REVIEW OF MINIMUM FLOWS AND LEVELS FOR THE LOWER ALAFIA RIVER, FLORIDA

Scientific Peer Review Report

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Prepared For:
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Scientific Peer Review of The Determination of Minimum Flows for the Lower Alafia River Estuary, Florida

EXECUTIVE SUMMARY

These studies were conducted by the Southwest Florida Water Management District (the District) because Florida Statutes (§373.042) mandate the District's evaluation of minimum flows and levels (MFLs) for the purpose of protecting the water resources and the ecology of the Lower Alafia River Estuary from "significant harm" related to the continued and expanding municipal and industrial freshwater diversions from the Alafia River to meet water demands of the fast growing Tampa coastal region. With appropriate water management, including science-based MFL rules for environmentally safe operation of water supply impoundments and diversions, the District can ensure that the Lower Alafia River and its associated tidal (estuarine) marshes and brackish wetlands will continue to provide essential food and cover for the myriad of marine and estuarine-dependent fish and wildlife that need them. These measures can also help to restrict the invasion of marine predators, parasites and disease organisms that can negatively affect or even destroy an entire year-class of young organisms, potentially decreasing the surplus production of resident fishery populations that provide seafoods in harvestable quantities.

The Review Panel was generally impressed by the District's investment in obtaining adequate data for the study (e.g., 3032 vertical profiles of salinity, temperature, DO, etc. in the 1999-2003 database), and the thoroughness of the MFL analyses described in the document. The District's goals, indicators and definitions, as developed and explained in the subject report, seem reasonable and appropriate. The Panel finds reasonable the District's conclusion that the proposed MFL will not cause habitat and population losses greater than 15% from the river's use as a water supply source. The Panel also believes that the District's selection of an appropriate low flow threshold of 120 cfs is both reasonable and essential to the success of the MFL in protecting living estuarine resources in the Lower Alafia River.

The Review Panel supports the District’s finding that changes in the shallow-water distribution of estuarine-dependent fishes and invertebrates is related to freshwater inflow. Increasing freshwater discharges attract these organisms, particularly the young-of-the-year, into areas that provide instream habitat (i.e., food and cover) in which they can survive and grow. However, the weak relationships found between inflows and the abundances of major fish and invertebrate species indicate that other physical, chemical and biological conditions are limiting biotic production in the Lower Alafia River. Since these factors are discussed in detail by the District, the Review Panel concludes that the consideration of fish and invertebrates was adequate. For example, the river suffers from periodic algal blooms and low dissolved oxygen concentrations. Complicating matters, there are strong seasonal cycles in temperature, salinity and dissolved oxygen, related to the cooler, dry (winter-spring) seasons versus the warmer, wet (summer-fall) seasons. The Review Panel concurs with the District’s finding that dissolved oxygen, especially near the bottom, is often undesirably low (hypoxic) and can increase mortality of inhabiting fish, shellfish and other organisms.

The Review Panel finds that the District’s hydrological analyses and discussion are adequate, as are the numerical simulations. To the Review Panel, it appears that the LAMFE model application has the required accuracy and resolution to adequately simulate circulation and salinity patterns of the future water management scenarios in enough detail for use in decision-making.

And finally, there is the larger issue of freshwater inflows to Hillsborough Bay, a secondary bay of the Tampa Bay complex most often containing mesohaline water and exhibiting estuarine function due, at least in part, to the fact that the Alafia River has the second largest contributing watershed in the entire Tampa Bay watershed. The District’s evaluation of water supply withdrawals allowed under the proposed MFL rule indicates that the withdrawals will constitute only a small percentage of the freshwater resources to

Hillsborough Bay and, thus, the Panel agrees that it is not likely to produce any "significant harm" to the Bay's ecological health and productivity.

Overall, the Review Panel finds that the District's technical assumptions, ecological criteria, and analytical results that were used to develop an appropriate MFL rule for this estuary are adequate and reasonable, but the Panel strongly recommends continued monitoring to verify that the MFL is having its intended effect of protecting ecological health and productivity of the estuary.

INTRODUCTION

The Southwest Florida Water Management District (the District) is mandated by Florida statutes to establish minimum flows and levels (MFLs) for state surface waters and aquifers within its boundaries for the purpose of protecting the water resources and the ecology of the area from "significant harm" (Florida Statutes, 1972 as amended, Chapter 373, §373.042). 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. While this is always important, it is especially important in a riverine estuary where up to 19% of streamflows are potentially going to be withdrawn in the future to provide water supplies for the region’s growth.

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 also has continued to voluntarily commit to independent scientific peer review of its MFLs determinations as good public policy.

After a site visit on October 26, 2007 to perform a reconnaissance survey of the Lower Alafia River study area , the Scientific Review Panel discussed the scope of the review and subsequently prepared their independent scientific reviews of the draft report and associated study documents. The reviews were compiled by the Panel Chair and edited by all Panel Members into the consensus report presented herein.

BACKGROUND

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 may all be altered in ways that negatively effect 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 impoundment and diversion, 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 effect 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 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, is detailed in Flannery et al. (2002).

REVIEW

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 the minimum flow rule.

The District’s management goals for the Lower Alafia River were developed to sustain the ecological integrity of this tidal river segment by maintaining a biologically appropriate salinity regime and associated dissolved oxygen (DO) level in this hypereutrophic (excessively nutrient rich) riverine estuary. This nutrient enriched condition makes the river susceptible to developing high concentrations of phytoplankton and nuisance algae during low flow periods that supersaturate the water with DO during the day and then cause hypoxic (severe low DO) at night that can greatly increase the mortality of fish and invertebrate populations. As a result, an additional and very important part of the District's proposed MFL is the identification of a low-flow threshold below which no water diversions would be allowed to cause any DO impacts in the river. The District also concludes that a reduction in the median abundance of a species found sensitive to freshwater inflow (juvenile red drum, *Sciaenops ocellatus*) greater than 15% is not acceptable without triggering "significant harm" to this and other living fish and wildlife resources that may not be as sensitive.

The Review Panel agrees that the District has conducted a comprehensive technical study to determine minimum streamflow requirements for use in managing water resources of the Lower Alafia River, an estuary of the Tampa Bay complex. A criteria of no more than a 15% change in any percentile of abundance, as compared to the estuary's baseline condition, was used as the threshold for "significant harm." While the use of 15% as a threshold is a management decision, the Panel agrees that this is a reasonable approach for avoiding the most serious negative impacts on the ecosystem. The remainder of this report is focused on review of the data, methods and analyses used as a basis for the District's recommended MFL.

The analysis primarily revolves around using regression equations relating several common physical, chemical and biological variables to freshwater inflows at Bell Shoals Road, which is located about 18 km from the mouth of the river (see Figure 1).

Specifically, the District's proposed MFL was determined based on the following procedure:

1. Regressions were developed between inflow and abundance of a suite of fish and invertebrates based on empirical analyses of samples collected in the Lower Alafia River (via both plankton tows and seine and trawl samples).

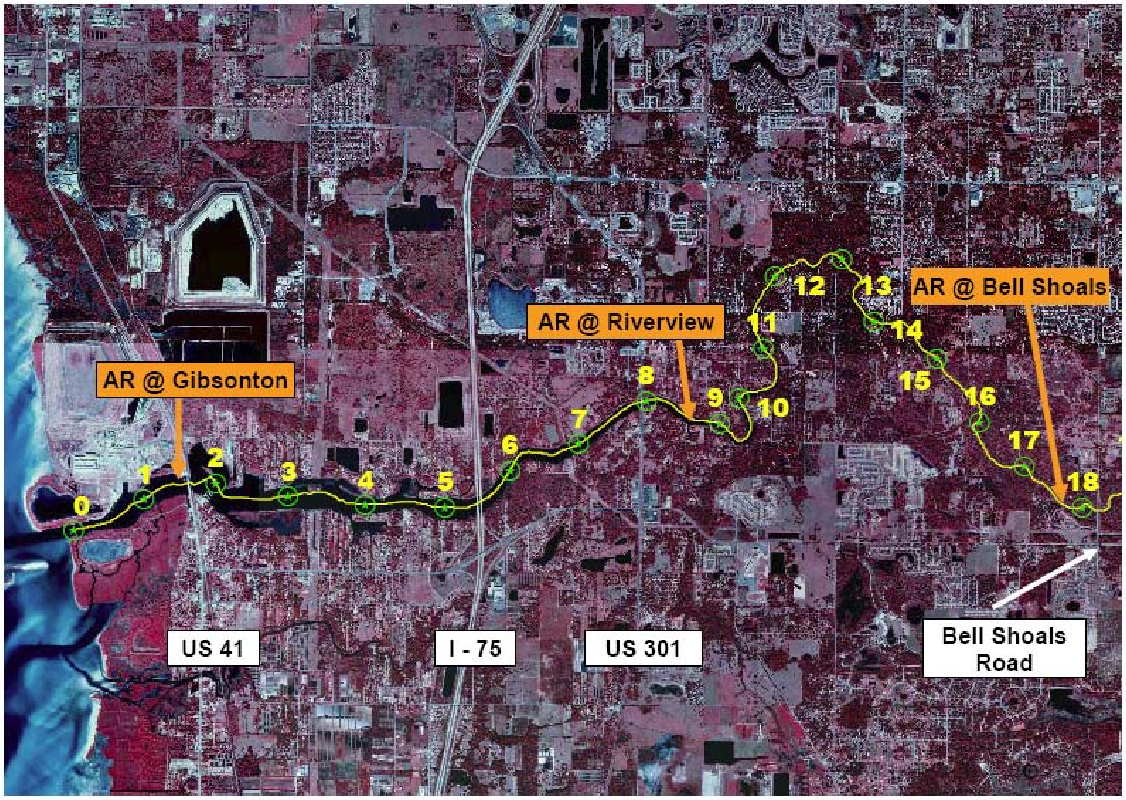

Figure 1. Lower Alafia River, river kilometer at centerline, major roads, and three USGS continuous water quality recorder sites.

2. Daily inflows to the estuary were calculated for the baseline period of 1987 – 2003, given different withdrawal scenarios (with and without a minimum cut-off of water supply diversions).

3. The regression equations were used to predict abundance under the various withdrawal schedules based on the calculated daily inflows associated with each scenario.

4. Predicted abundances were used to construct a cumulative distribution function for the suite of organisms under consideration for each scenario.

5. The predicted cumulative distribution functions (CDF) of organism abundance were compared to CDFs under baseline conditions to determine the % change in

> each percentile. A criteria of no more than a 15% change in any percentile of abundance as compared to baseline was used as the threshold for “significant harm.”

The proposed minimum flow limit for the Lower Alafia River is an allowable reduction of up to 19% of inflow to the upper estuary (calculated as the sum of the estimated flow at Bell Shoals Road plus flow at Buckhorn Springs), with a low flow cut-off of 120 cfs. This scenario was shown to keep the predicted negative changes in abundance of all species to less than 15%. The District’s analysis focused on the abundance of mysid shrimp and juvenile red drum associated with each scenario, because these indicator organisms are biologically important and sensitive to changes in inflow. They are also key species in the estuary (mysid shrimp as an important food source for larval fish; red drum as an ecologically and economically important game fish).

Next, the District evaluated the effect of the proposed MFL on numerous other indicators of estuarine condition (i.e., abundance and distribution of other fish and invertebrates, DO concentration, chlorophyll concentration and the location of peak chlorophyll, location of isohalines and their relationship to both wetland habitat and bottom area). In each case, the steps outlined above were followed, except that the relationships between inflow and the characteristic in question were not always regressions and the predicted changes associated with different inflow scenarios were sometimes obtained by hydrodynamic modeling. In the end, the District concludes that applying the proposed MFL would be protective of these other characteristics as well, since they all proved less sensitive to changes in inflow than mysid shrimp and juvenile red drum.

The District has done a thorough job with the technical part of this document. The report provides a more or less complete picture of the Lower Alafia River. Moreover, the overall analytical approach is sound science. Additional technical comments on various parts of the District’s MFL report are provided below:

Theoretical Aspects of Hydrodynamic River Models

In addition to the regression analyses of empirical (observed) data, the District applied a numerical simulation model (i.e., LAMFE) to determine the change in volume and bottom area of saline water as a function of freshwater inflow into the Lower Alafia River. A particle tracking subroutine contained in LAMFE also was used to compute estimates of the riverine estuary's hydraulic residence time and pulse-residence time.

Over the past 25 years, there have been many free-surface hydrostatic numerical hydrodynamic models developed for application in rivers, reservoirs, estuaries and coastal bay areas. Generally, the major delineation between models pertains to their spatial dimensionality. Every hydrodynamic model starts from equations that represent the three-dimensional (3-D) conservation of mass and momentum in a water body. If salinity and/or temperature are to be simulated, there will also be 3-D transport equations for the conservation of salt and/or heat. Models developed for unsteady flow computations in rivers generally make the assumption that the flow is fairly uniform over the cross section of the river and the governing 3-D equations are integrated over the cross section to yield one-dimensional (1-D) equations that can be solved for the variation of the flow and water surface along the river. These 1-D numerical hydrodynamic models are often used for flood routing in major rivers (e.g., Mississippi, Ohio, etc.).

In the relatively shallow bays and estuaries, the flow and water density often don't vary significantly over the water depth. Therefore, the governing 3-D equations are integrated over the water depth to yield two-dimensional (2-D) vertically-averaged equations. In these models, the variation of the flow and the salinity and/or temperature is computed in the horizontal plane of the water body. These models are referred to as 2-D vertically-averaged hydrodynamic models. Some of these models account for the horizontal variation of water density in the momentum equations.

In relatively narrow and deep reservoirs, the temperature over the water depth can become stratified, while there may be very little variation of the flow and temperature over the width of the reservoir. Similarly, in relatively narrow estuaries the salinity can be stratified over the water depth but exhibit little variation over the width of the estuary. For these types of water bodies, the governing 3-D equations are integrated over the width to yield 2-D laterally-averaged equations. With such models, the variation of the flow and salinity or temperature in the water column profile is computed longitudinally down the primary axis of the reservoir or estuary. These models, including the District's LAMFE model, are referred to as 2-D laterally-averaged hydrodynamic models.

The LAMFE model accounts for the influence of water density variations, caused by differences in the concentration (weight) of the salt in various water layers, on the flow field in the momentum equation (i.e., baroclinic terms are included). Having a model that includes more resolution of the vertical (depth) dimension was essential in the Lower Alafia River application because the vertical salinity gradient in the water column (i.e., stratification) of the riverine estuary is generally quite pronounced. For example, the median salinity difference between the surface and near bottom of the water column at the Riverview gage is about 10 psu, as computed from salinity data collected from 1999 to 2003 at the surface, which is lighter and fresher, and at > 2 meters depth where the water is heavier and saltier.

The second most used delineation of numerical hydrodynamic models is related to the numerical solution scheme employed to solve the governing conservation equations. The two most used solution schemes are referred to as the finite difference method and the finite element method. In the finite difference method, derivatives in the governing equations are replaced with differences in discrete values of the dependent variables specified on a numerical grid to compute the solution to the equations. By comparison, a solution is assumed (usually as a polynomial) in the finite element method and the governing equations are used to minimize the error in the assumed solution.

Usually finite difference solutions are made on a structured numerical grid, whereas finite element solutions are made on unstructured nets or meshes. This normally results in finite difference models being more computationally efficient than finite element models; however, finite element models can often reproduce the geometry of the study area in a more recognizable form with higher resolution. Other available solution methods include the boundary element method and the finite volume method. Finite volume models can be viewed as a special case of finite element models. Finite difference models that utilize grids where the computed variables are staggered over the cell faces and at the cell center, such that mass fluxes are computed in and out of the cell, are basically structured grid finite volume models. The LAMFE model utilizes the finite difference method of solution and, thus, is a 2-D laterally-averaged, finite difference model.

Numerical models can be classified as using explicit, implicit or semi-implicit mathematical code. In explicit models, all terms in all the governing equations are evaluated at the old time step in the time integration scheme. This results in limitations being placed on the computational time-step allowed for stable computations. Generally the most restrictive limitation relates to the free-surface gravity wave. In other words, the time-step must be less than the time required for the free-surface gravity wave to travel over the length of a spatial computational cell. Other limitations are related to the speed of the water not being allowed to travel over more than one cell within a time-step, diffusion criteria, friction criteria and internal density waves due to water column stratification. Totally implicit models evaluate all terms in the governing equations at the new time-step in the time integration and there are no limitations on the allowable time-step from a stability consideration. However, there still may be accuracy considerations. Semi-implicit finite difference models evaluate some terms at the new time-step and some at the old time-step, resulting in some limitations on the time-step being removed while others remain. For example, it is highly desirable to remove the extremely restrictive limitation on the time-step related to the speed of the free-surface gravity wave. With the above understanding, the District’s LAMFE model can be classified as a semi-implicit, 2-D laterally averaged, finite difference, hydrodynamic (circulation) and conservative mass (salinity) transport simulation model.

There are different finite solution schemes for solving the governing difference equations. LAMFE uses what is called a “predictor-corrector scheme.” Initially, the longitudinal velocity is computed over the vertical for each column in the grid with only the vertical viscosity and bottom and side friction taken implicitly. Once the longitudinal velocity is determined over the vertical for each column, the vertical velocity and water surface elevation are determined. This is referred to as the “predictor step.” If the computations stop at this point, one could consider the computations to have advanced values for the longitudinal velocity, vertical velocity and water surface elevation to the next time-step. However, the time-step would be restricted by the speed of the free-surface gravity wave and the model would not be very efficient for long-term computations. In LAMFE, the computations continue for the longitudinal velocity, which are now advanced to the next time-step with the water surface elevation (baratropic) term expressed implicitly in the momentum equation.

Ultimately, an equation is derived for the water surface elevations computed at the new time-step at all longitudinal locations in a numerical grid that involves a tri-diagonal system of linear equations that can be solved very efficiently. Once the water surface elevations at the new time step are determined, it is very easy to solve for the longitudinal velocity and the vertical velocity over the longitudinal and vertical dimensions in the numerical grid. This is called the “corrector step.” The salinity is then advanced to the next time-step using the new velocity field with the vertical diffusion term expressed implicitly.

The Review Panel finds that the numerical solution scheme employed in the LAMFE model results in free-surface gravity wave speeds and values of vertical viscosity/diffusion and friction that do not restrict the allowable computational time-step. The time-step is still restricted by the speed of a transient water particle; however, this is not normally overly restrictive in this type of application. This means that the LAMFE model is extremely computationally efficient. For example, given the numerical grid employed on the Lower Alafia River and a simulation time-step of 240 seconds, the ratio of real time to computational time is in excess of 18,000—a very impressive accomplishment considering that typical ratios of real time to computing times of some other 2-D vertically averaged models, such as the older and more popular RMA2 river model, normally don't exceed 100.

Another thing that differentiates numerical hydrodynamic models from each other is the coordinate system employed to represent the geometry of the water body. The LAMFE model utilizes a Cartesian coordinate system in both the longitudinal and vertical direction. In some 2-D vertically averaged and 3-D finite difference models, a transformed boundary-fitted coordinate system is utilized in the horizontal dimensions. In some 2D laterally averaged and 3D models, a type of vertical boundary-fitted coordinate system that is commonly referred to as a "sigma grid" is utilized. With a vertical sigma coordinate system, a coordinate line always follows the free surface and another line always follows the bottom topography. Interior lines and the line following the water surface then move in time with the rise and fall of a water surface that fluctuates with marine tidal flows and river flows. Such a grid system is able to model the bottom topography quite well, whereas if a Cartesian grid is utilized alone in the vertical, then the bottom topography appears "stair stepped" and jagged.

The problem with a sigma vertical coordinate system is that water column stratification cannot be simulated very well near significant slopes in the bottom topography unless the grid resolution is quite fine. This problem is not encountered in models that utilize a Cartesian vertical grid, since derivatives of the horizontal pressure gradient terms in the momentum equations are evaluated along levels of constant pressure. Thus, a grid system that utilizes a Cartesian vertical grid but still models the bottom topography accurately would seem to be the best of both worlds. The LAMFE model does this by representing the bottom topography in a piece-wise linear fashion, while still utilizing a Cartesian system over the remainder of the water depth. This procedure does result in some rather complicated control water volumes along the bottom of the river channel, but once the numerical computer coding is accomplished, it presents no particular complication in the computations.

Another interesting feature of the LAMFE model is how it models the free surface of the water. In many models using a Cartesian vertical coordinate, the top layer is initially set to be thick enough that as the water surface declines, it can never fall though the bottom of the top layer, which would constitute an instability causing the model to “bomb.” In many of the early laterally averaged models, such as LARM and the early CEQUAL-W2 (based on LARM), the water surface is allowed to move between vertical layers, but the top layer has to be the same for all longitudinal columns. However, the LAMFE model allows for the water surface to move among vertical layers without it having to be in the same vertical layer in every longitudinal column. As with the treatment of the bottom, this is accomplished by constructing control volumes in which computations are made that can extend over more than one layer.

An important component of both 3-D and laterally averaged 2-D hydrodynamic models is the computation of vertical turbulence, as reflected through the eddy coefficients for viscosity and diffusivity. There are several vertical turbulence models that have been employed in the past. These include algebraic formulations and what are known as one and two-equation subroutines that involve solving partial differential equations for the kinetic energy of turbulence and either the dissipation or the length of the turbulence, when the two-equation form is employed. The LAMFE model allows the user to select from several options for computing the vertical eddy coefficients for diffusion and viscosity.

A one-equation form, referred to as the Total Kinetic Energy (TKE) version, was used in the District’s application of the LAMFE model to the Lower Alafia River. The TKE turbulence model solves a partial differential equation for the turbulent kinetic energy by assuming a particular shape for the length scale of turbulence, subject to certain constraints. The vertical eddy coefficients are then computed using these two variables. In general, the Review Panel believes that the two-equation form, referred to as the K-$\in$ model, performs better. An interesting exercise that is beyond the scope of this review would involve running the LAMFE model on the Lower Alafia River using both the TKE and the two-equation K-$\in$ turbulence models, and comparing the results obtained from the two different numerical simulations.

The LAMFE model also contains a numerical subroutine for computing the transport of mass-less particles for use in computing their residence times in a water body. If the particles are released uniformly over the entire estuary, then an estuarine residence time for a particular percent of particles to pass through the lower boundary can be computed. If the particles are released at the head of the estuary, then a pulse residence time can be computed for any particular area of interest within an estuary on the basis of the percent of particles that move past the location in a specified time interval.

The advective transport of each particle from one time-step to the next is computed using the flow velocities previously computed by LAMFE. As is done in many particle-tracking models, the diffusive movement is computed using a random walk procedure. The total movement of the particle is then the sum of the two. In LAMFE, if a particle hits the bottom or free surface, it is inserted back into the water column. Except for the complexities involved in inserting the particle back into the water column due to how the bottom and free surfaces are treated in LAMFE, the particle-tracking subroutine in LAMFE is very similar to others in the scientific literature.

Part of the process of convincing the scientific community to accept a numerical hydrodynamic model is to demonstrate that the model solves the correct equations and that those equations are programmed in a computer code correctly. The District’s work in the discipline of numerical modeling has produced several relevant papers in the peer-reviewed scientific journals. The Review Panel agrees that the theoretical aspects of the LAMFE model are acceptable and efficient for the problem it is being applied to by the District, and that the model has been rigorously tested through application to several test cases for which analytic solutions already exist. These include a seiche oscillation (sloshing) problem in a water body with a sloping bottom, a co-oscillating wave problem in a closed channel with a sloping bottom, and a test commonly called the “dead-sea” problem. In the latter test, a vertical salinity profile is specified that is constant over the horizontal dimensions in a water body with a sloping bottom. With no outside forcing applied, there should be no movement of the water.

The LAMFE computations were extremely accurate for all of the above test cases, demonstrating that the proper equations have been coded without any “bugs” in the computer code. Therefore, the Panel concludes that the LAMFE computer code is a well-developed numerical hydrodynamic model that contains all the physics required to accurately simulate water bodies that can be represented in a laterally-averaged sense.

Application of the LAMFE Model to the Lower Alafia River

An adequate model code is only the beginning of predicting an estuary’s circulation and salinity patterns. It is essential that enough hydrographic data be collected to be able to define boundary conditions, which may also be fluctuating, and to determine the internal topography and bathymetry of the estuary’s domain. The Panel acknowledges the District’s investment in making sure that adequate data for the estuary were available for the MFL analyses.

LAMFE was applied to an approximate 4.5 year period, from May 10, 1999 to December 23, 2003. Observed water surface elevations and salinities were available for specifying boundary conditions, in this case tidal flows, at the mouth of the river. Freshwater inflows for specifying boundary conditions at the upstream end of the modeled river segment were obtained at the Lithia streamgage located about 24 km above the mouth.

Variables computed are the longitudinal and vertical components of the streamflow velocity, the longitudinal and vertical variation of the salinity, and the water surface elevation along the river. Although temperature was not computed, its effect on water density was included by using measured values in the field and then interpolating over the numerical grid at each time-step. All significant forces affecting the circulation and salinity patterns were included in the model’s computations except for wind, which the

District and the Panel agree is minimal under more or less normal (non-hurricane) wind conditions because the river is relatively narrow and sheltered.

Numerical Grid--The model's numerical grid only contains 84 computational cells in the longitudinal direction, yet covers a total distance of 24 river kilometers. This means there is room for more cells to improve the resolution of hydrodynamic problems near river reaches of interest because of the model's exceptionally low run-time on commonly available personal computers. There were up to 22 layers of water simulated in the water column (depth) profile of each computational cell. The horizontal cell dimensions varied from 100 to 400 m, while the thickness of the vertical layers varied from 0.3 to 0.6 m. Bell Shoals, at about river kilometer 18 above the mouth, acts under most conditions as an internal hydraulic control similar to that of a broad-crested weir across the river. Above the shoals, the river bottom rises fairly rapidly so that the bottom elevation becomes higher than the water surface elevation downstream of the shoals. Consequently, the model grid must be extended upstream to the Lithia streamgage at river kilometer 24, instead of stopping at Bell Shoals or at the streamgage slightly upstream of Bell Shoals, which is used in all of the subsequent regression analyses of chemical and biological variations that are associated with the ecological health and productivity of the study area. The Panel finds that there is no meaningful conflict between the upstream boundary of the regressions and the simulation model that can not be easily accounted for in the MFL determination.

The features described above in the discussion of hydrodynamic modeling concerning how the free surface and bottom topography are treated in the LAMFE model are of great utility in the model's application to the Lower Alafia River. In other words, the District developed and applied the right model for its intended use on their particular river problem.

Available Data--There were four USGS gage locations with water surface elevation and salinity data available for setting the downstream boundary conditions and for comparison with model results. These data stations were (1) Gibsonton near the river mouth, which provided lower boundary conditions; (2) near Gibsonton, located about 2.73 km above the lower boundary of the model, (3) Riverview, located about 7 km above the lower boundary, and (4) the Bell Shoals gage, located a few hundred meters upstream of the shoals near river kilometer 18. Salinity data were available at three depths in the water column at the Gibsonton gage; however, similar data were only available near the bottom at the other gage near Gibsonton and near surface and bottom at the Riverview gage.

No velocity data were available for model calibration/validation. The Panel suggests that velocity measurements at the river's lower boundary with the coastal bay over several characteristic tidal cycles (72-hour minimum) would provide valuable modeling information. Acoustic Doppler Current Profilers (ADCP's) are specifically designed to easily collect 3-D current patterns at high resolution and integrate them into highly accurate estimates of water entering or leaving the river over the cycle of flood and ebb tides.

Calibration/Validation--In numerical hydrodynamic model applications, generally part of the available data is used to calibrate the model through the adjustment of model parameters such as friction and perhaps parameters in the turbulence routine employed. In the Alafia River application, the first 900 days of the data period were used for model calibration, with the remaining 780 days used for model validation.

During calibration of the LAMFE model, the side friction, bottom friction, and two parameters in the TKE turbulence routine were varied to reduce the differences (error) between the simulated water surface elevations and salinity, and those actually observed and measured by the District. Model results for water surface elevations compared extremely well for the entire simulation period at the near Gibsonton and Riverview gages. Since these two gages are close to the lower boundary where water surface elevations are specified, not simulated, this would be expected. However, the results weren't as good 18 km upstream at the Bell Shoals gage. The differences are more pronounced during episodic storm events over the upper Alafia River basin (e.g., simulation hours 2520; 16,570; and 20,650 as reported by SWFWMD 2007). There are also noticeable differences during times of low flow.

The poor comparisons during storms may be related to geometry errors (i.e., river widths upstream of the shoals that are input to the model may not be as accurate as needed). During the low flow periods when model performance isn't quite as good, Bell Shoals may be exercising some hydraulic control over the flow that isn't modeled directly through an internal boundary condition in the LAMFE model. However, the District reports collecting adequate data in the shoals area for use in specifying the river's bathymetry for the model's application. Regardless of the reasons for the discrepancy between the modeled water surface elevations and the observed elevations at the Bell Shoals gage, this has virtually no influence on the salinities being simulated below the shoals and, thus, does not restrict the District's use of the LAMFE model in the MFL analysis.

The salinity differences (modeling error) between those measured in the field and those computed by the LAMFE model at the near Gibsonton and Riverview gages also aren't as good as the Panel would like to see; nevertheless, the model does replicate the general patterns and proper responses to freshwater inflows and marine tidal flows from water surface set ups and set downs in Tampa Bay and the nearby Gulf of Mexico. In general, it appears that the computed and observed means of the time-varying salinities at the two gages compare relatively well; whereas, at the Riverview gage, the actual tidal fluctuation is significantly larger than that computed by the LAMFE model. The Panel suggests a couple of reasons for this: (1) If the model is computing a greater intrusion of the saline front into the river than actually occurs, then the observed data would be expected to show more variation with tides than that computed by the model. The vertical turbulence routine in the model would have some influence on this. (2) The upstream tidal prism computed by the model could have some error, which might result from an inaccurate specification of river widths in the top layer. The District will have to explore this problem a little more in order to improve the river's simulation with this model. This does not mean that the model is not accurate enough to be used for simulating and comparing the differences in effects of water withdrawal scenarios on river flows and salinities.

There are times in the simulation when the difference in the computed and measured salinity of the middle study reach of the river at the Riverview gage differs by as much as 10 psu, a large discrepancy considering that freshwater is near 0 psu and full-strength seawater is only about 35 psu. The Panel suspects that this is related to the volumes of ungaged flow estimated by the HSPF rainfall runoff model from the watershed downstream of the Bell Shoals gage. As noted by the District, estimating ungaged flows can involve considerable error at times. This is partly due to the limitations of the watershed model, but the Panel believes that it is related, in large part, to the interpolation of spatially-limited, spot rainfall records to cover the entire watershed being modeled.

The District has noted that convectional storms, which dominate the summer rainy season, can be very localized, with large differences in rainfall occurring over short distances on the ground. This is unfortunate because the 87 square miles of ungaged area represents approximately 21% of the total Alafia River drainage basin and the rainfall runoff from this area (ungaged inflow) is estimated to average at least 23.6 % of the total freshwater inflows to the Lower Alafia River from 1989-2003 (SWFWMD 2007). One solution might be to gage more of the ungaged drainages that flow into the river. Another might be to investigate the use of Doppler radar to estimate rainfall over more of the drainage area than what is recorded at the few weather stations available.

Model Simulation Results--Although the salinity validation is not extremely good, the Panel believes that the manner in which the model is used in the MFL analysis negates this issue. In other words, the model wasn’t used to predict absolute values of salinity without error, but rather was used to simulate salinity differences due to changes in the freshwater inflows. In this case, changes in water volume and bottom area for ranges of salinity (e.g., < 1 psu, < 6 psu and < 15 psu) were computed as a function of freshwater inflows. These model results were then used by the District to define and support the recommended MFL’s operating rules for river management that do not allow changes in water volume and bottom area for the target salinity ranges to be reduced by more than 15%, the point at which larger reductions could cause “significant harm” to living resources under Florida statutes.

The LAMFE model was also used to assess the impact of streamflow reductions on oyster beds located 1 to 4 km upstream of the river’s mouth. Again, model results showed that the MFL will have little impact on this important biotic community that cannot easily or quickly move in response to changes (Note: the Eastern oyster, *Crassostrea virginicia,* is scientifically recognized as a “foundation” species because it biogenically creates habitat for itself and other biota). In this region, the river is wider and there are certainly some lateral variations of salinity that would have been revealed by a more complete 3-D model, but the results of the 2-D LAMFE model are adequate to show little impact on oyster reefs in this reach of the river.

In another relevant application, the LAMFE model was driven with a series of non-dynamic (constant) inflows to compute estuary and pulse residence times using the model’s particle-tracking subroutine. There were 18 different inflows tested ranging from 14 to 1826 cfs. With a 14 cfs streamflow, the riverine estuary’s residence time was 4 days (d) for 50% of the particles and 19.9 d for 95% of the particles to exit the lower boundary and flow into the bay. At a streamflow of 1826 cfs, the estuary residence time was 0.4 d for 50% removal and 1.0 d for 95% removal. On the other hand, the pulse residence time varies depending on the location selected to start from within the estuary, longer for far away areas and shorter for those closer to the bay.

The particle tracking exercise is useful for assessing the impact of flow reductions on estuarine residence times because they can directly impact the amount of phytoplankton and nuisance algae that can buildup in the lower river without being “washed out” to the bay. Interestingly, it also clearly showed that the LAMFE model computes the proper behavior of the flow field near saline fronts. In such areas, the flow tends to move upward, which is reflected by the particles moving upward into the top layer of the water column in the model’s simulation after their uniform virtual insertion over water depth.

Statistical Regression Models

The District used the period 1987 and 2003 for the statistical analyses. The District's report provides data to demonstrate that this was a representative time period because it included a prolonged drought during 2000 and 2001, which would tend to produce conservative results when interpreted for use in setting the MFL for the Lower Alafia River. Various withdrawal scenarios were then applied to the baseline hydrograph to yield a time series of daily flows that could be used either as input to the LAMFE model to predict salinity (although only flows between 5/10/99 and 12/23/03 were used for LAMFE), or as direct input to empirical analyses that statistically predict the abundance of various living resources where there were sufficiently strong relationships between antecedent inflow and the abundance of a given fish or invertebrate. The Panel finds this to be a reasonable approach.

Statistical regression models also were used to predict the locations of various isohalines (salinity concentrations) as a function of freshwater inflows for both surface and near bottom (> 2 m depth) waters at all tide stages. The predictions for location of the surface water isohalines were used to evaluate how changes in flow would influence the availability of shoreline and wetland habitat for fish and wildlife. The fact that these relationships are empirically-based means that all the many physical factors that can affect isohaline location do not have to be explicitly stated in the statistical regression models because they are already inherently included. The Panel concurs that this is an acceptable approach for evaluating changes in flow and the statistical models presented in Appendix 5-B (SWFWMD 2007) do a reasonable job (i.e., regression coefficients range from 0.6 to 0.95).

The District presents several other regression models to predict salinity, none of which were used in the MFL analysis. Since it appears to the Panel that only the locations of surface water isohalines were used in determining the MFL, it would be clearer to include these equations in the main report and put the rest of the information in the appendices.

Moreover, the Panel recommends discussing only the regressions for isohaline location and deleting the others, some of which (e.g., Appendix 5-C) are difficult to follow.

Water Quality Relationships

The District collected water quality data regularly between 1999 and 2003 at both fixed stations and variable location (moving) stations keyed to specific salinity values of interest along the estuary's salinity gradient. The District used this data, as well as information collected by Tampa Bay Water HBMP and EPCHC, in the MFL study. These data sets were sufficient to provide an understandable and more or less complete overview of water quality in the region.

Dissolved Oxygen – Several different aspects of DO were evaluated in the MFL study:

1. Regressions were developed to predict bottom water DO in specific segments of the river based on flow and temperature [for river kilometers 0 to 9, $r^2 = 0.48 – 0.72$; for river kilometers 9 to 15, $r^2 = 0.53 – 0.63$] and these were used to evaluate the effects of various withdrawal scenarios. Focusing on bottom water seems reasonable to the Panel, since that is where severe hypoxia (deficiency of oxygen) is most often observed stressing fish and most other aquatic species to the point of mortality. The proposed MFL of 19% streamflow reduction with a 120 cfs low flow cut-off did not change the predicted DO concentration by more than 0.5 mg/L in any segment of the lower river.

2. Logistic relationships that relate inflow to the probability of DO < 2 mg/L in bottom waters of various river segments were also used by the District to evaluate the effects of water supply withdrawals. The percentage of correct predictions with the logistic regressions ranged from 66% to 82% ($r^2 = 0.66 – 0.82$). The District's proposed MFL did not increase the probability of hypoxia by more than 10% in any segment.

3. Other logistic relationships developed for the Tampa Bay Water Program (which predicted the occurrence of bottom waters with DO < 2.5 mg/L when flows were > 112 cfs) were also applied with similar results. As a result, this additional set of predictions does not add anything to the District's own analysis; however, taken together, these analyses provide robust support for the notion that the occurrence of bottom water hypoxia would not be increased by more than 10% under the proposed MFL. In this regard, the 120 cfs low flow cut-off is a particularly important operational rule protecting fish and other inhabiting organisms because bottom DO decreases extremely rapidly at low flows, particularly below 120 cfs in the Lower Alafia River, especially from about river kilometer 6 to 12.

The Panel notes that DO concentrations were often estimated to be < 2 mg/L, even under "naturalized" baseline flow conditions without any withdrawals from this hypereutrophic riverine estuary. This creates potential violations of Florida's state water quality standards, which contain DO criteria for Class III marine waters such as these that call for an instantaneous minimum of 4 ppm and a daily average of not less than 5 ppm (4 and 5 mg/L DO concentration, respectively). This standard may be practical and scientifically appropriate for inland freshwaters, but it is problematic in warm shallow estuaries with high biological productivity. For example, with 100% saturation of 25ºC (77ºF) freshwater (0 psu) at sea level atmospheric pressure (760 mm), the DO concentration is 8.4 mg/L, declining to 6.2 mg/L when both salinity and temperatures are high (35 psu at 30ºC or 86ºF), and this is for sterile water with no biological or chemical oxygen demand. If the coastal waters are alive with biota and contain any pollutant runoff, then there is no way to consistently maintain DO concentrations above 4 mg/L at night when plants switch from O_2 production (i.e., sunlight-driven photosynthesis) to O_2 consumption (i.e., plant respiration).

Most fishes and macro-invertebrates that are adapted to live in shallow tropical or sub-tropical coastal estuaries are also adapted to tolerate the low (~2 mg/L) DO concentrations that frequently occur in these warm waters at night. However, they generally require DO saturation to be above 30% for continued survival, which at 30ºC is equivalent to ~2.5 mg/L DO. Waters below 30% saturation are referred to as “hypoxic,” a condition that induces great physiological stress and mortality in most aquatic animals. When hypoxia occurs, most free-swimming organisms will stop using the area’s habitats. This effect was observed in the Lower Alafia River where fish and shrimp were found to avoid hypoxic areas (Peebles 2005; Matheson et al., 2005), just as they do in other urbanized riverine estuaries along the Florida Gulf coast (e.g., Lower Hillsborough River, MacDonald et al. 2006).

Although it is beyond the scope of this MFL study, the existing situation is unlikely to change without effective implementation of a total maximum daily load (TMDL) program that includes watershed controls and better management of stormwater drainage. In terms of the MFL, the Panel concludes that the District’s goal of not increasing the probability of occurrence of low DO and high chlorophyll-*a* concentrations from blooms of phytoplankton and nuisance algae is realistic for this urbanized river segment.

Phytoplankton – Several different aspects of the phytoplankton response to flow were evaluated:

1. Logistic regressions that relate inflow to the probability of DO supersaturation (an indication of high phytoplankton production during the day) were used by the District to evaluate the effects of water supply withdrawals. The percentage of correct predictions with these logistic regressions ranged from 81% to 95%. The District’s proposed MFL did not change the probability of supersaturation by more than 10% in any segment of the lower river.

2. Logistic regressions were also developed that relate inflow to the probability of high (> 30 µg/L) chlorophyll-*a* concentrations that can indicate eutrophic (nutrient rich) conditions (> 40 µg/L is hypereutrophic). These were used by the District to evaluate the effects of withdrawal. The percentage of correct predictions from these logistic regressions ranged from 66% to 87%. The

District's proposed MFL did not change the probability of high chlorophyll-*a* concentrations by more than 10% in any segment of the lower river.

3. Regression relationships that predict the location of peak chlorophyll-*a* concentrations as a function of inflow were used by the District to evaluate the effects of water supply withdrawals, but the coefficient of determination [r^2] for river stations is only 0.40 in this statistical equation. The proposed MFL moved the location of both the median (50th percentile) and 10th percentile peak chlorophyll-*a* concentrations by ~0.5 km (i.e., from river kilometer 6.0 to 6.5 and river kilometer 4.1 to 4.6, respectively), but it did not affect the location of the 90th percentile peak concentration, which is associated with low river flows. The volume and area between the 10th and 90th percentile locations were reduced by 19% and 20%, respectively, due to the downstream movement of the 10th percentile location during higher inflows. As the District points out, the 0.5 km shift is not likely to matter, since phytoplankton concentrations tend to be very high in the middle portion of this hypereutrophic river anyway.

4. The District also presents results for a regression analysis that takes into account both river and bay stations [$r^2 = 0.52$], with very similar results to that described above. The District should consider deleting this portion of the analysis (Fig. 5-71 B), since there are other controlling factors besides river flow that likely influence phytoplankton in the open bay system. The r^2 increases due to the higher number (n) of observations with bay stations added, but they appear to mostly add scatter and bring the statistical curve down so that the predicted location of the chlorophyll-*a* peak is likely too far downstream at higher river flows.

The chlorophyll-*a* concentrations are extremely high in the Lower Alafia River when compared to nearby streams, such as the Little Manatee and Peace Rivers. However, the data presented suggest that the occurrence of supersaturation of DO, the occurrence of high chlorophyll-*a* concentrations, and the location of the peak chlorophyll-*a* concentration will not be changed substantially by the implementation of the proposed MFL. Once again, the low flow cut-off for water supply withdrawals is important because chlorophyll-*a* concentrations peak at flows < 100 cfs, particularly in the middle segments (river kilometers 6 to 15) of the riverine estuary. Moreover, the logistic regressions show that the probability of chlorophyll-*a* values exceeding 30 µg/L in these segments increases greatly at low flows. At flows less than 120 cfs, the chlorophyll-*a* peak also moves upstream to nursery habitats more vulnerable to the resulting hypoxia.

Inflow Effects on Fish and Invertebrates

Smaller fish and invertebrates collected by plankton tows (Peebles 2005) and larger organisms collected by seine and trawl (Matheson et al. 2005) were all evaluated using the same approach. For the various organisms collected, relationships were developed between inflow and both their overall abundance and their center of distribution in the estuary. From the plankton net data, five potential indicator organisms were used by the District in the MFL analysis. Similarly, nine species from the seine and trawl sampling were identified as indicators of biological change.

Abundance--Peebles (2005) describes the steps used to develop regressions between inflow and abundance for the ichthyoplankton and other larval species, which included using only data where the species was observed (i.e., no zeros in the statistical data), eliminating high flow days where the target organisms were washed out of the river, using variable antecedent inflow to optimize the regression coefficient, and focusing on the longer-term recruitment responses to inflow (as opposed to relationships that show only “catchability”). The final regressions had antecedent inflows that varied between 16 and 120 d, and r^2 values that ranged from 0.1 to 0.45.

The regressions developed to predict the abundance of larger fish and invertebrates were handled differently than those for the larval (planktonic) stages of the indicator species (Matheson et al. 2005). Observations where the organisms were not found (the zeros) were included in the statistically analyzed data set, some relationships were limited to the months when that species was in the river or in particular zones of the river, and various model forms were applied. In this case, the antecedent inflow period ranged from 35 to 343 d, and the r^2 values ranged from 0.13 to 0.39. The Panel notes that the relationships for red drum were modified by MacDonald (2007) to correct for hatchery-reared fish in the field collections. This is because between 2000 and 2003 over one million juvenile red drum were released into the Alafia River; nevertheless, wild red drum represented 93.4% of red drum collections in 2000 and only declined to 68.0% in 2002 before rising again to 76.7% in 2003. Interestingly, the catch-per-unit-effort peaked at about 400 cfs (42-d and 168-d lagged inflow), suggesting an optimum inflow response.

Inflow-abundance regressions were used to predict animal abundance in the river under “naturalized” baseline flows without water supply withdrawals and under various withdrawal scenarios. The predicted difference in abundance between the proposed MFL (19% streamflow diversion with 120 cfs cutoff) and the baseline condition was less than 15% for all species caught in the plankton net samples, except adult mysid shrimp, which are an important prey item for drums, croakers, and other estuarine-dependent fishes (Figure 8-8, SWFWMD 2007). When all the sample data was included, adult mysid shrimp abundance was estimated to decline 16% when inflows were low (below the median), close enough to the 15% limit to be more or less equivocal; however, when high “washout” flow events were removed from the data set, the statistical results showed declines in abundance in the range of 19% to 20%. Thus, it could be concluded that the mysid shrimp adults, not the juveniles, require higher inflows (>130 cfs) to maintain their median abundance than the other organisms examined (Fig. 3.8.5, Peebles 2005). The juvenile mysids seem to be able to utilize the estuarine nursery habitats in the Lower Alafia River and maintain their median abundance with only about 100 cfs of inflow. None of the predicted decreases was >15% at median and higher flows because the low flow cut-off of water supply withdrawals helps to maintain abundances at lower flows.

Statistical analysis of the seine and trawl sample data showed some predicted reductions in abundance greater than 15% under the proposed MFL. Predicted reductions in the Seminole killifish (*Fundulus seminolis*) abundance were greater than 15% across the board (Table 8-8). Although this resident fish species spends its entire life cycle in the river and can tolerate fluctuating salinity, its abundance is highest in the upstream areas (see Fig. 56, Matheson et al. 2005). As flow decreases, especially during drought, this fish species will likely move upstream into tidal freshwater areas.

The red drum or "redfish" was identified as an economically and ecologically important species that is sensitive to changes in inflow and could serve as an indicator species. Red drum response to changes in inflow is difficult to interpret because the regression for inflow vs. abundance takes the form of a quadratic equation, so the percent flow reductions from baseline were less than 15% at higher percentiles (corresponds to higher flows) and greater than 15% at low percentiles (corresponds to low flows). When the 120 cfs low flow withdrawal limit is applied as proposed in the MFL, the greater reductions at low flows are offset by the lesser reductions at higher percentiles (Tables 8-7 and 8-8, SWFWMD 2007) that occur for the red drum at moderately high inflows (Figures 6-32C and 8-3C, SWFWMD 2007). The above analysis was done using the entire flow record, and not just dry periods. When the analysis is limited to only those days when the baseline flows were below the median, corresponding to a dry period, the median abundance of very small red drum (< 39 mm) is reduced 40% and larger juvenile red drum (40-150 mm) are reduced 25% (Table 8-12, SWFWMD 2007). This means that reductions in fish abundance during prolonged dry periods can occur as a result of water supply withdrawals. This, in turn, causes the Panel some concern that red drum needs may not be met during drought intervals, in spite of the fact that no water supply withdrawals will be made below 120 cfs under the MFL rule.

One final point is that the comb jellies (*Mnemiopsis*) showed an opposite response to changes in flow: as flow decreases, salinity increases in the lower end of the river and the abundance of comb jellies increases with it. An increase in *Mnemiopsis* abundance is undesirable because these organisms can consume a lot of plankton and, in so doing, become very detrimental to the food supply and survival of larval and juvenile fishes. However, except at very low freshwater inflows (Figure 8-4, SWFWMD 2007), the abundance of comb jellies only increases gradually. The Panel notes that the predicted abundance of *Mnemiopsis* at very low flows (> 90th percentile) is the same as the baseline condition due, again, to the MFL's 120 cfs low flow cut-off; therefore, stabilizing the population at the low end of the distribution curve with the low-flow limit is both desirable and appropriate.

Distribution--The approach taken for this part of the report was similar to that described above, except that regressions were developed that relate inflow to the location of the center of distribution of each organism rather than its overall abundance. A total of 9 species were evaluated from the plankton net data and 10 species were evaluated from the larger fish and invertebrate data from the seines and trawls. Regressions for the planktonic species used antecedent inflows that varied between 1 and 105 d, and produced r^2 values that ranged from 0.18 to 0.7. Regressions for the larger fish and invertebrates used antecedent inflows that varied between 1 and 364 d, and produced r^2 values that ranged from 0.12 to 0.48.

The difference between the proposed MFL and the baseline conditions in terms of the predicted location of the Km_u (distribution center of the catch-per-unit-effort) for each species was always less than 15%. For species caught in plankton nets, shifts ranged from 0 to 0.5 km; whereas for the larger fish and invertebrates, they ranged from 0 to 0.6 km. In both cases shifts were smallest at the 90th percentile, which reflects the beneficial effects of the MFL's low flow cut-off at 120 cfs. The difference between the location of the 10th and 90th Km_u was used to estimate both the volume of water and area of river bottom in which the organisms were distributed. In order to determine how the habitat available to an organism might shift, the predicted shifts in Km_u were used to predict changes in volume and area that would occur under different flow conditions. Under the District's proposed MFL, only grass shrimp (*Palaemonetes*) and bay anchovies (*Anchoa*) showed predicted decreases in volume and area greater than 15%.

For the seine and trawl data, differences in Km_u were used to predict changes in area and shoreline length (rather than volume). Under the proposed MFL, none of these predicted changes were greater than 15%. The Panel appreciates the District's recognition that a shift in Km_u could affect organisms if they are shifted to areas with less desirable habitat.

The Panel is also impressed with the detailed approach the District has taken with this part of the MFL document. The Peebles (2005) and Matheson et al. (2005) reports provided a wealth of data on fish and invertebrates, and the statistical and graphical analyses were quite thorough. Some of the regression coefficients are very low (i.e., $r^2 = 0.1 – 0.2$), which is not surprising given that many other factors besides flow can influence organism abundance and distribution in an estuary, including predator-prey relationships and the availability of food and cover, particularly in prime nursery habitats. The Panel is reassured by the collective biotic response to the District's proposed MFL and finds that the MFL is predicted to be protective of numerous species, and not just one indicator species, using sound scientific and statistical methods.

Sessile habitat

Bottom Area-- The LAMFE model was used to predict changes in salinity under different flow scenarios and the results for each case were used to produce cumulative distribution functions for the amount of bottom area and river volume that would be exposed to different salinity ranges (< 1, < 6, and <15 psu), which were compared to baseline conditions. The proposed MFL (with the low flow cut-off) did not change the amount of bottom area or volume in any salinity range by more than 15%. Upon the request of the Panel, these results were broken down further by the District to evaluate the interval within each salinity range (1-6, 6-15 psu) and in each case the difference between the proposed MFL and the baseline condition, in terms of both bottom area and volume, was far less than 15%.

Isohaline Location-- Regression models developed by Janicki Environmental to predict the location of the 0.5, 2, 4, 11, and 18 psu surface isohalines were used to determine how the different flow scenarios would affect the location of each isohaline, the length of total shoreline upstream of each isohaline, and the length of classified wetlands along the shoreline upstream of each isohaline. These scenarios were run for both the whole year and the springtime dry season, since the latter period would be the maximum salinities to which salt-sensitive plants might be exposed. For the whole year, the 19% withdrawal rate changed the locations of the isohalines by 0.3 – 0.7 km (Table 8-27), which did not change the length of total shoreline by more than 15%. It did, however, cause larger decreases in the length of wetland shoreline upstream of both the 2 and 4 psu isohalines. At the Panel's request, these results were broken down further by the District to evaluate the amount of shoreline available between the specified isohalines. In the 15 – 20% withdrawal scenarios, the distance between the 2 and 4 psu isohalines were changed by only 0 to 0.1 km; nevertheless, the change in location translated to a reduced amount of shoreline associated with this interval. Specifically, the interval between 2 and 4 psu was reduced 26% under the 20 % withdrawal scenario, whereas the other intervals increased in length. Data on wetland shoreline were not given, but presumably this would decrease as well between 2 and 4 psu, and the lower salinity range (0.5 – 2 psu) would be expanded. The District did not address any biotic threshold problems with this slight change in the estuary's salinity gradient.

For the dry spring season, the location of the isohalines under baseline conditions was already shifted upstream (0.9 – 1.4 km) in comparison to their median locations for the whole year. Applying the proposed MFL (with the low flow cut-off) changed them only slightly (an additional shift of 0.1 – 0.2 km). Neither the length of total shoreline nor the length of wetland shoreline was reduced by more than 15% when compared to baseline dry season conditions. Part of this is due to the fact that the isohalines are already shifted upstream past that portion of the shoreline with the most vegetated wetland habitats. This can affect nursery habitats for juvenile fish and shrimp that use these wetland areas for food and cover. Moreover, the increasing salinities bring with them more marine conditions, including the invasion of marine predators, parasites and disease organisms (Overstreet 1978 and Overstreet et al. 1977). To the Panel, this means that it is possible that wetland shoreline losses, though small (< 15%), could have a larger impact than expected. Potentially, the District's proposed low-flow limit in the MFL will help mitigate, but can not protect, these young organisms from natural drought during their peak seasonal utilization of estuarine nursery habitats in the springtime.

Oyster Zone – The District used the location of oyster reefs (river kilometers 1 to 4), as mapped by Mote Marine Lab, coupled with analysis of optimal salinities for oysters, defined as 12 to 25 psu. Simulations with the LAMFE model predicted how various flow scenarios might affect surface/intertidal (0.1 to -1.0 m) salinities between river kilometers 1.7 and 3.8. Salinities at these locations ranged from near 0 to 33 psu (seawater = 35 psu), and the proposed MFL did not cause any noticeable change.

Other Indicators – There is information in the main body of the District's report detailing how LAMFE model predictions were used to evaluate potential changes in both benthic macroinvertebrates and mollusks, but these results were not included in the MFL analysis.

The District's Proposed MFL

The District has put together an impressive amount of information about the Lower Alafia River, both in terms of field data collection, empirical analyses and simulation modeling. Taken together, the Panel finds that the District's overall approach is reasonable and scientifically sound. The report provides physical, chemical and biological support for the District's proposed MFL, which allows for water supply withdrawals up to 19% of streamflow in the Lower Alafia River with a 120 cfs low flow cut-off of diversions. As a policy decision that has been employed in other MFL efforts, the District set 15% loss of ecological resources as the limit beyond which "significant harm" was likely to occur. When the proposed MFL was applied to the Lower Alafia River, it did not allow water supply operations to cause more than a 15% change in the large majority of key measures and living resources considered. The low flow cut-off is critically important to the success of the MFL, as is demonstrated by the fact that so many of the negative impacts were ameliorated by adding the low flow limit to the proposed MFL, including the thresholds for plankton blooms and low DO (hypoxia) stress on most aquatic organisms of interest.

There is also the larger issue of freshwater inflows to Hillsborough Bay, a secondary bay of the Tampa Bay complex most often containing mesohaline water and exhibiting estuarine function. The Alafia River has the second largest contributing watershed in the entire Tampa Bay watershed and is characterized as having a mean average streamflow of 433 cfs (Table 2-3, SWFWMD 2007). The District's evaluation of water supply withdrawals made under the proposed MFL rule indicates that the withdrawals will constitute only an average 5.8% of total bay inflow (Table 8-45, SWFWMD 2007), 6.7% if direct precipitation on the bay is not included. The Panel agrees that this low percentage is not likely to produce any "significant harm" to the bay's ecological health and productivity.

The proposed MFL will allow the amount of water supply drawn from the river to double over current withdrawals, if not the existing permits. At present, existing withdrawals average 34.6 cfs, which represents 7.8% of the total freshwater inflow to the Lower Alafia; whereas, under the proposed MFL (with unlimited diversion capacity), the amount available averages 66.6 cfs, or 15.1% of the total inflow (based on mean average inflows during the baseline period).

As the District moves forward to supply water in the future to the people, their economy and their environment, the Panel highly recommends that the District continue to monitor the Lower Alafia River for the purpose of verifying that the MFL is having its intended effect; that it is adequately protective of ecological health and productivity in this estuarine area of the Tampa Bay complex. The verification monitoring should include streamflows, tidal flows, basic water quality, salinity, DO, chlorophyll, comb jellies, mysid shrimp and red drum, particularly during the dry season, which coincides with the spring peak utilization of nursery habitats in the Lower Alafia River by estuarine-dependent species.

The Panel also recognizes that some studies continue and more data (e.g., plankton surveys, fish and invertebrate surveys, water quality samples) are being collected that were not possible to include in the District's MFL analysis. The principle of adaptive management suggests that it would be useful for the District to revisit this topic periodically, as enough new data become available. And finally, the Panel believes that the District recognizes the fact that, although inflows may be sufficient, living estuarine resources may still suffer at times due to stresses associated with other environmental perturbations (i.e., ammonia or phosphate concentrations) and pollutants (i.e., urban runoff). Therefore, the MFL is geared towards ensuring that the resources are not harmed due to low flow.

Other Comments

The District is to be commended for their thorough response to the questions raised by the Panel Members after their initial reading of the District's draft report. There are a number of items in the District's response that could be useful and informative to readers if they were included in the District's final report. These are given below for the District's consideration and potential inclusion:

1. The information in Table R-1, showing the existing permitted withdrawals in relation to the proposed MFL. Figures R-1 and R-2 are also helpful informative.

2. A presentation of nutrient input from the springs and the relative importance of dissolved inorganic nitrogen (DIN) from Buckhorn Spring to the riverine ecosystem's productivity. Additional information, particularly during the dry season, should be included if it is in the best available data compiled by the District on this riverine estuary

3. Information on nutrient loading in relation to flow. Even though nutrient loading is usually driven by flow, especially during pulsed-events from storm runoff, a

graph of load vs. flow, or effective loading rate (mass load divided by hydraulic residence time) versus flow, would be more useful than Figure R-4.

4. Information on bottom area and shoreline length between isohalines that were presented in Tables R-4, R-5 and R-6).

5. Appendix 4-B introduces a new term ("transient") into the discussion of "pulse residence time" (Miller and McPherson 1991), which could be eliminated because the fact that particles can move back and forth before exiting the estuary's lower boundary and escaping into the bay does not affect the amount of time it takes them to leave an area like the level of inflows does. The report could also include a discussion of the fact that chlorophyll concentration represents a biological response to the interaction between the availability of nutrients to fuel phytoplankton growth and the matter of whether the water mass stays in a particular place long enough for the phytoplankton to respond.

6. An Appendix showing the plots presented by Peebles (2005) and Matheson et al. (2005) for the indicator species used in the MFL would be helpful, since they are so important in the District's MFL analysis.

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