DEVELOPMENT OF AN INTEGRATED ECOSYSTEM MODEL TO DETERMINE EFFECTIVENESS OF POTENTIAL WATERSHED MANAGEMENT PROJECTS ON IMPROVING OLD TAMPA BAY

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Abstract—The Tampa Bay estuary has undergone a remarkable ecosystem recovery since the 1980s despite continued population growth within the region. However during this time, the Old Tampa Bay (OTB) segment has lagged behind the rest of the Bay's recovery relative to improvements in overall water quality and seagrass coverage. In 2011, the Tampa Bay Estuary Program, in partnership with the Southwest Florida Water Management District, began development of an integrated set of numerical and empirical modeling approaches to evaluate management actions to improve the ecology of the OTB estuarine segment. The goal was to integrate watershed, hydrodynamic, water/sediment quality, and ecological models (light and biota) to simulate changes in OTB ecology in response to the future implementation of large-scale management actions. The potential management actions evaluated: 1) completely diverting stormwater/freshwater input from a portion of the subwatershed that historically drained to the Gulf of Mexico, 2) diverting 100 percent of the directly discharged advanced wastewater treatment effluent to OTB from the subwatershed, 3) physically altering causeways along road expanses that intersect OTB, 4) reducing stormwater nutrient loads by 25 percent throughout the subwatershed, and 5) various combinations of these actions, as well as, other secondary management actions. The integrated set of models were used to evaluate the net environmental benefits to OTB's water quality (light environment and dissolved oxygen conditions), sediment quality (reduced accumulation of organic-rich sediments), potential expansion of seagrasses, and benthos/nekton habitat suitability. Based upon this evaluation, management actions that produced the greatest simulated improvements relative to costs are being considered for further evaluation in the OTB segment and subwatershed.

INTRODUCTION

The Tampa Bay estuary has been recognized as one of the few national and worldwide examples of a coastal ecosystem in recovery despite continued urbanization and population growth within its watershed (Greening et al. 2014). Baywide seagrass coverage continues to expand and now has approached levels commensurate to the extent last observed in the 1950s, a recovery goal set by the community through the Tampa Bay Estuary Program's (TBEP) Comprehensive Conservation and Management Plan (TBEP 2006). However, periodic setbacks have been observed in some of the Bay's extent, particularly in the Old Tampa Bay (OTB) management segment (Figure 1).

Compared to other areas of the Bay, OTB's recovery has lagged. The primary ecological issues of concern in OTB leading up to the development of this project included:

- organic sediment (muck) accumulation in the upper portions of OTB,
- limited seagrass expansion in distinct, poor circulation areas of OTB,
- alteration of freshwater inflows from managed channels discharging to OTB, and
- the periodic occurrence of nuisance algal blooms (*Pyrodinium bahamense*).

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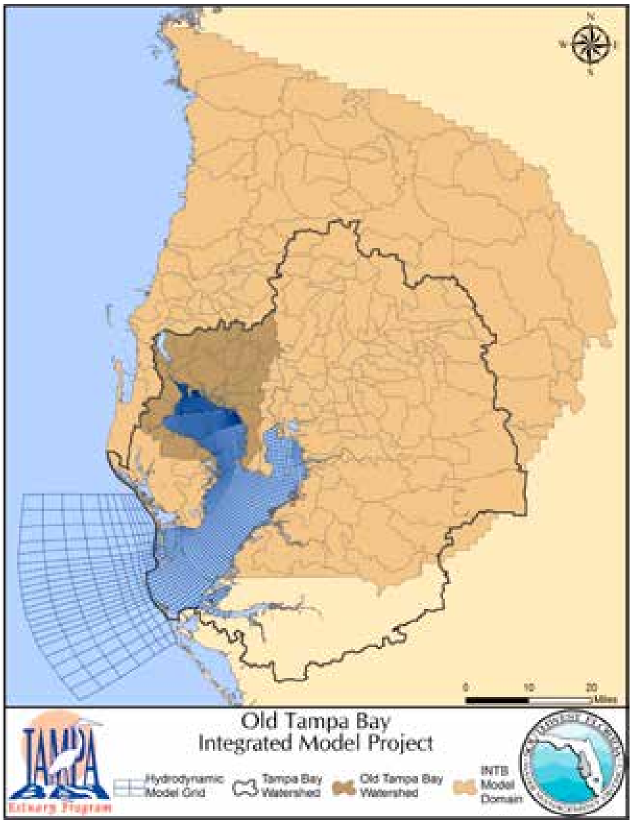

Figure 1—Overview map highlighting the Tampa Bay watershed, Old Tampa Bay watershed, watershed model domain (INTB), and hydrodynamic/water quality model domains.

In response, the TBEP, in partnership with the Southwest Florida Water Management District (SWFWMD), sought to develop an integrated ecosystem model to determine potential management actions that could further enhance OTB's recovery and address the primary issues outlined above. The integrated model envisioned, included the development of a linked watershed, bay hydrodynamic, water/sediment quality, and set of ecological models (biota and seagrass suitability). This new tool would then be used to simulate the net environmental benefits of potential, large-scale management actions relative to baseline conditions in OTB. Because much has been done in the Tampa Bay region to kick-start the Bay's recovery (e.g., wastewater treatment plant upgrades, enhanced stormwater regulations, residential fertilizer use ordinances, etc.), the models were intended to simulate actions that would require significant investment and buy-in from the region in order to implement. Such actions as bridge/causeway infrastructure modifications, modifying managed freshwater inflows, and continued wastewater/stormwater infrastructure improvements were considered.

METHODS

The overall project was broken into five discrete, serial tasks. Task 1 included the development of 10 management actions that were hypothesized to potentially improve OTB's condition. Development of the management actions enlisted support and feedback from the Tampa Bay resource management community through a series of stakeholder meetings conducted in 2011-2012. Task 2 included the assimilation of available data sources for development of an integrated set of models and identification of potential data gaps that would be needed to be filled to fully develop the modeling system. Task 3 involved generation of a Model Development Plan and a US Environmental Protection Agency (USEPA) approved quality assurance project plan (QAPP). Task 4 included the actual development, calibration and validation of the integrated model system over a 2000-2009 baseline period relative to available monitoring datasets. Task 5 simulated the net environmental benefits of the 10 identified management actions from Task 1 under the integrated set of models relative to baseline (2000-2009) conditions in OTB. This last task further prioritized the 10 potential management actions relative to their overall, anticipated implementation costs. Descriptions of each of the modeling components selected for use under this project follows.

Watershed Model

The Integrated Northern Tampa Bay (INTB) Model was deemed best suited for the watershed modeling component of the OTB integrated model system. INTB couples HSPF and MODFLOW, simulating surface water-ground water processes and their interactions for uplands and water bodies (Geurink and Basso, 2013). The INTB is used by Tampa Bay Water and SWFWMD for water supply planning in the region.

Bay Hydrodynamic Model

ECOMSED was selected as the hydrodynamic model, as there was an existing ECOMSED model application for the entire spatial domain of Tampa Bay. While the grid resolution and focus on OTB was not sufficient for this project, the experience and knowledge gained from previous studies aided in the development of the OTB application of ECOMSED. Another key factor in this selection was the existing model code that directly linked ECOMSED to the chosen bay water quality model (RCA).

Bay Water Quality Model

This component of the integrated model system was to be used to assess the effectiveness of management actions towards improving water quality, water clarity, and the potential for expanding seagrass coverage. Given the factors that influence seagrass growth and survival, the resultant bay water quality model was required to relate nutrients, suspended solids, and color to phytoplankton biomass and available light, utilizing advective and tidal linkages through the chosen hydrodynamic model. The RCA model code was selected. Familiarity with the model code was important to allow modifications or enhancements as necessary (i.e., the addition of CDOM, groundwater loadings, and benthic algae dynamics) and so that model calibration/verification could be performed more efficiently. The RCA model has been in existence for more than 20 years, has a proven track record, and has pre- and post-processing tools applicable under this project.

Ecological Model Components

An Optical Model component was used to predict water clarity from RCA outputs at suitable spatial and temporal scales with respect to seagrasses. The capability of modeling the spectral characteristics of light, rather than just as percent photosynthetically active radiation (percent PAR), allowed additional assessments for determining potential areas where seagrass coverage could increase/decrease as a result of management alternatives being implemented. The ability to model spectral distributions of light was key to the evaluation. The recommended Optical Model for the OTB integrated model system was the empirical optical model originally developed by Kirk (1981).

A secondary ecological model was also developed. The Environmental Favorability Function (EFF: Real et al., 2006), a derivative of logistic regression, was selected to quantify the effects of changes in water quality on fishes and benthic macroinvertebrates in OTB. The advantages of using the EFF model over standard logistic regression includes reducing prediction bias due to differences in taxa prevalence and the ability to directly compare taxa with different presence/absence ratios. The goal of using the EFF model was to describe changes in environmental favorability under a set of environmental conditions as predicted by the ECOMSED and RCA models.

Net Environmental Benefit (NEB) Analysis

The predicted results from each management action simulation using the integrated model (a model run) were compared to the baseline period (i.e., 2000-2009) for various, a priori key ecological attribute (KEA) outputs from each of the model components. For each management scenario, a 10-year mean KEA was compared to the 10-year mean KEA over the Baseline, and a score was calculated. The score for each KEA has been defined such that a positive score represents a potential benefit (a desirable outcome) and a negative score indicates a potential decline (an undesirable outcome) relative to the Baseline condition for each KEA. The NEB scores for each KEA were calculated and summarized at several spatial scales including three subareas that related to the original issues of concern in OTB.

RESULTS & DISCUSSION

Model Calibration and Skill Assessments

Following initial construction of each of the model components, all models were calibrated to the observed conditions during the 2000-2009 period. Model calibration refers to the adjustment of model coefficients and model resolution in order to minimize the overall error in simulating the variables of interest over the full range of hydrologic and meteorological conditions that occurred during the 2000-2009 period. The effectiveness of the model calibration was then assessed using various skill assessments and diagnostics. The goal was to minimize the overall model error for the full simulation period, with specific focus on OTB. A full description of the model calibration and skill assessment can be found in Janicki Environmental, Inc. (2014). Model skill assessment included comparisons error of variables of interest with a set of predefined values (i.e., skill assessment criteria). Model skill assessment included both qualitative evaluations (i.e., time series plots, contour plots, etc.) and quantitative evaluations using metrics (e.g., relative error, root mean square error, correlation coefficients) of model output in comparison to observed conditions.

The following skill assessment results were obtained for each of the modeling components under this project:

- Watershed Model – all seven (7) of the criteria were met;
- Bay Hydrodynamic Model – eighteen (18) of the twenty-four (24) criteria were met;
- Bay Water Quality Model – thirty-two (32) of the forty-eight (48) criteria were met;
- Optical Model – seven (7) of the eight (8) criteria were met;
- EFF Models – benthos – six (6) of the eight (8) criteria were met; fish – nine (9) of the eleven (11) criteria were met.

Net Environmental Benefit Analysis

Muck accumulation in upper OTB--Outputs from the Bay hydrodynamic and water quality models from the upper portions of OTB were used to assess potential changes in sediment muck accumulation. The KEAs that are most relevant to muck accumulation included: salinity and water age (ECOMSED outputs); organic carbon content in the sediments (RCA output); chlorophyll-a, total nitrogen, and dissolved inorganic nitrogen in the water column (RCA output).The management scenario that resulted in the highest NEB score relative to the muck accumulation issue was Scenario 9 – the combined nonpoint (25 percent) and point source (100 percent) reduction management action. Other positive scores were found for those scenarios that included either reduced flows from Lake Tarpon or other nutrient load reductions. The nonpoint source reduction scenario (2) and the combined 100 percent Lake Tarpon Outfall Reduction and causeway alterations scenario (10) also resulted in relatively high NEB scores.

In addition to the net environmental benefit analysis, the rate of organic carbon deposition was also examined. Reducing the rate of deposition is necessary to achieve any reduction in the amount of muck as the amount of muck at any point in time is a function of the rate of deposition and the rate of decomposition of the deposited organic carbon.

Table 1 presents a comparison of the total mass of organic carbon (tons) deposited in upper OTB over the 10-year model period (2000-2009) under the Baseline condition and each of the management action scenarios examined. Scenarios 1 and 10 (100 percent Lake Tarpon discharge diversion scenarios) resulted in large reductions in organic carbon deposition. The combined nonpoint and point source reductions (Scenario 9) also resulted in relatively high reductions in organic carbon deposition in that portion of OTB.

***Limited Seagrass Recovery*—**Limited seagrass expansion has occurred in several areas of OTB; however, results presented here are summarized for the entirety of OTB. The KEAs used to calculate these NEB scores were: percent PAR (Optical Model output), colored dissolved organic material (CDOM, RCA output), chlorophyll-a (RCA output), total suspended solids (RCA output), and area with adequate light (Optical Model output).

The highest NEB score was recorded for the combined nonpoint and point source reduction management action (Scenario 9) (Fig. 2). The nonpoint source reduction management action (Scenario 2), the point source load reduction management action (Scenario 3), and the combined 100 percent Lake Tarpon Outfall Reduction and causeway alterations management action (Scenario 10) also resulted in relatively high NEB scores.

Table 2 presents comparisons of the area with adequate light to support seagrass between the Baseline and each management action scenario. The values presented are the resulting adequate light acreages in Year 10 of the 10-year modeling period (2000-2009). Therefore, these values reflect the response to the cumulative changes in the nutrient loading and other management actions over that 10-year period.

***Nuisance Algal Blooms*—**The project team determined that the issue of concern relating to the occurrence of nuisance algal blooms in OTB could not be adequately addressed using the existing model outputs. Additional data collection efforts were recommended to better understand the life history, bloom initiation and distributions of the primary (*Pyrodinium bahamense*) alga of concern in this region. The TBEP is considering additional studies to address these information gaps on the alga species.

Table 1—Total mass of organic carbon deposition to upper Old Tampa Bay (OTB) over the 10-year model period relative to the Baseline and each scenario run with gross and percent differences between these mass estimates. Positive differences indicate improvements in potential muck accumulation in this focus area.

Management Action Scenario	Baseline (tons)	Scenario (tons)	Difference (tons)	Difference (%)
1-100% diversion of Lake Tarpon inflow	1,516,342	1,308,844	207,498	13.7
2-Gross 25% reduction in OTB nonpoint source loads	1,516,342	1,405,782	110,560	7.3
3-100% reduction in point source discharges to OTB	1,516,342	1,401,651	114,691	7.6
4-Alterations to Courtney Campbell Causeway	1,516,342	1,509,742	6,600	0.4
6-Alterations to Howard Frankland Bridge & Causeway	1,516,342	1,518,492	-2,150	-0.1
7-50% diversion of Lake Tarpon inflow	1,516,342	1,440,301	76,041	5.0
8-Combined Scenarios 6 & 7	1,516,342	1,440,360	75,982	5.0
9-Combined Scenarios 2 & 3	1,516,342	1,322,157	194,184	12.8
10-Combined Scenarios 1, 4 & 6	1,516,342	1,306,755	209,586	13.8

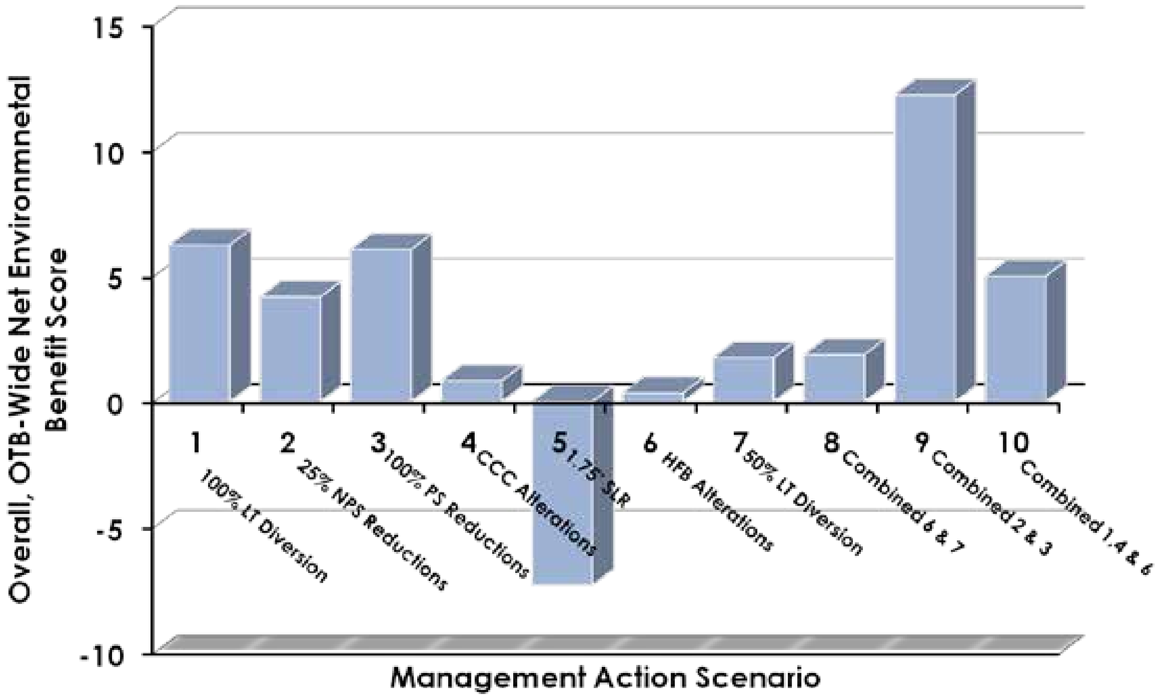

Figure 2—Overall results of combined net environmental benefit (NEB) analyses across the entirety of OTB relative to the 10 management action scenarios simulated under this project. Positive and negative scores relate to positive and negative benefits, respectively.

Table 2—Comparison of the number of acres with adequate light to support seagrass after a 10-year model run period (2000-2009) under the Baseline and each scenario with gross and percent differences between these areal estimates. Positive differences indicate improvements in the areal light conditions supportive of seagrass growth throughout Old Tampa Bay (OTB).

Management Action Scenario	Baseline (acres)	Scenario (acres)	Difference (acres)	Difference (%)
1-100% diversion of Lake Tarpon inflow	10,558	11,101	543	5.1
2-Gross 25% reduction in OTB nonpoint source loads	10,558	10,791	233	2.2
3-100% reduction in point source discharges to OTB	10,558	10,774	216	2.0
4-Alterations to Courtney Campbell Causeway	10,558	10,497	-61	-0.6
6-Alterations to Howard Frankland Bridge & Causeway	10,558	10,543	-15	-0.1
7-50% diversion of Lake Tarpon inflow	10,558	10,706	148	1.4
8-Combined Scenarios 6 & 7	10,558	10,728	170	1.6
9-Combined Scenarios 2 & 3	10,558	11,491	933	8.8
10-Combined Scenarios 1, 4 & 6	10,558	11,191	633	6.0

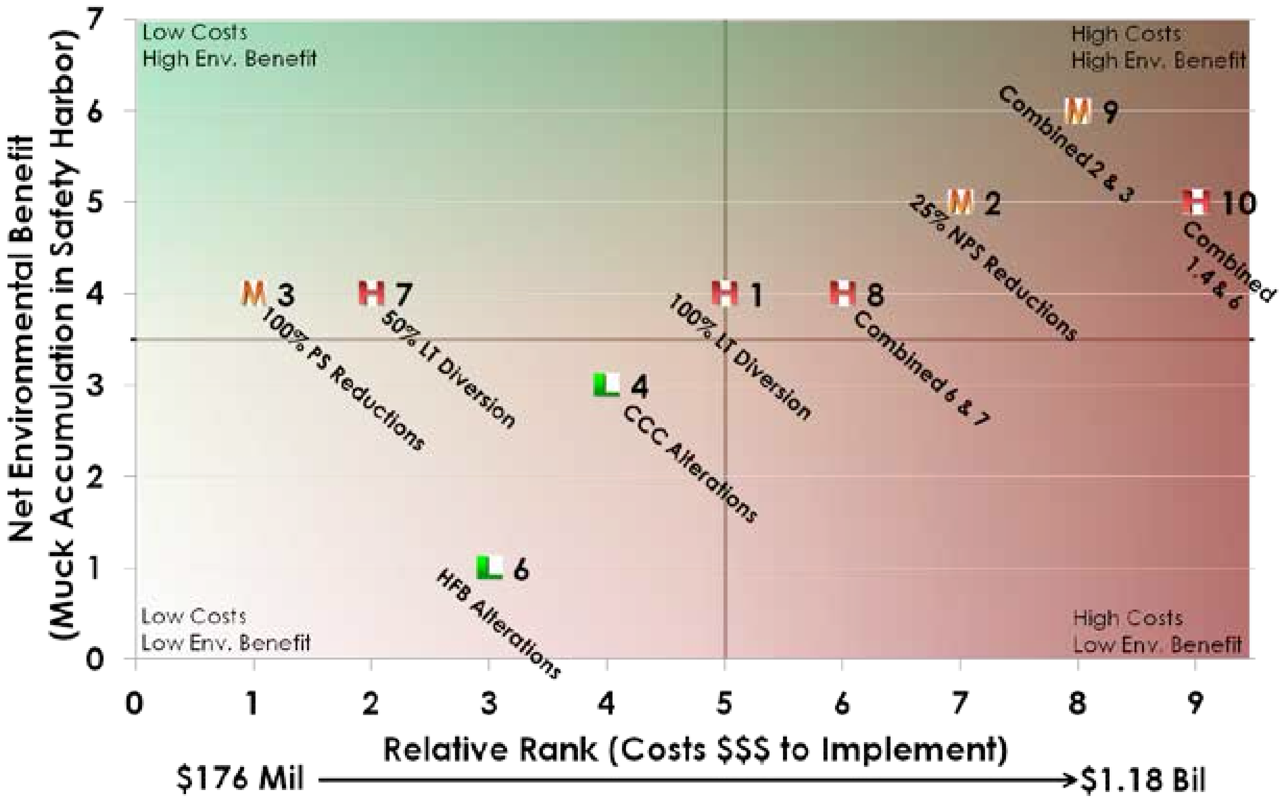

Figure 3—Comparison of pertinent net environmental benefit (NEB) scores for each management action scenarios (#) relative to potential implementation cost rankings for the muck accumulation issue in upper Old Tampa Bay (OTB).

Implementation Cost Considerations

Muck accumulation in upper OTB—For each priority issue, a comparison of the NEB scores relative to the costs to potentially implement the management actions was made. Figure 3 displays the NEB ranking for each of the scenarios along the y-axis (higher is better), and the relative cost ranking along the x-axis, for the issue of muck accumulation in Safety Harbor. Data points also indicate the relative permitting constraints: High (H); Medium (M); and Low (L).

Scenario 9, the combined nonpoint (25 percent) and point source (100 percent) reduction management action, resulted in the highest NEB with a modest permitting constraint, although at the highest implementation cost. The nonpoint source reduction scenario (2) also returned a high NEB ranking with a modest permitting constraint at a somewhat lower cost.

Limited Seagrass Recovery—Figure 4 displays the NEB ranking for each of the scenarios along the y-axis, and the relative cost ranking along the x-axis for the priority issue of limited seagrass expansion in two problematic areas in Old Tampa Bay (Feather Sound region and northwest Hillsborough County drainage areas).

As was observed with the muck accumulation issue, Scenario 9, the combined nonpoint (25 percent) and point source (100 percent) reduction management action, resulted in the highest NEB with a modest permitting constraint, although at the highest implementation cost for promoting more seagrass expansion in select areas of OTB. The nonpoint source reduction scenario (2) also returned a high NEB ranking with a modest permitting constraint at a somewhat lower cost, and the point source load reduction scenario (3) resulted in the same NEB ranking at an even lower cost.

CONCLUSIONS

An integrated set of watershed, bay hydrodynamic, bay water quality, and bay ecological models was developed under this project. The resulting KEA outputs from each of the modeling components were individually assessed to determine a NEB score, and pertinent scores were summarized according to priority issues and areas in OTB. The resulting NEB analyses indicated that combined efforts to reduce point source (primarily domestic wastewater treatment plants) and nonpoint source (primarily urban/suburban stormwater inputs) nutrient inputs to OTB's watershed and embayment would have the greatest overall benefit to ecology, however

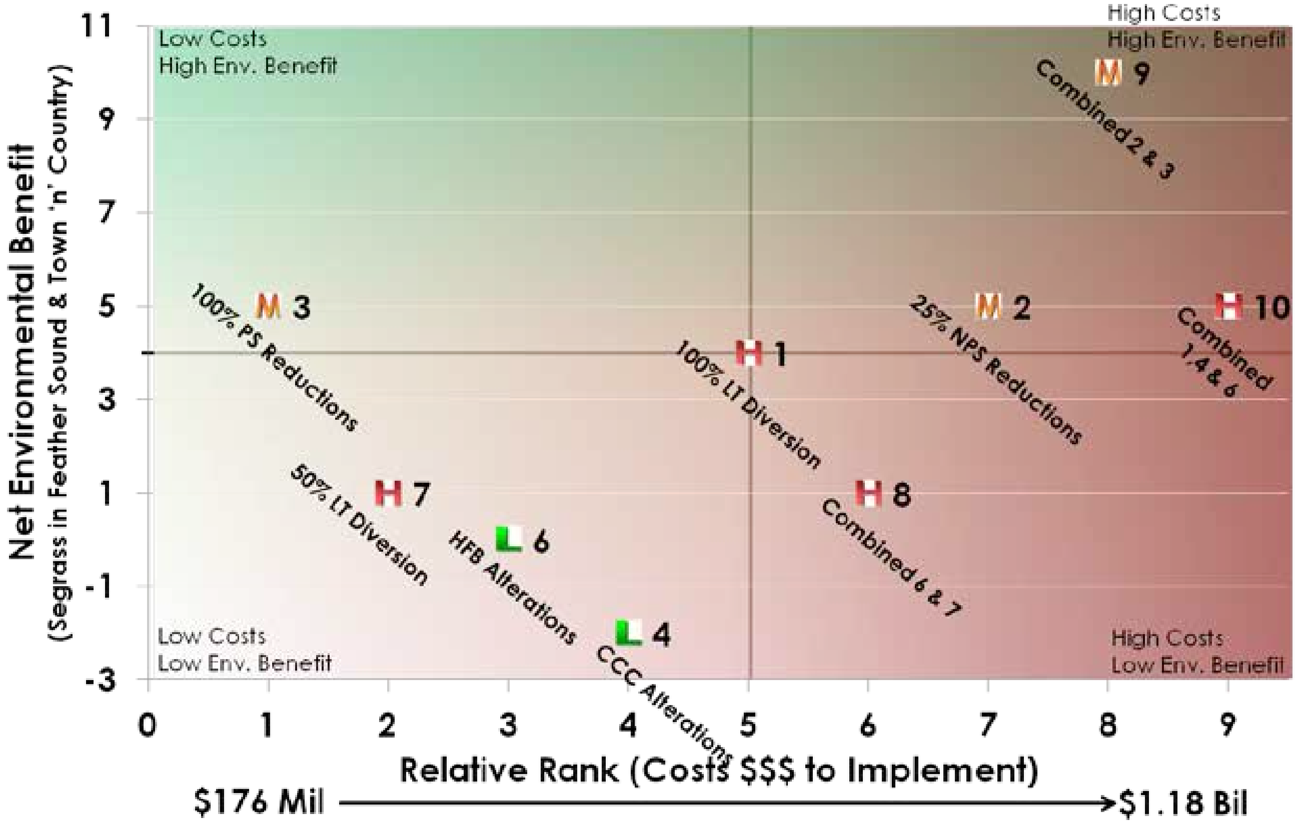

Figure 4—Comparison of pertinent net environmental benefit (NEB) scores for each management action scenarios (#) relative to potential implementation cost rankings for seagrass recovery in two areas of Old Tampa Bay (OTB), Feather Sound region and northwest Hillsborough drainage areas.

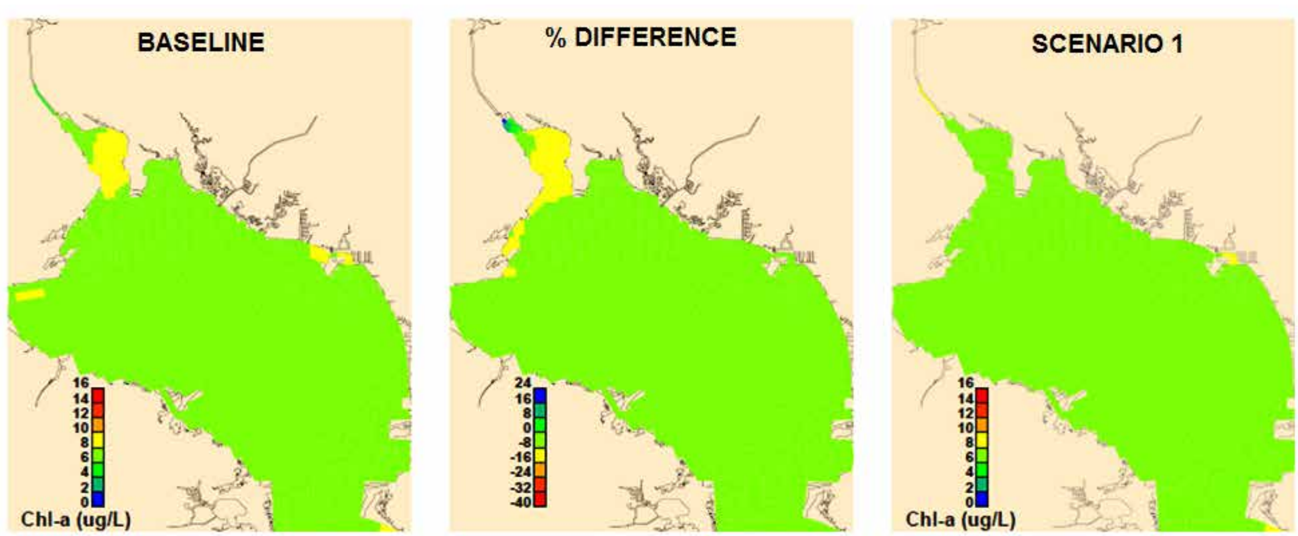

Figure 5—Localized differences (scenario - baseline as a percentage, middle panel) in chlorophyll-a (µg/L) conditions in OTB simulated from the 100% Lake Tarpon Outfall diversion scenario (1, right panel) relative to the calibrated, baseline condition (left panel) averaged over the 2000-2009 period.

at an extremely high implementation cost. Localized issues (e.g., muck accumulation in upper OTB) would also benefit from localized management actions (e.g., reductions in Lake Tarpon outfall discharges, Figure 5) at lower costs; however, overall benefits to OTB's entire ecology were less prominent. Physical alterations (e.g., causeway modifications) also showed similar localized benefits to specific issues; however causeway modifications appeared to have minor or negligable ecological benefits in OTB. In addition, causeway modification benefits also appeared to be better enhanced when combined with other actions (e.g. reducing Lake Tarpon outfall discharges, point source/nonpoint source reductions), adding to potential implementation costs. As resource managers in the region begin to plan for further ecosystem recovery in OTB, the modeling results from this assessment and further application of the integrated model system can be used to weigh benefits to the environment versus costs to implement actions in order to promote the most cost-effective solutions to improve OTB's ecology.

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