MINIMUM FLOWS FOR THE TAMPA BYPASS CANAL, TAMPA, FLORIDA

Scientific Peer Review Report
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Prepared For:
Southwest Florida Water Management District
2379 Broad Street
Brooksville, Florida 34609-6899

Prepared By:
Scientific Peer Review Panel

Panel Chair and Report Editor:

Gary L. Powell, President
Aquatic Science Associates
2700 Bee Caves Road, Suite 101
Austin, Texas 78746-5660
garypowell@austin.rr.com
(512) 347-1088

Panel Members:

Dr. Paul A. Montagna
The University of Texas at Austin
Marine Science Institute
750 Channel Drive
Port Aransas, Texas 78373-5015
paul@utmsi.utexas.edu
(361) 749-6779

Dr. Raymond Walton, P.E.
Dr. Henry Hu, P.E.
WEST Consultants, Inc.
12509 Bel-Red Road, Suite 100
Bellvue, Washington 98005-2535
rwalton@westconsultants.com
(425) 646-8806

Minimum Flows for the Tampa Bypass Canal, Tampa, Florida

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EXECUTIVE SUMMARY

The Tampa Bypass Canal (TBC) was constructed between 1966 and 1982 by the U.S. Army Corps of Engineers for the purpose of flood control in the Hillsborough River basin. This included excavating the bed and banks of Six Mile Creek/Palm River, as well as substantial parts of the floodplain, leaving no instream or riparian habitats intact and greatly expanding the width, depth, and volume of the native drainage. The Southwest Florida Water Management District has made two attempts to study the effects of freshwater inflows in the TBC and to evaluate the need for a minimum flow level in this floodway. These studies were conducted (1) because Florida Statutes (§373.042) mandate the District's evaluation of minimum flows and levels (MFLs) for the purpose of protecting the water resources and the ecology of the affected area from "significant harm," (2) because the original area had once been a part of a tidal creek with a functional estuarine nursery that helped produce an abundance of seafoods of commercial and recreational interest in the Tampa Bay area, and (3) because of the continued expansion of municipal and industrial water diversions from the area to meet the ever increasing water demands of the fast growing Tampa coastal region. In the end, the District's net conclusion is that the TBC flood control system is so highly altered 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 TBC at this time.

The District's goals, indicators, and definitions, as developed and explained in the subject report seem reasonable and appropriate to the Review Panel. The District's conclusion that an MFL for mangroves in McKay Bay is unnecessary is also well justified since there is no technical disagreement that mangroves can tolerate very high salinities, and that the soil salinity is not directly proportional to surface water salinity in mangrove wetlands. The Review Panel supports the District's conclusion that an MFL for oysters is not warranted as well because (1) the oysters can tolerate existing and future salinity ranges in the TBC/McKay Bay complex, including the salinities expected when TBC discharge is zero; (2) increasing stratification and decreasing dissolved oxygen with increasing TBC flows is contraindicated for oyster survival, growth, and reproduction; (3) much of the oyster mortality in the area appears due to high flood flows which decrease salinities to lethal levels; and (4) shellfish harvesting in McKay Bay is prohibited by the Florida Department of Environmental Protection for reasons of human health.

While birds are charismatic and appealing to use as an indicator, they are obviously highly mobile, difficult to census and rarely related to freshwater inflows directly. The Review Panel concurs that it is reasonable for the District not to attempt development of an MFL for the resident or transient bird species, unless fresh surface water for wildlife consumption becomes limiting in the area.

The Review Panel supports the District's finding that changes in the shallow-water distribution of estuarine-dependent fishes in the area suggests that freshwater discharges in the TBC attract these organisms, particularly the young-of-the-year, into an area that provides little instream habitat (read: food and cover) for them to survive and grow within, leading to presumed higher mortalities than they would experience in more natural estuarine nursery habitats. Though this can only be proved by a study of survival rates in and outside the TBC, which the Review Panel would support, the Panel also believes that the high mortalities are nevertheless a logical scientific conclusion by the District based upon the existing data and information.

In addition, the weak relationships found between inflows and abundances of the fish and invertebrates indicate that other physical, chemical, and biological conditions are limiting biotic production in the TBC. Since these appear to be well known and discussed in detail by the District, the Review Panel concludes that the consideration of fish and invertebrates was adequate though incomplete. For example, the Review Panel concurs with the District's finding that dissolved oxygen near the bottom is often undesirably low (hypoxic) and lethal to inhabiting fish and shellfish.

The Review Panel agrees that the District's hydrological analyses and discussion are adequate, as are the expanded salinity analyses; however, the hydrodynamic modeling of circulation and salinity patterns in the study area suffers from so many problems that it is difficult to have confidence in the results or to conclude that this mechanistic model was an appropriate tool to analyze salinity impacts due to TBC flow modifications. To the Review Panel, it appears that the current model application does not have the required accuracy or resolution to adequately simulate the circulation and salinity patterns of the water management scenarios in enough detail for use in decision-making. From the Panel's point of view, it is obvious that a reliable, high-resolution, numerical model application would have been a distinct asset in the District's evaluation of MFLs for the TBC. Nevertheless, the Review Panel concurs with the District's general conclusion that the changes in salinity associated with flow reduction scenarios using flows less than 100 cubic feet per second (cfs) are small and rather insignificant ecologically compared to the magnitude of ambient salinities and their natural variability.

The Review Panel believes that the District's selection of a low flow threshold (LFT) of 30 cfs (i.e., the 10th percentile flow frequency of the TBC), was entirely reasonable, even if the District concluded that it is unnecessary based on (1) the biological abundance analysis, which indicates that if the withdrawal rate is set to the lower value (40%), then the estimated abundance of the selected taxa appear virtually independent of the LFT; and (2) the water quality (i.e., salinity and DO) analyses, which indicate that the differences among water management scenarios are nearly indistinguishable and, thus, are probably ecologically negligible.

Overall, the Review Panel agrees with the District's approach of examining the relationships among TBC flows, water quality (i.e., salinity and dissolved oxygen), and biotic inhabitants (i.e., oysters, benthic infauna, fish and invertebrates, birds, and vegetation). In general, the Review Panel also agrees with the District's conclusions that the plants and animals inhabiting the area won't 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.

However, this does not mean that the Review Panel accepts in any way the idea that freshwater inflows and their associated sediments, nutrients, and salinity gradients are of debatable ecological benefit to bays and estuaries. Indeed, just the opposite is true as we understand the science of these valuable coastal environments. However, the inflows are less important if there are little or no functional habitats to provide food and cover in the TBC, and they 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 diseases in a high salinity coastal environment.

One solution to this problem might be the construction of a low-water weir or an inflatable fiber-dam at the mouth of the TBC to restrict biological immigration without restricting outflow from the floodway. From the Review Panel's view, a better solution to the overall ecological problem with the TBC/McKay Bay complex and its future as part of an urbanized estuary may be to rehabilitate remaining wetlands adjacent to the TBC and along its northeast shoreline; however, this is beyond the current scope of the Panel's review.

INTRODUCTION

The Southwest Florida Water Management District (the District) is mandated by Florida statutes to establish minimum flows and levels (MFLs) for state surface waters and aquifers within its boundaries for the purpose of protecting the water resources and the ecology of the area from "significant harm" (Florida Statutes, 1972 as amended, Chapter

373, §373.042). The District implements the statute directives by annually updating a list of priority water bodies for which MFLs are to be established and identifying which water bodies the District will voluntarily undertake independent scientific review. Under the statutes, MFLs are defined as follows:

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

Revised in 1997, the Statutes also provide for the MFLs to be established using the "best available information," for the MFLs "to reflect seasonal variations," and for the District's Board, at its discretion, to provide for "the protection of nonconsumptive uses." In addition, §373.0421 of the Florida Statutes states that the District's Board "shall consider changes and structural alterations to watersheds, surface waters and aquifers, and the effects such changes or alterations have had, and the constraints such changes or alterations have placed on the hydrology of the affected watershed, surface water, or aquifer…." As a result, the District has identified a baseline condition that realistically considers the changes and structural alterations in the hydrologic system when determining MFLs. While this is always important, it is especially so with the Tampa Bypass Canal which represents a major physical alteration of the former Six Mile Creek and Palm River, which now no longer exist.

Current state water policy, as expressed by the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code) contains additional guidance for the establishment of MFLs and provides that "…consideration shall be given to the protection of water resources, natural seasonal fluctuations, in water flows or levels, and environmental values associated with coastal, estuarine, aquatic and wetlands ecology, including:

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

As a result of Florida Statute amendments to §373.042 in 1996, the Governing Board of the District approved a MFLs Rule (Chapter 40D-8, Florida Administrative Code) in October 1998 that contained methodologies used to establish minimum levels in 15 lakes, 41 wetlands, and 7 wells in the northern Tampa Bay area. In accordance with the statutory guidelines previously cited, an independent scientific Peer Review Panel was assembled by the District, as requested by Hillsborough County, Tampa Bay Water, and the Environmental Confederation of Southwest Florida. The Panel's Final Report (Bedient et al. 1999) concluded that "…the methodologies proposed by the District for establishment of Minimum Levels are generally sound and reasonable," whereas, the Panel found that "the zero Minimum Flow for the TBC is not supported by the data, and the analyses fail to address the frequency and duration of zero discharge." Since the District had a very limited time to study the issue originally, an effort to revisit the matter was instituted. The District also has continued to voluntarily commit to independent scientific peer review of its MFLs determinations as good public policy.

In July 2005, the District empanelled another independent scientific peer review to evaluate the May 15, 2005 Draft MFL Report for the Tampa Bypass Canal. Peer reviewers were instructed to review the draft document and determine the following:

1. Are the conclusions reached justified by the available data and the procedures/techniques used by the District in evaluating the data, and

2. Are there alternative procedures/techniques that would be preferable or useful in evaluating the MFL for the water body?

After a conference call on August 29, 2005 to discuss the scope of the review, the panel members independently prepared their scientific reviews of the draft report and associated study documents. The reviews were compiled and edited by the Panel Chair into the written report presented herein.

BACKGROUND

The Tampa Bypass Canal (TBC) was constructed between 1966 and 1982 by the U.S. Army Corps of Engineers for the purpose of flood control in the Hillsborough River basin. The TBC extends about 14 miles from Cow House Creek in the lower Hillsborough flood detention area to McKay Bay, where it discharges into the open estuary. A coastal stream, Six Mile Creek, and its lower two-mile reach, known since the 1920's as the Palm River, were completely excised to create the floodway of the TBC (HDR 1994). This included excavating the bed and banks of the stream, as well as substantial parts of the floodplain, leaving no instream or riparian habitats intact and, consequently, greatly expanding the width, depth, and volume of the drainage.

Overall, the post-construction volume of the TBC is estimated to be 13 times greater than the pre-development condition (SWFWMD 2005). For example, Flood Control Structure No. 160 (S-160) terminates tidal intrusion about 4.7 miles upstream from the mouth of the TBC at McKay Bay. Here the stream was originally 50 feet wide and about 3.5 feet deep with lush vegetation; however, after TBC excavation, the dimensions of the drainage were increased to 500-630 feet wide, 20 feet deep, and the sides were armored with rip rap to safely carry floodwaters away from the cities of Temple Terrace and Tampa. Since 1985, a pump station on the Harney Canal, an arm of the middle pool of the TBC, has been used to augment water supplies needed from the Hillsborough River Reservoir by the City of Tampa Water Treatment Plant. Downstream the Tampa Bay Water TBC pump station was completed in 2002 and diverts additional water supplies from either above or below Flood Control Structure No. 162 (S-162), which separates the middle pool from the lower pool.

Because the original area had once been a part of a functional estuarine nursery that produced an abundance of seafoods of commercial and recreational interest, because of the continued expansion of municipal and industrial water diversions from the area to meet the ever increasing water demands of the fast growing Tampa coastal region, and because of the limited time available to the District to study the situation, the District's 1999 report and determination that a minimum TBC flow of zero would not significantly harm the living resources of the estuary has been repeatedly called into question, starting with the first Peer Review Panel (Bedient et al. 1999). In response to this previous Panel's specific recommendations, the District conducted additional studies valued at $247,000 on the TBC/McKay Bay complex, which are summarized in the District's 2005 Draft MFLs Report that is the subject of this current peer review.

REVIEW

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

The District has four management goals for the TBC (Page 1-5, SWFWMD 2005). The goals were developed to sustain ecological integrity of the TBC segment between S-160 and the 22nd Street Causeway, a distance of 7.4 km or about 5 miles. Briefly, the purpose of Goal 1 is to maintain a biologically appropriate salinity regime and associated dissolved oxygen levels. Goal 2 lists fishery and non-fishery resources to be protected. Goals 3 and 4 are not ecosystem management goals *per se*; rather, they are operational definitions of the measurement units (e.g., salinity, species abundance and diversity) and the benchmark period (i.e., 1983 to present) used in the determination of the TBC MFLs. Also, it should be noted that Goals 1 and 2 are strong because they were developed using a broad stakeholder process.

In addition, two important *a priori* assumptions are made by the District: (1) that a habitat loss greater than 15% is not acceptable (Page 1-6) without triggering significant harm to the ecological resources, and (2) that the low-flow threshold for determining MFLs should not go below the 10th percentile flow rate (i.e., 30 cfs at S-160 = 19.4 mgd) calculated from the baseline flow record, since streamflows below that are not likely to be sufficient for ecological maintenance. Another important definition for the TBC MFL determination is that it will be expressed only as a freshwater inflow rate without a water level component because water level is dominated by the daily rising and falling of Gulf tides in this tidal flood channel and its receiving bay system. All of the goals, indicators, and definitions developed in the report's first chapter seem reasonable and appropriate to the Review Panel.

The second chapter of the District's report summarizes results from past studies in the TBC. A few recurrent themes among the studies are striking; namely, that the TBC is a relatively high salinity environment which is relatively insensitive to salinity change with changing discharge regimes in the flood control system. Moreover, there is chronic dissolved oxygen (DO) impairment, especially with depth, because of salinity stratification in the TBC where the excavated bottom is below sea level, creating a more or less stagnant water mass in the flood channel. This impairment of DO in the bottom waters of the TBC has important biological consequences, such as the failure of the larger benthic (bottom-dwelling) organisms, the macrobenthos, to show statistical relationships with varying flow regimes in the District-supported studies. Based on these facts, the District's net conclusion can only be that the TBC flood control system is so highly altered that resource protection will be difficult if not impossible to achieve by water flow management alone.

The third chapter of the report describes the current status of ecological resources in the TBC/McKay Bay complex and their usefulness as indicator species for determining MFLs. A brief review of each section is given as follows:

Oysters

The description of the Eastern oyster (Crassostrea virginicia) as a "keystone" species is incorrect (Page 3-1). In estuarine science, organisms like the oyster are more accurately referred to as "foundation" species. The difference in jargon is technical, but it's also crucial to scientific understanding because both are ecologically important in opposing ways. A keystone species has a disproportionate affect on communities relative to its abundance and, thus, keystone species are always top predators in the trophic structure. In contrast, a foundation species is one that biogenically creates habitat for itself and others, such as oyster reefs and seagrass beds. Otherwise, oysters are correctly described as being very important in providing ecological services that maintain the integrity of coastal ecosystems on the Gulf and Atlantic coasts of the U. S.

One conclusion, that the salinity gradient is not limiting to oysters because they are found along the entire study reach, is overstated based on the data and information presented alone (Page 3-6). The presence of oysters in an area is not informative about the state of health of the populations. For example, they could be growing and reproducing well in one reach with lower salinities, and be slow growing or sick and dying with disease and predation in a high salinity reach. Therefore, the Review Panel believes more information on the resident oyster populations would be needed than just their presence or absence to support a comprehensive statement like "the salinity gradient is not limiting," especially when it is well known that marine predators, parasites and disease organisms are invasive and can heavily damage oyster populations in the higher salinity areas of coastal bays and estuaries (Overstreet 1978, Longley et al. 1994). That's why the oyster, which can grow well and reproduce in a laboratory tank approximating near seawater strength conditions, are never found successfully doing the same in the natural environment. Rather, the most productive oyster reefs are usually in areas with salinities frequently less than 50% seawater strength, which can be osmotically stressful to the oyster's internal physiology, but more importantly restricts the invasion of the aforementioned marine predators, parasites, and disease organisms that can attack and devastate oyster populations.

The overall conclusion of this section is that oysters can tolerate the existing and future salinity ranges in the TBC/McKay Bay complex, primarily because the oyster can tolerate the salinities expected when TBC discharge is zero (Page 3-7). Therefore, the District concludes that the development of a MFL for oysters is not warranted. That extreme floods at the highest flow rates could reduce salinities to lethal levels for such estuarine-dependent species is not really an issue in coastal management because all natural environments, especially bays and estuaries, are adapted to disturbance events. In fact, it is likely that floods that can harm or even kill some oysters will have a net positive effect overall because they also wipe out the marine predators, parasites and disease organisms that attack the oyster population.

This kind of disturbance/succession model is common to all ecological habitats, both aquatic and terrestrial. Moreover, the idea of controlling disturbances, such as grassland and forest fires, has proven to be such a poor management concept that it has necessitated artificial fires (i.e., controlled burns) to correct the situation. For example, there is plenty of evidence that a good flushing periodically from a flood is good for bays and estuaries, and vital to maintaining the ecological health and productivity of coastal ecosystems.
The fact that these flood events are not really controlling the hydraulics or salinity of the TBC/McKay Bay complex on a daily basis is confirmed by the fact that total flushing of the bay is due 96% to tidal exchange and only 4% to freshwater inflows (PBS&J 1998). This makes the recommendation to limit TBC floodwater discharges larger than 2,000 cfs to a maximum duration of two weeks (Page 3-9) probably unnecessary and potentially unachievable with the flood control structures and limited water storage capabilities that comprise the current TBC system.

Vegetation

Since the construction of the TBC eliminated the instream and riparian habitats of the original tidal (estuarine) creek and replaced it with a deep, wide flood channel with shorelines armored by rip-rap, there doesn't seem to be much vegetation left in the TBC to be concerned about, except for the plankton blooms that can exacerbate the hypoxia (low dissolved oxygen). The District's conclusion that an MFL for mangroves in McKay Bay is unnecessary is also well justified. There is no question among the Review Panel that mangroves can tolerate very high salinities, and that the soil salinity is not directly proportional to surface water salinity in mangrove wetlands.

Birds

While birds are charismatic and appealing to use as an indicator, they are obviously highly mobile, difficult to census and rarely related to freshwater inflows directly. The Review Panel notes that in most cases, if the vegetated and benthic habitats that birds use for nesting and feeding are protected, then this type of wildlife can naturally take care of themselves without more intrusive management. The Review Panel concurs that it is reasonable for the District not to attempt development of an MFL for the resident or transient bird species, unless fresh surface water for wildlife consumption becomes limiting in the area, which is not projected by anyone. On the other hand, rehabilitating forgotten wetlands and restoring lost ones is always a good idea in an urbanized estuary, simultaneously benefiting a wide array of fish and wildlife.

Fish and Invertebrates

Although not explicitly stated, this section is mainly about epibenthic and planktonic invertebrates that share fish habitat. It is pretty clear that there is a mixed amount of functional and structural groups present, and that they all have different inflow responses and requirements (Peebles 2004). Three types of changes in the biological community structure were noted (Page 3-14); (1) seasonal changes were most consistent and the ichthyoplankton (larval fish) populations exhibited the strongest seasonal response, (2) changes in the composition of planktonic invertebrates (e.g., calanoid copepods) were caused by "washout" from the TBC during high (flood) flow events, and (3) changes in the shallow-water distribution of estuarine-dependent fishes in the area suggests that freshwater discharges in the TBC attract these organisms, particularly the young-of-the-year, into an area that provides little instream habitat (read: food and cover) for them to survive and grow within, leading to presumed higher mortalities than they would experience in more natural estuarine nursery habitats. Though this can only be proved by a study of survival rates in and outside the TBC, which the Review Panel would support, it is nevertheless a logical scientific conclusion by the District based upon the existing data and information. That fish eggs, larvae, and true planktonic organisms are entrained in the salty "tongue" of water that moves upstream along the bottom of the TBC when downstream discharges of freshwater exceed 100-400 cfs is a fact that leads to real concerns about the TBC as a "dead-end" for these organisms. Especially, when considering that any small organism that has swam or drifted with the saltwater movement 4.7 miles up the TBC will find little there but the S-160 flood control structure, which is not considered a quality nursery habitat by any means, and from which it's too far to safely migrate back down to McKay Bay where better habitat exists.

Therefore, while large floods can flush out the marine salinities and some marine organisms from the estuarine system and recharge it with new nutrients and sediments, the management of small amounts of freshwater discharge into a flood control channel like the TBC is problematic as our current scientific understanding would suggest it is an attractive nuisance at best, an observed habitat bottleneck in a truncated arm of the estuary with little nursery function in the objective view, or worse, a deadly "minnow trap" for the young of many coastal species. Only if the amount of adult reproduction and availability of these young organisms is not limiting to the estuary, can the concern be dismissed about high mortality in a floodway that has little nursery habitat now and in the future because of its federal flood control purpose.

Benthos

This section of the report deals with the invertebrates that are primarily infaunal, living within the sediments relatively fixed in place. Benthic infauna are generally good biotic indicators because they "sample" the environment continuously and, thereby, become recorders of preceding events. In contrast, most field sampling regimes are discrete and only provide information on the conditions during the sampling period. The focus here is on analyzing biotic patterns in species abundance and community composition. This is good, but there are two other important factors: (1) biomass, which indicates productivity; and (2) vertical distribution, which reveals interactions with the overlying water column. Another item overlooked is the dominant species in different salinity zones. For example, Table 3-9 (Page 3-23) ranks species according to depth, but not salinity. A key factor in creating a benthic index is to take the average salinity regime of the area into account.

The benthic section is based primarily on two scientific studies, one by Grabe et al. (2004) and one by Rakocinski (2004). The Grabe report is based on a data set from the Environmental Protection Commission of Hillsborough County (EPCHC) and the analyses are based on the non-parametric, multivariate multidimensional scaling (MDS) approaches developed by Clarke and Warkwick (2001), and implemented in the Primer-e software (Clarke and Gorley, 2001). In contrast, the Rakocinski report combined the EPCHC data with the Water & Air Research, Inc. (WAR) data. Rakocinski also used a completely different Canonical Correspondence Analysis (CCA), which is a linear parametric approach to analyzing the data. He also employed neural network modeling to predict community response to abiotic variables. Whereas, the Grabe approach is the current standard method, the Rackocinski approach combines a more traditional approach with some novel twists.

Clarke and Warwick developed the non-parametric approaches for several good reasons, but primarily because multivariate community structure data are notoriously non-normal in distribution and the data matrices are full of zeros, creating a serious difficulty for traditional parametric analyses. This latter issue is what really makes the parametric analyses unsuitable because two species that do not occur in two samples will have a perfect linear correlation; however, the perfect correlation is non-informative because two samples being similar because something is not there is generally considered nonsensical. While both approaches are valid, they can come to very different conclusions because they are so different logically and analytically and, in this case, used partially different data sets. The TBC report implies this is the case, but then states that "Grabe also reported that there was no statistically significant relationship between salinity and the number of taxa…" (Page 3-24). The context of this statement appears to be incorrect because the Grabe et al. report did not analyze numbers of taxa; rather, it analyzed the community composition in a species-dependent manner.

In addition, the Grabe et al. report did find significant relationships between the way the community changed and 14-day cumulative inflow, a clear indication of a relationship between infaunal community structure and inflow regime. Rakocinski (2004) used salinity as a surrogate for inflow and also found strong influences on benthic community structure. Thus, both studies came to the same conclusion that freshwater inflow affects benthos. Another interesting finding in both reports is that while DO is an important variable, it is the 3^{rd} or 4^{th} most important variable and usually behind salinity, inflow, depth, and temperature.

Water quality

The two most important findings are that (1) within the TBC/McKay Bay complex below the tidal boundary created by the S-160 flood control structure, salinity does not vary much, except at the highest flood discharges that "washout" tidal waters and living organisms alike; and (2) salinity stratification is strongly related to flow rates. The TBC is also characterized as chronically low in the dissolved oxygen needed for respiration by fish and most other aquatic organisms due to stratification of the water column and the high loads of organic and other nutritive materials introduced by point and non-point sources, primarily stormwater runoff from urbanized areas to the floodway.

Salinity

Since the District's previous (1999) studies of MFLs in the area, additional data have been collected and analyzed statistically. The District's 2005 report shows some of the general salinity structure of the TBC, and demonstrates that the system increasingly stratifies with increasing flow (e.g., Figure 3-2, Page 3-8). It is curious, however, that

Figure 3-2 reports data from 1983-2003, whereas Figure 3-10 uses data from 1974-2003. Why the same data set was not used for both analyses is not revealed. In addition, since the TBC is about 20 feet or 6 meters deep, the analysis of "sample depth >= 3 m" merely reflects the lower half of the water column (Figure 3-2, Page 3-8), as opposed to a more focused evaluation of observed bottom salinities. For example, the presentation of surface and bottom observations for the modeling exercise (Figure 3-24, Page 3-42) better illustrates the magnitude of stratification, at least with regard to the simulated values. A similar treatment in the empirical analysis could have been of more value.

The District's 2005 report (Section 3.7, Page 3-24) mentions that the salinity-flow regression equations were updated by Janicki Environmental (PBS&J 2003), but offer only a few figures and a table to report what was probably a substantial analysis. It is not clear from the discussion whether the regression equations considered the duration of flow, a concern of Bedient et al. (1999), or were simply a function of instantaneous flow. In addition, the results are not shown for all alternatives (i.e., only water flow scenarios S2 and S4 were given) and even these results were not compared with the results of the numerical modeling to lend confidence to either analysis.

Dissolved Oxygen

The Review Panel concurs with the District's finding that bottom DO is often undesirably low, hypoxic to inhabiting fish and invertebrates. The expanded data and statistical analyses support the District's conclusion that DO values generally decrease with increasing flows, except for Segment 7 immediately below the S-160 structure where DO declined with declining flows (Page 3-35). Again, since the TBC is about 20 feet or 6 meters deep, the analysis of DO at "sample depth >= 3 m" merely reflects the lower half of the water column (Table 3-13b, Page 3-34). A true analysis of salinities near the bottom (i.e., within 1 meter) may have produced a much clearer view of the DO problem being evaluated.

One line of reasoning in the District's report about the DO levels is unconventional—the report states that during the more quiescent low to moderate flow periods, the hydraulic residence times are longer and the water column is more well-mixed "…allowing algal blooms to develop and raise DO levels" (Page 3-35). This is counter to the prevailing scientific understanding of algal blooms that holds that they lead to lower net DO levels because night-time respiration is greater than the DO produced during the day. Also, decomposing or grazed algae contribute to the biological oxygen demand (BOD), further reducing DO levels. The important difference in interpretation is that the reduced flow scenarios where DO increases are more likely to be related to the reduced amount of salinity stratification, rather than the observed increases in algal blooms. In other words, the observations are probably due to a physical phenomenon where DO can not diffuse across the salinity lens and benthic respiration is actually driving the DO reduction.

Mechanistic Modeling

Estimating minimum flows also includes identifying and evaluating ecosystem characteristics that can be mechanistically linked to the management goals, not just inferred through observed statistical relationships. Mechanistic modeling was specifically recommended by Bedient et al. (1999) for the District's future studies. In the MFLs determination for the TBC, the "mechanisms" included the impacts of freshwater inflows on salinity and dissolved oxygen through the analysis of potential changes in inflow hydrology. Generally, temperature was not considered as a variable that could be modified with altered hydrology. Hydrodynamics (e.g., circulation and salinity patterns, water stage levels) and water quality (e.g., temperatures and dissolved oxygen) were evaluated using a combination of statistical analyses of measured data and the application of a numerical ocean model. The model used is a version of the Princeton Ocean Model (POM), and the simulated flow scenarios are described in detail in Luther and Meyers (2005). This document was also reviewed because it contains significant background information needed to evaluate the District's 2005 report on the TBC.

Hydrology

Without debating the sample station selections or the appropriateness of individual data sets, the hydrologic analyses and discussion seem to be adequate. Clearly, the physical modification of the original watershed and hydrological system has been tremendous, to say the least. The multiple connections between the TBC and the Hillsborough River and neighboring drainages make the situation all the more complex, while providing needed flexibility to manage water resources for flood control and water supply in the area. However, since bays and estuaries are known to require substantial amounts of fresh water to supply sediments and nutrients, and maintain salinity gradients characteristic of their nursery functions (Longley et al. 1994), reduced freshwater inflows to the receiving estuary, McKay Bay, are a major concern. Indeed, the tidal (estuarine) marshes and brackish wetlands of associated coastal streams and rivers provide essential food and cover for a myriad of marine and estuarine-dependent fish and wildlife, while restricting the invasion of marine predators, parasites and disease organisms that can negatively affect or even destroy an entire year-class of young organisms, and consequently limiting the surplus production of resident populations that provide seafoods in harvestable quantities. Nevertheless, examination of the hydrological data supports the District's finding that McKay Bay receives on average nearly twice as much freshwater as it did historically due to massive alterations in the contributing watersheds, and that this freshwater is episodically delivered through a flood-control conveyance structure, the TBC, that is approximately 10 times larger than the original coastal stream from which it was constructed. The issue of whether a more constant low flow should be discharged down the TBC is also of interest here.

Hydrodynamic Modeling

The District's TBC report describes the application of a version of the three-dimensional Princeton Ocean Model (POM) in general terms. It is the modeling report of Luther and Meyers (2005) that provides the scientific details. While this is a standard practice and is not criticized here, it does mean that it is important for scientific reviewers to consider both the District's report and the Luther and Meyers (2005) report to understand the use of modeling results and how they were obtained from the numerical simulations of varying flow scenarios. For example, the District's report contains only a very limited description of the particular model used, how it was applied and calibrated, and the purpose of the modeled scenarios (Section 2.16.1, Page 2-31). It is not made clear why the POM was selected when there are known problems with its application to shallow estuaries and narrow confined channels, why the modeling was limited to circulation (water velocity, direction, and stage levels), salinity and temperature, and why dissolved oxygen was not modeled even though its importance to the District is made clear.

The District's brief glimpse of the salinity calibration in the TBC report (Figure 3-24, Page 3-42) does highlight a problem with the model, since the figure shows relatively good agreement between observed and modeled salinities, except when surface salinities (observed and modeled) decline significantly during large (flood) discharge events. During these periods, bottom salinities in the model also decline significantly, indicating a vertically, well-mixed model. However, observed bottom salinities decrease much less, indicating actual salinity differences between the model and reality on the order of 10-20 psu. [Note that the modeling discussion correctly uses "practical salinity units" (psu), while elsewhere in the District's report salinity is reported as "parts per thousand" (ppt) salt, which is no longer the preferred measure of salinity.] This lack of a freshwater flow effect on the more stagnant bottom waters could be seen more easily if salinity differences (bottom-surface) had been compared between the model simulations and the field observations. Given that the model does not seem to reproduce near-bottom salinities well, and that many important ecological resources are defined or influenced by near-bed salinities, it is difficult to conclude that this model was an appropriate tool to analyze salinity impacts due to hydrologic modifications in the study area.

The results of the POM application to the TBC/McKay Bay complex is presented in Section 3.9.2 of the District's TBC report . While it is easy to criticize the unusual color scheme that is used to represent the distribution of salinities (e.g., see salinity scale on Figure 3-25, Page 3-43), the results as presented in the District's report appear to have been used appropriately. Again, the greatest concern is what lies behind the numbers and Figure 3-25 gives a hint to this concern. Since the Review Panel believes that it is important to demonstrate appropriate selection and application of the main mechanistic model used, a brief review of the Luther and Meyers (2005) report follows.

In the regional application, the POM model has 10 layers and about 200 cells (or "boxes"), which is generally adequate for estimating the overall patterns of circulation and salinity. However, most of the TBC is only one model cell wide and all layers in a computational cell of this model have the same uniform horizontal dimensions of width and length that may not fit the local vertical geometry of the area being modeled. This means that where cells align with the channel, widths at all depths are the same. By comparison, a model such as CE-QUAL-W2, which was applied to Sulphur Springs for that MFL study (SWFWMD 2004), allows for varying widths and depths to better represent the varying dimensions of the water body. Similarly, the TxBLEND model used by the Texas Water Development Board for dynamic long-term (e.g., year or longer) bay simulations is a computationally efficient finite element model that allows for higher resolution of the spatial solution, including wetting and drying of tidal area habitats, than many contemporary models by using thousands of computational cells to better resolve the problem in a timely manner (Powell et al. 1997).

The use of the POM configured with only one cell defining the entire width of the TBC will almost certainly skew hydrodynamics and, thus, the salinity/temperature processes that are being mechanistically simulated by the model. Additionally, the POM is an orthogonal curvilinear model. In non-technical terms, this means that the computational cells of the model's grid or mesh can be bent to follow the geometry of the area; however, the cells in the POM model of the TBC have been set up in a mostly square-grid fashion. As a result, water flow must make abrupt, right angle changes in direction instead of following the true shape and dimensions of the water body. In the POM model, different terms in the governing momentum equation can take on different and, perhaps, uncomplimentary roles.

The hydrodynamic modeling report of Luther and Meyers (2005) describes the setup, calibration, and application of the three-dimensional circulation model to simulate salinity distributions for different freshwater inflow scenarios. While a large portion of the report is used to present the model results for different freshwater inflow scenarios, it only provides a very brief discussion on model calibration. The simulated water surface elevations seem to agree reasonably well with the observed water surface elevations, which is usually the easiest measure to accurately simulate; however, there are significant discrepancies between the simulated and observed salinities at certain times. In particular, for large freshwater inflows, the model is not able to simulate the observed vertical stratification. At the open boundary of the regional model, the difference between the simulated and observed salinity is generally several psu units for many days, especially for the mid-depth waters. This difference is important because it is on the same order of magnitude as are the simulated salinity difference between different water use scenarios, making the interpretation of results somewhat ambiguous. The hydrodynamic modeling report does not provide a detailed explanation for this significant discrepancy.

The Luther and Meyers report (2005) shows fair agreement between modeled and observed salinities at the open boundary of the regional model, except between "model days" 900-1000 (Figure 13, Page 101). This was missed throughout the water column, but no explanation was offered. Good model agreement is also shown at Maydel Drive when salinities are high and flows are probably low, but not for bottom salinities when surface salinities are low and flows are probably high (Figure 14). First, it would be very useful to plot modeled versus observed salinity differences (bottom-top). Second, it would be very useful to include the associated TBC flow rates with the results. Unfortunately, the results appear to indicate that the POM model application does not capture stratification in the TBC very well during higher flow events. This is an important deficiency which could be caused by a number of factors including (a) the uniformity of cell widths over the vertical that does not adequately represent actual channel shapes, and (b) the numerical approach to modeling vertical eddy viscosity and diffusivity in the POM model.

On or about "model day" 250, Luther and Meyers (2005) report that observed top and bottom salinities both drop (probably due to a flood flow event), while the modeled salinity drops much lower than observed on the surface, and the simulated bottom salinity actually increases (Figure 15). Again, this phenomenon is not explained and presents an additional modeling problem.

Because the main purpose of the modeling is to predict changes in salinity due to changes in TBC freshwater inflow, and because such changes are generally small between different water management scenarios, it is important that the model exhibit good performance in simulating the salinity field. To the Review Panel, it appears that the current model application does not have the required accuracy or resolution to adequately simulate the circulation and salinity patterns of the water management scenarios in enough detail for use in decision-making. Since the model performance needs to be improved, a number of technical considerations are offered that could significantly affect the salinity computation:

- Are the grid alignment and grid resolution (horizontally and vertically) in the regional model adequate to define the geometry of the system?
- Does the spatial and temporal resolution of wind data have a significant influence on the circulation and salinity distribution?
- Is the numerical scheme used to solve the advection and diffusion equation for salinity sufficiently accurate to avoid the problem of artificial numerical diffusion?

Moreover, the hydrodynamic modeling report of Luther and Meyers (2005) needs some significant editing. Many tables in the report are not cited or discussed in the text, the units of water surface elevations shown in Figure 12 are not correct, and the quality of many plots is poor where text is embedded in the figures. An unusual criticism of the color legend for salinity is also noted because similar colors are used in displaying the results for quite different levels of salinity, making it hard to distinguish the important salinity differences in the figures. The modeling report does mention the names of local streams and stations, but they are not labeled on the figures, so their physical locations in relation to the computational domain of the model are unnecessarily difficult to discern. Lastly, it would be very useful to provide a modeled flow plot through time along with the resulting salinity distribution that is being simulated.

In addition, the report by Luther and Meyers (2005) states that POM does not simulate wetting and drying of wetlands represented by the computational cells. While this may not be a serious problem in the overall bay-wide model, it can be a significant drawback in the smaller regional model of the TBC/McKay Bay complex where intertidal areas abound. A minimum cutoff depth of 0.6 meters was used in the regional model, basically to include only areas below low tide, which again biases cell width with depth.

The modeling report does not explain why “fine tuning” wasn’t part of the study (Page 20), and what impact this might have had on their results. On the other hand, the modeling report concludes that “the model yields a realistic simulation of the circulation and salinity…” which is not all together convincing since no observations of “circulation” (velocities, drogues, etc.) are presented and only water surface elevations, which are easily simulated, are shown. Clearly, plots of salinity differences are called for but not produced, and where useful comparisons are produced (e.g., Figures 16-18), the scales of the graphs can differ, making comparison’s unnecessarily difficult. It would also be useful for Luther and Meyers (2005) to discuss and explain why some features are lagged between the surface and bottom (e.g., salinity drop between model days 50-60). In general, the biggest criticism of the modeling report is that it seems to present a mass of results with little focus on what the simulations were intended to assess. For example, if near-bottom salinities are important for oysters and other benthic organisms, then the results should show these variations in some detail to make the point about how the water management scenarios do or do not differ.

The lack of confidence in the numerical modeling leads us to believe that the best way to assess the current and potential future impacts of altered hydrology on the hydrodynamics of the TBC/McKay Bay complex is to make a new model application. If the District’s time and resources are too limiting, then the next-best plan is a wider use of field observations of freshwater inflows, salinity, and DO. A concern of Bedient et al. (1999) was that the regression analyses of salinity (and dissolved oxygen) only considered the magnitude of the low flows, not their duration. While they did recommend using a mechanistic model on the problem, they offered no alternatives for analyzing the additional salinity data that would be forthcoming from the District-supported studies and other monitoring activities. Nevertheless, from our review it is obvious that a reliable, high-resolution, numerical model application would have been a distinct asset in the District's evaluation of MFLs for the TBC.

In general, given the shortcomings of the numerical modeling, we would recommend that the observed salinities be used to evaluate the effects of altered hydrology, but that flow durations should be considered. Having said this, we do concur with the District's general conclusion that the changes in salinity associated with flow reduction scenarios using flows less than 100 cfs are small compared to the magnitude of ambient salinities and its natural variability. This can be shown by considering, for example, the tidal prism above Maydel Drive, where the resulting average tidal flow (assuming a 2-ft tidal range) is on the order of 400 cfs. Given that the scenarios analyzed generally have the largest changes in flow below 50 cfs (e.g., Figure 2-12, Page 2-13), or about 13% of the tidal flow, then flow reductions on the order of 10 cfs, only about 3% of the tidal flow, would be expected to have a quite small effect in altering the structure of the water column, which is consistent with the District's findings.

<u>Technical Approach</u>

Chapter 4 of the District's 2005 Draft MFL Report for the TBC describes the technical approach and summarizes the results of studies reported in Chapter 3. The Review Panel agrees with the District's approach of examining the relationships among TBC flows, water quality (i.e., salinity and dissolved oxygen), and biotic inhabitants (i.e., oysters, benthic infauna, fish and invertebrates, birds, and vegetation). In general, the Review Panel concurs with the District's conclusions that the plants and animals inhabiting the area won't 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.

However, the discussion of the two benthic studies by Grabe and Rakocinski is way too brief in view of the importance they were given in the District's expanded studies, and it is additionally not entirely consistent with those studies and their findings, which were labeled "inconclusive" (Page 4-2). The contention that DO, or lack thereof, is controlling benthic dynamics needs to be tempered by the fact that these two studies showed clear indications that salinity is affecting the benthic dynamics, which could mean that the salinity change scenarios in the TBC/McKay Bay complex could be as important as the DO change scenarios. Ironically, the report's conclusion about this may be correct for the wrong reason because if salinity change in the TBC is relatively insensitive to changes in flow, then the Grabe and Rakocinski studies clearly indicate that changes in benthos will likely not occur and, thus, the argument that no MFLs are necessary for the TBC is probably a sound argument.

The case for the fish and invertebrates is not so clear, because 34 of the taxa analyzed did show some rather weak (i.e., coefficients of determination, r^2, are 13-18%) but statistically significant relationships between TBC flow and their abundances. Potentially, this was caused, at least in part, by the analytical approach taken that lumped the McKay Bay segments and the TBC into one combined unit from S-160 downstream to the 22nd Street Causeway. A better spatial resolution in the analysis might have revealed additional and stronger relationships. Nevertheless, a reduction in daily median flows from the baseline condition (96 cfs) to the planned future condition (65 cfs), was estimated to result in a 13.1 % reduction in the edible pink shrimp (<u>Farfantepenaeus duorarum</u>), a 13.2% reduction in resident bay anchovies (<u>Anchoa mitchilli</u>), and an 18.9% reduction in the opossum shrimp (<u>Americamysis almyra</u>) that serves as a popular prey (food) item for many larger animals in the estuary. An overall average loss of 15% among the selected taxa, which is the District's assumed threshold for significant harm to the living resources of the area, was associated with a daily median TBC flow of 65 cfs. Greater losses among the estuarine resident and dependent species were estimated to occur with further reductions in freshwater inflow, except for the observed and predicted increases in coastal ocean species, including the marine predators, parasites, and disease organisms that would invade the area as it becomes more marine and less estuarine.

Also, at higher water withdrawal rates (e.g., 60% versus 40% of TBC flow), the selection of the low flow threshold (LFT) that limits potential diversions during low flow periods becomes more critical. The Review Panel believes that the District's selection of an LFT of 30 cfs, which represents the 10^{th} percentile flow frequency of the TBC, was entirely reasonable, even if the District concluded that it is unnecessary based on (1) the abundance analysis, which indicates that if the withdrawal rate is set to the lower value (40%), then the estimated abundance of the selected taxa appear virtually independent of the LFT; and (2) the water quality (i.e., salinity and DO) analyses, which indicate that the differences among water management scenarios are nearly indistinguishable and, thus, are probably ecologically negligible.

Summary of Results

Chapter 5 of the District's 2005 Draft MFL Report summarizes results of the evaluation of MFLs for the TBC. The weak physical, chemical, and biological responses to TBC flows within the management range suggest that even a minimum flow of zero would not, by definition, trigger significant harm. On the other hand, the Review Panel concurs with the District's decision to revisit its earlier (SWFWMD 1999) conclusion that the minimum flow could be zero, and finds that the District's more recent decision (SWFWMD 2005) to decline establishment of an MFL for the TBC at this time is both prudent and reasonable for this federal flood control structure.

However, this does not mean that the Review Panel accepts in any way a proposition that freshwater inflows and their associated sediments, nutrients, and salinity gradients are of debatable ecological benefit to bays and estuaries. Indeed, just the opposite is true as we understand the science of these valuable coastal environments. However, the inflows are less important if there are little or no nursery habitats that provide food and cover in the TBC, and they 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 diseases in this high salinity environment (Overstreet and Howse 1977, Overstreet 1978, Longley 1994).

Alternative Solutions

One solution to this problem might be the construction of a low-water weir or an inflatable fiber-dam at the mouth of the TBC to restrict biological immigration without restricting outflow from the floodway. A better solution to the overall ecological problem with the TBC/McKay Bay complex and its future as part of an urbanized estuary may be to rehabilitate remaining wetlands adjacent to the TBC and along its northeast shoreline (see Figure 1 satellite photo). This could be reasonably accomplished by beneficially using relatively small amounts (<30 cfs) of treated wastewaters or raw freshwater supplies from the TBC above S-160, or both, to irrigate and fertilize the wetlands. To restore their ecological function in the estuary, a hydrological connection between the wetlands and McKay Bay will also be required. If the opening into these wetlands is near the mouth of the TBC, then the signal from the fresher waters will cause a biological response wherein young organisms will be attracted into brackish marsh habitats where they will find food and cover, fewer marine predators, and a greater chance of survival and growth than if they proceed up the TBC.

Figure 1. Color aerial satellite photo of the Tampa Bypass Canal and adjacent wetlands near McKay Bay, Florida.

SPECIFIC EDITORIAL COMMENTS

Page	Paragraph	Line	Comment
i	3	3	"Prolonged low salinities" do not by themselves "establish vertical salinity stratification."
i	4		The paragraph is unclear.
1-3			Could use a figure here like Figure 2.1.
1-4	2	3	Richter et al. 1966 is not in the literature cited, but there is a Richter 1996 in the V section.

Page	Paragraph	Line	Comment
1-6	2		To be precise, the Texas Water Development Board set the harvest constraint on the mathematical programming (optimization) model such that the feasible solutions produced would have results wherein no individual species would have a harvest or catch less than 80% of its historical average. In no case are all of the species allowed to decline 20%, so that the overall seafood harvest is 80% of historic. Indeed, for most bays analyzed, the optimized monthly inflow solution produces fishery harvests that are near or even greater than the historic average using much less water than the historic average flow.
1-7	1		Again, the Texas Water Development Board set the flow constraint on the mathematical programming (optimization) model such that each of the monthly freshwater inflow solutions would fall between the ecosystem's 10th and 50th percentile flows. One explanation for the constraint is that flows below the 10th percentile were considered too low for ecological maintenance, even in months where freshwater inflows are not that crucial, and flows larger than the median (50th percentile) might produce more seafoods if they occurred in the right months, but they are above normal and would require an "act-of-God" that is not appropriate as a regulatory target. Similarly, periodic hurricanes may be beneficial for bay and estuary ecosystems over the long-term, but you can't require one in a water permit.
1-7	2		The notion that "…'flow' most legitimately equates to water velocity" is too simple. Technically, flow = (area) x (velocity). So the statement only holds true if area is constant in this tidal system. The author is probably trying to say, "as flows increase, velocities increase", which conveys the notion that flows are more strongly related to velocity than they are to area (or depth).
1-7	3		"The volume of water moved through a stream can be particularly important to an estuary" is true in many ways, but the sentences that follow are a bit misleading. First, there is no notion of a time scale in the discussion. Second, while it is true that the volume of freshwater that mixes with tidal saltwater in the bays and channels determines their salinity, it is important to remember that stratification may result in only a fraction of the available volume being involved in the dilution.
2-1			Page 2-1 appears 3 times. Page 2-2 appears twice. The section appears to have been renumbered several times.
2-2	3	2	States that the TBC was constructed between 1967 and 1983; however, Section 1.7 (Page 1-5), previously told the reader that it was completed in December 1982. So what happened in 1983?

Page	Paragraph	Line	Comment
2-3	1		The "Harney Canal (C-136)" and other locations mentioned in the text should be shown on at least some geographic map, photo or drawing in Chapter 2. Unfortunately, the reader must await the drawing presented in Figure 3-11 to understand the relationships among the physical components.
2-5	5	1	Typographical error: "n" should be "in" at paragraph beginning.
2-20		29	Typographical error: "corrected" should be "correlated."
2-23			Title of Section 2.13.4 appears in two pieces on the same lines.
2-23	1	8	Typographical error: "o" should be "to" at end of line.
2-31			The discussion of prior studies is very thin; for example, the modeling study description provides no references to the work and does not even identify the model used. Other than noting that studies were done, the text does not provide the "summary of prior studies" that the title of Section 2.15 (page 2-30) promises.
			The modeling report's figures do not show distances, though it does show latitude and longitude, which are of little practical use to the reader.
3-7			Units for salinity should be consistent in tables and figures throughout this chapter and the report as a whole. Moreover, some text and tables (e.g., Table 3-3) have no units provided.
3-8	Figure 3-2		Figure 3-2 does not define the label "COX_SALINITY" on the y-axes of the graphs and units are given in the title as "ppt" instead of "psu" but are not shown on the graphs.
3-15	Table 3-7		The table header needs to identify the equation and its terms in order for the reader to understand the table.
3-21	Figure 3-7		Is the graph plotted from data provided in Table 3-8? The figure needs a legend or an explanation of what the different curves are.

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