Restoring the Rookery Bay Estuary

A project connecting people and science for long-term community benefit

Rookery Bay
National Estuarine Research Reserve

ACKNOWLEDGMENTS

Restoring the Rookery Bay Estuary Project

The Restoring the Rookery Bay Estuary Project focused on collaborative watershed management through hydrologic, ecologic, and social science research, education, and partnerships. Guided by a diverse stakeholder group, the effort was coordinated by the Rookery Bay National Estuarine Research Reserve in Naples, Florida, and resulted in a wide range of management recommendations.

Project Start Date: March 16, 2012
Project Completion Date: June 30, 2015
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For more information

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Thank you

It is with heartfelt gratitude that we THANK the many dozens of people, from near and far, who helped this project reach its successful completion. Every single person who answered an email or telephone request, attended a meeting, sat through a presentation, or worked for or with the internal project team was a link in the chain of success. We particularly want to thank the Project Advisory Group members who helped us realize that true watershed management can only be accomplished through collaborations with a wide range of people and organizations. Another big thanks to the staff at the University of New Hampshire for funding support and being truly wonderful colleagues. Finally, all of the staff and volunteers at the Rookery Bay Reserve who helped with everything from budgets, contracts, and purchasing, to GIS support, setting up meetings, cleaning up meetings, hosting project guests, stuffing folders, and everything in-between. To all who helped out—Thank You!

University of New Hampshire

National Estuarine Research Reserve System Science Collaborative

Rookery Bay National Estuarine Research Reserve

Keeywaydin Island is one of the few remaining unbridged barrier islands in Florida and is managed by the Rookery Bay National Estuarine Research Reserve.

TABLE OF CONTENTS

Next page: The barrier island beach at the south end of Keewaydin Island is the most visited public access point within the Rookery Bay Reserve.

Applying watershed management techniques in southwest Florida

The Rookery Bay National Estuarine Research Reserve (RBNERR) managed a grant-funded project called Restoring the Rookery Bay Estuary: Connecting People and Science for Long-term Community Benefit from March 2012 through June 2015. The project was funded by the National Estuarine Research Reserve System's Science Collaborative, a cooperative agreement between the National Oceanic and Atmospheric Administration and the University of New Hampshire. The project focused on using watershed management techniques to improve understanding of the Rookery Bay watershed and estuary which is located between Naples and Marco Island in southwest Florida. The aim of the project was on understanding altered freshwater inflows to the estuary and potential ecological effects, and also on water resources decision-making in the region. The intention was to use this new information to guide future research and management activities. The project was also important because this part of Collier County is slated for intense future development, is in an area where potable water is captured for use by a growing population, and the downstream estuary represents nearly half of RBNERR's managed areas.

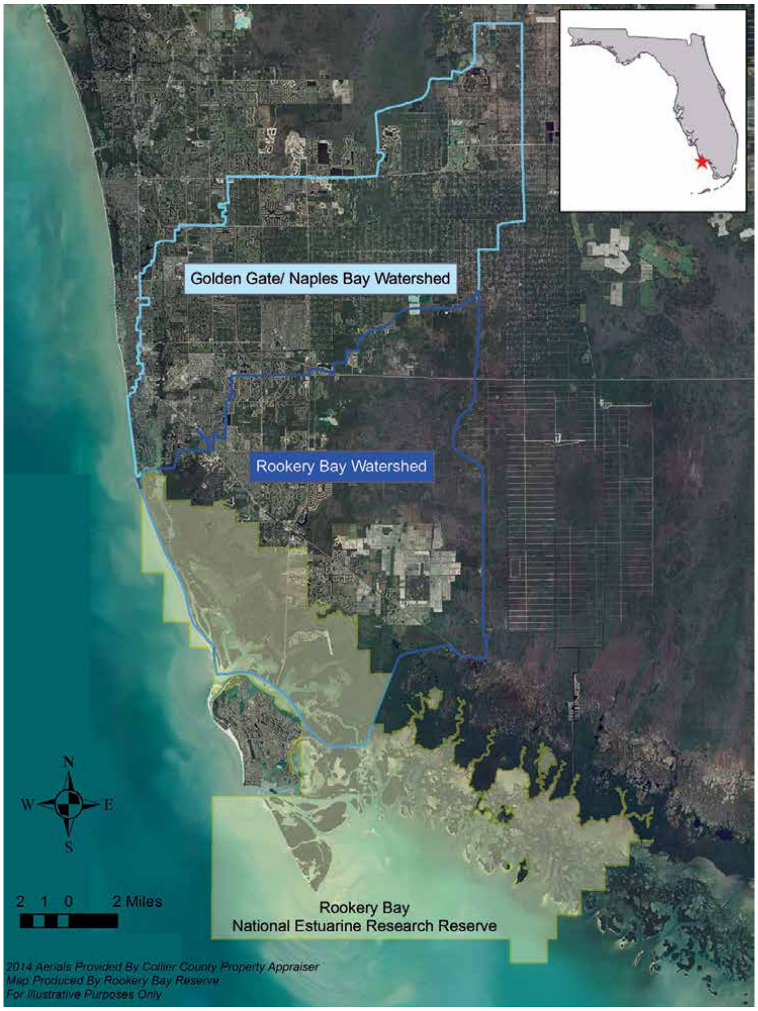
The project had approximately 20 different elements including ten new research projects in the areas of hydrology, ecology, and human dimensions. In addition, a successful strategy was the use of a Project Advisory Group comprised of 30 stakeholders from local, state, and federal government entities, non-profits, and the business sector. The project also resulted in a series of recommendations that were shared through one-on-one meetings, public presentations, and one-page handouts. This document is the projects' final report and summary of activities, but also is intended to share project outcomes and recommendations with decision-makers. More details can be found on the Friends of Rookery Bay website at www.rookerybay.org/restoreRB.

Management problem and context

The Rookery Bay National Estuarine Research Reserve (RBNERR) is surrounded by the growing population of Collier County, in southwest Florida. Part of a national network of 28 NERRs, the RBNERR is a partnership program between the National Oceanic and Atmospheric Administration (NOAA) and the Florida Department of Environmental Protection. RBNERR manages 110,000 acres of land and water that is part of the Everglades ecosystem. Its mission is to provide a basis for informed stewardship of estuaries in southwest Florida through research and education. Of particular interest to the RBNERR is the Rookery Bay estuary and the Rookery Bay watershed.

The Rookery Bay watershed is upstream of the northwest portion of the RBNERR in an area slated for intense future development, although existing competing land uses already include residential and commercial developments, agriculture, rock mining, golf courses, and conservation lands. In addition, this watershed includes a City of Marco Island utilities site where the majority of their potable water is captured from a stormwater canal that is approximately 1.5 miles upstream of Henderson Creek and the RBNERR headquarters.

The downstream receiving waters, called the Rookery Bay estuary, are highly affected by altered freshwater inflow due to upstream land use and a complex system of weirs, gates, canals, ditches, and stormwater ponds.

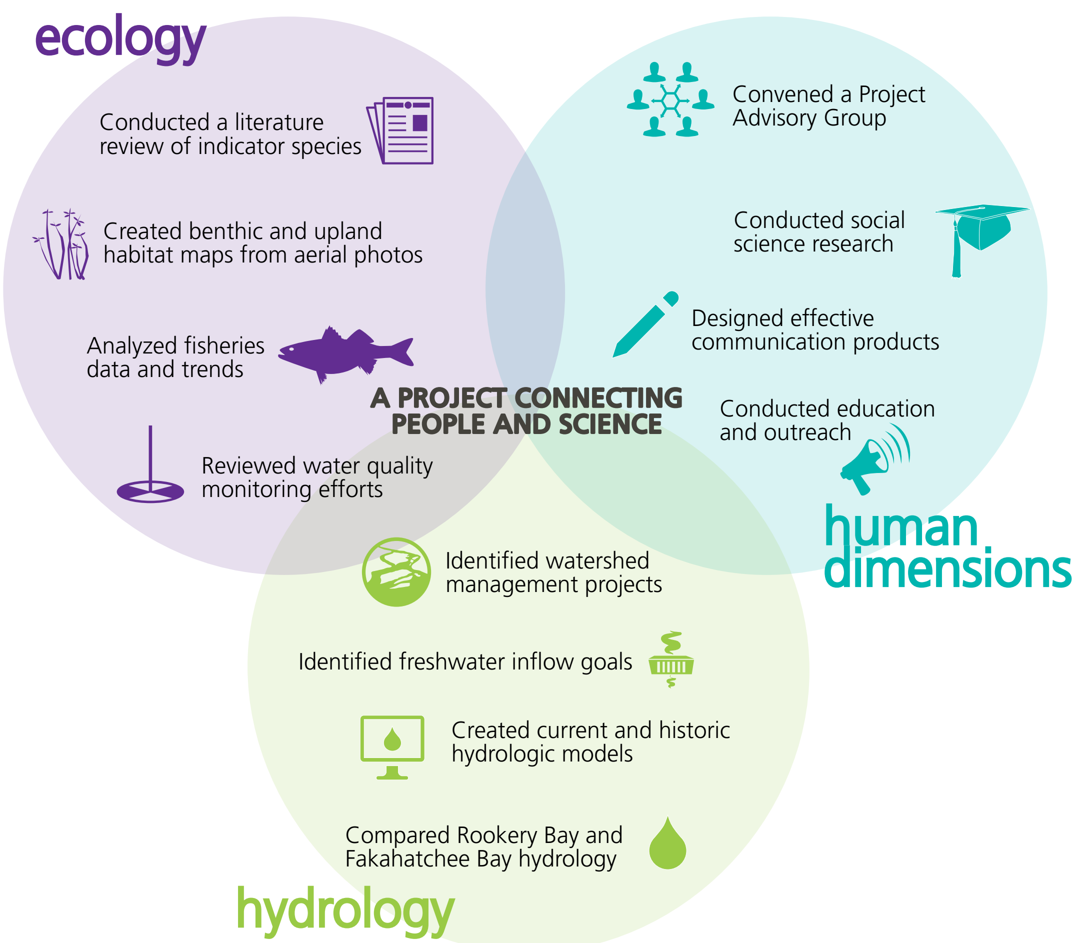


The Rookery Bay National Estuarine Research Reserve is located in Collier County in southwest Florida.

These water management systems are operated seasonally to shunt water off the land in the rainy summer season to prevent flooding, and to hold back water to recharge aquifers in the dry winter season. Collier County government and the South Florida Water Management District are the primary stormwater managers and they balance the competing needs of adequate flood control, aquifer recharge, and minimizing downstream impacts to coastal waters including the quality, quantity, and timing of freshwater discharges. The Rookery Bay estuary requires a delicate balance of fresh water coming from the land, combined with salt water from the Gulf of Mexico, to sustain the health of aquatic habitats, fish, and shellfish. The estuary provides important ecosystem services and has tremendous commercial and recreational value. Balancing the water needs of people with the needs of natural systems is an ongoing issue for the community.

To proactively address these pressing coastal management issues, the RBNERR received an $815,000 grant from the NERRS Science Collaborative during March 2012 through June 2015 to conduct the Restoring the Rookery Bay Estuary Project: Connecting People and Science for Long-term Community Benefit. There were more than 20 project elements in three categories: hydrology, ecology, and human dimensions. The project focused on two goals:

1. Better understanding of altered freshwater inflows to the Rookery Bay estuary and how that has affected the ecologic health of the estuary, and,
2. Better understanding of local water-resource decision making, at both the personal and institutional levels.



Guiding principles

The project was guided by two important principles, which were the approach required by the National Estuarine Research Reserve System's Science Collaborative and formal watershed management techniques. The Science Collaborative puts Reserve-based science to work for coastal communities by engaging the people who need the science in the research process—from problem definition and project design through implementation of the research and use of its results in coastal decisions. In addition, the project team utilized a watershed management approach which included a series of cooperative, iterative steps to:

- characterize existing conditions,
- identify and prioritize problems,
- define management objectives, and
- develop and implement protection or remediation strategies as necessary[1].

40%

The Rookery Bay Reserve manages approximately 40% of the Collier County coastline.

The Marco Lakes site (upstream of the Rookery Bay NERR, shown) is an important potable water source for the City of Marco Island. The City partnered on the project, which focused on balancing the water needs of people with those of natural systems.

Convening a Project Advisory Group

Early in the project a Project Advisory Group (PAG) was formed to advise and guide the research process. By the project's conclusion, the PAG included approximately 30 stakeholders with expertise in water resources management from diverse sectors including local, state, and federal governments, non-profits, and the private sector. This group filled two functions: vetting ideas in advance, and then reviewing final results after contracted projects were completed. The range of information gained was broad, and included hydrologic modeling, benthic habitat mapping, and social science research. This project has successfully identified effective approaches for water management decision making and brought significant new environmental science data to the community.

An internal team of Rookery Bay Reserve staff also met frequently and included the Project Coordinator, Research Coordinator, Stewardship Coordinator, and the Coastal Training Program Coordinator, along with an engineering consultant.

Outcomes, methods, and data

A wide variety of scientific approaches were used to characterize the existing conditions in the Rookery Bay watershed, to understand decision making in the community, and to encourage outcomes such as informed management actions.

A Project Advisory Group was formed to advise and guide the research process and included approximately 30 stakeholders with expertise in water resources management.

Current water management on Henderson Creek includes the opening and closing of a weir to control water flow.

Understanding altered freshwater inflows

To better understand altered freshwater inflows to the Rookery Bay estuary, a series of surface and groundwater models were created and then used to analyze several scenarios. These hydrologic models included a natural systems model that represented pre-development, or historic, conditions in the Rookery Bay watershed and a current conditions model. A hydrologic model is a computer-based representation of the water cycle, which is the movement of water on, above, and under the earth's surface. Taylor Engineering and Interflow Engineering provided the modeling services, and they were contracted through a Florida Department of Environmental Protection competitive qualifications-based selection process. In addition, watershed management projects that were proposed within the Collier County Watershed Management Plan were identified. This series of hydrology-related project elements resulted in recommendations related to the future use of models, the identification of watershed sub-basins with water deficits and overages, and increased understanding of the challenges and benefits of proposed watershed projects.

Projects

H1. **Current conditions Rookery Bay watershed model:** Developed a current conditions local scale hydrologic and hydraulic model for the Rookery Bay watershed.

H2. **Natural systems Rookery Bay watershed model:** Based on the current conditions model, developed a natural systems model for the Rookery Bay watershed that represented pre-development conditions.

H3. **Identification of estuarine inflow goals:** Compared the current and natural systems models to identify potential estuarine inflow goals.

H4. **Henderson Creek weir/gate operation scenario:** Conducted a model scenario to determine if historical condition flows could be more closely approximated by modifying the current operation and/or configuration of the weir and gate structures on Henderson Creek to address the current differences in seasonal flow distributions.

H5. **Belle Meade Agricultural Area conversion scenarios:** Conducted a model scenario of the potential conversion of the Belle Meade Agricultural Area to urban development, including three flow-ways and varying discharge rates.

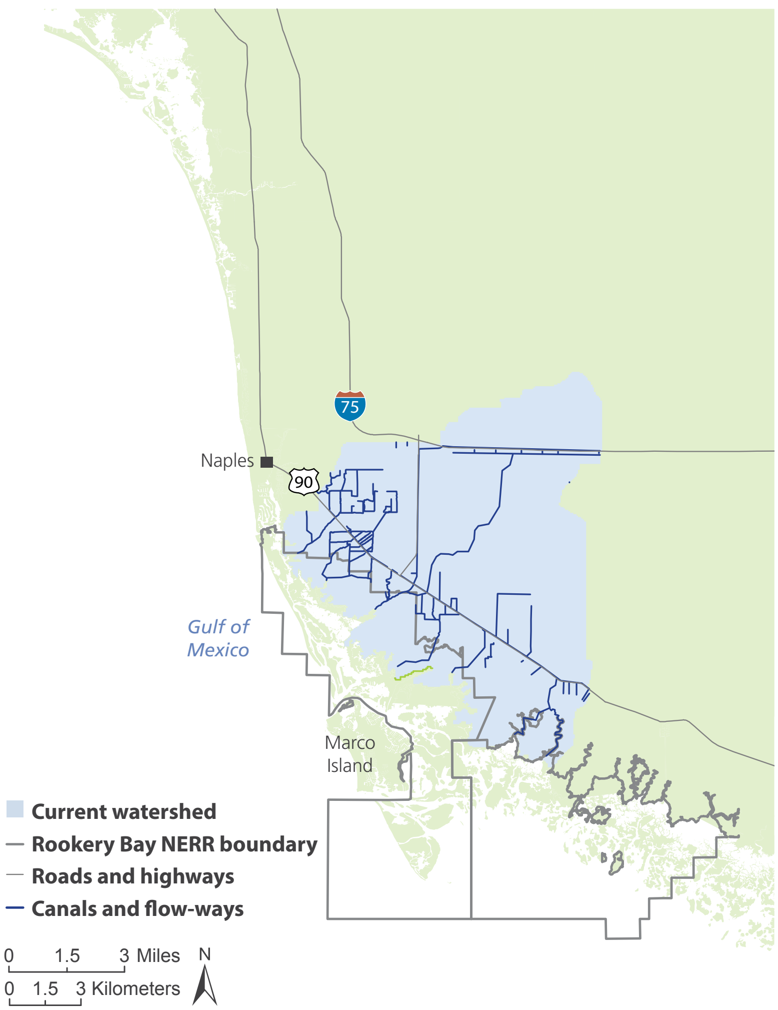
H6. **Rookery Bay/Fakahatchee Bay watershed comparison:** Compared the hydrology of the Rookery Bay watershed to the hydrology of the Fakahatchee Bay watershed to determine its suitability as a hydrologic restoration reference site.

H7. **Compilation of proposed watershed improvement projects within the Rookery Bay watershed:** Identified, grouped, and described 25 watershed improvement projects included in the Collier County Watershed Management Plan.

H1. Current conditions Rookery Bay watershed model

The current conditions model was derived from the existing Big Cypress Basin and Collier County MIKE SHE/MIKE-11 regional county-wide model that had a 1,500 foot per side grid-cell size and was used in the development of the Collier County Watershed Plan. The new model was refined to a 375 foot per side grid-cell size so that it was at a local scale which provided 16 times greater resolution within the study area. The local scale model covers approximately 12% of the original regional model domain. The simulation period was also updated to 2002–2012, which is a more robust data set, from the original model which covered a 2002–2007 data set.

Examples of model input data included: topography, measurements from aerial photos, rainfall, potential evapotranspiration, land use/land cover, hydraulic structures, vegetation crop data, saturated zone/groundwater parameters, soil profiles, and consumptive use of ground water and surface water. Flows included sheet flow overland, subsurface flows, and aquifer flows. Recorded consumptive water-use data was provided by the City of Marco Island Utilities Department for the Marco Lakes facility and therefore it was not derived from permit requirements as is typical for other large scale water users. Full results can be found in the final report: *Henderson Creek Watershed Engineering Research Project: Task 2.7—Interim Hydrodynamic Modeling Report MIKE SHE/MIKE-11 Model Development.*

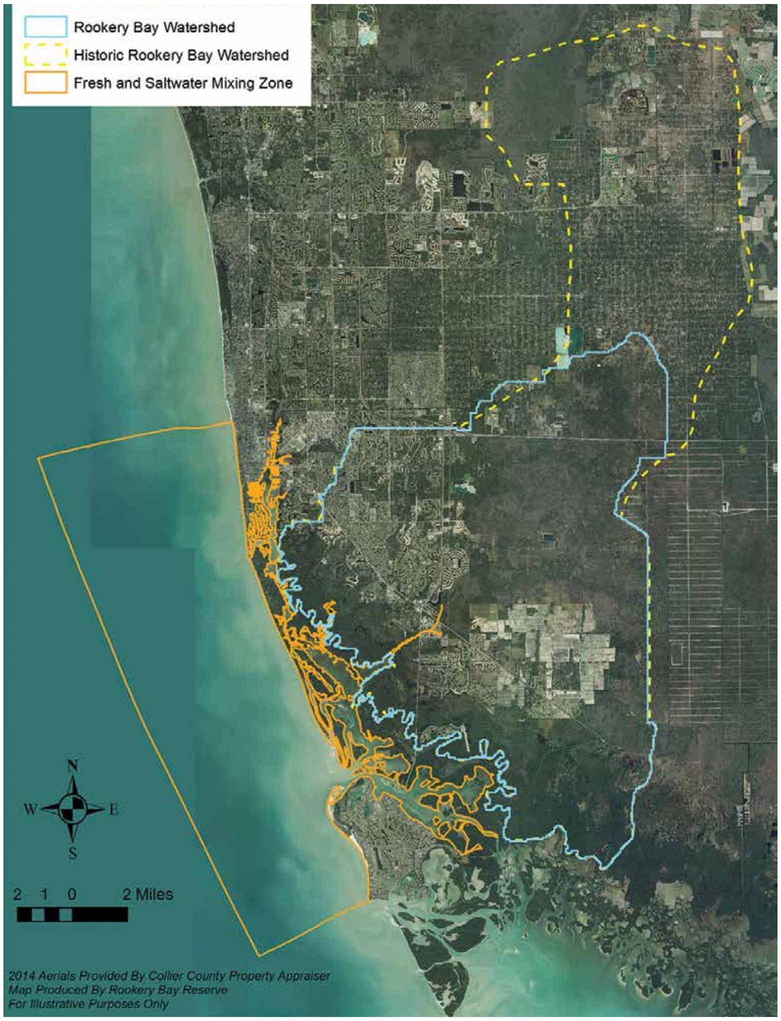


The current Rookery Bay watershed is 167 square miles and includes land uses such as residential and commercial development, agriculture, rock mining, golf courses, and conservation lands.

H2. Natural systems Rookery Bay watershed model

The natural systems model represents historic conditions and is based on the current conditions model after removing the human-made land uses such as roads, canals, and developments. A pre-development vegetation map created by the South Florida Water Management District was used as a reference for historic land use. Specific data, such as saturated zone layering, rainfall, potential evapotranspiration, soils, and land-use dependent parameters, etc., were held constant to ensure that differences between the two models were solely attributable to anthropogenic changes in the watershed. Full results can be found in the final report: *Henderson Creek Watershed Engineering Research Project: Task 2.7—Interim Hydrodynamic Modeling Report MIKE SHE/MIKE-11 Model Development.*

The Rookery Bay watershed current conditions and natural systems models are available on the internet at http://cerpmap1.cerpzone.org/arcgisapps/cerpmms/mmsviewer/ under the title Henderson Creek/Rookery Bay Watershed Engineering Research Project. The Model Management System website is a project of the South Florida Water Management District, whose modeling team reviewed and provided comments on the Rookery Bay models.



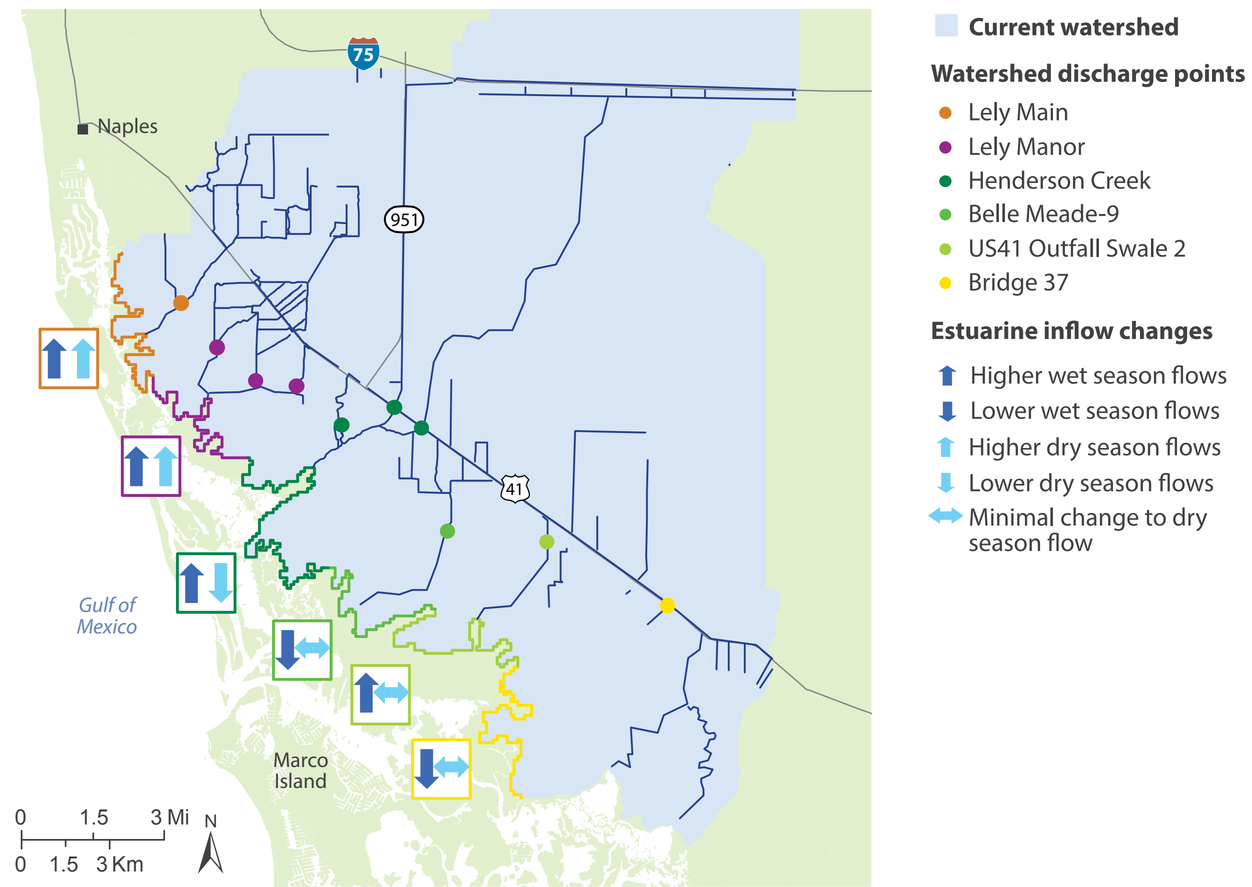
The historic watershed was 247 square miles of undeveloped wetlands that provided fresh water to the estuary through uninterrupted sheet flow. The 80 square mile difference between the current and historic size of the watershed was caused by the construction of roads, canals, and developments.

H3. Identification of estuarine inflow goals

The current and natural systems watershed models were developed for the Rookery Bay watershed in order to determine current and historic freshwater discharges to the Rookery Bay estuary. These calculations were done at ten watershed discharge locations that were identified, along with watershed sub-basins and their corresponding discharge rates along the coastal transects. The full results of these comparisons can be found in the final report: *Henderson Creek Watershed Engineering Research Project: Task 2.7—Interim Hydrodynamic Modeling Report MIKE SHE/MIKE-11 Model Development.*

The results of the comparisons included:

- Evapotranspiration was shown to have decreased by approximately three inches per year on average from historical to existing conditions. This was expected as the historical model domain is dominated by wetland and upland land-use types. Urbanization and drainage tend to reduce evapotranspiration. Furthermore, total surface water flows are similar on a unit area basis between the two scenarios. However, sheet flow has decreased considerably while baseflow to canals has increased. These results are to be expected as more water is thought to have been available historically for overland flow due to the absence of ditching



The colored dots identify the ten primary freshwater discharge locations for the Rookery Bay watershed, along with the corresponding color-coded sub-basin. The arrows show changes in flow under current conditions when compared to historic conditions.

H3. Continued

and draining found throughout the watershed under existing conditions. Groundwater baseflow is higher in existing conditions due to the presence of drainage canals which penetrate into the highly permeable surficial aquifer.

- Simulated seasonality in the summed coastal flows has shifted slightly from historical to existing conditions according to the model results. Slightly higher wet-season flows occurred in the historical conditions model. Additionally, under existing conditions, flows are higher for the 15% to 70% exceedance probabilities, meaning that for most mid-range flows, the existing conditions simulation showed a higher flow rate. Above the 90% exceedance probability, the existing conditions flows were lower than historical flows or nonexistent. However, overall, the simulated existing and historical average monthly and seasonal flows are surprisingly similar.

- Watershed-wide, the summed freshwater deliveries were predicted to be very similar overall under historical and existing conditions. This result is consistent with the water budget comparison, which suggested that although the flows have shifted from a sheet flow dominated system to a groundwater dominated system (baseflow to canals), the overall flow volumes are similar on a unit basis.

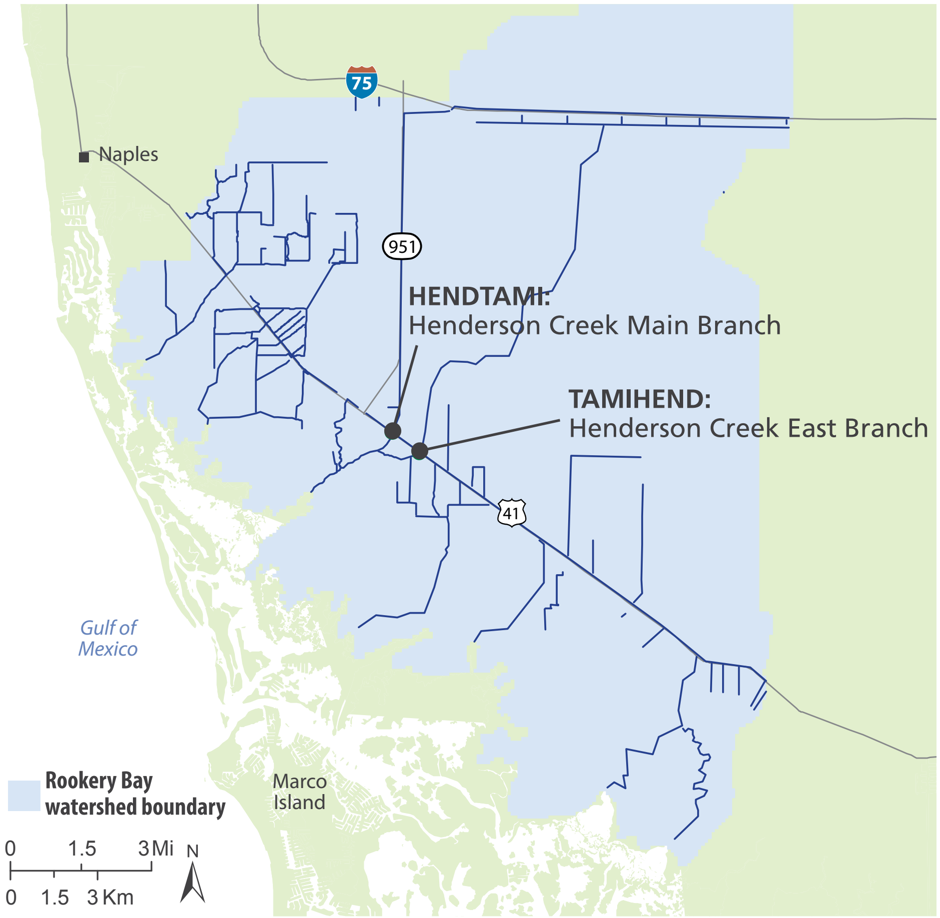
- The area north of the current Henderson Creek/Rookery Bay watershed (i.e., the historic watershed area north of the current Golden Gate Canal) that historically would have contributed flow to the Henderson Creek/Rookery Bay system was a relatively insignificant part of the overall water budget, but did contribute some flow during extremely wet periods.

- The results for the individual coastal inflows, provided separately for each basin/transect, suggest that the volume and timing differs spatially and seasonally between historical and existing conditions. Most notably, it appears the construction of the I-75 and Henderson Creek Canals have concentrated wet season flows in Henderson Creek at the expense of areas to the east, which have less flow now than historically. Other notable differences are related to land-use changes and associated drainage improvements. This result suggests that future management options focusing on spatial redistribution of flows, as opposed to projects that seek to change the timing of flows by storing fresh water for later releases, may have the greatest chances of success.

H4. Henderson Creek weir/gate operation scenario

The results of efforts to compare the current conditions model to the natural systems model revealed that the cumulative overall volumes of fresh water delivered to the Rookery Bay estuary from the Rookery Bay watershed were nearly the same. However, these simulations revealed significant changes had occurred in the seasonal distribution of flows, with a decrease in dry season flows and an increase in wet season flows within the Henderson Creek sub-basin.

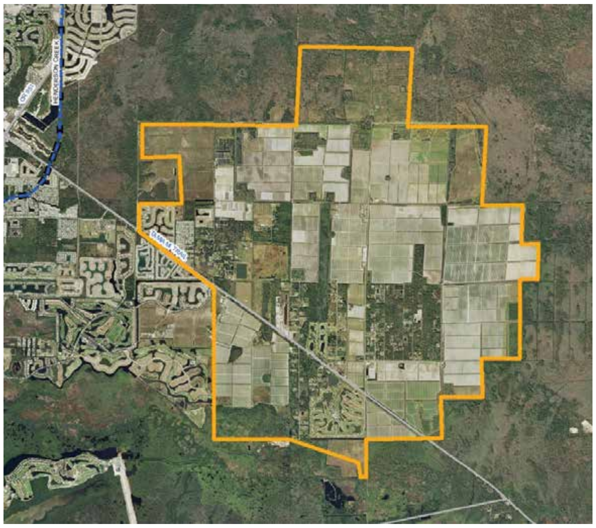
The purpose of the Henderson Creek Weir/Gate Operation scenario was to determine if historical condition flows could be better approximated by changing the operation and/or configuration of the HENDTAMI and TAMIHEND structures on Henderson Creek in an effort to address the differences found in the seasonal flow distribution using the previously developed current conditions model. Specifically, the gate operations were revised so that more water was allowed to flow through the structures during the dry season, while storing as much as possible in the wet season without creating adverse upstream or downstream impacts. The iterative simulation process resulted in the conclusion that a revised gate operation schedule would provide a better representation of the dry season flow when compared to the historical conditions, and the proposed operations would not create negative impacts within the Henderson Creek sub-basin for surface water (including overland flow) and ground water. In addition, these flow goals could be accomplished without the need for a new structure or the costs associated with infrastructure changes. The full results of this scenario can be found in: *Henderson Creek Watershed Engineering Research Project: Task 2.5—Interim Technical Memorandum, Henderson Creek Weir and Gate Operation Scenario Simulation*.



The purpose of the Henderson Creek Weir/Gate Operation Scenario was to determine if the historical flow conditions could be better approximated by changing the operation of the HENDTAMI and TAMIHEND structures on Henderson Creek (locations shown).

H5. Belle Meade Agricultural Area conversion scenarios

These two scenarios had the goal of forecasting freshwater flows downstream of the Belle Meade Agricultural Area after it had been converted to medium density urban residential development, consistent with the Collier County Comprehensive Plan. The scenarios both included the use of a spreader canal and three flow-ways. However, one scenario focused on maximum allowable runoff of 0.15 cubic feet per second per acre (cfs/acre) and the other on 0.04 cfs/acre. The physical conversion from agriculture to urban land use was simulated using information from published sources. Topographic changes associated with conversion to urban land use were assumed to be consistent with other developments near the study area. This scenario also simulated three flow-ways through the developed areas to route offsite sheet flow from the north of the current agricultural area southward towards U.S. 41. This scenario did not aim to provide a design level analysis from the land-use conversion, but rather answer the broader scale question: "How would the assumed differences in land use affect runoff to the Rookery Bay estuary in terms of the quantity and timing of flows?" Full results of these scenarios can be found in the final report: *Henderson Creek Watershed Engineering Research Project: Task 4.2.3—Final Technical Memorandum Model Simulation of Belle Meade Agricultural Area Conversion.*



Belle Meade Agricultural Area

Current wetlands and proposed flow-ways

Freshwater flows are currently routed around the Belle Meade Agricultural Area (top) which is located a few miles east of the intersection of U.S. 41 east and Collier Boulevard. In the future, this land is likely to be converted to residential development. Several watershed management plans suggest creating three flow-ways (bottom) through the former agricultural area to allow distributed flows to the coast and the estuary. Data source: Belle Meade Stormwater Management Master Plan, 2005 Aerial photos from Collier County; Wetlands/flow-ways from Scheda 2006.

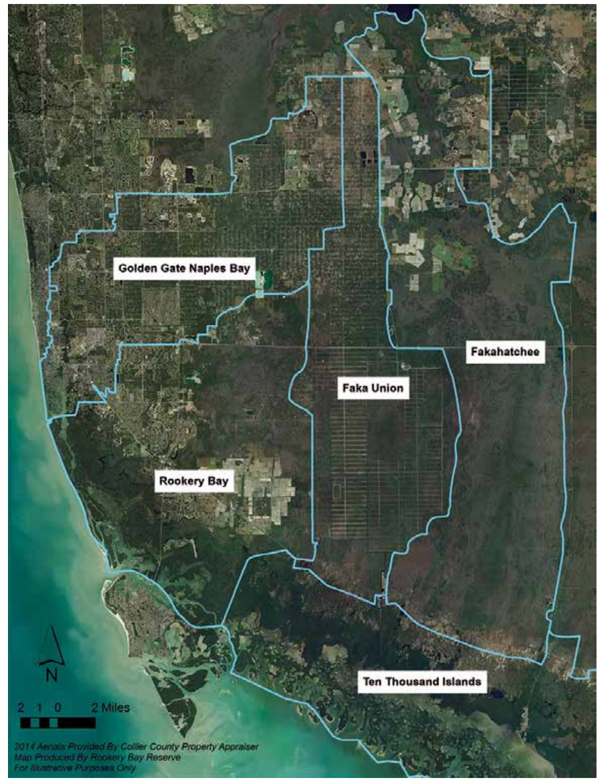
H5. Continued

The Future Scenario simulations showed that:

- Both scenarios would contribute 4% to 5% more fresh water to the Rookery Bay estuary for the 0.04 cfs/acre and 0.15 cfs/acre configurations, respectively.
- The additional flows are attributed to the opening up of the flow-ways, which allows water to flow in the historical flow pattern.
- An assessment of surface water levels, overland flow depths, and groundwater levels did not show any detrimental effects. However, the model did not simulate flood conditions associated with large storms (e.g., 100-year events).
- U.S. 41 outfall swale No. 2 generates larger freshwater input to the Rookery Bay estuary, when compared to existing conditions. This is likely due to the additional water routed through the proposed flow-ways upstream of U.S. 41.
- Flows through some coastal transects were improved, insofar as the model predicted some shift towards a more historical flow regime. But other alternatives may be warranted that further investigate the potential to improve the geographic distribution of flow to the Rookery Bay estuary.

Stormwater drainage canals, like the one shown, are built to prevent flooding in urban areas, but they have the unintended consequence of significantly lowering underground water levels resulting in the draining of nearby wetlands.

H6. Rookery Bay/Fakahatchee Bay watershed comparison



For restoration purposes, the Fakahatchee watershed (labeled on map) was compared to the Rookery Bay watershed to determine its suitability as a hydrologic reference site.

In order to assess the suitability of the Fakahatchee Bay watershed as a hydrologic reference site for the nearby Rookery Bay watershed, the Rookery Bay/Fakahatchee Watershed Comparison was conducted. Fakahatchee Bay's watershed is mostly undeveloped state-protected lands that outflow into RBNERR's eastern boundary and is in close proximity to the Rookery Bay watershed: thus, the two watersheds experience similar environmental and atmospheric conditions. The analysis included defining and comparing hydrologic characteristics such as surface area, land-cover types, soil types, surface water flow patterns, and groundwater levels, as delineated in the Rookery Bay natural systems and current conditions models. In addition, an identical analysis was conducted for the Fakahatchee Bay watershed and compared with the MIKE SHE/MIKE-11 model results at several locations. The watershed comparison included seasonality, volume, and frequency of freshwater flows to each bay. Comparison of the hydrologic watershed characteristics between Rookery Bay (current and historic) and Fakahatchee Bay reveals unique aspects that contribute to the hydrologic function of each watershed. The data below summarizes the watershed area, developed and undeveloped land-use percentages, soil hydrologic group breakdown, and total length of surface water flow features within each system. Full results of these scenarios can be found in: *Henderson Creek Watershed Engineering Research Project: Task 2.6—Fakahatchee Bay Hydrologic Existing Conditions Simulation*.

The results of the hydrologic comparison included:

- The Fakahatchee Bay's watershed, in its existing condition, is less developed but not completely free from anthropogenic impacts. Fakahatchee Bay's watershed contains significantly more B/D type soils and less C/D type soils which impacts rainfall runoff infiltration rates (see table on page 16).

- The United States Geological Survey published a report in 1977, "The Effect of the Faka-Union Canal System on the Water Levels in the Fakahatchee Strand, Collier County, Florida." The report documents Fakahatchee Strand (Fakahatchee Bay's watershed) as a unique feature that had its headwaters connected to the Okaloacoochee Slough, which differentiates it from the historic function of the Rookery Bay watershed.

- MIKE SHE/MIKE-11 results indicate the Fakahatchee Bay watershed contributes about 2.4 times the volume of water for the period of 2003–2012 than the historic Rookery Bay.

H6. Continued

However, given that the two watersheds cover unique surface areas, model results for seasonality, accumulated runoff depth and frequency were normalized on a per unit acre basis to facilitate a more representative comparison between the two watersheds.

- Seasonality: The Fakahatchee Bay watershed consistently delivers more fresh water per unit area to Fakahatchee Bay than the Rookery Bay watershed does to its own bay. The dry season months of January–May show little difference between watersheds with respect to watershed runoff contributions in inches. However, when examining the wet season runoff depths, the differences between watersheds are greatest in August–November, which in general corresponds to the highest rainfall depths.
- Accumulated runoff depth: The accumulated runoff depth from the Fakahatchee Bay's watershed is about two times the runoff depth per unit area than from historic Rookery Bay's watershed.
- Frequency: Fakahatchee Bay's watershed contributes low-frequency, high-flow events over longer time periods when compared with historic Rookery Bay's watershed. However, for high-frequency, low-flow events, historic Rookery Bay's watershed contributes more water than Fakahatchee Bay's watershed.
- Considering the rather large differences in normalized freshwater deliveries and the limited (but significant) flow alterations that have occurred within the Fakahatchee watershed, this analysis does not strongly support the use of Fakahatchee Bay's watershed as a reference site. Notably, an investigation into the effects of these differences on salinity distributions within the Rookery and Fakahatchee Bays was beyond the scope of this analysis. Until such an investigation is completed, the suitability of Fakahatchee Bay as a reference site for Rookery Bay should not be ruled out.

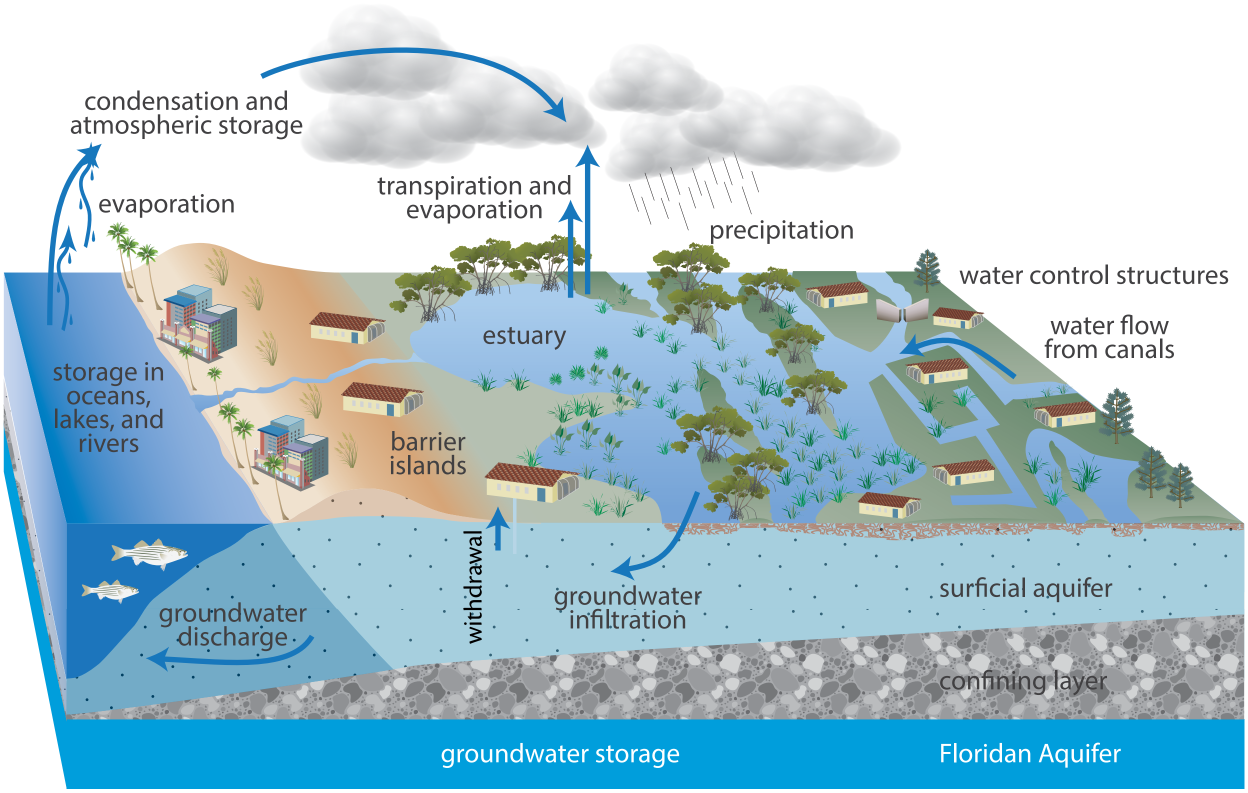
Comparison of land uses and soil type of the Fakahatchee Bay and Rookery Bay watersheds.

Fakahatchee Bay Hydrologic Existing Conditions Simulations			
	Existing Rookery Bay	Historic Rookery Bay	Fakahatchee Bay
Watershed area (square miles)	167	247	237
% Undeveloped land use	30	100	87
% Developed land use	70	0	87
% Soil group A	1	1	<1
% Soil group A/D	73	72	71
% Soil group B/D	3	8	25
% Soil group C/D	17	15	4
Surface flow paths (miles)	128	15	86

H7. Compilation of proposed watershed improvement projects within the Rookery Bay watershed

To identify potential management actions that would address the freshwater inflow deficits and overages identified through the modeling efforts, the project team identified, grouped, and described 25 watershed improvement projects that were already identified and included in the Collier County Watershed Management Plan and the Belle Meade Stormwater Master Plan. These projects were intended to address the quality, quantity, and timing of freshwater inflow to the estuary, as well as, prevent flooding and recharge the aquifer. Knowledge of these projects may help stakeholders make more informed decisions about water resources management in the region. Full results found in: *A Compilation of Proposed Watershed Improvement Projects within the Rookery Bay Watershed Collier County, Florida.*

For decades, water resource plans included a diversion of water from Naples Bay (shown) into the Henderson Creek/951 canal with the goal of reducing flows to Naples Bay. The hydrologic modeling conducted for the project demonstrated that the Henderson Creek sub-basin already has excessive wet season flows and new planning efforts are focusing on a diversion to the east into the Belle Meade flow-way.



A conceptual diagram illustrating water cycle processes included in the local scale model.

Rookery islands within the Rookery Bay Reserve serve as night roosts for several species of herons, egrets, ibis, cormorants, and pelicans which are collectively known as "coastal water birds." Since bird populations are dramatically impacted by the quantity and quality of habitat and food resources, they can serve as sentinels for estuary health.

Identifying ecological changes and effects

To better understand how altered freshwater inflows to the Rookery Bay estuary have affected the ecology of the area, a series of research projects were conducted. An additional goal of the ecological research was to identify potential indicator species and research approaches that could be applied over the long-term to monitor estuarine health and the potential impacts of future watershed management projects. The research conducted as part of this project included upland mapping contracted to the Institute for Regional Conservation and benthic habitat mapping contracted to Scheda Ecological Associates to identify trends and establish baseline conditions to assess future changes. There were also several efforts to review previous studies. One effort reviewed three fisheries research projects to identify trends, which was conducted by the Conservancy of Southwest Florida as a sub-contractor to RWA Engineering. Another effort looked at published literature on ecological indicators identified by other researchers, which was conducted by Scheda Ecological Associates, a sub-contractor to Taylor Engineering. This series of projects resulted in the identification of data gaps along with recommendations focused on future research and monitoring to capture changes and trends in ecological health of the estuary.

Projects

E1. **Literature review of existing biological data to identify potential biological indicators for the Rookery Bay estuary:** Examination of historical and existing biological research conducted within the Rookery Bay estuary and other southwest Florida estuaries to identify useful research, data gaps, and potential indicator species for potential future monitoring.

E2. **Benthic habitat maps for the Rookery Bay Reserve from aerial photo interpretation:** High-resolution aerial photos were obtained for the Rookery Bay Reserve and were interpreted to create benthic habitat maps.

E3. **Submerged Aquatic Vegetation (SAV) trend analysis for the Rookery Bay estuary:** Historic aerial photos were interpreted for approximate acres of SAV and compared to current estimates to identify potential trends.

E4. **Historical fisheries data analyses in Rookery Bay:** Comparison of three otter trawl surveys between 1970 and 2010 to identify trends in fish community composition and abundance.

E5. **Vegetation mapping and trend analyses at the Rookery Bay watershed discharge locations:** Historic aerial photos were interpreted for vegetation types at the Rookery Bay watershed discharge locations and compared against current estimates to identify potential trends.

E6. **Review of regional water quality monitoring:** Identification of the agencies monitoring water quality including their approaches and locations.

E1. Literature review of existing biological data to identify potential biological indicators for the Rookery Bay estuary

The purpose of this effort was to identify research that had previously been conducted in Rookery Bay and other southwest Florida estuaries, to identify data gaps, and stimulate thinking about potential indicator species for future monitoring. The work was contracted to Taylor Engineering whose sub-contractor Scheda Ecological Associates conducted the work. The methodology included electronic searches using open-access, limited-access, and subscription-access databases including Google Scholar, University of Miami library, U.S. Fish and Wildlife Service, U.S. Geological Survey, South Florida Water Management District, and through direct communication with researchers and managers. In addition, eight local research scientists were contacted and they responded to an electronic questionnaire or to a telephone interview. Potential indicators that were identified included vegetation such as seagrass, mangroves, and aquatic plants; shellfish such as the eastern oyster and commensals, crabs, other crustaceans; and fishes. Full results can be found in: *Literature Review of Existing Biological Data to Identify Potential Biological Indicators for the Rookery Bay Estuary*.

Summary results included:

- Seagrass cover was determined to be declining due to unknown causes when compared to historical presence.[3]
- Changes is macroalgae abundance due to salinity variance may significantly alter fish abundance.[4]
- Mangroves have a wide salinity tolerance, particularly those found in southwest Florida, and therefore may not be used directly as a biological indicator. However, mangroves may be used as indicators of coastal change since variance in hydrology and estuary salinity may change mangrove distribution.[5]

White grunt is one of the many types of fish found in the Rookery Bay estuary.

Oyster reefs provide habitat for fish and other species and filter water throughout the estuary.

E1. Continued

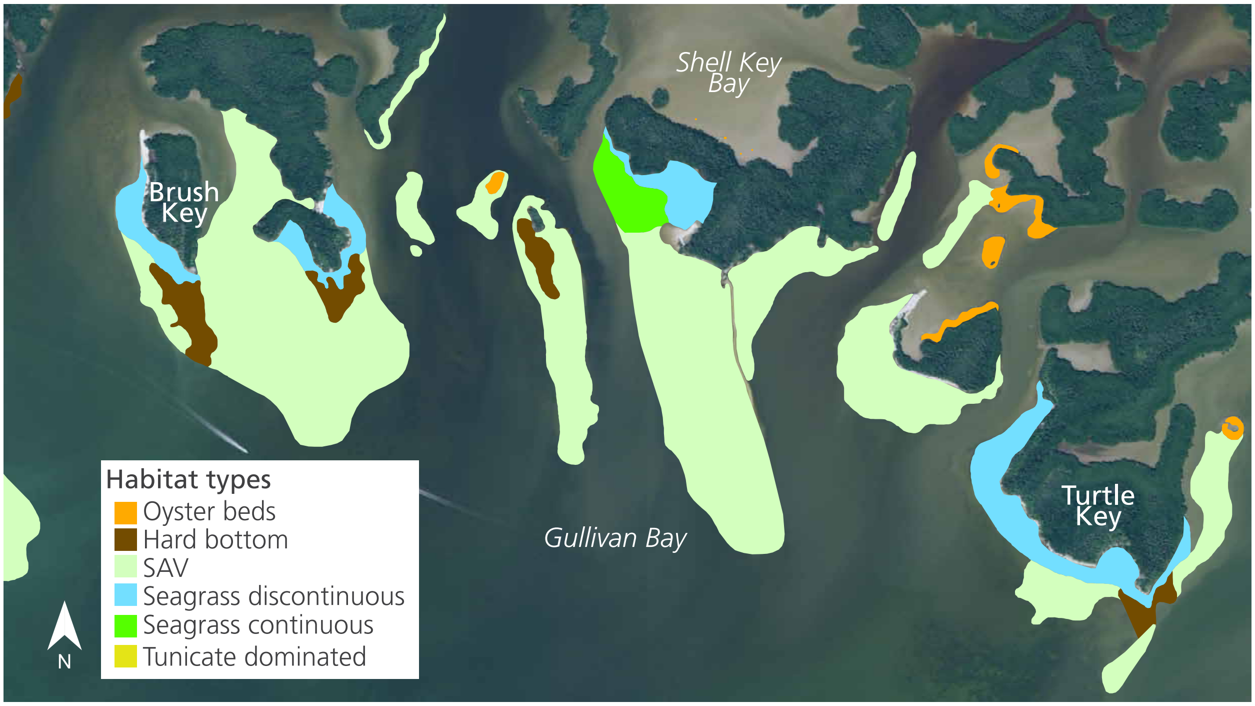
- Changes in salinity may not directly influence mangroves, but the sessile communities on their roots such as oysters, sponges, and tunicates may be potential indicators.[6]
- There is extensive data available pertaining to oyster mapping and salinity tolerances.
- Regardless of salinity tolerances, increased flow rates may actually displace oyster larvae and remove them from the estuary.[7,8]
- A study was conducted to investigate the relative abundance of stenohaline and euryhaline oyster reef crab populations for managing freshwater inflow to estuaries.[9]
- Henderson Creek has high salinity fluctuations due to management strategies, and it appears that the crab populations responded to each salinity change, resulting in higher and lower stenohaline to euryhaline ratios than other estuaries investigated.[9]
- Multiple studies have been conducted that compare nekton species composition as a biological indicator of altered freshwater inflow between three south Florida estuaries including Faka-Union, Henderson Creek, and the Fakahatchee Bay. The Fakahatchee Bay is used as a reference site due to the natural sheet flow delivery of fresh water to the system as compared to Henderson Creek which has the weir at its mouth that regulates freshwater inflow.
- Comparison of studies conducted over the past 30 years have shown a change in species composition of fish that is believed to be directly related to changes in salinity, sediment type, and aquatic vegetation. Some of these fish are commercially significant to the region.

The Rookery Bay estuary supports many commercial and recreational fisheries.

Mangroves respond to changes in hydrology and therefore are a potential indicator of coastal change.

E2. Benthic habitat maps for the Rookery Bay Reserve from aerial photo interpretation

High-resolution aerial photos were obtained for the RBNERR on December 10, 2014 using a standardized approach specifically needed for benthic habitat mapping. This included specific flight conditions such as zero cloud cover, less than ten mph of wind, and low tide in the winter when water clarity tends to meet the two-meter depth requirement. This effort was contracted through Florida Gulf Coast University and was conducted by their sub-contractor Aerial Cartographics of America. This was the first time that high resolution aerial photos were specifically obtained for the RBNERR of this type and quality. The photos were then color-balanced to enhance underwater signatures and were interpreted by Photo Science who was a sub-contractor of Scheda Ecological Associates and Taylor Engineering. The photo-interpreted signatures were identified and mapped for submerged aquatic vegetation (SAV), oysters, hard bottom, and tunicates using the universal codes designated for habitats by the Florida Water Management Districts. During the photo-interpretation phase, a series of site visits were conducted to ground-truth imagery signatures. These site visits included an underwater researcher characterizing the benthic habitats using a mask and snorkel and completing a data sheet at 215 total sites. Seventy-six of those sites were also surveyed using underwater video-photography. These results were archived and incorporated into the final map and Geographic Information System database. Full results can be found in: *Rookery Bay Watershed Engineering Research Project: Task 3.6.3 Final Report and Map—Photo-Interpretation and Mapping for the Rookery Bay Reserve*.



Results from mapping below-water habitats in the Ten Thousand Islands revealed six different habitat types present. Tunicate dominated habitat was not found in this location.

The final results and acreages of habitat coverage included:

- SAV: SAV consists of macroalgae (drift or attached) or areas with a mixture of primarily macroalgae and limited visible seagrass bed signatures. This category (code 9100) totaled over 3,347 acres or approximately 4% of the entire mapped area. This category was the most prevalent natural habitat feature mapped within the study area. Since this is the first comprehensive mapping effort for this region, no statements can be made in relation to whether this coverage is typical or not.

- Oysters: Typically oyster beds (code 6540) are mapped to the same (0.5 acre) threshold as the other natural features (SAV, seagrass, hard bottom, etc.) however, the oyster beds were delineated to a 0.25 acre size. This change in mapping threshold is possible due the distinct "edge" that oyster beds produce. By doing so, approximately 71% more oyster polygons are included in this mapping effort (779 total oyster polygons; 550 of which were below the 0.5 acre size). Please note, that oysters which are attached to the propagules of red mangrove were not delineated or mapped. This category totaled over 149 acres or 0.2% of the entire mapped area.

- Mono-specific seagrass: Seagrass beds which were mono-specific in nature, i.e., were not mixed with macroalgae species, were delineated as either discontinuous (code: 9113) or continuous (code: 9116). The resultant acreages were as follows: 127 acres of continuous seagrass coverage or 0.2% and 1,372 acres or 1.6% of discontinuous seagrass, which equates to a total of 1,499 acres of mono-specific seagrass beds or 1.8% of the entire mapped area. Please note, this acreage estimate does not include

Shoal grass (top) is commonly found in shallow waters and provides important habitat for fish and shellfish. Barnacles and oysters (center) and tunicates (bottom) are encrusting organisms, which are cemented to the substrate and cannot move when the salinity of the water becomes intolerable.

E2. Continued

additional extant seagrass mixed with macroalgae and characterized as SAV (code: 9100).

- Hard bottom: Hard bottom (code: 6560) communities (coral species, sponges, live rock, etc.) had a distinctive signature and thus were also mapped separately to identify the presence of this natural feature within the study area. This category yielded 213 acres or 0.25% of the entire mapped area. Again, this resource was only mapped if it was above the minimum mapping unit threshold and if it was the dominant feature; mixed classes, that also had some limited hard bottom communities embedded within were not mapped as hard bottom, rather they were mapped to correspond with the visibly dominant resource. This determination is made by the photo-interpreter; essentially, if the visible signature resembles the known hard bottom signature, it was mapped accordingly, even if other habitat features (e.g., macroalgae) were contained within a particular polygon and equated to >50% coverage. This is considered standard practice for this type of remote sensing work; otherwise it becomes very difficult to consistently map mixed class polygons.

- Unvegetated bottom/Tidal flats: The remaining bottom classification was comprised of unvegetated bottom/ tidal flats (code: 6510) communities and totaled 79,771 acres or 94% of the entire mapped area. Many of these areas may also have small amounts, less than the mapping threshold, of embedded natural resources, (e.g., SAV, seagrass, hard bottom, etc.); however, these were mapped as tidal flats. This sort of percentage is not unusual, for example Tampa Bay's mapping resulted in approximately 95% of that study area be being mapped as unvegetated bottom; there is no norm for this percent cover as each study area is driven by the physical makeup (i.e., depths, slopes, sediment types, etc.) of the waterbody in question.

- Tunicates: A very unique feature within the study area was noted; in two separate locations a mono-specific bed of tunicates (sea squirts) was discovered. These locations had thousands of individual organisms completely carpeting the bottom of the bay and resulted in an identifiable signature. Thus, this signature was identified and mapped as tunicates (code: 9200); the total acreage of this community was 4 acres.

Live bottom habitats can include hard and soft corals, sea squirts, sponges, algae, and seagrasses.

E3. Submerged Aquatic Vegetation (SAV) trend analysis for the Rookery Bay estuary

A common approach to identifying historic conditions within a natural system is to analyze historic aerial imagery for benthic habitat signatures such as SAV and oysters. RBNERR contracted Taylor Engineering who sub-contracted Scheda Ecological Associates to photo-interpret historic aerial images and compare these to the recently obtained benthic habitat maps to determine trends in SAV coverage over time. The study area was the Rookery Bay estuary, downstream of the Rookery Bay watershed. The historic conditions aerial image was a composite of 1928 and 1940 aerial images, and resulted in an estimate of 988 acres of SAV coverage. The second aerial image examined was from 1962, and resulted in an estimate of 1,442 acres of SAV coverage. The 2014 aerial assessment represented current conditions and included habitat categories such as continuous mono-specific seagrass, patchy mono-specific seagrass and SAV (mixed seagrass and macroalgae). Since the historic

During the photo interpretation phase, researchers surveyed benthic habitats using a mask and snorkel, recorded their data, and video-taped underwater conditions.

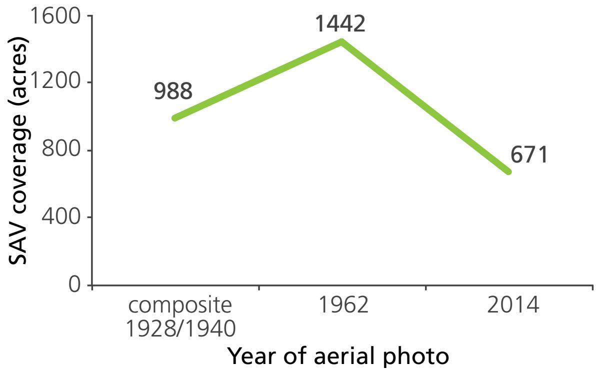
photos lacked this level of detailed analysis potential, the current categorical acreages were combined to yield an estimated total of 671 acres of SAV within the study area. The difference in acreage was a loss of

Manatee grass is often found growing with turtle grass and is one of the preferred foods of manatees.

E3. Continued

317 acres from the 1928/1940 estimate and a loss of 771 acres from the 1962 estimate, respectively. While historic acreage estimations are limited by the fact that it is not possible to verify them, an overall decline is not unexpected, as most of Florida's open water estuaries have shown significant declines in seagrass coverage from the 1950s through the 2010s.[10] Most of these declines can be attributed to anthropogenic impacts such as dredge and fill activities, eutrophication, boat propeller scarring, and alterations in the quality, quantity, and timing of freshwater flows. Large salinity variations, in particular, make it difficult for seagrass and many estuarine-dependent sessile populations to survive.

In addition to the overall estimated acreage loss, there were several areas within the study site that showed specific changes. In particular, the area directly downstream and within Henderson Creek had SAV mapped in the historic conditions map, but these were absent in the 2014 map, which showed that the primary resource detected within the Henderson Creek area was oyster beds. Conversely, in Hall Bay, SAV and seagrass beds were mapped from the 2014 aerials, but they were not as prevalent as in the historic aerial images. Full results can be found in two reports: *Rookery Bay Watershed Engineering Research Project: Task 3.3—Historic Aerial Mapping* and *Analysis for the Rookery Bay Estuary and Rookery Bay Watershed Engineering Research Project: Task 3.7—Addendum to the SAV Trend Summary Technical Memorandum.*



Submerged aquatic vegetation (SAV) trend analysis results confirmed that SAV populations increased in Rookery Bay in 1962 and have decreased over time.

E4. Historical fisheries data analyses in Rookery Bay

Three fisheries studies were performed within the Rookery Bay estuarine complex using otter trawls during night sampling at four stations representing differing habitats. Captured fish were identified and counted in each of the studies. The studies included:

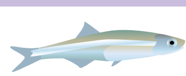
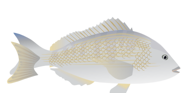
- Yokel (1983) University of Miami dissertation from June 1970 to July 1972.[11]
- Rookery Bay "Learning Through Research" (unpubl. data) from January 1990 to December 1991.
- Wilke (in prep.) Florida Gulf Coast University thesis from July 2011 to June 2013.

The purpose of this research project was to compare the results of the three studies and explore any trends in community composition and abundance. The project was contracted to RWA, Inc. who sub-contracted the Conservancy of Southwest Florida. Primer-E multivariate statistical software was used to explore fish community structure during the 40-year period.

The results suggested that there have been significant changes in the fish communities of the Rookery Bay estuary since the 1970s and these changes may be attributable to water management practices and possible habitat loss from the resulting hydrologic conditions. A divergence in the Rookery Bay fish assemblages occurred between the 1970s and 1990s with more similar compositions between 1990s and 2010s. The change from the 1970s to 1990s corresponds with the installation of weirs in the headwaters of Henderson Creek in the 1980s and the subsequent modifications to timing and quantity of freshwater inflow.

The composition of fish communities among the sampling stations have become more similar to one another over time and this perceived trend may have resulted from the observed loss of seagrass habitat in Rookery Bay between the 1970s and the 2010s. Lastly, fish assemblages during the wet season have become increasingly different over time from those in the dry season. This trend could also be the result of hydrologic alterations in the watershed during the 40 year interim, most notably the installation of the weirs in the Henderson Creek Canal.

The percent composition of total catch of three fish species which were all present during the three studies.

Fish composition by study year				
Fish Species		1970s	1990s	2010s
Bay anchovy		1%	6%	18%
Mojarra		30%	65%	58%
Pinfish		46%	5%	11%

E4. Continued

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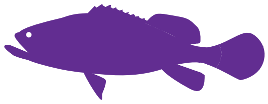

1.2 million average total seafood landings in Collier County annually.

Stevens et al. (2008)[12] found that the influence of freshwater inflow on fish community structure was greatest during the wet season when salinity gradients become more fully established. This is the period when extreme salinity fluctuations occur in Rookery Bay due to the release of stormwater via the weirs. Salinity has traditionally been the central parameter in estuarine analyses[13] but there are many environmental factors that determine the spatial and temporal distribution of fish. The results of the study indicated five fish taxa (pinfish, mojarras, anchovies, pigfish, and lane snapper) contributed the most to the historical differences in the Rookery Bay fish community. Trends in the relative abundance of these taxa can be correlated to their respective salinity tolerances or preferences relative to anthropogenic alterations of freshwater inflow to Rookery Bay. However, other factors such as bottom type and food resources need to be recognized as potential alternatives to the influence of the altered freshwater inflow on fish abundance patterns.[12] Full results can be found in: *Historical Fisheries Data Analyses for Restoring the Rookery Bay Estuary Project*.

Atlantic tarpon are an economically important species found in the Rookery Bay estuary. Photo: NOAA Southeast Fisheries Science Center.

Estuaries like Rookery Bay provide important habitat for many recreationally and commercially important species of fish. Photo: Florida Sea Grant.

E5. Vegetation mapping and trend analyses at the Rookery Bay watershed discharge locations

To determine whether vegetation has been altered by historic changes to the quality, quantity, and timing of freshwater inflows to the Rookery Bay estuary, RBNERR hired the Institute for Regional Conservation (IRC) to map vegetation at watershed discharge locations. These had been previously identified through the hydrologic modeling effort. In addition, IRC was also tasked with historic aerial photo interpretation of these sites to perform a habitat change analysis. The results included a classified vegetation map with an extensive geodatabase that was assembled with past (1940) and present (2010) vegetation types based on aerial photograph interpretation and field ground-truthing.

Throughout all the study sites, there were common changes that occurred between 1940 and 2010. In general, the study sites current conditions were more open and there was less woody vegetation than in 1940. This is most likely due to fire supression over the past 70 years, although some state owned lands (including RBNERR uplands) have developed prescribed fire programs. Fire promotes more open graminoid ecosystems, while a lack of fire encourages more shrubs and tree species. From 1940–2010 there has been approximately 23 centimeters of sea level rise with concomitant changes in freshwater sheet flow.[14-16] Additionally, there have been large areas of direct clearing for development which were mapped as Human Impacted. Substantial invasive exotic plant infestations now occur in all areas. Full results can be found in: *Habitat Mapping and Trend Analyses: Rookery Bay Watershed Discharge Locations.*

Freshwater discharge locations (shown) were mapped for current vegetation and then compared to historic vegetation through analysis of historic aerial images from the 1940s.

E5. Continued

Summary of the mapped vegetation areas, including trends and suspected causal factors.

Mapping area	Vegetation trends from 1940 to 2010	Suspected causes
Lely Main Canal (405 acres)	Freshwater and brackish (already tidally influenced in 1940) marshes changed to mangrove and buttonwood dominated wetlands. Remnants of the end of the cypress strand destroyed by the Lely Canal excavation changed to mangrove forest. Large areas of slash pine dominated areas in lower elevations were replaced by buttonwood.	Sea level rise, increased inland access by tides from downstream ditches, and shortened freshwater hydroperiods upstream with less sheet flow.
Lely Manor Canal-12_1 (155 acres)	Freshwater and brackish marshes changed to mangrove and buttonwood dominated wetlands. A large freshwater forested wetland trended towards freshwater shrub or buttonwood and mangrove dominated wetlands. The end of the cypress strand converted to shrub wetland. Of the small amount of pineland mapped, the edges changed to buttonwood.	Sea level rise, minor increase in tidal access from downstream ditching, altered or shortened freshwater hydroperiod at end of cypress strand.
Lely Manor Canal 01_2 (139 acres)	Cypress strands shifted to mixed pine and cypress wetland. Although most of mapped area was above direct tidal influence in 1940, cypress and pineland shifted to cabbage palm and in some cases buttonwood in the lowest elevations downstream.	Shortened freshwater hydroperiod and only minor influence of sea level rise at the most downstream locations.
Lely Manor Canal 13 (431 acres)	Biggest change in acreage observed was cypress strand shifting to mixed pine and cypress wetland. Fresh and brackish marshes (already tidally influenced in 1940) shifted to mangrove and buttonwood dominated areas. The ends of the cypress strands and some lower edges of pineland converted to cabbage palm and freshwater shrub dominated wetlands.	Shortened freshwater hydroperiod and influence of sea level rise at the most downstream locations.
C-4 Canal 00 (Eagle Creek and Fleisher Parcels) (62 acres)	Direct human impacts already evident in area in 1940 from farming, habitation, and dredging of Eagle Creek wetlands. Dredging soon followed along Henderson Creek. Freshwater and brackish marsh changed to buttonwood and mangrove dominated areas. Pineland shifted to buttonwood or cabbage palm woodlands. Cypress died off at the ends of the strands which were cut off by development just upstream (off site).	Direct human impacts changed physiography of site and sea level rise and elimination of freshwater sheet flow from upstream.

E5. Continued

Mapping area	Vegetation trends from 1940 to 2010	Suspected causes
Belle Meade 7 and Henderson Creek (407 acres)	Cypress wetlands shifted to wax-myrtle or mixed cypress and slash pine dominated areas suggesting shortened hydroperiods. Organic soil loss evident. Mangroves confined to ditches.	Shortened freshwater hydroperiod. Direct human impacts from development south of U.S. 41.
Belle Meade 9 (Fiddler's Creek) (385 acres)	Reduction in fresh and brackish marsh with increase in buttonwood and mangrove. Slash pine shifting to buttonwood. Buttonwood areas along edge of development with whitevine thickets and abundant cattail in the marshes suggesting potentially high nutrient inputs.	Sea level rise, altered distribution of freshwater inputs with elimination of sheet flows, constricted or partially obstructed tidal flows downstream. Possible increased nutrient inputs from upstream housing development.
U.S. 41 Outfall Swale No 2-00 (Auto Ranch Road) (148 acres)	Cypress and hardwood wetlands showed only minor changes since 1940. Large areas of marsh have become dominated by willow. Cattail is very abundant, and it is suspected to have increased, but an increase since 1940 cannot be determined because of a lack of clear signatures in 1940 images. This site has high elevation uplands, high relief, most of which seem more or less unchanged except for very long fire suppressed and increased abundance of woody vegetation.	Sea level rise, but tidal flows obstructed and constricted by downstream spoil features. Possible lengthened freshwater hydroperiod and possible increased nutrient inputs from upstream agriculture.
Bridge 37 (Collier-Seminole State Park, South Old Marco Road) (846 acres)	Nearly half of the marsh areas became mangrove or buttonwood dominated, as well as some cypress and hardwood swamp. Pineland has shifted to buttonwood dominated woodlands on west side. Cypress died back in the lower elevation center at the ends of the strands leaving hardwood or palm woodlands just above the mangrove ecotone. Cypress also died back along the outside edges of the strand swamp further upstream.	Sea level rise, increased inland access by tides from downstream ditches, shortened freshwater hydroperiods upstream, freshwater sheet flow also disrupted by spoil from road features, and suspected increased nutrient inputs in northwest corner of mapped area.

E6. Review of regional water quality monitoring

The quality of water that discharges from a watershed can have impacts on downstream estuarine life and therefore was of interest to the project team. Collier County conducts the majority of water quality monitoring in the area, although RBNERR also has one long-term monitoring site in the Rookery Bay estuary. In general, both Collier County and RBNERR have not identified any considerable water quality concerns at this time, although the Rookery Bay estuary has been identified by the Florida Department of Environmental Protection in their Total Maximum Daily Loads Program for nutrient and chlorophyll *a* impairments. Determining whether there are water quality problems in the Rookery Bay estuary was problematic because data was being captured by several different agencies and organizations, who archived the data in different databases, and it was not analyzed in a cohesive manner. This situation made it impossible to get a clear picture of water quality within this watershed and estuary, which appears to be the situation throughout Collier County.

The recommendation of the project team is that an effort be made to promote cross-agency coordination on water quality monitoring including shared analysis and reporting. While it was clear that agency staff who work in water quality monitoring do their best to coordinate and communicate on a regular basis, it is the responsibility of agency leadership to provide a forum, tools, and incentives that will help elucidate a clearer picture of water quality in the region. This approach could lead to efficiencies that may also allow for a more comprehensive and systematic approach to water quality monitoring throughout Collier County. Ultimately, a regional water quality monitoring plan would benefit the community.

Water quality monitoring includes taking measurements using a datasonde.

Rookery Bay Reserve staff engaged in water quality monitoring.

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Kayakers explore the amazing world that exists within the 110,000 acres of mangrove forests, uplands, and protected waters of the Rookery Bay Reserve.

Capturing attitudes and educating stakeholders

To better understand water resources decision making and how to include stakeholders in the design and delivery of research and educational products, and to educate diverse stakeholders about water resources management, a range of activities were included in the project. Two social science research projects were conducted to identify the attitudes, beliefs, and behaviors held locally about water resources in both personal and professional situations. Conducted by Nova Southeastern University, this was the first social science research conducted in Collier County on watershed management. The Project Advisory Group provided insights on the design and analysis of all major research efforts and assisted in sharing the information with others. A series of presentations were also given throughout the region, and information was shared through the creation of handouts for decision-makers. A poster for students and teachers was created by Dawn Witherington, and an exhibit on land use in the Rookery Bay watershed was installed in RBNERR's Environmental Learning Center. Information is also posted on the Friends of Rookery Bay website at www.rookerybay.org/restoreRB.

Projects

HD1. **Literature review of attitudes, beliefs, and behaviors related to water and water-related decision making:** Examination of previous research conducted about water-related attitudes, beliefs, and behaviors, with a focus on Florida, including educational programs that sought to create change.

HD2. **Qualitative case study research on attitudes and perceptions of stakeholders in the Rookery Bay Reserve watershed:** Local interviews with 15 diverse stakeholders to enhance collaboration on watershed management.

HD3. **Convened a Project Advisory Group (PAG):** A series of 13 meetings were conducted over the course of the project to gain stakeholder input and guide research projects.

HD4. **Research on water councils, watershed groups, and watershed management:** Online research to identify effective watershed management strategies.

HD5. **Community presentations:** A series of presentations were conducted to educate various audiences about watershed and water resources management.

HD6. **Poster for teachers and students:** A poster was developed to share project results with teachers and students.

HD7. **Factsheets for decision-makers:** Scientific findings were shared with decision-makers through the creation and dissemination of a series of factsheets.

HD8. **Exhibit in the Rookery Bay Environmental Learning Center:** To connect residents and visitors to the research conducted, an exhibit was installed in the Reserve's Environmental Learning Center.

HD1. Literature review of attitudes, beliefs, and behaviors related to water and water-related decision making

In order to identify previous social science research about water-related attitudes, beliefs, and behaviors, with a focus on Florida, including educational programs that sought to create change, a literature review was conducted. A number of possible search terms were developed, and 38 databases were searched for relevant literature. Materials reviewed included peer-reviewed research articles, theoretical models, and agency reports. Full results can be found in: *Social Science Literature Review: Restoring the Rookery Bay Estuary Project*.

The literature review addressing attitudes, beliefs, and behaviors related to water yielded the following four themes:

- The importance of determining local attitudes about water prior to an intervention
- Methods to identify water-related attitudes
- The relationship between environmental attitudes and behaviors
- Explanatory models related to environmental attitudes and behaviors

Literature pertaining to involving community members in water-related decision making resulted in six themes:

- Recommended approaches to community water management planning
- Situation assessment and process design
- Models and best practices in community collaborative decision making
- Conditions for success in launching a collaborative process
- Managing/implementing collaborative processes
- Evaluating collaborative processes to enable interested parties to learn from experience

Fresh potable water is important to the community for human health, economic, and recreational uses.

The literature review related to educational efforts that change water-related attitudes, beliefs, and behaviors uncovered four themes:

- The value and impact of conservation education
- How people receive water-related information
- Models of environmental public education
- What information to provide to stakeholders

HD2. Qualitative case study research on attitudes and perceptions of stakeholders in the Rookery Bay Reserve watershed

The purpose of this case study was to:

- Understand attitudes and behaviors related to water usage among residents in the Rookery Bay watershed;
- Explore community members' interest and experience in engaging in water-related decision making in personal and professional contexts; and,
- Describe community members' experiences of receiving and responding to information about water-related issues.

Fifteen in-depth, qualitative interviews were conducted with representative stakeholders that were divided roughly in half between two categories: diverse community stakeholder groups and those directly engaged in water management decision making at the agency and governmental levels. Data analysis followed the standards for qualitative case studies and included two cycles of coding[17] followed by the development of themes. The findings were organized by a summary of the individual participants' perspectives followed by thematic results related to the research objectives. Full results can be found in: *Attitudes and Perceptions of Stakeholders in the Rookery Bay Reserve Watershed: Qualitative Case Study Research*.

Research findings

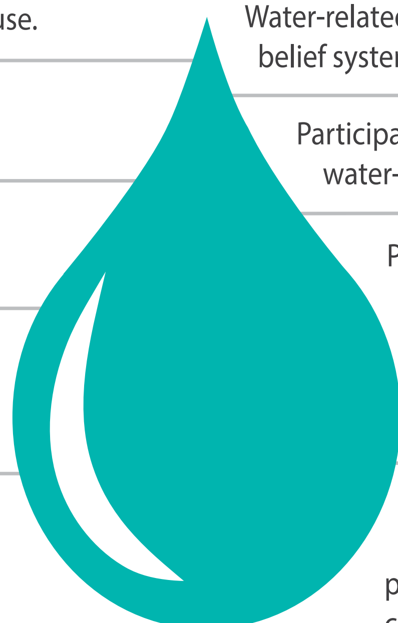
Participants consider economic factors when making decisions about water use.

Water is a primary draw for the community.

There are perceived tensions between stakeholders.

Participants percieve unequal enforcement of water-related regulations.

Lack of understanding of water management practices contributes to conflict.



Water-related decisions seem to be based on belief systems.

Participants link scientific data to water-related decision-making.

Participants would like more inclusive water management and believe better communication would foster collaboration related to water management.

Conservation-related professional behavior seems to positively impact personal conservation-related behavior.

HD2. Continued

Themes developed through social science research in Collier County, Florida, that included 15 in-depth interviews with stakeholders focusing on attitudes and perceptions related to water resources management.

Summary of development themes	
Water-related attitudes and beliefs	
Theme 1	Participants perceive availability, quantity, cleanliness, and quality as the most important aspects of water.
Theme 2	Participants identify a range of benefits and uses of water.
Theme 3	Participants highly value natural features of the local environment.
Theme 4	Participants perceive water to be a primary draw for the community.
Theme 5	Participants perceive tension between stakeholders.
Theme 6	Participants perceive tension between economic, social, and environmental interests.
Theme 7	Participants do not see common ground between environmentalists and developers.
Water-related behaviors and decisions	
Theme 8	Participants' water-related decisions seemed to be based on belief systems.
Theme 9	Conservation-related professional behavior seems to positively impact personal conservation-related behavior.
Theme 10	Participants link scientific data to water-related decision making.
Theme 11	Participants consider economic factors when making decisions about water use.
Perceptions and experiences of water management	
Theme 12	Lack of understanding of water management practices contributes to conflict.
Theme 13	Participants seem to view water management in terms of "us versus them."
Theme 14	Participants perceive water-related regulations as both necessary and frustrating.
Theme 15	Participants perceive unequal enforcement of water-related regulations.
Theme 16	Participants believe better communication would foster collaboration related to water management.
Theme 17	Participants would like to see more inclusive water management practices.
Receiving water-related information	
Theme 18	Participants seek unbiased information.
Theme 19	Participants seek convenient information.
Theme 20	Participants receive much environmental information through personal communication.
Theme 21	Participants appreciate electronic channels of information.

HD3. Convened a Project Advisory Group (PAG)

The Project Advisory Group was comprised of stakeholders with knowledge and expertise in water resources management including representatives from local, state, and federal governments, non-profits, and the business sector. Contractors were included on the PAG to provide technical advice as necessary. A series of 13 meetings were convened between September 2012 through May 2015 with a focus on watershed and water resources management through field trips and presentations. Meeting support services were provided by the Friends of Rookery Bay. Most meetings were evaluated through either a paper survey administered during the meeting or an online survey emailed just afterward and these elicited positive responses. Several brainstorming sessions were used as a tool for PAG members to provide input on specific issues or approaches. The PAG members expressed a desire to continue meeting and frequently commented that they learned new things that they would apply in their work.

A series of 13 meetings were convened as part of the Project Advisory Group whose job was to advise and guide the research process.

Date	Attendees	Location
September 14, 2012	9	Field trip via kayak to see Henderson Creek and RBNERR Environmental Learning Center (ELC)
November 16, 2012	12	Field trip to Marco Island water supply sites and RBNERR ELC
February 1, 2013	15	RBNERR ELC
April 12, 2013	14	Field trip to watershed discharge locations and RBNERR ELC
July 12, 2013	11	Field trip and trawl on Naples Bay and RBNERR ELC
October 18, 2013	19	Field trip to Golden Gate Canal diversion sites and RBNERR ELC
January 23, 2014	17	RBNERR ELC
March 13, 2014	15	RBNERR ELC
May 29, 2014	19	Florida SouthWestern State College (FSW)
September 29, 2014	20	FSW
December 4, 2014	19	Field trip to Merritt Pump Station and FSW
February 26, 2015	25	FSW
May 28, 2015	22	FSW
Total meetings: 13	**217**	

HD4. Research on water councils, watershed groups, and watershed management

The Project Coordinator conducted online research to identify effective strategies and approaches for creating and managing water councils and watershed groups to apply with the PAG. In addition, the research demonstrated a variety of techniques used in watershed management including a range of programs and strategies. The information is summarized in the report entitled: *Summary Report: Research on Water Councils, Watershed Groups, and Watershed Management, August 2014.*

The Project Advisory Group included approximately 30 stakeholders with expertise in water resources management. When asked to brainstorm preferred results of the project, the following suggestions were made in regard to watershed management:

- Establish a permanent Rookery Bay watershed advisory working group;
- Convene community working groups/advisory panels;
- Integrate county water personnel, water management district personnel, local conservation lands personnel, and other pertinent personnel to form a group who can adequately address the water and ecological needs of permitting, construction, monitoring and management of the resources in the county or region within the county;
- Revive the Big Cypress Watershed Group (which ended shortly after funding for the graduate student coordinator lapsed); and,
- Create a "Rookery Bay Western Watershed Restoration Community Panel" to monitor and assist plan implementation.

> *"A watershed approach provides a coordinating framework for management that joins public and private sector efforts to address the highest priority water and land-related problems within hydrologically-defined geographic areas called watersheds. A watershed approach considers the effect of landscape-level changes on the watershed and seeks to incorporate multiple benefits in projects, including improvements in water quality, water supply, recreation, and habitat. A watershed approach also seeks to integrate projects and approaches across different agencies, organizations, and jurisdictional boundaries within a watershed."*
>
> —Council for Watershed Health

HD5. Community presentations

Educating various audiences about watershed and water resources management was an important tool for connecting with stakeholders and ensuring that project outcomes were available long after the project funding concluded. Several approaches were applied including presentations to local stakeholders groups (see table below). In addition, a series of four handouts were developed with contracted support from the University of Maryland Center for Environmental Science's Integration and Application Network. Project information was also posted on the Friends of Rookery Bay website at www.rookerybay.org/restoreRB.

A series of presentations were conducted throughout the project to engage and inform stakeholders and ensure that project outcomes were communicated to a range of audiences.

Date	Duration	Event
September 30, 2013	45 minutes	Presentation to the Greenscape Alliance
November 21, 2013	20 minutes	Presentation to the City of Marco Island Waterways Advisory Committee
January 7, 2014	60 minutes	Presentation at the RBNERR Lunch and Learn Series
February 11, 2014	30 minutes	Presentation to the City of Marco Island Beautification Committee's Marco Island Community Forum
April 8, 2014	45 minutes	Presentation at the Isles of Capri Civic Association
November 6, 2014	20 minutes	Presentation at the Big Cypress Research Symposium
February 5, 2015	50 minutes	Training for landscapers as part of the Green Industries Best Management Practices
February 6, 2015	20 minutes	Presentation at the American Water Resources Association Meeting
February 11, 2015	45 minutes	Friends of Rookery Bay members night

HD6. Poster for teachers and students

The Rookery Bay Reserve has provided field-based environmental education programs for students and teachers for more than 20 years. To share some of the project results with this audience, a poster was developed in cooperation with artist Dawn Witherington. The poster highlights the Rookery Bay watershed and educates about freshwater inflows to the estuary, the economic importance of estuaries, and common wildlife found within the Rookery Bay estuary. The poster is available for download at www.rookerybay.org/restoreRB.

A poster was developed for students and teachers that focuses on the value of the Rookery Bay estuary.

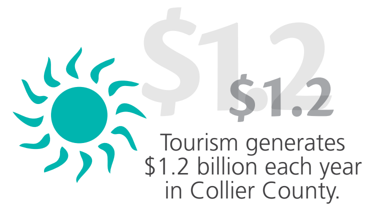
HD7. Factsheets for decision-makers

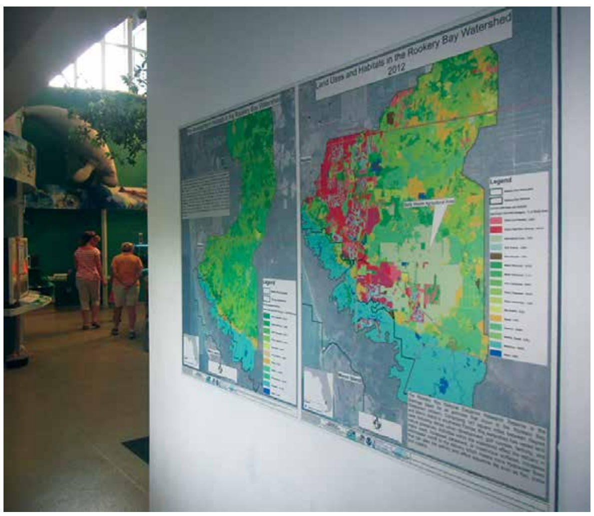
To share the scientific findings and support water resources decision making in the region a series of one-page factsheets were developed. The handouts are fairly technical, but are aimed at decision-makers who have some basic knowledge of water resources management and local issues in southwest Florida. "Identifying freshwater flows" explains the hydrologic model; "Identifying changes in aquatic habitats" focuses on habitat mapping; "Understanding fishery trends" describes the analyses of fishery data; and, "Understanding local attitudes" summarizes social science research about water-related attitudes, beliefs, and behaviors. An overview of the entire project was also created in a four-page fold-out version called "Restoring the Rookery Bay Estuary through collaborative watershed management." The factsheets can be downloaded at www.rookerybay.org/restoreRB.

Scientific findings were shared with decision-makers through the creation and dissemination of a series of factsheets.

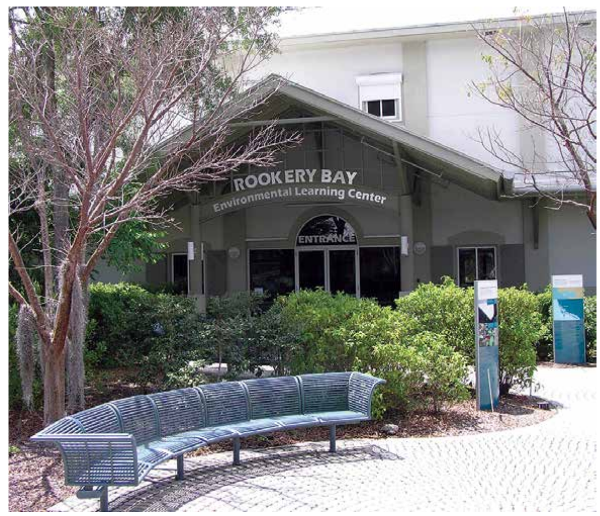
HD8. Exhibit in the Rookery Bay Environmental Learning Center

To connect residents and visitors to the research conducted during the project, an exhibit was installed in the Rookery Bay Environmental Learning Center. Two images, developed by contractors using Geographic Information System technology, depict the myriad land uses in the Rookery Bay watershed. The left side shows habitats that were present within the 247-acre, pre-development watershed and to the right, the habitats and varying land uses in the 167-acre watershed today. The Rookery Bay watershed has changed tremendously over the past several decades and the addition of roads, canals, farms, and development has altered the quality, quantity, and timing of fresh water that reaches the Rookery Bay estuary.





A new exhibit was installed in the Rookery Bay Reserve's Environmental Learning Center that compares habitats and land-use changes within the current and historic Rookery Bay watershed.



The Environmental Learning Center is a 16,500 square-foot facility with four research laboratories, classrooms, and 140-seat auditorium.

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Managing the Rookery Bay watershed for different, sometimes competing, uses is key for protecting and restoring the estuary.

Watershed management in action

This three-year collaborative effort resulted in a thorough review of watershed management projects, discussions about action plans that benefit the community, and the introduction of new environmental science research. Numerous stakeholders provided input and many individuals and organizations involved in watershed management participated in project activities. This has resulted in several immediate outcomes and several long-term recommendations in areas such as environmental science research and modeling, watershed management project planning and implementation, and in collaborative stakeholder management. The long-term results of this project may not be realized for many years, but the human dimensions of the project are an important consideration for future watershed management efforts in southwest Florida.

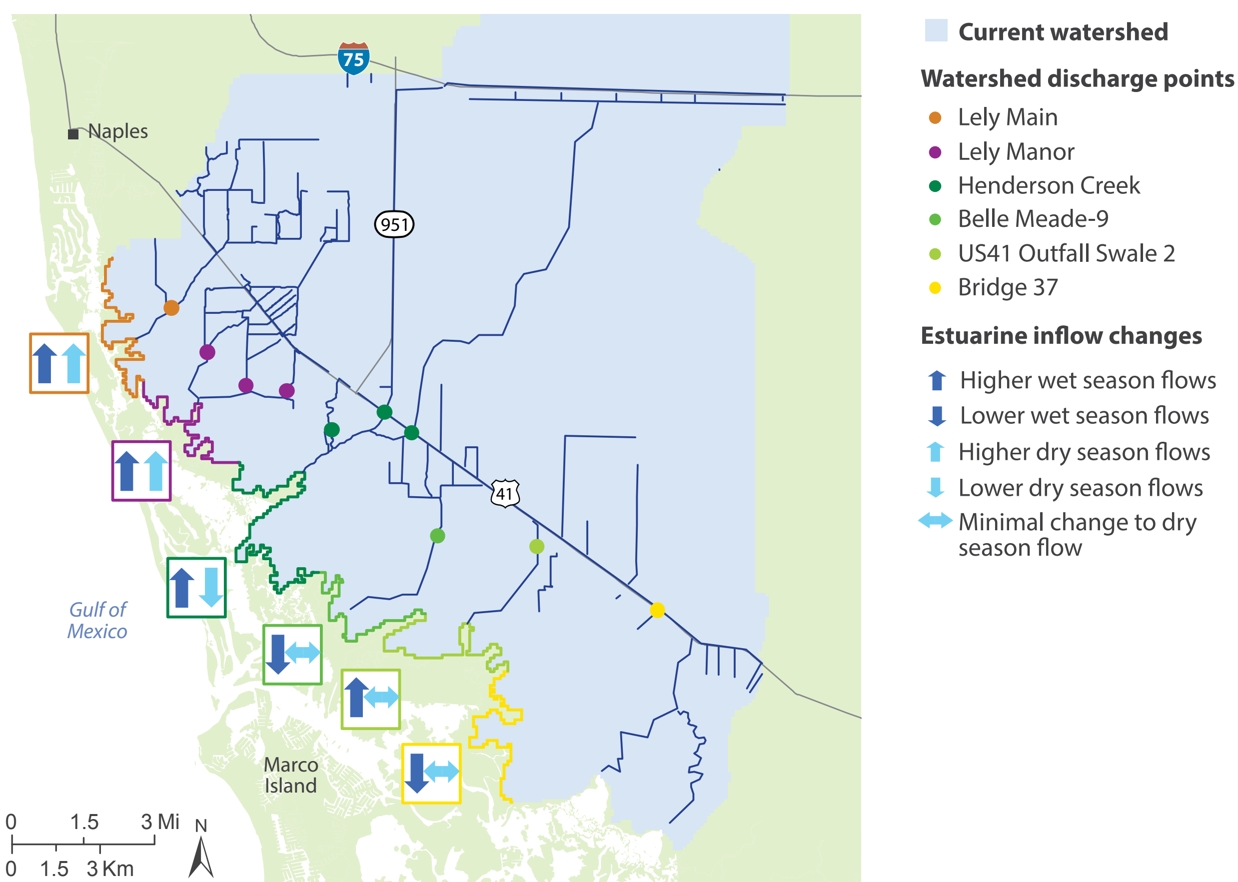
Outcomes

- **Golden Gate Canal diversion project, revised:** For several decades, watershed plans had proposed a diversion of water from the Golden Gate Main Canal into Henderson Creek/ Collier Boulevard Canal which empties into the Rookery Bay estuary. The intent of this diversion project was to prevent excessive freshwater flows from disrupting the delicate balance of fresh and salt water in Naples Bay by re-routing it to Rookery Bay, which was thought to be starved for fresh water. Hydrologic modeling results gained through the Restoring the Rookery Bay Estuary Project that compared historic and current conditions within the Rookery Bay watershed revealed that this sub-basin does not need additional freshwater inflows during the summer rainy season. However, this watershed does have storage capacity and water deficits to the east in the Belle Meade flow-way. The revised watershed plans now focus on diverting water from the Golden Gate Main Canal into the Belle Meade flow-way which will not only restore Naples Bay, but will rehydrate this historic flow-way and improve downstream conditions in the Rookery Bay estuary.

- **Collier-Seminole State Park/S.R. 92 flow obstructions revealed:** An under-studied area was revealed during the Restoring the Rookery Bay Estuary Project in the southeastern corner of the Rookery Bay watershed that is downstream of the Picayune Strand Restoration and part of the Comprehensive Everglades Restoration Plan. Preliminary results of the hydrologic model demonstrated some extreme water deficits in this location, likely from the road construction of U.S. 41 east and S.R. 92 which cut off the historic sheet flow to the estuary. Collaboration between several local, state, and federal partners has resulted in the development of a new suite of projects to improve hydrologic modeling data, remove exotic vegetation, install culverts, and remove other flow obstructions as an early effort to restore the Belle Meade flow-way.

- **Guiding cost-effective community projects:** A proposed development near Henderson Creek and just upstream of the Rookery Bay estuary included a large drainage canal, matching the size of existing culverts, to allow proper stormwater drainage. Water resources managers met with developers and suggested using the hydrologic model from the Restoring the Rookery Bay Estuary Project to better determine the actual size that would be necessary to facilitate adequate drainage, while mitigating potential excessive flows to the estuary. The result was a 60% reduction in the size of the drainage canal that succeeded in saving the developer money and space within the development and minimized excessive flows to the estuary. In addition, the developer opted to divert the stormwater through a filter marsh which should improve water quality.

- **Improved watershed management:** A series of 13 meetings of water resources managers over three years increased understanding of the importance of communication, collaboration, and coordination about watershed management. As a result, local governments are engaging more directly in the integrated and systematic approach, called watershed management, and there are plans to continue regular meetings including stakeholder input sessions beyond the dates of the project.



The colored dots identify the ten primary freshwater discharge locations for the Rookery Bay watershed, along with the corresponding color-coded sub-basin. The arrows show the changes in flow under current conditions when compared to historic conditions.

Recommendations

Based on the best-available science, the following recommendations will support the restoration and continued health of the Rookery Bay estuary and watershed:

Watershed management recommendations

- Address the altered flow distributions by correcting flow excesses and deficits by sub-basin. The general trend is excessive flows to the west of Collier Boulevard/Henderson Creek and deficits to the east.
- Restore hydroperiods within the southern Belle Meade flow-way to historic conditions by mitigating the draw-down and draining effects of nearby canals (Collier Boulevard/ Henderson Creek and I-75 canals).

Increase dry season flows to the Henderson Creek sub-basin to as close to historic levels as possible (3–5 cubic feet per second).

- Address and improve the aging infrastructure and lack of best management practices within the communities along Henderson Creek and the S.R. 951/Henderson Creek Canal.
- Continue efforts to minimize pulse flows to the estuary which can negatively impact estuarine habitats and are typically associated with stormwater management systems.
- Focus near-term capital improvement projects within the Rookery Bay watershed on the estuarine interface and focus mid-term projects on the Belle Meade flow-way restoration. This approach will prepare the area for long-term plans to divert water from the Golden Gate Main Canal to restore Naples Bay.
- Complete the salinity model for the estuary and couple it with the Rookery Bay watershed model to develop a comprehensive and predictive upstream/ downstream management tool to evaluate restoration efforts and capital improvement projects.

Habitat restoration (top) provides numerous community benefits. Rookery Bay routinely convenes stakeholders to discuss water resources management (bottom).

- Update and maintain the local scale model and salinity model on a regular basis so that it can be used as a management tool.
- Support the use of the local scale model and its scientific results for a range of professionals including private developers, permitting staff, transportation planners, water managers, environmental researchers, etc.
- Increase comprehensive and inclusive watershed planning and prioritization in the region to better accomplish cost-effective management goals, including the implementation of these recommendations.

Research and monitoring recommendations

- Expand knowledge on juvenile sport fish species, such as snook, tarpon, and redfish/red drum, which were not represented in the reviewed fisheries studies. This information is needed to help guide restoration or conservation of the remaining habitat of these economically-important species.
- Establish a comprehensive monitoring and mapping effort at the ten watershed discharge points and corresponding downstream open-water estuary sites to evaluate the success of restoration projects.
- Conduct comprehensive mapping of submerged habitats in the Rookery Bay estuary, including species identification and ongoing monitoring, to determine if management recommendations are effective in restoring lost fisheries habitat.
- Expand strategic water quality monitoring and data analysis to better identify salinity patterns.
- Direct future research to address the following knowledge gaps:
    - A lack of modeling in the southeastern corner of the Rookery Bay watershed near S.R. 92 and Collier-Seminole State Park. This area will be affected by both Picayune Strand Restoration and Rookery Bay watershed projects, however little reliable data is available to support management decisions.

Rookery Bay Reserve staff routinely monitor water quality chemistry and nutrients (top). Water quality data is uploaded remotely from a marsh restoration project (bottom).

- A lack of understanding about the specific local effects of altered freshwater inflows to economically important estuarine plants and animals.
- A lack of understanding about the specific local effects of altered freshwater inflows in the altered wetland areas between the watershed discharge points and the open water estuary. This area potentially represents some low-cost opportunities to mitigate altered flow impacts and restore both the hydrology and ecology of the area.

Human dimensions recommendations

- Economic information about various water uses and issues can help the community make more informed decisions about water use.
- Water and related issues are important to the community. Active water management can support and maintain its appeal.
- Tensions and differences can create conflict and ill will among community members. A proactive approach through stakeholder collaboration and inclusion in water management decisions can resolve tensions.
- Inequalities may also create tensions. The perception of fairness better supports collaboration and positive experiences.
- Water resource managers need to engage in education programs and knowledge sharing.
- Understanding community values and beliefs can help water managers make better decisions.
- Scientific data is important to collect and disseminate to the community.
- Water managers should look for ways to increase communication and encourage participation in water management decision making.
- Professionals with water conservation expertise may be influential in educating other community members.

Hundreds of boats line the shores of Keewaydin Island, a barrier island beach within Rookery Bay Reserve (top). Rain gardens are a great way for members of the community to help prevent pollution from stormwater runoff (bottom).

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National Estuarine Research Reserve System Science Collaborative

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