Appendix 10-2: Coastal Ecosystems Research Plan Update

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INTRODUCTION

Per Section 373.4595, Florida Statutes, the three major goals of the Caloosahatchee and St. Lucie Watershed Protection Programs are to (1) establish pollutant load reductions based upon adopted Total Maximum Daily Loads (TMDL), (2) develop a goal for salinity envelopes and freshwater inflow targets, and (3) reduce the frequency and duration of undesirable salinity ranges while meeting other water-related needs in the region. Three research themes support these program goals: water quality, salinity envelopes and freshwater inflow targets, and environmental operations.

1. **Water Quality Goals:** A goal of the research program is to provide robust scientific support and better understanding of the effects of nutrients and other applicable water quality parameters [e.g., chlorophyll *a* (Chl-*a*), dissolved oxygen (DO)]. The research program aims to quantify and improve the understanding of (1) the relationship between the biological resources upon which water quality goals are based and aspects of water quality that water quality goals seek to improve, and (2) the roles of nutrient loading and biogeochemical processes in controlling water quality parameters (e.g., Chl-*a*, DO, and nutrients).
2. **Salinity Envelopes and Freshwater Inflow Targets:** These envelopes and targets help inform management decisions regarding the quantity of freshwater discharged to the St. Lucie and Caloosahatchee Estuaries. The goal of the program is to reduce the uncertainty in these resource-based targets and to quantify not only the magnitude, frequency, and duration of undesirable flows and salinities, but also identify critical periods when meeting targets is most ecologically beneficial.
3. **Environmental Operations:** South Florida is one of the few places in the world where controlled releases of freshwater are routinely made to coastal estuaries. The 2008 Lake Okeechobee Regulation Schedule (LORS) provides guidance for managing flood control releases to the Caloosahatchee and St. Lucie Estuaries. In addition, the Final Adaptive Protocols for Lake Okeechobee provide guidance for making low level releases to the Caloosahatchee estuary during the dry season. One goal of this program is to determine release scenarios that minimize the damage to estuarine resources caused by high flows during the wet season and maximize the benefits of low flows during the dry season.

The South Florida Water Management District (SFWMD or District) conducts research and monitoring to detect internal responses of the Caloosahatchee River Estuary (CRE) and St. Lucie Estuary (SLE) to the external inputs of freshwater and dissolved and particulate matter. There are three general areas of estuarine responses to variations in freshwater inflow and material loading: hydrodynamics, water quality, and biota. Coupled research and monitoring are necessary to explore the fundamental effects of environmental drivers (i.e., inflow, salinity, light, nutrients, and temperature); develop mathematical models in order to help predict potential responses with fluctuations in the environmental drivers; and apply the improved fundamental understanding of

the potential responses to better manage freshwater and biological resources in coastal watersheds and estuaries.

FUTURE RESEARCH

WATER QUALITY GOALS

- **Seagrass and Nutrients.** *A quantitative linkage between seagrass health and nutrient loading needs to be established in both estuaries.*

Based on the conceptual model that excessive nutrient loading causes algae blooms which in turn reduce light penetration and hence availability to sustain growth (Twilley et al., 1985), reductions in nutrient loads should reduce the frequency and magnitude of algae blooms and enhance water clarity and seagrass growth. While this scenario has been demonstrated in other systems (e.g., Tampa Bay; Greening and Janiciki, 2006; Greening et al., 2011) the links between nutrient loading, phytoplankton blooms, light attenuation, and seagrass growth have not been well investigated or established in either the CRE or SLE and remain uncertain. Other mechanisms by which nutrient loading may affect light and seagrass performance such as enhanced growth of epiphytic algae on seagrass blades have not been adequately monitored or explored. Future research should focus on establishing a quantitative link between seagrass health and nutrient loading. The Segmented Simulation Model described below is designed to address these linkages.

- **Oxygen Dynamics.** *The cause of low dissolved oxygen needs to be better understood to assist appropriate management actions.*

Both the Caloosahatchee and St. Lucie Estuaries have segments listed as impaired for DO and nutrients. Hypoxic and anoxic events have been reported in both systems. Causative agents for the DO impairment were both a high biological oxygen demand (BOD) and high levels of chlorophyll (http://www.dep.state.fl.us/water/tmdl/adopted_gp3.htm). The two causative agents suggest different origins for the DO impairments. The high BOD suggests that loading of labile organic matter from external sources might cause low concentrations of DO. By contrast, high levels of chlorophyll suggest that excess nutrient loading leads to internal production of algae which fuel a high oxygen demand when they die. The two scenarios may lead to different management recommendations. Future research should focus on the timing, spatial distribution, and causes of low DO (hypoxic, anoxic) events.

SALINITY ENVELOPES AND FRESHWATER INFLOW TARGETS

- **Frequency and Duration of Exceedances.** *The quantification of the frequencies and durations that flows and salinities can exceed envelope limits will improve management of freshwater discharges to estuaries.*

Salinity and flow envelopes have been established for the Caloosahatchee and St. Lucie (SFWMD et al., 2009a,b). The upper and lower bounds of these envelopes are well known and supported by salinity tolerances of oysters, seagrasses and other submerged aquatic vegetation (SAV) determined from the literature, monitoring data and laboratory experimentation (SFWMD et al., 2009a,b). The major uncertainty associated with these envelopes is not the magnitude of their limits, but rather, the frequency and duration of exposure to salinities and flows outside the boundaries of these envelopes. For example, high discharge events may play the same role as fire in some other systems, but again the frequency at which these should occur is not known. Comparing and contrasting ecological changes during the extremes of flood and drought with normal conditions represents a promising avenue of investigation.

ENVIRONMENTAL OPERATIONS

- **High Freshwater Discharges.** *The quantification of the duration of exposure to high flows that can be tolerated by estuarine resources can inform better management of these high flows on such resources.*

The 2008 LORS allows for and proscribes regulatory releases of freshwater to both the Caloosahatchee and St. Lucie estuaries. Relatively high discharges are required when lake water level is high and these discharges can damage estuarine resources. Quantifying the duration of exposure that estuarine resources (oysters, seagrass) can tolerate could inform management of these high flows and their effects on estuarine resources.

RECENT AND ONGOING RESEARCH

This component of the WY2015 update summarizes the research and monitoring projects of the CES that are directly relevant to the RWPP's for the CRE and SLE (**Table 1**) and identifies areas for future research. Completed and ongoing projects (completed vs. WY2015) were categorized by estuary (CRE versus SLE), water quality vs. water quantity (WQ vs. Q). An inventory of 18 projects were listed and summarized for this document (below). The projects are briefly introduced while Appendix 10-1 of this volume includes summaries of each project.

The ecosystem scale responses of the CRE and SLE were explored through the development of seasonal inorganic nitrogen (N) and phosphorus (P) budgets. A segmented simulation model of the CRE was developed to link freshwater inflows and nutrient loading to salinity gradients, water quality, submarine light, and seagrass survival. The CES partnered with the Florida Department of Environmental Protection (FDEP) to complete a combined hydrodynamic-water quality model with a graphical user interface (GUI) for the CRE A study was conducted to quantify variations in submarine light and the relative contributions of turbidity, Chl-*a*, and colored dissolved organic matter (DOM) with freshwater inflow to the CRE. The importance of sediment nutrient sources and the internal loading of N and P to the water column of both the CRE and SLE are being evaluated through a study of sediment-water exchanges of dissolved materials in the wet season. The reactivity and bio-availability of dissolved organic nitrogen (DON) in the Caloosahatchee River is being explored in a series of laboratory experiments.

The Adaptive Protocol Release Study (APRS) was a concerted effort to measure the responses of hydrography, water quality, zooplankton, and juvenile fish to regulated, dry season releases of freshwater from Lake Okeechobee to the CRE. While the first studies in 2012 and 2013 emphasized low level releases in the dry season, efforts are being extended toward higher inflows indicative of the late dry season and wet season in WY2015. The Florida Department of Environmental Protection, U.S. Geologic Survey, South Florida Water Management District, and Lee County conducted a joint monitoring project to measure inflows from several major tributaries to the CRE from 2007–2013. Over the past few years, a model of the inflows from the tributaries and groundwater to the CRE (WaSh) was created, with refinements planned for WY2015. Similarly, the continued refinement of the WaSh model for the SLE is ongoing. The three-dimensional (3-D) hydrodynamic model of the CRE was calibrated using observations of water level at the downstream boundary, salinity time series, and measurements of net flows in the lower estuary. Interannual and intraannual variations in the status of aquatic living habitat (oysters and SAV) in both estuaries are described elsewhere in this update of the RWPPs for WY2015.

Table 1. Information regarding the District's Research and Water Quality Plan update for the River Watershed Protection Plans (RWPPs) for Water Year 2015 (WY2015) (May 1, 2014–April 30, 2015). Research components for the Caloosahatchee River Estuary (CRE) and St. Lucie Estuary (SLE) were specified for water quality (WQ) or water quantity (Q). Components are either completed or ongoing in WY2015.

Estuary	Type	Component	Purpose	Status
CRE	WQ	Nutrient Budgets	Response of estuary to DIN and DIP loading	Completed
	WQ	Segmented Simulation Model	Linkages among inflow, water quality, light, and seagrass	Completed
	WQ	FDEP model & GUI	Description of FDEP estuary model and interface	Completed
	WQ	Light Study	Gradients and attributes of submarine light	Completed
	WQ	Sediment Nutrients & Cycling	Wet season study of sediment-water exchanges	WY2015
	WQ	Potential Reactivity of DON	Bio-availability of DON in Caloosahatchee River	WY2015
	Q	Adaptive Protocol Release Study	Significance of APRS for hydrography, zooplankton, and fishes	Completed
	Q	Tributary inflows	Assessment of freshwater inflow from the tidal basin	Completed
	Q	Watershed Hydrology Model (WaSh)	Modeling of surface- and groundwater inflow from tidal basin	Completed
	Q	Hydrodynamic Model Calibration	Calibration of water levels, circulation, and salinity	Completed
	Q	Adaptive Protocol Release Study	Further investigations to support adaptive protocols	WY2015
	Q	Watershed Hydrology Model (WaSh)	Improved modeling of inflow from tidal basin	WY2015
	Q	Aquatic living habitat	Observed responses of SAV and oyster with freshwater inflows	WY2015
SLE	WQ	Nutrient Budgets	Response of estuary to DIN and DIP loading	Completed
	WQ	Sediment Nutrients & Cycling	Wet season study of sediment-water exchanges	WY2015
	Q	Watershed Hydrology Model (WaSh)	Improved modeling of inflow from tidal basin	WY2015
	Q	Aquatic living habitat	Observed responses of SAV and oyster with freshwater inflows	WY2015
BOTH	WQ & Q	Linkages Between Q & WQ	Analyses of freshwater inflow and estuarine water quality	WY2015

INORGANIC NITROGEN AND PHOSPHORUS BUDGETS FOR THE CALOOSAHATCHEE AND ST. LUCIE ESTUARIES

Christopher Buzzelli

Interactions among geomorpholgy, circulation, and biogeochemical cycling determine estuary responses to external nutrient loading. The Caloosahatchee and St. Lucie Estuaries on opposite sides of Florida are small, sub-tropical water bodies with highly modified watersheds. While natural variations in freshwater inflow and associated salinity changes are part of estuarine dynamics, anthropogenic modification of water delivery to afford flood protection and public safety can create unstable salinity distributions that adversely affect estuarine biota. In order to better manage watershed nutrient inputs, the goal of this study was to develop seasonal dissolved inorganic nitrogen (DIN) and phosphorus (DIP) budgets for the CRE and SLE from 2002–2008.

Methods

In 1993 the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program on Global Environmental Change (IHDP; http://www.loicz.org/; http://nest.su.se/mnode/) initiated a project to investigate biogeochemistry of the coastal zone (Gordon et al., 1996; Smith et al., 2005; Swaney et al., 2011). The approach has been used to investigate CNP cycling in hundreds of coastal environments (Smith et al., 2005; Giordani et al., 2008; Swaney et al., 2011). The Land Ocean Interactions in the Coastal Zone (LOICZ) approach was used to generate water, salt, and DIN and DIP budgets for the CRE and SLE.

Results

Freshwater discharge to both estuaries revealed long-term variability with maximum values in the wet seasons of 2003-2005 followed by minimal inflow for both seasons beginning in 2006. Freshwater input from the tidal basins generally reflected patterns of surface flow. Estuary-wide, average DIN concentrations in both the CRE and SLE exhibited inter-annual climatic fluctuations similar to patterns of inflow from 2002-08. The production of internal DIN increased with DIN loading to the CRE in the wet season. Results were more variable in the SLE with net internal DIN produced in the 2002, 2004 and 2005 wet seasons but consumed in the wet seasons of 2003 and 2006 and the dry seasons of 2004 and 2005.

In contrast to DIN, DIP concentrations in the CRE were remarkably consistent across all seasons and years. There was no obvious relationship between the external loading of DIP and internal DIP concentrations in the CRE except that concentrations declined with extreme inflow in 2004-05. The CRE demonstrated an overall balance between internal production and consumption of primary production over all seasonal budgets. Primary production in the SLE increased significantly with external DIP loading. This included DIP consumption and a bloom of a cyanobacterium (*Microcystis aeruginosa*) following hurricane-induced discharge to the SLE in 2005 (Phlips et al. 2011). Additionally, while denitrification provided a microbially-mediated N loss pathway for the CRE, this potential was not evident for the SLE where N_2 fixation was favored.

Significance

Nutrient budgets indicated that net internal production or consumption of DIN and DIP fluctuated with inter- and intra-annual variations in freshwater inflow, hydrodynamic flushing, and primary production. Although both coastal water bodies possess similar watershed patterns of

agriculture and urbanization and ranges in flushing time, these two estuaries have very different biogeochemical attributes. The budgets revealed that the internal production of C, N, and P was more influenced by external loading to the SLE than the CRE. While the CRE is 2.5 times larger and receives twice the freshwater inflow, DIP and DIN loadings are only 60-70 percent of those to the SLE. While both nitrogen (N) and phosphorus (P) loads influence sub-tropical estuaries, the CRE was more sensitive to nitrogen inputs while the SLE responded sensitive to phosphorus inputs.

The recognition that sub-tropical estuaries have the potential to respond to both N and P inputs is an important step to establish nutrient load limits (Smith et al., 2006; Wulff et al., 2011). However, merely setting criteria for either total or dissolved nutrient loading based on their correlation to water column concentrations fails to appreciate the complexity and uncertainty of estuarine biogeochemical cycling (Dodds, 2003). In both the discharge and the receiving basin, the DIN:DIP ratios are often very different than the TN:TP ratios due to the differential composition and reactivity of dissolved organic N and P (DON and DOP; Smith et al., 2005). Freshwater inflow to the SLE has a comparatively high TN:TP ratio (~14:1), but a much reduced DIN:DIP ratio (~3.0; Doering 1996; SFWMD 2012a). While most of the TP is available as DIP (DIP:TP = 0.7), most of the TN is in the form of DON with DIN comprising only 30 percent of TN. DON is a potentially important component in CNP cycling in sub-tropical estuaries like CRE which possesses comparatively low concentrations of water column N (Eyre et al., 2011). Like many estuaries, there is limited understanding about the effects of DOP and DON cycling on primary production and system metabolism in the SLE and CRE (Smith and Hollibaugh, 2006; Loh, 2008). Future studies should examine the partitioning and reactivity of TP and TN external loading and internal concentrations including dissolved and particulate organic and inorganic fractions.

A SEGMENTED SIMULATION MODEL FOR THE CALOOSAHATCHEE RIVER ESTUARY

Christopher Buzzelli

Variations in freshwater inflow have ecological consequences for estuaries. Conventional wisdom emphasizes nutrient loading as the stressor that promotes algal biomass, decreases submarine light penetration, and degrades seagrass habitats. However, freshwater inflow depresses salinity and introduces colored dissolved organic matter (CDOM) that greatly reduces submarine light. Predicting the potential effects of the magnitude and composition of inflow on estuaries over a range of spatial and temporal scales requires reliable mathematical models. The goal of this study was to develop and apply a model of ecosystem processes with variable freshwater inflow to the CRE in southwest Florida.

Methods

The modeling framework combined inputs of freshwater and materials from the watershed, daily predictions of salinity, a box model for physical transport, and simulation models of biogeochemical and seagrass dynamics. The CRE was split into 3 segments to estimate transport of water column constituents. Each segment contained a sub-model to simulate changes in the concentrations of organic nitrogen and phosphorus (ON and OP), ammonium (NH_4^+), nitrate-nitrite (NO_x^-), ortho-phosphate (PO_4^{-3}), and Chl-*a* (CHL). The seaward segment also had sub-models for seagrasses (*Halodule wrightii* and *Thalassia testudinum*). The model was used to explore the relationships between freshwater inflow, nutrient loading, submarine light, and

seagrass survival. First, external nutrient loads were reduced by lowering inflow (Q_0 series). Second, load reductions were accomplished by decreasing the incoming concentrations of dissolved inorganic nitrogen and phosphorus (DIN and DIP Series). The model also was used to explore the partitioning of submarine light extinction due to Chl-*a*, CDOM, and turbidity.

Results

The model provided realistic predictions of ON in the upper estuary during wet conditions since organic nitrogen is associated with freshwater inflow and low salinity. Although simulated CHL concentrations were variable, the model proved to be a reliable predictor in time and space. While predicted NO_x^- concentrations were proportional to freshwater inflow, NH_4^+ was less predictable due to the complexity of internal cycling during times of reduced freshwater inflow. Overall, the seagrass sub-models performed exceptionally well despite the absence of epiphytes, nutrient effects, or sophisticated translocation in the formulation.

Results indicated that attempting to control nutrient loading by decreasing freshwater inflow could have minor effects on water column concentrations but greatly influence the abundance of submarine light and seagrass biomass. This is because of the relative importance of Q_0 to salinity and submarine light. Although light penetration and seagrass biomass decreased with increased inflow and CDOM, Chl-*a* accounted for more submarine light extinction in the lower estuary.

Significance

The model is useful to investigate the relative importance of CDOM versus CHL in submarine light availability throughout the CRE, assess if reductions in nutrient loads are more feasible by controlling freshwater quantity or N and P concentrations, and explore the role of inflow and flushing on the fates of externally and internally derived dissolved and particulate constituents. The model output was used to help identify desirable levels of inflow, nutrient loading, water quality, salinity, and submarine light for seagrass in the lower CRE.

MODELING OF THE CALOOSAHATCHEE WATERSHED AND ESTUARY HYDROLOGY AND ECOSYSTEM PROCESSES IN SUPPORT OF TOTAL MAXIMUM DAILY LOADS OF NUTRIENTS

Florida Department of Environmental Protection
and Peter Doering

The excessive loading of nitrogen (N) to estuaries can promote phytoplankton blooms. Because primary production in the CRE is N-limited, there is potential for algal blooms in the upper estuary under some freshwater inflows (Buzzelli et al., 2013a). The Northern Everglades and Estuaries Protection Program (NEEPP) and the Basin Management Action Plan (BMAP) associated with the Total Maximum Daily Load require reductions in nutrient loads and concentrations for the CRE (SFWMD 2012b). The TMDL for the Caloosahatchee estuary calls for a 23 percent reduction in loading of total nitrogen (TN) (Bailey et al., 2009). The goal of this study was to develop a linked model of watershed-estuary hydrology and water quality for the CRE. This work was supported by the FDEP.

Methods

The Hydrologic Simulation Program uses a Fortran Model funded and supported by the FDEP to simulate flow and water quality in the Upper Caloosahatchee River Watershed (C-43 Basin) and the Tidal Basin (downstream of S-79). The model simulates flow and water quality constituents such as temperature, five-day biological oxygen demand (BOD), nitrogen, phosphorus, Chl-*a*, and DO. Recent improvements include extending the period of record from 2003 to 2010, incorporating NEXRAD rainfall data and replacing initial data from weather stations, modifying the model to include new information on irrigation and drainage supplied by the agricultural community and conducting further calibration using measured flow information from 2007-2010.

The Caloosahatchee Estuarine Water Quality Model was developed by the FDEP to support TMDL development for the CRE. The model uses an Environmental Fluid Dynamics Code (EFDC) platform. Recent improvements include extension of the model grid and an improved light attenuation model has been added to the water quality module. The simulation period is extended and now covers 2003 to 2009. The model was originally developed by Dynamic Solutions LLC. They developed a GUI to display and post process results. The SFWMD acquired this GUI and can now run the model.

Significance

This effort will help identify monitoring and engineering projects that to better control the inputs of nutrients from the watershed to the estuary. Reductions in nutrient loads (particularly N) should lead to improved water quality in the estuary. These water quality improvements should benefit the distribution and density of ecologically and economically valuable seagrass habitats. This effort allows the SFWMD and the FDEP to apply the same modeling platform to address water quantity and water quality issues in the Caloosahatchee River Watershed and Estuary.

COLORED DISSOLVED ORGANIC MATTER AND SUBMARINE LIGHT IN THE CALOOSAHATCHEE RIVER ESTUARY

Zhiqiang Chen

Light availability is one of most important factoring controlling primary production by phytoplankton, microalgae, and SAV in many estuaries (McPherson and Miller, 1987; Gallegos, 2001; Coble, 2007; Buzzelli et al., 2012). Submarine light is modulated by concentrations of phytoplankton (Chl-*a*), turbidity, and CDOM. The relative contributions are important because efforts to reduce nutrient loading to estuaries focuses on limiting phytoplankton derived Chl-*a* (Greening et al., 2011). The importance of CDOM fluctuates with freshwater inflow and can be the dominant factor spatially or temporally in South Florida estuaries (McPherson and Miller, 1987; Christian and Sheng, 2003; Kelble et al. 2005; Doering et al., 2006). While CDOM or color has been monitored sporadically in the CRE, there has not been a thorough and systematic assessment of its role in submarine light attenuation over time and space. The goal of this study was to characterize the mixing and reactivity of CDOM and evaluate the contribution of CDOM to submarine light attenuation in the CRE.

Methods

This study used a combination of field and laboratory studies from March 2009-January 2011. CDOM was determined at 12-13 mid-channel stations along the salinity gradient from the

S79 to San Carlos Bay. Mixing diagrams were generated to assess the departure from conservative properties between the two estuarine end members. The effects of photolysis and flocculation of CDOM were quantified in laboratory studies designed to duplicate mixing between the end members. Turbidity and Chl-*a* values were determined at the mid-channel stations during the last 5 surveys. The relative contributions among the constituents were quantified using multiple linear regression that assumed a constant contribution from pure water from a depth of 2.0 m.

Results

The effects of CDOM were enhanced in the upper estuary and increased with freshwater inflow (Bowers and Brett, 2008). CDOM exhibited three apparent mixing patterns, with 1) conservative behavior or 2) addition at lower inflow and 3) loss at higher inflow. Laboratory studies indicated that while flocculation was not a major loss process for CDOM, but photolysis was important. Light attenuation in the CRE was controlled primarily by CDOM in the upper estuary and by turbidity in the lower estuary, with the average contribution of CDOM to total light attenuation of 55 percent (2–92 percent) and turbidity of 23 percent (3–79 percent). The contribution of Chl-*a* to light attenuation was less than both CDOM and turbidity, accounting for about 12percent on average (2–24 percent), regardless of location.

Significance

This study found that CDOM was the dominant component to submarine light attenuation in the CRE. This is significant because management plans to reduce nutrient loading to the CRE might reduce Chl-*a* concentrations, but may not necessarily improve submarine light for submersed plant habitats (Le et al., 2013). Plans to improve water clarity should consider the contributions from CDOM and turbidity.

SEDIMENT-WATER EXCHANGES AND INTERNAL SOURCES OF NUTRIENTS IN THE ST. LUCIE AND CALOOSAHATCHEE RIVER ESTUARIES IN THE WET SEASON

Teresa Coley

Nutrient loads from the sediments to the water column in the shallow estuaries of South Florida is one of the key processes that determines the rate at which estuarine water quality will respond to reductions in loads from the watershed (Buzzelli et al. 2013b). Little information is available on the contribution of sediments to the nutrient budgets of the CRE and SLE. Sediment organic matter, accumulated through storm water runoff and the erosion of canals and/or shorelines, is potentially a large and consistent source of nutrients to the water column via sediment diagenic processes. Synoptic measurements of sediment-water exchanges were made in the CRE and SLE during the dry season 2008 (Howes et al., 2008a; Howes et al., 2008b; Buzzelli et al., 2013b). While this study was valuable, it was conducted under drought conditions and decreased water temperature and freshwater inflow. The goal of this study was to quantify rates of dissolved exchanges across the sediment-water interface to estimate the importance of internal loading of nutrients in the CRE and SLE during the wet season. This study is presently under contract and scheduled for July 2014 with final deliverables due in 2015.

Methods

The methods for the 2014 study will be the same as those employed in the 2008 study (Howes et al., 2008a,b). Sediment cores will be collected at the 50 locations identified in each estuary during the 2008 studies and incubated in a makeshift laboratory setting under in situ temperatures and light levels. Incubations will be performed under both light and dark conditions. Flux rates will be calculated based on time series measurements of water column nitrogen and phosphorus and averaged over light and dark conditions for an estimate of daily nutrient load from the sediments to the water column (positive flux rates) or removal of nutrients from the water column to the sediment (negative flux rates). Additional measurements of surface sediments will quantify nutrients in the surface porewater, organic matter, and benthic phototrophs (i.e., algae at the sediment surface).

Significance

This study supports implementation of the Caloosahatchee River Watershed Protection Plan, the St. Lucie River Watershed Protection Plan, and the Northern Everglades and Estuaries Protection Program by measuring one of the key processes that determines the rate at which estuarine water quality will respond to reductions in the nutrient load from the watershed. The larger the sediment nutrient load to the water column, the lower the capacity for the estuary to assimilate nutrient loads from the watershed, and the longer it will take for management measures (i.e., Best Management Practices) in the watershed to be expressed as improvements to estuarine water quality. Data from this project will be incorporated into water quality models and allow the District to more accurately quantify the assimilative capacities of the Caloosahatchee Estuary and the St. Lucie Estuary, the effects of load reductions on water quality and the rate at which water quality will respond to implementation of load reductions in the watershed.

THE REACTIVITY AND MICROBIAL UTILIZATION OF DISSOLVED ORGANIC NITROGEN IN THE CALOOSAHATCHEE RIVER

Cassondra Thomas

As previously noted, the excessive N loading to estuaries can promote phytoplankton blooms. Because primary production in the CRE is N-limited, there is potential for algal blooms in the upper estuary under some freshwater inflows (Buzzelli et al., 2013a). The NEEPP and BMAP associated with the TMDL require reductions in nutrient loads and concentrations for the CRE (Wetland Solutions, 2012; SFWMD, 2012b). As previously noted, the TMDL for the Caloosahatchee Estuary calls for a 23 percent reduction in loading of TN (Bailey et al., 2009). The SFWMD and Lee County are partners in the development of the C-43 Water Quality Treatment Area Testing Project (C-43 WQTA Project) to reduce material loads to and improve downstream water quality in the CRE. The water entering the C-43 canal from Lake Okeechobee from 1981–2011 at S-77 has an average TN concentration of 1.76 mg/L. However, approximately 70 to 90 percent of the incoming TN is composed of DON (Wetland Solutions, 2012). Unfortunately, little is known about the availability of DON to phytoplankton and bacteria in most estuaries (Smith and Hollibaugh, 2006; Loh, 2008). The goal of this upcoming study is to conduct laboratory experiments to explore the reactivity of DON in the freshwater Caloosahatchee River.

Methods

Bimonthly water samples will be collected along the Caloosahatchee River from a location upstream and downstream of the S-77, S-78, and S-79 structures in WY2015. The sources of microbial inoculum will consist of in situ bacteria and phytoplankton as well as a treatment with inoculum from the more estuarine water column community downstream of S-79. Several water quality parameters will be measured during the incubation periods including phosphorus and N species, chlorophyll, dissolved organic carbon, leucine aminopeptidase (an enzyme that indicates microbial utilization of protein-bound N), and the phytoplankton community composition.

Results and Significance

Results from this study will inform (1) the microbial uptake rate of DON in the water column, (2) the transformation of N into different forms (inorganic, particulate) and potential for water column N to be incorporated into wetland soils, and (3) the potential for development of harmful algal blooms. These results will help researchers and water managers better understand the potential effectiveness of the C-43 WQTA Project on reducing TN loads to the CRE.

ADAPTIVE PROTOCOL RELEASE STUDY OF THE CALOOSAHATCHEE RIVER ESTUARY- HYDROGRAPHY

Christopher Buzzelli

Freshwater inflow brings nutrients that can stimulate phytoplankton in the upper reaches of an estuary. Low discharge can result in excess phytoplankton-derived organic matter (Dettmann, 2001; Sheldon and Alber, 2006; Buzzelli, 2011). By contrast, rapid flushing pushes phytoplankton downstream too quickly to permit sinking or biological consumption (Doering et al., 2006; Lucas et al., 2009). Between these extremes exists inflows that promote phytoplankton growth, zooplankton abundance, and larval and juvenile fishes (Kimmerer, 2002; Lucas et al., 2009; Gillson, 2011). There is little information on the effects of low level releases on the CRE. The goal of the APRS of the CRE was to evaluate the potential effects of short-term inflow strategies on water quality and plankton abundances during the dry season. This study was unique because it combined the operational capacity to regulate Lake Okeechobee inflow through S-79 with the ability to detect ecological responses along the salinity gradient using rapid data acquisition (Buzzelli et al., 2014).

Methods

There were seven research cruises in early from Jan-Apr and nine cruises from Jan-May 2013 to quantify relationships between inflow and estuarine attributes. Average inflow of 450 cfs was targeted for the pulses. An on-board, flow-through system provided surface water temperature, salinity (S), pH, dissolved oxygen, turbidity, and in situ Chl-*a* (in situ CHL) at 5 sec intervals along the ~45 km length between S-79 and San Carlos Bay. Mid-channel stations provided vertical profiles of the water column and zooplankton samples. The vertical profiles were interpolated in two-dimensions (distance and depth) to examine variations in the distribution and stratification of salinity. Since the cruises were approximately bi-weekly, the downstream locations where salinity was 10 (S_{10}) and the maximum concentration of Chl-*a* (Chl-*a* max) on each date were plotted versus freshwater inflow at S-79 the previous 14 days.

Results

Salinity increased throughout the CRE with decreased freshwater inflow. Salinity increased nearly linearly between 10 and 40 km for each cruise date before rapidly increasing near the oceanic end. The downstream locations of S_{10} and Chl-*a* max were positively related to inflow. Results indicated that the position of S_{10} increased to approximately 32 km with increased 14 d inflow from S-79. While the relationship between 14 d total inflow and the location of Chl-*a* max was similar to that for S_{10}, the position of the Chl-*a* max was more variable. Phytoplankton growth is influenced by inflow, temperature, light, nutrients, grazing, and sinking. Thus, there were conditions related to diminished inflow that could promote phytoplankton blooms in the upper estuary. First, water column stratification in the winter could have stimulated remineralization and primary production. Second, inflow ceased as water temperature increased to 26.0° C by April to promote algal growth.

Significance

The APRS presented a unique opportunity to evaluate the effects of short-term inflow strategies on water quality and plankton abundances during the dry season. The hyperbolic relationship between inflow and S_{10}suggests that low level inflow during dry can be used to maintain favorable salinity gradients in the CRE. It is possible for phytoplankton blooms to occur in the upper estuary with minimum freshwater inflow in the dry season.

ADAPTIVE PROTOCOL RELEASE STUDY OF THE CALOOSAHATCHEE RIVER ESTUARY – ZOOPLANKTON

Marion Hedgepeth

Freshwater inflow brings nutrients that can stimulate phytoplankton in the upper reaches of an estuary. Low discharge can result in excess phytoplankton-derived organic matter (Dettmann, 2001; Sheldon and Alber, 2006; Buzzelli, 2011). By contrast, rapid flushing pushes phytoplankton downstream too quickly to permit sinking or biological consumption (Doering et al., 2006; Lucas et al., 2009). Between these extremes exists inflows that promote phytoplankton growth, zooplankton abundance, and larval and juvenile fishes (Kimmerer, 2002; Lucas et al., 2009; Gillson, 2011). There is little information on the effects of low level releases on the CRE. As previously noted, the goal of the APRS was to survey the potential effects of low level releases from S-79 on water quality, zooplankton, and fish abundance.

Methods

There were seven research cruises in early from Jan-Apr and nine cruises from Jan-May 2013 to quantify relationships between inflow and estuarine attributes. Average inflow of 450 cfs was targeted for the freshwater pulses. There were nine mid-channel locations for vertical profiles of the water column and zooplankton sampling. In 2012 zooplankton samples were collected during daylight hours using a submersible pump. Zooplankton samples were obtained by towing a 0.5m diameter paired bongo net with 210 µm mesh in 2013.

Results

Reduced freshwater inflow of approximately 450cfs permits the upstream intrusion of salt water that can be conducive to increased plankton production in the oligohaline and upper euhaline parts of the upper estuary.

Zooplankton abundance was greatest from ~5.5-11.0 km downstream of S-79. Adult and larval copepods were the dominant taxa present. Overall, the greatest zooplankton abundances corresponded with the chlorophyll maxima.

Significance

Results from these studies suggest that it is possible for low-level freshwater releases to stimulate phytoplankton and zooplankton production in the upper and mid Caloosahatchee River Estuary. The stimulation of the lower trophic components of the food web has implications for larval and juvenile fishes in the early part of the calendar year.

ADAPTIVE PROTOCOL RELEASE STUDY - JUVENILE FISHES

Marion Hedgepeth

Freshwater inflow brings nutrients that can stimulate phytoplankton in the upper reaches of an estuary. Low discharge can result in excess phytoplankton-derived organic matter (Dettmann, 2001; Sheldon and Alber, 2006; Buzzelli, 2011). By contrast, rapid flushing pushes phytoplankton downstream too quickly to permit sinking or biological consumption (Doering et al., 2006; Lucas et al., 2009). Between these extremes exists inflows that promote phytoplankton growth, zooplankton abundance, and larval and juvenile fishes (Kimmerer, 2002; Lucas et al., 2009; Gillson, 2011). There is little information on the effects of low level releases on the CRE. As previously noted, the goal of the APRS was to survey the potential effects of low level releases from S-79 on water quality, zooplankton, and juvenile fish abundance.

Methods

There were nine cruises from Jan-May 2013 to quantify relationships between inflow and estuarine attributes. Average inflow of 450 cfs was targeted for the freshwater pulses. There were nine mid-channel locations for vertical profiles of the water column and zooplankton sampling. Juvenile fish were collected at fixed shoreline stations adjacent to the mid-channel stations for discrete water quality measurements and zooplankton. Collections were made using replicate hauls of 10 m x 25 m area of the near-shore environment using a 6.1 m center bag seine with a 3.2 mm mesh.

Results

There was temporal variability as juvenile fish assemblages changed over the period sampled between the early (1/10-4/4/13) and late (4/18 -5/2/13) dry season. The early and late dry season assemblages were distinguished from one another by a lack of winter recruiting species like *Callinectes sapidus* (blue crab) combined with an influx of spring recruits of *Lagodon rhomboides* (pinfish) and *Orthopristis chrysoptera* (pigfish) later in the dry season. The differences between groups of stations mostly reflected a transition of dominate nekton from *Menidia* spp. (silversides) and *Gambusia holbrooki* (mosquitofish) at upstream stations to higher salinity estuarine residents such as mojarra in the mid-estuary to numerous marine transient species near the mouth of the estuary.

There were spatial differences in species assemblages between the early and late periods. Three groups of juvenile fish were observed along the estuarine salinity gradients in the early dry season 2013. The juvenile fish community split into two groups along the length of the CRE in

the late dry season. While species richness and diversity were generally greater in the upper estuary, there were no discernable temporal variations in these community indicators. The composition of the juvenile fish assemblages correlated to salinity, temperature, and DO and not necessarily freshwater inflow.

Significance

The composition and density of juvenile fish assemblages in the lateral shoals were less related to low-level freshwater inflow than the water quality conditions (temperature, salinity, dissolved oxygen) that commonly modulate fish population dynamics. Future studies should focus more on the larval fish community in the closer to the main channel of the CRE. This community should be more directly linked to the planktonic food web that is more influenced by freshwater inflow from upstream.

ADAPTIVE PROTOCOL RELEASE STUDY OF THE CALOOSAHATCHEE RIVER ESTUARY - WY2015

Teresa Coley

Freshwater inflow brings nutrients that can stimulate phytoplankton in the upper reaches of an estuary. Low discharge can result in excess phytoplankton-derived organic matter (Dettmann, 2001; Sheldon and Alber, 2006; Buzzelli, 2011). By contrast, rapid flushing pushes phytoplankton downstream too quickly to permit sinking or biological consumption (Doering et al., 2006; Lucas et al., 2009). Between these extremes exists inflows that promote phytoplankton growth, zooplankton abundance, and larval and juvenile fishes (Kimmerer, 2002; Lucas et al., 2009; Gillson, 2011). While previous surveys focused on low-level releases to the CRE, a wider range of inflows should be evaluated to better understand the relationships with estuarine ecology. Continuing efforts in WY2015 will emphasize a variety of inflow conditions.

The primary goal of this project is to develop an empirical relationship between freshwater inflows, salinity, water quality and the nursery function of estuarine Low Salinity Zone using Chl-*a* and zooplankton biomass as the ecological metric. This relationship is being developed for different freshwater release scenarios, primarily under dry season conditions in the Caloosahatchee Estuary, according to the 2008 LORS and Adaptive Protocols for the Management of Lake Okeechobee.

Methods

In situ water quality surveys (Chl-*a*, salinity, temperature, turbidity, and dissolved oxygen) are conducted in conjunction with the collection of vertical profiles (survey parameters) and surface water samples for nutrients (TN and TP), Chl-*a* and zooplankton at 9-16 fixed station locations along the central axis of the CRE.

Results and Significance

The results of this project will be used to inform the duration, shape and magnitude of freshwater releases for the benefit of water quality and planktonic attributes of the CRE. The field and analytical approaches applied to the CRE will be refined for future use in the Loxahatchee River and St. Lucie Estuaries.

MONITORING OF TRIBUTARY INFLOWS IN THE TIDAL CALOOSAHATCHEE RIVER BASIN

Fawen Zheng

Freshwater inflow through tributaries and submarine groundwater discharge (SGD) is important to the maintenance of estuarine salinity (Burnett et al., 2006). Despite the importance of combined tributary and SGD inflow, it has not been sufficiently quantified for the CRE (Charette et al., 2013). Historically, the limited monitoring and overall poor understanding of the role of tributary and SGD inflows have inhibited the ability to effectively represent all the sources of freshwater in predictive models. Unfortunately, historically there has been limited monitoring of freshwater in the tidal Caloosahatchee basin for the development of accurate models. The goal of this study was to quantify freshwater inflows through lateral creeks to the CRE.

Methods

The tidal Caloosahatchee River Basin (TCRB) is the drainage area between S-79 and Shell Point. Tributaries within the TCRB include Telegraph Creek, Orange River, Popash Creek, Billy's Creek, and Hancock Creek. The FDEP, the U.S. Geologic Survey (USGS), and the SFWMD jointly conducted a monitoring project to measure five major tributaries flow from the end of 2007 to March of 2013. In addition, Lee County funded a program to measure Whiskey Creek flow from 1994 to present.

Results

The average daily inflow ranged from 1.8-37.0 cfs in the dry season and 18.8-164.5 cfs in the wet season. The six tributaries drain ~60 percent of the total area of the TCRB with the remaining ~40 percent unmonitored. The drainage areas of Telegraph Creek (53,806 acres) and the Orange River (54,780 acres) account for 20.1 and 20.5 percent of the total drainage areas, respectively. The Orange River has relatively greater rates of freshwater inflow because its watershed has more urban area compared to the wetland, forest, and agricultural land uses in the Telegraph Creek watershed.

Significance

These data are essential for the development of models to predict the contributions of the TCRB to the freshwater budget of the CRE. Results from the dynamic models are linked to hydrodynamic models to simulate circulation, transport, and salinity in the estuary.

MODELING OF TRIBUTARY AND GROUNDWATER INFLOWS TO THE TIDAL CALOOSAHATCHEE RIVER BASIN

Fawen Zheng

As previously noted, freshwater inflow through tributaries and SGD is important to the maintenance of estuarine salinity (Burnett et al., 2006). Despite the importance of combined tributary and SGD inflow, it has not been sufficiently quantified for the CRE (Charette et al., 2013). As previously noted, historically the limited monitoring and overall poor understanding of

the role of tributary and SGD inflows have inhibited the ability to effectively represent all the sources of freshwater in predictive models. The goal of this study was to develop a hydrologic and hydraulic model for the TCRB. The TCRB is indicative of the South Florida coastal zone has a high water table, high rates of soil conductivity and infiltration, and tidal effects on subterranean mixing.

Methods

A similar model for the St. Lucie Watershed (WaSh) was developed to reflect the attributes of the South Florida coastal zone. In this study, the hydrologic module of WaSh was further modified to better reflect groundwater responses to rainfall. A semi-implicit scheme facilitates better simulation of exchanges between surface water and groundwater with rainfall and infiltration. The model was calibrated with the measured flow data at six tributaries and two primary river stations from 2008–2010 and verified with the data from 2011–2012.

Results

The simulated flow and groundwater stage show good agreement with the measured data. Model representation of tributary inflows reflected the 2008–2010 data with accuracies ranging from ~0.6 (Popash and Hancock Creeks) to ~0.8 (Orange River). The modifications significantly improve the ability to simulate groundwater dynamics in the TCRB.

Significance

The WaSh model was developed to improve the ability to model salinity in South Florida estuaries including the CRE. Accurate representation of the contributions of tributary and groundwater inflows greatly is essential for hydrodynamic models of estuarine transport and salinity. The long term simulation from 1965–2012 will be completed in 2014. Modeling tributary and groundwater inputs over this time span facilitates linkages to the primary source of freshwater at Franklin Lock (e.g., S-79) and permits application to alternative scenarios for various coastal watershed projects including the determination of minimum freshwater inflows and the optimization of proposed upstream reservoirs.

IMPROVEMENTS TO THE ST. LUCIE WATERSHED TRIBUTARY AND GROUNDWATER MODELING SYSTEM

Fawen Zheng

As previously noted, freshwater inflow through tributaries and SGD is important to the maintenance of estuarine salinity (Burnett et al., 2006). This is particularly important for small estuaries with watersheds that were heavily modified for agriculture or urbanization (Buzzelli, 2011). The St. Lucie Watershed is indicative of the South Florida coastal zone with a high water table, high rates of soil conductivity and infiltration, and tidal effects on subterranean mixing. This watershed epitomizes this type of coastal environment that has been split into approximately 10 different sub-basins that are interconnected through groundwater and channelized surface flows. Accurate representation of the combined point source and diffuse sources of freshwater to the SLE is essential for the simulation of estuarine hydrodynamics and salinity gradients (Ji et al., 2007; Wan et al., 2013). A series of hydrologic watershed (WaSh) models were previously developed for each sub-watershed for SLE in 2006 (Wan et al., 2006; SFWMD, 2009). The goal

of this study was to update the St Lucie WaSh model to include modified watershed boundaries and incorporate a GUI.

Methods

Simulations were conducted in 2014 to test the WaSh GUI using the ArcGIS 10.1 platform and updated sub-basin boundaries. The sub-basins included C-44 & S-153, C-23, C-24, C-25, C-25 East and downstream area, Basin1, North Fork, South Fork, and Basins 4-6. These simulations covered the entire spatial domain of the St. Lucie Watershed incorporating the most recent land use data from 2008–2009.

Results

The updated model significantly improved the ability to represent groundwater exchange between the sub-basins. Hot-start functionality was added to the model which will help more conveniently conduct model run, especially for long term simulation. The model was upgraded to be capable of routing channel flow through multiple outlets and preliminarily calibrated using hydrologic data from 2005–2013.

Significance

The St. Lucie WaSh model continues to evolve as a water management tool. Output from the model is connected to the SLE hydrodynamic model used to simulate circulation and salinity in the estuary. Refinements to water quantity predictive ability of the WaSh model for the SLE watershed will continue in WY2015. Additionally, the water quality component will be developed to better represent diffuse nutrient inputs to the SLE. Finally, long term simulations from 1965–2013 will be conducted for application to landscape scale water management scenarios for South Florida.

CALIBRATION OF THE CALOOSAHATCHEE RIVER ESTUARY HYDRODYNAMIC MODEL

Detong Sun

Predicting the potential effects of the magnitude and composition of inflow on estuaries over a range of spatial and temporal scales requires reliable mathematical models. Modeling estuarine hydrodynamics, net circulation, and salinity gradients is essential for effective management of watershed freshwater inflows, water quality, and biological resources in the coastal basin (Cerco and Cole, 1994; Condie et al., 2012). This is particularly true for the Caloosahatchee River Estuary (CRE). The goal of this study was to calibrate a 3-D hydrodynamic model of the CRE.

The CH3D model for the CRE was developed from the CH3D Charlotte Harbor model (Sheng, 2002). The original Charlotte Harbor model was calibrated using 2-month hydrodynamic and salinity data collected during the summer of 1986 at six stations located in Pine Island Sound and around the Peace River in Charlotte Harbor. The South Florida Water Management District (SFWMD) extended the model to the Caloosahatchee River using 16-month continuous monitoring data in the Caloosahatchee River and San Carlos Bay (Qiu, 2003). The model was further calibrated with three-year measured data (October 2001–December 2004) at five stations in the Caloosahatchee River (Sheng and Zhang, 2006; Qiu et. al., 2007).

Methods

The CH3D model for the CRE was further validated using a long-term time series of surface elevation from tidal data collected at the NOAA station in Naples, FL. These data served as the downstream boundary condition. Freshwater inflow at S-79 and the tributaries in the upper CRE provided the upstream boundary. This included the contribution of freshwater from the tidal basin downstream of S-79 using a linear reservoir model (Wan et al., 2006). Model results were compared to salinity observations at seven stations (S79, Bridge 31, I-75, Ft. Myers, Cape Coral, Shell Point, and Sanibel Island). Finally, the model underwent fine tuning using a three year time series of net flows measured at Marker 52 and Shell Point.

Results

Model simulations spanned October 1, 2000–December 31, 2011. There was good agreement between predicted and observed tidal discharges. Statistical analyses indicated excellent correlation between modeled and measured salinities among the monitoring stations. The model captured tidal circulation, salinity distributions, and the essential hydrodynamic attributes of the CRE. Model results were reliable for both dry and wet years and seasons.

Significance

The ability of the model to accurately represent circulation, salinity, and depth makes it a useful tool for the management of freshwater and estuarine resources. It is presently being used for various applications over time scales ranging from daily to interannual.

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