SCIENTIFIC PEER REVIEW OF HYDROBIOLOGICAL MONITORING PROGRAM IN FIVE WATERBODIES POTENTIALLY AFFECTED BY TAMPA BAY WATER SUPPLY PROJECTS

Scientific Peer Review Report

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Scientific Peer Review of Hydrobiological Monitoring Program in Five Waterbodies Potentially Affected by Tampa Bay Water Supply

EXECUTIVE SUMMARY

The Scientific Peer Review Committee (the Committee) was generally impressed by Tampa Bay Water's long-term investment in comprehensive monitoring data. This effort allows Tampa Bay Water to verify compliance with special conditions its water use permits and with the Minimum Flows and Levels (MFLs) established by the Southwest Florida Water Management District for the Hillsborough River, the Alafia River, and the Tampa Bypass Canal. Other water bodies included in the Hydrobiological Monitoring Program (HBMP) include McKay Bay and Hillsborough Bay, important parts of the greater Tampa Bay and Estuary complex.

The Committee agrees with the HBMP finding that changes in the shallow-water distribution of estuarine-dependent fishes and invertebrates are related to freshwater inflow. Increasing freshwater discharges attract these organisms, particularly the young-of-the-year, into areas such as the Hillsborough and Alafia Rivers that provide nursery habitats (i.e., food and cover) in which they can survive and grow. However, the generally weak statistical relationships found between inflows and the abundances of major fish and invertebrate species, as described in the District's MFL reports for the Lower Hillsborough River (SWFWMD 2006) and the Lower Alafia River (SWFWMD 2007), indicate that other physical, chemical and biological conditions are limiting biotic production in these rivers. These factors were discussed in detail by the District, leading to the conclusion that these rivers chronically suffer from algal blooms and low dissolved oxygen concentrations. Complicating matters, there are strong seasonal cycles in temperature, salinity and dissolved oxygen, related to the cooler, dry (winter-spring) seasons versus the warmer, wet (summer-fall) seasons.

The Committee finds that there is ample monitoring data showing that dissolved oxygen, especially near the bottom, frequently results in undesirably low (hypoxic) conditions in some areas of these rivers, blocking migration and increasing mortality of inhabiting fish, shellfish and other organisms. This makes monitoring for *in-situ* water quality parameters like salinity, temperature, dissolved oxygen and chlorophyll-*a* just that much more important. In addition, this situation is unlikely to change without effective implementation of a total maximum daily load (TMDL) program or similar effort that includes watershed controls and better management of stormwater drainage.

Any efforts to adjust and refine the monitoring program will need be done with a judicious hand. The Committee does not want to see the past data mothballed under a new HBMP design. Rather, we call for a renewed effort to mine the existing data for its embedded secrets. To that end, we recommend that significant resources be put into analyzing the data for times series and covariance with flows and withdrawals. This may be the only way to differentiate the impact of water use from other impacts, both natural and man-made. The Committee agrees that Tampa Bay Water should avoid simply repeating analyses that have been done previously with little success in identifying statistically useful relationships. Further, the Committee believes that the analyses have been more limited than the data has been at this point in the long-running HBMP.

In the meantime, the Committee also recommends that Tampa Bay Water consider modifying the existing probability sampling program to bolster the targeted, near-continuous monitoring component that is essential for compliance with water use permits. Further, if the future monitoring program is to rely more on fixed station design, it is even more important to ensure that these sites are representative of the specific ecosystem being monitored or that they are located at important hydraulic control points within the system. The Committee believes that if water withdrawal impacts are not detectible in the water quality data of these warm, nutrient rich water bodies, then they will almost certainly not be detectible in the biological samples either. The Committee notes that this is not always the case under extreme oligotrophic conditions, where nutrients can be so low that effects can **only** be seen in biota, which is why scientists often use nutrient loading as an important system metric.

Finally, there is the larger issue of freshwater inflows to Hillsborough Bay, a secondary bay of the Tampa Bay Complex most often containing mesohaline water and exhibiting estuarine function due to inflows from rivers (i.e., Hillsborough and Alafia) with the largest watersheds in the entire Tampa Bay region. The District's evaluation of water supply withdrawals allowed under the proposed MFL rules indicates that the withdrawals will constitute only a small percentage of the freshwater resources to Hillsborough Bay. The Committee agrees that these withdrawals are not likely to produce any "significant harm" to the Bay's ecological health and productivity, but continued monitoring to verify that outcome and detect changes is still warranted in the future.

Committee Recommendations

Tampa Bay Water's goals, indicators and definitions, as developed and explained in the 2010 update report (PBS&J 2011), seem reasonable and appropriate. However, the Committee believes that after a decade of sampling under the HBMP, a structured and systematic evaluation of the HBMP is needed. This review should be primarily conducted internally with other stakeholders in the HBMP, and should be facilitated by some independent oversight (peer review).

A tool that has been used successfully elsewhere to facilitate monitoring program evaluation involves the development of a conceptual model showing the direct and indirect effects of water withdrawals. These are sometimes followed with factor-train analysis or other techniques to refine the stimulus-response linkages and help develop the accompanying model narrative. Moreover, the thoughtful development and use of conceptual models provides information about ecosystem linkages, facilitates the identification and testing of hypotheses, and helps communicate to the public why the HBMP is important to people and their environment in the Tampa Bay area.

Major elements of this evaluation should include:

- Review of goals – which ones are valid now and which agency owns each goal.

- Conceptual model development and identification of testable hypotheses/questions (Note: this process provides an avenue toward agreements on the questions, including who owns each question). Feedback loops are critical and may have to be addressed in special studies beyond the HBMP monitoring.
- Systematic analysis of existing data and evaluation/optimization of the sampling design. The HBMP is typical of some other large-scale monitoring efforts that are frequently data rich and information poor, or at least not as informed as expected after all the effort. The focus of the analytical activities should be to refine and validate the conceptual model and address as many of the testable questions as possible. These questions should be developed in conjunction with any new modifications to the existing HBMP. The Committee believes that it may be possible to fully address and dismiss some questions with the existing data.
- The development of an index for macrobenthos and fishes in wet, dry, and normal years.
- A revised monitoring/sampling design based on results from the elements above, which includes consideration of a routine process of peer review and updating of the HBMP.

The Committee understands that Tampa Bay Water and its HBMP is not responsible for and does not "own" all of these monitoring/sampling elements and scientific studies. This means that any reasonable chance of success in resolving the scientific issues associated with freshwater inflows to the Tampa Bay Complex and maintaining the ecological health and productivity of the water bodies of interest here will depend on the support of cooperating agencies as well.

INTRODUCTION

The Southwest Florida Water Management District (the District) is mandated by Florida statutes to establish minimum flows and levels (MFLs) for state surface waters and aquifers within its boundaries for the purpose of protecting the water resources and the ecology of the area from "significant harm" (Florida Statutes, 1972 as amended, Chapter 373, §373.042). Once set in the District's rulemaking process, MFLs become important operating standards for water suppliers, such as Tampa Bay Water and its water use permits (WUPs). The monitoring required by the District's permits involves Tampa Bay Water detecting environmental changes and evaluating the potential for "significant harm" from water withdrawals, but not from other users or polluters. The original (2000) HBMP design group considered what might constitute an unacceptable environmental impact from permitted withdrawals as follows:

> *A detected change, supported by statistical inference or a preponderance of evidence, from the pre-operational abundance, distribution, species composition, or species richness of biological communities of concern in the Lower Hillsborough River, Lower Palm River/TBC, McKay Bay, or Lower Alafia River reporting units that can be attributed to reductions in freshwater inflows caused by the permitted surface water withdrawals.*

BACKGROUND

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

Inflow-related changes in estuarine conditions consequently can affect living estuarine resources, both directly and indirectly. Many estuarine organisms are directly linked to salinity: the distribution of plants, benthic organisms and fishery species can shift in response to changes in salinity (Lippson et al. 1979, Drinkwater and Frank 1994, Ardisson and Bourget 1997). If the distributions become uncoupled, estuarine biota may be restricted to areas that are no longer suitable habitat for their survival, growth and reproduction. Potential effects of human activities, particularly freshwater impoundment and diversion, on the adult and larval stages of fish and invertebrates include impacts on migration patterns, spawning and nursery habitats, species diversity, and distribution and production of lower trophic (food) level organisms (Drinkwater and Frank 1994; Longley 1994). Changes in inflow, especially from large impoundments and water withdrawals, will also affect the delivery of nutrients, organic matter and sediments, which in turn can affect estuarine productivity rates and trophic structure (Longley 1994).

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

District's MFL, along with some of the underlying biological studies that support the percent-of-flow approach, is detailed in Flannery et al. (2002).

<u>Water Bodies of Concern</u>

Drinking water withdrawals by Tampa Bay Water have the potential to impact the following ecosystems:

- Alafia River,
- Hillsborough River,
- Tampa Bypass Canal/Palm River,
- McKay Bay, and
- Hillsborough Bay.

The Committee understands the basic environmental condition of each water body to be variable and has summarized them below with HBMP recommendations, some of which involve switching from randomized sampling to use of more fixed stations where variability can be better understood and segregated into impacts from Tampa Bay Water withdrawals versus the combined impacts from other ecosystem stressors (e.g., drought and pollutant discharges).

Alafia River

The Alafia River is a hypereutrophic (excessively nutrient rich) ecosystem that is self regulating and will maintain hyper-eutrophic conditions for some time in the future. The Committee understands that there are a large number of discharges within the watershed, which suggests the need to collect additional information relative to municipal, industrial and agricultural activities in the watershed. While this monitoring is beyond the HBMP, Tampa Bay Water should consider some assessment periodically in defense of its water supply responsibilities, which could be jeopardized by the watershed activities of others.

Significant wetlands occur along its shores (natural and restored) although residential dredge and fill operations have decreased the amount of wetlands in the lower river. Flow and morphology are largely natural except for a portion of the river near the mouth that has experienced significant dredging. The Alafia River is characterized by a natural salinity gradient that shifts up and downstream with increasing and decreasing flows in a predictable manner. Significant amounts of mostly shallow shoreline habitats exist for all salinity zones and flow conditions. As a result, some relatively strong relationships exist between the distributions of biological resources and the amount of critical habitats.

Recommendation: Monitoring program elements should be maintained in the Alafia River in the future with sampling of biological resources concentrated in index periods. Vegetation mapping by aerial photography with ground truthing and shoreline surveys may safely be reduced to once every 10 years, or as needed, because of the generally slow landscape response times to incremental changes in flows. The Committee understands that the analyses included in the 2012 Interpretative Report are being prepared to meet permit compliance requirements. However, there is still an additional study needed to focus on identification of potential fixed sampling sites for locating continuous-recording in-situ water quality instruments and optimization of the biological sampling program, including identification of appropriate index periods for sampling macrobenthos and fish/nekton. Continuous-recording in-situ measurements of water quality (potentially including salinity, temperature, pH, dissolved oxygen [DO], turbidity, chromophoric dissolved organic matter [CDOM], and chlorophyll-a) may be particularly valuable for improved modeling to predict the impacts of water management activities in the watershed, including water use withdrawals. It may also be the only data with enough resolution to detect the small changes arising from water withdrawals versus the larger combined impacts of weather and pollutant discharges in the watershed.

Hillsborough River

The Hillsborough River is a highly urbanized riverine estuary that receives large amounts of urban runoff and associated pollution loadings. Much of the shoreline is hardened and natural wetlands are largely non-existent. The Hillsborough River flow regime is highly managed to control flooding and provide drinking water for the City of Tampa. Low salinity nursery habitats are maintained in the upper reaches of the Hillsborough River by pumping freshwater from Sulfur Springs and other sources to the base of the dam and reservoir. Water in the Hillsborough Reservoir is often of very poor quality with large plankton blooms. Macrobenthic samples that were collected in January, February, March, July, August, and September from the Hillsborough River have been processed; whereas, samples collected in other months have been archived. Unfortunately, the time periods of greatest macrobenthic abundances and highest probability of meaningful relationships with flow include months (April and May) for which samples were not processed. As a result, relationships between taxa and abundances of macrobenthos and flow are relatively weak. Relationships between the abundances of fish and nekton are also relatively weak. Maintaining the existing monitoring scheme in the Hillsborough River is unlikely to provide additional information about the condition of this ecosystem.

Recommendation: Monitoring in the Hillsborough River probably should be reduced to continuously monitoring in-situ water quality (potentially including salinity, temperature, pH, DO, turbidity, CDOM and chlorophyll-a) at key locations to ensure that brackish and low salinity habitats are maintained in the river below the dam and reservoir. If sampling of juvenile fishes continues, the Committee recommends sampling only during a spring index period. Some of the remaining resources previously allocated to the Hillsborough River could be expended on analysis of existing HBMP data and identification of fixed representative sites for the continuous water quality monitoring installations.

Tampa Bypass Canal

The Tampa Bypass Canal (TBC) is a federal (USACOE) flood control structure constructed by excavating the entire lower Palm River, greatly widening and deepening the channel to reduce flooding impacts on the City of Tampa. The salinity gradient is weak with much of the TBC having a relatively uniform high mesohaline to polyhaline salinity, except during periods of high rainfall and flooding when it can be completely washed out with freshwater runoff. Water quality in the TBC is generally poor with anoxic and hypoxic conditions existing in waters greater than 2 m in depth, especially in the upper portions of the canal. Vertical stratification of the water column is prevalent in the canal, but not in the receiving water body, McKay Bay, because of its larger water volume and better tidal circulation. DO levels in the TBC decline with increased flow due to increased water column stratification associated with higher flows. Maintaining the existing monitoring scheme in the Tampa Bypass Canal is unlikely to provide additional information about the condition of this ecosystem.

Recommendation: Monitoring in the Tampa Bypass Canal should be reduced to continuously monitoring in-situ water quality (potentially including salinity, temperature, pH, DO, turbidity, CDOM and chlorophyll-a) at a couple of key locations upstream and downstream in the TBC. Identification of key fixed locations for continuous water quality monitoring should be an objective of any additional analysis of historical HBMP data.

McKay & Hillsborough Bays

Estuarine habitats in Hillsborough Bay, a secondary bay of the greater Tampa Bay system, and in McKay Bay, a tertiary nursery bay, have been radically altered through urbanization and industrialization associated with development and growth of the City of Tampa. Both bays currently serve as centers for industry and shipping. Most of the channels are maintained by dredging and few natural wetlands remain. Substantial portions of these systems have been classified as having degraded sediment and water quality associated with long term pollution loadings and urbanization processes (U.S. Environmental Protection Agency 2004). Ecosystem conditions in Hillsborough Bay are not directly related to drinking water withdrawals and, thus, Tampa Bay Water probably should not be conducting any monitoring in the bay area without a better rationale for the expenditures. Maintaining existing monitoring activities in McKay Bay is also unlikely to provide additional information about the condition of this ecosystem, although McKay

Bay has the potential to be restored by conversion of causeway to bridge areas and increasing connectivity and flushing.

Recommendation: Monitoring activities in McKay Bay should be reduced to continuously monitoring in-situ water quality (potentially including salinity, temperature, pH, DO, turbidity, CDOM and chlorophyll-a) at key fixed locations (i.e., index sites) identified through analysis of the existing data. Some of the remaining resources allocated to McKay Bay could be expended analyzing the existing data to determine if it can provide additional information about the degree to which Tampa Bay Water withdrawals may or may not affect ecological conditions in the bay. The Committee believes that if impacts are not detectible in the bay's water quality data, then they will almost certainly not be detectible in the biological samples either.

COMMITTEE REVIEW

In the time available to the Committee, it was not possible to review and evaluate all the HBMP reports, monitoring activities, data, statistical analyses, modeling, and special studies that have been conducted in the five water bodies of interest over the past dozen years. Therefore, the Committee focused on evaluating the general HBMP approach and methods, including implications and inherent assumptions, and how they might affect scientific findings and conclusions.

The Committee also considered the HBMP's analysis and synthesis activities, especially those that: (1) defined spatial and temporal patters; (2) identified, adapted, and/or refined the performance of environmental quality indicators; (3) evaluated the effectiveness of river monitoring and assessment; and (4) determined the consequences of water withdrawals on ecosystem properties and services. Throughout its review, the Committee has focused on the following questions:

1. Is the current HBMP adequately, over- or under-monitoring any element or parameter or reporting unit as a whole relative to the Tampa Bay Water's water use permits, the District's MFL rules, and the stated objectives of the HBMP?

2. What refinements or other changes to the HBMP are recommended to ensure cost-effective and appropriate monitoring relative to the aforementioned rules, permits, and HBMP objectives?

Recommendations that may assist Tampa Bay Water in improving the efficiency and effectiveness of the HBMP, while still meeting permit compliance objectives, were identified when appropriate.

Seasonal variability of inflow and habitat utilization confounds the development and use of any single numerical rule for river flow during 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, the District risks over protecting the environment and under protecting the people's right to beneficially use the freshwaters. As a practical matter, the environmentally safe operation of water impoundment and/or diversion systems requires condition-appropriate rules for the waterway to avoid using good time rules in bad times and visa versa.

Since pumping limits in Tampa Bay Water's water use permits are based, in large part, on the District's MFL studies, a brief summary of each MFL of interest is presented here:

Lower Hillsborough River

Based on monitoring, modeling and experimentation, the District originally proposed an MFL equivalent to 20 cfs of freshwater flow 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 recommended 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 20 cfs MFL was eventually increased to 24 cfs during the spring low flow period (April to June) based on the findings of McDonald et al. (2006) and the District's Scientific Peer Review Panel (2007) to provide for increased utilization of low salinity estuarine nursery habitats. MacDonald et al. (2006) also determined that the lowest potential for estuarine impact from freshwater impoundment and diversion activities is the fall/winter (November-February) period when the fewest estuarine species are present. However, it is also apparent to the Committee that during times of drought, the necessary flows may not be available, water managers will be in drought contingency operations, and low salinity habitats are not likely to be maintained throughout the upper Hillsborough River to the extent desired.

Alafia River

The District's management goals for the Lower Alafia River were developed to sustain the ecological integrity of this tidal river segment by maintaining a biologically appropriate salinity regime and associated DO levels in this hypereutrophic (excessively nutrient rich) riverine estuary. This nutrient enriched condition makes the river susceptible to developing high concentrations of phytoplankton and nuisance algae during low flow periods that supersaturate the water with DO during the day and then cause hypoxic (severe low DO) at night that can greatly increase the stress and risk of mortality among fish and invertebrate populations. As a result, an additional and very important part of the District's MFL rule is the identification of a low-flow threshold (120 cfs) below which no water diversions would be allowed, thus eliminating the risk of potentially exacerbating any DO problems in the river. The 120 cfs low flow cut-off is a particularly important operational rule protecting fish and other inhabiting organisms because the chlorophyll peak moves upstream into nursery habitats more vulnerable to the resulting hypoxia and bottom DO decreases extremely rapidly below 120 cfs in the Lower Alafia River, especially from about river kilometer 6 to 12.

A criterion of no more than a 15% change in any percentile of abundance, as compared to the Alafia estuary's baseline condition, was used as the threshold for "significant harm."

While the use of 15% is a somewhat controversial management decision, the Committee agrees that this is a reasonable approach for avoiding the most serious negative impacts on the ecosystem. Inflow-abundance regressions were used to predict animal abundance in the river under "naturalized" baseline flows without water supply withdrawals and under various withdrawal scenarios. The District concluded that a reduction in the median abundance of a species found sensitive to freshwater inflow (juvenile red drum, *Sciaenops ocellatus*) greater than 15% was not acceptable without triggering "significant harm" to this and other living fish and wildlife resources that may not be as sensitive. The predicted difference in abundance between the District's MFL limits (i.e., 19% streamflow diversion with 120 cfs cutoff) and the baseline condition was less than 15% for other species caught in the plankton net samples, except adult mysid shrimp, which are an important prey item for drums, croakers, and other estuarine-dependent fishes. The juvenile mysids seem to be able to utilize the estuarine nursery habitats in the Lower Alafia River and maintain their median abundance with only about 100 cfs of inflow. None of the predicted decreases was >15% at median and higher flows because the low flow cut-off of water supply withdrawals helps to maintain abundances at lower flows.

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

Tampa Bypass Canal

The District's MFL approach consisted of examining the relationships among Tampa Bypass Canal flows, water quality (i.e., salinity and DO), and biotic inhabitants (i.e., oysters, benthic infauna, fish and macroinvertebrates, birds and vegetation). In general, the District found that the plants and animals inhabiting the area would not change much with the future water management scenarios analyzed, that the flood control functions of the waterway take priority over the living resources under state and federal statutes anyway, and that the watercourse has been so drastically altered from its native condition that estuarine nursery habitats are basically lacking and, thus, an MFL determination for the TBC is not applicable without a more reasonable expectation of success in making it a functional nursery area that improves ecological health and productivity (SWFWMD 2005). In the end, the District's net conclusion was that the flood control system is so altered and artificial that resource protection will be difficult if not impossible to achieve by water flow management alone and, therefore, the District declined establishment of a minimum flow level for the Tampa Bypass Canal at that time.

However, this does not mean that the Committee accepts any proposition that freshwater inflows and their associated sediments, nutrients, and salinity gradients are of debatable ecological benefit to bays and estuaries, such as McKay Bay. Indeed, just the opposite is true in the science of these valuable coastal environments. However, the inflows are less important if there are little or no nursery habitats in the Canal that provide food and cover to young organisms, and these inflows can be contraindicated if they attract young organisms into a dead-end floodway, where high mortalities are expected from oxygen stress and the presence of marine predators, parasites, and disease organisms in this high salinity environment (Overstreet and Howse 1977, Overstreet 1978, Longley 1994).

<u>Monitoring System Defined</u>

Environmental monitoring is conducted to assess the status of the environment, detect changes in status, and guard against the deleterious effects of anthropogenic activities. Monitoring includes time-series environmental measurements, conceptual and numerical modeling, research and special studies, data management, analysis, synthesis, and interpretation. Monitoring activities are an essential component of Tampa Bay Water's environmental management system and are intended to produce information that:

- Ensures compliance with water withdrawal permits (compliance monitoring);

- Verifies conceptual and numerical models (model validation monitoring); and
- Identifies and quantifies multi-year changes (surveillance and trends monitoring) of environmental conditions in the five water bodies of interest, especially the two large tidal rivers (i.e., Hillsborough and the Alafia Rivers), which provide environmental intelligence to water managers assessing the consequences of drinking water withdrawals.

The goal of environmental monitoring of all kinds — compliance, conceptual model validation and trends — is protection of the environment, its living resources, and the quality of life for its human inhabitants as well.

Goals & Objectives

Without clear goals and objectives, monitoring activities are nothing more than the haphazard collection of data (NRC 1990). Goals must be converted into testable hypotheses through a series of cause and effect linkages. Analytical results and scientific conclusions of the HBMP will only be as coherent as the original conceptualization of the problem.

The compliance, conceptual model validation and surveillance goals of the HBMP, as stated in the 2010 update (PBS&J 2011), are given as follows:

> *Compliance Goal:* The stated compliance goal of the HBMP is "to generate information at an appropriate scale and resolution to determine if the permitted water supply projects are in compliance with District rules."
>
> *Model Validation Goal*: To provide reasonable assurance that reduced flows in the Tampa Bypass Canal, Hillsborough River and Alafia River attributable to Tampa Bay Water's permitted surface water withdrawals do not deviate from the normal rate and range of fluctuation to the extent that:
>
> - Water quality, vegetation, and animal populations are adversely impacted in affected streams and estuaries;

- Salinity distributions in tidal streams and estuaries are significantly altered as a result of withdrawals;
- Recreational use or aesthetic qualities of the resource are adversely impacted.

The Committee understands that from the District's perspective, and pursuant to its rules, the first two model validation goals are actually considered to be part of the compliance goal, particularly monitoring of salinity, DO and chlorophyll-*a*.

Surveillance and/or Trends Goals: The stated ecosystem surveillance goals of the HBMP are:

- Document existing conditions in the potentially affected ecosystems;
- Enable the detection of changed conditions in the potentially affected ecosystems; and
- Determine if the detected changed conditions are attributable to reductions in freshwater inflows.

These HBMP goals and objectives were developed through a series of workshops and meetings that included Tampa Bay Water, the District, other appropriate regulatory agencies, affected governmental entities, regional scientists and stakeholders. However, the Committee finds that these goals were not converted into testable scientific hypotheses or questions. For example, questions which identified ***specific impacts*** of water withdrawals on ***specific resources*** at ***specific times*** for ***specific purposes***, such as detecting "significant harm" to the river systems, were not clearly defined. In addition, no distinction was made among the categories of goals (compliance vs. model validation vs. trends). As a result, the following issues were not always clear:

- Which goals are important to whom?
- Which entity/agency requested or "owns" what goal? And why?
- What are the priorities for each goal?
- When were specific goals being addressed?

Recommendation: *The goals and objectives defined for the HBMP need to be categorized and prioritized as primary and secondary. The "owner" of each goal needs to be identified and decisions relative to future monitoring activities associated with that goal need to be made by that entity and Tampa Bay Water. It is clear that compliance and some conceptual model validation goals are the responsibility of Tampa Bay Water (i.e., they own these goals). The Committee agrees that conceptual models are most useful for understanding mechanisms and pathways, and for developing hypotheses to test potential relationships between freshwater withdrawals, water quality and biological indicators. However, the Committee believes that the larger overall validation of a conceptual model is a scientific exercise potentially involving ecological studies that seem well beyond the scope of mere compliance with water use permits. It is also clear that Tampa Bay Water initially owned the trends goal; however, the degree to which Tampa Bay Water wholly owns the trends goal in the future is debatable. Many agencies benefit from this information (e.g., the County, the District, Tampa Bay National Estuary Program, Florida Department of Environmental Protection, and the State of Florida) and these entities may have to accept ownership for some of the trends goals in the future as well.*

Conceptual Modeling: A Process for Conversion of Monitoring Goals into Testable Questions

Environmental monitoring focuses on measuring the condition of resources through space and over time, with the intent of providing data which reflect changes in the status and trends of the system or system components. Because environmental systems are inherently complex and because the public and water managers are increasingly concerned with environmental changes, conceptual models and diagrams are simple and effective tools for synthesizing and communicating ideas about system dynamics, for identifying key system components (e.g., identify parameters to measure), and for communicating to both policy-makers and the public why the HBMP is important to people and the environment in the Tampa Bay area.

Initial efforts to develop a conceptual model of the direct and indirect impacts are often accompanied by factor-train analysis (Figure 1) or similar techniques like DPSIR models (OECD 1993) to refine the stimulus-response linkages and help develop the accompanying narrative. In the end, the Committee believes that a well-constructed conceptual model provides a scientific framework for analysis and synthesis work that might otherwise become expensive *ad-hoc* activities in the monitoring program.

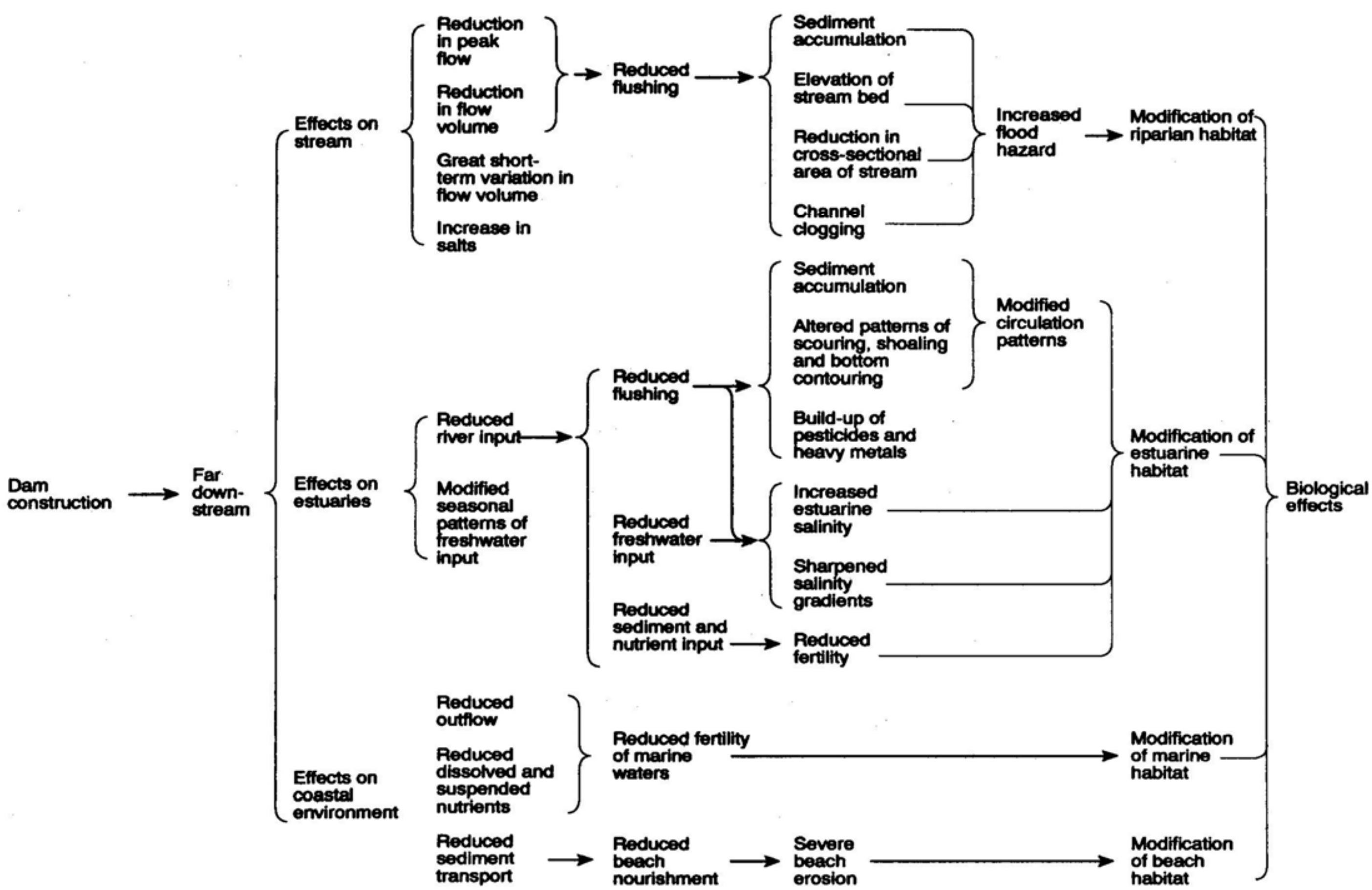

Figure 1. Factor-train analysis of downstream effects of dam construction on wetlands, including estuarine and marine environments (after Darnell et al. 1976). [The Committee notes that only major physical and chemical events are presented in this example.]

The process of developing conceptual models is frequently as important to the success of the monitoring program as the actual model itself. The exchange of information that occurs among scientists, managers, and the general public during the development and revision process almost always contributes to a shared understanding of system dynamics and appreciation of the diversity and complexity of information needed to conduct an efficient and effective monitoring program. Failures of major monitoring programs to achieve their stated goals have been repeatedly attributed to the absence of sound conceptual models that articulate key system components and their interactions (NRC 1990; NRC 1995; Busch and Trexler 2003).

Although conceptual mechanisms of impact were presented in the original (2000) HBMP design document describing how freshwater withdrawals could lead to water quality changes (e.g., altered salinity distribution) that in turn could lead to biological impacts (e.g., changes in species abundance and distribution), the Committee believes that a more complete and focused conceptual model will be required in the future. The Committee understands that there was little data available on the water bodies of interest at the time the HBMP was being designed. Thus, the Committee recommends that the previous conceptual ideas be improved and expanded, based upon what has been learned over the past decade. The lack of a more complete and realistic conceptual model in the early design phase of monitoring programs elsewhere has led to unfocused data collection, analysis and synthesis activities. For example, the Committee appreciates that some of the previous HBMP studies seem only tangentially related to Tampa Bay Water's permit compliance, conceptual model validation, or detecting changes in the ecological health and productivity of the five water bodies of interest. Furthermore, Tampa Bay Water's concern that the current HBMP is not efficient, cost effective, or providing information that directly addresses compliance and permitting issues is confounded by the absence of a logical and fully vetted conceptual model.

Deciding just what should be included in a conceptual model depends on monitoring goals, available knowledge, and the level of uncertainty allowed or required by the highly variable nature of the ecological data. Generally, a conceptual model begins as a qualitative description of causal links between a stressor and system responses (e.g., Figure 1) and is expanded until the desired ecological or societal endpoints are reached and all goals are addressed. Failure to include an important source of variability can result in unrealistic assumptions about how undesired outcomes occur.

For example, the lack of an atmospheric source term in nutrients budgets for the Chesapeake Bay led to erroneous predictions and incomplete water quality management strategies (Fisher et al. 1988; Tyler 1989). Similarly, if the HBMP does not formally include or exclude non-point source (ungaged) runoff volumes from the portions of the Hillsborough and Alafia River watersheds downstream of the last USGS streamgage into water budgets and estimates of freshwater inflows to the bays and estuaries, these inflows may increase uncertainty in monitoring conclusions and environmental management decisions relative to drinking water withdrawals. Since the Alafia WUP and analyses do include a flow adjustment factor to account for ungaged inflows, the Committee believes that this may be a larger confounding issue currently in the Hillsborough River. As a result, the Committee suggests that Tampa Bay Water should consider reevaluating the water budgets used as the basis for estimating freshwater inflows and make a formal determination about which runoff volumes from associated ungaged areas of the urban/suburban watersheds are small enough to be more or less irrelevant to the larger gaged flows from upstream sources.

Conceptual models can take the form of narratives, tables, factor matrices, or box-and-arrow diagrams. Diagrams are usually necessary to clearly communicate linkages between systems or among system components, and to demonstrate the importance of feedback loops. Many monitoring programs use a combination of diagrams, tables and narratives. It may be useful to combine several forms because there is not a single "correct" conceptual model for representing an ecosystem. Most successful monitoring programs usually end up with a set of conceptual models that consist of diagrams and accompanying narratives. The narratives describe the diagrams, justify the functional relationships in them, and cite sources of information and data on which the models are based. The same general conceptual model may be used to represent the Hillsborough River, Alafia River, Tampa Bypass Canal and McKay Bay, but the specific links, indicators, and testable questions will need to be adapted to address the specific site-based concerns associated with each unique ecosystem.

Conceptual models are important in all phases of monitoring activities. In the beginning, simple conceptual models provide a framework for identifying what to measure, where and when measurements should be made, and why specific measurements should be taken. Later, conceptual models are essential tools for refining and adapting monitoring programs (e.g., refining the indicator list, developing alternative hypotheses, focusing analyses, etc.) to effectively and efficiently address the objectives. Finally, virtually all monitoring programs are subject to changes in support resources (both increases and decreases) and/or alterations to stated goals. Without a sound conceptual basis for adapting monitoring activities to new goals and/or changing resources, decisions about how to best modify a monitoring system are not as certain or likely as successful.

The Committee observed that the existing HBMPs for the Hillsborough River, Alafia River, Tampa Bypass Canal and McKay Bay appear to be based on an implied conceptual model. It could be summarized as follows: freshwater withdrawals by Tampa Bay Water will reduce freshwater flows and cause upstream movement of salinity isohalines potentially resulting in harmful alterations to critical spawning and nursery areas, changes to biological distributions (e.g., juvenile fish and their prey), water quality (e.g., DO and chlorophyll-*a* concentrations) and shifts in the distribution of shoreline vegetation. The implied conceptual model is, however, never explicitly defined and the testable hypotheses associated with each linkage are not identified.

Recommendation: *Tampa Bay Water should develop a suite of conceptual models that represent the Hillsborough River, Alafia River, Tampa Bypass Canal and McKay Bay, including associated narratives. These models should identify the resources at risk, define the direct and indirect causal links, qualitatively predict responses, define testable questions, and provide a focus for analysis and synthesis activities. The models should be vetted and refined with stakeholders and outside experts. The extensive HBMP data sets and the many special studies that have been conducted, combined with the available* *scientific literature, provide powerful information sources for defining appropriate conceptual models and for adapting the implied HBMP conceptual model into an effective and efficient tool for the monitoring program.*

<u>Conceptual Model Example for the HBMP</u>

An example of a simple conceptual model for the HBMP which can be understood by the public and general audiences is provided in Figure 2. This hypothetical model can be easily expanded into a detailed ecosystem conceptual model for regulatory and scientific applications.

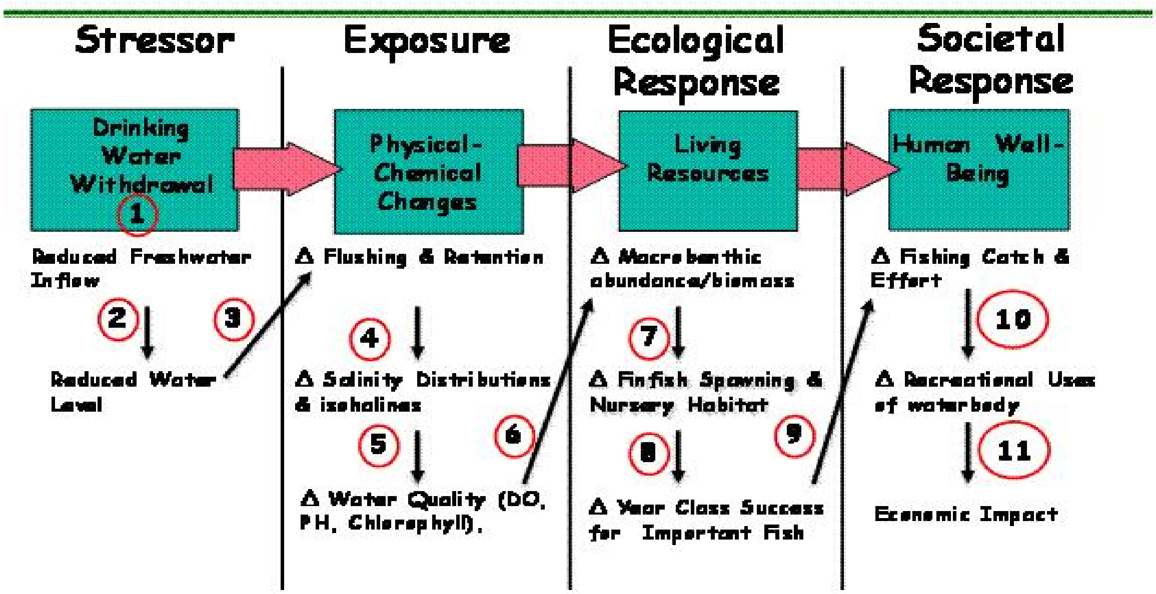

Figure 2. Hypothetical conceptual model of drinking water withdrawals and impacts on estuarine habitats (The Committee notes that the numbered links in the model refer to the example questions below).

As previously mentioned, a conceptual model also provides a scientific framework for the identification of testable questions and hypotheses. The Committee believes that without demonstrated significant impacts on the hydrology, hydraulics and water quality of the tidal rivers, there is little expectation of profound effects on the living ecosystems, or even detectable effects on their economic value and recreational use, but that may not yet have been formally established and communicated to the public and policy-makers in order that the HBMP can be sized appropriately. The kinds of questions stakeholders might ask about the conceptual model might include, but are not limited to, the following examples:

Question 1--What is the effect of drinking water withdrawals on the spatial and temporal distribution of freshwater inflows, especially during critical periods (e.g., low flows, high flows, average flows, annually and over the long term)?

Question 2--What is the effect of drinking water withdrawals on water levels and the amount of aquatic habitat during critical periods (e.g., low flows, high flows, average flows, annually and over the long term)?

Question 3--What is the effect of changes in drinking water withdrawals on system flushing and materials retention during critical periods (e.g., low flows, high flows, average flows, annually and over the long term)?

Question 4--What is the effect of drinking water withdrawals on salinity distributions in ecologically important areas (e.g., nursery habitats) during critical periods (e.g., low flows, high flows, average flows, annually and over the long term)?

Question 5--What is the effect of drinking water withdrawals on the concentration and distribution of ecologically important water quality indicators (e.g., DO, pH, turbidity, CDOM, chlorophyll-*a*, and major nutrients) in ecologically important places, during ecologically critical time periods?

Question 6--What is the effect of drinking water withdrawals and their associated changes in physical-chemical conditions on ecologically important macrobenthic community parameters (e.g., abundance of representative benthic organisms) during critical periods (e.g., low flows, high flows, average flows, annually and over the long term)?

Question 7--What is the effect of drinking water withdrawals and associated changes in the physical-chemical environment and macrobenthic community (i.e., through food web linkages) on spawning and nursery activities of ecologically important fish and shellfish (e.g., abundance of representative fish, crustaceans and mollusks) during critical periods (e.g., spawning and nursery periods of valued species, low flows, high flows, average flows, annually and over the long term)?

Question 8--What is the effect of drinking water withdrawals on the year class success of economically important fisheries in the five water bodies covered by the HBMP? How does year class success of valued species in the affected system compare to similar nearby systems that are not affected by similar water withdrawals (i.e., at reference sites)?

Question 9--Have drinking water withdrawals had any definable effects on recreational and/or commercial catch in the affected water bodies? How do catch statistics in the affected water bodies compare to similar nearby ecosystems (i.e., at reference sites)?

Question 10--Have drinking water withdrawals had any identifiable effects on recreational use of the affected water bodies?

Question 11--What are the direct and indirect economic impacts of drinking water withdrawals on the affected systems?

The Committee suggests that a good place for Tampa Bay Water to start would be to examine the more realistic conceptual models previously prepared for evaluating withdrawals from other Florida rivers, such as the Peace River and the St. Johns River.

<u>Identification of Resources at Risk</u>

Resources to support the HBMP in its current form are limited. Therefore, all available resources must be focused on the parameters or indicators of greatest concern, as well as those parameters that are likely to respond, directly and indirectly, to drinking water withdrawals and changes in freshwater inflow. The selection criteria used to identify HBMP indicators included most of the indicator selection criteria provided by monitoring guidance documents (e.g., NRC 1990) including stable response over sampling timeframe, standardized method of measurement, variable related to historical conditions, provides early warning, cost effective to measure, provides new insights, responsive, unambiguously interpretable, low measurement error, and easy to quantify. However, the Committee notes that the District selected and used certain indicator species in the previously summarized MFL studies in the absence of any specific conceptual models.

Strong emphasis was placed on the statistical characteristics of HBMP indicators; less emphasis was placed on the relevance of indicators to ecosystem health and productivity. A long list of resources at risk was identified for the HBMP. This list of resources at risk must be reduced and refined to those parameters that: (1) are clearly linked to monitoring goals and objectives in a testable manner (i.e., through a conceptual model), (2) have statistical characteristics that support rigorous model validation and testing of hypotheses, and (3) have predicted levels of response/impact that are meaningful to affected ecosystems, regulatory agencies and the public (i.e., have high relevance). Emphasis should be placed on reducing redundancy and improving relevance and unambiguously interpretable responses.

Recommendation: The Committee suggests that the HBMP list of resources at risk should be reviewed and reduced to eliminate redundancy and enhance relevance. The final list of indicators should be unambiguously linked to monitoring goals through a conceptual model and be responsive to predicted changes in freshwater inflow associated with Tampa Bay Water's drinking water withdrawals during critical ecological periods. Stakeholders should be involved in the process used to review and modify the final list of HBMP indicators.

Sampling Design

"que por el hilo se sacará el ovillo"

(translation: by a small sample, we may judge the whole piece)

– Miguel de Cervantes

As previously mentioned, few reliable data were available for water quality, habitat distributions, and biological distributions from the Hillsborough River, Alafia River, Tampa Bypass Canal, or McKay Bay before 1998. In response to this deficiency, the HBMP allocated considerable resources to obtaining adequate numbers of representative (unbiased) samples of the potentially affected ecosystems. A randomized, stratified sampling approach that was more or less consistent across program elements was applied and considerable effort was expended identifying, evaluating and collecting data from hundreds of sample sites. The original sampling approach has been maintained for over a decade at a cost of approximately $1 million annually. It was a reasonable and appropriate approach for characterizing ecosystems for which little historical information existed. However, after a decade of sampling, it is time to re-evaluate and optimize the sample design to make it more cost effective and efficient.

For example, one of the major analytical issues identified in the biological data is the frequency of zeros in the sample data. An optimization analysis may elevate this issue by identification of a sampling index period when the resources of concern (e.g., peak recruitment periods for macrobenthos and nekton, sensitive or vulnerable life stages, etc.) are abundant and have a high probability of being present in the habitats of interest, especially nursery habitats. In addition, plots and figures in the HBMP materials provided to the Committee suggest that a rigorous evaluation of the strata may determine that for many indicators, multiple adjoining strata are not statistically different and can be combined for monitoring purposes. This may result in a substantial reduction in the number of samples required to detect responses.

The HBMP instituted by Tampa Bay Water consists of multiple components including water quality, plankton, vegetation, benthic infauna, and fish and shellfish monitoring activities. The HBMP is a combination of probability and targeted surveys which are designed to address different questions. Both probability and targeted surveys for water quality assessment are widely used throughout the US and Europe.

In typical probability surveys, sampling sites are selected across geographic regions using a specified statistical approach where every individual in the population has a chance of being selected (Stevens and Olsen 2004). A probability based design has a known non-zero probability of inclusion for every point within the population (area of interest). The probabilities need not be equal, nor do they need to be independent. Stratification is one example of unequal probability sampling; cluster sampling or sampling on a regular grid are examples of non-independent designs. However, the randomness at some level of the site selection process protects this form of design from selection bias (Olsen et al. 1999). Therefore, under best conditions, results from the sample may be extrapolated to the entire area of interest. Under the worst conditions, probability sampling does not show effects as quickly or as economically as does the fixed station design of targeted sampling.

If inferences to populations or areas are to be made, the question arises as to whether to use design-based or model-based inferences. Design-based inferences need few assumptions and gain their efficiency from the design of the sampling with no additional assumptions. Olsen et al. (1999) emphasized that the lack of additional assumptions was important when monitoring results were to be used in litigation or public policy. However, design-based inferences do require a probability-based sampling design, where every location in the population has a known probability of being included in the sample.

Model-based inferences require a statistical or numerical model of variations in the attributes of interest. This approach uses the sampling data to parameterize the model, and then uses the model to make inferences about the area of interest. Thus, model-based inferences can use non-probability based sampling data (targeted sampling), as long as the model holds equally well for the sampled locations and the unsampled locations. Probability samples by their design guarantee that the model holds equally well for sampled and unsampled locations. Non-probability samples that are biased in any way by factors not accounted for in the model (e.g., water depth or vegetation type affecting a spatial Kriging model) may well produce a parameterized model that fits the sampled locations differently than the unsampled locations and, thus, produces biased estimates. The alternate argument is that probability surveys tend not to sample a large number of sites with high levels of human disturbance. If such sites are relatively uncommon in an overall population, probability surveys will not likely include very many of them, even though managers may be well aware of their existence and consider them a priority.

Targeted surveys (non-probability) generally used selected site locations to address specific questions of interest (e.g. to evaluate regulatory compliance at point-source discharges, to track trends over time at compliance sites, or to evaluate the effectiveness of restoration projects). Targeted surveys are not statistically based, but this is not detrimental to survey objectives provided that unbiased population estimates are not required. The Committee finds that both survey types are vital to a comprehensive monitoring program and provide complementary information.

Targeted sampling designs may be based on expert judgment of sites deemed to be representative, or by convenience. Targeted samples are often thought to be more efficient or cost-effective than probability samples by being considered "representative" with much smaller sample sizes than in probability samples. However, even the best targeted samples may have substantial biases in their means and variances (Edwards 1998, Stoddard et al. 1998, Peterson et al. 1999). Targeted sampling based on convenience may greatly reduce the logistical cost per sample, but convenience sampling tends to introduce biases because of the sample locations (e.g., often near roads, bridges, or other places of easy opportunity).

Concerns about HBMP expenses have caused managers to assess cost reductions through optimization of the monitoring activities. Since the HBMP consists of a combination of probability and targeted sampling components, it will most probably benefit from some type of joint analysis. This condition is not exclusive to the HBMP, but is a common condition in many state and federal environmental assessments and regulatory programs. Optimizing the HBMP will require considerable data analysis and expert assistance in order to reconcile its components into a lean and efficient monitoring program.

In the past decade, there have been increased efforts to combine probability and targeted surveys into 'integrated' condition assessments (Overton et al. 1993, Paul et al. 2008, Stein and Bernstein 2008). Paul et al. (2008) mentioned that "the quandary facing resource managers…is what to do with existing monitoring sites when new monitoring requirements lead them to probability-based designs." One of the main reasons to merge disparate sampling programs is that targeted sites often have valuable information (including time series data) that is not available at probability sites. Nevertheless, the Committee notes that the trend is away from targeted designs and towards more probability sampling.

There is more information in the literature about how to incorporate targeted sampling into probabilistic programs than for addressing how to collapse spatial probability sampling into targeted "sentinel" sampling sites. Overton et al. (1993) provided two approaches to resolving this problem of merging monitoring programs: statistical and narrative. In the statistical approach, probability sites are clustered into subsets based on a set attributes of the indicator variables of interest. Spatial boundaries for these subsets are determined and the targeted sites are assigned membership to the probability subsets according to their geographical proximity.

Overton et al. (1993) used 'similarity' as a criterion for assigning targeted sites to probability subpopulations. By similarity, it is assumed that any grouping of sampling sites is done to minimize the estimated variance of the fixed sampling design. Paul et al. (2008) defined three criteria for evaluating similarity: (1) targeted sites must be representative of the area from which they were selected, (2) the cumulative distribution functions (CDFs) of indicator variables from targeted and probability sample populations must not be statistically different, and (3) the correlation structure between indicator variables from targeted sites must be equivalent to that from probability sites. There are many ways to group sampling sites according to similarity including cluster analysis (e.g., unsupervised learning – hierarchical, k-means, etc.), classification analysis (e.g., supervised learning – discriminant function analysis, Bayesian analysis, etc.), orthogonal factorial analysis (e.g., principal component analysis (PCA), empirical orthogonal function (EOF) analysis, etc.), geostatistical analysis (Kriging, minimum mean shortest distance (MSD), fractal dimension, etc.), and other more esoteric approaches such as spatial sample annealing derived from remote sensing applications.

Examples abound of instances where sampling networks were "optimized" through statistical analysis (Van Groenigen et al. 2000, Caeiro et al. 2004, Harmancioglu et al. 2004, Liu et al. 2009). Often these redesigns have been used in furthering the understanding of patterns and process of water quality at the ecosystem level (Boyer et al. 1997, Burd and Jackson 2002, Caccia and Boyer 2005). One advantage of this approach has been that instead of relying on preconceived determination of strata, the spatial strata develop as a result of the analysis. An example activity would be to classify/cluster all Alafia River data according to measured variables over the period of record. A PCA would most probably result in the first PC including some aspect of inflow/salinity. Boyer et al. (1997) and Caccia & Boyer (2005) ran PCA on both the mean and variance of their standardized data. This way the variability of each measured parameter was explicitly included in the model. Clustering was then performed on resulting factor scores for each site and "zones of similar influence" established.

In the narrative approach (Overton et al. 1993), results from probability and targeted surveys are derived independently and then compared (Stein and Bernstein 2008). The requirements to employ a narrative approach are much less stringent than for a statistical approach and may be as simple as comparing cumulative distribution functions (CDFs) using a nonparametric Kolmogorov-Smirnov test. The Committee suggest that further analysis of HBMP data be tried using this approach.

In their review of national-scale environmental monitoring programs in the United States, Olsen et al. (1999) briefly discussed the tradeoff between a unified sampling design versus several separate but coordinated sampling designs. They discussed three alternatives: (1) replacing the extant monitoring programs with a single new unified national environmental monitoring program, (2) choosing a 'leading candidate survey' among each set of similar extant programs and supplementing it to replace the other surveys, and (3) keeping independent programs but increasing coordination across surveys. They implied that increased coordination across extant independent surveys was the better path forward.

A second major decision for HBMP managers is whether (a) to make inferences to unsampled locations and base management actions on status or trends estimated over regions or (b) to select targeted, sentinel locations and manage based on responses at those locations without inferences to unsampled locations. While the list of HBMP hypotheses is in flux, some hypotheses do exist and can be appropriately tested with data from targeted sites without inference to unsampled locations. However, the Committee notes that such reliance on responses at targeted sites runs two major risks in long-term monitoring programs. If a sentinel site responds in one direction while other sentinel sites do not respond or have the opposite response, the inability to make inferences to unsampled locations prevents agreement on what might be the appropriate management modification. There is also a substantial chance that data from targeted/sentinel sites chosen for the original hypothesis will not be able to address the modified hypothesis. The modified hypothesis may require inferences to unsampled areas or may require a different set of sentinel sites to answer the question. Monitoring designs that support inferences to unsampled locations may not be optimally informative for the modified hypotheses, but their inferences should be able to provide at least approximate (and unbiased) data for any related hypotheses. The Committee agrees with Stein and Bernstein (2008) that the most effective way to 'integrate' probability and targeted surveys is to use probability results as an unbiased regional framework for interpreting targeted results. Different estimates from probability and targeted surveys may lead to different decisions about how to re-allocate resources that must be resolved by managers.

Another issue with the initial HBMP sampling design noticed by the Committee is the amount of habitat that could be sampled and the number of samples collected in each stratum are not equal (e.g., samples in some habitats appear to have unequal inclusion probabilities complicating analyses involving shoreline length, bottom area and/or volume estimates). For example, the number of samples that were collected from critical low salinity nursery habitats may be lower than in other habitats. The Committee recognizes that it is probably inappropriate to fully optimize the sampling design before a vetted conceptual model with testable hypotheses had been developed.

As a final point, the three major categories of goals (compliance, conceptual model validation, and trends) may best be addressed by different sample designs. The compliance goal may best be addressed by concentrating monitoring activities on physical parameters, water quantity, quality, and withdrawal rates in the specific places of concern where key values of flow, salinity, DO, and chlorophyll-*a* were defined during the District's studies to determine minimum flows and levels needed to avoid "significant harm." The conceptual model validation goal may be best addressed by focused sampling of "key" indicators during "index" periods (e.g., ecologically characteristic estuarine-dependent fishes in peak recruitment during the low flow spring period). The trends or surveillance goal may be best addressed using fixed stations at key places using high frequency sampling that, depending upon the variable, might be monitored for example on an hourly, monthly or even seasonal basis, as appropriate.

Recommendation: *The Committee believes that the initial randomized, stratified sampling design should be optimized to focus HBMP sampling activities in places and time periods that reduces sampling costs while increasing the power of analyses to detect changes. Emphasis should be placed on identifying sampling opportunities when the probability of measuring responses is highest (e.g., recruitment or other periods when abundances are high and the probability of zeros are low) and when the potential for adverse impacts is greatest (e.g., during low spring flows). In addition, the Committee believes that it may be necessary to use different sampling designs to address differing goals.*

Data Rich – Information Poor

If there was no uncertainty in the impact of drinking water withdrawals (or other anthropogenic activities) on the environment, monitoring requirements would not be included in water use permits. Unfortunately, the uncertainty associated with predicting impacts of human activities on environmental conditions is usually large (Holling 1973, 1978; NRC 1986; Wolfe 1988; Paine 1981; NRC 1990) and identifying the sources and consequences of uncertainty is often as valuable as predicting and assessing the impacts (NRC 1986, 1990). Effective monitoring programs generally allocate substantial resources on data management, analysis, and synthesis activities that may include special studies. A general rule of thumb is that the resources allocated to data collection and data management/ analysis/synthesis activities should be roughly equivalent.

Uncertainty stems from many sources and takes many forms (e.g., model error, sampling design, measurement error, natural variability, and incomplete scientific understanding of the ecosystem). In well understood systems, uncertainty is mainly a result of measurement error. In poorly understood systems, it may be difficult to predict whether an assumed effect will occur. In many cases, the nature of effects is clear and only their timing, location or extent is uncertain. For example, the effects of organic enrichment on benthic communities are well documented (e.g., Pearson and Rosenberg 1978), but the actual severity and extent of changes that will occur in any specific ecosystem are not predictable yet. The lack of clear assessment findings is probably the single greatest weakness of most monitoring programs (emphasis added by the Committee, as it applies to other aspects of the HBMP as well).

Tampa Bay Water's HBMP has collected a lot of appropriate data and sometimes treated it as isolated facts. In some cases these data are not the information needed to determine whether drinking water withdrawals are harming the receiving water bodies in an unacceptable manner. The Committee points out that *information* is data that has been analyzed, synthesized and organized for a specific purpose, and endowed with relevance and purpose (Drucker 1988, NRC 1990). A successful monitoring program provides mechanisms to ensure that the data collected are converted into the information required to address goals and answer the framing questions identified during development of a conceptual model. Conversion of monitoring data into information involves a range of activities, including data management, statistical and graphical analyses, predictive modeling, and research.

The goals of analytical activities should be to: (1) summarize and simplify the inherent complexity in the available data; (2) test for spatial and temporal change and differences; (3) answer pre-defined questions and generate new ones; (4) evaluate the consequences of the findings; and (5) determine the uncertainty associated with the findings and try to identify ways of reducing uncertainty. Analytical plans should be developed prior to data collection and should be included as the basis for the sampling design. Successful analytical programs:

- Partition spatial and temporal variations into their major sources (e.g., natural and anthropogenic; regional and site-specific, seasonal and year-to-year);
- Are based on an understanding of linkages among physical, chemical, and biological attributes (i.e., a conceptual model);
- Determine the consequences of assumptions made for the sampling design and analytical approach, and evaluate the sensitivity of the analyses to these assumptions; and
- Summarize results in easy-to-understand graphs, maps, and tables (e.g., not complex scatter plots that include extreme data points). The Committee observes that the inclusion of extreme data points in scatter plots makes it difficult to visualize parameter distributions in space and time. To enable readers to better visualize and understand the results of the graphical analysis, the Committee recommends not including extreme data points in scatter plots or maybe switching to a log-log axis format or cumulative sum control chart (CUSUM), a sequential analysis technique typically used for monitoring change detection (Manly 2001, Mesnila and Petitgas 2009), whichever makes the clearest display. Similarly, it is common practice when statistical relationships are strongly influenced by a few extreme points to rerun such analyses without the outlier(s)

("winsorize") to ascertain the effect of unusual data structures on statistical relationships, or the lack thereof.

The existing HBMP data span more than a decade (2000-2012) and include frequent sampling of multiple strata. Unfortunately, the spatial and temporal patterns in these extensive data sets have been described mainly by scatter plots and routine graphics, as observed by the Committee in the available 2010 HBMP Interpretative Reports (PBS&J 2011). Some of the special studies have characterized the spatial and temporal patterns for selected indicators more fully; however, the findings of special studies were not always been integrated into the interpretative reporting (e.g., Janicki Environmental 2009). As a result, some of the major questions that remain incompletely addressed after over a decade include:

- What are the most appropriate indicators to measure and where in the potentially impacted ecosystems?
- Is the conceptual model implied and used in the design of the HBMP the most appropriate one for assessing water withdrawal impacts? Does it assess both direct and indirect impacts? Does it need to be adapted based on the information that has been compiled over the last decade?
- What level of impact from water withdrawals could be detected, and for which indicators in the existing HBMP design? During what time periods or flow regimes?
- If the existing HBMP does not detect the impacts of water withdrawals, is it because there are no impacts or because the monitoring program design is not adequate to detect one? (The Committee believes that reduced water flow and quality impacts have been adequately detected, while significant or harmful impacts to benthic infauna and fish/nekton are much less apparent and may not be significant or even detectible.)

In addition, the probability sampling program has not been useful in providing time series information. Time series analysis requires fixed interval data to estimate relationships between measured variables. Time series analysis accounts for the serial correlation usually present in closely spaced sequential data. Other techniques for estimating totals of finite populations are based on survey sampling theory. This method uses fixed-interval "sampling" to form a finite sampled population from a continuous one. Cross correlation and autoregressive integrated moving average (ARIMA) models are particularly useful tools in discovering and predicting effects of flow on dependent variables. The key for using these semi-continuous data relationships is to make sure the targeted site is representative of the surrounding area.

Another method of analysis that may be tuned to time series data is the cumulative sum control chart (CUSUM), a sequential analysis technique typically used for monitoring change detection (Manly 2001, Mesnila and Petitgas 2009). Briceno and Boyer 2010 used CUSUM to illustrate hurricane disturbance effects on phytoplankton time series. In addition, Briceno et al. (2010) used CUSUM approach to determine thresholds for nutrient enrichment in setting numerical estuarine nutrient criteria for the State of Florida. These kinds of interval analysis approaches might be useful in determining discontinuities in salinity time series as a function of water withdrawals.

Recommendation: *The Committee believes that Tampa Bay Water should emphasize synthesis and integration activities over the next few years and consider a corresponding reduction in data collection activities. It is critical that stakeholders be involved in development of analytical plans and synthesis activities. Specific analysis plans should be developed for each goal. The major sources of variation should be quantified and all the testable questions identified in the conceptual modeling process should be answered to the degree possible. Rigorous statistical approaches for reducing uncertainty should be identified and evaluated.*

Water Quality Monitoring

Based on the data and analyses provided to the Committee, it appears that water quality measurements, particularly salinity, DO and chlorophyll-*a*, are primary variables controlling biotic abundances, distributions and the ecological health and productivity of these impacted systems. Although single point-in-time (i.e., instantaneous) water quality measurements were made during the random stratified sampling, they have not been sufficient for rigorous characterization of spatial and temporal patterns, and such sampling provides little or no information about diel patterns of DO stress or continuous measures of salinity fluctuations from day to day. Also, pH values in hypereutrophic ecosystems (e.g., Alafia River) have large diel shifts in pH associated phytoplankton blooms; therefore, pH should be monitored continuously as a measure of the degree of eutrophication.

The semi-continuous measurements of salinity, temperature, DO and chlorophyll-*a* have proven very useful in determining temporal trends in river dynamics related to flow. However, the Committee thinks that Tampa Bay Water and the District should be aware of the problems associated with *in situ* sampling of chlorophyll-*a*:

1. Light history, temperature, turbidity, chromophoric dissolved organic matter (CDOM), and other fluorescent components present in the water may have significant effects on fluorescent readings independent of the chlorophyll-*a* concentration. However, all of these factors can be controlled and/or corrected to a degree if the user is aware of their effects.

2. Light history can have significant effects on the fluorescence in algal cells. For example, at low light levels, algal cells can optimize the light uptake by pushing chloroplasts to the outer edge of the cell or by producing more chlorophyll-*a* per cell. Both of these responses can result in data that falsely represents the algal biomass.

3. Temperature has an inverse relationship with fluorescence. For example, in a vertical profile, as the temperature decreases, the fluorescence will increase independent of chlorophyll-*a* concentration. A temperature drop of 10 °C in a vertical profile would result in a 14% overestimation of chlorophyll-*a* due to temperature changes alone. While this example may be a bit extreme for South Florida, any temperature error can be compensated for by employing a

chlorophyll-*a*/temperature algorithm in post-processing. In general, the best way to minimize errors is to calibrate with phytoplankton standards of known chlorophyll-*a* content that are as close as possible in temperature to that of the environmental water under investigation.

4. Interference from suspended solids as turbidity may result in elevated chlorophyll-*a* readings. Laboratory experiments indicate that the turbidity interference is on the order of 0.03 $\mu g^{-1}\ l^{-1}$ per NTU. For example, water with a turbidity of 100 NTU would produce an apparent chlorophyll-*a* reading of 3 $\mu g^{-1}\ l^{-1}$. This turbidity error may be compensated for by employing a chlorophyll-*a* /turbidity algorithm in post-processing.

5. Chromophoric dissolved organic matter (CDOM) may also affect chlorophyll-*a* fluorescence response by overlapping that of chlorophyll. CDOM is usually derived from terrestrial run-off, fringing marshes and shoreline vegetation. Combining fluorimetry with other simultaneous measurements of bio-optical and biogeochemical sensors, Claustre et al. (2000) have separated the surface CDOM signal from that of chlorophyll-*a* fluorescence. This CDOM error may be compensated for by employing a chlorophyll-*a*/CDOM algorithm in post-processing. In addition, CDOM is very useful in many cases as a semi-conservative tracer of flow and mixing, and has been used in past modeling efforts in other areas (Stedmon et al. 2010).

6. Fluorometric chlorophyll-*a* values must be evaluated carefully in freshwater, estuarine or coastal systems where higher levels of chlorophyll-*b* (and in some cases, chlorophyll-*c*) may cause considerable interference and render the conventional fluorometric methods unreliable. In typical freshwater samples, the conventional fluorometric methods may be unusable for the measurement of chlorophyll-*a*. Fluorometric chlorophyll-*a* values using narrow band pass filters may be used for samples collected in freshwater, estuarine and coastal systems

without concern for significant interference from pheophytin, other pheopigments, or chlorophyll-*b*.

7. Finally, field optical measurements are particularly susceptible to fouling, not only from long-term buildup of biological and chemical debris, but also to shorter-term formation of bubbles from passing boats with outboard engines. Binning data on 15-30 minute time intervals helps to reduce spurious bubble measurements. For studies longer than a few hours where the user is not present at the site, monitoring instruments with mechanical wipers are recommended.

The Committee notes that DO concentrations often were estimated to be < 2 mg/L, even under simulated "naturalized" baseline flow conditions without any withdrawals from the Hillsborough River, Alafia River, and Tampa Bypass Canal. These DO values violate Florida's 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 (4 and 5 mg/L DO concentration, respectively). This standard may be practical and scientifically appropriate for inland freshwaters, but it is problematic in warm shallow estuaries with high biological productivity. For example, with 100% saturation of 25ºC (77ºF) freshwater (0 psu) at sea level atmospheric pressure (760 mm), the DO concentration is 8.4 mg/L, declining to 6.2 mg/L when both salinity and temperatures are high (35 psu at 30ºC or 86ºF), and this is for sterile water with no biological or chemical oxygen demand. If the coastal waters are alive with biota and contain any pollutant runoff, then there is no way to consistently maintain DO concentrations above 4 mg/L at night when plants switch from oxygen production (i.e., sunlight-driven photosynthesis) to oxygen consumption (i.e., respiration), and bacterial respiration further reduces DO levels.

However, there is a method for determining an alternative standard, if justified (and the Committee believes that it is justified here), and the Department of Environmental Protection, the District, Tampa Bay Water, Tampa Bay National Estuary Program and others should probably consider this refinement in some of the HBMP areas. The

Committee is aware that Tampa Bay Water has at least petitioned for the reclassification of portions of the Alafia River and Tampa Bypass Canal to Class I (drinking water supply). This activity also seems beyond the scope of the HBMP.

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."

The State of Florida has initiated a review of its surface water criteria for DO (http://www.dep.state.fl.us/water/wqssp/docs/do/do-tech-supp-doc-110811.pdf). The current surface water quality criteria for DO, based on early EPA guidance, have been in effect since the 1970's. Much new information has been amassed, which has greatly improved the knowledge base needed to develop more appropriate criteria. For example, many natural waterbodies with healthy biological communities often exhibit DO levels below the existing DO criteria. The Committee believes that using DO percent saturation rather than concentration may be more appropriate for the warm, saline waters of South Florida.

Little discussion of nutrients was included in the 2010 HBMP Update Report (PBS&J 2011), but the Interpretive Report (PBS&J 2010) did include a robust discussion as to the drivers of nutrient distributions and influence of nutrients on phytoplankton and, ultimately, benthos and fish. Although the HBMP is not primarily concerned with nutrient sources and distributions, there remains a large audience for this type of information because it is necessary for management of the resource. Flushing time as affected by flows and any significant withdrawals may have impact on internal nutrient cycling and retention of nutrients in the ecosystem. The Committee understands that the District has an applied hydrodynamic model that can evaluate flushing time. In its own defense, the Committee suggests that some aspect of a regular nutrient monitoring be continued by Tampa Bay Water with an eye to the future HBMP sampling design.

Recommendation: *The Committee strongly recommends that Tampa Bay Water utilize continuous-recording, multi-parameter, water quality meters to collect in-situ water quality data and to compliment the continuous-recording streamgages and tidal gages that are required for modeling and simulation studies. The units will make water quality monitoring more efficient and they should be equipped with an appropriate selection of sensors, potentially including water depth, temperature, salinity (conductivity), pH, DO, turbidity, CDOM and chlorophyll-a. All units should be sourced from one manufacturer to reduce staff training costs and simplify calibration of probes and sensors, have the same suite of sensors, and probably should be purchased as pairs—one unit in the water and the other back in the lab being calibrated and readied for deployment at the next exchange interval. During the exchange, field personnel servicing the installations should also collect grab samples for independent laboratory analysis of monitored parameters, especially salinity, chlorophyll-a and turbidity. Laboratory calibration of in situ automated data collection is a necessary and general practice to verify that the installed meters are functioning correctly. The Committee notes that when a water depth probe is included in the package, the units become de facto tide gages if they are secured (fixed) and not floating. Since new tide gages can be rather expensive to establish, this is a way to obtain similar data in needed locations at a fraction of the cost. Statistical assessment of the HBMP database and the previously discussed analytical recommendations should be sufficient to identify where the most representative locations are for the new water quality meter installations, and to verify continued usefulness of the existing metered sites. The Committee also believes that a more rigorous analysis of existing water quality data could be sufficient to begin formally answering questions about detectible impacts of water withdrawals.*

Biological Communities and Distributions

Most estuarine biota, especially benthic invertebrates and fishes, are not uniformly distributed along an estuarine gradient; rather, the distributional ranges, abundance peaks and kinds of organisms found are generally determined by physiological tolerances to physical and chemical conditions that exist along the estuarine gradient, the presence of ecological habitats containing both food and cover, and biological interactions (e.g., competition and predation) among species and trophic levels. Major physical and chemical factors affecting estuarine biota are salinity distributions, other water quality distributions (particularly temperature, DO, turbidity and nutrient concentrations), sediment characteristics and water depths, currents and levels (elevation stage determines amount and availability of intertidal wetlands and other shallow water habitats), and physiological stresses from toxic pollutant exposure.

A natural minimum in species richness and biotic diversity occurs in the transition zone between true freshwater environments and oligohaline (0.5-5 psu) salinities. Along the estuarine salinity gradient, most planktonic and benthic organisms have relatively predictable patterns of occurrence, depending upon life stage and time of year, with many overlapping abundance peaks (i.e., a complex continuum of distributions – see Figure 3 (from Flannery briefing at HBMP Workshop, January 22, 2012). Relatively predictable changes in the kinds and abundances of macrobenthic invertebrates and many other biota are known to occur with changes in sediments, water depth, and water quality variables (e.g., salinity and DO). The Committee believes that the effects of such major sources of variability in biotic distributions need to be accounted for in order to rigorously assess the degree to which drinking water withdrawals are potentially impacting the five affected water bodies of interest here.

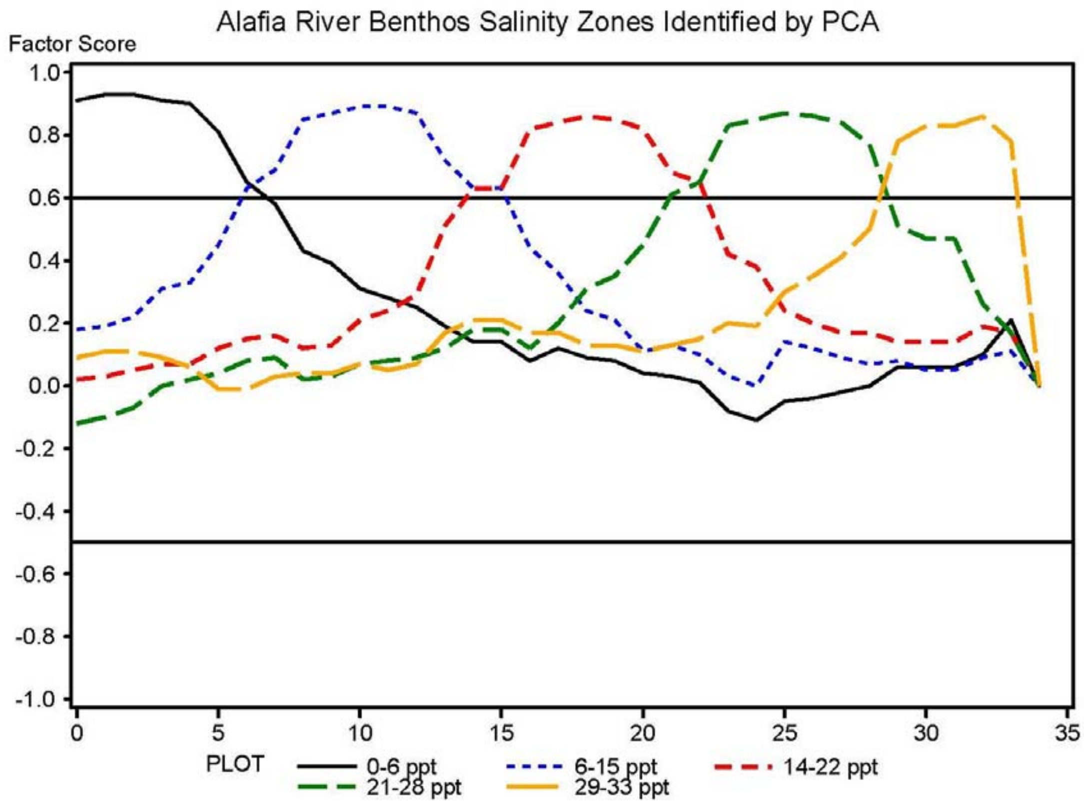

Figure 3. Summary of benthic communities observed along the estuarine salinity gradient of the Alafia River (from Flannery 2012).

Macrobenthic Invertebrates

Sediments and the surfaces of submerged objects, such as rocky outcroppings and pilings, provide habitat to many species that live in and on the sediment and the surfaces of hard substrates. The benthic invertebrates play crucial roles in the estuarine food web by providing food for juvenile fishes, by removing particles from the water column through filter feeding, and by participating in essential materials processing and biogeochemical cycling through deposit feeding (e.g., Lippson et al. 1979). The HBMP is designed to use changes in the kinds and abundances of macrobenthic invertebrates (i.e., bottom-dwelling biota >0.5 mm collected using a Young modified Van Veen grab sampler) as a key indicator of the impact of drinking water withdrawals.

The available scientific literature (e.g., Pearson and Roosenberg 1978, Holland et al. 1987, McManus and Pauley 1990, Lerberg et al. 1998, Engel et al. 1994) suggests that the kinds and abundances of macrobenthic invertebrates have proven to be relatively sensitive and reliable indicators of anthropogenic impacts (e.g., coastal development, eutrophication, chemical contamination) and natural environmental factors (salinity distribution/freshwater inflow, sediment characteristics) (Boesch and Rosenberg 1981, Weisberg et al. 1997). Macrobenthic invertebrates are good indicators of environmental quality because they are relatively sessile, are easy to sample and have predicable responses to natural and anthropogenic environmental variability. Moreover, a plethora of basic scientific knowledge is available on their life history and functional roles in estuarine ecosystems. Most importantly, the kinds and abundance of macrobenthic organisms are an integrative measure of environmental conditions over their life spans (months to years) and represents the cumulative effect of previous environmental exposures and conditions.

Reliable and accurate application of macrobenthic indicators in regional and national monitoring and assessment programs, including Tampa Bay Water's HBMP, require that important environmental variations, such as changes in sediments, salinities and DO, be accounted for before changes from anthropogenic sources (i.e., drinking water withdrawals) are identified and quantified (e.g., Karlin et al. 2008, Holland et al. 1987). This is particularly true for the HBMP since the Committee understands that the projected environmental changes (upstream movement of salinity isohalines) from drinking water withdrawals are likely to be small (2-3 psu on average, depending upon specific location in the rivers), are unlikely to result in major changes to the abundance and distribution of macrobenthos, and are likely to be masked by the larger natural background variations.

Salinity and sediment characteristics (e.g., grain size) are the major environmental factors influencing the natural distribution of estuarine and tidal freshwater macrobenthic organisms (e.g., Holland et al. 1987; Janicki Environmental, Inc. 2007). Macrobenthic responses to natural variability in salinity and sediment properties are relative easy to estimate (e.g. analysis of covariance using salinity and sediment characteristics as covariates, and season and strata as blocking variables). This is especially important during spring recruitment periods when abundances are high and early life stages that are sensitive to salinity levels generally dominate the community. The HBMP interpretative reports do not include analyses that quantified variation associated with salinity and sediment effects and/or partition variation due to season and strata. However, the Committee understands that this has been evaluated to some extent as part of HBMP special studies and other projects, such as the District's MFL studies. The Committee believes that these types of analyses are necessary to rigorously assess the likely small responses of macrobenthos to drinking water withdrawals and associated changes in the salinity gradient.

Hundreds of sediment and macrobenthic invertebrate samples have been taken and processed for the HBMP. Yet, a map of sediment distributions has apparently not been developed. Similar maps have been developed by the Tampa Bay NEP for other parts of Tampa Bay. During the Committee's site visit (January 21, 2012), it was apparent that substantial portions of the upper portions of the Alafia and Hillsborough rivers contain rock outcroppings and other hard substrates that would not be reliably sampled by the macrobenthic sampling gear used in the HBMP. If a sediment map had been produced, it is likely that benthic sampling would have been discontinued in the upper (non-estuarine) regions of these rivers long ago.

Several macrobenthic invertebrates were identified in the 2010 Update Report as key biotic indicators. The approach used to identify these species was not clearly defined other than a statement that they were the ones that occurred with sufficient frequency and abundance to allow meaningful analysis. Selection criteria for identification of "key biotic indicators" must, however, also consider likely response patterns, life history, sensitivity to perturbation of concern, and many other factors before a reliable indicator can be identified. The only graphic that could be identified that provided distributional information for key species identified in the HBMP was in the District's MFL briefing by Flannery (January 22, 2012). The Committee notes that selection of the stout razor clam, *Tagelus plebius*, as a key indicator species for some of the potentially impacted habitats seems to conflict with the known life history characteristics of this species and suggests that the sampling gears and methods used for the HBMP only marginally represent actual abundances and distributions of juveniles of this species (e.g., Holland and Dean, 1977a, 1977b). According to Chanley and Castagna (1971), the larvae complete pelagic development at a smaller size (155–170 µ) than any other known bivalve veliger.

Recommendation: The Committee believes that a special study synthesis of the available scientific information on macrobenthic invertebrates of the Hillsborough River, Alafia River and Tampa Bypass Canal should be conducted if the previous synthesis performed by the District is found insufficient to answer HBMP questions. This should include, but may not be limited to, HBMP monitoring data, life history information, previous analyses, concordant data from similar estuarine systems, and probable responses of key species and community properties to streamflows and water withdrawals. The goal of this synthesis is to assess the effectiveness of macrobenthic invertebrates as indicators of Tampa Bay Water's freshwater withdrawals in the ranges allowed by the District's MFL rules and water use permits. Emphasis should be placed on evaluating macrobenthic responses during critical low flow periods and during time periods when water withdrawals may influence the amount of bottom habitat exposed to hypoxic waters. The synthesis report should be peer reviewed by an independent panel. In order to avoid data gaps, the Committee agrees that continued benthic sampling in the months between December and May seems most appropriate and efficient (Janicki Environmental 2009). Based on the results, the Committee is confident that a decision can be reached scientifically to continue, modify or discontinue the benthic monitoring element for each ecosystem sampled in the current HBMP (i.e., Hillsborough and Alafia Rivers, Tampa Bypass Canal and McKay Bay).

Finfish and Nekton Communities

Hundreds of finish and nekton samples have been taken and processed for the HBMP; however, a map of finfish and crustacean spawning, nursery and feeding habitats has apparently not been developed. Nor was a general narrative developed describing how valuable finfish and nekton resources use the affected ecosystems and their habitats differentially.

The Committee finds that changes in the shallow-water distribution of estuarine-dependent fishes and invertebrates are related to freshwater inflows. Freshwater discharges into the tidal estuary attract these organisms, particularly young-of-the-year, into areas, such as the Hillsborough and Alafia Rivers, that provide nursery habitats (i.e., food and cover) in which they can survive and grow. However, the weak statistical relationships found between inflows and the abundances of major fish and invertebrate species, as described in the District's MFL reports for the Lower Hillsborough River (SWFWMD 2006) and the Lower Alafia River (SWFWMD 2007), indicate that other physical, chemical and biological conditions are limiting fisheries production in these rivers. These factors were discussed in detail by the District, which concluded that these rivers suffer frequently from algal blooms and low DO concentrations, causing physiological stress and mortality. Complicating matters, there are strong seasonal cycles in temperature, salinity and DO, related to the cooler, dry (winter-spring) seasons versus the warmer, wet (summer-fall) seasons. The Committee finds that there is ample monitoring data showing that DO, especially near the bottom, is often undesirably low (hypoxic) in some areas of these rivers, blocking migration and increasing mortality of inhabiting fish, shellfish and other organisms. This makes monitoring for *in-situ* water quality parameters like salinity, temperature, pH, DO and chlorophyll-*a* just that much more important.

Most fishes and macro-invertebrates that are adapted to live in shallow tropical or sub-tropical coastal estuaries are also adapted to tolerate the low (~2 mg/L) DO concentrations that frequently occur in these warm waters at night. However, they generally require DO saturation to be above 30% for continued survival, which at 30ºC is equivalent to ~2.5 mg/L DO. Waters below 30% saturation are referred to as "hypoxic," a condition that induces great physiological stress and mortality in most aquatic animals. When hypoxia occurs, most free-swimming organisms will stop using the area's habitats. This effect was observed in the Lower Alafia River and Tampa Bypass Canal where fish and shrimp were found to avoid hypoxic areas (Peebles 2005; Matheson et al., 2005), just as they do in the other major urbanized riverine system in this estuary, the Lower Hillsborough River (MacDonald et al. 2005). Perhaps it would be useful to consider graphing percent saturation of DO instead of just mg/L concentrations.

Recommendation: The Committee believes that a special study synthesis of the scientific information that is available on the fish and nekton of the Hillsborough River, Alafia River and Tampa Bypass Canal should be conducted if the previous synthesis performed by the District is found insufficient to answer HBMP questions. This should include, but may not be limited to, HBMP monitoring data, life history information, previous analyses, concordant data from similar estuarine systems, and probable responses of key species and community properties to changes in streamflows and water withdrawals. The goal of this synthesis is to assess the effectiveness of fish and nekton as indicators of Tampa Bay Water's freshwater withdrawals in the ranges allowed by the District's MFL rules and water use permits. Emphasis should be placed on evaluating fish and nekton responses during critical low flow recruitment periods and during periods when water withdrawals may influence the amount of habitat exposed to hypoxic waters or block fish migration and movement patterns. The synthesis report should be peer reviewed by an independent panel. In order to avoid data gaps, the Committee agrees that continued fish/nekton sampling in the low flow spring season that coincides with peak utilization by juveniles seems most appropriate and efficient. Based on the results, the Committee is confident that a decision can be reached scientifically to continue, modify or discontinue the fish and nekton monitoring element for each ecosystem sampled in the current HBMP (i.e., Hillsborough and Alafia Rivers, Tampa Bypass Canal, and McKay Bay). The Committee is aware of the District's current study to examine the use of fish abundance and diversity for establishing MFLs for rivers in southwest Florida.

<u>Macrobenthic and Juvenile Fish Environmental Quality Indices</u>

A wide range of approaches exist for developing benthic and fish indices of environmental quality (e.g., Weisberg et al. 1997, Engel et al. 1994, Karr 1991) and large amounts of suitable macrobenthic and juvenile fish data exist that can be used to develop benthic and fish indices for the HBMP's water bodies of concern. The TBNEP has developed a Benthic Condition Index for the region and the FMRI has several recruitment indices for valued fish species that are applicable to ecosystems covered by the HBMP. Therefore, it appears that reasonable and reliable macrobenthic and juvenile fish indices can be developed for application by modifying these existing indices using HBMP data. The Committee understands that this has been done to some extent in HBMP special studies and other projects, such as the District's MFL studies, with indices focused on withdrawal-related changes. Once developed these indices would be valuable tools for cost effectively monitoring future conditions and for integrating and presenting monitoring results. Not only would the number of samples that would need to be processed be greatly reduced, but assessments based on environmental quality indices are much easier for managers and the public to understand.

Recommendation: The Committee believes that Tampa Bay Water should consider the feasibility of leading a group effort to modify existing macrobenthic and fish/nekton condition and recruitment indices for application to HBMP water bodies in the future. If these indices can be modified and validated, they may be a powerful assessment tool for many users, including the HBMP. An approach for developing the index might include:

- *Convening a team of benthic and fish experts to define the parameters to be included in the indices, identify appropriate index sampling period(s) and identify the specific data to be used for index development and validation. This team should include representatives of the team of scientists currently developing a national coastal benthic index in order to benefit from their experience and knowledge.*
- *Developing the indices using the existing HBMP data, holding in reserve selected validation data representing high, low and normal flow conditions.*
- *Validating the indices using the reserved data.*
- *Applying the index to the monitoring data collected by the HBMP using a CDF approach for each year of the HBMP data collected so far.*

- *Developing a future monitoring and assessment strategy and schedule for macrobenthos and juvenile fish in the Hillsborough River, Alafia River and McKay Bay.*

The Committee believes that indices are useful tools for communicating more than just the general status of an environmental resource, but in some cases they may not be particularly useful for assessing small impacts in a compliance framework. The Committee agrees that such indices would be helpful with regard to environmental stewardship, but that Tampa Bay Water should probably not be the sole entity responsible for this effort. As discussed previously, such "ownership" issues and the willingness of cooperating agencies to help support special ecosystem studies that are beyond the scope of the HBMP will determine the success of any future efforts to maintain the ecological health and productivity of the water bodies of interest here.

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