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ANTHROPOGENIC MODIFICATION OF BARRIER ISLANDS FOR ESTUARINE WATER QUALITY AND SEDIMENT MANAGMENT

Gary A. Zarillo[1]

Abstract

Estuarine water quality and barrier island sand management issues are geographically and dynamically linked in along the eastern seaboard of the U.S. The outer planning horizon for both are at aa time scale on the order of 50 years. Thus, model experiments were conducted to represent occasional temporary anthropogenic connections to the coastal for the purpose providing flushing of the back-barrier estuarine environment and to provide back-barrier sand sources for the longer term that will be accessed in the future when rising sea level requires barrier island roll over. Results of the study indicate that small, temporary tidal inlets can be strategically places to promote flushing and improve estuarine water quality. At the same time flushing Inlets can be used to generate and store sand sources in to be later accessed by nature or anthropogenic activates to promote resiliency of barrier island coasts.

Key words: Anthropogenic modification, Barrier Islands, Tida1 Inlets, water quality

1. Introduction

The barrier island systems along the eastern coast of the U.S. and other geologically similar settings developed over the millennial time scale in response sea level transgression and interaction of waves, tides, storms, and sediment supply. The essential geologic ingredients include a stable or slowly rising sea level, adequate sediment supply on a relatively flat topographic surface. Enough physical energy is required to build a shoreface that translates landward and upward along a trajectory that diverges from the slope of the underlying topographic surface. In microtidal settings where barrier islands are long, narrow. and linear in overall morphology. Breaching by tidal inlets and storm over wash are natural processes that redistribute large volumes of sediment over time providing a platform for barrier island migration and the development of sediment flats and mash vegetation. Inlet dynamics also provide for more or less continued natural flushing of back barrier estuarine systems and influence the basis of estuary ecosystem functioning. Human occupation of the barrier systems has dramatically altered these natural processes and resulted in unforeseen changes in barrier dynamics. Among the anthropogenic alterations having the most profound influence on a barrier systems are the creation of stabilized tidal inlets, prevention of new tidal inlets to promote flushing.

2. Statement of the Issue

The U.S. Congressional Rivers and Harbors Act of 1960 authorized the U.S. Army Corps of Engineers to protect against beach erosion and storm surge. This has resulted in a nearly 50-year effort of shore protection projects along the U.S. east coast barrier island system. Part of this effort has often included a policy to close storm breaches across barrier island and close larger storm cuts that could become long lasting and migrating tidal inlets. From our knowledge of how barrier islands originate and evolve, there is an understanding that storm and tidal inlet reworking of barriers an integral part of the natural processing that maintains barrier systems on the millennium time scale. Flood shoal features and over wash sands provide a sediment supply for long term barrier migration. It is also known that inlets provide a window into the coastal ocean for water exchanges with estuarine systems. In this project, model experiments are conducted to test the feasibility of anthropogenic

[1]Department of Ocean Engineering and Sciences, Florida Institute of Technology, 150 West University Blvd, Melbourne, FL. 32901, USA. zarillo@fit.edu

manipulation of barrier islands in the form of small flushing inlets to improve estuarine water quality and temporary inlets designed for sand transfer to the back-barrier side for later use by nature or man-made activities to maintain the barrier island.

3. Project Location and Background

Two morphologically similar bur ecological different coastal barrier and estuarine systems are consider in this study. The Indian River Lagoon system encompasses a large portion of the east central and south-central Florida coast. From an estuary morphological classification point of, the IRL is considered a bar built estuary separated from the coastal ocean by narrow microtidal barrier islands that evolved in the mid Holocene as the rate of seal level rise slowed (Figure 1). The natural watershed of the IRL is a narrow band of watershed sub-basins consisting of local drainage that has been in re-occupied Pleistocene tidal drainage. The IRL is shallow and usually vertically well mixed except when receiving freshwater releases from water control structures establish to reduce flooding. The decades of decline in water quality of the IRL and the connected Mosquito Lagoon (ML) is exemplified by recent harmful algae blooms (HAB) and episodic reductions in sea grass coverage. The factors constituting to water declines are thought to include eutrophication from excessive nutrients in residential and agricultural runoff as well as the accumulation of chemically active organic rich muck sediments that accumulated in the lower reaches of tributaries connect to Florida's system of canals and water control structures. Another contributing factor could be reduction of natural flushing though tidal inlets and episodic opens to the coastal ocean cause by storm breaching of the barrier system. Although the IRL responds to low frequency sea level oscillation propagating in the from the coastal ocean, tidal influence and tide produced flushing is limited to within a few kilometers of inlet entrances. Wind forcing is known to promote flushing but at a time scale of several months to a year or more.

The companion system to the sub-tropical IRL is Great South Bay (GSB) along the south coast of Long Island, NY (Figure 2). The Great South Bay system is similar to the IRL in that it consists of a series of morphological compartments that are hydrologically discrete. Great South Bay is connected to the coastal ocean by a scattering of stabilized tidal inlets that provide limited flushing benefits. Watershed sub basins connected to GSB are developed on glacial outwash plains and moraine sediments deposited in the late Pleistocene to early Holocene. The modern barrier system to the south of GSB was derived from erosion and littoral dispersion of Pleistocene sediment sources over the past 5,000 years). Like the IRL barrier islands the Long Island barriers can be over washed and breached by storm surg. New Inlet noted in Figure 2, is one of several cuts originating from the impacts of Superstorm Sandy in October 2012 was allowed to remain open since of occurred within the property of Fire Island National Seashore. Monitoring in the eastern compartment of GSB connected to the coastal ocean by New Inlet indicates, improved water quality in the aftermath of the storm (Flagg al, 2013). In other compartments of GSB, tidal influence and flushing is restricted by the tidal energy dissipation of the long conveyance channel of Fire Island Inlet and causeways that dissect the western most compartment of GSB. Further, total freshwater runoff and influx of ground water is thought to be on the order of only a few cubic meters per second and does not provide adequate flushing.

The geologic and geomorphic record of IRL barrier and GSB barrier systems show evidence of storm cuts in the past in the form of relict flood shoals and washover terraces (Leatherman and Allen 1975, Zarillo and Hennessy, 1987). However, over the past 50 to 75 years shore protection strategies have included protection against storm breaching and closure of newly opened inlets to limit storm surge along interior shorelines and shore erosion related to littoral sand impounded witnin tidal inlet shoals. This process along with expanding human infrastructure in the watersheds are the major contributing factors to declines in water quality on both estuaries.

Closure of natural inlets for shorter term shore protection may have a negative impact on sand management and shore protection in the longer term at time scales on the order of 50 years and longer. Geologically frequent reworking of microtidal barrier islands by migrating inlet, which involves creation of sandy flood shoal platforms that may be incorporated into the barrier superstructure and provide a later source of sand for the barrier island rollover process. Once established, relict flood shoals can become a large reservoir of sand as repeated washover episodes increase elevation and areal extent (Hennessy and Zarillo, 1987).

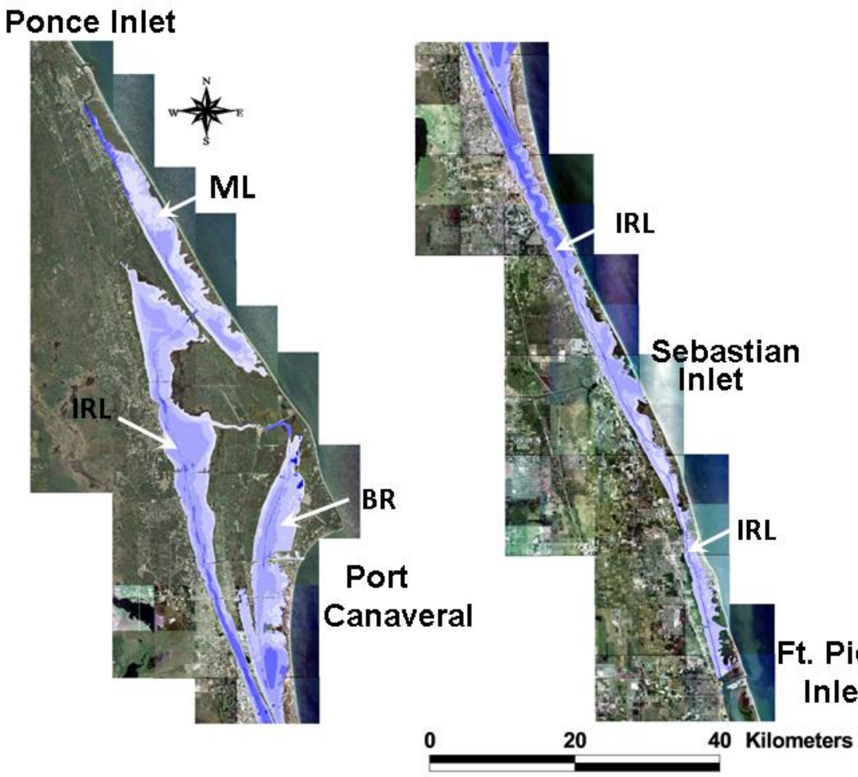

Figure 1. Configuration of the Indian River Lagoon compartments including the Mosquito Lagoon (ML), Banana River (BR) and the main body of the IRL. Left panel is the north section and right panel is the south section

Figure 2. Configuration of Great South Bay, Long Island, NY and associated tidal inlets including New Inlet opened by a 2012 hurricane.

4.0 Model setup

4.1 Flushing model setup

Efforts to slow the decline and improve water quality have followed similar pathways in both the IRL and GSB. Best management practices (BMPs) have been implemented in the IRL guided by watershed controls and monitoring in the estuary. Estuarine management efforts in Great South Bay include ongoing monitoring, several major water quality assessment projects. Despite these efforts, water quality declines continue. In the wake of recent HAB episodes in both the IRL and GSB renewed is renewed interest in methods of increasing flushing rates and decreasing flushing time of these estuaries.

Model experiments were conducted to test the feasibility of constructing occasional temporary anthropogenic connections to the coastal to promote flushing of the back-barrier estuarine environment for improved water quality and potentially to provide back-barrier sand sources for the longer term that will be accessed in the future when rising sea level requires barrier island roll over For these experiment two types of models were employed; 1) a three dimensional (3D) environmental model that include constituent transport as well as hydrodynamics and 2) a quasi 3D coastal process model designed to address tide and wave driven sand transport

The Environmental Fluid Dynamic Code (EFDC) was set up for two barrier island systems, one along the east coast of Florida and one long the south shore of Long Island, New York. Figure 3 provides an overview of the EFDC model grid covering the IRL system from Ponce de Leon Inlet (Ponce Inlet_ to the vicinity of Ft. Pierce Inlet approximately 90 km to the south. Both estuaries consist of a series of morphologic compartments most of which have limited tidal influence. At the north end of the Mosquito Lagoon (ML) compartment of the IRL tidal exchange and flushing are provided by Ponce Inlet. The middle and southern section of the ML having very little tidal influence and no direct connection to the coastal other is known to be poorly flushed (Zarillo et al., 2011)

Great South Bay is compartmentalized as seen in Figures 2 and 4. Among h the eastern compartments, only the easternmost section served by New Inlet (Figure 4) is readily flushed and subject to improving since the opening of New Inlet in 2012. The mid-section of GSB is served by Fire Island Inlet, but suffers from occasional HAB events due to poor flushing. The western compartment of GSB is served by Jones Inlet and East Rockaway Inlet (Figure 2). Although the coastal ocean in this western area has a mean semidiurnal tidal range of more than a meter, much of the tidal energy is expended over expansive salt marshes and tidal flow is restricted by narrow and shallow tidal channel and by causeway-bridge systems that cross GSB to the barrier island. Figure 4 shows the configuration of the EFDC model computational grid set over Great South Bay.

Features and numerical recipes of the EFDC model that are consistent with modeling in the IRL and GSB environments are covered in Tetra Tech,2007. Briefly, EFDC is multi-parameter finite difference model represents estuarine flow and material transport in three dimensions. It has been extensively applied to shallow estuarine environments in Florida, Long Island, New York and other coastal states of the U.S. Examples can be found in Zarillo, 2006, Zarillo et al.,2011 and Tetra Tech, 2005.

EFDC's hydrodynamic scheme solves the three-dimensional, vertically hydrostatic, free-surface, turbulent-averaged primitive equations of motion for a variable density fluid (Tetra Tech, 2007). Also solved are the dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature. The EFDC is also directly coupled to a water quality model, the kinetic processes of which are derived and updated from the Chesapeake Bay three-dimensional water quality model, CE-QUAL-ICM (Park et al. 1999). However, in this application for flushing experiments, only hydrodynamics and transport options were applied. Major time series inputs to establish model boundary conditions include water level salinity and water temperature freshwater inflows and air-sea interaction data loaded into. Forcing at the model ocean boundaries consisted of a time series of water elevation that combine tidal constituents with low frequency water level time series that represent synoptic to seasonal shifts in water level that are important in both areas (Zarillo et al, 2014; Connell and Zarillo, 2003). The tidal inlet locations shown in Figures 1 and 2 mark the location of ocean boundaries where water level times series were applied.

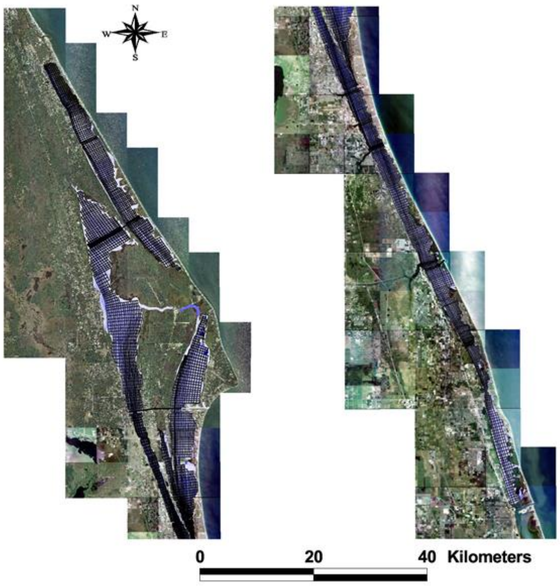

Figure 3. Indian River Lagoon computational grid Left panel is the north section and right panel is the south section.

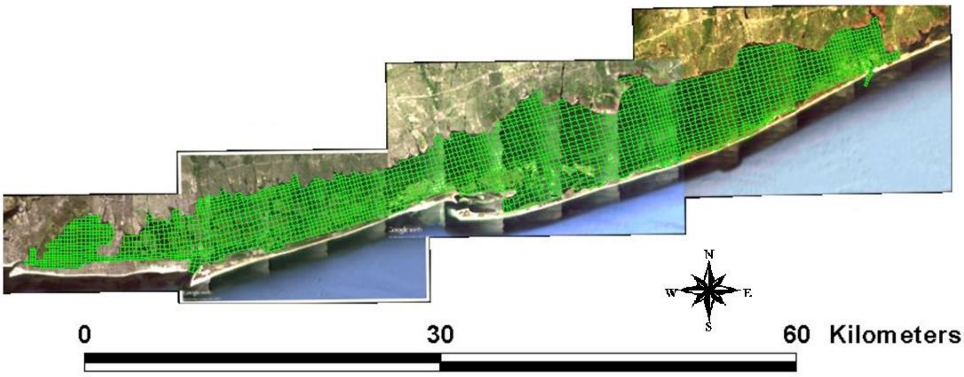

Figure 4. Configuration of the computational grid over Great South Bay, Long Island, NY.

4.2. Sand Resource Model Setup

A major issue with establishing new tidal inlets, either temporary or permanent across narrow barrier islands is the management of sand resources for shore protection and mitigation of erosion of downdrift barrier segments. These issues are elucidated for Long Island's south shore coast in a recent regional shore protection plan by the U.S. Army Corps of Engineer (USACOE, 2016). A large number of publications and shore protection technical reports address this issue on the east central Florida Coast, including Zarillo et al, 2016). To address this issue within the scope of this study a hypothetical inlet placed on the central Florida was examined using the USACOE Coastal Modeling System (Sanchez et al, 2014). A similar model experiment for the Long Island Coast is described in Kraus et al, 2003), which examined the feasibility of supplementing or replace Fire Island Inlet with a new tidal inlet placed just to the east providing a shorter route into GSB and presumable reducing dredging costs for navigation and improving flushing rates for the central GSB compartment. The 2003 experiment did not include a prediction of sediment transport and related topographic change. In the present study a narrow and relatively shallow hypothetical inlet was placed in a CMS model grid abut 10km north of the existing Sebastian Inlet on the central Florida coast The numerical and model setup procedures for the CMS-FLOW and CMS -WAVE models included in this experiment are reviewed in Sanchez et al, 2014 and Lin et al., 2008. CMS consists of several modeling codes including CMS-WAVE, which calculates spectral wave propagation properties: refraction, diffraction, reflection, shoaling, and breaking. It also provides wave information that can be applied to sediment transport formulas within CMS-FLOW. The full Coastal Modeling System includes coupling of CMS-WAVE with CMS-FLOW, which calculates circulation, sediment transport, and morphological change. In addition to wave, tide, and wind forcing, the sediment transport sub-model was set up using spatially varying sediment textures based on field sampling.

5.0 Model Experiments

5.1 Great South Bay

Table 1 list the model experiments based on hypothetical modification of the IRL and GSB for improved flushing and storage of sand. Figure 5 shows the locations of a hypothetical new flushing inlet located about 8 km east of Fire Island Inlet and location of a hypothetical flushing inlet about 8 km to the west of Fire Island Inlet. At his same location, a hypothetical pump station is tested in the mode. (Figure 5) Among the 5 model cases listed in Table 1, two of the alternatives involve the cutting of new inlets, including model case 3 in which the new inlet would replace Fire Island Inlet, which is specified to be closed in the model test. Model cases 4 specifies a pump station move sea water from the coast ocean into GSB. For each case, the initial centration of 200 ppt dye concertation was specified for the entire model domain.

Table 1.Model Alternatives for Great South Bay

Model Case	Model Duration
1 Existing	125 days
2. Flushing inlet, FI inlet open	125 days
3. New FI Inlet, FI Inlet closed	125 days
4. Fire Island Pump Station	125 days
5. Flushing Inlet West GSB	125 days

Figure 5. Hypothetical flushing inlets placed in the h Great South Bay model domain.

Figure 6 compares model cases1 (A) and model case 2 (B, Table 1) after 20 days of simulation. As seen by the deep blue color at the east compartment of GSB, this compartment is completely flushed within 20 day sof model simulation due to the presence of the inlet cut by a hurricane in 2012. All other compartments of GSB still held concentrations of numerical dye. However, some flushing of central compartments occurre d due to a combination of the flushing inlet cut just to the east of Fire Island Inlet, which remains open in th e simulation. After 50 days of simulation, the combination of a new flushing inlet and Fire Island Inlet provides almost total flushing of numerical day from the central compartment of GSB (compare Figures 7 Aand 7B).

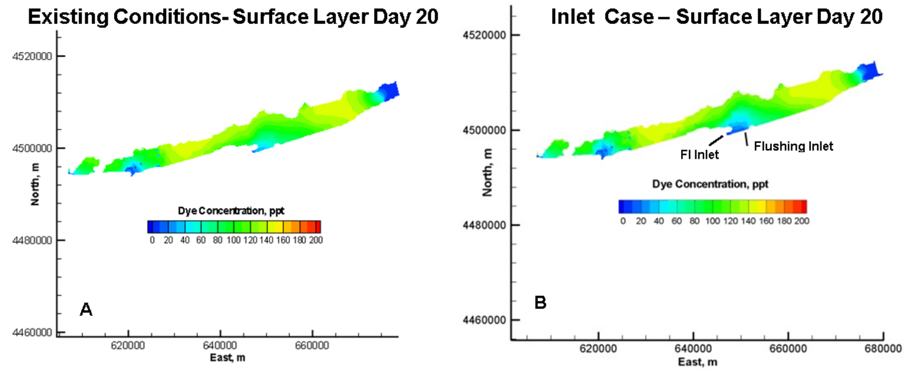

Figure 6. Comparison of great south bay predicted flushing patterns at 20 days for the existing configuratio n (A) and for opening of a flushing tidal inlet (B).

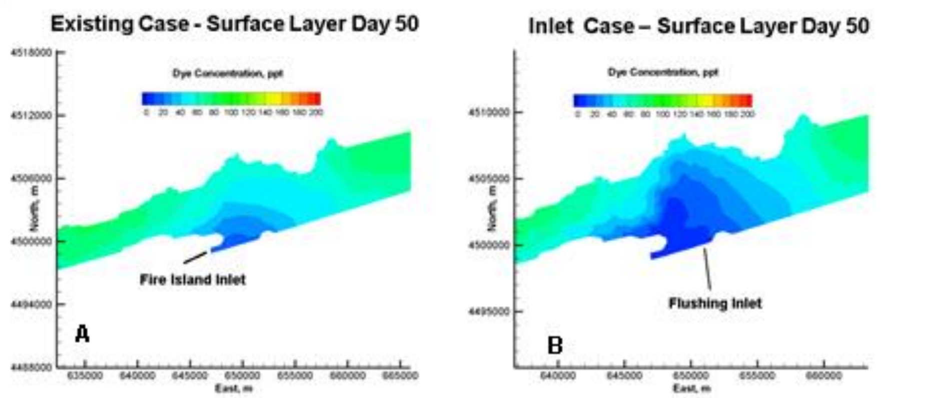

Figure 7. Comparison of Great South Bay predicted flushing patterns at 50 days for the existing configuration(A) and for opening of a flushing tidal inlet (B).

Figure 8B show the results of model case 3 (Figure in which a new flushing inlet remains open and Fire Island Inlet is hypothetically closed to tidal exchanges with e the coastal ocean. The presence of a narrow flushing inlet results in notably smaller flushing effects compared to having only Fire Island Inlet open (Figure 8A) or a combination of Fire Island Inlet and he flushing inlet (Figure 7B)

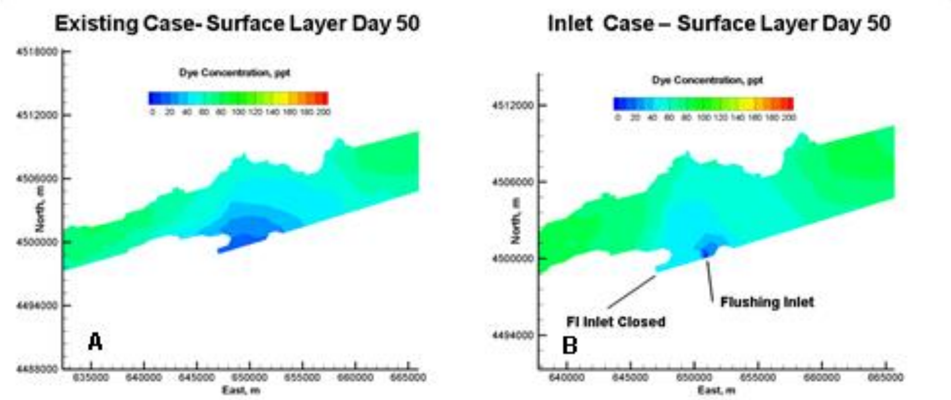

Figure 8. Comparison of Great South Bay predicted flushing patterns at 50 days for the existing configuration (A) and for a combination of opening of a flushing tidal inlet (B) and closure of fire island inlet.

Figure 9 compares model cases 1 (A) and model case 4 (B, Table 1) after 50 days of simulation. In this comparison, the flushing inlet to the east of Fire Island Inlet is replaced with a pump station having a 10 m^2/s capacity. The overall results are similar to the case 2B as shown in Figure 7B. The central compartment of GSB is largely flushing of dye, but the remaining dye concentrations are slightly higher than those results from the flushing inlet

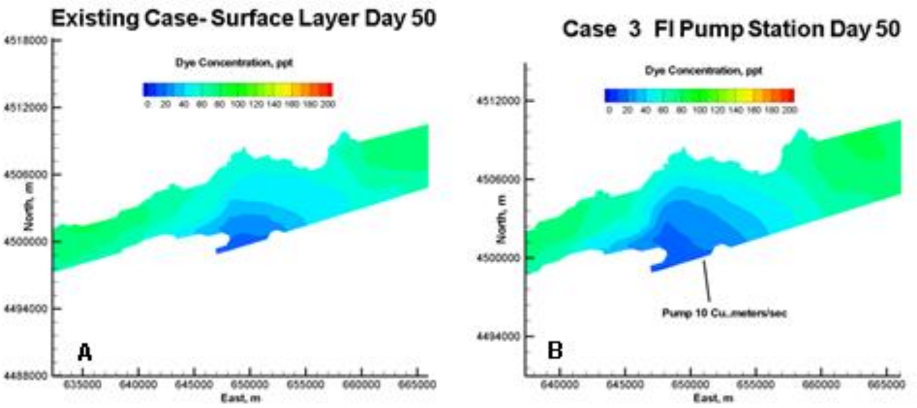

Figure 9. Comparison of Great South Bay predicted flushing patterns at 50 days for the existing configuration (A) and for flushing by a hypothetical pump station (B).

Figure 10 compares flushing of the Great South Bay compartment west of Fire Island inlet for existing condition and the placement of a hypothetical flushing inlet at a location west of Fire Island as shown in Figure 6 (case 5, Table 3). This compartment is poorly flushing under present conditions due to distance form either Fire Island or Jones Inlet and the presence of bridge and causeway structures bounding either end of the compartment (Figure 2).

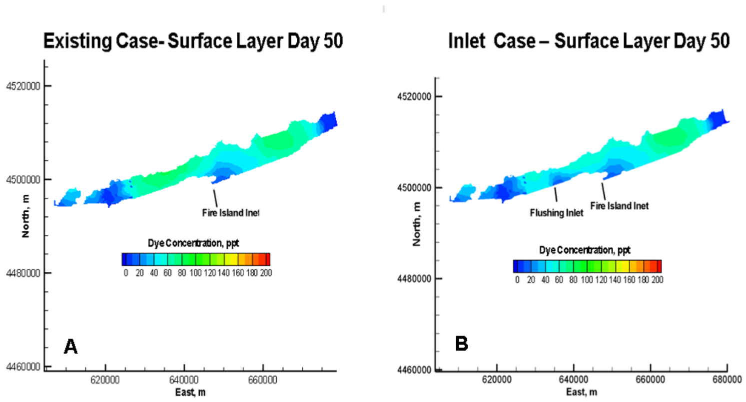

Figure 10. Comparison of Great South Bay predicted flushing patterns at 50 days for the existing configuration(A) and for opening of two flushing tidal inlets (B).

5.2. Indian River Lagoon

Table 3 lists the model flushing experiments in the Indian River Lagoon basin. In each experiment an initial dye concentration 20 ppt was specified within the entire IRL system. Each model experiment was run for approximately one year. Sea water from the coastal ocean exchanging into the model domain was specified to have a dye concentration of zero

Table 2. Model alternative – Indian River Lagoon system

Model case	Model Duration
1. Existing	365 days
2. Flushing Inlet Mosquito Lagoon	365 days
3. Flushing Inlet Banana River	365 days
4. Weir at Canaveral Lock	365 days

Figure 11 shows the configuration of a narrow flushing inlet in the southern compartment of the Mosquito Lagoon, which is known to have extremely slow flushing rates that can exceed a year (Zarillo et al, 2011). The inlet was places at a location where the barrier island superstructure is narrow and have been over washed and cut by storm surge in the past. Figure 12 compares the predicted numerical dye concentrations for the existing condition and model test case 2 after 70 days of simulation (Figure 12B, Table 2)

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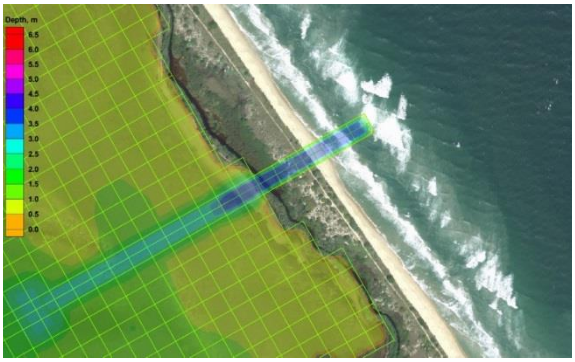

Figure 11. Configuration of a flushing inlet at the southern end of the Mosquito Lagoon, Florida

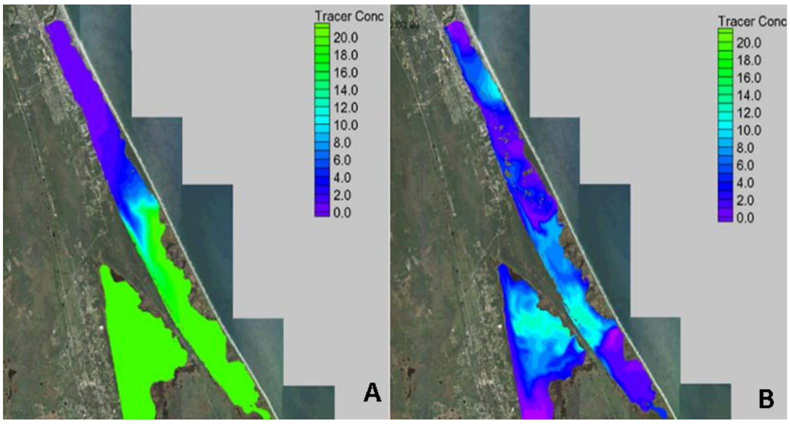

Figure 12. comparison numerical dye concentrations for the existing condition (A) and model test case 2 after 70 days of simulation in the Mosquito Lagoon (Figure 12B, Table 2)

Figure 13 shows the configuration of model case 3, a hypothetical flushing inlet in the east compartment of the IRL known at the Banna River. This compartment is frequenctly subjust to prolonged harmful algae bloom (HAB). The final hypothetical configuration involves a weir structure located near the Port Canaveral water locks as shown in Figure 14. In this case (Case 4, Table 3) the model weir is designed to operate as a function of tide produced water levels that will force flow over the weir at higher tidal elevation and largely prevent return flow during lower tidal levels. Comparison of model results show that the weir allows notably improved flushing after 50 days of the southern compartment of IRL's Banana River (Model Case 4, Table 3) compared to the existing case in which the Port Canaveral Locks are generally closed except for occasional boat traffic.

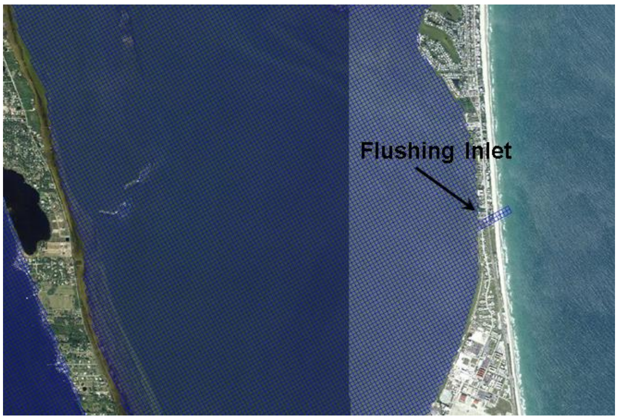

Figure 13. Configuration of IRL model case 3, a hypothetical flushing inlet in the east compartment of the IRL known at the Banna River (see Figure 1 for loacation)

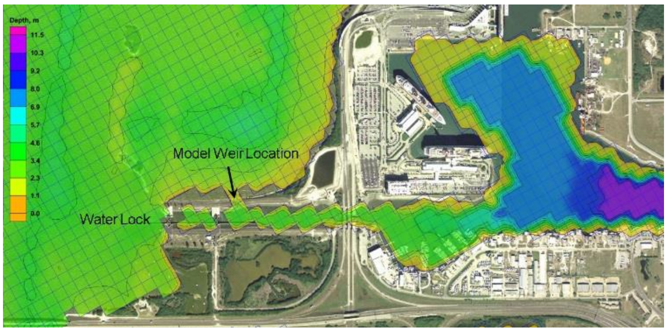

Figure 14. Hypothetical configuration involves a weir structure located near the Port Canaveral water locks.

Figure shows that the presence of the flushing inlet in the Banana River produces flushing time that could potentially reduce the occurrence of HAB events. However, the weir structure on the interior of Port Canaveral Harbor (Figure 14) produced less flushing. The results depicted I Figure 15 are after a model run of about 200 days, which shows that under existing conditions the northern compartments of this IRL segment are nor well flushed.

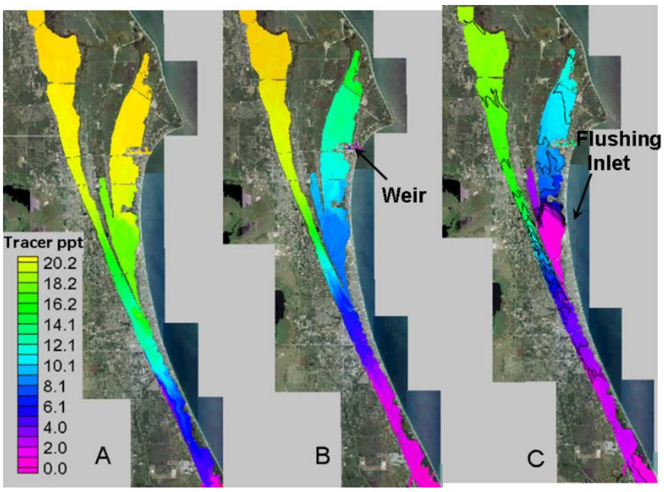

Figure 15. Comparison of predicted flushing of numerical dye at 200 days for the existing configuration (Case1 , Table 2) a weir structure located in Port Canaveral (Case 4) and a flushing inlet located at the south end of the Banana River.

5.3 Potential for storing sand resources

One model experiment was conducted to test the feasibility of creating anthropogenically induced sand transfer to the back-barrier for future use by natural or man-made activities. This is based on the premise that even temporary small flushing inlets as depicted in the model tests will impound sand and reduce littoral sediment supply. Flushing inlets may be opened for periods of a few weeks to improve water quality conditions as in the GSB experiments. Some systems like the IRL may require temporary inlets to be opened for longer periods to register notable flushing effects. Thus, the shallow flushing scale inlet placed in a CMS model grid abut 10km north of the existing Sebastian Inlet was examined for its potential to impound sand resources at a time scale of 6 to 12 months. Figure 16 shows the predicted morphologic change at the inlet after a simulation time of about 180 days. Within the flood shoal deposits on the bay side of the inlet the predicted sediment accumulation represents about 494,000 cubic yards of sand

The IRL flushing model experiments compare well with measured sediment volume accumulations at the new tidal inlet opened in the eastern compartment of Great South Bay in 2012. Approximately 1 million cubic meters of sand were deposited in the New Inlet flood shoal during the 12-months after the initial opening of the inlet. For both the Florida and Long Island experiments, model results indicate minimal effects on back-barrier tidal range from small openings and tidal inlets. However, model experiments also showed that small and shallow openings can produce large volumes of back barrier sediment accumulation that could be used in sand management scheme that account for short term impacts of temporary tidal inlets on littoral sand budget. Further, small temporary tidal inlets could serve the dual purpose of flushing the back barrier estuary and stock piling sand to compensate for lost sand accumulations from natural migrating tidal inlets.

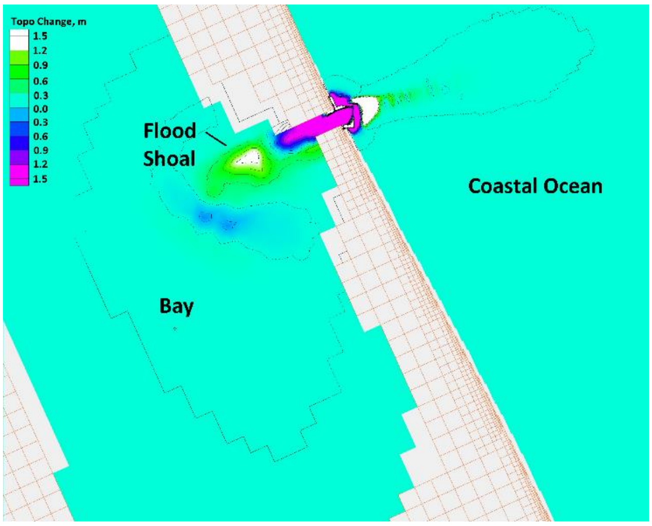

Figure 16.

5.0 Conclusions

Model results show that flushing time may be notably decreased for historically poorly flushed estuarine compartments using small, temporary inlets or water control structures. Experiments also demonstrate the potential conflict between geologically short term planning for shore protection and longer term planning for eventual barrier island migration.

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