FINAL REPORT

By:
THE LOWER HILLSBOROUGH RIVER MINIMUM FLOW SCIENTIFIC PEER REVIEW PANEL

To:
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EXECUTIVE SUMMARY

This report is an independent peer review of the scientific and technical data and methodologies supporting the proposed 10 cubic feet per second (cfs) minimum flow rule for the Lower Hillsborough River published on March 12, 1999 by the Southwest Florida Water Management District (SWFWMD). The primary reference for this review was the technical report entitled, "An Analysis of Hydrologic and Ecological Factors Relating to the Establishment of Minimum Flows for the Hillsborough River" (SWFWMD 1999). This technical report describes the Hillsborough River, the background for establishing a minimum instream flow, and scientific data and methods used for establishing the minimum flow rule. A large number of other documents containing previous studies and original data sources were supplied by the SWFWMD and examined.

The peer review panel was tasked to determine if the proposed minimum flow rule, i.e., the value of 10 cfs, was based on defensible scientific analyses. The panel reviewed the report and supplemental documentation to determine if a justification for selecting 10 cfs was provided, and to determine the impact this instream flow value would have on the environmental quality of the Lower Hillsborough River. Based on the panel's review, there is little scientific support for selection of 10 cfs. The primary technical report and supplemental documents do not state clear management objectives for establishing the minimum flow rule. Objectives for establishing the rule should indicate the expected result, e.g., maintaining specific river miles (or volumes), at a range of proscribed salinity profiles, during specified periods, for specific hydrologic conditions. Given management guidance, data could be scientifically analyzed to support a minimum flow rule.

Four types of data (or methodologies) are presented in the primary technical report and supplemental documents: empirical models of measured salinity versus flow, empirical models of measured dissolved oxygen (DO) versus flow, a physical dynamic model of predicted salinity over the length of the river, and habitat use by oligohaline species. Trends in data indicate a continuum of benefits with increased reservoir releases. There are no clear break points or convergence points in the data presented, which could define a flow rate that would provide an optimal benefit to the ecology of the river. The DO models are poorly constrained and probably can't be used to determine a minimum flow rule. In both the empirical and dynamic salinity models, high salinity conditions can be found at zero flow conditions, and amelioration observed at flow rates greater than 2 cfs. The dynamic model is probably the best management tool to set a minimum flow rule. Oligohaline species require a range of 1 to 4 practical salinity units (psu). The dynamic model indicates that size of oligohaline habitat increases linearly with flow rates greater than 2 cfs. Absent a clear management objective and lack of break points in the data, the choice of 10 cfs as the minimum flow is arbitrary. There is no link between the data presented and the decision processes used to arrive at 10 cfs.

The technical data presented appear to be complete and the best available at the time of the determination. Quality assurance/quality control procedures are not provided, but the measurements are sufficiently routine not to warrant concern. Overall, the data, approaches to analyzing the data, and the dynamic salinity model are scientifically valid. There are details of data use and interpretation that are nonstandard and could be improved, but these details of data interpretation would not change the general conclusions of the panel. There are two major deficiencies in the data analysis: ignoring seasonality of flows, seasonal effects on salinity, and consequent effects organisms; and a lack of resolution of the vertical structure of the water column in the river and oligohaline habitats.

The data presented demonstrate oligohaline habitats can be nonexistent with zero flows and a minimum flow rule would ameliorate this condition. The data also indicate that rerouting Sulphur Springs water to the base of the dam, while improving water quality marginally between the dam and Sulphur Springs, would not ameliorate the high salinity conditions during zero flow conditions. The salinity of Sulphur Springs (at 1.5 psu) is simply too high.

At best, the 10 cfs rule should be considered an improvement over the current condition and an experiment in adaptive management. The scientific and technical data indicate that an adaptive management approach should be taken, because there is no scientific evidence for choosing one instream flow value over another. The process of adaptive management requires a clear management goal (e.g., maintaining 1 or 2 km of oligohaline habitat during certain seasons), monitoring (which can be restricted to the region a short distance downstream from the dam within the managed segment), determining if the expected changes are occurring (within an acceptable range of uncertainties), and reevaluating the minimum flow rule on short-term intervals. Setting the management goal will require evaluation of the biological communities and environmental setting of the region to be managed, and policy decisions on which sustainable resources are to be protected or optimized. Monitoring could be economical because the primary variables (DO and salinity) are inexpensive to measure, but must be measured with better vertical resolution than in the past to provide useful management information. This focused monitoring activity would provide information that could contribute to both the interim instream minimum flow target and the final rule. This interim target should be re-evaluated on very short time scales (no longer than one year) as opposed to the five year period suggested in the primary technical report.

INTRODUCTION

Purpose

The purpose of this report is to present findings of an independent scientific peer review of the scientific and technical data and methodologies supporting the proposed Minimum Flow Rule for the lower Hillsborough River published on March 12, 1999 by the Southwest Florida Water Management District ("District"). The District was directed by the Florida legislature to establish minimum flows for surface water courses and minimum levels for aquifers and surface waters. Under the statute, a minimum flow for a given surface water course is the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area. The minimum water level is the level of the ground water in an aquifer, or the level of surface water, at which further withdrawals would be significantly harmful to the water resources of the area.

Prior to establishing a minimum flow or level, scientific or technical data and methodologies are subject to independent scientific peer review if requested by a substantially affected person. After approving its proposed rule establishing a minimum flow for the lower Hillsborough River, the District received petitions requesting independent scientific peer review from the Environmental Protection Commission of Hillsborough County, Tampa Bay Water, and the City of Tampa (collectively the "Requesters"). An independent peer review is defined by Florida Statutes to mean the review of scientific data, theories, and methodologies by a panel of independent, recognized experts in the fields of hydrology, hydrogeology, limnology, and other scientific disciplines relevant to the matters being reviewed.

The panel's task was to review scientific and technical data and methodologies used in the development of the proposed minimum flow for the lower Hillsborough River. In particular we reviewed a scientific paper prepared by District scientists, entitled "An Analysis of Hydrologic and Ecological Factors Relating to the Establishment of Minimum Flows for the Hillsborough River" (SWFWMD 1999) that describes the scientific methods used by the District for establishing the minimum flow. This scientific paper was accompanied by copies of its supporting references.

Charge

The charge for the peer review panel was to review scientific and technical data and methodologies used in the development of the proposed minimum flow rule for the lower Hillsborough River. The panel focused its review on the technical paper prepared by District scientists that describes the scientific methods used by the District for establishing the minimum flow (SWFWMD 1999). The scientific paper was accompanied by copies of supporting references. The panel was also provided with supplemental technical documents recommended by or developed by the Requesters, and questions intended to highlight some of the Requesters' issues of concern. The panel requested additional information (via the web conference board) that had not been initially provided by the District. All panel requests for information were met by the District in a timely manner.

Development of the proposed minimum flow was a result of legal and policy interpretations of the minimum flows and levels statute. The panel was asked to treat legal and policy considerations as assumptions or conditions for the technical review and therefore not within the scope of scientific peer review. The statute requires use of the best information available, seasonal variations (when appropriate), and consideration of structural alterations for calculating the minimum flow.

Specifically, the panel was asked to evaluate the methods used by the District for the minimum flow and address the following:

A. Determine whether each methodology is scientifically reasonable by evaluating the scientific and technical analyses utilized by the District to develop the minimum flow methodology. To do so, the panel was asked to consider the following questions.
   1. Review the information and data that support each methodology to determine the nature and character of the information utilized.
      a. Were reasonable quality assurance assessments performed on the information?
      b. Was relevant information available but discarded without proper justification?
      c. Were data used in establishing the minimum flow collected properly?
      d. Was the "best information available" as of July 1997 utilized for developing the minimum flow?
   2. Review the technical assumptions inherent in each methodology:
      a. Are the assumptions reasonable and consistent given the "best information available?"
      b. Were types of information available that could have been used to eliminate any of the assumptions?
      c. Are the assumptions stated clearly? What, if any, assumptions are implied or inherent in the methodologies?
      d. Were other analyses available that would require fewer assumptions but provide comparable or better results?
   3. Review the procedures and analyses used in developing quantitative measures:
      a. Were the analyses appropriate and reasonable given the "best information available?"
      b. Do the analyses include all necessary factors?
      c. Were the analyses correctly applied?
      d. Were any limitations and imprecisions in the information reasonably handled?
      e. Are the analyses repeatable?
      f. Are the conclusions supported by the data?

B. If a given methodology is not scientifically reasonable based on the evaluation conducted pursuant to questions A.1 through A.3 above or as judged by other means determined by the Panel, the Panel shall:
   1. Enumerate and describe scientific deficiencies and evaluate the error associated with the enumerated deficiencies.
   2. Determine if the identified deficiencies within the methodology can be remedied.

3. If the identified deficiencies can be remedied, then enumerate and describe the necessary remedies, including the precision, accuracy, and an estimate of time and effort required to develop and implement each remedy.
4. If the identified deficiencies cannot be remedied, then identify one or more alternative methodologies which are scientifically reasonable. If an alternative methodology is identified by the Panel, the Panel shall also describe the precision, accuracy, and estimate the time and effort required to develop and implement the other scientifically reasonable methodologies.

C. If a given methodology is scientifically reasonable, based on the evaluation conducted pursuant to questions A.1 through A.3, or as judged by other means determined by the Panel, but perhaps does not embody the preferred methodology as determined by the Panel, then the Panel may enumerate another scientifically reasonable methodology and develop a qualitative assessment of the relative strengths and weakness of the other scientifically reasonable methodology (e.g., precision, accuracy, and the time and effort required to develop and implement the other scientifically reasonable methodology).

Panel Organization

The peer review panel was composed of four academic scientists with complementary backgrounds: Dr. Paul Montagna (estuarine ecologist with expertise in benthos and inflow effects on estuarine communities), Dr. Scott Nixon (estuarine ecologist with expertise in nutrient cycling), Dr. Richard Palmer (civil engineer with expertise in hydrology and water resource management), and Dr. Mark Peterson (fish biologist with expertise in oligohaline habitats).

Panel Activities

The peer review panel conducted all of its work according to the terms of the Florida sunshine law. All meetings and communications among panelists were held at a noticed open meeting or on the District's web conference site, which is available for public viewing. The panel met to consider the minimum flow during the following dates:

Date (1999)	Activity
July 25	Training on use of District web site
August 6	Site visit to Hillsborough River in Tampa
August 25	Web Conference
September 8	Web Conference
September 13	Panel Workshop in Tampa
September 14	Public Meeting in Tampa
October 18	Panel Workshop in Tampa
October 26	Panel comments on Final Report due on Web Conference

REVIEW OF METHODOLOGIES

The panel identified four methodologies that were used in the technical document (SWFWMD 1999) to determine the minimum flow: 1) salinity measurements and empirical determinations of flow effects on salinity, 2) dissolved oxygen (DO) measurements and empirical determinations of flow effects on DO, 3) salinity modeling and estimation of isohaline volumes as a function of flow, and 4) fish and wildlife distributions in habitats with differing salinity. The scientific and technical data and methodologies are reviewed separately below.

Salinity Measurements

General comments

There is no clear statement in the technical document as to what salinity range is considered desirable. Neither is there a calculation of how much flow is needed to obtain a desired salinity range. Salinity measurements were evaluated for empirical relationships between flow and measured salinity. It is assumed that this relationship was used to determine the minimum flow.

In general, the salinity methodologies appear reasonable. The basic assumption of the methodology is that salt is conservatively mixed when diluted with freshwater inflows. Fresh water losses occur due to evaporation, withdrawal, or diversion. Withdrawal and diversion do not appear to occur below the dam. Evaporation is very low because the exposed surface is low relative to volume in a narrow river, which is not true in a broad shallow bay. Therefore, the basic assumption is scientifically justified. However, the report never discusses why salinity is a good proxy for freshwater inflow effects. On the other hand, there are no other approaches to evaluate salinity data without fewer assumptions. In general, it is a very reasonable and common practice to try and determine the functional dependency of salinity on inflow rates. It is also common to fit the relationship with moving averages.

There are several problems in this methodology however. In general, there is a lack of balance (i.e., uneven sampling effort) in the data sets, and this always leads to analysis problems and potential misinterpretation of data trends. Salinity data could have been collected better. One problem is that data were generally collected monthly. There are 13 lunar cycles per year and 12 months. Therefore, most estuarine ecologists actually collect 13 samples per year and not 12. This allows the collector to always collect at a low or high tide at midday, removing tidal stage height and daylight hour problems from the data. This problem doesn't exist with continuous collections, because data can be averaged over a 24-hour day. There is insufficient information to determine if quality assurance/quality control (QA/QC) of data has occurred. There is no mention in original documentation as to how, or if, salinity meters were calibrated or checked against independent measurements. After salinity data were collected, it appears that data management plans were sufficient to ensure that quality of the data, i.e., does not appear to have problems with transcriptions, etc. No data appear to have been discarded.

The problems listed above lead to disagreement with some interpretations of salinity data in the technical document. A significant problem is that the data set is skimpy, especially for low or no flow periods during droughts (dry periods). This inevitably leads to weak functional relationships between salinity and flow at low levels. A second problem is that the log-linear models don't appear to fit the data any better than a simple step function (L-shaped) model. The implication is that based on salinity alone, there is no justification for minimum inflows of more than 2 cfs to maintain an oligohaline habitat between the dam and Sulphur Springs. However, more data are needed, not more analyses, before this can be stated with certainty. Also, meta-analysis of all combined data sets, rather than by individual data sets would be useful.

Specific comments

Salinity values near Sulphur Springs may be overestimated because sites were upstream and downstream from the site rather than in the immediate vicinity adjacent to the Springs (p. 3.4).

Table 4.1 (p. 4.6) exhibits a classic problem encountered when using unbalanced data sets. The means for 3 m do not correlate with the means above (2 m) and below (bottom) it. This is because only selected values are shown. This method is poor, and the 3 m data should be deleted from Table 4.1 and for consideration in setting a minimum flow. It is better to just conclude that the bottom was of variable depth > 2 m. This is also a serious flaw in all figures of Appendix C, and may account for considerable variability in the data presented in the figures of Appendix C.

The presentation of data in Appendix C is flawed. It is easy to misinterpret the entire section, because the label of the ordinate says it is the sum of salinities measured for vertical profiles (0 m + 1 m + 2 m + 3 m). In fact, all data from 0 m, 1 m, 2 m, and 3 m are plotted. The mean, excluding 3 m as stated above, should be plotted. The problem is exacerbated for low flow conditions because the paucity of samples introduces more bias. Basically, only salinity at 3 m during high tides is known. Sampling at the same tidal stage each time avoids this problem. At the least, each depth should have been plotted with a different symbol. The other implication is that the scatter in the data is meaningless, especially during low flow conditions.

The Sulphur Springs outfall is important to demonstrate effects of zero flow (i.e., no discharge) conditions in the Lower Hillsborough River (Table 4.2, p. 4.8). Salinity values upstream of the outfall at the base of the dam are higher than just above (0.31 mi) or below (0.42 mi) the outfall. This indicates that a "reverse estuary" condition exists during no flow periods. This would be very detrimental to estuarine communities.

Remarkably few data are being analyzed and reanalyzed (Coastal, WAR/SDI, this study). Apparently, data exist for only four years (1981 - 1982, 1991, and 1993). It is not apparent that those years are typical or represent potential extremes.

Salinity will respond to increasing flow in a negative curvilinear fashion. However, a simple negative hyperbolic function, as show in Appendix C, is not necessarily the best model, nor the only model. It is apparent that small inflows decrease salinity substantially at station 3. Analysis at station 2 hasn't been performed. This is unfortunate, because station 3 is probably influenced by Sulphur Springs and not dam release alone.

All the salinity models integrate or average flow over a variable period of days prior to calculating functional relationships. Several periods (0, 3, 8, and 14 days) are used. A strong case that any specific period is correct is not presented. Data presented make it appear 0 is wrong, but the results in this and the reference documents make it difficult to determine how long a period is most appropriate. This has to be resolved to determine an empirical flow-salinity relationship.

The salinity differences between the U.S. Geological Survey (USGS) data and the WAR/SDI data are most likely due to differences in rainfall during the periods of recordings (Section 4.4.1). The USGS data were taken during a wetter period (81 in/y) than the WAR/SDI study (53 in/y). The correct interpretation is that average salinity is about 2 practical salinity units (psu) higher in dry than wet periods. The important question is what is the long-term (i.e., 100-y) average? And, how do these periods fit in the context of the long-term average? Again, this points to the lack of data used for the analysis.

Data in Appendix E are useful to deduce minimum flows, but the data may only represent conditions in wet periods. It clearly indicates that with no discharge salinity can range from 0 to near 14 psu at Rowlett Park Drive, and will remain at less than 1 psu with any inflow volume (even as low as 2 cfs) (p. E-4). The data presentations in Appendix E also clarify the length of the period for which flow should be integrated or averaged. Same day (0-day flow) release is the best because the graph contains two straight lines: one for 0 flow and one for greater than 0 flows. Therefore, the statement that the USGS data "does not lend itself to model development" (p. 4.19) isn't supported. The data may be misinterpreted. The data indicate that during high inflow years, flows greater than 2 cfs will maintain oligohaline habitats at station 2. This interpretation is supported by Table 4.10 and all figures in Appendix G. Based on the USGS data, salinity has a "L-shaped" response to inflow, where at near zero flow a range of salinities exists, and oligohaline habitats are maintained when flow is greater than 0. It appears as is 2 cfs is the critical flow rate to maintain oligohaline habitats at the base of the dam.

Salinity data presented in Figures 4.2 - 4.4 also indicate that 0-day flows are best for use to set minimum flows, and 2 cfs is the value at which oligohaline habitats could be maintained in surface waters at Rowlett Park Drive. Because of the paucity of data of bottom salinities, 2 cfs appears fine for bottoms as well. However, the richest data set is for the mid depths, and here there is an interesting difference. It appears that same-day release of 5 cfs is necessary to constantly maintain an oligohaline habitat at mid-depths in Rowlett Park Drive.

The curvilinear lines based on logarithm functions for the 3, 8, and 14 day flows will overestimate salinity, thus overestimated required minimum inflow (Table 4.12 and Fig. 4.6). This leads to the statement on p. 4.32 that flow of 10 cfs is needed to maintain a salinity range of 1.0 - 1.3 psu. The correct function is no function, or a step or "L-shaped" function.

Page, 6.2, states that 10 cfs is needed to maintain salinities at Rowlett Park in the range of 1.0 - 1.3. This statement is based on the assumption that salinity is a log-linear function of flow, not a step function.

Dissolved Oxygen Measurements

General comments

Dissolved oxygen (DO) values do not appear to have been used in a quantitative way to set the minimum flow of 10 cfs. This was in agreement with the findings of the Hillsborough River and Palm River/TBC minimum flow advisory group convened by the Tampa Bay National Estuary program who concluded, ". . . the empirical models cannot be used to reliably predict dissolved oxygen concentrations at fixed stations within the river or to predict the frequency with which specified dissolved oxygen concentrations will be achieved throughout the river." (SWFWMD 1999, N-1). The District was prudent and correct in its statement that, "At this juncture, the District suggests the further evaluation of the effects of minimum flows on DO concentrations in the lower river should involve the implementation of a minimum flow and monitoring the response." (SWFWMD 1999, p. 6.4). In spite of the fact that considerations of DO did not make an explicit contribution to the decision regarding minimum flow, the unequivocal importance of DO makes it useful to share some observations gained from reviewing the DO data base.

Specific comments

The continuous DO measurements at mid-depth at numerous stations obtained by USGS and reported in Metcalf and Eddy (1983) demonstrate that biological metabolism in the river is high and that there are large diel changes in DO even at mid depth when flow is very low (< 50 cfs). However, measurements at mid depth are less useful than near-surface and near-bottom measurements because the mid depth level may alternately fall above or below the pycnocline as the tide floods and ebbs.

High flow rates may be needed to improve DO. Metcalf and Eddy (1983) concluded that, "Moderate freshwater releases (10 to 400 cfs) significantly improve average DO concentrations at Columbus Drive, Sligh Avenue, and 22nd Street whereas average DO concentrations at Platt Street remain the same" (p. 2-23). This would place the 10 cfs minimum flow on the lowest edge of that required to achieve some improvement in DO. On page 2-28, "moderate flows" are described as 100 – 500 cfs and, later still, on page 6-10, the report did not even evaluate releases below 50 cfs as a means to improve DO levels.

The flow-DO model developed by Metcalf and Eddy (1983) included some biology (sediment oxygen demand). The model did not include water column oxygen production or consumption (except as parameters that could be adjusted to improve the fit of the model output with observations) or vertical density structure in the water columns. Vertical density is a critical consideration for onset of hypoxia. The model is not credible as a management tool and it is not surprising that it performed poorly at low flows when biological dynamics are especially important in influencing DO levels.

The most ambitious attempt to relate flow to DO was the recent assessment by Coastal Environmental (1997). As with the earlier Metcalf and Eddy (1983) effort, this study produced regression equations relating DO concentration measurements to fresh water discharge measurements at the Hillsborough River dam. The Coastal Environmental (1997) report did not attempt to assess the quality of the field DO measurements, but there is no obvious reason to question the measurements themselves. The data base consisted of monthly DO measurements collected between 1991 - 1993 at eight stations along the length of the river. Measurements were made around midday (1000 – 1400 hours) at 1 m depth intervals from near-surface to near-bottom. Temperature and salinity were measured simultaneously. Regressions of the form:

$$\text{DO (midday)} = a + b \ln(\text{flow} + k) + c\,(\text{temp.})$$

were computed for each depth interval at each station. After various attempts, the best fit was obtained using discharge measurements averaged over 3 or 14 days preceding the DO measurements, depending on location. It is unclear why water temperature was included in the regression but salinity was not, because the saturation concentration of DO varies significantly with both salinity and temperature. For example, at 25 °C fresh water in equilibrium with air contains about 8.25 g O_2 m^{-3} while water with a salinity of 30 contains only about 7 g O_2 m^{-3}.

A potentially more serious problem is that Coastal Environmental (1997) wanted to adjust the regressions to produce calculations of daily mean and minimum DO values from the mid day measurements, arguing that mean and minimum DO values would be more useful as management tools. The adjustment was made by developing linear regressions relating measured mid day DO to measured daily means and minimums in a separate data base of continuous DO measurements from four stations during a different time period (1981 - 1982 and 1991 - 1993) obtained by the USGS. The problem is that USGS measurements were made at mid depth. The fact that strong relationships were found between midday DO and daily mean and minimum DO at mid depth does not necessarily indicate that the same relationships would apply between mid depth, mid day DO and daily mean or minimum DO at other depths. For example, we might expect that DO variation would be much greater near the surface.

The basic, unadjusted, regressions of mid day DO as a function of flow are weak as a management tool. The residuals of the regressions are quite high at low flow values and the r^2 values fall below 0.5 over 50% of the time (Coastal Environmental 1997, p. 6-7). There is a strong tendency for the regressions to over predict DO at low concentrations (Table 1).

Table 1. Freshwater inflow vs. DO regression models of the Lower Hillsborough River. Frequency of over and under prediction of midday DO for observations ≤ 3 g O_2 m^{-3} as reported in Appendix G, Coastal Environmental (1997).

Station	Depth	Over predictions	Under predictions
2	surface	1	0
	1 m	3	0
	2 m	6	0
	bottom	6	0
3	surface	6	0
	1 m	11	4
	2 m	11	3
	bottom	10	5
5	surface	5	0
	1 m	11	2
	2 m	11	6
	bottom	13	10
6	surface	2	0
	1 m	12	1
	2 m	9	8
	bottom	9	7
7	surface	no values ≤ 3	
	1 m	10	1
	2 m	12	6
	bottom	13	6
8	surface	no values ≤ 3	
	1 m	6	0
	2 m	13	2
	bottom	11	3

Appendix I in the Coastal Environmental (1997) report develops regression relationships between the depth of maximum salinity change and the rate of fresh water inflow, and between the depth of maximum DO change and the rate of inflow. The report claims that these relationships indicate the pycnocline is deeper with higher rates of fresh water inflow. While this interpretation appears reasonable, the data do not support the conclusion. For example, at Station 8 the pycnocline can be relatively deep at low, medium, or high flows. It seems odd that there was no attempt to relate the strength of vertical stratification (bottom density - surface density) to the rate of fresh water inflow. That would have been a more useful analysis, even though the vertical density measurements are not as detailed as desirable.

The Coastal Environment (1997) report used DO - flow regressions to calculate changes in habitats in the river as a function of fresh water discharge (Table 7.3, p. 7-4). Aside from the problems with the regressions themselves, this analysis seems flawed because habitat change is based on predicted DO changes at 1 m depth. No justification is given for using this depth. Oxygen problems are restricted to sub-pycnocline waters and the pycnocline is often below 1 m. The choice of 1 m makes it appear there is no change in low DO area when going from 0 to 10 cfs discharge, but an increase in hypoxia (2 - 4 g m^{-3}) when going to 20 or 30 cfs. When combined with the prediction of an increase in low salinity (0 - 4 psu) habitat when going from 0 to 10 cfs, these results seem to lead directly to a clear choice of 10 cfs for the minimum discharge. Even though this analysis wasn't specifically cited among the reasons for the choice of 10 cfs as described by SWFWMD (1999), it could have influenced the decision. If this is the case, a poor analysis contributed to the decision. If one wanted to accept the flow - DO regressions and adjustments as valid, the more meaningful low DO habitat criteria would be changes in near-bottom water DO. Even within the context of the flow - DO regressions, the regressions for 1 m were not significant for Stations 7, 8, or 9 and the r^2 for 1 m was < 0.5 at Stations 5-9 (p. 6-7).

Salinity Modeling

General comments

To complement the field data collected on the Hillsborough River and to investigate alternative reservoir operating policies, Dr. Xin Jian Chen created a two-dimensional hydrodynamic model of the Lower Hillsborough River. This model is summarized in the technical report (SWFWMD 1999) and documented in Appendix O of that report. The model is defined as a laterally averaged model that is solved using a finite element method. Two data sets were used to calibrate the model, one from September 1981 through August 1982 and a second set describing June 1997. This data set contained data on 15-minute increments.

The LAMFE (Laterally Averaged Model for Estuary) was developed specifically for this application. The model makes use of conventional continuity, momentum, and salinity equations, which are solved using a finite element method. The model is programmed in FORTRAN 77; however, source code for the model was not made available for review.

There are typically three stages for the deployment of a computer model for use in evaluating water resource modeling: verification, calibration, and validation. The process of verification implies that the model is functioning as the designer intended and that it can produce results that correspond to those that would occur in simple, theoretical settings. Calibration is the process of comparing model results to data collected in the field and modifying model parameters to improve the correlation between model results and data for a specified data set. Validation is the process of using the "calibrated" model to generate estimates of system response and comparing those to field data. In the validation process model parameters are not modified to improve the correlation between generated and observed data.

The LAMFE model was parameterized for the Hillsborough River data set. It was then tested for simplified, steady state conditions and other situations. The quality of these results is not reported in the documentation

The LAMFE model was calibrated using real-time stage data at 15-minute intervals collected by the USGS at Platt Street, Sligh Avenue, and 22nd Street from September 1981 through September 1982. It is not clear if the calibration process was distinguished from the verification process. Figure 7, in Appendix O, presents an example of the ability of the model to replicate field observations. In that figure, the model is shown to underestimate field observations at 22nd Street, while overestimating field observations at Columbus Drive.

Specific comments

In Appendix B (of Appendix O) comparisons are presented of the simulated and measured surface elevations in the Hillsborough River. The model appears to have performed well in reproducing the elevations, although some deviations are clearly present. Two months of data were presented in each graph making comparisons somewhat difficult. Simulated and measured salinity is also presented in this appendix. There is considerable deviation between the two, although most simulated data are within 2 psu of the measured data.

Forty-five scenarios were defined for investigation of salinity levels as a function of the amount of water released from the Hillsborough River, the amount of release from Sulphur Springs, and the amount of Sulphur Springs water pumped to the dam face. The volume of water at various salinity ranges was presented (Table 1 in Appendix O) as well as graphs of the salinity distributions as a function of distance downstream from the dam face. In general, the presentation of results is clear, and the impacts of releases from the dam can be determined, particularly at high rates of releases from the dam.

Following the Public Meeting held in Tampa, Dr. Chen provided supplemental runs of the 2D hydrodynamic model for the Lower Hillsborough River. These runs were made specifically to illustrate the impacts of various reservoir releases and rerouting of the Sulphur Spring water to the base of the dam. These runs were divided into two categories, the first with Sulphur Springs flows set at a constant 31 cfs, and the reservoir releases varied from 0 to 30 cfs by increments of 2 cfs. The second set of runs were made in which a constant release of 31 cfs is considered, where the Sulphur Springs water is pumped to the dam face, in intervals of 2 cfs, and the remainder of the flows of Sulphur Springs are made at their current location. The results of these runs are very interesting and revealing (Chen 1999). Each set is discussed below.

Set 1 - Current Sulphur Spring Flows and Increments of 2 cfs at the Dam Face

The first set of 16 runs of the model simulated salinity under releases from the dam at 2 cfs increments and unaltered flows from Sulphur Springs. Four of the runs with releases at 0, 10, 20, and 30 cfs provide useful information to predict extent of oligohaline habitats with respect to flow rates. Increasing flows in this low range has a significant and incremental impact on the location of the salinity of the first 5 kilometers downstream from the dam. As the release is increased from 0 to 10 to 20 to 30 cfs, the portion of water that has salinity values less than or equal to 1 psu increase significantly downstream. At 30 cfs, the portion of water at less than or equal to 1 psu extends to approximately 3 km, at 20 cfs, that contour extends to 2 km, at 10 cfs it extends to approximately 0.75 km, and at 0 cfs, there is no 1 psu contour. Similarly, the region for which the total depth of the water column is less than or equal to 4 psu extends to 2.6 km at 30 cfs, to 1.75 km at 20 cfs, to 0.9 km at 10 cfs.

Set 2 - Sulphur Spring Flows Pumped to Dam Face at 2 cfs Increments

The second set of 15 runs simulate zero flow from the dam, and incremental flows pumped from Sulphur Springs. The changes in salinity structure are significantly less dramatic. Moving an increasing amount of Sulphur Springs water to the dam face does have an impact, particularly in the first km downstream from the dam face, but the impact is relatively minor beyond 1 km. Moving all of the Sulphur Springs water to the dam face results in a salinity profile for the first 5 km that is similar to leaving the Sulphur Springs releases at their current location and releasing 4 cfs at the dam face.

Summary Comments

From these runs (Chen 1999) it is clear that there is a relatively smooth transition in the salinity profile as the releases from the dam are increased, that is, incremental dam releases provide incremental improvements in the salinity profile. There does not appear to be any breakpoints in this analysis. The decision on the appropriate instream flow value could be based on the distance downstream, and the depth, that low salinity water is desired.

Fish and Wildlife Distributions

General comments

The fish and wildlife distributions in this tidal river are important because they define freshwater and oligohaline assemblages that can be influenced by the minimum flow rule. Tidal rivers are defined as water bodies that receive freshwater from areas other than runoff (from the upstream watershed), are flushed to some extent during a tidal cycle and are subject to salt intrusion from downstream areas (Hackney et al. 1976). These important tributaries are part of the estuarine landscape that is known for its biodiversity and productivity worldwide (Gunter 1967, Szedlmayer 1991, Peterson and Ross 1991, Wagner and Austin 1998).

Many estuarine-dependent fishes and crustaceans like snook (*Centropomus undecimalis*), red drum (*Sciaenops ocellatus*), and pink shrimp (*Farfantepenaeus duorarum*), for example, utilize all or a portion of tidal rivers as nursery habitat. These estuarine-dependent transients, tidal river residents like members of the families Atherinidae (silversides), Cyprinodontidae (killifishes) and Poecillidae (livebearers), and secondary freshwater species like sunfish and black basses (Centrarchidae), and catfishes (Ictaluridae) comprise the fish fauna of low salinity tidal rivers. There is a strong relationship between salinity and size in a great number of estuarine-dependent transient fishes and crustaceans in estuaries and coastal ecosystems (Sykes and Finucane 1966, Rogers et al. 1984, Szedlmayer 1991, Killam et al. 1992, Coastal Environmental 1992, Peebles and Flannery 1992, Wagner and Austin 1998), indicating that young developmental stages of organisms are found abundantly in low salinity habitats.

The District indicates (p. 4.34) that creating a freshwater zone below the dam would support reproducing populations of invertebrates that characterize other tidal freshwater reaches of the bay. Subsequent survival and reproduction of these invertebrates throughout the year might stabilize the food webs below the dam which may allow for higher production of fishes and wading birds. These more stabilized populations may also extend downstream during the wet season. Although they call for a permanent freshwater zone, they indicate "...even a small freshwater zone would represent a significant change from the existing condition."

The overall intent of the District in developing the minimum flow for the Lower Hillsborough River was to "reconnect" the upper and Lower Hillsborough River during the entire year, focusing on the dry season (November-June). Their goal was to "...evaluate various flows of fresh or near-fresh water on the downstream ecosystems" (p. 1.2). Continued quality and quantity of freshwater input from above the dam are important factors in marsh and Tampa Bay productivity, and contribute to the near shore productivity as well. Freshwater inflow not only dilutes saline tidal waters but transports nutritive, organic, and sedimentary materials that promote productivity and maintain marsh environments, while diluting pollutants. Reduction of freshwater flow to estuaries can cause reduced fishery resource production via increased salinities, reduced mixing and increased stratification, intrusion of marine predators, parasites, and diseases upstream, groundwater contamination, increased hypoxia, and loss of euryhaline plant and animal species characteristic of estuarine habitats to name a few (Longley 1994).

The majority of information provided in the District's plan is on estuarine-dependent fishes and benthos, with less import on freshwater, marine or other wildlife (birds) species. Although they indicate maintaining a permanent freshwater segment of the Lower Hillsborough River may be important for wading birds, resident freshwater fishes and invertebrate prey, they did so only in a cursory manner.

Manatees typically utilize freshwater spring habitats throughout Florida due to the constant water temperature in winter months. In Tampa Bay, Lewis and Estevez (1988) indicated that Patton (1980) found that the number of manatees varied seasonally but peaked in winter aggregating around industrial thermal discharge areas and also noted aggregations around the mouth of the Alafia River. Janicki et al. (1995) also noted manatees in seagrass beds (> 10 psu) in Tampa Bay but they did not note them in any of the other habitat types examined, although on the initial site visit, Tony Janicki indicated that manatee do enter the Lower Hillsborough River in winter. In a review of the known data available on manatees, Killiam et al. (1992) noted that 8% of the estimated 1856 manatees in the United States were found in Tampa Bay in winter and there were 12 areas (power plants, fertilizer companies, and bayous/rivers) within Tampa Bay that provide critical habitat including the Hillsborough River. In Tampa Bay, manatees aggregate in these relatively warm areas when temperatures are consistently below 20°C (December-February); thermal mortality rates increase in colder water (Killiam et al. 1992). There are three critical manatee environmental requirements: 1) warm waters in winter, 2) fresh water for drinking, and 3) abundant seagrass for food (reviewed in Killiam et al. 1992). During their winter residency period, manatee typically feed on submerged and floating aquatic macrophytes in these tidal freshwater habitats (Killiam et al. 1992), but they have been noted to feed on macroalgae near the Alafia River mouth (Lewis et al. 1984) and cordgrass, *Spartina alterniflora*, in coastal Georgia (Baugh et al. 1989). Baugh et al. (1989) report other studies indicating manatee feed on alternate vegetation in the absence of submerged and floating macrophytes in Georgia and Florida.

One of the recommendations of the Hillsborough River and Palm River/Tampa Bypass Canal Minimum Flows Advisory Group (see Appendix N-1-4 and p. 3.3) is to evaluate the impact of the diversion of Sulphur Spring water to the reservoir on manatees and changes in water quality. Given that the dry season in the Tampa Bay area is between November and June (p. 2.8) and is characterized by low water levels, minimal to no-flow conditions, and reduced water quality in the Lower Hillsborough River, removal of all or part of the spring water may adversely influence use of this area by manatee. During winter months, manatees may visit Sulphur Springs due to its constant, warmer temperature and if this water is diverted above the dam, its thermal influence may be reduced or eliminated and thus may affect use of this habitat by manatee. Given the 1) already estimated reduction in flow of Sulphur Springs from historic average flows of about 40 cfs to about 31 cfs (p. 2.4), 2) current periodic water withdrawals and 3) current poor water quality, additional withdrawals from Sulphur Springs may result in worsened water quality if all or most of the flow is diverted.

Based on the salinity profiles provided in Figures 5.1 - 5.14, leaving Sulphur Springs flow natural and providing 10 cfs at the dam would provide a reduced salinity structure in the area of the Spring compared to other alternative models, except when flows at the dam are greater. Diversions from Sulphur Springs were not as effective at increasing the volumes of waters less < 1 psu, due to the spring water having a salinity of 1.2 psu (p. 6.3). However, diversions may reduce the vertical salinity profile near Sulfur Springs (p. 6.3), although salinity values may be higher due to use of data upstream and downstream of the springs (p. 3.4). Although the plan does not specifically discuss how their suggested 10 cfs affects manatees, it does evaluate its influence on water quality issues. These water quality issues are pertinent to the manatee issue.

Dissolved oxygen concentration patterns in aquatic systems can be severely altered by habitat modifications and subsequent stratification coupled with increased nutrient loads (Odum

1970, Stanley and Nixon 1992, Sklar and Browder 1998). Dissolved oxygen profiles are further influenced when water temperature increases, stimulating stratification and vertical segregation of water masses. In the Little Manatee River, Florida, Peebles and Flannery (1992) noted that freshwater discharge displaces phytoplankton downstream but when flow rates are low and nutrient concentrations are elevated, phytoplankton biomass becomes elevated, which can result in elevated respiration of primary consumers and caused hypoxia. This occurs particularly when water is static and not flowing downstream. Metcalf and Eddy (1983) also suggested that the effects of the sediment oxygen demand on dissolved oxygen would be most pronounced under low flow conditions. These events individually and cumulatively alter the nursery function of estuaries. Low oxygen has been shown to influence distribution and abundance of fish and crustaceans in the Gulf of Mexico (Renaud 1985) and Chesapeake Bay (Breitburg 1992) but its influence can affect sessile and mobile organisms differently. For example, Renaud (1986) experimentally determined that white (*Litopenaeus setiferus*) and brown shrimp (*F. aztecus*) can detect and thus avoid hypoxic waters. Pihl *et al.* (1992) determined that hypoxia modified diet of fishes in Chesapeake Bay because they were able to eat moribund benthic organisms, which may change the energy flow in estuaries. Additionally, Pihl (1994) noted a dietary shift in demersal fishes in Sweden because of changes in species composition of benthos due to hypoxic bottom waters. They indicated that repeated hypoxic stress might favor small-sized prey with a short life cycle, which would in turn favor small-sized fishes. Finally, Breitburg *et al.* (1997) determined that trophic interactions in Chesapeake Bay were modified in low but not lethal conditions in that predation on larval fishes increased by sea nettles (a jellyfish, *Chrysaora quinquecirrha*) but decreased by juvenile striped bass (*Morone saxatilis*). These modified trophic interactions indicated variation in species physiological tolerance to low dissolved oxygen, the effects of low oxygen on escape behavior of prey, and swimming and feeding behavior of predators. These field and experimental data clearly illustrate the influence of low dissolved oxygen on both fishes and invertebrate prey.

Peebles and Davis (1989) and Peebles and Flannery (1992) determined benthic resources probably play a greater role as food for young fishes than do water column resources in the Little Manatee River, Florida. Given the clear interplay between low dissolved oxygen and trophic interactions of estuarine organisms, and the apparent strong linkages between fish predation and benthic resources in the Tampa Bay area, one cannot simply discuss the influence of low oxygen on fishes without also focusing on their prey. The vertical oxygen profiles given in the report coupled with longitudinal profiles along the Lower Hillsborough River illustrate the complexity of this issue.

Naturally flowing tidal rivers are critical-habitat for a great number of species of differing ecological histories (Peterson and Meador 1994). To maintain tidal river biodiversity and productivity, these ecosystems must be preserved in a natural state that allows for the coupling of upstream and downstream segments. However, the Hillsborough River has been severely impacted over the past century and a number of nonnative fishes can be found in the upper, more natural, portion of the system as well as in the Tampa Bay Bypass Canal system (Barnett 1972, Attardi et al. 1982, Water and Air Research 1989). Additionally, there is concern (WAR/SDI 1995) that salinity gradients should be varied so as to not create a "habitat bottleneck" which can be formed immediately downstream of control structures (p. 8-6). While control structures impede upstream migration of fishes, potential environmental cues are still being delivered to these migrating fish over the structure which may create a situation where young fish are crowded into a small area where water quality may deteriorate causing death and disease, as well as starvation and increased predation. However, estuarine-dependent species typically only utilize these low salinity habitats for a relatively small portion of their life history, do not require permanent freshwater areas, and thus may not be "packed" into a habitat bottleneck as suggested above.

Seasonal variation in a number of abiotic parameters is a common pattern in estuarine systems. In fact, recruitment events of many estuarine organisms are timed to take advantage of this variability. For example, Sykes and Finucane (1966) determined that Tampa Bay species of commercial importance varied seasonally and spatially within the bay, which corresponded to seasonal salinity variation. Hughes (1969) determined that postlarval pink shrimp (*F. duorarum*) could perceive and respond to salinity changes as small as 1 psu. He found postlarvae were more active in high salinity and that in low salinity they dropped to the substratum whereas juveniles were positively rheotactic when "normal" seawater salinities were encountered, thus swimming against the current. When salinities were lower (ebb tide), juvenile pink shrimp swam downstream with the current. This mechanism facilitated offshore movement of the larger pink shrimp. These data illustrate the need to maintain normal freshwater flows from tributaries to bays for recruitment of this commercially important crustacean. Perez (1969) also determined that juvenile spot (*Leiostomus xanthurus*) and Atlantic croaker (*Micropogonias undulatus*) both responded to gradual rates of salinity change by increased swimming compared to fixed or severely fluctuating salinity conditions, allowing young fishes to move into areas in the estuary where salinity fluctuation was gradual or constant compared to severely fluctuating. Rogers et al. (1984) determined that individuals of several seasonal recruiting species (Atlantic flounder, *Paralichthyes lethostigma*, Atlantic menhaden, *Brevoortia tyrannus*, silver perch, *Bairdiella chrysoura*, and spot) appear to move preferentially to primary nursery zones at the most inland locations in Georgia, subsequently moving to deeper or more saline waters as they grow. Recruitment was timed to spring freshwater flows into the marsh. In the Tampa Bay area, Peebles and Davis (1989) determined that peak spawning activity occurs between March and August in the Little Manatee River with early juvenile estuarine-dependent species (*C. undecimalis*, spotted seatrout, *Cynoscion nebulosus*, and *S. ocellatus*) concentrated in low salinity areas (> 75 % abundance in < 18 psu). This pattern was also noted for the greater Tampa Bay estuary by Coastal Environment (1992). Finally, Longley (1994) determined that estuaries are by definition dynamic and water management activities should attempt to parallel those dynamic patterns of freshwater inflow "...within the productive range, both seasonally and annually..." "The seasonal timing of freshwater inflows is most important because adequate inflows during critical periods of reproduction and growth can produce greater benefits than constant inflows throughout the year."

The District spent considerably more time with the "dynamic" component of this system than the "static" habitat template component of the system (*sensu* Sklar and Browder 1998). The District provided information about the nature of altered versus natural habitats throughout the river (p. 4.2) and indicated that only 4,070 linear feet (3.3 acres) of potentially restorable habitats were found in the Lower Hillsborough River, with 76% of the shoreline being hardened with riprap, bulkheads or fill (p. 2.4). There are no natural shorelines below the I-275 bridge, and about 89% of vegetated habitats are found above Rowlett Park bridge (p. 4.2).

Lewis and Estevez (1988), Zarbock et al. (1995), and Sklar and Browder (1998) have indicated that it is imperative to consider both static and dynamic overlays of environmental conditions, structural habitat, and resources in management considerations. In doing so, managers can get a better estimate of habitat parameters in space and time which will delineate those areas that are essential-habitat for young fishes and those that are highly productive. Thus, freshwater must be allowed to flow downstream such that low salinity overlaps with vegetated habitats, both of which are necessary for young of many species (Lewis and Estevez 1988).

More emphasis should be placed on integrating the vegetation and salinity gradient data along the length of the Lower Hillsborough River to better resolve and interpret the influence of these two important habitat components on habitat use by young estuarine-dependent fishes and possibly manatees. Given the lack of significant aquatic vegetation along the river at this time, consideration should be given to restoration of available areas above I-275 to maximize critical-habitats. Although the estuarine-dependent data provided indicate altered shoreline areas in the Lower Hillsborough River do provide critical habitat for some commercially important estuarine-dependent species (*A. mitchilli, S. ocellatus, and C. nebulosus*). The FMRI (p. 3.6) noted that because of their sampling technique associated with bulkheaded areas, their estimates may be high because it is easier to collect on a flat, hard surface relative to a natural marshy habitat. Indeed, Peterson *et al.* (2000) quantified changes in habitat use patterns in fishes and crustaceans in mesohaline to polyhaline estuarine habitats in Mississippi due to loss of emergent vegetation and physical habitat alteration (bulkheading, rip-rap). Similar abiotic conditions (i.e., salinity and D.O.) among sites were evident, but different CPUE of young fishes and crustaceans among sites were documented. These alterations of estuarine habitats individually and cumulatively alter the nursery function of estuaries (Odum 1970, 1982).

Specific comments

Relatively high numbers of some fishes associated with hardened structures may be biased because seines against a flat surface allow for less escape into marsh grass (p. 3.6).

Many of the studies used to address fishes did not sample in deeper waters of the Lower Hillsborough River for juvenile and adult fishes (Attardi et al. 1982, WAR, Inc. 1989, Peebles and Flannery 1992, WAR/SDI 1995). FMRI studies used 21-m bag seines with 3.2 mm mesh (<1.5 m depths) and 6.1-m otter trawls with 38 mm outer and 3.2 mm liner (1-7.6 m depths), 183-m bag seines with 38.5 mm mesh (< 2 m depths).

REVIEW OF MINIMUM FLOW DETERMINATION

Issues in Determination

The four main issues used in the determination of the minimum flow rule were: salinity measurements, DO measurements, salinity modeling, and suitable habitat for oligohaline species.

Using measured salinity to predict salinity under different flow regimes is problematic. The minimum flows advisory group of the Tampa Bay National Estuary Program (including Coastal Environmental) concluded that ". . . the empirical model cannot be used to reliably predict salinity levels in the river nor changes in salinity-based habitats due to dam releases when flows are greater than 0 cfs and less than 30 cfs" (SWFWMD 1999; Appendix N-1, p. 3). The apparently satisfactory r^2 values on the regressions must be due to the wide range of flow values and good agreement at high flow. The plots of predicted vs. observed salinity demonstrate little agreement at higher salinity (low flow). The regressions predict a narrow range of salinity values above 10 psu while the observations cover a wide range. The advisory panel was correct. These regressions should have no role in setting the minimum flow at 10 cfs.

Low DO conditions exist at certain times in the Lower Hillsborough River, but this problem is not likely to be resolved by a minimum flow rule. The approach in analyzing the DO data was reasonable and appropriate, except for a lack of attention to vertical density differences. Unfortunately, the desirable degree of vertical detail for density and DO is necessary. The DO data are not sufficiently well behaved or constrained to lead to, or support, a minimum flow of 10 cfs. Substantially higher flows may be required to change bottom DO values downstream.

The salinity model does provide information to predict flow levels needed to maintain salinities at ± 1 psu under certain conditions. Size of the <1 psu salinity zone, whether measured as a volume of water or distance downstream from the dam face, increases with increased flow from 0 to 30 cfs. The increase is incremental and there is no obvious breakpoint. However, absent a specific salinity habitat goal, these models by themselves do not suggest a minimum flow rule.

Estuarine-dependent species typically only utilize low salinity habitats (0 - 10 psu) for a relatively small portion of their life history and they do not require permanent freshwater areas. The key to managing severely altered ecosystems like the Hillsborough River is to create a salinity gradient of sufficient size (i.e., volume or reach) to benefit both secondary freshwater fishes, tidal river residents, and estuarine-dependent fishes such that biodiversity will approach a natural tidal river fauna. Overall, the objective stated in Section 4.7 (SWFWMD 1999, p. 4.34, first paragraph) is correct: "given the high salinity values that can occur near the dam during no discharge condition, even a small freshwater zone would represent a significant change from the existing condition." However, because a desired volume or habitat size is not stated as a goal in the technical document, it is not evident that 10 cfs is the appropriate minimum flow.

Summary of Determination

As stated in the determination section (SWFWMD 1999, section 6.4, p. 6.4), the minimum flow rule should provide improvements to the ecological characteristics immediately below the dam. The data presented demonstrate oligohaline habitats can be nonexistent with zero flows and a minimum flow rule would ameliorate this condition. The data also indicate that rerouting Sulphur Springs water to the base of the dam would not ameliorate the high salinity conditions during zero flow for two reasons: it's a "zero-sum game" in that new fresh water is not actually added to the system, and the salinity of Sulphur Springs water (at 1.5 psu) is too high to significantly dilute salt water. A minimum flow would provide a benefit by maintaining an oligohaline habitat, but the choice of 10 cfs appears arbitrary. There is no trail of logic linking the data sets examined to 10 cfs as the target instream flow. Seasonality is also ignored. It is not known if a minium flow is necessary or more valuable at different times of the year, but this is likely to be the case.

Because of the lack of a link between the data and selecting a 10 cfs minimum flow target, the rule should be considered an "experiment." The District's strategy of an iterative approach (adaptive management) is the best course to follow. An interim minimum flow should be established and monitored (with more attention to seasonality and vertical resolution than in the past). The choice of an initial minimum flow rate is inescapably arbitrary and a value above 10 cfs is almost certainly more likely to produce significant detectable change than the proposed minimum. The duration of the "experiment" should be short, with a reassessment after one year rather than the five years as proposed in the technical document (SWFWMD 1999, p. 6.4). The routine monitoring of DO, temperature, and salinity are relatively easy and inexpensive, and the data can be processed and analyzed rapidly. The more challenging problem is to decide on the goals of the minimum flow. Without a set of prioritized quantitative goals it will not be possible to use monitoring data to decide if the management "experiment" is successful or not.

The process of adaptive management requires a clear management goal (such as, maintaining 1 or 2 km of oligohaline habitat during certain seasons), monitoring (which can be restricted to the managed segment), determining if the expected changes are occurring (within an acceptable range of uncertainties), and reevaluation of the minimum flow rule on short-term intervals. Without knowing how much (or when) oligohaline habitats are required, there is no clear, compelling minimum flow rate. Therefore, setting the management goal will require evaluation of the biological communities and environmental setting, and policy decisions on which sustainable natural resources are to be conserved, protected, or optimized. Monitoring could be economical because the main variables of interest (DO and salinity) are inexpensive to measure. However, DO and salinity should be measured with better vertical resolution than in the past. This focused monitoring activity would allow for annual evaluation and refining of the minimum flow rule. In summary, it is best to engage in a process of stating goals and then using data to evaluate progress toward the goals.

RESPONSE TO CHARGE

The Charge to the Panel requested peer evaluations on three issues: the reasonableness of the methods used, which encompasses reasonableness of the data quality, assumptions, and procedures; to identify deficiencies in the methods or data; and to suggest other approaches or methods that could be used to set minimum flow rates.

Reasonableness

The quality of the existing information appears acceptable. Although there is scant mention of QA/QC protocols, the salinity and DO measurements are relatively standard, and it is taken on faith that the data presented are valid. Some concerns about fish and wildlife data were detailed above.

The general approach of the methodologies used was not clearly discussed in the technical document (SWFWMD 1999). Nor were assumptions explicitly stated. It is not clear what integrative method, or logic, was used to derive a minimum flow rate from the data presented. Each of the four methodologies (salinity measurements, DO measurements, salinity modeling, and suitable habitat for oligohaline species) was reasonable. But there was no clear linkage among the methodologies, nor was there a scientific basis or clear decision process that led from analysis of data to 10 cfs. The most significant problem was absence of a clearly stated, quantitative, management goal. In absence of a goal, it is impossible to determine if 10 cfs is adequate, because there are no criteria to judge it by.

The approach did not build upon methods used in other areas of the country. Generally, a management objective is stated, and a series of compartmentalized uncertainties quantified, so that the estimated response can be judged successful within an acceptable range of error.

Deficiencies

As stated many times previously, the lack of a quantitative management goal is a serious deficiency in the methodology and general approach. Most of the technical data and procedures suffer from only small errors as detailed above. However, there were several shortcomings that were more severe. The shortcomings are described below.

There was insufficient detail of vertical structure of the water column for salinity, but particularly for DO measurements. This can lead to large uncertainties in predictions because the Hillsborough River is highly stratified. It also leads to the tidal alias in the salinity data, where tidal stages at measurement masks or confounds the response measured. These errors were largely due to continuous measurements being taken at just mid-depth in the water column.

Temporal changes in salinity and DO data were largely ignored. Salinity likely has a strong seasonal signature, because long-term average rainfall varies seasonally. Natural flow rates vary from year-to-year, so the minimum flow must be based on the long-term range of conditions that exist in the system. It is necessary to identify the low and high ranges of inflow (at least to the 95% confidence level) and ensure that measurements are made to encompass those conditions. There also appears to be a strong diel signature in DO measurements that were not accounted for. In general, the minimum flow must account for temporal changes on scales of a day, season, and 100-year events.

The amount of fish in deeper water has not been adequately accounted for. This is especially important to define oligohaline habitats and the potential for the minimum flow rule to affect natural resources.

The dynamic model of salinity appears well conceived and executed. However, it is not apparent that the calibration and verification process were separate exercises.

Other Approaches

The main point being advocated in this review is that the District must set management goals and criteria first. To set the goal, the District must determine the nature of the problem that is being resolved. Unfortunately, there is no one flow rate that will solve all problems, some problems can't be solved with minimum flow rules, and any given strategy that optimize for a certain community does it at the peril of others. Once a goal is adopted, then data can be evaluated to determine the degree of certainty that the goals can be met. The goals should accommodate seasonality and vertical structure within the water column.

Determining the area of oligohaline habitat required is difficult. The District could compare salinity, dissolved oxygen and vegetation distributions under the proposed minimum flow parameters focusing on the importance of these habitat overlays to estimate area of utilization of fishes and benthos (*sensu* Sklar and Browder 1998).

Many different approaches have been taken to determine minimum inflows. For example, it might be desirable to protect sustainable resources. This general approach has been taken to set minimum flow for Texas estuaries (Longley 1994). It was policy to set flows to optimize production of seven species: white shrimp, brown shrimp, blue crab, bay oyster, red drum, spotted sea trout, and black drum. In general, policy decisions about which natural resources are to be sustained must be prior to inflow optimization studies. The scientists and engineers must know what they are trying to optimize. Policy decisions must be made on many different levels: which species to include, relative weighting of species, selection of inflow-response equations, and inflow constraints (i.e., acceptable degree of uncertainty).

In rivers of the northwest, minimum instream flows have been specified to provide a level of protection for the aquatic environment. Quantitative instream flow methods are generally based on historic flows, hydraulic conditions, and/or habitat protection (Jowett 1997). Historic flow methods rely on recorded or estimated flow regimes of the river and typically assume that some percentage of mean flow is needed to maintain a healthy channel ecosystem, but ecological factors are not considered explicitly. Hydraulic methods relate hydraulic geometry to discharge and most commonly use variation in wetted perimeters to specify flows (Reiser et al. 1989). River width is considered the primary indicator of food-producing area for a stream, and the general goal is to keep the channel full to maximize food production. Hydraulic methods are not generally used to determine seasonal flow requirements. Habitat methods maintain optimum levels of fish habitats to retain a percentage of habitats at mean flows, or to provide a minimum amount of habitats. The most common method in this group is the instream flow incremental methodology (IFIM), which allows consideration of factors that influence stream ecosystems (e.g., physical habitat, flow regime, and temperature) (Bovee 1982). Although habitat methods are well suited for takeoff situations, these methods may focus too closely on the habitat of the target species (Jowett, 1997). Also, these methods result in single-valued discharges that do not incorporate the sequence or seasonality of varying flows.

Methods for setting river instream flows have been criticized as overly simplistic by reducing complex ecosystem interactions. Richter et al. (1996, 1997) contend that traditional methodologies may not completely represent, or provide insight into, the complex and varied life cycles of instream species, biotic interactions, or geomorphic change. Furthermore, the role that hydrologic variation plays in structuring biotic diversity within river systems (Stanford et al. 1996) suggests that ecosystem integrity depends on maintaining or restoring some pattern of natural flow variability (Richter et al. 1996, 1997, Poff et al. 1997). In particular, high-flow and low-flow events may serve as limiting conditions that provide critical opportunities or stresses to a wide range of instream species (Poff and Ward 1989). Because flows outside the range of naturally-occurring minimum and maximum values may be detrimental to the instream ecosystem, many years of gage data may be needed to accurately describe a river's natural flow regime (i.e., the characteristic pattern of flow quantity, timing, and variability). More specifically, five components of the flow regime that may regulate instream ecological processes include magnitude, frequency, duration, timing, and rate of change of discharges (Poff et al. 1997). These components are thought to represent ecosystem health because they measure availability or suitability of habitats for specific life cycle requirements and influence the stress or mortality associated with extreme conditions such as droughts or floods and are included in an approach known as indicators of hydrologic alteration (Richter et al. 1996).

Recommendations for management options

The establishment of instream flow requirements is often based upon one of three methods, historic flow methods, hydraulic methods, and habitat methods. For the Hillsborough River, instream flow requirements are being proposed based on estimates of salinity and the argument that 10 cfs is a larger value than that which has been released regularly during the past twenty years.

It is of value to view this question from a decision theory perspective. There appears to be little scientific evidence that 10 cfs is the "correct" value. As noted in the July 29, 1998 Proceedings of Public Hearing of the Southwest Florida Water Management District, higher flows would improve water quality and salinity in the river. In cases where the scientific evidence does not provide precise management solutions, evaluation of several alternatives is appropriate. One option is releasing 10, 20 or 30 cfs from the dam, and for each of these flows evaluate improvements to or impacts on water quality, and the probability that such releases would result in these impacts.

The District would benefit by adopting an adaptive management approach as suggested in the proceedings. The initial minimum inflow rule should be viewed as an experiment. For example, setting multiple instream flow targets that are a function of watershed conditions is used throughout the Western U.S. Triggers for shifting between these targets can present challenges. Monitoring the effects of the rule will provide data to fill existing data gaps, and more information to make optimal decisions in the future. The rule can then be changed on short time scales to take advantage of new information as it becomes available. The key is a strong monitoring program to demonstrate that environmental benefits expected by adopting the minimum flow rule are obtained. The advantage of this adaptive approach is the ability to supply more water to the river when it is possible and to share shortfalls more equitably between urban water demands and the river when necessary.

The District should modify their plan to consider seasonally minimum flows that would parallel seasonal flows in natural tributaries of Tampa Bay. These flows must consider the seasonal uses of these habitats by various organisms for reproduction, overwintering, or foraging. For example, some invertebrates cue on large drops of salinity to initiate spawning, and in winter manatees enter tributaries.

Two construction projects should be considered. Aeration of water before discharge from the dam (p. 6.4) would improve conditions for fish and wildlife. Marsh plant buffer zones could be constructed near the 114 runoff out falls to naturally filter runoff.

Recommendations for future monitoring

The District would benefit by monitoring the effects of the minimum flow rule. The minimum flow is likely to primarily affect oligohaline habitats near the dam. For this reason, monitoring should focus on the upper 3 miles of the River. Future monitoring should strive to more fully resolve vertical profiles of dissolved oxygen (DO) and density structure. This type of sampling is routinely achieved with readily available technology. Continuous recording meters for DO, salinity, and water level should be placed at the bottom and just below the lowest low tide levels. Two depths, rather than one mid-depth location, are needed to assess the vertical stratification of salinity and DO as a function of low flows. Ideally, meters would be placed at three locations with varying distance from the dam. Flow meters at each location are also necessary to calibrate salinity models at low flow. A QA/QC program should be developed for all instrumentation, so there are no intercomparability issues to resolve and quality of the data is above question

In addition to continuous recorders, site visits should be conducted to monitor the length of the River to determine downstream effects. Sampling trips should be planned to sample at the same time of day and same tidal stages at each location. This would avoid confounding salinity measurements with tidal cycles on sampling days. If it is desirable to monitor DO, planning field trips will be difficult. Short trips bracketing midday over several days could account for large diel changes in DO. Alternately, the District must recognize that DO measurements over the length of the River are confounded with time of day.

The dynamic salinity model is a useful tool for choosing monitoring locations. Certain geographic localities are predicted to be at transition zones during minimum flow events, and data from these locations are the most valuable. The data would also be useful in refining the dynamic model as well.

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