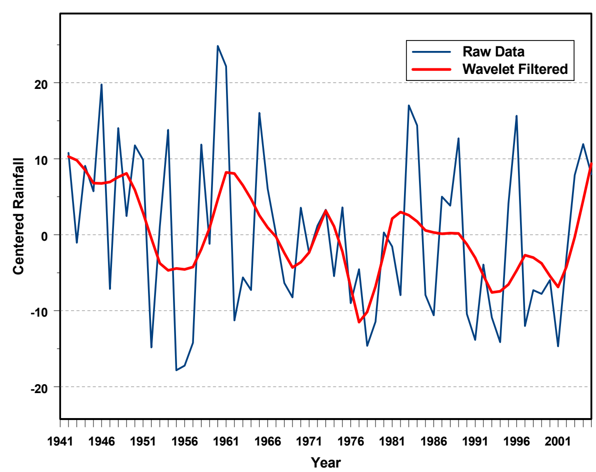


Figure 6 Comparison of Raw Rainfall Data to Wavelet Filtered Rainfall Data

[29] Helsel, D.R., Hirsch, R.M., 1995, *Statistical Methods in Water Resources – Studies in Environmental Science 49*, Elsevier, Netherlands, 529p.

$$Z = \begin{cases} 0 \text{ if no significant withdrawal} \\ 1 \text{ if significant withdrawal} \end{cases}$$

and the model becomes:

$$Flow = \beta_0 + \beta_1 Rain + \beta_2 Z + \varepsilon$$

There are two assumptions with this model. The first assumption is that the impacts from withdrawal, once begun, continue through to the present time. The second assumption is that we can determine when the impacts began. To address these assumptions it was first necessary to identify the ground-water basin providing water to Weeki Wachee springs. A prior USGS study[30] of the hydrology of the coastal springs provides an approximate delineation of the basin which is shown in Figure 7.

With the basin delineated all the permitted withdrawal points were identified. Reported withdrawal quantities were extracted from the SWFWMD data base and totaled for each year. Unfortunately, this data, shown in Figure 8, only goes back as far as 1975 but it clearly shows an increase in withdrawals over time that appear to peak in recent years at around 45 to 50 mgd.

The assumption that the withdrawal impact, once begun, continues to the present would appear reasonable. The second assumption of being able to define the year in which impacts begin poses a more difficult problem.

The solution employed was to let the regression model determine when the impacts began. In order to do this, the model was run sequentially with the first run assuming that the entire period of 1941 to 2004 was impacted. The second run would assume that the impact began in 1942 and so on. After each run, 64 in this case, the results of the model including the F-test results, R-squared results were examined. The model run with the best results was then chosen and the parameter coefficients were examined for statistical significance and for reasonable sign. By reasonable sign it is meant that the parameter coefficient for rainfall should be positive and for impact negative. Since the model is solving for flow in cfs the parameter coefficient for impact is also in cfs.

[30] Knochenmus, Lari A, Yobbi, Dann K., 2001, *Hydrology of the Coastal Springs Ground-Water Basin and Adjacent Parts of Pasco, Hernando, and Citrus Counties, Florida*, U.S. Geological Survey, Water Resources Investigations Report 01-4230, 88p.

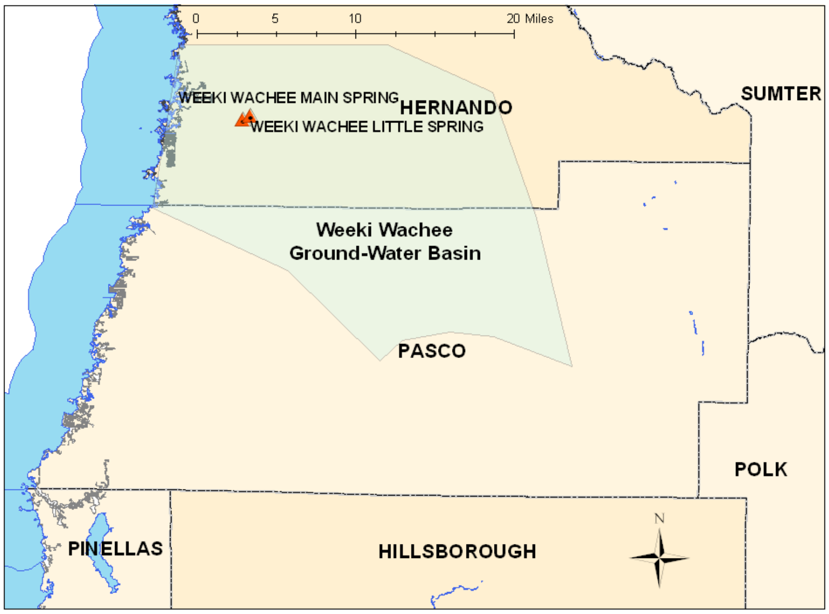


Figure 7 Location of Weeki Wachee Ground-Water Basin

Thus the value of the impact parameter coefficient is the model's best estimate of the impact not attributable to rainfall.

Some experimentation was also conducted in the choice of model rainfall parameters. That is, in addition to current rainfall for each year, rainfall lagged by one and two years were input to determine the optimum model form. Ultimately it was found that the best model incorporated lagged rainfall rather than current rainfall.

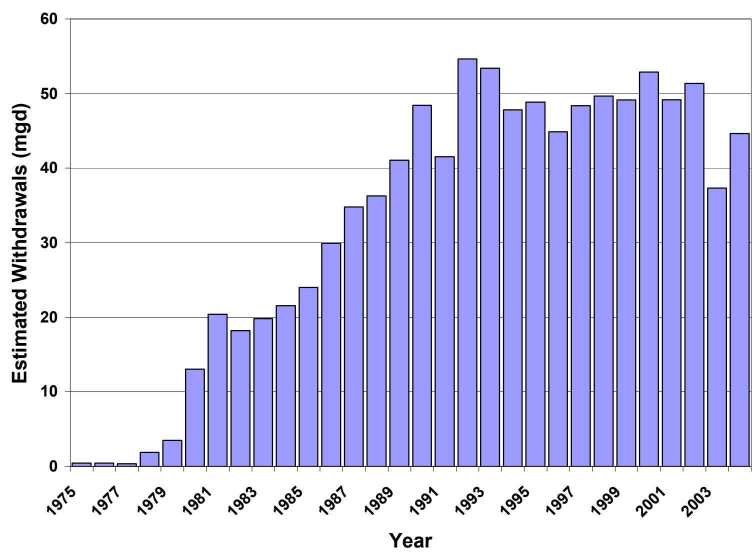


Figure 8 Reported ground-water withdrawals within the Weeki Wachee ground-water basin

One advantage of using this regression model is that it is possible to calculate upper and lower confidence bounds on the regression model and the impact value.

Regression Results

Initial attempts to construct the regression model were not successful. No model constructed was able to explain more than about 50% of the flow variability and the model coefficients were suggesting that water was actually being added to the system. These poor results led to further experimentation with the wavelet filtered data where it was found that if the data from 1941 to 1950 was excluded the results were notably improved. The reason for this is presently unknown.

After running the model sequentially if was found that the best model had the impacts beginning in 1972 and with the following results:

Flow = 123.4 + 1.3 * Lagged Rainfall – 25.5 * Impact

With an adjusted R-square value of 72.6%

A chart of the wavelet filtered flow along with the regression model predicted flow is shown in Figure 9.

While the R-square value of 73% is an improvement over previous models, it is not as high as expected. A third of the flow behavior is unexplained by this model. There are two potential factors that might have a bearing on the modest R-square value.

First, there is no Floridan aquifer data in the model. Unfortunately, there are no long-term Floridan monitoring wells in the area that go back to even 1951. The best available would be the Weeki Well 11 which goes back to 1967. While this well could have been used, it is also used to calculate the spring flow. Modeling spring flow with a well that is used to calculate flow was considered to be circular logic.

Another consideration is that the Weeki Wachee springs are in close proximity to the community of Spring Hills. Population in this community has been steadily increasing over time and the preponderance of households rely upon septic tank systems. The effects of these discharges upon the spring flow have not been quantified in this model.

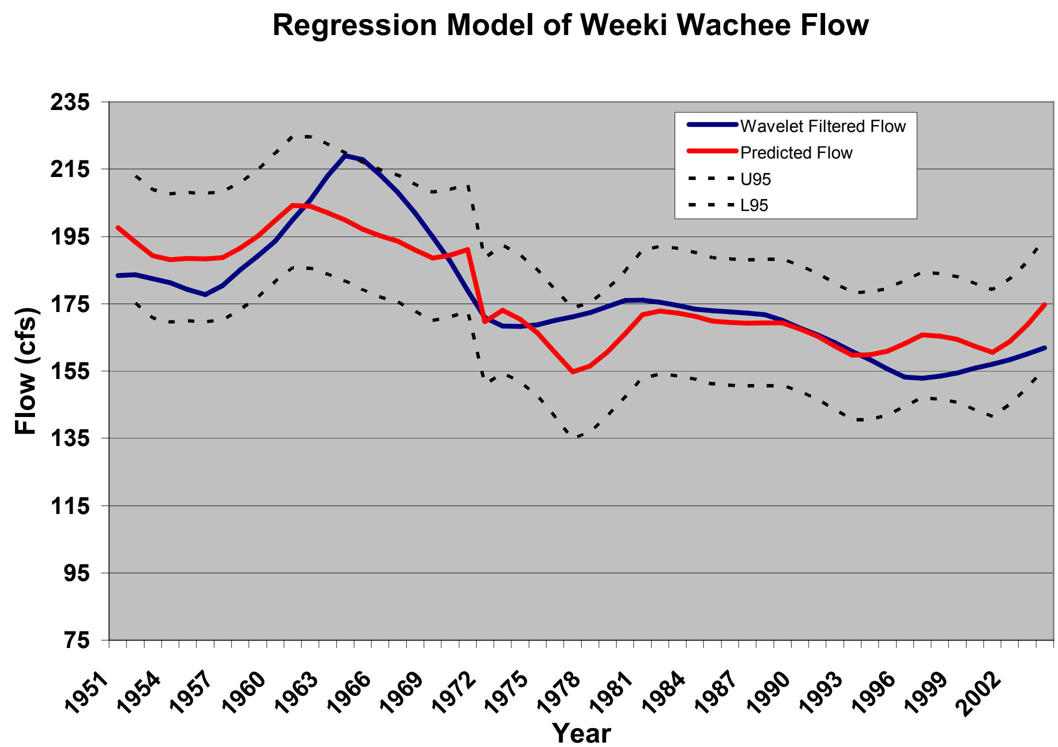


Figure 9 Wavelet Filtered Flow vs. Predicted Flow

<u>Conclusions</u>

The use of wavelet transforms allowed for the separation of "noise" from original flow and rainfall data. There are clear similarities in the behavior of both Weeki Wachee flow and Brooksville rainfall data. A cyclic behavior with a period of approximately 25 years can be seen in both flow and rainfall and an overall decline in both sets of data that commences around 1965.

A regression model was used to estimate the amount of decline in spring flow that could not be attributed to rainfall. The model is considered adequate with an R-square value of 73% although a higher value had been hoped for. Because the R-square value is not high the resultant estimation of non-rainfall impacts are considered approximate.

Appendix 2-2

Technical Memorandum
January 22, 2008

TO: Mike Heyl, Chief Environmental Scientist, Ecological Evaluation Section
Marty Kelly, Ph. D., Manager, Ecological Evaluation Section

THROUGH: Mark Barcelo, P.E., Manager, Hydrologic Evaluation Section

FROM: Ron Basso, P.G., Senior Professional Geologist, Hydrologic Evaluation Section

Subject: Predicted groundwater withdrawal impacts to Weeki Wachee Spring based on numerical model results

1.0 Introduction

Weeki Wachee Spring, located at the headwaters of the Weeki Wachee River, lies just southwest of the junction of U.S. Highway 19 and State Highway 50 (Figure 1). The river extends westward 7.5 miles from the main spring vent through predominantly lowlands (coastal swamps and marshes) to the Gulf of Mexico. There are nine springs associated with or in proximity to the Weeki Wachee system (SWFWMD, 2001). With the exception of first magnitude Weeki Wachee Spring main vent, most of the springs in the Weeki Wachee area have very limited flow and water quality data. Mean annual discharge for the Weeki Wachee main spring averaged 173 cubic feet per second (cfs) or 112 million gallons per day (mgd) for the period 1931-2006.

Weeki Wachee Spring discharges from the bottom of a conical depression with gentle side slopes. The spring pool measures 165 ft (50.3 m) east to west and 210 ft (64 m) north to south. Spring depth is 45 ft (13.7 m) over the vent in the center of the pool (Florida Geological Survey, 2001). Bare limestone is located near the vent, but none is exposed around the pool edges. The water is clear and light greenish blue, and a boil is visible in the center of the pool. Thick, filamentous algae cover the majority of the spring bottom, and there are some native aquatic grasses in the spring pool. The spring is rich with fresh and salt water fishes and aquatic turtles.

Prior to establishment of a Minimum Flow (MF), an evaluation of hydrologic changes in the vicinity of the spring is necessary to determine if the water body has been significantly impacted by existing groundwater withdrawals. The establishment of the MF for Weeki Wachee Spring is not part of this report. This memorandum describes the hydrogeologic setting near the spring and provides the results of several numerical model simulations of predicted spring flow change due to existing groundwater withdrawals.

2.0 Hydrogeologic Conditions

In most of Tampa Bay Water's central system wellfield area, a distinct, surficial sand aquifer overlies the semi-confined Upper Floridan aquifer. However, a rather sharp transition to a regionally unconfined Upper Floridan aquifer occurs along a line from northwest Pasco County through the northern part of Cross Bar wellfield to the Brooksville Ridge physiographic region

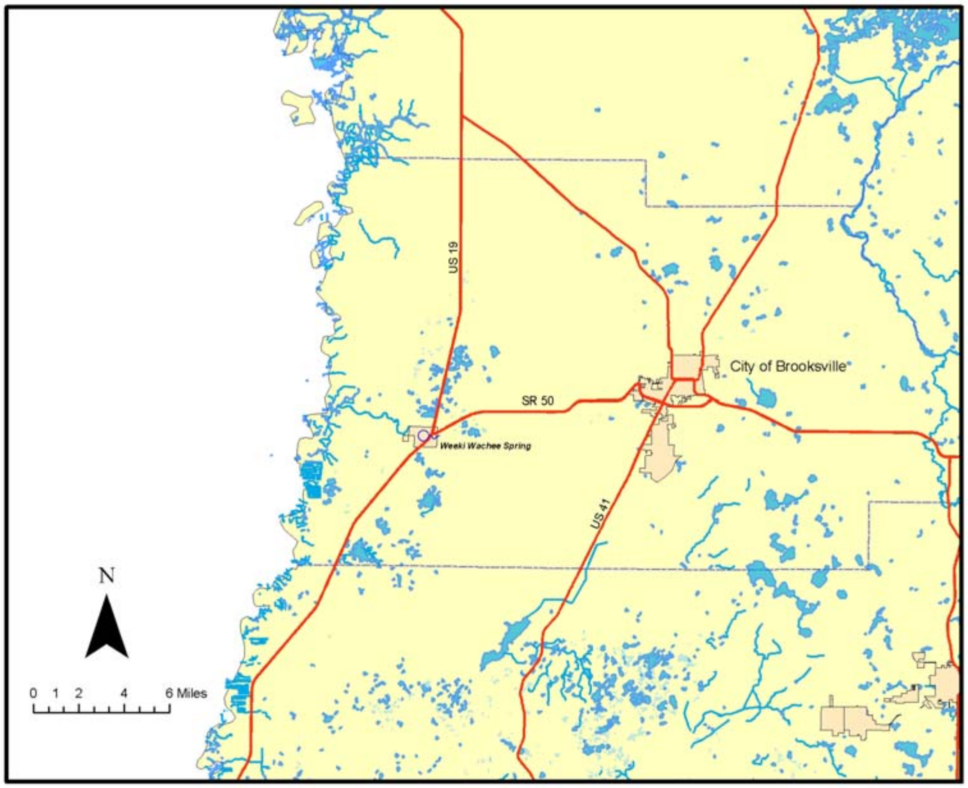


Figure 1. Location of Weeki Wachee Spring.

(Figure 2). North of this boundary, the Upper Floridan Aquifer (UFA) is primarily unconfined except beneath the clay-rich, low infiltration soils of the Brooksville Ridge. Where the UFA is unconfined is a highly karst-dominated region. Dissolution of limestone is an active process via infiltration of rainwater because the limestone units of the UFA are close to land surface and poorly confined. Numerous sinkholes, internal drainage, and undulating topography that are typical of karst geology dominate the landscape. These active karst processes lead to enhanced permeabilities within the Floridan aquifer. Reported transmissivity values of the Upper Floridan aquifer based on three aquifer performance tests in western Hernando County range from 200,000 to 1,200,000 ft^2/day (SWFWMD 1999). Three first-magnitude springs (> 100 cfs discharge), the Crystal River group, Homosassa, and Weeki Wachee are found within this region. In addition, the highest recharge rates to the UFA occur in west-central Hernando and Citrus Counties with values ranging between 15 and 22 inches per year (Ross and others, 2001).

3.0 Numerical Model Results

A number of regional groundwater flow models have included the Weeki Wachee Spring area. Ryder (1982) simulated the entire extent of the Southwest Florida Water Management District. In 1993, the District completed the Northern Tampa Bay groundwater flow model that covered a 2,000 square mile area of Hillsborough, Pinellas, Pasco, and Hernando Counties. In 2002, the USGS simulated the entire Florida peninsula in their Mega Model of regional groundwater flow (Sepulveda, 2002). The most advanced simulation of the Weeki Wachee Spring region and

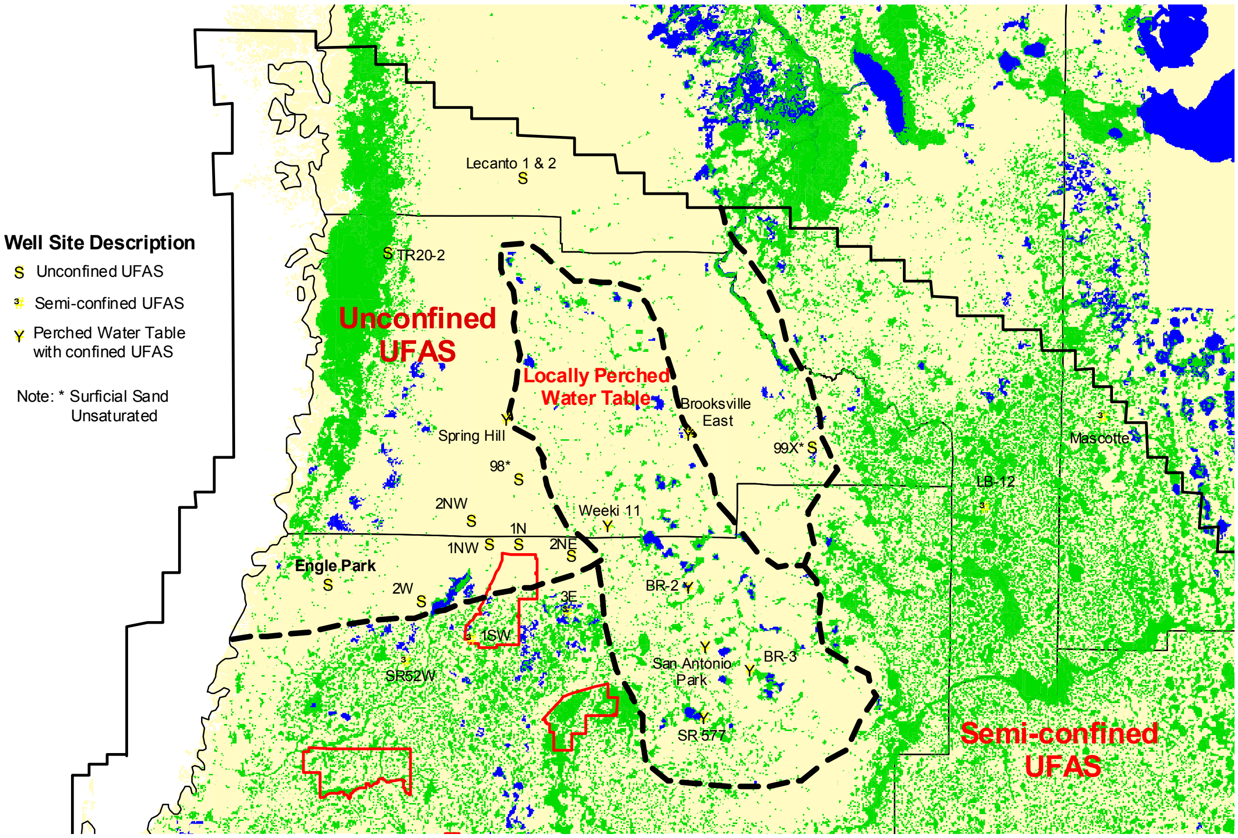


Figure 2. Location of hydrogeological provinces within the Northern Tampa Bay area (Basso, 2004).

surrounding area is the Integrated Northern Tampa Bay model. The construction and calibration of this model was part of a cooperative effort between the SWFWMD and Tampa Bay Water, a regional water utility that operates 11 major wellfields in the area. The Integrated Northern Tampa Bay (INTB) Model covers a 4,000 square-mile area of the Northern Tampa Bay region (Figure 3).

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

The model code used to run the INTB simulation is called the Integrated Hydrologic Model (IHM) which combines the HSPF surface water code and the MODFLOW ground-water code using interprocessor software. During the INTB development phase, several new enhancements were made to move the code toward a more physically-based simulation. The most important of these enhancements was the partitioning of the surface into seven major land use segments: urban, irrigated land, grass/pasture, forested, open water, wetlands, and mining/other. For each land segment, parameters were applied in the HSPF model consistent

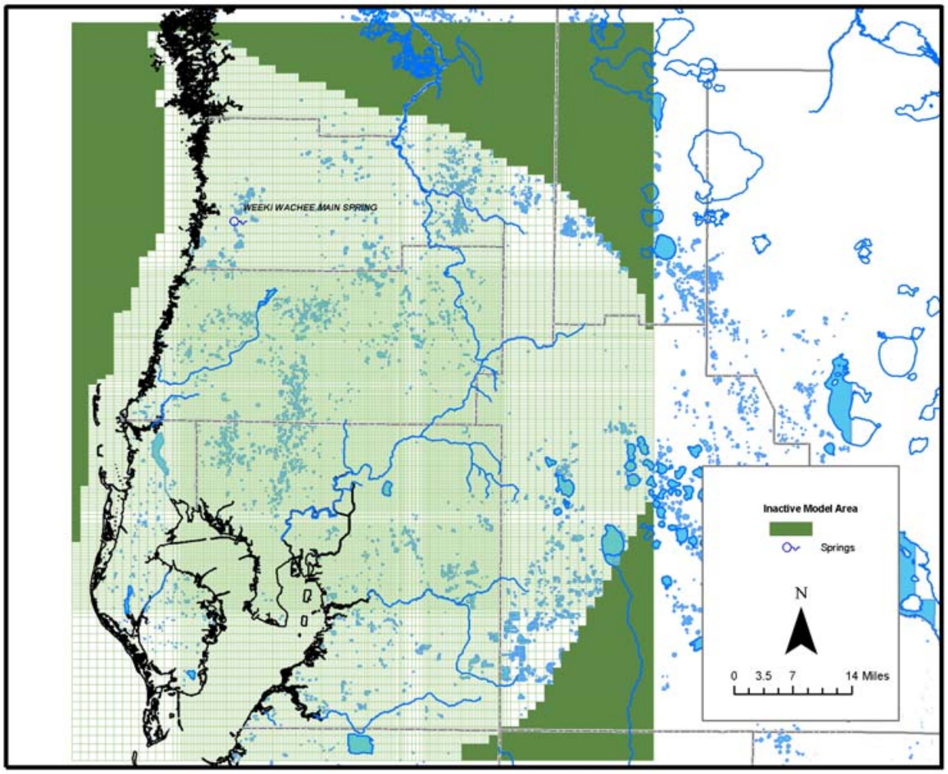


Figure 3. Groundwater grid used in the INTB model.

with the land cover, depth-to-water table, and slope. Recharge and ET potential were then passed to each underlying MODFLOW grid cell based on an area weighted-average of land segment processes above it. Other new software improvements included a new ET algorithm/hierarchy plus allowing the model code to transiently vary specific yield and vadose zone storages.

The INTB model contains 172 subbasin delineations in HSPF (Figure 4). There is also an extensive data input time series of 15-minute rainfall from 300 stations for the period 1989-1998, a well pumping database that is independent of integration time step (1-7 days), a methodology to incorporate irrigation flux into the model simulation, construction of an approximate 150,000 river cell package that allows simulation of hydrography from major rivers to small isolated wetlands, and GIS-based definition of land cover/topography. An empirical estimation of ET was also developed to constrain model derived ET based on land use and depth-to-water table relationships.

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

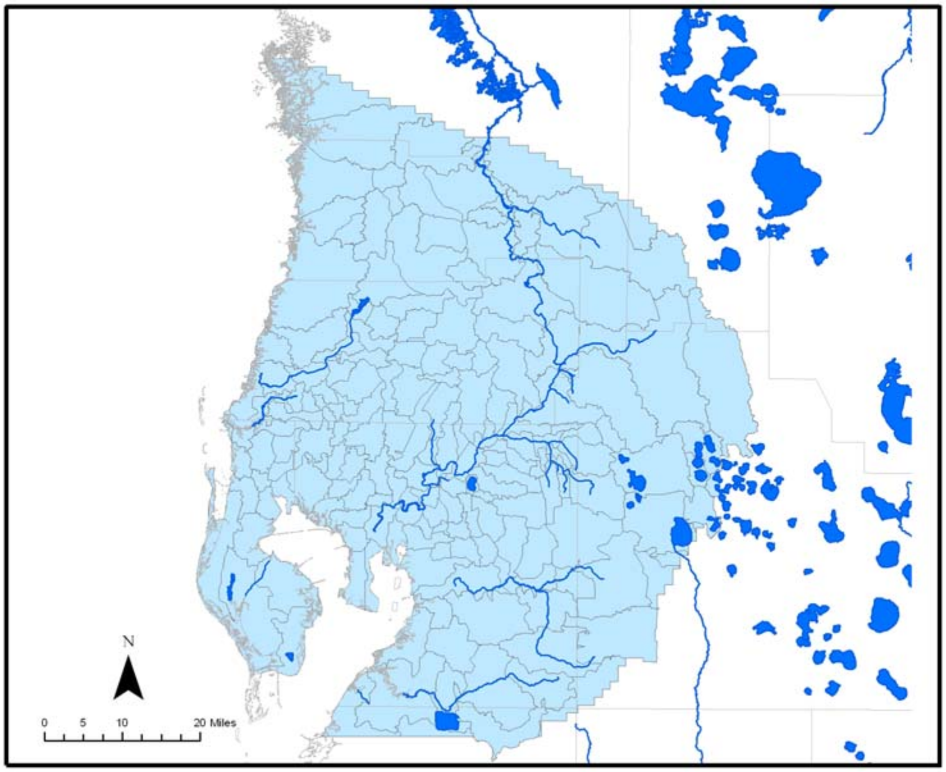


Figure 4. HSPF subbasins in the INTB Model

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

One model scenario was run with the INTB model. This scenario consisted of simulating the impacts from groundwater withdrawn within the Northern West-Central Florida Groundwater Basin (NWCFGWB) and the Central West-Central Florida Groundwater Basin (CWCFGWB). This area of withdrawals totaled 334 mgd (average 1989-1998) and is shown in Figure 5.

The results of the INTB model scenario showed that Weeki Wachee Spring discharge was reduced by 25.6 cfs with 334 mgd of combined pumping in the CWCFGWB and NWCFGWB averaged over a five-year period. The spring flow reduction was calculated over the 1993-1998 period because this was the period of observed data that exists from daily measurements of Weeki Wachee River flow.

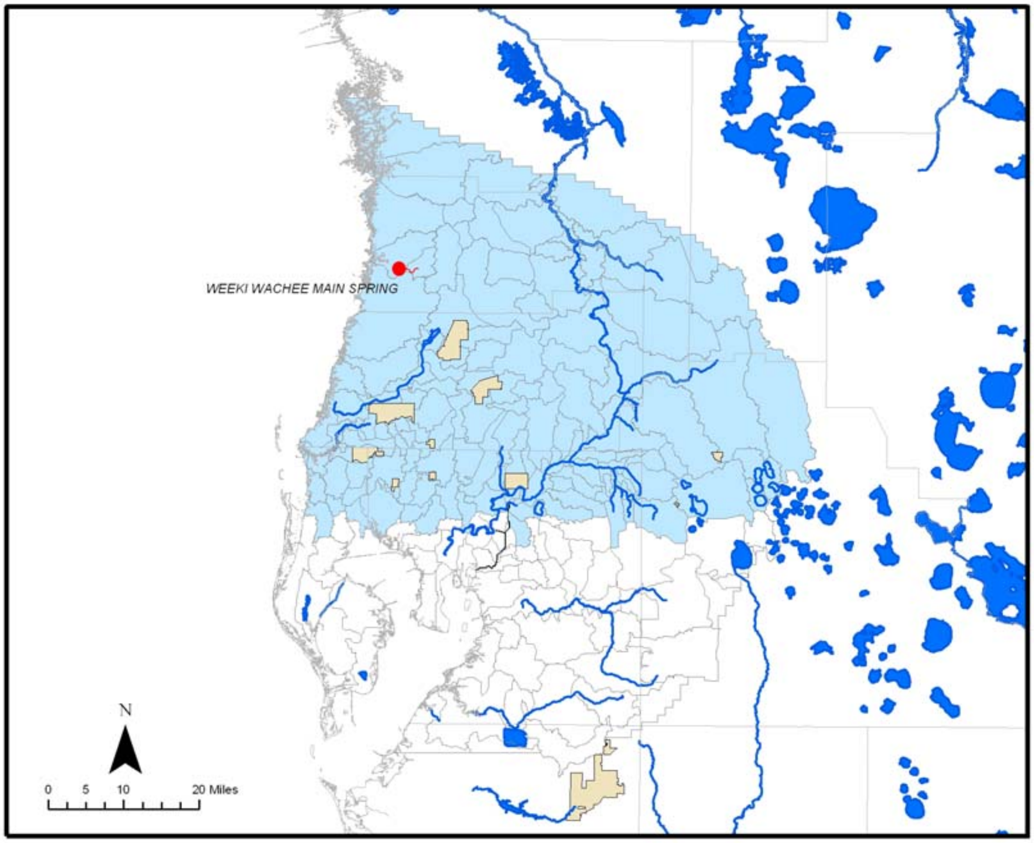


Figure 5. INTB scenario where impacts to the hydrologic system were simulated due to groundwater withdrawals of 334 mgd (1989-1998 average) in the shaded area.

3.1 Additional INTB Model Scenarios

Three additional model scenarios were run to measure the impact on Weeki Wachee flow due to consumptively-used limestone mining quantities in Hernando County, the proposed reduction in groundwater withdrawals for Tampa Bay Water's central wellfield system required by 2008, and the impact on UFA water levels due to septic tank recharge in the Spring Hill area of Hernando County. Each of these scenarios reduces the impact on spring flow as predicted by the regional assessment described above.

3.1.1 Limestone Mining Consumptive Use Quantities

Mining companies typically de-water pits to extract limestone for cement processing and other uses in the Northern District. These de-watering quantities are usually routed to another pond on-site or hydraulic barriers where the water infiltrates back into the unconfined Upper Floridan aquifer. Consumptively used quantities, water that does not percolate back into the aquifer, generally consists of water lost through product entrainment, personal sanitary, truck washing, and on-site irrigation. Some specialized losses are associated with cooling tower water, cement plants, and calciner industrial processes.

Most of the limestone mines located on the Brooksville Ridge in Hernando County are “dry” mining operations since the water level in the Upper Floridan aquifer is well below the top of the limestone surface. These mines do however withdraw groundwater to augment large recirculation ponds which provide infiltration to the Upper Floridan aquifer. The largest type of this operation is the Florida Crushed Stone facility near Brooksville which contains over 2,000 acres of recirculation ponds to supply cooling water for a power plant and water needs for a crushed stone plant, calciner, and cement plant.

In a technical memorandum, SWFWMD determined consumptively-used quantities for 14 mining and associated industrial facilities located in the northern part of the district (SWFWMD, 2006). Consumptively used quantities were derived by reviewing the water balance information contained within each individual water use permit file. Most losses were identified as product entrainment but some specialized losses were associated with cooling water for a power plant, a calciner, and a cement plant. If long-term average rainfall is equal to pond evaporation, then these losses are the consumptively used quantities for the mining permits. A total of six limestone mining and associated industrial water use permits are located in Hernando County.

In the INTB model, groundwater quantities for limestone mining totaled approximately 20.5 mgd in Hernando County as an average for the period 1989-1998. Results of the SWFWMD (2006) analysis estimated total consumptive use for six facilities in Hernando County at 4.1 mgd. For this scenario, groundwater withdrawals were reduced approximately 80 percent to account for actual water lost in the mining or industrial processes. Figure 6 illustrates the increase in UFA water levels when mining withdrawals were adjusted for consumptively-used quantities. Weeki Wachee spring flow increased by 1.9 cfs when these mining withdrawals were adjusted.

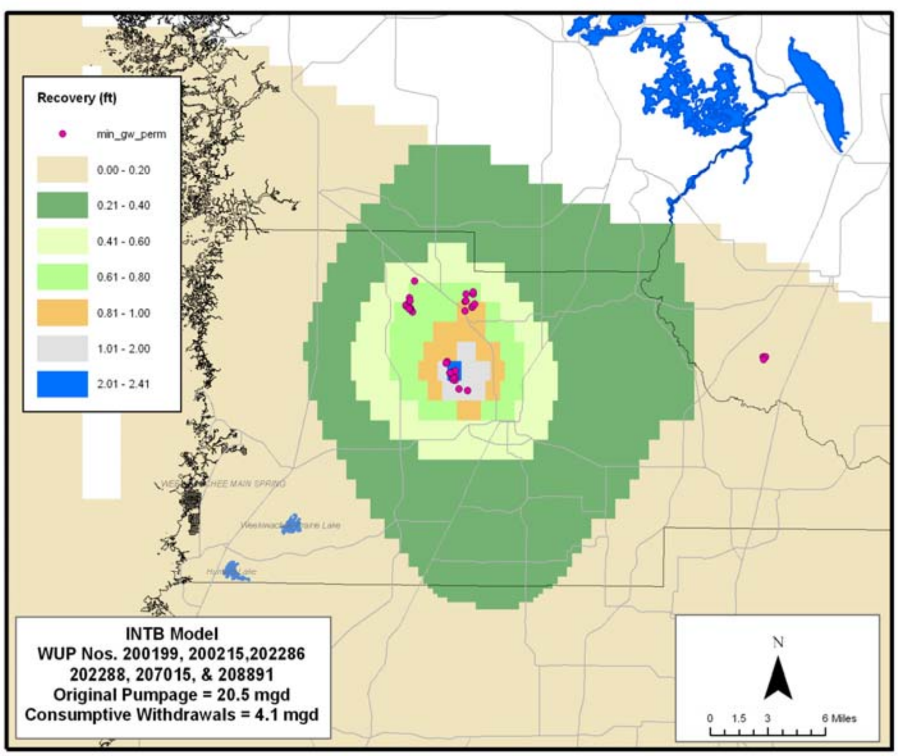


Figure 6. Predicted increase in UFA water levels due to adjusting mining withdrawals for consumptively-used quantities.

3.1.2 Tampa Bay Water Wellfield Reduction
By 2008, as part of the Northern Tampa Bay wellfield recovery plan, TBW is expected to withdraw average annual groundwater withdrawals of approximately 90 mgd from their 11 wellfields located in Hillsborough, Pasco, and northeast Pinellas Counties. Long-term average withdrawals from these 11 wellfields ranged between 140 to 150 mgd during the late-1990s. In this scenario, the Cross Bar and Cypress Creek wellfields were reduced by 50 percent and the Starkey, Eldridge-Wilde, Section 21, South Pasco, Morris Bridge, and Cosme-Odessa wellfields were reduced by 30 percent from their 1989-1998 average rates. The Cypress Bridge, NW Hillsborough, and North Pasco dispersed wellfields were left at their existing withdrawal rates. This resulted in an overall reduction of 45 mgd from the 1989-1998 current withdrawals in the INTB model.
Figure 7 indicates the predicted increase in UFA water levels due to a cutback of 45 mgd in 1989-1998 average withdrawal quantities. Weeki Wachee spring flow increased by 4.2 cfs due to this reduction in groundwater withdrawals.

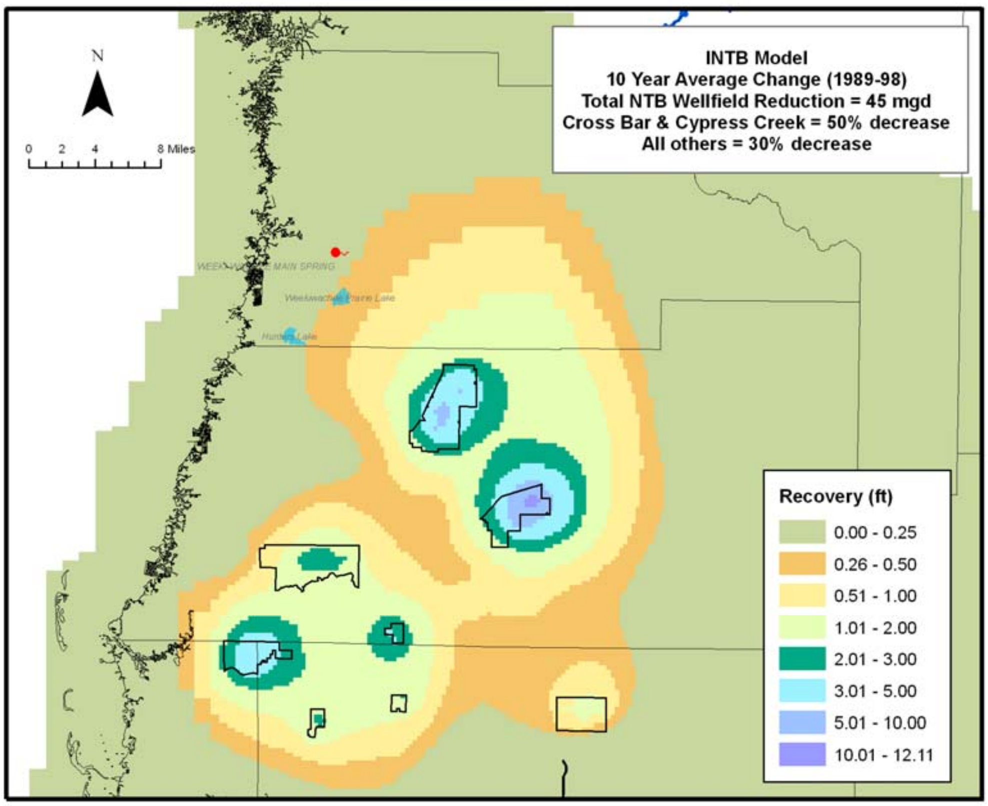


Figure 7. Predicted increase in UFA water levels due to a reduction of 45 mgd in TBW wellfield withdrawals.

3.1.3 Septic Tank Recharge in the Spring Hill Area

According to state department of health records, there were approximately 52,000 septic tanks located within Hernando County in 2005 (Florida DOH, 2007). In the unconfined portion of the UFA, these systems provide additional recharge to the groundwater system that is not accounted for in the current INTB model. LBG, Inc. determined that in the West Hernando County Public Supply Service area (largely the Spring Hill residential community) there were 26,558 septic systems in 2006 (LBG, 2007). According to the Hernando County Utility's records, flow averages 200 gallons per day (gpd) of wastewater for each household in their service area (LBG, 2007). This equates to a total septic tank recharge value of 5.3 mgd. To simulate this effect in the INTB model, this recharge rate was applied to 197 model grid cells over the high density residential area of Spring Hill via injection into the unconfined UFA at a rate of 0.027 mgd per cell (Figure 8).

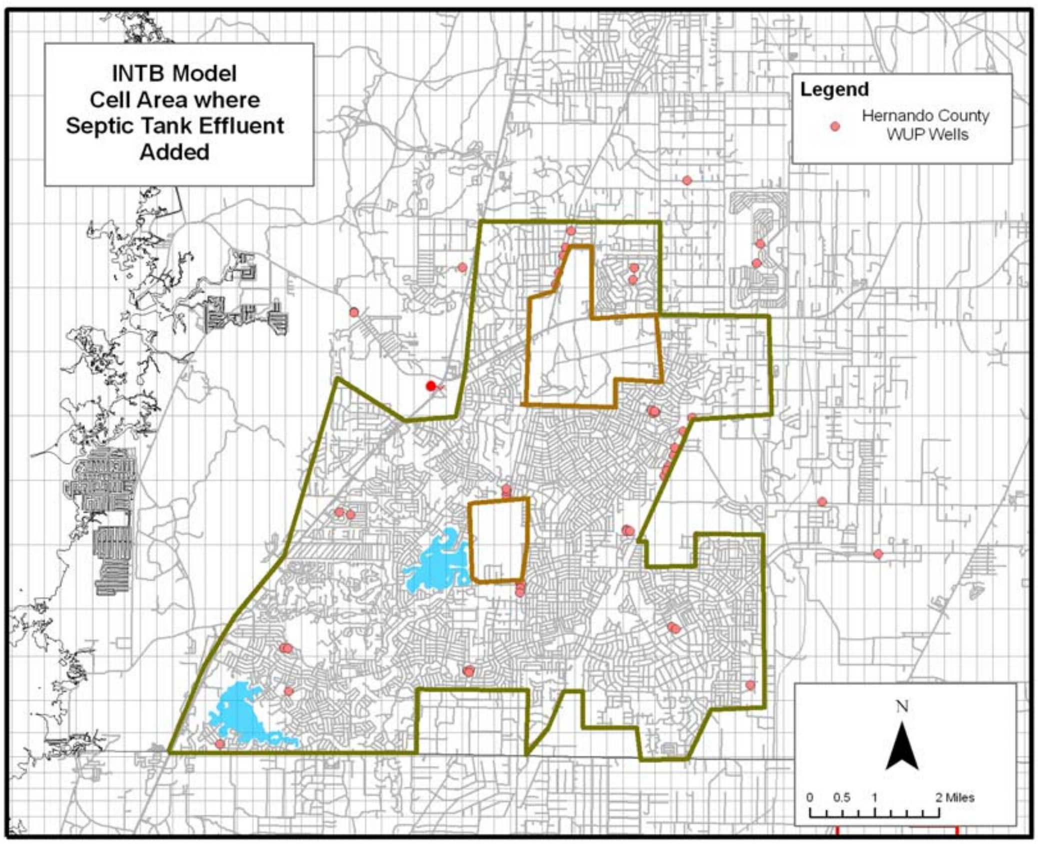


Figure 8. Area where septic tank recharge of 5.3 mgd was applied in the INTB model.

Figure 9 shows the predicted increase in UFA water levels due to the application of 5.3 mgd of septic tank recharge in the Spring Hill area. Weeki Wachee spring flow increased by 2.5 cfs due to the application of this additional recharge.

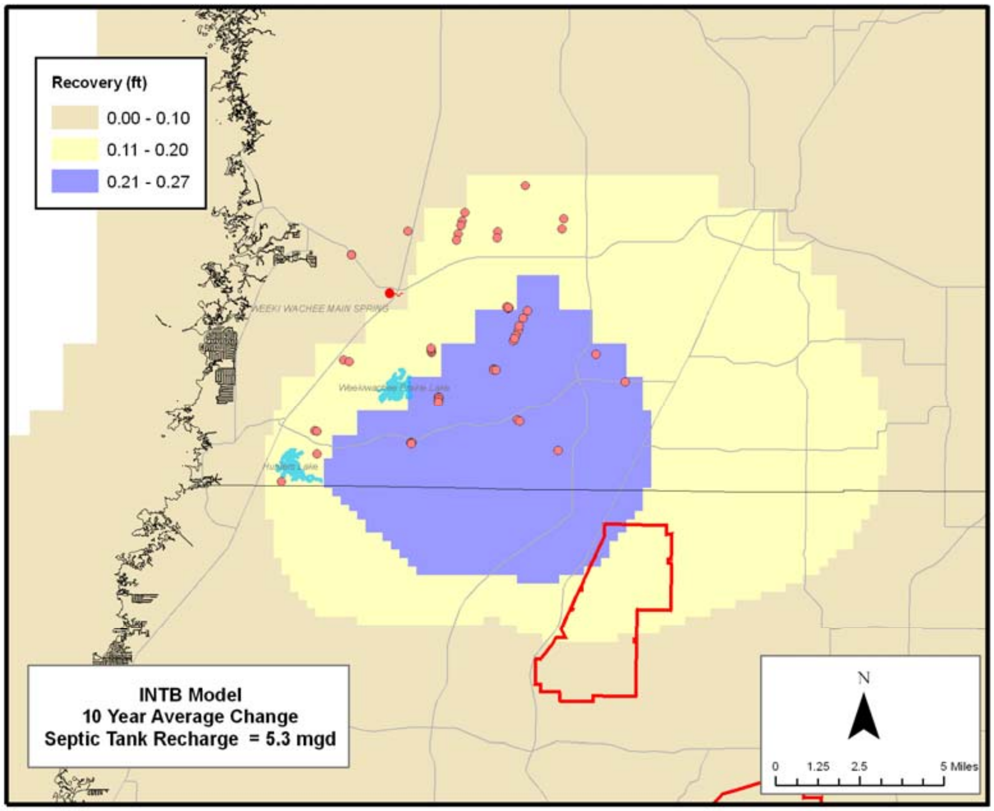


Figure 9. Predicted increase in UFA water levels due to the application of 5.3 mgd of septic tank recharge.

3.2 Northern District Model Scenario

The SWFWMD Northern District groundwater flow model was completed in September 2007 by the consulting firm HGL, Inc. The domain of the Northern District groundwater flow model (NDM) includes portions of the SWFWMD, the St. Johns River Water Management District (SJRWMD), and the Suwannee River Water Management District (SRWMD). The flow model encompasses the entire extent of the CWCFGWB and NWCFGWB. The eastern boundary of the regional groundwater flow model extends just east of the Lake County/Orange County line. The western boundary of the model domain extends approximately five miles offshore of the Gulf of Mexico.

The regional model finite-difference grid consists of 182 columns and 275 rows of 2,500 ft uniform grid spacing (Figure 10). The NDM is fully 3-Dimensional with top and bottom elevations specified for each model layer. Topographic elevations were assigned to the top of model layer 1 from a digital elevation model provided by SWFWMD, based on the USGS 30m National Elevation Dataset (NED). The Florida Geological Survey supplied elevation data for all other layers in the model.

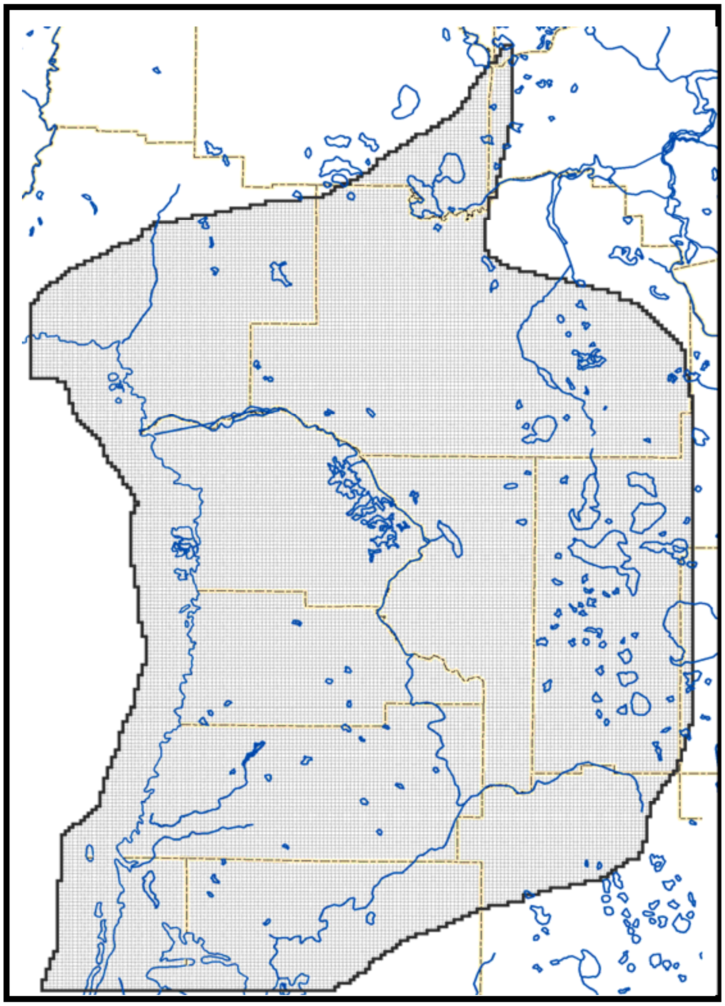


Figure 10. Groundwater grid in the Northern District model.

The NDM consists of seven layers that represent the primary geologic and hydrogeologic units including: 1. Surficial Sands; 2. Intermediate Confining Unit (ICU); 3. Suwannee Limestone; 4. Ocala Limestone; 5. upper Avon Park Formation; 6. Middle Confining Unit (MCU) I and MCU II; and the 7. lower Avon Park Formation or Oldsmar Formation. The UFA is composed of the Suwannee Limestone, Ocala Limestone, and Upper Avon Park; the Lower Floridan aquifer (LFA) is composed of the permeable parts of both the lower Avon Park and the Oldsmar Formation. Due to the permeability contrasts between the units, each unit is simulated as a discrete model layer rather than using one model layer to represent a thick sequence of permeable units (e.g., UFA). In regions where the UFA is unconfined, the second model layer represents the uppermost geologic unit in the UFA. The Suwannee Limestone is absent over a large part of the model domain. Where the Suwannee Formation is absent, model layers 3 and 4 represent the Ocala Limestone. The Ocala Limestone is absent in some local areas in the northernmost region of the model domain. In those areas, model layers 3 through 5 represent the Avon Park Formation. With the exception of the eastern part of the domain, the Oldsmar Formation is assumed to have a relatively low permeability being similar to the permeability of the overlying MCU II, which includes the lower Avon Park. Consequently, with the exception of the eastern part of the model domain, the finite-difference cells representing the LFA (model layer 7) are inactive and groundwater flow is not simulated.

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

The groundwater flow and solute transport modeling computer code MODFLOW-SURFACT was used for the groundwater flow modeling (HGL, 2005). MODFLOW-SURFACT is an enhanced version of the USGS modular three-dimensional groundwater flow code (McDonald and Harbaugh,
1988).

To note drawdown in the UFA and potential impacts to Weeki Wachee Springs flow, the NDM was simulated under steady-state conditions using 1995 withdrawals and compared to predevelopment conditions (zero withdrawals). Based on the impacts of 1995 groundwater withdrawals (450 mgd) over the NDM domain, predicted reduction in Weeki Wachee Springs discharge was 9.7 cfs.

4.0 Summary of Weeki Wachee Spring Flow Impact

The results of the first INTB model regional scenario showed that Weeki Wachee Spring discharge was reduced by 25.6 cfs as an average over the 5-year period from 1993-1998 due to groundwater withdrawals of 334 mgd in both the CWCFGWB and NWCFGWB. Refinement of these impact scenarios was conducted by adjusting existing mining withdrawals in Hernando County to reflect only consumptively-used quantities, accounting for TBW wellfield reductions as mandated under the Northern Tampa Bay Recovery Plan, and including the impact of septic tank recharge on the groundwater system in western Hernando County. The sum of these changes to overall spring flow reduced the groundwater withdrawal impact to Weeki Wachee Spring by 8.6 cfs.

Based upon the simulation results from both the INTB and Northern District models, the projected reduction to Weeki Wachee Spring discharge from current groundwater withdrawals varies from 9.7 to 21.2 cfs without any changes due to TBW recovery operations. As mandated in 2008, TBW central system wellfields will withdraw an average of 90 mgd. The INTB model projects that groundwater withdrawal impacts will be reduced by another 4.2 cfs once these quantities are realized.

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10.2 Appendices – Chapter 3

Appendix 3-1

River	River km	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Sum BB	N*subO*	N*subT*	Freq	Abud	Dens
Weeki Wachee	0.0	Rup	3	4	4	2	5	3	2	3	3	3	32	10	10	1	3.2	3.2
		Drft	3	4	5			1					13	4	10	0.4	3.25	1.3
Weeki Wachee	0.2	Myr								0.5			0.5	1	10	0.1	0.5	0.05
		Pot		1			2		1				4	3	10	0.3	1.3333	0.4
		Rup	5	2	5	1		0.5	2	5	2	2	24.5	9	10	0.9	2.7222	2.45
		Drft	5	3	4	3	4	1	3	4	2	2	31	10	10	1	3.1	3.1
Weeki Wachee	0.4	Rup	2	4	3	3	1	2	1	4	3	2	25	10	10	1	2.5	2.5
		Drft		4	2	3	5	5	1	4	3	2	29	9	10	0.9	3.2222	2.9
Weeki Wachee	0.6	Myr		0.1	0.1								0.2	2	10	0.2	0.1	0.02
		Rup	4	4	4	2	2	1	1	1	3	2	24	10	10	1	2.4	2.4
		Drft	4	5	4	4	2	1	1	2	4	5	32	10	10	1	3.2	3.2
Weeki Wachee	0.8	Myr						1		1			2	2	10	0.2	1	0.2
		Rup	3	3		4	3	5	2	2	2	5	29	9	10	0.9	3.2222	2.9
		Drft	3	4		5	4	5	3	2	2	5	33	9	10	0.9	3.6667	3.3
		Bare			5								5	1	10	0.1	5	0.5
Weeki Wachee	1.0	Rup	4		1	1	2	1			0.1	1	10.1	7	10	0.7	1.4429	1.01
		Zan		3	5	5	3	5	5	5	5	5	41	9	10	0.9	4.5556	4.1
		Drft	4		2	2	1					2	11	5	10	0.5	2.2	1.1
Weeki Wachee	1.2	Rup			2	2			4	1	2		11	5	10	0.5	2.2	1.1
		Zan	5	1			5	5	4	5	5	5	35	8	10	0.8	4.375	3.5
		Drft	1	1				1					3	3	10	0.3	1	0.3
Weeki Wachee	1.4	Myr			2	5							7	2	10	0.2	3.5	0.7
		Pot			2								2	1	10	0.1	2	0.2
		Zan	5	2			4	5	2	4		5	27	7	10	0.7	3.8571	2.7
		Drft	4	2	3								9	3	10	0.3	3	0.9
		Bare									5		5	1	10	0.1	5	0.5
Weeki Wachee	1.6	Zan						5	5	5	5	5	25	5	10	0.5	5	2.5
		Root				1	4						5	2	10	0.2	2.5	0.5
		Bare	5	5	5								15	3	10	0.3	5	1.5
Weeki Wachee	1.8	Zan	1	2	2	4						5	14	5	10	0.5	2.8	1.4
		Root							2	1			3	2	10	0.2	1.5	0.3
		Bare					5	5			5		15	3	10	0.3	5	1.5
Weeki Wachee	2.0	Pot			2	2							4	2	10	0.2	2	0.4
		Zan	5			5	5			0.1		2	17.1	5	10	0.5	3.42	1.71
		Root							1	3	3	3	10	4	10	0.4	2.5	1
		Drft		2		2		4	1				9	4	10	0.4	2.25	0.9
Weeki Wachee	2.2	Pot	5										5	1	10	0.1	5	0.5
		Zan		5	5	4							14	3	10	0.3	4.6667	1.4
		Root					2	2	0.5	1	0.5	1	7	6	10	0.6	1.1667	0.7
Weeki Wachee	2.4	Val		0.5									0.5	1	10	0.1	0.5	0.05
		Myr	0.5										0.5	1	10	0.1	0.5	0.05
		Pot		1							1	2	4	3	10	0.3	1.3333	0.4
		Bare			5	5	5	5	5	5			30	6	10	0.6	5	3

Species Codes

Hydrilla verticellata	Hyd	Ruppia maritima	Rup	Bare	Barren bottom
Myriophyllum spicatum	Myr	Sagittaria kurziana	Sag	Drft	Drift algae
Najas guadalupensis	Naj	Vallisneria americana	Val	Root	Rooted algae
Potamogeton pectinatus	Pot	Zanichellia palustris	Zan		

Appendix 3-1 (Continued)
Macrophyte Results

River	River km	Species	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Sum BB	N*subO*	N*subT*	Freq	Abud	Dens
Mud River (WW)	1.4	Myr			2	5							7	2	10	0.2	3.5	0.7
		Pot			2								2	1	10	0.1	2	0.2
		Zan	5	2			4	5	2	4		5	27	7	10	0.7	3.8571	2.7
		Drft	4	2	3								9	9	10	0.9	1	0.9
		Bare									5		5	1	10	0.1	5	0.5
Mud River (WW)	1.6	Myr		2		1			1	0.5		0.5	5	5	10	0.5	1	0.5
		Rup				2			4	4	5	3	18	5	10	0.5	3.6	1.8
		Zan	5	3	3	5	3	4					23	6	10	0.6	3.8333	2.3
		Drft	2	2		2		2	2	3	4	5	22	8	10	0.8	2.75	2.2
Mud River (WW)	1.8	Myr		1		3	2	2	4	2	0.5	1	15.5	8	10	0.8	1.9375	1.55
		Pot				1							1	1	10	0.1	1	0.1
		Rup						2		2			4	2	10	0.2	2	0.4
		Zan	5	5	2	5	5	1		5	4	5	37	9	10	0.9	4.1111	3.7
		Drft		3	1				1		1	1	7	5	10	0.5	1.4	0.7
Mud River (WW)	2.0	Myr	2		1	4	3	1	2	2			15	7	10	0.7	2.1429	1.5
		Rup	2	1	4		3	4	3		2	1	20	8	10	0.8	2.5	2
		Zan	5	5	4	4		4	3	5	5	5	40	9	10	0.9	4.4444	4
		Drft							4	2	2	2	10	4	10	0.4	2.5	1
Mud River (WW)	2.2	Myr		2	2					2	3		9	4	10	0.4	2.25	0.9
		Pot		1									1	1	10	0.1	1	0.1
		Rup	5		4	3		3	3		2		20	6	10	0.6	3.3333	2
		Zan	2	1							3	5	11	4	10	0.4	2.75	1.1
		Drft	4	5	5								14	3	10	0.3	4.6667	1.4
		Bare					5						5	1	10	0.1	5	0.5
Mud River (WW)	2.4	Myr		1	5	5	2		2	3	5	5	28	8	10	0.8	3.5	2.8
		Rup		3		2	2				2		9	4	10	0.4	2.25	0.9
		Zan	5	5		2	2	5	5	3			27	7	10	0.7	3.8571	2.7
		Drft	2					2	2				6	3	10	0.3	2	0.6
Mud River (WW)	2.6	Myr	5	5							4		14	3	10	0.3	4.6667	1.4
		Pot		1		2			2	1	5	2	13	6	10	0.6	2.1667	1.3
		Zan			2		5	1					8	3	10	0.3	2.6667	0.8
		Drft			4	5	5	4	5	4	5	4	36	8	10	0.8	4.5	3.6
Mud River (WW)	2.8	Myr		4	2								6	2	10	0.2	3	0.6
		Pot			2	4							6	2	10	0.2	3	0.6
		Zan	5	5									10	2	10	0.2	5	1
		Drft	2	2	5			1	1	5	5	5	26	8	10	0.8	3.25	2.6
		Bare					5						5	1	10	0.1	5	0.5
Mud River (WW)	3.0	Myr	2	2	3	1	0.5			1			9.5	6	10	0.6	1.5833	0.95
		Pot		1	2	2				5	3		13	5	10	0.5	2.6	1.3
		Zan		3									3	1	10	0.1	3	0.3
		Drft		5	2	4	1						12	4	10	0.4	3	1.2
		Bare						5	5				10	2	10	0.2	5	1
Mud River (WW)	3.2	Bare	5	5	5	5	5	5	5	5	5	5	50	10	10	1	5	5
Mud River (WW)	3.4	Myr		2									2	1	10	0.1	2	0.2
		Pot	4	4									8	2	10	0.2	4	0.8
		Drft			5	5	5	5	5			5	30	6	10	0.6	5	3
		Bare								5	5		10	2	10	0.2	5	1
Mud River (WW)	3.6	Myr	0.5										0.5	1	10	0.1	0.5	0.05
		Pot	0.5										0.5	1	10	0.1	0.5	0.05
		Drft	5	5	5	5	5	5	5	5	5	5	50	10	10	1	5	5
Mud River (WW)	3.8	Bare	5	5	5	5	5	5	5	5	5	5	50	10	10	1	5	5

Species Codes

Hydrilla verticellata	Hyd	Ruppia maritima	Rup	Bare	Barren bottom
Myriophyllum spicatum	Myr	Sagittaria kurziana	Sag	Drft	Drift algae
Najas guadalupensis	Naj	Vallisneria americana	Val	Root	Rooted algae
Potamogeton pectinatus	Pot	Zanichellia palustris	Zan		

10.3 Appendices – Chapter 4

Appendix 4-1 Tidal Harmonics

Regression coefficients for the tide prediction described in Section 4.1 are provided and are based on elapsed hours since 1/1/2001 at Bayport, Florida.

```
REM *********** TIDE HARMONICS *************
REM ******* Bayport_TidePrdct.syc **********
REM ******* Harmonic periods, hrs **********
REM ******* Semidiurnal Periodicity, hrs ***
M2 = 12.42
S2 = 12.00
N2 = 12.66
K2 = 11.97
T2 = 12.01
L2 = 12.19
REM ****** Diurnal Periodicity, hrs
K1 = 23.93
O1 = 25.82
P1 = 24.07
Q1 = 26.87
M1 = 24.84
J1 = 23.10
REM ***** Add lunar synodic month based on 29.53059*24
Mth= 708.7
REM ***** Add seasonal
Yr = 8766
2pi = 2*3.1417

REM ***** Define regression coefficients
Bo=0.49625
REM ********* Add Semidiurnal coefficients
REM ********* Coefficients for sine / cosine pairs.
M2_S = -0.47013067      REM *** M2 regression coef. for sine(elapsed time)
M2_C =  0.81657189      REM *** M2 regression coef. for cosine(elapsed time)
S2_S   = -0.32190687
S2_C   = 0.05176407
N2_S   = 0.01392475
N2_C   = 0.14778310
K2_S   = 0.06891806
K2_C   = 0.12088384
T2_S   = 0.01603469
T2_C   = 0.00469044
L2_S   = -0.04186755
L2_C   = 0.02595982
Rem ***********  Diurnal
K1_S   = 0.40612680
K1_C   = 0.30638176
O1_S   = 0.18794729
O1_C   = 0.42051744
P1_S   = -0.05215339
```

```
P1_C   = 0.13085372
Q1_S   = -0.05766436
Q1_C   = -0.04980391
M1_S   = 0.00651543
M1_C   = 0.01256147
J1_S   = 0.00816081
J1_C   = 0.03735435
Rem ******  Monthly
MTH_S   = 0.00137102
MTH_C   = 0.01134091
Rem ******** Annual
Yr_S    = -0.22646445
Yr_C     = -0.18937638

REM   Let julian=date-DOC(dat(date(,'YYYY'),1,1)+(minute/1440)
REM   Let Elap_hrs=Julian*24

Let Mod_HT=Bo+,
      M2_S*SIN(2pi*ELAP_HRS/M2)+M2_C*COS(2pi*ELAP_HRS/M2)+,
      S2_S*SIN(2pi*ELAP_HRS/S2)+S2_C*COS(2pi*ELAP_HRS/S2)+,
      N2_S*SIN(2pi*ELAP_HRS/N2)+N2_C*COS(2pi*ELAP_HRS/N2)+,
      K2_S*SIN(2pi*ELAP_HRS/K2)+K2_C*COS(2pi*ELAP_HRS/K2)+,
      T2_S*SIN(2pi*ELAP_HRS/T2)+T2_C*COS(2pi*ELAP_HRS/T2)+,
      L2_S*SIN(2pi*ELAP_HRS/L2)+L2_C*COS(2pi*ELAP_HRS/L2)+,

      K1_S*SIN(2pi*ELAP_HRS/K1)+K1_C*COS(2pi*ELAP_HRS/K1)+,
      O1_S*SIN(2pi*ELAP_HRS/O1)+O1_C*COS(2pi*ELAP_HRS/O1)+,
      P1_S*SIN(2pi*ELAP_HRS/P1)+P1_C*COS(2pi*ELAP_HRS/P1)+,
      Q1_S*SIN(2pi*ELAP_HRS/Q1)+Q1_C*COS(2pi*ELAP_HRS/Q1)+,
      M1_S*SIN(2pi*ELAP_HRS/M1)+M1_C*COS(2pi*ELAP_HRS/M1)+,
      J1_S*SIN(2pi*ELAP_HRS/J1)+K1_C*COS(2pi*ELAP_HRS/J1)+,
      Mth_S*SIN(2pi*ELAP_HRS/Mth)+Mth_C*COS(2pi*ELAP_HRS/Mth)+,
      Yr_S*SIN(2pi*ELAP_HRS/Yr)+Yr_C*COS(2pi*ELAP_HRS/Yr)
End
```

Appendix 4-2
Data Sources

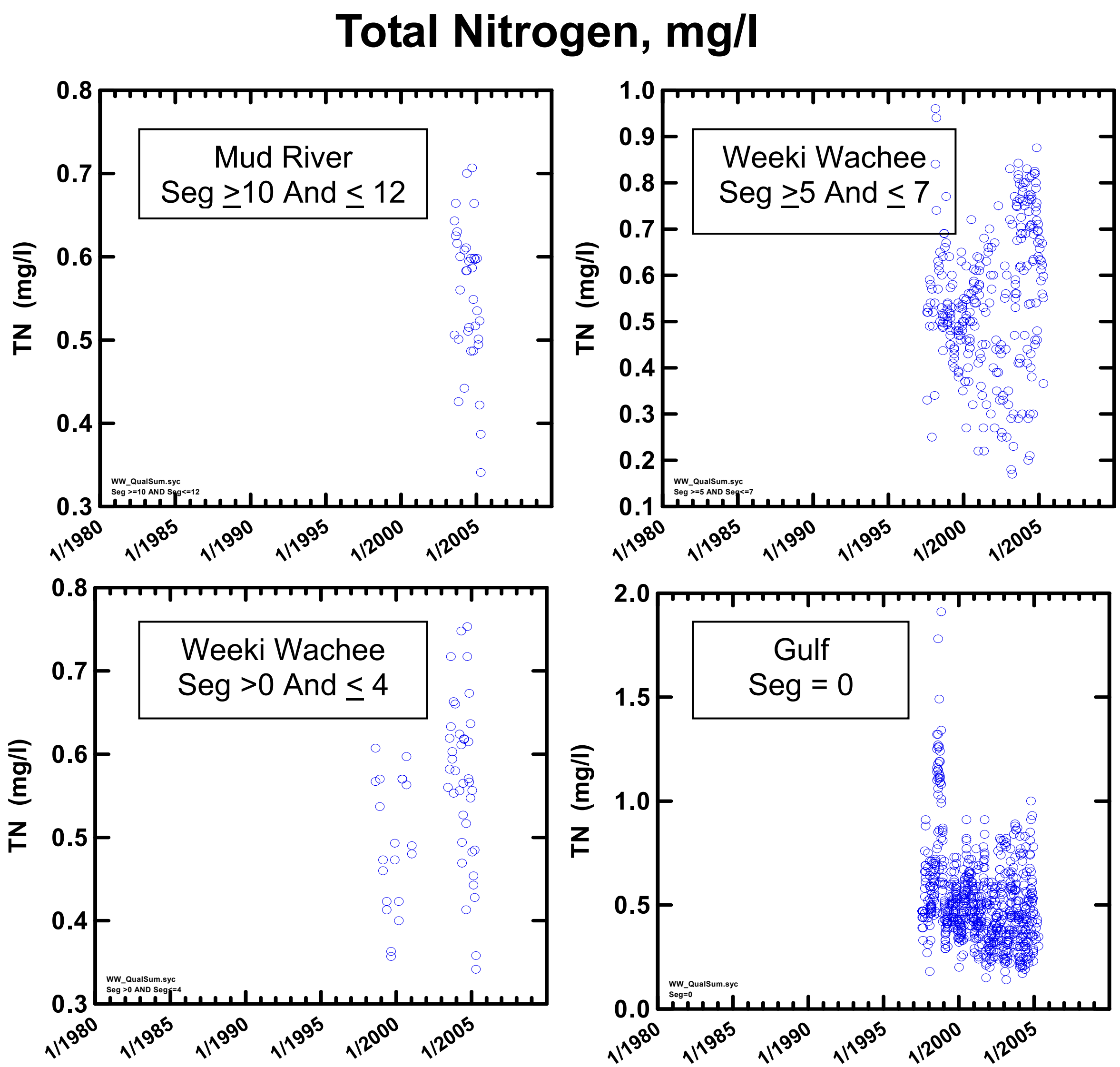
Water quality data was compiled from a variety of historical and recent monitoring efforts. Units were standardized and locations normalized to a river thalweg with river km = 0 at the mouth of the Weeki Wachee River. Salinity was calculated from Cox polynomials wherever conductivity was recorded. Daily flow was linked with sampling date. Sample times (where recorded) were normalized to GMT-5 hrs and the tide height at Bayport was estimated for the time of sampling.

Associated Project Description, or Citation	Parent File Name	Source Description	Date_Rcvd or Created	Rcd_From Affiliation
Fraser, T. et al. 2004. Water Quality Characteristics of the Nearshore Gulf Coast Waters Adjacent to Pasco County. Project Coast. University of Florida	2003 and 2004 combined river data.xls	Proj_Coast_mdb	3/23/2006	V. Craw, SWFWMD
Fraser, T. et al. 2001. Water Quality Characteristics of the Neashore Gulf Coast Waters Adjacent to Citrus, Hernando and Levy Counties. Final Report. Project Coast. University of Florida.	2003 and 2004 combined river data.xls	Proj_Coast_mdb	3/23/2006	V. Craw, SWFWMD
Fraser, T. et al. 2004. Water Quality Characteristics of the Nearshore Gulf Coast Waters Adjacent to Pasco County. Project Coast. University of Florida	Springs_Pasco COAST data through 2004.xls	Proj_Coast_mdb	3/23/2006	V. Craw, SWFWMD
Fraser, T. et al. 2001. Water Quality Characteristics of the Neashore Gulf Coast Waters Adjacent to Citrus, Hernando and Levy Counties. Final Report. Project Coast. University of Florida.	Springs_Pasco COAST data through 2004.xls	Proj_Coast_mdb	3/23/2006	V. Craw, SWFWMD
Dixon, L.K. 1986. Water Chemistry. Volume 1 in a Series: A Data collection program for selected coastal estuaries in Hernando, Citrus and Levy Counties, Florida. Prepared for SWFWMD Brooksville, Fl by Mote Marine Laboratory. October, 1986.	Weeki_profiles.sas7bdat	MML_84_85, WMD_85_86 USGS_1984	6/13/2005	S. Flannery, SWFMWD L.Dixon, Mote Marine Lab Q. Wylupeck, SWFWMD D. Yobbi, USGS
Yobbi, D.K. and L.A. Knochenmus. 1986. Effects of River Discharge and High-Tide Stage on Salinity Intrusion in the Weeki Wachee, Crystal, and Withlacoochee River Estuaries, Southwest Florida. USGS WRI Report 88-4116.	Weeki_profiles.sas7bdat	MML_84_85, WMD_85_86 USGS_1984	6/13/2005	S. Flannery, SWFMWD L.Dixon, Mote Marine Lab Q. Wylupeck, SWFWMD D. Yobbi, USGS
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	WWLAST.SSD		6/13/2005	S. Flannery, SWFMWD Q. Wylupeck, SWFWMD
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	WWLST.SSD		6/13/2005	S. Flannery, SWFMWD Q. Wylupeck, SWFWMD
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	WWALLDAT.SSD	WMD_91	6/13/2005	S. Flannery, SWFMWD Q. Wylupeck, SWFWMD
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	WK_QUAL.SSD		6/13/2005	S. Flannery, SWFMWD Q. Wylupeck, SWFWMD
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	MERGE2.SSD		6/13/2005	S. Flannery, SWFMWD Q. Wylupeck, SWFWMD
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	HYDROLOG.SSD		6/13/2005	S. Flannery, SWFMWD Q. Wylupeck, SWFWMD
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	OuputMFL_0603_0705.xls	WMD_02_05	---	M. Dachsteiner, SWFWMD C. Woolden, SWFWMD
SWFMWD, 1994. Weeki Wachee Diagnostic/ Feasibility Study. Quincy Wylupeck- SWFMWD Project Manager	Weeki_Wachee Profile Data 2003-2005.xls	WMD_02_05	---	M. Dachsteiner, SWFWMD C. Woolden, SWFWMD
	Weeki Wachee Salinity Data for 1994-1996.sas7bdat	WMD_94_96		S. Flannery, SWFMWD Q. Wylupeck, SWFWMD

Data Sources, continued.

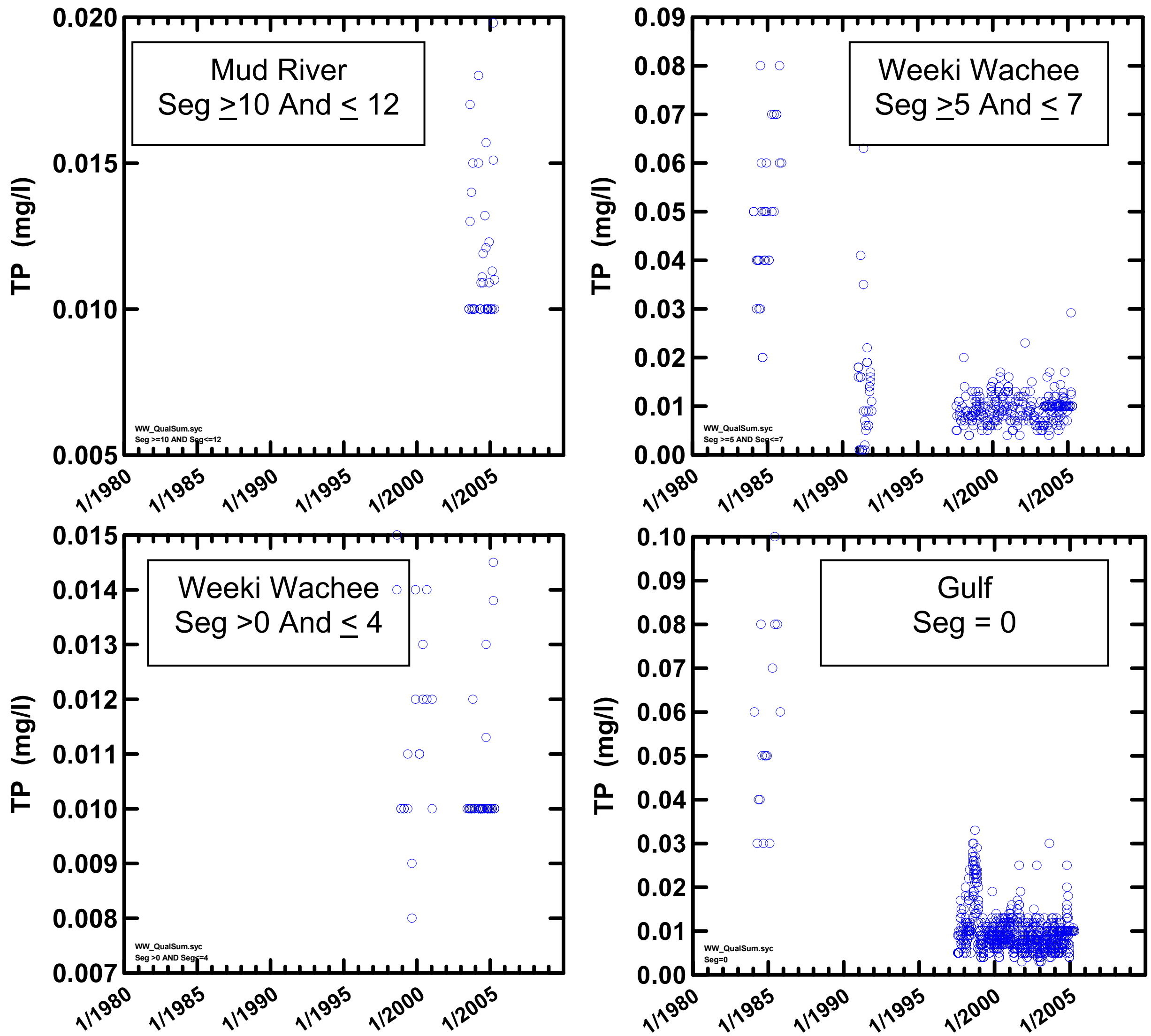
Associated Project Description, or Citation	Parent File Name	Source Description	Date_Rcvd or Created	Rcd_From Affiliation
Dixon, L.K. 1986. Water Chemistry. Volume 1 in a Series: A Data collection program for selected coastal estuaries in Hernando, Citrus and Levy Counties, Florida. Prepared for SWFWMD Brooksville, Fl by Mote Marine Laboratory. October, 1986.	Weeki_mote_chem.sas7bdat	MML_84_85	1/28/2005	S. Flannery, SWFMWD L.Dixon, Mote Marine Lab
Dixon, L.K. 1986. Water Chemistry. Volume 1 in a Series: A Data collection program for selected coastal estuaries in Hernando, Citrus and Levy Counties, Florida. Prepared for SWFWMD Brooksville, Fl by Mote Marine Laboratory. October, 1986.	Weeki_mote_photom.sas7bdat	MML 1984-1985	11/28/2005	S. Flannery, SWFMWD L.Dixon, Mote Marine Laboratory
Janicki Environmental, 2006, Analysis of Benthic Community Structure and It's Application to MFL Development in the Weeki Wachee and Chassahowitzka Rivers	Weeki_Wachee_Profile_Mar05.sas7bdat	JEI_Benthos	5/12/2005	Janicki Environmental,Inc
Fraser, T. et al. 2001. Physical, Chemical and Vegetative Characteristics of Five Gulf Coast Rivers. University of Florida	WW_UF_WQ_Rpt.xls	UF_ 5 Rivers Rpt	4/10/2006	Keypunch from report appendices
Fraser, T. et al. 2004. Water Quality Characteristics of the Nearshore Gulf Coast Waters Adjacent to Pasco County. Project Coast. University of Florida	UF_WW.xls	Proj_Coast_mdb	4/3/2006	T. Frazer, UF
Fraser, T. et al. 2001. Water Quality Characteristics of the Neashore Gulf Coast Waters Adjacent to Citrus, Hernando and Levy Counties. Final Report. Project Coast. University of Florida.	UF_WW.xls	Proj_Coast_mdb	4/3/2006	T. Frazer, UF
Fraser, T. et al. 2004. Water Quality Characteristics of the Nearshore Gulf Coast Waters Adjacent to Pasco County. Project Coast. University of Florida	UF_SIM.xls	Proj_Coast_mdb	4/4/2006	
Fraser, T. et al. 2001. Water Quality Characteristics of the Neashore Gulf Coast Waters Adjacent to Citrus, Hernando and Levy Counties. Final Report. Project Coast. University of Florida.	UF_SIM.xls	Proj_Coast_mdb	4/4/2006	

Appendix 4-3
Water Quality Trend Graphics



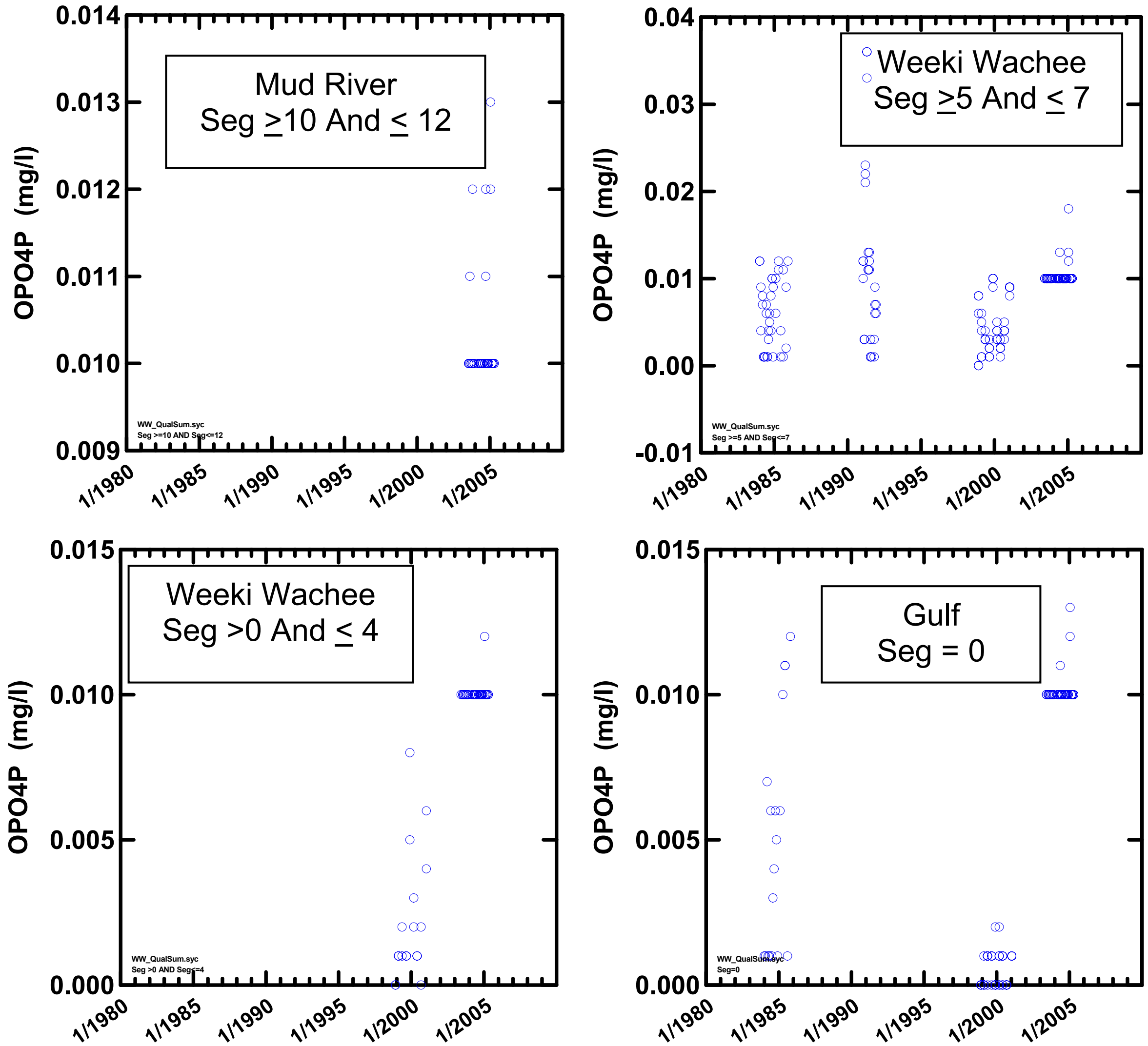
Water Quality Trend Graphics, continued

Total Phosphorus, mg/l

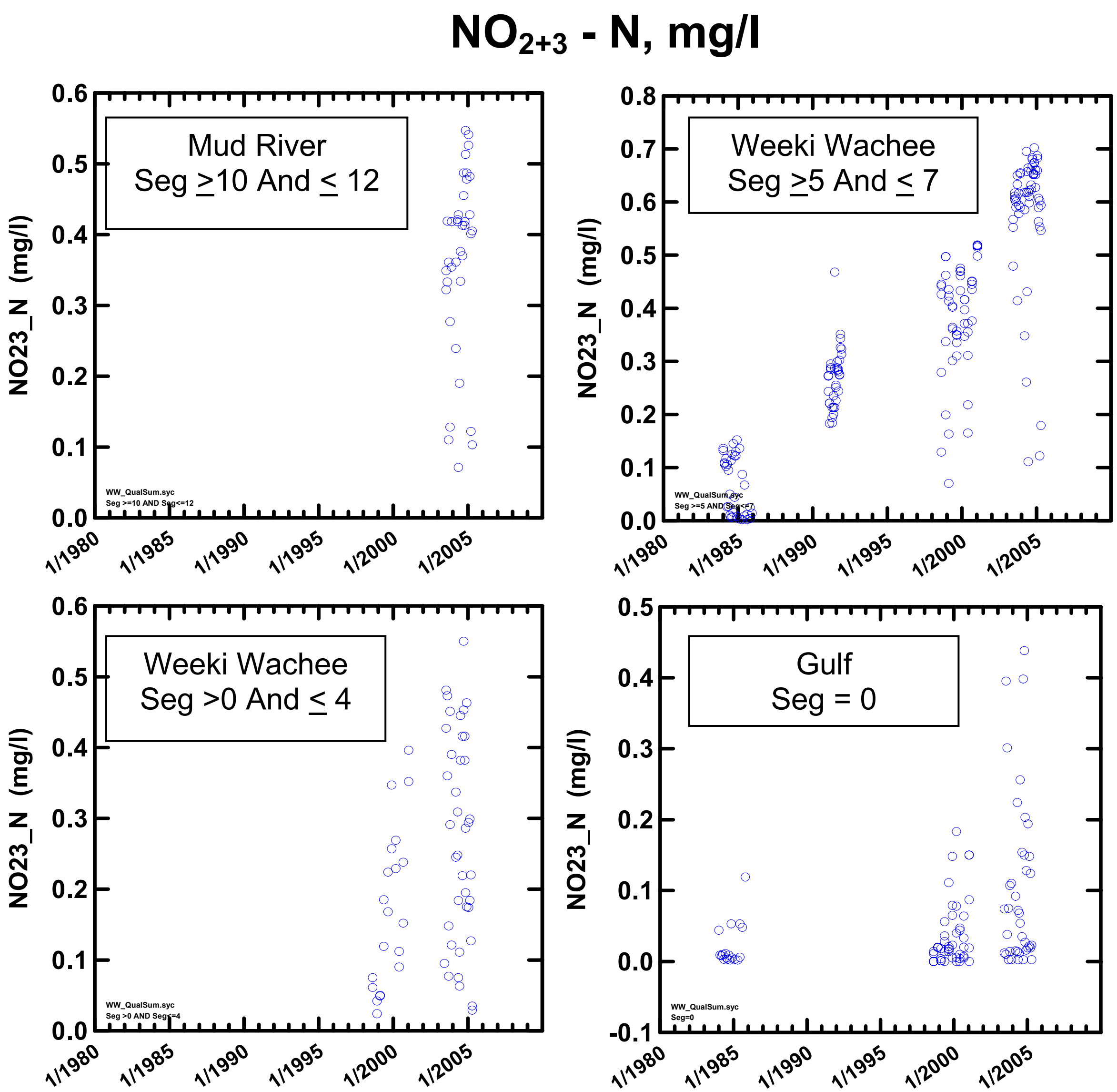


Water Quality Trend Graphics, continued.

Ortho-Phosphate - P, mg/l

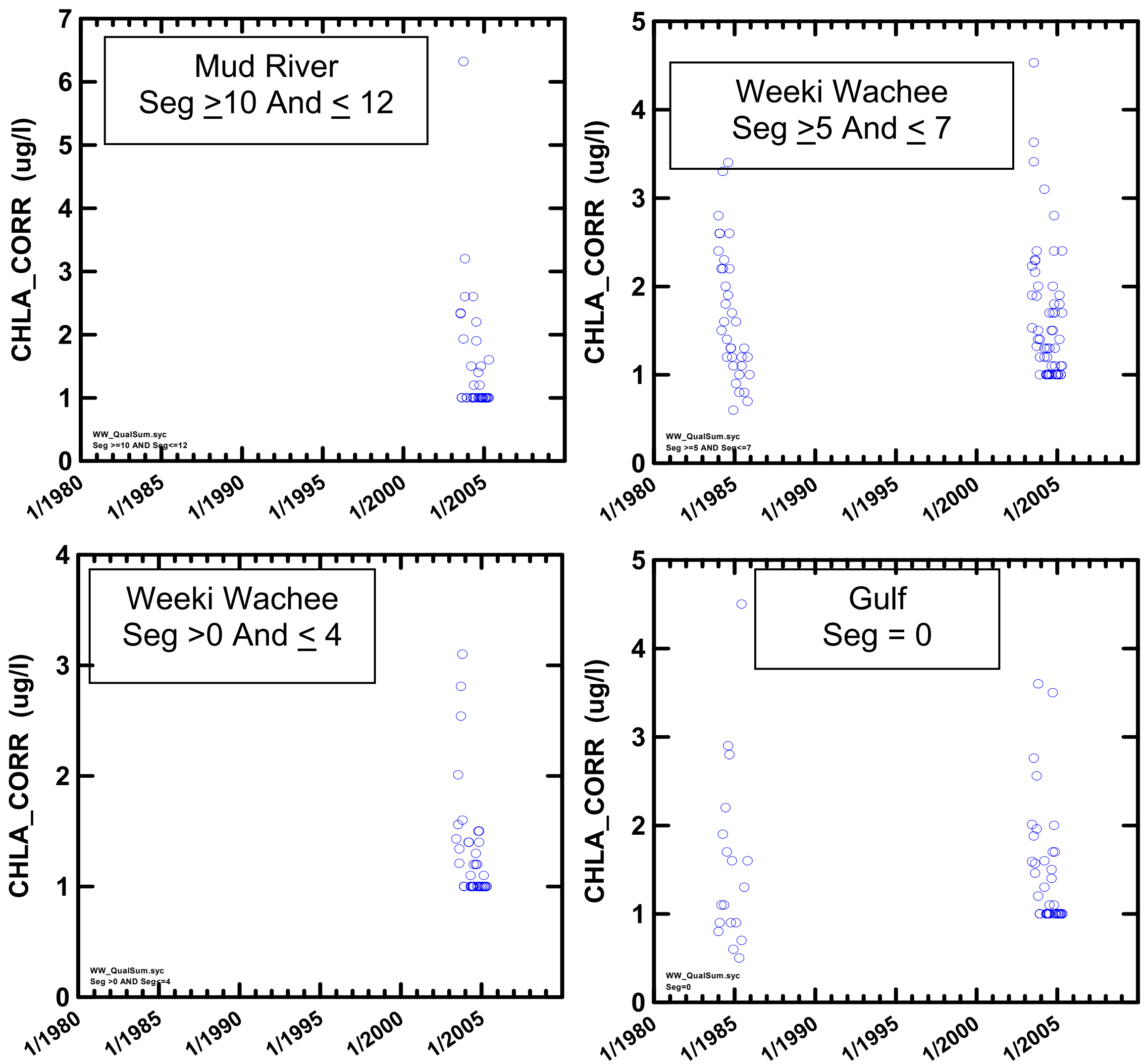


Water Quality Trend Graphics, continued.



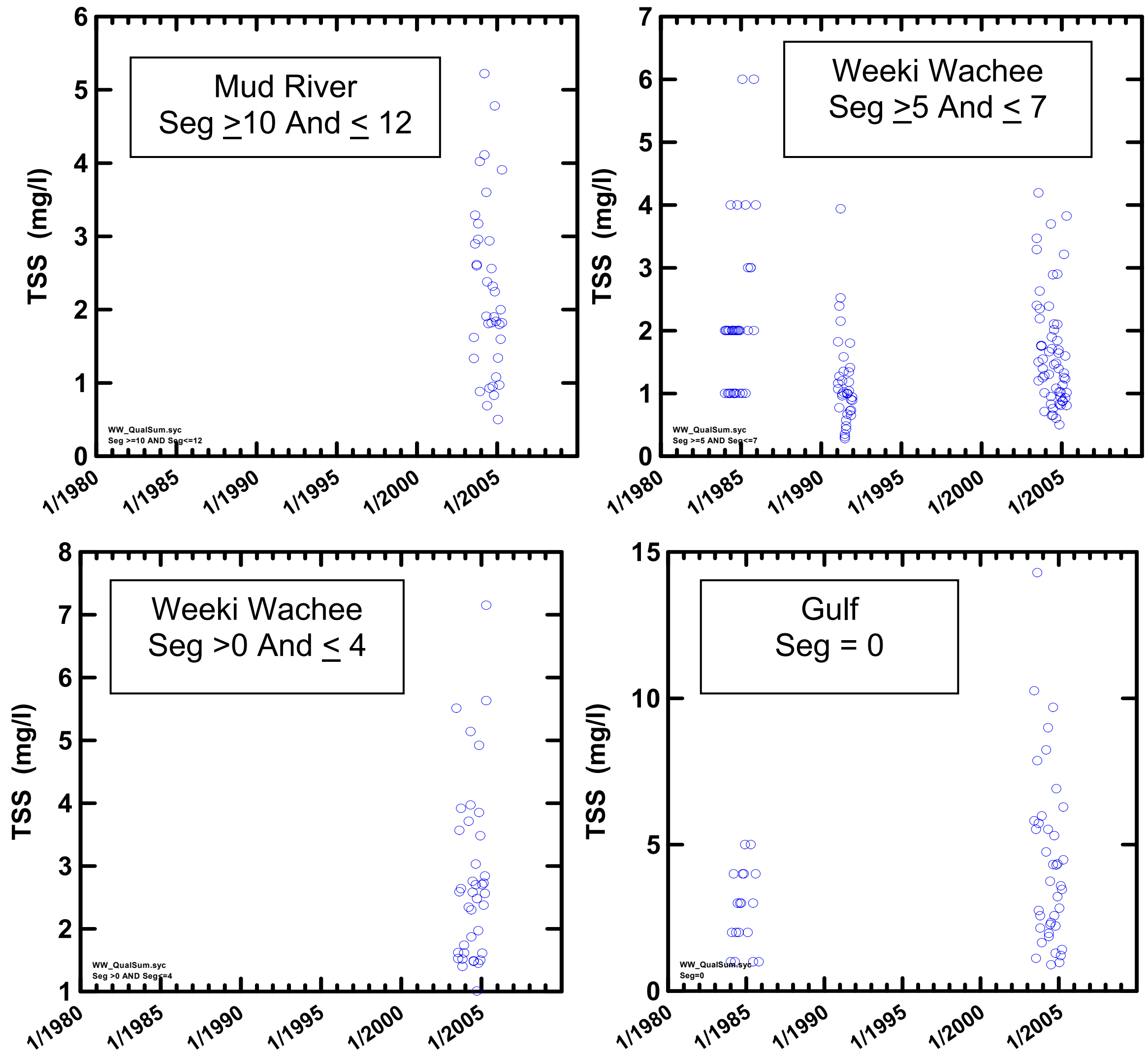
Water Quality Trend Graphics, continued.

Chlorophyll a (corrected), ug/l



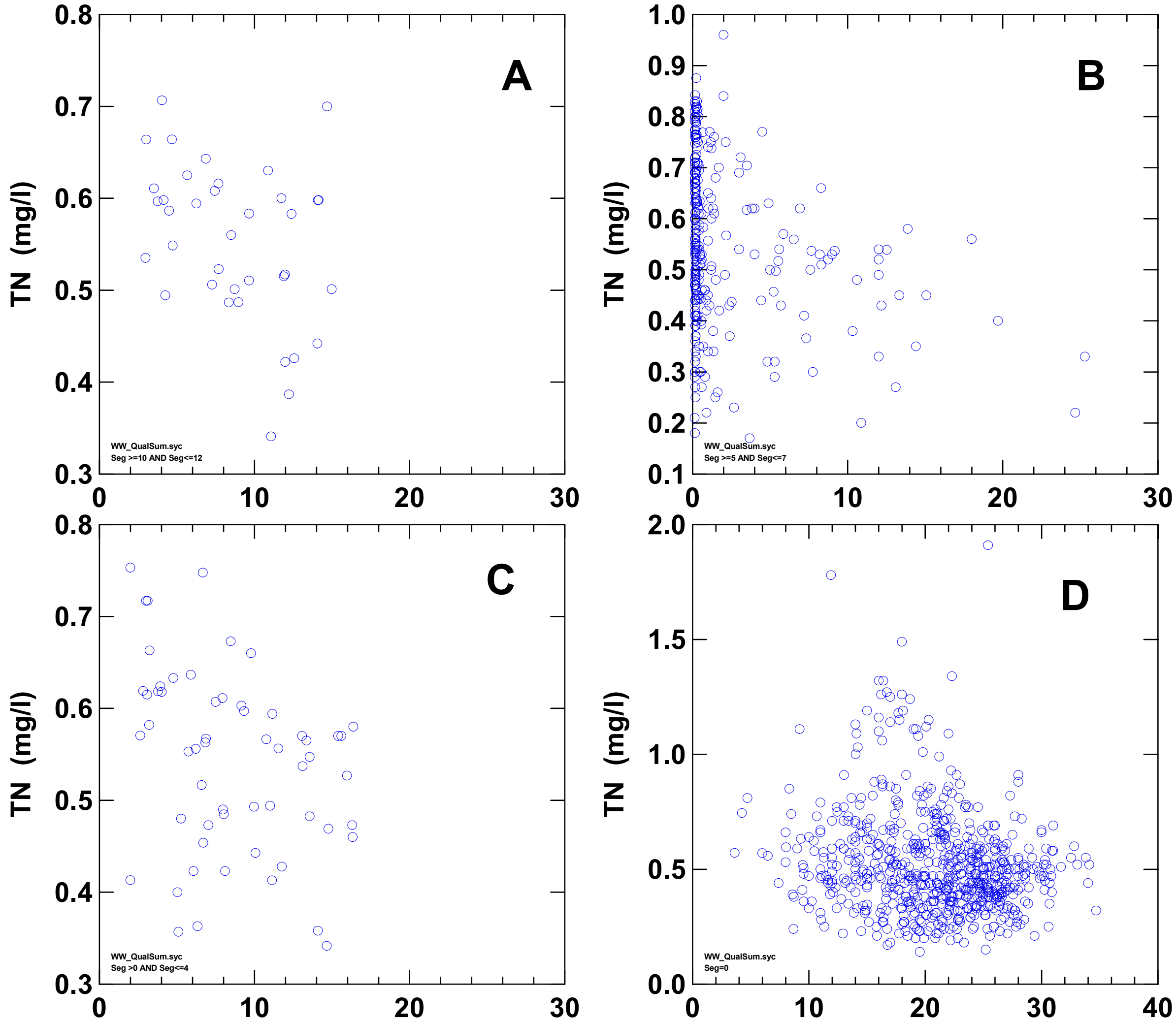
Water Quality Trend Graphics, continued.

Total Suspended Solids, mg/l



Water Quality Trend Graphics, continued.

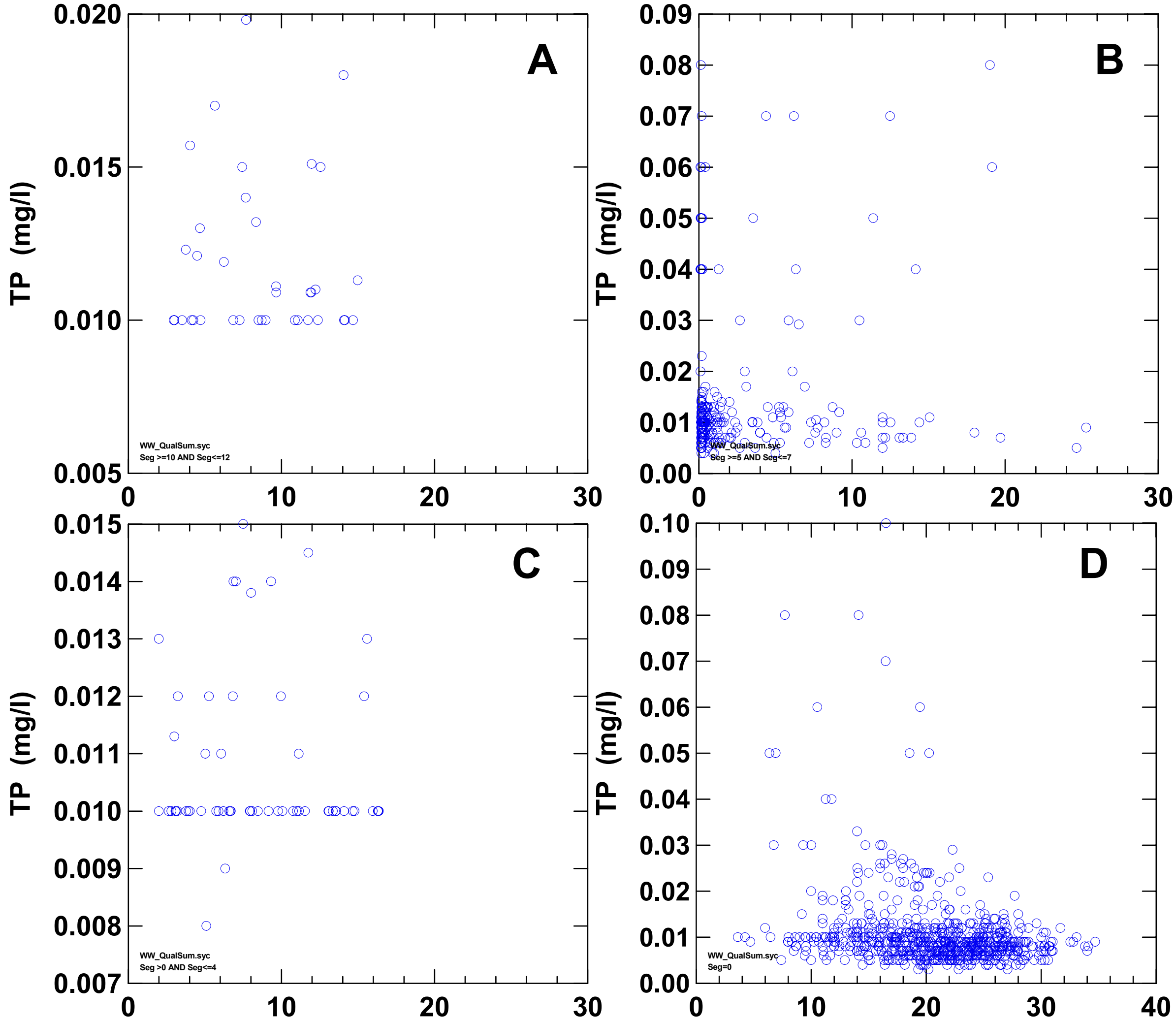
Total Nitrogen, mg/l vs. Salinity



A = Mud River Seg ≥ 10 and ≤ 12   B= Weeki Wachee Seg ≥ 5 And ≤ 7
C = Weeki Wachee Seg >0 and ≤ 4   D = Gulf Seg = 0

Water Quality Trend Graphics, continued.

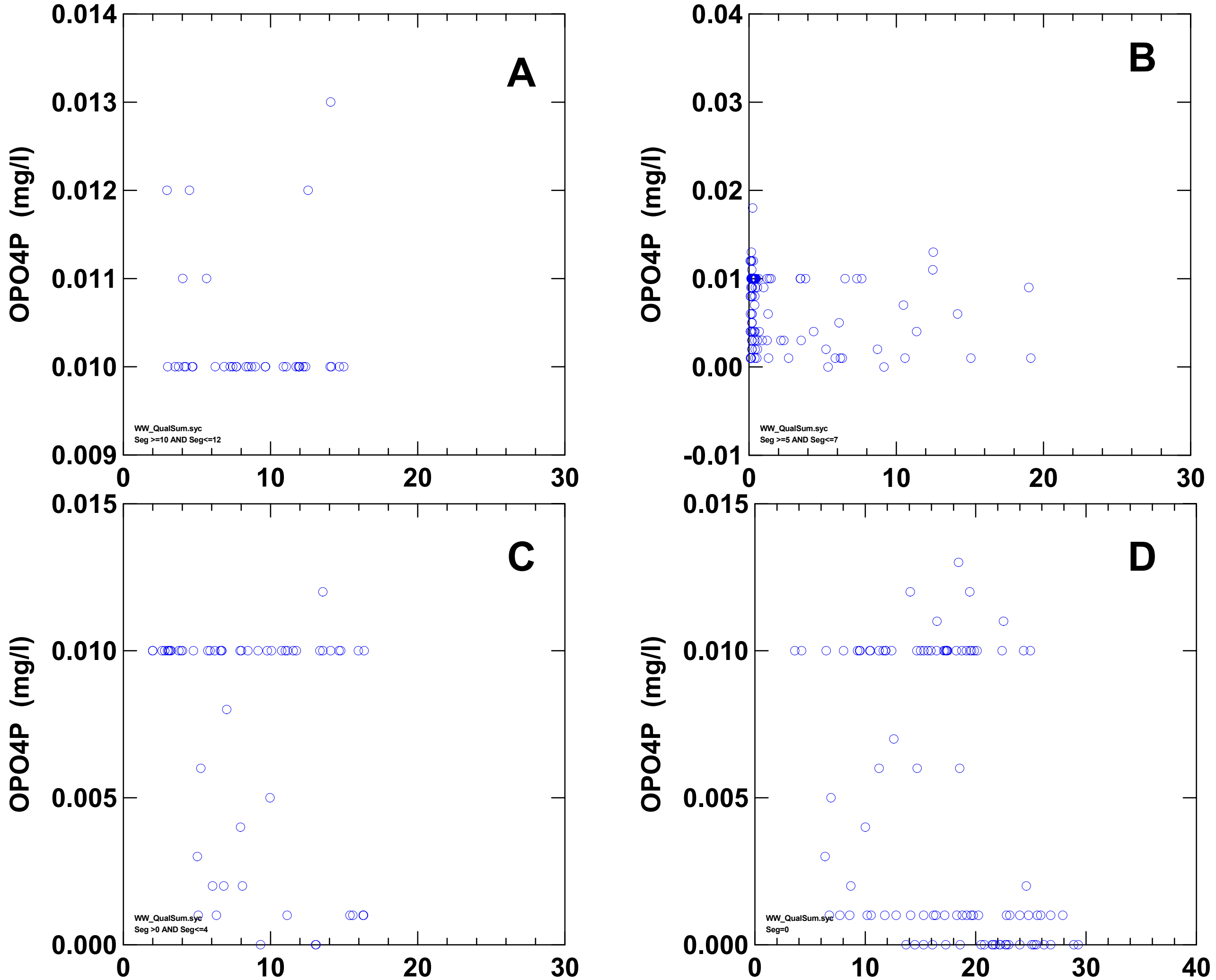
Total Phosphorus, mg/l vs. Salinity



A = Mud River Seg ≥ 10 and ≤ 12 B= Weeki Wachee Seg ≥ 5 And ≤ 7
C = Weeki Wachee Seg >0 and ≤ 4 D = Gulf Seg = 0

Water Quality Trend Graphics, continued.

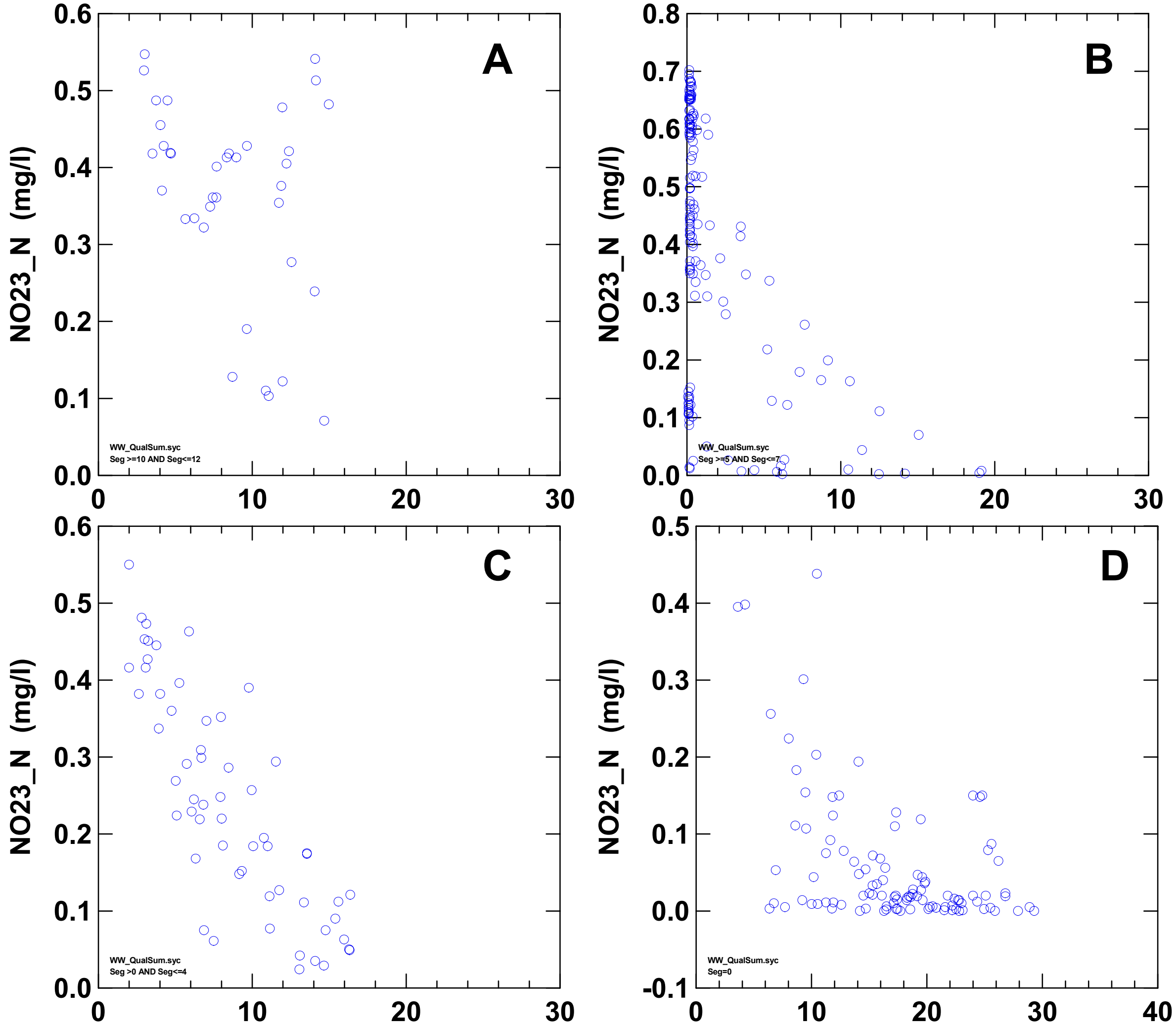
Ortho-Phosphate - P, mg/l vs. Salinity



A = Mud River Seg ≥ 10 and ≤ 12   B= Weeki Wachee Seg ≥ 5 And ≤ 7
C = Weeki Wachee Seg >0 and ≤ 4   D = Gulf Seg = 0

Water Quality Trend Graphics, continued.

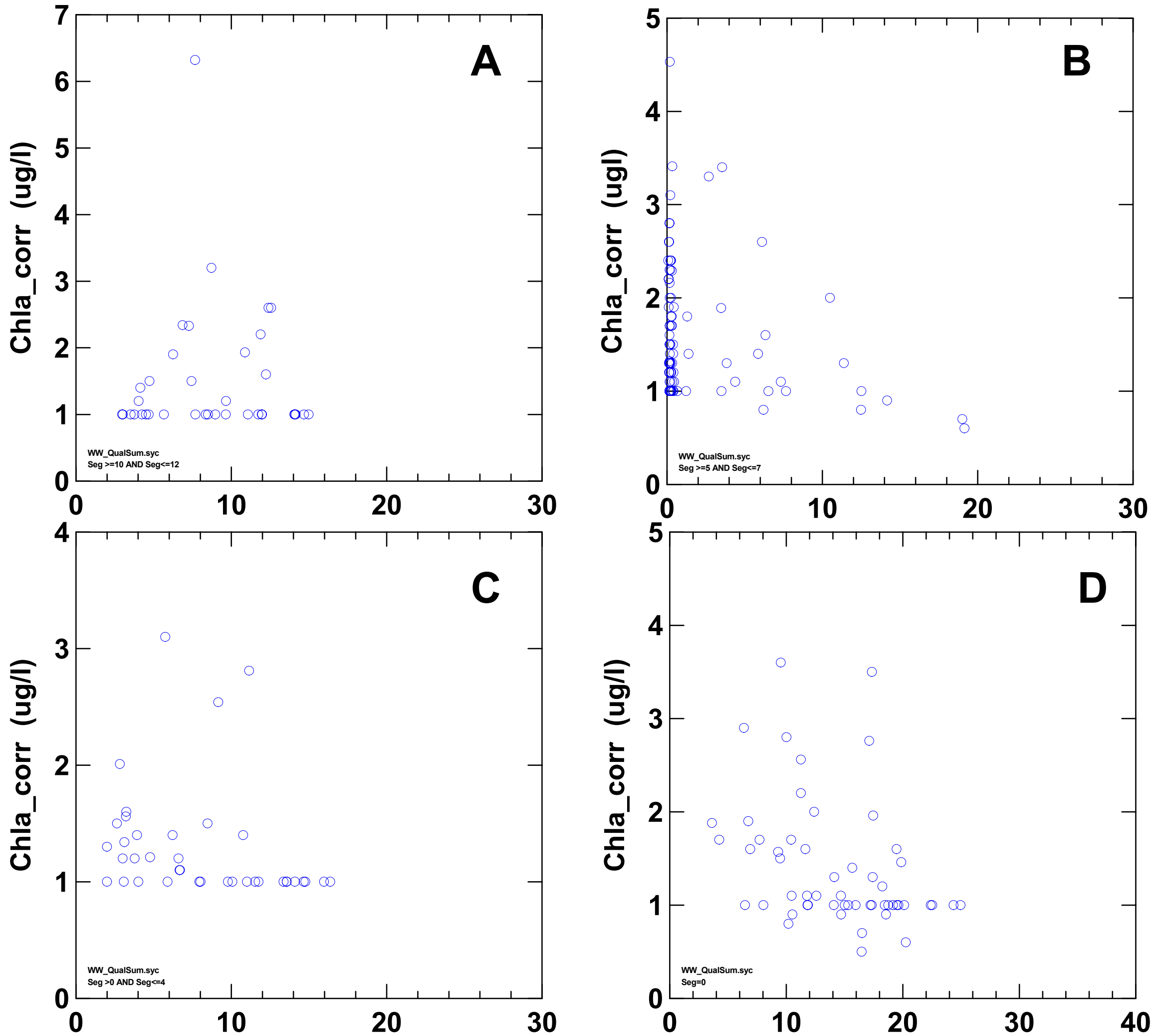
NO_{2+3} - N, mg/l vs. Salinity



A = Mud River Seg ≥ 10 and ≤ 12 B= Weeki Wachee Seg ≥ 5 And ≤ 7
C = Weeki Wachee Seg >0 and ≤ 4 D = Gulf Seg = 0

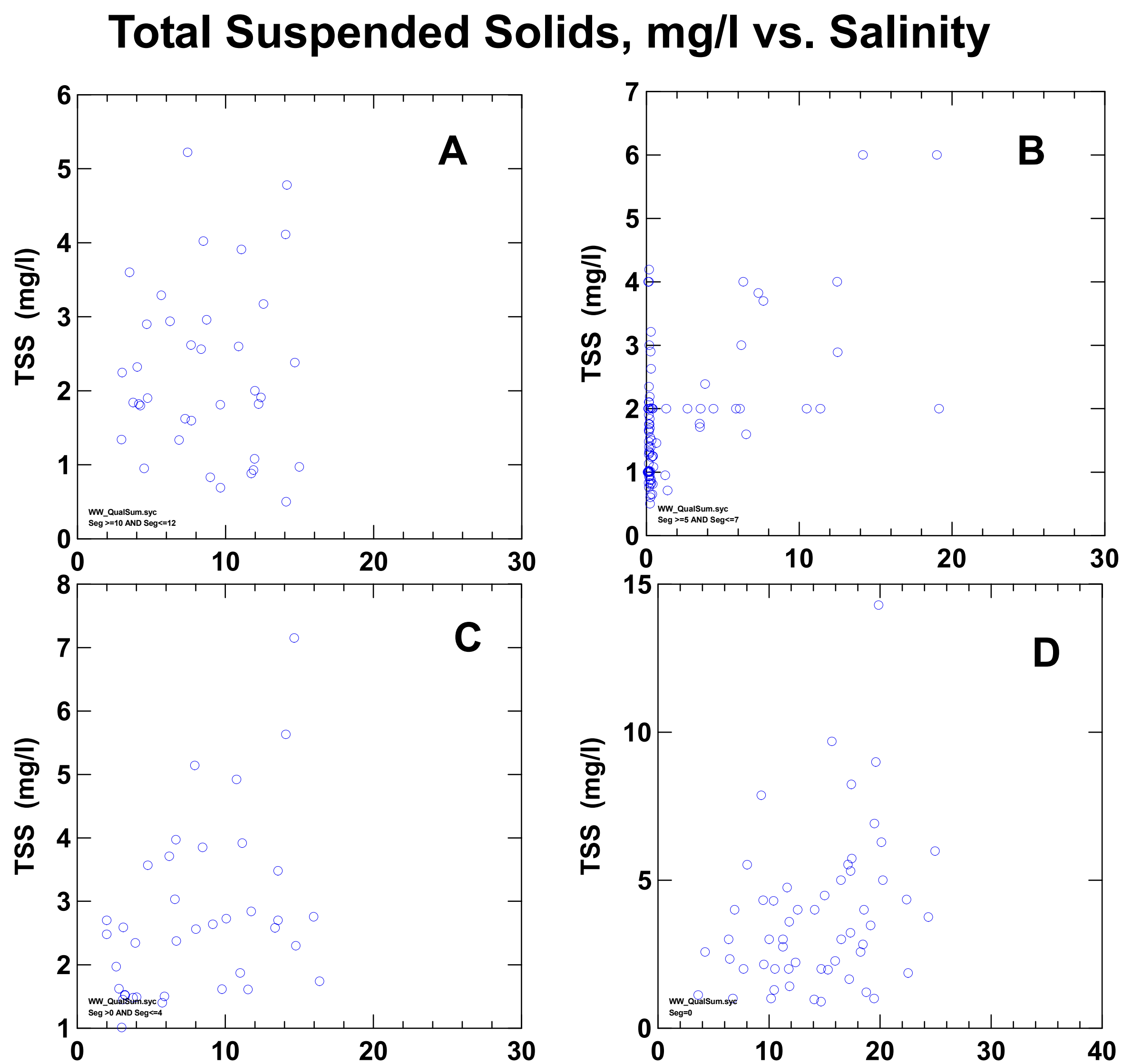
Water Quality Trend Graphics, continued.

Chlorophyll a (corrected), ug/l vs.



A = Mud River Seg ≥ 10 and ≤ 12 B= Weeki Wachee Seg ≥ 5 And ≤ 7
C = Weeki Wachee Seg >0 and ≤ 4 D = Gulf Seg = 0

Water Quality Trend Graphics, continued.



A = Mud River Seg ≥ 10 and ≤ 12 B= Weeki Wachee Seg ≥ 5 And ≤ 7
C = Weeki Wachee Seg >0 and ≤ 4 D = Gulf Seg = 0

United States Department of the Interior

U. S. FISH AND WILDLIFE SERVICE

7915 BAYMEADOWS WAY, SUITE 200
JACKSONVILLE, FLORIDA 32256-7517

IN REPLY REFER TO:

July 24, 2008

Martin Kelly
Southwest Water Management District
2379 Broad Street
Brooksville, FL 34604-6899

Dear Mr. Kelly,

The U.S. Fish and Wildlife Service (Service) would like to thank you for the recent meeting with you and your staff regarding the proposed minimum levels and flows (MFL) for the Weeki Wachee River system. The Service has reviewed the draft technical report, *Weeki Wachee River System Recommended Minimum Flows and Levels,* prepared by the Southwest Water Management District (District). The District proposes for both the wet and dry season flows of the Weeki Wachee system to be maintained at 90% of the baseline annual flows adjusted for anthropogenic impacts; this recommendation results in a MFL established at 10% reduction in historically measured flow regimes. Several resources were considered for determining the proposed MFL including habitat areas and volumes associated with salinity, submerged aquatic vegetation and thermal refuge for manatees in the estuary and lower riverine sections of the system. Conservative estimates were used on several important factors when determining the availability of the thermal refuge for the manatees to be used in the MFL calculations.

The Service has authority and responsibility to protect and conserve the Florida manatee under two Federal laws, the Endangered Species Act of 1973 (ESA) and the Marine Mammal Protection Act of 1972 (MMPA). Natural springs, by their dependable provision of natural warm water, are an important habitat element for the recovery of the manatee. Accordingly, we place great emphasis on maintaining flows sufficient to provide warm water for both the current and future populations of manatees. Our current status review of the Florida manatee (West Indian Manatee 5-Year Review, 2007) clearly defines "the establishment of MFLs for natural springs to guarantee sufficient manatee winter habitat" as a critical component to the recovery of the Florida manatee.

Based on the current manatee use of Weeki Wachee system, the proposed MFL will provide adequate warm water refuge habitat. More importantly, it will afford enough estimated thermal refuge to support the entire northwest population of manatees, as well as substantial population growth at high flow conditions. We support continual annual monitoring of this system to ensure the target MFL is being maintained and manatee warm water habitat is not compromised. We would appreciate annual monitoring reports and notices regarding any changes to the MFL once it is established.

Thank you for taking the time to discuss this MFL and for our opportunity to review and comment on your work. We believe your proposed MFL has taken manatees into consideration to meet the current federal statutes as well as the mutual state and federal goals to provide a secure future for this unique resource.

Sincerely,

Dave L. Hankla
Field Supervisor

Florida Fish
and Wildlife
Conservation
Commission

Commissioners
Rodney Barreto
Chair
Miami

Brian S. Yablonski
Vice-Chair
Tallahassee

Kathy Barco
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Executive Staff
Kenneth D. Haddad
Executive Director

Nick Wiley
Assistant Executive
Director

Karen Ventimiglia
Deputy Chief of Staff

Office of Policy and
Stakeholder
Coordination
Mary Ann Poole
Director
(850) 410-5272
(850) 922-5679 FAX

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(800) 955-8770 (V)

MyFWC.com

October 8, 2008

Martin Kelly, Ph.D.
Southwest Florida Water Management District
2379 Broad Street
Brooksville, FL 34604-6899

Re: Weeki Wachee River System recommended Minimum Flow and Level, Hernando County

Dear Dr. Kelly:

The Marine/Estuarine Subsection of the Florida Fish and Wildlife Conservation Commission's (FWC) Division of Habitat and Species Conservation has coordinated the agency review of the recommended Minimum Flows and Levels (MFL) for the Weeki Wachee River System. Provided below are FWC's comments and recommendations regarding this MFL.

Project Description

To protect Florida's water resources from "significant harm" the Florida Legislature directed the Florida Water Management Districts to establish MFLs for lakes, streams, and rivers (Chapter 373.042, Florida Statutes.). In compliance with this legislative directive the Southwest Florida Water Management District (SWFWMD) has drafted a recommended MFL for the Weeki Wachee River System. The Weeki Wachee River flows over 7 miles from its starting point at Weeki Wachee Spring. This river system has a 38-square-mile watershed and an approximate 260-square-mile springshed. The SWFWMD used the time frame of 1984 to 2004 to establish a baseline flow that averaged 162 cubic feet per second (cfs) for the Weeki Wachee River.

Potentially Affected Resources

Anthropogenic effects mainly in the form of groundwater withdrawals have resulted in an estimated 17 cfs decline in spring flow since 1961. The reduction of flow within both the watershed and springshed could affect spring, riverine, and estuarine habitats along with their associated diverse assemblage of fish and wildlife. The SWFWMD examined a variety of environmental indicators for their sensitivity to a reduction of flow levels. The resources considered included fish, invertebrates, mollusks, manatee warm-water habitat, benthic communities, submerged aquatic vegetation, and salinity regimes. Modeling evaluations of these resources did not indicate a break-point or resource collapse for any of these factors before reaching a 15% change in habitat availability, which is the SWFWMD's measure for significant harm that was based on Gore et al. (2002). The most restrictive outcome was found in the changes for the salinity regime of the lower river, which would have resulted in the MFL being based on a predicted shift in the 15 parts per thousand (ppt) isohaline; however, these results were deemed unreliable due to the influence of the Mud River and its highly saline flow. The flow from the Mud River has been sporadically measured and these measurements have indicated a highly variable flow of -51 to +128 cfs.

Due to these variable conditions, the 15-ppt isohaline was not selected as the determining factor for the MFL; rather the MFL is based on a mean percent flow reduction of all composite criteria used during a high-flow period and a low-flow period. The mean flow reduction of all the criteria used is recommended as being 10.1% during low-flow scenarios and 10.7% during high-flow scenarios. The SWFWMD has noted that these reductions would take into account current flow reductions (about 9.5% reduction when compared to baseline period average to date) due to groundwater withdrawals, so remaining reduction capacity would be between 0.6 and 1.2% in flow.

Comments and Recommendations

Due to the proposed MFL, we expect a small reduction of existing manatee warm-water habitat in the Weeki Wachee River. Warm-water habitat is considered the limiting factor for the manatee population in Florida. This becomes considerably more relevant when projections into the future suggest that warm-water habitat created by the thermal discharges of coastal power plants will diminish, which could affect over half of the estimated manatee population that currently uses them. Warm-water habitat for manatees provided by natural spring systems is therefore critical to the recovery of this species into the future.

Although a relatively small number of manatees currently use the Weeki Wachee River as a warm-water refuge, this can change rather quickly as history has shown at Volusia Blue Spring. Over the course of 38 years manatee use of Volusia Blue Spring increased over 1700% (n = 11 in 1970 to n = 202 in 2008). The FWC believes the SWFWMD's use of an average of 10 manatees using Weeki Wachee River as a warm-water site is an underestimate. The Weeki Wachee River has had few winter aerial surveys, which have been conducted under less than optimal visibility conditions due to the abundant vegetation overhanging the river along its margins. The all-time high count number of 34 manatees observed on February 13, 2006, is an indication that many more manatees are familiar with, and use, this warm-water refuge; and manatees are documented as exhibiting a great degree of site fidelity in the use of warm-water refuges.

Conclusion

The SWFWMD's proposed minimum flow level set at a 10% reduction in historic flow would reduce manatee warm-water habitat from the area and volume that was available within the Weeki Wachee River system historically. The FWC does not advocate a loss of warm-water habitat; however, the proposed 10% reduction in the baseline flow of the Weeki Wachee River system has already largely occurred and represents the current system.

Summary

The FWC compliments the SWFWMD on its thorough review of the data and potential impacts to the natural resources of this river system. After reviewing the information involved in the development of this MFL, the FWC believes that the effects of this MFL will not be significant on the current fish and wildlife resources of this river system and that this MFL is consistent with the agency's position regarding the establishment of MFLs in Florida spring systems. If any significant changes to this plan occur, we request the opportunity to review any such changes and comment accordingly.

If you or your staff would like to coordinate further on the recommendations contained in this letter, please contact Ron Mezich at 850-922-4330 or by email at ron.mezich@MyFWC.com.

Sincerely,

Mary Ann Poole

Mary Ann Poole, Director
Office of Policy and Stakeholder Coordination

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cc: Nicole Adimey, USFWS

Scientific Peer Review of the Proposed Minimum Flows and Levels for the Weeki Wachee River System

Prepared By:

Scientific Peer Review Panel
July 31, 2008

Panel Chair and Report Editor:

Gary L. Powell, President
Aquatic Science Associates
8308 Elander Drive
Austin, Texas 78750-7842

Panel Members:

Joseph N. Boyer, Ph.D.
Southeast Environmental Research Center, OE-148
Florida International University
Miami, FL 33199

Billy H. Johnson, Ph.D., P.E., D.WRE
Computational Hydraulics and Transport LLC
300 Front Street
P.O. Box 569
Edwards, MS 39066

Sam B. Upchurch, Ph.D., P.G.
SDII Global Corporation
4509 George Road
Tampa, FL 33634

Prepared For:

Martin H. Kelly, Ph.D.
Director, Minimum Flows & Levels Program
Southwest Florida Water Management District
2379 Broad Street, U.S. Hwy 41 South
Brooksville, Florida 34604-6899

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EXECUTIVE SUMMARY

The Southwest Florida Water Management District (District) has completed a study to establish Minimum Flows and Levels (MFL) for the Weeki Wachee River System (WWRS). The approach was to determine a flow regime that would protect the ecology of the river system by analyzing data on historical flows, current flows, water quality and biological responses to flows dominated by artesian spring discharges from the groundwater aquifer.

The proposed MFL starts with a management goal, as directed by Section 373.042 of the Florida Statues, to provide environmental streamflows wherein “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.” Since what constitutes “significant harm” is not legally defined in the statutes, it could be presumed that one purpose of the MFL report is to define it scientifically. The methodology to meet this goal depends on linking assumptions, past practices, data analyses, and salinity models. The District starts with the assumption that a 15% loss of habitat is acceptable as being protective of the natural resources. This assumption is not thoroughly explored in the study, but is explained as being based on previous management practices with some support from the scientific literature. The Panel believes that one size probably does not fit all and that some ecosystems may well tolerate reductions greater than 15% while others may tolerate considerably less, especially if they are already stressed by physical, chemical or biological factors other than streamflow. A more defensible goal might be the maintenance of ecological health and productivity, but it is unlikely to be easier to estimate.

Rivers and estuaries exist in a continuum from fresh water to marine habitats; alteration of inflow causes spatial shifts in salinity relative to existing habitat. This fact implies that in order to determine the limit at which further withdrawals would be significantly harmful to the ecology of the area, the District must make a policy decision about what is an acceptable loss of habitat (or resources) from further withdrawals. Choosing 15% as an allowable level of resource loss is

such a public policy decision. More importantly, the percent-of-flow reduction approach ensures that historical hydrological regimes will be maintained, albeit with some reductions in flow.

Overall, the District is to be commended for preparing an excellent report that summarizes a large quantity of data and analyses, produced from many studies, into a document that is coherent and relatively easy to read. The District is also to be commended for voluntarily seeking peer review of its technical documents.

Although the numbering of the appendices is somewhat confusing, they are well written and reasonably thorough as well. The supporting data and information used to develop the proposed MFL is technically sound. As described in the District's report, the data collection methods were appropriate, as were the findings and interpretations made from all analyses reviewed by the Panel.

During the initial meeting of the Panel, District representatives indicated that the MFL was intended to protect the springs and their discharges that dominate flows of the WWRS. With few exceptions, the data presented for development of the WWRS MFL also support MFLs for the springs, although these were not specifically defined in the District's report. Since Florida statutes direct the District to adopt MFLs for "all first magnitude springs, and all second magnitude springs within state or federally owned lands purchased for conservation purposes," the Panel believes that the District should consider revising this document in such a way that it covers the MFLs for the associated springs, as well as the river and estuary.

The Panel noted concerns about the salinity regression equations and the numerical modeling that were employed in estimating the allowable flow reductions. The salinity regressions did not include salinity at the estuary mouth as an independent variable and the numerical modeling did not include salinity as a boundary condition at Mud Springs. In addition, the numerical model did not appear to include the effect of a substantial slope in the bathymetry of the WWRS, resulting in simulations with virtually no tidal dampening upstream, a potentially serious hydraulic error.

Determining a low flow need during a high flow period is virtually impossible. This accounts for much of the problem with the District's evaluations of fish and invertebrates. The District used 16 of the best or most applicable sets of results to establish flow reductions that met threshold criteria for freshwater habitat, salinity habitat, benthos and mollusks. In addition, the District presents a graphical summary of the results that includes 32 measures of resource loss due to streamflow reductions. Several of these, particularly those that are most conservative, involved extrapolations beyond the river reach of concern, including some extrapolations into the Gulf of Mexico. Because they are beyond the domain of the regressions, or were biased by high flow study conditions, the District decided to base the MFL for the WWRS on the mean percent-of-flow reduction allowed for seasonal Block 1 (10.1 % flow reduction) and seasonal Block 3 (10.7% flow reduction).

In the end, the District recommended that both the wet and dry season flows for the WWRS be maintained at 90% of the baseline (read: naturalized) flows after the effects of human usage have been eliminated from the flow record. The fact that existing human usage is presently at or near the 10% limit means that little or no additional flow reductions will be allowed. After review, the Panel concurs with this recommendation.

Scientific Peer Review of the Proposed Minimum Flows and Levels for the Weeki Wachee River System

INTRODUCTION

The Southwest Florida Water Management District (the District) is mandated by Florida statutes to establish minimum flows and levels (MFLs) for certain surface waters and aquifers within its boundaries for the purpose of protecting the water resources and the ecology of the aquatic ecosystems from "significant harm" (Florida Statutes, 1972 as amended, Chapter 373, §373.042). What constitutes "significant harm" is not legally defined by the statutes; therefore, the Panel believes that one purpose of the District's MFL report should be to define it scientifically.

The District implements the statute directives by annually updating a list of priority water bodies for which MFLs are to be established and identifying which of these will undergo a voluntarily independent scientific review. Under the statutes, MFLs are defined as follows:

1. A minimum flow is the flow of a watercourse below which further water withdrawals will cause significant harm to the water resources or ecology of the area; and
2. A minimum level is the level of water in an aquifer or surface water body at which further water withdrawals will cause significant harm to the water resources of the area.

Revised in 1997, the Statutes also provide for the MFLs to be established using the "best available information," for the MFLs "to reflect seasonal variations," and for the District's Board, at its discretion, to provide for "the protection of nonconsumptive uses." In addition, §373.0421 of the Florida Statutes states that the District's Board "shall consider 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…." As a result, the District has identified a baseline condition that realistically considers the changes and structural alterations in the hydrologic system when determining MFLs.

Current state water policy, as expressed by the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code) contains additional guidance for the establishment of MFLs, providing that "…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."

The District's Board also has continued to voluntarily commit its MFLs determinations to independent scientific peer review as a matter of good public policy.

After a site visit on June 10, 2008 to perform a reconnaissance of the Weeki Wachee River System (WWRS) study area, the Scientific Review Panel discussed their initial observations, the assigned scope of the peer review, and subsequently prepared their independent scientific reviews of the draft report and associated study documents. The independent reviews were compiled by the Panel Chair and edited by all Panel Members into the consensus peer review report presented herein. This review assesses the strengths and weaknesses of the overall scientific approach, its conclusions and recommendations. The scope also allows the panel to suggest additional data and/or approaches that might be incorporated into the process used for establishing minimum flows. This peer review is provided to the District with the Panel's encouragement to continually enhance the scientific basis of the decision-making process.

GENERAL COMMENTS

Overall, the District has prepared an excellent report that summarizes a large quantity of data and analyses, produced from many studies, into a document that is coherent and relatively easy to read. This is no small task because of the legal, social, and economic constraints of recommending a resource-use strategy on such a complex ground water/surface water ecosystem. Many people support the view that setting MFLs in rivers and estuaries is one of the most daunting tasks facing resource managers today. The District's commitment to sound public policy is further illustrated by the voluntary submission of its MFL determinations for scientific peer review.

The supporting data and information used to develop the provisional MFL is technically sound. The data collection methods were appropriate and the data appropriately used in all analyses. The Panel was not tasked with conducting a quality assurance audit; however, it appears from the report and supporting documents that, to the best of our knowledge, standard procedures and protocols were followed, and no indicators of concern were noted by the Panel.

The panel is not aware of any essential data that were excluded from analyses of the river and the estuary. It is clearly evident that the data used for the development of the MFL was the best information available. Technical assumptions are inherent in data collection and analysis. Throughout the report, the District makes reasonable attempts to describe these assumptions.

Further, the analytical procedures and technically interpretations are reasonable and generally based on the best information available. Most importantly, the District has a clear management goal that is widely supported by scientists, managers, and stakeholders. That goal, as stated in the MFL document, involves the use of a 15% change in habitat availability as a measure of significant harm for the purpose of MFLs development.

Chapter 373.042(2) of the Florida Statutes directs the state water management districts to adopt MFLs for "all first magnitude springs, and all second magnitude springs within state or federally owned lands purchased for conservation purposes." Therefore, in addition to establishing MFLs for the Weeki Wachee River System, the District is required to set MFLs for Weeki Wachee

Spring, Twin Dees Spring and possibly Salt Spring and Mud Spring, depending on land ownership. The District should consider revising this document in such a way that it covers the MFLs for the appropriate springs as well as the river and estuary.

Clearly, the work that's been done relative to the river includes the majority of the scientific information necessary for a Weeki Wachee Spring MFL. The additional information needed to address MFLs for the springs themselves may be relatively minor. In fact, additional investigations may be limited to evaluation criteria for (1) maintenance of groundwater flows for contact recreation at Weeki Wachee Spring and (2) the relationship of groundwater flows to nitrogen enrichment of the river. The latter issue is included because most Florida springs show a positive correlation of nitrate and spring discharge, so maintenance of flow cannot always be used for control of this nutrient. Public perception is often the opposite; therefore, a discussion of nutrients and their relationship to flow is recommended. In the end, the MFLs for Weeki Wachee and the other springs will probably be based on their contributions to flow in the river itself. This is implied in the District's report (page 36, SWFWMD 2008) that states "the MFL for the Weeki Wachee, expressed as an allowable percent reduction, will be applied to the Weeki Wachee estuarine system which includes Mud and Salt springs." The Panel notes that Twin Dees Spring is not mentioned here, but apparently should be.

The quantity, quality and timing of freshwater input are characteristics that define an estuary. Freshwater inflows affect estuarine (tidal) areas at all levels; that is, with physical, chemical and biological effects that create a vast and complicated network of ecological relationships (Longley 1994). The effects of changes in inflows to estuaries are also described in Sklar and Browder (1998) and reviewed in Alber (2002). This scientific literature describes and illustrates how changing freshwater inflows can have a profound impact on estuarine conditions: circulation and salinity patterns, stratification and mixing, transit and residence times, the size and shape of the estuary, and the distribution of dissolved and particulate material, which may all be altered in ways that negatively affect the ecological health and productivity of coastal bays and estuaries.

Inflow-related changes in estuarine conditions consequently will affect living estuarine resources, both directly and indirectly. Many estuarine organisms are directly linked to salinity:

the distribution of plants, benthic organisms and fishery species can shift in response to changes in salinity (Drinkwater and Frank 1994; Ardisson and Bourget 1997). If the distributions become uncoupled, estuarine biota may be restricted to areas that are no longer suitable habitat for their survival, growth and reproduction. Potential effects of human activities, particularly freshwater diversion and groundwater pumpage, on the adult and larval stages of fish and invertebrates include impacts on migration patterns, spawning and nursery habitats, species diversity, and distribution and production of lower trophic (food) level organisms (Drinkwater and Frank 1994; Longley 1994). Changes in inflow will also affect the delivery of nutrients, organic matter and sediments, which in turn can affect estuarine productivity rates and trophic structure (Longley 1994).

There are a number of approaches for setting the freshwater inflow requirements of an estuary. The District has selected to use a "percent-withdrawal" method that sets upstream limits on water supply diversions and groundwater pumpage as a proportion of river flow. This links daily withdrawals to daily inflows, thereby preserving natural streamflow variations to a large extent. This type of inflow-based policy is very much in keeping with the approach that is often advocated for river management, where flow is considered a master variable because it is correlated with many other factors in the ecosystem (Poff et al. 1997; Richter et al. 1997). In this case, the emphasis is on maintaining the natural flow regime while skimming off flows along the way to meet water supply needs. Normally, regulations are designed to prevent impacts to estuarine resources during sensitive low-inflow periods and to allow water supplies to become gradually more available as inflow increases. The rationale for the District's MFL, along with some of the underlying biological studies that support the percent-of-flow approach for the WWRS, is built upon the analyses previously performed on the Upper Peace River (SWFWMD 2002) as peer reviewed by Gore et al. (2002) and in other scientific literature summarized by Flannery et al. (2002).

Setting minimum flow rules requires several steps: (1) setting appropriate management goals; (2) identifying indicators to measure characteristics that can be mechanistically linked to the management goals; (3) reviewing existing data and collecting new data on the indicators; and (4) assembling conceptual, qualitative, and quantitative models to predict behavior of the indicators under varying flow regimes. The first two steps above represent the overall approach to setting a minimum flow rule.

A standard of no more than a 15% change in any biological relevant resource, as compared to the estuary's baseline (i.e., naturalized flow) condition, was used as the threshold for "significant harm." While some may argue that the use of 15% as a threshold is a more or less arbitrary management decision, the Panel agrees that, in the absence of specific physiological or ecological thresholds which might reflect significant harm to the living resources, this is a reasonable approach for avoiding the more serious negative impacts on the ecosystem.

PHYSICAL/CHEMICAL DRIVING FACTORS

The MFL for the WWRS is built on estimating the percentage flow reduction causing 15% loss of resource or habitat. The main physical/chemical drivers for these resources and habitats are:

1. Spring Discharge
2. Groundwater Pumpage
3. Seasonal Patterns (Blocks)
4. Mud River Discharge
5. Tidal Forcing
6. Salinity Distribution
7. Water Quality
8. Temperature Regime

Spring Discharge and Groundwater Pumpage

Annual discharge since 1929 has fluctuated between 117-253 cfs. Trend analysis has shown that declines in discharge between 1970 and 1999 were due to anthropogenic and climactic factors. Various models in the District's MFL report (2008) show that groundwater pumpage has an estimated impact on spring discharge from 9.7 to 25.2 cfs. Yet an empirical data plot does not show pumpage to significantly affect flow (Figure1).

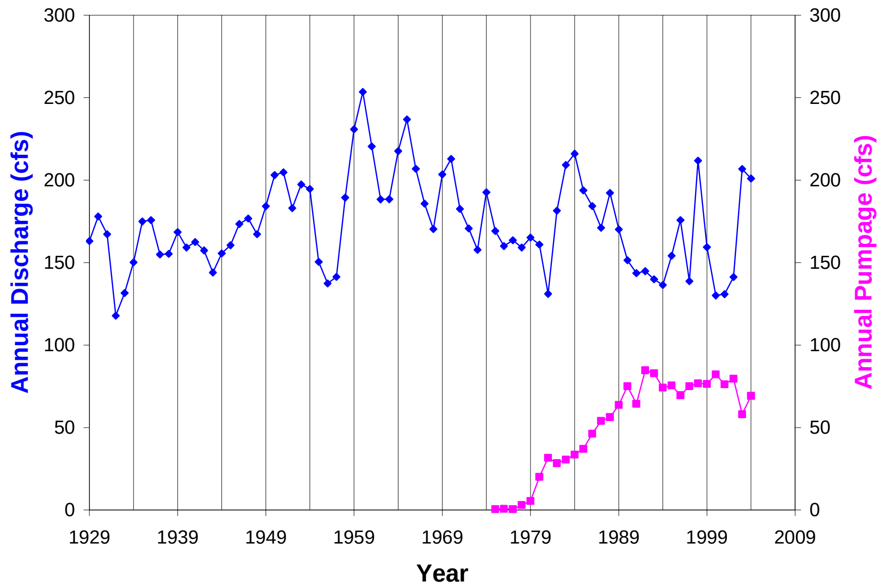

Figure 1. Time series plot of Weeki Wachee annual discharge (cfs) and pumpage (cfs).

A plot of rainfall, springflows and pumpage from 1975 to 2004 (data from Schultz 2007) only suggests a weak relationship between rainfall and springflows with one to two year lags in response (Figure 2). Further, the District's MFL report (SWFWMD 2008) states that "Annual pumpage was compared with annual spring discharge and a significant inverse relationship was found." However, a graphical analysis of the data prepared by the Panel did not confirm this finding (Figure 3).

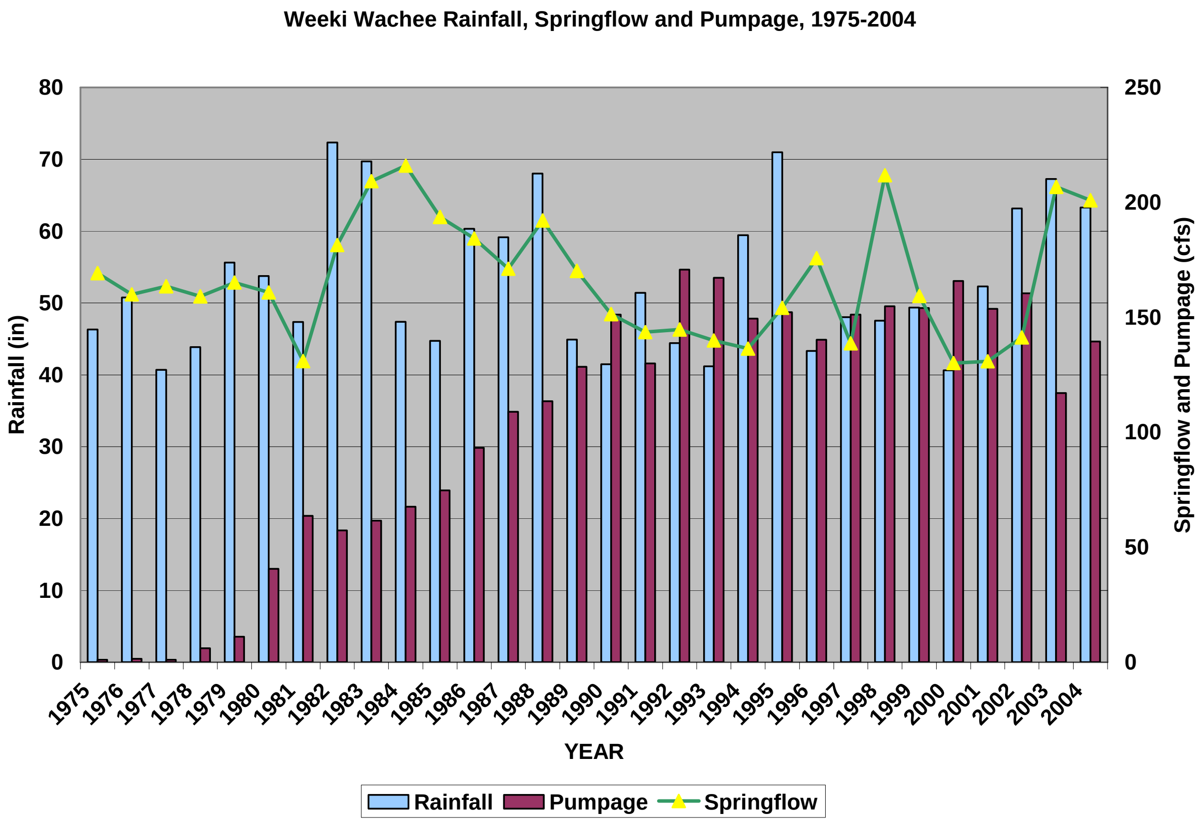

Figure 2. Weeki Wachee Springflow, Pumpage and Rainfall, 1975 − 2004.

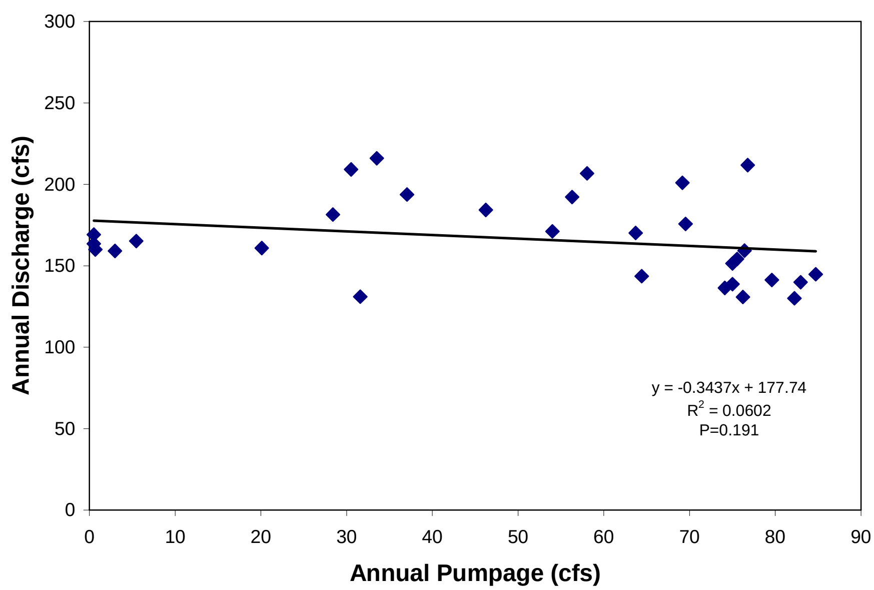

Figure 3. Regression of Weeki Wachee Spring annual discharge and pumpage.

It is possible that the effect of pumpage is countered by an increase in precipitation over the last 30 years. The Panel examined the relationship between discharge and precipitation as a possible indicator (Figure 4). One would expect that under similar conditions, rainfall and discharge would be related. Discharge and precipitation are significantly related but not very predictive. Perhaps a lag term needs to be applied because of the long residence time of the aquifer.

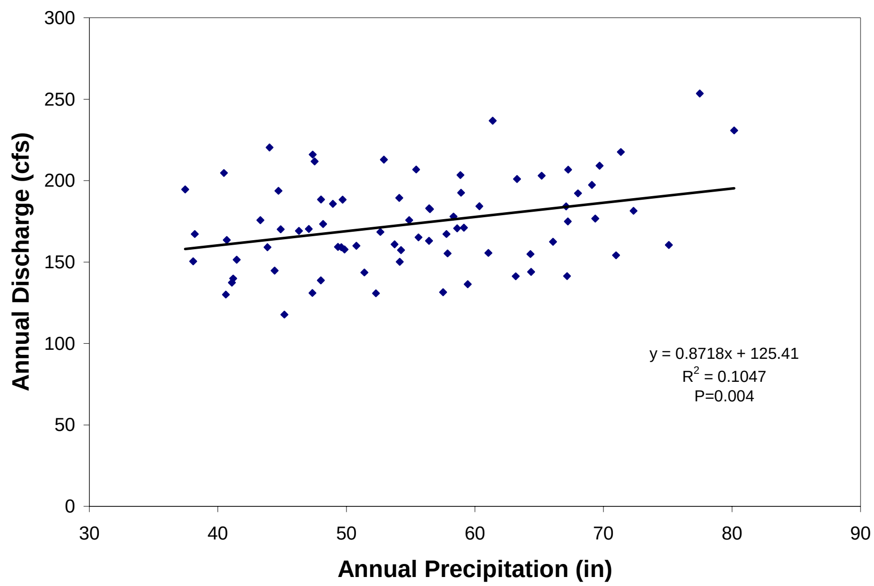

Figure 4. Regression of annual precipitation and Weeki Wachee Spring discharge.

Another way to look at this is by plotting the discharge:precipitation ratio (Figure 5). It is clear that there has been no great change in the relative amount of discharge. While the ratio has been declining since the 1960s, it is not any lower than it was prior to then. If pumpage was having a significant effect on discharge, it should be evident from this graph.

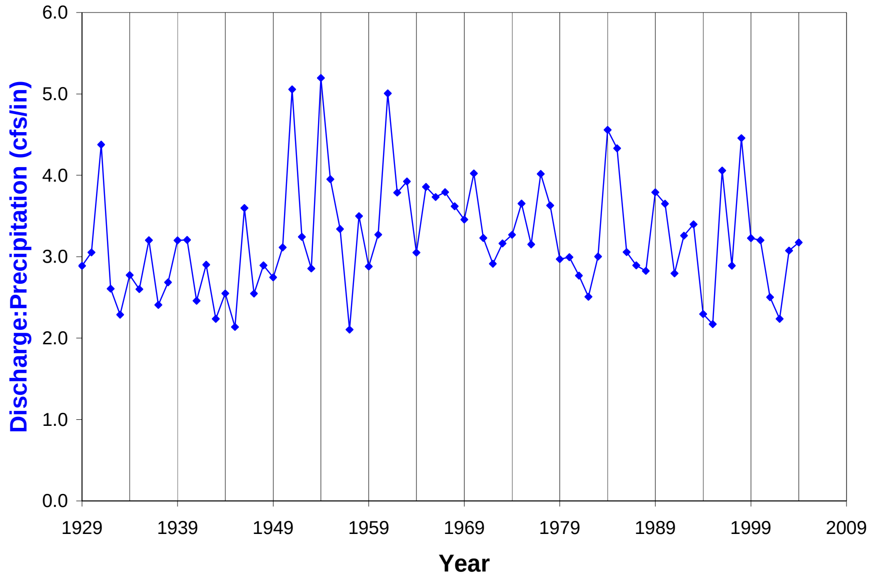

Figure 5. Time series plot of Weeki Wachee Spring annual discharge:precipitation ratio.

One potential explanation for the lack of a strong relationship between groundwater pumpage and spring discharge is the pumpage data itself. The surface drainage basin for Weeki Wachee Spring covers ~38 square miles (mi^2), but the springshed is much larger (~260 mi^2) and extends into adjacent Pasco County. This means that land use, water management practices and hydrogeological conditions outside the local area are affecting the Weeki Wachee Spring discharge. The District's report indicates that the pumpage data are from Hernando County, yet the largest wellfields in or near the springshed, in terms of pumpage, are in Pasco County. Therefore, inclusion of the Pasco County pumpage data, coupled with appropriate response lags, might strengthen the apparent relationships. Moreover, a thorough characterization of the springshed, rather than the surface-water basin, will assist in establishing the background and basis for the District's development of MFLs for Weeki Wachee and the other springs in the system, as required by Florida statutes.

Regression Equations for Tide and Salinity

The District needed to develop regressions for predicting salinity in the system since many of the biological impacts of reduced flow are related to salinity. Initially the thinking was that the salinity regressions would likely have the tide at Bayport as an independent variable. Thus, a regression equation for the harmonic constituents of the tide at Bayport was developed (page 49, SWFWMD 2008). It appears that this equation contains an error of omission; that is, it omits the phase-lag term for each tidal constituent, which would be added to the time term. The tidal signal could have been removed by applying an approximate 60-hr low pass filter to the water level data. The addition of the two low frequency constituents is important because this seasonal water level change has been found to affect salinities in other Gulf Coast estuaries. However, in the final development of the salinity regression equation that was used by the District in determining the MFL, the predicted tide at Bayport was not used.

Before developing regression equations to predict salinity at a particular point on the WWRS and to predict the longitudinal location along the river of bottom isohalines, a regression analysis was undertaken to predict the salinity at Bayport. Various components were considered as independent variables (e.g., springflows, flow from the Withlacoochee River, Gulf tides, wind, etc.). It was found that springflows have virtually no impact on salinity at Bayport. Although a regression equation was developed with a coefficient of determination (r^2) of ~0.6, predicted salinity at Bayport was not included as an independent variable in the regressions for salinity in the WWRS.

Regressions were developed for salinity at a particular river location and for the location of a particular bottom isohaline. These ended up with the following equational forms:

$$\text{Salinity} = \beta_0 + \beta_1 * \text{Flow} + \beta_2 * R_{km}$$

$$R_{km} = \beta_0 + \beta_1 * \text{Flow} + \beta_2 * \text{Bottom Salinity Isohaline}$$

Obviously, many regression equation forms are possible; however, one particular form containing an auto-regressive salinity term with appropriate time lag is often used to improve salinity regression equations in estuarine systems. With this form of the equation it is simple to solve for one of the variables (e.g., flow) given values for the other two. This character of the isohaline equation was of great utility in determining the MFLs. The r^2 for the regression equation used to predict the location of an isohaline zone has a reasonable value of 0.66.

Nevertheless, a major concern with the salinity regression equation is that the salinity at the river mouth is not included as an independent variable. Although the analysis described in the District's report concluded that flow from Weeki Wachee Spring did not have a significant impact on salinity at the river's mouth near Bayport, the salinity level in the river system is obviously dependent on the salinity level in the nearshore Gulf waters. This is an important boundary condition in the numerical model, described below, which was applied to assess the impact of flow reductions on the thermal regime. The regression equation for the location of salinity isohalines is used extensively in determining what flows result in a 15% reduction of various biological resources. It seems clear to the Panel that boundary salinity at the river mouth should have been included as an independent variable in the predictive equations.

Application of the EFDC Numerical Model to WWRS

The Environmental Fluid Dynamics Code (EFDC), a three-dimensional finite difference hydrodynamic model, was applied to the WWRS by Applied Technology and Management, Inc. (ATM 2007). The purpose of the modeling effort was to determine the level of flow reduction that would result in a 15% reduction of the thermal regime that is tolerable by the West Indian manatees. Manatee habitat refuge areas and volumes were defined as waters that met the following criteria:

- Daily average temperatures were greater than 20° C over a critical 3-day period
- Passage for manatee was available upstream based upon District defined minimum depths

When conducting a review of numerical modeling, the review is initially focused on the following questions:

- Are the mathematical model's physics adequate for its intended use?
- Is the numerical grid adequate to resolve the spatial component?
- Are sufficient data available for model calibration and validation?
- Has model calibration and validation been achieved?

A Task Committee of the American Society of Civil Engineers (ASCE) is currently in the process of publishing a monograph describing model verification, calibration and validation. Verification is the process of demonstrating that the proper physical equations are correctly solved and that the computer code is free from errors. The EFDC is a well known model that is supported by the EPA and contains all the basic physics required to make hydrodynamic computations in estuaries and coastal areas. As such, users can be confident that the EFDC is a well-verified numerical hydrodynamic model. Calibration and validation are part of the user's application of the verified model's code to a particular water body. Specifically, calibration is the process of varying model parameters so that the simulation matches the observed data. In the strictest sense, validation is then the process of taking the calibrated model and applying it to a different data set in order to demonstrate its accuracy using the same model parameters set in the calibration phase.

In practice, the demarcation between calibration and validation can become a little fuzzy. If the model is calibrated to a relatively short data set (perhaps a month or two) that does not cover a period in which all processes governing the hydrodynamics of the water body occur, the model should be applied to a separate data set to make sure it is still working correctly. However, if the model simulation covers a long enough period of time (i.e., many months or even years) during which virtually all processes occur, if the model's parameters are within acceptable ranges, and if the parameters stay the same during the long simulation period, the case can be made that both calibration and validation have been achieved.

The Panel's comments on the calibration and validation of the EFDC model, as applied by ATM to the WWRS, are given below. These observations are based on results presented in the consultant's report "Impacts of Withdrawals on the Thermal Regime of the Weeki Wachee River" (ATM 2007).

The ATM report shows the curvilinear numerical grid in the horizontal plane (Figure 4-1) and with the river's bathymetry displayed on the grid (Figure 4-2). Strictly speaking, the EFDC is only applicable on grids that are completely orthogonal. It can be seen that the Weeki Wachee system grid is not totally orthogonal; however, there have been many applications of orthogonal grid-based models, such as the EFDC and the Princeton Ocean Model (POM), to computational grids that aren't totally orthogonal with satisfactory results. The length of grid cell sides in the horizontal dimension ranges from about 100 – 200 feet (30.5 – 61 meters, m). In the estuarine portion of the grid, there are 3 cells across the river's channel. The middle cell represents a central portion of the channel that is on the order of 6.6 – 9.8 feet (2 – 3 m) deep; whereas, the two lateral cells on either side represent shallow areas on the order of 3.3 feet (1 m) or less. The EFDC employs what is called a "sigma stretched grid" in the vertical dimension. This is a model grid where the top of the top layer follows the water surface and the bottom of the bottom layer follows the estuary's bathymetry. Four sigma layers were used in the model's application to WWRS.

The period from November 1, 2003 through February 28, 2004 was used in the calibration of the numerical model. Water surface elevation, salinity and temperature data were available to drive the Gulf boundary of the grid. Water discharge and temperature of the Weeki Wachee Spring were specified at the head of the river. In addition, a constant discharge of 45 cfs and a constant temperature of 73.4 ºF (23 ºC) were specified at Mud Spring. Although salinity at Mud Spring can often be quite high (e.g., 20 parts per thousand salt, ppt, or about 57% seawater salinity), there is no discussion in the ATM report about an assumed or measured salinity boundary condition at Mud Spring. If the modelers assumed that artesian groundwater discharges from Mud Spring were fresh, then this could be a serious error.

Interior data for comparison with model results were available at 3 stations. Water surface elevation, salinity, and temperature were available at Station No. 02310551 (river kilometer 2.3 = R_{km} 2.3). At Stations Nos. 02310545 (R_{km} 3.6) and 02310530 (R_{km} 7.3) only water surface elevations were available. In the ATM report, Figure 3.12 clearly shows that the tide is essentially damped out at Station No. 02310530, 4.5 miles (7.3 km) above the river's mouth, which is expected from the river's slope over the distance inland from the Gulf of Mexico.

Figures 4.11 and 4.12 in the ATM report show the comparison of computed water elevations with the observed data at R_{km} 3.6 and R_{km} 2.3, respectively. Although it is difficult to see the comparison very well in these plots because of the compressed time scale, the comparison does not appear to be very good. In addition, the ATM report states, without explanation, that at R_{km} 7.3 (Station No. 02310530) the model still computes a strong tide, although the tide at this point should be essentially damped out.

Figure 3-2 in the ATM report shows the bottom elevation along the river, while Figures 3.10 and 3.12 show observed water surface elevations. These graphs reveal a rather strong slope in the water surface from R_{km} 2.3 to 7.3. This slope is on the order of 3 – 4 m (9.8 – 13.1 ft) over a distance of 5 km (3.1 miles). This significant slope in the water surface probably results in the observation that the tide is mostly dampened at Station No. 02310530 (R_{km} 7.3). Unfortunately, the discordant bathymetries shown in Figures 3-2 and 4-2 of the ATM report suggest by comparison that the impact of this slope is not included in the EFDC model, another potentially serious error.

EFDC was developed for application in estuarine and coastal areas. In those areas, when starting the model "cold," the water surface is assumed to be flat. If the model's application to the WWRS was set up to have a flat water surface as the initial condition, then the riverine portion will not behave correctly. The ATM report does not show a plot of the water surface elevation at the head of the river, but the Panel suspects that the model functions such that the tide propagates all the way up the river and, thus, the model's calibration for water surface elevation is questionable.

ATM report Figures 4.13a and 4.13b show comparisons of computed and observed salinities at R_{km} 2.3 (Station No. 02310551). At this point close to the Gulf, the salinity is characteristically "spiky" as saline Gulf water moves in on flood tides and then moves out on the ebb each day. The time series plots indicate that the comparison of observed and predicted salinities is not very good in a dynamic sense, with the model under-predicting salinity levels at a point fairly close to the mouth of the river and the influence of the Gulf. The Panel believes that at least some of this problem with salinity simulation may be due to the numerical grid and the Mud Spring boundary condition.

In a hydrodynamic model study, one generally makes runs on grids with varying resolution to determine the impact of the grid on the accuracy of the solution. Apparently, this was not done, or at least not reported, in the present study. While the longitudinal resolution of the horizontal dimension is probably sufficient in the computational grid (Figure 4-1, ATM 2007), the Panel believes that the number of sigma layers should have been varied to understand the impact of using more than 4 layers on the model's solution.

Another potential issue with the numerical grid relates to what is commonly called the "sigma problem." When applying a model using a sigma stretched grid to represent the vertical dimension in an estuary with a channel having shallow areas on the sides, false motions of streamflow can occur along with false horizontal diffusion. If the water column is stratified in the channel by fresher water overriding more saline water, the important stratification and resulting density currents can be eroded away during long term simulations. It is widely recognized among modelers that a substantial amount of lateral resolution in the horizontal dimension of the model's grid is required to minimize this problem. As noted above, the EFDC model application to the WWRS is only three cells wide. Since only the last few kilometers of the river are estuarine, and since vertical stratification of salinity in the water column doesn't appear to be large in most of the river, the "sigma problem" may be small yet still play a role in the salinity simulations.

The agreement between computed and recorded temperatures at Station No. 02310551, 2.3 km (1.4 miles) above the river's mouth, is generally fair (Figures 4.14a and 4.14b, ATM 2007). However, matching temperature in a model that does not have the hydrodynamics well calibrated is easier than matching salinity since surface heat exchange plays a big role in the temperature of the water body. Perhaps the study's focus on estimating the temperature refuge area for Manatees is why a greater effort was not made to improve the simulation of circulation and salinity patterns in the WWRS.

Determining the Impact of Flow Reductions on the Thermal Regime

In the application of the numerical model to determine the impact of flow reductions on the thermal regime, an analysis of the air temperature record at Weeki Wachee Spring was performed to select a critical condition period. The winter of 2000 – 2001 was identified as a critical condition period when the mean daily air temperatures ranged as low as 1.7 ºC (35.1 ºF). Since temperatures at Bayport were not available to drive the boundary condition, a regression equation was developed ($r^2 = 0.90$) which relates water temperature at Bayport to three-day average air temperatures as the independent variable. It is possible that testing different averaging intervals and including the day of the year as an independent variable might have yielded even better results.

Two baseline conditions of high and low flows were simulated over the representative period from October 2004 to March 2005 when temperatures might become critical for Manatee health and survival. With each baseline condition, Weeki Wachee flows were reduced to determine the impact on the river's thermal regime in terms of the volume and area of water with a three-day average temperature ≥ 20 ºC (≥ 68 ºF). Only those cells with a minimum depth greater than 3.8 ft (1.2 m) were considered adequate for the Manatee. As can be seen in Figure 6.1 of the ATM report, only a few of the cells in the numerical model actually met the 3.8 ft criterion at minimum tide. It was found that a 10% reduction in the high flow scenario reduced the volume by more than 15%; however, only a 5% reduction in the low flow scenario reduced the volume of the thermal refuge by more than 15%. Nevertheless, even when the 15% loss limit is violated, it appears that the WWRS can support far more manatees than have ever been observed to utilize the river's thermal refuge. This outcome tends to negate, at least in part, the uncertainties the Panel found in the presented EDFC model application.

Water Quality

The District merged and integrated some 23 disparate datasets spanning the 1984 through 2005 period of record into one comprehensive database. As such, the District is to be commended for its effort to use the best available data. On the other hand, the District's water quality data analysis was rather cursory. The District did provide a decent discussion of the overall chemical characteristics of the system; however, only one graph was provided (i.e., nitrate versus salinity) and that was for the entire period of record. The Panel would like to have seen some representative constituent concentration – salinity plots for other variables over specific sampling events, seasons and flow regimes.

The District's primary conclusion about water quality was that nitrate had increased dramatically in the artesian spring discharges over time. This is consistent with studies of other spring systems in Florida and does not bode well for future water quality conditions. As reported by the District (SWFWMD 2008), the saving grace for the WWRS is that total phosphorous levels are almost always below 0.01 parts per million, ppm (0.3 μM). Therefore, primary (plant) production in these ecosystems is strongly phosphorus-limited causing phytoplankton chlorophyll-*a* concentrations to remain very low (~1.0 parts per billion, ppb) and the water to be clear. Nevertheless, it is important to recognize that any increase in phosphorus loading will cause a tremendous increase in phytoplankton biomass (i.e., algal blooms), probably resulting in low dissolved oxygen (hypoxic) events that can greatly increase the mortality of fish and other aquatic animals.

The District did not include water quality *per se* in setting the MFL. This was because, unlike many other riverine estuaries, the limiting nutrient (i.e., phosphorus) is supplied from the marine end of the system. As a result, it is important that the MFL not be set too low because the resulting encroachment of marine waters into the WWRS will also bring in phosphorus. If the nitrogen-phosphorus mixing zone occurs within the river, then it will promote increased phytoplankton biomass and all the inherent problems that come with excessive nutrient enrichment (i.e., eutrophication) of tidal river segments.

Submerged Aquatic Vegetation

There are five generally accepted natural controllers affecting the distribution and production of submerged aquatic vegetation (SAV): light penetration, salinity regime, sediment physical characteristics, sediment depth, and dissolved nutrient regime. Light is generally the primary factor in SAV production, while the other factors are usually considered more important in species distribution. Only species distribution as related to salinity was presented by the District, and only from the 2005 survey, in spite of the fact that there have been four surveys of SAV in the WWRS since 1995.

According to the MFL report (SWFWMD 2008), the District originally wanted to develop a resource criterion based on salinity but found that salinity was not the dominant factor. As a result, they did not pursue any type of habitat requirements or modeling using other factors. The Panel suggests that the District consider putting more effort into addressing SAV habitat requirements so that they can be included in the MFLs of coastal waters associated with tidal (estuarine) river segments.

Benthic Organisms

Bottom-dwelling organisms, such as aquatic insects, worms, mollusks and crustaceans, occupy an important intermediate level in an estuary's food-chain between primary producers (e.g., phytoplankton and vascular plants) and higher levels of secondary production (e.g., fishes). Benthic organisms are generally considered to be sessile or weakly motile, and are often used as indicators of change in water bodies. While benthic community structure typically is influenced more by salinity and substrates, benthic production is most often a function of food generated from nutrients. However, high nutrient levels (i.e., eutrophication) can cause low dissolved oxygen (hypoxia) to occur near the bottom, which results in higher mortalities and can drastically limit benthic production.

The WWRS is dominated by spring discharges that are more or less of constant flow and temperature. In addition, the river exhibits low nutrient levels (i.e., oligotrophic conditions), causing it to have low levels of primary production. Since the observed water quality (i.e., salinity, temperature and nutrient) variations in the WWRS are relatively small, the benthic communities are not normally exposed to widely variable conditions. Nevertheless, analysis of pooled benthic data from 1984-1985 (Culter 1986) and 2005 (Janicki Environmental 2006) did produce significant relationships between salinity and benthic abundance, diversity and species (taxa) richness in the WWRS. If the salinities typically found in the downstream areas with fine sediments utilized by the benthic infauna were displaced upstream into areas with hard limestone substrates as a result of flow reductions, then the effects on the benthos would be magnified.

Janicki Environmental (2007) also compiled and reanalyzed benthic data from samples taken in 12 tidal rivers in Southwest Florida over a 20+ year period of record using cluster analysis and principal components analysis. Univariate logistic regressions were used additionally to estimate the probability of species occurrence as a function of salinity. The resulting salinity optimums and tolerances for selected benthic species were considered in the District's MFL determination, particularly in relation to flow reductions that could potentially reduce the availability of low (< 7 ppt, oligohaline) and medium (7-18 ppt, mesohaline) salinity habitats by more than 15%.

Mollusks

Mollusk surveys of the WWRS were conducted by Estevez (2005). While the total number of taxa found, only 15, was similar to that previously reported by Culter (1986), the overall species diversity and abundance in the WWRS is low, probably for the same reasons discussed above for the benthos; namely, oligotrophic waters and the prevalence of rocky substrates. Relative to 8 other tidal rivers along the west coast of Florida analyzed by Montagna (2006), the WWRS exhibits a fauna so depauperate that it makes analysis and interpretation of species data relative to flows and associated measures difficult and largely unsatisfactory. Nevertheless, Estevez (2005) suggests that significant reductions in flows could cause infilling of the lower river bottom with algae and other organic material that would create very unfavorable habitat conditions for mollusks and other benthic organisms. In the end, the District utilized significant relationships between salinity and the species abundance of two intertidal species (*Polymesoda caroliniana* and *Littoraria irrorata*) in the lower river, and the oyster (*Crossostrea virginicia*) at the mouth of the river, to compute a 15% loss of peak abundance for these species under reduced WWRS flows.

Fish and Planktonic Invertebrates

Matheson et al. (2005) sampled fishes by seine and trawl, and planktonic organisms by plankton net from May 2003 through December 2004. Unfortunately, this sampling occurred during a period when WWRS flows were higher than the mean average flow for the prior 9 years. Determining a low flow need during a high flow period is virtually impossible. Further, this difficulty is enhanced by the fact that the estuarine portion of the river is very compressed and extends upstream less than 2 km (1.2 miles) from the river's mouth under normal conditions. As a result, important fish species, such as the bay anchovy and sand seatrout that typically dominate fish assemblages in estuarine (tidal) river segments of the region, were in extremely low abundance in the WWRS.

Zooplankton net samples were dominated by larval fishes (killifish, gobies and blennies) and larval invertebrates (crabs, shrimp and mysids). Matheson et al. (2005) report that planktonic invertebrates that were common in other tidal rivers of the region were uncommon or even absent in the WWRS, again probably because of the high flow period sampled. One interesting capture in the upper river involved two specimens of the rare mysid, *Spelaeomysis*, a species normally associated with underground aquifers. Invertebrate collections by seine in the WWRS were dominated by grass shrimp, daggerblade shrimp and blue crabs.

The District attempted to relate fish and zooplankton abundance, and location of maximum occurrence, to flows in the WWRS; however, the results were generally weak with coefficients of determination below the District's assumed acceptable threshold (i.e., $r^2 \geq 0.30$). The most interesting significant positive relationship found was that between the abundance of harpacticoid copepods, which are prey (food) for young estuarine-dependent fishes, and 120-day lagged flows on the WWRS. Unfortunately, the fish and invertebrate analyses were not used by the District to determine the WWRS MFL because of the confounding high flows underlying the sampling period and the unusual or unreasonable responses suggested by most of the statistical regressions, including the predicted elimination of typical estuarine species under more normal (e.g., median) flow conditions.

Freshwater Habitats

Approximately 1.2 miles (2 km) above the mouth of the WWRS the estuarine portion of the river gives way to a freshwater reach that continues upstream to the headwaters at Weeki Wachee Spring. The District evaluated this segment of the WWRS using the Physical Habitat Simulation (PHABSIM) Model. Specifically, a time-series analysis was conducted on the 1967 − 2004 period of record. Using habitat suitability curves from the PHABSIM, freshwater flow needs were established that met a goal of maintaining 85% of the specific habitat requirements of largemouth bass, spotted and bluegill sunfishes, and the diversity of benthic macroinvertebrates. Although the PHABSIM has been criticized as being error-prone due to its low level methods and hydraulics, and somewhat controversial because the associated habitat suitability curves lack the sophistication to deal with common species interactions (e.g., competitive displacements, predator-prey), and other ecological relationships among freshwater species, the Panel accepts the District's rationale for using this method to estimate flow reductions in the freshwater reach of the study area that result in a 15% loss in each of the 13 habitat measures tested.

Integration of Results to Determine WWRS MFL

The District used 16 of the best or most applicable sets of results discussed above to establish flow reductions that met threshold criteria for freshwater habitat, salinity habitat, benthos and mollusks (Table 8-1, SWFWMD 2008). Allowable streamflow reductions in the low flow seasons (Block 1) varied from 6.0% for 15 ppt salinity habitat to 15.8% for 2 ppt salinity bottom habitat. Similarly, allowable streamflow reductions during the higher flow seasons (Block 3) varied from 4.2% for 15 ppt salinity habitat (based on extrapolation into Gulf waters) to 17.2% for 2 ppt salinity bottom habitat.

In addition, the District presents a graphical summary of the results (Figure 8-1, SWFWMD 2008) that includes 32 measures of resource loss due to streamflow reductions. Several of these, particularly those that are most conservative, involve extrapolations beyond the river reach of concern, including some into the Gulf of Mexico. Because they are beyond the domain of the regressions, or were biased by high flow study conditions, the District decided to base the MFL for the WWRS on the mean percent-of-flow reduction allowed for seasonal Block 1 (10.1 %

flow reduction) and seasonal Block 3 (10.7% flow reduction). In the end, the District recommended that both the wet and dry season flows for the WWRS be maintained at 90% of the baseline (read: naturalized) flows after the effects of human usage have been eliminated from the flow record. The fact that existing human usage is presently at or near the 10% limit (Figure 2-18, SWFWMD 2008) means that little or no additional flow reductions will be allowed from groundwater use. After review, the Panel concurs with this recommendation.

Additional Spring MFL Development

The report does not develop background information necessary to characterize groundwater conditions relative to the four springs. If the District decides to revise the report to support MFLs for the springs, then a better discussion of the groundwater system including regional (springshed) geology, hydrogeology, karsts, and groundwater quality is needed. For example, considerable work has been done by the District on the position of the salt-water transition zone, including potentiometric and salinity analyses. Discussions of how the potentiometric surface has varied over time will assist in developing the historic changes in spring flow. Further, characterization of coastal potentiometric and interface configurations will assist in understanding capture zones and why the springs vary in salinity. The effects of tides (if any) on groundwater elevations should also be considered. This is especially important with respect to the well used to characterize discharges of the Weeki Wachee Spring.

Finally, the Panel doubts that the MFLs would affect Hospital Hole, a major karst feature with stratified water quality located within the Weeki Wachee River. However, since Hospital Hole is a popular dive site that provides important evidence concerning the saltwater transition zone, it also should be discussed.

ERRATA and EDITORIAL COMMENTS

Page	Paragraph	Line	Comment
5	2		This paragraph deals with an ideal situation where there is a clear "break point" that identifies significant harm. The discussion is problematic because only the most limiting criterion would have a break point that represents significant harm. Other break points might include criteria that are subject to the harm standard or may not represent any significant diminution in ecological function at all. Also, this paragraph sets up the expectation that a break point exists and, if it is not present, some readers will feel this is either indicative of the District's failure to identify significant harm or that there is no significant harm to be identified in the system. Perhaps this paragraph could be revised in such a way as to set up expectations that are consistent with the report's results.
6	2	11	It is preferable to cite the Texas methodology as Powell et al. (2002). Also, note that this scientific journal paper illustrates the methods by using their application to Galveston Bay and the Trinity-San Jacinto Estuary.
6	3		The paragraph speaks to biological data being collected at near natural flows and not at the point of resource collapse. As written it suggests that significant harm corresponds with resource collapse. Of course the whole purpose of establishing significant harm is to prevent resource collapse and, hopefully, the District's standard for "harm" prevents it from permitting anything close to flows or levels that could cause resource collapse.
7	2		In complex environmental multivariate systems, it is rare to get high correlation coefficients or coefficients of determination. Even so, many scientists believe that the Comrey and Lee (1992) correlation coefficient classification scheme is pretty weak and should not be relied upon as a benchmark for quality of goodness of fit. Significance levels have been developed for bivariate and multivariate coefficients of determination and correlation coefficients, and these would be better for discussions of statistical significance. Indeed, Comrey and Lee's thresholds for coefficients of determination may not be adequate descriptors of the quality or goodness of fit of the District's data.

Page	Paragraph	Line	Comment
8			As a practical matter, the number of observations per parameter is case and variance driven, and is not applicable to every situation. Further, emphasizing the fact that scientists working on "real world" problems in nature rarely have enough samples to meet the criteria listed here opens the MFL determination for criticism and weakens the strength of an otherwise excellent report. Perhaps it would be better to simply discuss the significance of the correlations based on alpha levels or probabilities derived from goodness-of-fit criteria and let the number of degrees of freedom and the tests for significance in the parametric and non-parametric statistics drive whether or not the observations are significant and useful.
9			Section 1.5 summarizes the District's approach for developing minimum flows for riverine and estuarine systems. If the District agrees with the Panel's suggestion to revise its report so that it can stand for the MFLs for the springs as well, then a discussion of the application to the springs needs to be included as well.
10	2		PHABSIM is not an "ecological model" *per se*. Rather, in its original formulation, it was a simplified and error-prone one dimensional method to estimate amounts of wetted usable area (read: aquatic habitat) in Rocky mountain coldwater streams. In its current form, the PHABSIM model represents, at best, a quasi-two dimensional technique that has largely been replaced with more advanced and accurate hydraulic models that can be applied with a lot less brute force labor.
12	5		While the report notes that English units are used in accordance with the Governor's requirement for simplicity in writing, in many cases metric units still are used rather than common English units. The District noted two exceptions − distance, expressed in kilometers, and water depth, expressed in meters. Many readers would probably say these are the wrong exceptions, finding river miles and depth in feet much more readily understandable by the public. Metric units should probably be reserved for chemical concentrations and related water quality parameters that are not familiar to the general public anyway.

Page	Paragraph	Line	Comment
14			Some additional things that the District should consider for inclusion are, in no particular order: • Whether or not the springs serve act as estavelles and backflow during storm surges and the like. Discuss the cave system and the cave exploration that has been undertaken by Underwater Research. • Note that there were issues concerning dredging part of the Weeki Wachee River in 2004 by the Attraction. • Note describing the 1976 turbidity event, what was determined to be the cause, and how it relates to the closed drainage basins that exist in the Spring Hill area. • Briefly discuss the Weeki Wachee Attraction and its impact on both water quality and water use in the area. • If there have been any dye tests or other testing to make connections between sinkholes or water wells and the springs, then those should be discussed. • Discuss the distribution and sources of nitrate. Time series showing nitrate concentrations over time is already within the report and could be pulled in as part of the discussion of the springs. • Discuss the dimensions and geological conditions of each of the four named springs in this system. • Discuss the internally drained basins and the distribution of sinkholes and karsts within the springshed. • Provide an overall geology discussion that includes the geological strata that constitute the aquifer system(s) in the area and, equally important, the large Plio-Pleistocene sand dunes that underlie this Spring Hill development.

Page	Paragraph	Line	Comment
14			• Discuss the Kohout circulation system at the salt-water transition zone and why Salt Springs and Mud Springs are saline. This discussion could include the work done by USF on the depth to the saltwater transition zone in the area and the pattern of the regional potentiometric surface, which shows reentrants where the freshwater springs are located and salients where the saltwater springs are located. • Discuss the flow pattern of water to the springs based on the potentiometric surface. This should be coupled with the springshed map. • Discuss the effects of tides, not only in terms of salinity, but in terms of water levels in the groundwater system and in the spring. The effect of tides on spring discharge and the discharge record is important. How do tides affect the discharge measurements from the spring? Is there any chance of aliasing or other uncertainties in the discharge record? • The effects of land use and the location of well fields should be included as part of the springshed description. Land uses in the near-field areas of the spring are discussed, but not in detail. • The attendance and history of the Weeki Wachee Attraction should probably lead to a discussion of the number of bathers in the spring and especially the maximum bathing load and its relationship to spring discharge.
14	1	10	The definition of a first magnitude (not “order”) spring in Florida is a median discharge of 100 cfs or greater based on historical data (Copeland 2003). The definition provided in the District’s report is somewhat erroneous in that it is described in terms of an “average flow.”

Page	Paragraph	Line	Comment
21			The reliance on just Wolf (1990) and Knochenmus and Yobbi (2001) as the only sources for Section 2-3 is somewhat disappointing. The District has published a number of excellent works that include significant information about the springshed. The Weeki Wachee springs and watershed have also been studied by the Florida Geological Survey and the USGS. Also, if this document is to deal with the MFLs for Twin Dees and Weeki Wachee (and perhaps Mud and Salt Springs as well), then considerably more information needs to be provided relative to the springshed and the regional geology. Again, while Mud and Salt Springs are mentioned several times prior to this section, we do not know what the magnitude of the springs are and whether or not they must be considered as part of the MFL process under Florida statutes. Perhaps this should be addressed in the report's introduction. In addition, the District has funded a number of geophysical studies through the University of South Florida that document a salt-water transition zone along the Springs Coast. The position of the salt-water transition zone is important to know because it explains why Mud and Salt springs are salty and why Weeki Wachee Spring is not. Also, the potentiometric surfaces that are developed twice a year by the District in cooperation with the U.S. Geological Survey show reentrants and salients that correspond to the saline- and fresh-water springs along the coast. It is important to understand and explain this plumbing system in simple terms because it affects the behavior of the river, the estuary and the springs.

Page	Paragraph	Line	Comment
21	1		The platform to which the District's report is referring is known as the "Florida Platform" and that term should be utilized throughout because there are other names for other features that utilize the term platform in Florida. Also, the sentence that starts with "The limestone and dolomite…" should read "The near surface limestone and dolostone…." Dolostone is a better term than dolomite for the rock. These strata were deposited between the beginning of the Eocene Epoch at 55 (not 58) million years ago and early Miocene time ending at approximately 15 million years ago. This would include the Tampa member of the Peace River formation. The Miocene Epoch extended to about 5 million years ago and was characterized by deposition of sand and clay deposits that are developed in portions of the springshed. These and the Tampa Member constitute the Hawthorn Group. The Floridan Aquifer is that portion of the Eocene to Miocene section that consists of limestone and dolostone, but is not the only material deposited during the Eocene and Miocene Epochs.
21	2		This section cries for a map showing the geomorphic features within the springshed. There are several that are very important including the Brooksville Ridge and the coastal dunes that underlie much of the modern town of Spring Hill.
22			The regressions shown in Figure 2-7 were made by the USGS to estimate spring discharges from water levels in the Weeki Wachee Well. It is important to know whether or not changes in the rating between the Weeki Wachee Well and discharge at the springs has any effect on the long term data. Obviously, the differences in the regressions over time suggest that something has changed. What was it?
26	1	13	The sentence states that Figure 2-13 depicts the pumpage in Hernando County as an example of the accumulation of pumpage within the springshed. The District should consider adding pumpage in Pasco county to this analysis since large wellfields that are within the springshed are located in Pasco County. The pumpage reflected in Figure 2-13 apparently does not include these wellfields and, therefore, minimizes the issue of pumpage as a controlling factor on the discharge from the spring.

Page	Paragraph	Line	Comment
26			The implication of the regression line in Figure 2-12 is that it represents a reduction in flow from the spring(s). It's important to ask the question about how much of any trend that is present in the post-1960 data is reflective of pumpage as opposed to climatic events. 1960 was a significant tipping point in terms of rainfall as well as water levels in the area. There is a wide-spread pattern similar to the Weeki Wachee discharge pattern with a peak in water levels and/or discharge in the 1960s all the way from the Georgia line to the southern part of the District's service area. You can relate that pattern to rainfall and, in some cases, to changes in gages, measurement methods, and human activities. To simply place a regression line on a graph and then jump into talking about change from 1960 to present begs the question as to why the discharge increased from 1930 to 1960. This is also a good place to talk about the AMO and the different process that may affect water levels and discharges.
27	1	4	Remove the word "and" at the end of the line.
27	1	5	Location of the Sharpes Ferry Well, in relationship to the Weeki Wachee Well and Spring, should be given. Also provide some justification for saying that it is unimpacted.
30-31			References for the Northern Tampa Bay Model and Northern District Model are needed here.
31	2	5	If UFA stands for "upper Floridan aquifer," does that mean SAS stands for "surficial aquifer system?"
32	1	2	Why is the average 17 cfs of anthropogenic impact linearly proportioned over the 1961-2004 period? Why not allocate proportions according to the increases in pumpage or rainfall patterns? Does this mean that years with high discharge have the same percent flow reduction as low-flow years? This seems doubtful.
33			The District used three different methods for estimating a baseline flow condition that is as free of anthropogenic impacts as possible. This is variously referred to as "normalized" annual discharge, "standardization" of springflows, and "adjusted" flows. However, most hydrologists would recognize the adjusted discharge plot in Figure 2-17 as an attempt to create a "naturalized" flow record, wherein human impacts have been removed by adding back to the observed record any water withdrawals, such as pumpage, and subtracting out any water additions, such as wastewater discharges that could supplement aquifer recharge.
35	2	6	Indicate that the 12.7 cfs pumpage adjustment is an average and that it is being added to flow blocks based on medians. The appropriateness or effect of mixing these central tendency values is not addressed in the report.

Page	Paragraph	Line	Comment
36	2	7	Replace word "allied" with "applied."
44			An attempt should probably be made to explain the "spike" in % organic sediment of Weeki center line (red) at R_{km} ~ 1.5.
59	4	1	The use of Cox polynomials (Cox 1967, Jaegar 1973) represents an older method of estimating salinity from conductivity measurements that has an accuracy of about ± 0.003, where the error is due to seawater constituents, such as SiO_2, which cause changes in density but no change in conductivity. In 1978, the Practical Salinity Scale (PSS) was introduced to refine the traditional definition of salinity in uniform terms of a new international equation of state for seawater based on the conductivity ratio of a seawater sample to a standard KCl solution (Lewis and Perkin 1978) with an error of ± 0.001 across the world's oceans (Hill et al. 1989). However, errors rise to ± 0.01 or more in the lower salinity waters of coastal bays and estuaries where the use of the PSS caused many concerns (Parsons 1982). Moreover, since ratios have no units, Millero and Poisson (1981) noted that the new PSS is dimensionless and scales such as parts per thousand (either ppt or ‰) should not be used. The correct way to report practical salinity is as a number (e.g., the sample had a salinity of 35). This has caused some confusion and even led to the introduction of another scale referred to as "practical salinity units" (psu) that is also technically invalid. Although considered incorrect by many oceanographers and scientific journal editors, the Panel's peer review used the same convention as the District in this report and referred to salinity values as ppt with apologies to Millero and Poisson, and virtually all the major oceanographic groups (i.e., ASLO, CERF, IAPSO, ICES, IOC, UNESCO, SCOR, etc.).
71	1		The text refers to Figures 5-1a and 5-1b; however, the figure title on page 72 only refers to "top" and "bottom" panels, and the figures themselves are not labeled.

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Staff Response to:
Scientific Peer Review of the
Proposed Minimum Flows and Levels for the Weeki Wachee River System
Prepared by the Scientific Peer Review Panel July 31, 2008.

Geographic Scope of MFL

During the initial meeting of the Panel, District representatives indicated that the MFL was intended to protect the springs and their discharges that dominate flows of the WWRS. With few exceptions, the data presented for development of the WWRS MFL also support MFLs for the springs, although these were not specifically defined in the District's report. Since Florida statutes direct the District to adopt MFLs for "all first magnitude springs, and all second magnitude springs within state or federally owned lands purchased for conservation purposes," the Panel believes that the District should consider revising this document in such a way that it covers the MFLs for the associated springs, as well as the river and estuary.

It is the District's intention that the MFL developed for the Weeki Wachee River system apply to Weeki Wachee Spring, Mud Spring, Salt Spring, Twin Dees, Jenkins Spring, Weeki Wachee River, and the Mud River. Additional text has been added to final report to emphasize this point. With the exception of Weeki Wachee Springs and River, the inclusion of the other system components is largely pragmatic as there are no long-term flow measurements of the remaining components. The flow used to develop the MFL is calculated at a point about ten percent (0.8 mi) of the downstream distance to the Gulf from the main spring. These measurements include the contribution from Twin Dees. Mud Spring and Salt Spring are not regularly monitored and thus we have no long-term record of discharge. The District considered establishing some short-term discharge measurements, but both sites are tidal and would require more expensive instrumentation to measure net flow. This, coupled with the fact that the discharge is very saline and will probably never be subjected to withdrawals resulted in the decision to apply a system-wide MFL limitation. In addition, Jenkins Springs, which flows directly to the Gulf, is also considered part of the system due to its proximity (0.8 miles south), tidal inundation and lack of discharge data from which to develop a separate MFL.

The Panel noted concerns about the salinity regression equations and the numerical modeling that were employed in estimating the allowable flow reductions. The salinity regressions did not include salinity at the estuary mouth as an independent variable ... Obviously, many regression equation forms are possible; however, one particular form containing an auto-regressive salinity term with appropriate time lag is often used to improve salinity regression equations in estuarine systems. With this form of the equation it is simple to solve for one of the variables (e.g., flow) given values for the other two. This character of the isohaline equation was of great utility in determining the MFLs. The r2 for *the regression equation used to predict the location of an isohaline zone has a reasonable value of 0.66. Nevertheless, a major concern with the salinity regression equation is that the salinity at the river mouth is not included as an independent variable. Although the analysis described in the District's report concluded that flow from Weeki Wachee Spring did not have a significant impact on salinity at the river's mouth near Bayport, the salinity level in the river system is obviously dependent on the salinity level in the nearshore Gulf waters. This is an important boundary condition in the numerical model, described below, which was applied to assess the impact of flow reductions on the thermal regime. The regression equation for the location of salinity isohalines is used extensively in determining what flows result in a 15% reduction of various biological resources. It seems clear to the Panel that boundary salinity at the river mouth should have been included as an independent variable in the predictive equations.*

Initially the District considered including a boundary salinity in the flow/salinity regression but chose not to do so because at that time the District fully expected salinity at the mouth to be dependent on the river flow. In other words, boundary salinity would not qualify as an independent variable since it was assumed that it would be collinearly related to another independent term, namely flow.

For this reason, the District instead attempted to include a surrogate term (Withlacoochee River flow) that was independent of the Weeki Wachee flow, but one that might reasonably impact salinity in the near-Gulf boundary waters. The Withlacoochee River is large surface drainage system (1,170 mi^2 compared to 38 mi^2 Weeki Wachee that is expected to influence the near-Gulf salinities along the coast. The District experimented with including a Withlacoochee (same-day and lagged flows - transformed and untransformed) flow term in the regression, but these largely turned out to be insignificant or improved the regression only marginally. However, in retrospect, once the salinity at Bayport was shown to be independent of river flows, another form of the regression including Bayport salinity as an independent term should have been evaluated at the time the report was written.

In response to the panel's comments, the District evaluated the impact of adding a boundary salinity term to the existing regression model. For each sampling date, the furthest off-shore (minimum offshore distance of -0.41 Rkm) bottom salinity was assigned as the boundary term. The distance varied some with date but virtually all were between -0.41 and -0.91 Rkm. Boundary salinity was assigned to a total of 36 sample dates and the multiple parameter regression of the form below was evaluated.

$$Rkm_{isohaline} = \beta_o + \beta_1*(1/Flow) + \_\beta_2*Salinity + \beta_3*Boundary\_Salinity$$

This form resulted in a slight improvement over the original model which did not include the boundary term. The original form exhibited an r^2_{adj} = 0.66 (n= 632, SE estimate

=0.86) while the r^2_{adj} of the revised form was slightly higher at 0.74 (n=340, SE estimate = 0.66) with no evidence of multicollinarity (VIF ~ 1.0) and all terms were significant.

The District contrasted the results predicted by the two forms for a range of salinities and found that the difference in predicted values was lowest (e.g. +/- 0.2 km) at the lower isohalines and increased (e.g. +/- 0.6 km) at the higher salinities. Differences were on the same order of magnitude as the standard error of estimate of either model form and the District has chosen not to re-run the evaluations for the Weeki Wachee MFL. A graphic presentation of the differences is included as Attachment 1.

The District also considered including a lag term for the Weeki Wachee River. A comparison of cumulative river volume to average discharge was completed to determine approximate flushing time. The average daily flow for the baseline period (1985 – 2005) is 159 cfs (389,006 m^3/d). The volume of the river at mean tide level is estimated at 372,095 m^3. Thus, the average turn-over rate is less than a day suggesting that same day flows were the most appropriate flow term to evaluate.

Spring Discharge and Groundwater Pumpage

> *Annual discharge since 1929 has fluctuated between 117 -253 cfs. Trend analysis has shown that declines in discharge between 1970 and 1999 were due to anthropogenic and climactic factors. Various models in the District's MFL report (2008) show that groundwater pumpage has an estimated impact on spring flow from 9.7 to 25.2 cfs. Yet an empirical data plot does not show pumpage to significantly affect flow (Figure 1). A plot of rainfall, spring flows and pumpage from 1975 to 2004 (data from Schultz, 2007) only suggest a weak relationship between rainfall and spring flows with one to two year lags in response (Figure 2). Further, the District's MFL report (SWFWMD 2008) states that "Annual pumpage was compared with annual spring discharge and a significant inverse relationship was found." However, a graphical analysis of the data prepared by the Panel did not confirm this finding (Figure 3.)*

The District has re-written this section of the report to address the panel's comments.. Unfortunately, the Section 2.4 and Figure 2-13 in particular were prepared before the z-score, wavelet analysis and integrated groundwater modeling were available. The Hernando County pumpage depicted in Figure 2-13 is not representative of the springshed pumpage affecting flows at Weeki Wachee spring. The appropriate record of historical pumpage is included as Appendix 10.1 in a Technical Memorandum by R. Shultz, which appears as Figure 2-13 in the final report.

As stated in the report and re-iterated by the panel, the decline in pumpage is a combination of both anthropogenic and climatic effects. The challenge is to differentiate and the three independent approaches all removed, or neutralized the impact of rainfall in some fashion. These facts are indisputable:

> a) There has been a statistically significant increase (ktau = 0.74, $p \leq 0.0000$) in groundwater pumpage in the Weeki Wachee springshed since 1965.
> b) Annual rainfall at Weeki Wachee has not changed significantly since 1965 (ktau = 0.04, p =0.76)
> c) The relationship (ktau = +0.24, p = 0.05) between rainfall and spring flow is marginally stronger and opposite to the relationship between springshed pumpage and spring flow (ktau = - 0.24, p = 0.06)

In order to further characterize the effect of pumpage on spring flow, a series of correlations between spring flow and lagged annual rainfall were developed. The best fit was obtained with a one-year lag. A LOWESS smooth was then applied to the discharge data (rain_lag1 as independent variable) and the discharge residuals (representing the discharge not explained by rainfall) were then compared to annual pumpage. Both the parametric (r = - 0.40, p = 0.028) and the non-parametric (tau = - 0.31, p = 0.015) correlations were significant indicating that even when the effect of rainfall is removed, pumpage remains a major contributor to the decline in spring flow.

Water Quality

> *The District merged and integrated some 23 disparate datasets spanning the 1984 through 2005 period of record into one cohesive database. As such, the District is to be commended for its effort to use the best available information. On the other hand, the District's water quality data analysis was rather cursory. The District did provide a decent discussion of the overall chemical characteristics of the system; however, only one graph was provided (i.e. nitrate versus salinity) and that was for the entire period of record. The Panel would like to have seen some representative constituent concentration – salinity plots for other variables over specific sampling events, seasons and flow regimes.*

The District acknowledges the comment and will include a discussion of salinity vs. water quality parameters in future reports. The District did however include a series of 26 graphs portraying water quality time series as a function of river segments in the appendix that may have been overlooked. Parameters presented in the appendix include time series plots of total nitrogen, total phosphorus, ortho-phosphate phosphorus, nitrate + nitrite nitrogen, pheophytin-corrected chlorophyll a, total suspended solids and ammonia nitrogen at four longitudinal segments of the system. In addition to the time series, graphs of salinity vs. these same water quality parameters have been added to the appendix of the final MFL document.

The peer review has also commented that most …*Florida springs show a positive correlation of nitrate and spring discharge . . .* Assuming the panel was referring to concentration and not loading, it should be noted that Weeki Wachee exhibits this correlation only weakly, but does exhibit a much stronger correlation to time. Attachment 2 summarizes the relationship of NO_x -N concentration as a function of a) flow, b) date and c) date vs. LOWESS residuals of NO_x-N predicted from flow and d) flow vs. the residuals of NO_x-N predicted from date. While a weak relationship between flow and concentration is evident, there is a much stronger relationship between time and concentration.

EFDC Model

> *The Panel's comments on the calibration and validation of the EFDC model, as applied by ATM to the WWRS, are given below. These observations are based on results presented in the consultant's report "Impacts of Withdrawals on the Thermal Regime of the Weeki Wachee River" (ATM 2007). . . .*
>
> *Although salinity at Mud Spring can often be quite high (e.g., 20 parts per thousand salt, ppt, or about 57% seawater salinity), there is no discussion in the ATM report about an assumed or measured salinity boundary condition at Mud Spring. If the modelers assumed that artesian groundwater discharges from Mud Spring were fresh, then this could be a serious error. . . .*
>
> *Figure 3-2 in the ATM report shows the bottom elevation along the river, while Figures 3.10 and 3.12 show observed water surface elevations. These graphs reveal a rather strong slope in the water surface from R_{km} 2.3 to 7.3. This slope is on the order of 3 – 4 m (9.8 – 13.1 ft) over a distance of 5 km (3.1 miles). This significant slope in the water surface probably results in the observation that the tide is mostly dampened at Station No. 02310530 (R_{km} 7.3). Unfortunately, the discordant bathymetries shown in Figures 3-2 and 4-2 of the ATM report suggest by comparison that the impact of this slope is not included in the EFDC model, another potentially serious error. . . .*
>
> *In a hydrodynamic model study, one generally makes runs on grids with varying resolution to determine the impact of the grid on the accuracy of the solution. Apparently, this was not done, or at least not reported, in the present study. While the longitudinal resolution of the horizontal dimension is probably sufficient in the computational grid (Figure 4-1, ATM 2007), the Panel believes that the number of sigma layers should have been varied to understand the impact of using more than 4 layers on the model's solution.*

ATM has responded as follows:

The Southwest Florida Water Management District (SWFWMD) has requested that ATM address comments made on the report titled “Impacts of withdrawals on the thermal regime of the Weeki Wachee River”, (ATM 2007). The comments were compiled by an independent review panel for the SWFWMD. Several of the comments focused on the EFDC model application to the Weeki Wachee River system and two particular modeling issues were noted by the SWFWMD and need to be addressed. The comments are paraphrased in the form of questions here:

1) Was Mud Springs boundary condition modeled as a saline or a freshwater input in the EFDC model application to the Weeki Wachee River system?
2) Did the model bathymetry represent the physical conditions to a sufficient extent to produce the expected tidal signal damping in the upstream reaches of the river.

As noted by the reviewers, the hydrodynamic and thermal model EFDC chosen by ATM to simulate the circulation and water temperature conditions in the Weeki Wachee River system contains all of the requisite physics in its basic formulation. The comments therefore focus mainly on the various options chosen for the model application to the river system such as the grid, boundary conditions and calibration. The following response to the comments will briefly address some of the issues mentioned in the review, in addition to the two specific questions noted above, as they have some bearing on those issues.

Although the report did not discuss the long model application process, a number of grid resolution iterations were performed in both the horizontal and the vertical directions before the final grid was selected. The grid as presented in the report did not show appreciable differences (i.e. improvements) in predictive quality from grids with twice the resolution in the vertical and horizontal. The higher resolution grids did however take 8-10 times as long to run, when the reduced time step is taken into account due to the very small overall physical dimensions of the system and correspondingly small cell sizes, making not only the calibration a slow process, but the multiple, longer term management scenario production simulations prohibitively long. The model system was developed to be a management model and long run times clearly reduce its utility. The reviewers indicate that the sigma problem may be affecting the salinity simulations and they may be correct as it is a well known problem, but it is not clear whether the implied increased resolution needed is practical or beneficial at these very small physical scales. It should be noted that most of the sigma problems are horizontally 2-D in nature and that in the EFDC model this was dealt with by John Hamrick (the original developer) some time ago through a density algorithm that maps the density gradients to the z-grid rather than sigma grid. The original problem to which we believe that the reviewers are referring, was leaking over the sides of channels into the adjacent cells, should not be an issue in this application, both due to the sigma-z fix and the fact that upper portion of the river is essentially 1-D in design.

Mud River Boundary Condition

The Mud River boundary condition of the EFDC model application did include salinity as an input. The boundary was specified as constant values for both the calibration and the critical conditions scenarios. For the model calibration time period, while there was no time series data available for the Mud River salinity, there was an on-going water quality field program collecting data (including salinity) approximately on a monthly basis. During the November 2003 through February 2004 period there were two sets of samples taken, roughly one month apart, at the Mud River spring site (station M1). An average value of 17ppt was calculated from that data, corresponding to specific conductivity of 27,200 us/cm.

For the critical scenario runs, a slightly different approach was taken, as the environmental conditions used were a composite of different factors affecting the flow and temperatures. For those scenarios, we used a constant salinity of 12.6 ppt, corresponding to specific conductivity of 21,100 us/cm, as calculated from USGS data from 1988-1989 and 1992.

EFDC Model Bathymetry

The bathymetry used in the model grid came from depths measured by the SWFWMD in longitudinal transects ranging from the area just Gulfward of the Bayport pier to the head of each of the rivers. As the grid cells were larger than the resolution of the bathymetric scale for the most part, each cell depth was originally calculated as an aggregate average of the data that fell in that cell. Empty cells, where they did occur, were filled through interpolation and extrapolation techniques. The grid cell depths were then review and compared to the measured bathymetry and edited where necessary, maintaining both the meaningful maximum depths and the cross-sectional area (cross-sectional depth transects were taken at 175 locations throughout the river system).

Part of the model calibration process was to review the computer generated and hand edited bathymetry and balance the bathymetric profile, cross sections and gradients (if known) in the area, with the model predicted tidal wave (and damping), circulation patterns, salinity intrusion and water temperature. The key focus was to be able to model the known physical response of the system to the known external physical forcing. The ultimate goal then being the capability to predict the changes that the system would experience for altered input conditions (i.e. spring flow in this case), particularly the impact on the temperature in the colder winter months.

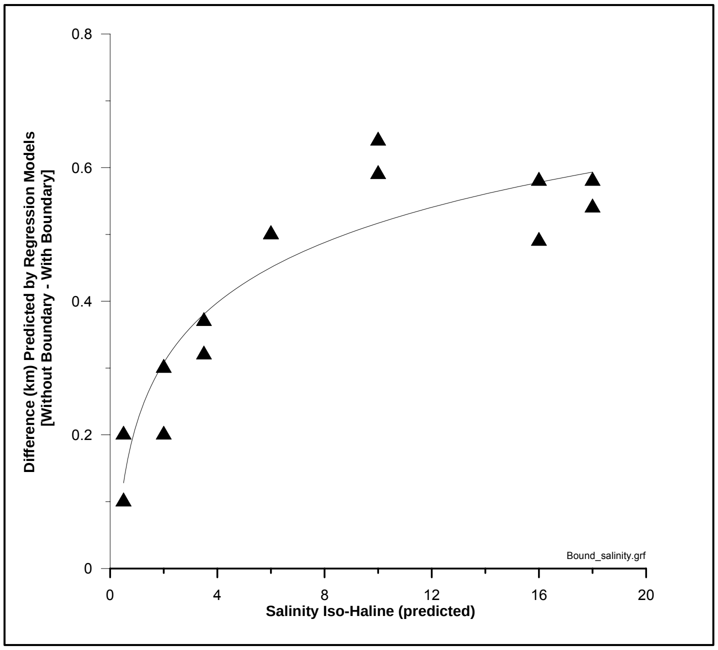
While the final model bathymetry does not perfectly mirror the intricacy of the measured profile, an attempt was made to adequately represent the range of depths and the trends of the bottom profile as closely as possible for the discrete nature and grid resolution of the finite difference model. The longitudinal gradient through the system is represented such that the water depth, when compared to mean sea level (the Gulf datum), in the upstream portion of the Weeki Wachee is near zero. A balance was struck between detailed representation of the bathymetry and the predictive capability of the model in terms of tides, salinity and most important, the temperature primarily by maintaining the centerline profile which controls the estuarine circulation and therefore the salinity and winter, cold-water intrusion into the system. The water surface elevation response in the upstream portion of the river does not show full damping of the tidal signal, but experiences a significant diminution (greater than 50% decrease) and increased mean elevation in the upstream direction. The resulting calibration is not perfect, as noted, but adequately represents the magnitudes and trends of the circulation in the system and allows for accurate temperature prediction as both the graphical (Figures 4-14a,b) and statistical representations show (Table 4-1). It can be seen that the differences in the 5^{th}, 50^{th} and 95^{th} percentiles for temperature are primarily about 0.25^{o} C and all less than 0.58^{o} C.

Errata and Editorial Comments

Page 5 Paragraph 2	Discussion revised and figures removed.
Page 6 Paragraph 2	The preferred citation added to the final report.
Page 6 Paragraph 3	Discussion revised and figures removed.
Page 9	The District intended that the MFL developed for the Weeki Wachee Spring and River be applied to the Weeki Wachee spring complex. Text has been added to clarify this point.
Page 12 Paragraph 5	Comment noted. The physical descriptions, primarily Chapter 2, have been supplemented with English units.
Page 14	Some additional discussion of the geology has been added to the body of the report, but with all respect due to the panel, staff has chosen not to incorporate all the details suggested. Staff acknowledge that the suggested information may be of significant technical interest, but its inclusion will not contribute to the quantification of habitat/resource to changes flows due to withdrawals.
Page 14 Paragraph 1	Line 10 comment noted and text revised.
Page 21 Paragraph 1	Suggested edits have been incorporated.
Page 22	Point of clarification. While the USGS periodically updates their discharge regression, (D. Yobbi, personal communication) the regressions presented in Figure 2-7 were developed by the District and not USGS.
Page 26	The regression line presented is an unbiased representation of the decline in spring flow since 1960. Ensuing text identifies it as the result of both changes in climate and anthropogenic impacts. Additional text has been added to indicate the relationship to AMO periods and to emphasize that regionally flows peaked in the 1960s.
Page 26 Paragraph 1	Line 13. Figure 2-13 has been replaced with a depiction of pumpage within the Weeki Wachee springshed.
Page 27 Paragraph 1	"and" removed.

	A justification that Sharpes Ferry Well is unimpacted is included as Attachment 3.
Page 30-31	Acronyms have been defined and citations added.
Page 32 Paragraph 2	After the effects of rainfall have been removed, discharge can be expressed as a linear (albeit weakly so) function of pumpage (see text response). Short of modeling the time-series of pumpage, applying the impacts in a linear fashion appears to be a reasonable approach. It should be noted that the impact, expressed as a percentage of observed flow, would not be linear. That is to say, if a 10 cfs impact is imposed on an observed flow of 120 cfs, the percentage impact will be different than if the same 10 cfs impact were applied to a dry year with flows of only 100 cfs. Thus, the anthropogenic impact was applied on top of year-to-year variations due primarily to rainfall.
Page 35 Paragraph 2	Since the 17 cfs correction was applied in a linear fashion, both the median and the mean for the baseline period are the same. A note to this effect has been added to the report.
Page 36 Paragraph 2	Corrected
Page 59 Paragraph 4	Comments noted. The advantage of the Cox equations (as modified by Brown) and reported by Jaeger is that the seawater dilutions were prepared using river water in lieu of distilled water. Nevertheless, the comment is noted and the District will re-evaluate the various options for calculating an apparent "salinity" from conductivity readings.
Page 71 Paragraph 1	Legend corrected.

Attachment 1 – Comparison of salinity regression model results with / without boundary salinity.



Attachment 2 – Response of nitrate/nitrite concentration to flow and time.

Flow vs. concentration		
Pearsons r	0.055	p = 0.4487
Spearman rho	0.245	p =0.0006
Date vs. concentration		
Pearsons r	0.8984	p < 0.0000
Spearman rho	0.7593	p < 0.0000
Date vs Concentration Residuals (from Flow)		
Pearsons r	0.9022	p < 0.0000
Spearman rho	0.7533	p < 0.0000
Flow vs Concentration Residuals (from date)		
Pearsons r	0.1769	p = 0.0144
Spearman rho	0.2023	p = 0.0049

Attachement 3. – Sharps Ferry Well

Potential Impacts to Sharp's Ferry Well

The Sharp's Ferry well has been used to monitor Upper Floridan aquifer water levels since 1947. The well measurements were discontinued in 2002. Because this monitor well has the long history of recorded water levels, it makes an excellent candidate to use as a surrogate to observe long-term climatic variability in west-central Florida.

The peer review panel on the Upper Hillsborough River indicated that the MFL report for Crystal Springs did not provide enough support that the Sharp's Ferry well represented an area of relatively little anthropogenic influence. To address that issue, the USGS Mega Model was utilized to predict water level drawdown in the Upper Floridan aquifer in the vicinity of the Sharp's Ferry well under current withdrawal conditions (Figure 1) The Mega Model[1] withdrawals were 55.2 mgd for Marion County using the 1993-94 well package. Estimated and metered groundwater withdrawn in the County averaged 54.2 mgd for the three-year period from 2001-2003. The model predicts a decline of 0.3 ft in the Upper Floridan aquifer due to existing withdrawals in the area.

In addition to the model run, existing 2002 water use near the Sharp's Ferry was plotted and is illustrated in Figure 2. Closest groundwater withdrawals are located two miles to the northeast and they average less than 0.1 mgd. The City of Ocala municipal wellfield withdrawals, which averaged 12 mgd in 2002, are located approximately seven miles west of the Sharp's Ferry well.

As a final tool to measure potential impact to the Sharp's Ferry water level, a cumulative sum graph was created of annual rainfall versus mean annual water level from the Sharp's Ferry well. (Figure 3). In the cumulative sum analysis, any major deviation in slope that occurs for more than five years would indicate an influence other than rainfall affecting water levels in the well. To make the analysis more sensitive to potential changes, 30 feet was subtracted from each year's water level at the Sharp's Ferry well. The plot indicates no significant deviation in slope suggesting climatic influences dominate the historic fluctuation of water levels at this well.

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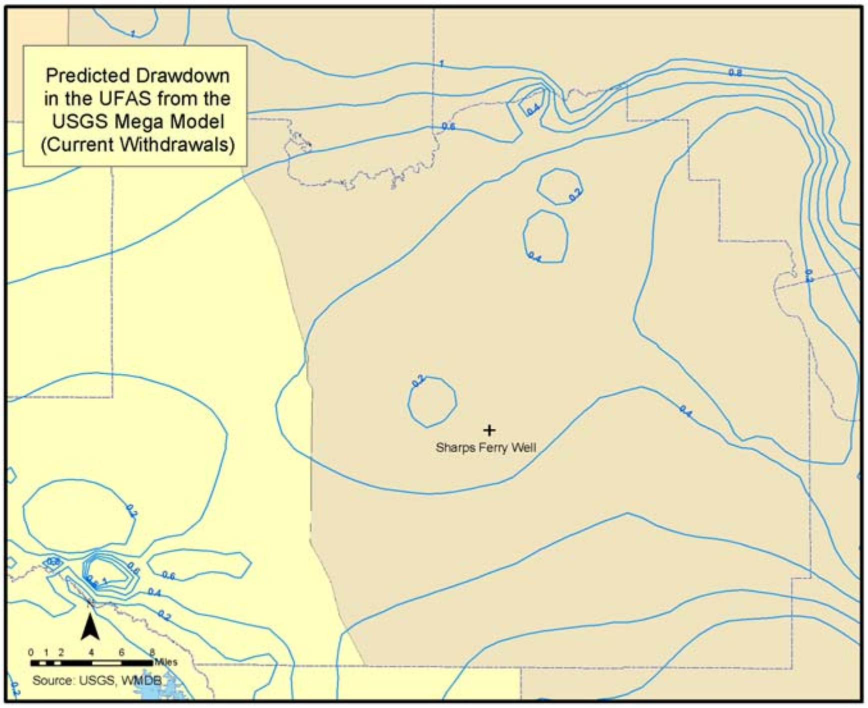
[1] Sepulveda, N. 2002. Simulation of Ground-Water Flow in the Intermediate and Floridan Aquifer Systems in Peninsular Florida, U.S. Geological Survey WRI Report 02-4009, 130 p.



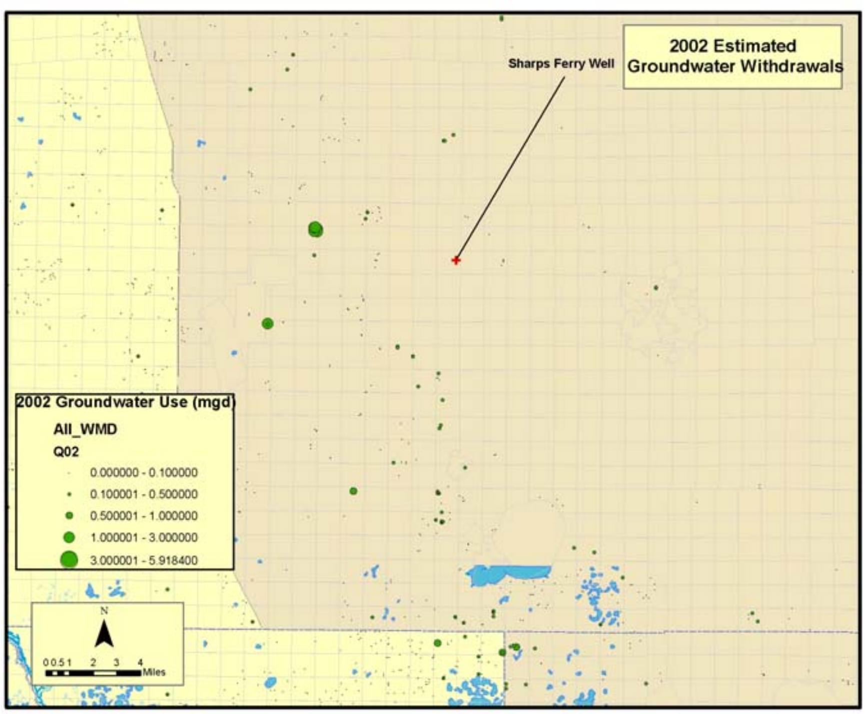


Figure 1. Predicted drawdown (feet) in the Upper Floridan aquifer due to current withdrawals based on the USGS Mega Model.

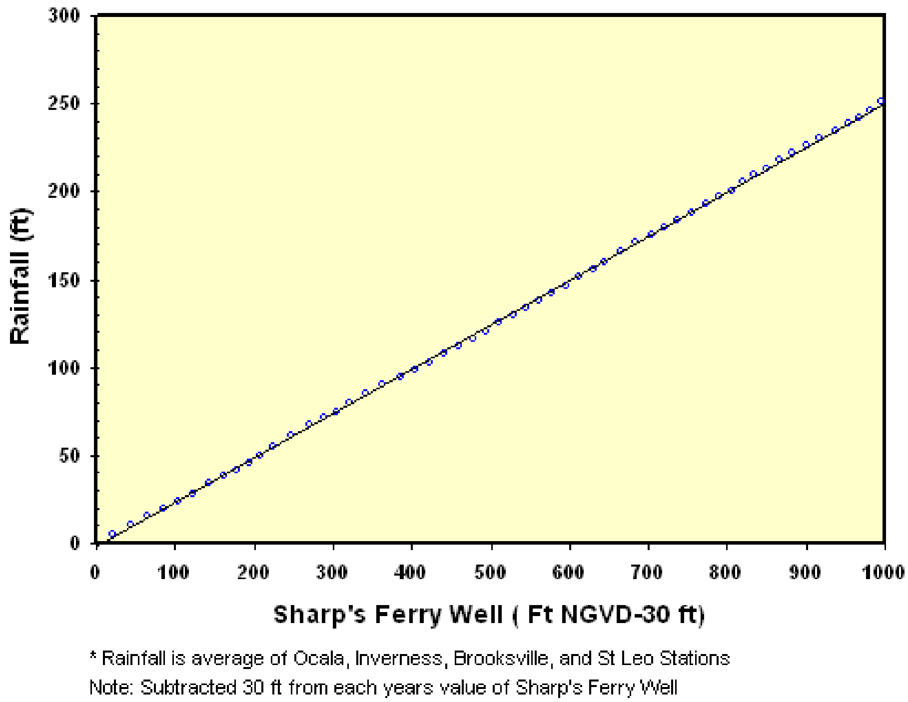


Figure 2. Estimated and metered 2002 water use in the vicinity of the Sharp's Ferry well.

Figure 3. Cumulative sum of Sharp's Ferry water level versus rainfall (1947-2002).