Scientific Peer Review of the Lower Hillsborough River Low Flow Study Results and Minimum Flow Recommendation

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Executive Summary

The Southwest Florida Water Management District (District) has completed a study of the Lower Hillsborough River (LHR) and made recommendations for setting minimum flows to protect the natural resources of the river. The original minimum flows and level (MFL) for the LHR was set February 23, 1999 at a level of 10 cubic feet per second (cfs) in order to protect the oligohaline habitat at the base of the Hillsborough River Reservoir Dam. Since 1999, the District has formulated a new management goal for the LHR with the help of studies and reports from the Tampa Bay National Estuary Program. The new management goal is: *"To provide a minimum flow that would extend a salinity range of < 5 ppt from the Hillsborough Reservoir Dam toward Sulphur Springs."* Based on monitoring, modeling, and experimentation; the District recommends a new MFL for the LHR equivalent to 20 cfs freshwater to extend the < 5 ppt zone from the base of the Hillsborough River Reservoir Dam toward Sulphur Springs under low flow conditions. In addition, the District recommends the MFL be adjusted for seasonal hydrologic conditions by linking flow over the dam to the annual 90% exceedance flow (from 1990 – 1999) as measured at the USGS Zephyrhills gage.

The District has provided sufficient and sound scientific justification for proposing an MFL of at least 20 cfs for the LHR. The supporting data and information used to develop the provisional MFL are technically sound. The data collection methods were appropriate, and used in an appropriate manner in all analyses. The primary tool used to evaluate various inflow regimes is the LAMFE model, which has been subject to previous peer-review and has been found to be robust.

According to the LAMFE model, 50% of the river's volume from the dam to Sulphur Springs is expected to be oligohaline (<5.0 ppt) about 48% of the time at 20 cfs versus about 64% of the time for 24 cfs. This is an important finding because it indicates that a flow higher than 20 cfs may be needed during the springtime when utilization of estuarine nursery habitats in the LHR will be greatest. So, would the proposed MFL of 20 cfs be adequate to meet the District's stated goals? The answer appears to be: just barely and not in all seasons. The District itself states that the beneficial return per unit of freshwater inflow invested is maximum at 24 cfs, and declines thereafter. Some would argue that if 20 cfs barely meets the goals, then 24 cfs could provide an important margin of safety for the MFL by increasing the frequency of its competency in providing the intended benefits.

Seasonal variability of inflow and habitat utilization confounds using any single number rule for all times of the year. If the minimum flow is set too high in an effort to increase the margin of safety for the operating rule, then the District risks over protecting the environment and under protecting the people's right to beneficial use of the waters. As a practical matter, the environmentally safe operation of impoundment and diversion systems requires condition-appropriate rules for the waterway to avoid using good time rules in bad times and visa versa. An obvious alternative would be to provide a minimum of 24 cfs during the period of increased utilization of the estuarine nursery habitats, which is in the spring from April through June, as recommended by MacDonald et al. (2006), and 20 cfs for the remaining months of the year. However, it is also apparent that during times of drought, the necessary flows may not be available and water managers will be in drought contingency operations.

In summary, the District staff is to be commended for producing a comprehensive report that is well-written and meets high technical standards. The report documents the need for the MFL, appears to be based on the best technical information available, and contains appropriate analyses to support the recommended MFL.

Scientific Peer Review of the Lower Hillsborough River Low Flow Study Results and Minimum Flow Recommendation

Introduction

The Southwest Florida Water Management District (District) has completed a study of the Lower Hillsborough River (LHR) and made recommendations for setting minimum flows to protect the natural resources of the river. Florida statutes require that the District set a minimum flow that protects water resources from "significant harm." The original minimum flows and level (MFL) for the LHR was set February 23, 1999 at a level of 10 cubic feet per second (cfs) in order to protect the oligohaline habitat at the base of the Hillsborough River Reservoir Dam.

Since 1999, the District has formulated a new management goal for the LHR with the help of studies and reports from the Tampa Bay National Estuary Program. The newly recommended management goal is:

"To provide a minimum flow that would extend a salinity range of < 5 ppt from the Hillsborough Reservoir Dam toward Sulphur Springs."

This goal is based on studies that show the oligohaline biotic community, including freshwater benthic macroinvertebrates and juvenile stages of important estuarine-dependent fish, would benefit from salinities < 5 ppt. In addition, the District has performed monitoring studies and controlled release experiments to examine the effects of flows ranging from 10 – 30 cfs. As a result of the new resource management goal and studies, the District is recommending a new MFL for the LHR that is equivalent to 20 cfs freshwater in order to extend the < 5 ppt zone from the base of the Hillsborough River Reservoir Dam toward Sulphur Springs under low flow conditions. In addition, the District recommends that the MFL be adjusted for seasonal hydrologic conditions by linking flow over the dam to the annual 90% exceedance flow (from 1990 – 1999) as measured at the USGS Zephyrhills gage.

The monitoring program, experimental studies, studies supporting the management goal, and methodology supporting the 20 cfs MFL recommendation are described in a report entitled, "Lower Hillsborough River Low Flow Study Results and Minimum Flow Recommendation" (SWFWMD 2006). To create the recommended minimum flows, the District focused on three primary issues: (1) determining adequate freshwater inflows to meet the specified salinity goal of maintaining oligohaline (< 5.0 ppt) conditions in the river virtually all of the time from the base of the dam to Hannah's Whirl, and most of the time past Hannah's Whirl toward Sulphur Springs 2.2 miles (3.5 km) downstream from the dam; (2) evaluating a range of adequate freshwater inflows up to 30 cfs, per the settlement agreement, for their ability to minimize existing problems with dissolved oxygen (DO) concentrations in the water column; and (3) evaluating the subsequently recommended 20 cfs for its ability to eliminate adverse biotic effects from a reverse salinity gradient that forms under low flow conditions

The purpose of the current document is to provide a scientific, peer review of the minimum flow recommendation report in accordance with District policies. The current peer review panel comments will address the scientific data, analyses and findings, and the degree to which they deal with the above concerns while estimating a biologically-based minimum flow for the lower Hillsborough River.

The scope of the review is to provide a written report that comments on the documents and other materials used to support the concepts and data presented in the draft report, including the initial MLF peer report (Montagna et al., 1999). Two members of the panel (Boyer and Powell) participated in a field reconnaissance of the LHR on December 15, 2006 to view the aquatic habitats of this tidal river segment first hand. Montagna had previously participated in a similar field trip during the first peer review effort in 1999. 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.

The remaining parts of the review are organized into two hierarchical sections: (1) general comments regarding the entirety of the report, guided by the scope of work assigned to the panel, and (2) specific comments for each chapter. This review is a consensus document produced jointly by the peer review panel.

General Comments

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 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 ecosystem. Many support the view that setting MFLs in rivers and estuaries is one of the most daunting tasks facing resource managers today. The District is also to be commended for voluntarily seeking peer review of its technical documents.

The supporting data and information used to develop the provisional MFL is technically sound. The data collection methods were appropriate, and used in an appropriate manner in all analyses.

Units of measure in the District's report are used inconsistently with flows given in English units (e.g., cubic feet per second, cfs) and distances given in metric units (e.g., kilometers, km). As a general rule, scientific works employ only metric units while public reports intended for the educated layman and decision-makers often use the more familiar English units. It would be appropriate if the report had all values and units in metric, and included the English values and units in parentheses.

About 25 years ago Millero and Poisson (1981) noted that the practical salinity scale is unit-less 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). Frankly, this has caused nothing but confusion, and even the introduction of the false scale of psu, i.e., practical salinity units. Although considered incorrect by many scientists, this review will use the same convention used in the report and refer to salinity as ppt with apologies to Millero and Poisson.

A detailed quality assurance audit was not conducted by the panel, so the panel cannot know if adequate quality assurance assessments were performed. Such an audit would include examining standard operating procedures, data objectives, sample collection, chain-of-custody protocols, laboratory analyses, data management procedures, and a variety of other quality assurance procedures and standards specific for each measurement or analytical approach. Quality assurance audits are quite time consuming and require on-site examination of facilities and records. The panel was not asked to review standard procedures. Although a detailed audit was not performed, 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 data that were excluded from analyses. 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. The approach that is most laden with assumptions is the hydrodynamic and conservative mass (i.e., salinity) transport model. Here again the assumptions appear to be based on the best information available.

Overall, the procedures and analyses are technically appropriate and reasonable, and based on the best information available. Given the large amount of data, previous peer review, and extensive public comment, a wide range of factors were incorporated into the District's analysis and are correctly applied.

The District has obviously paid close attention to the previous peer review and adopted their recommendations. The most important point is that the District now has a clear management goal, which is widely supported among stakeholders in the community. The Management Goal, as stated in the MFL document, is: "To provide a minimum flow that would extend a salinity range of < 5 ppt from the Hillsborough Reservoir Dam <u>toward</u> Sulphur Springs" (our emphasis). Some readers would interpret the word <u>toward</u> to mean <u>to</u>, but they are semantically distinct. Several stakeholders commented on this distinction as well. Regardless of the semantics, it is clear that a low salinity (oligohaline) zone is desired near the dam because it would complete the salinity gradient in the tidal river segment, would help support freshwater and estuarine species present in this zone, and would interact beneficially with the more or less natural shoreline communities and riparian habitats. These benefits improving ecological health and productivity would accrue in the upper portion of the LHR from the dam 16.3 km (river mile 10) from the river's mouth at the bay downstream passed Hannah's Whirl at about 14 km (river mile 8.7) toward Sulphur Springs at 12.8 km (river mile 7.95).

The District has done an excellent job in justifying the importance of this oligohaline zone for maintaining biological communities using analyses of benthic invertebrates and fish community structure. Salinity distribution is a strong driver of the biological components in estuarine ecosystems, including the plankton, benthos and fishes, and is of primary concern here for the maintenance and preservation of desired biota. Estuarine nursery habitats must also have salinities low enough to provide protection from marine predators, parasites, and disease organisms (Overstreet 1978). This is another important reason why the young of so many coastal marine fishery species are adapted to migrate inshore and up the estuary to low salinity nursery habitats. Indeed, one beneficial effect of increasing inflows to the LHR, particularly above 10 cfs, is the rapid downstream displacement of the hydromedusa (*Clytia sp.*), which can compete with and even consume larval fishes that are utilizing the prime nursery habitats upstream (MacDonald et al. 2006).

The District has demonstrated that there is a strong relationship between flow and salinity below the dam. Both the empirical and simulation models showed that increasing flow results in decreases in salinity within the targeted reach. The question then becomes how much of the year, and for which months of the year, should salinity be kept < 5 ppt?

Because the entire segment of the LHR below the dam is a tidally affected reach, lunar and wind tides can carry marine waters into the river making it impossible to maintain permanent freshwater (< 0.5 ppt) conditions, even near the dam. The freshwater conditions present during wet periods will naturally give way to brackish conditions in the tidal river segment during prolonged dry periods. As a result, the District has proposed a "seasonal adjustment" that would suspend the minimum flow rule during periods when the USGS Zephyrhills gage reaches "the annual 90% exceedance frequency flow for the period 1990-1999." Unfortunately, these exceedances occur predominantly in the late spring of dry years, which coincides with the period when the biological communities of the river need the fresh water the most. In addition, compelling evidence from larval recruitment surveys show the spring is the most critical time for juvenile estuarine fish migrations into the upper river. For these reasons, the District should consider setting a slightly higher minimum flow in the springtime using a precautionary principle that acknowledges the considerable room for error present here. Should future analysis or monitoring data show that less water would sustain these oligohaline communities, then the recommended MFL could easily be decreased.

The LAMFE model is an important tool in the determination of the recommended MFL. The District accepted an external assessment of the model (Janicki 2005 Technical Memorandum) that concludes it is "robust and useful for predicting the temporal and spatial trends in salinity of the LHR." Consequently, the District relied on the LAMFE model simulations to justify the recommended MFL of 20 cfs in order to meet the stated management goal. However, the model results showed that the proposed 20 cfs MFL would not be sufficient to maintain the oligohaline zone in river bottom waters during drought years (Figures 6-50 and 7-11, SWFWMD 2006). The 2005 Technical Memorandum also revealed that the LAMFE model overestimated salinity, particularly in the bottom waters of the upper reaches, but did not quantify the error as a function of flow. This is a simulation problem that needs to be resolved, as it is inconsistent to rely on the LAMFE model to recommend a MFL, yet overlook the same model output showing frequent bottom water exceedances during the 1998-2002 simulation period. Although the District's report suggested that using the model would result in conservative management actions, it nonetheless requires some rethinking to properly use it in the MFL determination. Nevertheless, it is apparent that both the empirical and simulation models indicate that river flow of about 24 cfs, or higher, is required to maintain the oligohaline zone during the major estuarine recruitment season in dry years. However, the review panel also understands that during such times of drought, the necessary flows may not be available and water managers will be in drought contingency operations.

Specific Comments

1. Physical and Hydrologic Characteristics

Chapters 3, 4, and 5 describe the physical and hydrological attributes of the watershed and water quality of the Hillsborough River system. There is year-to-year variability in rainfall, runoff, and inflow, but the largest change over time has resulted from increased urbanization and water demands. Indeed, only about one-quarter of the LHR shoreline is classified as natural. Also, as stated in the report, "in the last three decades, it was not unusual for the flow from the dam to be near zero for at least half of the year." The lack of habitat and flow clearly indicates that the ecosystem is only marginally functioning as a "river." However, this was not always the case. Current (1974-2004) reservoir outflows are dramatically different from historical outflows (1940-1973). Re-drawing District report Figures 2-10 and 2-11 (SWFWMD 2006) demonstrates how large the disparity of flows is between the two time periods (Figure 1). If the 25th percentile flow (i.e., the 75% flow duration) is examined, then the flow difference would be approximately 81 cfs in the earlier period, decreasing to only about 0.2 cfs in the latter period. This should be considered a virtual dewatering of the river most of the time.

Overall, the system is highly managed, wherein salinity near the dam is strongly related to the water releases. The river suffers from periodic algal blooms and low dissolved oxygen concentrations. There are strong seasonal cycles in temperature, salinity, and dissolved oxygen, related to the cooler, dry (winter through spring) seasons versus the warmer, wet (summer through fall) seasons.

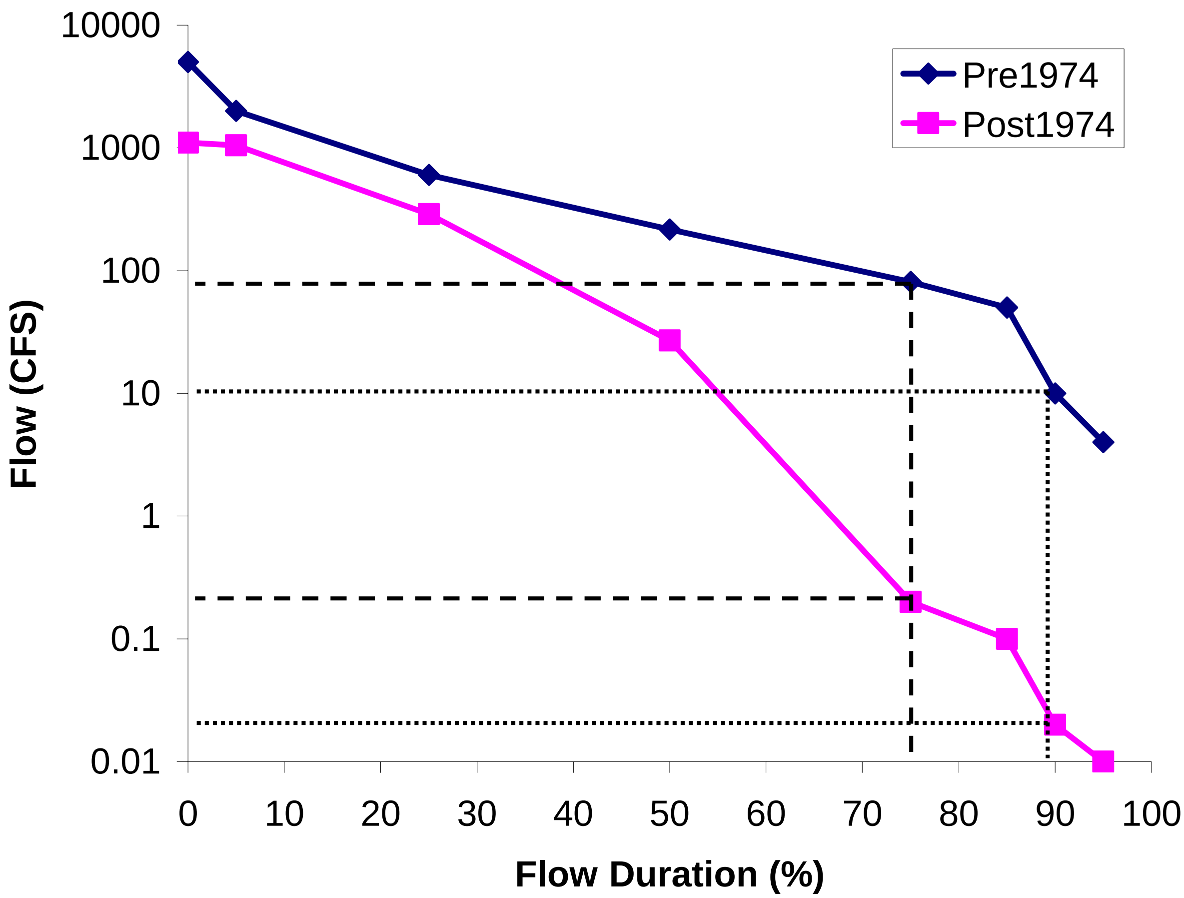

Figure 1. Redrafting of Figures 2-10 and 2-11 (SWFWMD 2006) demonstrates the large disparity between historical outflows from the Hillsborough River Reservoir during the 1940-1973 and the 1974-2004 periods of record .

2. Biological Characteristics

Chapter 5 describes the biological communities and their responses to salinity conditions over time. The benthic community is relatively impoverished and generally represented by different but somewhat overlapping communities in the polyhaline, mesohaline, and oligohaline zones. Stress from hypoxia and sediment contaminants is a problem, especially in the wet seasons. Only the benthic community immediately downstream of the dam appears to be affected by freshwater inflow. Succession occurs between seasons and flow events where oligohaline species are replaced by more brackish estuarine species. Overall, the District has done an adequate job of justifying the management goal's oligohaline zone between dam and Sulfur Springs using a multivariate analysis of benthic community structure (Figure 5-9, SWFWMD 2006).

Although the Venice System of salinity classification (1958 and 1959) has been criticized for its applicability or lack thereof (den Hartog 1960 and 1974; Price and Gunter 1964), it continues to be widely used, albeit in slightly modified forms, such as in the classification of wetlands and deepwater habitats of the United States (Cowardin et al. 1979; Table 1).

Table 1. Salinity modifiers used in a salinity classification system (adapted from Cowardin et al. 1979).

Coastal Modifiers[a]	**Inland Modifiers**[b]	**Salinity (‰ or ppt)**	**Specific Conductance (µMhos at 25°C)**
Hyperhaline	Hypersaline	>40.0	>60,000
Euhaline	Eusaline	30.0-40.0	45,000-60,000
Mixohaline (Brackish)	Mixosaline[c]	0.5-30.0	800-45,000
Polyhaline	Polysaline	18.0-30.0	30,000-45,000
Mesohaline	Mesosaline	5.0-18.0	8,000-30,000
Oligohaline	Oligosaline	0.5-5.0	800-8,000
Fresh	Freshwater (Limnetic)	<0.5	<800

[a]Coastal modifiers are used in the marine and estuarine systems.
[b]Inland modifiers are used in the riverine, lacustrine, and palustrine systems.
[c]The term “Brackish” should not be used for inland wetlands or deepwater habitats.

While salinities below 0.5 ppt are considered limnetic (freshwater), the gradation between fresh and hypersaline waters is continuous; therefore, any boundary demarcations are artificial, as is the 5 ppt breakpoint between low salinity (oligohaline) and medium salinity (mesohaline) habitats. Thus, it is not surprising that a principal components analysis (PCA) of fish and invertebrate collections from the mid-Atlantic region (primarily in Chesapeake Bay and Delaware Bay) by Bulger et al. (1993) indicates a slightly lower breakpoint based on the abundance and distribution of the organisms being analyzed. Because there are similar species in Florida, this study was used by the District to justify a 4 ppt breakpoint in the Sulphur Springs habitats (SWFWMD 2004). A more recent analysis and PCA of biological samples collected in the LHR was able to resolve a 5 ppt demarcation in the structure of the benthic community (SWFWMD 2006). However, the same study delineated the fish community of the lower Hillsborough River into four salinity zones: Zone 1 (0-2 ppt), Zone 2 (2-15 ppt), Zone 3 (15-27 ppt), and Zone 4 (27-32 ppt). Zone 1 had the highest abundance of freshwater species (e.g., bluegill, bass, hogchoker, mosquito fish, etc.). Zones 2-3 had the highest numbers of brackish species (e.g., snook, ladyfish, silversides, gobies, grass shrimp, etc.), and Zone 4 had an increased frequency of occurrence of more marine species (e.g., blue crabs, pinfish, bay anchovy, menhaden, drums and croakers).

Results from MacDonald et al. (2006) indicate that estuarine fishes and invertebrates that penetrate up the tidal segment of the Hillsborough River have mostly negative responses to increasing freshwater inflows, particularly above 30 cfs, causing them to move downstream and away from the best upstream nursery habitats, which can not move. Further, they respond in a stronger and more predictable manner than the freshwater species immediately below the dam or the more marine species downstream towards the river’s mouth at the bay. MacDonald et al. (2006) also found that inflows between 20 and 30 cfs, or higher, appeared important in increasing the abundance and richness of the freshwater taxa, but not the estuarine or marine taxa.

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) dissolved oxygen (DO) concentrations that frequently occur in these warm waters at night; however, organisms in the lower Hillsborough River avoided hypoxic (<2 mg/L) areas (MacDonald et al. 2006). While this suggested to the authors that a DO concentration of 2 mg/L is an important threshold below which both abundance and taxa richness declines significantly, their data indicate a much higher fish abundance and species richness at 2.5 mg/L than at concentrations near 2.0 mg/L. A similar analysis of benthos was not presented in the report.

DO was found to decrease with depth and distance from the dam, and this gradient was strongest during prolonged low flow periods and after episodic precipitation events bring turbid runoff from the adjacent urbanized watershed into the tidal river segment via storm drains and culverts (Catalano et al. 2005). This caused DO concentrations to be inversely related to flow pulses, particularly in the downstream reach of the Hillsborough River. In this reach, the presence of hypoxic waters effectively blocks migratory organisms from entering or leaving the river's nursery habitats upstream. These events also create violations of state water quality standards, which contain DO criteria for Class III marine waters that call for an instantaneous minimum of 4 ppm and a daily average of not less than 5 ppm. Such a 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 ppt) at sealevel 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 ppt 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, then there is no way to consistently maintain DO concentrations above 4 mg/L under these conditions at night when plants switch from O_2 production (i.e., photosynthesis) to respiration. Furthermore, most fishes 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 inhabiting organisms. Thus, the District's goal of maintaining DO concentrations above 2.5 mg/L in the oligohaline zone seems scientifically sound and realistic for this highly urbanized river segment. Moreover, this 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.

Based on their study of fish between Sulphur Springs and the dam, Catalano et al. (2005) suggested that the best minimum flow to preserve obligate freshwater and oligohaline fishes was between 4 and 42 cfs; that is, 4 cfs eliminated freshwater conditions and drastically reduced oligohaline (<5 ppt) habitats, while 42 cfs provided freshwater and oligohaline conditions from the dam to the end of their study reach3.6 km (2.2 miles) below the dam. Unfortunately, they lacked data on intermediate (5-41 cfs) flows and were not able to detect any thresholds that could be useful in developing biologically-based minimum flows and levels (MFLs) for the Hillsborough River.

MacDonald et al. (2006) determined that the lowest potential for estuarine impact from freshwater impoundment and diversion activities is the November-February period when the fewest estuarine species are present; whereas, the highest potential for impacts is during the April-June period when naturally low freshwater inflows can occur simultaneously with increasing use of nursery habitats by the young fish and macro-invertebrates. Moreover, they conclude that creation of a persistent low-salinity (oligohaline) zone in the upper portion of the tidal river segment above Sulphur Springs would be beneficial to estuarine species, even if a permanent freshwater community cannot be established immediately below the dam because of periodic salinity intrusions into this tidal river segment.

3. Relationship Between Flow and Water Quality

Chapter 6 reports on empirical analyses and simulations to explore how salinity, DO, and chlorophyll respond to flow rates. The chapter also summarizes results from the controlled release experiments.

3.1 Salinity

The District's report acknowledges some of the weaknesses of empirical analyses. The reported relationships are especially problematic because responses of individual water quality measurements are a function of the historical inflow regime (i.e., the timing, frequency, duration, and extent of the events) coupled with the tidal conditions at the time of the measurement. Thus, it is not surprising that empirical relationships are at best only marginally significant (Figures 6-2 – 6-7, SWFWMD 2006). Empirical data among sampling programs were not integrated into a single database for analysis, leaving spatial gaps in the analysis and restricting discussions to individual sampling sites.

One important study is the controlled release experiment. The objective of the seven experiments was to obtain data in the range of 10 – 30 cfs needed to "verify and refine the District's LAMFE model" (SWFWMD 2006, p. 100). Fresh water was released from the dam or routed from Sulphur Springs to the base of the dam. Sulphur Springs water has a salinity of about 1.2 ppt. Experiments were performed during dry seasons, but under a variety of naturally occurring tidal and salinity conditions. The important finding of these experiments was that salinity variability was reduced only when flows approached or exceeded 20 cfs.

Unfortunately, the data from the controlled release experiments were not integrated into an empirical model, nor were results synthesized to provide any general conclusions as to their effectiveness, except to say that "initial downward salinity response to a new inflow source was more rapid than the subsequent upward salinity response when the new inflow source was halted."

The LAMFE model is a two-dimensional (2-D), laterally averaged, z-coordinate, hydrodynamic and conservative mass (read: salinity) transport model based on a finite difference scheme, which was developed and utilized by the District to simulate conditions in the confined tidal channel of the lower Hillsborough River (Chen 2003). The model appears to be essentially a 2-D numerical code stood on its side so that it can mimic 3-D salinity structure with depth. The LAMFE model only has 88 cells in its entire computation grid for the tidal river segment from its mouth at the bay to the dam upstream at 16.3 km (river mile 10.1), with cell sizes ranging from 50 meters to 800 meters in length. The model was recalibrated using data from the February 7, 2001 to December 8, 2002 period, then was run for two later verification intervals without any additional efforts at calibration (Janicki 2005).

Next, the calibrated model was employed to simulate riverine conditions from 1998 through 2004 with the model's output compared to observed salinity data from the United States Geological Survey (USGS), the Environmental Protection Committee of Hillsborough County (EPC), and the Hydro-Biological Monitoring Program (HBMP). The results revealed that the model over-predicts salinity in the tidal river segment with the greatest errors typically occurring in the dry season when salinities are highest. Bottom salinity mean errors were as high as 2.1 ppt when compared to the USGS data, 2.4 ppt when compared to the EPC data, and 3.2 ppt when compared to the HBMP data. This means that the model would be considered an adequate simulator, not an excellent simulator with mean errors less than 2.0 ppt. In theory, all models are wrong at some level; however, in practice, many are useful at simulating conditions of interest. This appears to be the case for the currently applied version of the LAMFE model, which if used conservatively can replicate the river's salinity structure with enough accuracy to make it useful in evaluating various proposed management scenarios.

The LAMFE model was initially exercised with five (5) freshwater inflow scenarios over the 5-year (1998-2002) simulation period: no minimum flows (baseline condition), 10, 20, 30 and 40 cfs minimum flows. In evaluating the scenarios, no Sulphur Springs water was assumed to be routed to the base of the dam. Further, in all simulation runs the downstream model boundary conditions for tidal elevation and salinity were based on actual measurements taken at Platt Street near the mouth of the river from 1998 through 2002. This means the model is realistically taking into account the effects of variable estuarine conditions in the bay as they influence the tidal river segment of the LHR.

Simulation results show that salinity was affected most in the upper portion of the tidal river segment near the dam. The results also indicate that an undesirable reverse salinity gradient in the river above the Sulphur Springs outfall (Montagna 1999) is eliminated by freshwater inflows greater than 20 cfs (SWFWMD 2006). Moreover, increasing flows from 20 to 30 cfs (see Figures 6-62 and 6-63, SWFWMD 2006) only expands the oligohaline (<5.0 ppt) zone downstream from the dam by about 1 kilometer (i.e., from river kilometer 13, just above the Sulphur Springs outfall at river kilometer 12.8, to river kilometer 12 below it). The same figures show that increasing flows from 20 to 30 cfs also expands the mesohaline zone (e.g., 10-12 ppt) a similar amount; that is, from river kilometer 9 to river kilometer 8 in the middle reach of the tidal river segment. Moreover, Figure 6-50 (SWFWMD 2006) illustrates that even at flows of 30 cfs, there are whole months in the springtime of dry years where the salinity exceeds 5 ppt at Station 105, just meters downstream of the dam. The lower reach of the river near the bay continued to have salinities of about 25 ppt under all inflow scenarios.

3.2 Dissolved Oxygen

A biologically important management goal is the District's intent to maintain DO levels above survival thresholds for fish and other biota. One issue of concern is that the District has set the lower limit of DO concentration at 2.5 mg/L. This is in contrast to State water quality standards(State of Florida Rule 62-302.530 covering Class III waters), which declare that, for predominantly fresh waters, DO "shall not be less than 5.0. Normal daily and seasonal fluctuations above these levels shall be maintained." For predominantly marine waters, the same standards state that DO "shall not average less than 5.0 in a 24-hour period and shall never be less than 4.0. Normal daily and seasonal fluctuations above these levels shall be maintained."

However, there is a method for determining an alternative standard, if justified. State of Florida Rule 62-302.800 Site Specific Alternative Criteria specifies:

> *"Type I Site Specific Alternative Criteria: A water body, or portion thereof, may not meet a particular ambient water quality criterion specified for its classification, due to natural background conditions or man-induced conditions which cannot be controlled or abated. In such circumstances, and upon petition by an affected person or upon the initiation by the Department, the Secretary may establish a site specific alternative water quality criterion when an affirmative demonstration is made that an alternative criterion is more appropriate for a specified portion of waters of the state. Public notice and an opportunity for public hearing shall be provided prior to issuing any order establishing alternative criteria."*

Empirical flow-DO relationships indicate that increasing flows to 20 cfs would increase DO in the area below the dam to Hannah's Whirl, as a function of decreased residence time, and eliminate most (~95%) of the violations of the 5 mg/L State water quality standard for bottom DO from the dam downstream 2.3 km (1.4 miles) in the oligohaline zone (Fig. 6-21, SWFWMD 2006). The statistical model also estimates that 41% (10.9 acres) of the bottom habitat in this reach of the river experiences low (< 2.5 mg/L) DO at the current 10 cfs minimum flow, decreasing to 27% (7.2 acres) at the proposed 20 cfs MFL. Increasing flows to 30 cfs decreases the low DO bottom area to 16% (4.4 acres), while 40 cfs reduces the area to only 8% (2.2 acres).

However, increased flows also depressed the DO farther downstream between Hannah's Whirl and Sligh Avenue. This finding indicates that nutrient and biological oxygen demand (BOD) loading from upstream sources are affecting the river's ecological health and productivity. In addition, water quality in the Hillsborough Reservoir is substantially degraded relative to the river just below the dam where the current 10 cfs introductions of better quality Sulphur Springs water are being made. Release of high nutrient waters through the dam may act to promote algal biomass production, which in turn drives supersaturation of oxygen during the day with concomitant hypoxia at night. This diurnal effect is clearly seen in the DO data. Upstream BOD loading has a more direct effect on DO concentrations as it promotes the consumption of oxygen by bacterial degradation and respiration of the organic material. Both of these processes are in effect in the LHR and considerably confound the District's intent to provide an appropriate MFL.

The dilemma, that increased flows upstream may decrease DO downstream, is at the heart of the overall LHR management issue. Getting the water right in terms of quantity, quality, timing, and distribution is especially confounded by the water quality issue in this case. Increasing flow from the dam will provide oligohaline habitat, which may not be usable by fish, because the resulting hypoxia downstream may act as a barrier to their upstream migration. Without a source of low nutrient and low BOD water, increasing flows through the dam may produce new problems. It appears that this dilemma can only be resolved by improving water quality in the Hillsborough Reservoir or finding new sources of clean freshwater for the LHR.

Finally, the LAMFE model was not used to simulate DO or nutrient concentrations as a function of flow and loading. This is an important approach, and that the District should endeavor to expand the model to include a water quality module in the future, which will likely require an increase in the resolution of the computational grid as well.

4. Evaluating Minimum Flows

Chapter 7 compares salinity simulation runs to evaluate a range of possible minimum flows with the District's MFL recommendation following in Chapter 8. Graphical analyses were used to evaluate the spatial extent and temporal persistence of the previously modeled conditions to meet the salinity criteria; namely, to provide an oligohaline (0.5-5.0 ppt) salinity zone from the Hillsborough River dam at 16.3 km (river mile 10.1) downstream passed Hannah's Whirl 14 km (at river mile 8.7) and on towards Sulphur Springs 12.8 km (at river mile 7.95), a total distance of 3.5 km (2.2 miles). The results indicate that there is a rather large increase in spatial and temporal effectiveness of the proposed 20 cfs minimum flow to meet the goal over the existing 10 cfs minimum flow. Although incremental improvements in spatial and temporal effectiveness continued as freshwater inflows were increased to 30 and 40 cfs, they were distinctly smaller. For example, Table 7-1 indicates that the oligohaline volume, as a percent of the entire river segment's volume from dam to mouth, increases from 4.5% at 10 cfs to 7.3% at 20 cfs, a 62% volumetric increase in this desired condition; however, further flow increases to 30 and 40 cfs only result in volumetric improvements on the order of 36% and 23%, respectively.

The cumulative distribution function (CDF) plots are also informative (e.g., Figs. 7-11 and 7-23, SWFWMD 2006). Unfortunately, as with most other analyses except those for DO, they do not show a clear breakpoint for a biologically-based MFL. For example, Figure 7-23 shows that 50% of the river's volume (total water column) from the dam to Sulphur Springs will be oligohaline (<5.0 ppt) about 48% of the time at 20 cfs versus about 64% of the time for 24 cfs. This is an important finding indicating that a higher flow than the recommended 20 cfs MFL may be needed during the springtime period of greatest utilization of estuarine nursery habitats in the lower Hillsborough River.

These findings raise an important question: would the proposed MFL of 20 cfs be adequate to meet the District's stated goals? The answer appears to be: just barely and not in all seasons. The District itself answers the question by indicating that the beneficial return per unit of freshwater inflow invested is maximum at 24 cfs, and declines thereafter. Some would argue that if 20 cfs barely meets the goals, then 24 cfs could provide an important margin of safety for the MFL estimate by increasing the frequency of its competency in providing the intended benefits. In addition, increasing the MFL to 24 cfs during the seasonal peak of increased utilization of estuarine nursery habitats in the Tampa Bay ecosystem would encourage recovery of the environment's ecological health and productivity.

Seasonal variability of inflow and habitat utilization illustrates a problem with any single number used for all times of the year. If the minimum flow is set too high in an effort to increase the margin of safety for the operating rule, then the District runs the risk of over protecting the environment and under protecting the people's right to beneficially use the waters or visa versa. As a practical matter, the environmentally safe operation of impoundment and diversion systems requires condition-appropriate rules to avoid using good-time rules in bad times and visa versa. An obvious alternative would be to provide a minimum of 24 cfs during the period of increased utilization of the estuarine nursery habitats, which is in the spring, from April through June according to MacDonald et al. (2006), and 20 cfs for the remaining months of the year.

5. The MFL Recommendation

Chapter 8 presents the District MFL recommendation. The District has provided sufficient and sound scientific justification for proposing an MFL of at least 20 cfs for the Lower Hillsborough River, especially when considering current water conditions as the law allows.

The District's recommended MFL of 20 cfs envisions the use of multiple freshwater sources to meet the MFL. One solution suggested by the District builds on the current diversion of 10 cfs from Sulphur Springs at 12.8 km (river mile 7.95) and its pipeline transport upstream to the dam 16.3 km (at river mile 10.1). The proposed solution would increase the spring diversion to 15 cfs and match it with at least 8 cfs of water passed through the dam (total = 23 cfs because Sulphur Springs discharges are slightly salty at ~1.2 ppt). This is a typical "pass through" rule for the impoundment that is coupled with adjustments based on the amount of water flowing into the reservoir from its upstream watershed. However, the diversion from a downstream spring system is somewhat unusual. Nevertheless, it appears that the District's assessment is well founded that the current 10 cfs diversion of springflows upstream to the dam has produced significant ecological benefits near the dam, as well as reduced the salinity stratification and consequent DO problems near the spring's outfall into the river by improving vertical mixing of the water column.

Sulphur Springs has an average discharge rate of 34.3 cfs, of which the City of Tampa utilizes an average of about 2.9 cfs as a supplemental water source in their distribution system when upstream reservoir levels are low. Further, the City holds a permit to withdraw up to 31 cfs from the springs, which is essentially all of the spring flows, especially in seasonally dry months (e.g., June) when discharges from the springs average only about 28.9 cfs (SWFWMD 2006). The District has previously (SWFWMD 2004) recommended an MFL for Sulphur Springs of 18 cfs to protect the spring run ecosystem and its biota, with a drought contingency allowance to reduce minimum flows to 13 cfs when water levels in the upstream dam and reservoir system fall to 19 feet, indicating an impending water supply shortage. There is a further provision to reduce flow to 10 cfs during low tidal stages in the river, as long as it does not result in a salinity incursion > 1 ppt into the upper spring run. It is apparent that not all demands on the spring system can be met simultaneously, including the newly proposed 15 cfs diversion upstream to the dam; however, water allocation is not within the panel's scope of review.

Aquatic ecosystems and their fish and wildlife inhabitants do not benefit from flow reductions through drought contingency operations, but such reductions are often critical for the socioeconomic systems that flows also support. Thus, it is reasonable for the District to recommend a seasonal drought adjustment based upon upstream flows into the reservoir. Crystal Springs discharges into the river near the City of Zephyrhills are much less variable than runoff from the rest of the upper watershed, providing most of the base flows in that portion of the river during dry periods. Because the annual 90th percentile exceedance flow at the Zephyrhills stream gage is 58 cfs, the District proposes to proportionally reduce the MFL for the Lower Hillsborough River from 20 cfs to 10 cfs as the upstream flows at Zephyrhills decline from 58 to 28 cfs. This adjustment seems reasonable. However, only 8 cfs may be passed through the dam under one solution proposed by the District, so it is unclear why the proportional reduction is not just applied to the 8 cfs. In practice, the MFL will be required on average about 165 days (45%) of each year; whereas, seasonal reductions of the MFL would occur only about 10 % of the time. Furthermore, the flow reductions may not be needed at all if a beneficial use of advanced treated wastewaters is made part of future water management plans for the Lower Hillsborough River. However, no return flows that have little or no treatment should be released into the tidal river segment for environmental purposes because of its potential to contaminate the waterway and further damage aquatic resources. Modern wastewater treatment systems can be a significant contributor to water reuse and environmental health, as has been shown repeatedly in other areas of the country.

There appears to be an inconsistency between lines 2 and 3 on page 192 and an earlier statement. In Chapter 2, page 6, paragraph 2, the text states "Crystal Springs, located near the city of Zephyrhills, discharges average 58 cfs in the upper watershed." However, at the top page 192, it is stated that "the median of the annual 90% exceedance flows at the Zephyrhills gage exceeds 58 cfs." Can the average spring discharges and the median of 90th percentile exceedance frequency flows in the river both be the same?

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